3. Assessment of the Sablefish Stock in Alaska

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Executive Summary

Summary of Changes to the Assessment

Moderate changes to the assessment methodology were implemented for the 2021 sablefish (*Anoplopoma fimbria*) SAFE. Previously, for the 2020 SAFE, model *16.5_Cont* was used as the assessment model. However, increasing retrospective patterns in recent recruitment estimates were persistent as new data were added to the model. Since 2017, maximum Acceptable Biological Catch (ABC) projections based on model *16.5_Cont* using the North Pacific Fishery Management Council's (NPFMC) tier 3 FMP $B_{40\%}$ harvest control rule (HCR) had been deemed unreliable for sablefish due to overly optimistic population growth forecasts. For the 2021 SAFE, multiple model updates are being proposed, including refinements to the biological inputs, new selectivity and catchability parametrizations, and improved data reweighting approaches, all of which have helped to address retrospective patterns. The sablefish assessment authors explored a number of alternative models using a thorough model development exercise (Appendix G) and a new model configuration was developed (Appendix 3H). The final proposed model for the 2021 SAFE, *21.12_Proposed_No_Skip_Spawn*, resolves the recruitment estimation issues associated with model *16.5_Cont*, while maximum ABC projections are once again deemed adequate for the basis of management advice.

Appendices have also been updated and added. In particular, the Ecosystem and Socioeconomic Profile (ESP; Appendix 3C) and trawl removals of small sablefish in the Bering Sea (Appendix 3D) have both been updated with new data for 2021. New appendices are provided describing the updates to weight and growth (Appendix 3E), maturity (Appendix 3F), model updates and new parametrizations (Appendix 3G), final proposed model updates and the full factorial model building exercise (Appendix 3H), and the results of the previous model (*16.5_Cont*) applied to the new 2021 data (Appendix 3I).

Changes to the Input Data

New data included in the assessment model were relative abundance and length data from the 2021 longline survey, length data from the fixed gear fishery for 2020, length data from the trawl fisheries for 2020, age data from the longline survey and fixed gear fishery for 2020, updated catch for 2020, and projected 2021 – 2023 catches. Estimates of killer and sperm whale depredation in the fishery were updated and projected for 2021 – 2023. In 2021, there was also a NMFS Gulf of Alaska trawl survey; associated relative abundance indices and length data for the Gulf of Alaska in waters less than 500m were included in the assessment. Due to funding issues and timing constraints, 2020 fixed gear fishery catch-per-unit effort (CPUE) data from logbooks were unavailable. Because logbooks are a major component of the CPUE index, no fishery CPUE data point for 2020 was available. Additionally, the recommended model (*21.12_Proposed_No_Skip_Spawn*) includes revised estimates of growth-, weight-, and maturity-at-age using recently collected data.

Changes to the Assessment Methodology

The proposed model includes revised weight-, length-, and maturity-at-age. A variety of model parametrization refinements were also implemented, which focused on catchability and selectivity parameters. First, model *21.12_Proposed_No_Skip_Spawn* removed all catchability priors to enable unconstrained estimation of these parameters and to allow better internal scaling (see Appendix 3G for more details on catchability parametrization). Additionally, to address issues associated with recruitment estimation, recent catchability and selectivity time blocks (i.e., new parameter estimates starting in 2016) were implemented for the fixed gear fishery (i.e., catchability and selectivity) and longline survey (i.e., selectivity only). A recent time block for fixed gear fishery catchability and selectivity was warranted given the rapid alteration in gear composition since pot gear was legalized in the Gulf of Alaska (GOA) in 2017. Simultaneously, the low monetary value of small sablefish, which have dominated the population and landings since the mid-2010s, has likely affected the targeting of the fixed gear fishery. There have also been recent increases in abundance of younger fish in deep water strata in the longline survey, where they have not historically been caught (Figure 3.49). These changes in availability to the longline survey appear to have occurred only for certain age and size classes, which can be adequately modeled with the addition of a recent survey selectivity time block. Finally, Francis data reweighting was implemented. From a modeling standpoint, these changes improved fit to the longline survey index and juvenile cohort decay within the recent compositional data.

Summary of Results

The longline survey abundance index (relative population numbers, RPNs) increased by 9% in 2021 following a 32% increase in 2020. The trawl survey biomass index has increased nearly five-fold since 2013, with a 40% increase from 2019 to 2021 (Figure 3.10c). The age and length composition data from the various fishery (i.e., fixed gear and trawl) and surveys (i.e., longline and trawl) continue to indicate strong year classes in 2014, 2016, 2017, and 2018.

The proposed model (*21.12_Proposed_No_Skip_Spawn*) fits the recent indices and compositional data well. However, the model demonstrated worse fit to the fishery age composition compared to the previous model (*16.5_Cont*). The poorer fit to the age data is due to changes in relative data weights resulting from the Francis reweighting along with different trends in the rate of population growth between the indices and compositional data. The model does not demonstrate any major diagnostic issues and provides stable estimates of year class strength with no retrospective patterns.

With multiple observations now available of the 2014 year class, the estimate is lower than from previous models, but is still twice the size of mean recruitment. The 2016 year class appears to be the largest on record and estimates of the size of this cohort appear to have stabilized. Additionally, it now appears that the series of recruitment events from 2014 – 2018 reflect those of the late 1970s and early 1980s. Based on the strength of these recent year classes, biomass estimates have more than doubled from a time series low of 215,000 t in 2015 to 553,000 t in 2021, exceeding the highs of the mid-1980s (Figure 3.17). From the time series low in 2017, SSB has increased by 34% to 108,000 t in 2021, which is 36% of the unfished SSB (i.e., SSB_0). However, year classes since 2014 are projected to comprise over 50% of the 2022 spawning biomass (Figure 3.19). At the same time, the lack of fish greater than 10 years of age for an extremely long-lived species needs to be carefully monitored.

Sablefish are managed under Tier 3 of NPFMC harvest control rules. The updated point estimate of $B_{40\%}$, is 118,140 t. Since projected female spawning biomass (combined areas) for 2022 is 128,789 t (equivalent to $B_{44\%}$), sablefish is in sub-tier "a" of Tier 3. Spawning biomass is projected to continue to increase rapidly in the near-term (Figure 3.48), reaching $B_{44\%}$ in 2022 and $B_{51\%}$ in 2023. The updated point estimates of $F_{40\%}$ and $F_{35\%}$ from this assessment are 0.080 and 0.094, respectively. Thus, the maximum permissible value of F_{ABC} under Tier 3a is 0.080, which translates into a 2022 maximum permissible ABC (combined areas) of 34,863 t. The OFL fishing mortality rate is 0.094, which translates into a 2022 OFL (combined areas) of 40,432 t. Thus, current model projections indicate that the Alaskan sablefish stock is not subject to overfishing, not overfished, and not approaching an overfished condition.

The author recommended ABC for 2022 is the Tier 3a maximum permissible ABC of 34,863 t. The final whale-adjusted 2022 ABC is 34,521 t.

Summary Table

Quantity/Status	As estimated or specified *last* year for (model 16.5):		As estimated or recommended *this* year for (model 21.12):	
	2021*	2022*	2022*	2023*
M (natural mortality rate)	0.098	0.098	0.100	0.100
Tier	3a	3a	3a	3a
Projected total (age 2+) biomass (t)	753,110	789,584	574,599	582,536
Projected female spawning biomass (t)	134,401	191,503	128,789	153,820
$B_{100\%}$	317,096	317,096	295,351	295,351
$B_{40\%}$	126,389	126,839	118,140	118,140
$B_{35\%}$	110,984	110,984	103,373	103,373
F_{OFL}	0.117	0.117	0.094	0.094
$maxF_{ABC}$	0.100	0.100	0.080	0.080
F_{ABC}	0.042	0.048	0.080	0.080
OFL (t)	61,319	71,756	40,839	42,948
OFL_w (t)**	60,426	70,710	**40,432**	**42,520**
max ABC (t)	52,427	61,393	34,863	36,670
ABC (t)	22,551	29,723	34,863	36,670
ABC_w (t)**	22,237	29,309	**34,521**	**36,318**
Status	As determined *last* year for:		As determined *this* year for:	
	2019	2020	2020	2021
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

*2020 projections for biomass and SSB were 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. The same approach was utilized for the 2021 projections with specified catches of 23,700 t in 2022 and 24,400 t in 2023 (a yield ratio of 0.68 was assumed based on a 2021 estimated catch of 20,120 t and an ABC of 29,588 t). Similarly, the 2023 ABC is based on removals equivalent to the 2022 specified catch. This was done in response to management requests for a more accurate two-year projection. SSB and biomass are slightly less than presented when the full ABC is removed.

**ABC_w and OFL_w are the final author recommended ABCs and OFLs after accounting for whale depredation. They are also based on a 50% stair step from fixed apportionment towards author recommended 5-year average survey apportionment in 2022 and a 75% stair step in 2023 (i.e., following SSC recommendations from 2020).

Risk Table Summary

Given the large quantities of data, the high quality of data, and general agreement in recent population trends in the sablefish indices, there were no major concerns about the data used in the sablefish assessment. Similarly, there were no major retrospective patterns or other diagnostic issues with the proposed assessment model (*21.12_Proposed_No_Skip_Spawn*). As such, the **assessment considerations category for sablefish was rated '1 – Normal'**.

Although minor uncertainty in the exact magnitude of recent recruitment events exists, there are now enough observations of these cohorts to validate estimates of multiple large recent cohorts. Evidence is also mounting that the 2016 recruitment is likely the largest on record. However, sablefish age structure is severely truncated and the SSB relies heavily on these recent cohorts with little contribution from early 2000s year classes. Thus, the **population dynamics category was rated '2 – Increased Concern'**.

Overall, environmental and ecosystem indicators suggest stable temperatures at depth, moderate to warm surface temperature conditions, a mix of average to below average indicators of foraging conditions, no apparent increases in predation pressure, and reduction in potential competition due to juvenile sablefish moving off the shelf and into adult slope habitat. Given that no major concerns are apparent for sablefish, the **environmental and ecosystem category was rated '1 – Normal'**.

In recent years, there has been a rapid shift in the composition of the fixed gear fleet where pot gear now constitutes more than 50% of sablefish removals, which is not fully accounted for in the assessment. In addition, the rapid decline in overall market conditions, particularly due to the influx of small sablefish, may be contributing to differences in targeting and selectivity in all fisheries. Therefore, the **fishery performance category was rated '2 – Increased Concern'**.

Given the lack of major concerns for sablefish along with improved model performance of the proposed assessment model, no additional reductions in ABC are being recommended (though deductions for whale depredation are still incorporated). However, a few additional considerations are worth noting for future sablefish management. First, the projected maximum ABC would represent the largest catch since the late 1980s, which, due to high catches and extended periods of poor recruitment, was followed by subsequent declines in biomass and SSB. Similarly, given concerns regarding the contracted age structure, the abundance of older ages in the population should continue to be monitored. Alternate metrics of spawning potential, which better emphasize fully mature age classes (e.g., the biomass of ages > 10), could help maintain a strong spawning portfolio and avoid future contraction of the age structure, thereby improving resilience of the sablefish resource (Hixon et al., 2014; Lowerre-Barbieri et al., 2016; Licandeo et al., 2020). Similarly, given that sablefish are such a long-lived species along with the cyclic nature of sablefish dynamics, exploration of a capped (i.e., implementing a maximum cap on the ABC) management procedure (or an 'inventory management' strategy) for sablefish may be worthwhile. Compared to using a maximum yearly catch strategy, capped HCRs could aid in stabilizing long-term sablefish dynamics (i.e., help to prevent long-term cyclical declines as the resource transitions between high and low recruitment regimes; Licandeo et al., 2020).

Spatial Catch Apportionment

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). Based on biological rationale, the SSC adopted the five-year average survey apportionment method in 2020, which uses a five-year moving average of the longline survey proportions of biomass in each region. 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. It is important to emphasize that the recommended five-year average survey apportionment utilizes a moving five-year average, thus, the apportionment values change as new survey data is collected.

For 2021, the authors continue to recommend using the five-year average survey apportionment method. The area specific ABCs resulting from this approach are provided in the Table below. In 2020, the SSC instituted a four-year stair step approach to move from the fixed apportionment used prior to 2020 towards the five-year average survey apportionment. Assuming that the stair step approach will be continued in 2021, **the next step would be a 50% stair step from the 2020 fixed apportionment values towards the 2021 five-year average survey apportionment values**.

Apportionment Table (before whale depredation adjustments).

	Area						
Method	**AI**	**BS**	**WG**	**CG**	**WY***	**EY***	**ABC**
2021 ABC⁺	4,727	3,420	3,253	9,644	3,471	5,326	29,841
*Status Quo (Fixed at Current)***	5,558	4,001	3,799	11,226	4,066	6,213	34,863
2020 5-year Survey Avg.	8,231	5,742	4,296	8,945	2,990	4,660	34,863
*Fixed****	4,601	3,402	3,761	11,892	4,000	7,207	34,863
25% Stair Step	5,543	4,353	3,791	10,950	3,590	6,635	34,863
50% Stair Step**	**6,486**	**5,305**	**3,821**	**10,008**	**3,179**	**6,064**	**34,863**
75% Stair Step	7,428	6,256	3,852	9,066	2,768	5,493	34,863
5-year Survey Avg.^	**8,371**	**7,207**	**3,882**	**8,124**	**2,357**	**4,922**	**34,863**
50% Stair Step from 2021#	6,964	5,604	3,840	9,675	3,212	5,568	34,863

⁺This is the final 2021 ABC and associated regionally apportioned ABCs based on the 2020 SAFE. Other approaches utilize the 2022 ABC. Note that 2021 ABC is after the 95:5 hook and line : trawl split has been applied between WY and EY/SE, whereas all 2022 ABCs shown here are prior to this adjustment.

*Before the 95:5 hook and line : trawl split between WY and EY/SE shown below.

**Apportionment fixed (i.e., status quo) at the 2020 SSC recommended apportionment that used a 25% stair step from fixed apportionment to the 2020 5-year survey average apportionment.

*** Fixed at the 2013 assessment apportionment proportions (Hanselman et al. 2012b).

****A 50% stair step from fixed apportionment to the 2021 5-year survey average apportionment. This represents the next incremental step in the 2020 SSC recommended 4-year stair step approach.

^The 5-year survey average is the biologically recommended long-term apportionment strategy. This approach does not utilize a stair step (i.e., it represents a 100% step).

#The 50% stair step from the 2020 SAFE apportionment values to the 2021 5-year survey average apportionment is an alternative to a 50% stair step from the fixed apportionment.

Area Apportionment Percent Difference from 2021 ABC.

	Area*						
Method	**AI**	**BS**	**WG**	**CG**	**WY**	**EY**	**ABC**
Status Quo (Fixed at Current)	18%	17%	17%	16%	17%	17%	17%
2020 5-year Survey Avg.	74%	68%	32%	-7%	-14%	-13%	17%
Fixed	-3%	-1%	16%	23%	15%	35%	17%
25% Stair Step	17%	27%	17%	14%	3%	25%	17%
50% Stair Step	**37%**	**55%**	**17%**	**4%**	**-8%**	**14%**	**17%**
75% Stair Step	57%	83%	18%	-6%	-20%	3%	17%
5-year Survey Avg.	77%	111%	19%	-16%	-32%	-8%	17%
50% Stair Step from 2021	47%	64%	18%	0%	-7%	5%	17%

* Note that 2021 ABC is after the 95:5 hook and line : trawl split has been applied between WY and EY/SE, whereas all 2022 ABCs are prior to this adjustment. Thus, the differences in WY and EY are more extreme than in the final regional ABCs after all adjustments have been applied (e.g., as shown in the Final Whale Adjusted Catch Table by Region).

Regional estimates of sablefish harvest rate.

Method[**]	Area[*] AI	BS	WG	CG	WY	EY	Total
Status Quo (Fixed at Current)	0.03	0.03	0.06	0.10	0.14	0.10	0.06
2020 5-year Survey Avg.	0.05	0.04	0.07	0.08	0.10	0.08	0.06
Fixed	0.03	0.03	0.06	0.11	0.14	0.12	0.06
25% Stair Step	0.03	0.03	0.06	0.10	0.12	0.11	0.06
50% Stair Step	**0.04**	**0.04**	**0.06**	**0.09**	**0.11**	**0.10**	**0.06**
75% Stair Step	0.04	0.05	0.07	0.08	0.10	0.09	0.06
5-year Survey Avg.	**0.05**	**0.05**	**0.07**	**0.07**	**0.08**	**0.08**	**0.06**
50% Stair Step from 2021	0.04	0.04	0.06	0.09	0.11	0.09	0.06

[*]Before 95:5 hook and line : trawl split between WY and EY/SE shown below.

[**]Harvest rate is calculated as the region-specific catch divided by biomass for each apportionment scenario. Regional biomass (Age 2+) is taken from Table 3.16b with projected biomass and harvest rates based on maximum permissible ABCs for 2022 and 2023 (before whale depredation corrections). Analysis of spatial dynamics should be undertaken judiciously given the caveats associated with estimating regional biomass. Harvest rates are approximations for illustrative purposes only. Estimates do not account for spatial differences in selectivity due to trawl and fixed gear catch splits.

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 2022 and 2023 compared with the specified ABC in 2021. Because we are accounting for depredation in the longline survey abundance estimates, it is necessary to decrement the resultant 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 estimated whale depredation in the last three complete catch years (2018 – 2020) by the amount that the ABC is increasing or decreasing from 2021 to 2022 and 2023. This amount of projected depredation is then deducted from each area ABC to produce new area ABCs for 2022 and 2023 (ABC_w). In 2016, the SSC decided that these calculations should also apply to OFL, so the same procedure is applied to OFLs for 2022 and 2023 (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% reduction from the maximum permissible non-whale adjusted ABC. This varies slightly by area as projected whale depredation varies across regions. 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 five-year average survey apportionment method, but assuming a continuation of the SSC recommended 4 year stair step (i.e., a 50% step in 2022 from Fixed apportionment towards the 2021 five-year survey average apportionment with a subsequent 75% stair step in 2023).

Author recommended 2022 ABC (with whale depredation adjustments).

Area	AI	BS	WG	CG	WY*	EY*	Total
2021 ABC	4,727	3,420	3,253	9,644	3,471	5,326	29,841
2022 ABC	6,486	5,305	3,821	10,008	3,179	6,064	34,863
2018 - 2020 Avg. Depredation	16	26	81	41	44	89	297
Ratio 2022:2021 ABC	1.37	1.55	1.17	1.04	0.92	1.14	1.17
Deduct 3-Year Adjusted Avg.	-23	-41	-95	-43	-40	-101	-342
****2022 ABC_w**	6,463	5,264	3,727	9,965	3,139	5,963	34,521
Change from 2021 ABC_w	37%	55%	16%	5%	-9%	13%	17%

*Before 95:5 hook and line : trawl split between WY and EY/SE shown below.

**ABC_w is the author recommended ABC that accounts for whale depredation.

Author recommended 2023 ABC (with whale depredation adjustments).

Area	AI	BS	WG	CG	WY*	EY*	Total
2021 ABC	4,727	3,420	3,253	9,644	3,471	5,326	29,841
2023 ABC	7,813	6,580	4,051	9,536	2,911	5,778	36,670
2018 - 2020 Avg. Depredation	16	26	81	41	44	89	297
Ratio 2023:2021 ABC	1.65	1.92	1.25	0.99	0.84	1.08	1.23
Deduct 3-Year Adjusted Avg.	-27	-51	-100	-41	-37	-96	-352
****2023 ABC_w**	7,786	6,529	3,951	9,495	2,875	5,682	36,318
Change from 2021 ABC_w	65%	92%	23%	0%	-17%	8%	23%

*Before 95:5 hook and line : trawl split between WY and EY/SE shown below.

**ABC_w is the author recommended ABC that accounts for whale depredation.

Author recommended 2022 – 2023 ABCs by Sector in West Yakutat and East Yakutat/Southeast adjusted for the 95:5 hook-and-line : trawl split in the EGOA.

Year	West Yakutat	E. Yakutat/ Southeast
2022	3,437	5,665
2023	3,159	5,398

*ABCs represent total regional ABC across gears, but with the 5% trawl allocation in EY/SE reallocated to WY.

Author recommended 2022 and 2023 OFLs (with whale depredation adjustments).

Year	**2022**	**2023**
2021 ABC	29,841	29,841
OFL	40,839	42,948
3-year Avg. Depredation	297	297
Ratio	1.37	1.44
Deduct 3-year Avg.	-407	-428
***OFL_w**	**40,432**	**42,520**
2021 and 2022 OFL_w	**60,426**	**70,710**
Change from 2020 SAFE	-33%	-40%

*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	2020	387,000	--	16,883	14,393	12,494
	2021	390,000	--	21,475	17,992	12,919
	2022	240,600	--	22,794**	--	--
	2023	236,500	--	22,003**	--	--
BS	2020	116,000	--	2,174	1,861	5,301
	2021	142,000	--	3,396	3,396	3,667
	2022	168,000	--	5,264**	--	--
	2023	165,200	--	6,529**	--	--
AI	2020	154,000	--	2,952	2,039	1,210
	2021	175,000	--	4,717	4,717	1,359
	2022	121,200	--	6,463**	--	--
	2023	119,100	--	7,786**	--	--

*Biomass represents the value projected by the model used to determine the ABC in that year.

**Based on model *21.12_Proposed_No_Skip_Spawn* and assuming a 50% stair step from fixed apportionment towards author recommended 5-year average survey apportionment in 2022 and a 75% stair step in 2023. Also, these values are after the whale depredation adjustments described above.

Final Whale Adjusted Catch Tables by Region.

Year	**2021**				**2022***		**2023***	
Region	OFL_w	ABC_w	TAC	Catch**	OFL_w	ABC_w***	OFL_w	ABC_w***
BS	--	3,396	3,396	3,667	--	5,264	--	6,529
AI	--	4,717	4,717	1,359	--	6,463	--	7,786
GOA	--	21,475	17,992	12,919	--	22,794	--	22,003
WGOA	--	3,224	2,428	1,609	--	3,727	--	3,951
CGOA	--	9,527	8,056	5,868	--	9,965	--	9,495
***WYAK	--	3,451	2,929	2,156	--	3,437	--	3,159
***EY/SEO	--	5,273	4,579	3,286	--	5,665	--	5,398
Total	60,426^	29,588+	26,105	17,945	40,432	34,521	42,520	36,318

*Based on model *21.12_Proposed_No_Skip_Spawn* and assuming a 50% stair step from fixed apportionment towards author recommended 5-year average survey apportionment in 2022 and a 75% stair step in 2023.

**As of October 28, 2021 Alaska Fisheries Information Network, (www.akfin.org).

***After 95:5 trawl split shown above and after whale depredation methods described above.

^Based on the maximum permissible ABC projections from model *16.5_Cont*.

+The SSC recommended and council adopted 2021 ABC was greater than the 2020 SAFE author recommended ABC, but less than the 2020 SAFE maximum permissible ABC as determined using model *16.5_Cont*.

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 2020 – 2021 assessment and review cycle.

"The SSC revised and clarified the recommendation to maintain the status quo and only produce risk tables for full assessments (rather than all assessments, as indicated in the subgroup recommendation)." (SSC, June 2021)

We provide a risk table for the fourth time in 2021, as recommended by the SSC.

"For cases where a process external to the assessment is relevant to two or more risk categories, the SSC recommends that the narrative reflect the interconnected relationships that exist between rankings among risk categories (Appendix A, Preliminary Guidance and SSC recommendations, bullet 7). Additionally, the SSC supports the recommendation that the fishery/community performance column should focus only on factors that provide insight as to the condition of the stock and that economic and community impact information be excluded (Appendix A, Preliminary Guidance and SSC recommendations, bullet 6)." (SSC, June 2021)

"The SSC recognizes the current use of LK/TK/S in the population dynamics, ecosystem considerations and fishery/community performance columns, and highlights the desire to encourage usage of this information (Appendix A, Preliminary Guidance and SSC recommendations, bullet 6)." (SSC, June 2021)

"The SSC agreed that positive trends in the Assessment, Ecosystem or Fishery performance should not be included, as the default is that conditions are positive or neutral, and the default option is for no

reduction from maxABC. Therefore, the SSC recommended no changes to the language in the Risk Table template." (SSC, October 2021)

"There was also agreement that reducing the number of scoring levels from 4 to 3 would be helpful, but the JGPT asked to postpone this until next year's assessments as many authors had already begun working on risk tables for the upcoming season; the SSC agreed with this request." (SSC, October 2021)

The sablefish risk table write-ups follow these SSC recommendations and have been carefully worded to reflect any interconnected relationships across categories. Similarly, the fishery/community performance category description has been revised for 2021 to better reflect only indicators that inform on resource condition and not on aspects such as economic performance. Finally, the sablefish risk table presented follows the previous guidelines to not include positive trends in the Assessment, Ecosystem, or Fishery Performance categories, while the four categorical scoring levels have been retained. The authors understand that future risk table scores will likely have only three scoring levels.

"The SSC continues to support that reductions from the maximum permissible ABC should be infrequent and only for exceptional circumstances (Appendix A, Preliminary Guidance and SSC recommendations, bullet 9)." (SSC, June 2021)

"The SSC recommended maintaining the status quo, where authors are encouraged (but not required) to provide a recommendation on a reduction from maxABC, if warranted, and the Plan Teams and SSC would then evaluate and modify the reductions based on the information available for the stock." (SSC, October 2021)

Although the last few sablefish SAFE's have utilized the risk table scores to suggest reductions from the maximum permissible ABC, such reductions are not being recommended for the 2021 SAFE. A new model has been developed, which is believed to provide more reliable projections that no longer necessitate ABC reductions based on risk table justification.

SSC Concerns Specific to the Sablefish Assessment

In this section, we list new or outstanding SSC comments specific to the last full Alaskan sablefish assessment in 2020 and model updates developed for 2021 and presented during the fall meetings.

"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)

"The SSC appreciates the extensive work done in developing sensitivity analyses covering the topics of data weighting, selectivity parameterization, natural mortality, maturity, and other topics. The SSC looks forward to further development of several of these alternatives for more thorough consideration in 2021." (SSC Dec. 2020)

The SSC adds or reiterates the following additional recommendations for future assessments:

- *Use the 'Francis method', or other objective data-weighting approach, as an alternative to the base case method in the next stock assessment.*
- *Consider time-varying selectivity approaches to accommodate shifts in the fishery from hook-and-line to pots, as well as potential shifts in availability due to apportionment and the distribution of the biomass.*
- *Consider including time-varying or cohort-specific maturity curves, and/or weight-at-age relationships if supported by data.*
- *Consider further evaluation of time-varying and/or age-specific natural mortality.*
(SSC Dec. 2020)

Many modeling updates have been undertaken for the proposed model for the 2021 SAFE (model *21.12_Proposed_No_Skip_Spawn*), which address many of these concerns and requests. In particular, the proposed model includes updated biological inputs (including updated weight, growth, and maturity curves), incorporates a new time block for fishery and longline survey selectivity parameter estimates, and incorporates Francis reweighting methods. The model is better able to estimate recent recruitment events, while essentially eliminating retrospective patterns and retroactive downgrades in recruitment estimates. Although the new model does not necessarily fit the fishery age composition as well as the previous model, it better fits the survey index and is able to emulate the cohort decay observed in the compositional data in recent years. Overall, *21.12_Proposed_No_Skip_Spawn* appears to perform better and provide more consistent projection outputs, thereby eliminating the need for reductions from maximum ABC. Although we have presented a large number of alternate runs and model bridging exercises in our quest to identify the best performing and parsimonious parametrization of a recent selectivity time block (Appendices 3G and 3H), we have not pursued any of the alternate natural mortality parametrizations, developed in the 2020 SAFE, further. None of these models provided improved or more reliable performance, but we will continue to explore age- or time-varying natural mortality parametrization in coming years.

"The SSC requests that the authors present a bridging exercise where specific impacts of assuming a 2016 time block for fishery catchability are separated from that of assuming a recent shift in fishery and survey selectivity in the context of new data available for this assessment." (SSC Oct. 2021)

A full model bridging exercise is provided in Appendix 3H, as requested. The approach utilizes only data through 2020 (the same as other model development steps presented to the SSC in Oct. 2021), but we do not believe that the new data has any strong influence on the results or interpretations of model performance.

"With respect to changes in length-at-age and weight-at-age, the SSC agrees with the JGPT that for the current time the updated weight and growth data from 1996 – present should be used in the model. The SSC also agrees with the JGPT that additional work is needed on time blocks and if time blocks are brought forward, length-at-age and weight-at-age blocks should be consistent." (SSC Oct. 2021)

Per the SSC and PT requests, the authors developed weight-at-age for the pre-1996 time block using the length-weight parameters from the current time block and applying it to the historic length-at-age data (because no weight data was collected from the longline survey prior to 1996). However, the resulting historic weight-at-age curve differs substantially than the weight-at-age for the current time block (see Appendix 3E). Aside from being unrealistic, it also results in an abrupt discontinuity in the resulting SSB time series resulting in unbelievable and unreliable model outputs (see Appendix 3H). Given the issues with the historic data, the authors do not recommend using these data to develop weight-at-age curves.

"The SSC thanks the authors for their exploration of methods to incorporate the effects of skip spawning on the maturity schedule. The SSC requests that the authors include a figure with the updated author-preferred maturity curve with and without skip spawning, and the status quo maturity curve. The figure should include uncertainty estimates in the fitted relationship to inform sizes where additional sampling should occur and to provide for comparison with previously applied curves. The analysts have only two years of information from a limited geographic region in the GOA to inform skip spawning across the entire coast of Alaska. These two years differ substantially in the amount of skip spawning observed. The SSC agrees that additional data is needed to fully inform this option and the SSC supports the recommendation by Williams and Rodgveller for expanded data collection in 2022. The SSC recommends that future analyses of maturity and skip spawning include ageing imprecision, which may affect the perceived importance of length and age vs. only age on the biological process of maturity." (SSC Oct. 2021)

The updated maturity figure now includes uncertainty estimates and is provided in Figure 3.12c. Given the caveats noted by the SSC and also raised at the PT regarding using the available skipped spawning information, the authors have revised the model being proposed for the 2021 SAFE to no longer include skipped spawning information. Thus, the proposed model (*21.12_Proposed_No_Skip_Spawn*) utilizes the recently collected histological data and estimates age-based maturity using a GLM. This model is analyzed in detail in Appendix 3H and explained further in the maturity section of the 2021 SAFE.

"The SSC agrees that selection of a new post-2016 fishery CPUE catchability and selectivity time period is justified given the observed changes in distribution, gear and fisher behavior. The SSC requests that the author justify why longline survey selectivity and catchability would change at the same time as the fishery. The SSC notes that the proposed mechanisms for shifting selectivity at the youngest ages may already be changing again as the recent strong cohorts leave these ages. Therefore consideration of what selectivity to use for short- and longer-term projections may be increasingly important. The SSC requests consideration of alternative methods for constraining time varying selectivity as an alternative to ad hoc time blocks, in order to avoid future bias if/when selectivity changes occur." (SSC Oct. 2021)

Extensive justification and rationale for incorporating a recent selectivity time block in the longline survey is provided in the Model Updates and Justification section along with Appendices 3G and 3H. In terms of justification for the recent longline survey selectivity time block, there has been increased observations of young, small sablefish in deep water survey strata (> 400m) in recent years. Thus, it appears that small fish are moving into deeper water at earlier ages (see Figure 3.49), given that juveniles historically have been found in shallower depths (e.g., as observed in the trawl survey, which catches primarily small, juvenile sablefish and only samples consistently in shallower depths, < 500m; Figures 3.20 – 3.22). Similarly, because increases in RPNs in deeper water have primarily only occurred for small fish, the apparent increase in availability seems to only be occurring for certain age or size classes. Therefore, given the lack of any significant changes in survey protocols, it would seem reasonable to allow selectivity to vary in recent years, but not catchability (as the latter would imply a consistent change in availability across all year classes). Of course, this is only a hypothesis relating to availability of small, juvenile fish, and continued work and analysis of available data on distribution of year classes will be explored.

Future research will also explore alternate approaches to modeling time-varying selectivity, including an ongoing effort with the Woods Hole Assessment Model (WHAM) framework to better estimate unobserved variability in selectivity patterns and implement non-parametric selectivity options. Although the concerns raised regarding the change of selectivity as large year classes exit the fishery and survey may be valid, the authors note that additional recent year classes appear to be as large, if not larger, than those that were initially regarded as historically large. In particular, the recent 2017 and 2018 year classes now appear to be larger than the 2014 year class, while the 2016 year class appears to be the largest on record (and is still relatively young). There is also evidence (e.g., from the ADF&G survey) that the 2019 year class may also be quite large. To explore the impact of selectivity on projections, an alternate projection using the pre-2016 IFQ fixed gear fishery selectivity curve for the projection years was performed. The results from these projections indicated essentially no impact on the ABCs (33,218 mt for 2022 and 36,982 mt for 2023) and resulted in an increase in catch of about 1,000 mt per year over the course of the 10 year projection time period (i.e., due to the lower removal of juvenile fish, which allows a greater proportion of recent year classes to survive and add to SSB over the medium term). Although we agree that careful monitoring of both the fishery dynamics and resource dynamics is warranted to appropriately parametrize future changes in selectivity, we do not believe that it is a major concern at the time being, especially given the annual production of the sablefish assessment (i.e., projections are only used for 1 year of catch advice). Again, further investigations of alternate parametrizations of selectivity (e.g., non-parametric or random walk formulations) are ongoing and will likely be incorporated into future assessment models.

"The SSC recommends that the following models are advanced in 2021: 16.5, 21.10, a model that includes the features of 21.10 without the skip spawning option, and a model that addresses possible alternative treatment of longline survey selectivity and catchability." (SSC Oct. 2021)

As noted previously, the authors have slightly revised the proposed 2021 model since the October SSC meeting. The proposed model (*21.12_Proposed_No_Skip_Spawn*) matches this SSC request to include a model without skipped spawning. We also demonstrate the differences from the original *21.10_Proposed* in the Sensitivity Runs section, but do not include the full suite of diagnostics as the two models demonstrate essentially the same performance with only slight differences in SSB in the terminal year. Similarly, in the Sensitivity Runs section we provide comparisons and basic results for alternate runs requested by the SSC including a model without a recent survey selectivity time block (*21.28_Fish_q+Sel_Only*) along with a model that does not include a recent fishery catchability time block (*21.29_Fish_Sel_Srvy_Sel*). These models along with the full factorial suite of possible model combinations are compared and described in Appendix 3H. However, we do not present any models that include 'an alternate treatment of longline survey selectivity and catchability'. As explained in the Assessment Update Summary section and Appendices 3G and 3H, we believe that the proposed parametrization is appropriate and there was not enough time to pursue alternate parametrizations (though further research on this topic is ongoing). We also provide the full suite of results, plots, and projections for model *16.5_Cont* in Appendix 3I.

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

"The SSC repeats its previous request to update information on whale depredation. Given that whale depredation is incorporated into the assessment, the ecosystem driver should be regularly updated, especially as the fishery is undergoing rapid change in the prevalence of pot gear which should not be subject to depredation."

Once again, the authors emphasize that updated whale depredation coefficients will not have a large impact on the assessment or ABC calculations given that they are approximately 300 t per annum compared to a quota of 30,000 t. Similarly, because there is no depredation on pot gear and data from observed trips using pot gear are incorporated into the models used to estimate depredation, the increasing use of pot gear is implicitly incorporated into the depredation estimates. It is likely that this is one reason that depredation estimates have been decreasing in the central GOA since 2017 (Figure 3.15). Given the increasing retrospective patterns and desire to address model structure and parametrization in recent years, we emphasized model parametrization over updating whale coefficients in 2021. However, Megan

Williams, who originally developed the whale depredation coefficients and associated code, has volunteered to update the approach and has committed to having these estimates available for 2022. Thus, we expect new whale depredation coefficients to be available for the 2022 SAFE.

The SSC adds or reiterates the following additional recommendations for future assessments:
(SSC Dec. 2020)

- *Consider proposing modifications to the Tier 3 HCR to better match the dynamics of sablefish. This may require simulation of episodic and highly skewed recruitment dynamics. Consideration of the potential evidence for maternal effects beyond fecundity, since fecundity is already addressed by managing female spawning biomass. Provide evidence that maintaining a broad distribution of spawning ages has tangible long-term benefits to the stock.*

  A project with the goal of addressing the robustness of the NPFMC harvest control rule for long-lived species that exhibit spasmodic recruitment has been funded and initiated. A postdoc is currently being sought and will be hired via the University of Alaska with Professor Curry Cunningham as the advisor and multiple AFSC/MESA co-advisors. The goal of the project is to develop an MSE for sablefish that is able to directly simulate extreme spasmodic recruitment events and explore the impact of different harvest strategies. However, the authors would once again like to emphasize that it has been well established for sablefish-like species that capped management procedures and 'inventory management' strategies, which aim to maximize the number of years of good catch, often better maximize value and profit for the industry (along with maintaining the resource within safe biological limits) compared to HCRs that maximize yearly catch (Licandeo et al., 2020). Similarly, basing the HCR on an indicator of older, fully mature fish can avoid raising ABCs too rapidly when extreme year classes first enter the fishery and population. Although SSB is typically a good indicator of mature biomass, extreme recruitment events can inflate SSB if even a small proportion of recent year classes are assumed to be mature (e.g., as is the case with sablefish). It is recommended that a better metric for sablefish for use with the NPFMC HCR might be SSB of year classes that are at least ~80% mature (i.e., age-10+ fish; Table 3.12). A management procedure that caps catches in years of extreme recruitment and utilizes an indicator or metric that better emphasizes the SSB of fully mature cohorts would likely help to better maximize value for the directed fishery and ensure long-term healthy population sizes. The implementation of an MSE for sablefish will likely help demonstrate these facets and identify a more robust HCR for sablefish.

- *For next year's specifications, provide the yield associated with F40% for a range of apportionment methods such that the feedback from apportionment to SPR can be better understood.*

  It is unclear what is being requested by the SSC, as the current HCR and associated projections provide the yield associated with fishing at *F40%*, which is then apportioned to each area to develop the region-specific ABCs. We emphasize that because sablefish appears to be a single reproductive unit with high mobility, regional SPRs may not have strong biological meaning (Bosley et al., 2019). Additionally, without a spatial assessment, it is difficult to determine the level of biomass within different regions. Partitioning total stock biomass via longline survey regional catch is a crude approximation (e.g. Table 3.16b). Further analyses using these regional biomass partition calculations is not recommended by the authors, and it is likely that attempting to decipher regional sablefish dynamics from such analyses may provide unreliable and potentially biased perceptions. For 2021 the harvest rate (catch / biomass) associated with observed and projected catches and the various apportionment approaches is presented (Table

3.16c and in the apportionment tables). However these do not account for regional selectivity dynamics (i.e., due to trawl : fixed gear catch splits) and do not incorporate feedback between apportionment and biomass or yield projections. Thus, this may not fulfill the exact SSC request. Again, we caution against emphasizing these results or others based on biomass partitioning due to the extreme uncertainty associated with using longline survey regional RPWs as a proxy for future regional biomass distributions.

- *Provide an update on the status of fishery logbook information, including methods for calculating and including pot gear into the time series. The SSC requests that the authors identify specific fishery data gaps and potential approaches to address these gaps. The authors and agency staff are encouraged to work with the fishing industry to fill these gaps.*

  As noted below, logbook data is provided by the IPHC through an IFQ cost recovery grant. The 2020 logbook data was provided to authors late and it was not available in time for this year's SAFE. Therefore, an updated 2020 hook and line fishery CPUE index data point was not incorporated into the 2021 model. The future of the logbook data is uncertain due to increasing costs and limited funding in support of the grant. The SSC received a presentation regarding the status of incorporating electronic monitoring (EM) data into AFSC assessments during the October meeting. We hope to be able to develop catch rate indices from EM data in the future, but being able to determine both catch rates and effort from EM data is a work in progress. Incorporating pot gear into the assessment model and into the CPUE index is the focal point of a graduate student project funded by MESA under the supervision of Professor Curry Cunningham at the University of Alaska. It is expected that results of this work will be available to help inform the 2023 SAFE.

- *Support further genetic work toward a better understanding of stock structure within the coast wide distribution.*

  Genetic work for sablefish is ongoing at the AFSC. However, initial results indicate that sablefish in Alaskan waters likely constitute a single genetic stock, as has been reported by previous genetic analyses.

- *Consider what field studies are needed to better understand the potential for increased reproductive output, reduced rates of skip-spawning, and/or quality by large/old female sablefish.*

  Further work on understanding sablefish spawning and reproduction are a high priority. Funding is being sought for energetic and maturity analyses over a broad geographic range.

- *Evaluate the use of the mean vs. median recruitment estimates to better understand whether sequential reductions in large estimated recruitments may be related to the reduction in uncertainty as well as other factors. Perhaps review the material produced by the 2014 Plan Team working group on recruitment modelling for additional guidance.*

  Although an important topic, this is an issue suited for a broader research team across the AFSC. We look forward to incorporating guidance on this topic via any updates to the AFSC projection model in the future.

- *Include a summary of information available on the historical use of sablefish by coastal communities in the next ESP.*

Given that a full ESP was not implemented this year, new indicators were not incorporated. A request for indicators will be submitted for the Alaska sablefish ESP in January 2022 at the start of the new ESP cycle.

"The SSC was concerned that the CPUE data from the commercial fishery may not be available from the 2020 fishery. The SSC notes that this information is an important part of this assessment and requests that the author explore how this information could be processed more quickly."

The fishery CPUE logbook data is provided to the AFSC by the IPHC through their port sampling program. As such, the IPHC is responsible for collecting, collating, and QA/QC of the data that goes into the CPUE index (except for observer data, as the two datasets are combined to form the CPUE index). The collection of logbook data by the IPHC is supported through grants, which were not fully funded in 2020. Because of funding shortages, the logbook data was not prioritized resulting in delays and delivery to the AFSC during the last week of October. Thus, it was provided too late to incorporate into the assessment or include in the SAFE write-up. The authors will continue to advocate for receiving this data in time for inclusion in the assessment, but recognize, in light of funding shortages, that the sablefish logbook data are not prioritized over other mandated activities led by the IPHC. We are hopeful that this data lag is a one-time delay, but, given the nature of the funding situation, it is uncertain whether there will be similar issues in the future.

Plan Team Concerns Specific to the Sablefish Assessment

In this section, we list new or outstanding PT comments specific to the last full Alaskan sablefish assessment in 2020 and model updates developed for 2021 and presented during the fall meetings.

"The Teams request that the next ESP include a thorough socioeconomic analysis of the impacts of the bycatch on various fleets." (PT Nov. 2020)

A request for indicators will be submitted for the Alaska sablefish ESP in January 2022 at the start of the new ESP cycle. We plan to include this socioeconomic analysis on the impacts of bycatch on various fleets within that request.

"The Teams request that the authors explore the spatial distribution of the top four year classes (within the timeframe of the assessment) in the fishery data (i.e., repeat Figure 3.23 from the SAFE chapter using fixed gear fishery data) and consider the changing fishery dynamics. The Teams request that this exploration consider how the spatial distribution of these year classes in both the fishery and survey may have changed with respect to changes in the environment, and if possible compare them to the spatial distribution of the 1977 year class (if possible, given available data)." (PT Nov. 2020)

Given time constraints, this was not completed in time for the 2021 SAFE. We will attempt to have this analysis ready for the PT meeting or for the next SAFE cycle in 2022.

"The Teams recommended that, to the extent practical, the authors look into bycatch in the foreign pollock fishery to evaluate its impact on the sablefish stock, particularly if a similar pattern occurred when there was a large 1977 year class." (PT Nov. 2020)

The best available data for the pollock trawl fishery is already included in the catch time series and its impact seems to show a decline after the large recruitments in the late 1970s, which resulted in relatively high quotas.

"The Teams requested that authors explore vessel effects on the fishery CPUE indices, given the changing fleet dynamics and loss of data due to vessels switching to EM." (PT Nov. 2020)

"The Teams also recommended that the authors evaluate the CPUE index further and include pot gear if data are available." (PT Nov. 2020)

"The Teams recommended an evaluation of EM's impact on data available for the assessment." (PT Nov. 2020)

As noted in responses to SSC comments, a graduate student at UAF is currently working on incorporating pot gear into the CPUE index. Similarly, AFSC researchers are working on methods to develop catch rate and effort metrics from EM data. In the coming years, we expect to have analyses that include these two data sources into CPUE calculations.

"The Teams also requested that the authors revisit the age-independent natural mortality assumption, as age-specific natural mortality may be more appropriate." (PT Nov. 2020)

As noted in the response to the SSC comments, further exploration of natural mortality was not a priority this year, given the variety of other model parametrization changes incorporated into the proposed model. We will continue to explore alternate natural mortality parametrizations in the future, as time permits.

"The Teams requested that the authors continue their investigation into updating the maturity curve, which seems to suggest a shift to later age at maturity." (PT Nov. 2020)

As noted, the proposed 2021 model updates maturity using recently collected histological data, which is believed to better represent sablefish maturity compared to macroscopically collected data from the late 1970s that previously informed the sablefish maturity curve.

"The Teams recommended conducting investigations into cohort effects on growth.

The growth modeling produced a constant weight-at-age schedule, which is estimated from recent data (because there are limited observations on weight available in the early years); however, length at age is estimated as varying between two time blocks.

Because time-varying length at age would be expected to produce time-varying weight at age, the Teams recommended modeling weight-at-age in the same time blocks as used for length-at-age. This could be done by applying a length-weight relationship (estimated from the more recent data) to the estimates of length-at-age from the two time blocks." (PT Sept. 2021)

As noted in the response to SSC comments, development of a historical weight-at-age block that matched the historic growth regime was undertaken (Appendix 3E). However, the results demonstrated strong differences in weight between the two blocks. After running the assessment with the two weight blocks, it was determined that this model was unreliable given the resulting discontinuity in SSB caused by the strong transition in weight (Appendix 3H). Given sampling issues (and associated lack of weight data) prior to 1996, it is not recommended that these data be used to estimate weight-at-age. Cohort effects on growth will be explored in the future.

"The Teams agreed with the authors' approach and recommended the following: (1) that field studies to determine sablefish maturity be conducted in areas besides the central GOA, (2) that ageing error and uncertainty in length-at-age be considered in the determination of age/length-based maturity, and (3) that

potential year class effects that could skew the functional maturity curve be investigated." (PT Sept. 2021)

Although none of these were explored for the 2021 SAFE, they will be considered in the future if alternate maturity curves are again considered for inclusion in the model. However, the authors revised their recommendations regarding which maturity curve to include in the final proposed 2021 model. Whereas during the September PT meetings model *21.10_Proposed* utilized an age-length based GAM model that incorporated skipped spawning information, we are now recommending that an age-based GLM that does not include skipped spawning information be utilized (model *21.12_Proposed_No_Skip_Spawn*). Based on PT and SSC concerns and discussions, we determined that uncertainty in skipped spawning was likely too large to incorporate at this time. However, we hope to collect more data on skipped spawning from a broader geographic range and revisit sablefish maturity in the near future.

"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." (PT Nov. 2019)

"The Teams support all of these modeling changes, view the proposed model as an improvement relative to the current assessment model, and anticipate seeing comparisons between the proposed and existing models in the November Team meeting. The Teams recommended incorporating updated length and weight at age resulting from the growth modeling recommendations listed above (i.e., modeling growth for all available data, and consistency in modeled time-variation between weight-at-age and length-at-age) into the assessment when these analyses are completed." (PT Sept. 2021)

The final proposed model for the 2021 SAFE (model *21.12_Proposed_No_Skip_Spawn*) is essentially identical to model *21.10_Proposed* and demonstrates almost exactly the same model performance, except it removes the uncertainty associated with skipped spawning; thus, we believe the PT will deem it acceptable. However, as noted, adding a historical time block for weight-at-age to match the growth time blocks resulted in implausible weight-at-age values and this model change has not been incorporated in the final proposed model. As noted, this new model utilizes an additional selectivity time block that results in more consistent estimates of recent cohort sizes and resolves residual patterns in fits to the abundance indices.

Concerns Specific to Sablefish Apportionment

"The GPT also discussed the Spatial Management Policy with regard to sablefish. For sablefish, the SSC notes that scientific information indicates that there is considerable movement among management areas, and so, as long as ABC apportionment does not vary too greatly from estimated biomass by management area, there is no expected biological conservation concern. As the SSC's role is to focus on potential biological concerns, the SSC is not asking for specific action on sablefish under the Spatial Management Policy from the Council. However, if the Council wishes to explore the Spatial Management Policy for sablefish, the SSC would certainly participate and would focus on providing guidance regarding potential conservation concerns or sharing whether there is additional information that the Council may want to consider." (SSC Dec 2020)

"Therefore, the SSC suggests that the Council provide guidance to the analysts regarding any additional objectives for apportionment (e.g., socio-economic considerations, use of fishery information, etc.) such that alternatives for future specifications (2022+) can be evaluated against these objectives in addition to both survey distribution and overall exploitation rates under different apportionment methods. However,

the SSC recommends that authors consider apportionment methods that adhere to the goals of avoiding biological concerns by generally following survey estimates, while addressing the NPFMC's allocation goals. The SSC cautions against apportionment methods that differ appreciably from the surveyed distribution, as these may lead to future biological concerns." (SSC Dec. 2020)

"The Teams discussed additional information that could be provided in the future to help inform the implications of varying apportionment schemes and what the best forum is for providing that information outside of the assessment. Specifically, they requested calculation of the differential exploitation rates by area that would be realized under different apportionment schemes given the default allocation of catch by area to fixed and trawl gear (i.e., 50:50 in BSAI; 95:5 in GOA WYAK, SEO; rest of GOA 80:20). While information is currently sufficient to make changes to the apportionment for 2021, discussion noted that a separate workshop could be held in 2021 to provide additional information on a range of apportionments including both differential F rates as well as socio-economic considerations that are not included in the assessment. The Teams note that proposed alternate methods for computing subarea ABCs constitute "spatial management measures" that are referenced in Step 1 of the Council's Spatial Management Policy. The Teams recommend that the SSC and Council consider application of the Spatial Management Policy and thus host a Council workshop in 2021 to evaluate both the fishing mortality rates by gear associated with different apportionment schemes as well as the management and socio-economic considerations of alternatives. This workshop would satisfy step 2 of the policy, which is to "identify the economic, social, and management implications and potential options for management response". The Teams also referred back to the SSC requests from the June 2020 meeting regarding additional analyses, noting that these should also be included for the workshop. As opposed to the Teams convening a workshop on their own, convening this workshop as an outgrowth of the Council's spatial management policy is more consistent with the intent to pull in a broader range of Council and NMFS RO staff to address management concerns that are outside of the scope of the assessment and the expertise of the stock assessment authors." (PT Nov. 2020)

No specific updates to apportionment have been undertaken. The authors reemphasize that developing metrics associated with regional biomass partitioning is likely to be problematic given the inherent uncertainty in regional biomass calculations and high cross-region mobility of sablefish. A postdoctoral researcher is currently being hired to work on developing a spatial research model for sablefish that will enable better estimation of spatial biomass and associated regional exploitation. We have provided estimates of regional harvest rates (catch / biomass) based on partitioned biomass, apportioned catch, and projected biomass and ABCs (Table 3.16c and apportionment summary tables). The approach does not account for spatial differences in selectivity due to trawl : fixed gear catch splits. Again, we caution against emphasizing these results or others based on biomass partitioning due the uncertainty associated with using longline survey regional RPWs as a proxy for regional biomass distributions.

The authors have not received requests for alternate apportionment strategies since the 2020 SAFE cycle. WE also note that the lack of CPUE data for 2020 prevents the exploration of some of the previously requested alternatives (e.g., the NPFMC apportionment strategy). Additionally, previously requested industry alternatives, such as basing apportionment on the distribution of large fish, was demonstrated to provide apportionment values that differ strongly from survey apportionment (and essentially emulate the previously utilized fixed apportionment). Due to the departure of the lead apportionment analyst, further apportionment explorations are on pause at this time. However, if specific guidance for alternate apportionment strategies (i.e., that can be reasonably expected to not diverge significantly from survey-based apportionment) is provided by the NPFMC, the analyses will be undertaken as soon as is feasible and results will be disseminated.

"The SSC inquired about how the authors would advance this assessment toward the 5-year survey average apportionment approach in the final SAFE. The SSC notes that a 50% step (from the 2021

apportionment toward the 5-year average) would be consistent with the SSC's recommendation of a 25% step in 2021 and the intent of moving to full use of the 5-year average approach in the future. The SSC recommends presenting an alternative using a 100% step (the 5-year average) for comparison and to guide future consideration of the method." (SSC Oct. 2021)

As requested, the 2021 SAFE provides a suite of apportionment options and stair steps. However, the authors note that it would seem more appropriate, and in line with the approach implemented by the SSC in 2020, to use a 50% step from the 2020 fixed apportionment towards the 2021 SAFE 5-year survey average apportionment. Given that the 5-year average apportionment changes with each subsequent data year, taking stair steps between moving averages may be a bit a confusing and problematic. Utilizing a fixed base line based on the fixed apportionment utilized to set the 2020 ABC and applying successive stair steps from that value towards the 5-year average apportionment in a given year seems more straightforward. Utilizing this rationale results in the following series of ABC apportionment approaches: 2021 ABC apportionment utilizes a 25% stair step from fixed apportionment towards the 2020 5-year average survey apportionment; 2022 ABC utilizes a 50% stair step from fixed apportionment towards the 2021 5-year average survey apportionment; 2023 ABC utilizes a 75% stair step from fixed apportionment towards the 2022 5-year average survey apportionment; and 2024 ABC utilizes the full 2023 5-year average survey apportionment. However, other stair step approaches can be implemented upon request.

Introduction

Distribution

Sablefish (*Anoplopoma fimbria*) primarily 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. Juvenile sablefish that settle on the BS shelf are generally hypothesized to return to the deeper waters of the GOA as they mature, resulting in a general counter clockwise ontogenetic movement pattern (Sasaki, 1985; Hanselman et al., 2015). However, this pattern may not hold for recent year classes based on increasing longline survey RPNs in the BS at older ages and larger sizes, which could indicate that recent cohorts may be settling and remaining in the BS and Western GOA regions (Figures 3.23 and 3.49). Similarly, non-pelagic trawl catches in the BS region of recent cohorts have been increasing in the last few years, potentially indicating that these cohorts are remaining resident in the region as they grow (Appendix 3D). However, it is too early to fully understand the distributional dynamics of the large 2014, 2016, and 2017 (and potentially 2018 and 2019) year classes.

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 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.). More recently, gulf wide reports of abundant young of the year and subsequent age-1 fish began in 2014 and have been received at varying levels since that time. 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 many “6 inchers,” everywhere from Deep Inlet near Sitka to Cross Sound. 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 2019 year classes) in record numbers (see Appendix 3D), finding them “unavoidable,” from near Dutch Harbor to the Russian line and at all depths.

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

The time series of sampling in SJBB continued in 2021 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 13, 15, and 17, 2021. The ADFG fished four rods for 3 days and tagged ~140 juvenile sablefish. This number was down from 437 tagged sablefish in 2020 for an equivalent number of rod hours.

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 through 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.

2021 Sablefish Tag Program Recap

The Auke Bay Laboratory continued the 40+ year time series of sablefish tagging in 2021. Approximately 6,155 sablefish were tagged on the annual NMFS longline survey. Approximately 270 sablefish tags have been recovered in 2021 to date. Of those recovered tags, the longest time at liberty was a little over 41 years (15,110 days), the shortest recovered tag at liberty was for 35 days, and the greatest distance traveled was 2,357 nautical miles from a fish tagged in the Northwest Aleutian Islands on 5/25/1982 and recovered off the Oregon coast on 4/19/2021.

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.

IFQ management increased fishery catch rates and decreased the harvest of immature fish after implementation (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). However, the influx of large cohorts since 2016 has likely increased landings of immature fish in recent years.

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 and GOA (since 2017) IFQ fishery is allowed under regulation. Pot gear use in the BSAI began to increase in 2000 and the average percent of sablefish caught in pots from 2000 - 2021 in the BSAI was 43% 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 2017-2021, with a time series high of 77% in 2021 (as of October 25, 2021). The percent of fixed gear catch in the BS by pot gear was continuously high from 2000 - 2021, with an average of 61% of the fixed gear catch in pots. The AI matched the overall BSAI trend more closely, with highs in 2003 - 2007 and from 2017 - 2021, with the series high in 2021 at 76%. 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 on 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 ranged from 3 - 76% from 2000 - 2021. 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 24% in 2019 and then again to 47% in 2020. In 2021, the majority of removals by the fixed gear fleet was taken by pot gear (69%). The overall catch in pots in the GOA increased each year from 898 t in 2017 to 7,837 t in 2021, while hook and line catch has decreased from 8,163 t to 3,470 t (as of October 25, 2021). 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 deep-water 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 Aleutian Islands. In recent years there have been unprecedented increases in sablefish trawl removals (see the Bycatch and Discards section and Appendix 3D for a discussion of recent BS trawl fishery removals), 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 has constituted around 10% of total catch, but this proportion increased rapidly starting around 2016 and was at 31% in 2019 and 39% in 2020 (Table 3.1). A majority of these increases in the 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 trawl catch from 257 t in 2016 to around 4,500 t in 2020 (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. However, trawl removals appear to be diminishing again, with only 24% of removals being taken by trawl gear in 2021 (as of October 25, 2021). Reductions in trawl removals are likely being driven by the reduction in sablefish interactions within the pelagic trawl fleet in the Bering Sea (Appendix 3D), and BS trawl removals of 2,324 t were similar to the 2019 levels (Table 3.2).

Five State of Alaska fisheries land sablefish outside the IFQ program; the major State fisheries occur in Prince William Sound, Chatham Strait, and Clarence Strait with minor fisheries in the northern GOA and AI. The minor state fisheries were established by the State of Alaska in 1995, the same time that 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 were 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, 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 were 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. Since 2000, Amendment 41 banned trawling in the EY/SE management area, thus, the 5% trawl allocation for the EY/SE area has been added to the WY trawl allocation since that time. 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. For the BSAI, the MRA is 1% for all target species, except the MRA is 15% for fisheries that target flathead sole, Greenland turbot, northern rockfish, Pacific ocean perch, shortraker, and other rockfish.

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 1980s, which coincided with the domestic fishery expansion. Catches declined during the 1990s, increased in the early 2000s, and then declined to near 12,000 t in 2016. In the last five years, catches have continually increased to around 19,000 t in 2020, which is on par with removals from the mid-2000s (Table 3.1). Removals in 2021 are expected to be slightly higher than 2020, though current removals, 17,463 t (as of October 25, 2021), remain slightly below the 2020 value. Although increasing catch over the previous five years was associated with increasing trawl removals, directed fixed gear catch increased in 2021 whereas trawl removals decreased for the first time since 2014 (Table 3.1, Figure 3.1). TACs in the GOA are often 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. 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). The BS ABC was exceeded once again in 2021, whereas other regions appear to be below their associated ABCs (as of October 25, 2021) and total removals are well below the Alaska stock ABC.

Discards and Bycatch

Sablefish discards in groundfish target fisheries are highest in the hook and line along with trawl gear types, but the predominant source varies over times and across regions (Table 3.4). In both the BSAI and GOA in recent years, trawl gears have constituted the primary source of discards (Table 3.4). Generally, discards of sablefish in pot gear in non-sablefish fisheries has been low (pot includes halibut and Pacific cod targeting; Table 3.4). In 2020, sablefish removals in the midwater trawl walleye pollock fishery was at a high of 2,867 t and in 2021 it decreased to 956 t (as of 10/10/21); a moderate portion of the catch is discarded (trawl catch in the BS is discussed in more detail in appendix 3D). Catch was also substantial in the arrowtooth flounder fishery from 2020 - 2021 and the Kamchatka founder fishery from 2019 - 2021.

In the GOA, the rockfish trawl fishery had high catches of sablefish from 2018 - 2021 (641 - 801 t). Sablefish catch in the arrowtooth flounder fishery was high from 2017 - 2020 (490 - 1,190 t); however, in 2021, it dropped to 267 t.

Bycatch of targeted groundfish in the sablefish fishery has consistently been dominated by GOA shortspine thornyhead, rockfish, and sharks (Table 3.5). On average 75% of the shortspine thornyhead are retained and none of the shark. There is also substantial bycatch of GOA shortraker rockfish and arrowtooth flounder (Table 3.5). The next most abundant species are GOA other skates, longnose skate, and GOA rougheye rockfish.

Habitat areas of particular concern (HAPC) biota and non-target species are also caught in the sablefish fishery as bycatch. Every year the highest bycatch group are grenadiers (Table 3.6). The amount of grenadier has decreased each year since 2016 (Table 3.6). In 2016, 8,667 t of grenadier were removed, while this total decreased to 902 t in 2021. During the same period, the sablefish fishery has been increasingly adopting pot gear, which has less grenadier bycatch.

The predominant prohibited species catch (PSC) in the BSAI sablefish fisheries is golden king crab, of which nearly all are caught in pot gear (15,502 individuals / year on average for all gears in the BSAI; Table 3.7). Other crab species catches are highly variable. 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 13,535 in 2021 (Table 3.7, see “other” gear). Pacific halibut PSC is mostly in the GOA hook and line fishery. In 2021, the halibut bycatch estimate in the GOA is 46 t, but the mean from 2014 - 2021 was 308 t.

Discards of Small Sablefish in the Directed Fishery

Under current regulations, release of any sablefish by the sablefish IFQ fishery is prohibited so long as there is remaining IFQ for persons onboard the fishing vessel. Unusually large year classes of sablefish since 2014 have led to increased fishery catches of small sablefish with much lower economic value than more desirable (i.e., larger) market categories. The North Pacific Fishery Management Council (NPFMC) initiated action to consider allowing sablefish to be released by the IFQ fishery, prior to filling their quota, in December 2019. Two alternatives for analysis were developed by the Council: Alternative 1--no action; and Alternative 2--allow voluntary careful release of sablefish in the IFQ fishery.

The NPFMC conducted an initial review of the sablefish release allowance during its February 2021 meeting. While the intent of this action was to allow fishermen to release small sablefish, the elements/options did not include a size limit for sablefish or a mechanism for release mortalities to be deducted from IFQ accounts in-season. Few direct studies were available to narrow the range of potential sablefish discard mortality rates (DMRs), and any study specific to sablefish in Alaska would take years to provide useful results. Finally, the analysis highlighted substantial concerns related to fishery monitoring, catch accounting, and increased uncertainty in the sablefish stock assessment and estimation of biological reference points.

At the February 2021 NPFMC meeting, the Council suspended further action on this issue and requested that the IFQ Committee provide recommendations on the action’s relative priority. The IFQ Committee’s report to the Council in April 2021 indicated that the sablefish release allowance continued to be a high priority for the majority of the IFQ fleet. Given these recommendations, the Council made a motion at their October 2021 meeting to prepare and schedule for Council consideration of a small sablefish release Initial Review document when time and resources allowed.

Data

The following summarizes the data used for this assessment.

Table A. Data used in the 2021 model. Years in **bold** are data new to this assessment.

Source	Data	Years
Fixed gear fisheries	Catch	1960 – **2021**
Trawl fisheries	Catch	1960 – **2021**
Japanese longline fishery	Catch-per-unit-effort (CPUE)	1964 – 1981
U.S. fixed gear fishery	CPUE*, length	1990 – **2020**
	Age	1999 - **2020**
U.S. trawl fisheries	Length	1990,1991,1999, 2005 - **2020**
Japan-U.S. cooperative longline survey	CPUE, length	1979 - 1994
	Age	1981, 1983, 1985, 1987, 1989, 1991, 1993
Domestic longline survey	CPUE, length	1990 – **2021**
	Age	1996 - **2020**
NMFS GOA trawl survey	Abundance index	1984, 1987, 1990, 1993, 1996, 1999, 2003, 2005, 2007, 2009, 2011, 2013, 2015, 2017, 2019, **2021**
	Lengths	1984, 1987, 1990, 1993, 1996, 1999, 2003, 2005, 2007, 2009, 2011, 2013, 2015, 2017, 2019, **2021**

*2020 CPUE data was unavailable for the 2021 SAFE

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 Minor State fisheries 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 3.10, Figure 3.7). Attempts to estimate the amount of unreported catches by comparing reported catch to another measure of sablefish catch (i.e., sablefish imports to Japan, the primary buyer of sablefish) were attempted previously. However, the trends of reported catch and imports were similar, so the approach for catch reporting was altered in the 1999 assessment (Sigler et al. 1999). It was assumed that non-reporting was due to at-sea discards, thus discard estimates from 1994 to 1997 were applied 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 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 less than 1% 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 (Table 3.8). 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 (Table 3.8). 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 (Table 3.8). 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 alternate apportionment strategies. The mean CPUE is scaled to a relative population weight by the total management area size. 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.

The 2020 data from the sablefish volunteer logbook data was unavailable. Logbook data are provided through a grant with the International Pacific Halibut Commission (IPHC), whose staff collect the logbooks dockside and keypunch the data before providing it to the sablefish authors. Funding shortages prevented the data from being submitted in time for the assessment. The number of sets observed in 2020 were much lower than in previous years. These low sample sizes were likely due to: 1) an increase in pot fishing and electronic monitoring (EM) compared to trips using human observers and hook-and-line gear (i.e., the catch rate index is based only on hook and line gear at this time); 2) the observer deployment plan; and 3) the COVID-19 pandemic and the overall lower number of human observed trips for all fisheries in 2020. Work is ongoing to develop and incorporate catch rates from pot gear and EM data streams into the CPUE index, which may alleviate the reliance on logbook data in the future.

Observer Data

Defining Target

For analysis of observed sablefish catch rates in the sablefish directed 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, shortspine thornyhead, Pacific halibut, and Pacific cod. Whichever species 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.

Observed Catch

Without taking into account EM sets and focusing only on sablefish target sets that were used for catch rate analyses, the total weight of all sablefish in observed fixed gear sets represented 9% of the total catch (980 mt) in 2020. When looking only at pot gear, it increases to 10.5% and when just looking at HAL it decreases to 6.6%. The coverage is high in the BS (19%), but was mostly in the pot fishery. The percent of HAL catch observed in the AI was higher than in the BS. However, due to a low number of vessels this cannot be reported. The percent of fixed gear catch observed in the GOA ranged from 3 - 8%. Again, it is important to note that these data only includes sets where there was sufficient data to use for CPUE calculations.

Whales

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 13% in the BS, 1% in the AI, 3% in the WG, and 1% in the CG. Likely, because of small sample sizes, the annual range in the rate of depredation is 3 - 26% in the BS. Within the non-confidential time period in the AI (i.e., prior to 2015), depredation rates were under 4%. In the WG whale depredation has been variable, but in the majority of years it has been less than 7% (Figure A).

Observers also record sperm whale depredation; however, determining if sperm whales are depredating can be subjective, because they do not take a large majority of the catch like killer whales do. In the observer data, sperm whale depredation occurs in the GOA and less so in the AI. Depredation in the CG was highest in 2020, at 6% (Figure A). In the WY and EY/SE areas peaks were around 17% and 18%, respectively, which were the highest rates in the GOA. Both of these data points are not shown in the time series due to confidentially.

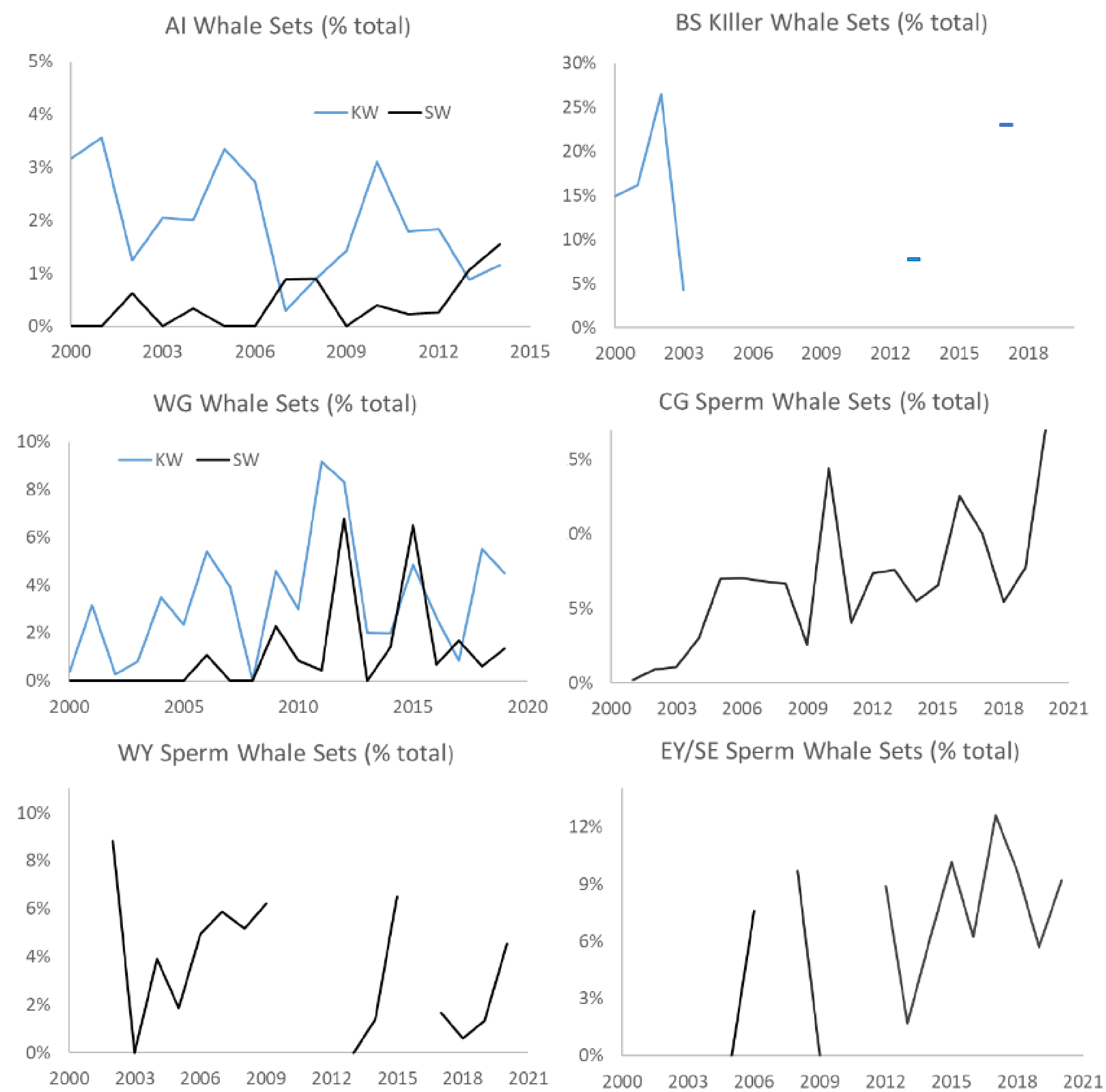

Figure A. Percent of human observed, sablefish targeted longline sets with whale depredation by FMP sub-area. Years with fewer than three vessels were not included due to confidentiality. Note that the x- and y-axes vary by panel.

CPUE

In 2020, there were increases in CPUE in every area, with the exception of a stable CPUE in the CG (Figure 3.5). Increases in CPUE were most notable in the BS, WG, and the EY/SE areas (Table 3.9, Figures 3.5 and 3.6). At the same time, the number of observed sets and vessels has declined in the AI, WG, CG, and more recently in the eastern GOA; in 2020 the number of observed HAL vessels decreased from 33 to 17 in the EY/SE, 24 to 6 in WY, and 25 to 5 in the CG (Table 3.9). Given continued increases in the AFSC longline survey from 2020 to 2021 in almost every region (Figure 3.5) and accounting for the one-year lag in fishery CPUE data compared to survey data in all areas, it is expected that further increases in CPUE are likely in observer data next year.

Logbook Data

Availability of 2020 Logbook Data

For the 2021 SAFE, 2020 logbook data were unavailable in time to analyze or incorporate into the assessment. Therefore, this section refers only to data through 2019.

Data Composition

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 for observer data. Logbook participation increased sharply in 2004 in all areas, primarily because the International Pacific Halibut Commission (IPHC) started collecting logbooks dockside in all areas. This increasing trend is likely due to the strong working relationship the IPHC has with fishermen, their diligence in collecting logbooks dockside, and because many vessels < 60 feet are now participating in the program voluntarily. In 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 and 6% of the catch was covered by human observers in 2019 (increasing to 9% in 2020). Some data are included in both data sets if an observer was onboard and a logbook was turned in.

Whales

Since 2017, whale presence and gear depredation were included in logbooks as voluntary fields. All sets with whales are included in the data summarized below, including sets that were taken out of CPUE analysis for data quality reasons. Whale depredation may be more subjective than presence during hauling and so presence data is shown in Table B. Whale data increased in 2018 likely due to an increase in vessels using the new logbooks, which were first printed in 2017 and included whale information for the first time. From 2018 to 2019, whale data was stable in 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 (see Table B below). Sample sizes in the CG, WY, and EY were higher than in other areas and the level of participation ranged from 86 - 90% in 2019. The WG had the next highest number of samples (average of 513 sets), with lower participation (55 - 77%). The AI has fewer samples, but had high participation in 2018 and 2019 (96 and 99%).

Whale data from logbooks show that killer whale depredation increased in the AI and the WG from 2017 to 2019 (Table B). Sperm whale presence is lowest in the AI and increases as you go east, with a slight decline from WY to EY. There were no trends in presence among areas in the Gulf of Alaska. The rate of sperm whale presence in the WG was consistently around 11% of sets on average. Sperm whale presence was similarly even over time in the CG with 21% of sets having sperm whales present. In WY, there was a peak of 42% of sets with sperm whale presence in 2018, whereas it was lower in both 2017 and 2019. In EY, there was a slight downward trend with a decrease in 2019 from 31% to 25%.

Table B. Available longline logbook data from trips targeting sablefish by region and year, with a summary of data on marine mammal observations. 'Total Sets' is the total number of sets recorded in sablefish logbooks; 'Total Sets with Data' is the number of sets where information on marine mammal presence was recorded (i.e., including presence or absence); '% Sets with Data' is the fraction of sets where mammal data was recorded; '% Sets with Mammals' is the number of sets where mammal information was recorded that had a positive observation (i.e., presence); '% Killer Whales' is the number of sets where mammal information was recorded that had a positive observation of a killer whale; and '% Sperm Whales' is the number of sets where mammal information was recorded that had a positive observation of a sperm whale. 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 is presented for the Bering Sea due to small sample sizes and confidentiality concerns (C). No data is provided for 2020, because logbook data was not available in time for the 2021 SAFE.

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	24	14	10
CG	2017	2,635	1,822	69	22	1	21
	2018	3,085	2,624	85	23	1	22
	2019	2,822	2,473	88	22	2	20
WY	2017	2,203	1,488	68	36	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	31	1	30
	2018	2,009	1,785	89	32	0	31
	2019	2,163	1,851	86	25	0	25

CPUE

Because of larger sample sizes in the logbook data set compared to observer data, logbook confidence intervals are generally narrower. 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-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). The logbook data does not show an increase as of 2019, but observer data did not show any increases until 2020, and so we may see similar CPUE increases when the 2020 logbook becomes available.

<u>Longline CPUE</u>

The final CPUE index excludes sets where there was killer whale depredation in observer data, but no data have been excluded from logbooks due to whale depredation. 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). The combined CPUE index demonstrated steady declines from the mid-2000s until 2018, with a precipitous drop between 2015 and 2016 (Figure 3.4). However, the index increased in 2019 and it is expected that further increases are likely as new data become available from logbooks given recent trends in the observer and longline survey data (Figure 3.5).

Electronic Monitoring Catch Rate Data

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 sub-sample of video is 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, target, and more. Unlike data from sets with human observers, the EM data stream made available to authors does not include measured weights nor a measure of effort, such as the number of hooks and hook spacing. Therefore, as of this time we cannot use EM data to estimate hook and line CPUE. However, efforts are underway to make this data available to authors for next year's assessment cycle.

Table C provides the number of sets, vessels, and the extrapolated number and weight of sablefish observed using EM for longline and pot gear. These sets have been defined as targeting sablefish, because they had the highest weight in the set.

EM data is most prevalent in the CG, WY, and EY/SE areas (Table C). Data is available starting as early as 2015 for HAL gear in the eastern GOA and it has the highest number of vessels participating. Data from 2015 - 2017 are considered test years. The shift to EM was initiated on longline vessels in EY/SE and so higher participation is expected in this area, particularly because small vessels are prevalent in EY/SE, which can have capacity issues for the number of people onboard. Out of all areas and years, the highest number of longline sets reviewed from EM was in the CG in 2018 and 2019 (Figure B). After 2019, the number of sets decreased in the CG, WY, and EY/SE areas. This is likely related to a decrease in observing during COVID-19 and the movement from HAL to pot gear.

Vessels fishing pot gear have been observed using EM since 2019. The most vessels fishing pot gear with EM are found in the CG and EY/SE. The number increased rapidly in the CG in 2020, as pots became more utilized and EM increased in popularity. The number of sets reviewed from EM was stable from 2020 to 2021 (Figure B).

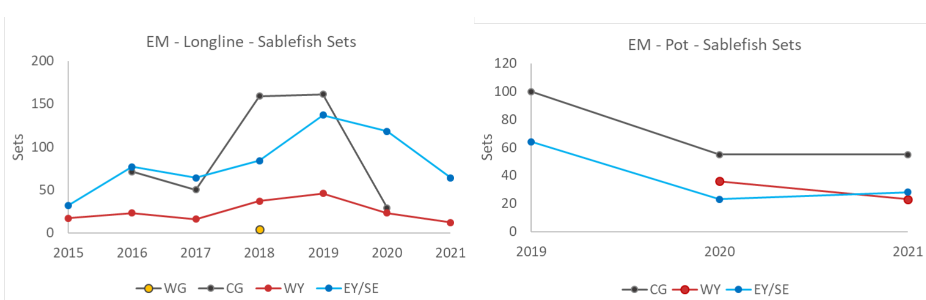

Figure B. The number of sets observed by FMP sub-area with electronic monitoring of longline (left panel) or pot gear (right panel). Data is not shown if there were fewer than 3 vessels.

Table C. The number of sets and vessels observed by electronic monitoring (EM) by year, FMP sub-area, and the extrapolated weight and number of sablefish in all EM sablefish directed sets. Data is listed separately for longline and pot gear. As of October 25, 2021, directed sablefish EM data currently extends to June 1, 2021. C indicates that the data is confidential, because there are fewer than three vessels.

	Longline					Pot			
Sub-area	Year	Vessels	Sets	Extrap. Wt	Extrap. #	Vessels	Sets	Extrap. Wt.	Extrap. #
AI	2018	C	-	-	-	No data	-	-	-
	2020	C	-	-	-	No data	-	-	-
BS	2020	C	-	-	-	No data	-	-	-
WG	2015	No Data	-	-	-				
	2016	No Data	-	-	-				
	2017	C	-	-	-	No data	-	-	-
	2018	C	-	-	-	No data	-	-	-
	2019	4	20	4,386	2,372	No data	-	-	-
	2020	C	-	-	-	6	26	18,185	10,087
	2021	C	-	-	-	No data	-	-	-
CG	2015	C	-	-	-				
	2016	3	71	39,697	13,078				
	2017	4	50	23,018	7,679	No data	-	-	-
	2018	19	159	79,679	30,844	No data	-	-	-
	2019	21	161	68,255	31,299	5	100	94,046	47,314
	2020	6	29	18,062	8,461	14	55	34,344	18,698
	2021	C	-	-	-	10	55	58,152	26,956
WY	2015	C	-	-	-				
	2016	3	23	32,014	9,769				
	2017	3	16	30,214	9,434	No data	-	-	-
	2018	9	37	41,882	14,423	C	-	-	-
	2019	12	46	33,065	12,988	C	-	-	-
	2020	8	23	23,241	8,649	7	36	12,609	5,296
	2021	4	12	7,852	3,698	3	23	39,419	13,003
EY/SE	2015	5	32	59,762	15,662				
	2016	12	77	97,363	27,204				
	2017	12	64	61,560	19,328	C	-	-	-
	2018	26	84	81,985	24,512	No data	-	-	-
	2019	30	137	121,810	37,127	5	64	29,921	16,532
	2020	30	95	93,696	31,278	7	23	12,465	4,484
	2021	12	64	67,496	21,419	7	28	25,856	9,670

Pot Fishery Effort and Catch Rates

In response to increased interest in using pot gear to catch sablefish, partially due to the increase in sperm whale depredation in the GOA, the North Pacific Fishery Management Council (NPFMC) passed a regulation in 2015 to permit pot fishing in the GOA starting with the 2017 fishery (81 FR 95435, January 27, 2017). The pot fishery is rapidly expanding throughout the GOA and was responsible for more than half of the fixed gear retained catch in Alaska in 2020, which was double the previous year pot catch. In WY in 2020, deliveries from pot trips increased by 370%, from 318,000 lbs. to 1,179,000 lbs. (Table D).

Table D. The count of vessels and the pounds of IFQ sablefish sold by gear type, area, and year. Areas include the Aleutian Islands (AI), Bering Sea (BS), Western GOA (WG), Central GOA (CG), West Yakutat (WY), and East Yakutat/Southeast (EY/SE). The column on the right (Count Vessels with 2 Gears) is the number of vessels that fished both pot and hook and line gear in that area and year. Data is confidential if it reflects fewer than 3 vessels.

		HAL		Pot		
FMP Subarea	**Year**	**Count Vessels**	**IFQ Sold (lbs.)**	**Count Vessels**	**IFQ Sold (lbs.)**	**Count Vessels with 2 Gears**
AI	2017	16	429,213	3	265,416	0
	2018	18	431,429	4	269,255	0
	2019	16	396,310	5	358,281	0
	2020	10	221,848	5	377,738	0
BS	2017	20	115,938	6	488,158	Confidential
	2018	19	162,074	7	462,033	0
	2019	17	180,040	7	602,809	0
	2020	15	148,579	12	895,506	3
WG	2017	54	1,759,939	6	488,243	0
	2018	50	1,599,184	11	781,649	Confidential
	2019	41	1,523,938	14	876,154	3
	2020	24	393,294	27	2,314,832	6
CG	2017	141	6,680,968	18	928,638	11
	2018	133	6,288,084	17	1,187,522	5
	2019	117	5,491,692	24	2,426,375	10
	2020	85	2,713,925	72	5,557,283	39
WY	2017	96	2,849,020	10	203,101	3
	2018	89	3,279,769	9	82,317	3
	2019	83	3,068,413	14	318,659	7
	2020	68	2,372,225	39	1,178,772	25
EY/SE	2017	164	5,411,114	10	285,291	4
	2018	169	5,925,810	12	310,968	9
	2019	157	5,741,841	14	508,811	4
	2020	143	5,420,364	44	1,067,486	26

Observer Sample Sizes and CPUE

In the observer data, the AI has fewer than three vessels in the majority of years and cannot be shown due to confidentiality concerns. In the BS, there is more data than in the AI, but vessel sample sizes decreased beginning in 2013, possibly related to observer restructuring. There are now four full years of pot fishing data in the Gulf of Alaska. The number of vessels and sets with observers has increased in the CG and EY/SE; however, it has decreased in the WG and WY (Table E). At the same time that observed trips were becoming less prevalent, EM was increasing in the GOA.

It is difficult to have confidence in the observer data CPUE estimates or trends over time for a few reasons. The proportion of each pot type (i.e., rigid pots compared to collapsible ‘slinky’ pots) has been shifting over time as slinky pots become more popular. These pots may have different fishing power than rigid pots and may have a different maximum catch due to their configuration and dimensions. As the proportion of slinky pots in the fishery is changing over time, this may introduce a bias in the time series. The standard errors of the CPUEs in Table E are large. This makes it difficult to discern any trends at this time. Overall, CPUE was higher in the GOA than in the BS, but that does not hold true in all years.

Logbook Sample Sizes and CPUE

Compared to observer data, there is more logbook data in all areas, except for the BS. The quantity of data increased in 2018 and 2019. The number of pot vessels participating in the logbook program is highest in the CG and WY. Vessels in the smaller length category (< 60 ft.) are not required to fill out a groundfish logbook, but do so to provide data for the assessment. There were few vessels < 60 ft. in the AI and BS, but 48% of vessels in the CG were, 53% in the WG, 57% in WY, and 79% in EY, on average.

Along with higher sample sizes, SEs were lower in the logbook data set 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, because, although the CPUE high was in 2018, it is accompanied by a high SE and so our confidence in this estimate is lower than in other years. The CPUEs in the AI were similar to those in the GOA, but are difficult to interpret due to low sample sizes.

Table E. The number of pot vessels (Vessels), pot set (Pots), string sets (Sets), catch-per-unit effort as lbs. / pot, and the standard error (SE) from human observers and logbooks. Data is for the Gulf of Alaska. When there are fewer than three vessels, the data is not shown due to confidentiality concerns (C). Data from 2020 is not currently available for logbooks.

Area	Source	Year	Vessels	Pots	Sets	Lbs. / pot	SE
CG	Observer	2017	3	1,156	28	28	12
		2018	7	5,230	167	45	14
		2019	7	3,271	97	58	12
		2020	7	9,555	229	48	12
	Logbook	2017	9	10,398	273	25	4
		2018	12	18,892	533	34	5
		2019	15	28,944	851	40	5
WG	Observer	2017	3	466	19	74	23
		2018	3	1,800	55	53	15
		2019	C	-	-	-	-
		2020	C	-	-	-	-
	Logbook	2017	3	2,936	74	49	12
		2018	8	12,628	344	33	9
		2019	7	11,653	246	34	6
WY	Observer	2017	C	-	-	-	-
		2018	5	758	35	64	25
		2019	4	859	32	70	22
		2020	C	-	-	-	-
	Logbook	2017	10	18,106	606	26	4
		2018	11	11,655	383	33	7
		2019	14	17,728	585	39	6
EY/SE	Observer	2017	C	-	-	-	-
		2018	3	358	21	48	20
		2019	4	1,236	54	60	7
		2020	7	1,524	46	44	8
	Logbook	2017	8	5,133	215	36	6
		2018	8	4,739	196	50	12
		2019	7	4,595	186	42	5

Pot Gear Data Challenges

Fishing practices and the gear being used by the pot sector are rapidly evolving. There is a new, coiled, tunnel shaped pot ('slinky pots') being adopted by many vessels, which is substantially different from traditional rigid pots. Slinky pots are lightweight and use less space on-deck, allowing vessels previously unable to fish pot gear to switch to slinky pots. Little is understood regarding the differences in fishing power among the different pot designs. Due to substantial differences in physical characteristics, it is likely that selectivity and CPUE may differ among pot designs. Currently, there is only one gear code assigned to sablefish pot gear for management purposes and no distinction can be made between pot types in existing observer data.

During this rapid increase of pot gear and slinky pot use in the GOA, vessels have experimented with using escape rings to help minimize catch of small sablefish; however, currently, no regulations exist requiring the use of escape rings or specifying an appropriate diameter to use. The use of escape rings and escape ring size affects the size distribution of catch and resultant CPUE, but, currently, there is no information on the size of escape rings or their prevalence in the fishery.

The short time series of pot data in the GOA contributes to the challenges of utilizing CPUE data at this time. A longer time series of ages, lengths, and CPUE is needed to adequately incorporate pot data into the assessment model as a unique fleet. However, work has been initiated to explore incorporating pot gear data into the combined CPUE index.

Pot Gear Research

1) Pot type has not been recorded in data sources thus far. Starting in 2022, there will be changes to how data are recorded:
    a. Fishery catch will be recorded as slinky or hard pots, so that both can be tracked through time.
    b. EM video review will include slinky and hard pot categories starting in 2022. This will be an important component, as EM has continued to grow in popularity, displacing observers.
    c. Observers will collect gear specifications in 2022 as part of a special project to quantify the gear types and configurations used in the fishery. Measurement types will include mesh size, escape ring presence and size, funnel size, dimensions, pot shape, and slinky or hard pot type. This will be coupled with a count of pots and the size distribution of the catch.
2) Research has begun on an approach to combine pot and HAL catch rate data with the goal of developing a single standardized CPUE index that accounts for both gear types and can be incorporated into the assessment.
3) Slinky pot CPUE and the size distribution of the catch was compared to data from HAL gear on the AFSC longline survey as a preliminary study using a handful of research days fishing both pot and HAL gear. Research efforts will continue on future surveys.

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 (stations < 500m). 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 Surveys

Overview: Catch, effort, age, length, weight (since 1996), and maturity data are collected during sablefish longline surveys. 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 provide 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, 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 2000s, 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 generally been steadily increasing with the 2021 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 2021 survey demonstrated similar CPUE for most stations compared to 2020 CPUE (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 six 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). Overall, longline survey RPNs have nearly tripled since time series lows in 2015, while RPWs have more than doubled over the same period. After increasing by 30% from 2019 to 2020, RPN growth has slowed, but still demonstrated a 9% increase in 2021. Similarly, RPWs increased by 45% in 2020 and 10% in 2021.

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, WG, and to a lesser extent in recent years in the CG (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 and consistent, including 11 affected stations in 2017, and 10 in 2019 and 2021 (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). In 2021, killer whales depredated at one station in the WG, which is the lowest number observed since 2010.

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 EG (WY and EY/SE) and the CG and occasionally depredate in the WG. In 2021, sperm whale depredation occurred at two stations in EY/SE, one station in the WY areas, and five stations in the CG (Table 3.11). Although sperm whales are sometimes observed in the WG, there has only been depredation observed at one station in 2012, 2017, and 2020; sperm whale depredation was not observed in the WG in 2021. In the AI, there was 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 historically, 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 increases in sperm whale presence and depredation at survey stations, as indicated by whale observations and results of recent studies, a statistical adjustment to survey catch rates using a general linear modeling approach was evaluated in the past (Hanselman et al. 2010). This approach demonstrated promise, but had issues with variance estimation and autocorrelation between samples. A new approach was subsequently developed using a generalized linear mixed model that resolved these issues (Hanselman et al. 2018), and has been used since 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. Comparison of RPNs from gully stations to the RPNs of slope stations in the GOA are undertaken to see if catches are comparable, or more importantly, if they portray different trends than the RPNs used in this assessment. Overall, gully catches in the GOA from 1990 - 2021 are well correlated with slope catches (correlation coefficient of 0.75; Figure 3.8b). 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. Since 2015, both slope and gully stations have increased rapidly with similar rates of increase (Figure 3.8b). In the future, we will continue to explore sablefish catch rates in gullies to determine their usefulness for indicating recruitment; they may also be useful for quantifying depredation, since sperm whales have rarely depredated on catches from gully stations.

<u>Trawl Surveys</u>

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. AI and BS 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; note that the survey was not conducted in 2020). GOA 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 also 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 was at its lowest level of the time series in 2013, but has more than quadrupled since that time, with a 40% increase from 2019 to a near time series high in 2021 (Table 3.10, Figure 3.4). These recent increases correspond well with associated trends in the longline survey RPWs and RPNs (Figures 3.3 – 3.4). The GOA trawl survey biomass estimates (< 500 m depth, Figure 3.4) and length data (< 500 m) are incorporated into the model.

IPHC Longline Survey

The IPHC conducts a longline survey each year to assess Pacific halibut. This survey differs from the AFSC longline survey in gear configuration and sampling design, but catches substantial numbers of sablefish. 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 longline 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. Despite these differences, qualitative comparisons to the other surveys that catch sablefish are useful and the IPHC survey may be considered for future incorporation into the model. However, length and age compositional data for sablefish are not taken on the IPHC survey, which may limit the usefulness of incorporating this survey into the sablefish assessment.

For comparison to the AFSC longline 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 compared the IPHC and the AFSC RPNs for the GOA (Figure 3.10a). The two series track moderately well, but the IPHC survey RPN has more variability. This is likely because it surveys shallower water on the shelf where younger sablefish reside and are more patchily distributed. Since the abundance of younger sablefish will be more variable as year classes pass through, the survey more closely resembles the NMFS GOA trawl survey index described above, which samples the same depths (Figure 3.10a). Note that the reduced relative abundance observed in the IPHC survey index in 2020 is likely due to survey disruptions and a reduced survey footprint because of the COVID-19 pandemic (i.e., no survey stations were sampled from the WGOA).

While the two longline surveys have shown consistent patterns for some years, they 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, reaching time series high (or near highs in the case of the trawl survey), particularly in the combined Western areas (Figures 3.3 – 3.4 and 3.7).

Population Trends in Nearby Regions Not Incorporated in the Assessment Model

Alaska Department of Fish and Game (ADFG) Southeast Inside Waters

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). For NSEI sablefish, longline survey CPUE increased dramatically (87%) from 2019 to 2020, the largest CPUE observation and largest inter-annual change on record for this index (Ehresmann and Olson, 2021a). However, there was a small (3%) reduction in the mark-recapture abundance index, which reflects a slight decline in the exploited sablefish stock in NSEI (Figure 3.11a). NSEI fishery CPUE declined strongly in the 1990s, but has been relatively stable with a slight upward trend since the early 2000s. The NSEI fishery CPUE was not updated in 2020 due to database limitations after the development of a new logbook application (Figure 3.11a). In SSEI waters, the longline survey CPUE had been declining from 2012 to 2015, but has seen an upward trend since that time (Ehresmann and Olson, 2021b). Similar to the NSEI longline survey, there was a substantial increase (40%) from 2019 to 2020 for the SSEI longline survey CPUE (Figure 3.11b). SSEI fishery CPUE increased 11% from 2019 to 2020, and the 2020 fishery CPUE was 12% greater than the 10-year mean. The lowest points in the time series of CPUE for each of these areas is around 2015, which corresponds to time series lows in biomass in the assessment. However, the assessment of the NSEI stock suggests that the abundance in that area has been increasing recently (Figure 3.11a), which corresponds with the strongly increasing abundance and biomass estimates for Alaskan Federal waters in the 2021 sablefish SAFE (Figure 3.17).

Canada

Sablefish stocks in coastal Canada are managed and assessed by Department of Fisheries and Oceans (DFO) Canada 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 2014, but rapidly increased from 2016 to 2019 (approximately tripling), yet it decreased in 2020 by 17%. The overall estimated biomass trend in B.C. is similar to the trend in Alaska with strong increases in the mid-2010s, but growth appears to have leveled off in the last couple of years (Figure 3.11c).

United States West Coast (Washington, Oregon, and California)

In 2021, a full assessment was conducted for the west coast sablefish fishery by the NOAA Northwest Fisheries Science Center (Kapur et al., 2021). After declines in abundance through the 1980s and 1990s, the resource rebuilt slightly in the early 2000s corresponding to a large 2000 year class, then remained stable for much the late 2000s and early 2010s. The west coast has also had an emergence of several recent above average year classes in 2008, 2010, 2013, and 2016, which has led to strong upward trend in biomass since the late 2010s (Figure 3.11d).

Coast wide Comparison of Population Dynamics

Historically, the recruitment estimates from the west coast and Alaska have been correlated, but recently that correlation has decreased. This reflects pattern where the west coast appears to have strong 2013 and 2016 year classes, while British Columbia is has strong 2013 and 2015 year classes, and in Alaska estimates show strong 2014 and 2016 year classes. These estimates raise the question if favorable environmental conditions trigger general reproductive success. Differences between these areas could be real or 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 scientists from the U.S. (west coast and Alaska regions), Canada, and the state of Alaska has been working 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 through management strategy evaluation (MSE). 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 and between laboratory age comparisons. The PSTAT held an MSE stakeholder workshop in April 2021. Materials and summary documents from the workshop can be found at https://www.pacificsablefishscience.org/.

Analytic approach

Model Structure

The proposed sablefish assessment model differs from model *16.5_Cont* due to slight alterations in parametrization and biological inputs, which are detailed below.

The age-structured model extends from earlier statistical catch-at-age (SCAA) models developed by Kimura (1990) and Sigler (1999), which arise from the work by Fournier and Archibald (1982). The model tracks population numbers-at-age by sex. The current configuration was reviewed and recommended by the Groundfish Plan Team in September 2021, then reviewed by the SSC in October 2021. The parameters, population dynamics, and likelihood equations are described in Box 1. The model was coded in the AD Model Builder software, a C++ based software for development and fitting of general nonlinear statistical models (Fournier et al. 2012). The model code is available from the first author upon request.

The model assumed a single Alaska-wide stock. Recruitment at age-2 is estimated as yearly deviations from the time series average recruitment value. Initial age structure in 1960 is derived based on estimated recruit deviations for each cohort in the initial age structure, which are then decremented based on natural mortality and the historic proportion of fixed gear fishing mortality up until the model start year. Primary demographic parameters are estimated outside the model and treated as fixed inputs, including maturity-, length-, and weight-at-age. Natural mortality is estimated as a time- and age-invariant parameter with a moderately informative prior. 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. The separability assumption is utilized to model each fishing fleet, where a yearly fishing mortality multiplier is estimated along with an age-based selectivity function (i.e., the fixed gear fishery assumes asymptotic selectivity, whereas the trawl fishery assumes dome-shaped selectivity). Three fishery-independent surveys (i.e., the 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 stock biomass (SSB) is the biomass of mature (based on input age-based maturity) females. Total biomass is the abundance of all sablefish age-2 and older multiplied by sex-specific input weight-at-age. Recruitment is measured as the number of age-2 sablefish. Fishing mortality is fully selected F, which is the instantaneous mortality at the age of maximum fishery selectivity.

Model Alternatives

Two model alternatives are presented for 2021:

1) Model *16.5_Cont* (2020 assessment model).
2) Model *21.12_Proposed_No_Skip_Spawn* (proposed 2021 assessment model).

The differences between the two models are that model *21.12_Proposed_No_Skip_Spawn* includes:

1) Updated growth and weight for the recent (post-1996) time block;
2) Revised age-based maturity estimates from recent histological maturity data;
3) Removal of catchability parameter priors;
4) An additional recent (post-2016) time block for the estimation of fixed gear fishery fleet catchability and selectivity parameters along with longline survey selectivity parameters;
5) Francis data reweighting.

Detailed descriptions of modeling changes and their impact on assessment results are provided in Appendices 3G and 3H, while the complete description of model *16.5_Cont* can be found in the 2020 SAFE document (though the description provided here matches the previous model except for the changes listed above; Goethel et al., 2020). Additionally, a complete description of model *16.5_Cont* results as applied to the full suite of new 2021 data is provided in Appendix 3I along with comparison figures from the 2021 proposed model (*21.12_Proposed_No_Skip_Spawn*). As noted, for simplicity the model descriptions and results presented in the main 2021 SAFE document pertain to model *21.12_Proposed_No_Skip_Spawn*.

Model Updates and Justification

As noted, model *21.12_Proposed_No_Spawn* includes a variety of parametrization refinements over model *16.5_Cont*. First, model *16.5_Cont* assumed moderately informative priors on all catchability parameters to help maintain consistency across the time series for the various longline survey iterations (i.e., Japanese, cooperative, and Alaska Fisheries Science Center), while also aiding in parameter estimation. Catchability parameters are critical scalars in an assessment and can have important impacts on how the model interprets associated data sets, given that it scales from the observed indices to the overall population size. Given the relatively long time series of the various abundance indices now available, the proposed model removed the catchability priors enabling unconstrained estimation of these parameters to allow better internal scaling (see Appendix 3G for more details on catchability parametrization).

To address difficulties estimating the magnitude of recent year class strength, recent catchability and selectivity time blocks (i.e., new parameter estimates starting in model year 2016) were implemented for the fixed gear fishery (i.e., catchability and selectivity) and longline survey (i.e., selectivity only). The main implication associated with allowing a recent change in fishery selectivity or catchability is that the availability of fish has changed, which is one factor causing increased observations of young, small fish in the length and age composition data. A recent time block for fixed gear fishery catchability and selectivity was warranted given the rapid alteration in gear composition since pot gear was legalized in the Gulf of Alaska (GOA) in 2017. In 2021, more than half of the catch was harvested by pot gear. Simultaneously, the low monetary value of small sablefish, which have dominated the landings since the mid-2010s, has likely affected the targeting of the fixed gear fishery.

Recent increases in abundance of younger fish on the longline survey in deep water strata (>400m), where they have not historically been caught, indicate that survey availability may have increased, but likely only for certain age and size classes (Figure 3.49). It is possible that these increases in juvenile abundance is simply a result of large recruitment events being observed across all depths (Figure 3.49). However, juvenile sablefish tend to prefer shallower depths as demonstrated by the lack of larger, older fish observed in the trawl survey, which only consistently samples to 500m (Figures 3.20 – 3.22). Additionally, historically large year classes are often first observed in shallower areas of the Bering Sea, which appears to be a quasi-nursery area (Sasaki, 1985). Therefore, it seems plausible that a change in depth distribution of juvenile fish may be occurring with these recent large year classes. There is some evidence that distributional shifts of small sablefish could potentially be linked to limited prey availability and environmental changes in areas of the Gulf of Alaska slope, given recent poor recruitment of other groundfish species (see discussions of ecosystem indicators in the Ecosystem and Socioeconomic Profile, ESP, in Appendix 3C). Because sablefish are extremely active and mobile, limited prey may motivate juvenile sablefish to extend their prey search radius and potentially move to deeper water at earlier ages. Additionally, low recent condition factors for juvenile (e.g., age-4 sablefish) may indicate that diet and prey availability has been poor for recent year classes as they begin to mature, particularly for the 2014 year class.

When accounting for potential changes in availability, an important consideration is whether availability changed for all ages or just for certain age or size classes. The former would indicate that there has been a change in catchability for the given gear, whereas the latter would indicate there has been an implicit change in the model-estimated selectivity. The assessment estimated selectivity (i.e., the probability of capturing a fish of a given size or age relative to the overall probability that the modeled fleet encounters and captures a fish in the population) is implicitly a combination of both gear selectivity (i.e., as might be estimated in a field study) and availability to the given gear (Punt, et al., 2013). Thus, changes in availability of certain age or size classes should be incorporated through refined selectivity parametrization instead of catchability, because the latter assumes availability of all age or sizes has changed. Given that there have been no major changes in survey protocols and that only juvenile age classes appear to be more available to the survey, it does not seem appropriate to incorporate a recent survey catchability time block. On the other hand, increased availability of certain age classes can be adequately accounted for by allowing for a recent time block in survey selectivity. A full factorial exploration of a recent (i.e., beginning in 2016) time block for catchability and selectivity in both the fixed gear fishery and longline survey was explored and the results presented in Appendix 3H.

The status quo assumption (i.e., model *16.5_Cont*) is that there has been no change in availability of sablefish to the gears. Under this assumption, recruitment has tended to be overestimated (as demonstrated by subsequent downgrades in year class strength), which is likely caused by an unknown (and not modeled) ecosystem driver that is causing an increase in mortality of juvenile sablefish. The result has been much lower than expected cohort sizes as recent year classes grow, mature, and are observed over subsequent years in the fishery and surveys. As discussed previously, the inability to adequately address reductions in cohort size as recent cohorts age is particularly problematic for projections, because they are overly optimistic about the fate and potential future productivity of the year classes. Conversely, allowing availability to the fishery and survey gear to vary (e.g., model *21.12_Proposed_No_Skip_Spawn*) improved recruitment estimation. This alternative matches observed high abundance at younger ages in recent compositional data and dampens year class estimates. Models that incorporate the recent time block in selectivity typically overestimate the proportion of age-2 recruits in the compositional data (due to increased estimates of selectivity), but tend to more accurately reflect the observed proportions of recent year classes as they age (e.g., at ages-4, 5, and 6). Moreover, allowing for a recent time block in survey selectivity leads to improved fits to the longline survey index, whereas model *16.5_Cont* tends to overestimate recent abundance indices.

The parametrization of the proposed model was based on a combination of observations from the fishery and survey along with data explorations and the results of the model building exercises (Appendices 3G and 3H). From a modeling perspective, allowing a recent time block for the fixed gear fishery catchability and selectivity parameters along with a time block for the longline survey gear was the most plausible and parsimonious parametrization. The retrospective patterns in recruitment improved, as did fits to the longline survey index. Without changes in selectivity, particularly the longline survey selectivity, retrospective patterns in recruitment were poor, indicating that the recent survey time block addressed recruitment estimation issues. Similarly, the recent fishery catchability time block improved the fit to the fixed gear catch-per-unit effort (CPUE) index and had a moderate impact on overall model scaling.

The proposed model includes a more formal data weighting approach based on the Francis method (Francis 2011, 2017). The previous model (*16.5_Cont*) assumed that the relative weights for each data set remained appropriate. These weights were recommended by the 2016 CIE review panel. These fixed weights were established before the first large year class (i.e., the 2014 year class) had recruited to the survey or fisheries and occurred at a time of relatively stable compositional data and low indices of abundance. Subsequently, by using fixed data weights that emphasize the compositional data, the model has been overestimating recruitment and predicting values of the longline survey abundance index that have exceeded observations by as much as 30% in recent years.

Parameters Estimated Outside the Assessment Model

Table F lists the parameters that are estimated independently of the assessment model and used as fixed inputs. Maturity and weight assume a single time block for the entire assessment period and were updated based on new data for the 2021 model. Growth assumes two time blocks (pre- and post-1996) and was also updated in 2021. Although models that utilized consistent time blocks for growth and weight were tested in 2021, the estimated weight-at-age for the historic time block was deemed unreliable (i.e., due to the lack of weight data collected on the longline survey prior to 1996; see Appendices 3E and 3H for a full description of weight estimation difficulties and assessment implications).

Table F. Maturity, growth, and weight equations used to define the biological inputs for the stock assessment model along with other fixed model inputs. All parameters are estimated independently and fixed in the assessment model. See Table 3.12 and Figure 3.12 for the age-based biological inputs.

Parameter name	Value		Source
Time period	1960 - 1995	1996 - current	
Length-at-age – females	$L_a = 75.5\left(1 - e^{-0.208(a+3.62)}\right) + \varepsilon_a$	$L_a = 81.2\left(1 - e^{-0.17(a+3.28)}\right) + \varepsilon_a$	Echave (2021; Appendix 3E)
Length-at-age – males	$L_a = 65.2\left(1 - e^{-0.2(a+4.09)}\right) + \varepsilon_a$	$L_a = 67.9\left(1 - e^{-0.23(a+3.3)}\right) + \varepsilon_a$	Echave (2021; Appendix 3E)
Maturity-at-age – females	$m_a = \frac{e^{(-5.1560+0.7331a)}}{1+e^{(-5.1560+0.7331a)}}$		Williams and Rodgveller (2021; Appendix 3F)
Weight-at-age – females	$\ln\widehat{W}_a = \ln(5.87) + 3.02\ln\left(1 - e^{-0.17(a+2.98)}\right) + \varepsilon_a$		Echave (2021; Appendix 3E)
Weight-at-age – males	$\ln\widehat{W}_a = \ln(3.22) + 3.02\ln\left(1 - e^{-0.27(a+2.41)}\right) + \varepsilon_a$		Echave (2021; Appendix 3E)
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. Trawl fisheries usually occur on the continental shelf and shelf break inhabited by younger fish, while catching small sablefish may be hindered by the large bait and hooks on longline gear. The transition towards pot gear in the fixed gear fishery may allow a higher proportion of small fish to be selected, but the location of fixed gear fishing activities (e.g., size-based targeting of more valuable larger fish) and the optional use of escape rings may limit the number of small sablefish retained by pots. The model assumes recruitment at age-2, which is when fish primarily become susceptible to the various gears. Age-based dynamics are then tracked 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

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 maximum lengths and weights of 68 cm and 3.2 kg for males and 80 cm and 5.5 kg for females (Table 3.12; Echave 2021).

New weight and growth relationships were estimated in 2021, because neither biological input had been updated since 2007 (Hanselman et al. 2007) and over a decade of new data from the longline survey was available to inform estimates. Concomitantly, concerns existed as to the potential impact that increased density of sablefish associated with multiple large recent year classes and extreme warming conditions might have on growth (Bond et al. 2015; Di Lorenzo and Mantua 2016). When growth and weight were last updated in the sablefish assessment in 2007 (Hanselman et al., 2007), data from two time periods (1981 – 1993 and 1996 – 2004) were utilized to define and model two growth regimes (pre- and post-1995). The time series breaks were determined by changes in sampling design for sablefish data collected on the longline survey. Conversely, individual weight samples from the longline survey started in 1996, so a single weight-at-age curve was used for the entire assessment period using data collected from 1996 – 2004. Due to these data limitations, the same time blocks, including a single time block for weight-at-age, were utilized in the 2021 parameter updates (see Appendices 3E and 3H for information on the data and model parametrizations explored). For the 2021 updates to weight and growth, the results from Echave (2021) were utilized where the recent growth curve and the single weight-at-age block were estimated using all available data from 1996 through 2019. The historic growth curve (pre-1995) remains unchanged from previous assessments. Based on the newly estimated growth and weight parameters, sablefish maximum length and weight have increased slightly (Table 3.12; Figure 3.12). However, growth rates have slowed, implying that fish are smaller at age during the critical early years while reaching maturity.

Maturity

The female age-at-maturity used previously was based on macroscopic maturity determination methods on samples collected during summer surveys from 1978 - 1983 (Sasaki, 1985). To obtain more up-to-date maturity estimates and explore changes in sablefish maturity among years, sablefish ovaries were collected in December 2011 and 2015 in the Central Gulf of Alaska (Rodgveller et al. 2016). This recent histological data were utilized to compare a variety of potential models of sablefish maturity (Appendix 3F). Although accounting for skipped spawning was explored and demonstrated to have important implications for interpretation of stock dynamics (Appendices 3G and 3H), the limited spatial extent and temporal variability in skipped spawning estimates led the PT and SSC to question the reliability of the maturity models that incorporated skipping (i.e., model *21.10_Proposed*). Therefore, an age-based logistic regression on microscopically (i.e., based on the recent histological data) determined maturity that ignored skip spawning was recommended. The resulting maturity-at-age (Table 3.12) is similar to that used in previous assessments, but with slightly higher maturity at younger ages and reduced maturity at intermediate (5 to 10) ages (Figure 3.12c). As further work to understand sablefish maturity is undertaken and more samples on skipped spawning collected, future maturity updates will continue to explore the potential to incorporate skipped spawning information.

Maximum Age

Sablefish are long-lived; ages over 40 years have been regularly recorded (Kimura et al. 1993) and the reported maximum age for Alaska is 94 years (Kimura et al. 1998). Canadian researchers report age determinations up to 113 years. The current assessment accounts for 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. Differences in aging are accounted for by sex and allowed to vary before and after 1996. Age-length conversions (Figure 3.12b) are used to convert predicted catch-at-age in each data source to predicted catch-at-length to allow fitting observed length compositions within the age-based assessment model. New age-length conversion matrices were constructed using the new growth curves with normal error fit to the standard deviations of the collected lengths-at-age (Figure 3.12b).

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). 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 determined using an area-wide Generalized Linear Mixed Model (GLMM) using year, depth strata, station, management area, and total number of effective hooks as explanatory variables (Hanselman et al., 2018). Since 2016, these results have been used to inflate catches at survey stations with depredation evidence, assuming an inflation 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, though in 2021 it was strongest in the Central Gulf of Alaska stations (Figure 3.14).

Killer and sperm whales in the fishery: Killer whales have a long history of depredating the commercial sablefish fishery, while sperm whales have become a problem more recently. Inflating longline survey estimates of abundance (RPNs) for the sablefish assessment needs to be done in tandem with correcting for depredation in the commercial fishery. Data from the observer program was used to compare CPUE data on “good performance” sets with those with “considerable whale depredation” to estimate fishery whale depredation (Peterson and Hanselman 2017). First, a Generalized Additive Mixed Modeling (GAMM) approach was used to estimate the whale effect on commercial sablefish fishery catch rates by management area. The proportion of sets impacted by killer whales and sperm whales was then modeled as a function of fishery characteristics to determine 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 2021, 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 - 2020). 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 as explanatory variables. 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 – 2020 ranged from 10 t to 270 t per area by killer whales in western Alaska management areas and 10 t to 130 t per area 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, though this trend reversed slightly in WY and EY/SE in 2020 (Figure 3.15). We have not fully investigated this, but it could be partly due to more of the catch being taken with pot gear. Killer whale depredation has been relatively steady at time series mean levels for the last 3 to 4 years, but dropped in all areas in 2020, with significant declines in the Western Gulf of Alaska region (Figure 3.15). We suspect that these substantial decreases in depredation are partly related to the large increase in the use of pot gear.

Research to update the fishery and survey depredation coefficients is currently being undertaken. However, the low total removals (i.e., compared to total catch) indicate that reestimation of depredation coefficients is unlikely to appreciably influence the assessment. Additionally, the increasing use of pot gear likely implies that depredation impacts in the fishery will continue to decline, which is implicitly accounted for in the depredation models, because data from observed pot gear trips (where no depredation occurs) is incorporated and used to inform model estimates.

Model Estimated Parameters and Description

Table G. Summary of the parameters estimated within the recommended assessment model.

Parameter name	Symbol	Number of Parameters
Catchability	q	7
Mean recruitment	μ_r	1
Natural mortality	M	1
SSB-per-recruit levels	$F_{35\%}, F_{40\%}, F_{50\%}$	3
Recruitment deviations	τ_y	89
Average fishing mortality	μ_f	2
Fishing mortality deviations	φ_y	124
Fishery selectivity	fs_a	15
Survey selectivity	ss_a	10
Total		252

Catchability

Catchability coefficients are separately estimated for the Japanese longline fishery, the cooperative longline survey, the domestic longline survey, the U.S. longline derby fishery (1990 – 1994), the U.S. longline IFQ fishery (1995 – 2015), the recent U.S. longline IFQ fishery (2016 – 2021), and the NMFS GOA trawl survey (7 parameters total). The recent (2016 – 2021) time block for the U.S. longline IFQ fishery catchability was added in the 2021 model. This accounted for changes in targeting (i.e., avoidance of low value small sablefish) and gear composition (i.e., rapid increases in pot gear usage, particularly since the repeal of the ban on pot gear in the Gulf of Alaska in 2017) in recent years (see Appendix 3G for further rationale).

Recruitment

Recruitment is parametrized as an average (μ_r; 1 parameter) with loosely constrained (standard deviation, σ_r, fixed at 1.2) yearly deviations (τ_y) for the years 1933 – 2020 (89 parameters). Deviations prior to the model start year (1960) are used to determine the initial age-specific initial abundance distribution in that 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 fixed gear fishery fishing mortality occurs each year prior to 1960. The recruitment value in the terminal year is set equal to the estimated median recruitment.

Fishing Mortality and Selectivity

The model treats the directed (longline and other fixed gear fisheries) and the primary non-directed (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; two parameters) and yearly deviations (φ_y; 1960 - 2021) from the average value and for each fishery (124 parameters).

Selectivity is modeled by sex and fishery, except for the Japanese longline fishery (1964 – 1981) for which a single combined-sex selectivity curve is estimated. Selectivity for the fixed-gear fishery is estimated separately for the "derby" fishery prior to 1995, the IFQ fishery from 1995 to 2015, and the recent IFQ fishery (2016 – 2021). A recent time block (2016 – 2021) was introduced in 2021 for the estimation of longline survey selectivity, as well.

Selectivity for the longline surveys and fixed-gear fisheries was modeled with a logistic function where sex-specific age at 50% selectivity ($a_{50\%}$) is estimated (i.e., 7 estimated parameters for the fixed gear fishing fleet, including a single parameter for the sex-combined Japanese fleet, and 6 for the longline survey fleets). Due to model instability, the other logistic selectivity parameter representing the difference in age at 50% selectivity and 95% selectivity, δ (i.e., controlling the slope of the curve) is shared among some similar gears and across sexes. The derby (i.e., first time block) fixed gear fishery and Japanese longline fishery have limited compositional data and a single δ parameter is estimated and shared across sexes and fleets. The other two fixed gear fishery time blocks have independently estimated, sex-specific δ parameters. However, sex-specific δ parameters are estimated for the longline survey fleets, then shared across all time blocks (i.e., for the cooperative survey, the domestic survey, and the recent selectivity time block for the domestic survey). In total, there are an additional 7 estimated logistic δ selectivity parameters (i.e., 5 for the longline fisheries and 2 for the longline surveys).

Selectivity for the trawl fishery and trawl survey were allowed to be 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). The right-descending limb is incorporated because the trawl survey and fishery infrequently catch older fish (i.e., due to fishing at shallower depths). There are 3 total estimated parameters for the trawl fishery gamma functions (i.e., sex-specific $a_{50\%}$ and a single δ parameter shared among sexes) and 2 estimated sex-specific parameters for the trawl survey power functions.

Natural Mortality

Sablefish natural mortality has been estimated to be about 0.1 (Funk and Bracken 1984; Johnson and Quinn 1988). 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. The age- and time-invariant parametrization of natural mortality from model *16.5_Cont* was maintained for the proposed model in 2021, where M was treated as an estimated parameter with a strong prior.

Spawning Biomass-per-Recruit (SPR) Parameters and Stock Status

SPR reference points (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 are based on the relative fishing mortalities between fleets, fishery selectivity, the estimated natural mortality, and input biological parameters (i.e., sex ratio, weight-at-age, and maturity-at-age). The relative fishing mortalities is based on the terminal year ratio of fishing mortality rates between fleets, while selectivity and any time-varying biological parameters are taken from the most recent period. 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.

Box 1	**Model Description**
y	Year, y=*1960, 1962,…T*
T	Terminal year of the model
A	Model age class, $a = a_0, a_0+1, \ldots, a_+$
a_0	Recruitment to the model at age-2
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
M_μ, σ_M	Prior mean, standard deviation for natural mortality
$\sigma_{r_\mu}, \sigma_{\sigma_r}$	Prior mean, standard deviation for recruitment variability

Population 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
$s_{a,s}^g = \dfrac{a^{\delta_{g,s}}}{\max(s_{a,s}^g)}$	Inverse power family
$s_{a,s}^g = \left(\dfrac{a}{a_{\max}}\right)^{a_{\max,g,s}/p} e^{(a_{\max,g,s} - a)/p}$ $p = 0.5\left[\sqrt{a_{\max,g,s}{}^2 + 4\delta_{g,s}{}^2} - a_{\max,g,s}\right]$	Reparameterized gamma distribution
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*
$\widehat{I_{y,g}} = q^g \sum_{a_0}^{a_+} \sum_1^s N_{y,a,s} s_{a,s}^g w_{a,s}$	Survey biomass index (weight)
$\widehat{I_{y,g}} = q^g \sum_{a_0}^{a_+} \sum_1^s N_{y,a,s} s_{a,s}^g$	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)
$L_M = \left(\ln \hat{M} - \ln M_\mu \right)^2 / 2\sigma_M^2$	Prior for natural mortality
$L_\tau = \sum_{y=1960}^{T} \frac{\tau_y^2}{2\sigma_r^2} + nln\widehat{\sigma_r}$	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

Data Reweighting

The specified variances associated with each data set fit within a stock assessment model affects model fit. Procedures to evaluate data weights based on the input variance were done following Francis (2011, 2017), which accounted for correlations among ages or length bins in the compositional data. Model *21.12_Proposed_No_Skip_Spawn* implemented Francis reweighting as the final step in the model development and data fitting procedure. Following the methods of Francis (2011), the abundance index weights were fixed based on the input observed variance of each index and the compositional data weights were iteratively adjusted using a two-stage approach. In Stage 1, the model was run with equal input compositional data weights (i.e., all sources of age and length composition data fit in the model were given a weight of 1.0; exploratory runs demonstrated that final weights were insensitive to initial weights). Then, the compositional data weights were adjusted following Method TA1.8 and weighting assumption T3.4 of Francis (2011, Appendix Table A1, therein; i.e., using the assumption of a multinomial distribution and accounting for correlations among ages or length bins). In Stage 2, the model was then rerun with the new weights. The weights were iteratively adjusted until the difference between the current weights and the revised weights were minimal (i.e., the weights converged; for sablefish this usually took less than 10 iterations). The final data weights were utilized for the final proposed model and all associated diagnostic and sensitivity model runs.

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 Markov Chain Monte Carlo (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 by 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, important management thresholds are defined by the NPFMC harvest control rules (HCRs). Biomass thresholds for the HCRs are based on spawning biomass and are determined by $B_{40\%}$ and $B_{35\%}$, while under the Magnuson-Stevens Act rebuilding plans are necessary when SSB falls below ½ B_{MSY} or $B_{17.5\%}$. 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 - 2017 year classes. The projected fishing mortality assumes the current yield ratio described in the Catch Specification section multiplied by maximum 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 Diagnostic Analyses

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). 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 2021 model in the current analysis). 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. '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 2021 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, including bias in the data (e.g., catch misreporting, non-random sampling) or different types of model misspecification and process error, such as incorrect parametrizations of natural mortality or temporal trends in values assumed to be time-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 historical 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 (2011 – 2020) compared to estimates from the current proposed model for 2021. It is important to note that for the *21.12_Proposed_No_Skip_Spawn* model, retrospective peels with terminal year prior to 2018 did not maintain a consistent parametrization with subsequent peels due to the handling of the recent fishery and survey selectivity and catchability parameter time blocks. In particular, the recent time block was removed for peels with terminal year prior to 2018, because limited or no data exist to estimate the parameters in the recent time block for those peels. Therefore, interpretation of the results of the retrospective analysis should be carefully undertaken, given the inconsistency in parametrization, and only peels with terminal years of 2018 through 2021 should be directly compared.

Historical Assessment Retrospective Analysis

A similar type of retrospective analysis, which addresses consistency across successive stock assessment applications with the actual data available in a given year, is a historical assessment retrospective analysis. Similar to a model retrospective, an historical retrospective analysis is undertaken with successive 'peels' of data, but does so by using the actual data sets available in the given terminal year. Two versions of this analysis were conducted. The first, and more traditional approach, compared the actual assessment outputs from the model used as the basis of management advice in a given year (we term this the 'all model' historical retrospective). The second approach utilized the current assessment model applied to the data available at the time of the given SAFE (we term this the 'current model' historical retrospective). The 'all model' retrospective allows comparison of how model and data changes over time have altered perceptions of stock status and resultant management advice. The 'current model' retrospective provides insight into how the new, but also refined (e.g., QA/QC of historical data), data may have altered model outputs in successive years. Much like a model retrospective, it also demonstrates how consistent the model is over time.

Additionally, both types of historical retrospective analyses allow comparison of short-term model projections to realized SSB from subsequent model runs. Thus, by including projected SSB, the historical retrospective can compare the performance and reliability of projected future stock dynamics and whether ABCs were appropriate. Mohn's rho was calculated in the same way as for the model retrospective using the 2021 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 two-year projection to the corresponding realized SSB in the 2021 Base model. The resulting value provides insight into the discrepancy between the expected SSB trajectory from projections to the SSB that was realized as the data were updated in subsequent years. For the 'all model' retrospective, we compared all model runs dating back to 2015. For the 'current model' retrospective, we assume a four year peel and compare the 2021 proposed model as applied to the available data from 2018 to 2021 (i.e., those years where enough data is available to estimate the recent selectivity time block).

Profile Likelihoods

Understanding how the various data sets influence parameter estimates is important for assessing model reliability, data quality, and addressing potential data conflicts. Developing likelihood profiles allows exploration of how the likelihood response surface varies for different values of a given parameter, both for individual data types and for the total negative log-likelihood. A profile likelihood is developed by incrementally varying a given parameter in the model around the maximum likelihood estimate, then graphing values of the various data likelihoods that result when the model is rerun with the parameter fixed at the those values. Analyzing the response surfaces can help determine which data are most influential for estimation of the given parameter, while also determining whether the model may be stuck at a local minima. Typically, likelihood profiles are developed for important scaling parameters (e.g., stock-recruit and catchability parameters) to better understand the degree of uncertainty in overall population biomass. Ideally, all data sets would demonstrate general agreement regarding parameter estimates, but certain data are often more informative for various parameters (e.g., age compositions are typically highly influential for the estimate of recruitment parameters, whereas associated indices and composition data often drive catchability parameters). Uninformative response surfaces for some data and parameter combinations are to be expected and are not necessarily cause for concern. However, strong data conflicts (i.e., strong response surface minima at divergent values of the parameter) for a given parameter can be indicative of either a poorly parametrized model, highly correlated parameters, or one or more low quality or unreliable data sets.

For the sablefish SAFE, data profiles were developed for the mean recruitment and the longline survey catchability parameters. These two parameters generally have the strongest influence on both population size and incoming recruitment trends and it is important to understand how well each is being estimated and whether discrepancies in the given parameter value exist across data sets. For each parameter, the model is rerun at incremental step sizes on either side of the MLE for that parameter until well-defined response surface shapes are observed. Profiles are broken down both by data type (i.e., age compositions, length compositions, indices, and total likelihood). For graphing purposes, the negative log-likelihood for a given data type is scaled by subtracting the minimum value, such that each response surface is equal to zero at the MLE for that data source.

Incremental Influence of New Data

A model data building analysis was developed to demonstrate how new data affected parameter estimates (e.g., the magnitude of the most recent year class). The 2021 catch data was added along with one additional new data point and the model was run. All steps included the catch data, because this was needed to adequately estimate fishing mortality in the terminal year. Additional data sources that were added incrementally included fixed gear fishery age and length compositions, trawl fishery length compositions, longline survey index with associated age and length compositions, and trawl survey index with associated length compositions. In the case of fishery independent surveys, the associated index was always added in combination with compositional data. Finally, when both age and length composition data were available for a given data source, each was added independently, and then an additional step was provided with both types of composition data added simultaneously.

Index Sensitivity Analysis

It is important to understand the influence that a given abundance or biomass index has on model performance. This can help isolate the independent effects of a given survey on model results by removing each survey from the model one at a time, then comparing the results to the full model. The analysis was implemented by independently removing the CPUE index, the longline survey index, and the trawl survey index, then comparing across model runs. When a given fishery-independent index was removed, all associated age and length composition data were also removed from the model.

Sensitivity Runs

A handful of alternative model parametrizations were compared to better understand the influence that changes associated with model *21.12_Proposed_No_Skip_Spawn* had on stock status and ABCs. These sensitivity runs aim to address a variety of SSC and PT comments and requests concerning model performance, and focus on providing a clear demonstration of the influence of using Francis reweighting, incorporating the recent catchability time block, and incorporating the recent survey selectivity time block. For the 2021 SAFE, the results of 6 alternate models are presented and compared, including: the 2020 model (*16.5_Cont*); the 2020 model with Francis reweighting applied (*21.9_Francis*); the 2021 proposed model but with skipped spawning information incorporated into the maturity model (*21.10_Proposed_w_SS*); the 2021 proposed model but without Francis reweighting applied (*21.27_Prop_No_Francis_No_SS*); the 2021 proposed model but without a recent time block for survey selectivity (*21.28_Fish_q+Sel_Only*); and the 2021 proposed model but without a recent time block for fishery catchability estimation (*21.29_Fish_Sel_Srvy_Sel*). A summary of sensitivity run models is provided in Table 3.20. Additionally, a full model building exercise for model *21.12_Proposed_No_Skip_Spawn* is provided in Appendices 3G and 3H. Finally, the full suite of results and diagnostics for model *16.5_Cont* are provided in Appendix 3I.

Results

Model Evaluation

The model likelihood components and key parameter estimates from the 2021 proposed model (*21.12_Proposed_No_Skip_Spawn*) were compared with the 2020 model (*16.5_Cont*) to better elucidate how data fits and population trajectories have changed with new model updates and data (Table 3.14). Additionally, a full model comparison is provided in Appendix 3I. The primary criteria for choosing a model were: (1) the best overall fit to the data (in terms of negative log-likelihood), (2) biologically reasonable patterns of estimated recruitment, fishing mortality, catchability, and selectivity, 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. Both models generally produce good visual fits to the compositional data, although model *16.5_Cont* provides a better overall fit to the fixed gear fishery age composition data (Appendix 3I, Figure 3I.12). However, despite overestimating initial year class age proportions when they recruit at age-2 (due to recent high age-2 selectivity estimates), model *21.12_Proposed_No_Skip_Spawn* is able to better fit recent cohort decay in both the fishery and longline survey, because recruitment estimates are not quite as large as model *16.5_Cont* (Figures 3.24, 3.22, 3I.18 and 3I.19). The proposed model improved fits to the recent increases in longline survey RPNs (Figure 3.3) and trawl survey biomass (Figure 3.4), whereas model *16.5_Cont* continued to overestimate recent RPNs by upwards of 30% (Figure 3I.9) and 50% in the case of the trawl survey biomass index (Figure 3I.10). Similarly, by allowing for a recent fishery catchability time block, model *21.12_Proposed_No_Skip_Spawn* is able to better fit recent CPUE data (Figure 3.4), which demonstrated a precipitous decline in 2015 and has yet to recover despite rapidly increasing population biomass. Perhaps most importantly, the retrospective bias in recruitment and SSB estimates for model *16.5_Cont* that has been observed in recent years persisted with the addition of the 2021 data (Figure 3I.3). The proposed model *21.12_Proposed_No_Skip_Spawn* effectively eliminates retrospective bias and appears better able to project near term population dynamics (Figures 3.44 and 3.50). Given the improved data fits, more reasonable population trends, and enhanced diagnostics, model *21.12_Proposed_No_Skip_Spawn* appears better suited than model *16.5_Cont* for the provision of sablefish management advice.

Time Series Results

Biomass Trends

Sablefish abundance and biomass dropped throughout much of the 1960s and 1970's (Figure 3.17, Table 3.16) as the population began to be heavily exploited, with catches peaking at 53,080 t in 1972 (Figure 3.1; Table 3.1). The population recovered in the mid-1980s due to a series of strong year classes in the late 1970's (Figure 3.17, Table 3.15), but population rebuilding may have occurred at variable rates in different areas (Table 3.16). The population then subsequently 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 15,000 t and 20,000 t), the biomass continued to subtly decline to a time series low of 215,000 t in 2015 (Figures 3.1 and 3.17). The large estimated 2014, 2016, 2017, and 2018 year classes (Figure 3.18) have led to recent rapid increases in total biomass; the 2021 biomass is estimated to be on par with the highest levels achieved in the mid-1980s (Figure 3.17). Based on partitioning using survey RPWs, recent increases in biomass 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 3.16).

SSB trends typically lag biomass increases by five years with less pronounced extremes, because SSB is less influenced by initial year class strength and only increases rapidly if a large year class survives to fully mature ages (e.g., age-10+) at high abundance (Figure 3.17). SSB fluctuated between 85,000 t and 95,000 t for much of the 2000s, and then declined to a time series low of 80,000 t in 2016. Since 2019, SSB has been rebuilding steadily, albeit not at the extreme rates estimated for biomass (Table 3.15; Figure 3.17). The SSB in 2021 was estimated to be at 108,000 t, which is on par with values in the mid-1990s, though still much below time series highs in the late 1960s of 180,000 t (Figure 3.17).

Unfished spawning biomass is estimated to be 295,000 t, while $B_{40\%}$ is 118,140 t (see the Summary Table). **Terminal spawning biomass is estimated to be at 36% of unfished spawning biomass (assuming average recruitment from 1977 – 2017), while the projected 2022 spawning biomass is estimated to increase rapidly to 44% of unfished spawning biomass**. However, the previous two above-average year classes, 2000 and 2008, only comprise 3% and 6% of the projected 2022 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 each comprise about 20% of the 2022 spawning biomass (while being 60% and 30% mature, respectively), whereas the similarly large 2017 and 2018 year classes are estimated to each contribute 4 – 6% of the projected SSB (despite being less than 20% mature; Figure 3.19). Given the long-lived nature of sablefish, overreliance on only a few young year classes can be problematic if survivorship to fully mature ages is low or decreases over the cohort lifespan (e.g., due to high fishing mortality, density-dependent condition factors, or declining ecosystem health). Similarly, because sablefish can be classified as spasmodic recruiters with short periods of extreme recruitment followed by long (e.g., ten year) spans of below average recruitment, it is likely that recent year classes will need to support the resource and fishery for the coming decade. Ensuring that recent cohorts survive to spawning age, while also maintaining a diversity of ages contributing to SSB can help guarantee a rich SSB portfolio, a healthy population, and steady harvest into the future.

Recruitment Trends

Annual estimated recruitment varies widely (Figure 3.18b). The largest historical recruitment event was the 1977 year class, which was followed by above average year classes in 1997 and 2000. After 2000, few strong year classes occurred until 2014 – 2018. The 2014 and 2017 year classes appear to be on par with the 1977 year class, while the 2016 year class looks to be the largest on record (Figure 3.18b). Although highly uncertain given the lack of informative composition data at this time, the 2018 year class appears to be near the time series high, too. 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 and 2016 year class also appeared early in all areas, although both were observed in higher magnitudes in the Western areas (Figure 3.23).

Average recruitment for the 1977 – 2018 year classes was 22 million 2-year-old sablefish per year. Sablefish recruitment is characterized by 'boom or bust' dynamics with short periods of spasmodic recruitment typically associated with moderate or low SSB and no discernible stock-recruit relationship (Figure 3.18c). The current slew of large year classes is similar to the pattern of high recruitment that occurred in the first half of the 1980s. However, that strong recruitment period was soon followed by a long period of anemic year classes through the late 1980s and early 1990s.

There is general agreement across the composition data supporting the large estimates of recent year class strength. Since 2017, the longline survey and fixed gear fishery age composition data has been composed primarily of age-2 through age-7 fish (Figures 3.24 and 3.32), which largely represent the 2014, 2016, and 2017 year classes. However, aging imprecision can be high for sablefish, especially for juvenile fish. Thus, as more observations of these recent cohorts are added to the model, there may be less 'smearing' across ages, resulting in one or two of the recent year classes being estimated as extremely large with others being closer to the time series average. Despite uncertainty in exact year class strength, it is unlikely that the total population size associated with these recent year classes will vary. Similarly, although the 2018 year class appears to be large, this estimate is largely being driven by the 2021 trawl survey data, which encounters primarily age-2 and age-3 fish (Figures 3.4, 3.20, and 3.21). When age composition data for 2021 become available in the 2022 SAFE, it is likely that the strength of this year class will diminish, given that the 2021 longline survey index and length composition data do not appear to support such a large estimate of the 2018 recruitment event (Figure 3.54).

Selectivity

Asymptotic selectivity was assumed for the longline survey and fixed gear fishery and dome-shaped (or descending right limb) for the trawl survey and trawl fishery (Figure 3.40). The age at 50% selection is 3.9 years for females in the longline survey and 4.4 years in the IFQ longline fishery, but these values decreased to 2.8 and 3.0 years, respectively, for the recent (post-2016) time block. Generally, selectivity has shifted towards younger fish for the longline survey and fixed gear fishery over time (Figure 3.40). Males tended to be selected at an older age than females in all fleets, likely because they are smaller at a given age. Selection of younger fish was higher during the derby fishery than the IFQ fishery, likely due to short open-access seasons leading to crowding of the fishing grounds, such that some fishers were pushed to fish shallower water where young fish reside (Sigler and Lunsford 2001). However, the trend appears to have reversed in the recent fishery selectivity time block, potentially due to changes in availability or the influence of pot gear that may have a higher selectivity on smaller fish if no escape rings are utilized. Compared to fixed gear, younger fish are more vulnerable and older fish are less vulnerable to trawl gear, because trawling often occurs on the continental shelf in shallower waters (< 300 m) where young sablefish reside. The trawl fishery selectivity is similar for males and females, but with much larger proportion of younger females being selected (Figure 3.40). The trawl survey selectivity curves differ between males and females, where males stay selected by the trawl survey for more ages (Figure 3.40). These trawl survey patterns are consistent with the idea that sablefish move onto 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). Over the last five years, fishing mortality has steadily declined and is on par with the low levels of the early 1980s. 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 to below limit values, while biomass is above limit values indicating that the resource is not overfished and overfishing is not occurring. Biomass is projected to continue to increase to above $B_{40\%}$, while fishing mortality is projected to be remain below $F_{35\%}$.

Data Reweighting

Following the application of Francis reweighting, the input data weights changed significantly from the fixed weights previously utilized in model *16.5_Cont* (Table H). In particular, age composition data was deemphasized, whereas size composition data was upweighted. Although the resulting data weights are somewhat surprising for an age-structured model with high quality ageing data, there may be a number of reasons that the age composition emphasis has been reduced. First, there are likely conflicting signals in the age and length data, which the model is having trouble rectifying. There are also likely unaccounted for issues in fitting the age data, which is making it difficult to simultaneously fit the age and length compositions from the fixed gear fishery. In particular, underestimation of ageing imprecision along with lack of full time-varying growth curves (and associated age-length transition matrices) could create discrepancies between the observed age and length proportions. Similarly, the age data is fit after combining across sexes, whereas length data is fit by sex. Given the differential growth by sex, model tension could be created by not fitting age data differentially by sex. Future model explorations that fit sex-specific age data and incorporate increased aging error will be explored. However, it is important to note that the overall fits to the age composition data are only slightly worse for model *21.12_Proposed_No_Skip_Spawn* compared to model *16.5_Cont* (Appendix 3I, Figure 3I.12). Additionally, model *21.12_Proposed_No_Skip_Spawn* is now better able to match recent cohort decay, as observed in the age composition data, as recent year classes age (Figures 3.24 and 3.32), while also providing a much more reasonable fit to the longline survey abundance index and trawl survey biomass index (Figures 3.3 and 3.4).

Table H. Input data weights (i.e., 'lambdas') assumed for each data source before (model *16.5_Cont*) and after (model *21.12_Proposed_No_Skip_Spawn*) Francis data reweighting was applied. Note that the Francis reweighting method assumes fixed weights for the indices.

Data Source	*16.5_Cont*	*21.12_Proposed_No_Skip_Spawn*
Fixed Gear Catch	50.000	50.000
Trawl Catch	50.000	50.000
Longline Survey RPN	0.448	0.448
Coop Survey RPN	0.448	0.448
Fixed Gear Fishery CPUE	0.448	0.448
Japan Longline Fishery CPUE	0.448	0.448
Trawl Survey RPW	0.448	0.448
Fixed Gear Age Composition	7.800	0.774
Longline Survey Age Composition	7.950	4.006
Coop Longline Survey Age Composition	1.000	1.209
Fixed Gear Fishery Length Composition Males	1.000	6.078
Fixed Gear Fishery Length Composition Females	1.000	5.340
Trawl Fishery Size Composition Males	4.100	0.299
Trawl Fishery Size Composition Females	4.100	0.383
Longline Survey Size Composition Males	1.000	1.514
Longline Survey Size Composition Females	1.000	1.633
Coop Survey Size Composition Males	1.000	1.070
Coop Survey Size Composition Females	1.000	1.454
Trawl Survey Size Composition Males	7.250	0.372
Trawl Survey Size Composition Females	7.250	0.410

Goodness of fit

The component contributions to the total negative log-likelihood are provided in Figure C. The longline survey age compositions constitute a large portion of the total likelihood, while the fixed gear fishery size composition data has the second highest contribution. Compared to model *16.5_Cont*, the longline fishery age composition data have a much lower contribution to the total negative log-likelihood (Table 3.14).

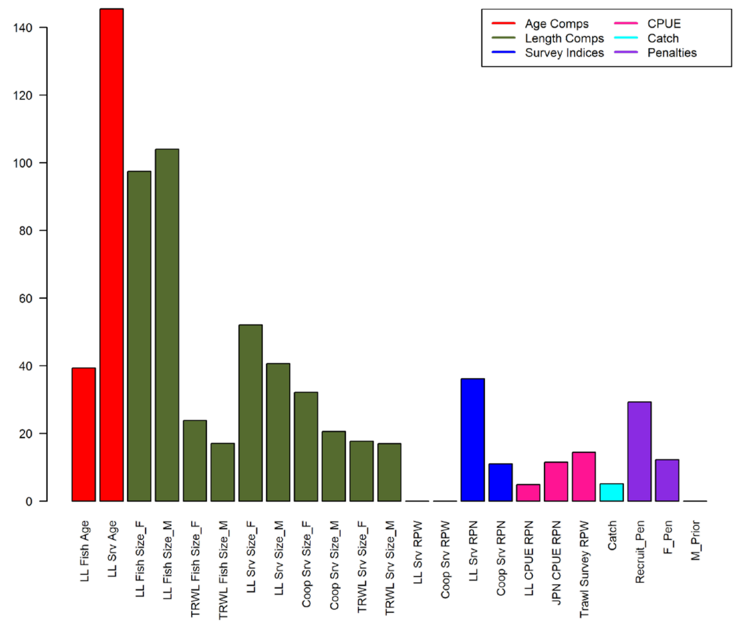

Figure C. Contributions to the total negative log-likelihood by data component.

Predicted abundance indices generally track within the confidence intervals of the observations, except for a few years for the trawl survey biomass index (Figures 3.3 - 3.4). The model generally fits the overall population trends from the indices very well, including the extreme rates of population growth in the last five years (Figure 3.3). The strong fit to the longline survey RPNs is particularly notable, given the increasing overestimate of RPNs observed in model *16.5_Cont* (Appendix 3I, Figure 3I.9). Similarly, the proposed model provides a more reasonable fit to the increases in the trawl biomass (Figure 3.4), whereas model *16.5_Cont* overestimates recent data points by upward of 50% (Appendix 3I, Figure 3I.10). The proposed model is also better able to account for the depressed state of the recent CPUE index, primarily due to the new time block on fishery catchability (Figure 3.4). Overall, there do not appear to be any major temporal patterns in index residuals in model *21.12_Proposed_No_Skip_Spawn*.

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). Since 2016, the age compositions have been dominated by young fish, with about 70% of the fish in the longline survey age composition being age 5 or younger. The magnitude of the 2014 year class in the survey age compositions has been generally underestimated by the model until 2020 (i.e., at age-6), at which point observations and predictions generally agree. Similarly, the model is severely underestimating the size of the 2016 year class in the 2020 age compositions. Given the new longline survey selectivity time block, which estimates a very high rate of age-2 selectivity, the model tends to greatly overpredict age-2 abundance in the survey. However, the model is better able to fit the subsequent decay of these recent large cohorts, though with a tendency to underestimate the proportions from recent year classes. The fit to the aggregated survey age data is very good, with only slight underestimation of the proportions at ages 3-7 (Figure 3.25a).

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 from the AI being age-30 or older. 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 sampled by the longline survey, where there is an apparent abundance of older fish that are unknown to the model. Underestimation of the proportion of age-30+ fish continued for several years, but is not as severe in the 2019 and 2020 data. Like the survey age proportions, the fixed gear fishery age data has been dominated by young fish since 2016. (Figure 3.32). More than 50% of the fish caught in since 2017 have been age-6 or younger. Once again, likely due to the recent time block of fishery selectivity and high estimates of age-2 selection, the model overpredicts the number of age-2 fish. However, it is able to adequately model the decay of these year classes, but with a tendency to underestimate the size of the 2016 year class (e.g., at age-4 in the 2020 data). The aggregate fit to the fixed gear fishery age compositions is generally mediocre (Figure 3.33), due to the reweighting procedure emphasizing fits to the length data over the age data. The proportion of fish at age-2 are overestimated, while those at ages 3-8 and in the age-31+ group are severely underestimated (figure 3.33).

The model fits the domestic longline survey lengths moderately well in the 1990s, but has improved over the last decade (Figures 3.37 – 3.39). The aggregated fits to the longline survey length compositions show a tendency to overestimate fish in the 55cm to 65cm range, and then underestimate the number of fish in the 65cm to 75cm range (Figure 3.39). Fit to the cooperative longline survey length compositions demonstrated a similar pattern (Figure 3.28). The length frequencies from the fixed gear fishery are predicted well in most years (Figures 3.29 - 3.30). The aggregated length compositions show good predictions, on average, with some underestimation at middle sizes for females (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 3.20 - 3.21 and 3.34 - 3.35). On average, however, the trawl lengths were fit moderately well by the model (Figure 3.22 and 3.36).

Overall, there were no strong apparent residual trends in the fits to the survey or fishery compositional data. Fits to the length composition data are more variable than those to the age composition, but this is to be expected given variability inherent in size data and the lower sample sizes in the trawl data. Additionally, the model is able to reconcile the extreme recruitment events apparent from the compositional data with the slightly more subtle population growth observed in the various indices, thereby providing solid fit to all data sources.

In comparison, model *16.5_Cont*, which estimates typically low recent selectivity of age-2 fish in the longline survey and fixed gear fishery, tends to predict much higher year class strength, but then overestimates the abundance of these year classes as they age, particularly in the fishery data (Appendix 3I, Figures 3I.18 and 3I.19). Thus, there is a clear tradeoff between estimating extremely large recent recruitment (i.e., model *16.5_Cont*) events to better fit age compositions at very young ages (e.g., ages 3 and 4, particularly for the longline survey data) with estimating large, but not extreme, recent recruitment and higher age-2 selectivity (model *21.12_Proposed_No_Skip_Spawn*) to better model the decay of recent year classes as they age (particularly the fixed gear fishery age composition data). Given that ageing precision decreases as sablefish age and that mortality process likely become less variable, there is less uncertainty in age composition data of older fish. Similarly, it is more important to understand the size of the mature population than the size of new year classes, particularly if cohort survival to maturity is low. Therefore, it appears that model *21.12_Proposed_No_Skip_Spawn* is likely providing a better estimate of the composition of mature fish in the population, though it may be slightly underestimating recent year classes. Conversely, by overfitting the composition of young age classes at the expense of fits to the abundance indices, model *16.5_Cont* is likely overestimating recent recruitment events, which is demonstrated by the continual retroactive downgrades of recent year class strength with this model (Appendix 3I, Figure 3I.3).

Uncertainty

The model estimates of projected spawning biomass for 2022 (128,789 t) and 2023 (153,820 t; based on the maximum permissible ABC) fall near the center of the posterior distribution of spawning biomass, with a high probability of being above $B_{40\%}$ in both years (Figures 3.45 and 3.47). The SSB is projected to continue to increase in the coming years before declining back towards $B_{40\%}$, though uncertainty in projected SSB is extremely high (Figure 3.48). Although the short-term forecasts have high probability of the resource being above $B_{40\%}$, the probabilities decrease in the longer term as recent cohorts age and abundance declines, but these projections are based on the assumption that recruitment levels will return towards time series averages in the future (Figure 3.47). Scatter plots of selected pairs of model parameters were produced to evaluate the shape of the posterior distribution (Figure 3.46). The plots indicate that the parameters are reasonably well defined by the data.

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 3.17). 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 Diagnostic Analyses

Model Retrospective Analysis

The retrospective issues associated with model *16.5_Cont* of overestimating recruitment (Appendix 3I, Figures 3I.1 and 3I.2) have been essentially eliminated in the proposed model (Figure 3.44). For retrospective peels with consistent parametrizations (i.e., those with terminal year of 2018 or later), there is essentially no retrospective pattern for model *21.12_Proposed_No_Skip_Spawn* (Figures 3.43 and 3.44). Although recruitment estimates vary as new data is added, the level of variability is negligible and does not represent a consistent trend (Figure 3.44). Similarly, SSB appears to demonstrate a slight trend of underestimation as data is removed, likely due to some slight rescaling (e.g., reestimation of catchability parameters), but a Mohn's $\rho = 0.06$ indicates that these patterns are not a large concern (this value also includes all peels including those with different parameterizations and a terminal year before 2018). Even including the model peels before 2018 where no recent time block is implemented for catchability and selectivity parameters, the model demonstrates consistent estimates, though with the pattern switching to consistent slight overestimation in SSB for earlier peels (Figure 3.43). More importantly, the impact of the recent parameter time blocks can be observed in the initial estimation of the 2014 year class by the 2017 retrospective peel run, where recruitment is estimated to be more than three times larger than in subsequent model peels that utilize the new parametrization (Figure 3.44). Without the new selectivity time blocks, particularly for survey selectivity (see Appendix 3H, Figure 3H.6), recruitment estimation difficulties persist in model *16.5_Cont* leading to the pervasive issue of overestimating recruitment (Appendix 3H, Figure 3I.3) and resulting maximum permissible ABC (Appendix 3G, Table 3G.6).

Historical Assessment Retrospective Analysis

Comparison of the SSB estimates and short-term projections from the adopted models since 2015 (i.e., the 'all model' historical retrospective) illustrates how recent models have been overestimating population growth (Figure 3.50a). Projections of SSB have typically been overly optimistic due to overestimates of recent recruitment events. The analysis also demonstrates the impact of the new parametrizations incorporated into model *21.12_Proposed_No_Skip_Spawn*, which lead to reduced recruitment estimates and more subtle projected population growth. Mohn's ρ for the two-year projections was nearly 30%, but this was primarily due to the strong parametrization differences between the 2021 model and previous year models (Figure 3.50a). When the same analysis is implemented, but model *16.5_Cont* is utilized for the 2021 model, the estimate of Mohn's ρ decreases to about 15% (Figure 3I.20). Although the models still demonstrated a strong pattern of overestimating SSB growth, projections from the 2020 and 2021 terminal year models demonstrated stronger convergence than in previous years, probably due to stabilization of the estimates for the strength of the 2014 and 2016 year classes.

Applying the proposed model to the data available at the time of previous assessments (i.e., the 'current model' retrospective) demonstrated that the two-year projections appeared to be remarkably consistent with realized SSB (Figure 3.50b). Much like the model retrospective analysis, no persistent patterns of over- or underestimation occurred and a low Mohn's ρ = -4% was calculated. Of course, these results are extremely overoptimistic, because they do not account for the array of potential model tweaks that might occur during the assessment process nor do they go back as far in time as the 'all model' historical retrospectives. Obviously, model *21.12_Proposed_No_Skip_Spawn* would not have been applicable in years immediately following the 2014 and 2016 recruitment events (i.e., 2016 to 2018 terminal model years). Thus, the proposed model is not a panacea, but it does appear that the two-year projections are surprisingly consistent with subsequent estimates of SSB (Figure 3.50b). If these patterns persist, it may indicate that ABCs could potentially be set for two years instead of on an annual cycle.

However, there has been slight incremental increases in the $B_{40\%}$ reference points indicating that there is some degree of a 'shifting baseline' in the determination of stock status. The change in reference points is mostly due to the inclusion of the most recent recruitment events, each of which have been above average, in subsequent reference point estimates. Thus, the recruitment and productivity upon which the reference point estimates are made have subsequently increased. Despite these changes in reference point targets, projected stock status was not impacted for any of the model peels. Based on the historical assessment retrospective analysis, it would appear that the proposed model is remarkably consistent and stable, while no major data changes or issues have been introduced.

Profile Likelihoods

A profile likelihood analysis for the log (mean recruitment) parameter demonstrated that the indices suggested slightly higher values (~3.25), whereas the compositional (i.e., age and length) data suggested slightly lower values (~1.5) compared to the MLE of 2.74. However, the recruitment penalty was the primary driver of the mean recruitment MLE (Figure 3.51).

The likelihood profile for the domestic longline survey log(catchability) parameter indicates that there is a slight tradeoff between the age composition data (estimate at ~2.4) and the indices (estimate at ~1.8), while the length composition data indicates a minimum of the response surface very close to the MLE of 2.0 (Figure 3.52). Overall, it appears that the longline survey catchability parameter is generally well estimated and no strong discrepancies exist among data sources.

Incremental Influence of New Data

As new data was added to the model, there were no strong changes in model dynamics or population trajectories (Figures 3.53). As is expected, the biggest differences across model runs with the various new data points was the strength of the 2018 year class (i.e., the most recent year class estimated in the model). In particular, the 2021 trawl survey data (index and length compositions) indicate that the 2018 year class is extremely large (Figure 3.53). Conversely, the 2021 longline survey data (index and length compositions) indicate that the 2018 year class is large but more similar to the recruitment events in the late 1990s and early 2000s. Given that the fishery length composition and all age composition data are lagged by one year, there is likely to be a refinement to the estimate of the 2018 year class once these data are available for the 2022 model. Similarly, the influence of the trawl survey data will be greatly reduced once all the other 2021 data are available, but the trawl survey remains a strong predictor of year class strength for terminal model years when the survey occurs. Thus, although the 2018 year class estimate may be reduced in the 2022 model, it is expected that this year class is likely to represent yet another strong recruitment event.

Index Sensitivity Analysis

Similar to the stepwise data addition exercise, the index jackknife illustrated results that were generally expected in regards to the influence of the trawl survey on terminal year recruitment estimates (Figure 3.54). In particular, removal of the trawl survey data resulted in a strong decline in the 2018 year class estimate (Figure 3.54). Conversely, removal of the longline survey data resulted in strong declines in year class strength over the last ten years, especially associated with the 2014 and 2016 year classes, but an increase in the 2018 year class (i.e., emphasizing the influence of the trawl survey data on the 2018 year class estimate). Removal of the longline survey data also strongly influenced the SSB time series, with a strong decline throughout much of the 2000s up until 2020 (Figure 3.54). Without the longline survey data, the model estimates a much more pessimistic stock status and limited rebuilding. Again, the influence of the longline survey data is not surprising, given the influence given to it in the model and the *a priori* perception that it is a strong indicator of sablefish dynamics. Conversely, removal of the CPUE index had little overall impact on the assessment results.

Sensitivity Run Results

Results for the sensitivity runs are provided in Table 3.20 and comparison of select model runs are provided in Figure 3.55. The results of model *16.5_Cont* have been discussed and are summarized in Appendix 3I. Compared to model *21.12_Proposed_No_Skip_Spawn*, model *16.5_Cont* demonstrates much higher recruitment estimates, terminal year SSB, stock status, and resulting ABCs. The influence of the increased data weights given to the compositional data is observed in the higher estimate of the 2018 year class, which directly influences the projected ABCs, because the model assumes that this and other recent year classes can be harvested at extremely high rates with little influence on the ability to maintain the resource at $B_{40\%}$. However, when Francis reweighting is applied (*21.9_Cont_Francis*), the 2018 year class is greatly reduced along with projected ABCs (Table 3.20). The influence of incorporating skipped spawning (*21.10_Proposed_w_SS*) is relatively minor, mainly acting to reduce recent SSB slightly, primarily due to a lower assumed maturity of the highly abundant recent year classes (Figure 3.55). In terms of parametrization changes, not incorporating a recent time block for longline survey selectivity (*21.28_Fish_q+Sel_Only*) had the strongest influence, resulting in much higher recent recruitment estimates and more rapid rebuilding (Figure 3.55). The greatly improved terminal stock status also led to a strong increase in projected ABCs (Table 3.20). However, not allowing for a recent longline survey selectivity time block led to a continued recruitment retrospective pattern on par with model *16.5_Cont* (Appendix 3H, Figure 3H.6). Conversely, not incorporating a recent time block for fishery catchability (*21.29_Fish_Sel_Srvy_Sel*) had minimal impact aside from a slight rescaling of the population SSB (Figure 3.55) and degraded fit to the CPUE index time series.

Harvest Recommendations

Reference Fishing Mortality Rate

Sablefish have been managed under Tier 3 of NPFMC harvest rules. Reference points were calculated using the average year class strength from 1977 - 2017. The updated point estimate of $B_{40\%}$, is 118,140 t. Since projected female spawning biomass (combined areas) for 2022 is 127,789 t (9% higher than $B_{40\%}$, or equivalent to $B_{44\%}$), sablefish is in sub-tier "a" of Tier 3. The updated point estimates of $F_{40\%}$, and $F_{35\%}$ from this assessment are 0.080 and 0.094, respectively. Thus, the maximum permissible value of F_{ABC} under Tier 3a is 0.080, which translates into a 2022 ABC (combined areas) of 34,863 t. The adjusted OFL fishing mortality rate is 0.094, which translates into a 2022 OFL (combined areas) of 40,432 t. 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 2021 numbers-at-age as estimated in the assessment. This vector is then projected forward to the beginning of 2022 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (yearend) catch for 2021. In each subsequent year, the fishing mortality rate is prescribed based on 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 2021 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 2022, 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 2022 and 2023, F is set equal to the F associated with the specified catch, which is the whale corrected ABC multiplied by the fraction of the 2021 ABC that was harvested (i.e., a harvest ratio of 68% in 2021). For the remainder of the future years, maximum permissible ABC is used. (Rationale: the recommended ABC is routinely not fully utilized and this projection may provide a better indication of projected resource dynamics based on the fraction of the ABC utilized in recent years).

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 2016 – 2020 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 2021, or 2) above ½ of its B_{MSY} level in 2021 and above its B_{MSY} level in 2031 under this scenario, then the stock is not overfished.]

Scenario 7: In 2022 and 2023, 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 2023, or 2) above 1/2 of its B_{MSY} level in 2023 and expected to be above its B_{MSY} level in 2033 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 3.19). In Scenario 2 (Specified Catch), 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 2022 and 2023. 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 for 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 (i.e., 2018 – 2020 for the 2021 catch). For catch projections in the next two years, we use the ratio of the terminal year catch to terminal year ABC to determine the fraction of the ABC to be removed in each projection year. This method results in slightly higher future ABCs due to the lower initial removals in the initial projection years.

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 2022, it does not provide the best estimate of OFL for 2023, because the mean 2023 catch under Scenario 6 is predicated on the 2022 catch being equal to the 2022 OFL, whereas the actual 2022 catch will likely be less than the 2022 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 (2020) is 19,005 t. This is less than the 2020 OFL of 50,481 t. Therefore, the stock is not being subjected to overfishing.

Harvest Scenarios #6 and #7 (Table 3.19) 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 2021:

a. If spawning biomass for 2021 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b. If spawning biomass for 2021 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c. If spawning biomass for 2021 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 3.19). If the mean spawning biomass for 2031 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 3.19):

a. If the mean spawning biomass for 2023 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2023 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2023 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2033. If the mean spawning biomass for 2033 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 3.19, 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 (2020) was specified as 50,481 t. The fishing mortality rate required to achieve the OFL would have been 0.152.

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 (burned-in and thinned) using the standard Tier 3 harvest rules. The projection shows wide credible intervals on future spawning biomass (Figure 3.48). The $B_{35\%}$ and $B_{40\%}$ reference points are based on the 1977 - 2017 year classes. This projection predicts that the mean and median spawning biomass will be above both $B_{35\%}$ and $B_{40\%}$ by 2022 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.

Additional ABC/ACL Considerations

Risk Table Definitions

The NPFMC and SSC now request that all authors submit risk table analyses for all full stock assessments. The risk table approach is used to highlight externalities to the assessment that may indicate potential issues that should be considered when managers are determining future ABC recommendations, but which are not directly accounted for in the assessment model. In particular, high risk table scores can be used justify setting an ABC below the maximum permissible ABC (as determined from standard projections and the NPFMC harvest control rules). Risk table categories and associated examples of issues to consider are provided in the Table below along with definitions of risk table scores.

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 four category evaluation are discussed in the following sections and summarized in the Risk Table Summary section.

Table I. Risk table definitions and example scoring.

	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

Assessment Related Considerations

Data and model uncertainty are typically considered first under this category for a stock assessment, which can typically be summarized by data quality, data fits, and model diagnostics. The sablefish assessment is data-rich and the quality of the data that goes into the model is generally considered to be quite high. For instance, it is one of the few stocks with a long-term dedicated survey (i.e., the longline survey) and multiple sources of age and size composition with high yearly sample sizes (e.g., > 1,000 otoliths aged per year for both the longline survey and fixed gear fishery; Table 3.8). Given the breadth and quality of data, there are no data concerns for sablefish, especially considering that the longline survey was able to be completed in 2020 and 2021 despite ongoing limitations for other surveys due to the COVID-19 pandemic.

The sablefish assessment is one of only a few assessments in the North Pacific that is fit to multiple abundance indices, including 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 47%, 32%, and 9% year over year for the last three years (Figure 3.10c). Similarly, the trawl survey biomass was at a time series low in 2013, but has increased almost five-fold since that time, with a 38% increase from 2019 to 2021 (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, especially given that CPUE indices are impacted by socioeconomic factors, such as targeting. 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. However, all indices share common recent growth trends, while the model is able to fit these data quite well.

Moreover, the age and length composition data continue to indicate strong year classes in 2014, 2016, 2017, and a potentially strong, albeit highly uncertain, 2018 year class. However, indications of extremely large recent year classes from the composition data conflicts to some degree with signals of overall population growth from the indices of abundance. These conflicting signals in the magnitude of recent recruitment events are an important source of model tension. There are two main interpretations of these data: 1) recent recruitment is extremely large as indicated in the composition data, but survey indices are not increasing as fast as expected based on these recruitment events (model *16.5_Cont*); 2) recent recruitment is very large, but has also been accompanied by increasing availability of certain age classes to the various gears (model *21.12_Proposed_No_Skip_Spawn*). Assuming the former (i.e., using model *16.5_Cont*) leads to model estimates of recruitment that appear to be overly optimistic and that are eventually retroactively downgraded as more years of composition data become available, while also resulting in poor fits to the survey indices. Conversely, using the latter assumption (i.e., model *21.12_Proposed_No_Skip_Spawn*) results in more consistent estimates of recruitment over time, albeit with an associated degradation in fit to the fixed gear fishery age composition data. However, it does appear that model *21.12_Proposed_No_Skip_Spawn* is better able to account for cohort decay in the fishery age composition data. Thus, these results indicate that either recent year classes are smaller than it appears based solely on compositional data or fish in these recent year classes have lower survival to older ages (or are not being observed at as high of rates as expected). Although there are clearly some diverging signals in the compositional and index data, there is general agreement that the population is increasing due to recent high recruitment. The proposed model is able to adequately balance fitting the two data sources, though some uncertainty remains about the assumption utilized regarding the potential for increased availability of young, small fish to the fishery and survey (i.e., allowing a recent selectivity time block). Thus, until these recent cohorts have been observed for a number of years in the compositional data, there is moderate uncertainty regarding the size of the cohorts.

Despite some data conflicts, the suite of diagnostic analyses implemented demonstrate that the proposed sablefish assessment is robust and consistent. Retrospective patterns have been effectively eliminated. Thus, there are no longer any strong concerns about overestimating ABCs due to overestimated recent cohort strength. However, it is expected that the 2018 year class is being driven by the 2021 trawl survey and may be downgraded when the 2021 age composition data is included in next year's assessment. As such, projections may be slightly overoptimistic due to overestimation of the 2018 year class, but not to the extent observed for model *16.5_Cont*.

As noted, there are a number of potential sources of process error for the assessment, such as lack of time-varying natural mortality or fully time-varying selectivity. Although the proposed model is believed to better reflect rapidly changing sablefish dynamics, the potential mechanisms that may be driving changes in availability and associated selectivity are not well understood. Similarly, the current assessment model also does not account for spatial processes, because it assumes a single homogenous population across the entire Alaska federal management area. 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, the lack of spatial structure in either fleet or population dynamics should be considered a source of potential assessment uncertainty in the current model.

In summary, the variety of data sources available for sablefish tend to show general agreement regarding population growth, and the proposed model is able to adequately fit all available data. Moreover, retrospective patterns and recruitment estimation difficulties associated with previous sablefish models (*16.5_Cont*) have been greatly reduced. Although there is uncertainty in the magnitude of recent year classes, particularly the 2018 year class, there are no major assessment related concerns for sablefish at this time. **Therefore, we rated the assessment related concern as 'level 1 – normal'.**

Population Dynamics Considerations

The age structure of sablefish is being strongly perturbed by an unprecedented surge in recruitment. The estimates of the 2014, 2016, 2017, and 2018 recent year classes are the most pertinent uncertainties to consider when making recommendations for future harvest levels. Ultimately, given the magnitude of these classes, there is long-term promise for the continued growth of the sablefish spawning stock biomass. However, projected rebuilding may be hampered if density-dependent mortality mechanisms exist or body condition declines during periods of high recruitment. 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 3D). 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 affect survival into mature ages (Figure D), and trawl removals are already directly incorporated into the assessment model. 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.

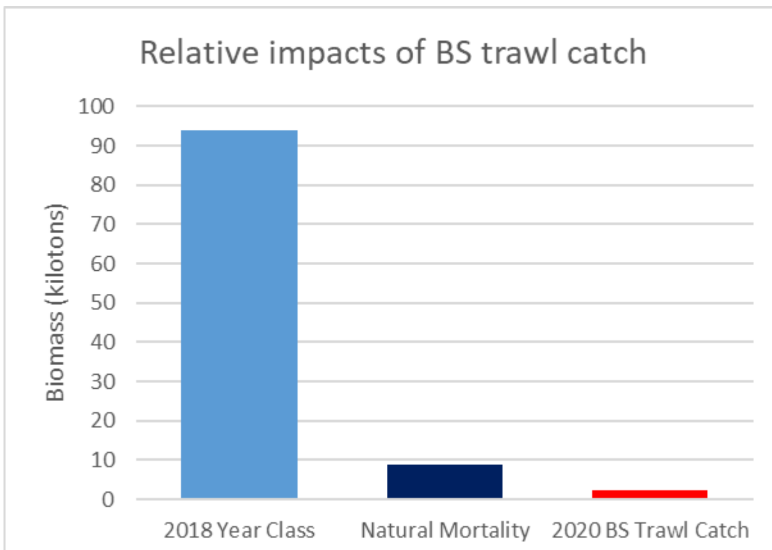

Figure D. Comparison of biomass of the 2018 year class to removals due to natural mortality and trawl fishing in the Bering Sea. Because Bering Sea trawl removals are primarily of young, small fish, the biomass comparison was made to only the most recent year class estimated in the model. Trawl fishing was estimated to remove less than 3% of the 2018 year class in 2021 (**assuming all removals came only from the 2018 year class**), whereas natural mortality removes around 10% of a given cohort annually.

Given that recruitment since 2000 had been weak for over a decade, the stock has seen a precipitous decline in older, fully mature fish (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 sudden transition to a high recruitment regime occurred 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 – 2018 year classes will comprise upwards of 50% of total SSB in 2022, 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). Any impediments to these recent year classes reaching fully mature ages could negatively affect 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.

Overall, productivity remains high and the 2018 year class was estimated to be of similar magnitude as recent year classes, while there is evidence that the 2019 year class may also be large (Appendix 3C). 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 associated with estimating the size of the recent year classes, the systematic truncation of the age structure over the last decade, and uncertainty in how many of these new recruits will actually survive to become mature spawners, there is moderate population dynamics concerns. **Hence, we rate the population dynamics as a 'level 2 – increased concern'.**

Environmental and Ecosystem Considerations

Appendix 3C provides a detailed look at environmental and ecosystem considerations specific to this stock within the Ecosystem and Socioeconomic Profile or ESP. Broad-scale information on environmental and ecosystem considerations are provided by the Eastern Bering Sea and Gulf of Alaska Ecosystem Status Report (EBS ESR and GOA ESR; Siddon 2021, Ferriss 2021). The text below summarizes ecosystem information related to Alaska sablefish provided from the ESP, EBS ESR, and GOA ESR.

Environmental Processes: GOA and EBS temperatures as a whole were close to average and/or cooler than last year. There were few days where sea surface temperatures exceeded the marine heatwave threshold in the GOA, and the overall pattern was cooler than average. While sea surface temperatures in the EBS were cooler than last year, they remained above average. Temperatures at depth, where sablefish are largely distributed, have remained relatively stable over time, with temperatures at the long-term average during 2021, but slightly above for the previous 5 years. The spring bloom as indicated by chlorophyll *a* concentration was much lower than average in the western GOA, although near average in the eastern GOA and south EBS, suggesting lower bottom up productivity in the western GOA that could influence the 2021 zooplankton prey base for smaller age-classes of sablefish. Peak timing of the bloom was progressively later from the eastern GOA to the south EBS, which may have implications for match with the zooplantkon prey for young-of-the-year (YOY) sablefish.

Prey: YOY and juvenile sablefish are opportunistic feeders. Current year estimates of zooplankton abundance are mixed, but largely average or below average. In the eastern GOA, euphausiid larvae density in Icy Strait was slightly above average, which has been shown to be correlated with sablefish recruitment in past years (Yasumiishi et al. 2015). Zooplanktivorous storm petrels at St Lazaria had average to below average reproductive success. In the western GOA, storm petrels at East Amatuli had below average reproductive success, but parakeet auklets at Chowiet had average reproductive success. YOY sablefish growth as measured in samples captured by rhinoceros auklets at Middleton Island showed near average growth, although sample sizes were small. Sablefish condition for juveniles, measured by age-4 females in the longline survey, improved in 2020 to slightly below average, up from an all-time low in 2017, suggesting that their foraging environment was improved. Most species of deep-diving, fish-eating seabirds (e.g., common murres and tufted puffins) had reproductive success that was well above average across the GOA in 2021, suggesting that forage fish prey were abundant. This is promising for young sablefish transitioning from nearshore nursery environments to adult habitat. However, the condition of large adult females in 2021 was lower than average, continuing the decreasing trend since 2018. This suggests that the adult foraging habitat on the slope is becoming limiting and may result in increasing the spatial distribution of the population to other regions and depths.

Competitors: Potential competitors with sablefish could be Pacific Ocean perch (POP) and pink salmon for zooplankton prey at YOY life stages, and adult Pacific cod, Pacific halibut, and arrowtooth flounder for forage fish prey at depth as adults. POP biomass has been steadily increasing since the mid-2000s and is now greater than GOA pollock biomass. Pink salmon returns were very high in 2021, and at those high numbers could be expected to exert a predatory pressure on zooplankton, as has been documented previously. Other adult apex groundfish are at relatively low abundance, and the spatial overlap with arrowtooth flounder, as estimated by the incidental catch of sablefish in the arrowtooth fishery, has declined to average levels. This suggests that the large sablefish year classes of 2014 - 2016 have moved off the continental shelf into adult sablefish habitat on the slope.

Predators: In general, stocks of groundfish predators of sablefish have generally remained low in the past few years. There are no indications that their impacts as competitors for forage fish prey or as predators on sablefish have increased. Population trends in sperm whales are not well known, and their predatory impacts on line-caught sablefish are addressed within the stock assessment model.

Overall, indicators suggest stable temperatures at depth, moderate to warm surface temperature conditions, a mix of average to below average indicators of foraging conditions, no apparent increases in predation pressure, and reduction in potential competition due to juvenile sablefish moving off the shelf into adult slope habitat. **Given that no major concerns are apparent for sablefish, we scored the environmental/ecosystem concern as 'level 1 – normal'.**

Fishery Performance Considerations

In recent years, there have been large changes to the mixture of gears contributing to sablefish removals that are not fully accounted for in the Alaska-wide assessment. For instance, there has been an increasing shift to pot gear in the Gulf of Alaska since its legalization in 2017, primarily to avoid whale depredation. During this period, there has also been quick adoption of recently developed collapsible 'slinky' pots, which are more easily utilized on smaller boats compared to traditional rigid pots. The rate of transition among pot gears is currently unknown and the difference in CPUE and selectivity is uncertain. While we are accounting for whale depredation, this shift in gear type is not presently being accounted for directly in the stock assessment model. Additionally, although longline CPUE has been extremely depressed, pot fishing CPUE in the EBS has been steadily rising since about 2010 (Appendix 3C, Figure 3C.2b). At the same time, the rapid decline in overall market conditions, particularly due to the influx of small sablefish, may be contributing to differences in targeting and selectivity in all fisheries, which is not accounted for in the assessment model. 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 fully time-varying selectivity. **Thus, we rated the fishery performance category as 'level 2 – increased concern'.**

Risk Table Summary

Overall, the highest score for sablefish in 2021 is a 'Level 2—Increased Concern'. Since the SSC prefers not rating the risk table overall on the highest score, we also note that 2 of the 4 scores are Level 2 with the remaining 2 scores being categorized as a Level 1 (Table J). Given the lack of major concerns for sablefish along with the improved model performance of the proposed assessment compared to the 2020 model, no deductions in ABC are being recommended. However, the lack of fish > 10 years of age for an extremely long-lived species is disconcerting. Additionally, the projected maximum ABC would represent the largest catch since the late 1980s and before that in the early 1970s. Both periods were associated with declines in biomass and SSB, due to high catches and extended periods of poor recruitment (Figure E). Given that sablefish are such a long-lived species along with the cyclic nature of sablefish dynamics, exploration of a capped (i.e., implementing a maximum cap on the ABC) management procedure (or an 'inventory management' strategy) for sablefish may be worthwhile. Compared to using a maximum yearly catch strategy, capped HCRs could aid in stabilizing long-term sablefish dynamics (i.e., help to prevent long-term cyclical declines as the resource transitions between high and low recruitment regimes), while also maximizing economic metrics (i.e., years with high catch of larger, more valuable fish; Licandeo et al., 2020). Similarly, alternate metrics of spawning potential, which better emphasize fully mature age classes (e.g., the biomass of ages > 10), could help maintain a strong spawning portfolio and avoid future contraction of the age structure, thereby improving resilience of the sablefish resource (Hixon et al., 2014; Lowerre-Barbieri et al., 2016; Licandeo et al., 2020).

Table J. Sablefish risk table.

Assessment Related Considerations	Population Dynamics Considerations	Environmental and Ecosystem Considerations	Fishery Performance Considerations
Level 1: Normal	Level 2: Increased concern	Level 1: Normal	Level 2: Increased concern

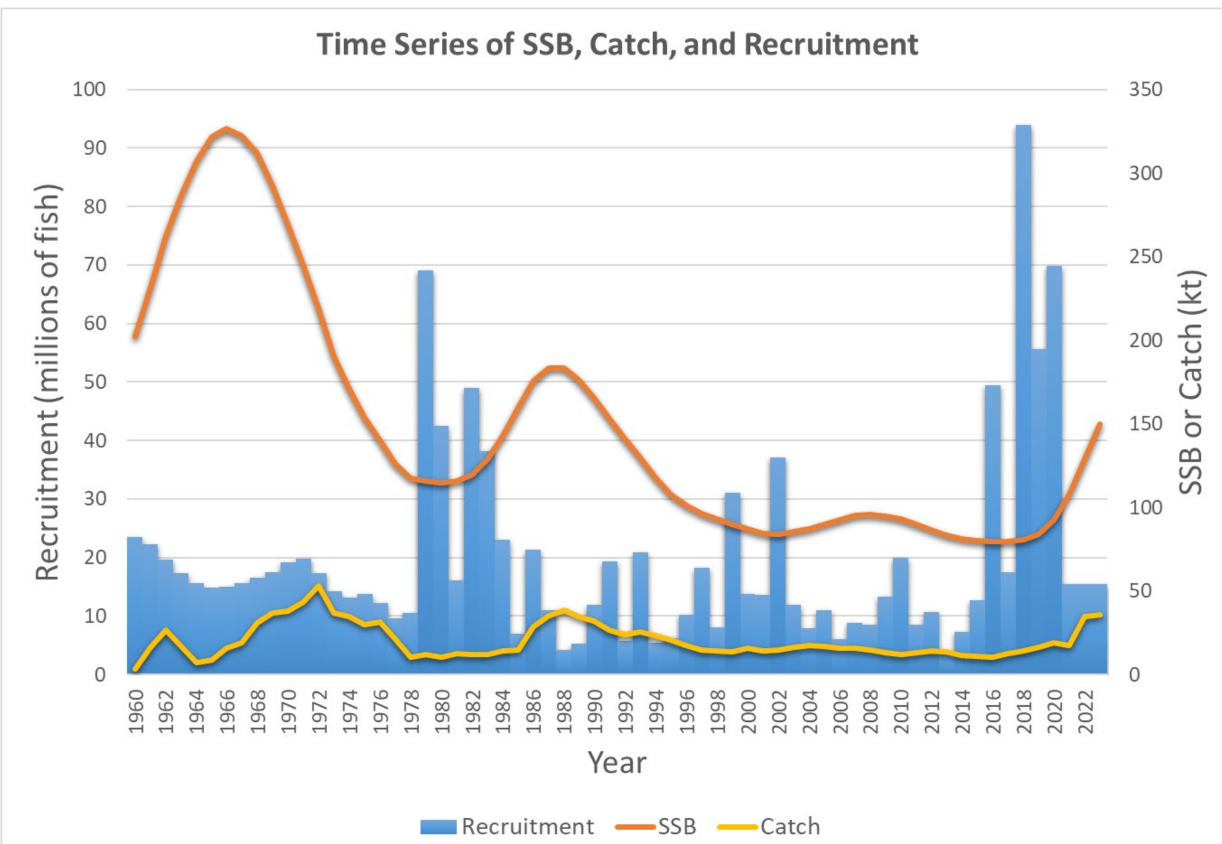

Figure E. Time series of sablefish SSB, catch, and recruitment. Projected dynamics for 2022 and 2023 are included based on the maximum permissible ABC and average recruitment. Note the cyclical dynamics associated with spasmodic recruitment. Transitory increases in SSB are followed by a persistent downward time series trend. Catches typically rapidly increase following high recruitment periods at the same time that recruitment returns back towards average levels.

Acceptable Biological Catch Recommendation

The maximum permissible ABCs from the proposed model (*21.12_Proposed_No_Skip_Spawn*) of 34,863 t in 2022 and 36,670 t in 2023 are being recommended.

Area Allocation of Harvests

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, it was 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 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 evaluated and reviewed. In 2020, results of a simulation analysis on apportionment were presented (Appendix 3D of the 2020 SAFE; Goethel et al., 2020) and it was recommended that a five-year (non-exponentially weighted) average survey apportionment method be adopted.

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, and WG) may lead to higher mortality on younger fish when year classes are above average, 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. 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 and recent, not fully mature, cohorts, 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 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 resource. The results of the simulation work, though limited in scope of process and observation error, indicated 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-2 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, the five-year average survey apportionment method was recommended by the SSC in 2020, 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 primary adult habitat). Additionally, the rolling 5-year average 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. However, as noted, limited tools exist to determine the impact of spatiotemporally and demographically varying removals.

2021 Apportionment Recommendation

For 2021, the author's preferred apportionment is the five-year average survey apportionment because: 1) it reflects our best estimate of the biomass distribution for sablefish; 2) the five-year average 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 five-year average survey apportionment method. The area specific ABCs resulting from this approach are provided in Table K.

In 2020, the SSC instituted a four-year stair step approach to move from the fixed apportionment used prior to 2020 towards the five-year average survey apportionment. The rationale for implementing a tiered approach was to avoid a sharp transition in the distribution of the ABC across regions. Assuming that the stair step approach will be continued in 2021, the next move would be a 50% step from the 2019 fixed apportionment values towards the 2021 five-year average survey apportionment values. Alternate values of the resulting regional ABCs are provided in Table K for various apportionment options as a basis of comparison, but the author recommended long-term ABC is the five-year survey apportionment (with little preference for how the steps are taken to reach the long-term method). Also, it is important to emphasize that the recommended five-year average survey apportionment utilizes a moving five-year average, thus, the apportionment values change each year as new survey data is added into the calculation. Therefore, as recent cohorts begin to age and redistribute, the apportionment values will similarly vary.

Table K. Apportionment table (before whale depredation adjustments).

Method	Area						ABC
	AI	BS	WG	CG	WY*	EY*	
2021 ABC+	4,727	3,420	3,253	9,644	3,471	5,326	29,841
*Status Quo (Fixed at Current)***	5,558	4,001	3,799	11,226	4,066	6,213	34,863
2020 5-year Survey Avg.	8,231	5,742	4,296	8,945	2,990	4,660	34,863
*Fixed****	4,601	3,402	3,761	11,892	4,000	7,207	34,863
25% Stair Step	5,543	4,353	3,791	10,950	3,590	6,635	34,863
50% Stair Step**	**6,486**	**5,305**	**3,821**	**10,008**	**3,179**	**6,064**	**34,863**
75% Stair Step	7,428	6,256	3,852	9,066	2,768	5,493	34,863
***5-year Survey Avg.**^*	**8,371**	**7,207**	**3,882**	**8,124**	**2,357**	**4,922**	**34,863**
50% Stair Step from 2021#	6,964	5,604	3,840	9,675	3,212	5,568	34,863

+This is the final 2021 ABC and associated regionally apportioned ABCs based on the 2020 SAFE. Other approaches utilize the 2022 ABC. Note that 2021 ABC is after the 95:5 hook and line : trawl split has been applied between WY and EY/SE, whereas all 2022 ABCs shown here are prior to this adjustment.

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

**Apportionment fixed (i.e., status quo) at the 2020 SSC recommended apportionment that used a 25% stair step from fixed apportionment to the 2020 5-year survey average apportionment.

*** Fixed at the 2013 assessment apportionment proportions (Hanselman et al. 2012b).

****A 50% stair step from fixed apportionment to the 2021 5-year survey average apportionment. This represents the next incremental step in the 2020 SSC recommended 4-year stair step approach.

^The 5-year survey average is the biologically recommended long-term apportionment strategy. This approach does not utilize a stair step (i.e., it represents a 100% step).

#The 50% stair step from the 2020 SAFE apportionment values to the 2021 5-year survey average apportionment is an alternative to a 50% stair step from the fixed apportionment.

Table I. Area apportionment percent difference from 2021 ABC.

Method	Area						ABC
	AI	BS	WG	CG	WY	EY	
Status Quo (Fixed at Current)	18%	17%	17%	16%	17%	17%	17%
2020 5-year Survey Avg.	74%	68%	32%	-7%	-14%	-13%	17%
Fixed	-3%	-1%	16%	23%	15%	35%	17%
25% Stair Step	17%	27%	17%	14%	3%	25%	17%
50% Stair Step	**37%**	**55%**	**17%**	**4%**	**-8%**	**14%**	**17%**
75% Stair Step	57%	83%	18%	-6%	-20%	3%	17%
5-year Survey Avg.	77%	111%	19%	-16%	-32%	-8%	17%
50% Stair Step from 2021	47%	64%	18%	0%	-7%	5%	17%

* Note that 2021 ABC is after the 95:5 hook and line : trawl split has been applied between WY and EY/SE, whereas all 2022 ABCs are prior to this adjustment. Thus, the differences in WY and EY are more extreme than in the final regional ABCs after all adjustments have been applied (e.g., as shown in the Final Whale Adjusted Catch Table by Region).

Table M. Regional estimates of sablefish harvest rate.

Method[**]	AI	BS	WG	CG	WY	EY	Total
Status Quo (Fixed at Current)	0.03	0.03	0.06	0.10	0.14	0.10	0.06
2020 5-year Survey Avg.	0.05	0.04	0.07	0.08	0.10	0.08	0.06
Fixed	0.03	0.03	0.06	0.11	0.14	0.12	0.06
25% Stair Step	0.03	0.03	0.06	0.10	0.12	0.11	0.06
50% Stair Step	**0.04**	**0.04**	**0.06**	**0.09**	**0.11**	**0.10**	**0.06**
75% Stair Step	0.04	0.05	0.07	0.08	0.10	0.09	0.06
5-year Survey Avg.	**0.05**	**0.05**	**0.07**	**0.07**	**0.08**	**0.08**	**0.06**
50% Stair Step from 2021	0.04	0.04	0.06	0.09	0.11	0.09	0.06

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

[**]Harvest rate is calculated as the region-specific catch divided by biomass for each apportionment scenario. Regional biomass (Age 2+) is taken from Table 3.16b with projected biomass and harvest rates based on maximum permissible ABCs for 2022 and 2023 (before whale depredation corrections). Analysis of spatial dynamics should be undertaken judiciously given the caveats associated with estimating regional biomass. Harvest rates are approximations for illustrative purposes only. Estimates do not account for spatial differences in selectivity due to trawl and fixed gear catch splits.

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., the NPFMC apportionment). These apportionment types rely on survey and fishery data. 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.

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 an OFL of 40,432 t for the combined stock in 2022. 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 interannual variation in growth (e.g., through internal estimation of growth parameters) and maturity, including accounting for cohort effects and skipped spawning.
3) Re-examine selectivity assumptions (i.e., including alternate non-asymptotic functional forms and alternate time blocks), as well as, how these assumptions are impacted by decisions about data weighting; develop non-parametric selectivity functions and explore the use of state-space modeling frameworks.
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.
7) Continue work to refine spatial models of sablefish.
8) Incorporation of the long time series of tag recaptures could help refine estimates of fishing and natural 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 coast wide 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. 2021 catches are as of October 25, 2021 (from www.akfin.org). The 2021 catch value is incomplete and does not include specified catch as incorporated in the assessment model. The values in this table are not adjusted for whale depredation.

		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	12,282	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	11,936	752	1,048	1,354	4,512	4,270	1,579	2,692	0	10,932	1,005	0.08
2011	12,996	707	1,027	1,397	4,924	4,941	1,903	3,038	0	11,816	1,180	0.09
2012	13,875	745	1,206	1,353	5,331	5,241	2,033	3,207	0	12,773	1,102	0.08
2013	13,667	654	1,070	1,383	5,193	5,367	2,117	3,250	0	12,630	1,037	0.08
2014	11,581	313	821	1,201	4,765	4,480	1,667	2,813	0	10,555	1,025	0.09
2015	10,982	210	431	1,013	4,643	4,686	1,858	2,828	0	9,891	1,090	0.10
2016	10,231	531	346	1,056	4,193	4,106	1,644	2,462	0	8,895	1,336	0.13
2017	12,269	1,153	590	1,182	4,843	4,502	1,692	2,809	0	9,997	2,272	0.19
2018	14,265	1,547	660	1,398	5,780	4,880	1,863	3,018	0	10,485	3,780	0.26
2019	16,565	3,143	655	1,547	6,289	4,932	1,807	3,125	0	11,411	5,154	0.31
2020	19,005	5,301	1,210	1,469	6,052	4,973	1,834	3,139	0	11,512	7,493	0.39
2021	17,463	3,570	1,311	1,484	5,800	5,299	2,152	3,147	0	13,230	4,233	0.24

Table 3.2. Catch (t) in the Aleutian Islands and the Bering Sea by gear type from 1991 - 2021. Both CDQ and non-CDQ catches are included. Catches in 1991 - 1999 are averages. Catch value as of October 25, 2021 (from www.akfin.org). The 2021 catch value is incomplete and does not include specified catch as incorporated in the assessment model. The values in this table are not adjusted for whale depredation.

		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	915	1,048
2011	141	47	839	1,027
2012	77	148	980	1,206
2013	87	58	925	1,070
2014	160	26	635	821
2015	12	15	403	431
2016	21	30	296	346
2017	270	129	191	590
2018	282	179	199	660
2019	203	241	210	655
2020	378	695	136	1,210
2021	515	634	163	1,311

		Bering Sea		
Year	**Pot**	**Trawl**	**Longline**	**Total**
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	271	752
2011	406	44	257	707
2012	433	93	219	745
2013	352	133	168	654
2014	164	34	115	313
2015	108	17	85	210
2016	158	257	116	531
2017	368	679	106	1,153
2018	382	1,018	148	1,547
2019	419	2,506	218	3,143
2020	563	4,467	271	5,301
2021	959	2,324	286	3,570

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		44,200	36,400	
1989	34,829		37,100	32,200	Pot fishing banned in Western GOA.
1990	32,115		33,400	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	28,800	
1992	24,042	34,070	25,200	25,200	Pot fishing banned in Bering Sea (57 FR 37906).
1993	25,417	33,250	25,000	25,000	
1994	23,580	35,860	28,840	28,840	
1995	20,692	25,730	25,300	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	22,800	19,580	19,380	Pot fishing ban repealed in Bering Sea except from June 1-30.
1997	14,607	45,560	17,195	16,820	Maximum retainable allowances for sablefish were revised in the Gulf of Alaska. The percentage depends on the basis species.
1998	13,874	27,840	16,800	16,800	
1999	13,587	24,700	15,900	15,420	
2000	15,570	21,500	17,230	17,230	
2001	14,065	20,700	16,900	16,900	
2002	14,748	26,100	17,300	17,300	
2003	16,411	28,900	20,890	20,890	
2004	17,520	30,800	23,000	22,550	
2005	16,585	25,400	21,000	21,000	
2006	15,551	25,300	21,000	20,660	
2007	15,958	23,746	20,100	20,100	
2008	14,551	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	11,936	18,030	15,230	15,230	
2011	12,996	18,950	16,040	16,040	
2012	13,875	20,400	17,240	17,240	
2013	13,667	19,180	16,230	16,230	
2014	11,581	16,225	13,722	13,722	
2015	10,982	16,128	13,657	13,657	NPFMC passes Amendment 101 to allow pot fishing in the GOA
2016	10,231	13,396	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	14,265	29,507	14,957	14,957	
2019	16,565	32,798	15,068	15,068	
2020	19,005	50,481	22,009	18,293	TAC smaller than ABC based on AP recommendation OFL changed to Alaska-wide
2021[1]	17,463	60,426	29,588	26,104	

[1] Catch is as of Oct. 25, 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) by FMP area for 2016 – 2021. The discard rate is the total discards divided by the total catch by year and gear. Source: NMFS Alaskan Regional Office Catch Accounting System via AKFIN (www.akfin.org), accessed on October 10, 2021. Discards are included in the assessment model catch assuming 100% mortality.

		BSAI			GOA			Combined		
Year	**Gear**	**Discard**	**Rate**	**Catch**	**Discard**	**Rate**	**Catch**	**Discard**	**Rate**	**Catch**
2016	H&L	73	18%	412	630	8%	8,296	703	8%	8,707
	Pot	1	1%	179	9	100%	9	10	5%	187
	Trawl	6	2%	287	178	17%	1,049	184	14%	1,336
	Total	80	9%	877	817	9%	9,354	897	9%	10,231
2017	H&L	54	18%	298	572	7%	8,163	625	7%	8,461
	Pot	25	4%	638	14	2%	898	39	3%	1,536
	Trawl	131	16%	807	484	33%	1,465	614	27%	2,272
	Total	209	12%	1,743	1,069	10%	10,526	1,279	10%	12,269
2018	H&L	73	21%	347	577	7%	8,348	650	7%	8,695
	Pot	40	6%	663	29	3%	1,123	69	4%	1,786
	Trawl	304	25%	1,196	1,614	62%	2,584	1,918	51%	3,780
	Total	417	19%	2,207	2,220	18%	12,054	2,637	18%	14,261
2019	H&L	151	35%	428	630	8%	7,853	781	9%	8,281
	Pot	27	4%	623	632	25%	2,507	659	21%	3,130
	Trawl	1,428	52%	2,747	1,268	53%	2,407	2,696	52%	5,154
	Total	1,607	42%	3,797	2,529	20%	12,767	4,136	25%	16,565
2020	H&L	223	55%	408	429	8%	5,408	652	11%	5,815
	Pot	31	3%	941	136	3%	4,756	167	3%	5,697
	Trawl	2,924	57%	5,162	1,243	53%	2,331	4,167	56%	7,493
	Total	3,178	49%	6,511	1,808	14%	12,494	4,986	26%	19,005
2021	H&L	61	24%	259	222	7%	3,090	283	8%	3,348
	Pot	63	5%	1,237	157	2%	7,076	219	3%	8,314
	Trawl	1,658	57%	2,890	426	35%	1,203	2,084	51%	4,093
	Total	1,782	41%	4,386	804	7%	11,369	2,586	16%	15,755
Mean	H&L	106	30%	358	510	7%	6,859	616	9%	7,218
	Pot	31	4%	714	163	6%	2,728	194	6%	3,442
	Trawl	1,075	49%	2,182	869	47%	1,840	1,944	48%	4,021
	Total	1,212	37%	3,254	1,541	13%	11,427	2,753	19%	14,681

Table 3.5. Mean bycatch (t) of FMP groundfish species in the targeted sablefish fishery from 2013 - 2021. 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 10, 2021.

	Hook and line			Other			All gears		
Species	D	R	Total	D	R	Total	D	R	Total
GOA Thornyhead	121	358	479	8	19	26	129	376	505
Shark	402	0	403	7	0	7	409	0	410
GOA Shortraker Rockfish	155	73	228	8	4	12	164	77	240
Arrowtooth Flounder	84	5	89	100	21	121	184	26	210
GOA Rougheye Rockfish	87	77	164	1	5	6	88	82	170
GOA Skate, Other	151	1	151	4	0	4	155	1	156
GOA Skate, Longnose	119	5	124	1	0	1	119	5	125
Other Rockfish	42	32	74	2	6	8	44	38	82
Pacific Cod	34	24	58	3	12	14	37	36	72
BSAI Skate	22	1	23	0	0	0	23	1	23
Greenland Turbot	9	0	9	19	4	23	27	4	31
GOA Skate, Big	8	2	10	3	4	7	11	6	16
Sculpin	5	1	5	3	13	16	8	14	22
GOA Demersal Shelf	1	0	1	13	12	25	13	13	26
BSAI Kamchatka	5	0	5	0	0	0	5	0	5
GOA Deep Water Flatfish	2	0	2	0	9	10	2	9	12
BSAI Shortraker Rockfish	1	11	12	0	0	0	1	11	12
Octopus	3	1	4	0	1	1	3	2	5
BSAI Other Flatfish	15	0	15	1	0	1	15	0	16
GOA Shallow Water	1	0	2	1	14	15	2	14	17
Pollock	0	0	0	0	0	0	0	0	0
Pacific Ocean Perch	2	0	2	2	0	2	4	0	4
Flathead Sole	3	0	3	2	1	3	5	1	5

Table 3.6. Bycatch of nontarget species and HAPC biota in the targeted sablefish fishery. Source: NMFS AKRO Blend/Catch Accounting System via AKFIN, October 10, 2021.

Group Name	2013	2014	2015	2016	2017	2018	2019	2020	2021
Benthic urochordata	0.0	0.0	0.5	0.0	0.9	0.3	0.1	0.0	0.0
Brittle star unidentified	0.1	0.6	2.1	0.3	0.6	0.6	0.4	0.3	0.4
Corals Bryozoans	12.7	5.1	4.5	5.6	2.1	9.5	3.4	1.2	1.0
Eelpouts	1.1	0.8	0.2	1.1	2.4	7.6	0.2	0.1	0.5
Grenadiers	13,638	6,928	6,783	8,667	6,113	5,216	3,650	1,935	902
Invertebrate unidentified	0.3	0.1	0.5	0.2	0.9	0.5	0.4	0.1	0.1
Misc. crabs	5.8	6.4	3.4	5.1	4.7	3.9	2.9	4.1	1.5
Misc. fish	19.9	19.2	15.7	6.9	21.4	29.1	141.8	46.1	13.7
Scypho jellies	0.0	5.5	0.2	0.2	0.0	0.6	0.7	0.3	0.2
Sea anemone unidentified	1.0	2.9	12.4	1.7	1.9	15.4	1.8	1.1	2.9
Sea pens whips	0.3	2.0	2.7	1.2	1.1	0.4	0.6	0.6	0.1
Sea star	14.5	10.3	9.0	6.4	19.9	14.0	5.8	7.7	2.8
Snails	8.8	3.7	3.3	0.2	2.8	2.9	7.9	2.9	3.3
Sponge unidentified	3.4	1.7	3.5	0.5	0.6	0.3	0.3	0.3	0.1
State-managed Rockfish	0.1	0.1	0.1	0.2	0.4	0.0	0.0	0.0	0.0
Urchins, dollars, cucumbers	0.9	0.8	2.5	0.2	0.2	1.1	1.3	0.5	0.2

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 8, 2021.

BSAI

	Year	Bairdi	Chinook	Golden KC	Halibut (t)	Other salmon	Opilio	Red KC
HAL	2014	-	-	576	33	-	-	40
	2015	-	9	177	23	-	-	206
	2016	22	0	49	7	-	27	5
	2017	9	0	0	2	0	12	2
	2018	8	0	0	5	0	17	10
	2019	6	0	3	2	0	21	0
	2020	2	0	0	4	0	12	0
	2021	2	0	0	1	0	12	0
	Mean	6	1	101	10	0	13	33
Other	2014	-	-	3,573	7	-	1,689	-
	2015	-	-	29,038	1	-	26	-
	2016	142	-	11,696	6	-	14	18
	2017	689	-	16,034	13	-	465	51
	2018	525	98	38,905	36	-	261	1,060
	2019	171	-	4,965	12	-	122	6
	2020	139	-	5,465	6	-	375	18
	2021	161	-	13,535	7	-	281	375
	Mean	228	12	15,401	11	-	404	191
Sum Means	**BSAI**	234	13	15,502	21	0	417	224

GOA

	Year	Bairdi	Chinook	Golden KC	Halibut (t)	Other salmon	Opilio	Red KC
HAL	2014	6	42	39	245	-	-	-
	2015	165	25	38	293	-	-	12
	2016	0	110	39	269	-	0	0
	2017	20	68	71	338	-	-	-
	2018	-	77	70	476	-	-	-
	2019	58	-	88	615	-	-	-
	2020	-	-	48	157	-	-	-
	2021	11	-	14	129	-	-	-
	Mean	32	40	51	315	-	0	1
Other	2014	-	-	18	2	-	-	-
	2015	25	-	-	3	-	-	-
	2016	-	-	47	11	-	-	-
	2017	150	-	26	9	-	-	-
	2018	2,760	-	-	46	-	-	-
	2019	200	-	92	15	-	-	-
	2020	1,766	-	39	59	-	-	-
	2021	376	-	10	44	-	2	-
	Mean	660	-	29	24	-	0	-
Sum Means	**GOA**	692	-	80	339	-	0	1

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		102,725		1,193	1,140
2020				9,241	9,122		104,723		1,186	1,188
2021	8,556						91,559			

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. Note that 2020 logbook data was not available in time for the 2021 SAFE report or assessment.

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
2020	C	C	C	0	0	2020	0.46	0.15	0.33	10	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
2020	0.59	0.06	0.10	13	3	2020	0.44	0.07	0.15	90	5

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
2020	0.56	0.11	0.19	68	6	2020	0.91	0.14	0.15	109	17

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 federal waters (depths 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. Fishery CPUE data for fishing year 2020 was not available in time for the 2021 assessment.

	RELATIVE POPULATION NUMBER		RELATIVE POPULATION WEIGHT/BIOMASS				
Year	**Coop. LL Survey**	**Dom. LL Survey**	**Jap. LL Fishery**	**Coop. LL Survey***	**Dom. LL 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	642		1,454	2,103	1,201	214
1991	386	580		1,321	2,031	1,066	
1992	402	499		1,390	1,718	908	
1993	395	550		1,318	1,842	904	250
1994	366	477		1,288	1,846	822	
1995		489			1,759	1,243	
1996		507			1,941	1,201	145
1997		478			1,850	1,341	
1998		475			1,678	1,130	
1999		527			1,788	1,326	104
2000		456			1,576	1,139	
2001		535			1,780	1,118	238
2002		551			1,895	1,143	
2003		517			1,710	1,219	189
2004		540			1,663	1,360	
2005		542			1,654	1,313	179
2006		571			1,844	1,216	
2007		509			1,627	1,281	111
2008		461			1,530	1,380	
2009		415			1,399	1,132	107
2010		459			1,528	1,065	
2011		556			1,680	1,056	84
2012		445			1,294	1,034	
2013		421			1,292	908	60
2014		484			1,467	969	
2015		386			1,201	848	67
2016		495			1,373	656	
2017		562			1,399	656	119
2018		611			1,260	623	
2019		900			1,798	745	211
2020		1,187			2,614	NA	
2021		1,298			2,888		291

*Indices were extrapolated for survey areas not sampled every year, including Aleutian Islands 1979, 1995, 1997, 1999, 2001, 2003, 2005, 2007, 2009, 2011, 2013, 2015, 2017, 2019, and 2021 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
2021	0	10			0	1	5	0	1	0	2	0

Table 3.12. Sablefish length (fork length, cm), weight (kg), and proportion mature by age and sex. Biological inputs are provided for both model *16.5_Cont* and *21.12_Proposed_No_Skip_Spawn*. Time period refers to the time blocks for which the given inputs are utilized in the associated model.

		Fork length (cm)						**Weight (kg)**				**Proportion Mature**	
	Time Period	**1960 -- 1995**		**1996 -- 2021**		**1996 -- 2021**		**1960 -- 2021**				**1960 -- 2021**	
	Model	***21.12_Proposed & 16.5_Cont***		***16.5_Cont***		***21.12_Proposed***		***16.5_Cont***		***21.12_Proposed***		***16.5_Cont***	***21.12_ Proposed***
	Sex	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Female**	**Female**
Age	2	48.9	52.2	48.1	46.8	47.9	48.0	1.0	0.9	1.1	1.1	0.01	0.02
	3	52.2	56.6	53.1	53.4	52.0	53.2	1.5	1.5	1.4	1.6	0.02	0.05
	4	54.9	60.1	56.8	58.8	55.3	57.6	1.9	2.1	1.8	2.0	0.08	0.09
	5	57.0	63.0	59.5	63.0	57.9	61.3	2.2	2.6	2.1	2.5	0.20	0.18
	6	58.7	65.4	61.6	66.4	60.0	64.4	2.5	3.1	2.3	2.9	0.39	0.31
	7	60.0	67.3	63.2	69.2	61.6	67.0	2.7	3.5	2.5	3.3	0.60	0.49
	8	61.1	68.9	64.3	71.4	62.9	69.2	2.8	3.9	2.7	3.6	0.77	0.67
	9	61.9	70.1	65.2	73.1	64.0	71.1	2.9	4.2	2.8	3.9	0.86	0.81
	10	62.6	71.2	65.8	74.5	64.8	72.7	3.0	4.4	2.9	4.2	0.92	0.90
	11	63.1	72.0	66.3	75.7	65.4	74.0	3.0	4.6	3.0	4.4	0.95	0.95
	12	63.6	72.7	66.7	76.6	66.0	75.1	3.1	4.8	3.0	4.7	0.97	0.98
	13	63.9	73.2	67.0	77.3	66.4	76.1	3.1	4.9	3.1	4.8	0.98	0.99
	14	64.2	73.7	67.2	77.9	66.7	76.9	3.1	5.1	3.1	5.0	0.99	0.99
	15	64.4	74.0	67.3	78.3	66.9	77.6	3.1	5.1	3.1	5.1	0.99	1.00
	16	64.6	74.3	67.4	78.7	67.1	78.1	3.1	5.2	3.2	5.2	0.99	1.00
	17	64.7	74.6	67.5	79.0	67.3	78.6	3.1	5.3	3.2	5.3	0.99	1.00
	18	64.8	74.8	67.6	79.3	67.4	79.0	3.2	5.3	3.2	5.4	1.00	1.00
	19	64.9	74.9	67.6	79.4	67.5	79.4	3.2	5.3	3.2	5.5	1.00	1.00
	20	65.0	75.0	67.7	79.6	67.6	79.7	3.2	5.4	3.2	5.5	1.00	1.00
	21	65.0	75.1	67.7	79.7	67.7	79.9	3.2	5.4	3.2	5.6	1.00	1.00
	22	65.1	75.2	67.7	79.8	67.7	80.1	3.2	5.4	3.2	5.6	1.00	1.00
	23	65.1	75.3	67.7	79.9	67.8	80.3	3.2	5.4	3.2	5.7	1.00	1.00
	24	65.2	75.4	67.7	80.0	67.8	80.4	3.2	5.4	3.2	5.7	1.00	1.00
	25	65.2	75.4	67.7	80.0	67.8	80.6	3.2	5.4	3.2	5.7	1.00	1.00
	26	65.2	75.4	67.8	80.1	67.9	80.7	3.2	5.4	3.2	5.8	1.00	1.00
	27	65.2	75.5	67.8	80.1	67.9	80.8	3.2	5.4	3.2	5.8	1.00	1.00
	28	65.2	75.5	67.8	80.1	67.9	80.8	3.2	5.4	3.2	5.8	1.00	1.00
	29	65.2	75.5	67.8	80.1	67.9	80.9	3.2	5.5	3.2	5.8	1.00	1.00
	30	65.2	75.5	67.8	80.2	67.9	80.9	3.2	5.5	3.2	5.8	1.00	1.00
	31+	65.2	75.5	67.8	80.2	67.9	81.0	3.2	5.5	3.2	5.8	1.00	1.00

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. Model comparison by contribution to the objective function (negative log-likelihood values) and key parameters of the 2020 model (*16.5_Cont*) and the proposed 2021 model (*21.12_Proposed_No_Skip_Spawn*). $a_{50\%}$ 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	**2020**	**2021**
Likelihood Components	Value	Value
Catch	6	5
Dom. LL survey RPN	61	36
Coop. LL survey RPN	15	11
Dom. LL fishery RPW	20	5
Jap. LL fishery RPW	10	11
NMFS trawl survey	28	14
Dom. LL survey ages	295	145
Dom. LL fishery ages	305	39
Dom. LL survey lengths	81	93
Coop LL survey ages	142	21
Coop LL survey lengths	44	53
NMFS trawl lengths	392	35
Dom. LL fishery lengths	48	201
Dom. trawl fish. lengths	389	41
Data likelihood	1836	711
Objective function value	1888	753
Key parameters	**2020**	**2021**
Number of parameters	240	252
SSB_{2020} (kt)	94	93
$SSB_{40\%}$ (kt)	127	118
SSB_{1960} (kt)	168	202
$SSB_{100\%}$ (kt)	317	295
SPR% 2020	29.7%	31.4%
$F_{40\%}$	0.10	0.08
$F_{40\%}$ (Tier 3b adjusted)	0.10	0.08
ABC (kt) Terminal Year + 1	52.41	34.84
$q_{Domestic\ LL\ Survey}$	7.96	7.23
$q_{Coop\ LL\ survey}$	5.96	5.17
$q_{Domestic\ LL\ Fishery\_pre\_2016}$	7.95	4.23
$q_{Trawl\ Survey}$	1.33	1.11
$a_{50\%}$ (Domestic LL survey, pre-2016)	3.62	3.86
$a_{50\%}$ (LL IFQ Fishery, IFQ pre-2016)	3.95	4.35
Avg. Year Class Strength (1977 - 2017)	23.03	20.37
σ_r	1.20	1.20

Table 3.15. Estimates of sablefish recruits (Age-2), total biomass (2+), and spawning biomass from the model *21.12_Proposed_No_Skip_Spawn* (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 2019 year class (terminal year 2021 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	9.6	1.1	29.5	317.8	270.4	411.6	126.1	101.1	179.7
1978	10.5	1.0	33.6	299.2	252.6	389.8	117.6	93.0	163.3
1979	69.1	33.2	116.7	357.0	300.6	461.5	115.9	91.9	155.7
1980	42.5	3.6	88.6	399.4	335.6	508.3	114.5	91.3	149.5
1981	16.1	1.7	63.5	418.7	357.3	530.8	115.9	93.9	147.8
1982	49.0	5.1	93.7	467.3	392.8	586.1	119.6	98.6	149.9
1983	38.2	6.8	89.9	508.6	436.5	634.6	128.7	107.6	159.5
1984	23.0	2.7	50.4	533.0	458.9	656.1	142.9	121.1	175.3
1985	6.9	0.9	24.9	532.1	461.0	652.0	159.5	136.0	194.4
1986	21.3	4.1	43.0	538.1	470.4	653.1	175.8	150.7	212.7
1987	11.0	1.5	25.4	514.9	451.1	624.2	183.3	157.2	221.6
1988	4.2	0.6	12.6	473.8	414.7	574.4	183.3	156.8	222.6
1989	5.3	0.9	14.3	426.7	372.9	519.0	176.2	149.8	215.0
1990	11.9	2.6	22.5	388.5	337.8	471.4	165.4	139.7	202.6
1991	19.3	7.0	32.7	364.9	317.1	444.5	153.3	128.9	187.9
1992	5.8	0.7	16.2	335.1	291.2	409.5	141.2	118.6	173.5
1993	20.9	12.4	30.9	324.8	282.3	396.4	129.7	108.6	159.6
1994	5.5	0.6	12.6	300.6	261.2	367.2	117.8	99.0	144.9
1995	6.2	1.3	13.3	278.0	240.6	339.3	107.9	90.2	132.8
1996	10.1	3.0	17.8	262.2	227.1	320.4	101.1	84.6	124.1
1997	18.3	10.5	29.0	259.0	224.6	316.7	96.5	80.9	117.9
1998	8.1	1.1	17.3	249.9	216.5	304.6	93.0	78.1	113.2
1999	31.1	20.6	45.6	266.2	230.0	326.7	89.9	75.8	109.3
2000	13.8	3.0	26.8	269.1	233.0	328.9	87.1	73.6	105.5
2001	13.6	2.9	27.6	269.2	232.4	329.3	84.3	71.3	102.6
2002	37.1	24.4	55.1	295.9	256.3	363.0	84.1	71.1	102.1
2003	11.9	2.0	23.3	299.4	258.8	365.4	85.3	72.3	103.5
2004	7.9	1.3	17.7	294.3	254.8	358.7	87.2	74.0	106.3
2005	10.9	4.5	19.0	287.8	249.3	351.3	89.6	75.8	109.2
2006	6.0	1.2	13.1	275.1	238.6	336.1	92.5	78.4	112.7
2007	8.9	3.1	16.1	264.1	230.1	323.2	95.1	81.0	116.1
2008	8.5	2.2	17.0	251.6	218.4	307.1	95.8	81.7	116.9
2009	13.4	5.5	23.4	245.8	213.5	300.3	94.9	80.9	115.9
2010	20.0	10.4	31.3	250.0	217.1	305.4	92.8	79.2	113.1
2011	8.6	1.4	18.6	245.5	213.7	298.3	90.1	77.0	109.6
2012	10.8	3.8	18.5	241.5	210.1	292.6	86.7	74.3	105.4
2013	3.7	0.5	9.8	228.4	198.4	276.7	83.3	71.2	101.3
2014	7.3	1.4	13.7	217.6	189.7	261.3	80.9	69.1	98.4
2015	12.7	5.6	21.4	214.6	187.6	257.5	80.0	68.5	97.3
2016	49.4	37.3	64.4	253.9	223.3	301.0	79.6	68.3	96.3
2017	17.4	6.1	31.9	269.3	236.9	317.7	79.6	68.4	95.9
2018	93.9	69.1	124.2	365.7	320.7	430.9	80.5	69.5	96.0
2019	55.6	28.5	86.9	436.5	387.1	510.4	84.0	73.0	99.2
2020	69.9	37.1	107.7	523.6	462.7	606.2	92.6	81.0	108.0
2021				552.5	483.9	634.0	107.5	94.3	123.8

Table 3.16a. Longline survey relative population weights (RPWs; (Age 2+, mt). Note that the Bering Sea is surveyed only in odd years and the Aleutian Islands only in even years. RPWs for years without a survey in these regions are interpolated based on the rate of change in Gulf of Alaska during those years multiplied by the previous estimate in the non-surveyed region. A five-year moving average of regional RPWs are utilized to determine area catch apportionment for sablefish.

Year	BS	AI	WG	CG	WY	EY	Total
1990	315	235	239	634	258	421	2,103
1991	150	256	185	586	263	591	2,031
1992	125	177	78	524	296	517	1,718
1993	50	219	226	590	266	492	1,842
1994	177	214	170	554	236	495	1,846
1995	169	205	188	558	210	429	1,759
1996	194	186	200	734	219	429	1,963
1997	157	148	172	637	187	399	1,701
1998	137	301	196	485	161	386	1,665
1999	125	305	180	565	162	382	1,719
2000	123	263	235	476	133	343	1,572
2001	255	265	277	528	113	319	1,757
2002	262	278	246	601	147	309	1,843
2003	219	262	250	566	133	270	1,700
2004	221	199	166	590	156	278	1,610
2005	260	181	252	445	119	352	1,609
2006	284	258	213	564	172	328	1,820
2007	286	195	128	454	156	340	1,559
2008	284	209	159	464	125	256	1,497
2009	71	205	210	443	121	293	1,344
2010	82	167	152	478	222	426	1,528
2011	91	183	204	669	167	366	1,680
2012	67	198	144	448	116	321	1,294
2013	254	168	100	383	99	288	1,292
2014	289	189	168	380	127	314	1,467
2015	135	171	96	358	173	267	1,201
2016	141	299	173	350	158	252	1,373
2017	181	295	137	412	142	232	1,399
2018	151	339	186	312	82	190	1,260
2019	426	420	177	360	133	282	1,798
2020	600	675	287	596	125	331	2,614
2021	916	661	298	561	145	308	2,888

Table 3.16b. Regional estimates of sablefish total biomass (Age 2+, kilotons) based on the yearly proportions of longline survey RPWs by area. Note that the Bering Sea is surveyed only in odd years and the Aleutian Islands only in even years. RPWs (and associated biomass presented here) for years without a survey in these regions are interpolated based on the rate of change in Gulf of Alaska during those years multiplied by the previous estimate in the non-surveyed region.

Year	Bering Sea	Aleutian Islands	Western GOA	Central GOA	West Yakutat	EYakutat/ Southeast	Total Alaska
1990	58.1	43.3	44.2	117.2	47.7	77.8	388.5
1991	27.0	46.0	33.2	105.3	47.2	106.2	364.9
1992	24.3	34.6	15.3	102.2	57.8	100.9	335.1
1993	8.9	38.6	39.8	104.0	46.9	86.7	324.8
1994	28.8	34.9	27.6	90.3	38.4	80.6	300.6
1995	26.8	32.5	29.6	88.1	33.2	67.8	278.0
1996	25.9	24.9	26.7	98.0	29.3	57.3	262.2
1997	23.9	22.6	26.3	96.9	28.5	60.8	259.0
1998	20.5	45.2	29.4	72.7	24.1	57.9	249.9
1999	19.3	47.2	27.9	87.6	25.1	59.1	266.2
2000	21.0	44.9	40.3	81.5	22.7	58.6	269.1
2001	39.0	40.6	42.4	81.0	17.3	48.9	269.2
2002	42.1	44.6	39.4	96.5	23.7	49.6	295.9
2003	38.6	46.2	44.0	99.7	23.4	47.5	299.4
2004	40.3	36.4	30.3	107.9	28.5	50.9	294.3
2005	46.4	32.4	45.1	79.5	21.3	63.0	287.8
2006	43.0	39.1	32.2	85.3	26.1	49.6	275.1
2007	48.4	33.0	21.7	76.8	26.5	57.7	264.1
2008	47.7	35.1	26.8	78.0	21.0	43.1	251.6
2009	13.0	37.4	38.5	81.1	22.2	53.6	245.8
2010	13.5	27.3	24.8	78.3	36.4	69.8	250.0
2011	13.4	26.8	29.8	97.7	24.4	53.4	245.5
2012	12.5	37.0	26.9	83.6	21.7	59.8	241.5
2013	44.9	29.7	17.6	67.8	17.4	51.0	228.4
2014	42.8	28.1	25.0	56.4	18.8	46.5	217.6
2015	24.2	30.6	17.2	63.9	31.0	47.8	214.6
2016	26.1	55.2	32.0	64.8	29.3	46.6	253.9
2017	34.9	56.8	26.4	79.3	27.3	44.6	269.3
2018	43.9	98.5	53.9	90.6	23.7	55.0	365.7
2019	103.5	101.9	42.9	87.5	32.2	68.4	436.5
2020	120.2	135.2	57.5	119.4	25.1	66.3	523.6
2021	175.2	126.4	57.0	107.3	27.7	58.8	552.5

Table 3.16c. Regional estimates of sablefish harvest rate (catch / biomass). Regional biomass (Age 2+) is taken from Table 3.16b, while catch is from Table 3.1 (downloaded October 25, 2021 from www.akfin.org). The 2021 catch value is incomplete and does not include specified catch as incorporated in the assessment model. Projected biomass and harvest rates are based on maximum permissible ABCs for 2022 and 2023. Analysis of spatial dynamics should be undertaken judiciously given the caveats associated with estimating regional biomass. Harvest rates are approximations for illustrative purposes only.

Year	BS	AI	WG	CG	WY	EY	Alaska-Wide
1991	0.04	0.05	0.06	0.11	0.09	0.06	0.07
1992	0.03	0.04	0.15	0.10	0.08	0.05	0.07
1993	0.08	0.05	0.02	0.11	0.10	0.06	0.08
1994	0.02	0.05	0.02	0.10	0.12	0.08	0.08
1995	0.03	0.03	0.06	0.09	0.12	0.08	0.07
1996	0.02	0.03	0.06	0.07	0.10	0.08	0.07
1997	0.02	0.03	0.05	0.06	0.07	0.06	0.06
1998	0.03	0.01	0.05	0.08	0.08	0.06	0.06
1999	0.03	0.01	0.05	0.07	0.07	0.05	0.05
2000	0.04	0.02	0.04	0.08	0.09	0.07	0.06
2001	0.02	0.03	0.04	0.07	0.10	0.07	0.05
2002	0.03	0.03	0.05	0.06	0.07	0.06	0.05
2003	0.03	0.02	0.05	0.07	0.08	0.07	0.05
2004	0.03	0.03	0.07	0.07	0.08	0.07	0.06
2005	0.02	0.05	0.04	0.08	0.09	0.06	0.06
2006	0.03	0.03	0.07	0.07	0.07	0.07	0.06
2007	0.02	0.04	0.10	0.08	0.08	0.06	0.06
2008	0.02	0.03	0.06	0.07	0.10	0.08	0.06
2009	0.07	0.03	0.04	0.06	0.08	0.05	0.05
2010	0.06	0.04	0.05	0.06	0.04	0.04	0.05
2011	0.05	0.04	0.05	0.05	0.08	0.06	0.05
2012	0.06	0.03	0.05	0.06	0.09	0.05	0.06
2013	0.01	0.04	0.08	0.08	0.12	0.06	0.06
2014	0.01	0.03	0.05	0.08	0.09	0.06	0.05
2015	0.01	0.01	0.06	0.07	0.06	0.06	0.05
2016	0.02	0.01	0.03	0.06	0.06	0.05	0.04
2017	0.03	0.01	0.04	0.06	0.06	0.06	0.05
2018	0.04	0.01	0.03	0.06	0.08	0.05	0.04
2019	0.03	0.01	0.04	0.07	0.06	0.05	0.04
2020	0.04	0.01	0.03	0.05	0.07	0.05	0.04
2021	0.02	0.01	0.03	0.05	0.08	0.05	0.03
2022	0.040	0.06	0.07	0.07	0.08	0.08	0.06
2023	0.04	0.07	0.07	0.08	0.09	0.09	0.06

Table 3.17. 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
$q_{Domestic\_LL\_Srvy}$	7.23	7.04	7.03	0.60	0.60	5.91	8.23
$q_{Coop\_LL\_Srvy}$	5.17	5.04	5.03	0.44	0.43	4.24	5.89
q_{Trawl_Srvy}	1.11	1.04	1.02	0.18	0.17	0.76	1.40
M	0.10	0.10	0.10	0.01	0.01	0.09	0.11
$F_{40\%}$	0.08	0.09	0.08	0.02	0.02	0.05	0.14
2021 SSB (kt)	107.47	108.48	108.16	7.40	7.43	94.95	123.94
2014 Year Class	49.39	50.27	50.20	7.19	6.85	37.61	64.52
2016 Year Class	93.93	94.58	93.80	13.91	13.79	69.06	124.47
2017 Year Class	55.61	56.90	57.05	14.03	14.93	27.48	86.38
2018 Year Class	69.90	70.01	68.95	18.09	18.06	37.15	107.82

Table 3.18. Comparison of the 2020 *16.5_Cont* model estimates (2020 SAFE) and the 2021 *21.12_Proposed_No_Skip_Spawn* model estimates (2021 SAFE). Recruitment is in millions of fish, while SSB and Biomass are in kilotons.

Year	**2020 SAFE** Recruitment	**2021 SAFE** Recruitment	Difference (%)	**2020 SAFE** Spawning Biomass	**2021 SAFE** Spawning Biomass	Difference (%)	**2020 SAFE** Total Biomass	**2021 SAFE** Total Biomass	Difference (%)
1977	4.4	9.6	118%	136.8	126.1	-8%	293.4	317.8	8%
1978	5.1	10.5	105%	124.0	117.6	-5%	267.3	299.2	12%
1979	83.7	69.1	-18%	117.9	115.9	-2%	326.7	357.0	9%
1980	25.4	42.5	67%	112.6	114.5	2%	359.5	399.4	11%
1981	10.4	16.1	54%	111.4	115.9	4%	379.5	418.7	10%
1982	40.9	49.0	20%	115.5	119.6	4%	417.9	467.3	12%
1983	24.0	38.2	59%	127.9	128.7	1%	445.2	508.6	14%
1984	41.0	23.0	-44%	144.6	142.9	-1%	485.3	533.0	10%
1985	2.3	6.9	196%	160.1	159.5	0%	489.6	532.1	9%
1986	20.4	21.3	4%	173.4	175.8	1%	497.7	538.1	8%
1987	17.3	11.0	-36%	179.0	183.3	2%	484.1	514.9	6%
1988	3.9	4.2	7%	177.9	183.3	3%	448.6	473.8	6%
1989	3.7	5.3	42%	170.5	176.2	3%	403.3	426.7	6%
1990	5.7	11.9	109%	160.0	165.4	3%	359.5	388.5	8%
1991	28.0	19.3	-31%	147.8	153.3	4%	340.8	364.9	7%
1992	1.2	5.8	369%	135.6	141.2	4%	311.5	335.1	8%
1993	22.4	20.9	-6%	124.1	129.7	5%	302.8	324.8	7%
1994	5.0	5.5	10%	112.9	117.8	4%	282.6	300.6	6%
1995	5.1	6.2	21%	104.5	107.9	3%	262.1	278.0	6%
1996	7.1	10.1	42%	99.3	101.1	2%	244.6	262.2	7%
1997	16.9	18.3	8%	95.7	96.5	1%	238.8	259.0	8%
1998	2.2	8.1	275%	92.4	93.0	1%	225.5	249.9	11%
1999	27.5	31.1	13%	88.6	89.9	1%	234.2	266.2	14%
2000	18.2	13.8	-24%	85.1	87.1	2%	241.9	269.1	11%
2001	8.3	13.6	65%	81.8	84.3	3%	240.3	269.2	12%
2002	40.4	37.1	-8%	81.0	84.1	4%	267.8	295.9	10%
2003	6.0	11.9	97%	82.5	85.3	3%	271.9	299.4	10%
2004	12.3	7.9	-36%	85.4	87.2	2%	274.3	294.3	7%
2005	5.4	10.9	102%	89.1	89.6	1%	266.4	287.8	8%
2006	10.1	6.0	-41%	93.7	92.5	-1%	259.2	275.1	6%
2007	7.1	8.9	26%	97.2	95.1	-2%	248.7	264.1	6%
2008	8.0	8.5	7%	97.4	95.8	-2%	237.2	251.6	6%
2009	6.8	13.4	97%	95.5	94.9	-1%	225.6	245.8	9%
2010	16.0	20.0	24%	92.6	92.8	0%	223.7	250.0	12%
2011	4.4	8.6	95%	89.2	90.1	1%	215.1	245.5	14%
2012	8.5	10.8	26%	85.1	86.7	2%	207.4	241.5	16%
2013	0.9	3.7	304%	80.7	83.3	3%	191.5	228.4	19%
2014	6.1	7.3	20%	76.7	80.9	6%	178.1	217.6	22%
2015	9.9	12.7	28%	73.4	80.0	9%	170.8	214.6	26%
2016	67.7	49.4	-27%	69.6	79.6	14%	220.5	253.9	15%
2017	26.6	17.4	-35%	66.2	79.6	20%	256.2	269.3	5%
2018	163.7	93.9	-43%	65.4	80.5	23%	420.7	365.7	-13%
2019	123.4	55.6	-55%	73.1	84.0	15%	596.7	436.5	-27%
2020				94.4	92.6	-2%	686.9	523.6	-24%

Table 3.19 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 1977 - 2017 year classes. The 'Specified Catch' scenario uses the proportion of the ABC utilized in 2021 to set the realized yield for 2022 and 2023.

Year	Maximum Permissible F	Specified Catch	Half Maximum F	5-year Average F	No Fishing	Overfished	Approaching Overfished
			Spawning Stock Biomass (kt)				
2021	107,469	107,469	107,469	107,469	107,469	107,469	107,469
2022	128,789	128,789	128,789	128,789	128,789	128,789	128,789
2023	150,033	153,820	155,853	152,589	161,901	148,008	150,033
2024	170,266	179,186	183,751	176,125	198,316	165,697	170,266
2025	185,276	194,859	207,633	194,883	232,730	177,897	182,737
2026	192,706	202,440	224,030	206,022	260,551	182,635	187,483
2027	193,082	202,476	232,465	209,646	280,111	180,738	185,351
2028	188,761	197,467	234,826	207,936	292,578	174,672	178,888
2029	182,144	189,980	233,501	203,310	300,115	166,799	170,542
2030	174,819	181,735	230,264	197,455	304,537	158,614	161,873
2031	167,625	173,652	226,170	191,315	307,018	150,864	153,666
2032	160,970	166,179	221,821	185,388	308,288	143,882	146,271
2033	155,028	159,506	217,564	179,928	308,826	137,790	139,811
2034	149,831	153,666	213,570	175,028	308,924	132,621	134,306
			Fishing Mortality				
2021	0.051	0.051	0.051	0.051	0.051	0.051	0.051
2022	0.080	0.054	0.040	0.062	-	0.094	0.094
2023	0.080	0.053	0.040	0.062	-	0.094	0.094
2024	0.080	0.080	0.040	0.062	-	0.094	0.094
2025	0.080	0.080	0.040	0.062	-	0.094	0.094
2026	0.080	0.080	0.040	0.062	-	0.094	0.094
2027	0.080	0.080	0.040	0.062	-	0.094	0.094
2028	0.080	0.080	0.040	0.062	-	0.094	0.094
2029	0.080	0.080	0.040	0.062	-	0.094	0.094
2030	0.080	0.080	0.040	0.062	-	0.094	0.094
2031	0.080	0.080	0.040	0.062	-	0.094	0.094
2032	0.080	0.080	0.040	0.062	-	0.094	0.094
2033	0.080	0.080	0.040	0.062	-	0.093	0.093
2034	0.080	0.080	0.040	0.062	-	0.092	0.092
			Yield (kt)				
2021	20,120	20,120	20,120	20,120	20,120	20,120	20,120
2022	34,863	23,707	17,732	27,331	-	40,839	34,863
2023	35,871	24,392	18,879	28,550	-	41,511	35,871
2024	35,770	37,403	19,462	28,892	-	40,909	41,890
2025	34,971	36,471	19,640	28,644	-	39,550	40,439
2026	33,775	35,119	19,538	28,027	-	37,807	38,592
2027	32,407	33,589	19,259	27,211	-	35,941	36,622
2028	31,009	32,034	18,879	26,311	-	34,112	34,695
2029	29,701	30,583	18,468	25,430	-	32,450	32,944
2030	28,539	29,291	18,065	24,620	-	31,006	31,422
2031	27,512	28,150	17,678	23,882	-	29,756	30,104
2032	26,602	27,141	17,309	23,210	-	28,639	28,943
2033	25,792	26,252	16,962	22,602	-	27,548	27,842
2034	25,081	25,478	16,648	22,069	-	26,544	26,813

Table 3.20. Summary of select sensitivity runs by category. Model names match those used in Figure 3.55. 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. Recruitment is in millions of fish.

Category	Representative Model Name	Model Description	nLL	# Parameters	Mean Recruit	$SSB_{2021}/SSB_{40\%}$	2022 ABC (kt)	Summary of Model Results
Base Model	*21.12_Proposed_No_Skip_Spawn*	Proposed base model (as described in main text), which includes all 2021 model updates, but does not include skipped spawning information for maturity calculations.	753	252	20	0.91	35	Improved diagnostics and effective elimination of retroactive downgrades in recruitment estimates, but reduced fit to fishery age composition data.
	21.27_Prop_No_Francis_No_SS	Same as model *21.12_Proposed_No_Skip_Spawn,* but without implementing Francis reweighting (i.e., using the fixed data weights of model *16.5_Cont*).	1952	252	26	0.99	49	Slightly worse fit to indices and improved fit to fishery age composition data compared to *21.12_Proposed_No_Skip_Spawn,* but with larger estimates of recent recruitment strength resulting in similar (but not quite as strong) retrospective issues as model *16.5_Cont*; increased recent recruitment leads to much larger ABCs.
Continuity Model	*16.5_Cont*	The 2020 (i.e., continuity) model that does not incorporate any updates to biological inputs, model parametrization, or Francis reweighting.	2138	243	24	1.06	67	Poor fit to indices and improved fit to fishery age composition data compared to *21.12_Proposed_No_Skip_Spawn,* but with much larger estimates of recent recruitment strength resulting in strong retrospective downgrades in recent recruitment; increased recent recruitment leads to an ABC almost twice as large as *21.12_Proposed_No_Skip_Spawn.*
	21.9_Cont_Francis	Same as model *16.5_Cont*, but incorporating Francis reweighting.	686	243	26	1.15	59	Slightly improved fit to indices and worse fit to fishery age composition data compared to *16.5_Cont,* but with reduced estimates of recent recruitment strength resulting in improved retrospective patterns (but still stronger retroactive recruitment downgrades compared to *21.12_Proposed_No_Skip_Spawn*).
Maturity	*21.10_Proposed_w_SS*	Same as model *21.12_Proposed_No_Skip_Spawn*, but incorporating skipped spawning information for maturity calculations using an age-length based General Additive Model (GAM).	753	252	20	0.88	35	Same patterns as *21.12_Proposed_No_Skip_Spawn*, but with slightly more pessimistic terminal stock status resulting from lower SSB (due to reduced maturity at younger ages in recent time period when skipped spawning is incorporated).
Model Parametrization	*21.28_Fish_q+Sel_Only*	Same as model *21.12_Proposed_No_Skip_Spawn*, but not incorporating a recent time block for survey selectivity.	717	250	27	1.14	55	Slightly worse fit to longline survey index compared to *21.12_Proposed_No_Skip_Spawn,* and estimates of recent recruitment strength and associated retroactive recruitment downgrades similar to model *16.5_Cont*; increased recent recruitment leads to much larger ABCs on par with *21.9_Cont_Francis*.
	21.29_Fish_Sel_Srvy_Sel	Same as model *21.12_Proposed_No_Skip_Spawn*, but not incorporating a recent time block for fishery catchability.	774	249	23	0.94	39	Similar patterns as *21.12_Proposed_No_Skip_Spawn*, but with poor fit to recent CPUE index; rescaling of SSB due to removal of recent catchability time block leads to slightly increased stock status and associated ABCs.

Figures

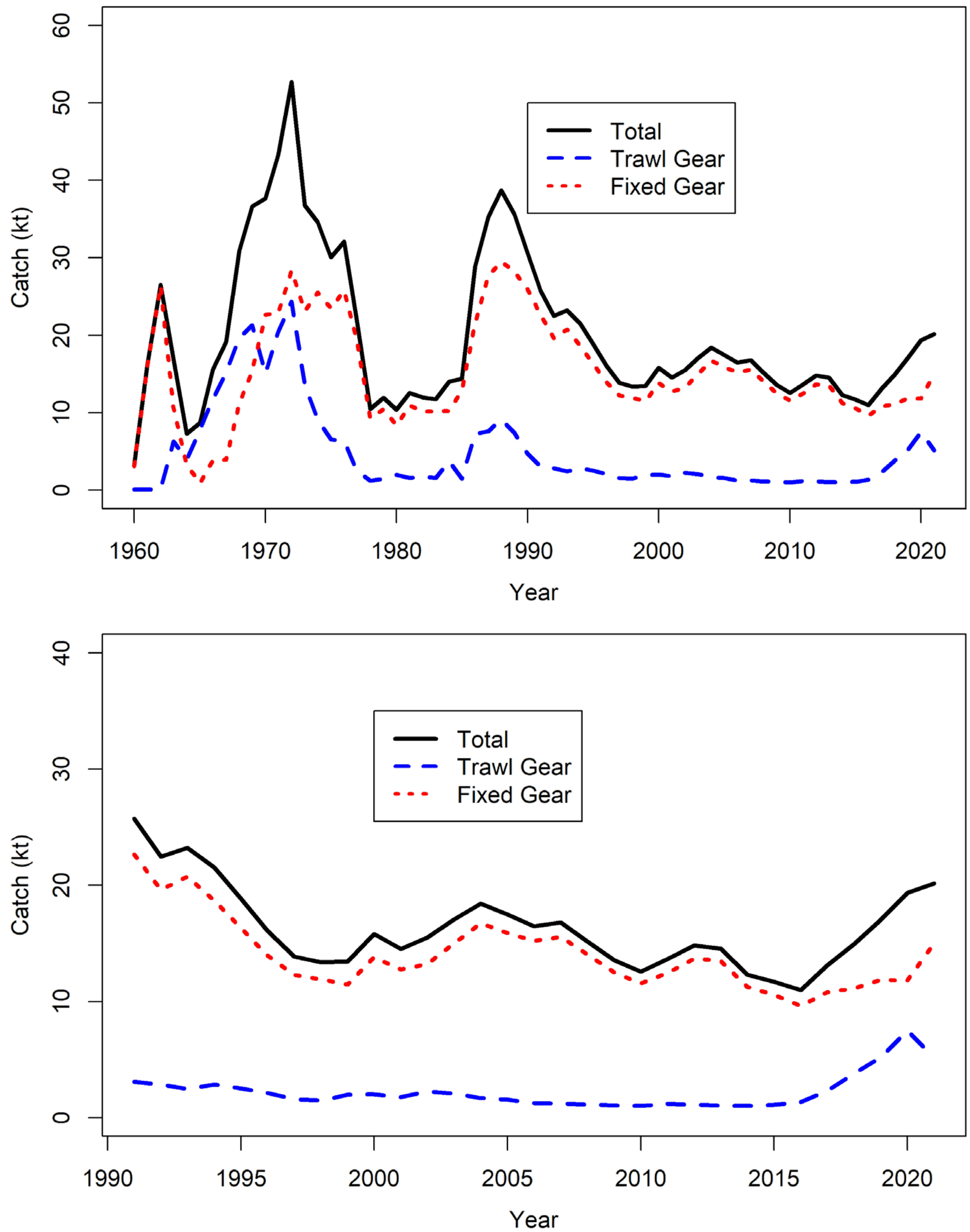


Figure 3.1. Long term and recent sablefish catch (kt) by gear type.

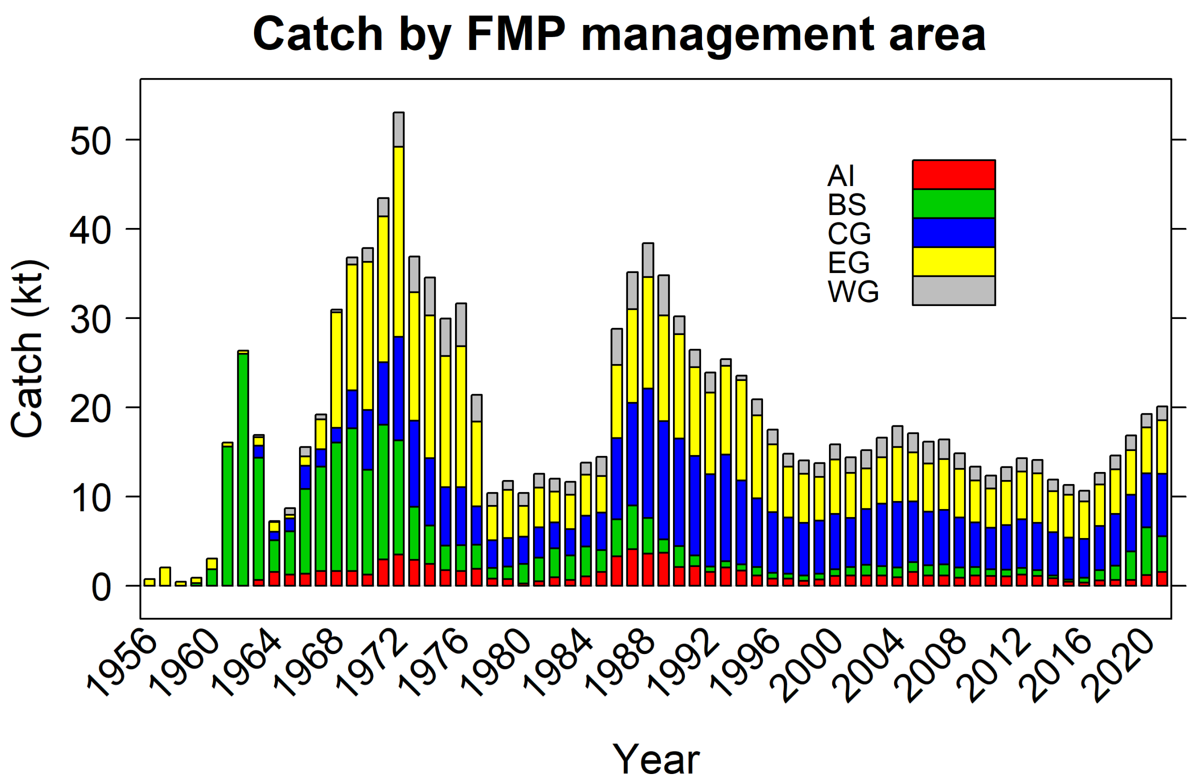


Figure 3.2. Sablefish fishery total reported catch (kt) by North Pacific Fishery Management Council area and year.

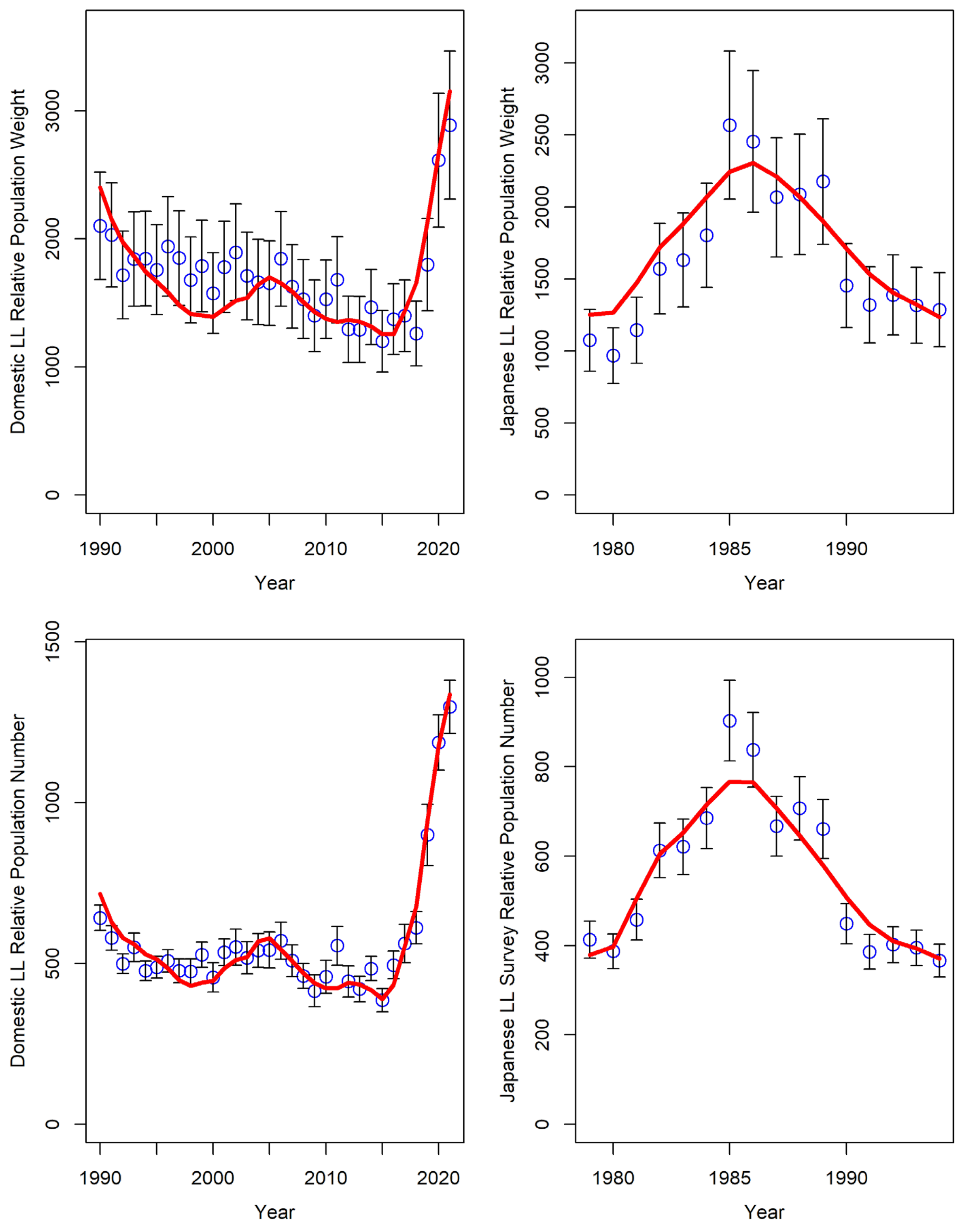


Figure 3.3. Observed and predicted sablefish relative population weight and numbers for 1990 - 2021 for U.S. longline survey and for 1979 - 1994 for U.S.-Japan cooperative survey. Points are observed estimates with approximate 95% confidence intervals. Solid red line is model *21.12_Proposed_No_Skip_Spawn* predicted value. The relative population weights are not fit in the model, but are presented for comparison.

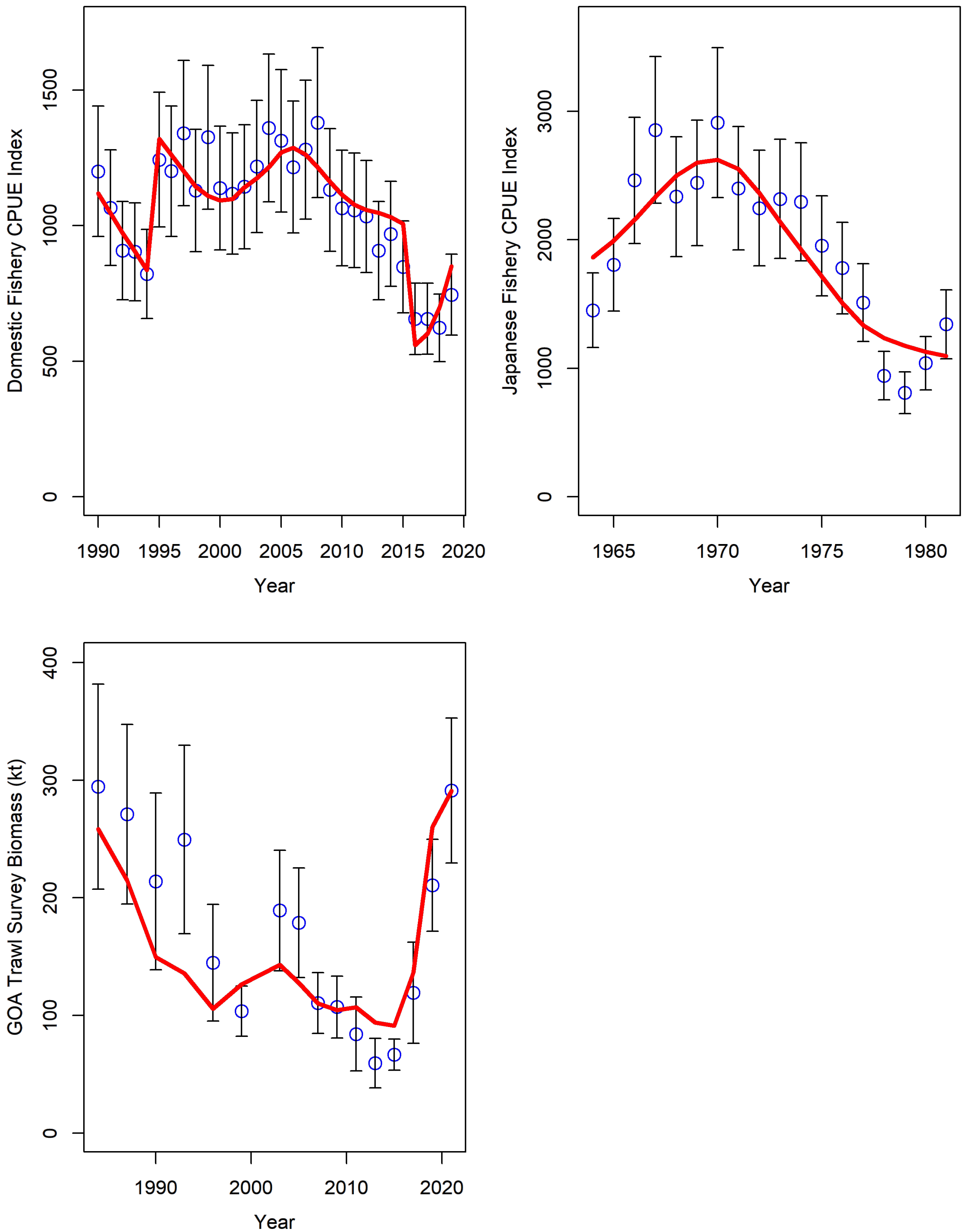


Figure 3.4. Observed and predicted sablefish abundance indices. Fishery CPUE indices are on top two panels. GOA trawl survey is on the bottom left panel. Points are observed values with approximate 95% confidence intervals, while solid red lines are model *21.12_Proposed_No_Skip_Spawn* predicted values.

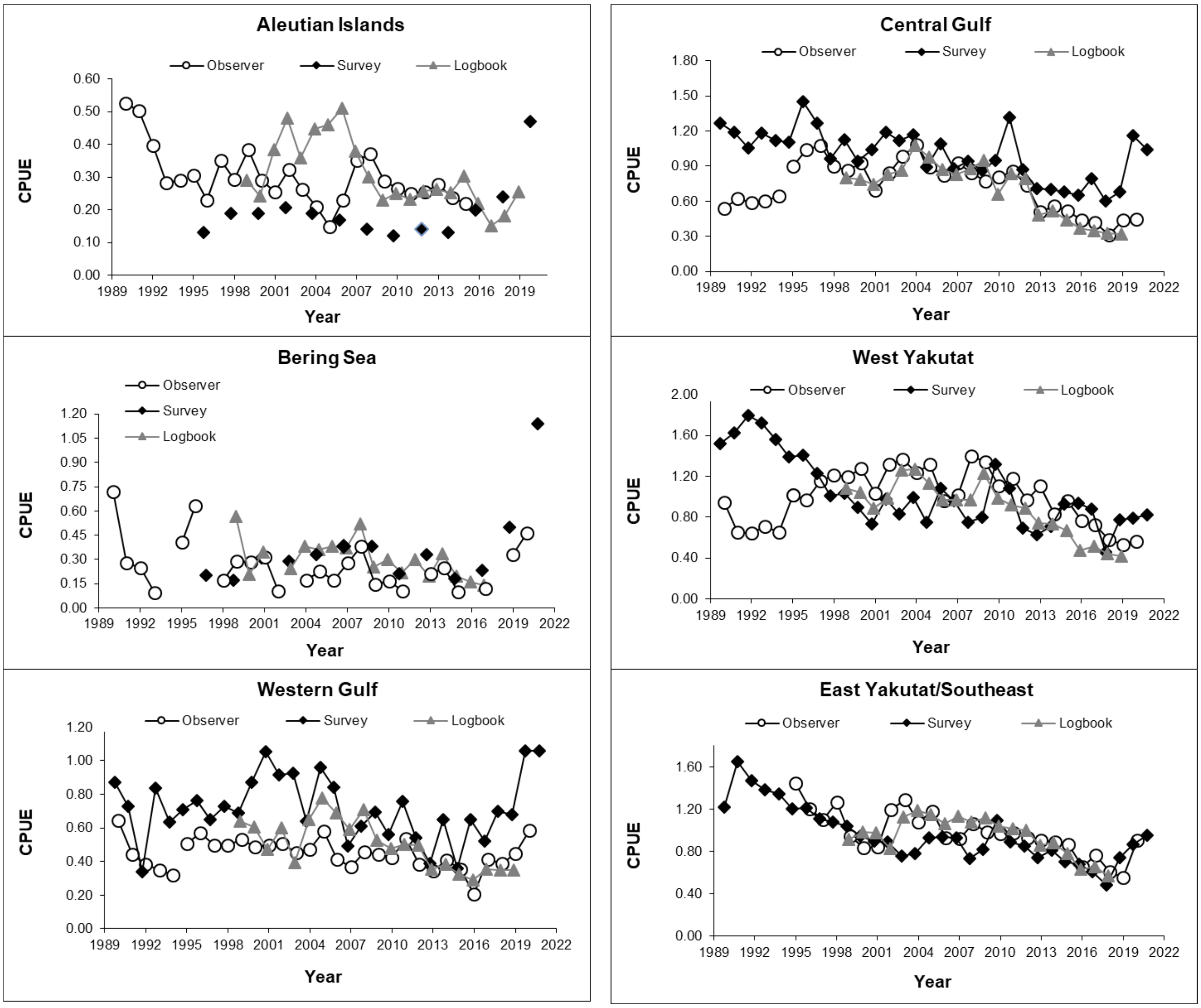


Figure 3.5. Average fishery catch rate (pounds/hook) by region and data source for longline survey and fixed gear fishery data. The fishery switched from open-access to individual quota management in 1995. Due to confidentiality concerns, data is not presented for years when there were fewer than three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

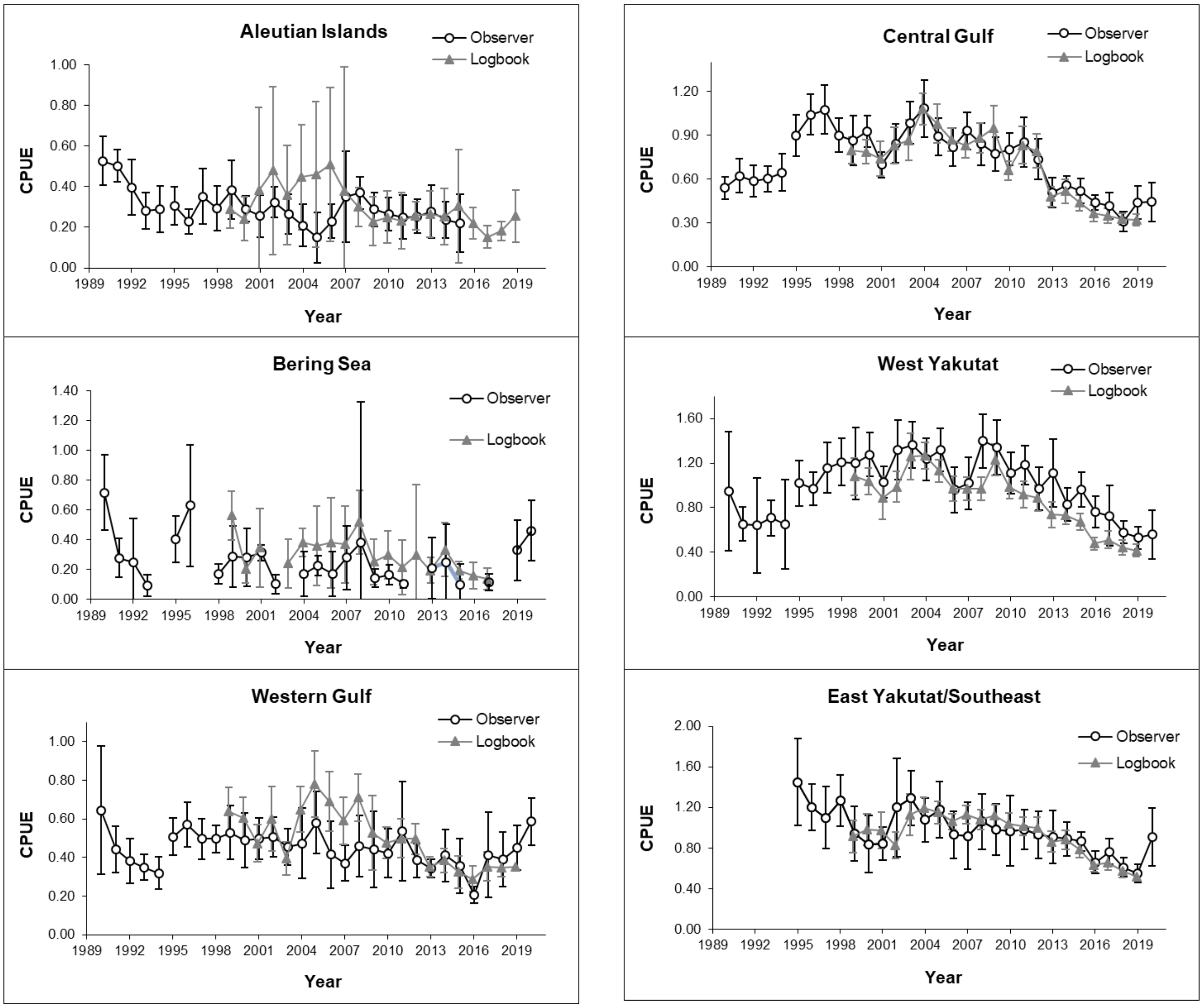


Figure 3.6. Average fixed gear fishery catch rate (pounds/hook) and associated 95% confidence intervals by region and data source. The fishery switched from open-access to individual quota management in 1995. Due to confidentiality concerns, data is not presented for years when there were fewer than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

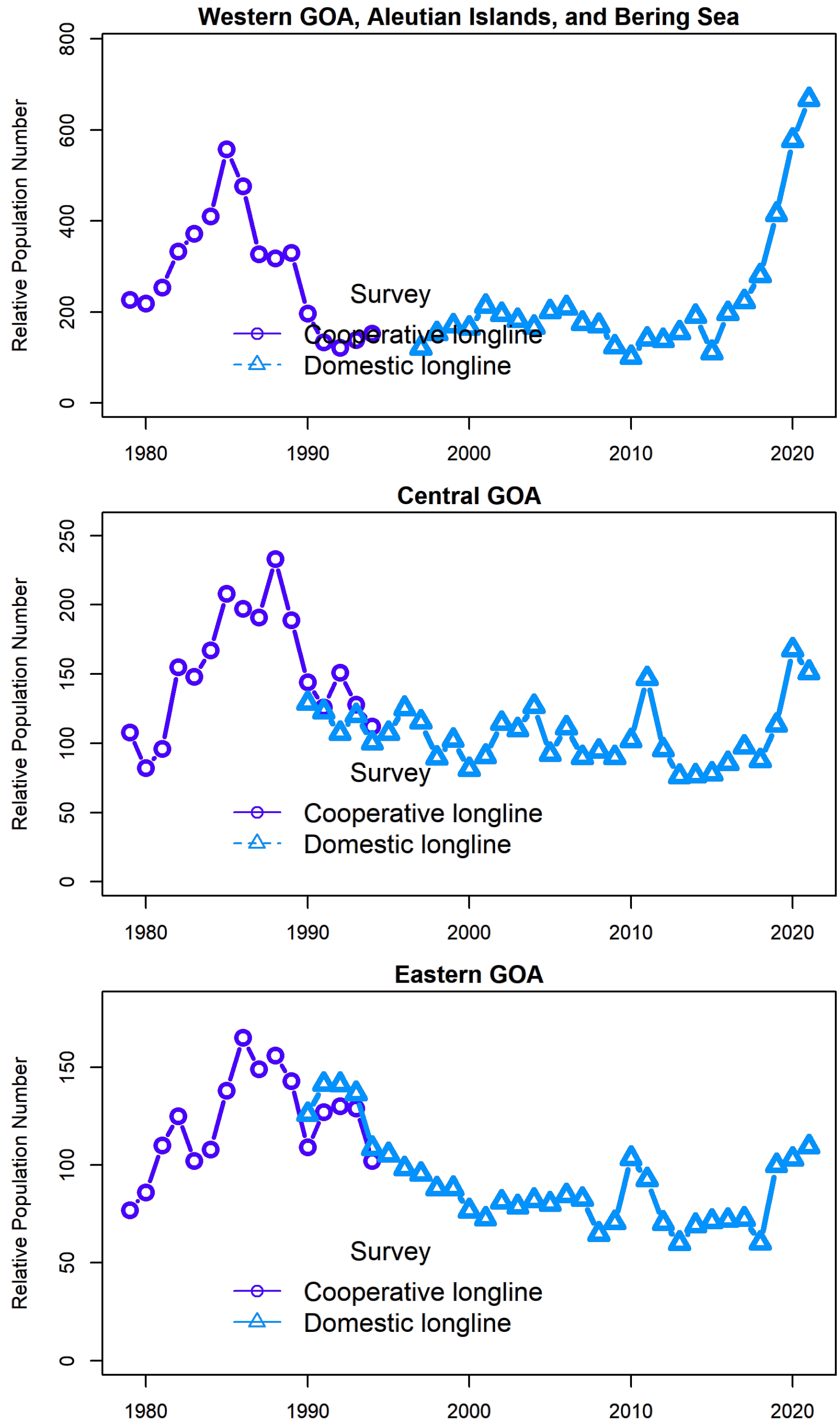


Figure 3.7. Relative abundance (numbers in 1000s) by region and survey. The Bering Sea, Aleutians Islands, and western Gulf of Alaska regions are combined in the first panel. The two surveys are the Japan-U.S. cooperative longline survey and the domestic (U.S.) longline survey. The values for the U.S. survey were adjusted to account for the higher efficiency of the U.S. survey gear.

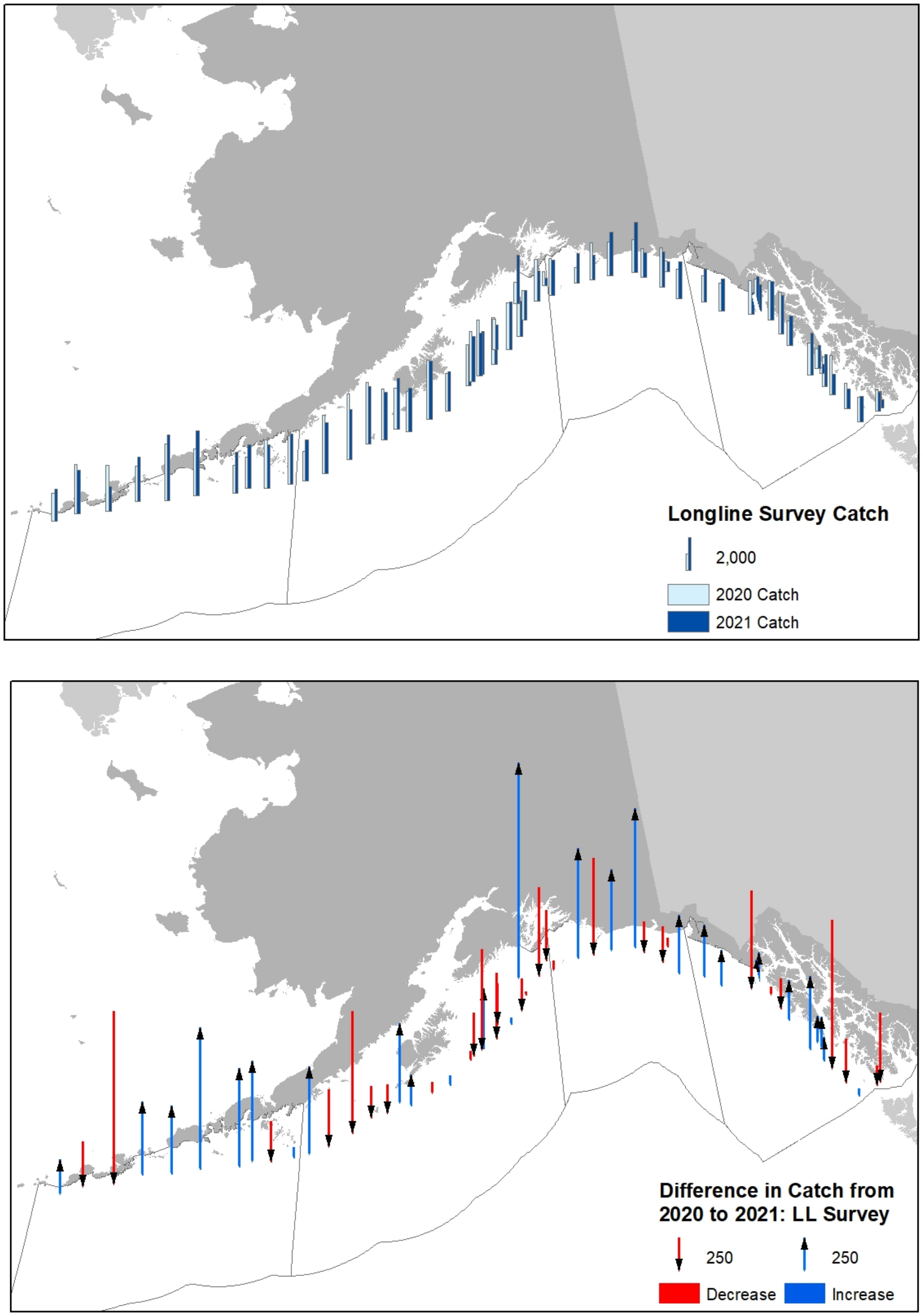


Figure 3.8a. Comparison of the 2020 and 2021 longline survey in the Gulf of Alaska. Top panel is in numbers of fish; bottom panel is the difference in numbers of fish from 2020 in the 2021 survey. Numbers are not corrected for sperm whale depredation.

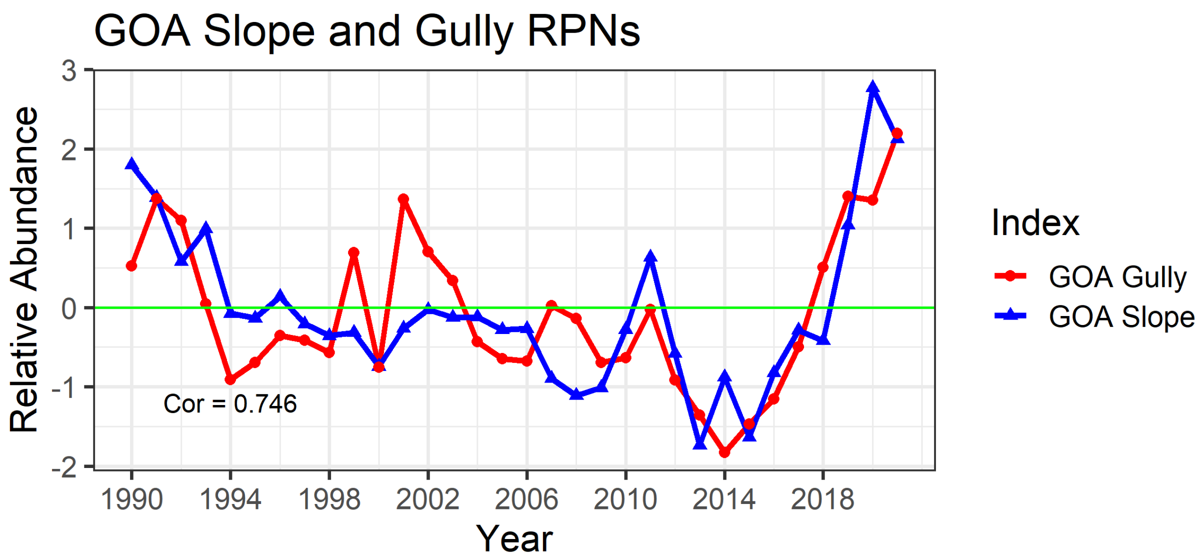


Figure 3.8b. Comparison of abundance trends in GOA gully stations versus GOA slope stations.

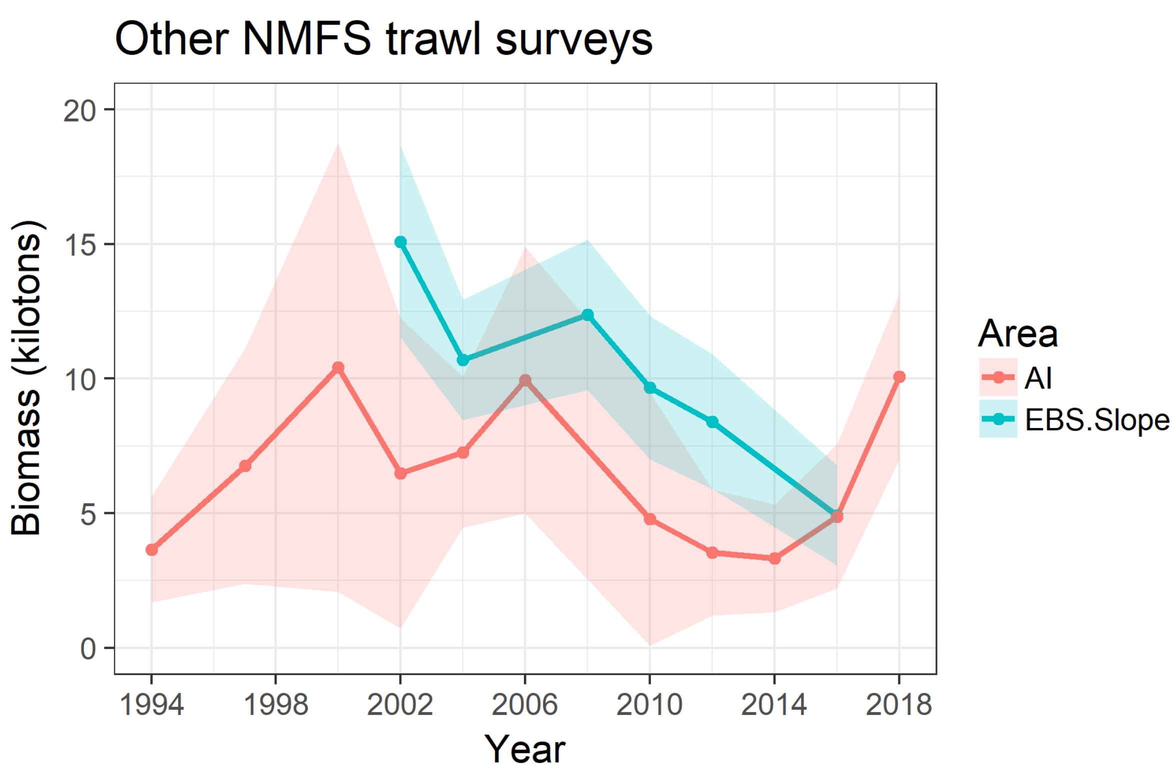


Figure 3.9. NMFS Bering Sea Slope and Aleutian Island trawl survey biomass estimates. There was no survey in 2020 due to COVID-19 pandemic.

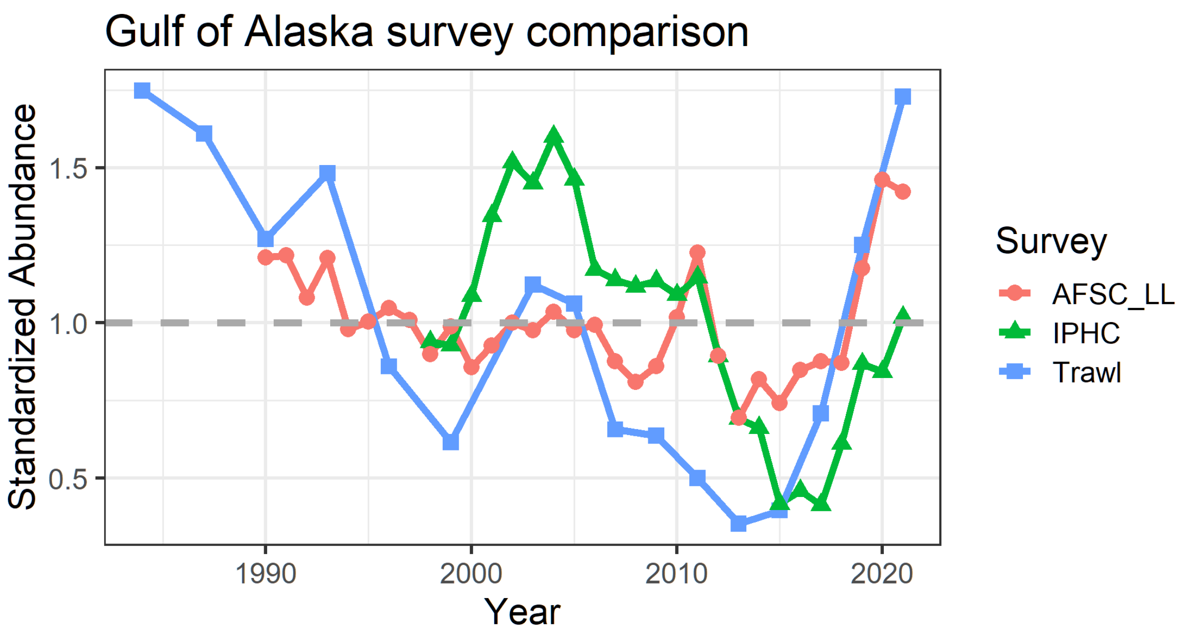


Figure 3.10a. Comparisons of the IPHC longline survey, the AFSC longline survey, and the NMFS trawl survey trends in relative abundance of sablefish in the Gulf of Alaska. Note that the IPHC survey was completed with a reduced survey footprint in 2020 due to COVID-19 related limitations, and data were not collected in the WGOA. The 2020 WGOA missing values were substituted with the average of the 2019 and 2021 WGOA RPNs for the purpose of this figure.

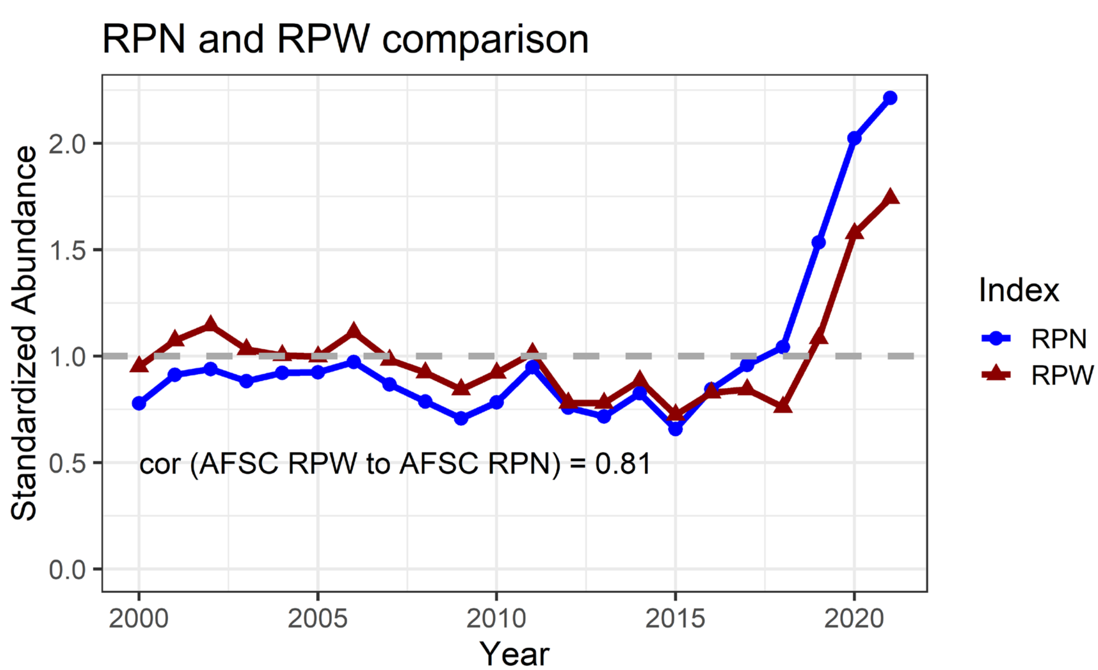


Figure 3.10b. Comparisons of AFSC longline survey indices. Relative Population Weight (RPW) is in weight and Relative Population Numbers (RPN) is in numbers. Only the RPN index is fit in the assessment model.

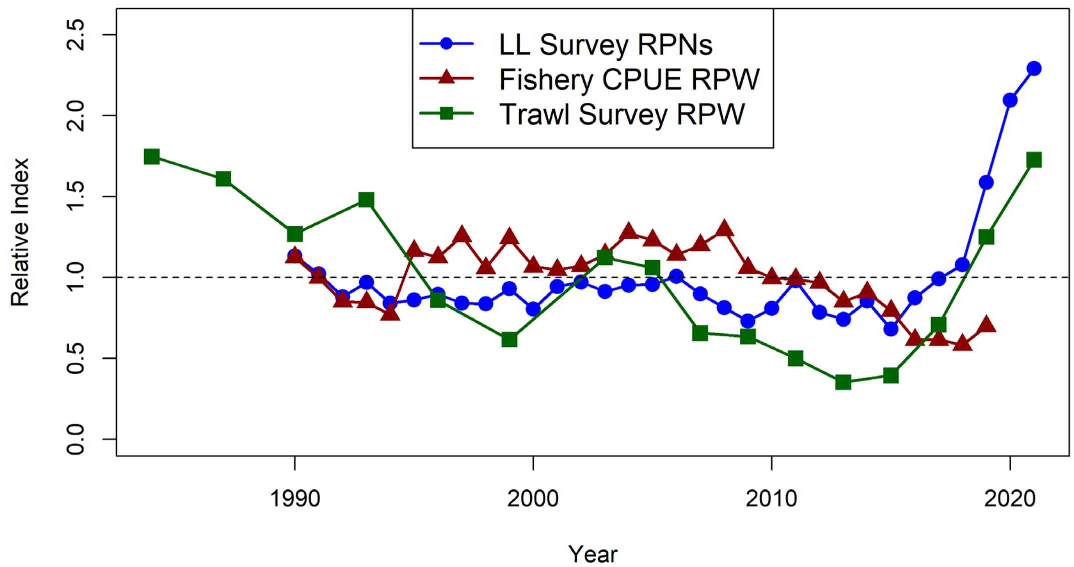


Figure 3.10c. Comparison of the three indices used in the stock assessment model including the AFSC longline survey RPNs, the fixed gear fishery CPUE, and the NMFS trawl survey RPWs. Each index is relativized to the associated mean value for the time series.

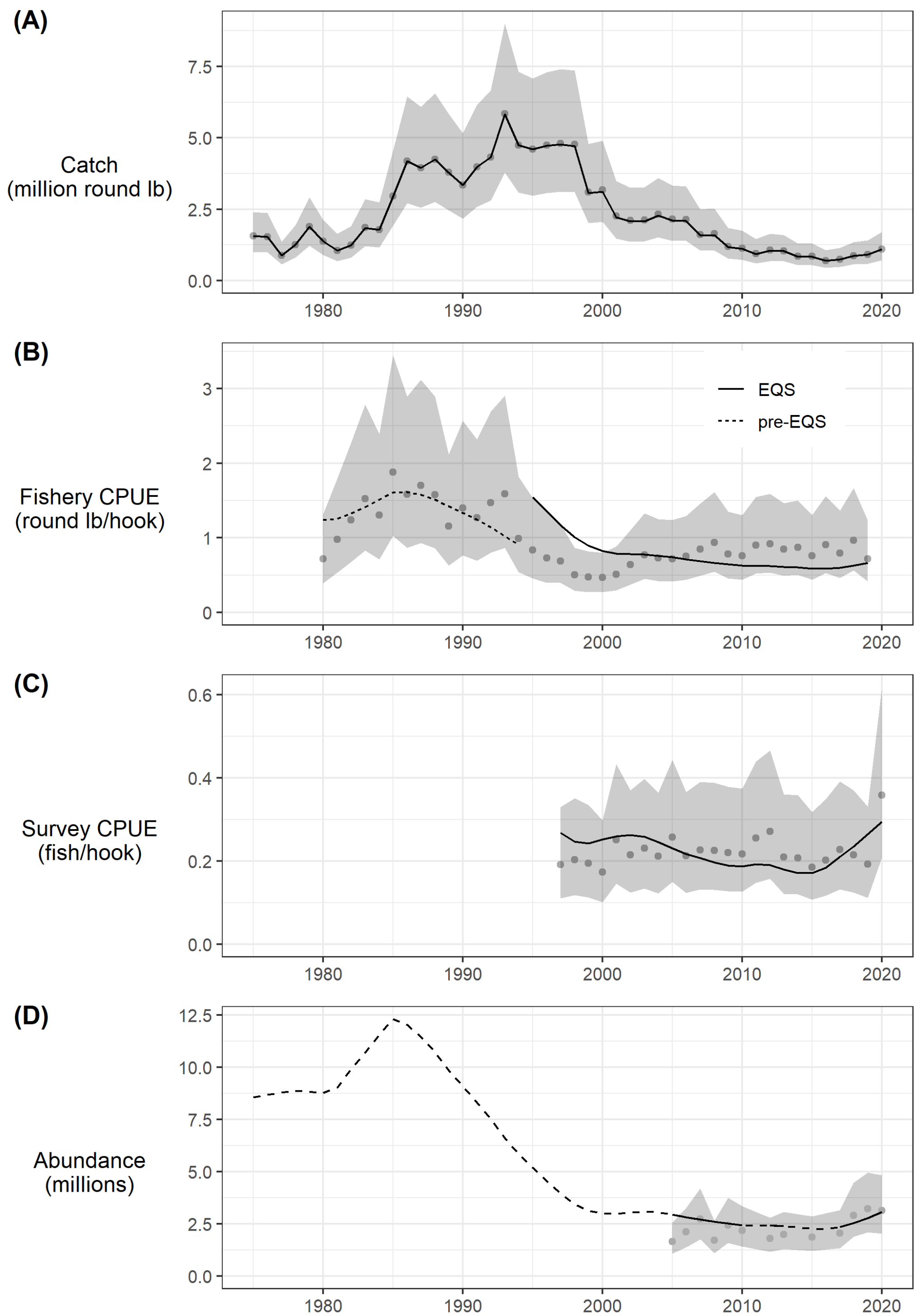


Figure 3.11a. Results of the Northern Southeast Inside (NSEI) sablefish stock assessment performed by the ADFG and reproduced here with permission (Sullivan et al., 2021). Observed data points are provided as grey dots and model predicted values as black lines. Assumed error distributions are given by 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).

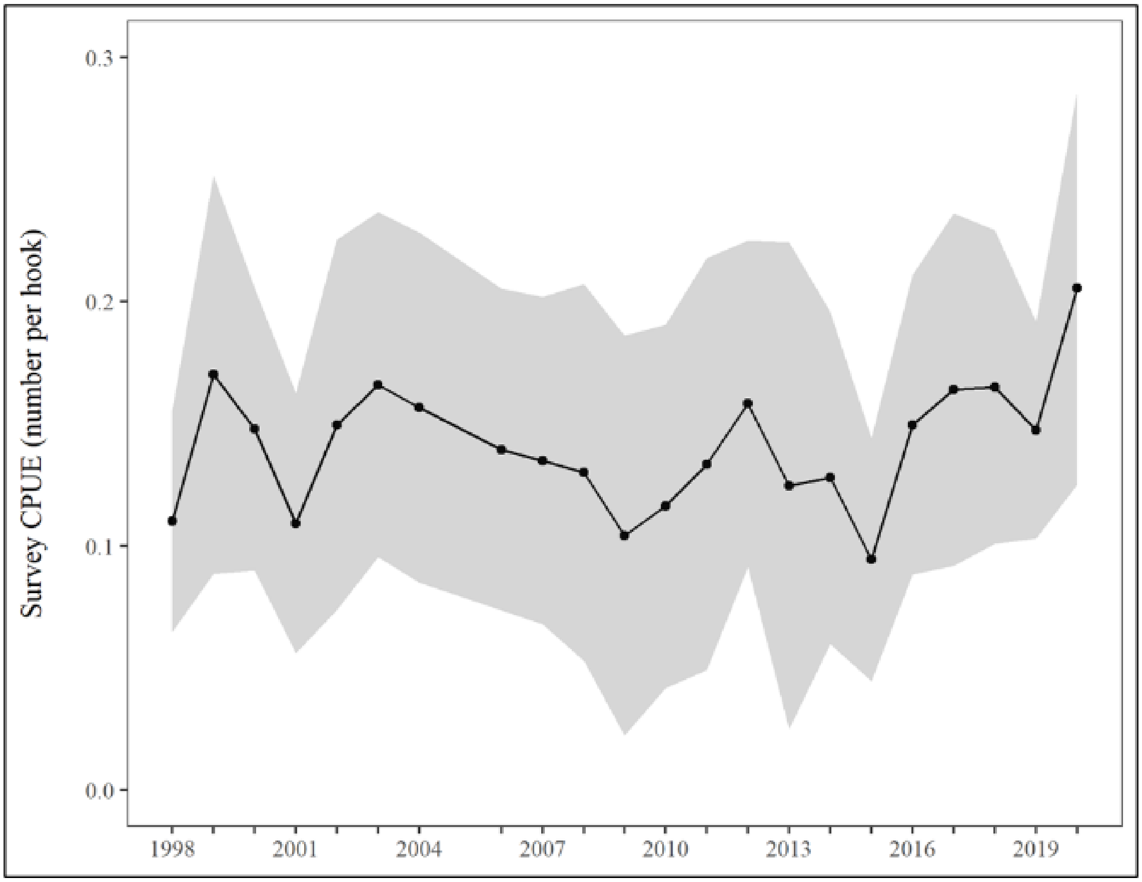


Figure 3.11b. Southern Southeast Inside (SSEI) sablefish longline survey catch-per-unit-effort (CPUE) in individuals per hook from 1998 to 2020 (except 2005). Reproduced here with permission (Ehresmann et al., 2021).

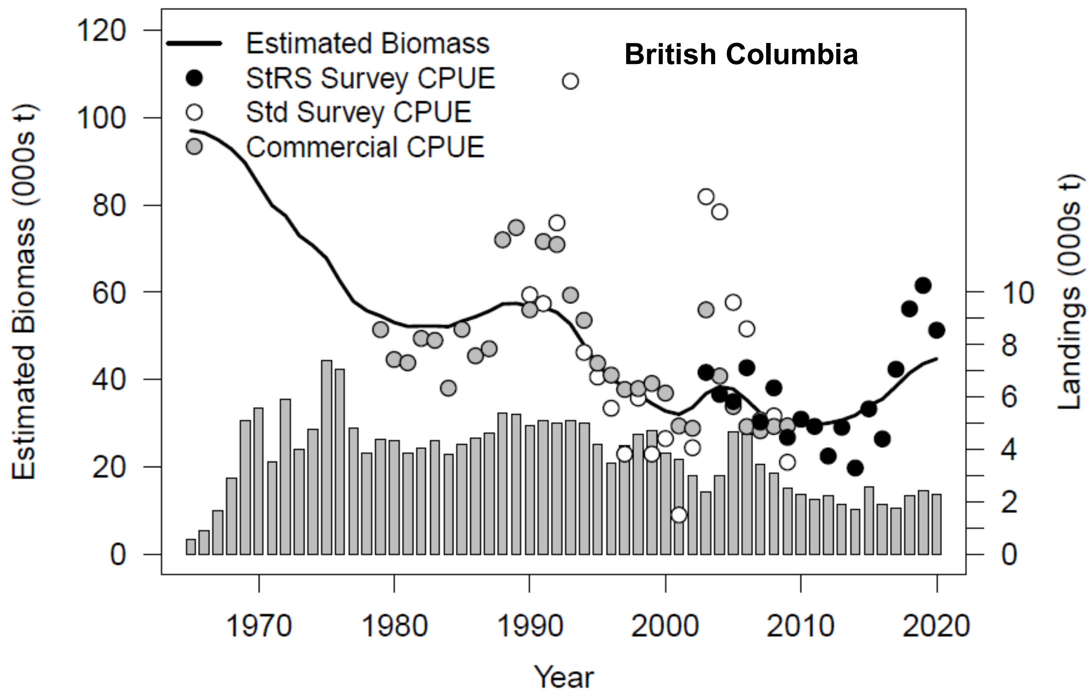


Figure 3.11c. Observed landings, commercial CPUE, and survey CPUE, as well as, estimated biomass from a surplus production model of British Columbia sablefish (from Brandon Connors, pers. comm.).

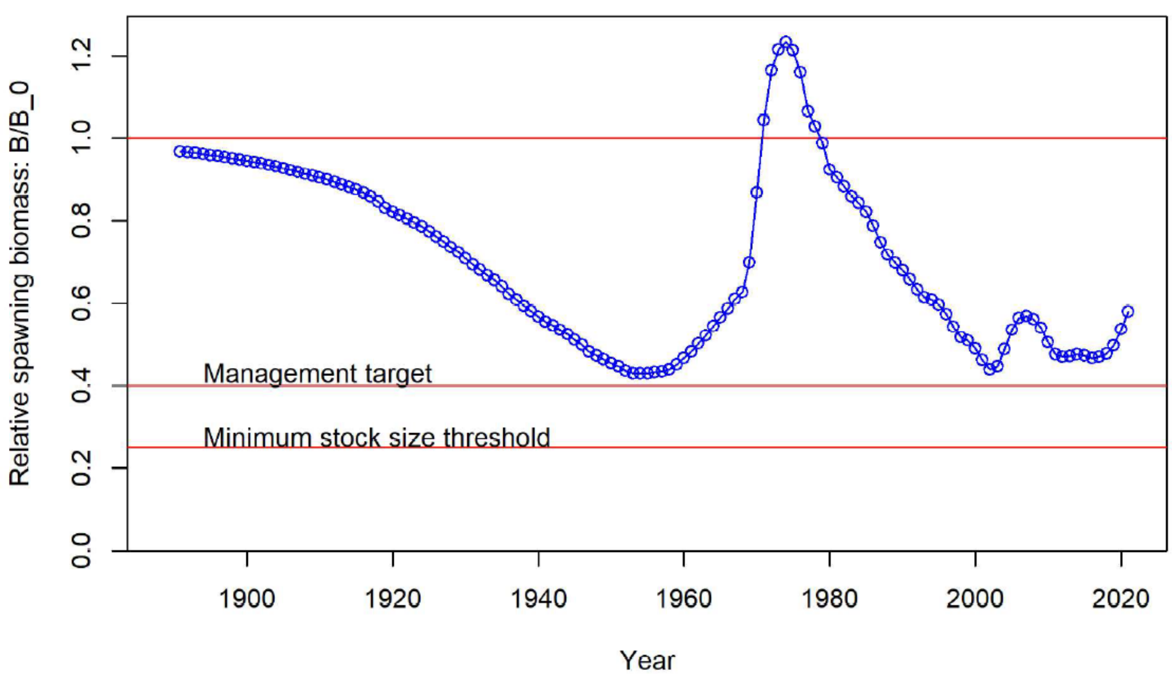


Figure 3.11d. Time series of total biomass relative to the unfished biomass for west coast USA sablefish (from Kapur et al. 2021).

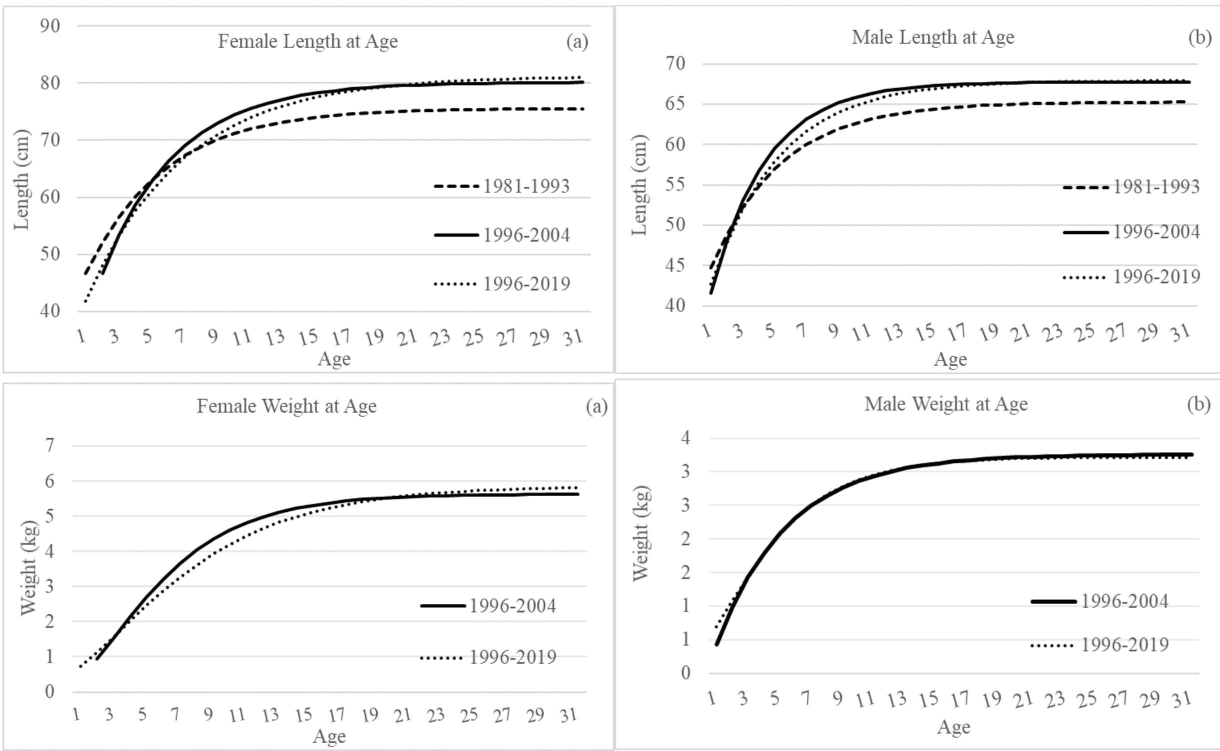


Figure 3.12a. Comparison of sablefish length-at-age (top panels) and weight-at-age (bottom panels) for females (a; left panels) and males (b; right panels). The 1981-1993 growth curve (dotted line) is used in both models *16.5_Cont* and *21.12_Proposed_No_Skip_Spawn* for the historic period (prior to 1996). For the recent period (1996 to present), the *16.5_Cont* model uses the growth curve based on data from 1996 – 2004 (solid line) and the *21.12_Proposed_No_Skip_Spawn* model uses the growth curve based on data from 1996 – 2019 (dashed line). For weight-at-age, a single weight regime is assumed and the *16.5_Cont* model uses data from 1996 – 2004 (solid line), while the *21.12_Proposed_No_Skip_Spawn* model uses all available data from 1996 – 2019 (dotted line).

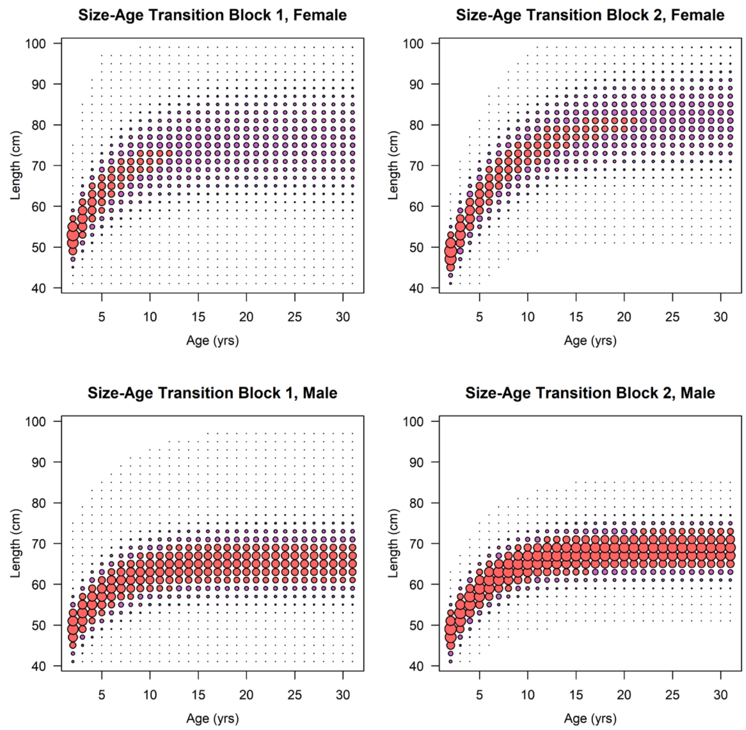


Figure 3.12b. Age-length conversion matrices for sablefish. Top panels are female, bottom panels are males, left panels are 1960 – 1995, and right panels are 1996 – 2021.

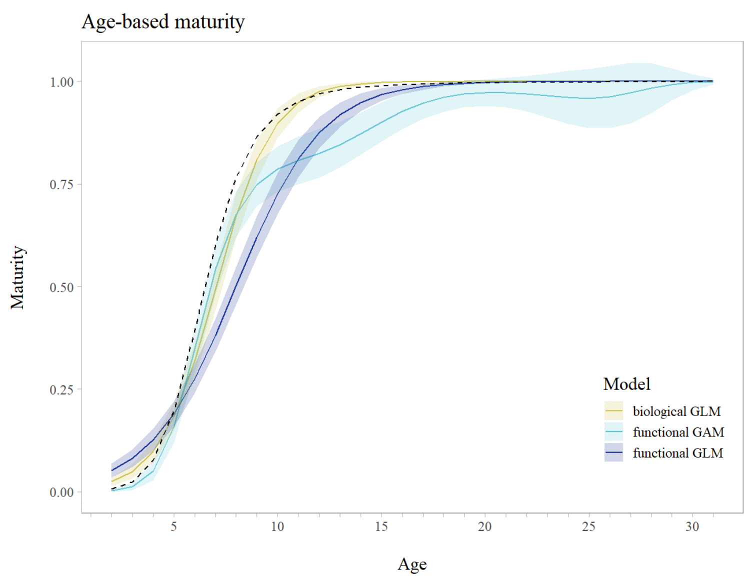


Figure 3.12c. Age-based maturity curves (lines) with associated 95% confidence intervals (shaded regions). The dashed black line is the age converted length-based macroscopic maturity curve from Sasaki (1985), which is used in model *16.5_Cont*. The yellow line is the biological (ignoring skipped spawning information) age-based maturity GLM based on recent histological (microscopic) data used in model *21.12_Proposed_No_Skip_Spawn*. For comparison purposes, the two blue lines demonstrate estimates of functional maturity (accounting for skipped spawning information) from age-based GLM and GAM models (see Appendices 3F and 3G for more information on these curves and model runs that incorporate alternate maturity inputs).

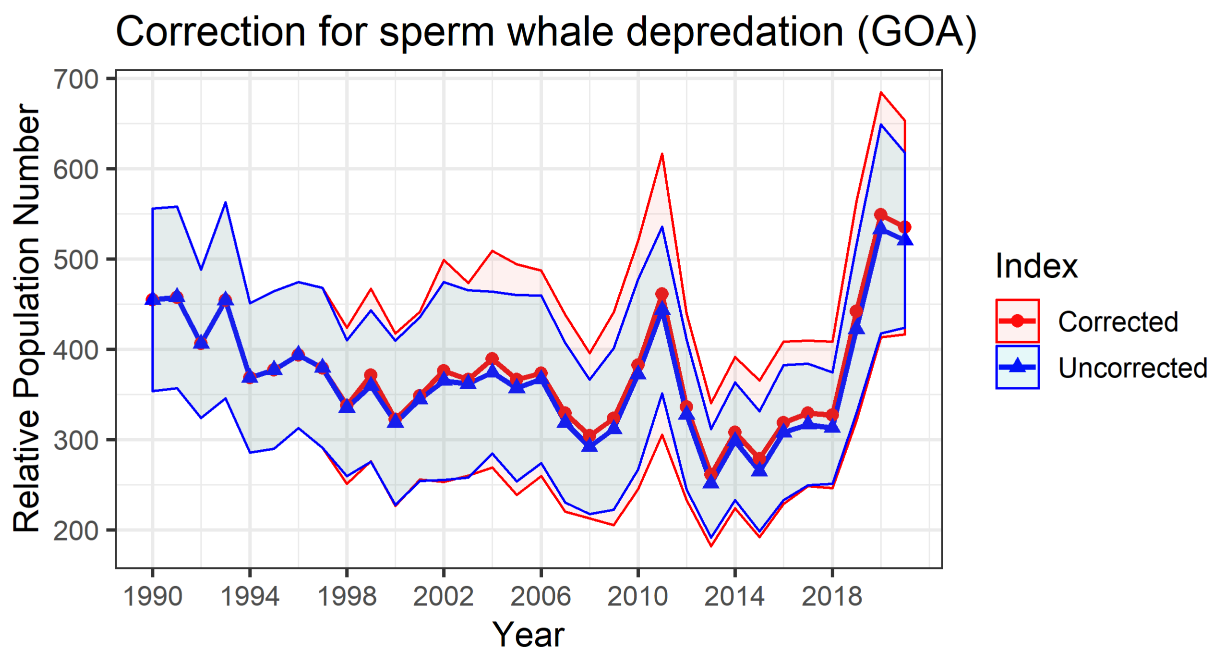


Figure 3.13. Total longline sablefish RPN index with (red circles) and without (blue triangles) sperm whale corrections 1990 – 2021. Shaded regions are approximate 95% confidence intervals.

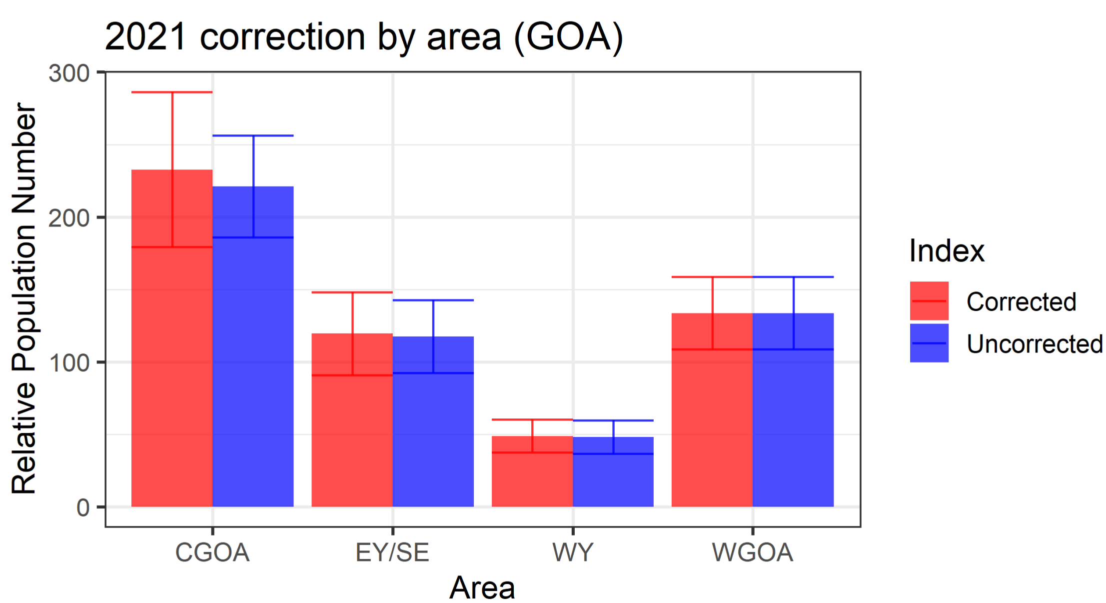


Figure 3.14. Longline sablefish RPN index by area with (red bars) and without (blue bars) sperm whale corrections. Error bars are approximate 95% confidence intervals. There was no sperm whale depredation in the BSAI region, so these regions are not included in this figure.

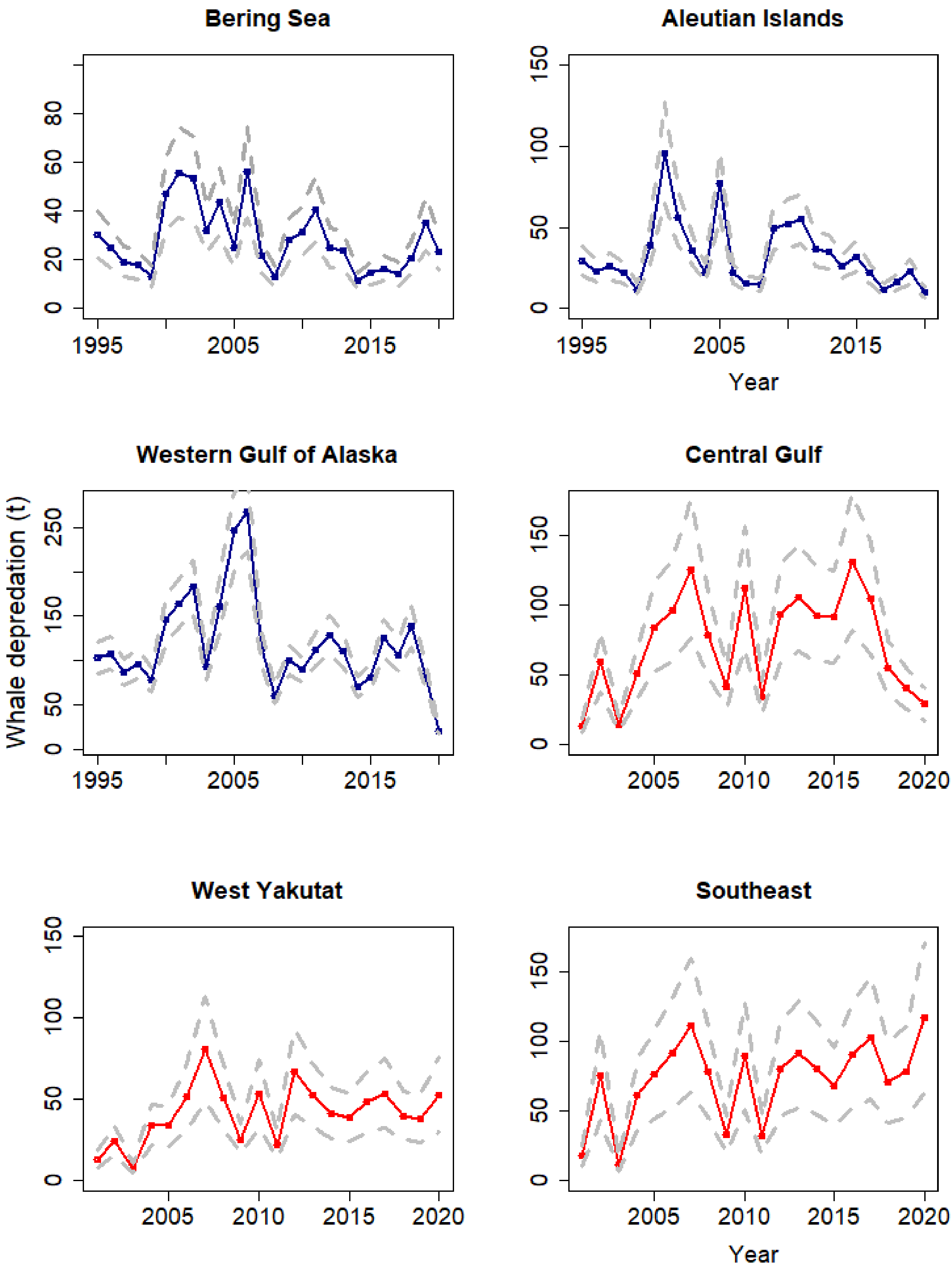


Figure 3.15. Estimated sablefish catch removals (t) with ~95% confidence bands by region due to sperm whale (red) and killer whale (blue) depredation, 1995 - 2020. 2020 is not a complete estimate.

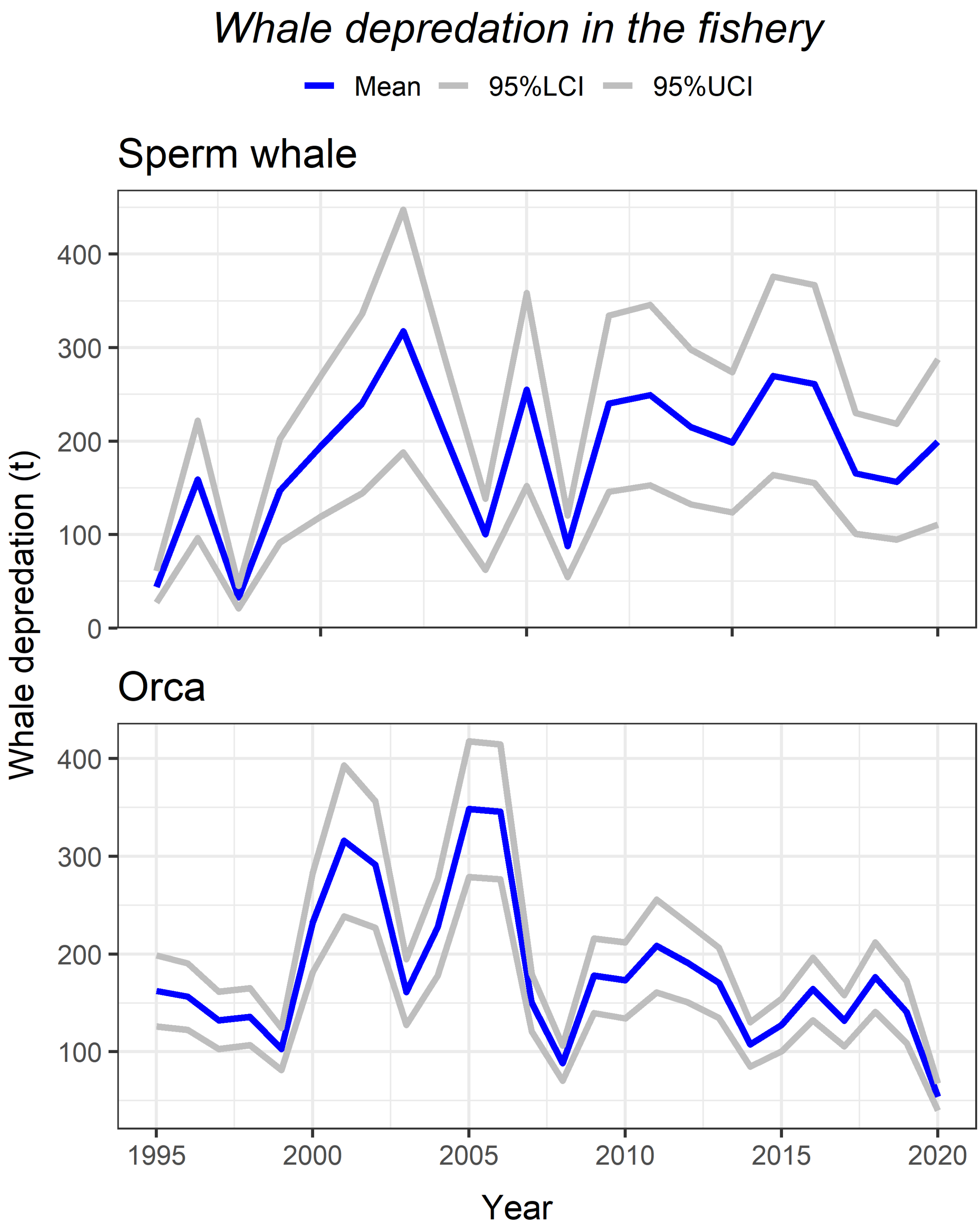


Figure 3.16. Additional estimated sablefish mortality (blue) by two whale species with 95% asymptotic normal confidence intervals (grey lines).

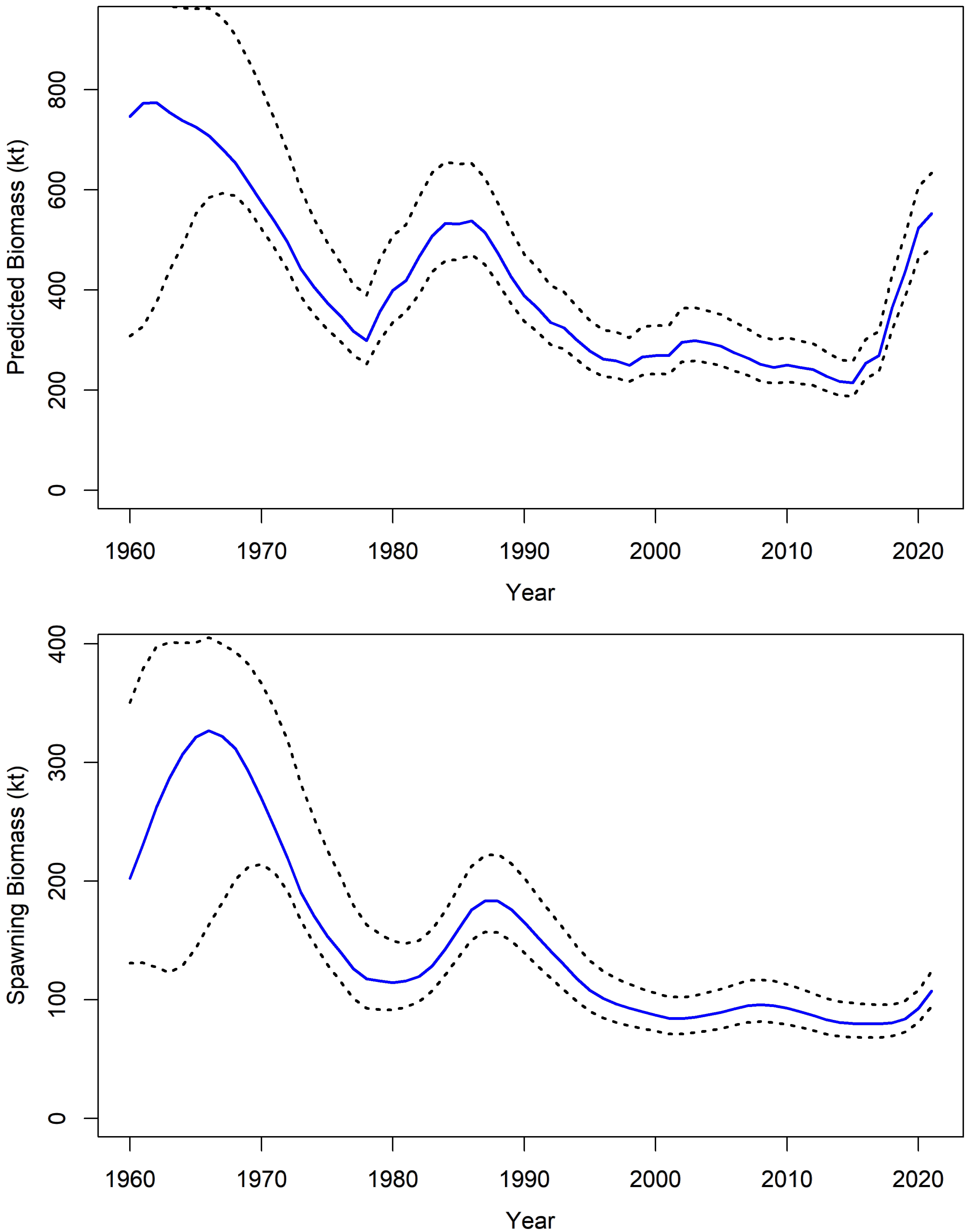


Figure 3.17. Estimated sablefish total biomass (top panel) and spawning biomass (bottom panel) with 95% MCMC credible intervals. Values are in kilotons.

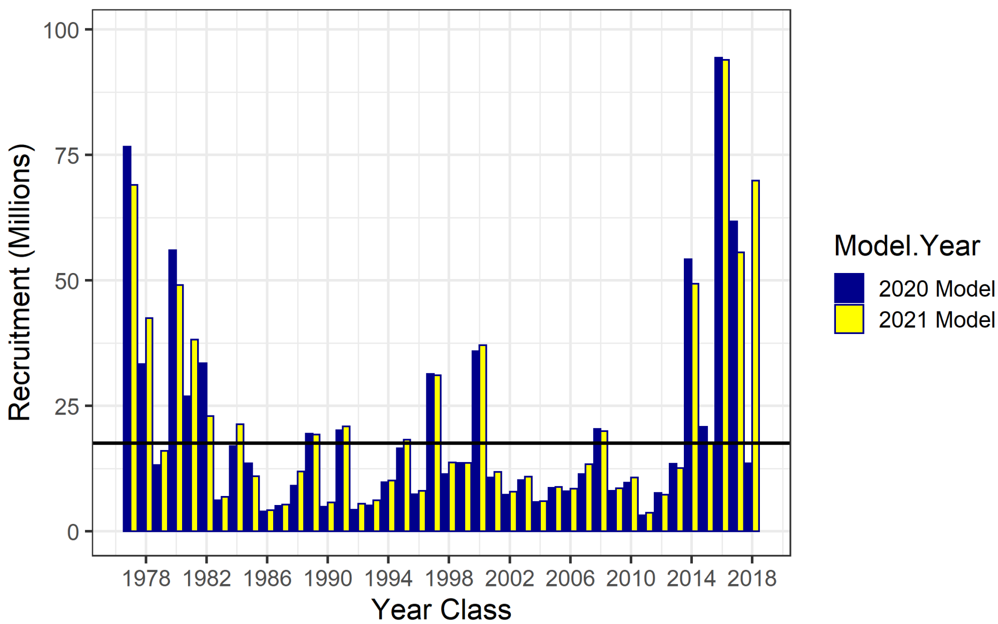


Figure 3.18a. Estimated recruitment by year class (1977 - 2018) in number of age-2 fish (millions of fish) for the 2020 and 2021 *21.12_Proposed_No_Skip_Spawn* models. Black line is mean recruitment from the 2021 model for 1977 to 2018 year classes. Note that the 2018 yearclass for the 2020 model is equivalent to the estimated mean recruitment value (μ_r) given that no recruit deviation is estimated in the terminal year.

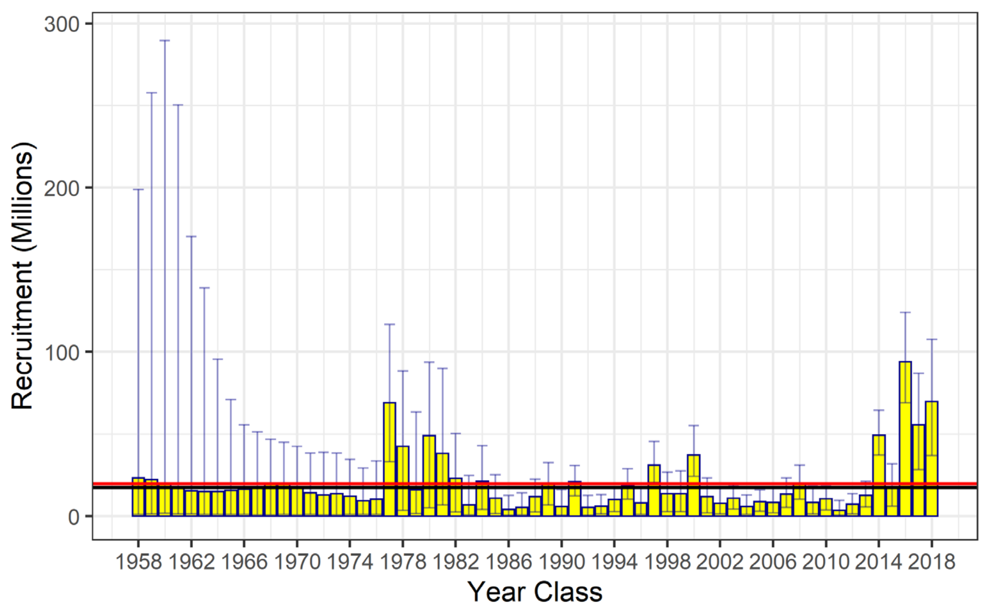


Figure 3.18b. Estimated recruitment of age-2 sablefish (millions of fish) with 95% credible intervals from MCMC by year class (recruitment year minus two). Red line is overall mean, while black line is recruitments from year classes between 1977 and 2018. Credible intervals are based on MCMC posteriors. The estimate for the 2019 year class (terminal year 2021 recruitment event) is omitted, because it is fixed to the estimated mean recruitment value (μ_r) with no deviation parameter estimated.

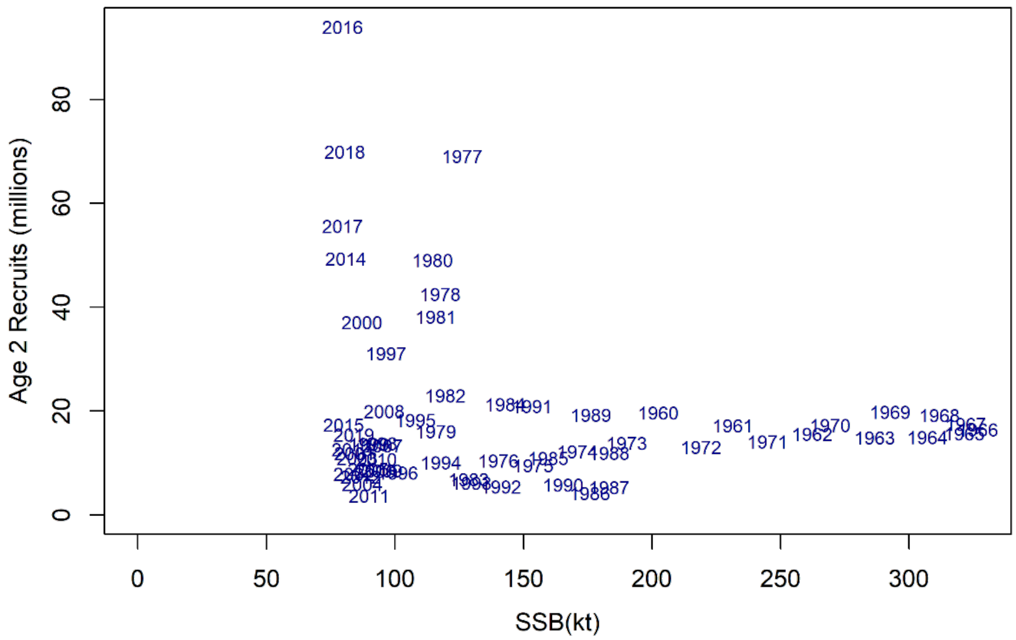


Figure 3.18c. Age-2 recruits (millions of fish) and corresponding spawning stock biomass (kt) for each year class (identified by plotted year text).

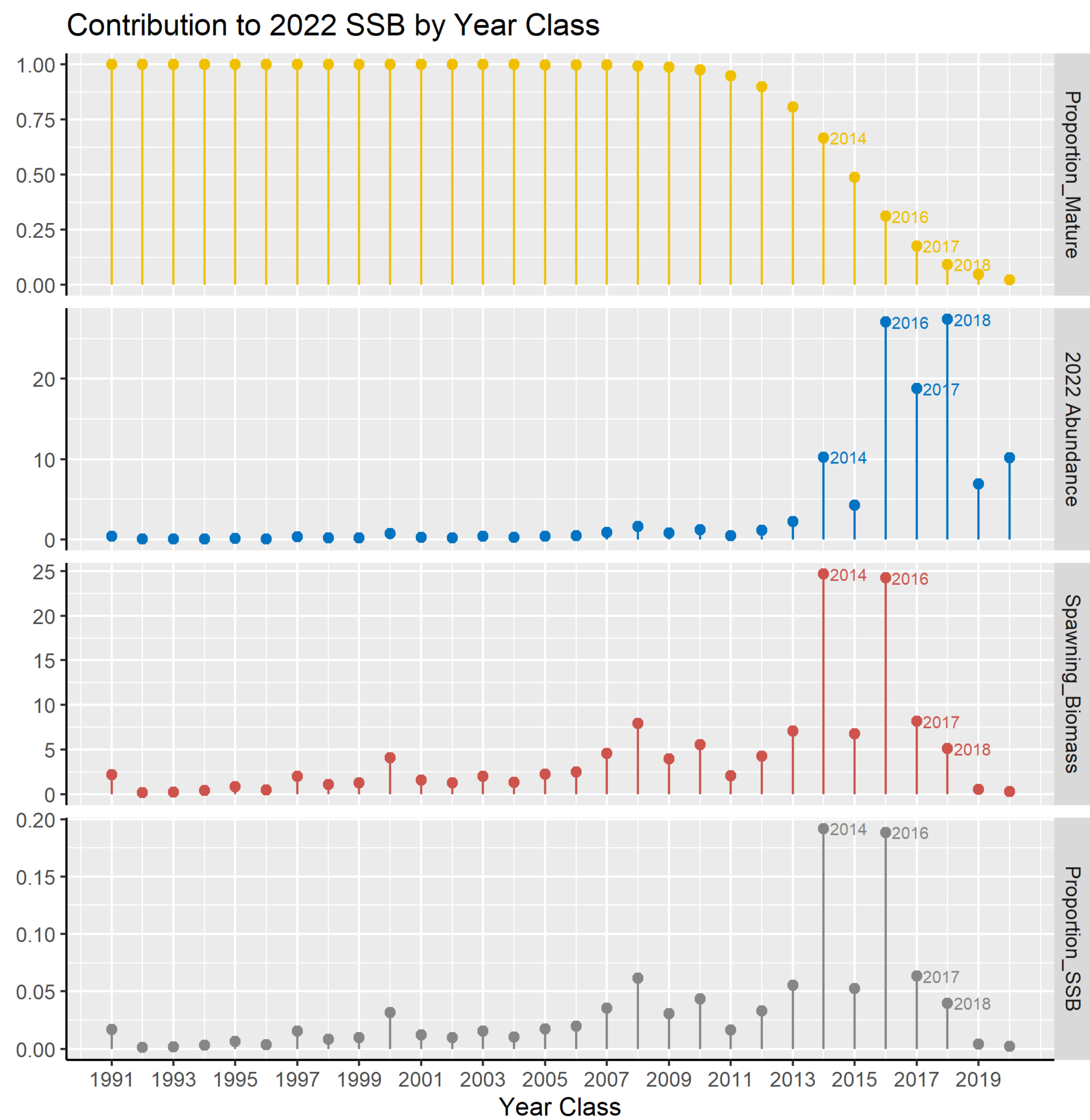


Figure 3.19. Proportion mature (top panel), projected 2022 female (assuming a 50:50 sex ratio) abundance (millions of fish; second panel from top), projected 2022 spawning stock biomass (kt; third panel from top), and proportional contribution to 2022 SSB (bottom panel) for each of the last 30 year classes. Note that the 1991 year class represents all contributions from all earlier year classes (i.e., fish in the plus group age). Abundance of the 2019 and 2020 year classes are based on mean recruitment, because these year classes have not yet been estimated in the 2021 assessment model.

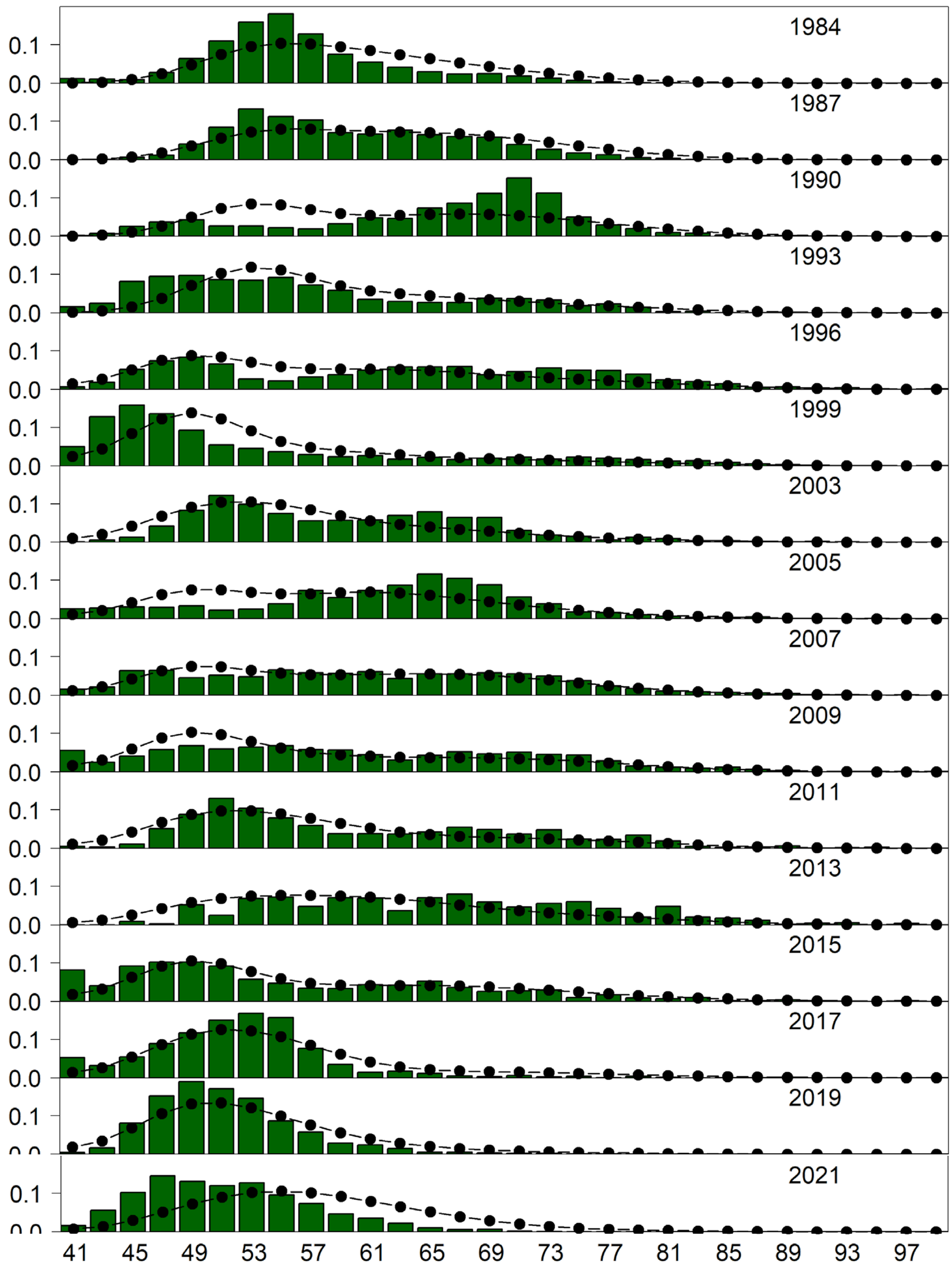


Figure 3.20. Gulf of Alaska bottom trawl survey length (cm) compositions for female sablefish at depths <500 m. Bars are observed frequencies and lines are predicted frequencies.

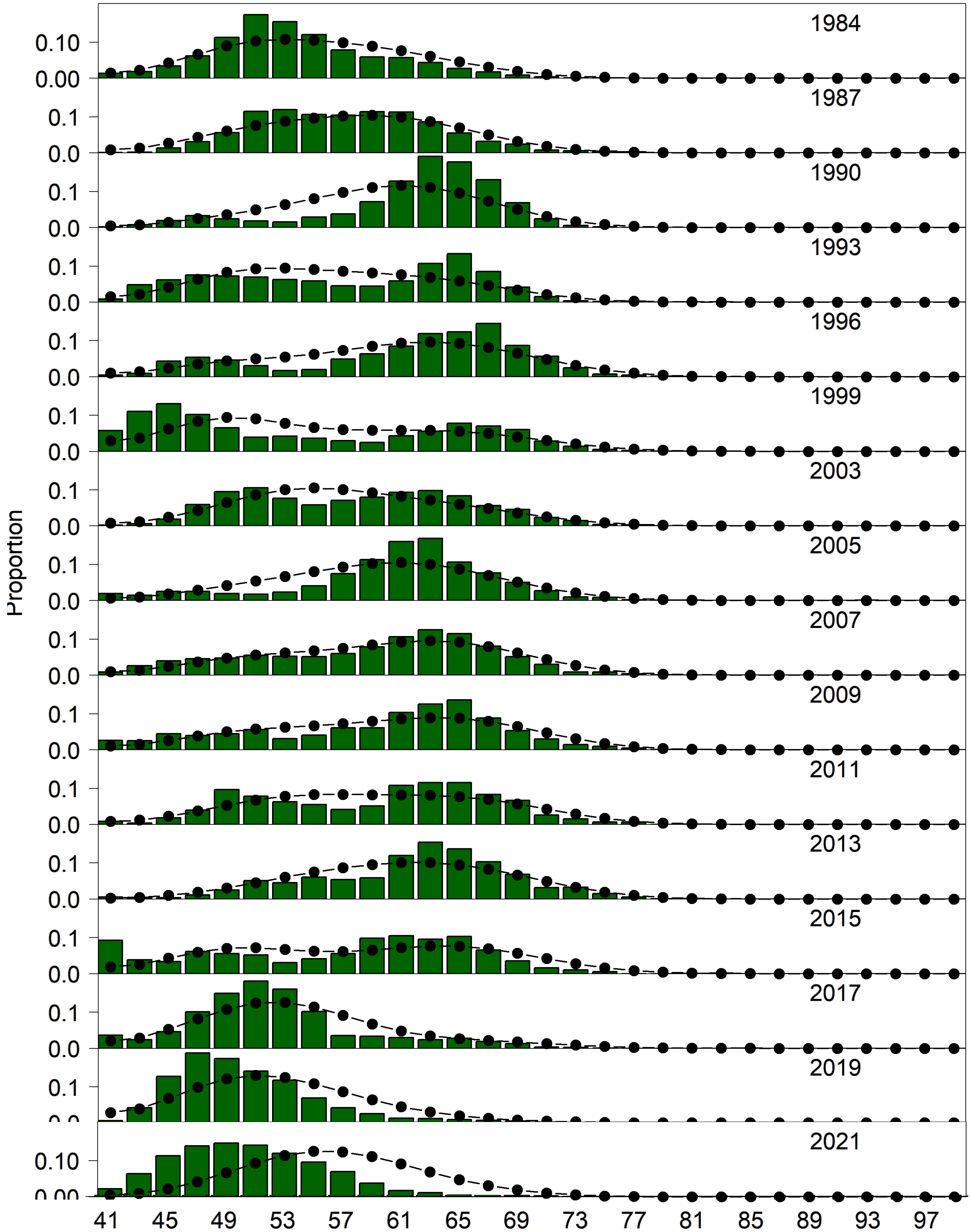


Figure 3.21. Gulf of Alaska bottom trawl survey length (cm) compositions for male sablefish at depths <500 m. Bars are observed frequencies and lines are predicted frequencies.

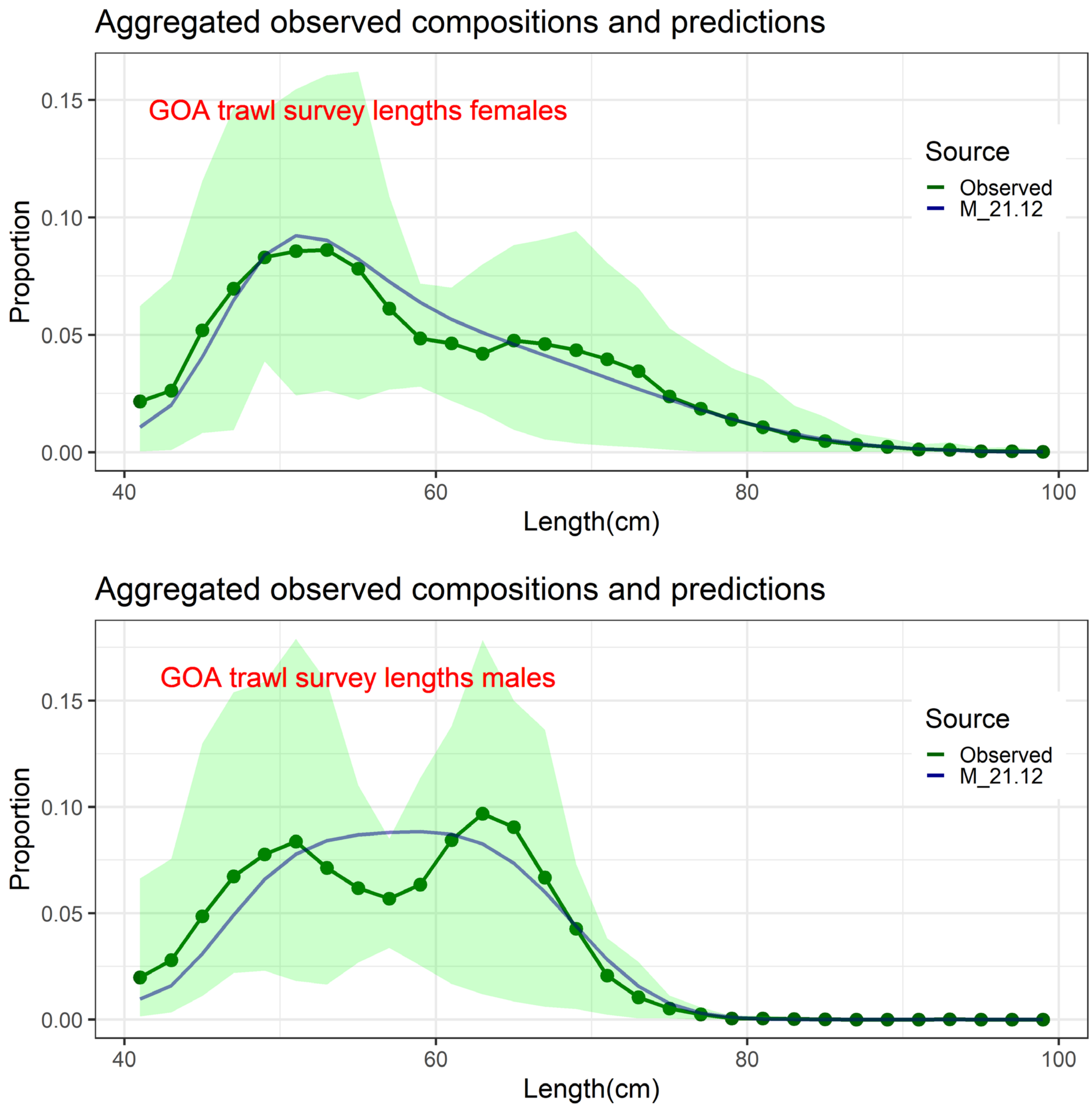


Figure 3.22. Mean observed (green line) Gulf of Alaska trawl survey length compositions aggregated across years along with the average fit of model *21.12_Proposed_No_Skip_Spawn* (blue line). The green bands are the 90% empirical confidence intervals. Fit to female length compositions are provided in the top panel and fit to male length compositions are provided in the bottom panel.

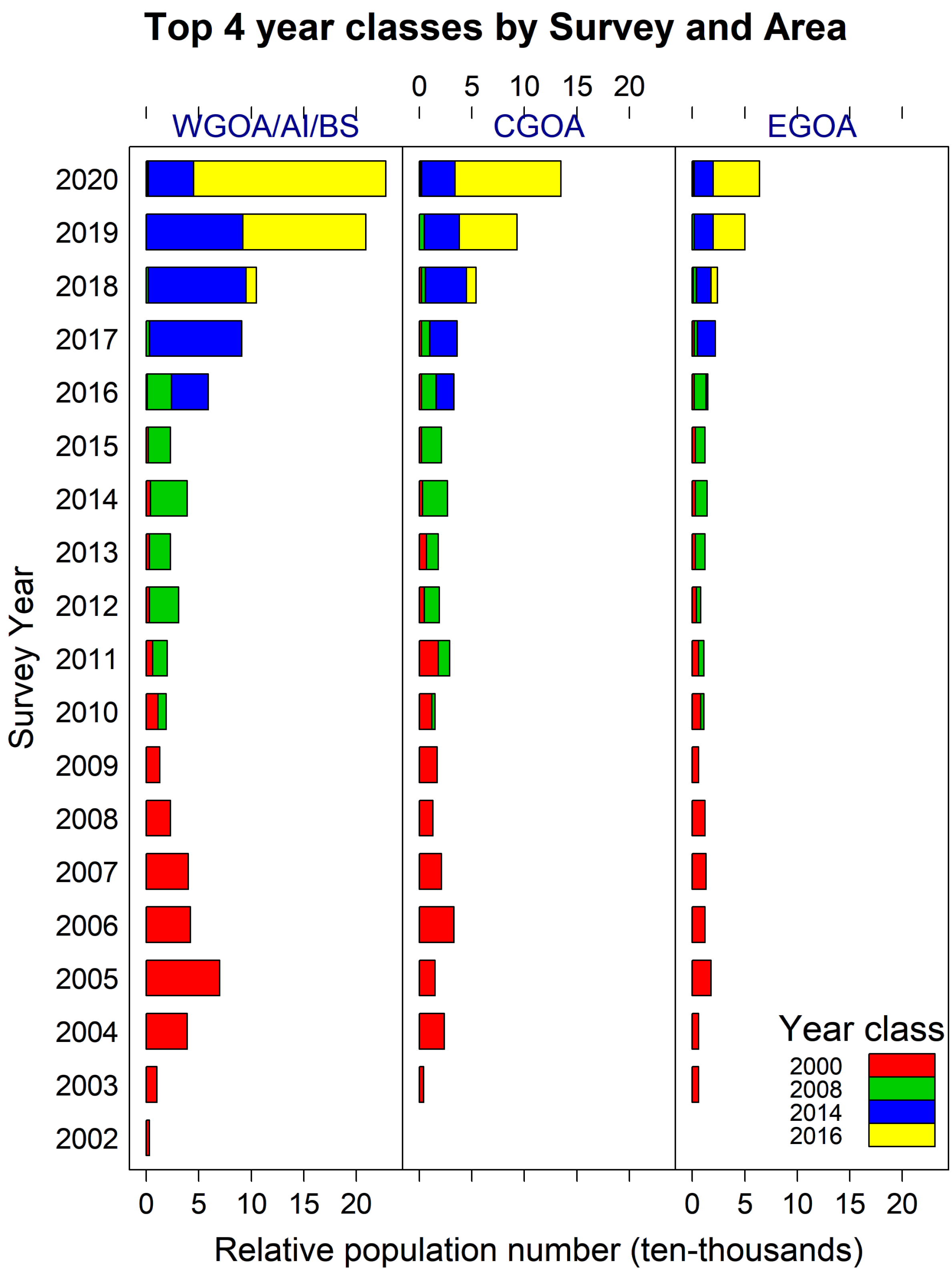


Figure 3.23. Above average 2000, 2008, 2014, and 2016 year classes' relative population abundance in the longline survey by year and area.

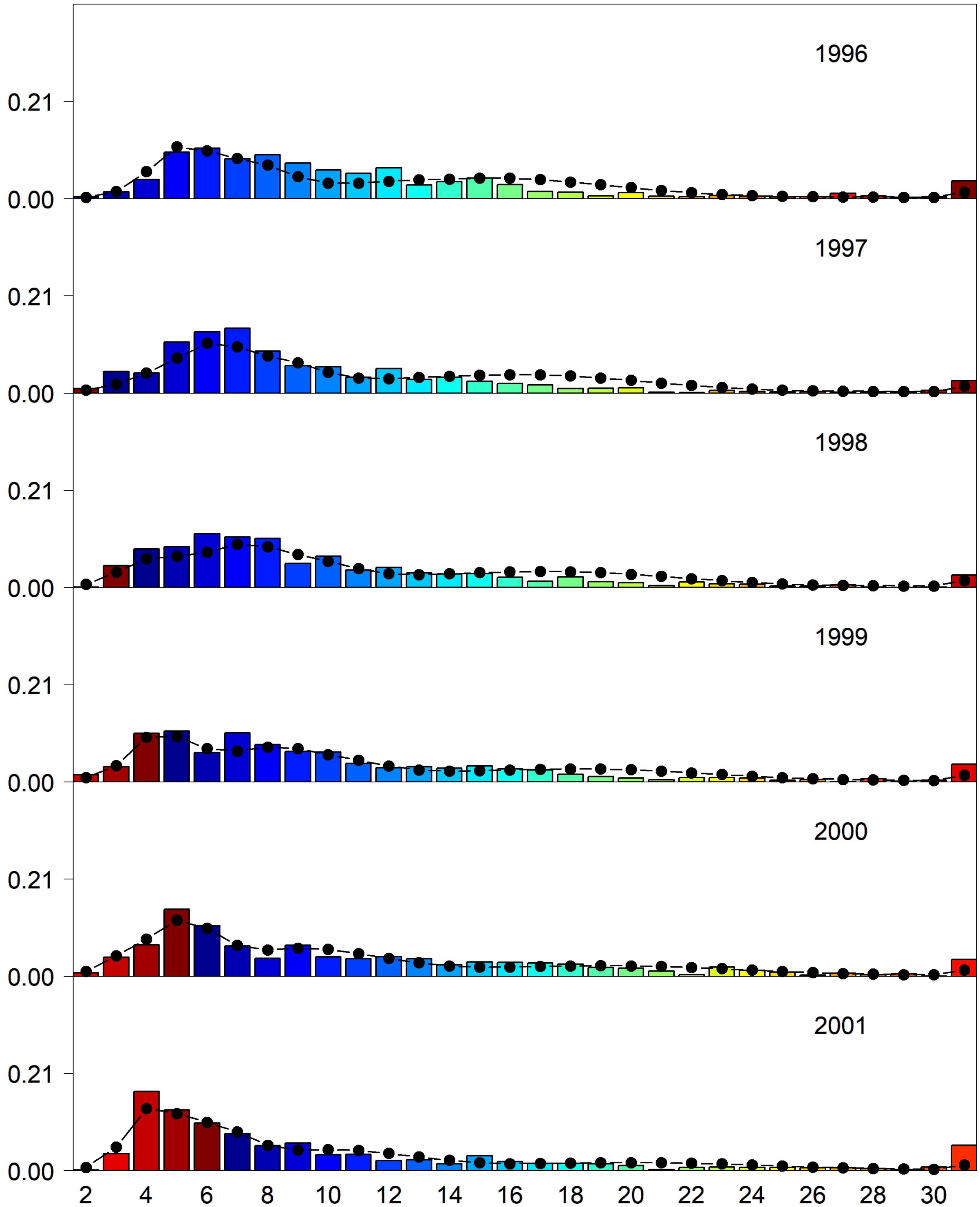


Figure 3.24. Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

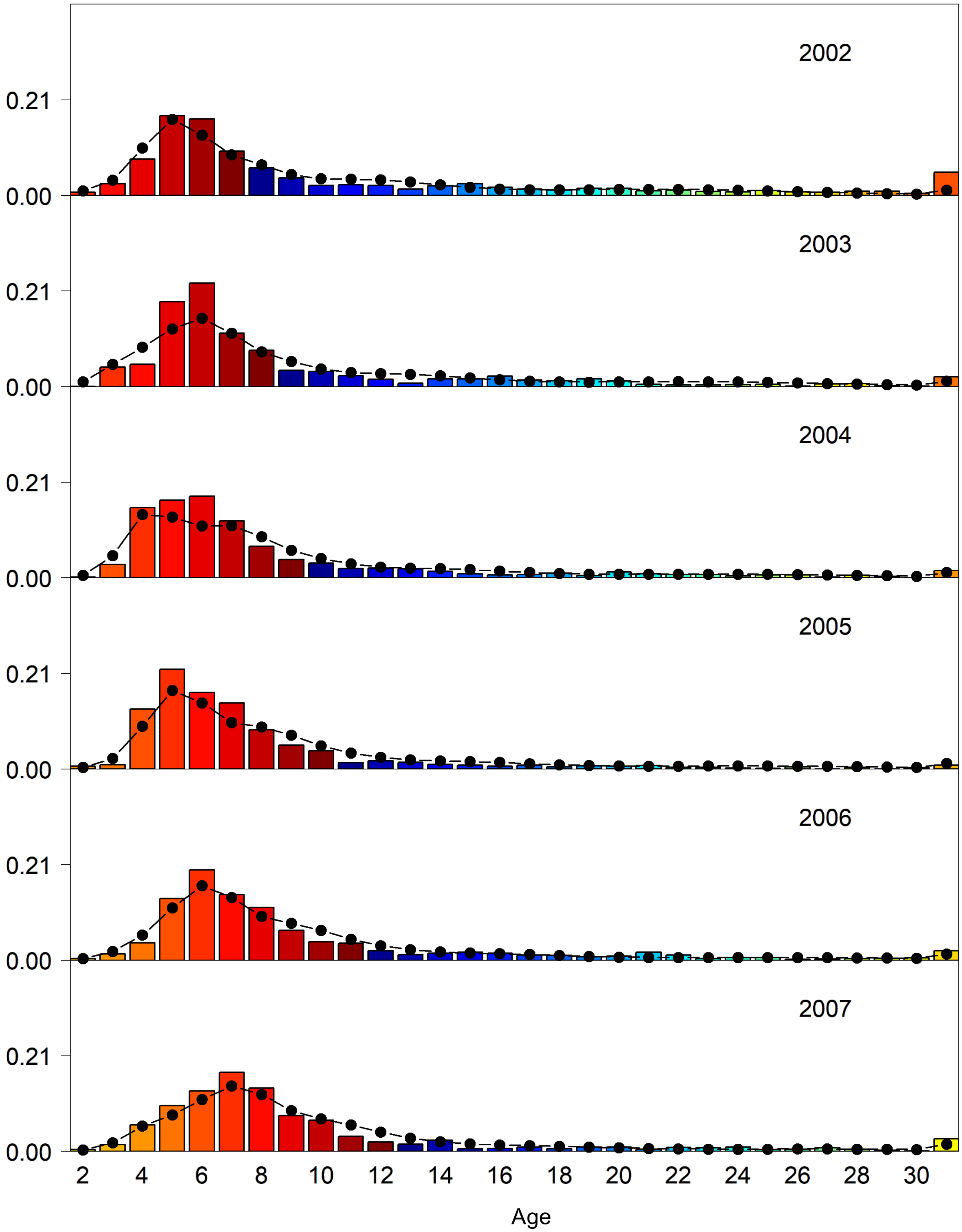


Figure 3.24 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

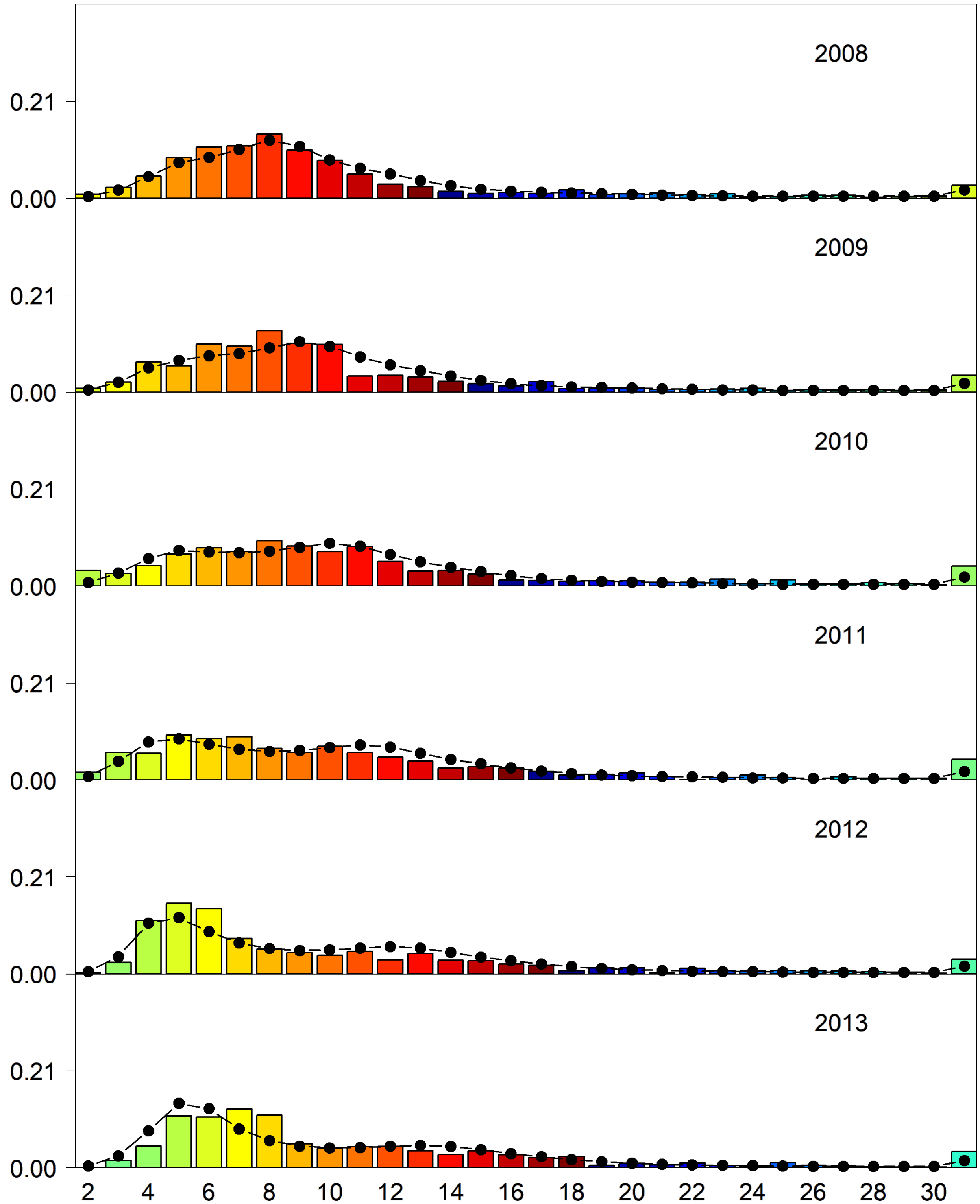


Figure 3.24 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

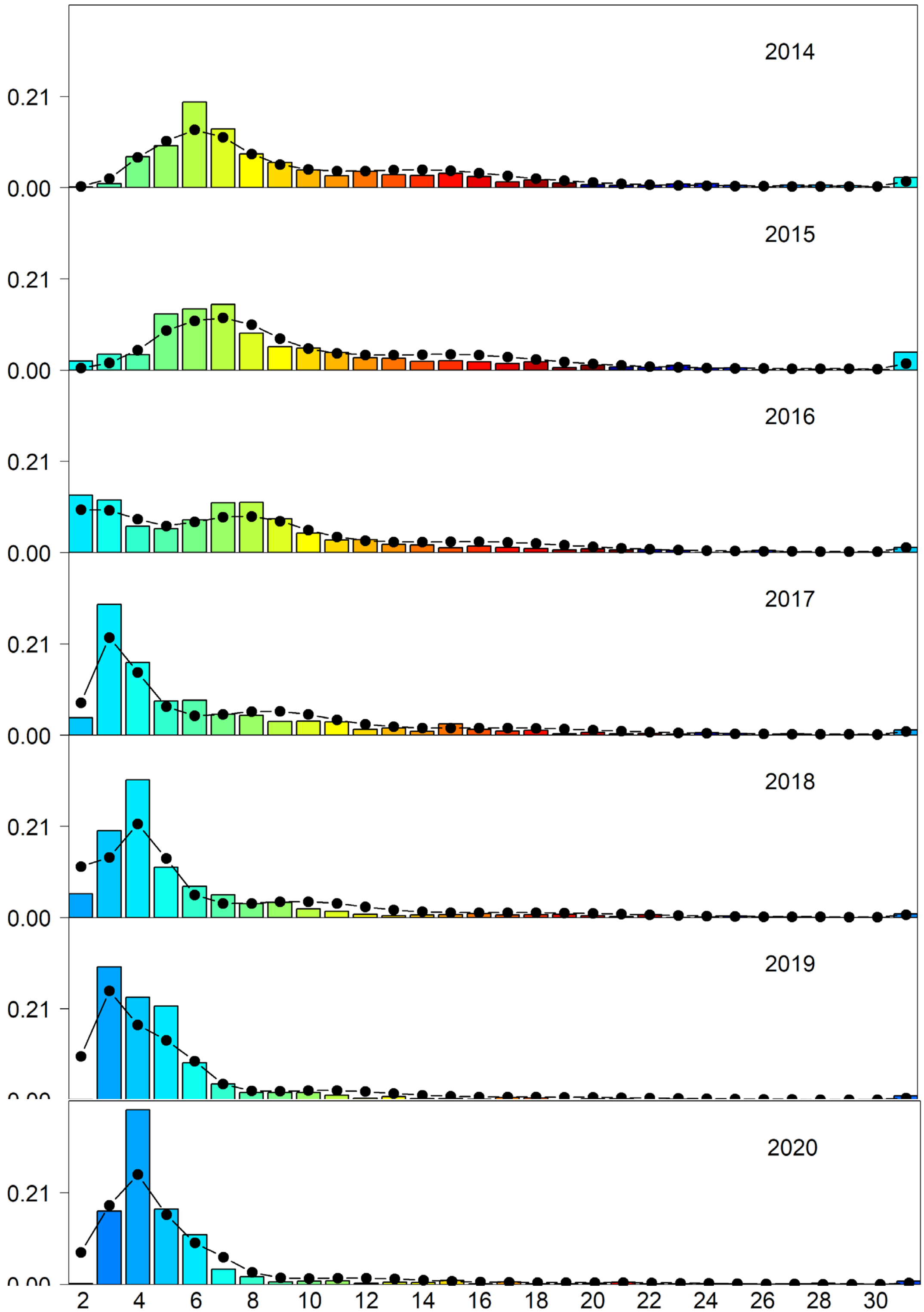


Figure 3.24 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

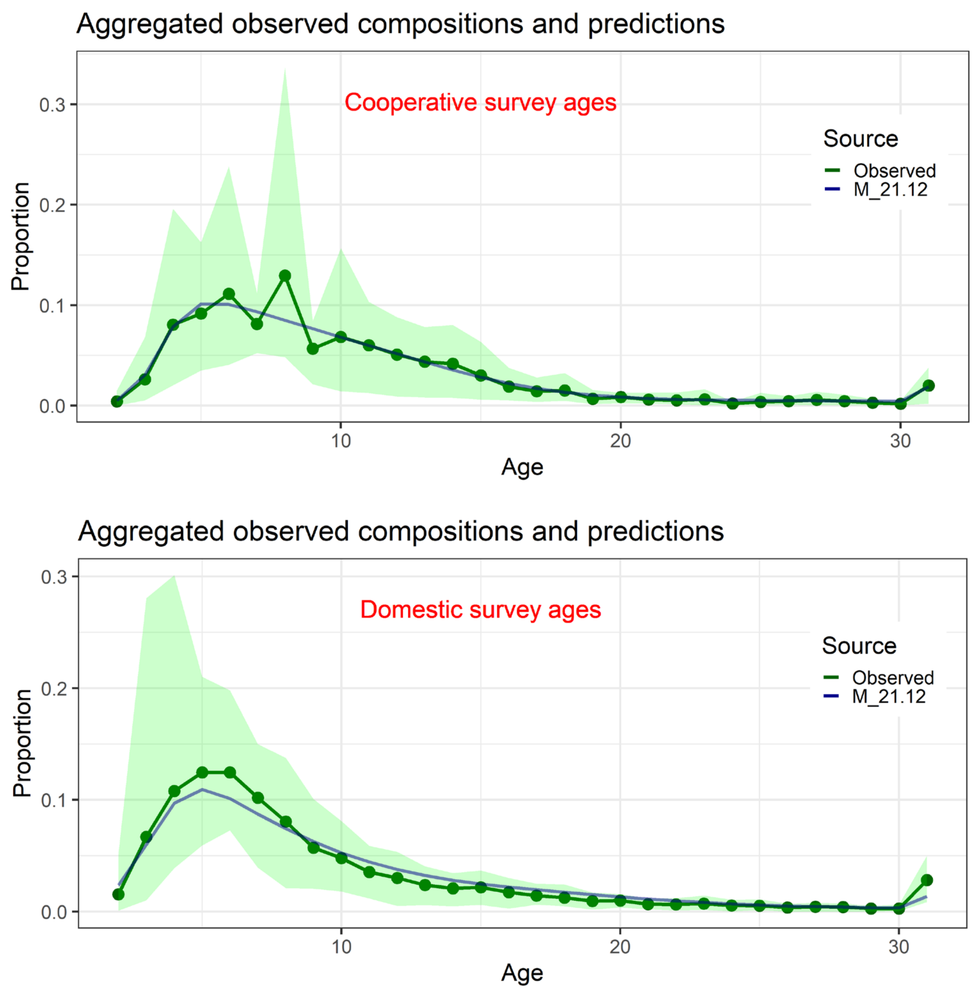


Figure 3.25a. Mean observed (green line) cooperative (top panel) and domestic (bottom panel) longline survey age compositions aggregated across years along with the average fit of the Base model (blue line). The green bands are the 90% empirical confidence intervals.

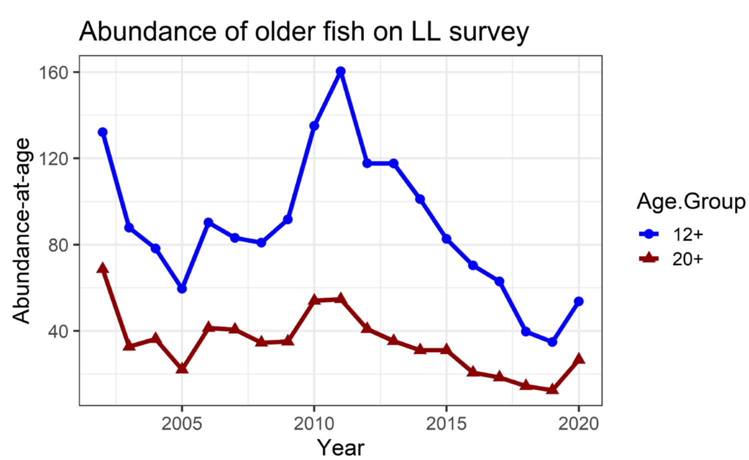


Figure 3.25b. Relative population numbers of fish age-12 and above (blue circles) and age-20 and above (red triangles) caught on the AFSC longline survey during 1999 – 2020.

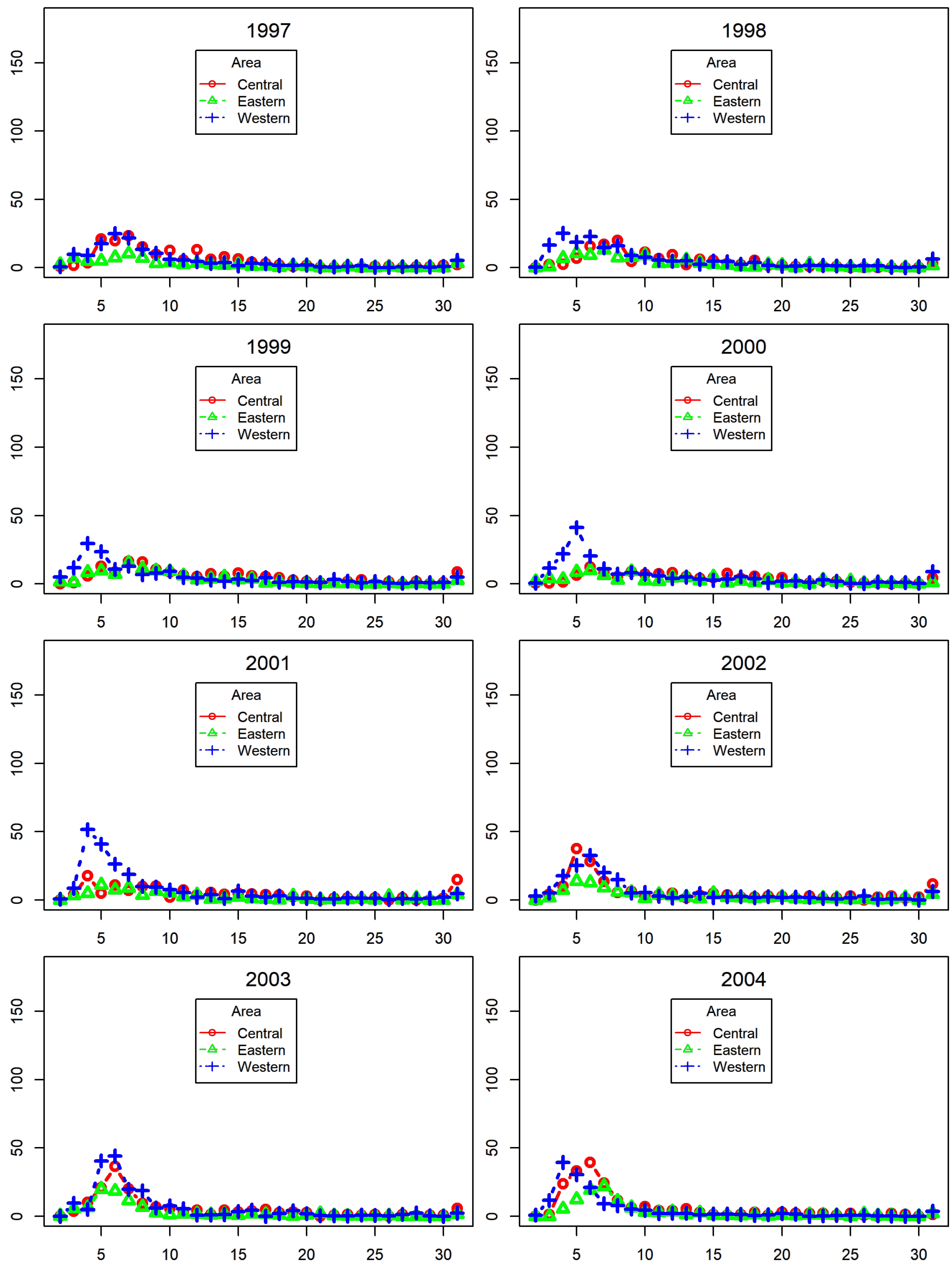


Figure 3.26. Relative abundance (number in thousands) by age (x-axis) and region (line color) from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined into the 'western' area.

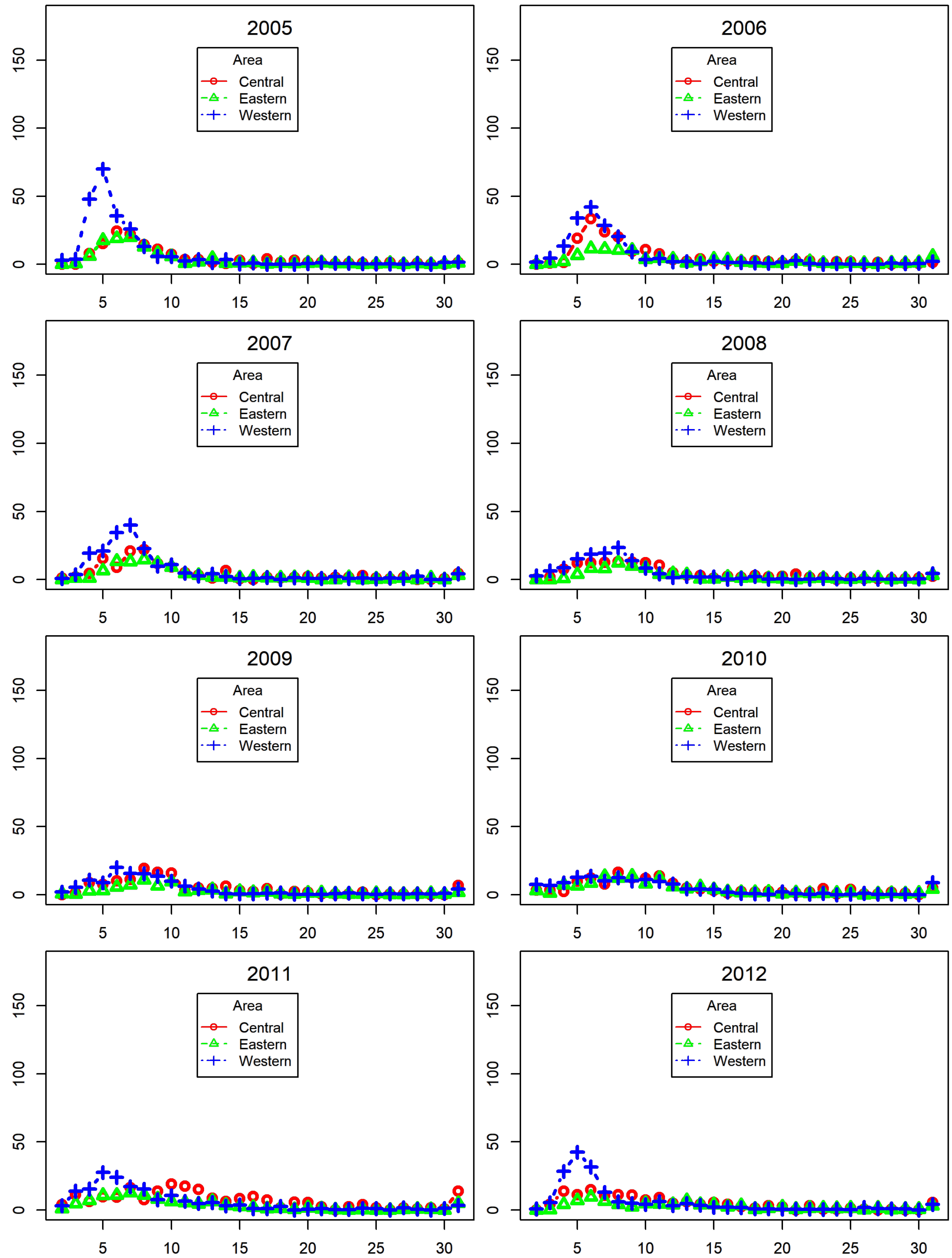


Figure 3.26 (Cont.). Relative abundance (number in thousands) by age (x-axis) and region (line color) from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined into the 'western' area.

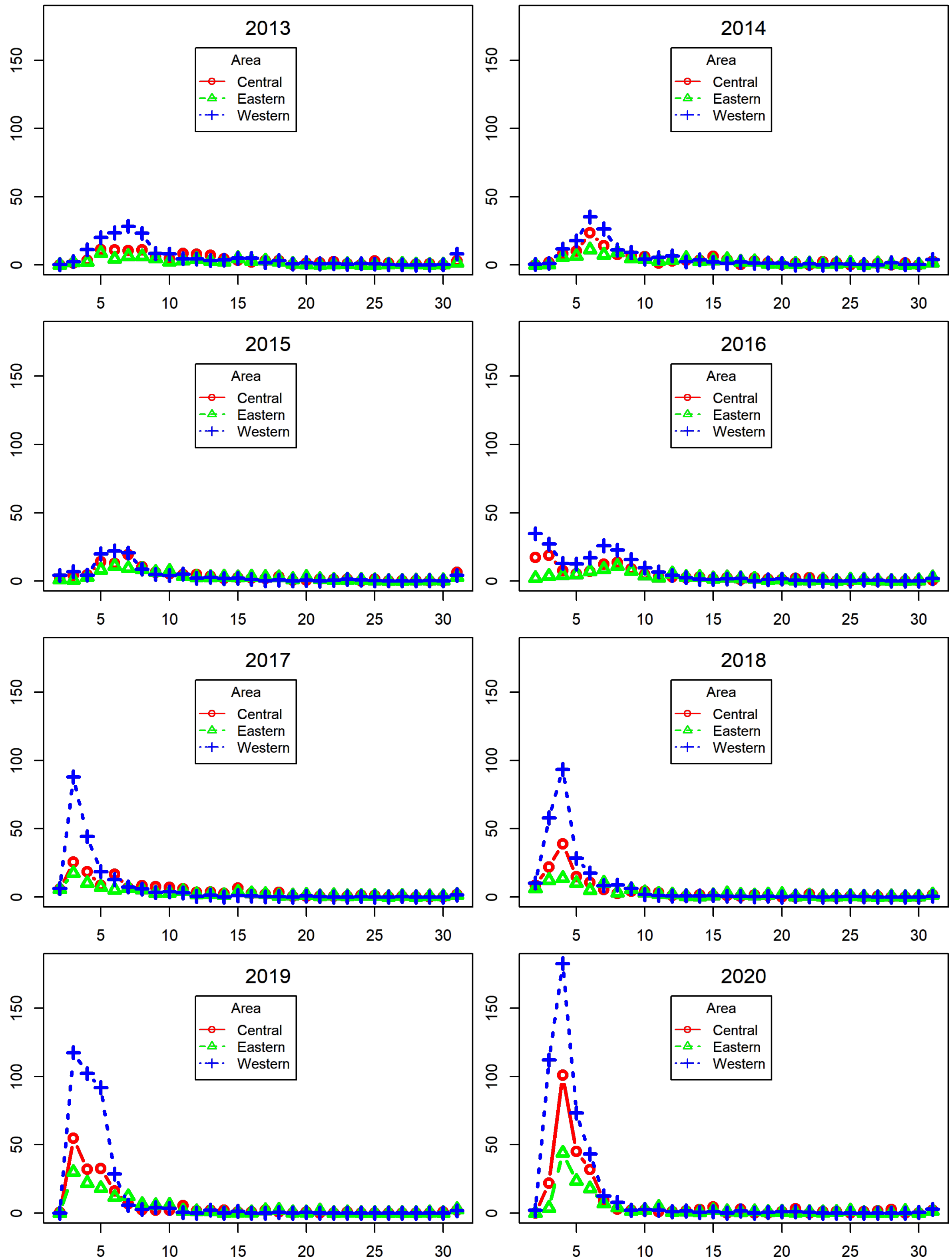


Figure 3.26 (Cont.). Relative abundance (number in thousands) by age (x-axis) and region (line color) from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined into the 'western' area.

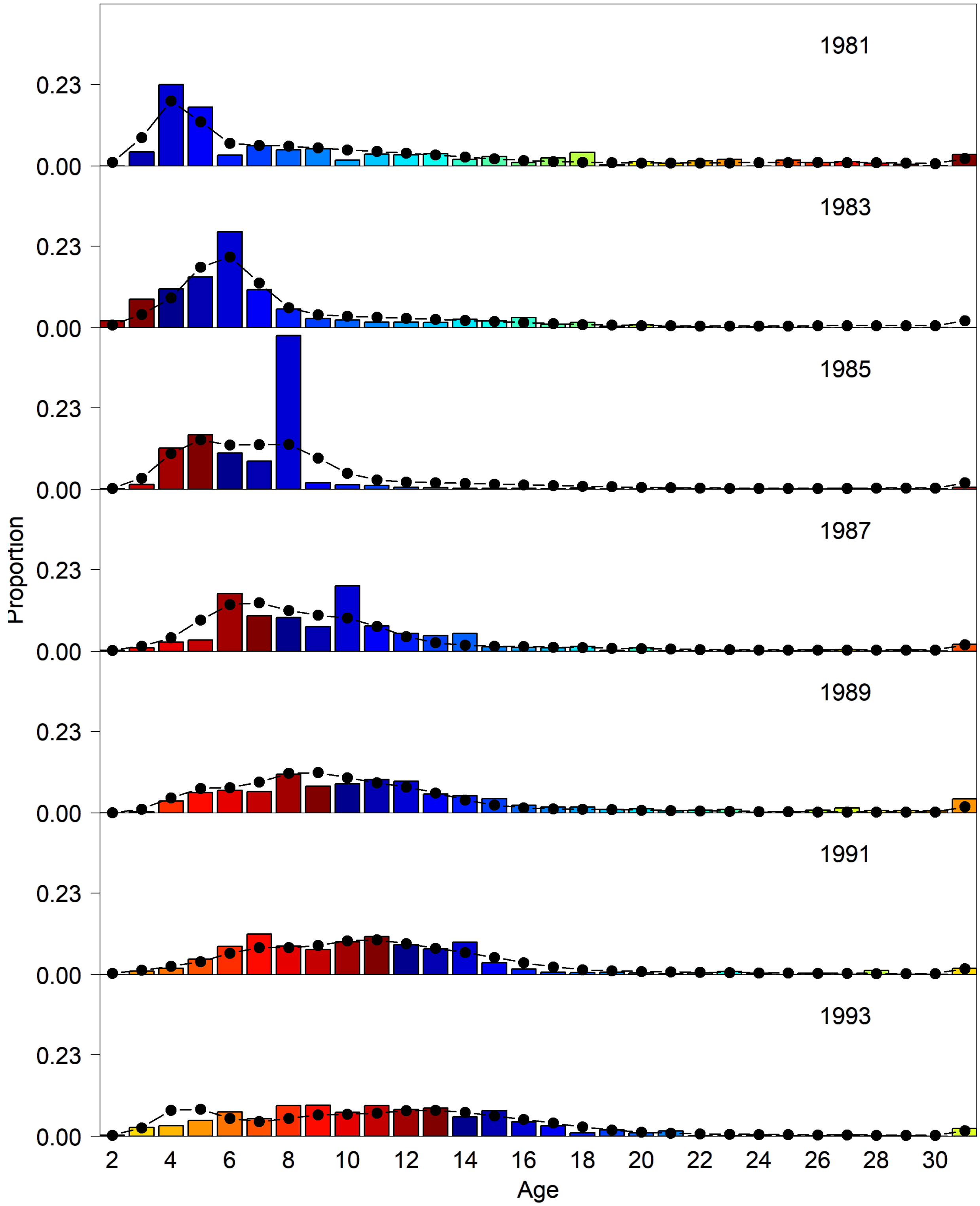
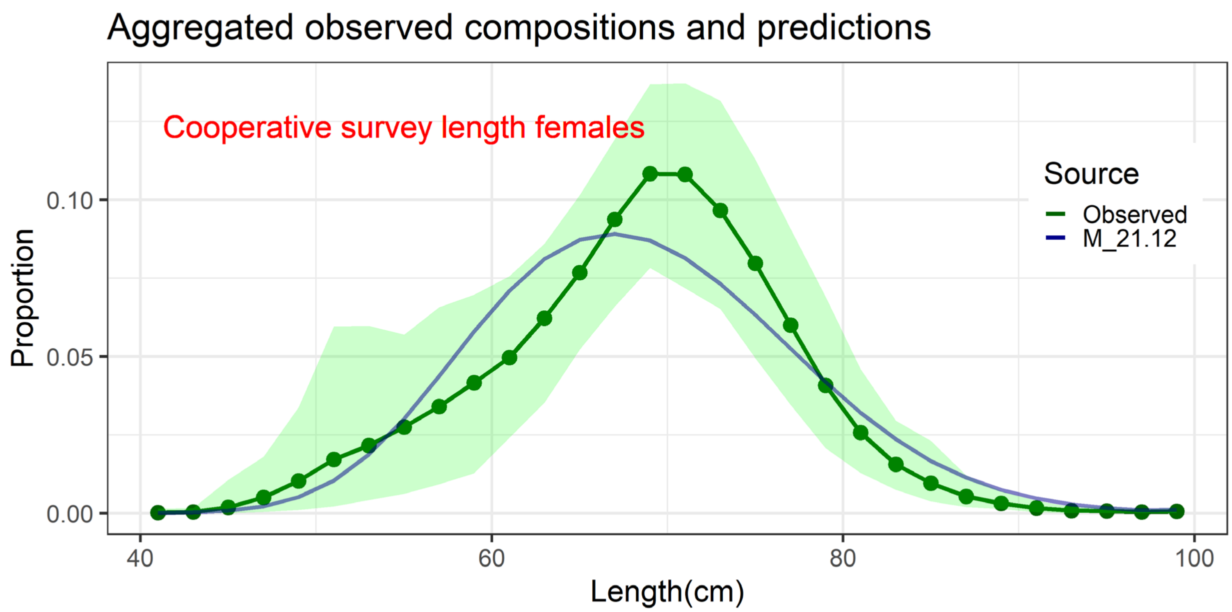


Figure 3.27. Japanese longline survey age compositions. Bars are observed frequencies and line is predicted frequencies.



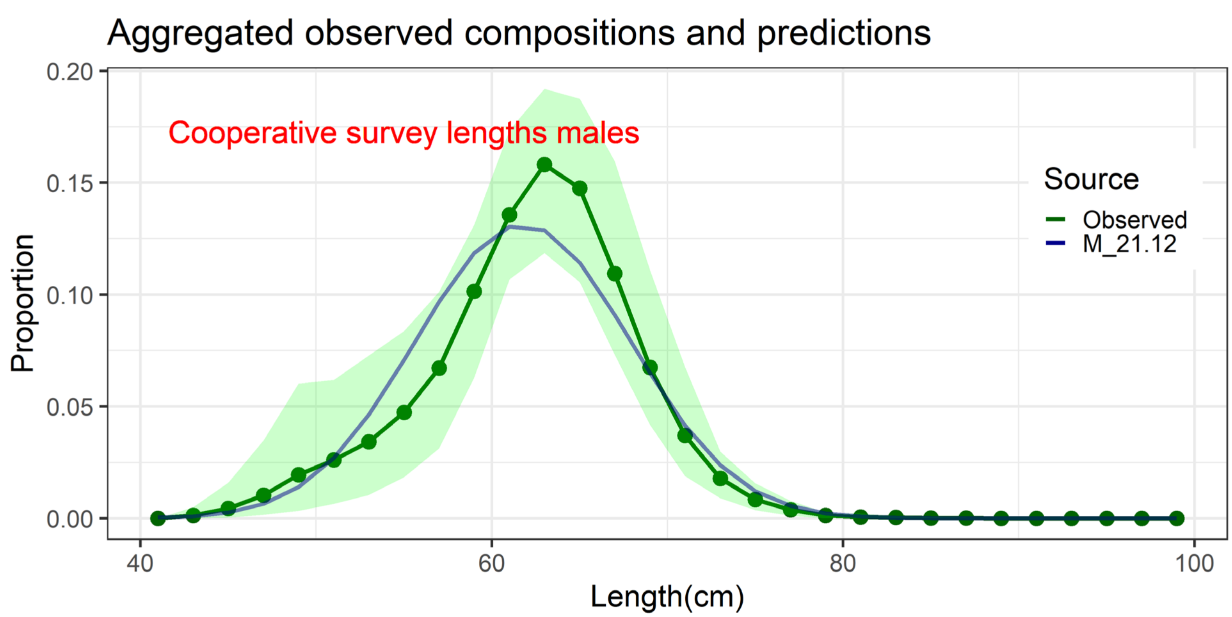


Figure 3.28. Mean observed (green line) cooperative longline survey length compositions aggregated across years along with the average fit of the *21.12_Proposed_No Skip_Spawn* model (blue line). The green bands are the 90% empirical confidence intervals. Fit to female length compositions are provided in the top panel and fit to male length compositions are provided in the bottom panel.

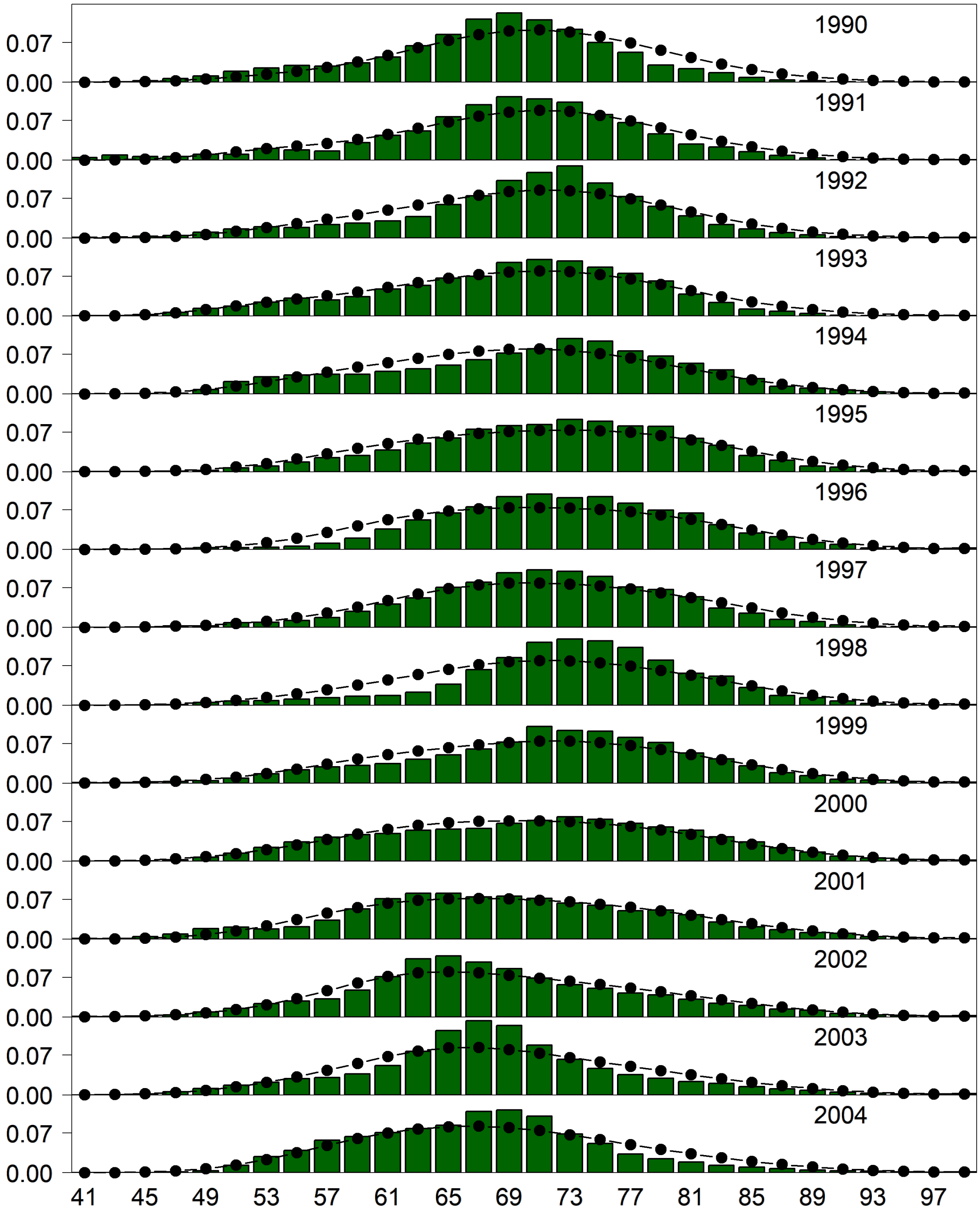


Figure 3.29. Domestic fixed gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

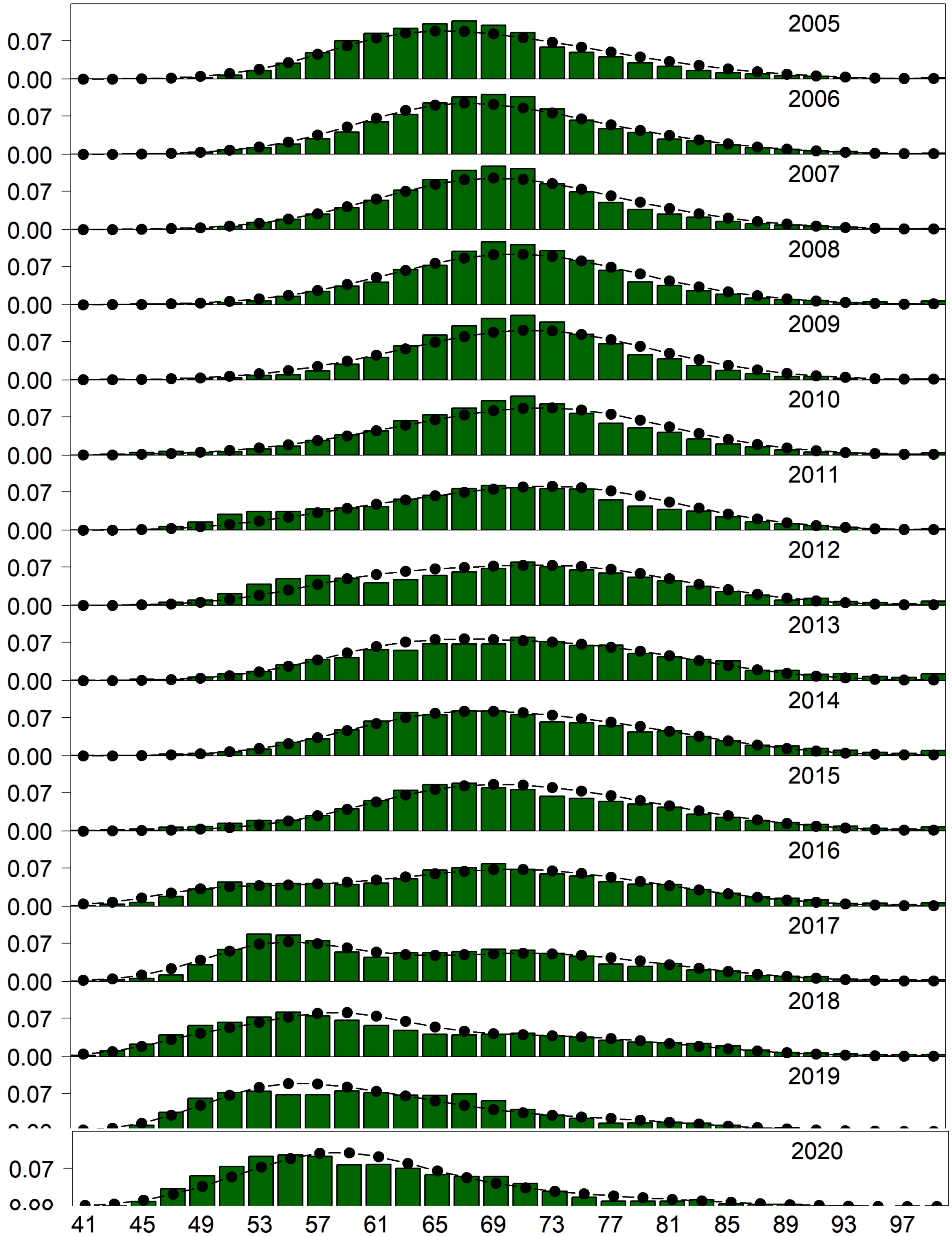


Figure 3.29 (cont.). Domestic fixed gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

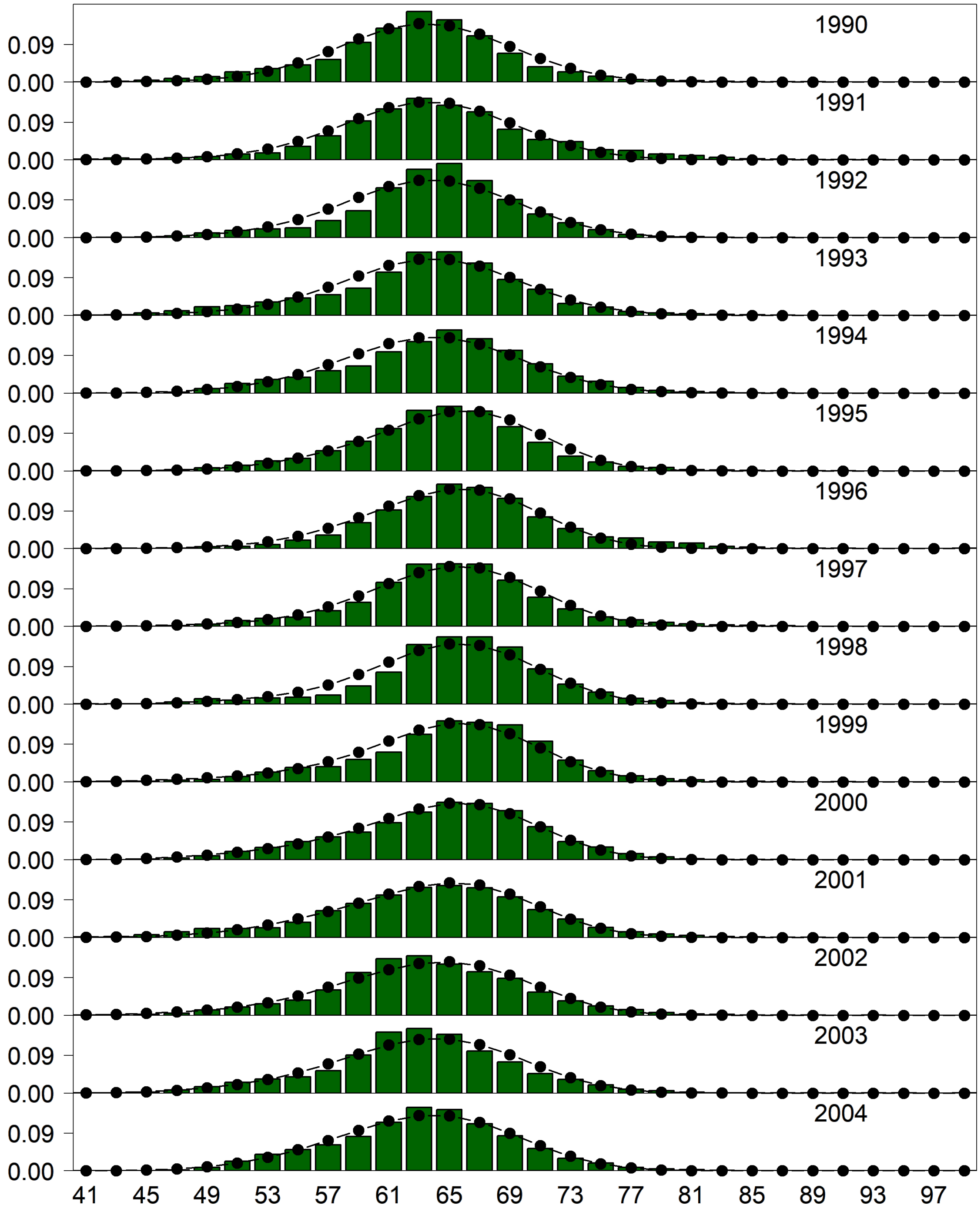


Figure 3.30. Domestic fixed gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

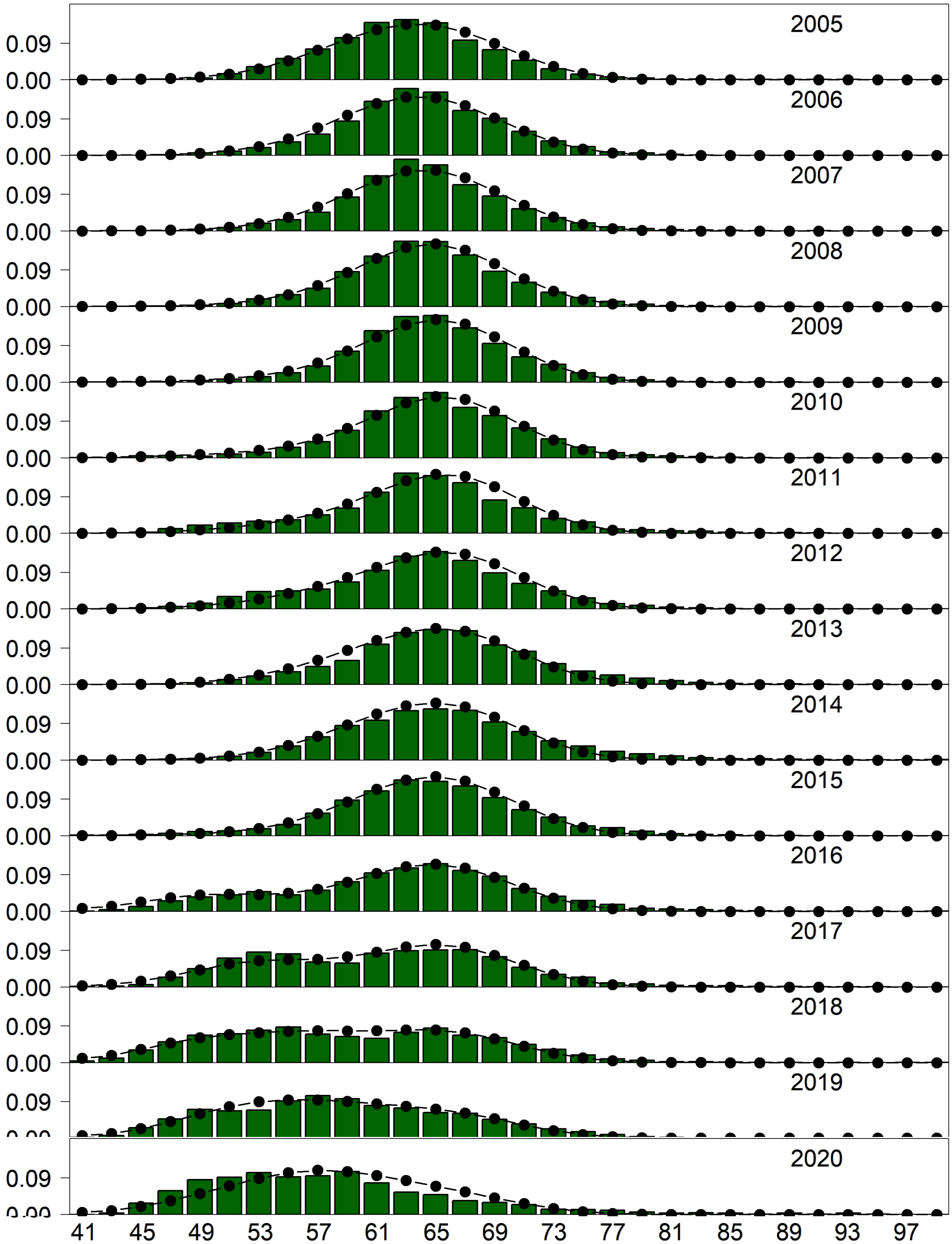


Figure 3.30 (Cont.). Domestic fixed gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

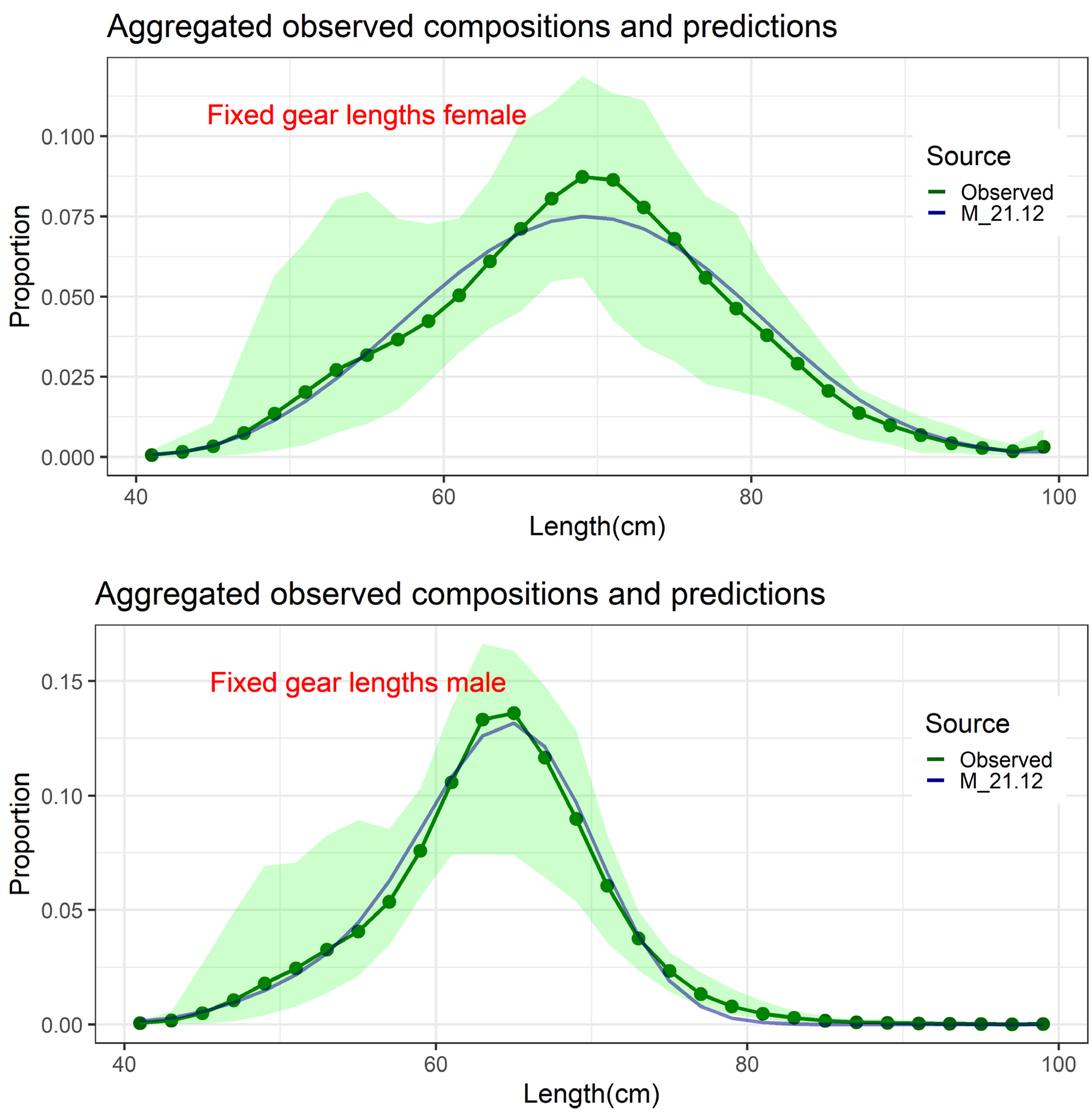


Figure 3.31. Mean observed (green line) domestic fixed gear fishery length compositions aggregated across years along with the average fit of the *21.12_Proposed_No_Skip_Spawn* model (blue line). The green bands are the 90% empirical confidence intervals. Fit to female length compositions are provided in the top panel and fit to male length compositions are provided in the bottom panel.

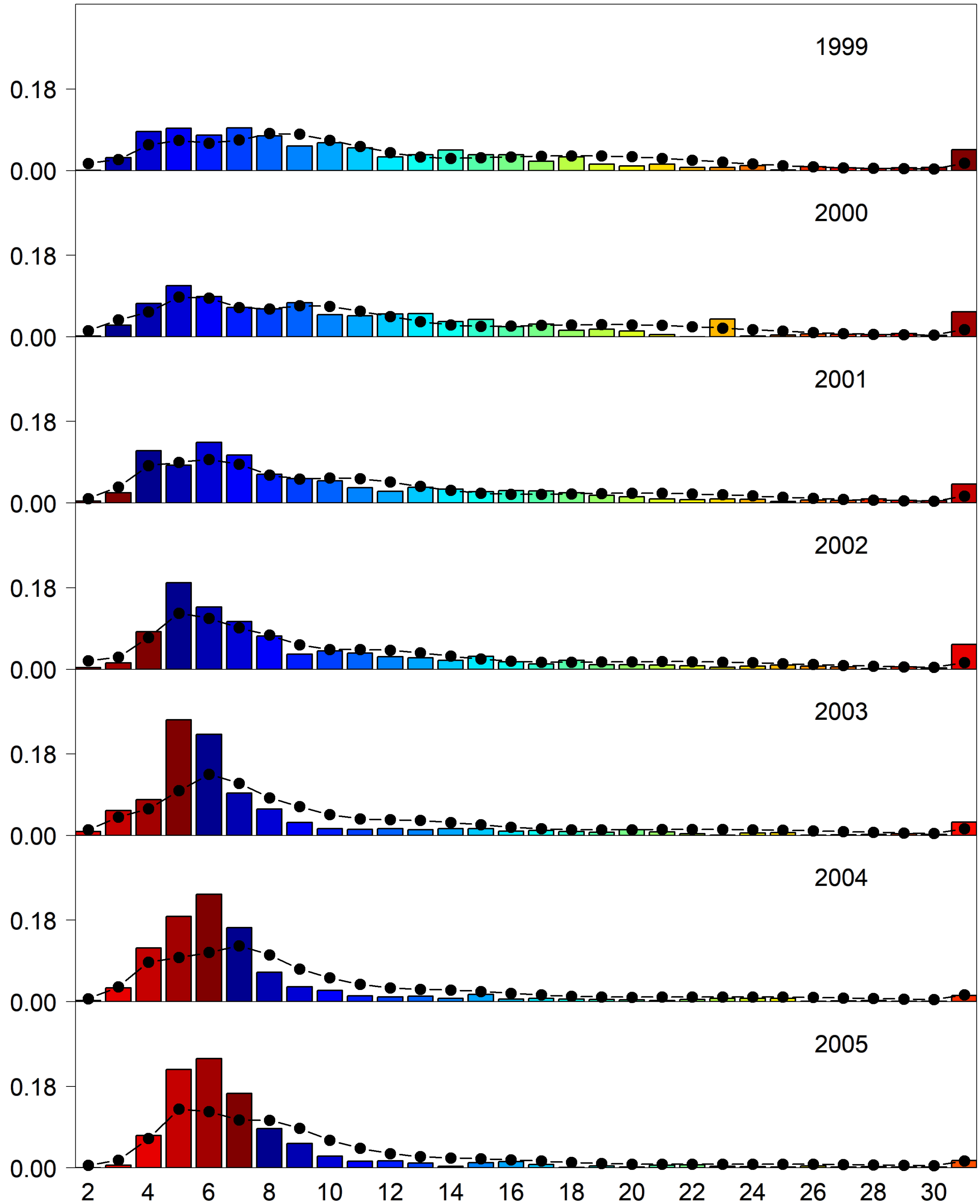


Figure 3.32. Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

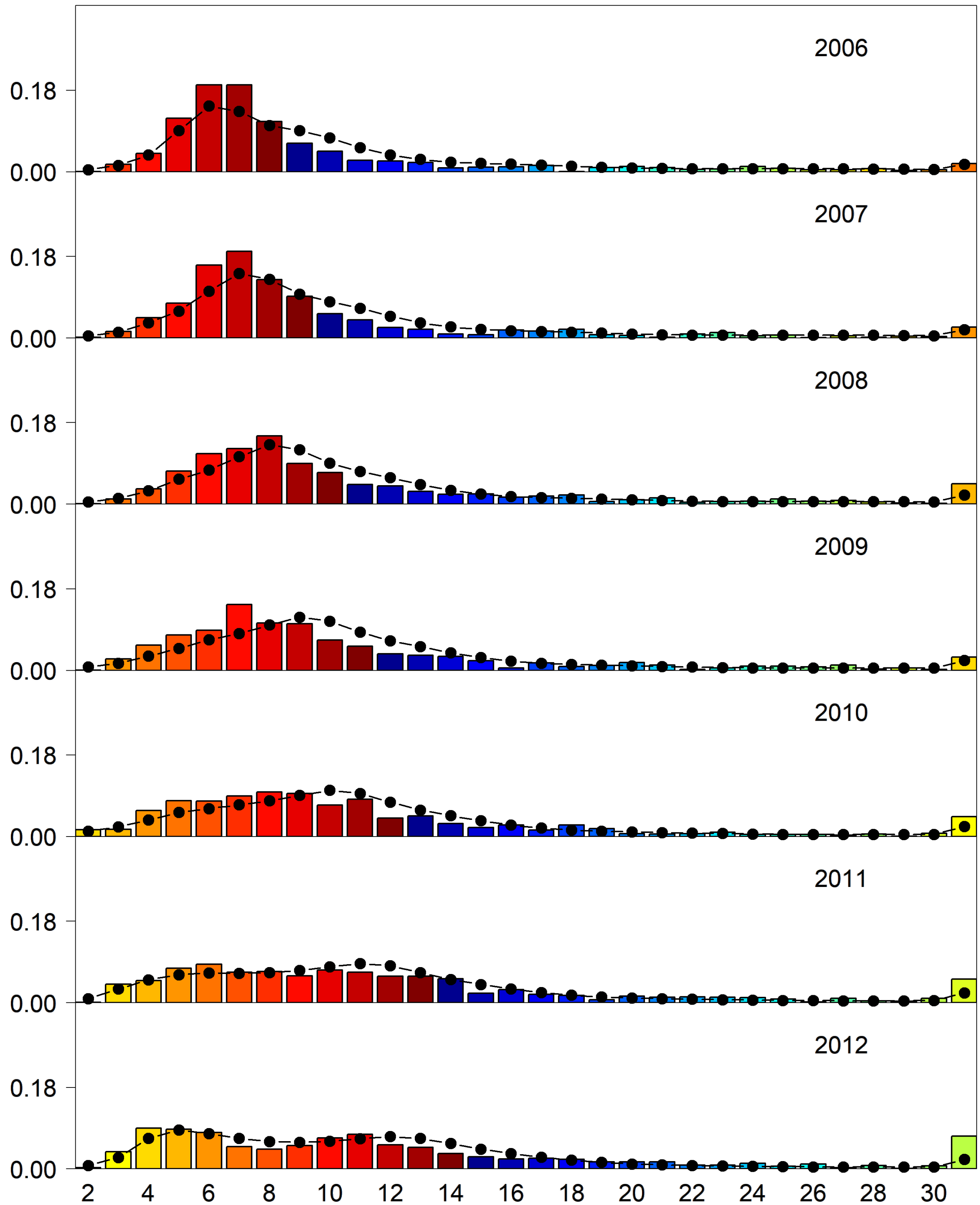


Figure 3.32 (cont.). Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

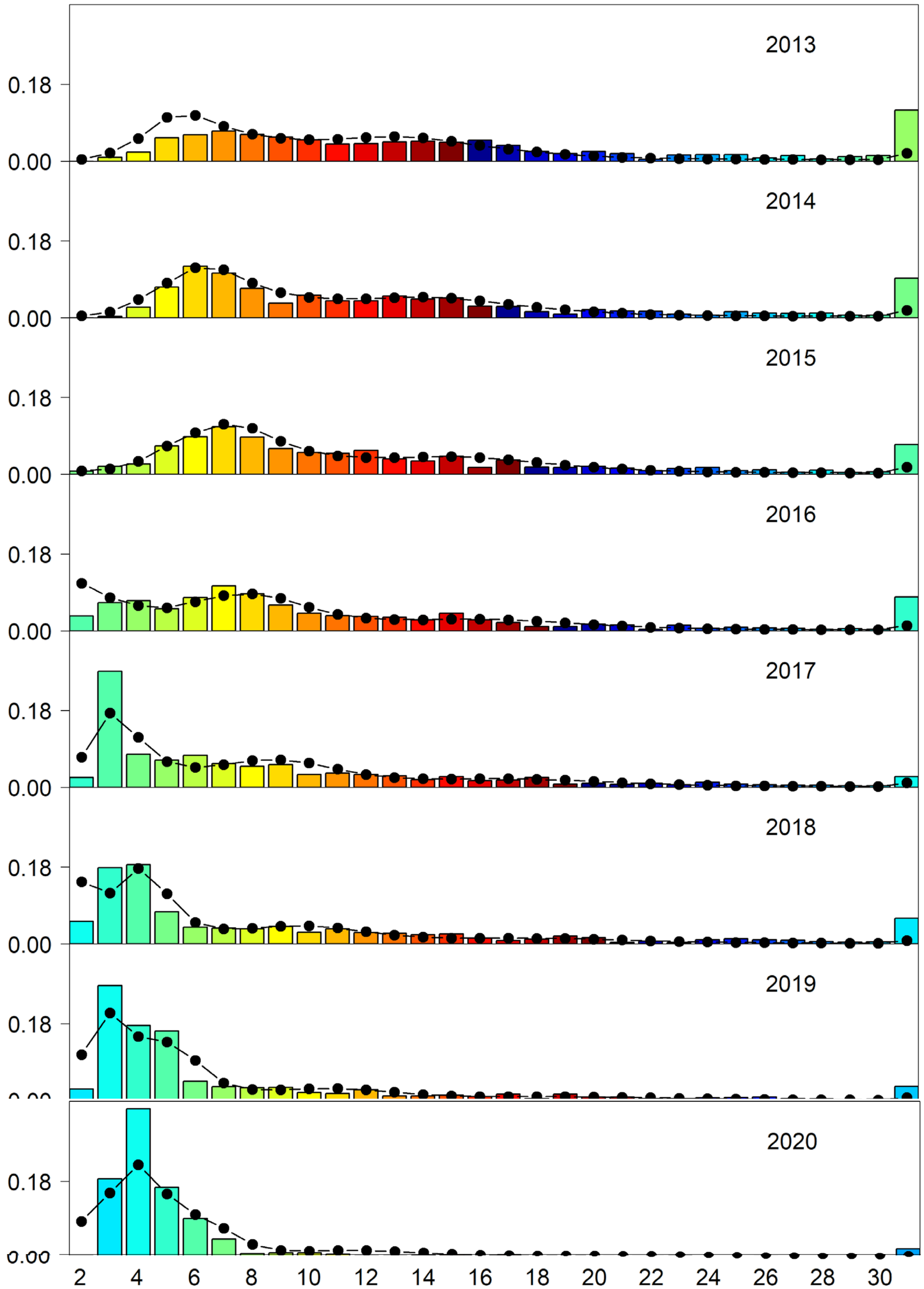


Figure 3.32 (cont.). Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

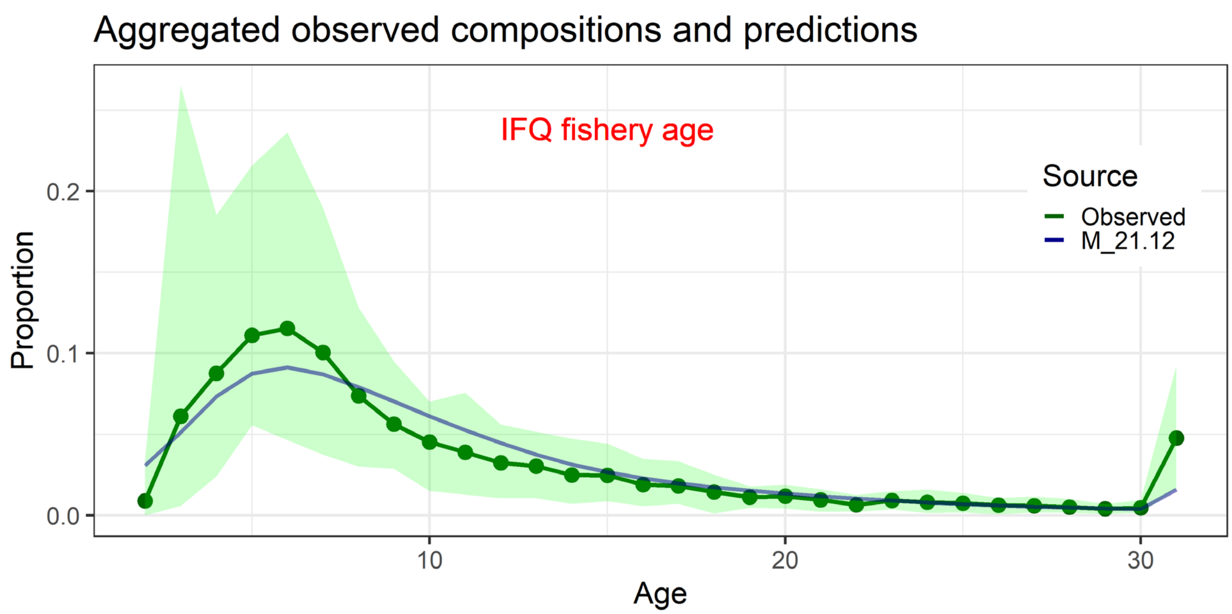


Figure 3.33. Mean observed (green line) domestic fixed gear fishery age compositions aggregated across years along with the average fit of the Base model (blue line). The green bands are the 90% empirical confidence intervals.

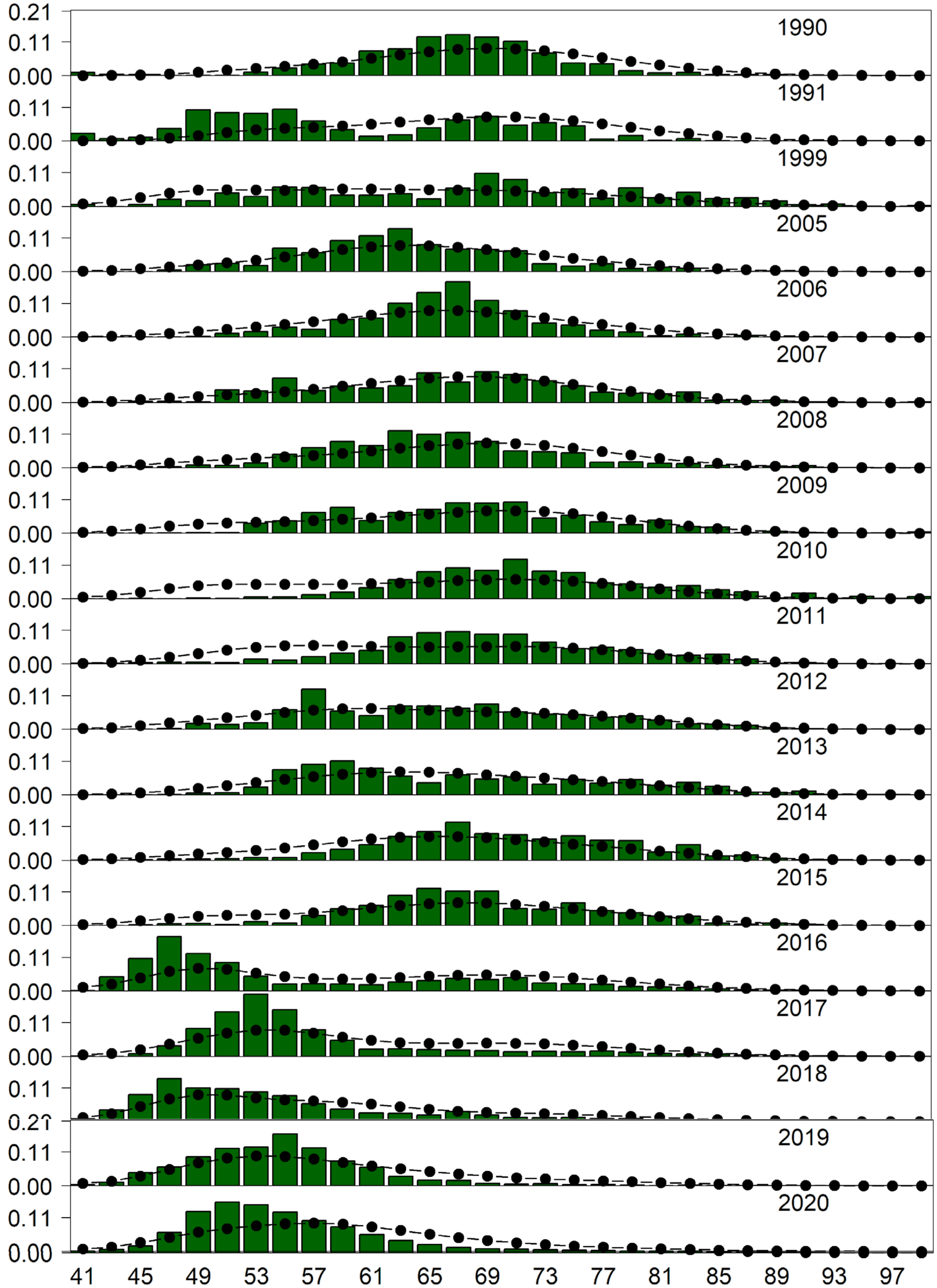


Figure 3.34. Domestic trawl gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

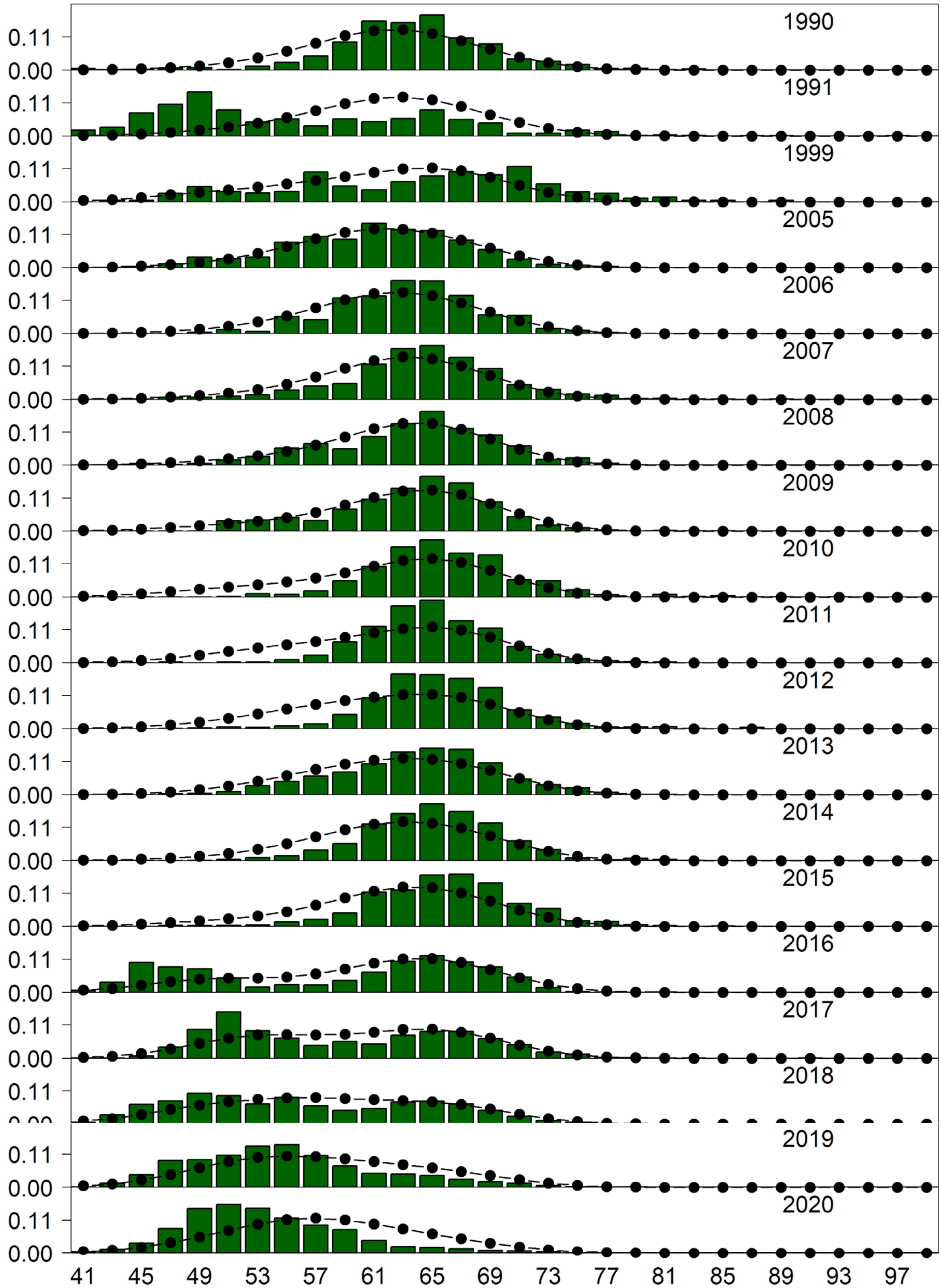
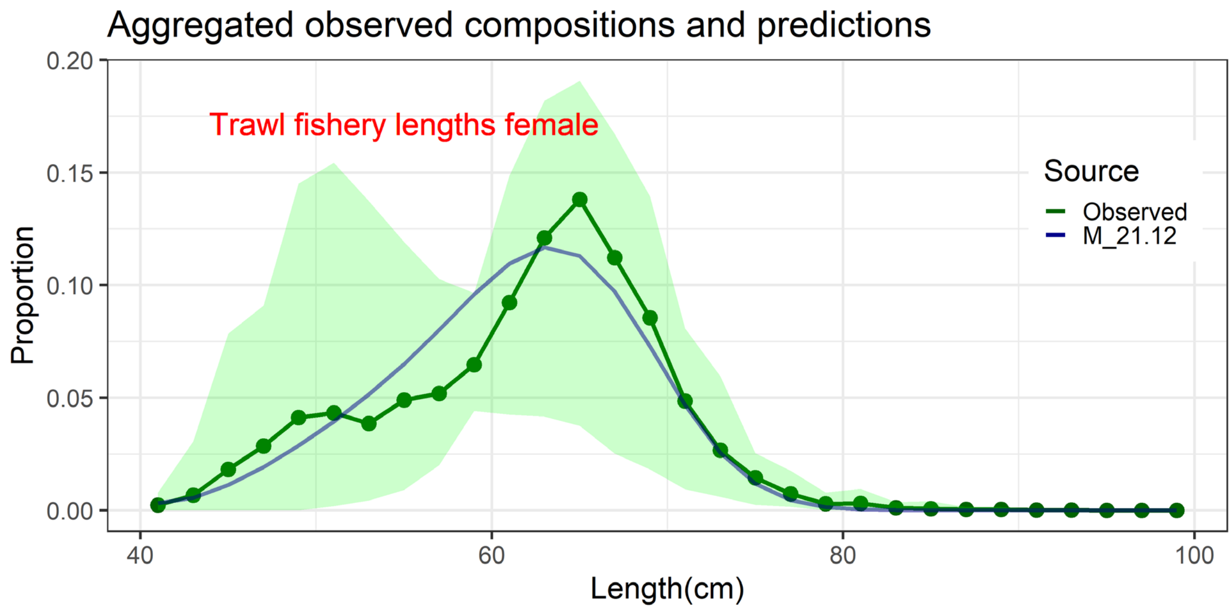


Figure 3.35. Domestic trawl gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.



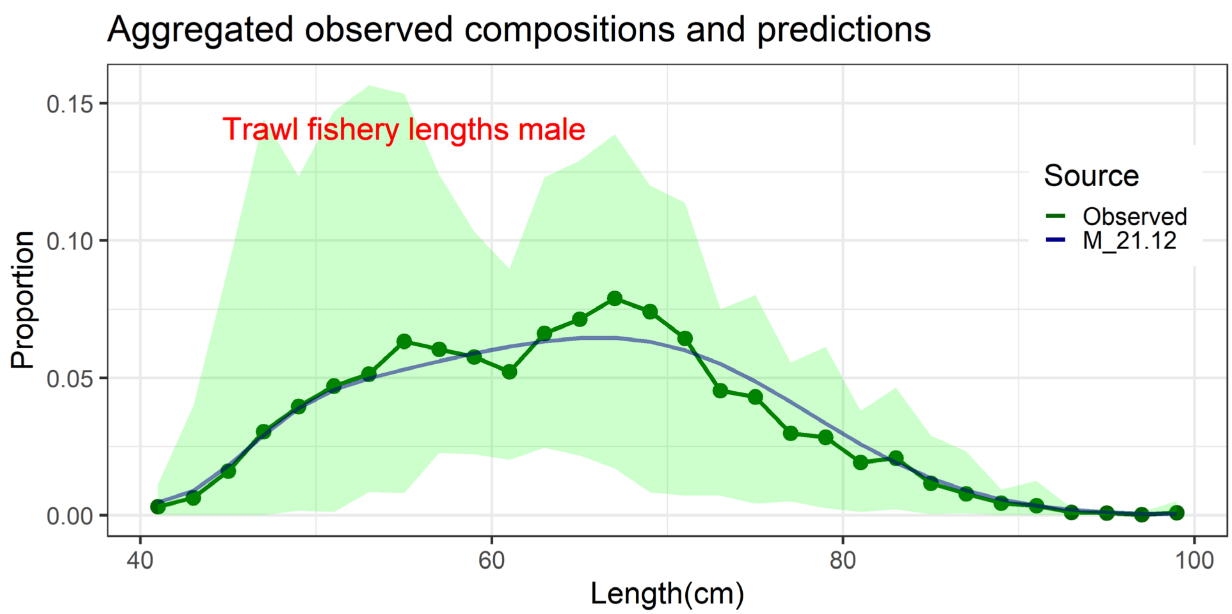


Figure 3.36. Mean observed (green line) domestic trawl fishery length compositions aggregated across years along with the average fit of the *21.12_Proposed_No_Skip_Spawn* model (blue line). The green bands are the 90% empirical confidence intervals. Fit to female length compositions are provided in the top panel and fit to male length compositions are provided in the bottom panel.

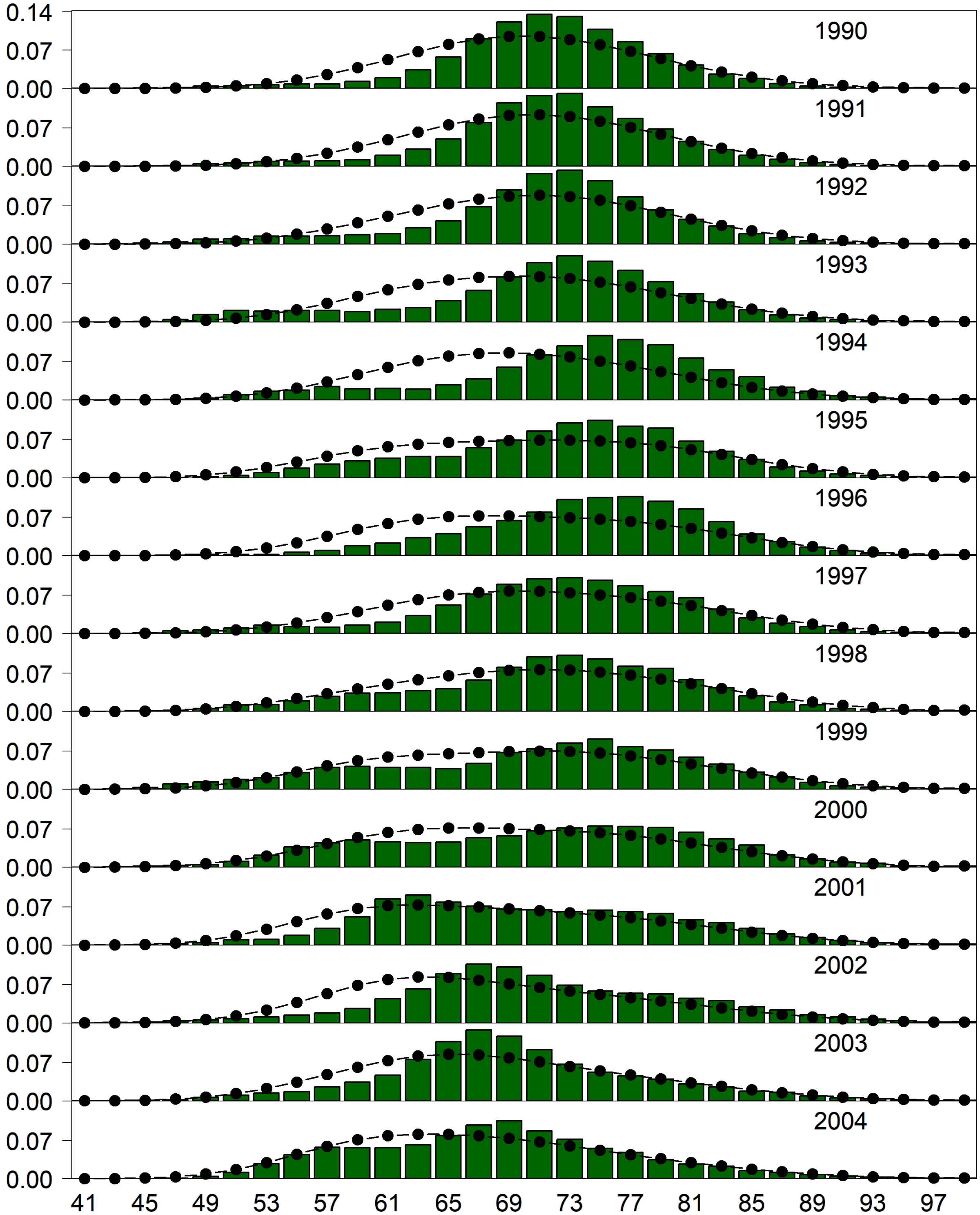


Figure 3.37. Domestic longline survey length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

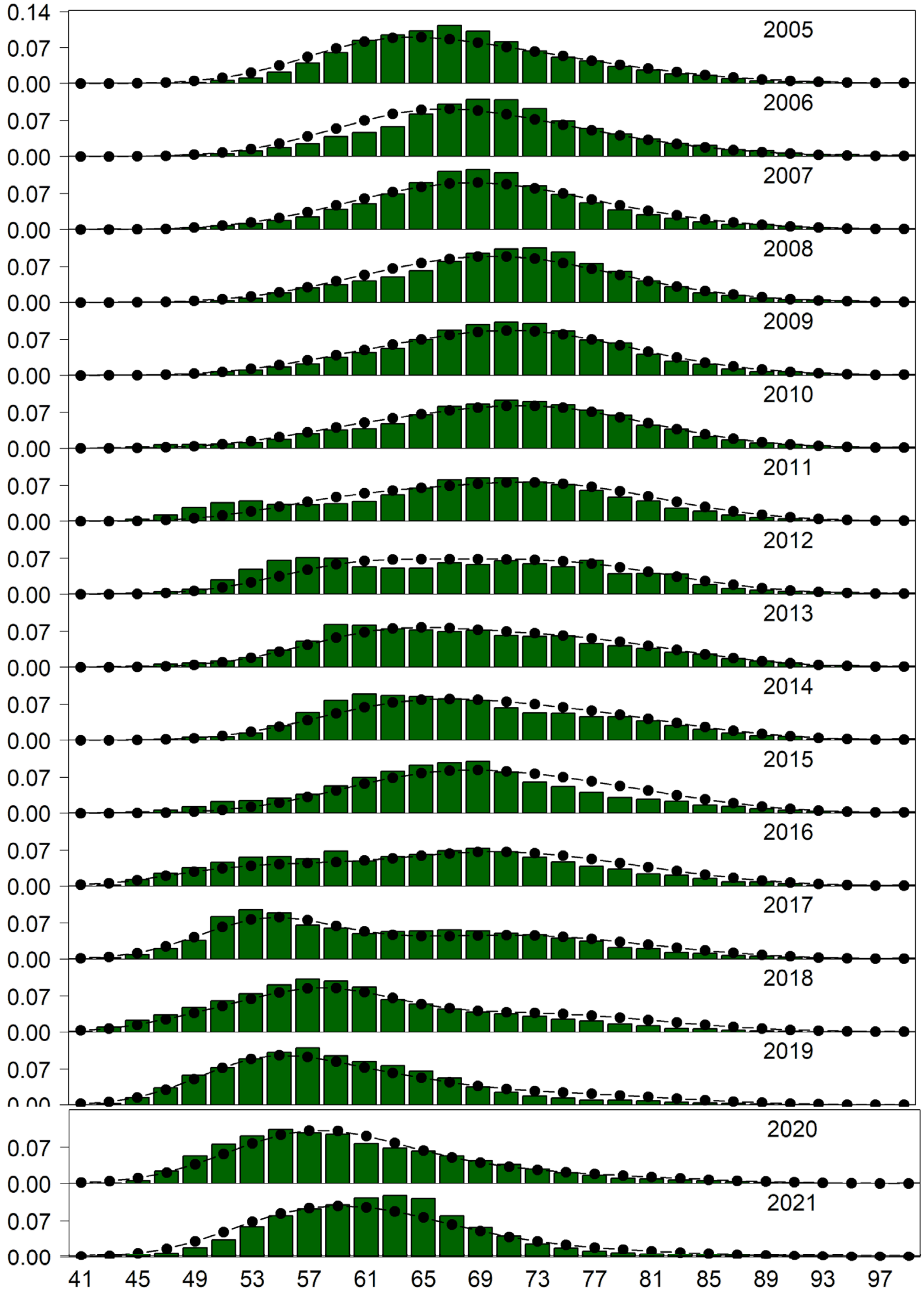


Figure 3.37 (cont.). Domestic longline survey length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

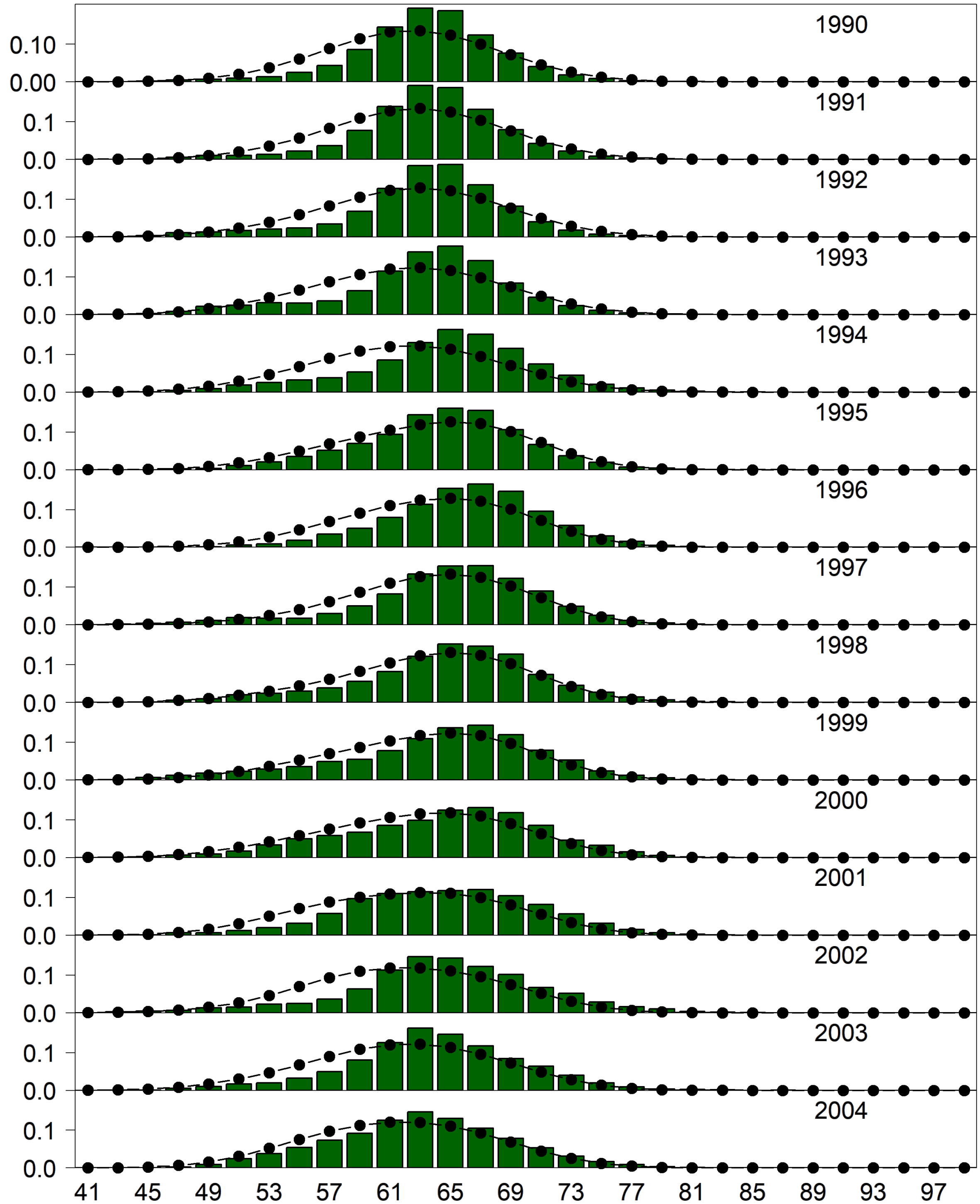


Figure 3.38. Domestic longline survey length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

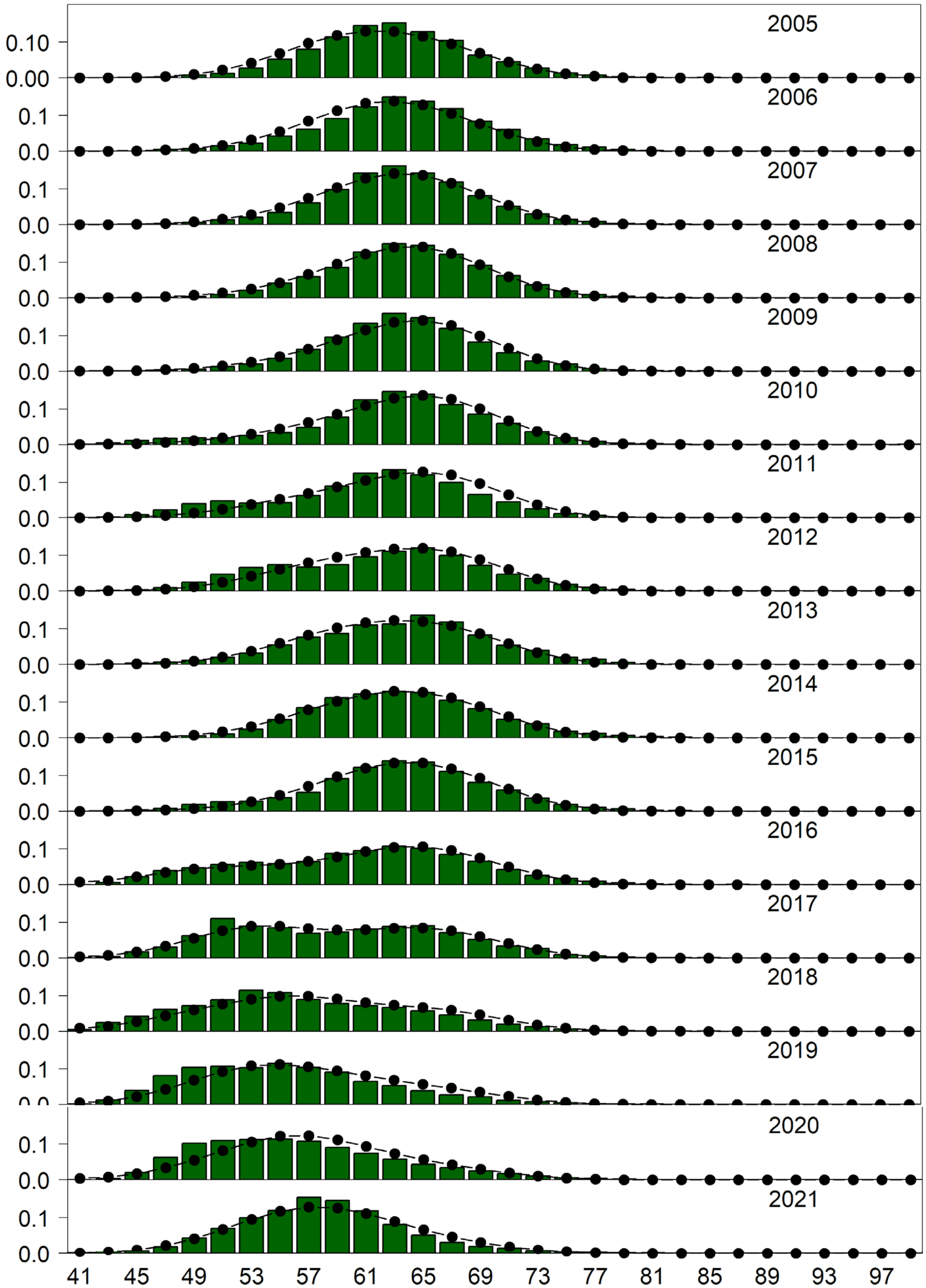


Figure 3.38. (Cont.). Domestic longline survey length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

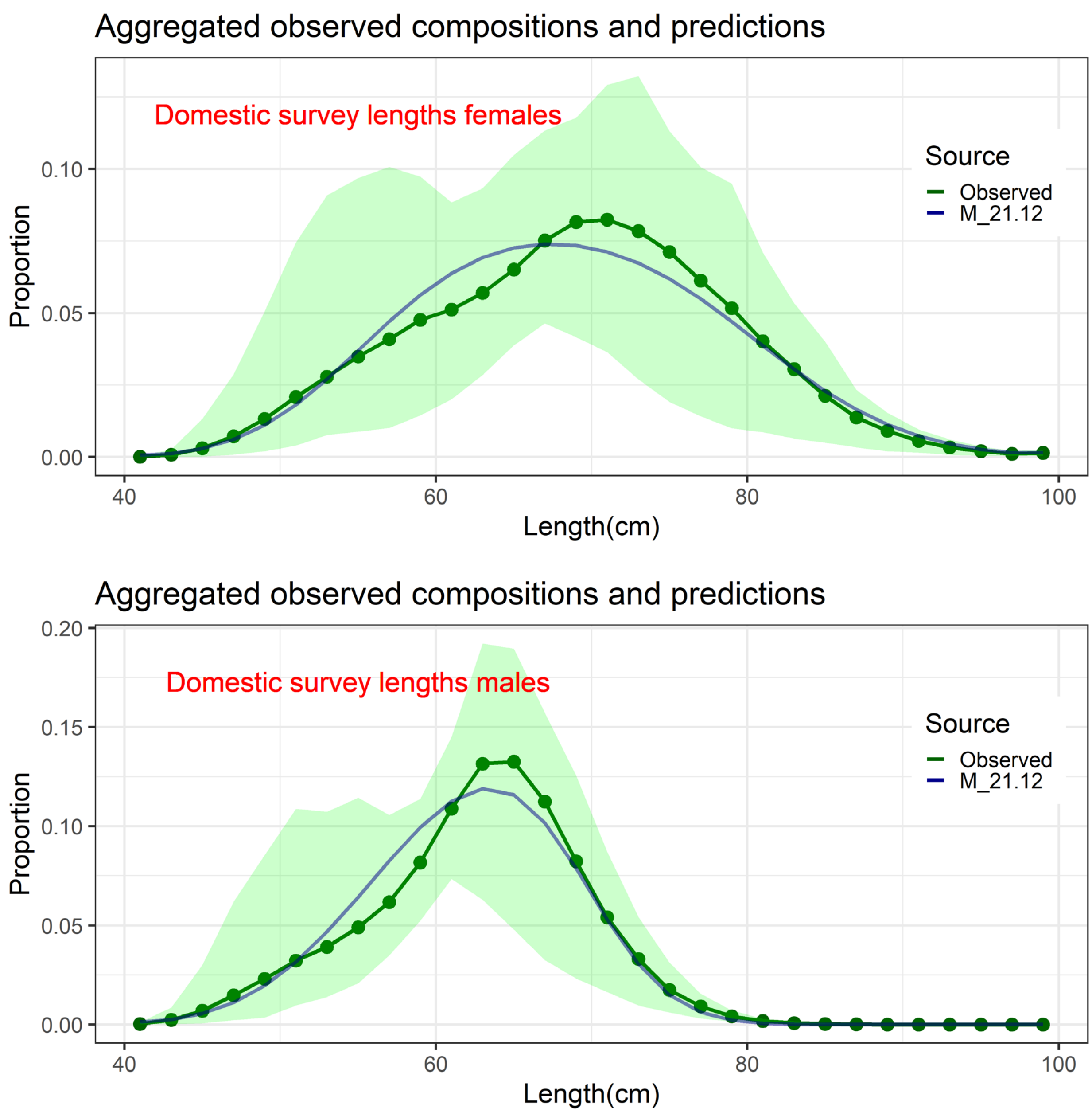


Figure 3.39. Mean observed (green line) domestic longline survey length compositions aggregated across years along with the average fit of the *21.12_Proposed_No_Skip_Spawn* model (blue line). The green bands are the 90% empirical confidence intervals. Fit to female length compositions are provided in the top panel and fit to male length compositions are provided in the bottom panel.

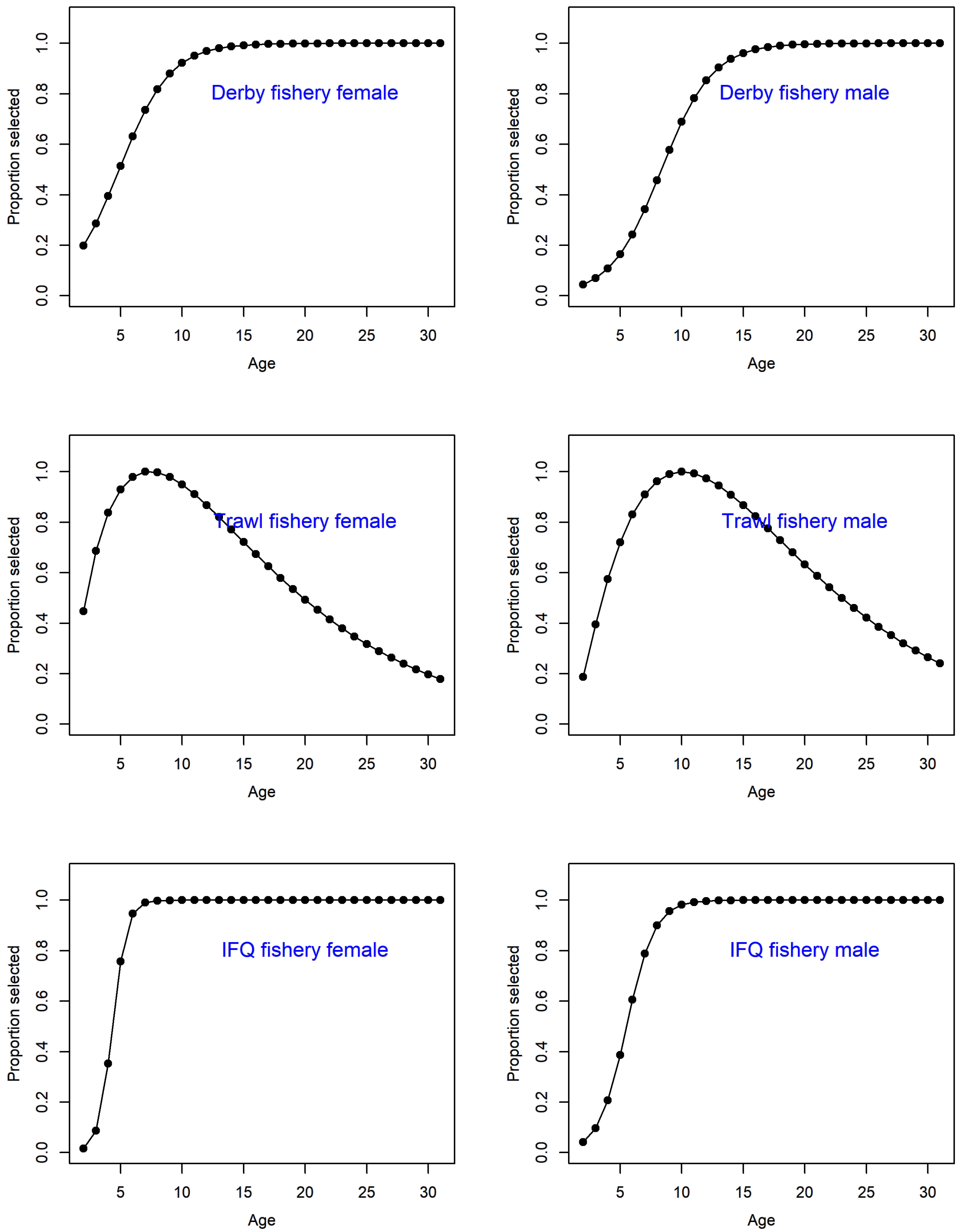


Figure 3.40. Estimated fishery and survey selectivity. The derby longline fishery occurred until 1994, then the fishery switched to an IFQ system in 1995. The recent time block for the IFQ fishery selectivity begins in 2016, as does the recent time block for the domestic longline survey.

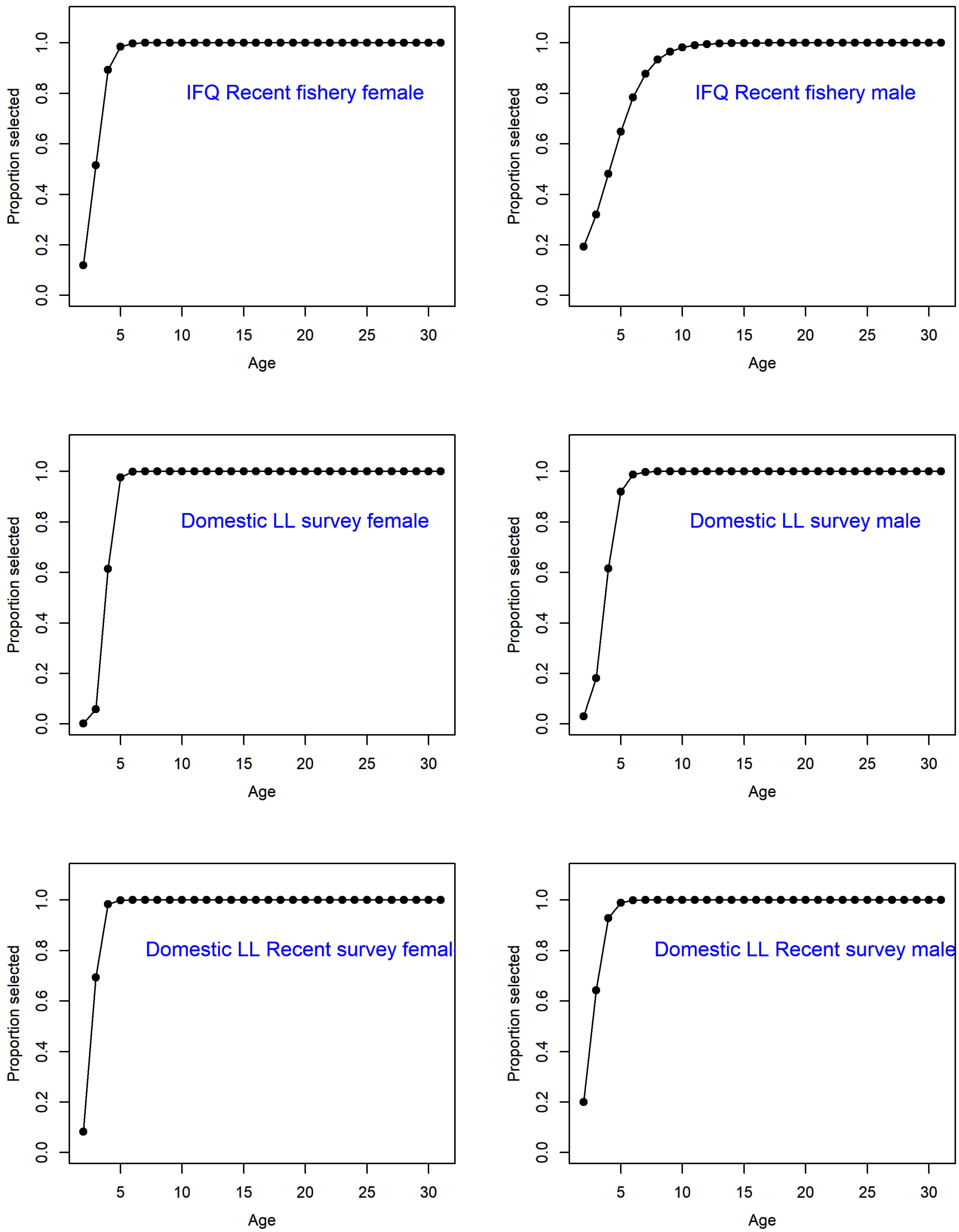


Figure 3.40 (Cont.). Estimated selectivity.

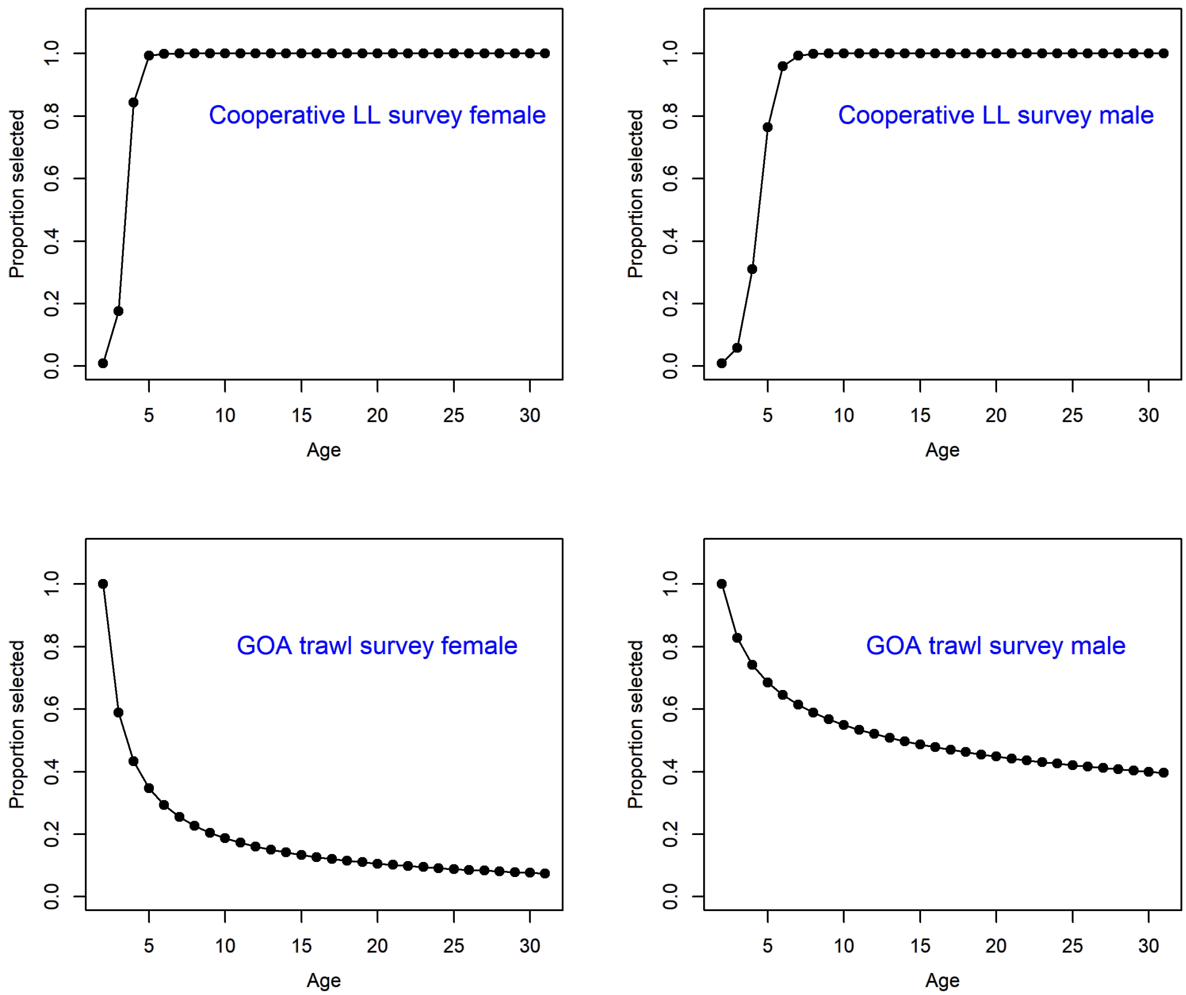


Figure 3.40 (Cont.). Estimated selectivity.

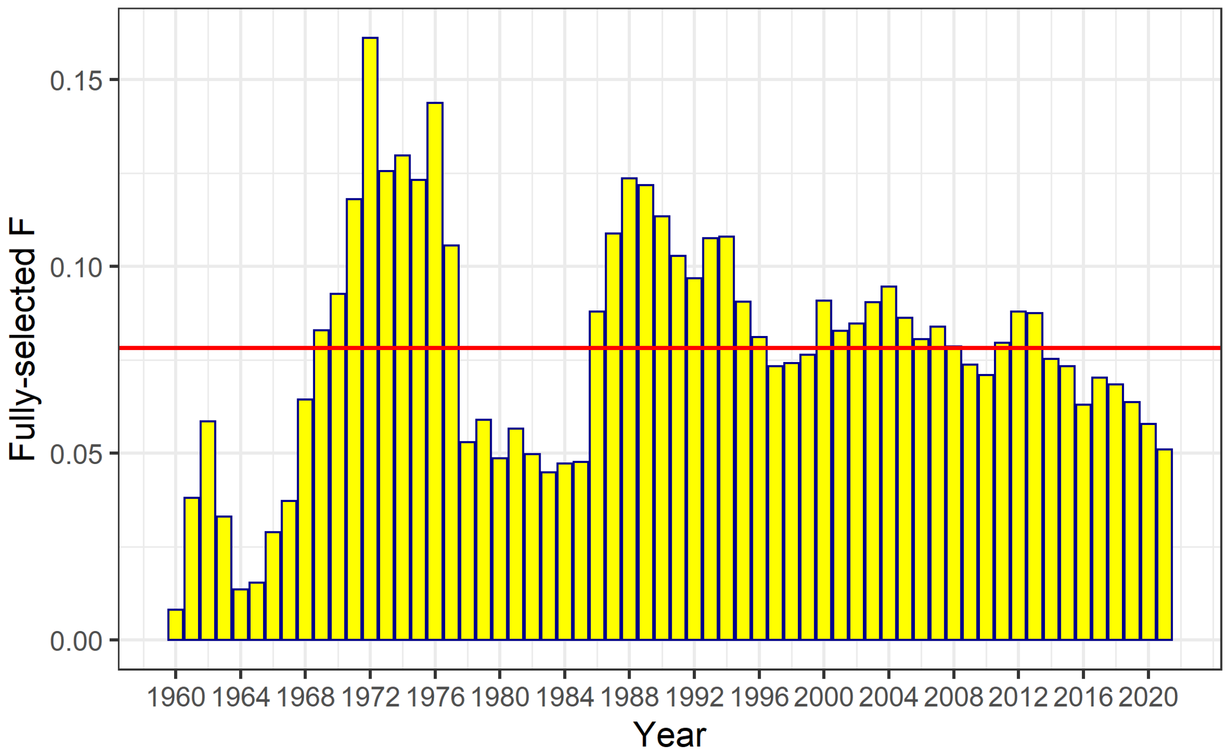


Figure 3.41. Time series of combined fully selected fishing mortality for fixed and trawl gear for sablefish. Red line is the mean fishing mortality for the entire time series.

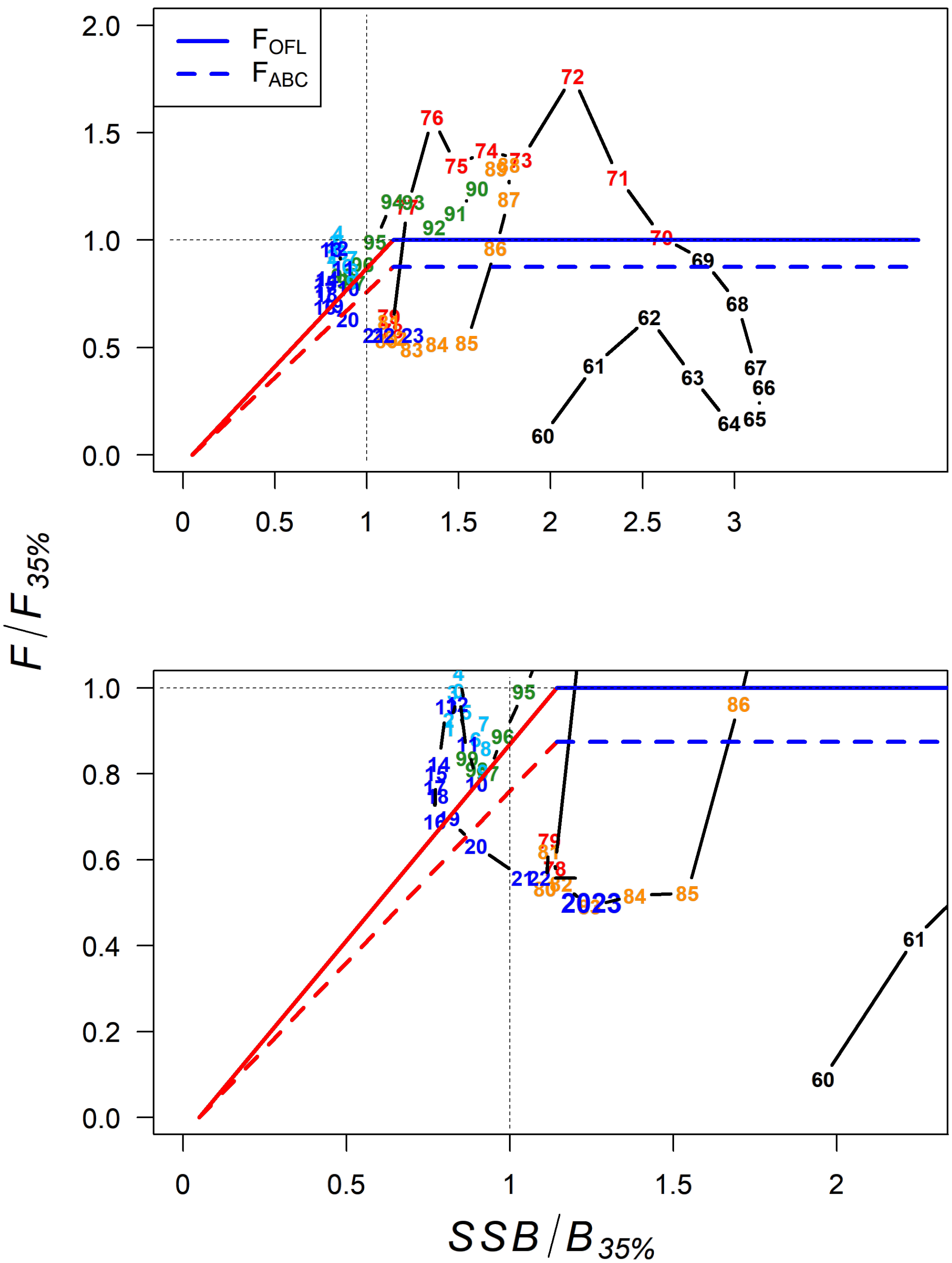


Figure 3.42. Phase-plane diagram of time series of sablefish estimated spawning biomass relative to the level at $B_{35\%}$ and fishing mortality relative to $F_{35\%}$ (equal to F_{OFL}) for the *21.12_Proposed_No_Skip_Spawn* model. F_{ABC} for the max ABC is equivalent to $F_{40\%}$, which is demonstrated 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.

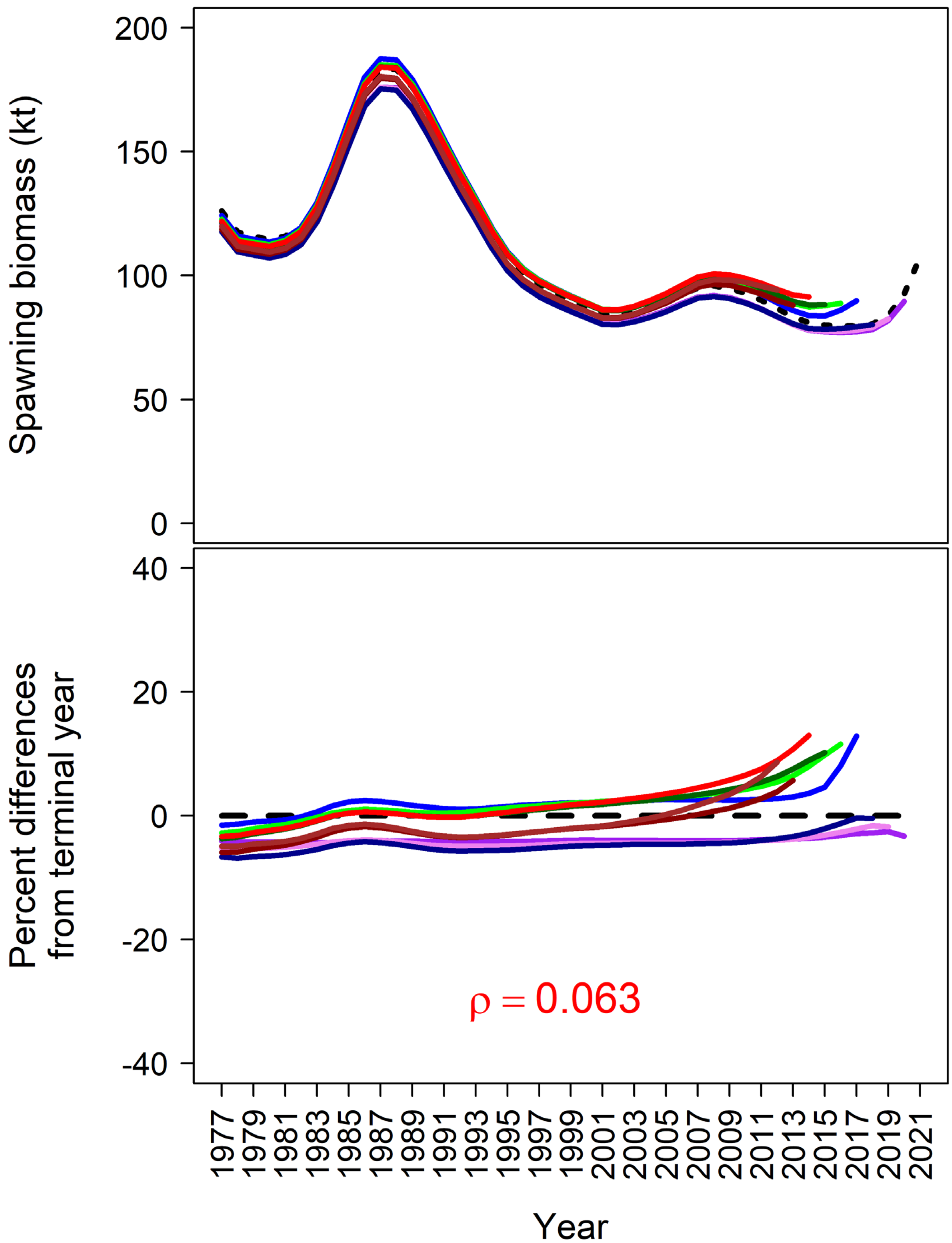


Figure 3.43. Retrospective trends for spawning biomass (top) and percent difference from terminal year (bottom) from 1977 - 2020. Mohn's rho (ρ) is provided in red (bottom panel). Note that model peels with terminal year of 2017 or earlier have a different parametrization of catchability and selectivity (i.e., no recent time blocks) from those with terminal years of 2018 or later and are not directly comparable.

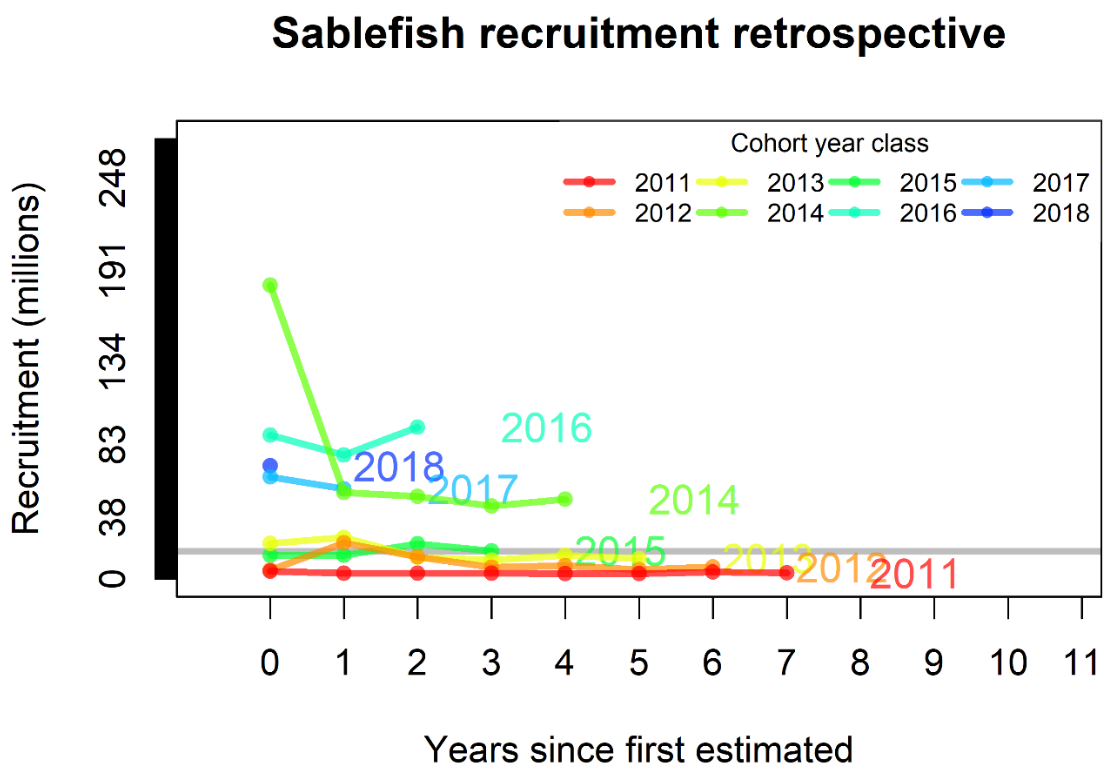


Figure 3.44. Squid plot of the development of initial estimates of age-2 recruitment for year class 2011 through year class 2018 from retrospective analysis. Number to right of terminal year indicates year class. Note that model peels with terminal year of 2017 or earlier have a different parametrization of catchability and selectivity (i.e., no recent time blocks) from those with terminal years of 2018 or later and are not directly comparable. The change in model parametrization is most notable in the initial estimate of the 2014 year class, which is first estimated in the 2017 model peel. Following the initial estimate, subsequent estimates become much more stable and similar as the new model parametrization is enacted in the following (2018) peel.

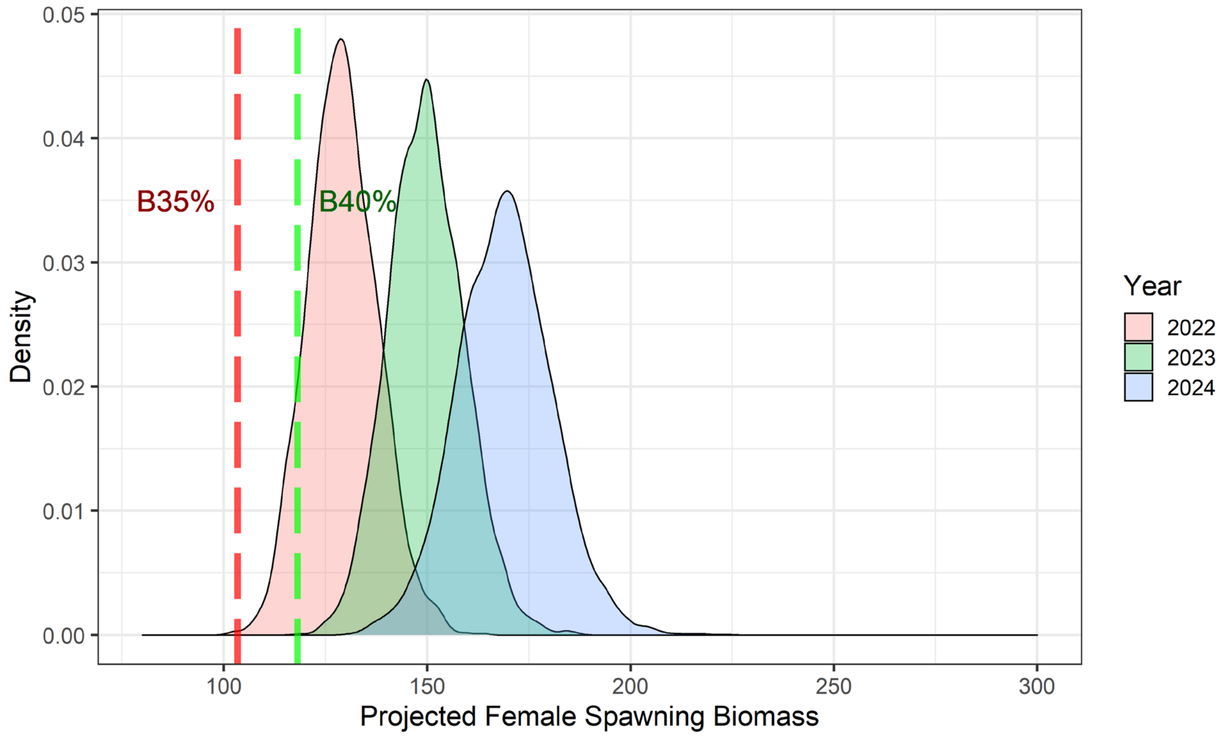


Figure 3.45. Posterior probability distribution for projected spawning biomass (kilotons) in years 2022 – 2024. The dashed lines are estimated $B_{35\%}$ and $B_{40\%}$ from the 2021 *21.12_Proposed_No_Skip_Spawn* model.

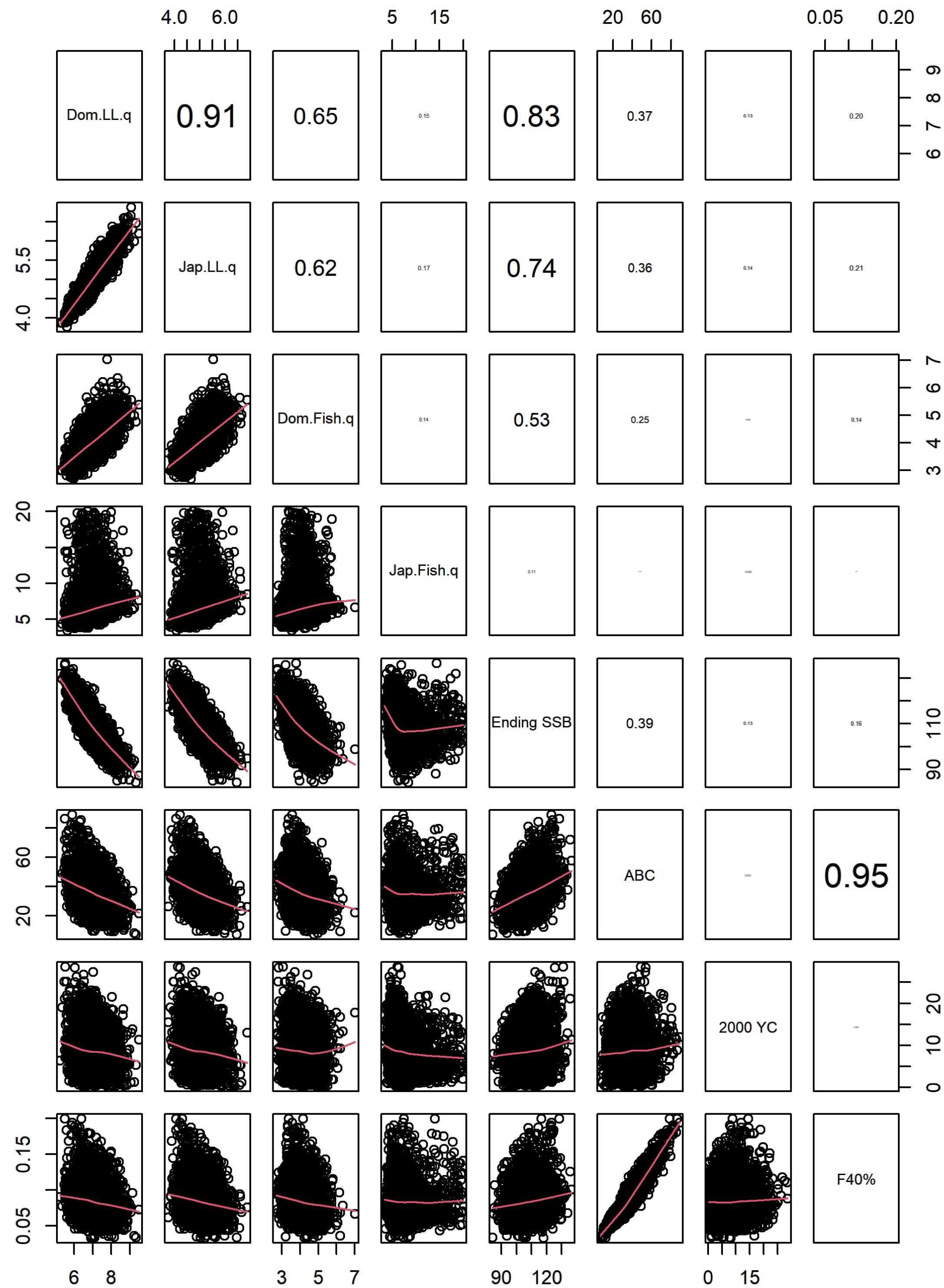


Figure 3.46. Pairwise scatterplots of key parameter MCMC runs. Red curve is loess smooth. Numbers in upper right hand panel are correlation coefficients between parameters.

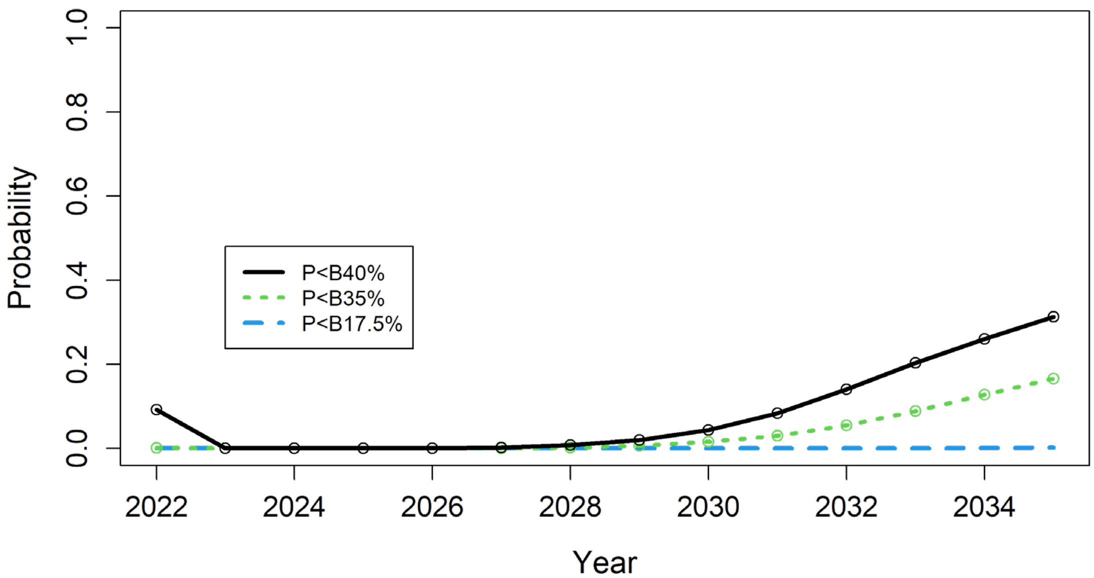


Figure 3.47. Probability that projected spawning biomass in a given projection year (from MCMC) will fall below $B_{40\%}$, $B_{35\%}$ and $B_{17.5\%}$.

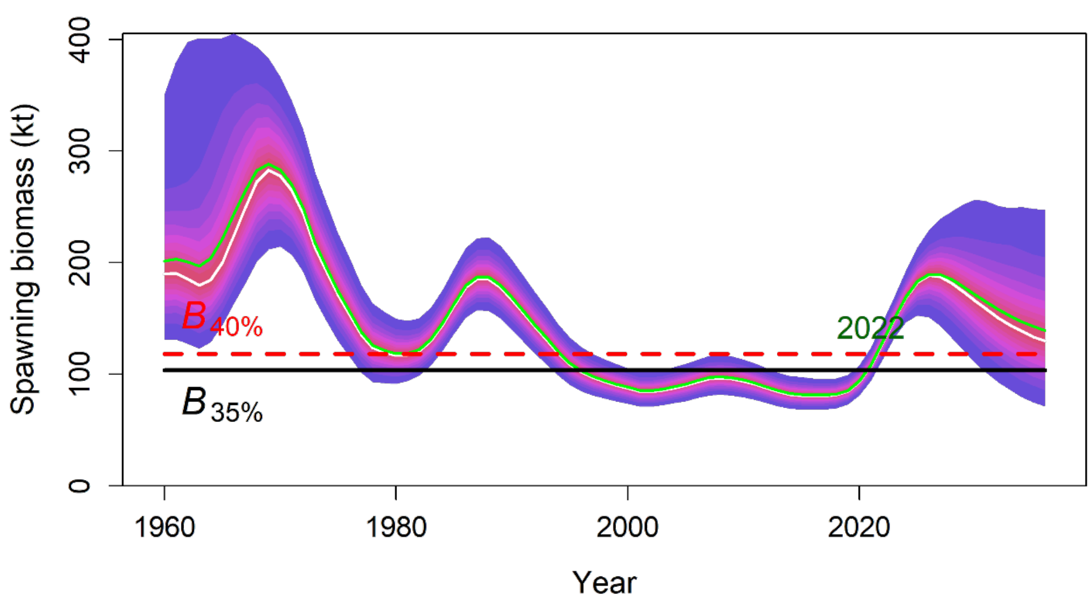


Figure 3.48. Estimates of female spawning biomass (kilotons) and their uncertainty from MCMC runs. White line is the median and green line is the mean, while shaded fills are 5% increments of the posterior probability distribution of spawning biomass based on MCMC simulations. Width of shaded area is the 95% credibility interval.

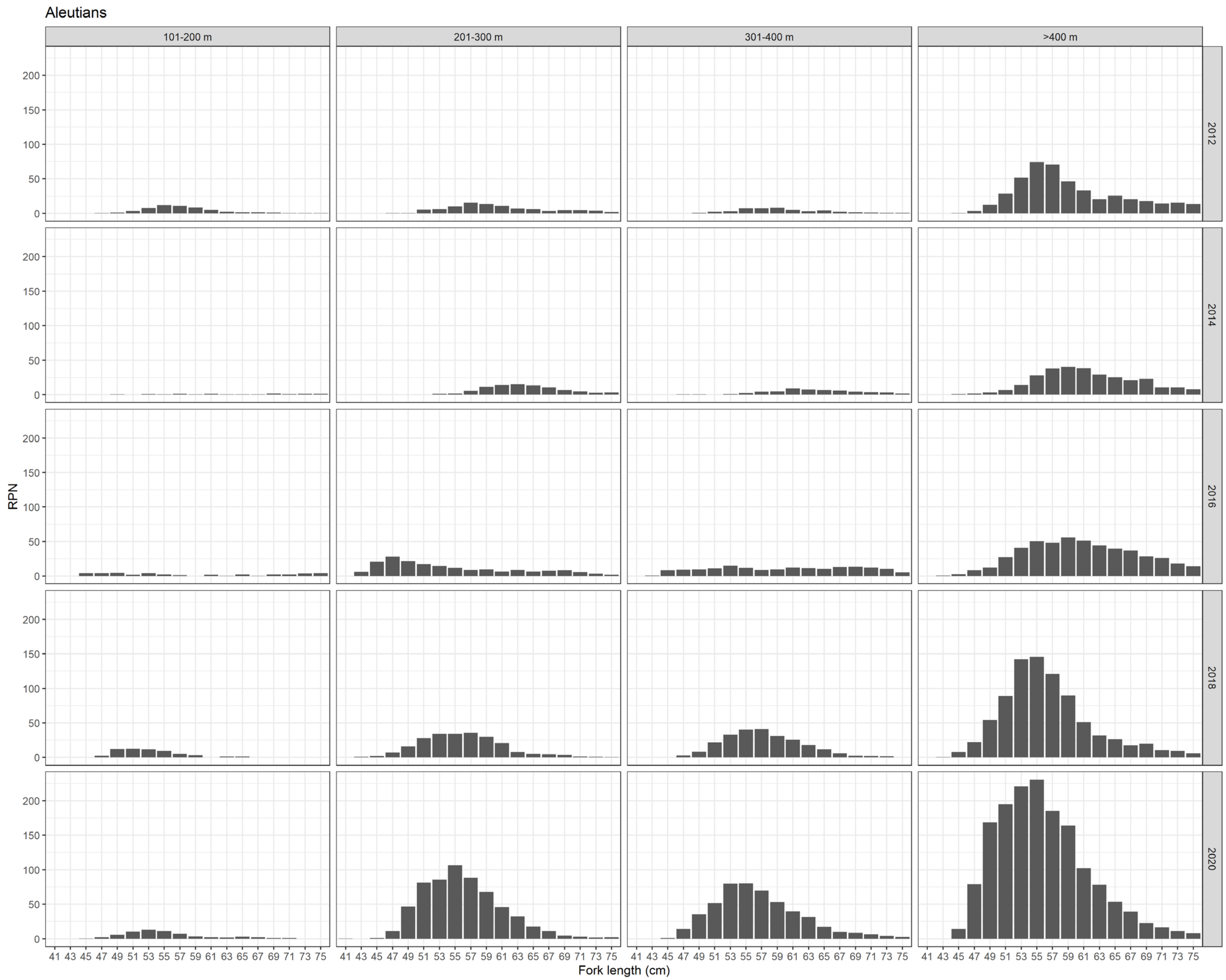


Figure 3.49a. Domestic longline survey relative population numbers (RPNs) by length for the Aleutian Islands region.

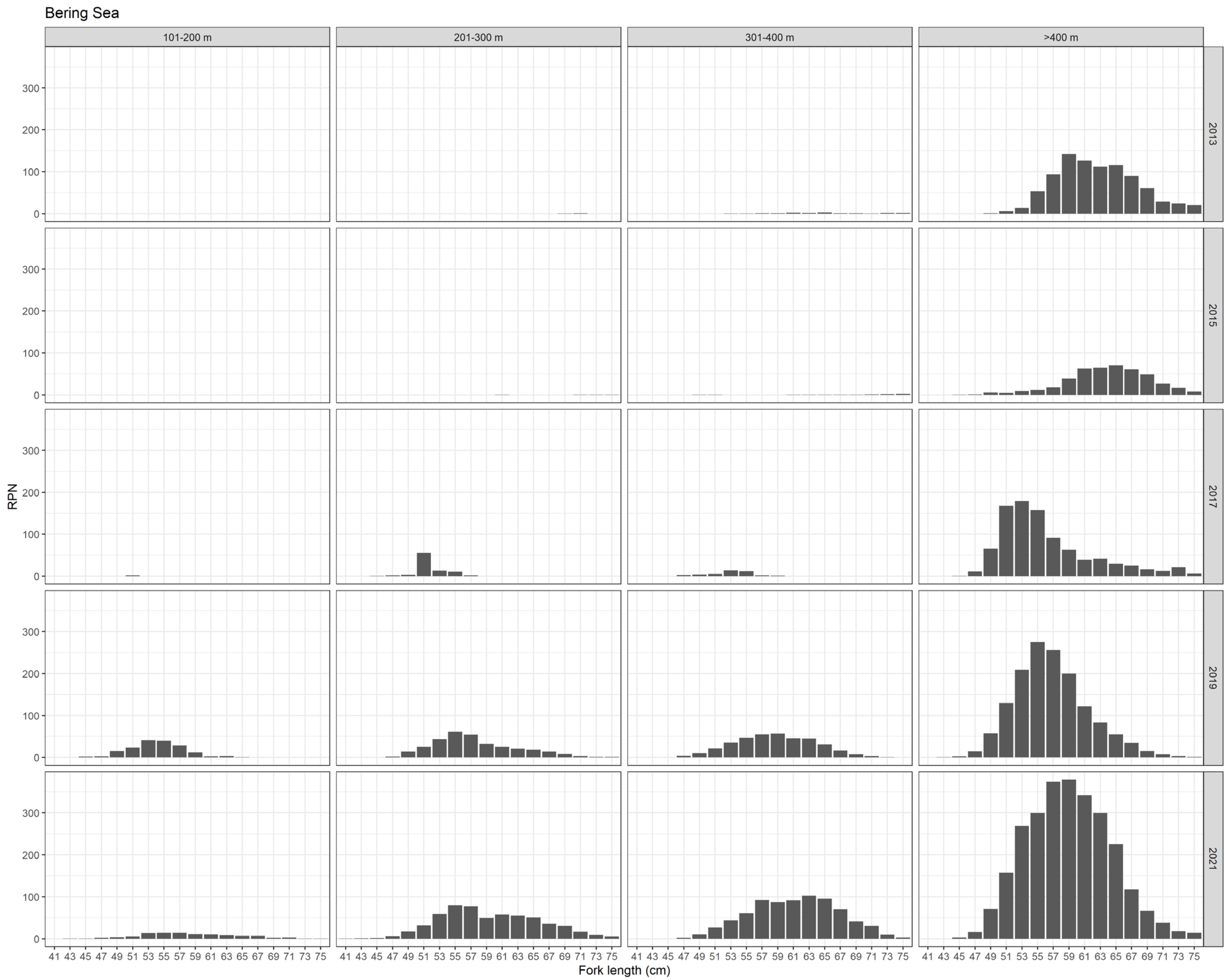


Figure 3.49b. Domestic longline survey relative population numbers (RPNs) by length for the Bering Sea region.

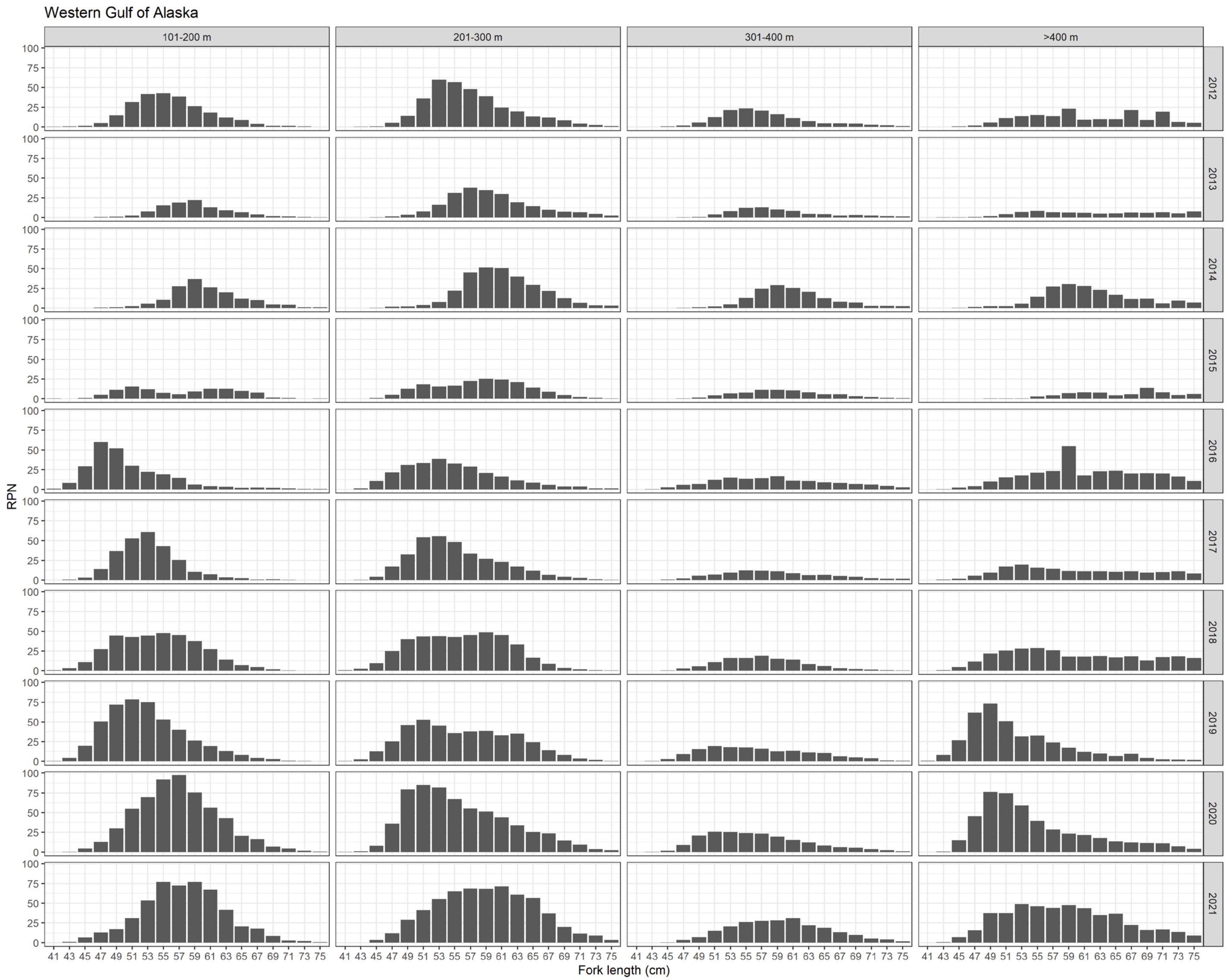


Figure 3.49c. Domestic longline survey relative population numbers (RPNs) by length for the western Gulf of Alaska region.

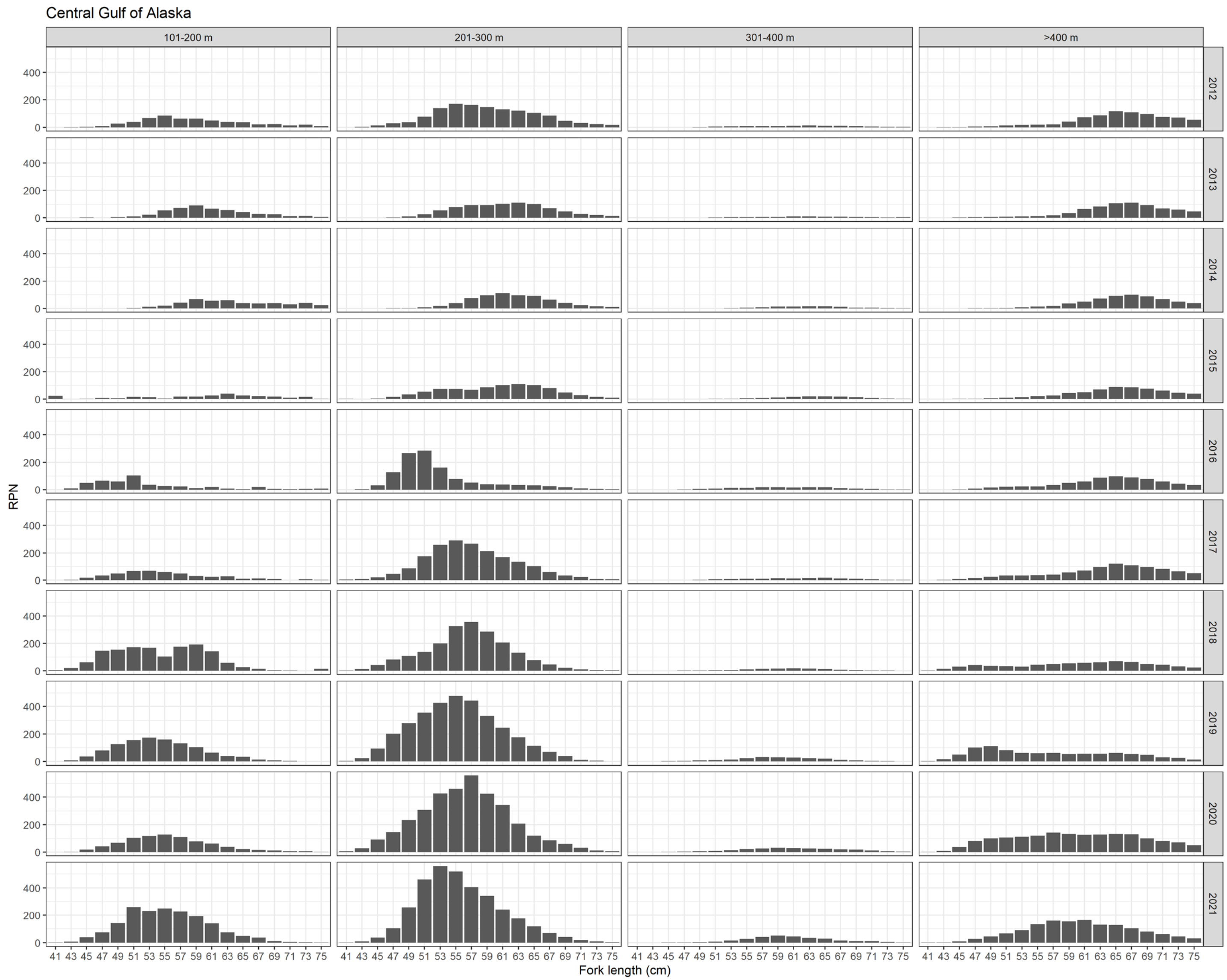


Figure 3.49d. Domestic longline survey relative population numbers (RPNs) by length for the central Gulf of Alaska region.

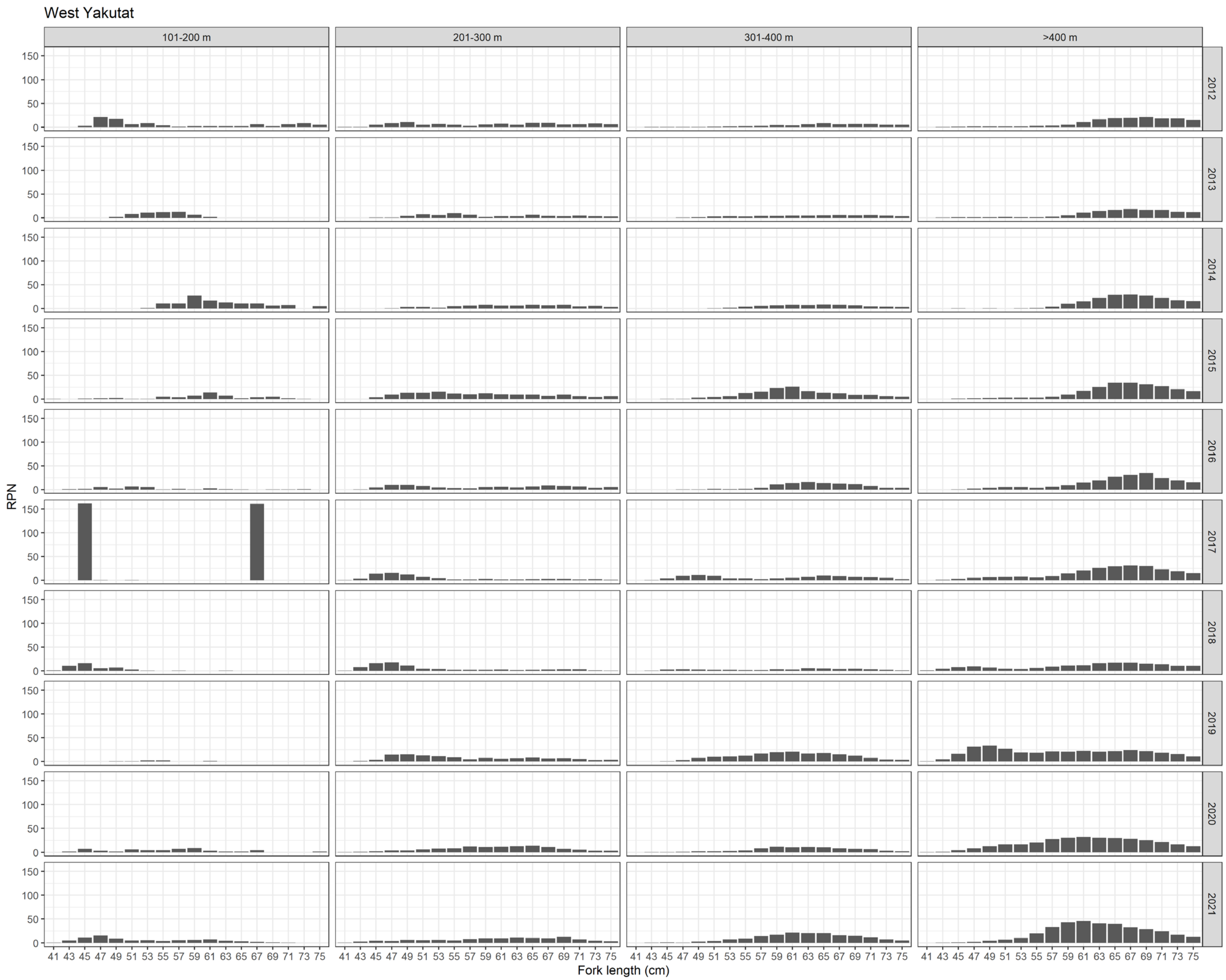


Figure 3.49e. Domestic longline survey relative population numbers (RPNs) by length for the West Yakutat (Eastern Gulf of Alaska) region.

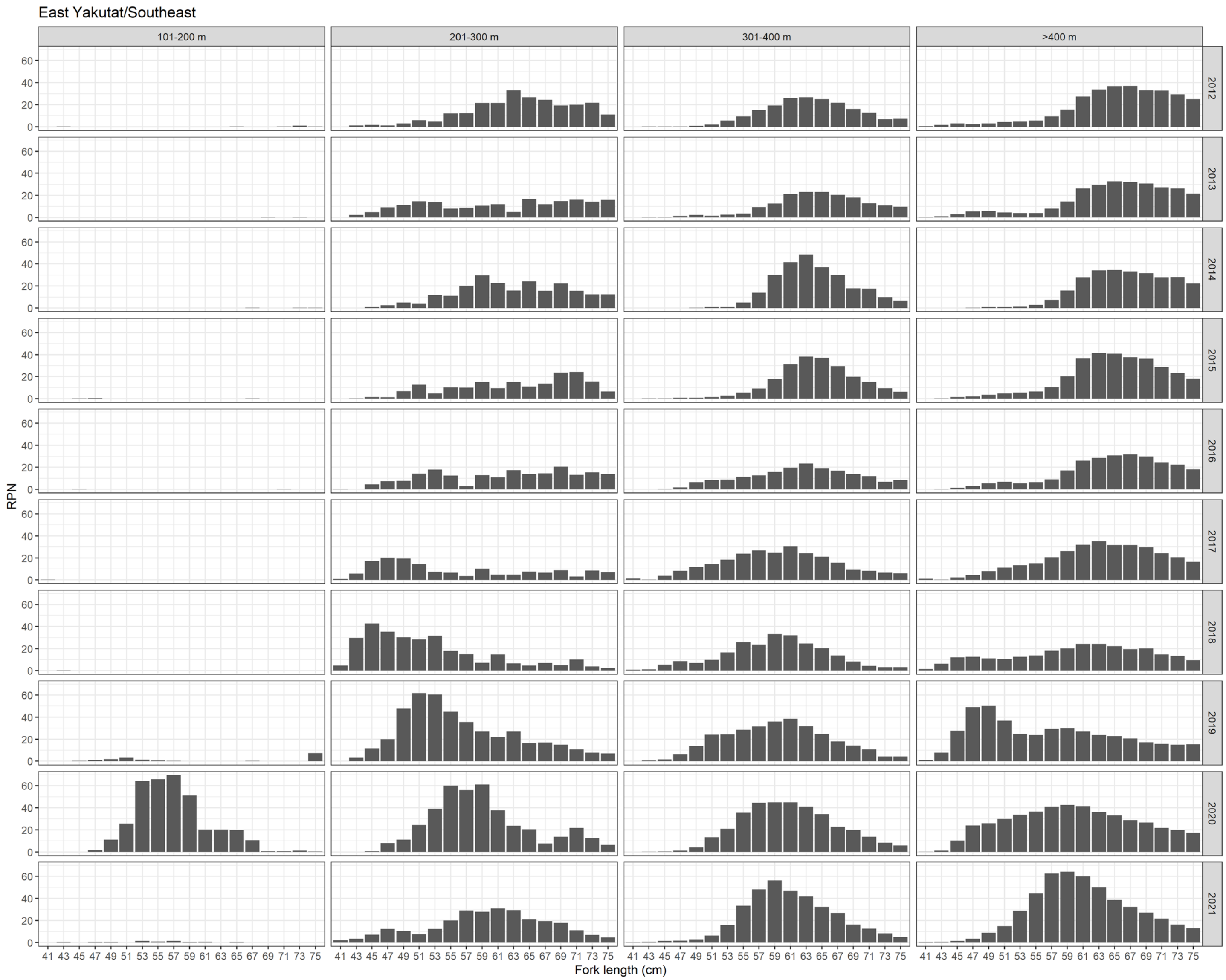


Figure 3.49f. Domestic longline survey relative population numbers (RPNs) by length for the East Yakutat/Southeast (Eastern Gulf of Alaska region).

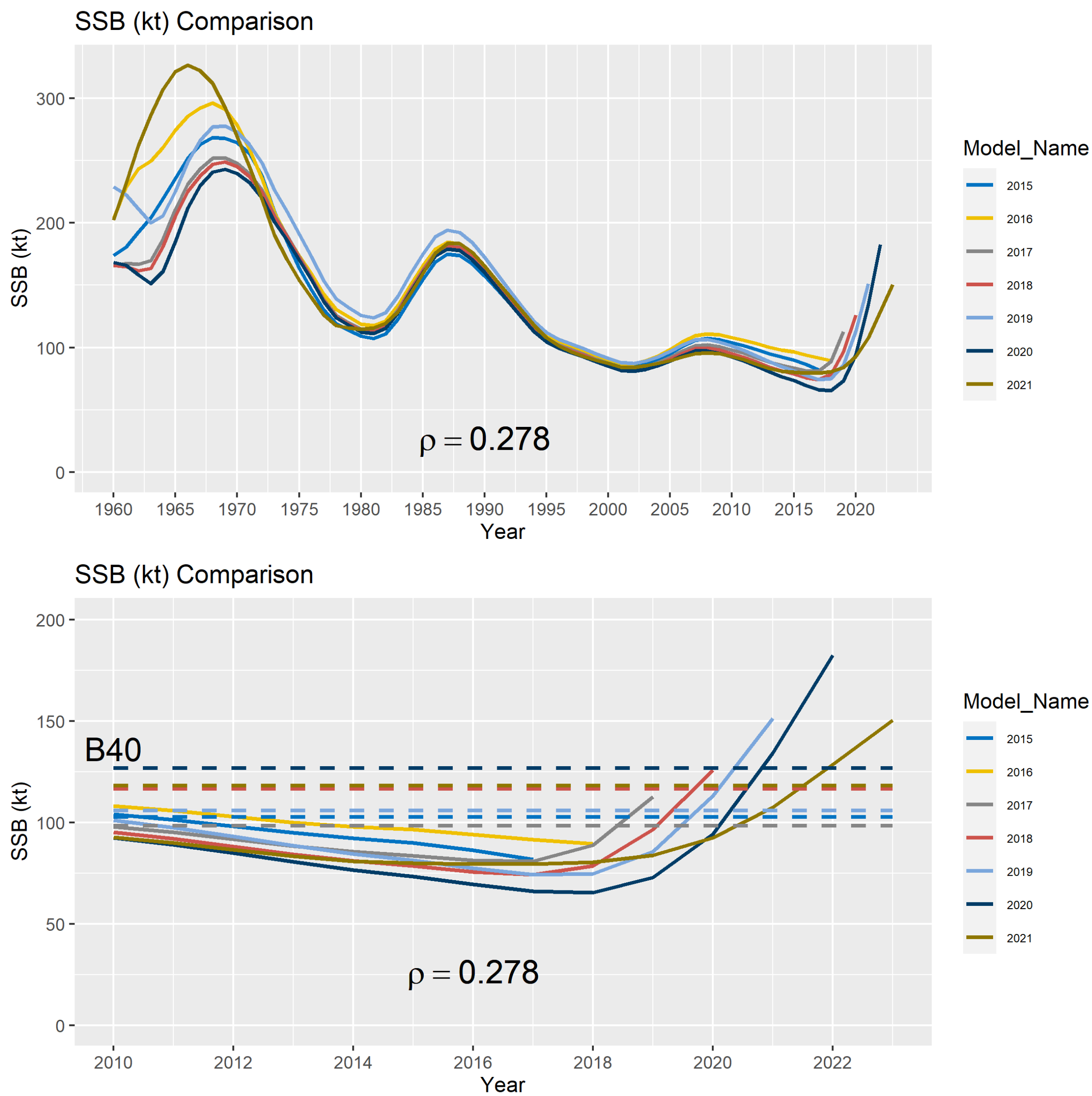


Figure 3.50a. Results of the ‘all model’ historical retrospective illustrating estimated and projected (terminal year + 2 year) spawning stock biomass (in kilotons). Results are based on the accepted model in each terminal model year and includes application of the *21.12_Proposed_No_Skip_Spawn* model for the 2021 model year. 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 for two year SSB projections is provided below the lines in each plot.

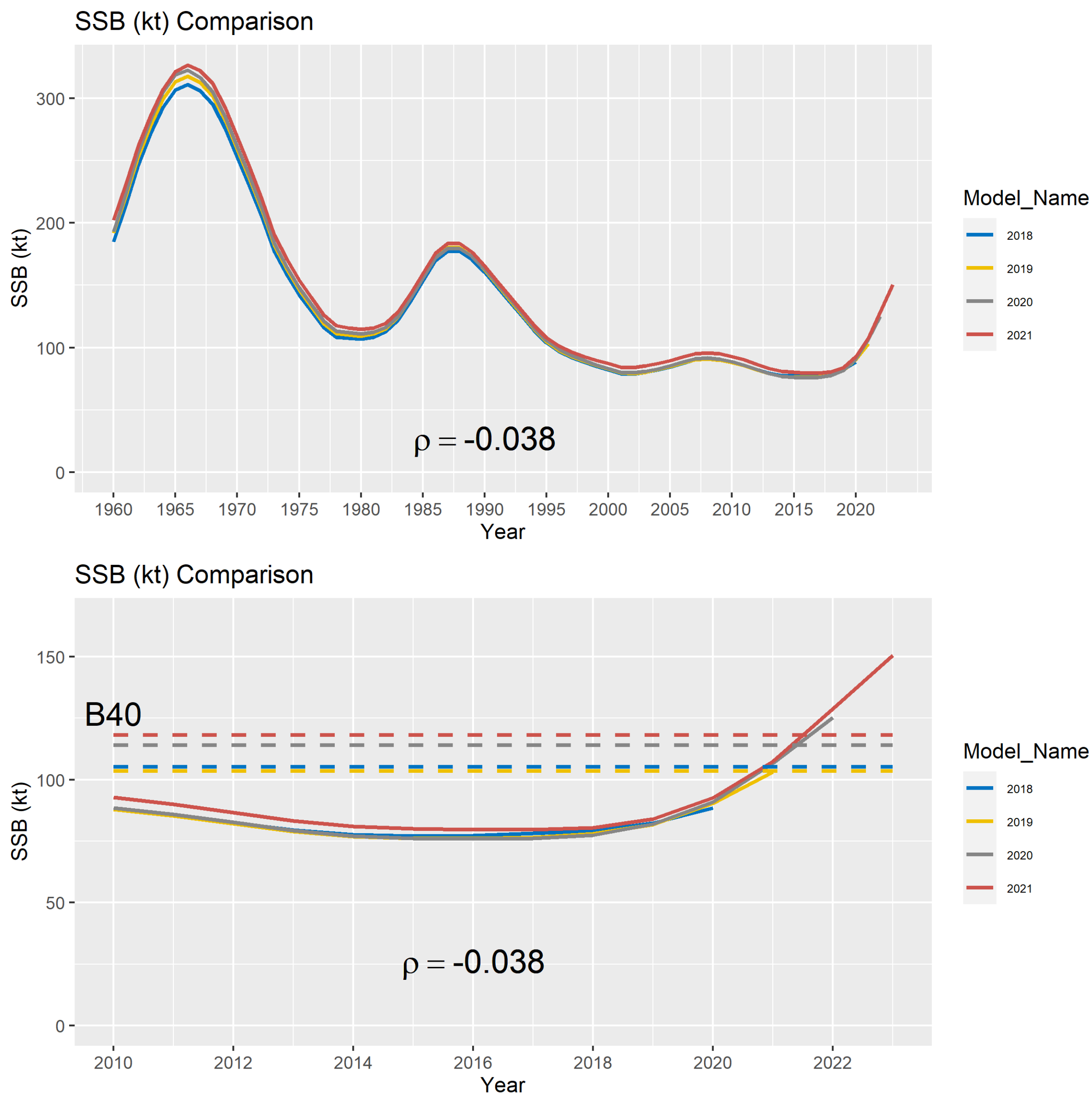


Figure 3.50b. Results of the 'current model' historical retrospective illustrating estimated and projected (terminal year + 2 year) spawning stock biomass (in kilotons). Results are based on application of the *21.12_Proposed_No_Skip_Spawn* model to the available data at the time of the last four sablefish assessments (i.e., terminal model years from 2018 to 2021). 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 for two year SSB projections is provided below the lines in each plot.

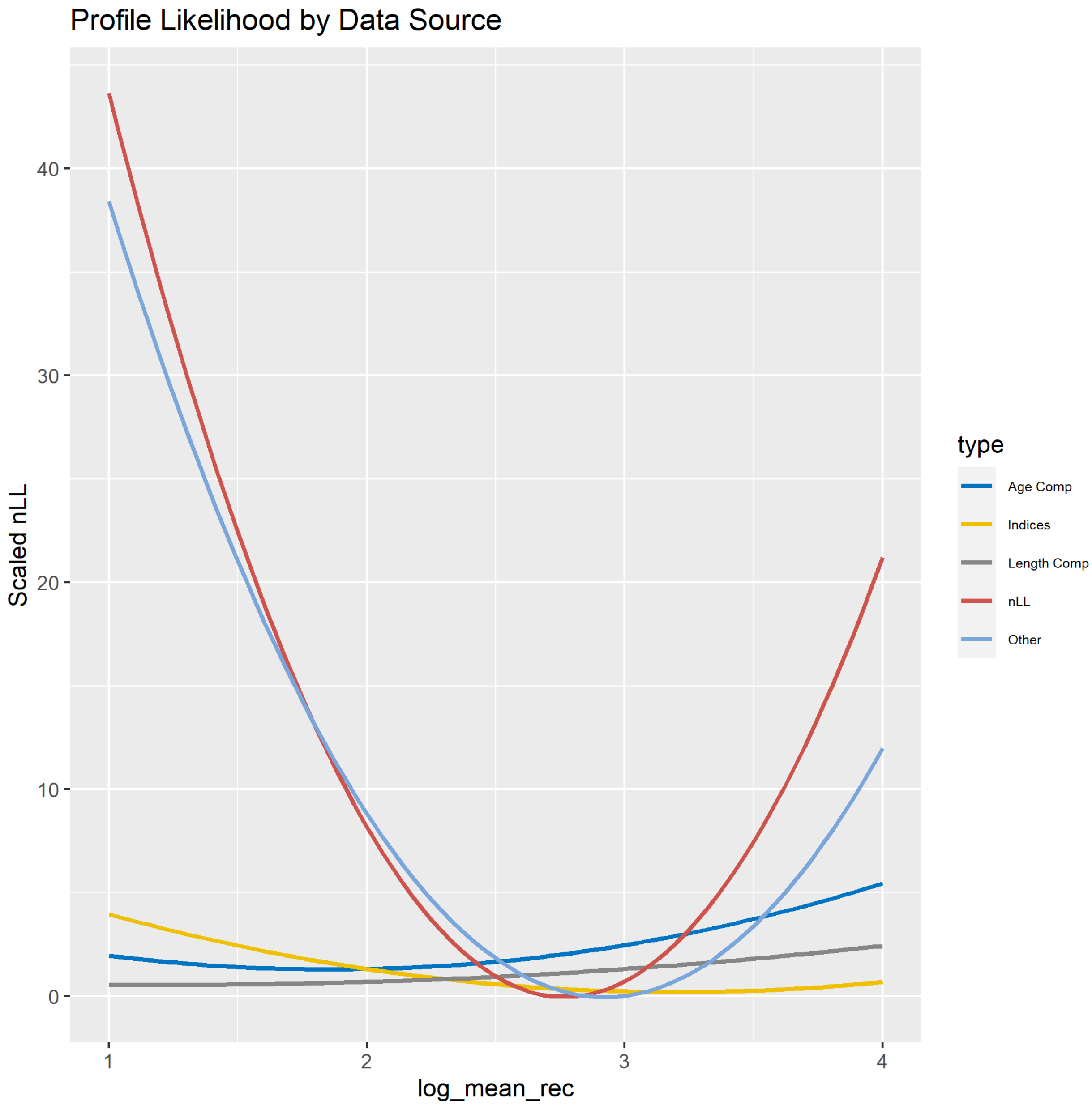


Figure 3.51. Likelihood profiles by data type (line color) for the mean recruitment parameter in logarithmic space.

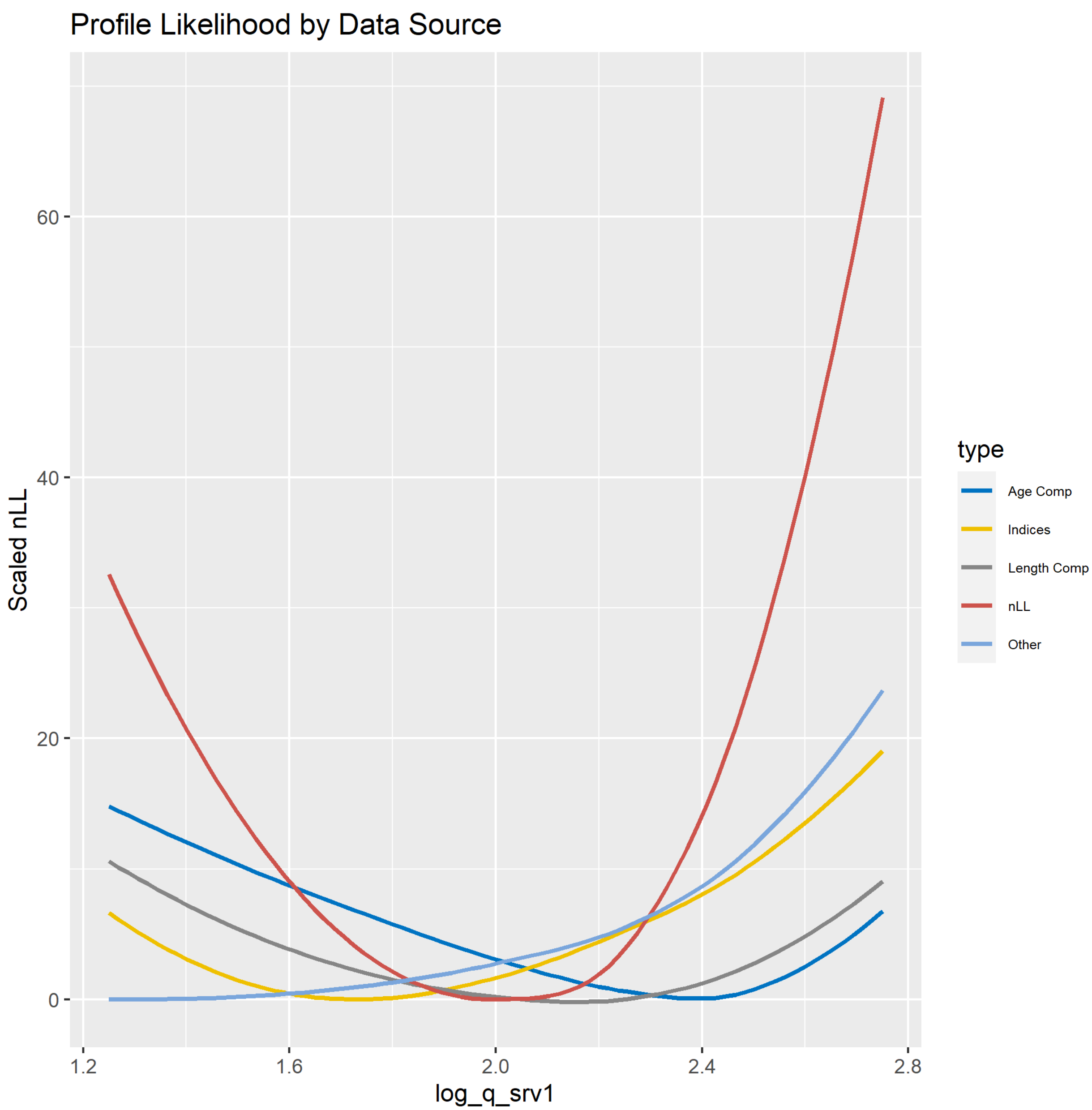
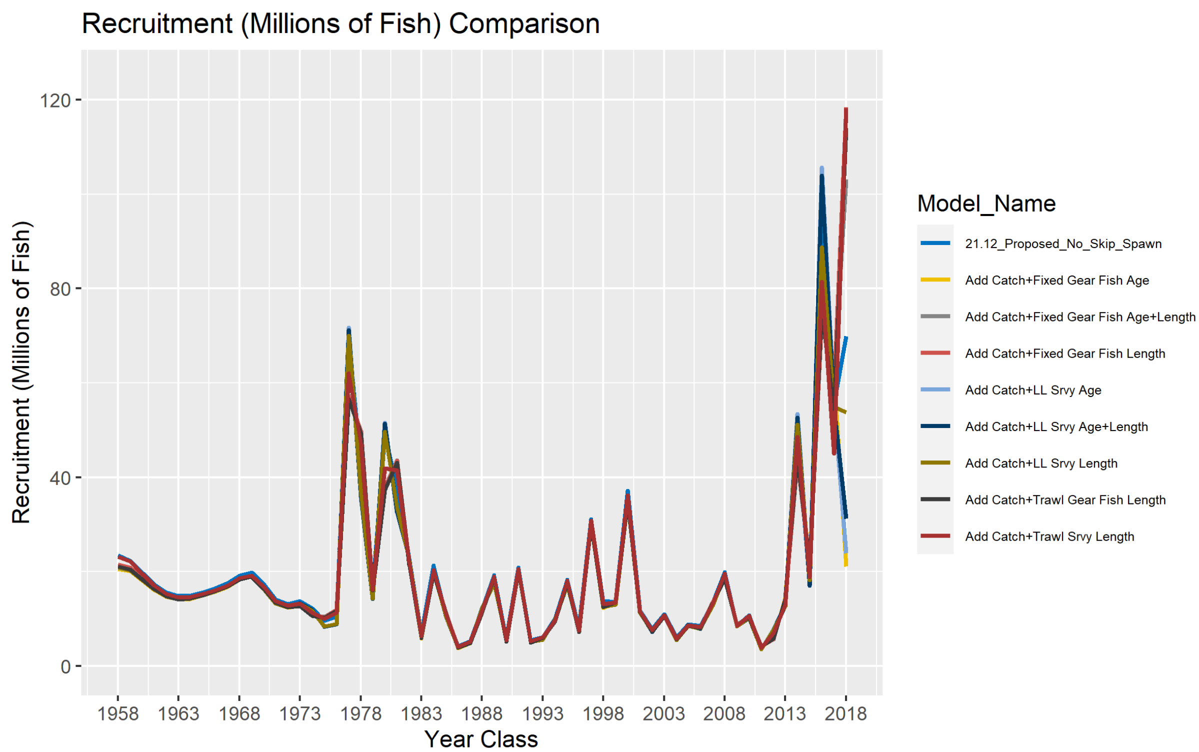


Figure 3.52. Likelihood profiles by data type (line color) for the domestic longline survey catchability parameter in logarithmic space.



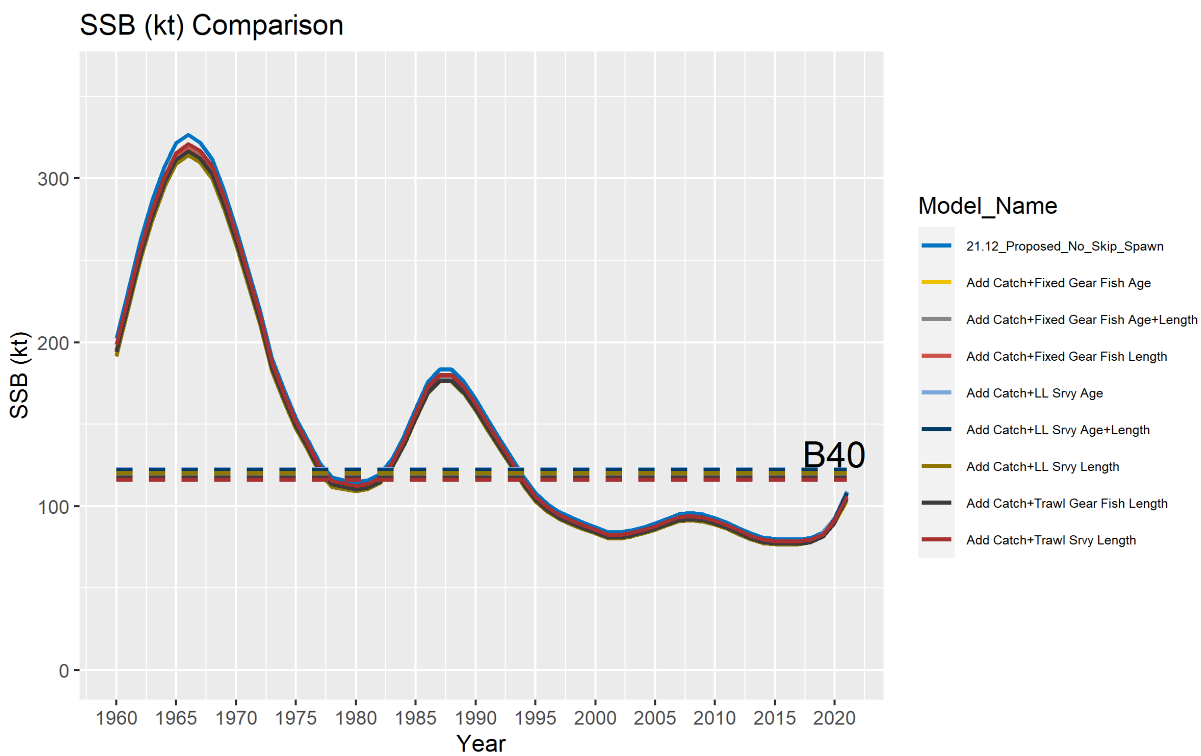


Figure 3.53. Results of a incremental data addition exercise where each new year of data available for the first time for the 2021 SAFE is added to the model and the model run. All model runs include the 2021 fishery catch data. For compositional data associated with fishery independent indices, each run also includes the associated survey index. The top panel illustrated the model estimated recruitment (millions of fish). The bottom panel depicts the time series of *SSB* (kt).

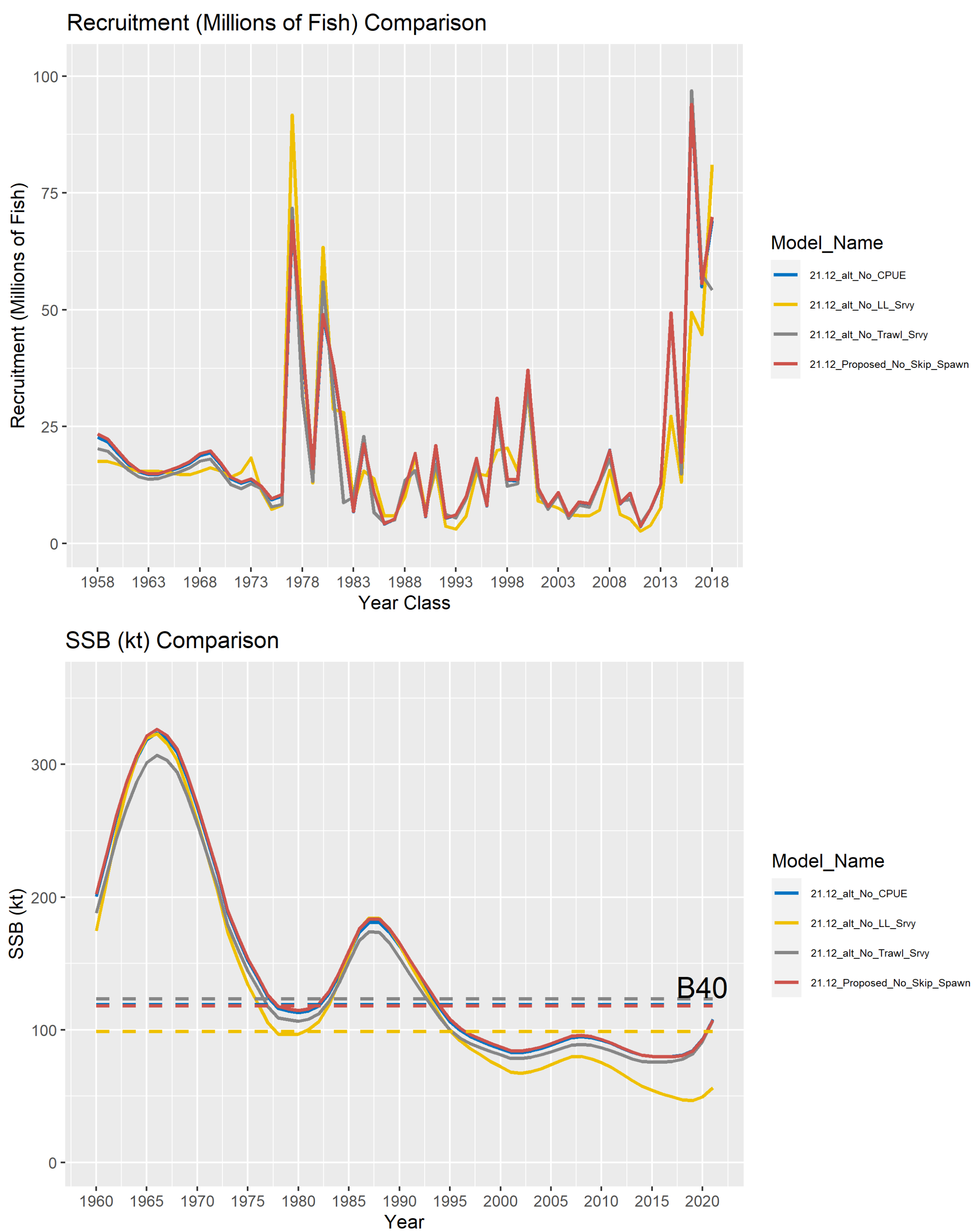


Figure 3.54. Results of an index sensitivity analysis where the model is rerun after removing each index (and any associated compositional data in the case of fishery independent surveys) one at a time. The top panel illustrated the model estimated recruitment (millions of fish). The bottom panel depicts the time series of *SSB* (kt).

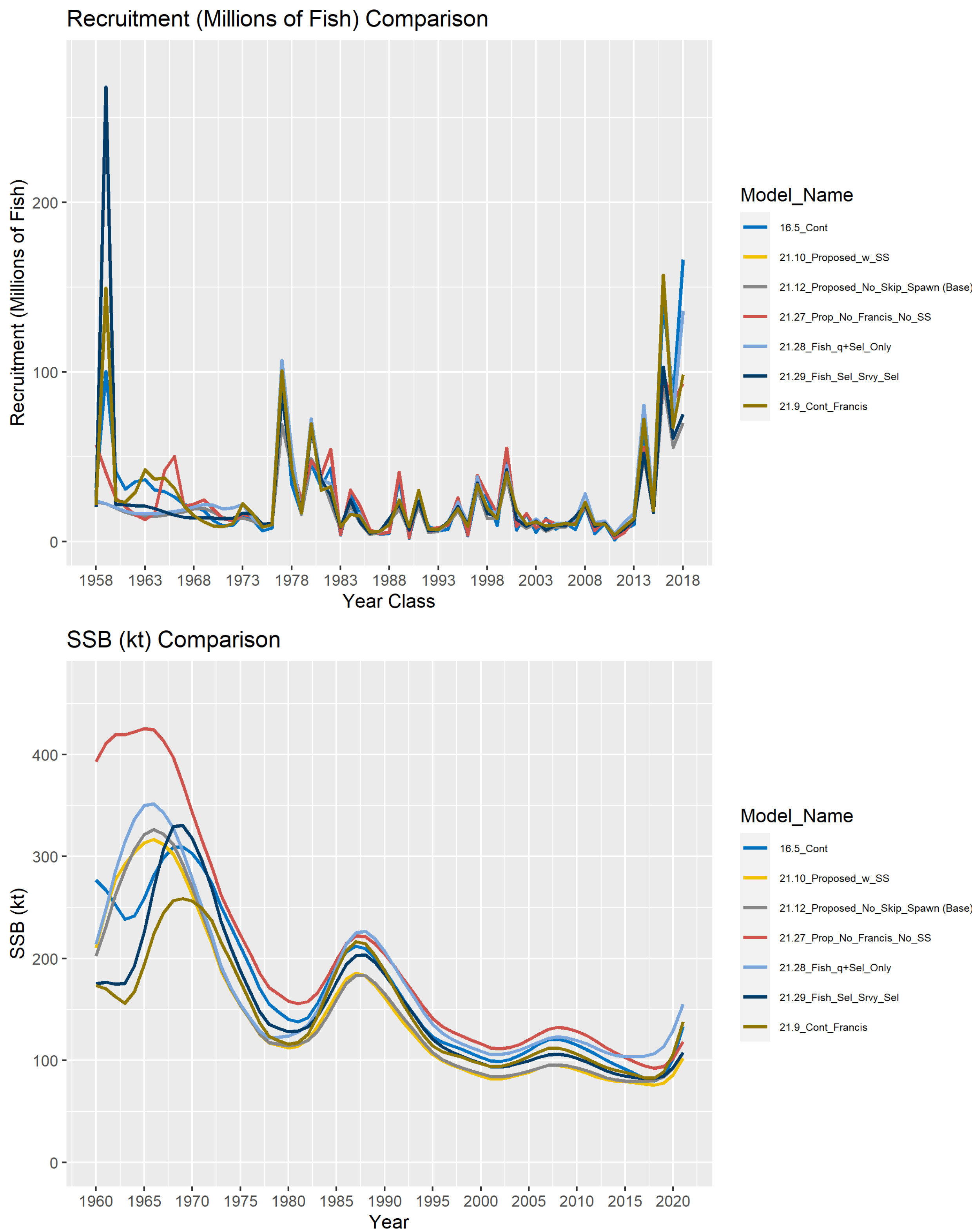


Figure 3.55. Results of select sensitivity runs (colored lines). Model descriptions and names are provided in Table 3.20. The top panel illustrated the model estimated recruitment (millions of fish). The bottom panel depicts the time series of *SSB* (kt).

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 five 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 were mailed to each IFQ holder before the beginning of each fishing season until 2020. A letter was included with the calendar that included details and rationale of the request for the fleet to avoid survey stations. Starting in 2021, the survey calendar was made available online (https://www.fisheries.noaa.gov/resource/document/alaska-sablefish-longline-survey-station-schedule) to reduce printing and mailing expenses. While the survey is being conducted, the skipper of the 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 2021 there were a few instance of vessel interactions. In the GOA, there were four interactions with pot boats (2 in East Yakutat/Southeast, 1 in the West Yakutat, and 1 in the Central GOA).

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 are not 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
2021	0	0	0	0	4	4	4	4

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 247 – 382 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 GOA, AI, and BS slope bottom trawl surveys (not all occur annually), 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 October 25, 2021.

Year	Trawl Survey	Japan-US Longline Survey	Domestic Longline Survey	IPHC Longline Survey*	ADFG Sport	Total
1977	3					3
1978	14					14
1979	27	104				131
1980	70	114				184
1981	88	150				238
1982	108	240				348
1983	46	236				282
1984	127	284				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	15	339
2011	8		277	39	16	340
2012	3		204	27	38	272
2013	4		178	22	25	229
2014	1		198	32	29	260
2015	9		175	17	46	247
2016	2		200	15	31	248
2017	7		218	11	48	284
2018	2		175	20	50	247
2019	15		249	36	60	360
2020	NA		343	23	16	382

* 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 - Report Card

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November 2021

With Contributions from:

Mayumi Arimitsu, Steve Barbeaux, Curry Cunningham, Bridget Ferriss, Jens Nielsen, Clare Ostle, Patrick Ressler, Cara Rodgveller, Elizabeth Siddon, Kally Spalinger, Jordan Watson, Sarah Wise

Current Year Update

The ecosystem and socioeconomic profile or ESP is a standardized framework for compiling and evaluating relevant stock-specific ecosystem and socioeconomic indicators and communicating linkages and potential drivers of the stock within the stock assessment process (Shotwell et al., *In Review*). The ESP process creates a traceable pathway from the initial development of indicators to management advice and serves as an on-ramp for developing ecosystem-linked stock assessments.

Please refer to the last full ESP and partial ESP documents for further information regarding the ecosystem and socioeconomic linkages for this stock (Shotwell et al., 2019, 2020, available online within the sablefish stock assessment and fishery evaluation report of Hanselman et al., 2019 (Appendix 3C, pp. 157-202) and Goethel et al., 2020 (Appendix 3C, pp. 190-218).

Management Considerations

The following are the summary considerations from current updates to the ecosystem and socioeconomic indicators evaluated for sablefish:

- Surface temperatures in the EGOA have cooled relative to 2020 and are below average with very few marine heatwave events. Bottom temperatures on the slope in the GOA have cooled to near average levels. The southern EBS has also cooled, but is still well above average. Chlorophyll *a* biomass is near average in both the EGOA and southern EBS and spring bloom timing is later in both regions than in 2020, but still early in the EGOA
- Zooplankton community size in the EGOA and WGOA were below average in 2020 implying a smaller sized community, possibly due to warm temperatures or grazing from meso-zooplankton
- Growth of YOY sablefish was near average but samples sizes were low, CPUE remained high for juveniles in the nearshore surveys suggesting overwinter and nearshore conditions were favorable
- Age-1 (<35 cm) sablefish from the bottom trawl survey were near average and similar to 2019, suggesting an average overwinter survival from 2020
- Condition of the 2016 year-class was near average in 2020, while current condition of adult females on the survey decreased from last year and is now below average
- Spatial overlap between sablefish migrating to adult slope habitat and the arrowtooth flounder population has decreased to average based on incidental catch in the arrowtooth flounder fishery
- Fishery CPUE indicators continue to show contrasting trends by longline and pot gear with continued below average CPUE in the GOA longline fishery and the highest CPUE of the time series in the BSAI pot fishery
- Catch of sablefish in non-sablefish targeted fisheries has decreased to a comparatively low value from an extremely high value in 2020 in the GOA, and decreased in the BSAI but is still very high, which may imply shifting distribution of sablefish into different habitat in the BSAI and settlement of the large 2016 year class into deeper waters of the GOA
- Condition of adult female sablefish in the GOA fisheries decreased from above average to below average, but sample sizes were small compared to previous years
- Real ex-vessel value and average price per pound have declined dramatically since 2017 and are now the lowest in the time series, in part due to smaller average fish size that have not grown to marketable sizes
- Downward pressure on fish product prices in the first-wholesale market coupled with cost pressure from COVID-19 mitigation efforts likely had impacts on decreasing ex-vessel prices
- Overall, ecosystem indicators were above average and socioeconomic indicators were average.

Modeling Considerations

The following are the summary results from the intermediate and advanced stage monitoring analyses for sablefish:

- The highest ranked predictor variables 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 (inclusion probability > 0.5)
- New research models are being explored regarding a spatially explicit life cycle model (SILC) that merges a spatially explicit assessment model with an updated sablefish individual based model (IBM), a temperature linked projection model, and a tag-integrated model to aid in the estimation of time-varying natural mortality linkages.

Assessment

Ecosystem and Socioeconomic Processes

Alaska sablefish or the northern population of sablefish, are assessed as a single population in the federal waters off Alaska from British Columbia to the Bering Sea (McDevitt, 1990, Saunders et al., 1996, Kimura et al., 1998). They have a propensity for large-scale movements (Heifetz and Fujioka, 1991, Hanselman et al. 2015) and adult sablefish are typically encountered between 200 and 1000 m along the continental slope, shelf gullies, and deep-sea canyons (Wolotira et al., 1993). A clear ontogenetic habitat shift occurs between the early juvenile and later juvenile to adult stages with progression from nearshore bays and inlets to the colder continental shelf and slope (Figure 3C.1). Sablefish are highly fecund, early spring, deep-water spawners with an extended spring through summer neustonic (extreme surface) pelagic phase that culminates in nearshore settlement in the early fall of their first year when sablefish are around 300-400 mm (Doyle and Mier 2016; Doyle et al. 2019). At some point following the first winter, sablefish juveniles begin movement to their adult habitat arriving between 4 to 5 years later and starting to mature within 3 to 6 years (Hanselman et al., 2019). Pelagic eggs in deep water over the slope and basin may provide a relatively stable environment for embryonic development as cold temperatures during winter favor slow development. Relatively large size at hatching (~6 mm) and rapid growth of larvae with good swimming ability likely confers an advantage in terms of larval feeding at the sea surface (Doyle et al., 2019). Peak abundance of larvae (May–June) coincides with advanced development of the spring peak in zooplankton production following the onset of stratification (measured by a shallowing of the mixed layer), which likely means a plentiful supply of prey. Sablefish larvae are characterized by early development of large pectoral fins to assist with swimming ability, but have delayed bone-development in their jaws potentially resulting in non-discriminating prey selection (Matarese et al. 2003; Deary et al., 2019). With the lack of overall ossification of the skeleton, pre-flexion sablefish larvae lack the rigidity in their jaw elements to quickly open and expand their mouths to suck in prey. Sablefish in this preflexion larval stage are only able to pick prey from the water and are thus restricted to prey that are small and prevalent. The temporal match with the onset of the zooplankton bloom suggests a need to be at the highest peak of productivity due to their non-discriminating prey selection (Deary et al., 2019).

Throughout the first year, larvae and age-0 fish grow very rapidly up until settlement in the nearshore environment (Sigler et al. 2001). Fish in the pre-settlement to settlement stages have fairly stable lipid content as they are putting energy toward growth and not toward lipid energy storage. Maturing juveniles to adult sablefish have a much higher percent lipid content than the earlier life stages; thus, there is an ontogenetic shift that is related to how sablefish store energy and may be related to the size at which fish migrate from nearshore to offshore waters. The variability in lipid content in maturing and adult sablefish could be attributed to some fish being mature and some being immature or skip spawning. For example, relative condition (body weight relative to length) and relative liver size (liver weight related to total weight), are higher in fish that will spawn than in skip spawning and immature female sablefish (Rodgveller, 2019). The lipid accumulation shifts suggest that the fish in the nearshore are still growing quickly with an associated high energetic cost, but as they move offshore the fish have relatively low energetic demands and can begin to allocate surplus lipid to storage with age as they grow (J.

Vollenweider, *pers. comm*.). The juvenile nearshore stage appears to continue to be an energetically demanding period as all surplus energy is allocated toward growth (protein). A potential alternative explanation for this pattern is that food is a limiting factor and surplus energy is not available. Later during the early offshore residence for juveniles, the energetic constraints are relieved and fish obtain surplus energy that is stored as lipid. In addition to reducing the pressure for rapid growth, the extreme increase in lipid storage may represent considerably better feeding grounds, and/or life history constraints to increase lipid content as the fish move into the deeper depths of the adult habitat as they age.

Sablefish have historically been harvested primarily by catcher vessels in the GOA, which typically account for upwards of 90% of the annual catch. In 2020, the GOA accounted for only 83% of the retained catch as catch levels in the BSAI increased. Most sablefish are caught using the hook-and-line gear type. Starting in 2017, directed fishing for sablefish using pot gear was allowed in the GOA to mitigate whale depredation. In 2020, there was a substantial increase in GOA pot gear catches. In 2019, hook and line accounted for 72% of the catch and pot gear 18%. In 2020, hook and line accounted for about 50% of the catch and pot gear about 48%. While pot gear catches increased in all areas of the gulf, the increase was most pronounced in the Western and Central Gulf. Media reports suggest that the introduction of slinky pots may have been a contributing factor as they offer hook and line fishermen access to pot gear despite limited deck space (A. Stubbs, *pers. comm.*). Unfortunately, the gear codes do not distinguish between slinky pots vs. other pot gear. The sablefish ABC rose by approximately 7000 t in both 2020 and 2021, even though TAC was increased more modestly. Sablefish catch levels relative to TAC in the GOA, typically between 85-90%, dropped to approximately 75% in 2020 suggesting that the downward pressure on price from COVID-19 may have been among the factors influencing harvest effort.

As a valuable, premium, high-priced whitefish, sablefish is an important source of revenues for GOA catcher vessels. The U.S. accounts for roughly 85-90% of global sablefish catch and Alaska accounts for roughly 70% of the U.S. catch. Canada catches roughly 10% of the global supply. A small amount is also caught by Russia, although this amount has been increasing since 2017. 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.

The Annual Community Engagement and Participation Overview (ACEPO) is a new report that evaluates engagement at the community level and focuses on providing an overview of harvesting and processing sectors of identified highly engaged communities for groundfish and crab fisheries in Alaska (Wise et al., 2021). 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. An analysis of commercial processing and harvesting data has been conducted at the stock level rather than community level for other ESPs to examine sustained participation for those communities substantially engaged in a commercial fishery. This analysis could be completed for sablefish in the future.

Indicator Suite

The following list of indicators for sablefish are organized by categories, three for ecosystem indicators (physical, lower trophic, and upper trophic) and three for socioeconomic indicators (fishery performance, economic, and community). A short description and contact name for the indicator contributor are provided. 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 Figure 3C.2a and Figure 3C.2b, respectively.

Ecosystem Indicators

Physical Indicators (Figure 3C.2a.a-d)

a.) Annual marine heatwave cumulative index over the central GOA (contact: S. Barbeaux).
b.) Late spring (May-June) daily sea surface temperatures (SST) for the eastern GOA from the NOAA Coral Reef Watch Program (contact: J. Watson).
c.) Late spring (May-June) daily sea surface temperatures (SST) for the southeastern Bering Sea from the NOAA Coral Reef Watch Program (contact: J. Watson).
d.) Summer temperature anomalies at 250 m isobath during the AFSC annual longline survey (contact: K. Siwicke).

Lower Trophic Indicators (Figure 3C.2a.e-l)

e.) Derived chlorophyll *a* concentration during spring seasonal peak (May) in the eastern GOA from the MODIS satellite (contact: J. Watson).
f.) Derived chlorophyll *a* concentration during spring seasonal peak (May) in the southeastern Bering Sea from the MODIS satellite (contact: J. Nielsen).
g.) Peak timing of the spring bloom averaged across individual ADF&G statistical areas in the eastern GOA region from the MODIS satellite (contact J. Watson)
h.) Peak timing of the spring bloom averaged across individual ADF&G statistical areas in the southeastern Bering Sea from the MODIS satellite (contact: J. Nielsen).
i.) Abundance of copepod community size from the continuous plankton recorder (CPR) for the offshore eastern GOA (contact: C. Ostle).
j.) Abundance of copepod community size from the continuous plankton recorder (CPR) for the offshore western GOA (contact: C. Ostle).
k.) Summer euphausiid abundance from the AFSC acoustic survey for the Kodiak core survey area (contact: P. Ressler).
l.) Age-0 sablefish growth rate from auklet diets in Middleton Island (contact: M. Arimitsu).

Upper Trophic Indicators (Figure 3C.2a.m-t)

m.) Sablefish catch-per-unit-effort (CPUE) and lengths from the ADF&G large mesh bottom trawl survey of crab and groundfish (contact: K. Spalinger).
n.) Summer length compositions extrapolated to the population of juvenile sablefish (<350 mm, likely age-1) collected on AFSC bottom-trawl surveys (contact: K. Shotwell).
o.) Mean age of sablefish female spawning stock biomass from the most recent sablefish stock assessment model (contact: D. Goethel)
p.) Measure of evenness or concentration of age composition by cohort of female sablefish from the most recent sablefish stock assessment model (contact: D. Goethel).
q.) Summer sablefish condition for age-4, immature female sablefish from the GOA AFSC longline survey (contact: J. Sullivan).
r.) Arrowtooth flounder total biomass from the most recent stock assessment model (contact: K. Shotwell).
s.) Incidental catch of sablefish in the GOA arrowtooth flounder fishery (contact: K. Shotwell).
t.) Summer sablefish condition for large adult (>=750 mm) female sablefish from the GOA AFSC longline survey (contact: J. Sullivan)

Socioeconomic Indicators

Fishery Performance Indicators (Figure 3C.2b.a-f)

a.) Catch-per-unit-of-effort of sablefish from the longline fisheries in the GOA (contact: D. Goethel).
b.) Catch per unit of effort of sablefish estimated from the pot fisheries in the eastern Bering Sea (contact: D. Goethel).

c.) Incidental catch estimates of sablefish in the GOA fisheries excluding the sablefish fishery (contact: K. Shotwell).
d.) Incidental catch estimates of sablefish in the Bering Sea fisheries excluding the sablefish fishery (contact: K. Shotwell).
e.) Sablefish condition for large (>= 750 mm) female sablefish from data collected randomly by observers in the GOA fisheries (contact: J. Sullivan).
f.) Sablefish condition for large (>= 750 mm) female sablefish from data collected randomly by observers in the BSAI fisheries (contact: J. Sullivan).

Economic Indicators (Figure 3C.2b.g-h)

g.) Annual estimated real ex-vessel value of sablefish (contact: B. Fissel).
h.) Average real ex-vessel price per pound of sablefish from fish ticket information (contact: B. Fissel).

Indicator Monitoring Analysis

There are up to three stages (beginning, intermediate, and advanced) of statistical analyses for monitoring the indicator suite listed in the previous section. The beginning stage is a relatively simple evaluation by traffic light scoring. This evaluates the current year trends relative to the mean of the whole time series, and provides a historical perspective on the utility of the whole indicator suite. The intermediate stage uses importance methods related to a stock assessment variable of interest (e.g., recruitment, biomass, catchability). These regression techniques provide a simple predictive performance for the variable of interest and are run separate from the stock assessment model. They provide the direction, magnitude, uncertainty of the effect, and an estimate of inclusion probability. The advanced stage is used for testing a research ecosystem linked model and output can be compared with the current operational model to understand information on retrospective patterns, prediction performance, and comparisons of other model output such as terminal spawning stock biomass or mean recruitment. This stage provides an on-ramp for introducing an alternative ecosystem linked stock assessment model to the current operational stock assessment model and can be used to understand the potential reduction in uncertainty by including the ecosystem information.

Beginning Stage: Traffic Light Test

We use a simple scoring calculation for this beginning stage traffic light evaluation. Indicator status is evaluated based on being greater than ("high"), less than ("low"), or within ("neutral") one standard deviation of the long-term mean. A sign based on the anticipated relationship between the indicator and the stock (Figure 3C.1) is also assigned to the indicator where possible. If a high value of an indicator generates good conditions for the stock and is also greater than one standard deviation above the mean, then that value receives a '+1' score. If a high value generates poor conditions for the stock and is greater than one standard deviation above 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. The scores over time allow for comparison of the indicator performance and the history of stock productivity (Figure 3C.3). We also provide five year indicator status tables with a color or text code for the relationship with the stock (Tables 3C.1a,b) and evaluate the current year status in the historical indicator time series graphic (Figures 3C.2a,b) for each ecosystem and socioeconomic indicator.

We evaluate the status and trends of the ecosystem and socioeconomic indicators to understand the pressures on the sablefish stock regarding recruitment, stock productivity, and stock health. We start with the physical indicators and proceed through the increasing trophic levels, economic, and community indicators as listed above. Here, we concentrate on updates since the last ESP. Overall, the physical, lower trophic, and fishery performance indicators scored average for 2021, while the upper trophic indicators were above average (Figure 3C.3). Compared to last year, this is a drop from above average for the physical indicators, the same for the lower trophic and fishery performance indicators, and an improvement from below average for the upper trophic indicators. However, we caution when comparing scores between odd to even years as there are two indicators (one lower, one upper trophic) missing in even years due to the off-cycle year surveys. Also, there have been survey delays due to COVID-19 in 2020 and 2021 that limited production or updating of one indicator. Economic indicators are all lagged by at least one year due to timing of the availability of the current year information and the production of this report. Economic indicators scored below average for 2020 (data received in 2021), which is a drop from above average in 2019.

For physical indicators (Table 3C.1a, Figure 3C.2a.a-d), the sablefish population is currently experiencing a series of unusually large year-classes, which are concurrent with large shifts in the physical environment. However, this year, large marine heatwave events were less frequent and the thermal environment (surface and bottom indicators) in both the EGOA and southeastern Bering Sea (SEBS) has cooled, although the SEBS remains above average. For lower trophic indicators (Table 3C.1a, Figure 3C.2a.e-l), estimates of chlorophyll *a* concentration in the EGOA and WGOA were near average in 2021 with later peak timing of the spring bloom but still earlier than average in the EGOA and now later than average in the SEBS, which may have implications for larval mismatch with prey (Figure 3C.2a.e-h). Continuous plankton recorder data were updated for 2020 for the oceanic GOA on the eastern and western sides (Figure 3C.2a.i-j). The copepod community size anomaly was strongly negative in both the Alaskan shelf and EGOA oceanic regions in the last 3-5 years, but it has oscillated in the WGOA oceanic region from positive in 2019 to negative in 2020. Additionally in 2020, the diatom abundance was negative on the EGOA and WGOA, while the zooplankton biomass anomalies were positive in both the Alaskan shelf and EGOA regions, but negative in the WGOA (Ostle and Batten, 2021a). There were similar trends in continuous plankton recorder data in the EBS. Copepod community size was positive in 2019 and negative in 2020, while diatom abundance was negative in 2019 and 2020 and meso zooplankton biomass was positive in 2019 and negative in 2020 (Ostle and Batten, 2021b). In warm conditions, smaller species tend to be more abundant and the copepod community size index was mostly negative throughout the recent marine heat wave periods. The decrease in diatom abundance could potentially be linked to the increase in temperatures or the slight increase in meso-zooplankton abundance, which may lead to increasing predation on diatoms in the area. Age-0 sablefish growth as measured in samples captured by rhinoceros auklets at Middleton Island showed near average growth, although sample sizes were small (Figure 3C.2a.l).

For upper trophic indicators (Table 3C.1a, Figure 3C.2a.m-t), sablefish CPUE from the nearshore ADF&G large mesh survey has been above average for the last six of seven years and remains high in 2021 (Figure 3C.2a.m). 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 (Figure 3C.4a). The high CPUE for 2020 and 2021 was largely driven by catches in the Kodiak area, while CPUE in 2018-2019 was up in all areas of the survey and there was an increase in catches in the eastern Aleutians in 2021 (Figure 3C.4a). This is consistent with the main assessment and AFSC longline survey that imply most of the population growth is in the western areas of the GOA. 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. Length frequencies from 2020 are similar to those in 2015 suggesting a strong 2019 year class similar to 2014. The length frequencies from 2021 match the growth of the 2019 cohort to age-2, but do not show any new cohorts at age-1 (Figure 3C.4b). Age-1 sablefish (measured by population extrapolated length frequencies of <35 cm fish) in the AFSC bottom trawl survey were average this year similar to the 2019 survey

(Figure 3C.2a.n). There were no updates to mean age and evenness of female adult sablefish as the sablefish stock assessment model is currently in review; however, preliminary model results suggest that the mean age and evenness of female adult sablefish is still well below average and may continue decline as the new year classes materialize. This suggests 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, particularly as skip spawning may be more prevalent in younger fish (Figure 3C.2a.o-p, Rodgveller et al., 2018). Body condition of female sablefish 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 fish on the AFSC longline survey was near average in 2020, suggesting the 2016 year class had sufficient prey resources just prior to maturing (Figure 3C.2a.q). This is in contrast to the lower condition of the age-4s for the 2014 year class and suggests that the 2016 year class will have stronger persistence than the 2014 year class. Arrowtooth flounder has been considered a primary predator of young sablefish, but this stock has been declining over the past decade (Figure3C.2a.r.). There were no updates for arrowtooth flounder biomass as the stock assessment is currently in review; however, recent survey estimates are slightly larger than in 2019 (bottom trawl survey) and 2020 (longline survey), but still well below average (Shotwell et al., 2021). Additionally, the incidental catch estimates of sablefish in the GOA arrowtooth flounder fishery have decreased to average suggesting lower levels of spatial overlap between the arrowtooth and sablefish populations (Figure 3C.2a.s). This suggests that the large sablefish year classes of 2014-2016 have moved off the continental shelf into adult sablefish habitat on the slope and are no longer competing with or experiencing predation by arrowtooth flounder. Condition of large adult female sablefish from the AFSC longline survey decreased to below average (Figure 3C.2a.t), which is a negative sign given the increasing reliance on the recent large cohorts. Samples sizes for large females have been slowly decreasing over time, which may be related to the truncated age structure of the population.

For fishery performance indicators (Table 3C.1b, Figure 3C.2b.a-f), the CPUE of sablefish in the GOA longline fishery (from observer data) has been below average since 2011 and remained below average in 2021 (Figure 3C.2b.a). This CPUE trend in the longline fishery is contrasted by the CPUE of the pot fishery in the eastern Bering Sea, which is now at the highest value for the time series (Figure 3C.2b.b). These contrasting trends are concerning as the current stock assessment model does not track pot CPUE and does not account for temporal fluctuations in gear selectivity. However, note some caution on interpretation on the contrasting trends as the number of observed trips has been decreasing in recent years due to the increase of electronic monitoring and logbook data were not available for 2020 or 2021. Sablefish catch in the non-sablefish target fisheries for the GOA decreased from a very high value in 2020 to a very low value in 2021, and also decreased in the BSAI from last year but remains well above average (Figure 3C.2b.c-d). 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 incidental catch may imply shifting distribution of the sablefish population into non-preferred habitat, which could increase competition and predation for sablefish. Condition of adult females in the GOA fisheries has decreased to an all-time low for the time series (Figure 3C.2b.e), but samples sizes of adult females severely declined from 2019 - 2021, potentially due to the increase in electronic monitoring and reduced fishing effort due to low prices, small fish, and COVID-19. The relative condition by region of the large female spawners may provide some insight into habitat quality by region and the subsequent economic value of these fish considering observed increase in lipids with increasing body size and condition.

Since 2017, the sablefish TACs have increased as a result of strong year-classes. Total catches increased 13% to 19.9 thousand t and retained catches increased 8% to 14.1 thousand t. The retention rate (ratio of retained catch to total catch), typically above 90% prior to 2017, has dropped to 71% in 2020. This is in part related to the higher catch of juvenile sablefish by Bering Sea trawlers targeting other species. Also, percent catch from the directed fixed gear sablefish fisheries was around 60% in 2020, which was the lowest point since early 1970s. However, retention rates in the GOA have also decreased from 90-95%

prior to 2017, to approximately 80% in 2018-2020 (Fissel et al., 2021). Revenues decreased 30% to $51.5 million in 2020 as ex-vessel prices fell 34% to $1.72/lb. (Table 3C.1b, Figure 3C.2b.g-h). The decrease in the ex-vessel price was a reflection of a commensurate decrease in first-wholesale price to $3.74/lb. First-wholesale value decreased to $61.9 million in 2020 (Fissel et al., 2021). The price decrease since 2017 is, in part, the result of smaller average fish size, as the large cohorts of younger year classes have not fully grown to a higher marketable price. 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 2020 (Fissel et al., 2021). Japan is the primary export market, but its share of export value has decreased from approximately 75% in 2011-2015 to 65% in 2016-2020. U.S. exports as a share of U.S. production has declined over time indicating increased domestic consumption (Fissel et al., 2020). China's share of export value has also been generally increasing. The U.S.-Japanese exchange rate weakened in 2020, 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 (Fissel et al., 2020). There was a notable decrease in prices for many of the products, such as sablefish, which ultimately go to foodservice sectors as a result of COVID-19 related foodservice closures. This downward pressure on fish product prices in the first-wholesale market coupled with cost pressure from COVID-19 mitigation efforts likely had upstream impacts on ex-vessel prices that decreased significantly.

Intermediate Stage: Importance Test

Bayesian adaptive sampling (BAS) was used for the intermediate 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 stage, the full set of indicators is first winnowed to the predictors that could directly relate to recruitment and highly correlated covariates are removed. We further restrict potential covariates to those that can provide the longest time series and that are available through the most recent year of recruitment estimation, or the most recent year class that is considered well estimated in the current operational stock assessment model (Figure 3C.5a). This results in a model run from 1996 through the 2017 year-class. We then provide the mean relationship between each predictor variable and log sablefish recruitment over time (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 (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 (Figure 3C.5).

Advanced Stage: Research Model 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) model is in development for sablefish that pairs output from an individual based model (IBM) with a 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 processes. The sablefish IBM is currently being updated to include temperature relationships in the early life stages (Shotwell et al., *In prep*.) as part of the Essential Fish Habitat (EFH) update. Information on connectivity from spawning to nursery areas will likely be used in the SILC model configuration. Once the SILC model is 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 by reducing uncertainty in the model, whereas risk tables and other adjustments can only reduce ABC.

Another way that the ESP may be used to forward an advanced research model is to include environmental forcing in future projections. Previous work (Shotwell et al., 2014) had identified SST as a potential driver of recruitment and demonstrated the potential benefits of including these in short-term projections (1-5 years). A new generic projection model has been developed for NPFMC stocks that has been applied using SST for sablefish (M. Veron pers. comm). This application may be a useful forward indicator in the ESP to compare to the operational projections and perhaps be used as an input into future risk tables.

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. Some 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. A large-scale zooplankton indicator that combines multiple data sources to determine a relative trend by region could potentially be developed to more adequately capture the habitat that sablefish encounter during their first year of life.

Refinements or updates to current indicators may also be helpful. The chlorophyll *a* biomass and timing of the spring bloom indicators were only partially specialized for sablefish. More specific phytoplankton indicators tuned to the spatial and temporal distribution of sablefish larvae as well as phytoplankton community structure information (e.g., hyperspectral information for size fractionation) could be more useful for understanding sablefish larval fluctuations. Increased sampling of weights on the longline survey could provide better information for condition indicators. It is also 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 several historical years of diet data collected for sablefish and many other groundfish that have not yet been incorporated into the Ecopath model (Aydin et al., 2007) that initially estimated predation and consumption rates for sablefish and other groundfish and were used in Ecosystem Considerations sections of the SAFE. 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 sizes from observers for sablefish where otoliths have been collected and aged to be able to examine age-based condition indicators. As noted earlier, the recent very low sample sizes for adult females may render some of these analyses intractable in the future. 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.

Outside of the SILC model applications, the sablefish IBM is currently being used to create dynamic spatial distribution of egg and larval EFH (Shotwell et al., *In prep*). This information could also be used to spatially tune physical and lower trophic indicators to more accurately reflect sablefish early life history distributions. Additional refinement of the spatially integrated life cycle (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. Summary indicators of tagging data or output from the research spatial model may be helpful for understanding movement dynamics and shifts in the spatial distribution of the stock. Other fishery performance indicators could include additional measures on pot gear or size grade and price compositions.

We plan to evaluate the information provided in the Economic SAFE and ACEPO report to determine what socioeconomic indicators could be provided in the ESP that are not redundant with those reports and related directly to stock health. This may result in a transition of indicators currently reported in this ESP to a different series of socioeconomic indicators in future ESPs and may include a shift in focus from engagement to dependency. Additional consideration of the timing of the economic and community reports, which are delayed by 1-2 years (depending on the data source) from the annual stock assessment cycle, should also be undertaken. The Scientific and Statistical Committee (SSC) recently recommended that local knowledge, traditional knowledge, and subsistence information may be helpful for understanding recent fluctuations in stock health, shifts in stock distributions, or changes in size or condition of species in the fishery. We could include this information as supportive evidence and perspective on many indicators monitored within the ESP. The SSC also recently requested that information on the historical use of sablefish by coastal communities be included in the next ESP and perhaps the ACEPO report can help identify avenues for summarizing this information.

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. The annual request for indicators (RFI) for the sablefish ESP will include these data gaps and research priorities along with a list of potential new indicators that could be developed for the next full ESP assessment.

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Tables

Table 3C.1a. First stage ecosystem indicator analysis for sablefish, including indicator title and the indicator status of the last five years. The indicator status is designated with text, (greater than = “high”, less than = “low”, or within 1 standard deviation = “neutral” of long-term mean). Fill color of the cell is based on the sign of the anticipated relationship between the indicator and sablefish (blue or italicized text = good conditions for sablefish, red or bold text = poor conditions, white = average conditions). A gray fill and text = “NA” will appear if there were no data for that year.

Indicator category	Indicator	2017 Status	2018 Status	2019 Status	2020 Status	2021 Status
Physical	Annual Heatwave GOA Model	neutral	neutral	*high*	neutral	neutral
	Spring Temperature Surface EGOA Satellite	neutral	neutral	*high*	neutral	neutral
	Spring Temperature Surface SEBS Satellite	neutral	*high*	*high*	*high*	neutral
	Summer Temperature 250m GOA Survey	neutral	neutral	neutral	neutral	neutral
Lower Trophic	Spring Chlorophyll a Biomass EGOA Satellite	neutral	neutral	neutral	**low**	neutral
	Spring Chlorophyll a Biomass SEBS Satellite	**low**	neutral	**low**	neutral	neutral
	Spring Chlorophyll a Peak EGOA Satellite	neutral	*low*	neutral	*low*	neutral
	Spring Chlorophyll a Peak SEBS Satellite	*low*	**high**	neutral	neutral	neutral
	Annual Copepod Community Size EGOA Survey	neutral	**low**	**low**	neutral	NA
	Annual Copepod Community Size WGOA Survey	neutral	**low**	*high*	neutral	NA
	Summer Euphausiid Abundance Kodiak Survey	**low**	NA	neutral	NA	NA
	Annual Sablefish Growth YOY Middleton Survey	neutral	neutral	*high*	neutral	neutral
Upper Trophic	Summer Sablefish CPUE Juvenile Nearshore GOAAI Survey	neutral	*high*	*high*	*high*	*high*

Indicator category	Indicator	2017 Status	2018 Status	2019 Status	2020 Status	2021 Status
	Summer Sablefish Age-1 GOA Survey	*high*	NA	neutral	NA	neutral
	Annual Sablefish Mean Age Female Adult Model	neutral	neutral	**low**	**low**	NA
	Annual Sablefish Age Evenness Female Adult Model	**low**	**low**	**low**	**low**	NA
	Summer Sablefish Condition Female Age4 GOA Survey	**low**	neutral	**low**	neutral	NA
	Annual Arrowtooth Biomass GOA Model	neutral	neutral	neutral	neutral	NA
	Annual Sablefish Incidental Catch Arrowtooth Target GOA Fishery	**high**	**high**	**high**	neutral	neutral
	Summer Sablefish Condition Female Adult GOA Survey	**low**	neutral	neutral	neutral	neutral

Table 3C.1b. First stage socioeconomic indicator analysis for sablefish, including indicator title and the indicator status of the last five years. The indicator status is designated with text, (greater than = "high", less than = "low", or within 1 standard deviation = "neutral" of long-term mean). Fill color of the cell is based on the sign of the anticipated relationship between the indicator and sablefish (blue or italicized text = good conditions for sablefish, red or bold text = poor conditions, white = average conditions). A gray fill and text = "NA" will appear if there were no data for that year.

Indicator category	**Indicator**	**2017 Status**	**2018 Status**	**2019 Status**	**2020 Status**	**2021 Status**
Fishery Performance	Annual Sablefish Longline CPUE GOA Fishery	**low**	**low**	**low**	neutral	neutral
	Annual Sablefish Pot CPUE EBS Fishery	neutral	neutral	*high*	*high*	*high*
	Annual Sablefish Incidental Catch GOA Fishery	neutral	**high**	**high**	**high**	*low*
	Annual Sablefish Incidental Catch BSAI Fishery	neutral	neutral	**high**	**high**	**high**
	Annual Sablefish Condition Female Adult GOA Fishery	neutral	neutral	neutral	*high*	**low**
	Annual Sablefish Condition Female Adult BSAI Fishery	NA	NA	NA	NA	NA
Economic	Annual Sablefish Real Exvessel Value Fishery	neutral	neutral	**low**	**low**	NA
	Annual Sablefish Real Exvessel Price Fishery	*high*	neutral	**low**	**low**	NA

Figures

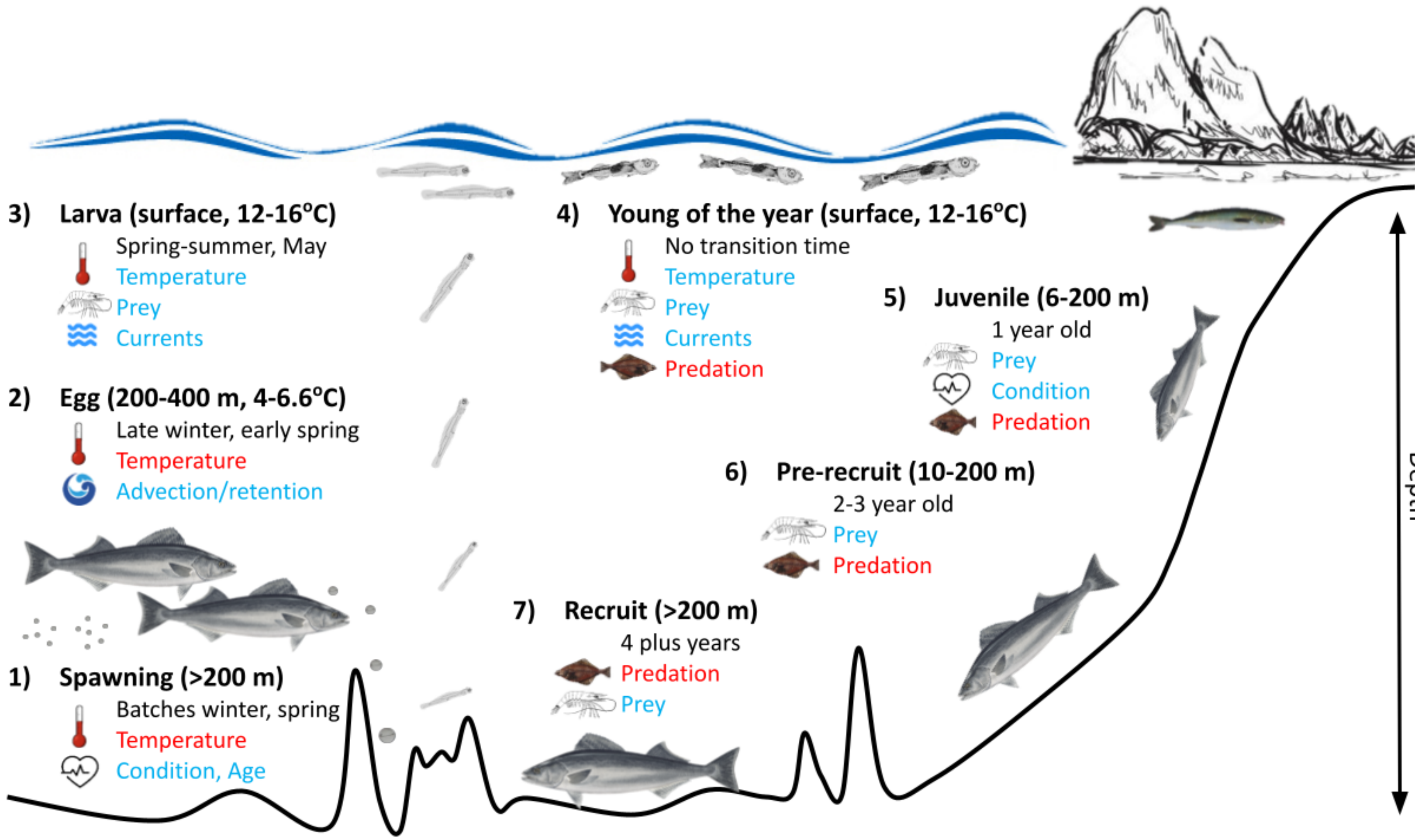


Figure 3C.1: Life history conceptual model for sablefish summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text means increases in process negatively affect survival, while blue text means increases in process positively affect survival.

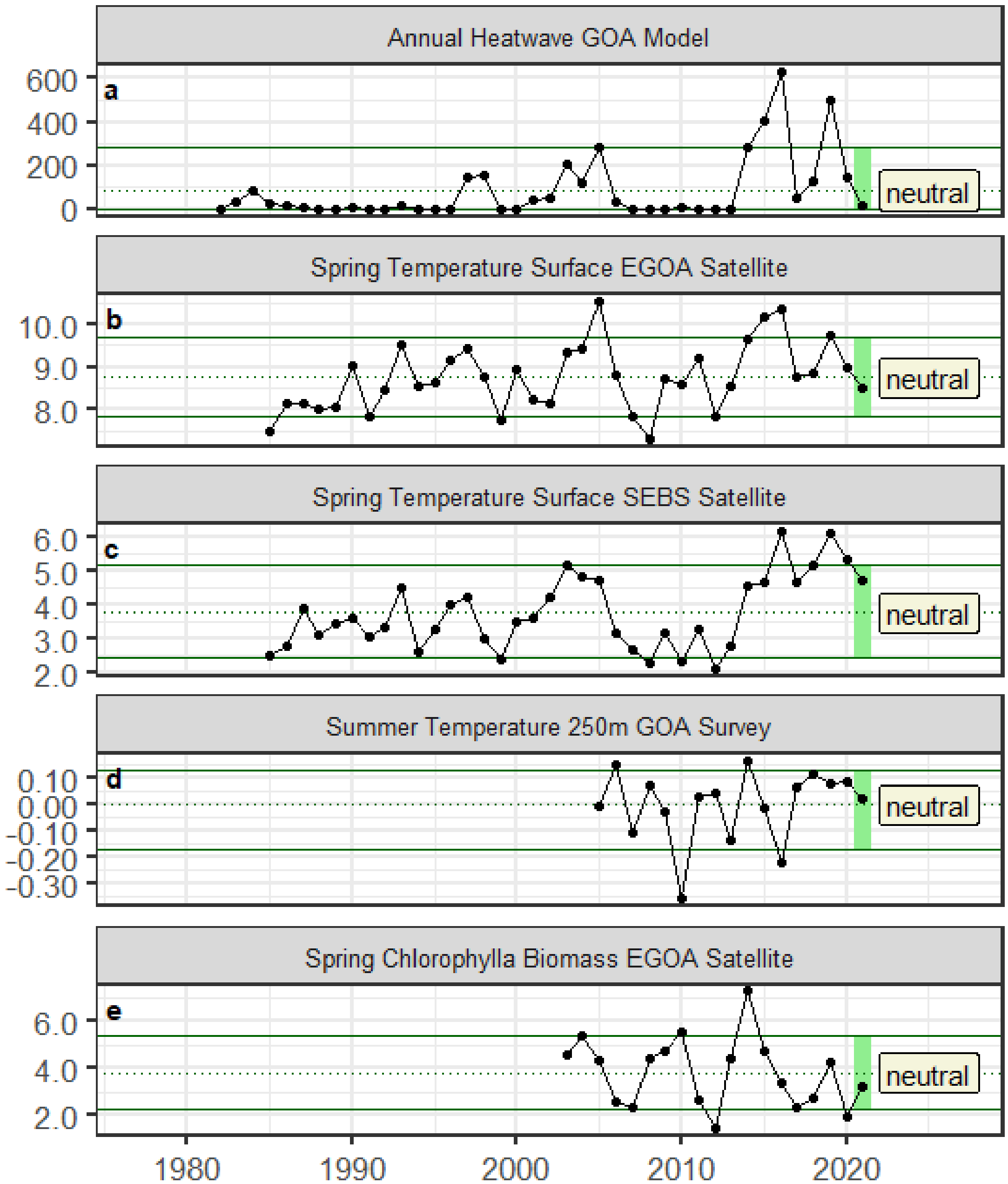


Figure 3C.2a. Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the most recent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

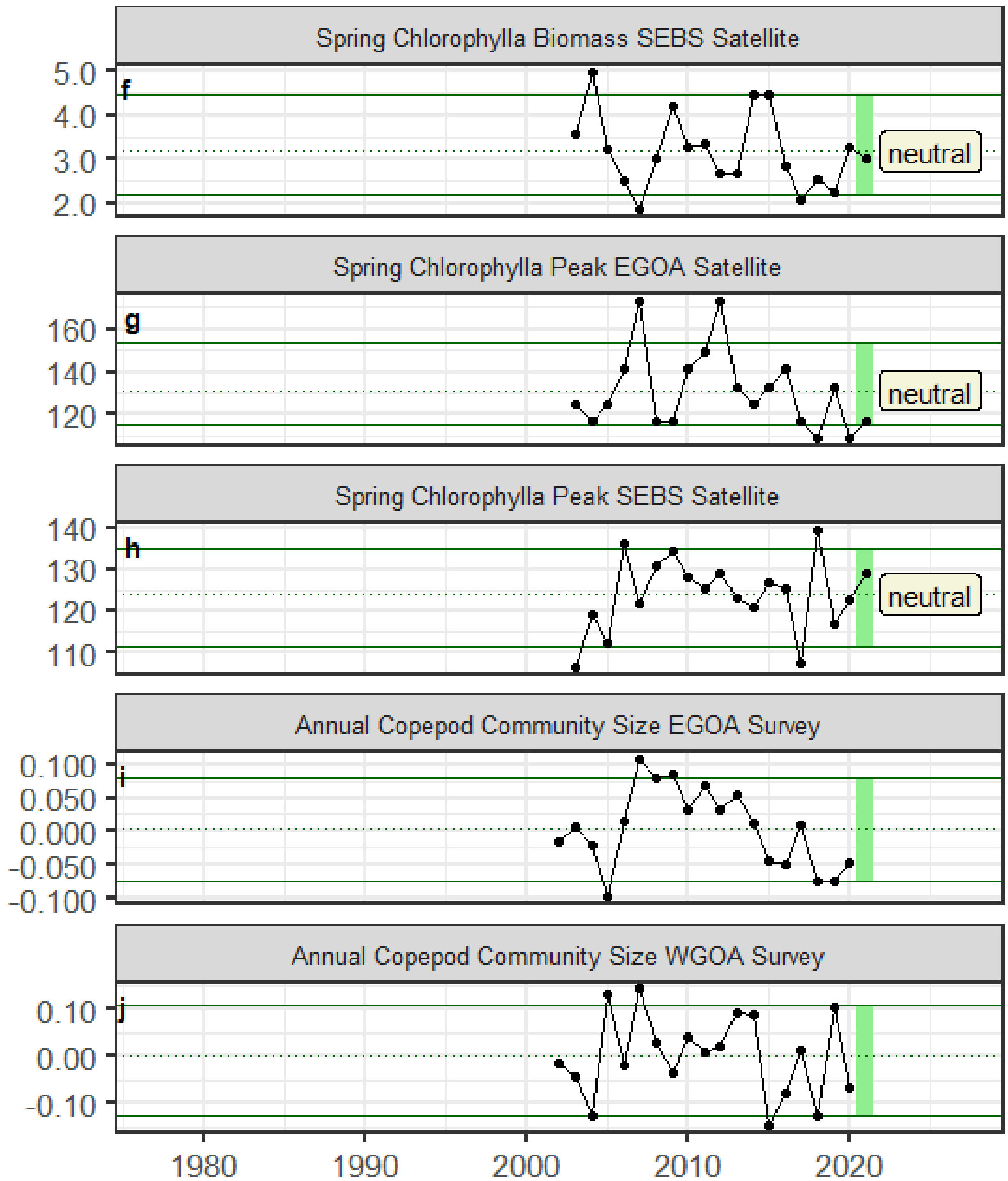


Figure 3C.2a (cont.). Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the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

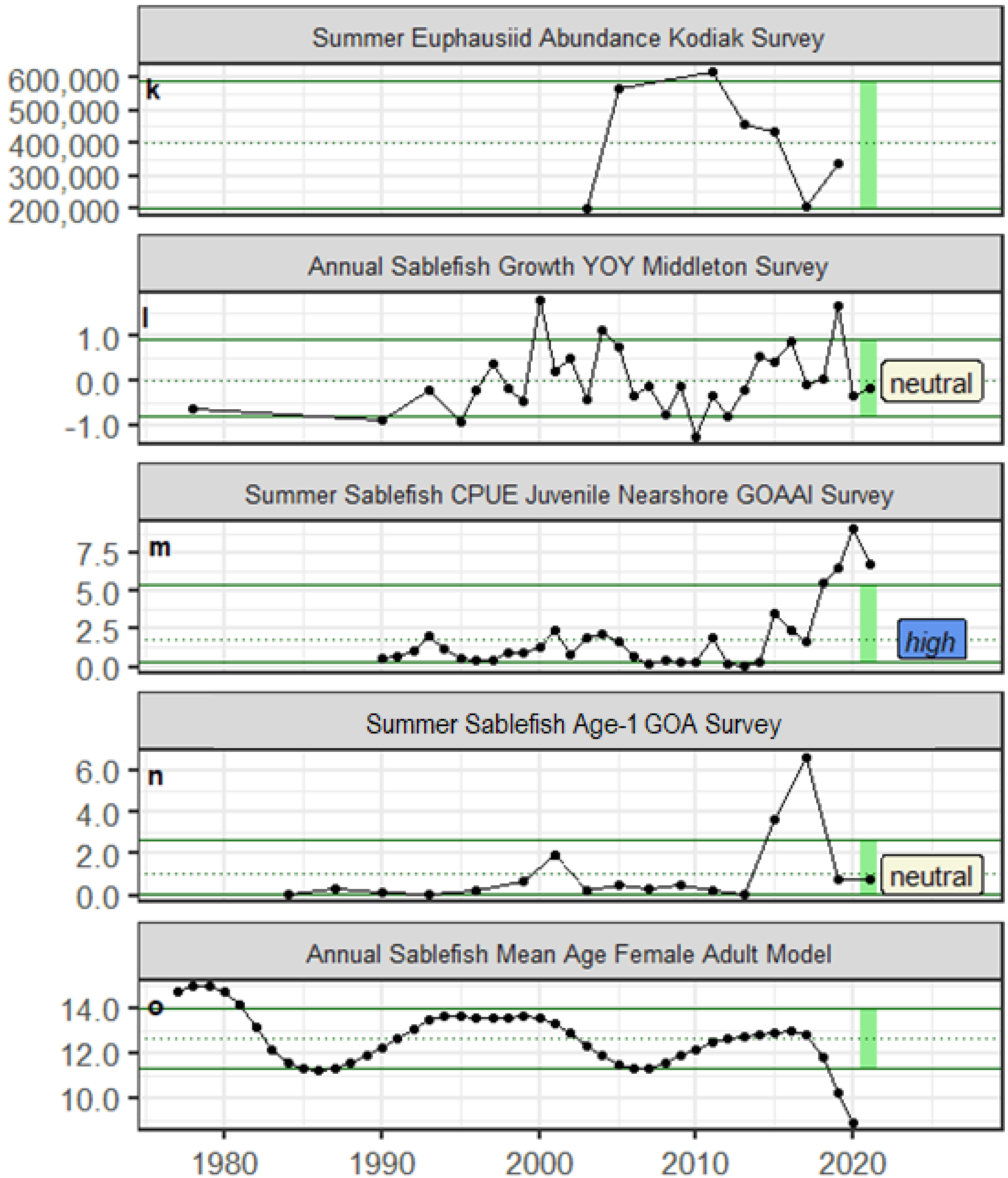


Figure 3C.2a (cont.). Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the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

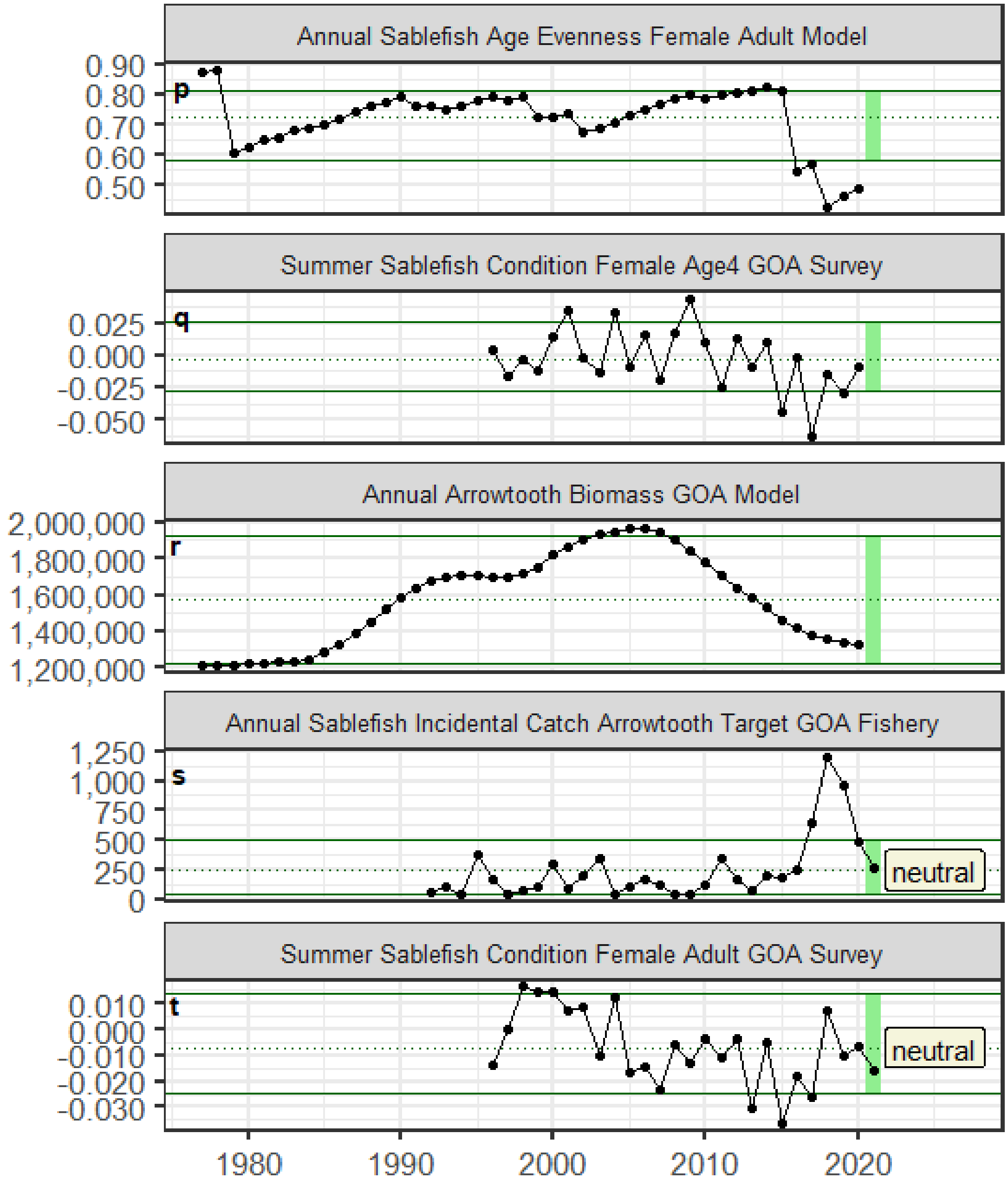


Figure 3C.2a (cont.). Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the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

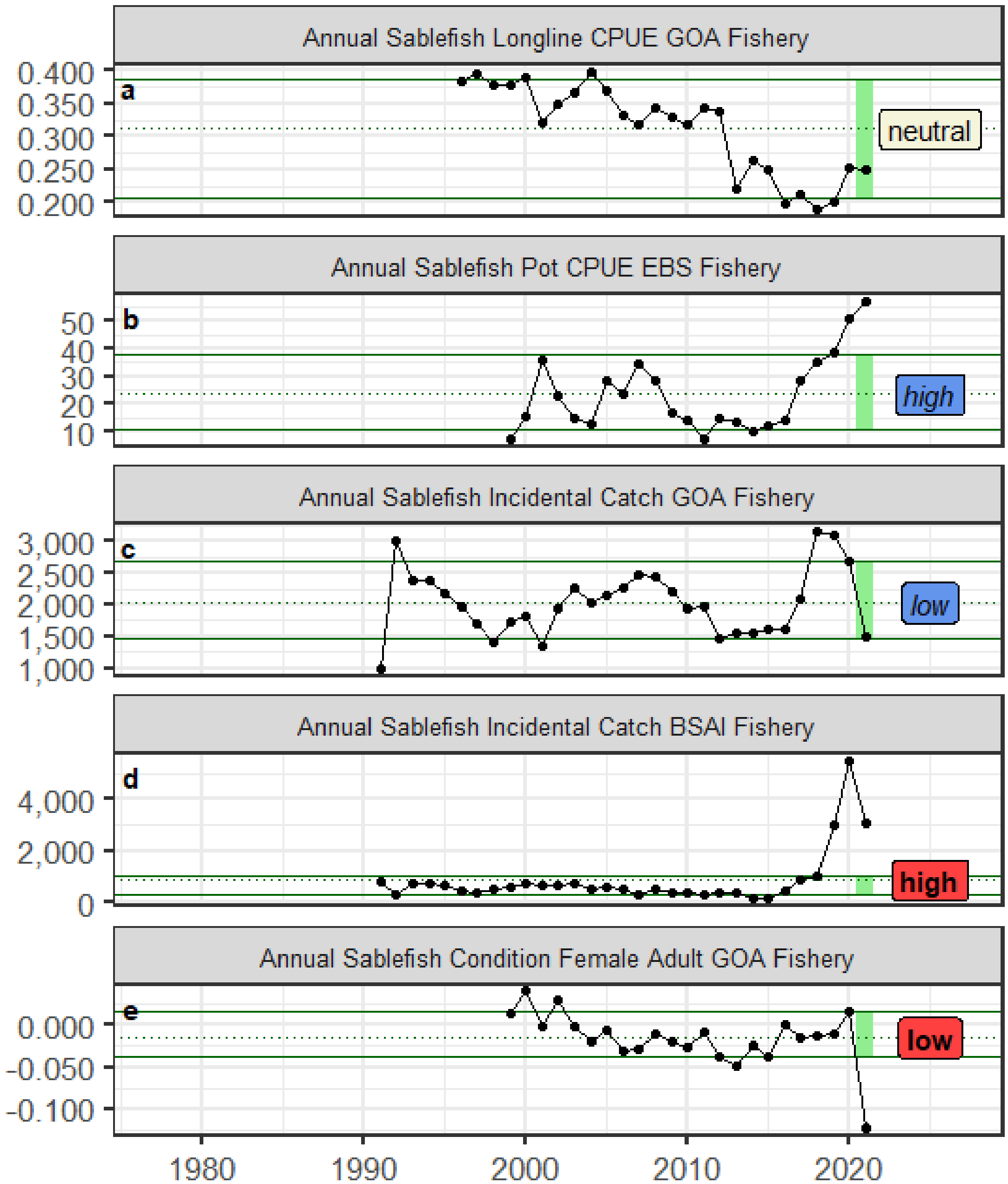


Figure 3C.2b. Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the most recent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

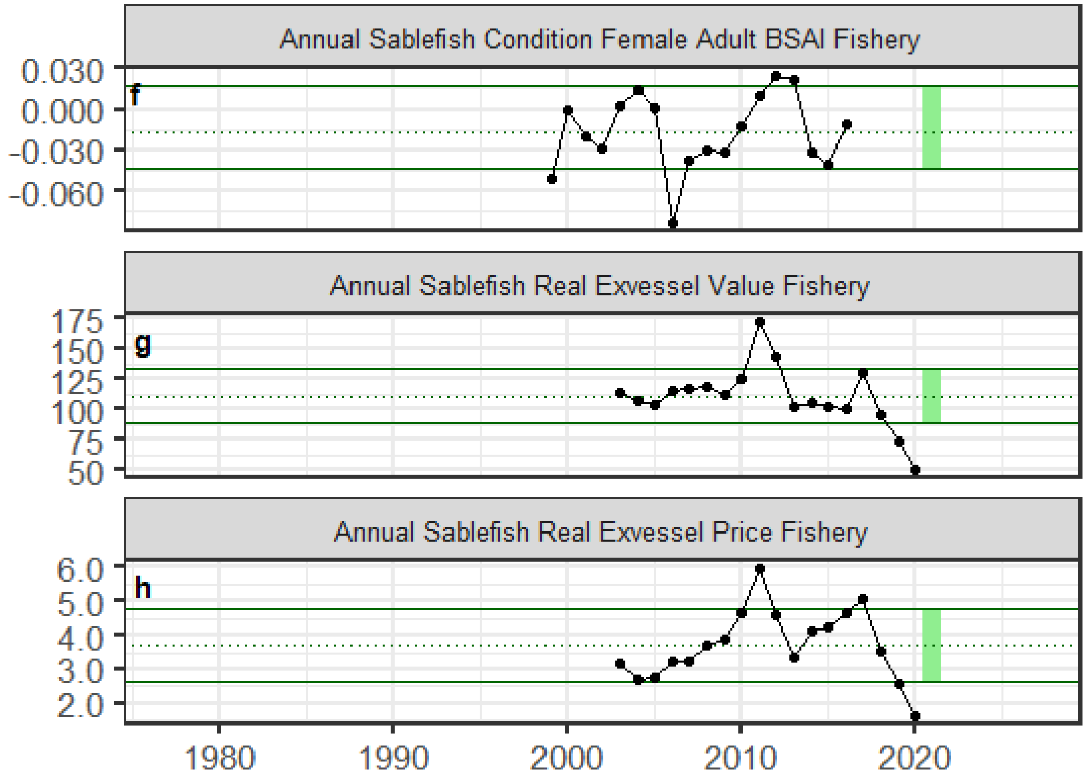


Figure 3C.2b (cont.). Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the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

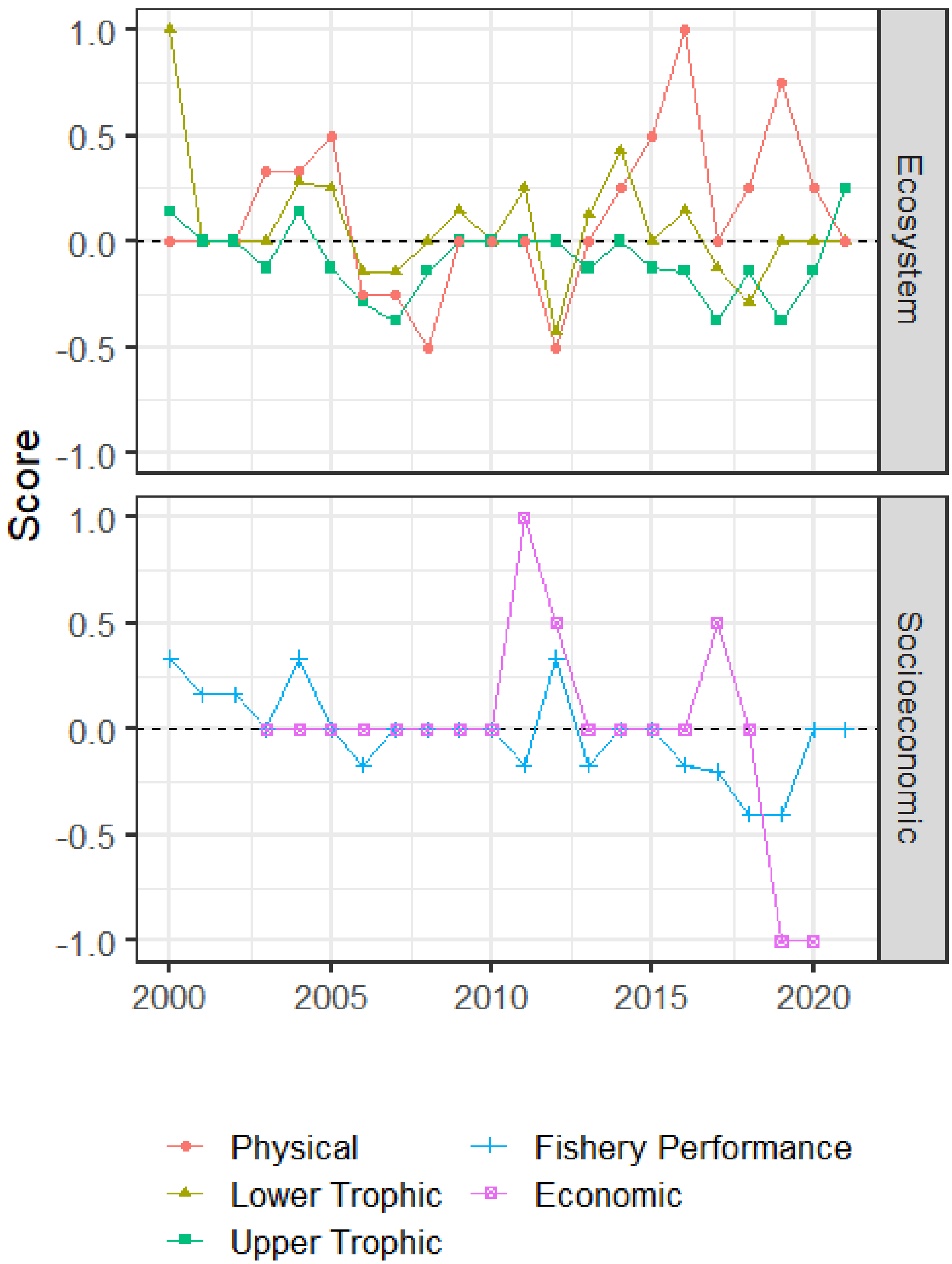
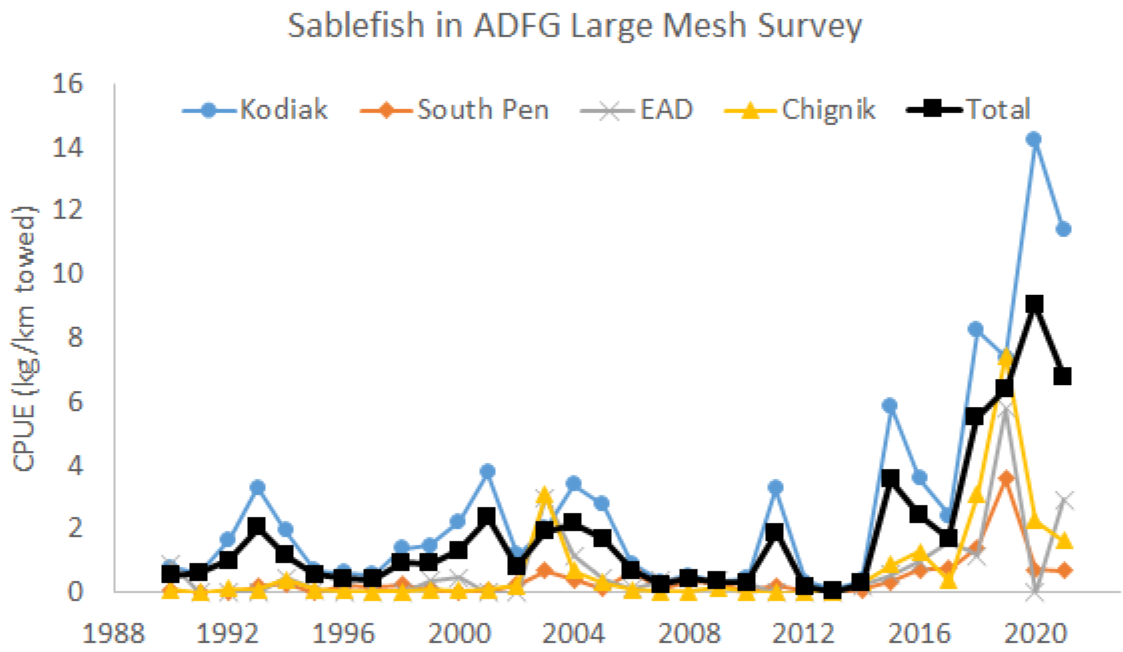


Figure 3C.3: Simple summary traffic light score by category for ecosystem and socioeconomic indicators from 2000 to present



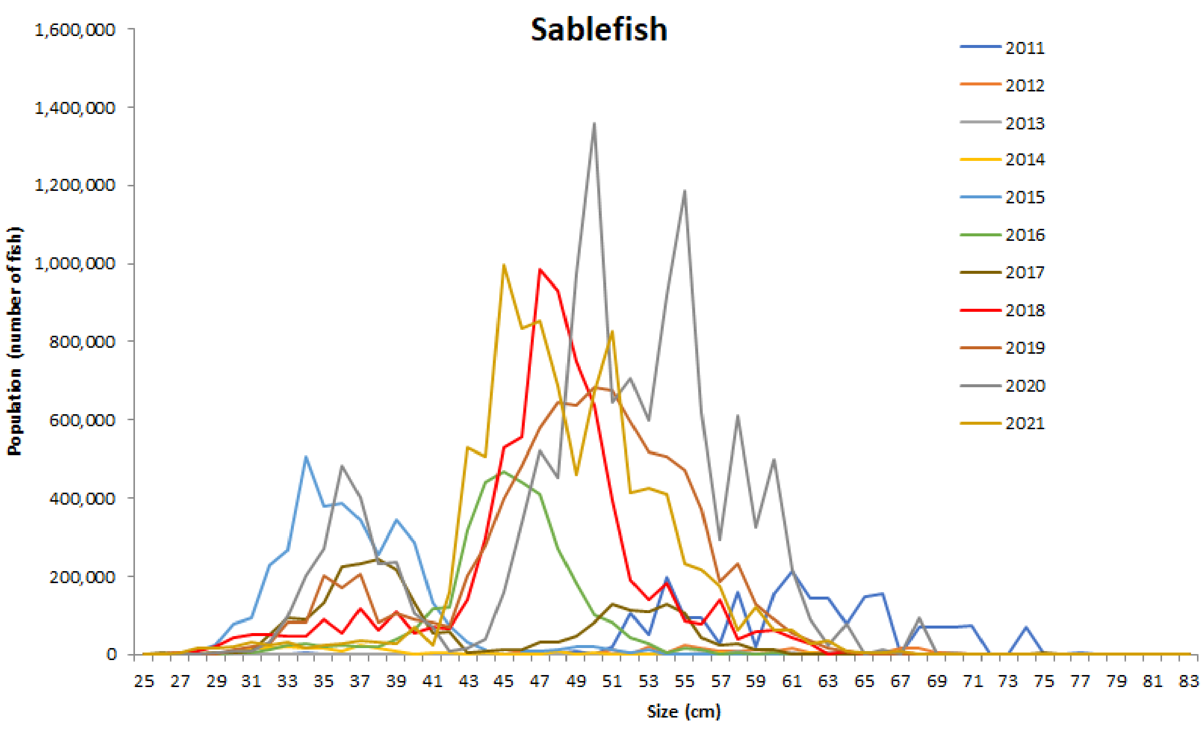


Figure 3C.4: Catch-per-unit-effort from 1990 to present and length (cm) composition (bottom graph) from 2011 to present of sablefish in the ADF&G large-mesh survey (EAD = Eastern Aleutians District).

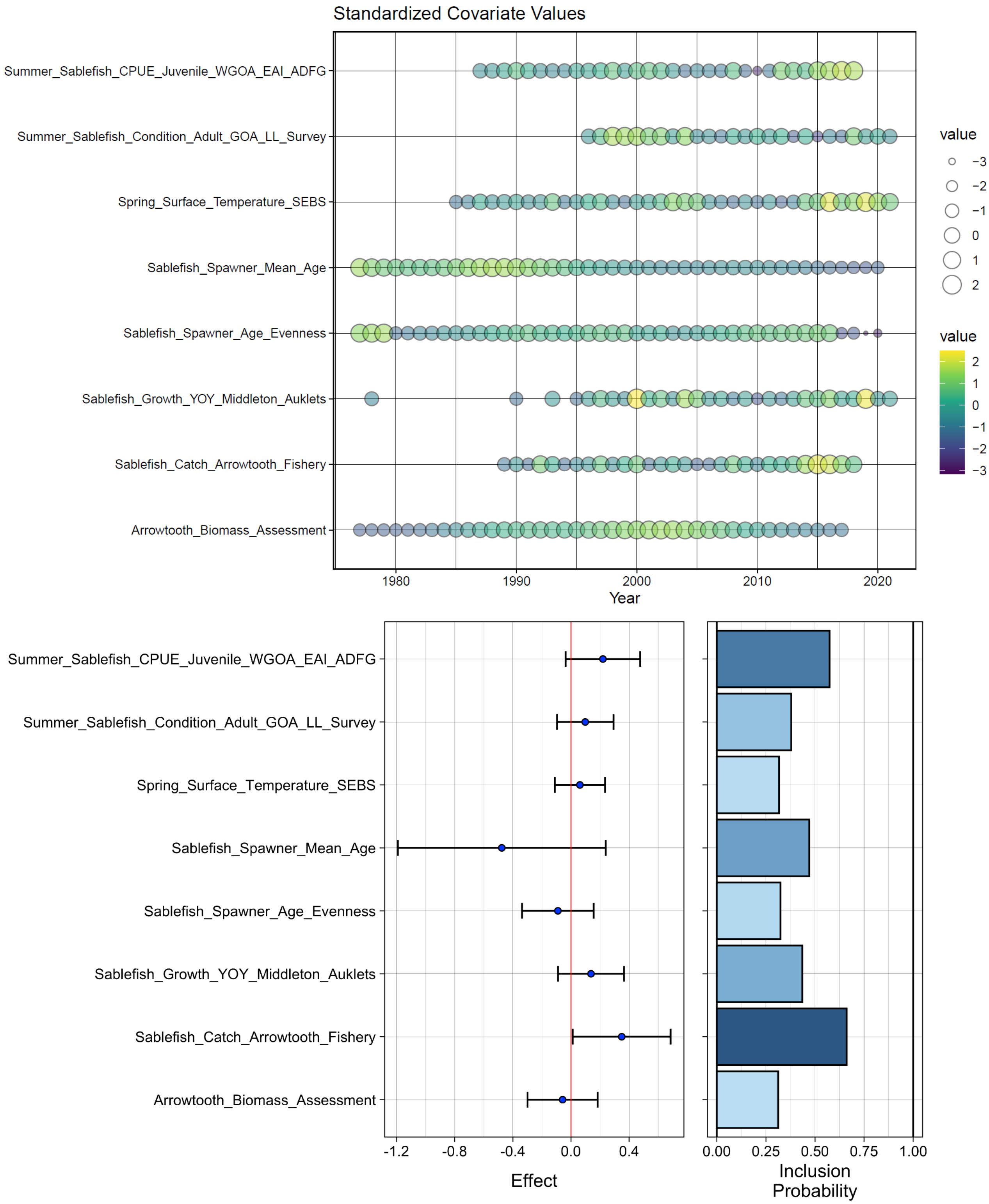


Figure 3C.5: Bayesian adaptive sampling output showing (top graph) standardized covariates and (bottom graph) the mean relationship and uncertainty (95% confidence intervals) with log sablefish recruitment, in each estimated effect (left bottom graph), and marginal inclusion probabilities (right bottom graph) for each predictor variable of the subsetted covariate set.

Appendix 3D. Trawl Catches of Small Sablefish in the Eastern Bering Sea

Recently, sablefish removals have increased dramatically in the pelagic and non-pelagic trawl fisheries occurring in the eastern Bering Sea (EBS; Goethel et al., 2020, appendix 3E). Prior to 2016, sablefish removals were relatively low in the non-pelagic trawl fisheries, and there were almost no sablefish removals in the pelagic pollock fishery (Table 3D.1). Increases in sablefish catch was particularly noticeable in the pelagic trawl fisheries occurring in the EBS in 2020, with catch in 2020 more than 7 times what it was in 2018 (Table 3D.1). In 2021, sablefish removals in pelagic trawl fisheries are still relatively high for this region, but declined to 1/3 of the high in 2020 (3,397 mt to 1,076 mt). Non-pelagic trawl fisheries continue to have relatively high levels of sablefish removals for the third consecutive year (as of 10/25/21; Table 3D.1). High removals of sablefish in pelagic trawl fisheries in 2020 were hypothesized to be age-1 fish from the 2019 year class (Goethel et al., 2020, appendix 3E). The decrease in pelagic trawl sablefish catch in 2021 may be because fish in the previously encountered large year classes have grown and are moving into deeper areas outside of the pelagic trawl fishery, and/or the 2020 year class may not be as large and is therefore not being encountered.

Observer collected lengths can be used to assess what sizes of fish are being encountered and if there have been any changes through time that may indicate the presence of different year classes. Length distributions from observer collections in the pelagic trawl fishery are similar between 2020 and 2021 (Figure 3D.1). As fish grow, they no longer are encountered in this fishery. The length distributions may not be reflective of the magnitude of year classes. In 2020, there is evidence of an influx of small fish, which were encountered in the first half of the year, possibly age-1 fish; however, the frequency of occurrence of these small fish was low. These small fish have not been evident in 2021 (Figure 3D.1). The average size of fish sampled in 2020 and 2021 are similar; the average in 2021 is only 0.8 cm larger than in 2020. Non-pelagic trawl gear encountered different sized sablefish than pelagic gear in some years. This leads to a broader length distribution than seen in pelagic trawl catch, likely because, as sablefish grow, they begin settling more closely to the bottom. The annual change in length distributions in the non-pelagic gear may be reflective of large year classes being encountered (Figure 3D.2). The lengths in 2016 are smaller, and encompass a narrow range of what is likely comprised of the 2014 year class (Figure 3D.2). The length distribution broadens in each subsequent year as more large cohorts are encountered. Beginning in 2018, there is evidence of more than one year class present in the non-pelagic trawl fishery (Figure 3D.2). As time progresses, these large year classes grow and this is reflected in the increase in the average lengths from 2018-2021. There is no evidence in the 2021 lengths of a large 2019 year class in the non-pelagic trawl fishery lengths.

When sablefish catch is present, the average weight 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). We focused on sablefish catch data in the EBS from 2015 to 2021 for non-pelagic trawl fisheries and 2016 to 2021 in the pelagic trawl fishery, due to a lack of data in 2015 from pelagic trawl gear (Table 3D.2). When the average weight for the haul was less than 0.5 kg, we assumed that age-1 sablefish were the predominant age group. The non-pelagic trawl fishery frequently encountered age-1 sablefish in 2015 and 2020, and to a lesser degree in 2017, indicating that the 2014, 2016, and 2019 year classes were more prevalent in the catch than normal (Figure 3D.3 and Table 3D.2). This is particularly visible in the 0-100 m depth strata (Figure 3D.3, top row). The pelagic trawl fishery also caught small sablefish in 2017 and 2020 in the shallow depth strata, which are the 2016 and 2019 year classes; there was no data in 2015, which precludes any information on a large 2014 year class. Following the appearance of large 2014 and 2016 year classes as age-1 in 2015 and 2017, the average weight of sablefish removals increased each subsequent year for all depths combined, suggesting that these fish continued to be intercepted as age-2, age-3, and age-4 in each subsequent year (Figure

3D.3). There was no strong evidence for a strong age-1 or age-2 year class in 2021, but since we take the average weight for a haul, these could be confounded if age classes were largely mixed.

In 2021, high sablefish removals continue to be prevalent in the non-pelagic trawl fisheries, but has declined in the pelagic trawl fishery in the EBS (Table 3D.1). However, observer data indicates that the bulk of sablefish removals in the EBS trawl fisheries consists of the ageing 2016 and 2019 year classes (Figures 3D.1 and 3D.2), and not age-1 fish from a 2020 year class (Table 3D.2). It is possible that sablefish will continue to be caught in large numbers in the EBS pelagic and non-pelagic trawl fisheries as the 2019 year class ages, and if sablefish distribution continues to overlap with areas where the walleye pollock fishery operates. (Figures 3D.4 and 3D.5). As one non-pelagic trawl fisherman stated in 2021: "*…black cod are showing everywhere. We started fishing close to Dutch Harbor and ended up almost by the Russian line and sablefish are showing in the shallow water and deep water. Something I noticed is that the fish are a little bigger."*

Tables

Table 3D1. Sablefish bycatch (t) in the non-pelagic and pelagic trawl fisheries occurring in the eastern Bering Sea.

Year	Non-pelagic	Pelagic	Total
2010	29	1	30
2011	44	0	44
2012	93	0	93
2013	133	0	133
2014	34	0	34
2015	17	0	17
2016	239	18	257
2017	588	91	679
2018	623	395	1,018
2019	1,283	1,223	2,506
2020	1,071	3,397	4,468
2021	1,248	1,076	2,324

Table 3D.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	190	77%	0	N/A
2016	204	2%	135	0%
2017	240	9%	439	43%
2018	151	1%	492	< 1%
2019	183	7%	890	< 1%
2020	123	37%	122	38%
2021	105	1%	295	< 1%

Figures

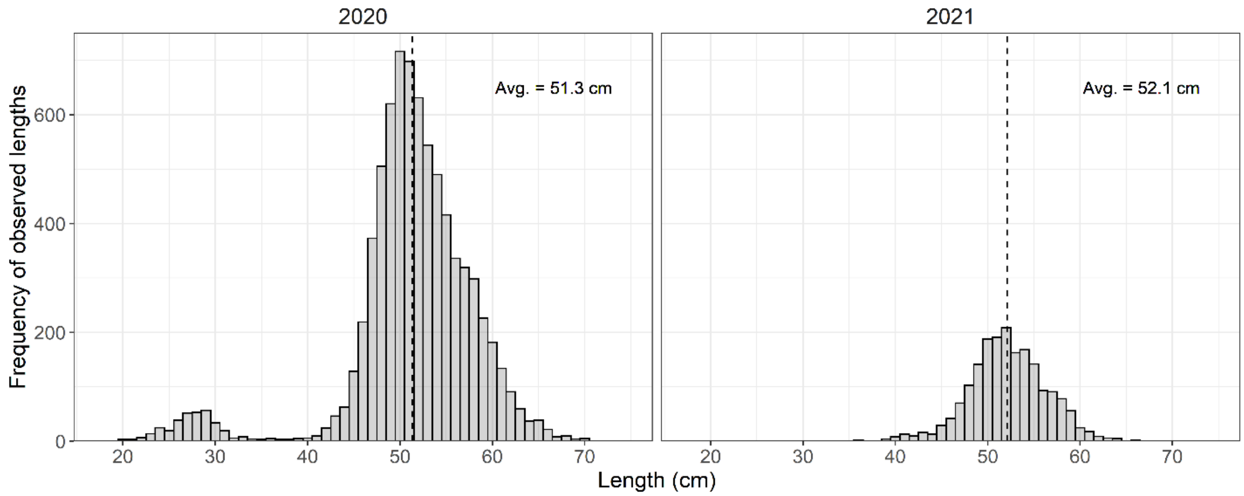


Figure 3D.1. Frequency of sablefish lengths measured by observers in eastern Bering Sea pelagic trawl fisheries. The vertical dashed line indicates the average length. Note that 2021 data are incomplete.

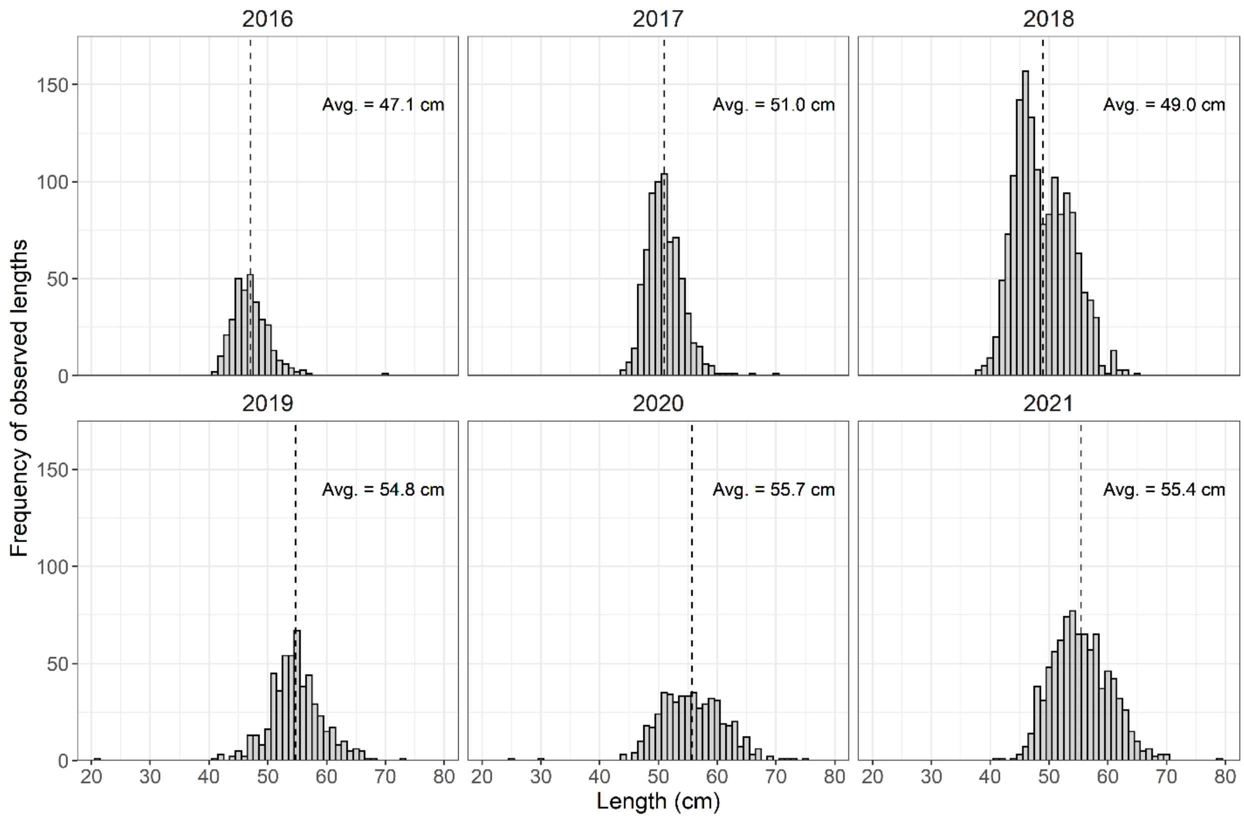


Figure 3D.2. Frequency of sablefish lengths measured by observers in eastern Bering Sea non-pelagic trawl fisheries. The vertical dashed line indicates the average length (values shown). Note that 2021 data are incomplete.

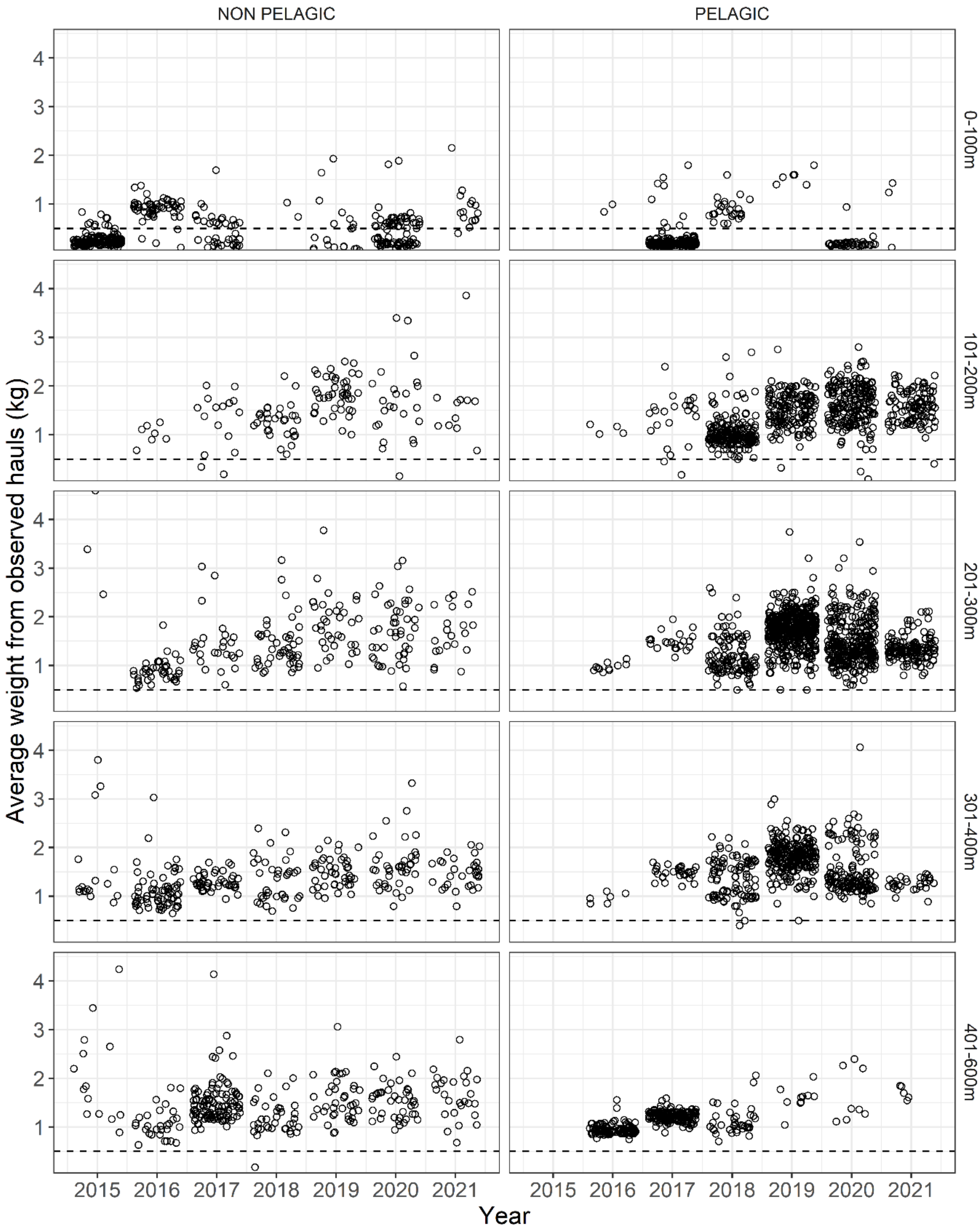


Figure 3D.3. Average weight of sablefish from observed hauls in the Eastern Bering Sea non-pelagic (left) and pelagic (right) trawl fisheries. Catches are separated by 100 or 200 m depth bins (increasing in depth from top to bottom panels). The horizontal dashed lines at 0.5 kg delineate likely age-1 sablefish dominating the catch when the point is below the line from older sablefish above the line. There was no sablefish catch data in the pelagic trawl fishery in 2015.

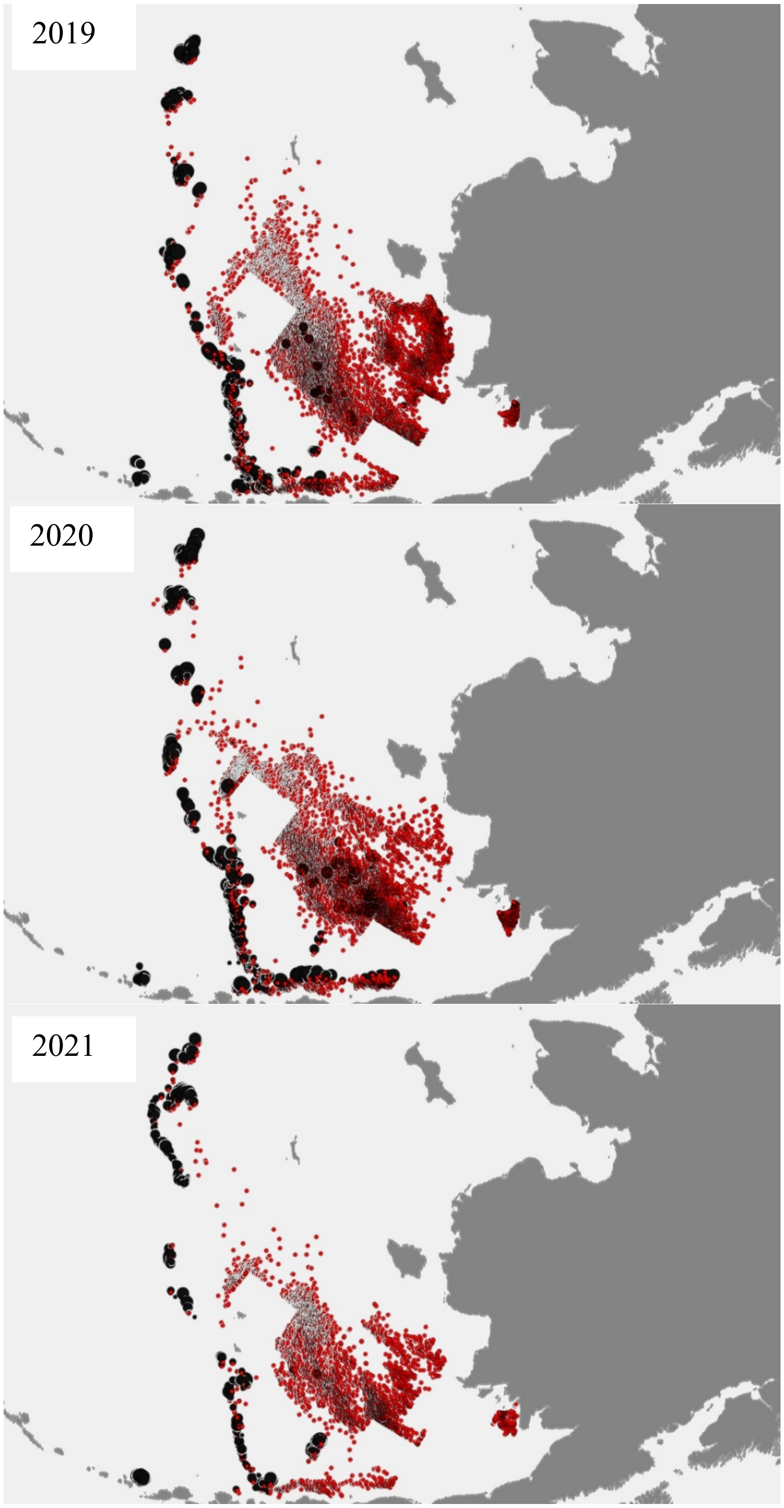


Figure 3D.4. Spatial distribution of observed sablefish bycatch (filled black circles where size reflects weight) and locations of observed non-sablefish catch (filled red circles reflect where catch occurred) in non-pelagic trawl gear in the eastern Bering Sea from 2019 to 2021. Data provided by the 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.

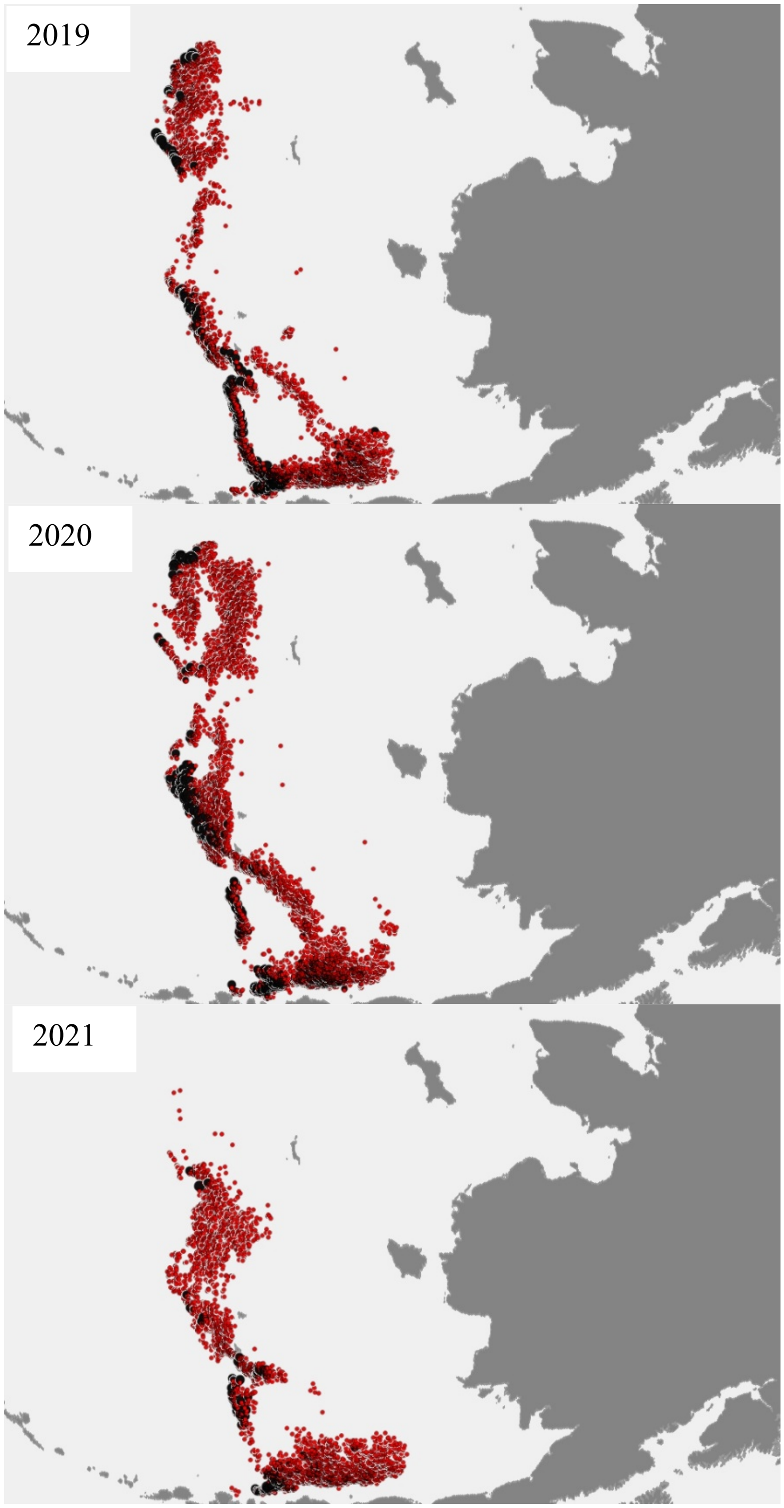


Figure 3D.5. Spatial distribution of observed sablefish bycatch (filled black circles where size reflects weight) and locations of observed Pollock catch (filled red circles reflect Pollock catch occurred) in pelagic trawl gear in the eastern Bering Sea from 2019 to 2021. Data provided by the NORPAC 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.

Appendix 3E. Updated Growth Analysis for Alaska Sablefish

Katy Echave

October 2021

Executive Summary

The Science and Statistical Committee (SSC) at the December 2020 North Pacific Fishery Management Council (NPFMC) meeting requested that the authors "consider including time-varying or cohort-specific maturity curves, and/or weight-at-age relationships if supported by the data." Results addressing this request were presented at the NPFMC Joint Groundfish Plan Team (JPT) meeting in September 2021. The JPT and subsequently the SSC (October 2021) recommended "incorporating updated length and weight at age resulting from the growth modeling for the recent time period (1996-present) to reflect the full extent of available data" (Echave 2021) as they were presented. This recommendation maintains separate growth estimates during the 1981 – 1993 bias corrected length-stratified time period that was incorporated into the 2008 stock assessment (Hanselman et al. 2007). Following this recommendation, the JPT and SSC requested additional work "modeling weight at age in the same time blocks as used for length at age." Because no weight data was collected prior to 1996, the current weight at age parameter estimates used in the sablefish assessment are calculated from 1996-2004 data, and applied to the entire time series (1960 - present, Hansleman et al. 2007, Goethel et al. 2020). Our updated weight analyses showed smaller maximum weights and faster growth during the historic (1981-1993) time period than what is currently applied in the assessment. However, because estimating growth using length stratified bias corrected mean length at age can produce less reliable parameter estimates (Perreault et al. 2020), in addition to the absence of weight data, we recommend that the updated weight information for the 1996-2019 time period continue to be applied to the entire time series. Our final recommendation for the 2022 sablefish stock assessment is to include growth information divided into two time periods (1981 - 1993, 1996 - 2019), and to apply updated weight information using the recent 1996-2019 data to the entire time series (1981 – present), for both males and females. This new information provides the most biologically plausible information to include in the stock assessment that accounts for the changing ecosystem and abundance of sablefish.

Introduction

Growth parameters for Alaskan sablefish have not been updated since Hanselman et al. (2007). For use in the 2008 sablefish stock assessment, the updated growth information from the longline survey was divided into the two time periods, 1981-1993 and 1996-2004, but weight-at-age was only estimated for 1996-2004 data because no weight data was collected on the longline survey prior to 1996. The choice of where to split growth regimes was not based on a visible shift in growth at that time, but on a change in sampling design on the longline survey (Hanselman et al. 2007). Data collected after 1996 were collected under a random sampling design, and sampling did not occur in all sablefish management areas during 1994-1995 (Rutecki et al. 2016). Since the last update of sablefish growth, there have been several above average year classes of sablefish (Goethel et al. 2020) coupled with extreme warming conditions in both the Gulf of Alaska (GOA) and Bering Sea (Bond et al. 2015, Di Lorenzo and Mantua 2016). For these reasons, it was requested that the authors "consider including time-varying or cohort-specific maturity curves, and/or weight-at-age relationships if supported by the data" (SSC, Dec. 2020). An updated analysis of sablefish growth was presented to the JPT (Sept. 2021) and SSC (Oct. 2021; Echave 2021), and both agreed with the authors that length and weight at age should be updated to reflect the full extent of available data (1996-present). It was then requested by both the JPT (Sept. 2021) and SSC (Oct. 2021) that there should be consistency in modeled time-variation between weight at age and length at age, i.e. authors should estimate weight at age for the 1981-1993 time period. Here we present results of the estimated weight at age parameters during the 1981-1993 time period, as well as all updated growth parameters to be used in the 2022 sablefish assessment (Echave 2021).

Methods

Length-at-Age Analysis

From 1981-1993, ages were sampled under a length-stratified design (a pre-determined number of otolith pairs were collected for each length). Estimates produced from length-stratified data create biased estimates of mean length at age for the population. This bias is caused by ageing smaller and larger specimens more often than would be aged under a random sampling design. This results in the mean size-at-age for early age groups to be too small, while the mean-size-at-age for the oldest age groups is too large (Goodyear 1995, Sigler et al. 1997, Bettoli and Miranda 2001). In order to correct this bias in the length-stratified data (1981-1993), we considered the length data for all years to be a random sample from the longline survey and used the samples to create bias corrected age-length samples of the 1981–1993 data, using the following method (Bettoli and Miranda 2001):

$$\overline{L_i} = \frac{\sum N_j(\frac{n_{ij}}{n_j})l_i}{N_i} \qquad \textbf{(Eq. 3E.1)}$$

where $\overline{L_i}$ is the mean length-at-age *i, l_j* is the length-at-age in subsamble *j*, N_j is the number of fish in the *j*th length-group, n_j is the number of fish subsampled in the *j*th length-group, n_{ij} is the number of fish in the *i*th age group and the *j*th length group, and N_i is the number of fish in the *i*th age group over all *j* length-groups. Fish age 31 years and older were pooled together into a 31+ age category (Hanselman et al. 2006). The von Bertalanffy (LVB) age-length model was fitted to bias corrected mean length at age data from 1981–1993 by nonlinear least squares,

$$L_a = L_\infty\left(1 - e^{-K(t-t_0)}\right) + \varepsilon_a \qquad \textbf{(Eq.3 E.2)}$$

where ε_a is an additive error term, and L_∞, κ, and t_o are model parameters. L_∞ represents the average maximum length, κ describes the mean growth rate, and t_o describes the mean theoretical age a fish would have been zero length (McDevitt 1990, Quinn & Deriso 1999). These methods and bias corrected LVB parameters have previously been approved and incorporated into the 2008 sablefish assessment (Hanselman et al. 2007).

Weight-at-Age Analysis

To obtain weight-at-age estimates for the historic time period (pre-1996), we first had to estimate the length-weight relationship with randomly collected length-weight data from 1996-2019 time period using the typical nonlinear allometric relationship:

$$\widehat{W} = \alpha L^\beta \varepsilon \qquad \textbf{(Eq.3 E.3)}$$

Here length *L, α,* and *β* are parameters estimated using non-linear least squares procedures. This equation was then combined with the bias-corrected length-at-age relationship to construct the LVB weight at age model (Quinn and Deriso 1999). Due to high parameter correlation with only one dependent variable, it is usually difficult to fit all four parameters at once, so a convenient method is to fix the allometric parameter *β*, determined from the length-weight relationship as a fixed parameter (Quinn and Deriso 1999). For this data set, there was a multiplicative error structure, so we log-transform the LVB model to:

$$\ln\widehat{W}_a = ln\, W_\infty + \beta\ln\left(1 - e^{-K(t-t_0)}\right) + \varepsilon_a \qquad \textbf{(Eq. 3E.4)}$$

where ε_a is a multiplicative error term, and ln W_∞ is exponentiated to obtain the estimate of W_∞. Nonlinear least squares was used to determine the best estimates of W_∞, κ, and t_0, while β is fixed at 3.02.

Results

Current parameters used to estimate weight at age prior to 1996 in the Alaska sablefish stock assessment are estimated from 1996 - 2004 data, and then applied to the pre-1996 time period because of a lack of weight data (Goethel et al. 2020). Current maximum weights are as follows: 3.16 kg for males and 5.47 kg for females (Goethel et al. 2020). Refined estimates for the pre-1996 time period from this analysis will result in smaller maximum sizes (2.9 kg for males and 4.56 kg for females) and faster growth than what is currently used in the stock assessment model (Table 3E.1, Figure 3E.1).

Discussion

Errors in growth estimates can drastically affect the management advice produced by stock assessment models, therefore reliable methods to estimate growth model parameters are vital. While length stratified sampling is a common practice in fisheries science, as is estimating growth with this type of data, growth estimates using length stratified bias corrected mean length at age can produce less reliable parameter estimates (Le Cren 1951, Froese 2006, Perreault et al. 2020). Prior to 2008, observed average weight at age was used from sablefish weight estimates (Sasaki 1985) since no weight data were collected prior to 1996. When growth was reevaluated in 2007, the newly estimated length-weight relationship (1996-2004 data) was applied to the bias corrected length at age relationship to obtain weight at age estimates for the pre-1996 time period, similar to what is presented in this document. However, when the authors attempted to separate the weight at age relationships into the same time periods as length at age (1981-1993 and 1996-2004), the assessment model fit was worse than simply using the new (1996-2004) weight at age data. Ultimately, the authors did not recommend using the separate weight at age models in the same two time periods as growth (Hanselman et al. 2007). The assessment model with updated growth in two time periods (1981-1993 and 1996-2004) and updated weight in one time period (1996-2004) was recommended, and approved (Hanselman et al. 2007).

Similarly, while our analysis revealed large differences in our parameter estimates versus what is used in the assessment, we do not recommend incorporating additional time blocks of weight into the sablefish assessment. Estimating growth using length stratified bias corrected mean length at age can produce less reliable parameter estimates (Perreault et al. 2020), as can estimating weight at age using length-weight data. An increase of an estimated maximum weight of ~1 kg between two time periods is likely more of an artifact of the data collection and growth modeling procedures, than from biological reasons. While using bias corrected length at age estimates was approved for the historic time period (Hanselman et al. 2008), the absence of weight data increases the unreliability of the weight at age estimates. For these reasons, we recommend that sablefish weight continued to be estimated using one time block, using the updated weight information for the 1996-2019 time period. Our final recommendation for the 2022 Alaska sablefish stock assessment is to include growth information divided into two time periods (1981-1993, 1996-2019), and to apply updated weight information using the recent 1996-2019 data to the entire time series (1981 – present), for both males and females (Table 3E.2). This new information provides the most biologically plausible information to include in the stock assessment that accounts for the changing ecosystem and abundance of sablefish.

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Tables

Table 3E.1. Estimated weight-at-age growth parameters with standard errors provided in parentheses for sablefish sampled during specified time periods.

Sex	Parameters	1981-1993[1]	1996-2004[2]	1996-2019[3]
Female	W_∞	4.60 (0.36)	5.47 (0.05)	5.87 (0.04)
	k	0.22 (0.03)	0.238 (0.005)	0.17 (0.002)
	t_o	-3.25 (0.24)	-1.39 (0.07)	-2.98 (0.06)
	n	4,788	5,767	15,358
Male	W_∞	2.92 (0.31)	3.16 (0.02)	3.22 (0.01)
	k	0.21(0.02)	0.356 (0.01)	0.27 (0.002)
	t_o	-4.68 (0.57)	-1.13 (0.09)	-2.41 (0.07)
	n	3,429	4,889	13,392

[1]Estimated parameters for the 1981-1993 time period, as presented in this paper.
[2]Weight-at-age parameters currently used in the sablefish stock assessment (Goethel et al. 2020).
[3]Recommended parameters to be applied to all time periods in the 2022 sablefish stock assessment (Echave 2021).

Table 3E.2. Final recommended growth parameters to be used in the 2022 Alaska sablefish stock assessment.

1981 - 1993	1996 – Current
Length at Age: Female	
$L_a = 75.5\left(1 - e^{-0.208(a+3.62)}\right) + \varepsilon_a$	$L_a = 81.2\left(1 - e^{-0.17(a+3.28)}\right) + \varepsilon_a$
Length at Age: Male	
$L_a = 65.2\left(1 - e^{-0.2(a+4.09)}\right) + \varepsilon_a$	$L_a = 67.9\left(1 - e^{-0.23(a+3.3)}\right) + \varepsilon_a$
Weight at Age: Female	
$\ln\widehat{W}_a = \ln(5.87) + 3.02\ln\left(1 - e^{-0.17(a+2.98)}\right) + \varepsilon_a$	
Weight at Age: Male	
$\ln\widehat{W}_a = \ln(3.22) + 3.02\ln\left(1 - e^{-0.27(a+2.41)}\right) + \varepsilon_a$	

Figures

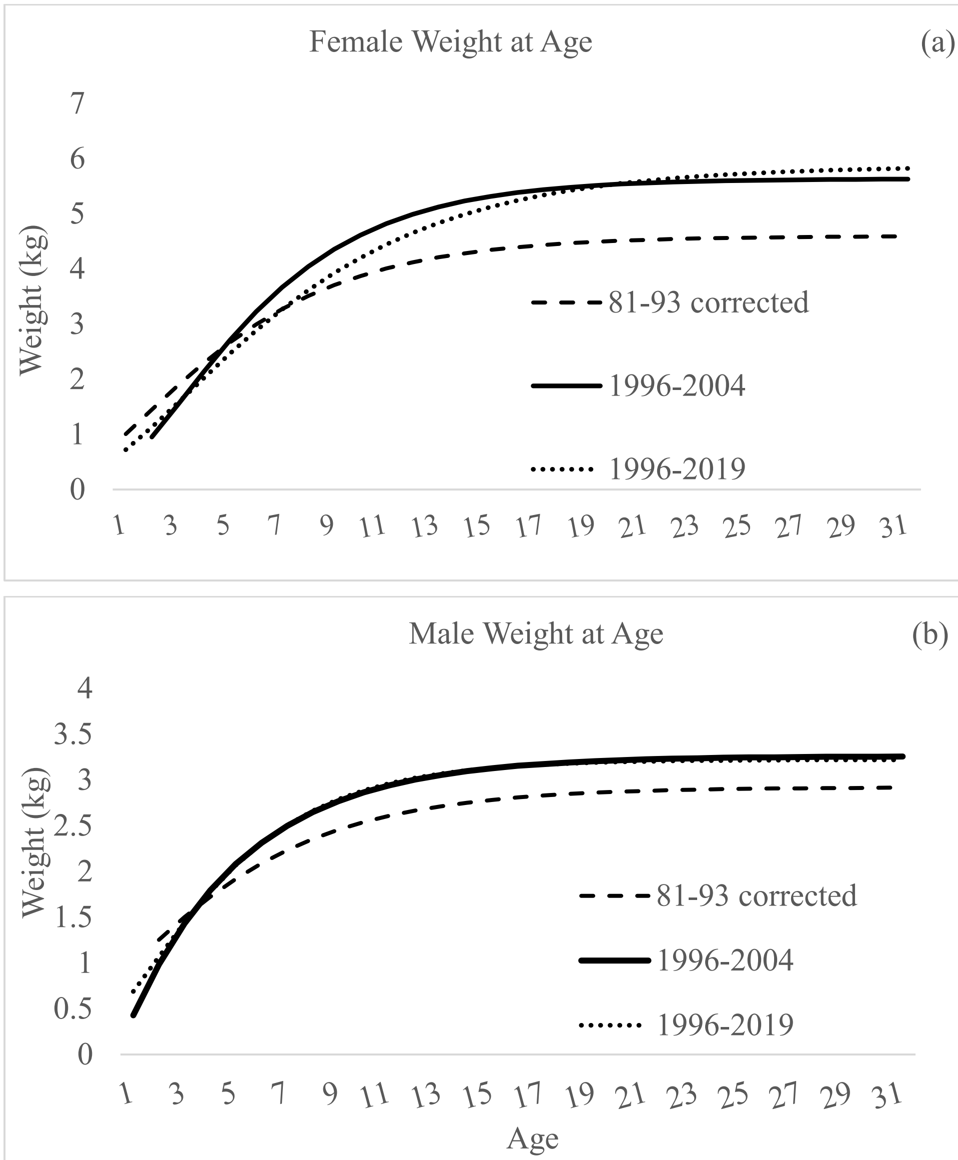

Figure 3E.1. Comparison of estimated weight-at-age growth curves for females (a) and males (b). The 1981-1993 corrected growth curve is from the analysis presented in this document, the 1996 - 2004 is what is currently used in the sablefish stock assessment (Goethel et al. 2020), and the 1996 - 2019 weight-at-age curve is what is being recommended to apply to all time periods for use in the 2022 Alaska sablefish stock assessment.

Appendix 3F. Updated Maturity Analysis for Alaska Sablefish

Ben Williams and Cara Rodgveller

September 2021

Introduction

The current female age-at-maturity model used in the Alaska stock assessment was estimated using macroscopic maturity determination methods on samples collected during summer surveys from 1978-1983 (Sasaki, 1985). Many factors may make these maturity data outdated or an inaccurate estimate of maturity. Macroscopic evaluations of maturity can be inaccurate because the stage of oocytes can be difficult to discern without the aid of histology (Hunter et al., 1992). In addition, these maturity data were categorized by fish length, which were later converted to ages for the stock assessment. It has also been observed that maturity determination for sablefish collected during the summer, 6-8 months prior to the winter spawning season (Sigler et al. 2001; Rodgveller et al. 2016), can be too early for accurate determinations of maturity during some months, because oocytes have not started to mature in all fish that will spawn (Rodgveller 2018).

To obtain more up-to-date maturity estimates and explore changes in sablefish maturity among years, sablefish ovaries were collected in December 2011 and 2015 in the Central Gulf of Alaska (GOA) for a study of age at maturity and fecundity (Rodgveller et al. 2016). Additionally, in the summer of 2015 female sablefish were collected on the Alaska Fisheries Science Center summer longline survey. Fish caught earlier than August did not consistently show signs of development towards spawning and skip spawners and immature fish could not reliably be differentiated from spawning fish. Fish collected in August did show signs of development towards spawning and immature fish could be separated because there was a gap in oocyte development between the immature and developing fish. Therefore, for the summer longline survey we have only included samples from August in this analysis. Using histological (microscopic) methods, skip spawning female sablefish (i.e. mature fish that will not spawn) were identified for the first time. Estimates of age at maturity and spawning stock biomass were affected by whether or not skip spawning fish were considered in maturity models (Rodgveller et al. 2018). Skipping rates of mature fish, those that have spawned in the past and are not in the current season, differed between these sampling years (a high of 21% in 2011 and 2 – 6% in 2015).

When skip spawning is present, logistic regression will generally fail to accurately represent the true proportion mature at a given age (Trippel and Harvey 1991). There have been some recent advancements to address skip spawning using the gonadosomatic index (Flores et al., 2014) or splines (Head et al., 2020), but in this examination we utilize generalized additive models (GAM), which are akin to the methods of Head et al. (2020). In this study, simulation analysis is used to generate maturity curves with skip spawning to examine the effects of skip spawning on maturity estimation using GAMs and general linear models (GLMs) along with the potential effects of not addressing the presence of skip spawning. Methods were then applied to sablefish samples from 2011 and 2015 to determine appropriate methods for incorporating skip spawning and the effects of including it or ignoring it on the resulting estimates of spawning stock biomass (SSB).

Methods

Simulations

Parameters for female maturity at age, maturity at length, length at age and weight at age were obtained from the 2020 sablefish stock assessment and fishery evaluation (SAFE, Goethel et al., 2020). A

Bernoulli random variable was generated ten thousand times for each simulated age, where a value of 1 is mature and 0 is immature, using the probability of being mature-at-age (m_a) from the SAFE (page 40). Similarly, a Bernoulli random variable was generated for 2, 5, and 10% skip spawning between ages 5 and 22, which is the age range where fish were found to skip spawn in collections made in 2011 and 2015, where a value of 1 indicates skip spawning and the functional maturity is 0 (effectively immature). Maturity was estimated using logistic regression (GLM) and a GAM with a logit link on 250 randomly sampled individuals by age, length, or age and length. Additionally, the true maturity-at-age (length) was estimated by summing the number mature by the sample size using the full dataset (10,000 x number of ages). Resulting maturity curves were examined graphically. Additionally, the root mean squared error is provided.

Sablefish Maturity

Sablefish maturity was estimated using all samples from the 2011 and 2015 collections with a GLM and a GAM on age, length, and age-length models using a binomial family with a logit link; knots were unconstrained for GAMs. The age-length models used the following forms:

GLM: maturity ~ age x length

GAM: maturity ~ s(age) + s(length).

The resulting maturity curves for sablefish were incorporated into the stock assessment model for examination of any changes to spawning biomass estimates.

Results

Simulations

Note that for clarity only simulations based upon 5% skip spawning are presented. Based upon simulation analysis, if skip spawning is present and a GLM is used to determine maturity-at-age then the maturity rate of younger fish will typically be overestimated followed by an underestimation of the true maturity rate. A GAM more accurately reflects the true maturity rate (Figure 3F.1). This same trend holds true for maturity-at-length (Figure 3F.2). Maturity models that account for age and length provide similar results (Figure 3F.3). If only age or length is accounted for in the model then the GAM performs best (Figure 3F.4), if the model is based upon age and length then either the GAM or GLM perform equally well for this scenario (Figure 3F.5).

Sablefish Maturity

Maturity curves at age show a substantial difference between the GAM, GLM, and current models (Figure 3F.6). When converted to maturity at age, the length-based maturity models are more similar, though discrepancies still arise (Figure 3F.7). The age/length GAM and GLM models provide similar results, which include a reduction in maturity-at-age for pre-1996 lengths from the current model and similar results for 1996-present (Figure 3F.8). Of note is the reduction in maturity at age of ages <5 for 1996-present, which has implications for SSB estimates. All of the updated maturity curves generally produce a reduction in SSB (Figure 3F.9). However, since the age-based GLM is particularly different from the current model (Figure 3F.6) it produces substantial shifts in SSB relative to all the other models (Figure 3F.9). As such, it has the greatest percent deviation and root mean square error from the base model (Figures 3F.10 & 3F.11).

Discussion

The incorporation of skip spawning redefines maturity as “functionally mature”, as opposed to “biologically mature” (Head et al. 2020), where functional maturity includes only those fish that are reproducing in the current season. Considering skip spawning fish as not functionally mature makes a meaningful difference in the shape of the maturity curve. The shape of the curve in turn affects the overall SSB generated from the assessment model. Given that a GLM cannot adequately estimate maturity from data that includes skip spawning it seems prudent to not use this type of model structure. Therefore calling the Sasaki (1985) maturity data, which is currently used in the assessment, into question as it was collected in the summer, was evaluated macroscopically, and did not include a code for skip spawning, which may all be problematic (Rodgveller 2016, 2018). The current maturity curve may be overestimating the number of spawners at younger ages as evidenced by the age, length, and age-length models for the 1996-present growth curve (Figures 3F.7 & 3F.8). The response at older ages is generally an overestimate as well.

If skip spawning were regularly present then the assessment would be well served to include this information. However, though many species worldwide have been observed to skip spawn the spatial and temporal aspects of skip spawning of sablefish in Alaskan waters has not been evaluated. If skip spawning occurs intermittently and for short periods of time it is likely unnecessary to consider it for stock assessment purposes, assuming the percent of fish at a given age is limited. If the amount of skip spawning is consistent then it may be possible to leave it unaddressed and note that there is a bias in the assessment, though it should act simply as a scalar of biological reference points. However, the limited information currently available (2 years) indicates variability is present in the annual amount of skip spawning (Rodgveller et al. 2018) and therefore should be researched further to understand the variation. Last, the maturity data were sampled from a small spatial area, which may not reflect the larger population condition. There are plans to obtain samples from the fishery in the Aleutian Islands, Central GOA, and the Eastern GOA in 2022 when the IFQ fishery opens in the spring. This is likely close to the spawning season and so ovaries will show evidence of past or imminent spawning. We hope to gather spatial data on maturity, skip spawning, and energetics for the first time. More years of data will be needed to evaluate the maturity and skip spawning rates for the population over time. Longline survey data from August in the Central GOA could be utilized more in the future with tissue collections and histological analysis of maturity status.

Overall, our recommendation would be to include skip spawning, preferably through the age/length model and prioritize research to address temporal and spatial data gaps. Adopting this model will provide a measure of maturity that incorporates changes in growth (Echave et al. 2012) and does not appear to have a substantial impact relative to the current estimate of SSB. However, the limited spatial extent and temporal variability in skipped spawning estimates led the PT and SSC to question the reliability of the maturity models that incorporated skipping. Therefore, an age-based logistic regression on macroscopically determined maturity that ignores skip spawning (i.e., utilizes biological maturity estimates) was recommended for the basis of updated maturity for the 2021 assessment. As further work to understand sablefish maturity is undertaken and more samples on skipped spawning collected, future maturity updates for the sablefish SAFE will continue to explore the potential to incorporate skipped spawning information.

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Figures

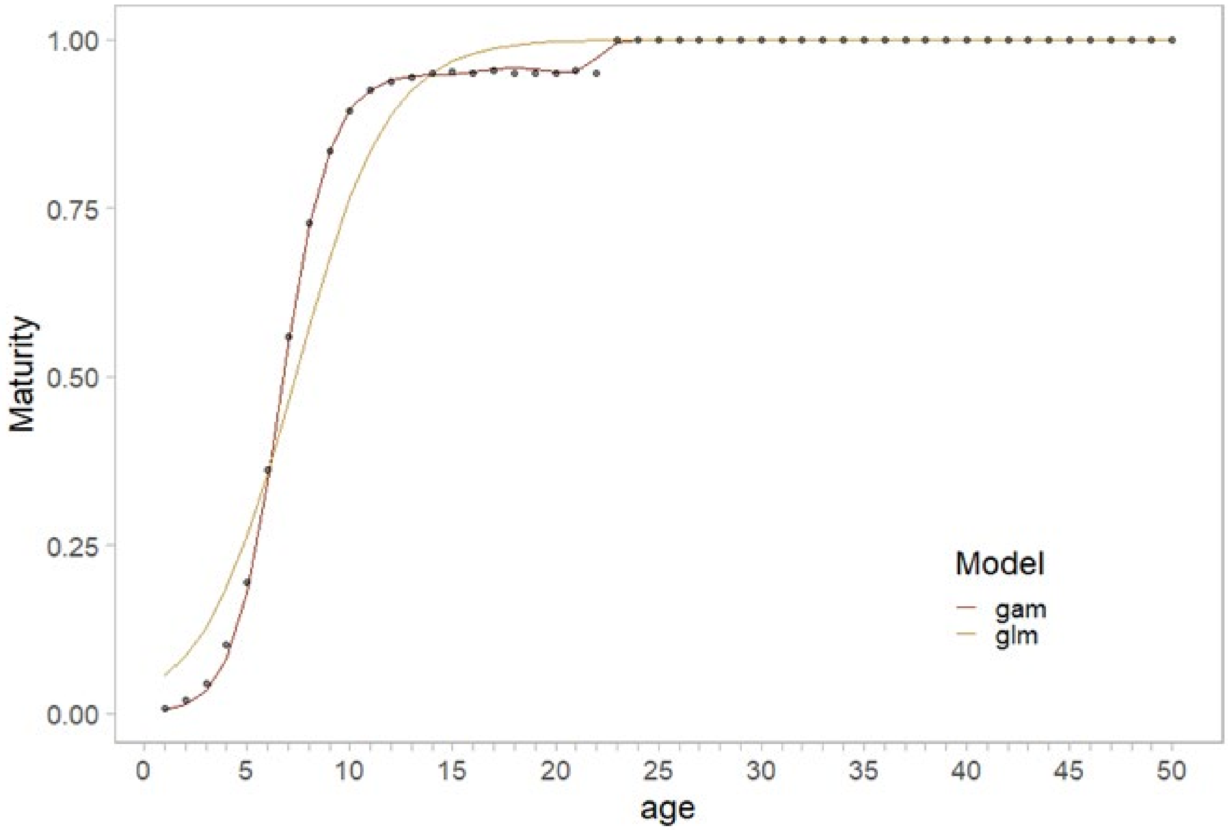

Figure 3F.1. Maturity-at-age based upon simulated maturity with 5% skip spawning between ages 5-22. The true maturity at age from the simulated data is represented by dots.

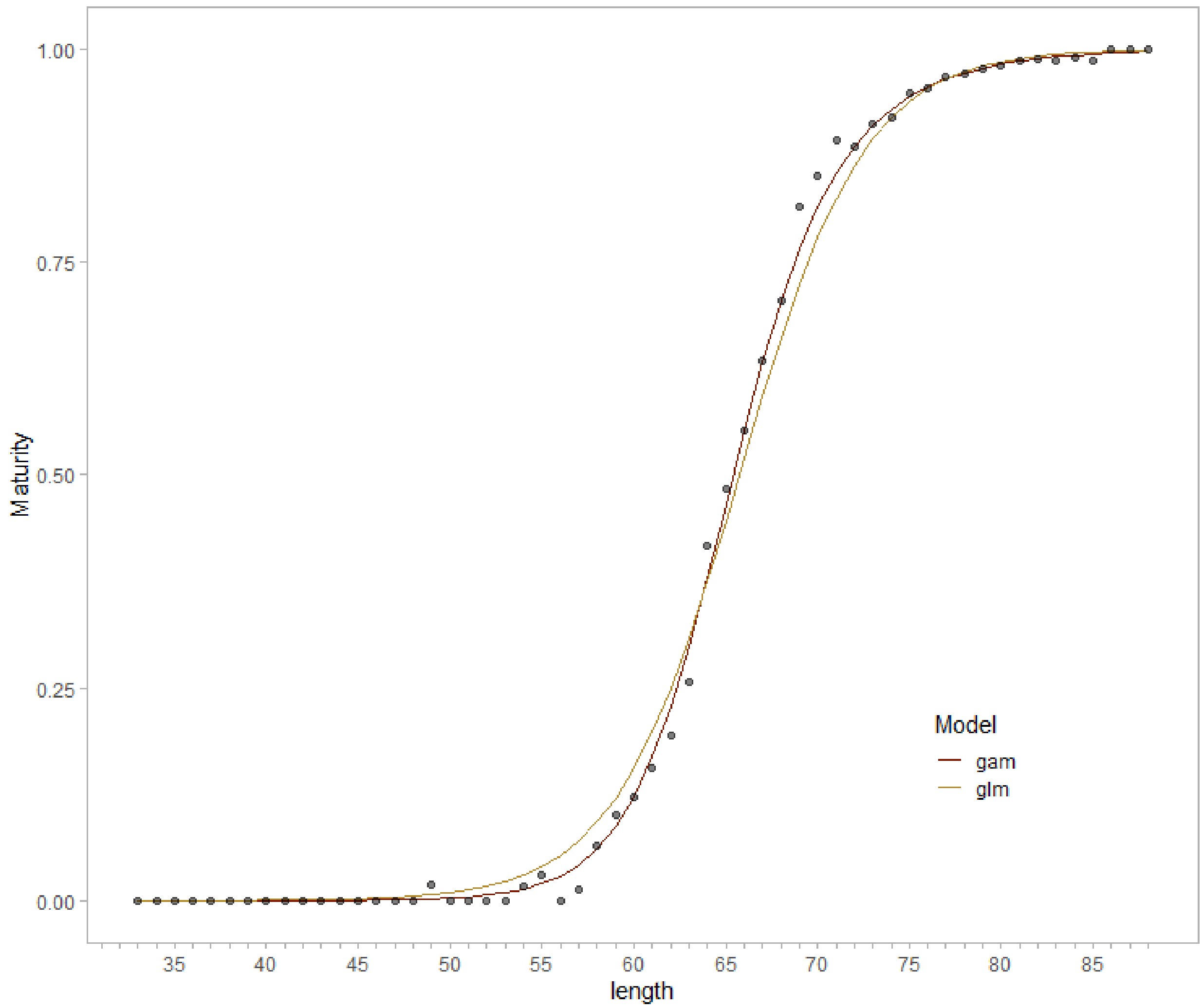

Figure 3F.2. Maturity-at-length based upon simulated maturity with 5% skip spawning between ages 5-22. The true maturity-at-length rate is represented by dots.

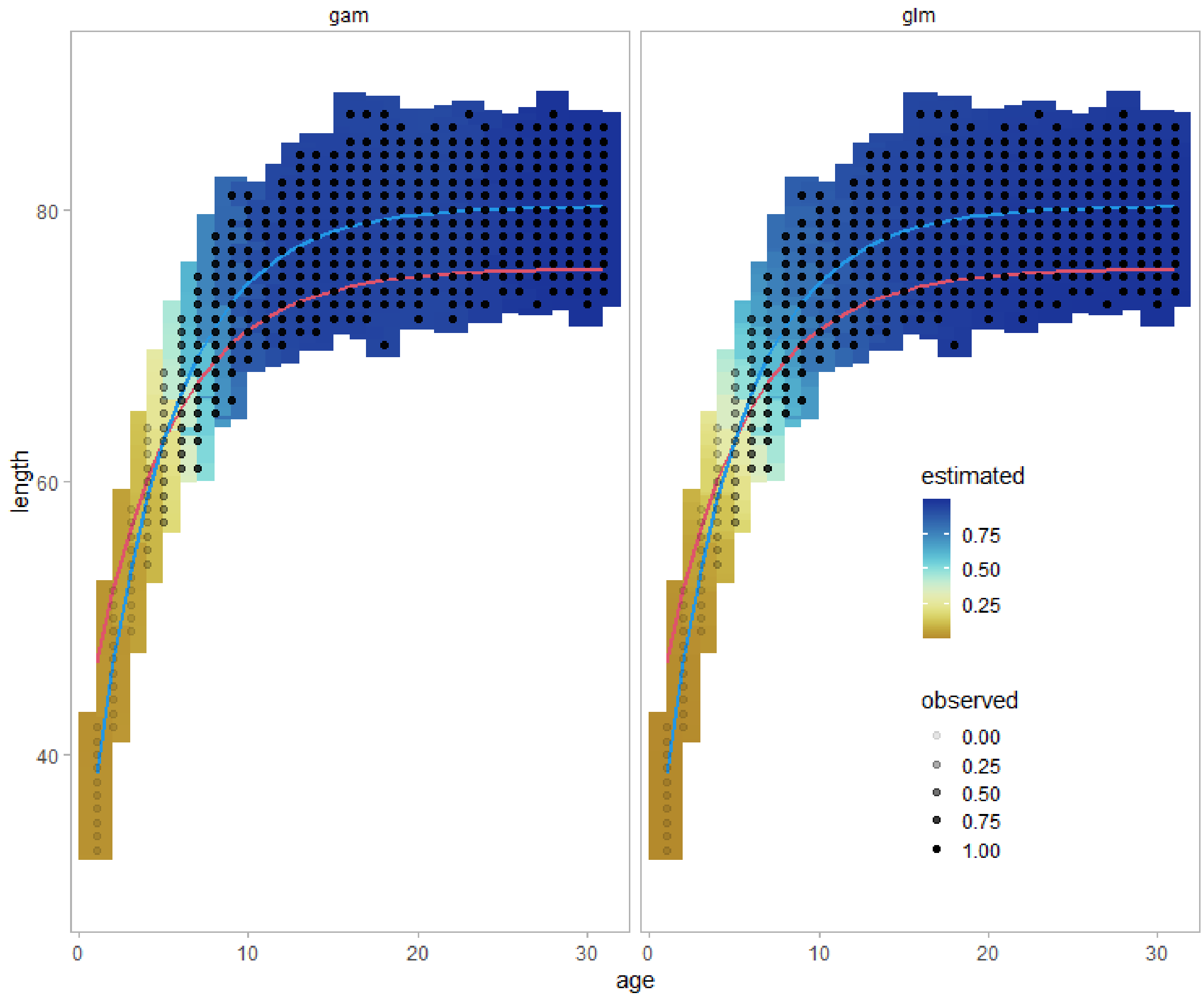

Figure 3F.3. Maturity-at-length and age based upon simulated maturity with 5% skip spawning between ages 5-22. The coloring indicates the modeled proportion mature at a given length for each age. The true maturity-at-length for each age rate is represented by dots, the shading of the dot indicates the proportion mature. The red line is the 1960-1995 growth curve and the blue line is the 1996-present growth curve from the SAFE.

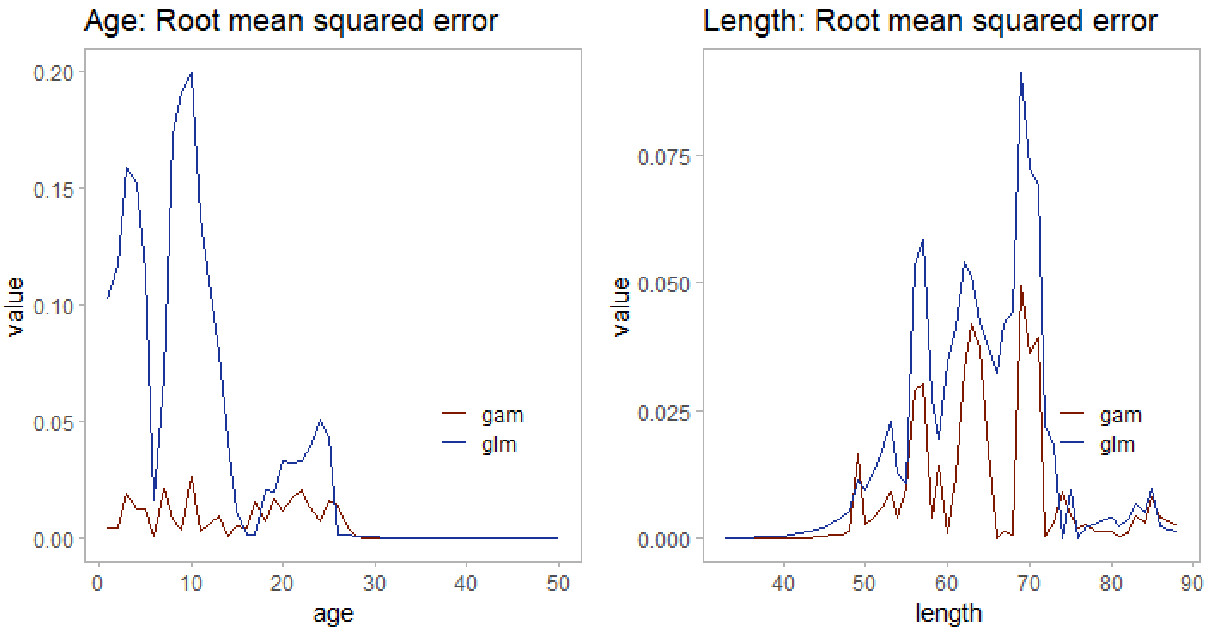

Figure 3F.4. The root mean square error of maturity estimates by age and length compared to the true maturity at age or length.

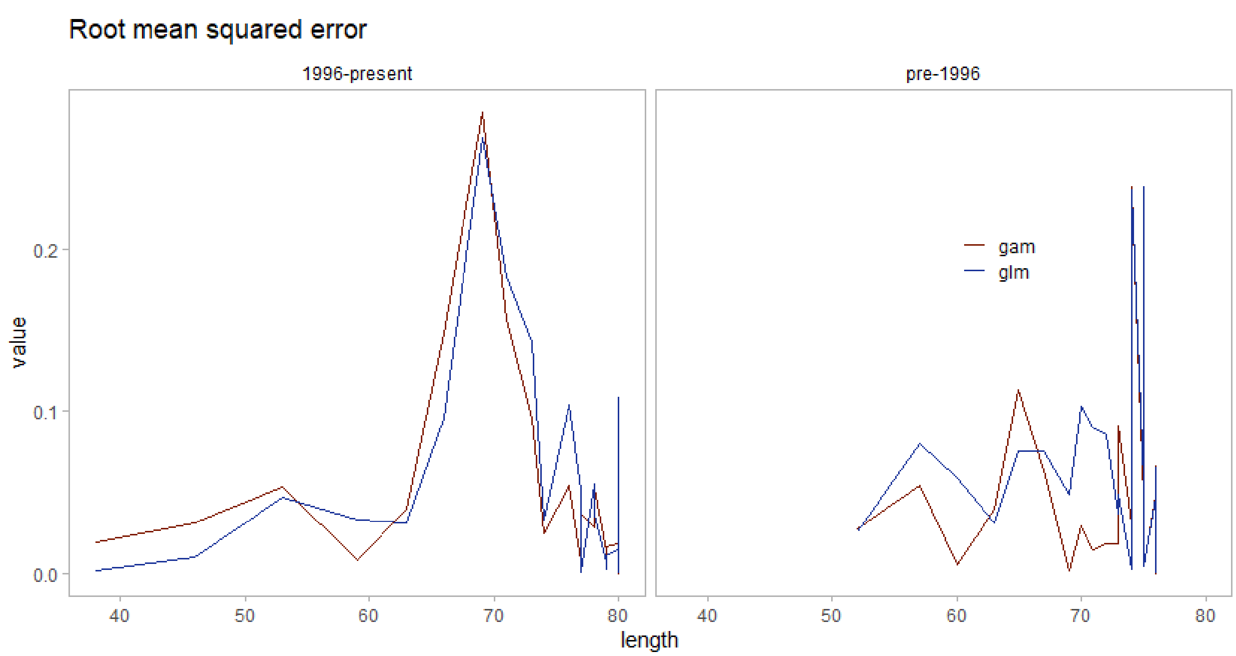

Figure 3F.5. The root mean square error of maturity estimates by age-length compared to the true maturity at age-length for the two female growth curves provided in the SAFE.

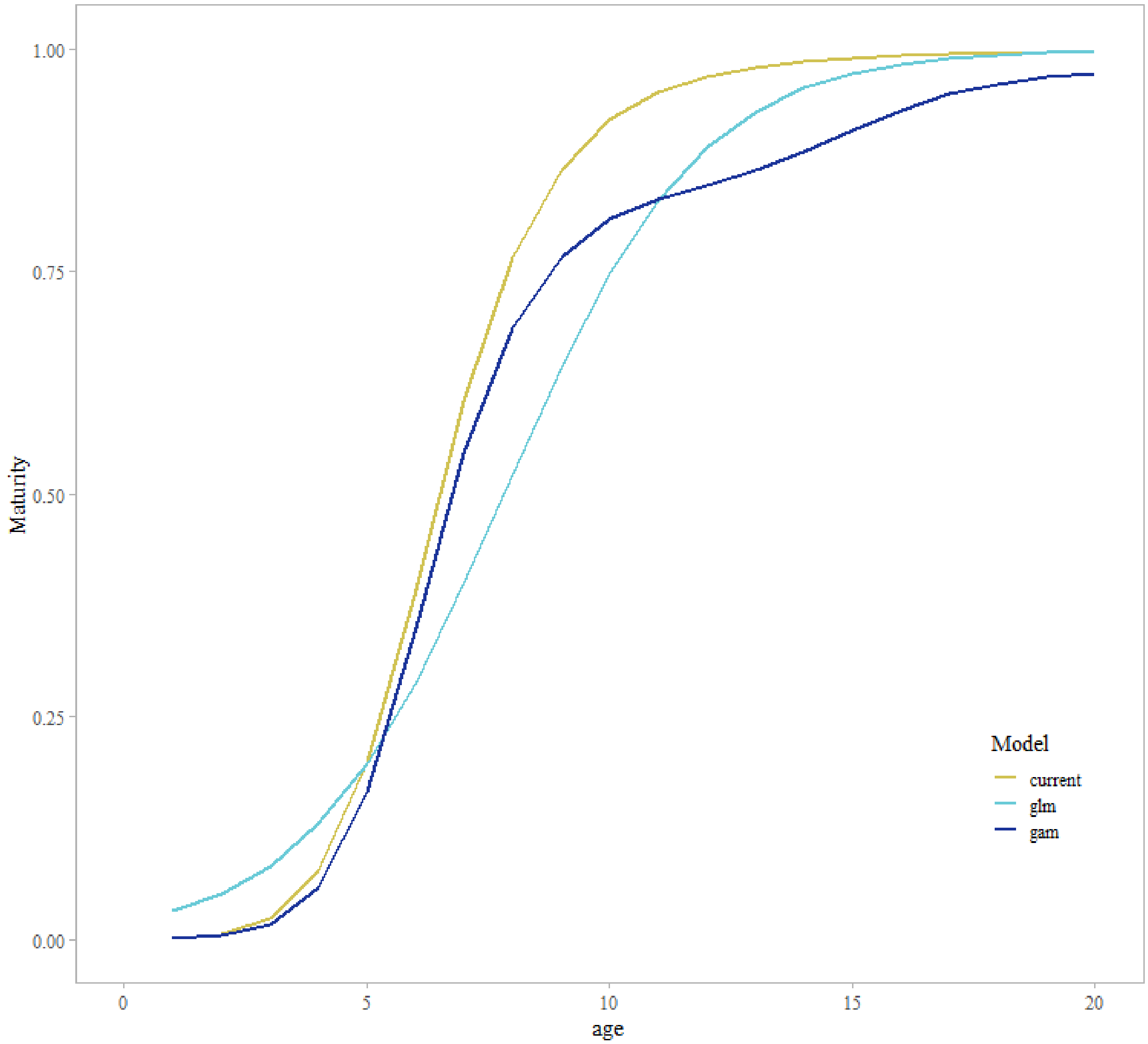

Figure 3F.6. Age-based sablefish maturity showing the current maturity curve and GLM and GAM based curves estimated using functional maturity. The current maturity curve is from Sasaki (1985).

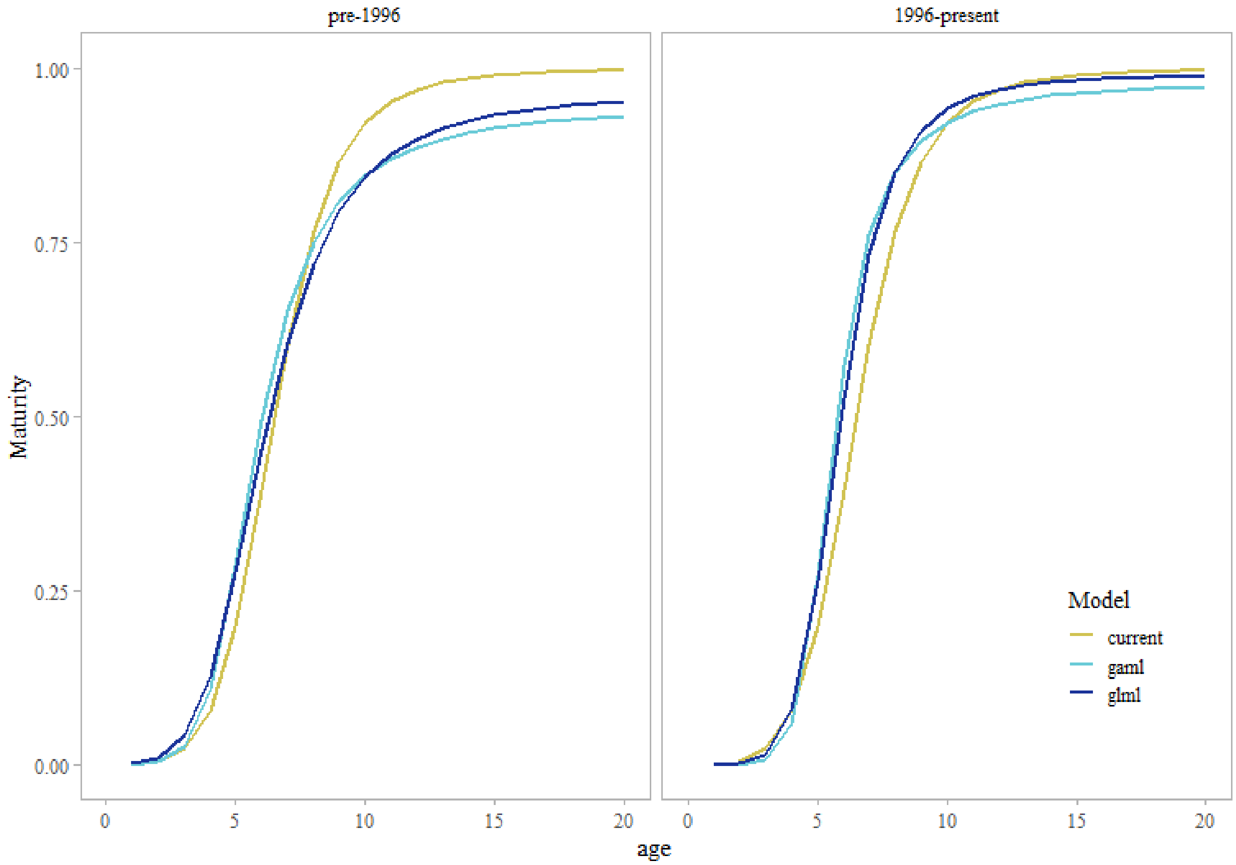

Figure 3F.7. Length-based sablefish maturity showing the current maturity curve and GLM and GAM based curves estimated using functional maturity. The two time periods are for different growth rates in the SAFE (Goethel et al., 2020). The current maturity curve is from Sasaki (1985).

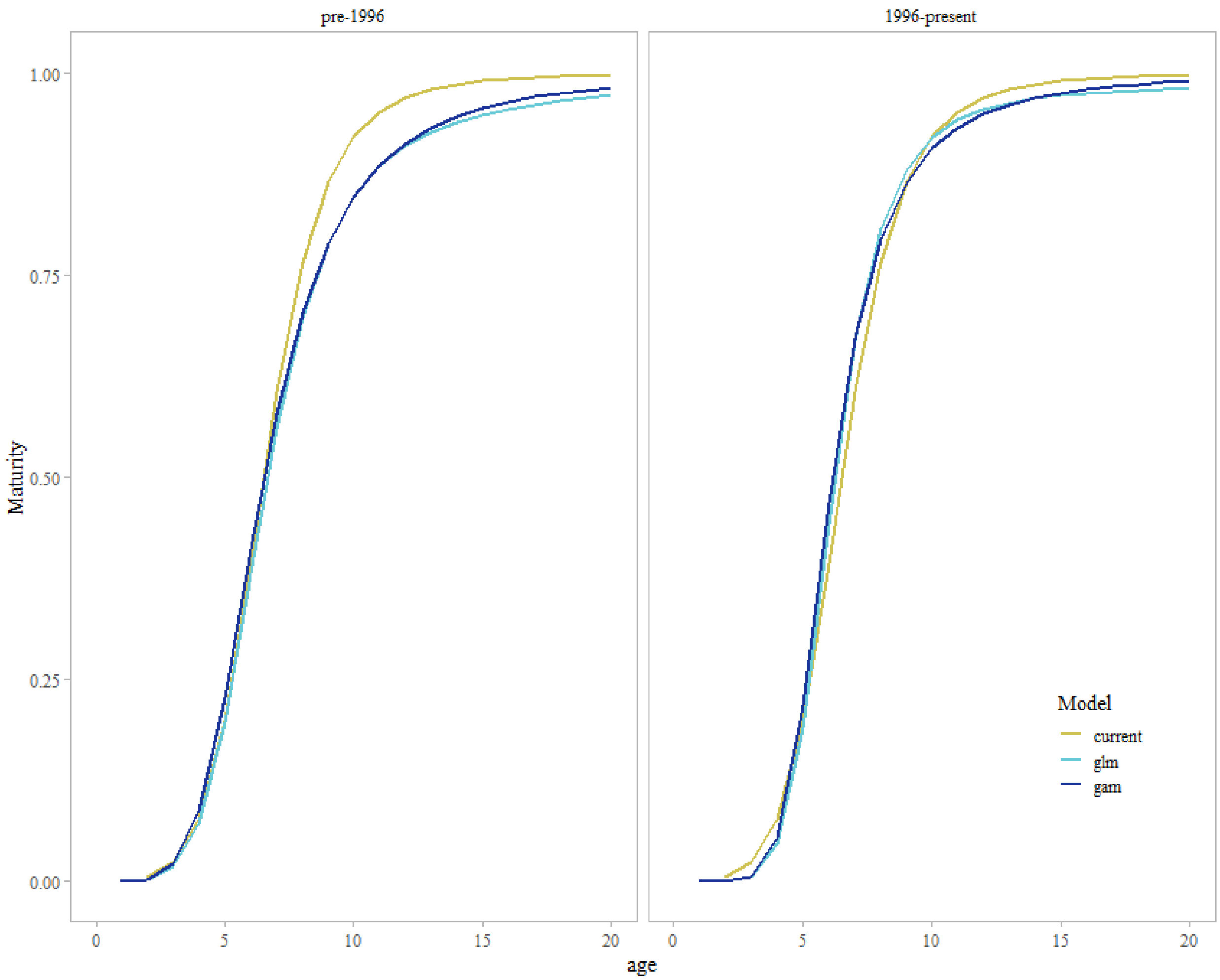

Figure 3F.8. Age/length-based sablefish maturity showing the current maturity curve and GLM and GAM based curves estimated using functional maturity. The two time periods are for different growth rates in the SAFE (Goethel et al. 2020). The current maturity curve is from Sasaki (1985).

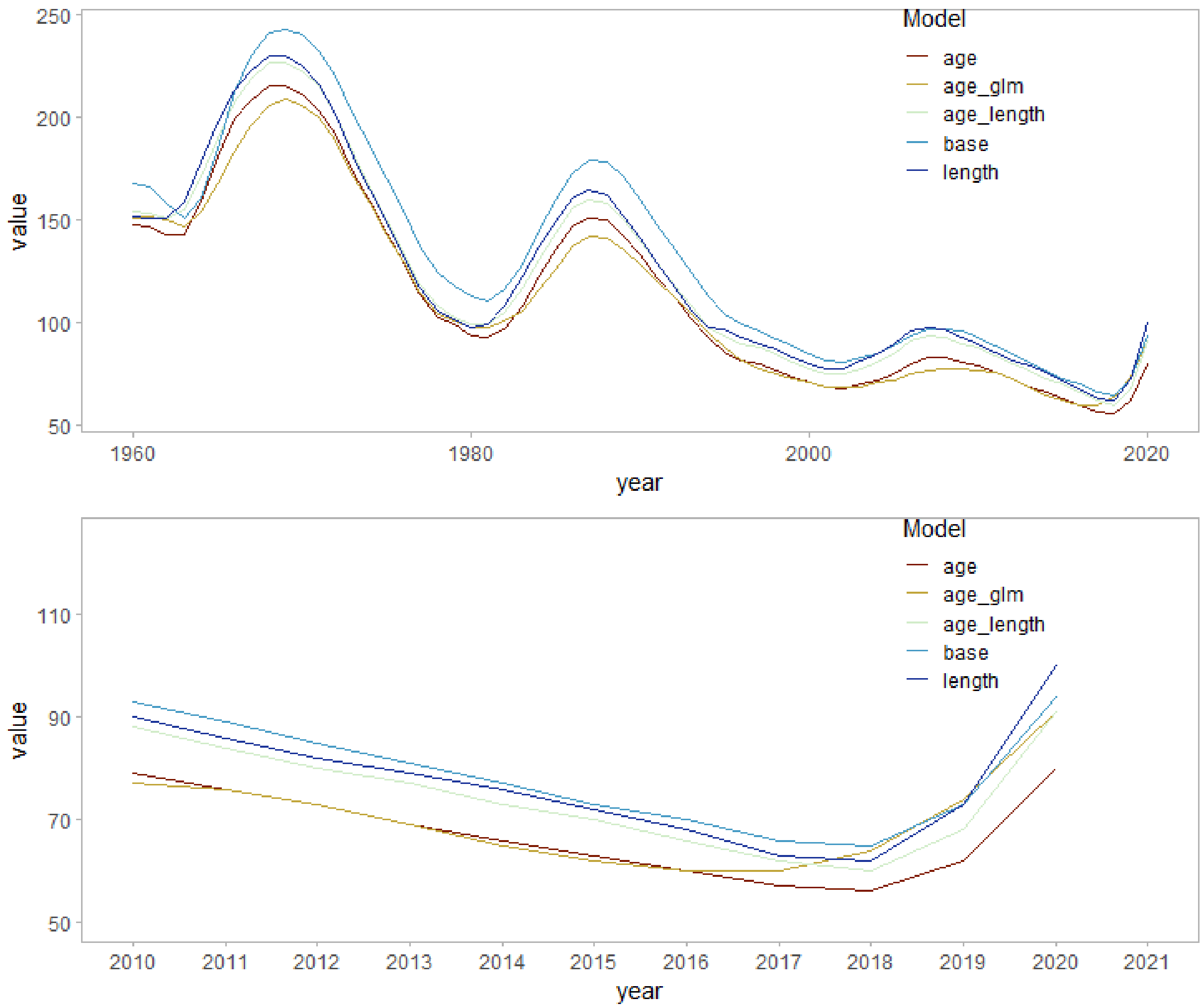

Figure 3F.9. Spawning stock biomass (SSB) estimates from the stock assessment and from three GAM (age, length, age-length) estimated and one GLM (age_glm) estimated alternate maturity models. The base model uses the current maturity curve.

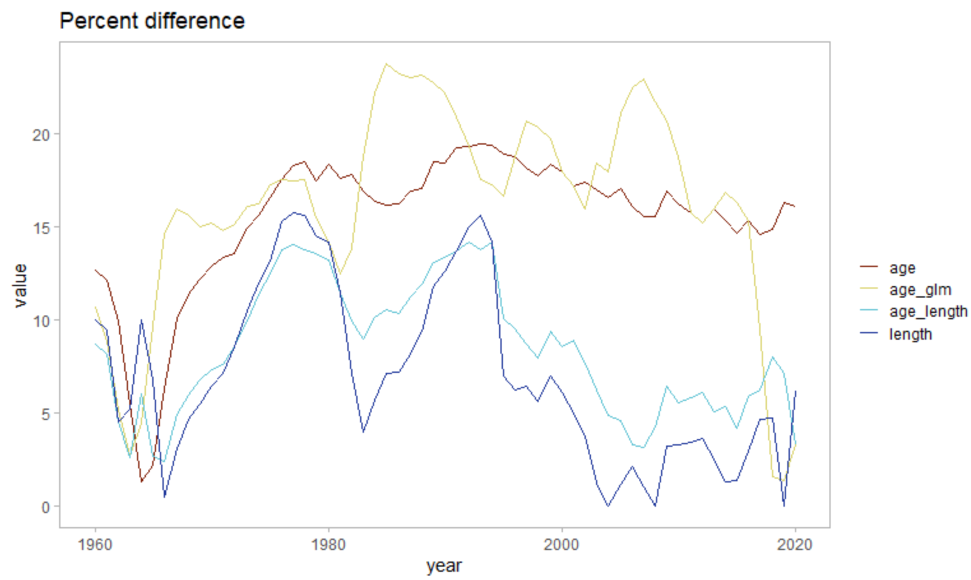

Figure 3F.10. The percent difference between the base stock assessment spawning stock biomass (SSB) and SSB from three alternate GAM (age, length, age-length) maturity models and an age-based GLM (age_glm).

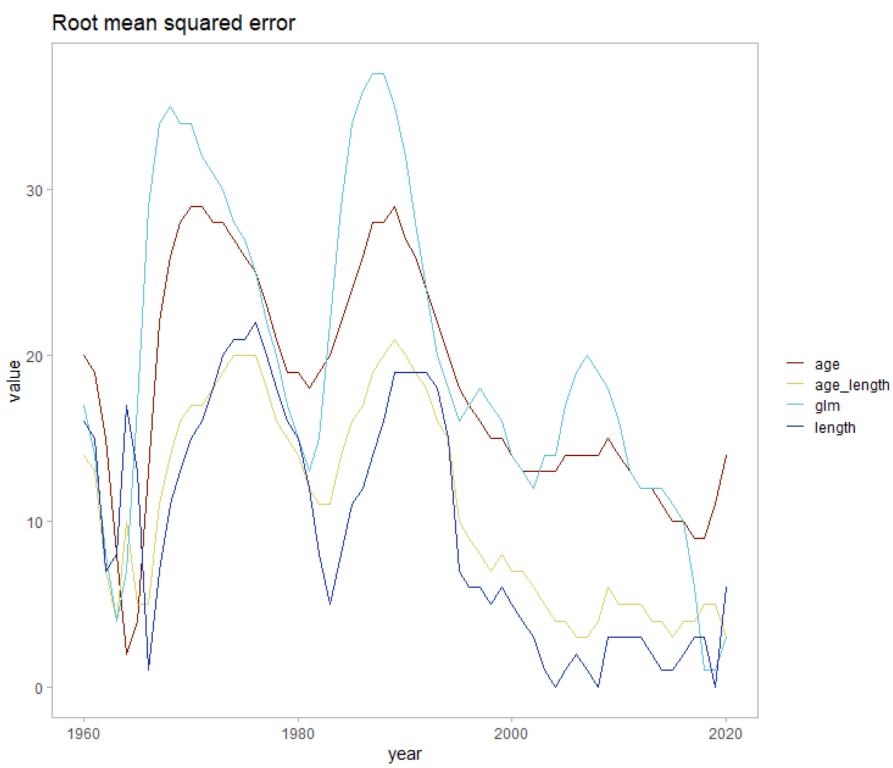

Figure 3F.11. The annual root mean squared error between the base stock assessment spawning stock biomass (SSB) and SSB three alternate GAM (age, length, age-length) maturity models and an age-based GLM (age_glm).

Appendix 3G. Alaska Sablefish Model Update

September 2021

Executive Summary

Rapid changes in the sablefish resource as well as the associated fisheries have proven difficult to address in the sablefish stock assessment model currently used for management advice. Over the last few years, the model has demonstrated increasing retrospective patterns and extensive retroactive downgrading of recent year classes. Updated data and analysis of growth, weight, and maturity indicate that values for these biological parameters used in the assessment should be revised. Similarly, degrading fits to important data sources (e.g., longline survey abundance indices) suggest that model parametrization and data weighting merit refinement. After exploring a variety of model updates and new parametrizations, the results of the current work suggest that five important changes would improve the 2021 sablefish assessment: 1) weight and growth for the recent time period (1996 – present) should be updated to reflect the full extent of available data; 2) maturity should be updated with an age- and length-based general additive model (GAM) that accounts for skipped spawning using histological information and incorporates data from recent maturity studies; 3) the catchability priors are no longer needed; 4) a recent time block for estimation of fishery and survey selectivity and fishery CPUE catchability will allow the model to better fit recent data and reduce internal model tension due to slightly incongruous trends in indices and compositional data; and 5) using data reweighting approaches (e.g., the Francis method) can help improve fits to abundance indices, limit retrospective patterns, and reduce retroactive downgrades in recruitment estimates and associated ABCs. Additionally, a brief update on the availability of data inputs for the 2021 SAFE is provided in Appendix A.1. Of particular importance, due to financial constraints, it appears unlikely that the fishery CPUE index will be updated in 2021.

Model *21.10_Proposed* is suggested as the best model for the provision of sablefish management advice, given that it incorporates each of the five proposed model changes. Model *21.10_Proposed* provides better fits to the longline survey RPN and fishery CPUE indices, albeit at the cost of degraded fits to the fishery age composition data. Compared to the current model (*16.5_Cont*), the resulting population trajectory from *21.10_Proposed* demonstrates less drastic reductions in SSB during the mid-2010s with more subtle rebuilding since 2017, primarily due to greatly reduced estimates of recent year class strength. Projected ABCs from the *21.10_Proposed* model are significantly lower than the *16.5_Cont* model and appear to be less volatile. Additionally, retrospective patterns and associated retroactive downgrades in recruitment year class strength have been reduced. Although the proposed model (*21.10_Proposed*) is not without flaws and requires further refinements to better reflect the dynamics of the sablefish resource and fishery, we believe it provides important tangible improvements over the current model (*16.5_Cont*). Note that recommendations in this document were revised after the October SSC meeting, and this document has been updated and superseded by Appendix 3H.

Introduction

The Alaskan sablefish (*Anoplopoma fimbria*) resource has undergone rapid changes in population dynamics over the last decade as multiple, nearly consecutive and extremely large year classes have entered the population (Goethel et al., 2020). Although the mechanistic drivers of these large recruitment events remain unclear (Shotwell et al., 2020), the resource complexion is now dominated by young, small, and primarily immature fish. Consequently, abundance and biomass has rebounded quickly from the lowest points on record in the mid-2010s to near historically high levels in recent years (Goethel et al., 2020). However, due to the partial maturity of these recent cohorts, spawning stock biomass (SSB), which forms the basis of the North Pacific Fisheries Management Council's (NPFMC) B_{40} harvest control rule

(HCR), has yet to demonstrate as rapid of a recovery (although SSB has increased from the all-time low in 2018). Potentially associated with the influx of multiple unprecedented year classes, there have been apparent changes in condition (Shotwell et al., 2020) and potential impacts on growth and maturity (Echave, 2021; Williams and Rodgveller, 2021). However, many of the biological parameters input into the sablefish stock assessment model have not been updated in over a decade. For instance, growth and weight were last analyzed and updated for the 2008 assessment (Hanselman et al., 2007; Echave, 2021), while the maturity curve used in the 2020 SAFE (and all previous assessments) was developed by Sasaki (1985) using data from the late 1970s and early 1980s (Williams and Rodgveller, 2021). Given the large amount of data on length, weight, and maturity collected on the annual sablefish longline survey, similar samples collected by at-sea observers, and targeted sampling of maturity status during winter spawning months using histological data (Rodgveller et al., 2016, 2018), there is now ample information to explore updates to sablefish growth and maturity curves for the stock assessment.

Concomitant with changes in the resource, there have been rapid shifts within the directed fixed gear individual fishing quota (IFQ) and non-target trawl sectors. Associated with the extreme recruitment events, both sectors have been inundated with catch of small, comparatively low value sablefish (Goethel et al., 2020). Increasing abundance of juvenile sablefish in the eastern Bering Sea has led to increases in sablefish bycatch in the pelagic trawl fisheries in that region (Goethel et al., 2020). Similarly, the rapid increase in catch of small sablefish by the directed fixed gear sector (i.e., including both longline and pot gear types), has led to exploration of regulations to allow the release of small sablefish within the fixed gear sector (NPFMC, 2021). At the same time as the increase in catch of small sablefish, there has been a swift transition from longline to pot gear within the fixed gear sector in the Gulf of Alaska (i.e., with over 50% of the total IFQ landings of sablefish coming from pot gear in 2020; Goethel et al., 2020). In particular, the development of collapsible ‘slinky’ pots has allowed smaller vessels that were unable to utilize rigid pots to explore the use of pot gear; slinky pots are also less expensive than traditional pots making them more enticing for a wider array of sablefish IFQ stakeholders. The increase in pot gear is likely due to a combination of the wider utility of the slinky pots along with the increases in sperm whale depredation in the Gulf of Alaska on longline gear (Hanselman et al. 2019), which pot gear essentially eliminates. Additionally, the ability to incorporate escape rings into pot gears can help reduce the number of small sablefish landed and potentially increase the overall value of the landed catch (i.e., given that the IFQ fishery operates under a mandatory 100% retention regulation and small fish have lower value per pound). The increase in landings of small sablefish began in 2016 (associated with recruitment at age-2 of the large 2014 year class) and the shift towards pot gear began in 2017 when it was legalized in the GOA region (Goethel et al., 2020). Under such management and fleet changes, Wilberg et al. (2009) suggest that incorporating time-variation in fishery CPUE catchability represents best practice for stock assessment models. Thus, given the rapid change in gear composition in the fixed gear fishery, there is a need to explore whether the selectivity and catchability (i.e., associated with the fishery CPUE index) of the aggregated fixed gear fishery modeled in the assessment (i.e., combining all longline and pot gear into a single fleet) has altered in recent years.

Around the same time, the sablefish longline survey began observing large numbers of young fish. For instance, the survey age and length composition has been dominated by fish from the 2014, 2016, and 2017 year classes for the last five years. Due to the influx of young, small fish, the resultant longline survey abundance index has increased 2.5 fold since 2015, which is the year with the lowest index value on record. In 2020, the longline survey abundance index again increased by 30% from the 2019 value (Goethel et al., 2020). Although the increasing abundance indices are being driven by extreme recruitment events, there appears to be an increase in catch of small fish in deeper waters where they have historically been rare. The mechanism driving the increases in catch of small fish in deeper water survey stations remain unknown, but it could be due to density-dependent effects (i.e., ‘spillover’ out of preferred juvenile habitat) or changes in water temperature. For instance, warmer shallow water may force young sablefish into deeper, cooler water at earlier ages. Such changes in apparent availability of small fish would influence survey selectivity. Given these changes in resource distribution and fishery composition, there is impetus to explore alternate model parametrizations for both selectivity and catchability (i.e., the addition of a new fishery and survey selectivity and fishery CPUE catchability time blocks all starting in 2016) to ensure that internal scaling and the effective age and length based selectivity being estimated by the model are appropriate.

Because catchability coefficients directly scale observed abundance or biomass indices to the actual total estimated population size, how these coefficients are parametrized within a stock assessment model can have important implications for determination of stock status and sustainable harvest levels (Wilberg et al., 2009). Currently, the sablefish assessment utilizes prior distributions for all catchability coefficients to ensure common scaling across indices as well as allowing longline indices to be temporally linked (i.e., maintain commonality in scaling across the assessment time frame where the longline survey transitioned from being run by Japanese scientists to a cooperative Japanese-U.S. survey, then eventually becoming run solely by the AFSC; Hanselman et al., 2007). Prior to the development of the catchability prior distributions, the sablefish model was sex-aggregated and had fewer abundance indices, thus fewer parameters. The domestic longline survey catchability was estimated freely, and the cooperative survey catchability had a fixed offset based on Kimura and Zenger (1988). The development of prior distributions was enacted to allow uncertainty in the link between abundance indices. But, it also served to stabilize parameter estimates, because, at that time, there was a more limited time series of data for many of the inputs to the assessment, particularly as the parametrization was moved to a two-sex model. However, stock assessment best practices generally suggest treating catchability parameters as free parameters to ensure adequate internal scaling within the assessment. Additionally, over the last few years, internal reviewers of the sablefish SAFE have requested explorations of model sensitivity to removal of the catchability priors.

Concurrent with exploring alternate parametrizations of selectivity and catchability, it is often advised that data weighting assumptions be refined to ensure that no single data input has undue influence on the model results and that the information content from abundance indices is adequately utilized (Francis, 2011, 2017). Given that selectivity and catchability can have a strong influence on internal scaling of the assessment model, if the parametrization of these values is altered it is important to ensure that the data are still being fit appropriately. Since 2016, the sablefish assessment has assumed fixed data weights based on advice during the 2016 CIE review. Recommendations from the CIE panel suggested that the longline survey index was being fit too precisely and the resultant proposed fixed data weights aimed to ensure that the age and length compositional data were more closely fit. Unfortunately, these weights were fixed prior to the influx of small fish and subsequent changes in the resource and fishery. In recent years, the assessment model has begun to demonstrate increasing retrospective patterns, primarily associated with uncertainty in the estimates of large recent year class strength. For instance, the estimate of the 2014 and 2016 year classes have been subsequently downgraded as new data have been incorporated into the model, with reductions to the 2014 year class exceeding 60% between first being estimated by the 2017 model and the current 2020 model estimate. Concurrently, the assessment model has demonstrated a propensity to predict longline survey abundance index values that are much larger than observed (e.g., overprediction by as much as 30% in recent years), which has led to potential overestimation of recruitment levels (i.e., as indicated by the retrospective patterns). The combination of priors on survey and fishery catchability as well as fixed data weights (i.e., with no use of data reweighting methods) could be potential sources for the observed retrospective patterns and degraded fit to recent longline survey data. Refining the model parametrization in combination with data reweighting methods (e.g., Francis reweighting) to better fit survey abundance indices may help reduce retrospective patterns and should be explored further.

Given the rapid changes in the resource and fishery and concomitant increases in retrospective patterns in the assessment, exploring a variety of potential model changes to the Alaskan sablefish assessment has been a high priority in recent years. Approaches for updating the biology (i.e., growth, weight, and maturity), model parametrization (i.e., addition of a recent fishery and survey selectivity time block along with alternate approaches to estimating catchability), and data weighting are described and the results compared, particularly in reference to the 2020 model. The final proposed model being recommended based on this work for the 2021 sablefish SAFE makes important strides towards better representing sablefish biology, while reducing retrospective patterns and improving model stability.

Methods

Stock assessment model updates and explorations were grouped into three categories: 1) biological inputs; 2) model parametrization; and 3) data reweighting (see Table 3G.1 for a list of model scenarios). Each model update was implemented individually to demonstrate the impact of each change as a one off alteration to the current 2020 Sablefish model (termed the Continuity model, *16.5_Cont*). A stepwise model building process was then implemented within each of the biological and model parametrization categories using a semi-factorial design (i.e., most, but not all, combinations of model changes were tested in a step-wise fashion, though not all model building steps are presented). For simplicity of presentation, we focus on the results of each update that is being recommended for inclusion in the final 2021 assessment. Although a variety of alternate model changes were tested, those deemed inappropriate, unrealistic, or otherwise unfit for operational assessment purposes (e.g., due to poor model performance, including poor fits to the data, unrealistic outputs, or stability issues) are not presented. Results within each category of model building are presented, then the final proposed model with data reweighting applied is compared to the continuity model (i.e., 2020 final model, *16.5_Cont*). Finally, results of important model diagnostics (i.e., data fits, residual patterns, retrospective analysis, and Markov Chain Monte Carlo) are analyzed and compared between the proposed model (*21.10_Proposed*) and the continuity model (*16.5_Cont*).

Continuity Model (*16.5_Cont*)

The 2020 sablefish final accepted assessment model (termed the Continuity model, *16.5_Cont*) is used as the basis of one off changes and baseline comparisons. The Continuity model is outlined in Goethel et al. (2020) and is implemented here exactly as it was for the provision of management advice in 2020. Model building towards the final proposed model for the 2021 sablefish SAFE (*21.10_Proposed*) is first undertaken within each group before the 'best' or most appropriate changes are combined into the final model. Each model scenario explored and discussed in this document is outlined in Table 3G.1.

It is worth noting that all models subsequent to *16.5_Cont* contain a single alteration to the trawl fishery selectivity parametrization to improve model stability and better match the assumptions inherent in the selectivity parametrizations of the other fishery and survey fleets. Essentially, the parameter determining the shape of the gamma selectivity function for the trawl fishery was altered to be shared between males and females, which matches how the fixed gear fishery and longline survey logistic selectivity shape parameters are treated. The change in parametrization leads to subsequent models having one less selectivity parameter to estimate compared to the Continuity model (*16.5_Cont*), but impacts on model results were negligible and not discussed further.

Biological Inputs

Three potential updates to biology were considered, including updating the length-, weight-, and maturity-at-age. However, because growth and weight are intertwined processes, changes to these inputs are considered as a single update.

<u>Growth and Weight</u>

Growth and weight were last updated in the sablefish assessment in 2008 with data through 2004 (Hanselman et al., 2007). Data from two time periods (1981 – 1993 and 1996 -2004) were utilized to define and model two growth regimes (pre- and post-1995; Figure 3G.1) where the time series breaks were determined primarily by changes in sampling design for sablefish data collected on the longline survey and used to estimate growth (Echave, 2021). Conversely, weight was not collected on the longline survey prior to 1996, so a single weight-at-age curve has been utilized for the entire assessment model time series using data collected from 1996 – 2004 (Figure 3G.2).

Based on updated data through 2019 and the results of a cluster analysis, Echave (2021) recommended that both the growth curve and weight-at-age be updated. Additionally, results suggested that a new time block be added (i.e., pre- and post-2004) to account for apparent changes in growth over the last decade. However, at the moment there are no explicitly known biological or environmental mechanisms that might be driving growth changes since 2004. As such, the added complexity of an additional growth block was not considered in the current analysis. Thus, for updates to weight and growth, we utilized the results from Echave (2021) utilizing the single time block model and all available data through 2019 (i.e., with no additional time blocks in either process). The historic growth curve (pre-1995) remains unchanged, while the recent (post-1995) growth curve was updated with the new data (Figure 3G.1). Similarly, the weight curve was updated with new data through 2019 and applied for all years in the assessment model (Figure 3G.2). As noted, weight and growth were updated simultaneously and treated as a single model update (*21.1_Wt+Grt*; Table 3G.1). The updated weight and growth parameters were maintained in subsequent models including *21.5_Upd_Bio_AL-Mat* and *21.10_Proposed*.

Maturity

Maturity in the sablefish assessment has always utilized a consistent age-based maturity curve developed by Sasaki (1985; see Figure 3G.3), which was based on macroscopic maturity classifications and lengths collected in the summer during the late 1970s and early 1980s. There are a variety of potential issues with using these historic maturity estimates, especially considering potential recent changes in maturity and the documentation of skipped spawning in sablefish (Rodgveller et al., 2016, 2018; Goethel et al., 2020; Williams and Rodgveller, 2021). Maturity data collected using histological (as opposed to macroscopic) methods provide a more accurate determination of sablefish maturity, including skipped spawning. Moreover, utilization of General Additive Models (GAM) can better account for skipped spawning that cannot be adequately addressed using the more commonly applied General Linear Models (GLMs; Trippel and Harvey, 1992; Williams and Rodgveller, 2021). Additionally, given that maturity is typically dependent on a mixture of both age and length processes, models that account for both the length and age of mature fish are likely to better reflect true population maturity rates. For sablefish, Williams and Rodgveller (2021) demonstrate that an age-length GAM based on histological samples of sablefish and accounting for skipped spawning is likely to provide the most reliable estimate of maturity-at-age. Although data on skipped spawning is limited to three directed studies and the rate is variable, simulations demonstrate that ignoring skipped spawning when it is present is likely to cause increased bias compared to incorporating skipped spawning in maturity estimates but getting the average population rate of skipped spawning slightly incorrect (Williams and Rodgveller, 2021).

Given the recommendations of Williams and Rodgveller (2021), three maturity curves based on analysis of the histological data were explored. First, maturity was updated using an age-based general linear model (GLM) that ignored skipped spawning information, but utilized the recent histological data (*21.2_Mat_Age_GLM_No_SS*). Although not a strict update of the maturity curve, this approach was deemed the most consistent with the methods of Sasaki (1985), but utilizing the more reliable and recently collected histological maturity information. However, given that skipped spawning has been observed for sablefish, use of the GLM maturity model was not recommended for further use (Williams and Rodgveller, 2021). Next, an age-based GAM maturity model, which includes skipped spawning information, was implemented using the histological data (*21.3_Mat_Age_GAM*). Finally, the recommended age-length based GAM maturity model, which also accounts for skipped spawning and uses the histological data, was utilized (*21.4_Mat_AL_GAM*). Because the latter model is partially based on length, changes to the growth curve cause changes to maturity-at-age. Thus, even though the maturity parameters are constant through time, the resultant maturity-at-age will change based on growth regimes in the assessment model. The input maturity-at-age based on the age-length GAM, therefore, differs before and after the growth time block in 1995, but also differs due to different underlying growth parameters in the Continuity model (*16.5_Cont*) and subsequent models that utilize the updated growth curves (note that maturity is input to the model, so the impact of changes in growth on maturity are calculated externally and input into the assessment). Based on recommendations by Williams and Rodgveller (2021) and the results of the current work, we utilize the age-length GAM maturity model for subsequent model building (i.e., *21.5_Upd_Bio_AL-Mat* and *21.10_Proposed*), but note that the input maturity for these models differs from that used in *21.4_Mat_AL_GAM* due to changes in the underlying growth parameters. Each of the maturity curves utilized in the various models are provided in Figure 3G.3.

Update All Biology

The final model building scenario in the 'Biology Update' category implemented the combination of updated growth, weight, and maturity (*21.5_Upd_Bio_AL-Mat*). As noted, the model utilized the age-length GAM maturity model, but based on the updated growth parameters.

Model Parametrization

Increasing retrospective patterns over the last few years have provided impetus to explore alternate model parametrizations to better fit the observed data and address changes in fishery and resource dynamics. During the 2020 SAFE a wide variety of sensitivity runs were explored (Goethel et al., 2020). Of these, adding a recent selectivity time block to address apparent changes in targeting and availability of young sablefish in the fixed gear fishery and longline survey demonstrated the most promise, while also being the most defensible based on direct observation and knowledge of sablefish biology and harvesting. Similarly, removal of catchability priors has been consistently highlighted as a relatively straightforward potential model change that could improve scaling and model performance. Thus, both of these changes to model parametrization were explored further. It is worth noting that natural mortality has been consistently noted as needing further exploration and potential parametrization refinement within the sablefish model. Although recent analysis led to improvements in the estimation of natural mortality using priors (Hanselman et al., 2018) and alternate age- and time-varying parametrizations were explored in-depth for the 2020 SAFE, added complexity to the natural mortality formulation has often led to increased model instability along with seemingly unrealistic model outcomes (Goethel et al., 2020). Natural mortality will continue to be explored in the future, particularly in association with the goal of developing a tag-integrated assessment for sablefish, but no new formulations were explored or will be put forward for inclusion in the 2021 model.

Removal of Catchability Priors

As a direct scalar between the indices of abundance or biomass and the estimated population size, adequate parametrization of catchability coefficients is crucial within assessment models. As noted, the 2020 model (*16.5_Cont*) assumed priors on all catchability parameters to maintain consistent scaling across surveys and aid in model stability (see Table 3G.A for prior distributions). However, the use of priors was implemented in 2007 and has not been addressed since that time, despite over a decade of additional data. To determine the impact of using catchability priors and to explore whether these parameters can be freely estimated, model *21.6_No_q_Prior* treated all catchability coefficients as freely estimated parameters (Table 3G.1). Although the number of estimated parameters did not explicitly change, the six catchability parameters were moved from constrained parameters to freely estimated. For subsequent model building scenarios, including *21.8_No_q_Add_Sel+q_Block* and *21.10_Proposed* models, all catchability coefficients were maintained as freely estimated parameters.

Table 3G.A. Prior distributions for each catchability coefficient estimated in model *16.5_Cont*.

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%

Addition of a Recent (Post-2016) Selectivity and Fishery CPUE Catchability Time Block

Sensitivity runs during the 2020 SAFE demonstrated that adding a selectivity time block in 2016 for both the fixed gear fishery and the longline survey improved fits to the longline survey relative population numbers (RPN) index, fishery and survey compositional data, and fishery CPUE index (Goethel et al., 2020). Additionally, given the rapid changes in the fixed gear fishery and data inputs associated with the fishery CPUE index, there is rationale to incorporate an associated recent time block for estimation of the fishery catchability coefficient. Adding a recent time block for fishery selectivity and associated catchability essentially assumes that fishery dynamics have changed, likely due to a combination of alterations 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). A similar time block for survey selectivity implicitly assumes that availability to the survey gear has changed (i.e., young fish have moved into survey areas in recent years, mainly in deeper waters where they have not typically been sampled in the past). The 2020 model (*16.5_Cont*) had trouble rectifying the rapidly increasing survey index, the influx of large numbers of small and young fish in both the survey and fishery compositional data, and the relatively stagnant fishery CPUE index. The added flexibility provided by adding a post-2016 selectivity time block along with an associated fishery CPUE catchability time block will likely allow the model to better rectify conflicting signals within the various data sources and potentially account for processes that cannot be explicitly modeled (e.g., changes in targeting on low-value small fish, increasing use of pot gear, and potential redistribution of small fish into areas not previously inhabited). To address these potential changes, *Model 21.7_Add_Sel+q_Block* estimated new fishery and survey selectivity parameters (i.e., $a_{50\%}$ for males and females; four parameters) along with a new fishery CPUE catchability (*q*) coefficient (i.e., one parameter) resulting in a total of five additional parameters to be estimated (Table 3G.1). The added time block and additional estimated parameters were maintained for the *21.8_No_q_Add_Sel+q_Block* and *21.10_Proposed* models.

Update All Model Parametrization

The final model building scenario in the ‘Model Parametrization’ category implemented the combination of removing catchability priors and allowing for a recent (post-2016) time block for fishery and survey selectivity and fishery CPUE catchability (*21.8_No_q_Add_Sel+q_Block*).

Data Weighting

Ensuring that a model adequately fits the available data is a prerequisite for developing a robust stock assessment. When fitting both abundance and compositional data in a model, data conflicts are common and determining appropriate statistical weights for each data source can be difficult. It is now considered best practices to perform reweighting procedures (e.g., Francis or McAllister-Ianelli) to ensure the model is ‘right-weighted’ and no single data source is dominating the negative log-likelihood and resulting model outputs (Francis, 2011, 2017). Additionally, it is suggested that reweighting procedures should be undertaken as the final step in the model development process to ensure consistent data weights that match the final assumptions and modeled processes (Maunder et al., 2017). Although a variety of reweighting approaches exist, the Francis method has been explored for other North Pacific species (e.g., GOA pollock and blackspotted/rougheye rockfish) and has been demonstrated to provide generally robust weights. Additionally, it can account for correlations among ages or length bins in the compositional data by iteratively adjusting the data weights such that model mean age or length reflects the mean age and lengths observed in the compositional data.

The 2020 model (*16.5_Cont*) used fixed input data weights based on recommendations from the 2016 CIE review and these weights have not been altered since that review. The re-weighting that occurred at that time was based on targeting a standard deviation of normalized residuals (SDNR) approximately equal to one for each of the age and length (i.e., when no ages were available from a given fleet) compositional data sources. Exploratory analysis during the 2020 SAFE suggested that these fixed weights could be one potential source for increasing retrospective trends. Thus, we implement Francis reweighting with the continuity model (*21.9_Cont_Francis*) to determine whether the reweighting appears to lead to better data fits or alternate interpretations of the dynamics. Similarly, the final proposed model for 2021 (*21.10_Proposed*) utilizes Francis reweighting, as well (see 2.5 Final Proposed Model).

The methods applied for data reweighting follow Francis (2011) where the abundance index weights were fixed based on the input observed variance of each index and the compositional data weights were iteratively adjusted using a two-stage approach. In Stage 1, the model was run with starting input compositional data (i.e., all sources of age and length composition data fit in the model) weights (exploratory runs demonstrated that final weights were insensitive to initial weights). Then, the compositional data weights were adjusted following Method TA1.8 and weighting assumption T3.4 of Francis (2011, Appendix Table A1, therein; i.e., using the assumption of a multinomial distribution and accounting for correlations among ages or length bins). In Stage 2, the model was then rerun with the new weights. The weights were iteratively adjusted until the difference between the current weights and the revised weights were minimal (i.e., the weights converge; for sablefish this usually took less than 10 iterations).

Final Proposed Model

The final model being proposed for the 2021 sablefish SAFE (*21.10_Proposed*) combines the results of each model building stage (i.e., the final ‘Biology Update’, *21.5_Upd_Bio_AL-Mat*, and ‘Model Parametrization’, *21.8_No_q_Add_Sel+q_Block*, models), then Francis reweighting was applied. The final proposed model (*21.10_Proposed*) is analyzed in depth, particularly in comparison to parameter estimates and data fits of the 2020 accepted model (*16.5_Cont*).

Model Performance Criteria

A variety of performance criteria were utilized to determine model stability, adequacy, and robustness, which were compared across models. Model convergence was a minimum requirement to be considered further and this was gauged by having a maximum gradient component < 0.001 and a positive-definite Hessian matrix. A critical component of determining model performance was the fit to the data, particularly the tradeoff between age composition data from the fixed gear fishery and longline survey compared with the fit to the longline survey RPN and fishery CPUE indices. Similarly, residual patterns were explored visually to determine if any major patterns with time, age, or length were present.

Although the negative log-likelihood (*nLL*) was utilized to gauge data fits, these were not necessarily directly comparable (e.g., due to changes in data weights and penalty terms).

For comparing the 2020 Continuity (*16.5_Cont*) and 2021 Proposed (*21.10_Proposed*) models, a full suite of diagnostic analyses were undertaken, including time series of model outputs, data fits, retrospective analysis, and Markov Chain Monte Carlo (MCMC). For the retrospective analysis, ten year data peels were utilized and Mohn's rho was calculated for terminal year SSB across all peels. Given the recent selectivity and catchability time block in the *21.10_Proposed* model, difficulties arise when performing retrospective peels before 2018. Essentially, very little data exists to estimate these additional parameters for 2016 and 2017 model peels. Although we still present the results of the retrospective analysis for all years, care should be taken when analyzing peels before and after 2018 given that these are fundamentally different models (we removed the recent selectivity and catchability time block for all peels prior to 2018). For MCMC runs, the posterior distributions were computed based on one million MCMC simulations. 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. MCMC runs were utilized to provide 95% credible intervals around estimates of SSB, biomass, and recruitment.

Results

All of the models explored converged with adequate maximum gradient values, indicating that most models were stable and parameter correlation was not a major issue (Table 3G.2). Additionally, all models resulted in generally similar negative log-likelihood values (though these necessarily differed dramatically for models utilizing reweighting approaches), parameter estimates, and population time series trends, which lends further credence that a global minima in the likelihood surface is being achieved (Tables 3G.2 - 3G.3, Figures 3G.4, 3G.5, and 3G.7).

Biology Updates

In terms of growth and associated weight, adding the full complement of data generally led to fish growing a bit slower yet reaching a larger maximum size in the recent (1996 – 2019) period (Figures 3G.1 – 3G.2). Updating maturity led to more complicated dynamics, given the range of maturity models (i.e., age-based and age-length based) explored. Using an age-based GLM and ignoring skipped spawning (model *21.2_Mat_Age_GLM_No_SS*) led to increased maturity at younger ages compared to Sasaki (1985; used in the *16.5_Cont* model), but slightly reduced maturity at ages five through twelve. Updating the maturity-at-age using an age-based GAM and the available histological data (model *21.3_Mat_Age_GAM*), including information on skipped spawning, led to decreases in the maturity at all ages, but particularly young and intermediate ages (i.e., ages two through five and nine through seventeen; Figure 3G.3). The impacts on younger ages is due to the use of a more flexible GAM (as opposed to a GLM) that better reflects true maturity when skipped spawning occurs at intermediate ages, while the decreases at intermediate ages is directly associated with increased skipped spawning observed for these age classes (Williams and Rodgveller, 2021). The age-length model (models *21.4_Mat_AL_GAM* and *21.5_Upd_Bio_AL-Mat*) provided similar age-based maturity estimates to the values from Sasaki (1985; used in the *16.5_Cont* model) for the early time period (pre-1996), but with similar decreases at intermediate ages (i.e., associated with skipped spawning as demonstrated in the updated age-based model; Figure 3G.3). In the recent time block (post-1996), maturity at younger ages was much lower for both growth models (i.e., based on the growth models used in the 2020 SAFE and the updated growth model), but then exceeded maturity from Sasaki (1985) for ages five through eight when the old growth curve was utilized (i.e., model *21.4_Mat_AL_GAM*). Conversely, using the age-length maturity model in combination with the updated growth curves (*21.4_Upd_Bio-AL-Mat*) led to maturity-at-age values that were consistently lower than Sasaki (1985) for all ages during the recent time block (post-1996).

Generally, updating the biological parameters did not alter model performance, parameter estimates, population trajectories, or fits to the data in any significant manner (Tables 3G.2 - 3G.3, Figure 3G.4). As expected, the primary impact was to rescale SSB and associated reference points, which directly influenced stock status and harvest recommendations (Table 3G.3). In particular, updates to growth and weight (model *21.1_Wt+Grt*) led to higher SSB, but similar increases in reference points given the new larger maximum size and weight; thus, the ABC decreased, because stock status was slightly lower than for model *16.5_Cont* (Table 3G.3).

Utilizing the age-based maturity GLM without skipped spawning information (model *21.2_Mat_age_GLM_No_SS*) moderately reduced SSB, but did not greatly alter SSB trajectories (Figure 3G.4). However, the biomass-based reference point only decreased slightly compared to a relatively strong reduction in terminal year SSB, which resulted in a lower stock status compared to the Continuity model (*16.5_Cont*) and a subsequent reduction in ABC (Table 3G.3). Updating the age-based maturity curve (model *21.3_Mat_Age_GAM*) had the largest impact due to the decreases in maturity-at-age, which led to strong scaling changes, including reductions in SSB albeit associated with similar reductions in the biomass reference point (Table 3G.3, Figure 3G.4). Utilizing the age-length maturity curve (model *21.4_Mat_AL_GAM*) led to an SSB trajectory about midway between the continuity (*16.5_Cont*) and updated age-based GAM maturity model (*21.3_Mat_Age_GAM*) and very similar to the trajectory of the model using the age-based GLM without skipped spawning information (*21.2_Mat_Age_GLM_No_SS*; Figure 3G.4). But, the biomass-based reference point actually increased slightly compared to model *16.5_Cont* (Table 3G.3), likely due to increased maturity values for the most abundant ages (i.e., ages five through eight) in the recent time block (post-1996).

The final 'Biology Update' model (*21.5_Upd_Bio_AL-Mat*), which incorporated the updated weight and growth curves along with the new age-length based maturity curve, closely matched the continuity model dynamics (*16.5_Cont*) for much of the time series, but estimated slower rebuilding in SSB over the last few years (Figure 3G.4). The lack of rebuilding in SSB is due to the updated age-length maturity curve indicating that maturity of young and intermediate aged fish is much lower than assumed in the Sasaki (1985) maturity curve utilized in the continuity model (*16.5_Cont*). Therefore, because much of the population increase in recent years has been due to large 2014, 2016, and 2017 year classes, the *21.5_Upd_Bio_AL-Mat* model implies that these year classes are not as mature as previously assumed and SSB has not recovered as quickly. Conversely, primarily due to the changes in weight and growth, the associated biomass-based reference points have increased (Table 3G.3). The dichotomous change in terminal SSB and biological reference points compared to the continuity model (*16.5_Cont*) leads to a significant decrease in the projected 2021 ABC (40 kt in the *21.5_Upd_Bio_AL-Mat* model compared to 52 kt in the *16.5_Cont* model).

Model Parametrization Updates

Similar to the biology updates, there were no major changes in general population trajectories, but magnitude and scale differed for the 'Model Parametrization' updates, especially in terms of the estimated strength of recent recruitment events (Tables 3G.2 - 3G.3, Figure 3G.5). Similarly, fits to the data, particularly the longline fishery CPUE index, demonstrated some important deviations across model scenarios (Figure 3G.6). Again, the primary impact across model scenarios was rescaling of SSB, associated reference points, and subsequent harvest recommendations (Table 3G.3).

The main effect of allowing the catchability parameters to be freely estimated (model *21.5_No_q_Prior*) was minor variation in the catchability estimates (Table 3G.4), which led to a rescaling of the SSB time series and slight reductions in recruitment estimates compared to the continuity model (*16.5_Cont*; Figure

3G.5). Although the reference points did not change to any great extent, the terminal year SSB was slightly lower than in the Continuity model (*16.5_Cont*) resulting in a reduction in the ABC (Table 3G.3). There was no appreciable change in model fits to the data, especially the abundance indices (Figure 3G.6).

Adding a time block to the longline survey and longline fishery selectivity and fishery CPUE catchability (*21.6_Add_Sel+q_Block*) resulted in strong improvements in the fit to the fishery CPUE index (Figure 3G.6). Concomitantly, the addition of the recent selectivity and catchability time block strongly reduced recent year class strength (Figure 3G.5). The SSB time series was rescaled to a similar level as model *21.6_No_q_Prior* with a slightly decreased terminal year SSB estimate, but the biomass-based reference point underwent similar reductions and stock status only decreased slightly compared to the Continuity model (*16.5_Cont*; Table 3G.3). However, the reduction in recent recruitment had a strong impact on projected biomass and rebuilding rates, which led to large reductions in the ABC (~35 kt), because the high projected ABC in future years associated with the Continuity model (*16.5_Cont*; Figure 3G.5) are due to exceptionally high (and uncertain) recent year class estimates. The main factors driving the results of model *21.6_Add_Sel+q_Block* were estimated increases in selectivity of young fish (e.g., ages two through four; see Figure 3G.14 for an example of changes in selectivity for the 'recent' time block from the *21.10_Proposed* model) and associated decreases in fishery catchability after 2016 (see Table 3G.4 for *q* estimates from the *21.10_Proposed* model). By reducing fishery catchability, the model was able to better rectify fishery CPUE, which underwent a strong reduction in 2016 and has yet to recover, with the longline survey index that has increased dramatically over the last five years (Figure 3G.6). However, the increased selectivity estimates on younger fish forces the model to downgrade recruitment estimates. Allowing an increase in survey and fishery selectivity since 2016 allowed the model to interpret the increasing proportion of small, young fish in the composition data as a mixture of a change in availability, as well as, large year classes.

The final 'Model Parametrization Update' model (*21.8_No_q_Add_Sel+q_Block*), which removed the catchability priors and added the recent fishery and survey selectivity and fishery CPUE catchability time blocks, underwent a similar rescaling of the overall SSB as the *21.6_Add_Sel+q_Block* model (Figure 3G.5). But, further reductions in recent recruitment estimates compared to previous models led the terminal SSB estimate and resulting stock status to be considerably more pessimistic compared to the continuity model (*16.5_Cont*; Table 3G.3, Figure 3G.5). The resulting downgrades in each of the 2014, 2016, and 2017 year classes was about 20-50% compared to the Continuity model (*16.5_Cont*; Figure 3G.5). Fits to the data generally followed the trends of model *21.6_Add_Sel+q_Block* with improved fit to the fishery CPUE data set compared to previous models. Most importantly, model *21.8_No_q_Add_Sel+q_Block* estimated a considerably lower terminal year SSB (74 kt) with only a slight decrease in the biomass-based reference point compared to model *21.6_Add_Sel+q_Block*, which resulted in an ABC of 29 kt. Once again, the reduction in ABC compared to the Continuity model (*16.5_Cont*) was strongly influenced by the large comparative reductions in recent recruitment estimates.

Data weighting comparisons

When Francis reweighting was applied to the Continuity model (*16.5_Cont*), the resulting model (*21.9_Cont_Francis*) estimated smaller recent recruitment events (particularly for the 2017 year class; Figure 3G.7) and demonstrated much better fits to the longline survey RPN index (Figure 3G.8), as well as the trawl survey biomass index (not provided). Although no strong scaling changes occurred in terms of SSB, the *21.9_Cont_Francis* model was more optimistic in terms of population trajectory in recent years with SSB not declining as rapidly and rebuilding quicker than the Continuity model (*16.5_Cont*; Figure 3G.7). Additionally, the terminal SSB was higher and the biomass-based reference point was considerably lower than in the Continuity model (*16.5_Cont*; Table 3G.3). However, because recruitment estimates for the 2017 year class were much smaller, the projected ABC decreased slightly from the *16.5_Cont* model.

As is expected from the Francis method, many of the final weights given to the compositional data were lower than the fixed weights used in the Continuity model (*16.5_Cont*; Table 3G.5). The implicit downweighting of the compositional data allowed the model to better fit the index data (Figures 3G.8 – 3G.9), which is extremely important in terms of model interpretation of recent year class strength. Recent year classes are notoriously difficult for integrated models to accurately estimate (i.e., due to only a handful of data observations of these events) and the rapid changes in apparent resource productivity as observed by the influx of young, small fish in the survey and fishery age and length composition data has led to large uncertainty in the Continuity model (*16.5_Cont*) estimates of recent recruitment events. Although these year classes were estimated to be historically large, they have been undergoing large retroactive downgrades as more data on the strength of these recruitment events have become available (Goethel et al., 2020). The higher emphasis given to compositional data forced the *16.5_Cont* model to closely fit the rapid shift in the composition data since 2016, which led to the unprecedented estimates of year class strength at the cost of greatly overestimating all of the abundance and biomass indices (e.g., by more than 30% in the case of the longline survey RPN index). The converse is true after reweighting in the *21.9_Cont_Francis* model, where the survey indices are now better fit and recruitment estimates are slightly decreased.

However, the resultant data weights provide greater emphasis to fixed gear fishery length compositions over all other compositional data sources, including the associated fishery age compositions. These weights are surprising given the relatively large number of sablefish otoliths sampled each year to determine age compositions (i.e., more than 1000 samples are taken from both the fishery and longline survey). Conversely, the longline survey age composition data is given more weight than the associated length compositions, but still lower relative weight than the fishery length composition data. It is unclear what underlying factor is driving the relative weights developed during the reweighting analysis, but there is likely model tension due to simultaneously fitting the length, age, and abundance index data sources. Additionally, uncertainty associated with assigning ages for young fish associated with the large recent recruitment events (i.e., ageing imprecision leading to a ‘smearing effect’ across large, consecutive year classes; Beamish and McFarlane, 1995) might be causing model difficulty rectifying age and length composition interpretations of year class strength for the 2014, 2016, and 2017 year classes. The decreased emphasis of fishery age composition data does lead to degraded fit to these data after reweighting (as discussed for the *21.10_Proposed* model; Figure 3G.20).

It is important to note that the resulting data weights explicitly counter the recommendations of the 2016 CIE, which suggested that the longline survey index was being too closely fit at the expense of the compositional data (hence the recommendation to increase the weights of the composition data). However, these recommendations were developed before the large 2014 and subsequent 2016 and 2017 year classes began to be observed in the data and did not account for the resultant extreme overestimation of the survey index. Although not presented, retrospective patterns were considerably reduced for the *21.9_Cont_Francis* model compared to the *16.5_Cont* model, where the reweighted model demonstrated higher stability and fewer model scaling issues when data were removed in subsequent peels.

Final proposed model

The final proposed model for the 2021 SAFE incorporates the improvements noted in each set of model building exercises, including updating weight, growth, and maturity (i.e., using the age-length maturity model), removing catchability priors, allowing for a recent fishery CPUE catchability along with fishery and survey selectivity time block, then using the Francis method to reweight the final model. In general, model *21.10_Proposed* melds the mixture of trends and changes from each of the *21.5_Upd_Bio_AL-Mat*, *21.8_No_q_Add_Sel+q_Block*, and *21.9_Cont_Francis* models. The resulting population trend and scale in terms of SSB is very similar to the *16.5_Cont* model, but with a more pessimistic trend during the mid-1990s and early 2000s followed by a more optimistic trend (i.e., flat instead of declining) over the last five to ten years similar to the *21.9_Cont_Francis* model (Figure 3G.7). Conversely, recent recruitment estimates are severely decreased compared to the *16.5_Cont* model and, notably, the 2017 year class estimate is even much lower than estimated in the *21.8_No_q_Add_Sel+q_Block* model (Figure 3G.7). The reductions in recruitment are largely driven by the increased fishery and survey selectivity on younger ages in the recent (post-2016) time block (as discussed for model *21.6_Add_Sel+q_Block*; Figure 3G.14) along with the reductions in relative weight given to the compositional data due to the application of Francis reweighting (as discussed for model *21.9_Cont_Francis*; Table 3G.5, Figure 3G.9). Compared to the continuity model (*16.5_Cont*), the new proposed model (*21.10_Proposed*) provides significantly improved fits to both the fishery CPUE and the longline survey RPN indices (Figure 3G.8). Of particular interest, the fit to the RPN index improves starting in the mid-2010s and continues through the terminal year (Figures 3G.8, 3G.17 - 3G.18). Whereas the *16.5_Cont* (and all other models developed) predict much lower RPNs than observed from 2014 to 2017 leading to strong declines in SSB during this period, the *21.10_Proposed* model better matches the timing of rebuilding observed in the survey RPN index resulting in a flatter population trajectory over this period (Figures 3G.7 - 3G.8). Similarly, by not overpredicting the value of the survey RPNs in the last three years, the *21.10_Proposed* model estimates more reasonable recruitment values that better reflect the observed data on abundance, which is then reflected by a more subtle rebuilding over the last three years (Figures 3G.7 - 3G.8). The terminal SSB estimate in the *21.10_Proposed* model is substantially lower than the *16.5_Cont* model, but the latter has an associated larger biomass-based reference point (likely due to the larger recent recruitment estimates and overall productivity), which results in almost identical stock status between the models (Table 3G.3). However, because recent recruitment estimates are greatly reduced in model *21.10_Proposed* compared to *16.5_Cont*, the resulting projected SSB does not increase as rapidly nor reach as high a magnitude; therefore, there are large reductions in future ABCs compared to *16.5_Cont* (i.e., an ABC of 27 kt in 2021 for the *21.10_Proposed* model; Table 3G.3, Figure 3G.12).

The final proposed model (*21.10_Proposed*) demonstrates limited retrospective patterns with a Mohn's rho of 8% compared with a value of 17% for the Continuity model (*16.5_Cont*; Figure 3G.10). Although the retrospective pattern is reduced compared to model *16.5_Cont*, the results must be carefully interpreted. Because of the 2016 time block for selectivity and fishery CPUE catchability, models before and after the 2018 peel are not necessarily directly comparable (i.e., for peels before 2018 there is no estimation of new catchability and selectivity parameters for the post-2016 time block). However, models with consistent parametrizations (i.e., 2020, 2019, and 2018 peels; the black, purple, and pink lines in Figure 3G.10) are nearly identical with minor scaling differences compared to model peels prior to 2017. Perhaps more importantly, the issue of retroactive downgrading in recent recruitment estimates (i.e., for the 2014 and 2016 year classes), which has been an emergent problem since 2018 for the Continuity model (*16.5_Cont*), has been essentially eliminated with the new proposed model (*21.10_Proposed*; Figure 3G.11). Again, it is worth noting the model parametrization difference between the 2017 and 2018 peels, which is clearly visible in the sudden decrease in the 2014 year class estimate (i.e., the original large value is based on the 2017 peel that does not include a recent time block for catchability and selectivity, which the subsequent 2018 peel does include; Figure 3G.11). Consistent estimates of recruitment from one year to the next, as observed with the *21.10_Proposed* model, helps to prevent overly optimistic projected ABC values (Table 3G.6), while also reducing the probability of future overfishing (because there is less probability that projected ABCs will be set too high due to overestimated recruitment). For instance, the impact of the potentially overoptimistic 2014 year class estimates (and subsequent year classes) in the *16.5_Cont* model are clearly observed in the resulting rapid increases in projected ABCs for this model in the retrospective analysis starting with the 2017 peel (i.e., 2018 projected ABC; Table 3G.6). Because the *21.10_Proposed* model has much more modest and stable recruitment estimates, the projected ABCs increase more subtly, though by approximately 7 – 8 kt in each of the last two years. Again, it is worth noting the change in model formulation within the retrospective analysis, which is clearly observed in the sudden decrease in ABC from 2018 to 2019 (i.e., from the 2017 and 2018 retrospective peels, respectively). Overall, it appears that implemented ABCs and realized catch have generally fallen within sustainable thresholds given the projected ABCs from the *21.10_Proposed* model (although there is a potential that landings in 2019 were slightly above desired levels), despite potential overly optimistic projections from the *16.5_Cont* model (Table 3G.6).

Based on the results of the MCMC runs for the *16.5_Cont* and *21.10_Proposed* models, levels of uncertainty appear to be similar for both SSB and biomass (Figures 3G.12 - 3G.13). Estimates of selectivity and fishing mortality generally agree among models, but with higher selectivity at younger ages in recent years for the new proposed model (*21.10_Proposed*; Figure 3G.14). Fishing mortality was generally similar across the two models with slightly lower values throughout much of the 2010s and a slower reduction in the last few years for the *21.10_Proposed* model (Figure 3G.15). Patterns in recruitment generally match, but, as discussed, the new proposed model (*21.10_Proposed*) estimates that recent year class sizes were much lower than predicted by the Continuity model (*16.5_Cont*; Figure 3G.16). Fit to the observed indices is much improved in the new proposed model (*21.10_Proposed*), particularly the fishery CPUE, longline survey RPN, and trawl survey biomass indices (Figures 3G.17 - 3G.18). The fits to the age and length composition data in the new proposed model (*21.10_Proposed*) are generally good and reflect similar patterns observed in the Continuity model (*16.5_Cont*; Figures 3G.19 - 3G.25). But, degradation in the fit to the fixed gear fishery age composition data was observed, particularly due to overestimation of age-2 fish and underestimation of age three to seven fish (Figure 3G.20).

Discussion

Rapid changes in the sablefish resource as well as the associated fisheries have proven difficult to address in the sablefish stock assessment model currently used for management advice, which has led to increasing retrospective patterns and extensive retroactive downgrading of recent year class strength (Goethel et al., 2020). Updated data and analysis of growth, weight, and maturity suggest that values for these biological parameters used in the assessment should be refined (Echave, 2021; Williams and Rodgveller, 2021). Similarly, degrading fits to important data sources (e.g., longline survey abundance indices) suggest that model parametrization and data weighting merit careful consideration. After exploring a variety of model updates and new parametrizations, the results of the current work indicate that five important changes should be considered for the 2021 sablefish assessment: 1) weight and growth for the recent time period (1996 – present) should be updated to reflect the full extent of available data; 2) maturity should be updated with an age-length GAM that accounts for skipped spawning using recent histological data; 3) the catchability priors are no longer needed; 4) a recent time block for estimation of fishery and survey selectivity and fishery CPUE catchability will allow the model to better fit recent data and reduce internal model tension due to slightly incongruous trends in indices and compositional data; and 5) using data reweighting approaches (e.g., the Francis method) can help improve fits to abundance indices, limit retrospective patterns, and reduce retroactive downgrades in recruitment estimates and associated ABCs. It is also worth noting that difficulties updating the fishery CPUE index for the 2021 SAFE (Appendix A.1) may have implications for the final 2021 assessment model, given that there is unlikely to be a 2020 CPUE index data point.

Therefore, model *21.10_Proposed* is suggested as the best model for the provision of management advice for the 2021 assessment year, given that it incorporates each of these model changes. The main impacts of these changes are that maximum weight and growth have increased, but the rate of growth is slightly lower for younger ages (Figures 3G.1 - 3G.2). Concomitantly, maturity is slightly lower than previously assumed, especially for young and intermediate ages in the recent time period (1996 – Present; Figure 3G.3). The addition of a recent (post-2016) selectivity and fishery CPUE catchability time block suggests that catchability has slightly decreased in the fixed gear fishery (Table 3G.4), but that the selectivity in both the fixed gear fishery and longline survey has increased for younger ages (Figure 3G.14). Finally, recent recruitment appears to be high and well above average levels, but not as extreme as predicted from the Continuity model (*16.5_Cont*); in fact, the recent recruitment trend appears to be similar to the pattern observed in the late 1970s and early 1980s when the largest historic year class (i.e., the 1977 year class) was observed (Figure 3G.16). Model *21.10_Proposed* provides much better fits to the longline survey RPN and fishery CPUE indices, which results in less drastic reductions in SSB during the mid-2010s with more subtle rebuilding since 2017 (Figure 3G.13). However, this does come at the expense of some degraded fits to fishery age composition data (Figure 3G.20). Consequently, the sablefish resource is not projected to rebuild to as high a level as previously thought (i.e., based on the Continuity model, *16.5_Cont*), though it is still expected to recover to well above the biomass-based reference points (Figure 3G.12). As a result, projected ABCs from the *21.10_Proposed* model are significantly lower than the *16.5_Cont* model (Tables 3G.3 and 3G.6). Fortunately, the projected ABCs based on the retrospective analysis from model *21.10_Proposed* appear to align well with implemented ABCs and resultant realized catch, despite the projected ABCs from the Continuity model (*16.5_Cont*) suggesting much higher sustainable catch levels (Table 3G.6). Moreover, projected ABCs appear to be less volatile using the proposed model (*21.10_Proposed*; Table 3G.6), while retrospective patterns and associated retroactive downgrades in recruitment year class strength have been greatly diminished.

Although the proposed model (*21.10_Proposed*) does not (and can never) perfectly describe the dynamics of the sablefish resource and fishery, we believe it provides important tangible improvements over the current model (*16.5_Cont*). Many updates are consistent with first principles (i.e., biological updates) or statistical and assessment modeling best practices (i.e., freely estimating catchability parameters and using data reweighting approaches), while others appear appropriate given existing hypotheses regarding sablefish dynamics (e.g., apparent increases in availability and selectivity, which may be due to density-dependent spillover from optimal juvenile habitat or warming water temperatures due to recent marine heatwaves that could be forcing juveniles into deeper, colder slope waters at earlier ages). Testing these hypotheses would require future process studies on fish behavior and gear selectivity. However, it is important to remember that the sablefish assessment assumes a single panmictic population across all management regions in Alaska, while the associated fishery dynamics are assumed homogeneous across the same domain. Thus, it can be difficult to relate observed or hypothesized changes at a regional scale to model changes at the Alaska-wide scale. Although it is hypothesized that recent density-dependent or environmental effects might have increased availability of small sablefish to the longline survey, thereby increasing recent selectivity of younger ages, such direct mechanistic explanations are not necessarily required to rationalize changes in model parametrization (i.e., allowing time-variation in catchability or selectivity parameters) that improve model performance and fits to observed data (Wilberg et al., 2009). In the future, continued improvements to the sablefish assessment model will be undertaken, including continued exploration of age- and time-varying natural mortality, alternate parametrizations of fishery selectivity (e.g., incorporating dome-shaped fishery selectivity or time-varying non-parametric approaches), better incorporation of pot gear dynamics into the assessment model, continued refinement to data weighting schemes, and the potential incorporation of the extensive tagging data available for sablefish. The sablefish team continually strives to refine and improve the sablefish assessment model and we envision that the proposed model updates will provide an important step towards continued sustainable management of the resource.

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Tables

Table 3G.1. Description of model runs with associated abbreviations.

Model Group	Scenario Name	Abbreviation	Description
Continuity	16.5. Continuity	*16.5_Cont*	The 2020 SAFE final model, which utilizes priors on catchability, fixed data weights, and no recent time blocks in the fishery or survey for catchability and selectivity parameter estimation.
Update Biology	21.1. Update Weight and Growth	*21.1_Wt+Grt*	The continuity model with updated weight and growth parameters based on the full complement of longline survey data from 1996-2019 (as described in Echave, 2021).
	21.2. Update Age-Based Maturity No Skipped Spawning	*21.2_Mat_Age_GLM_No_SS*	The continuity model with maturity updated using the age-based general linear model (GLM) and ignoring information on skipped spawning (i.e., strict update of maturity based on histological data only) from Williams and Rodgveller (2021).
	21.3. Update Age-Based Maturity	*21.3_Mat_Age_GAM*	The continuity model with maturity updated using the age-based general additive model (GAM) from Williams and Rodgveller (2021).
	21.4. Update Age-Length Maturity	*21.4_Mat_AL_GAM*	The continuity model with maturity updated using the age-length based general additive model (GAM) from Williams and Rodgveller (2021).
	21.5. Update Weight, Growth, and Age-Length Maturity	*21.5_Upd_Bio_AL-Mat*	The continuity model with weight and growth updated based on Echave (2021) and maturity updated using the age-length based general additive model (GAM) from Williams and Rodgveller (2021).
Model Parametrization	21.6. Remove Catchability Priors	*21.6_No_q_Prior*	The continuity model with all priors on catchability coefficients removed.
	21.7. Incorporate a Recent (post-2016) Time Block for Fishery and Survey Selectivity and Fishery CPUE Catchability Estimation	*21.7_Add_Sel+q_Block*	The continuity model with a recent time block (2016 - present) added to the longline fishery and longline survey for the estimation of selectivity parameters along with an associated fishery CPUE catchability parameter.
	21.8. Remove Catchability Priors and Add 2016 Selectivity and Fishery CPUE Catchability Time Block	*21.8_No_q_Add_Sel+q_Block*	The continuity model with all priors on catchability coefficients removed and a recent time block (2016 - present) added to the longline fishery and longline survey for the estimation of selectivity parameters and fishery CPUE catchability.
Data Weighting	21.9. Continuity with Francis Reweighting	*21.9_Cont_Francis*	The continuity model with data weights updated using the Francis (2011, 2016) reweighting method.
	21.10. Proposed Model	***21.10_Proposed***	The final proposed model where weight and growth are updated based on Echave (2021), maturity is updated using the age-length based general additive model (GAM) from Williams and Rodgveller (2021), catchability priors are removed, a recent time block (2016 - present) is added to the longline fishery and longline survey for the estimation selectivity parameters and fishery CPUE catchability, and data weights are updated using the Francis (2011, 2016) reweighting method.

Table 3G.2. The maximum gradient component (*Max Grad*), total negative log-likelihood (*nLL*), and number of parameters *(# Pars*) for each model run. Note that all models aside from the Continuity (*16.5_Cont*) and Francis reweighted Continuity (*21.9_Cont_Francis*) models include a minor update to the trawl fishery selectivity parameterization, which reduced the number of estimated parameters by one compared to the Continuity model (see Section 2.1).

Model	Converged?	Max Grad	nLL	# Pars
16.5_Cont	TRUE	0.000301006496384589	1888.1	240
21.1_Wt+Grt	TRUE	6.28388663045004e-05	1845.4	239
21.2_Mat_Age_GLM_No_SS	TRUE	8.94369828047811e-05	1889.7	239
21.3_Mat_Age_GAM	TRUE	6.91647880822961e-05	1889.7	239
21.4_Mat_AL_GAM	TRUE	8.63499946136482e-05	1889.7	239
21.5_Upd_Bio_AL-Mat	TRUE	5.75877264453965e-05	1845.4	239
21.6_No_q_Prior	TRUE	0.000174866710556766	1907.33	239
21.7_Add_Sel+q_Block	TRUE	0.000268053382307611	1840.25	244
21.8_No_q_Add_Sel+q_Block	TRUE	9.24286507245969e-05	1841.4	244
21.9_Cont_Francis	TRUE	2.6246219892387e-05	724.48	240
21.10_Proposed	TRUE	0.00151063289005471	776.66	244

Table 3G.3. Estimated terminal year (2020) parameters (i.e., fishing mortality, *F*, and spawning stock biomass, *SSB*), associated biological reference points and stock status determinations relative to a target SSB representing 40% (*SSB_40*) depletion from unfished SSB (SSB_0), and resultant Acceptable Biological Catch (*ABC*) based on the NPFMC B_{40} HCR. For models with time-varying biology or selectivity, reference points and associated calculations utilize the most recent time block of values.

Model	2020 SSB (kt)	SSB_40 (kt)	2020 SSB/SSB_40	2020 F	F_40	2020 F/F_40	F_ABC	2021 ABC (kt)
16.5_Cont	94.43	126.84	0.74	0.05	0.1	0.5	0.1	52.41
21.1_Wt+Grt	99.1	135.16	0.73	0.04	0.09	0.44	0.09	44.88
21.2_Mat_Age_GLM_No_SS	87.17	124.22	0.7	0.05	0.09	0.56	0.09	44.23
21.3_Mat_Age_GAM	79.99	117.98	0.68	0.05	0.09	0.56	0.09	44.94
21.4_Mat_AL_GAM	90.72	127.17	0.71	0.05	0.09	0.56	0.09	48.35
21.5_Upd_Bio_AL-Mat	85.31	130.76	0.65	0.04	0.08	0.5	0.08	39.75
21.6_No_q_Prior	88.86	126.44	0.7	0.05	0.09	0.56	0.09	47.32
21.7_Add_Sel+q_Block	80.81	117.4	0.69	0.05	0.09	0.56	0.08	34.61
21.8_No_q_Add_Sel+q_Block	74.05	115.28	0.64	0.06	0.09	0.67	0.08	29.1
21.9_Cont_Francis	101.42	112.57	0.9	0.05	0.11	0.45	0.11	51.25
21.10_Proposed	85	114.19	0.74	0.06	0.08	0.75	0.08	27.09

Table 3G.4. Comparison of catchability coefficient (*q*) estimates for each abundance or biomass index for the continuity (*16.5_Cont*) model, the model with catchability priors removed (*21.6_No_q_Prior*), and the new proposed model (*21.10_Proposed*). Note that the continuity (*16.5_Cont*) model uses priors on catchability parameters whereas the proposed model (*21.10_Proposed*) does not. Similarly, the proposed model (*21.10_Proposed*) has one additional catchability coefficient for the recent (post-2016) time block for fishery CPUE.

		Index							
		Coop LL Survey	LL Survey	LL Survey Post-2016	Trawl Survey	LL Fishery CPUE Pre-1995 (Derby)	LL Fishery CPUE Post-1995 (IFQ)	LL Fishery CPUE Post-2016 (IFQ Recent)	JPN LL Fishery CPUE
Model	**16.5_Continuity**	5.96	7.96	Not Estimated	1.33	3.98	5.93	Not Estimated	6.55
	21.6_No_q_Prior	6.22	8.35	Not Estimated	1.39	4.20	6.26	Not Estimated	6.38
	21.10_Proposed	5.36	7.73	Not Estimated	1.07	3.83	6.81	3.45	8.02

Table 3G.5. Comparison of input data weight for the continuity (*16.5_Cont*) model utilizing fixed data weights, the Francis reweighted continuity model (*21.9_Cont_Francis*), and the new proposed model (*21.10_Proposed*) that also utilizes Francis reweighting. Note that catch and index data weights are held constant throughout the Francis reweighting procedure. Additionally, indices have yearly input standard errors, while compositional data have yearly input effective samples sizes; neither of which are altered during the reweighting procedure.

	Model		
Data Source	*16.5_Cont*	*21.9_Cont_Francis*	*21.10_Proposed*
Fixed Gear Catch	50.000	50.000	50.000
Trawl Catch	50.000	50.000	50.000
Longline Survey RPN	0.448	0.448	0.448
Coop Survey RPN	0.448	0.448	0.448
Fixed Gear Fishery CPUE	0.448	0.448	0.448
Japan Longline Fishery CPUE	0.448	0.448	0.448
Trawl Survey RPW	0.448	0.448	0.448
Fixed Gear Age Composition	7.800	0.817	0.710
Longline Survey Age Composition	7.950	2.297	3.904
Coop Longline Survey Age Composition	1.000	1.123	1.167
Fixed Gear Fishery Length Composition Males	1.000	3.948	5.915
Fixed Gear Fishery Length Composition Females	1.000	4.423	6.223
Trawl Fishery Size Composition Males	4.100	0.324	0.327
Trawl Fishery Size Composition Females	4.100	0.523	0.396
Longline Survey Size Composition Males	1.000	0.904	1.772
Longline Survey Size Composition Females	1.000	0.986	1.885
Coop Survey Size Composition Males	1.000	1.229	1.182
Coop Survey Size Composition Females	1.000	1.923	1.960
Trawl Survey Size Composition Males	7.250	0.954	0.738
Trawl Survey Size Composition Females	7.250	1.274	0.719

Table 3G.6. Comparison of observed catch, enacted ABC, and model projected ABC from retrospective runs of the Continuity model *(16.5_Cont*) and the new proposed model (*21.10_Proposed*). Projected ABCs are from retrospective peels representing a terminal data year equal to the year column minus one. Note that the projected ABCs may differ from the SAFE recommended ABCs as the reported values are based on the current retrospective runs where data inputs may differ from that used in the final models. All values are in metric tons (mt). The 2021 reported catch is the value as of September 1, 2021 as reported on AKFIN.

			Model	
Year	**Catch (mt)**	**ABC (mt)**	***16.5_Cont***	***21.10_Proposed***
2011	12,978	16,040	14,600	12,750
2012	13,869	17,240	14,400	13,464
2013	13,645	16,230	14,000	13,122
2014	11,588	13,722	12,100	12,042
2015	10,973	13,657	12,700	12,989
2016	10,257	11,795	11,300	11,476
2017	12,270	13,083	11,900	12,241
2018	14,341	14,957	25,700	16,829
2019	16,624	15,068	27,300	12,755
2020	19,006	22,009	43,600	19,914
2021	***13,112***	29,588	52,400	27,086

Figures

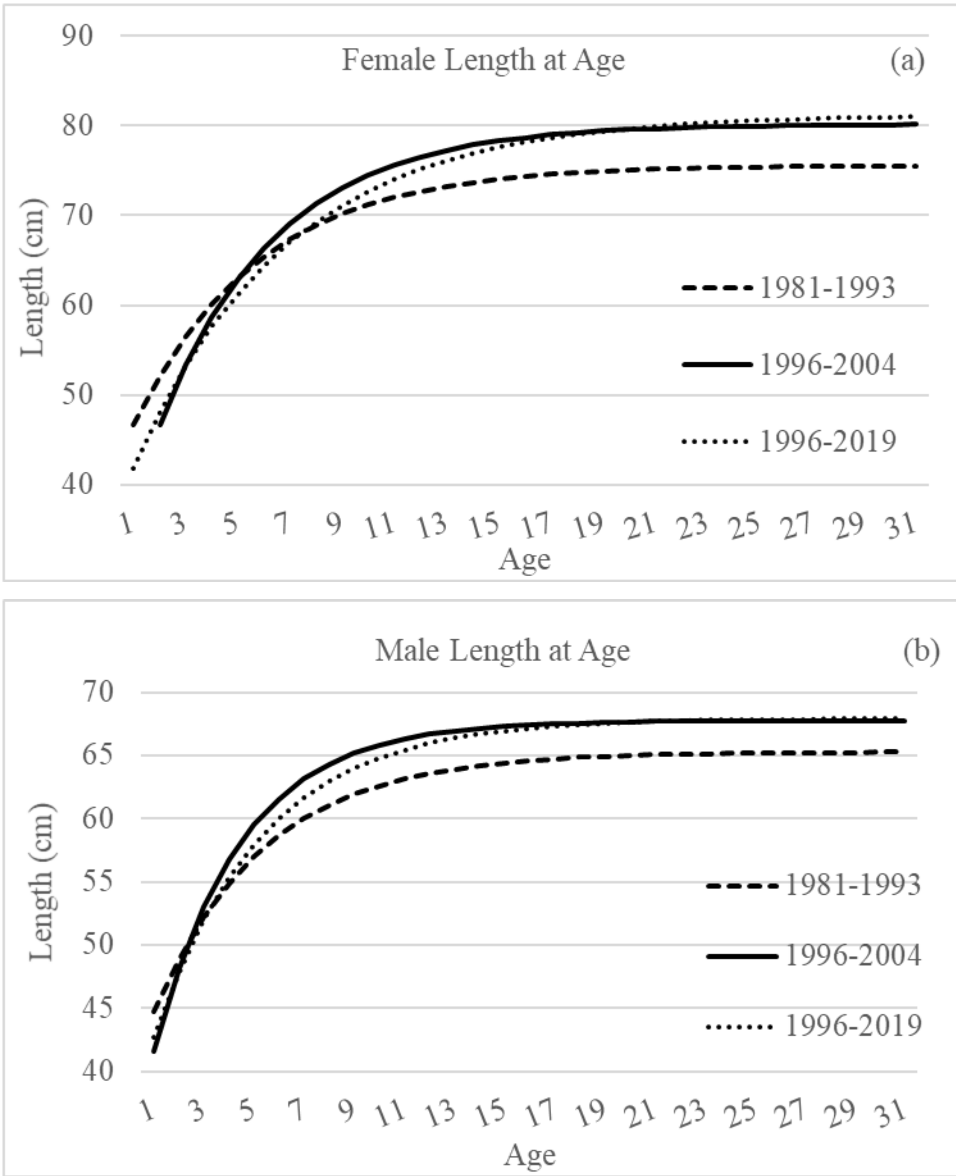


Figure 3G.1. Growth curves used in the continuity (*16.5_Cont*) model (1981 -1993 and 1996 – 2004) and the new proposed model (*21.10_Proposed*; 1981-1993 and 1996 – 2019), as described in Echave (2021). The top panel illustrates the growth curve for females and the bottom panels shows the growth curve for males.

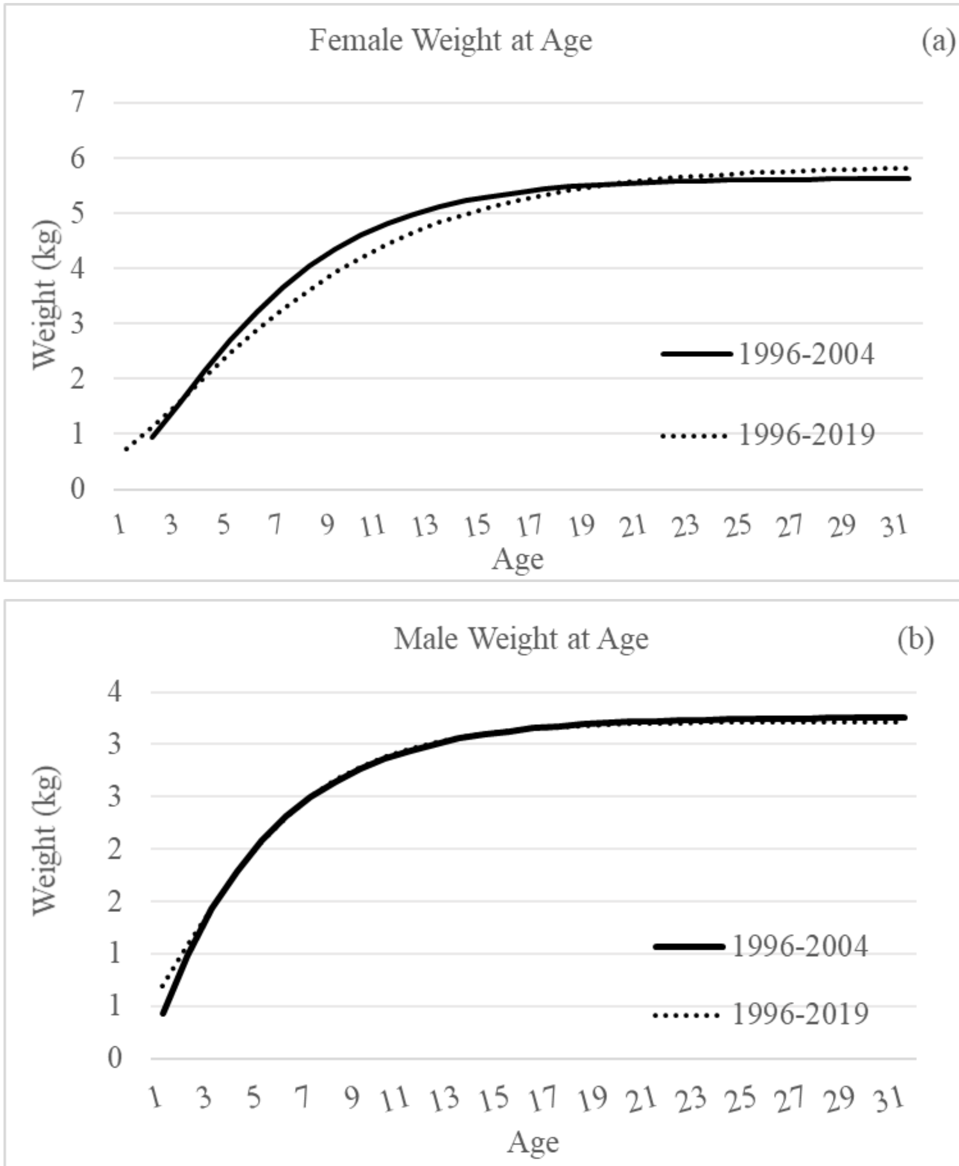


Figure 3G.2. Weight-at-age used in the continuity (*16.5_Cont*) model (1996 – 2004) and the new proposed model (*21.10_Proposed*; 1996 – 2019), as described in Echave (2021). The top panel illustrates the weight-at-age curve for females and the bottom panels shows the weight-at-age curve for males.

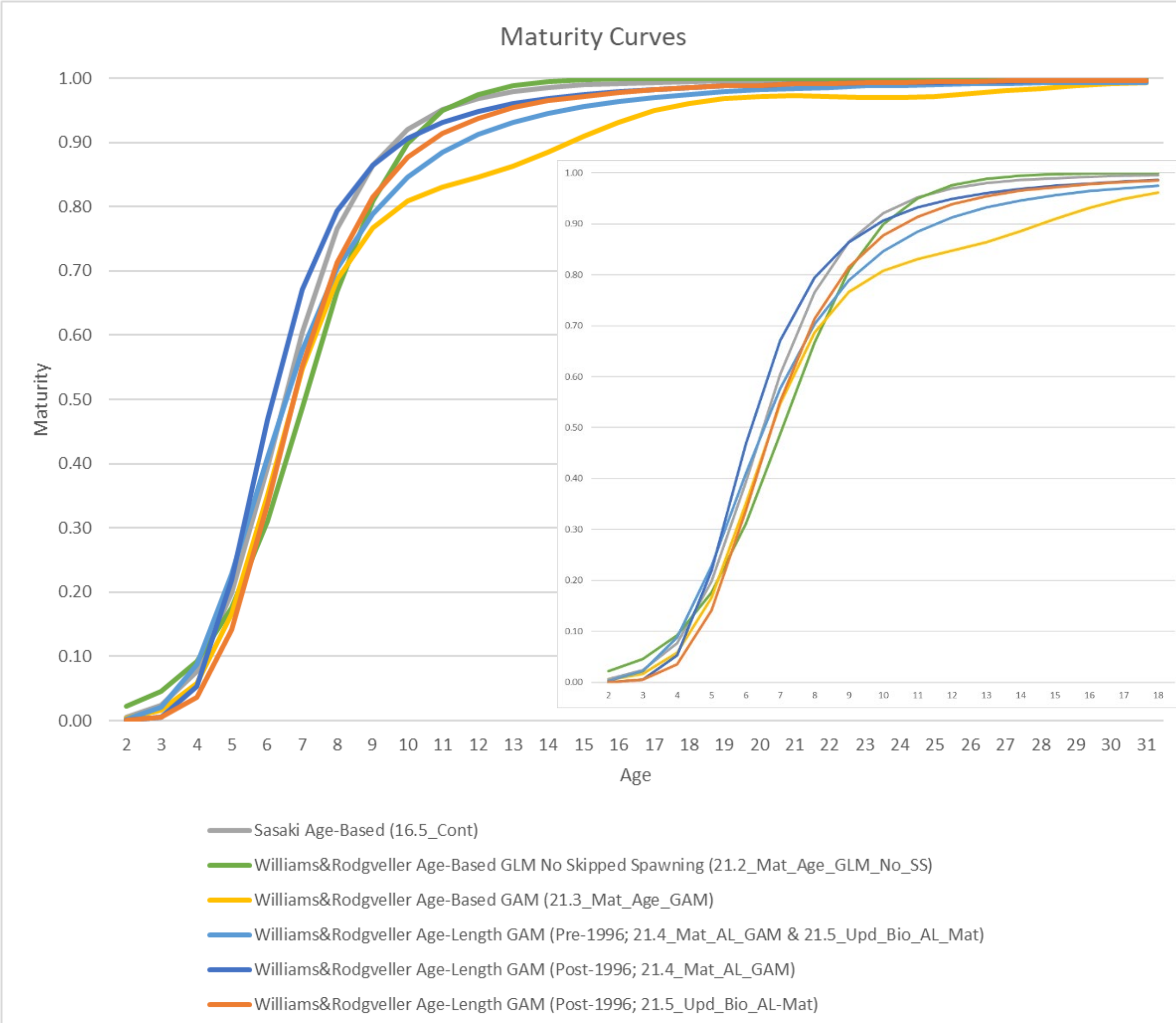


Figure 3G.3. Current and updated maturity-at-age curves as described in Williams and Rodgveller (2021). The grey line illustrates the Continuity (*16.5_Cont*) model using the results of Sasaki (1985), while the green line is the updated age-based maturity curve based on histological data, a generalized linear model (GLM), and not including skipped spawning information (used in the *21.2_Mat_Age_GLM_No_SS* model) from Williams and Rodgveller (2021). The yellow line is the updated age-based maturity using a General Additive Model (GAM) and including skipped spawning information (used in the *21.3_Mat_Age_GAM* model) from Williams and Rodgveller (2021). The blue and orange lines show the updated age-length based maturity curve using a GAM from Williams and Rodgveller (2021). The light blue line illustrates the pre-1996 maturity-at-age, which is used by all age-length based maturity models (given that growth prior to 1996 is constant across all model implementations). The dark blue line is the post-1996 maturity-at-age used in model *21.4_Mat_AL_GAM* and based on the growth parameters used in the Continuity model (*16.5_Cont*). The orange line is the post-1996 maturity-at-age, which used in the *21.5_Upd_Bio_AL-Mat* model, which uses the updated growth parameters. The light blue and orange age-length maturity curves are used in the new proposed model (*21.10_Proposed*). The change in maturity over time in the age-length GAM is due to the different growth stanzas (i.e., the updated growth curves developed by Echave, 2021, and illustrated in Figure 3G.1), despite constant maturity parameters being assumed for all model years (i.e., the age-length maturity model calculates new maturity values when growth changes). Inset provides zoomed in view of most dynamic ages.

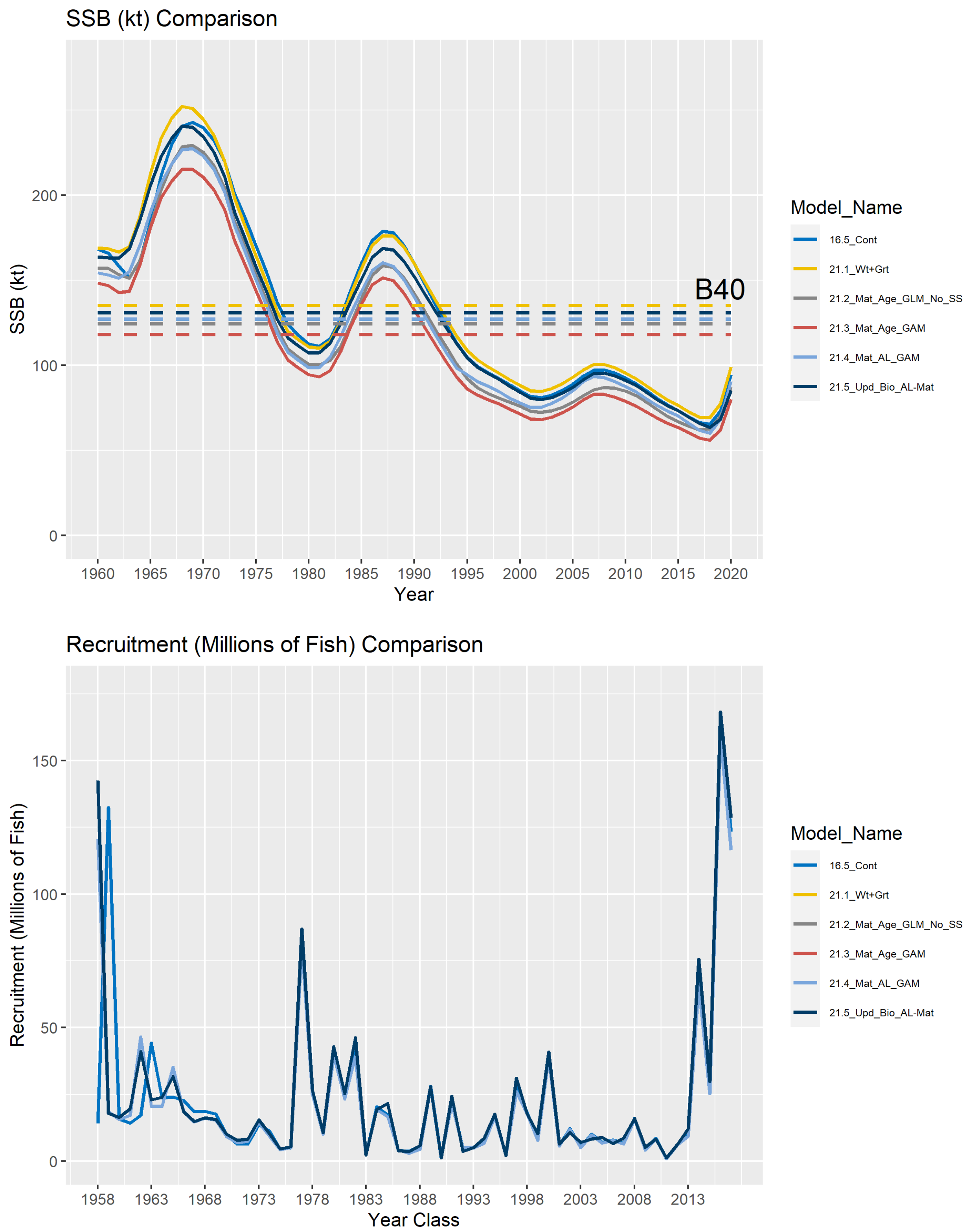


Figure 3G.4. Model comparisons for spawning stock biomass (top panel) and recruitment (bottom panel) within the 'Biology Update' grouping.

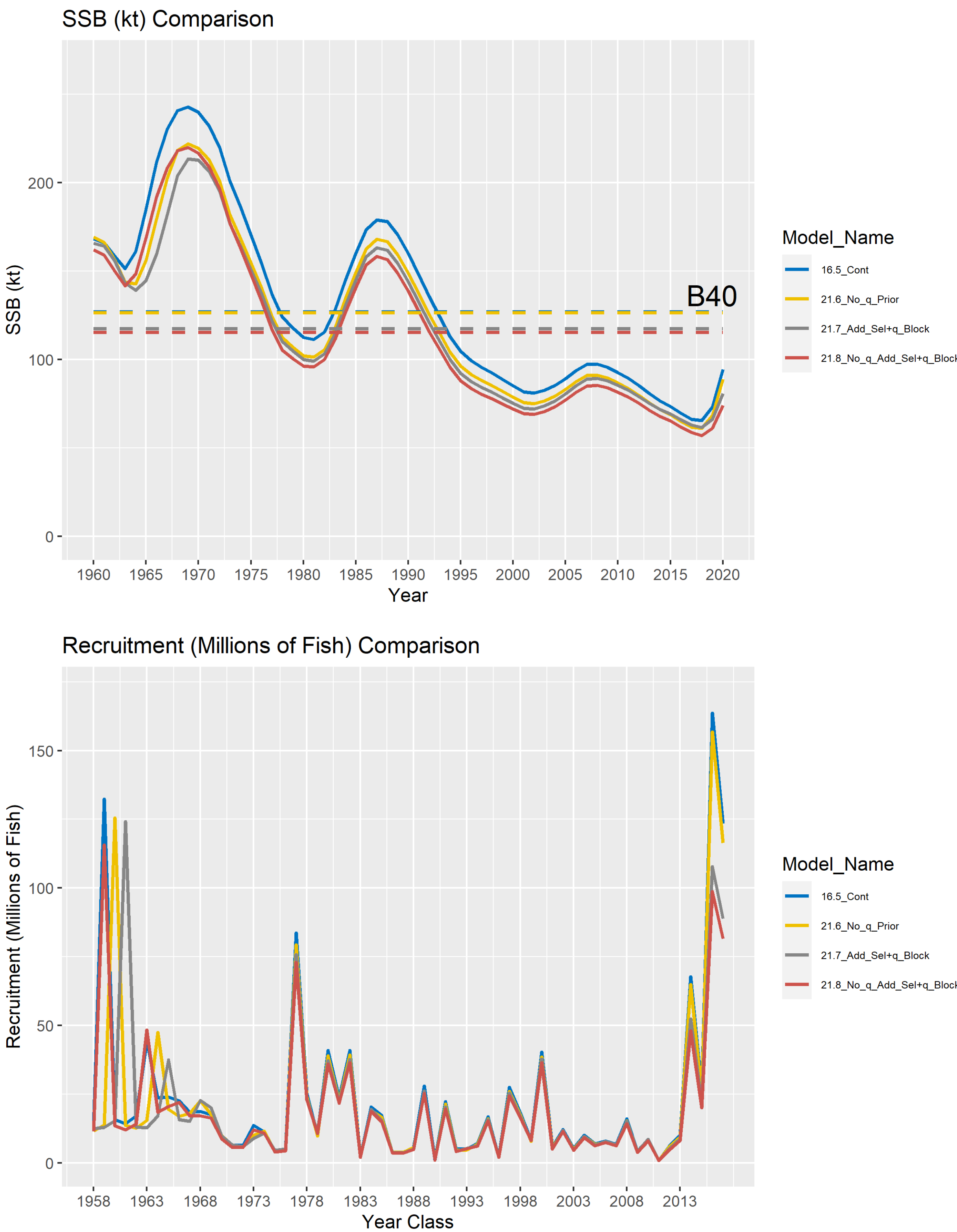


Figure 3G.5. Model comparisons for spawning stock biomass (top panel) and recruitment (bottom panel) within the 'Model Parametrization Update' grouping.

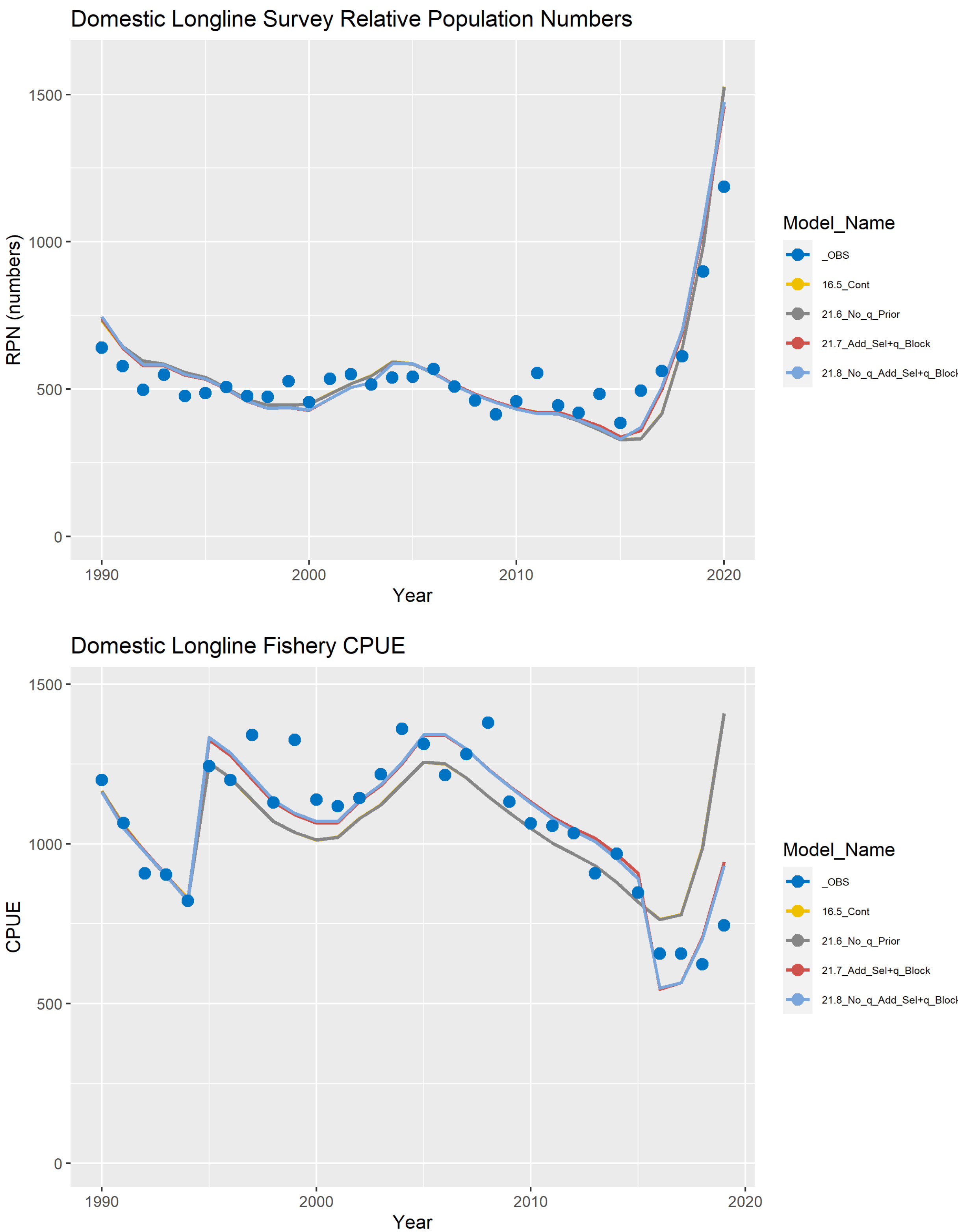
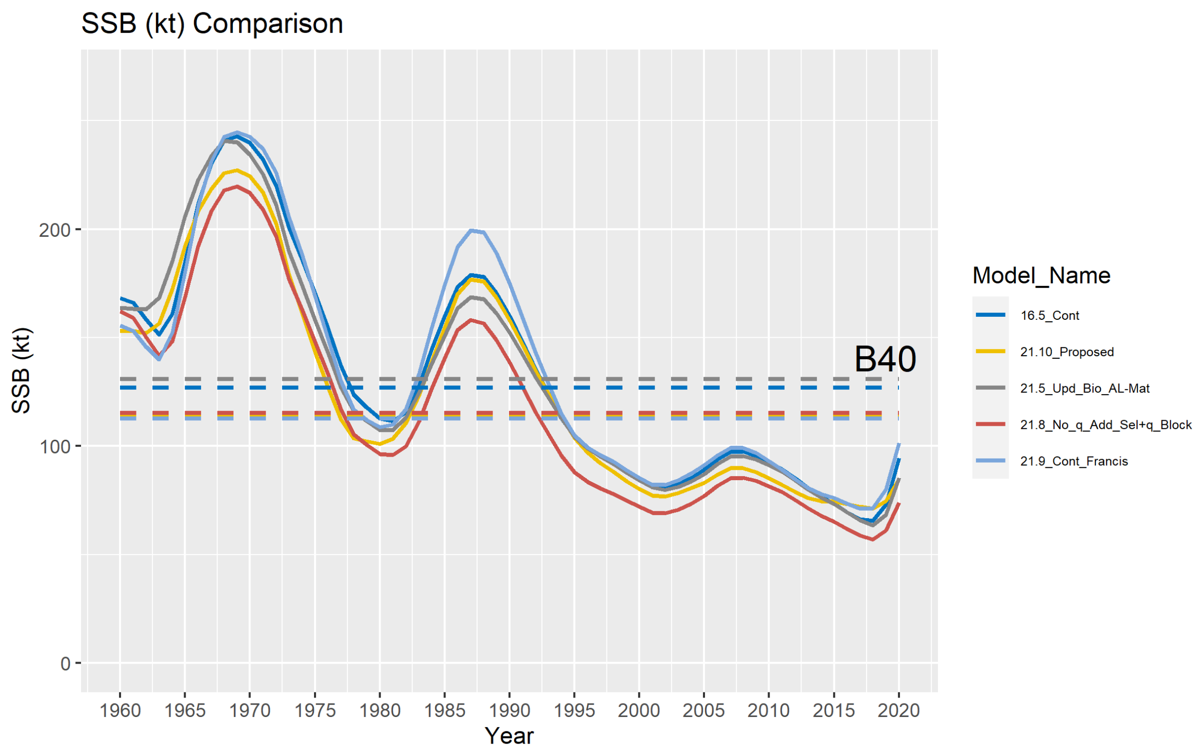


Figure 3G.6. Model comparisons demonstrating fit to the domestic longline survey relative population numbers (RPN) index (top panel) and domestic longline fishery catch-per-unit effort (CPUE) index (bottom panel) within the 'Model Parametrization Update' grouping.



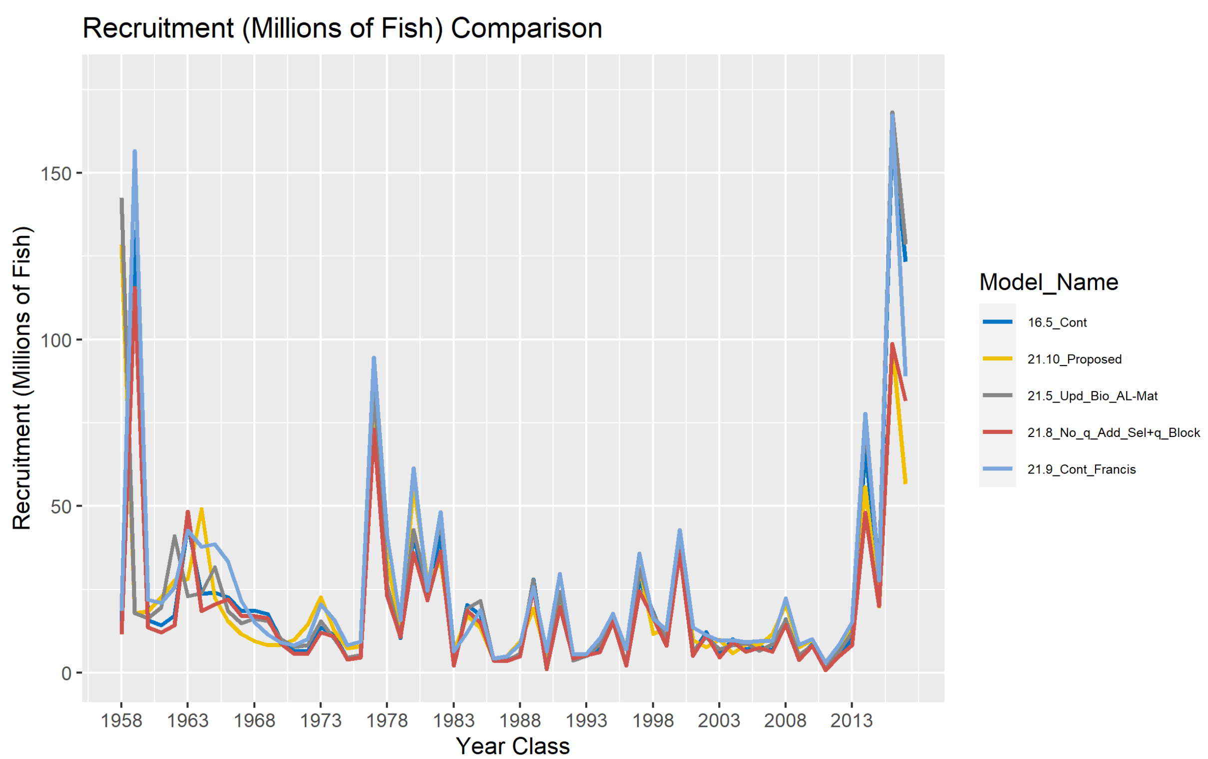
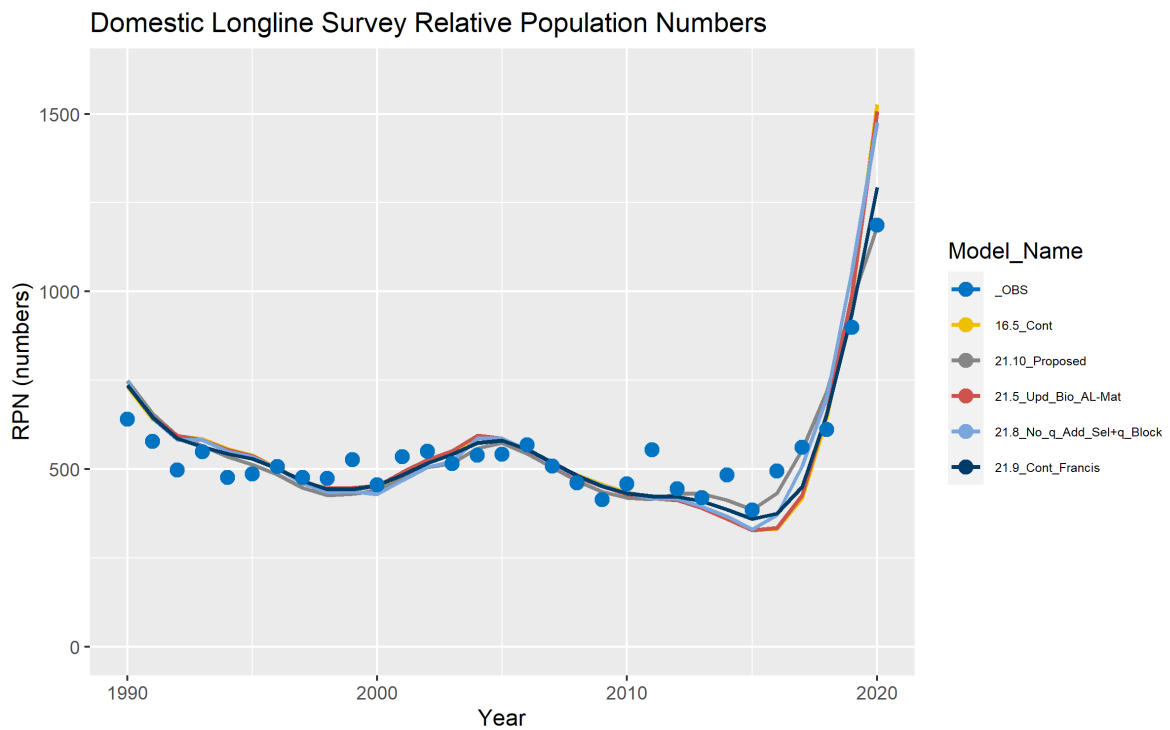


Figure 3G.7. Model comparisons for spawning stock biomass (top panel) and recruitment (bottom panel) within the 'Data Weighting' grouping, including the new proposed model (*21.10_Proposed*), the full 'Biology Update' model (*21.5_Upd_Bio_AL-Mat*), and the 'Model Parametrization Update' model (*21.8_No_q_Add_Sel+q_Block*).



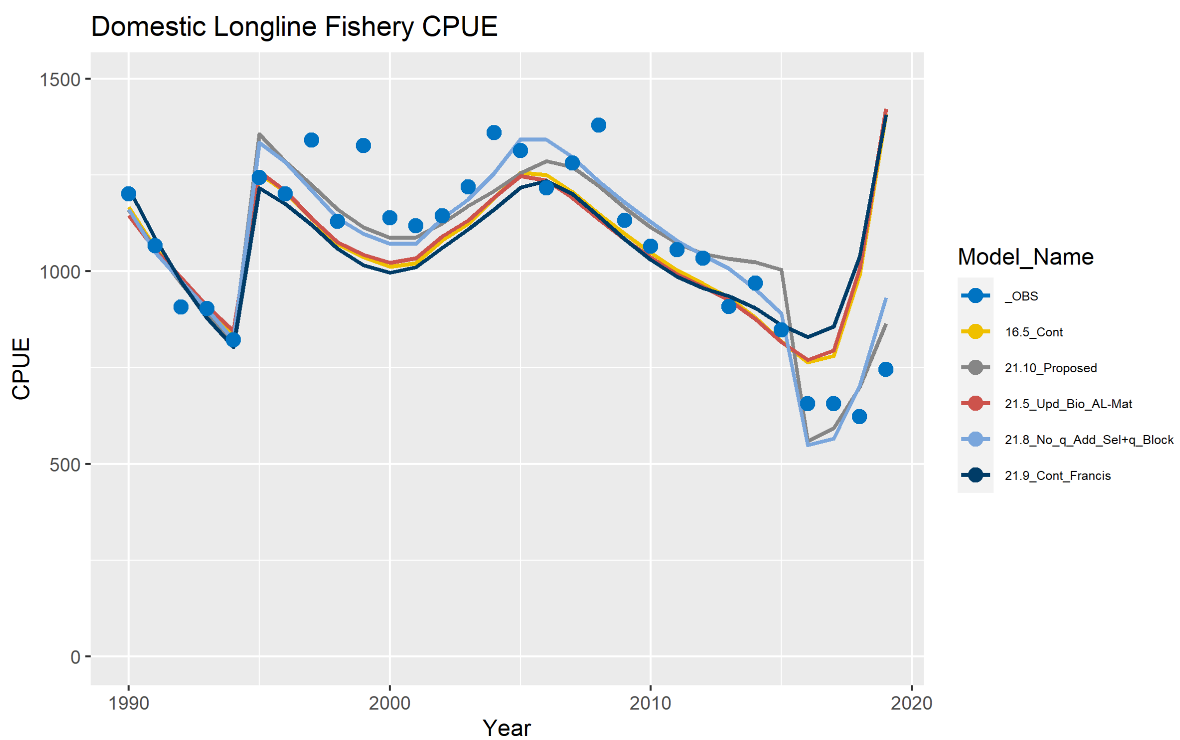


Figure 3G.8. Model comparisons demonstrating fit to the domestic longline survey relative population numbers (RPN) index (top panel) and domestic longline fishery catch-per-unit effort (CPUE) index (bottom panel) within the 'Data Weighting' grouping, including the new proposed model (*21.10_Proposed*), the full 'Biology Update' model (*21.5_Upd_Bio_AL-Mat*), and the 'Model Parametrization Update' model (*21.8_No_q_Add_Sel+q_Block*).

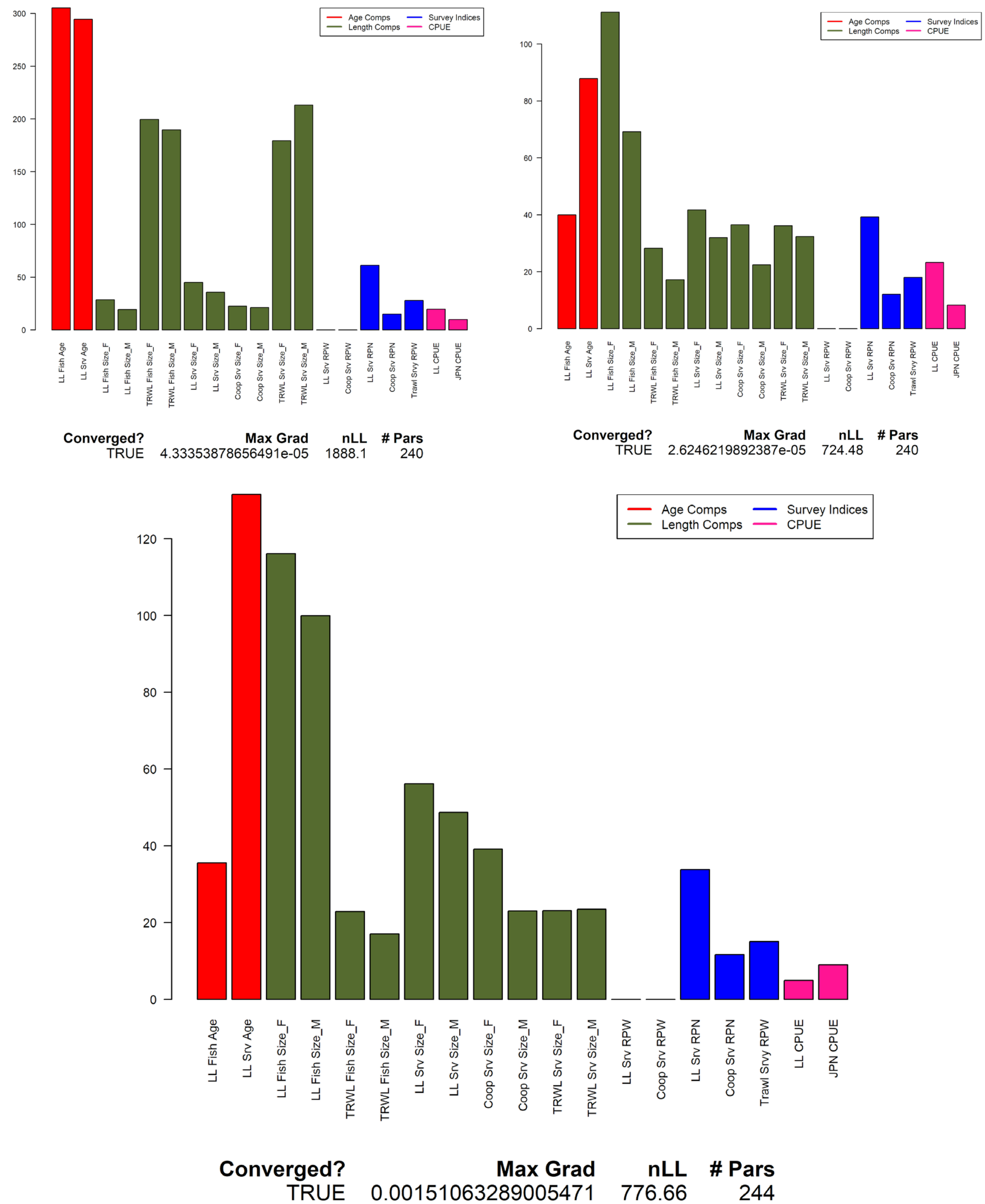


Figure 3G.9. Component contributions to the total negative log-likelihood for each data source fit in the model. Results for the Continuity model (*16.5_Cont*) are in the top left panel, the Francis Reweighted Continuity model (*21.9_Cont_Francis*) are in the top right panel, and the new proposed model (*21.10_Proposed*) are in the bottom panel. Note differences in y-axis scale across panels.

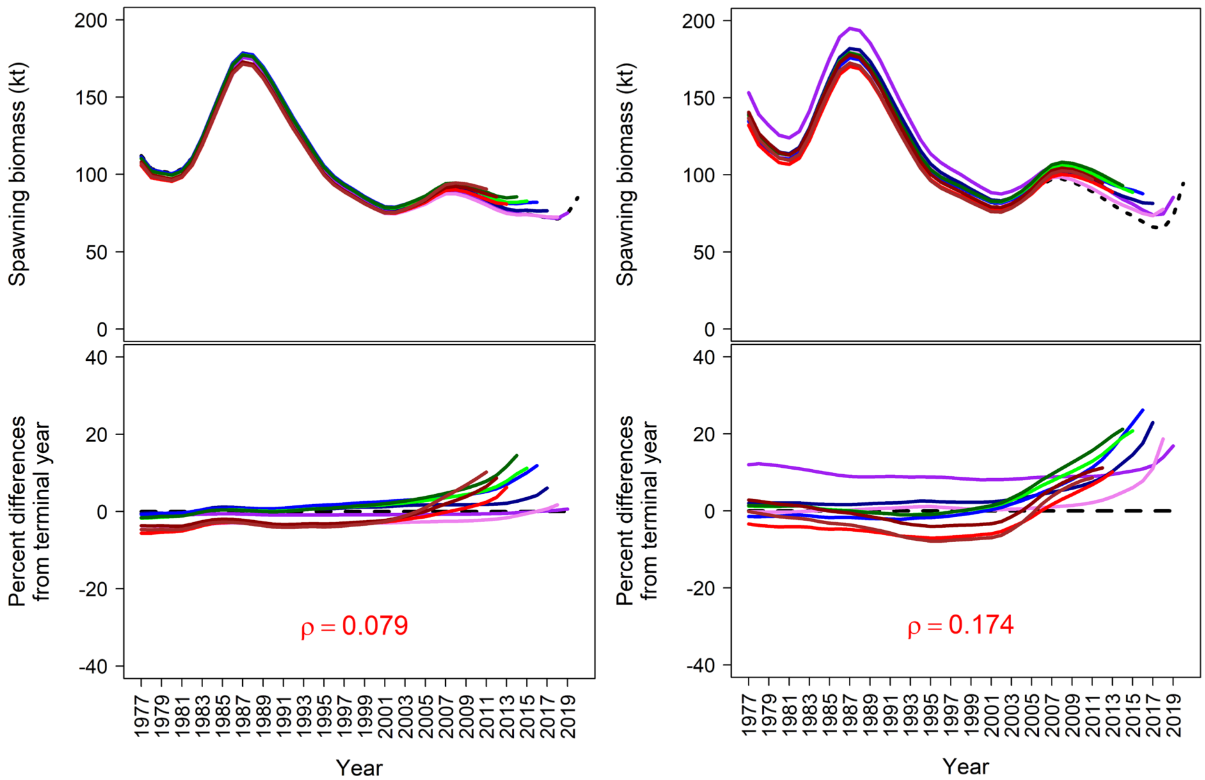


Figure 3G.10. Results of a retrospective analysis for spawning stock biomass for the new proposed model (*21.10_Proposed*; left panel) and the Continuity model (*16.5_Cont*; right panel). Mohn's rho (ρ) is provided in red. Note that the proposed model (*21.10_Proposed*) retrospective analysis has a model change starting with the 2018 retrospective year (i.e., estimation of new longline survey and fishery catchability and selectivity parameters for the post-2016 time block). Thus, comparison of models for retrospective years before and after 2018 (i.e., starting with the dark blue line) is problematic.

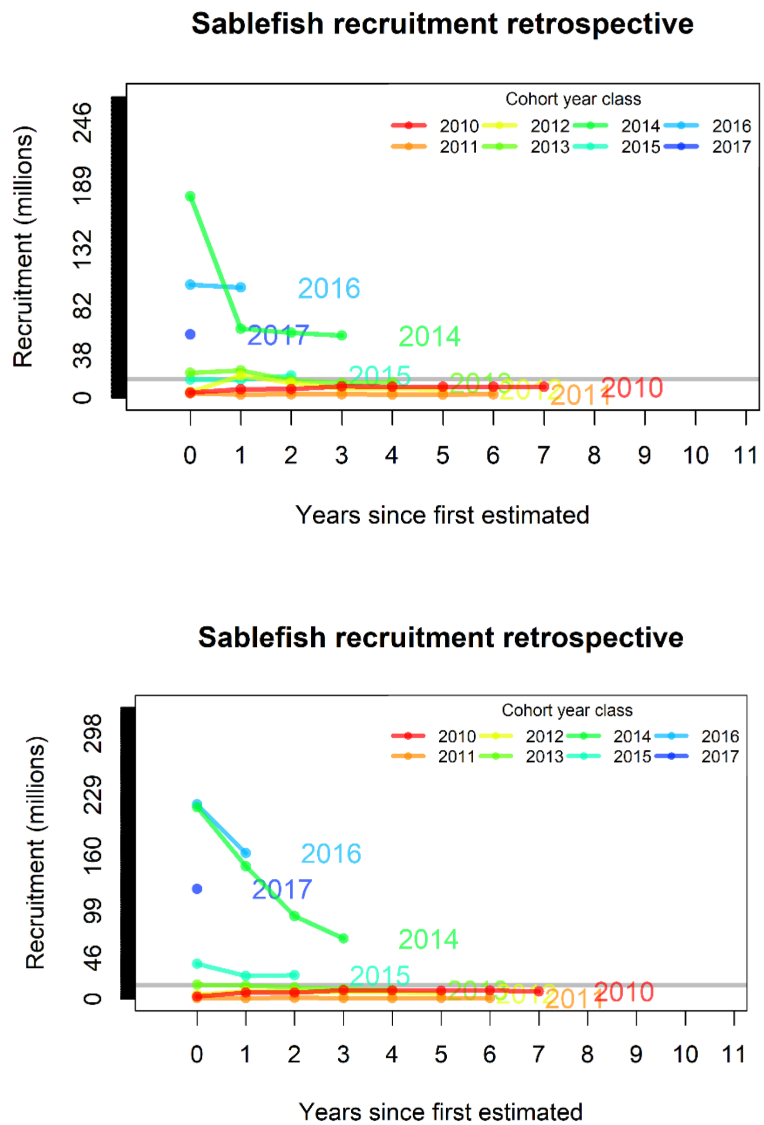


Figure 3G.11. Squid plot demonstrating the refinement of age-2 recruitment estimates as new data years are added to the model based on the results of a retrospective analysis for the new proposed model (*21.10_Proposed*; top panel) and the Continuity model (*16.5_Cont*; bottom panel). Note that the proposed model (*21.10_Proposed*) retrospective analysis has a model change starting with the 2018 retrospective year (i.e., estimation of new longline survey and fishery catchability and selectivity parameters for the post-2016 time block). Thus, comparison of models for retrospective years before and after 2018 is problematic. The transition between model parametrizations is clearly visible in the estimation of the 2014 year class (i.e., the first estimate is based on the 2017 model without a separate catchability and selectivity time blocks for the recent, post-2016, period, while subsequent estimates are based on models with a recent time block).

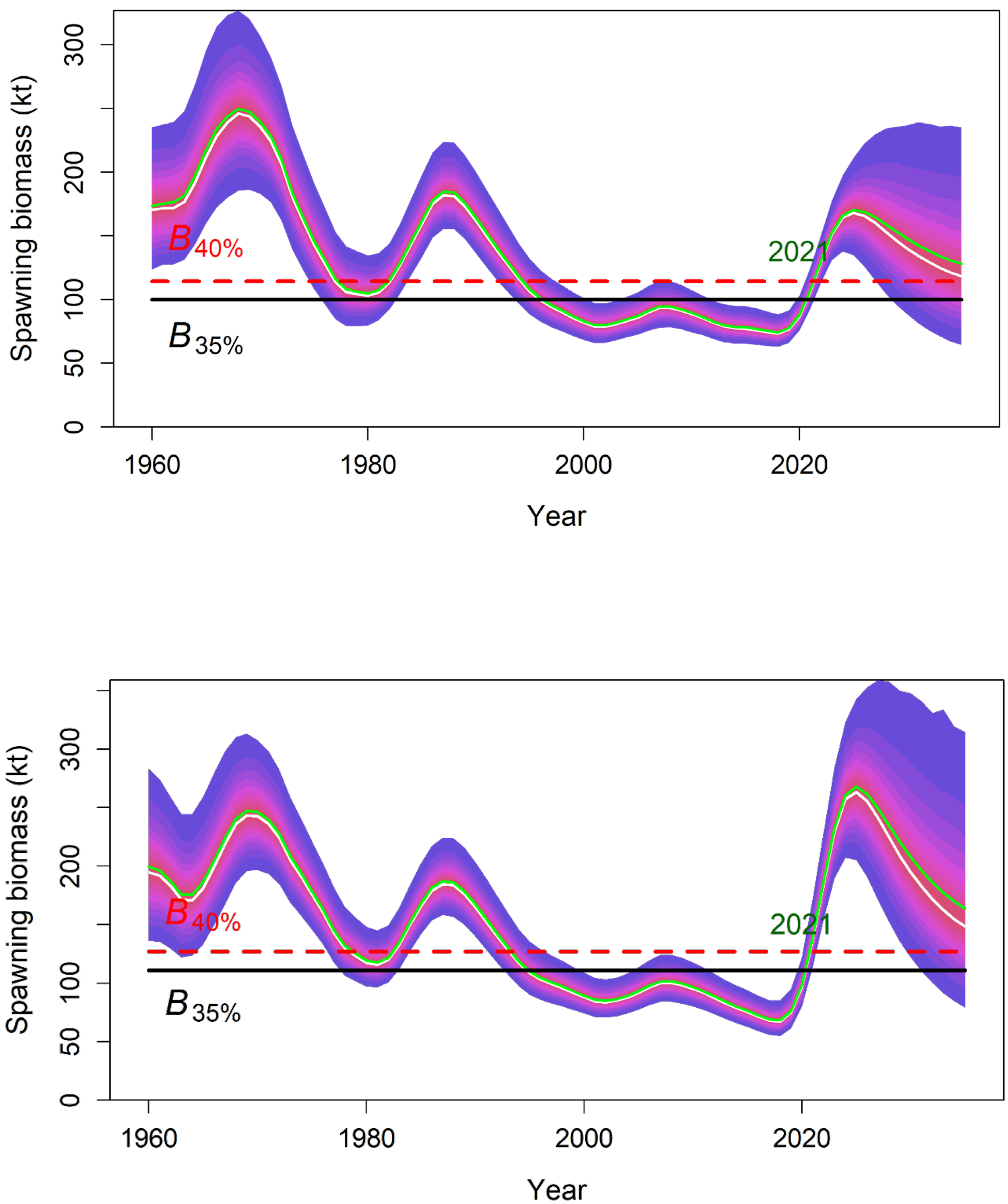


Figure 3G.12. Results of a Markov Chain Monte Carlo (MCMC) analysis demonstrating estimates of female spawning biomass (kilotons) and their uncertainty from MCMC runs. The results for the new proposed model (*21.10_Proposed*) are in the top panel and those for the Continuity model (*16.5_Cont*) are in the bottom panel. White line is the median and green line is the mean, while shaded fill is 5% increments of the posterior probability distribution of spawning biomass based on MCMC simulations. Width of shaded area is the 95% credibility interval.

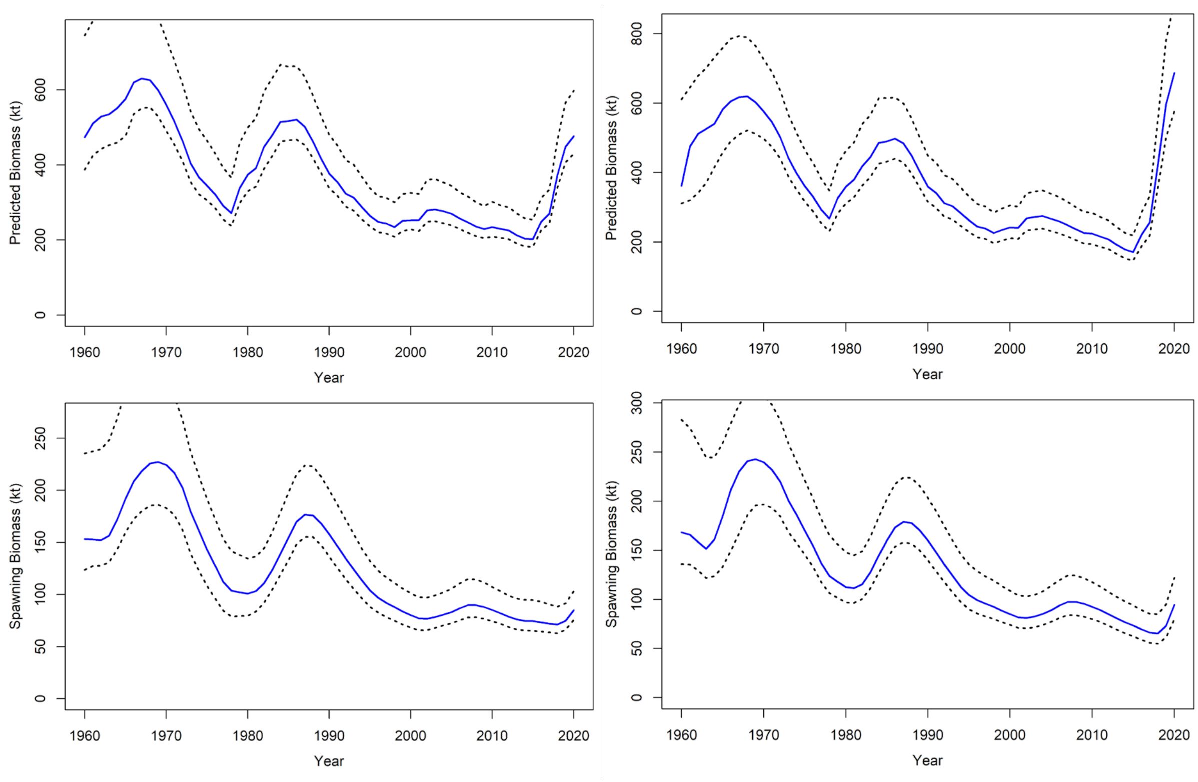


Figure 3G.13. Estimated sablefish total biomass (top panel) and spawning biomass (bottom panel) with 95% MCMC credible intervals. The results for the new proposed model (*21.10_Proposed*) are in the left panel and those for the Continuity model (*16.5_Cont*) are in the right panel. Values are in kilotons.

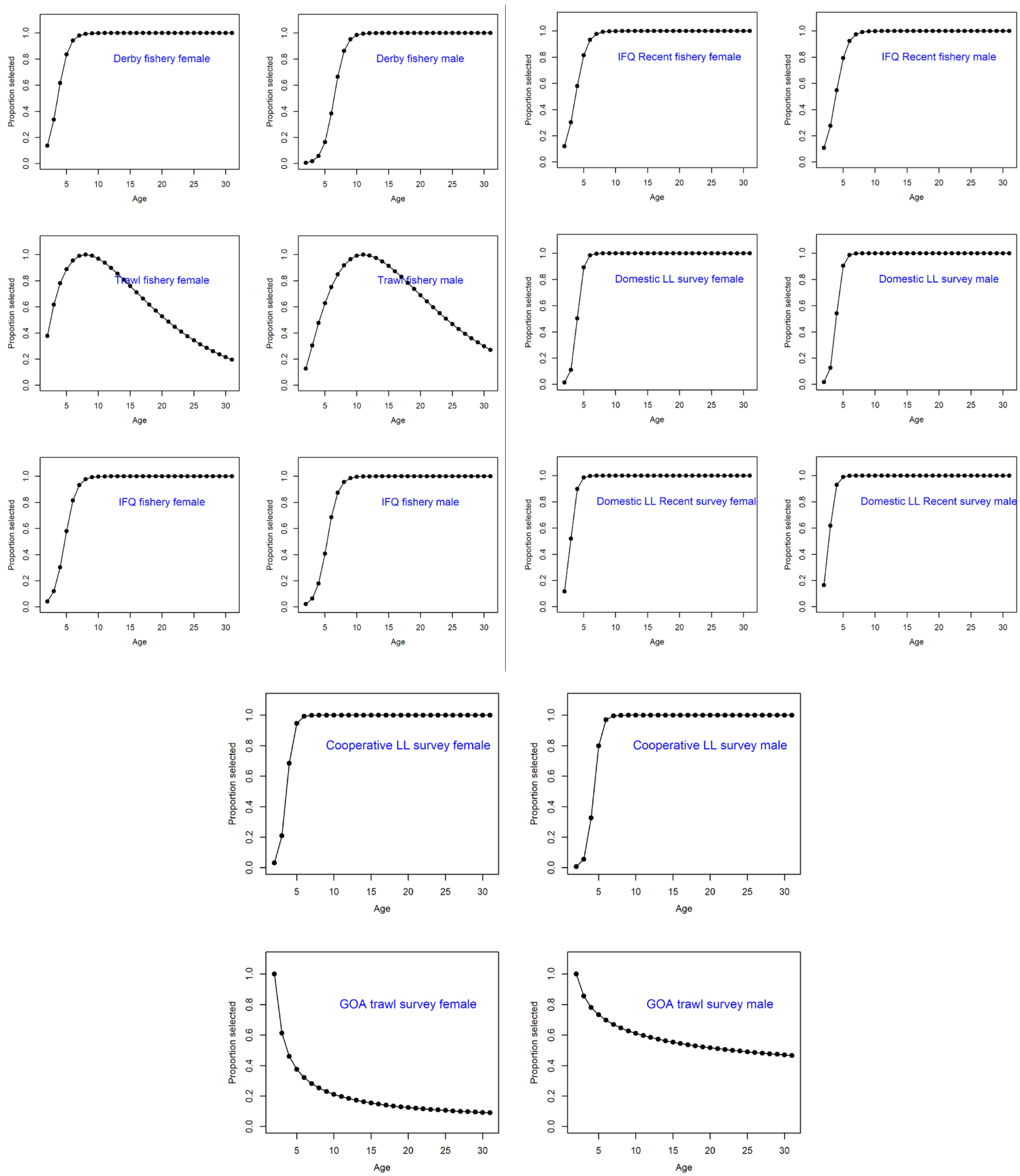


Figure 3G.14. Estimated fishery and survey selectivity for the new proposed model (*21.10_Proposed*). The derby longline fishery occurred until 1994, then the fishery switched to an IFQ system in 1995. The 'Recent' in the longline fishery and survey selectivity names represents the recent time block implemented in 2016.

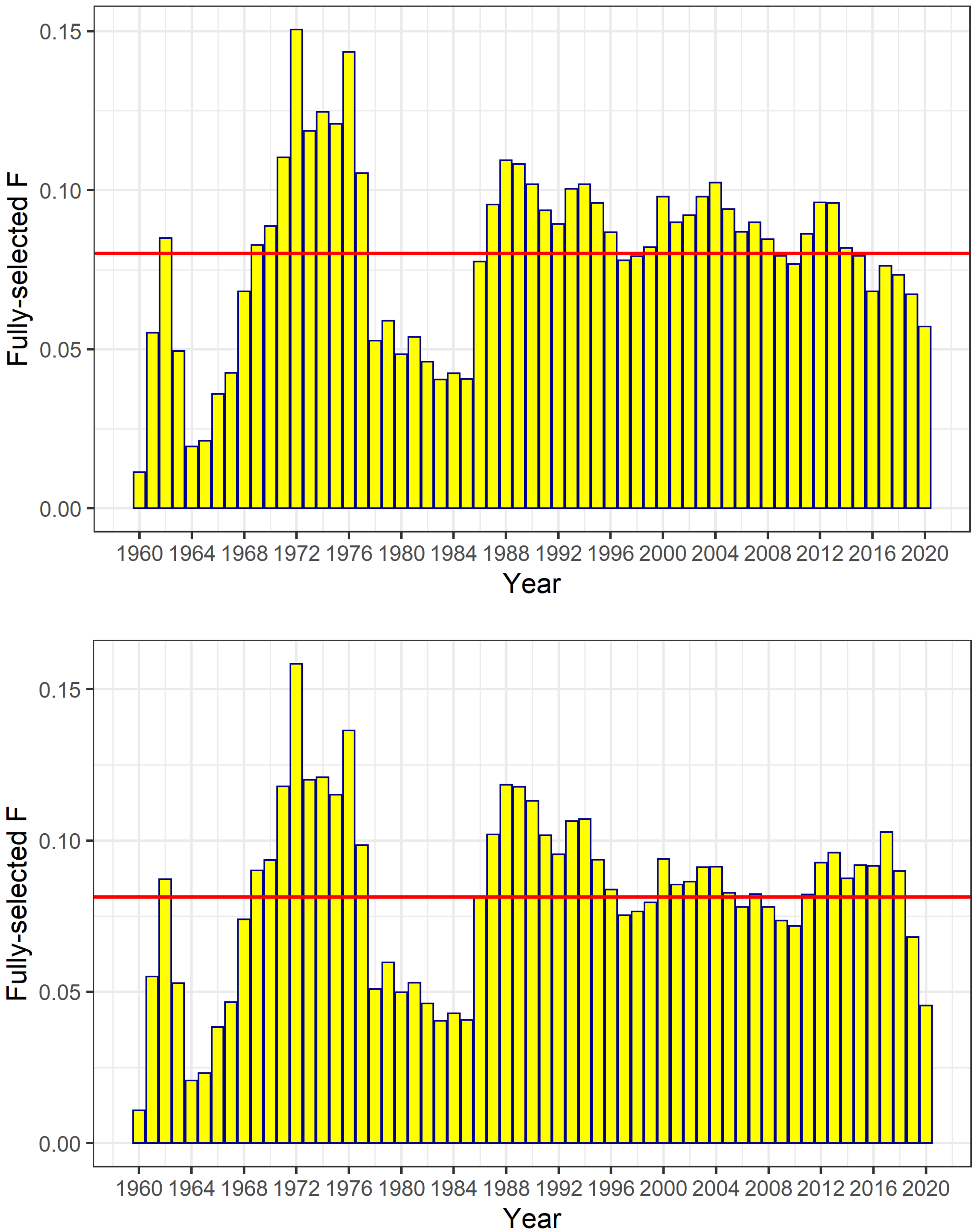


Figure 3G.15. Time series of combined fully selected fishing mortality for fixed and trawl gear for sablefish. The results for the new proposed model (*21.10_Proposed*) are in the top panel and those for the Continuity model (*16.5_Cont*) are in the bottom panel. Red line is the mean fishing mortality for the entire time series.

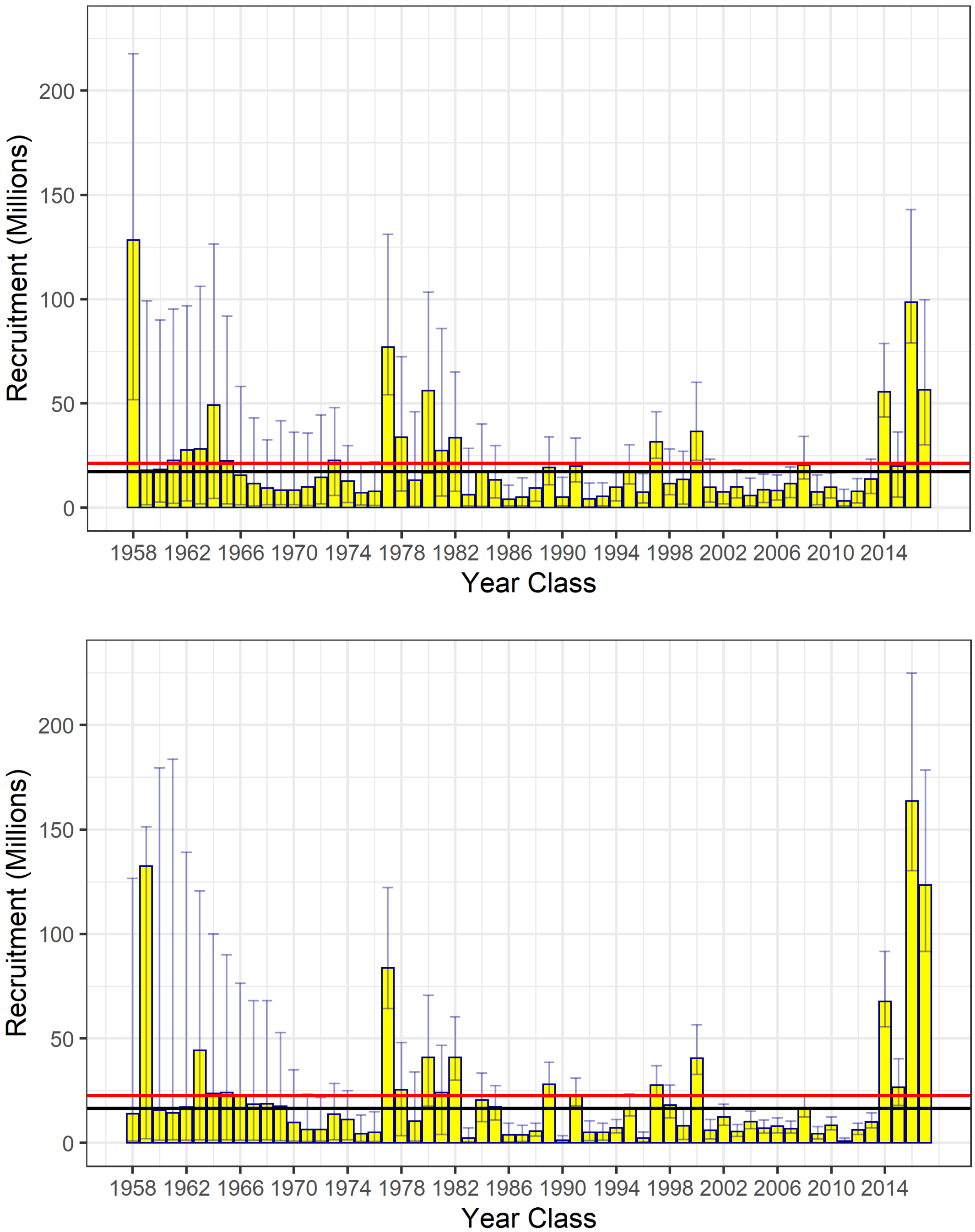


Figure 3G.16. Estimated recruitment of age-2 sablefish (millions of fish) with 95% credible intervals from MCMC by year class (recruitment year minus two). The results for the new proposed model (*21.10_Proposed*) are in the top panel and those for the Continuity model (*16.5_Cont*) are in the bottom panel. Red line is overall mean, while black line is mean for 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.

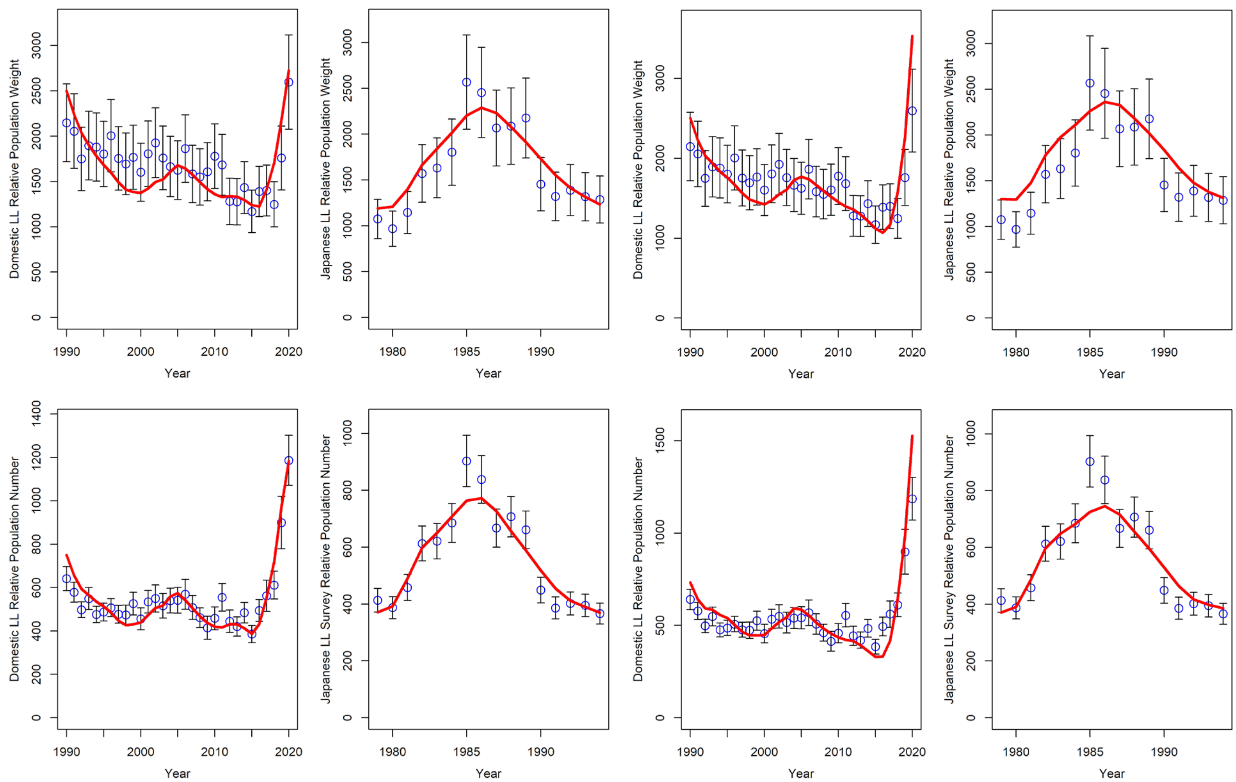


Figure 3G.17. Fits of the new proposed model (*21.10_Proposed*; left two columns) and the Continuity model (*16.5_Cont*; right two columns) to abundance indices. Observed and predicted sablefish relative population weight and numbers for 1990 - 2020 for U.S. longline survey and for 1979 - 1994 for U.S.-Japan cooperative survey. Points are observed estimates with approximate 95% confidence intervals. Solid red line is the model predicted values. The relative population weights are not fit in the models, but are presented for comparison.

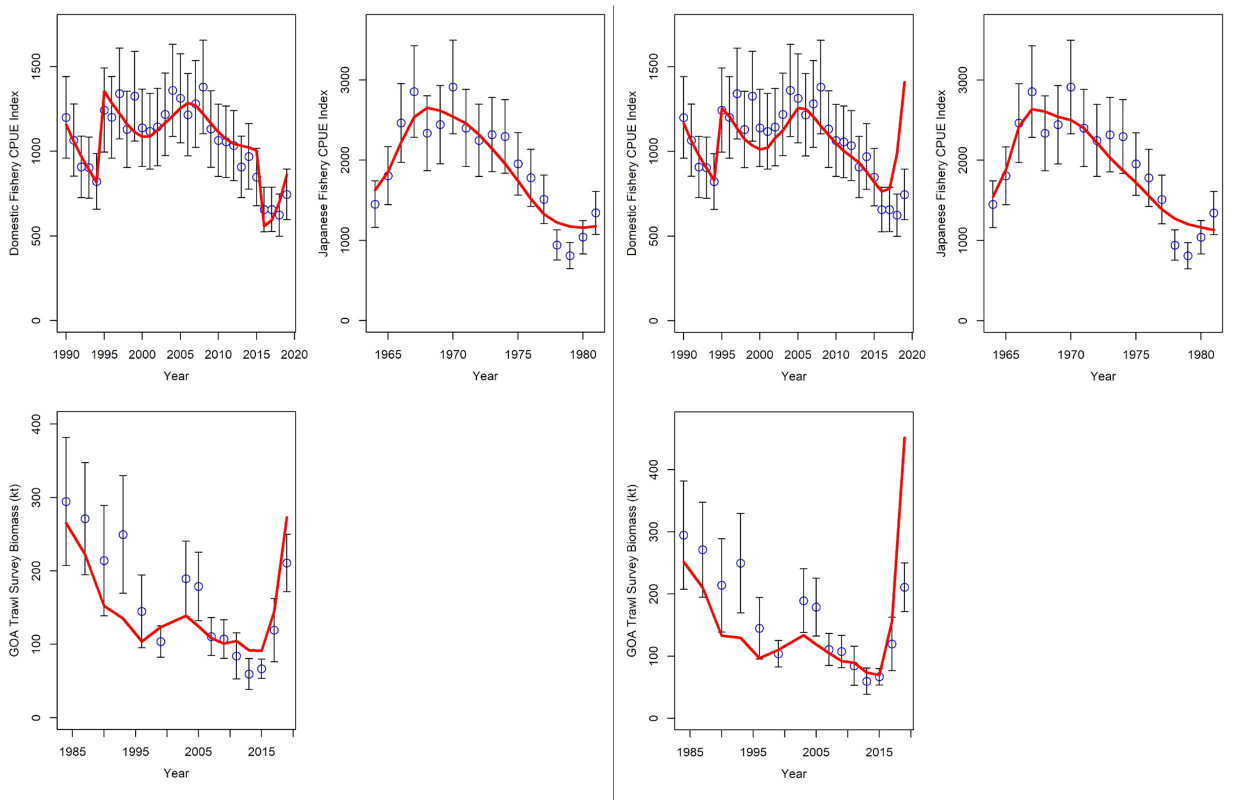


Figure 3G.18 Fits of the new proposed model (*21.10_Proposed*; left two columns) and the Continuity model (*16.5_Cont*; right two columns) to abundance indices. Fishery CPUE indices are on top two panels. GOA trawl survey is on the bottom left panel. Points are observed values with approximate 95% confidence intervals, while solid red lines are model predictions.

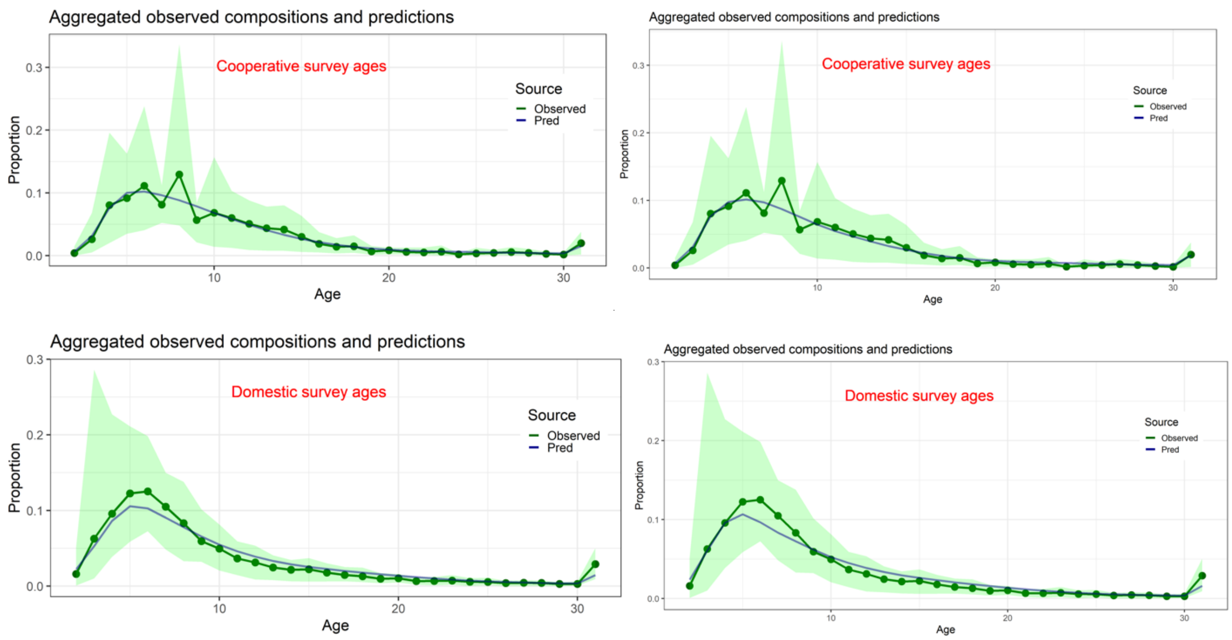


Figure 3G.19. Fits of the new proposed model (*21.10_Proposed*; left panel) and the Continuity model (*16.5_Cont*; right panel) to aggregated compositional data. Mean observed (green line) cooperative (top panel) and domestic (bottom panel) longline survey age compositions aggregated across years along with the average fit of the model (blue line). The green bands are the 90% empirical confidence intervals.

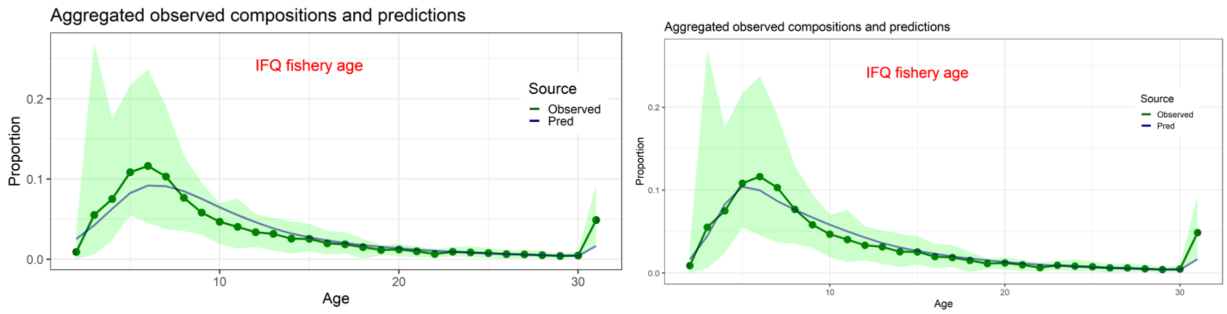


Figure 3G.20 Fits of the new proposed model (*21.10_Proposed*; left panel) and the Continuity model (*16.5_Cont*; right panel) to aggregated compositional data. Mean observed (green line) domestic fixed gear fishery age compositions aggregated across years along with the average fit of the model (blue line). The green bands are the 90% empirical confidence intervals. Note the perceptibly worse fits of the *21.10_Proposed* model for ages two through five.

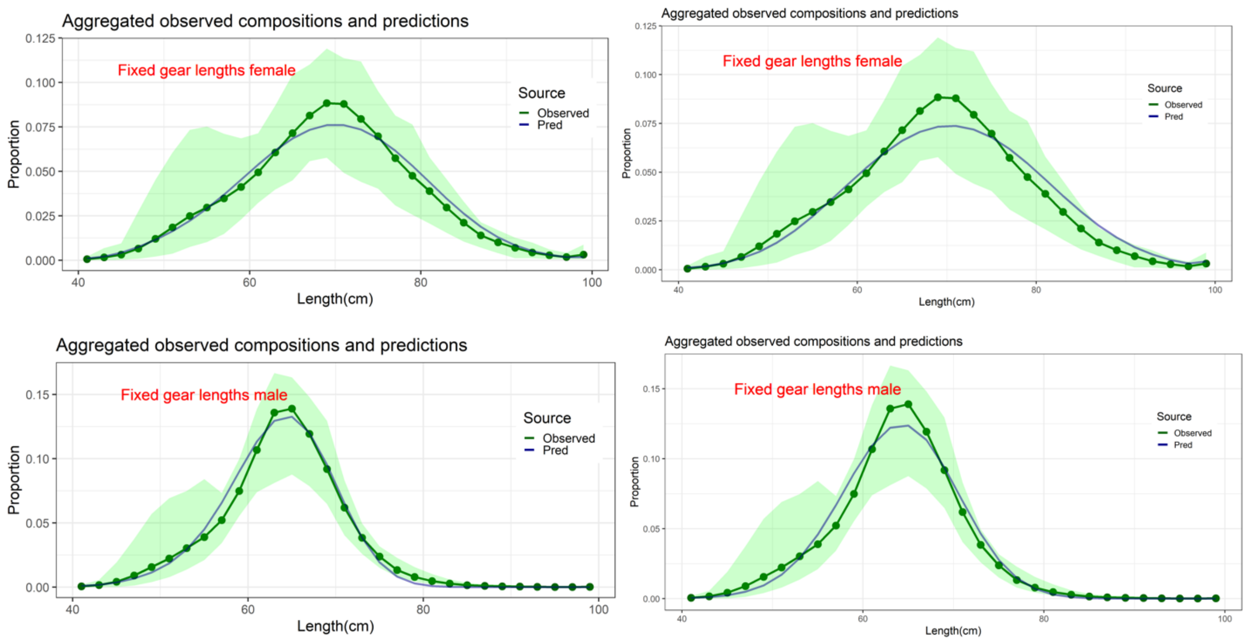


Figure 3G.21. Fits of the new proposed model (*21.10_Proposed*; left panel) and the Continuity model (*16.5_Cont*; right panel) to aggregated compositional data. Mean observed (green line) domestic fixed gear fishery length compositions aggregated across years along with the average fit of the model (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.

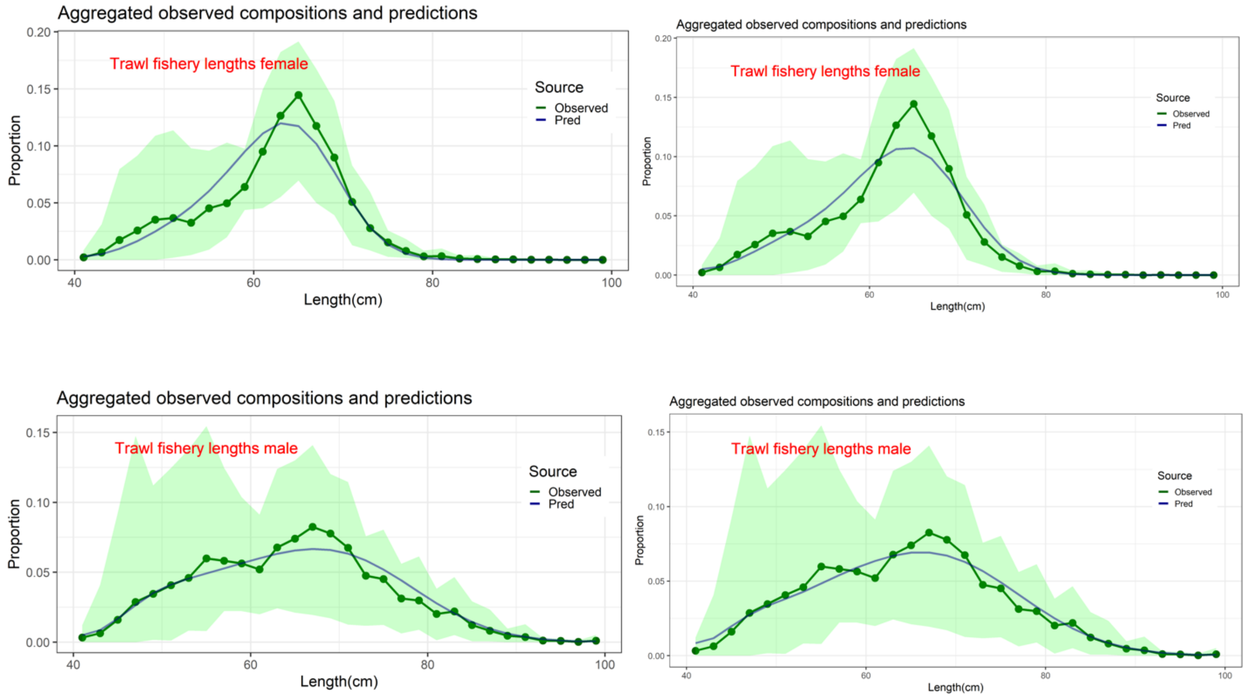


Figure 3G.22. Fits of the new proposed model (*21.10_Proposed*; left panel) and the Continuity model (*16.5_Cont*; right panel) to aggregated compositional data. Mean observed (green line) domestic trawl fishery length compositions aggregated across years along with the average fit of the model (blue 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.

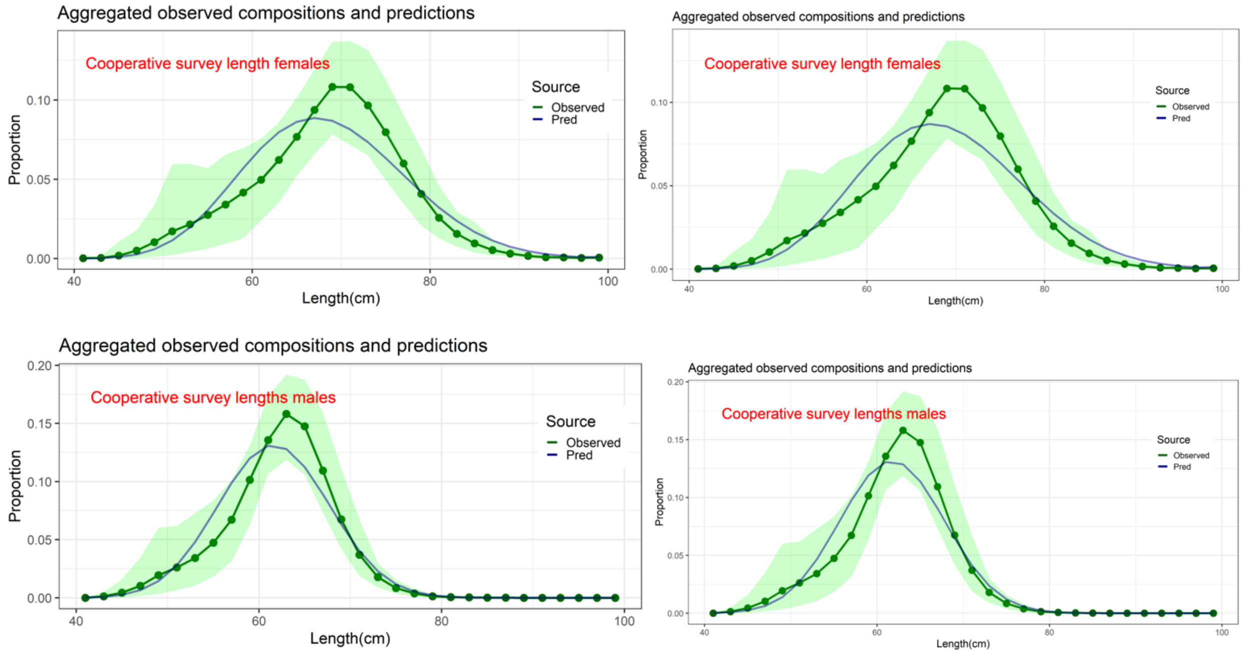


Figure 3G.23. Fits of the new proposed model (*21.10_Proposed*; left panel) and the Continuity model (*16.5_Cont*; right panel) to aggregated compositional data. Mean observed (green line) cooperative longline survey length compositions aggregated across years along with the average fit of the model (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.

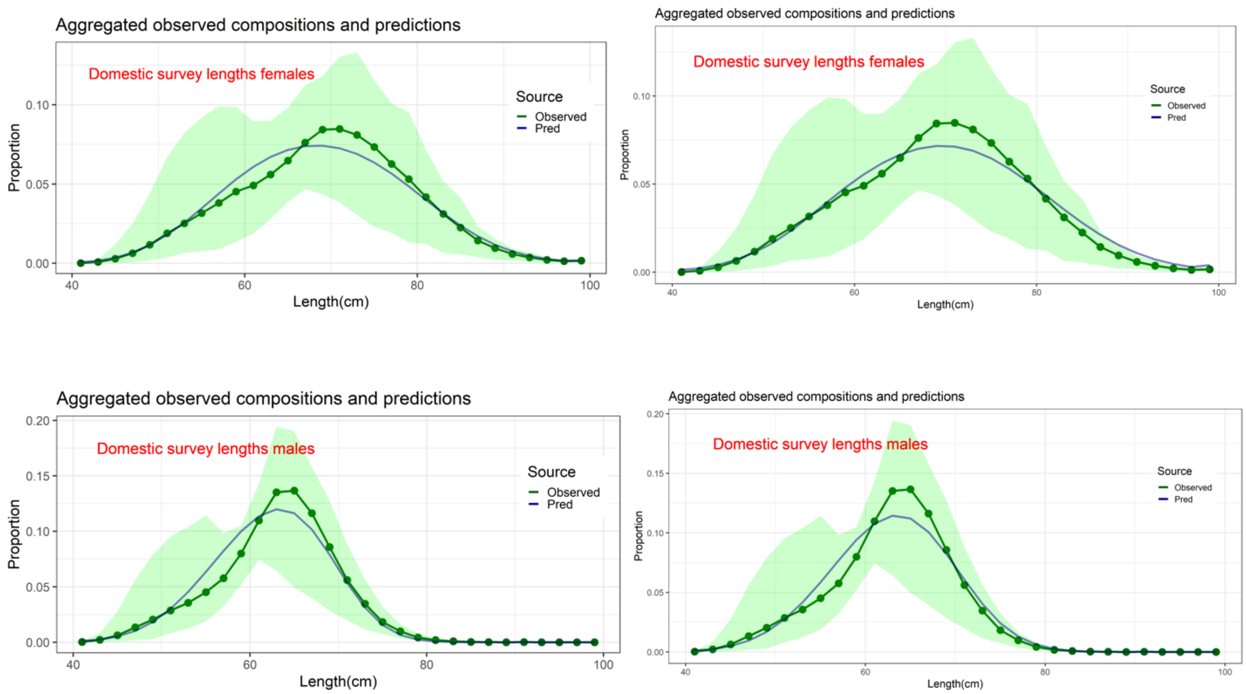


Figure 3G.24. Fits of the new proposed model (*21.10_Proposed*; left panel) and the Continuity model (*16.5_Cont*; right panel) to aggregated compositional data. Mean observed (green line) domestic longline survey length compositions aggregated across years along with the average fit of the model (blue 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.

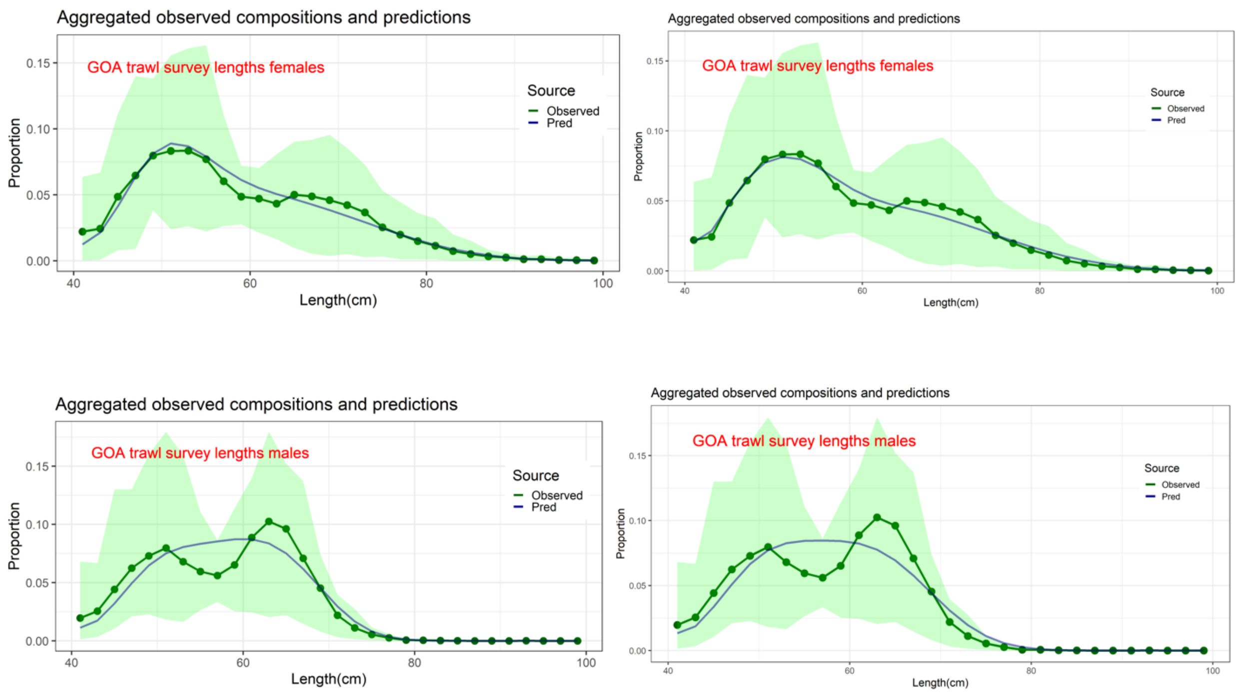


Figure 3G.25. Fits of the new proposed model (*21.10_Proposed*; left panel) and the Continuity model (*16.5_Cont*; right panel) to aggregated compositional data. Mean observed (green line) Gulf of Alaska trawl survey length compositions aggregated across years along with the average fit of the model (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.

Appendix 3H. SSC Requested Alaska Sablefish Model Updates

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October 2021

Executive Summary

Following the North Pacific Fisheries Management Council (NPFMC) September Plan Team (PT) and October Science and Statistical Committee (SSC) meetings, the results of Appendix 3G were updated with additional model runs as requested by each body. Those results are reported here. Three main sets of model runs were undertaken, including: 1) addition of an historic weight-at-age block to improve consistency among weight and growth blocking; 2) utilizing the age-based maturity curve without skipped spawning in the final proposed model; and 3) a full factorial model bridging exercise for the addition of recent selectivity and catchability time blocks. Given the lack of weight data prior to 1996 and other sampling issues associated with length data from the historic period, the resulting weight-at-age calculated from current length-weight parameters differed significantly from the current weight-at-age. The assessment results incorporating two weight-at-age time blocks (i.e., *21.11_Two_Weight_Blocks*) resulted in a strong discontinuity in the spawning stock biomass time series, leading to this model not being deemed reliable for further consideration. The model bridging exercise provided further insight on the impact of allowing fishery and survey selectivity and catchability to change in the recent (post-2016) time period. Given changes in targeting and gear composition in the fixed gear sablefish fishery, allowing both catchability and fishery selectivity to change in 2016 was deemed reasonable. However, model results indicate that allowing a recent fishery catchability time block had minimal influence on model results. On the other hand, recent increases in abundance of younger fish on the longline survey in deep water strata, especially in western regions, indicate that survey availability has likely increased, but only for certain age and size classes. Thus, it is likely unsuitable to allow a recent time block for survey catchability, which would imply that all fish have become more accessible to the survey gear. Conversely, increased availability or selectivity of certain age classes can be adequately accounted for by allowing for a recent time block in survey selectivity. Additionally, the model bridging exercise demonstrated that allowing survey selectivity to change in 2016 was likely the key driver of reductions in retrospective patterns for model *21.10_Proposed*. Thus, further support was provided for utilizing the parametrization changes (i.e., a post-2016 time block for fishery catchability and selectivity along with survey selectivity) incorporated into model *21.10_Proposed*. Finally, given the feedback from the PT and SSC regarding the uncertainty in skipped spawning estimates (i.e., only two years of data with high variability in skipped spawning rates), the model utilizing age-based maturity and ignoring skipped spawning, but incorporating all other updates of model *21.10_Proposed*, is now being put forth as the author's preferred model. This model, *21.12_Proposed_No_Skip_Spawn*, provides similar results as *21.10_Proposed*, but with slightly more optimistic terminal year stock status and associated minor increases in acceptable biological catches (ABCs). Future work to collect more data on skip spawning and better understand time-varying weight and growth are planned and will be incorporated into future sablefish stock assessments as this information becomes available.

Introduction

Three groups of model runs were undertaken to address concerns and requests made at the September PT and October SSC meetings. The first two requests involved refining biological assumptions (i.e., adding an historic weight-at-age time block and utilizing the age-based maturity model without skipped spawning in the final proposed model), while the third was to develop a more thorough model bridging exercise for the addition of a recent time block in fishery and survey catchability and selectivity parameters. All of the models developed in this appendix utilize the same model updates as model *21.10_Proposed* except for the explicit changes listed in the following sections and Table H.1. Similarly, all model runs utilized Francis reweighting to ensure further consistency in comparisons with model *21.10_Proposed*.

Methods

Two Weight-at-Age Blocks (*21.11_Two_Weight_Blocks*)

Concern was raised during both the PT and SSC meetings regarding the mismatch in time blocks between growth and weight. As with model *16.5_Cont*, model *21.10_Proposed* utilized two growth regimes (pre- and post-1996), but only a single weight-at-age time block for the entire time series based on data from 1996 - 2019. Because no weight data was collected on the longline survey prior to 1996 and sampling protocols differed substantially after 1996, the sablefish assessment has never implemented an historic weight-at-age time block. The pre-1996 length-at-age data was adjusted for sampling bias before being used to calculate the growth curve for the historic period (Hanselman et al., 2007), but using the resulting mean length-at-age to calculate other biological parameters, such as weight-at-age, is likely to produce unreliable parameter values (Echave et al., 2012). For this reason, previous assessments have not attempted to incorporate an historic weight-at-age time block and we maintained this assumption in model *21.10_Proposed*.

However, the PT and SSC recommended that consistency in length and weight time blocks would be preferred. Thus, it was suggested that allometric length-weight parameters estimated from the current (1996 – 2019) data be applied to the historic length-at-age data to develop an historic (pre-1996) weight-at-age time block. The resulting weight-at-age differed substantially from the current weight-at-age estimated directly from the weight and age data collected on the longline survey since 1996 (Figure H.1; see Echave, 2021 as updated in Appendix 3E). In particular, the asymptotic maximum weight for the historic period is 0.5 – 1.5 kg less than the current period, depending on sex (Figure H.1). As noted, these apparent differences over time are believed to be attributable to the lack of historic weight data and resulting unreliable estimates of historic weight-at-age from the bias-corrected length-at-age data.

Despite potential issues with the historical weight-at-age parameters, we developed model *21.11_Two_Weight_Blocks* to explore the impact of including an historic weight-at-age time block that better corresponded with the associated growth regimes assumed in the model.

No Skipped Spawning (*21.12_Proposed_No_Skip_Spawn*)

The SSC also raised a number of concerns regarding the approach utilized to update maturity in model *21.10_Proposed*. In particular, it was noted that the data on skipped spawning was limited to two years of sampling, represented a limited geographical region, and demonstrated high interannual variability in skipped spawning rates. Given the uncertainty in skipped spawning rates, the SSC requested a model run incorporating the updates of model *21.10_Proposed*, but utilizing biological maturity that does not account for skipped spawning (i.e., the age-based maturity model of model run

21.2_Mat_Age_GLM_No_SS). Thus, model *21.12_Proposed_No_Skip_Spawn* matches model *21.10_Proposed*, except that it uses the age-based biological maturity GLM model that does not include skipped spawning information (Figure H.2; note that this figure also includes uncertainty in the maturity estimates as requested by the SSC).

Full Factorial Selectivity and Catchability Model Building

Finally, the SSC requested a more complete model building exercise to better highlight and separate the impacts of each model parametrization update included in model *21.10_Proposed*, but mostly focused on understanding the individual changes incorporated into model *21.7_Add_Sel+q_Block*. Essentially, the request was to provide a full factorial model building exercise for the inclusion of a recent (post-2016) time block for the estimation of fishery catchability, fishery selectivity, survey catchability, and survey selectivity parameters. Although the authors had explored most of these modeling options previously, for simplicity of presentation and reader comprehension only the models deemed to be the most reliable and justifiable (in terms of real world observations and modeling best practices) were provided in the original document submitted to the PT and SSC. Here, we provide the results of each modeling step, including all combinations of whether or not to allow a recent time block in all four model parameters. The full list of model runs included in this exercise is provided in Table H.1, noting that model *21.10_Proposed* represents the model run that incorporates a recent time block in fishery catchability, fishery selectivity, and survey selectivity (i.e., there is not a higher numbered model with those changes incorporated). It should be emphasized that all of these model runs incorporate the biological updates, the removal of catchability priors, and implement Francis reweighting in the same manner as model *21.10_Proposed*. Thus, despite being a model building exercise for the changes originally made in model *21.7_Add_Sel+q_Block*, it is undertaken with all the other changes (aside from those related to recent selectivity or catchability time blocks) of model *21.10_Proposed* already incorporated.

Results

Neither of the biological updates (*21.11_Two_Weight_Blocks* or *21.12_Proposed_No_Skip_Spawn*) had a strong impact on stock status or resultant ABCs (Table H.2). However, as expected due to the substantial differences in weight-at-age between the two time blocks, the *21.11_Two_Weight_Blocks* model contained a strong discontinuity in SSB and biomass when transitioning between the two weight regimes (Figure H.3). The abrupt transition due to the disparate weight-at-age between the two time blocks further indicates that the historic weight parameters are not reliable and the assessment authors do not recommend that this approach be utilized.

Conversely, ignoring skipped spawning information in model *21.12_Proposed_No_Skip_Spawn* leads to nearly identical diagnostics and time series patterns as model *21.10_Proposed* (Figure H.3). The only tangible differences among these models was the slightly more optimistic rebuilding pattern observed in *21.12_Proposed_No_Skip_Spawn* over the last five years (Figure H.2), which is primarily due the increased maturity when skipped spawning is ignored at the currently highly abundant younger ages (Figure H.2). The more optimistic recent stock status also results in minor increases in future ABCs for *21.12_Proposed_No_Skip_Spawn* (Table H.2). Given the similarity in model diagnostics, data fits, and time series estimates to model *21.10_Proposed*, the full suite of tables and figures (as given for model *21.10_Proposed*) are not repeated here.

From a broad perspective when analyzing the model bridging runs, allowing recent time blocks and changes to the survey parameters was generally more impactful than similar changes to the fishery parameters (Table H.2 and Figure H.4). This is not surprising, because the survey data is given more emphasis in the model, as the survey index is the most reliable data source for scaling population abundance. As expected, allowing catchability parameters to change resulted in moderate rescaling of the

SSB time series (Figure H.4). Incorporating a recent time block in fishery catchability (model *21.13_Fish_q_Only*) generally increased population SSB scaling compared to other models, whereas a similar block for the longline survey catchability (model *21.16_Srvy_q_ony*) decreased population scale (Figure H.4). The new time block in fishery CPUE catchability allows the model to interpret the rapid decline in CPUE as a decrease in availability of fish to the gear. Conversely, the recent time block for survey catchability implies that fish are becoming more available to the survey gear, resulting in a downward scaling of biomass and a more pessimistic population outlook.

Moreover, allowing a recent time block in selectivity is generally more impactful than an associated time block in catchability, because the model interprets a selectivity change as less optimistic (i.e., lower) recent recruitment (Figure H.4). Because changes in catchability tend to scale the entire time series, whereas changes in selectivity more directly impact recent recruitment estimates (and associated recent SSB levels), allowing a recent selectivity block generally leads to more drastic reductions in stock status and associated ABCs (Table H.2). Though, changing either survey catchability (*21.16_Srvy_q_Only*) or survey selectivity (*21.17_Srvy_Sel_Only*) results in similar stock status estimates, whereas allowing a fishery selectivity time block (*21.14_Fish_Sel_Only*) is clearly more impactful than a fishery catchability block (*21.13_Fish_q_Only*; Table H.2). In terms of fits to the indices, no single model change led to any major differences, except that allowing for a recent fishery catchability time block led to much improved fits to the recent CPUE data (Figure H.5).

Allowing multiple parameters to change simultaneously typically tended to 'average' out the impacts observed for individual model changes. For instance, allowing fishery catchability and selectivity to be reestimated in the recent period (model *21.15_Fish_q+Sel_Only*) resulted in recent time series trends, stock status estimates, and ABC values that were midway between models that allowed either parameter to change individually (Table H.2, Figure H.4). Although, conversely, allowing survey catchability and selectivity to be reestimated during the recent time block (model *21.18_Srvy_q+Sel_Only*) led to a slightly more pessimistic outlook compared to allowing either parameter to change individually (Table H.2, Figure H.4).

One important difference observed between models that only allowed fishery parameters to change compared to those that incorporated changes in survey parameters, particularly survey selectivity, were the resultant retrospective patterns. A key facet of model *21.10_Proposed* was the reduction in retrospective patterns, especially the apparent elimination of retroactive downgrades in recruitment estimates (Figure 3G.11). Conversely, based on a retrospective analysis with model *21.15_Fish_q+Sel_Only*, it appears that only allowing changes to fishery parameters reduces recruitment retrospective patterns, but retroactive downgrades in recruitment are still present and relatively large (Figure H.6). It appears likely that one of the only approaches to removing these retrospective issues is to incorporate a recent time block in survey selectivity. It is also worth noting that only allowing changes to the fishery parameters led to large maximum gradient values, which indicates that these models were considerably less stable than models that allowed for only survey parameters to change or combined changes in both fishery and survey parameters (Table H.3). However, model *21.21_Fish_q_Srvy_q* demonstrated similar instability, further indicating that solely allowing catchability coefficients to be reestimated for the recent period was not a preferred model parametrization (Table H.3).

Generally, models that incorporated a recent time block for survey catchability were the most pessimistic unless paired with a model that also allowed fishery catchability to be reestimated (e.g., model *21.21_Fish_q_Srvy_q*). Similarly, allowing both survey catchability and fishery selectivity to be reestimated with (model *21.24_Fish_Sel_Srvy_q+Sel*) or without (*21.20_Fish_Sel_Srvy_q*) associated reestimation of survey selectivity, resulted in the lowest SSB and recruitment estimates and associated ABCs (Figure H.7, Table H.2). The impact of incorporating a recent fishery catchability time block was generally limited, with models *21.19_Fish_Sel_Srvy_Sel* and *21.10_Proposed* (i.e., which had the same parametrization, but included a recent time block for fishery catchability) demonstrating similar trends and ABCs (Figure H.7, Table H.2). As with the one off model parametrization updates, combining model changes did not greatly impact fits to the indices except when comparing models that allowed for a recent fishery catchability time block with those that did not (i.e., the former better fit the recent CPUE data; Figure H.8).

Model *21.10_Proposed* fell more or less in the middle of all the model-bridging runs in terms of both recent SSB and recruitment trends (Figure H.7). Similarly, stock status and ABCs were higher than models that only allowed a recent time block for survey parameters, but much lower than those that only allowed a recent time block for fishery parameters (Table H.2). The same pattern held true when comparing across the full suite of parametrizations in the model bridging exercise, with projected ABCs from model *21.10_Proposed* being just below both the median and the mean of all model runs.

Discussion

Within the model bridging runs, a number of important insights can be garnered by stepping through the one off changes in parametrization. Allowing a recent time block in either catchability or selectivity gives the model improved flexibility to address three main sources of data incongruity: apparent increases in recruitment observed in both fishery and survey age and length compositional data as demonstrated by sudden shifts towards younger and smaller fish since 2016; rapid increases in the survey RPNs since 2015, but which do not increase as rapidly as indicated by associated recruitment signals in the compositional data; and a drastic decrease in the fishery CPUE index in 2016 and a subsequent flat line of CPUE since that time. Generally, allowing recent changes in catchability enables the model to address these data conflicts through rescaling biomass and allowing the scaling coefficients to change before and after the 2016 time block; essentially the model is better able to fit the associated index by increasing or decreasing the catchability without negatively impacting the fits to the compositional data to a large degree. The primary implication of a change in catchability being that the availability to or targeting of the given gear has altered resulting in a change of the scaling coefficient between the gear and the population biomass. On the other hand, allowing the selectivity parameters to change tends to impact recruitment estimation more directly, because the model interprets the change in compositional data as a combination of increased recruitment in tandem with increased selectivity of the given gear. Thus, the implication becomes that the gear has become more selective, in this case on younger fish, causing reductions in the recruitment estimates. However, model selectivity is an amalgamated parameter often reflecting multiple real-world processes such as age-specific availability, gear selectivity, and targeting. By increasing selectivity estimates in recent years, the model is better able to reconcile the increased proportion of younger fish in the compositional data with the various indices (i.e., which have either decreased over the same period, in the case of CPUE, or simply not increased as rapidly as expected based on the influx of recruits in the compositional data, in the case of the longline survey RPNs).

Based on the model bridging exercise, it is clear that allowing a recent time block in any of the parameters improves model flexibility and helps the model rectify fits to the various data sources. However, there are important associated implications of each model change in terms of estimated recruitment and sustainable harvest levels. Thus, it is important to weigh each model change based on support for such a change from observed data and modeling best practices.

In the case of fishery parameters, there have been obvious changes in both targeting (i.e., to avoid small, low value fish) and gear composition (i.e., rapid increases in pot gear usage in the Gulf of Alaska) that are likely to have impacted both availability and selectivity. Concomitantly, the rapid decrease in CPUE in 2016 at the same time that most other data sources have been demonstrating opposing signals, indicates that there is unlikely to be a linear relationship between fishery catch rates and population biomass (i.e., despite increasing population biomass, catch rates have not increased at similar rates). Thus, there appears to be strong support from the observed data that catchability has changed in the last few years. Similarly, changes in gear composition imply that fishery selectivity is likely to be changing over the same period.

Therefore, it seems reasonable to incorporate a recent time block in both fishery catchability and selectivity in the sablefish stock assessment. However, it is important to reiterate that these changes alone do not remove the retrospective patterns, particularly those associated with overestimating recent recruitment events (Figure H.8).

In terms of the longline survey, there is indication that younger, smaller fish are becoming more prevalent in deeper survey strata in recent years, especially in the western GOA and BSAI (Figure H.9). Given that historically, recent recruits are typically found in shallower waters and predominantly absent from deeper survey strata, the recent influx is likely indicative of a combination of large recruitment events, but also increased availability to or selectivity of the survey gear for younger fish in deeper water. One theory that has been proposed is that increasing water temperatures have made deeper survey strata more suitable for sablefish, which has resulted in recent cohorts moving into deeper water at younger ages and smaller sizes. From a modeling perspective, increased availability of a limited size or age spectrum should not be modeled as a wholesale change in availability, and thus catchability, across the entire population. Rescaling the catchability coefficient would imply that all fish have become more accessible to the survey gear and results in rescaling of the entire time series of SSB and biomass (e.g., model *21.16_Srvy_q_Only*). On the other hand, increased availability or selectivity of certain age classes can be adequately accounted for by allowing for a recent survey selectivity time block. Additionally, as noted, allowing for a recent survey selectivity time block essentially eliminates retroactive downgrades in recruitment estimates. Thus, model *21.10_Proposed* resolves one of the major issues associated with the current sablefish assessment model (*16.5_Cont*), which may be resulting in overly optimistic maximum ABC projections from model *16.5_Cont*. Therefore, based on the suite of models tested, it seems reasonable to incorporate a recent time block for survey selectivity, but not survey catchability. Similarly, the assessment authors recommend pairing this change with a recent time block for fishery catchability and fishery selectivity, as is done in model *21.10_Proposed*.

In terms of biological updates, adding a historical weight-at-age time block (model *21.11_Two_Weight_Blocks*) did not seem reasonable, given the abrupt weight transition that resulted (Figure H.1) and the associated discontinuity in SSB and biomass estimates when the model switches between weight regimes (Figure H.3). There are a number of sampling issues with the historic biological data from the longline survey that are likely exasperated by these data spanning multiple survey platforms (i.e., the longline survey transitioned from being led by Japanese scientists to a cooperative Japanese-United States survey, then finally to a Alaska Fisheries Science Center survey through the 1980s and 1990s). Given the lack of weight samples during the historic period and associated sampling issues with the length-at-age data, the assessment authors do not recommend attempting to develop weight-at-age inputs from the historic period for the sablefish assessment. The results of model run *21.11_Two_Weight_Blocks* support this conclusion and the model is being dropped from further consideration for the sablefish stock assessment.

However, given the uncertainty in skipped spawning rates and the hesitancy of the SSC to adopt a maturity model incorporating skipped spawning, the assessment authors believe that ignoring skipped spawning information until more data is collected is a reasonable approach. Model *21.12_Proposed_No_Skip_Spawn* utilizes the same assumptions as model *21.10_Proposed*, but does not account for skipped spawning in the input age-specific maturity values. Given the similarities in performance, time series trends, data fits, and projected ABCs, it appears that model *21.12_Proposed_No_Skip_Spawn* is an adequate and appropriate alternative. Thus, the sablefish assessment authors are now recommending model *21.12_Proposed_No_Skip_Spawn* as the preferred model for the 2021 sablefish SAFE.

Tables

Table H.1. Description of model runs with associated abbreviations.

Model Group	Scenario Name	Abbreviation	Description
Update Biology	21.11. Add Historic Weight-at-Age Time Block	*21.11_Two_Weight_Blocks*	Model *21.10_Proposed* , but with an additional historic (pre-1996) time block for weight-at-age.
	21.12. Proposed Model with No Skipped Spawning	***21.12_Proposed_No_Skipped_Spawning***	Model *21.10_Proposed* , but using the age-based maturity model that does not account for skipped spawning (i.e., the maturity model used in model *21.2_Mat_Age_GLM_No_SS*).
Model Parametrization	21.13. Add Recent Fishery Catchability Time Block Only	*21.13_Fish_q_Only*	Model *21.10_Proposed* , but with only a recent time block for fishery catchability.
	21.14. Add Recent Fishery Selectivity Time Block Only	*21.14_Fish_Sel_Only*	Model *21.10_Proposed* , but with only a recent time block for fishery selectivity.
	21.15. Add Recent Fishery Catchability and Selectivity Time Block	*21.15_Fish_q+Sel_Only*	Model *21.10_Proposed* , but with only a recent time block for fishery catchability and selectivity.
	21.16. Add Recent Survey Catchability Time Block Only	*21.16_Srvy_q_Only*	Model *21.10_Proposed* , but with only a recent time block for survey catchability.
	21.17. Add Recent Survey Selectivity Time Block Only	*21.17_Srvy_Sel_Only*	Model *21.10_Proposed* , but with only a recent time block for survey selectivity.
	21.18. Add Recent Survey Catchability and Selectivity Time Block	*21.18_Srvy_q+Sel_Only*	Model *21.10_Proposed* , but with only a recent time block for survey catchability and selectivity.
	21.19. Add Recent Fishery and Survey Selectivity Time Block	*21.19_Fish_Sel_Srvy_Sel*	Model *21.10_Proposed* , but with only a recent time block for fishery and survey selectivity.
	21.20. Add Recent Fishery Selectivity and Survey Catchability Time Block	*21.20_Fish_Sel_Srvy_q*	Model *21.10_Proposed* , but with only a recent time block for fishery selectivity and survey catchability.
	21.21. Add Recent Fishery and Survey CatchabilityTime Block	*21.21_Fish_q_Srvy_q*	Model *21.10_Proposed* , but with only a recent time block for fishery and survey catchability.
	21.22. Add Recent Fishery Catchability and Survey Selectivity Time Block	*21.22_Fish_q_Srvy_Sel*	Model *21.10_Proposed* , but with only a recent time block for fishery catchability and survey selectivity.
	21.23. Add Recent Fishery Catchability, Survey Catchability, and Survey Selectivity Time Blocks	*21.23_Fish_q_Srvy_q+Sel*	Model *21.10_Proposed* , but with a recent time block for fishery catchability, survey catchability, and survey selectivity.
	21.24. Add Recent Fishery Selectivity, Survey Catchability, and Survey Selectivity Time Blocks	*21.24_Fish_Sel_Srvy_q+Sel*	Model *21.10_Proposed* , but with a recent time block for fishery selectivity, survey catchability, and survey selectivity.
	21.25. Add Recent Fishery Catchability, Fishery Selectivity, and Survey Catchability Time Blocks	*21.25_Fish_q+Sel_Srvy_q*	Model *21.10_Proposed* , but with a recent time block for fishery catchability, fishery selectivity, and survey catchability.
	21.26. Add Recent Fishery Catchability, Fishery Selectivity, Survey Catchability, and Survey Selectivity Time Blocks	*21.26_Fish_q+Sel_Srvy_q+Sel*	Model *21.10_Proposed* , but with a recent time block for fishery catchability, fishery selectivity, survey catchability, and survey selectivity.

Table H.2. Estimated terminal year (2020) parameters (i.e., fishing mortality, *F*, and spawning stock biomass, *SSB*), associated biological reference points and stock status determinations relative to a target SSB representing 40% (*SSB_40*) depletion from unfished SSB (SSB_0), and resultant Acceptable Biological Catch (*ABC*) based on the NPFMC B_{40} HCR. For models with time-varying biology or selectivity, reference points and associated calculations utilize the most recent time block of values.

Model	2020 SSB (kt)	SSB_40 (kt)	2020 SSB/SSB_40	2020 F	F_40	2020 F/F_40	F_ABC	2021 ABC (kt)
16.5_Cont	94.43	126.84	0.74	0.05	0.1	0.5	0.1	52.41
21.10_Proposed (Fish_q+Sel_Srvy_Sel)	85	114.19	0.74	0.06	0.08	0.75	0.08	27.09
21.11_Two_Weight_Blocks	86.33	118.16	0.73	0.06	0.08	0.75	0.07	25.86
21.12_Proposed_No_Skip_Spawn	90.65	115.73	0.78	0.06	0.08	0.75	0.08	27.71
21.13_Fish_q_Only	112.65	133.71	0.84	0.04	0.09	0.44	0.09	46.8
21.14_Fish_Sel_Only	97.3	124.51	0.78	0.05	0.09	0.56	0.09	40.88
21.15_Fish_q+Sel_Only	108.61	129.18	0.84	0.04	0.09	0.44	0.09	43.37
21.16_Srvy_q_Only	77.01	119.87	0.64	0.06	0.09	0.67	0.07	26.49
21.17_Srvy_Sel_Only	76.44	114.13	0.67	0.07	0.09	0.78	0.07	24.07
21.18_Srvy_q+Sel_Only	69.5	113.39	0.61	0.07	0.09	0.78	0.07	19.5
21.19_Fish_Sel_Srvy_Sel	83.12	109.23	0.76	0.06	0.09	0.67	0.08	28.46
21.20_Fish_Sel_Srvy_q	72.28	113.3	0.64	0.06	0.08	0.75	0.07	22.57
21.21_Fish_q_Srvy_q	112.09	135.15	0.83	0.04	0.09	0.44	0.09	46.72
21.22_Fish_q_Srvy_Sel	79.53	120.26	0.66	0.06	0.08	0.75	0.07	23.81
21.23_Fish_q_Srvy_q+Sel	100.3	124.77	0.8	0.05	0.09	0.56	0.09	37.59
21.24_Fish_Sel_Srvy_q+Sel	65.26	106.67	0.61	0.07	0.08	0.88	0.06	16.77
21.25_Fish_q+Sel_Srvy_q	101.69	123.92	0.82	0.04	0.09	0.44	0.09	40.1
21.26_Fish_q+Sel_Srvy_q+Sel	94.02	116.04	0.81	0.05	0.09	0.56	0.09	33.63

Table H.3. The maximum gradient component (*Max Grad*), total negative log-likelihood (*nLL*), and number of parameters *(# Pars*) for each model run.

Model	Converged?	Max Grad	nLL	# Pars
16.5_Cont	TRUE	0.000301006496384589	1888.1	240
21.10_Proposed (Fish_q+Sel_Srvy_Sel)	TRUE	0.00151063289005471	776.66	244
21.11_Two_Weight_Blocks	TRUE	0.000692870447777449	774.35	244
21.12_Proposed_No_Skip_Spawn	TRUE	0.00125271491419017	776.66	244
21.13_Fish_q_Only	TRUE	3.33625706505007	742	240
21.14_Fish_Sel_Only	TRUE	1.74131777047695	791.86	241
21.15_Fish_q+Sel_Only	TRUE	5.88144472434786	745.74	242
21.16_Srvy_q_Only	TRUE	0.000215480091933816	740.31	240
21.17_Srvy_Sel_Only	TRUE	0.000824333388974088	770.39	241
21.18_Srvy_q+Sel_Only	TRUE	0.00185149348725007	765.18	242
21.19_Fish_Sel_Srvy_Sel	TRUE	0.000220100597841635	819.07	243
21.20_Fish_Sel_Srvy_q	TRUE	0.000535959382404447	762.59	242
21.21_Fish_q_Srvy_q	TRUE	4.22001049392731	752.31	241
21.22_Fish_q_Srvy_Sel	TRUE	0.00131807088338517	751.44	242
21.23_Fish_q_Srvy_q+Sel	TRUE	0.000380195444413839	767.22	243
21.24_Fish_Sel_Srvy_q+Sel	TRUE	2.29215393007579e−05	808.09	244
21.25_Fish_q+Sel_Srvy_q	TRUE	0.364030935537516	737.16	243
21.26_Fish_q+Sel_Srvy_q+Sel	TRUE	0.000877056004660274	781.44	245

Figures

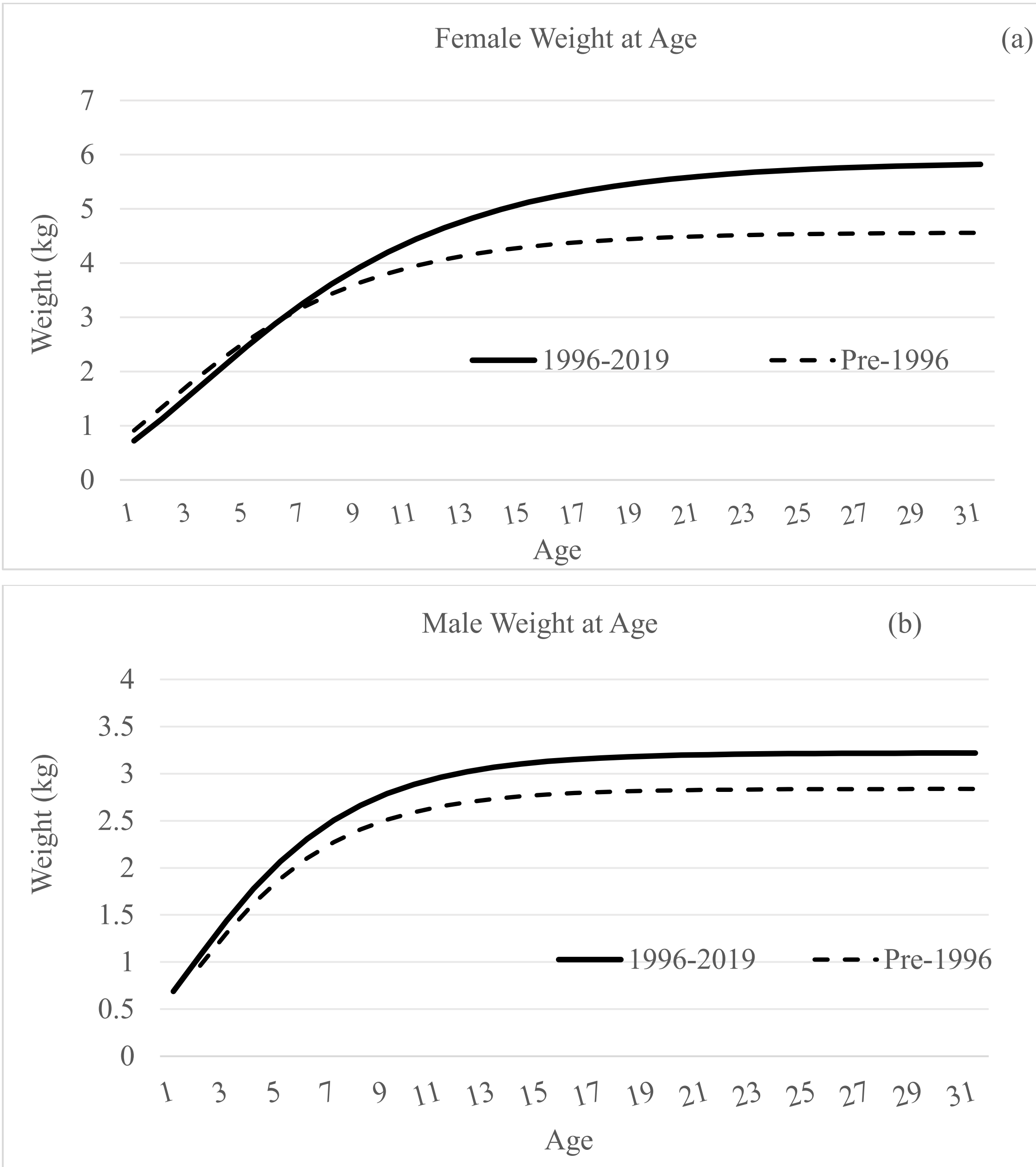


Figure H.1. Weight-at-age used in the various models, as described in Echave (2021). The solid black line is the updated weight-at-age used for the entire time series for all model runs except model *21.11_Two_Weight_Blocks*, which uses the weight-at-age derived from the current length-weight parameters and applied to the historical length-at-age data to develop a historical (pre-1996) weight-at-age (black dashed line). The top panel illustrates the weight-at-age curve for females and the bottom panels shows the weight-at-age curve for males.

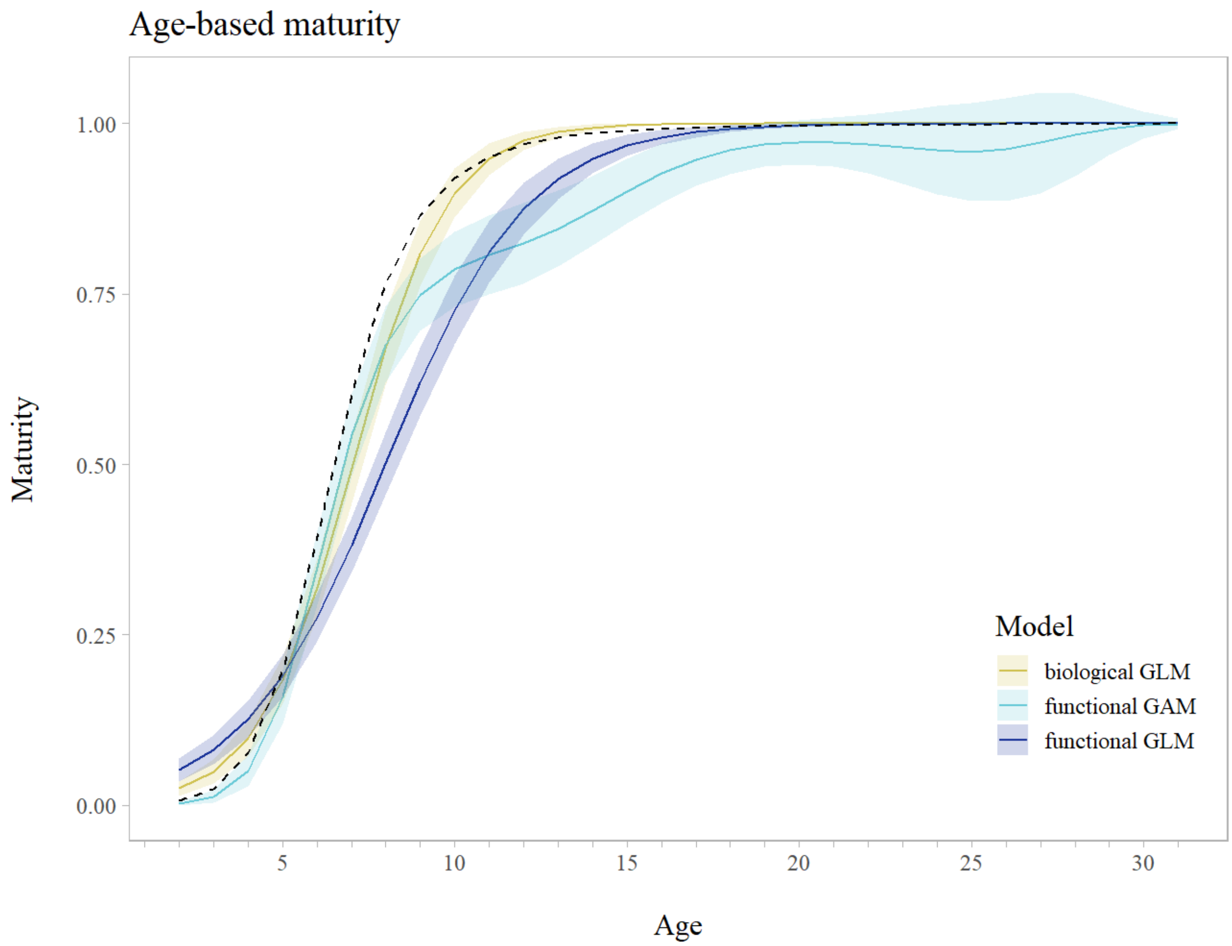


Figure H.2. Current (black dashed line) and updated maturity-at-age curves as described in Williams and Rodgveller (2021) with associated 95% confidence intervals (shaded regions). The age-based biological maturity curve that does not account for skipped spawning (yellow line) is utilized in the *21.12_Proposed_No_Skip_Spawn* model.

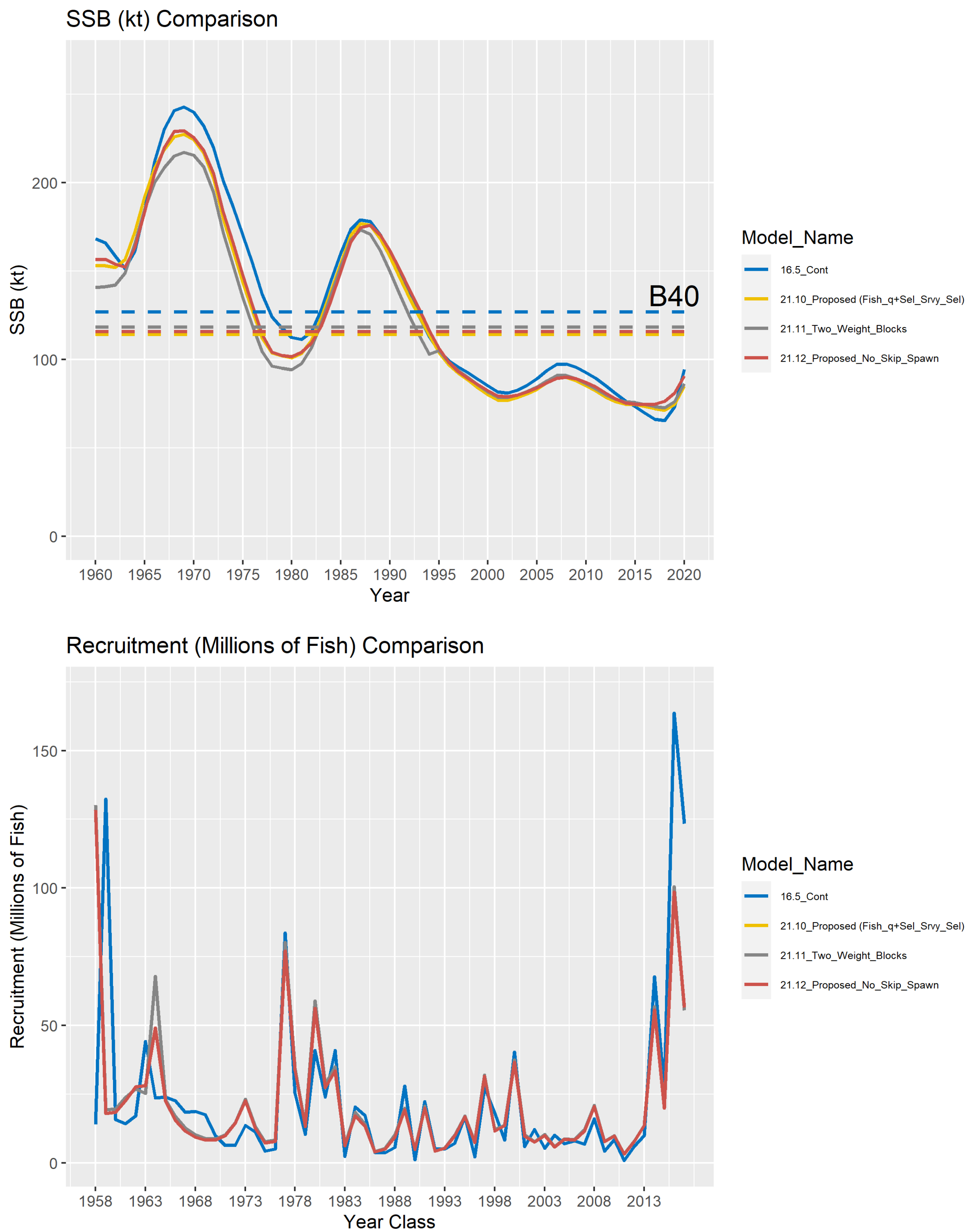


Figure H.3. Model comparisons for spawning stock biomass (top panel) and recruitment (bottom panel) within the 'Biology Update' grouping.

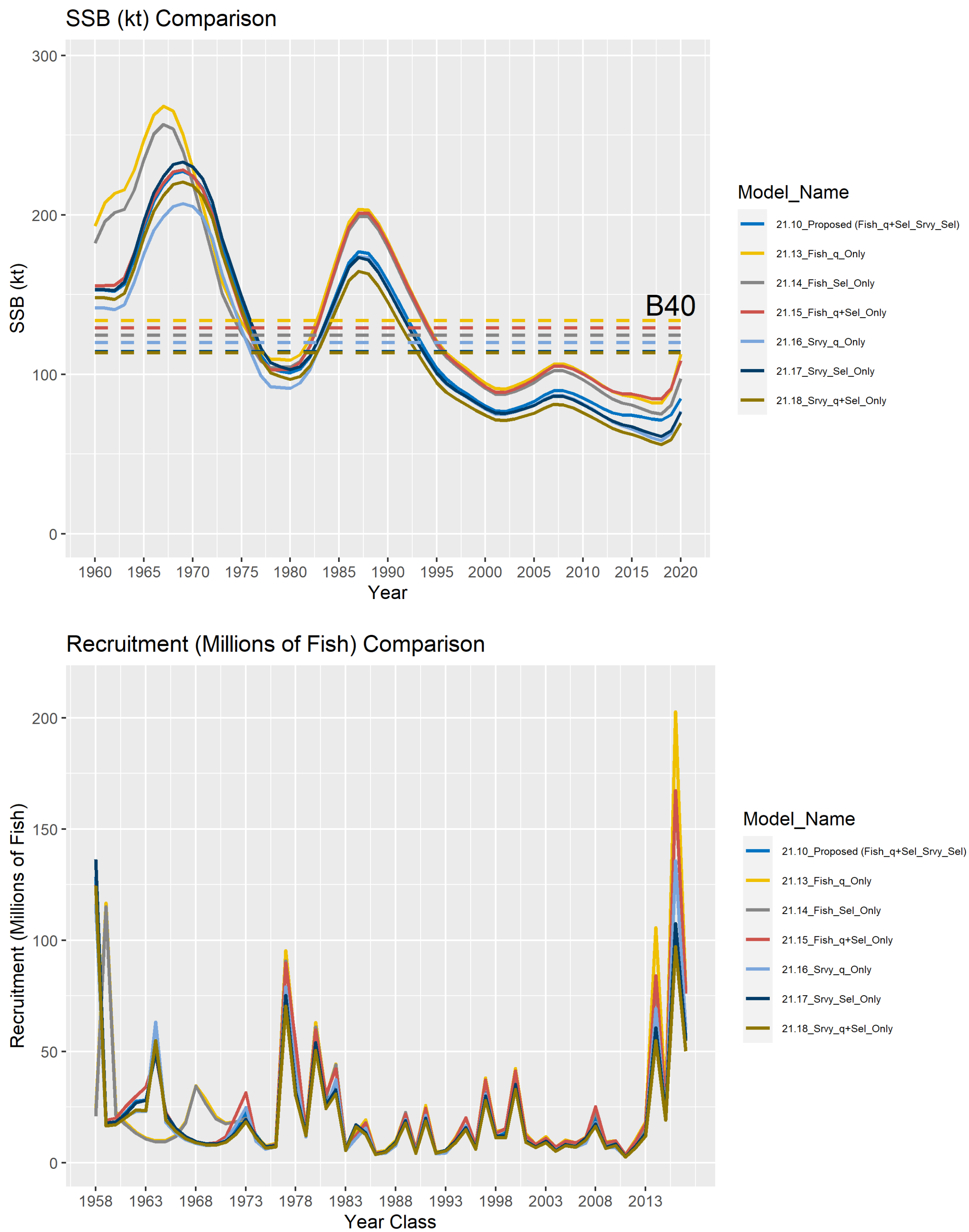


Figure H.4. Model comparisons for spawning stock biomass (top panel) and recruitment (bottom panel) within the ‘Model Parametrization Update’ grouping, including model runs with changes only for fishery parameters or survey parameters (i.e., not including runs that allow changes in both fishery and survey parametrizations).

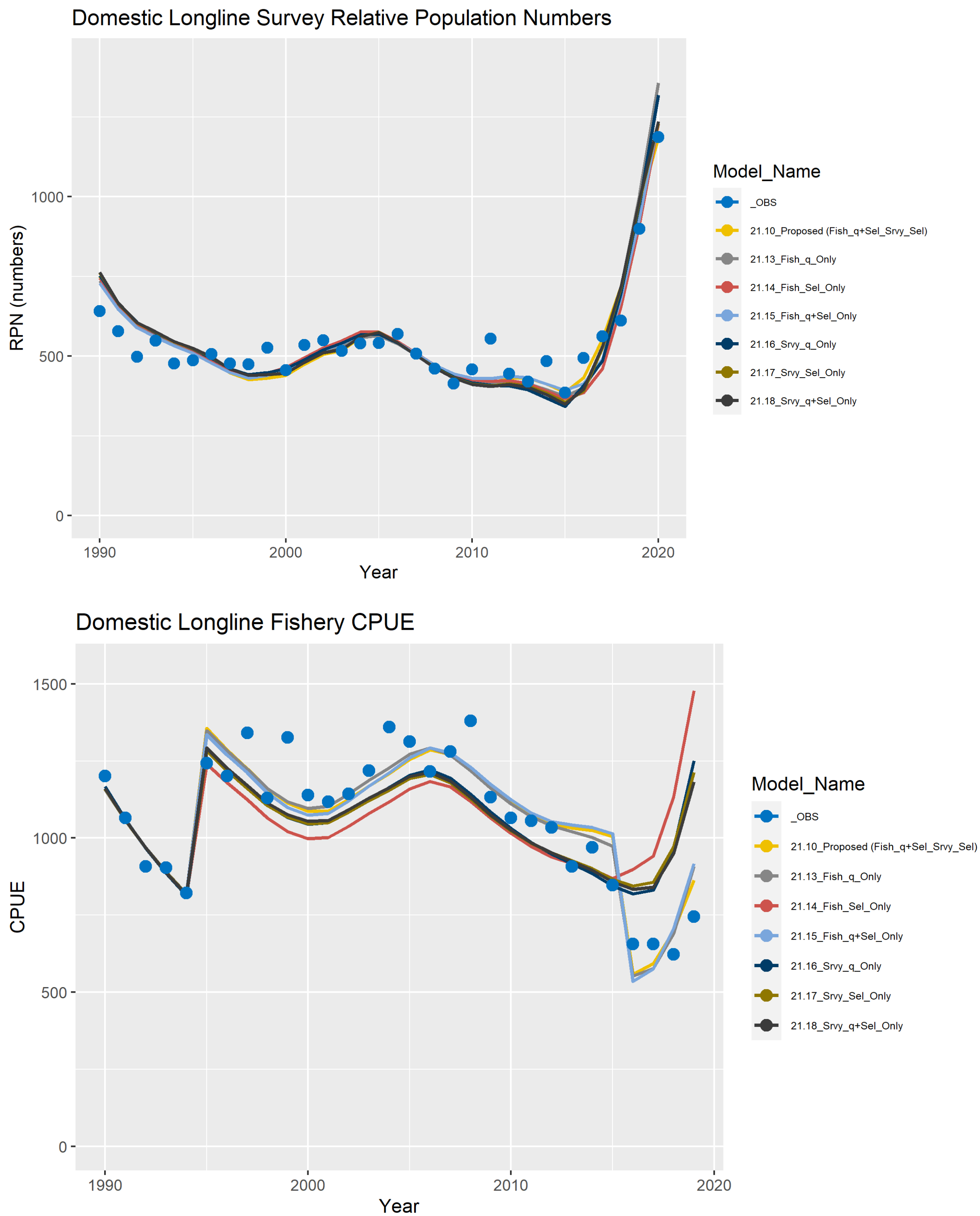


Figure H.5. Model comparisons demonstrating fit to the domestic longline survey relative population numbers (RPN) index (top panel) and domestic longline fishery catch-per-unit effort (CPUE) index (bottom panel) within the 'Model Parametrization Update' grouping, including model runs with changes only for fishery parameters or survey parameters (i.e., not including runs that allow changes in both fishery and survey parametrizations).

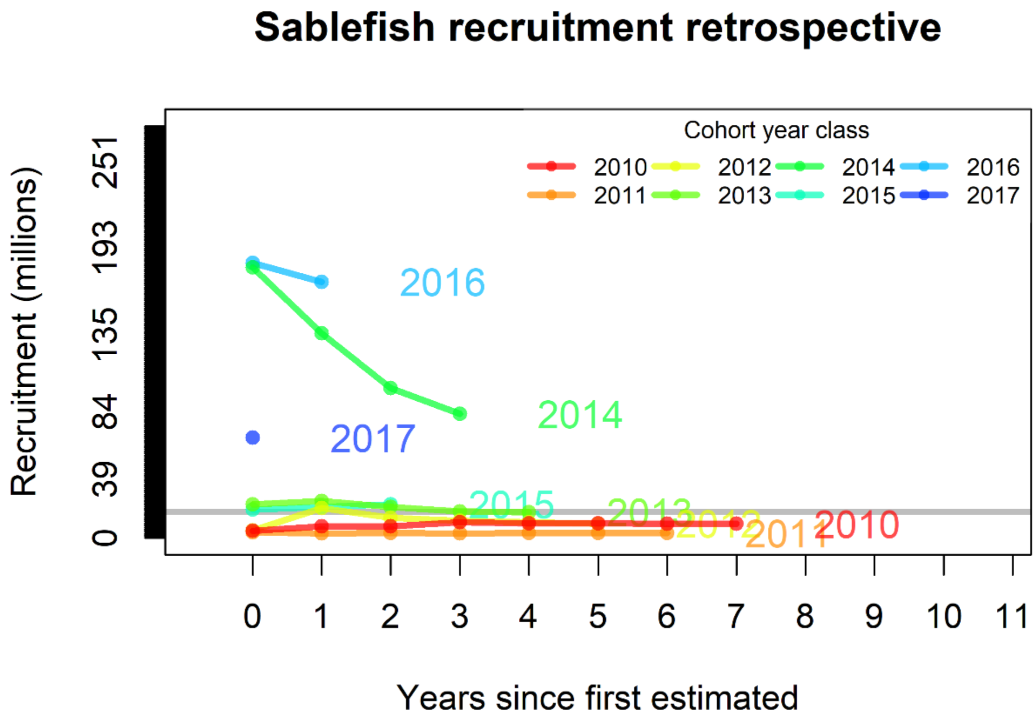


Figure H.6. Squid plot demonstrating the refinement of age-2 recruitment estimates as new data years are added to the model based on the results of a retrospective analysis for the model that incorporates a recent fishery catchability and selectivity time block, but does not include a recent survey selectivity time block (i.e., model *21.15_Fish_q+Sel_Only*). Note that the retrospective analysis includes a model change starting with the 2018 retrospective year (i.e., estimation of new fishery catchability and selectivity parameters for the post-2016 time block). Thus, comparison of models for retrospective years before and after 2018 is problematic.

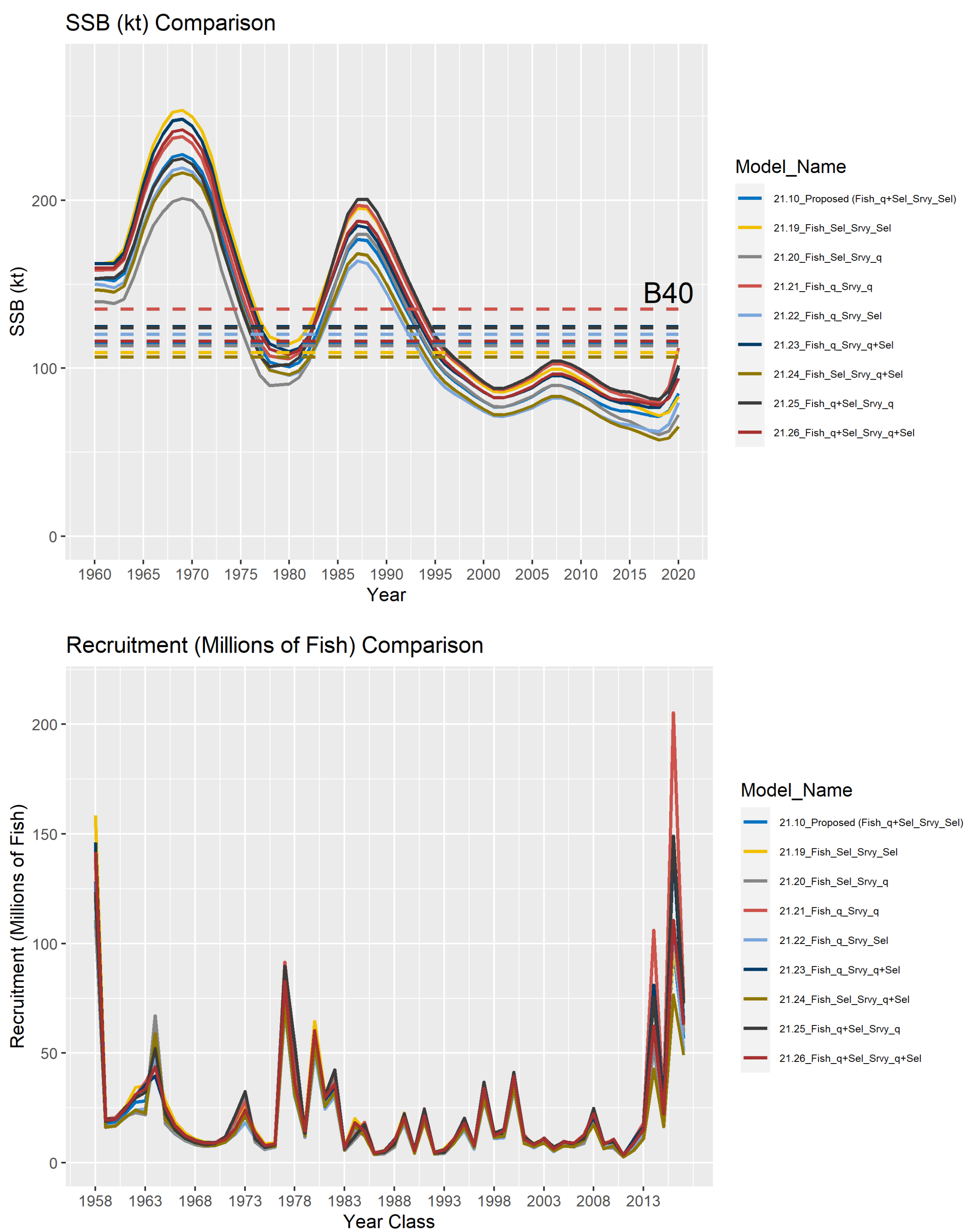


Figure H.7. Model comparisons for spawning stock biomass (top panel) and recruitment (bottom panel) within the 'Model Parametrization Update' grouping, including model runs with changes for both fishery parameters and survey parameters (i.e., not including runs that allow for changes only in fishery or survey parametrizations).

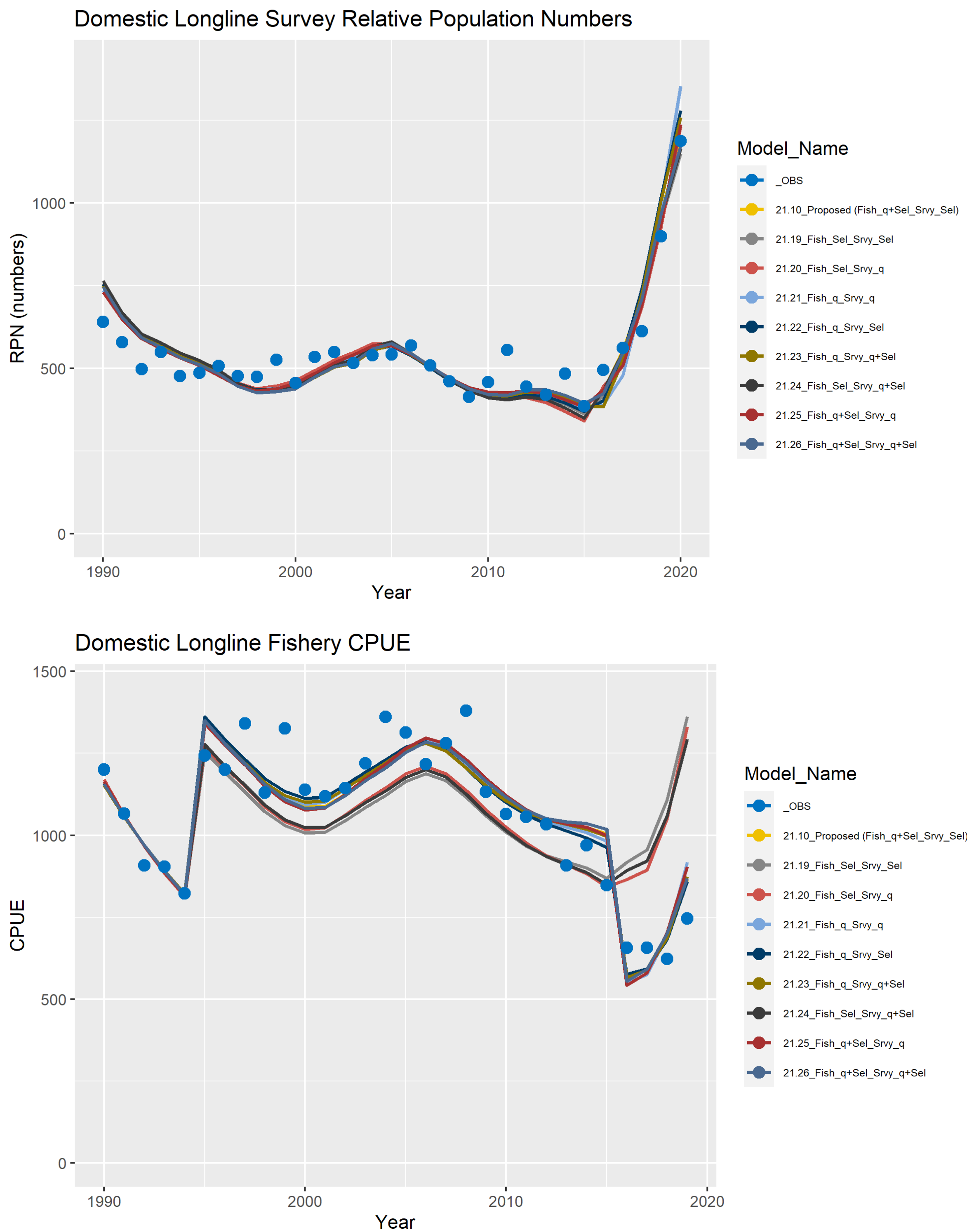


Figure H.8. Model comparisons demonstrating fit to the domestic longline survey relative population numbers (RPN) index (top panel) and domestic longline fishery catch-per-unit effort (CPUE) index (bottom panel) within the 'Model Parametrization Update' grouping, including model runs with changes only for fishery parameters or survey parameters (i.e., not including runs that allow changes in both fishery and survey parametrizations)

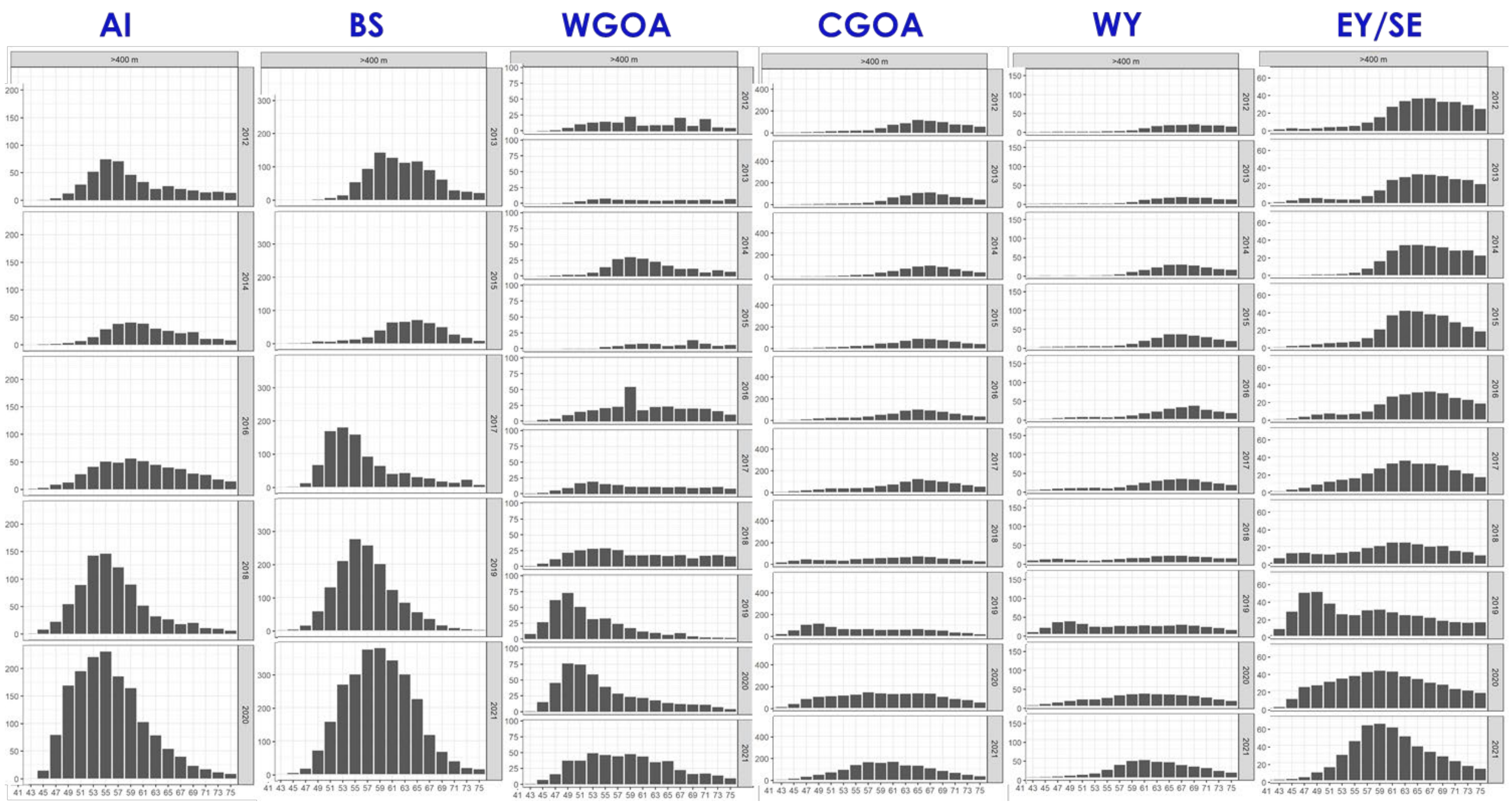


Figure H.9. Longline survey RPNs by area and length for recent years at depths greater than 400m. Note the increasing abundance of small fish in recent years, particularly in the BSAI and WGOA.

Appendix 3I. Model *16.5_Cont* Results and Comparisons to *21.12_Proposed_No_Skip_Spawn*

Executive Summary

Results from the 2020 model (*16.5_Cont*) are provided and compared with the proposed model for the 2021 SAFE (*21.12_Proposed_No_Skip_Spawn*) based on application to the full suite of new data available for the 2021 assessment year. These models are described in depth in the main text and Appendices 3G and 3H, thus no further text is provided here. The format of results follows the layout of the comparisons in Appendix 3G. The results demonstrate that model *16.5_Cont* continues to overestimate the size of recent recruitment events, resulting in further retroactive downgrades in recent year class strength with the addition of the 2021 data. The estimates of the 2014 year class appear to have reached a steady estimate, while those of the 2016 and 2017 year classes once again decreased drastically. Given the extremely large magnitude of the 2018 year class, it is expected that the estimate will be severely downgraded as future years of data become available. Overestimation of recruitment has caused projected maximum ABCs to be quite large (approximately twice the magnitude of those from the *21.12_Proposed_No_Skip_Spawn* model). It is probable that these projected ABCs are overly optimistic given subsequent downgrades in recruitment estimates. Although model *16.5_Cont* fits the fishery age composition data generally better than the *21.12_Proposed_No_Skip_Spawn* model, in recent years, the introduced survey and fishery selectivity time block in the latter model help it to better fit the age proportions at intermediate ages (i.e., as these large year classes grow and abundance decays due to mortality). It is unclear whether the recruitment estimates in model *16.5_Cont* are biased high to begin with or there is increased mortality at juvenile ages associated with these recent year classes, which the model does not incorporate. Given the improved fit to the decay of recent cohorts and the lack of a retrospective pattern in recruitment estimates with model *21.12_Proposed_No_Skip_Spawn*, it appears that the recent fishery and survey selectivity blocks allow the model to better account for recent dynamics. However, the exact mechanisms driving resource dynamics in recent years (i.e., very large recent recruitment events and associated high juvenile mortality versus large recent recruitment events and moderately increased availability of younger fish to the fishery and survey gear) remain uncertain. Further work examining model parametrization will continue in the coming years, but it is recommended that model *21.12_Proposed_No_Skip_Spawn* provides an improved assessment of the Alaska sablefish resource and should be utilized for the 2021 SAFE.

Tables

Table 3I.1. The maximum gradient component (*Max Grad*), total negative log-likelihood (*nLL*), and number of parameters *(# Pars*) for each model run.

Model	Converged?	Max Grad	nLL	# Pars
21.12_Proposed_No_Skip_Spawn	TRUE	0.000678008981443245	752.92	252
16.5_Cont	TRUE	0.000205493656629296	2138.41	243

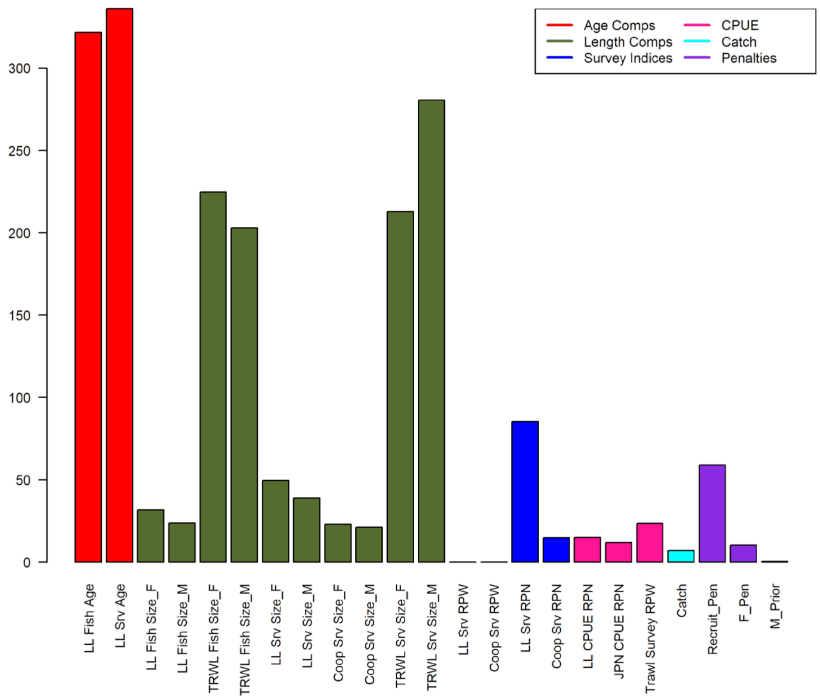
Table 3I.2. Estimated terminal year (2021) parameters (i.e., fishing mortality, *F*, and spawning stock biomass, *SSB*), associated biological reference points and stock status determinations relative to a target SSB representing 40% (*SSB_40*) depletion from unfished SSB (SSB_0), and resultant Acceptable Biological Catch (*ABC*) based on the NPFMC B_{40} HCR. For models with time-varying biology or selectivity, reference points and associated calculations utilize the most recent time block of values.

Model	2021 SSB (kt)	SSB_40 (kt)	2021 SSB/SSB_40	Mean_Recruit	2021 F	F_40	2021 F/F_40	F_ABC	2022 ABC (kt)
21.12_Proposed_No_Skip_Spawn	107.47	118.14	0.91	20.37	0.05	0.08	0.62	0.08	34.84
16.5_Cont	133.64	126.63	1.06	24.37	0.04	0.1	0.4	0.1	67.43

Table 3I.3. Sablefish spawning biomass (kilotons), fishing mortality, and yield (kilotons) for the seven projection harvest scenarios (columns) outlined in the Population Projections section for model *16.5_Cont*. Abundance is projected by drawing from the 1979 - 2018 recruitments. The 'Specified Catch' scenario uses the proportion of the ABC utilized in 2021 to set the realized yield for 2022 and 2023.

Year	Maximum Permissible F	Specified Catch	Half Maximum F	5-year Average F	No Fishing	Overfished	Approaching Overfished
			Spawning Stock Biomass (kt)				
2021	133,640	133,640	133,640	133,640	133,640	133,640	133,640
2022	183,444	183,444	183,444	183,444	183,444	183,444	183,444
2023	232,061	239,115	242,855	240,050	254,162	228,256	232,061
2024	275,447	293,004	301,728	294,782	330,567	266,475	275,447
2025	301,972	320,671	346,048	334,202	396,694	287,395	296,787
2026	307,867	326,211	368,517	351,949	441,428	288,426	297,483
2027	298,505	315,445	372,290	351,819	464,953	275,558	283,782
2028	281,457	296,503	364,556	341,160	473,361	256,352	263,536
2029	262,049	275,096	351,192	325,748	472,614	235,843	241,973
2030	243,009	254,159	335,682	308,892	466,691	216,451	221,608
2031	225,459	234,904	319,804	292,208	457,904	199,058	203,359
2032	209,835	217,789	304,500	276,508	447,659	183,920	187,488
2033	196,289	202,961	290,331	262,246	436,936	171,059	174,007
2034	184,755	190,337	277,559	249,592	426,363	160,333	162,753
			Fishing Mortality				
2021	0.038	0.038	0.038	0.038	0.038	0.038	0.038
2022	0.101	0.068	0.051	0.064	-	0.120	0.120
2023	0.101	0.066	0.051	0.064	-	0.120	0.120
2024	0.101	0.101	0.051	0.064	-	0.120	0.120
2025	0.101	0.101	0.051	0.064	-	0.120	0.120
2026	0.101	0.101	0.051	0.064	-	0.120	0.120
2027	0.101	0.101	0.051	0.064	-	0.120	0.120
2028	0.101	0.101	0.051	0.064	-	0.120	0.120
2029	0.101	0.101	0.051	0.064	-	0.120	0.120
2030	0.101	0.101	0.051	0.064	-	0.120	0.120
2031	0.101	0.101	0.051	0.064	-	0.120	0.120
2032	0.101	0.101	0.051	0.064	-	0.120	0.120
2033	0.101	0.101	0.051	0.064	-	0.120	0.120
2034	0.101	0.101	0.051	0.064	-	0.118	0.118
			Yield (kt)				
2021	20,120	20,120	20,120	20,120	20,120	20,120	20,120
2022	67,459	45,872	34,450	43,015	-	79,123	67,459
2023	73,101	49,709	38,939	48,100	-	84,439	73,101
2024	71,385	75,532	39,697	48,498	-	81,184	83,669
2025	66,652	70,299	38,634	46,699	-	74,680	76,828
2026	61,186	64,301	36,854	44,106	-	67,630	69,432
2027	55,949	58,564	34,873	41,363	-	61,111	62,598
2028	51,239	53,413	32,906	38,722	-	55,408	56,623
2029	47,098	48,893	31,032	36,265	-	50,510	51,496
2030	43,537	45,013	29,310	34,048	-	46,385	47,182
2031	40,571	41,782	27,788	32,121	-	43,016	43,660
2032	38,174	39,167	26,488	30,499	-	40,346	40,865
2033	36,187	37,001	25,357	29,106	-	38,118	38,559
2034	34,527	35,207	24,375	27,911	-	36,132	36,531

Figures



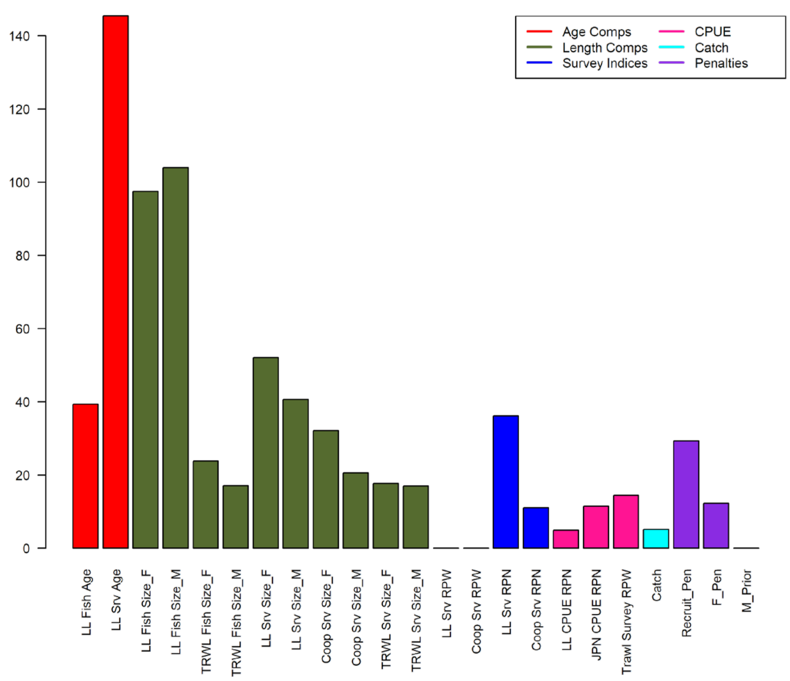


Figure 3I.1. Component contributions to the total negative log-likelihood for each data source fit in the model. Results for the Continuity model (*16.5_Cont*) are in the left panel and the new proposed model (*21.12_Proposed_No_Skip_Spawn*) are in the right panel. Note differences in y-axis scale across panels.

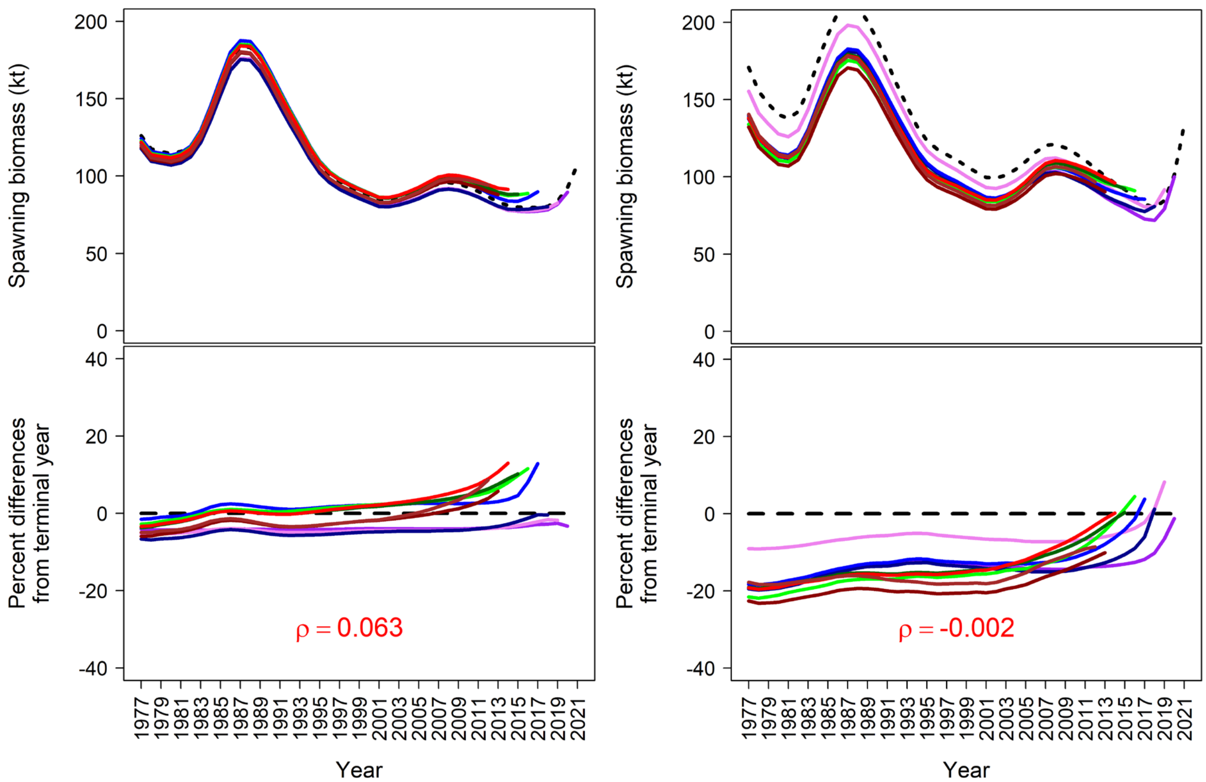


Figure 3I.2. Results of a retrospective analysis for spawning stock biomass for the new proposed model (*21.12_Proposed_No_Skip_Spawn*; left panel) and the Continuity model (*16.5_Cont*; right panel). Mohn's rho (ρ) is provided in red. Note that the proposed model (*21.12_Proposed_No_Skip_Spawn*) retrospective analysis has a model change starting with the 2018 retrospective year (i.e., estimation of new longline survey and fishery catchability and selectivity parameters for the post-2016 time block). Thus, comparison of models for retrospective years before and after 2018 (i.e., starting with the dark blue line) is problematic.

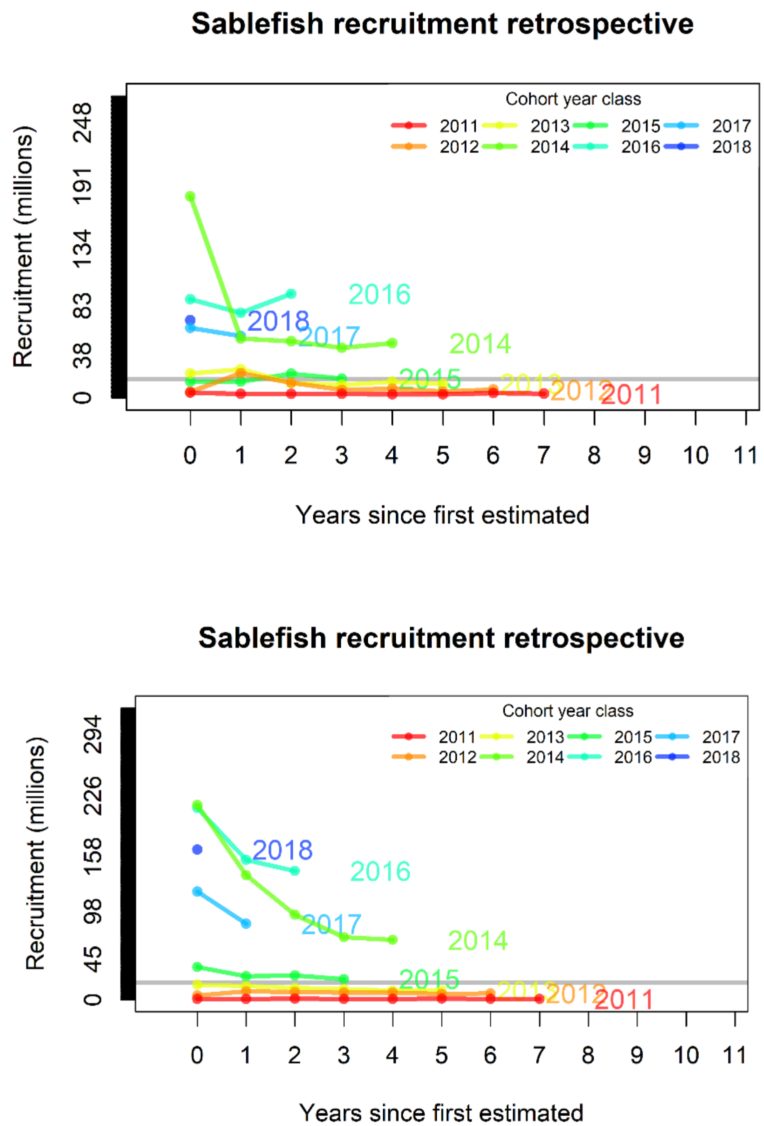
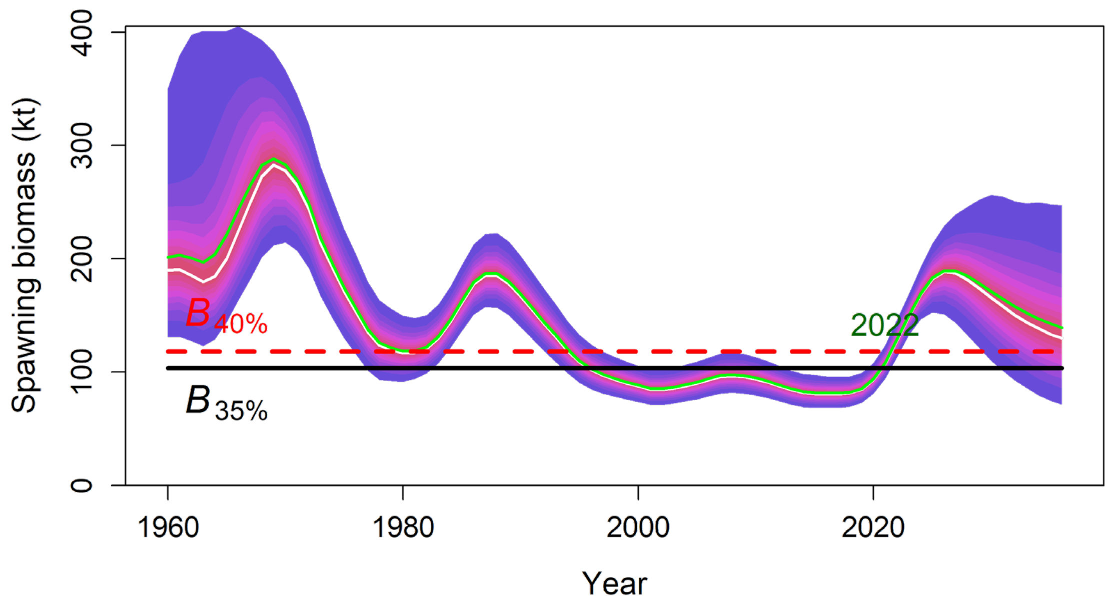


Figure 3I.3. Squid plot demonstrating the refinement of age-2 recruitment estimates as new data years are added to the model based on the results of a retrospective analysis for the new proposed model (*21.12_Proposed_No_Skip_Spawn*; top panel) and the Continuity model (*16.5_Cont*; bottom panel). Note that the proposed model (*21.12_Proposed_No_Skip_Spawn*) retrospective analysis has a model change starting with the 2018 retrospective year (i.e., estimation of new longline survey and fishery catchability and selectivity parameters for the post-2016 time block). Thus, comparison of models for retrospective years before and after 2018 is problematic. The transition between model parametrizations is clearly visible in the estimation of the 2014 year class (i.e., the first estimate is based on the 2017 model without a separate catchability and selectivity time blocks for the recent, post-2016, period, while subsequent estimates are based on models with a recent time block).



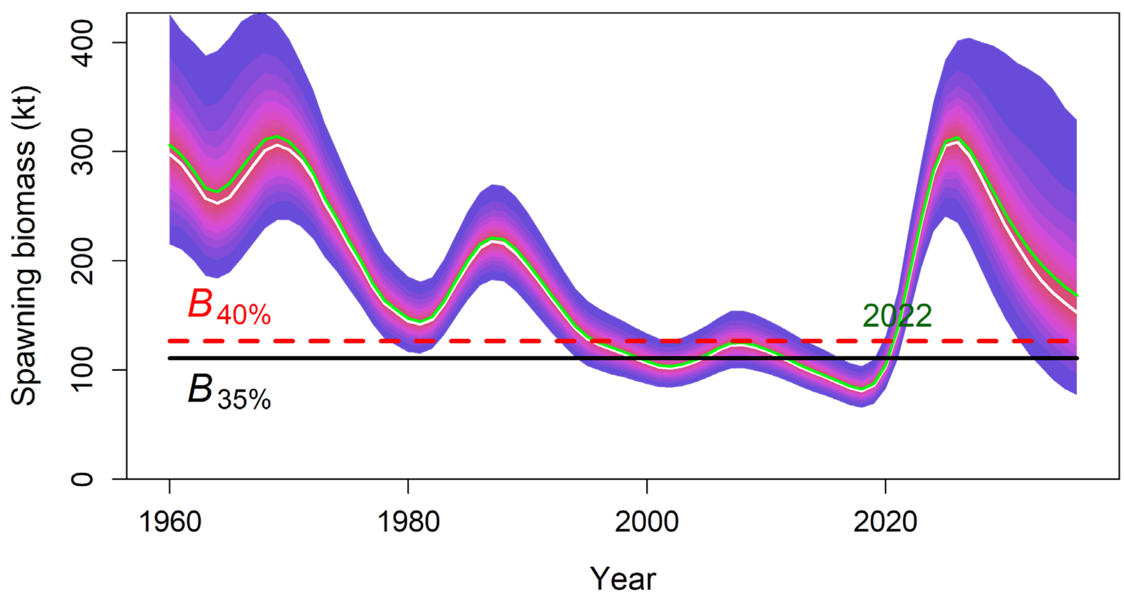


Figure 3I.4. Results of a Markov Chain Monte Carlo (MCMC) analysis demonstrating estimates of female spawning biomass (kilotons) and their uncertainty from MCMC runs. The results for the new proposed model (*21.12_Proposed_No_Skip_Spawn*) are in the top panel and those for the Continuity model (*16.5_Cont*) are in the bottom panel. White line is the median and green line is the mean, while shaded fill is 5% increments of the posterior probability distribution of spawning biomass based on MCMC simulations. Width of shaded area is the 95% credibility interval.

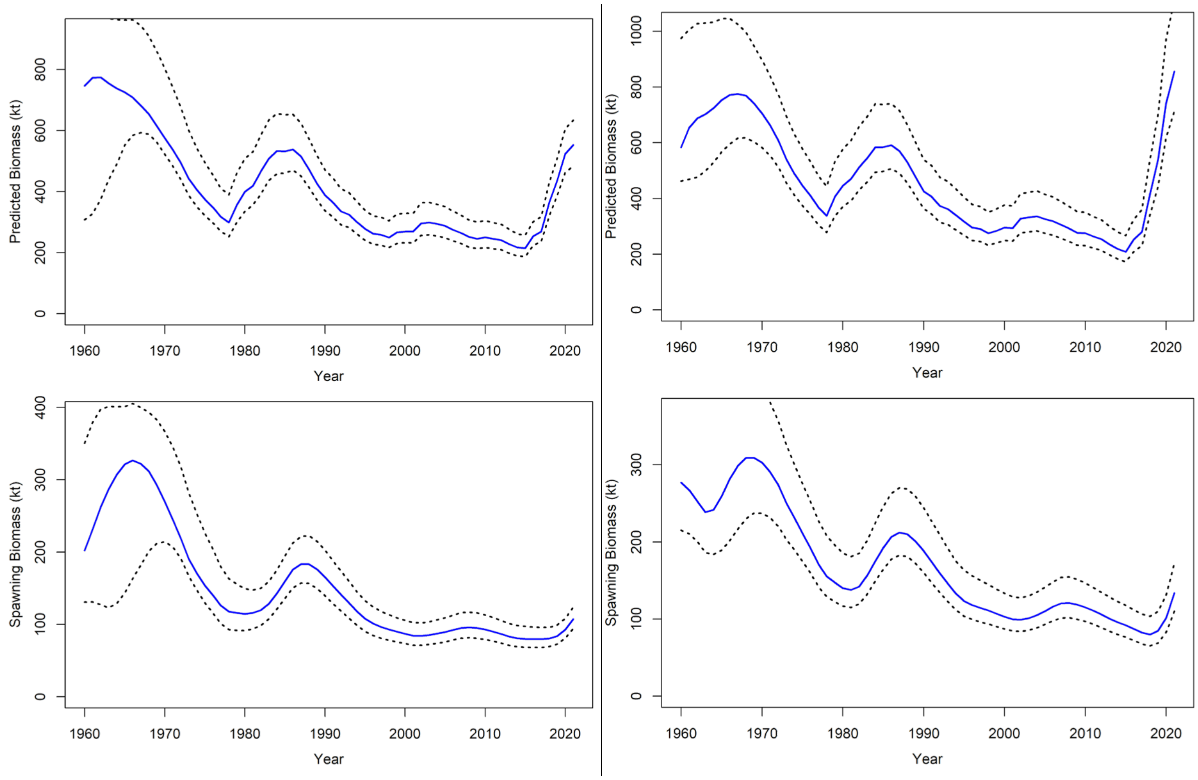


Figure 3I.5. Estimated sablefish total biomass (top panel) and spawning biomass (bottom panel) with 95% MCMC credible intervals. The results for the new proposed model (*21.12_Proposed_No_Skip_Spawn*) are in the left panel and those for the Continuity model (*16.5_Cont*) are in the right panel. Values are in kilotons.

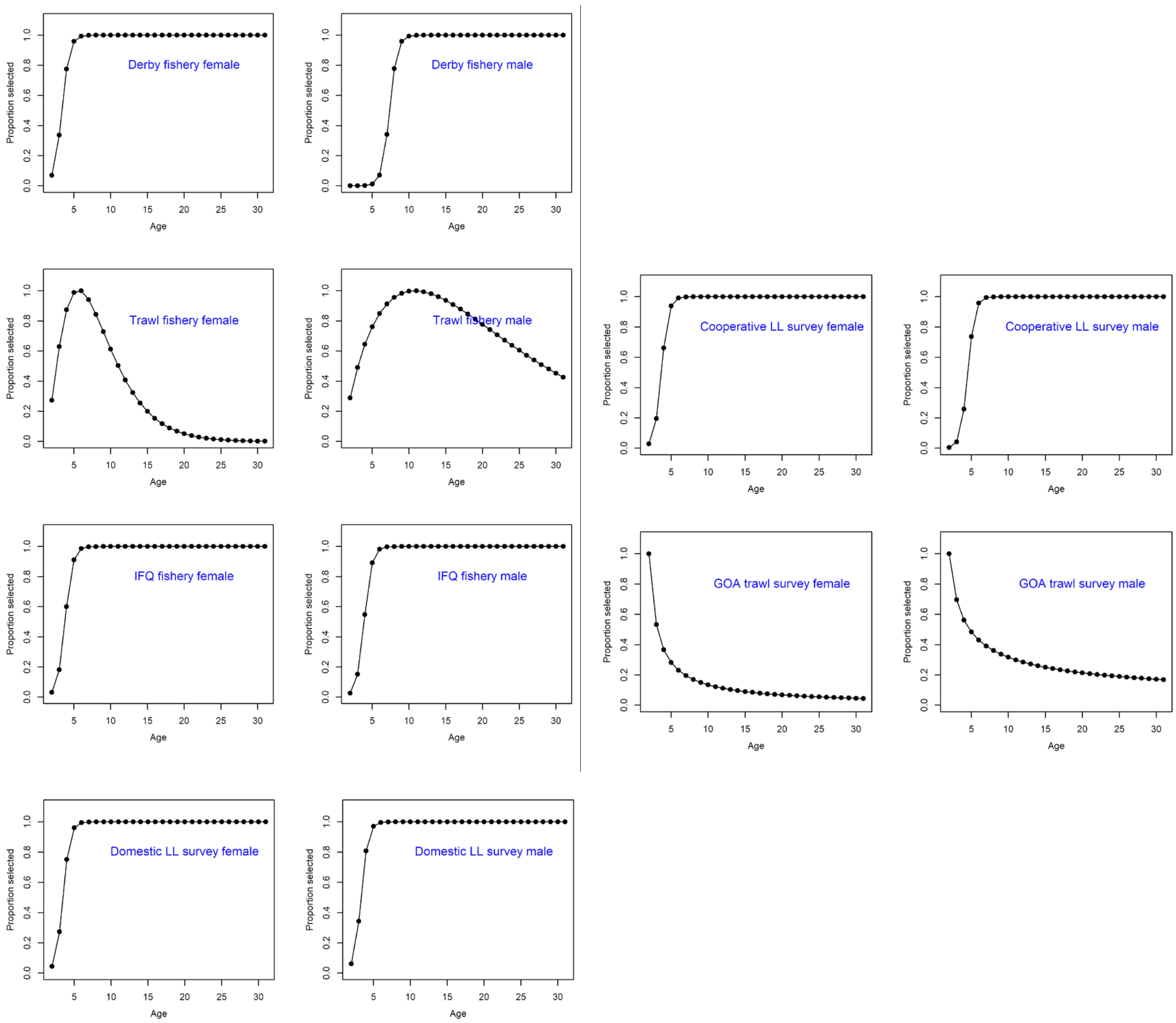


Figure 3I.6. Estimated fishery and survey selectivity for the continuity model (*16.5_Cont*). The derby longline fishery occurred until 1994, then the fishery switched to an IFQ system in 1995.

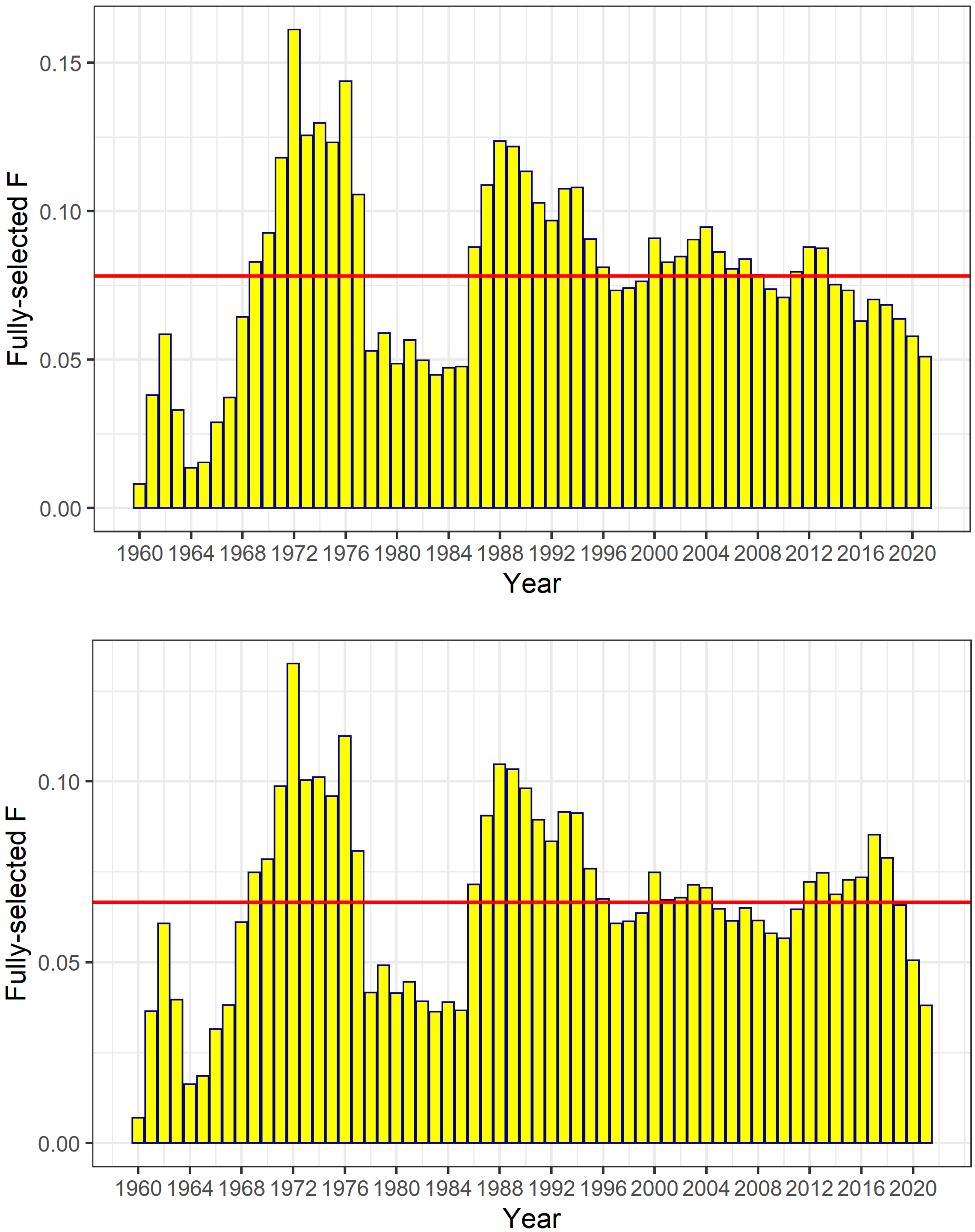


Figure 3I.7. Time series of combined fully selected fishing mortality for fixed and trawl gear for sablefish. The results for the new proposed model (*21.12_Proposed_No_Skip_Spawn*) are in the top panel and those for the Continuity model (*16.5_Cont*) are in the bottom panel. Red line is the mean fishing mortality for the entire time series.

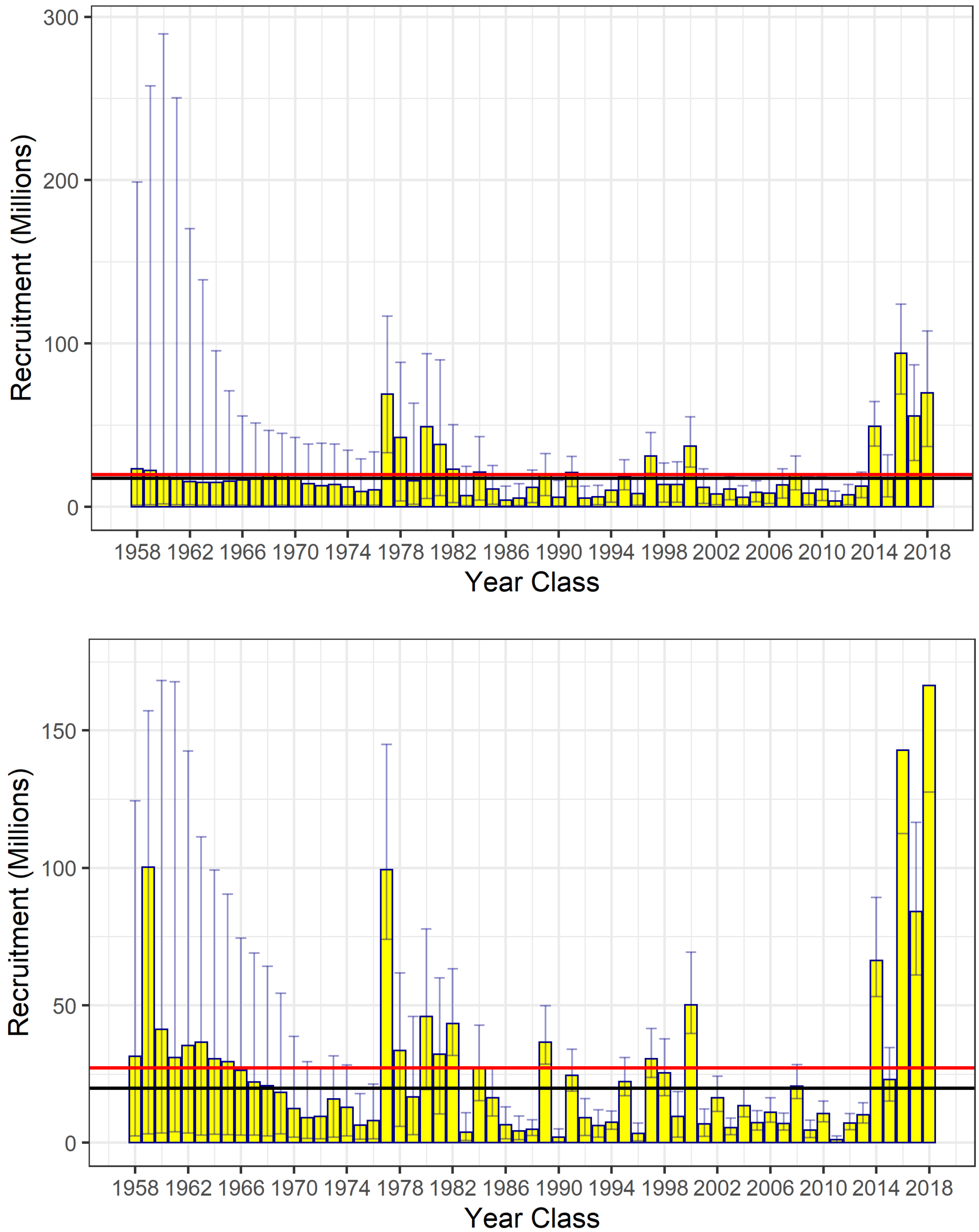


Figure 3I.8a. Estimated recruitment of age-2 sablefish (millions of fish) with 95% credible intervals from MCMC by year class (recruitment year minus two). The results for the new proposed model (*21.12_Proposed_No_Skip_Spawn*) are in the top panel and those for the Continuity model (*16.5_Cont*) are in the bottom panel. Red line is overall mean, while black line is mean for recruitments from year classes between 1977 and 2018. Credible intervals are based on MCMC posteriors. The estimate for the 2019 year class (terminal year 2021 recruitment event) is omitted, because it is fixed to the estimated mean recruitment value (μ_r) with no deviation parameter estimated.

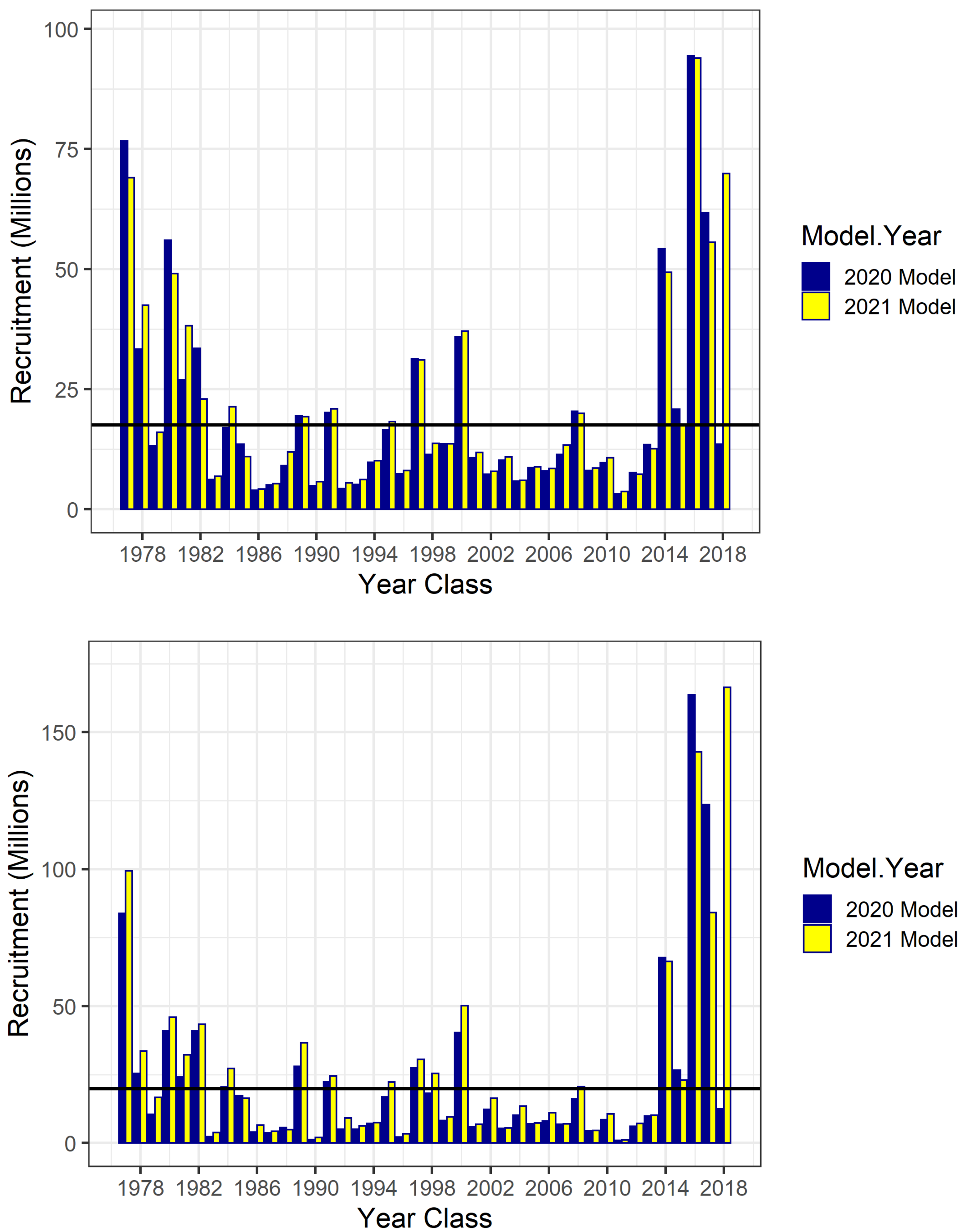


Figure 3I.8b. Estimated recruitment by year class (1977 - 2018) in number of age-2 fish (millions of fish) for the 2020 and 2021 *21.12_Proposed_No_Skip_Spawn* models (top panel) and *16.5_Cont* models (bottom panel). Black line is mean recruitment from the 2021 model for 1977 to 2018 year classes. Note that the 2018 yearclass for the 2020 model is equivalent to the estimated mean recruitment value (μ_r) given that no recruit deviation is estimated in the terminal year.

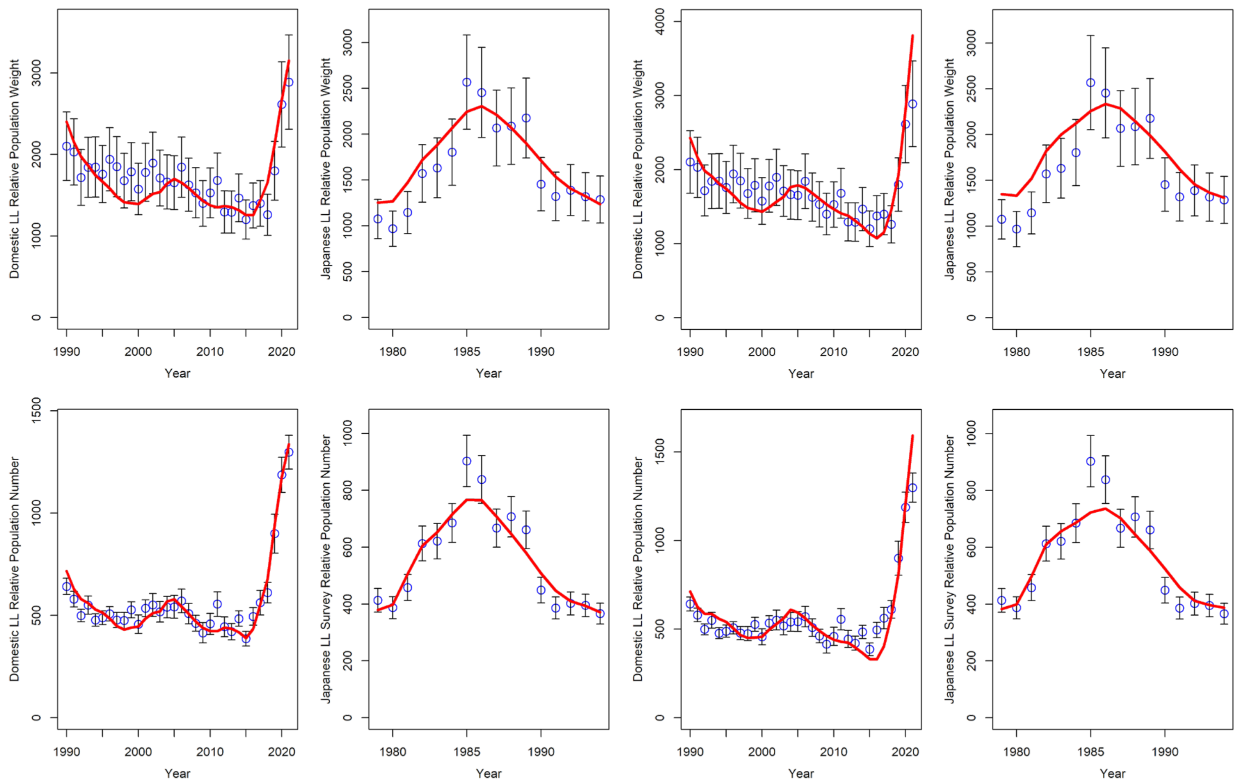


Figure 3I.9. Fits of the new proposed model (*21.12_Proposed_No_Skip_Spawn*; left two columns) and the Continuity model (*16.5_Cont*; right two columns) to abundance indices. Observed and predicted sablefish relative population weight and numbers for 1990 - 2021 for U.S. longline survey and for 1979 - 1994 for U.S.-Japan cooperative survey. Points are observed estimates with approximate 95% confidence intervals. Solid red line is the model predicted values. The relative population weights are not fit in the models, but are presented for comparison.

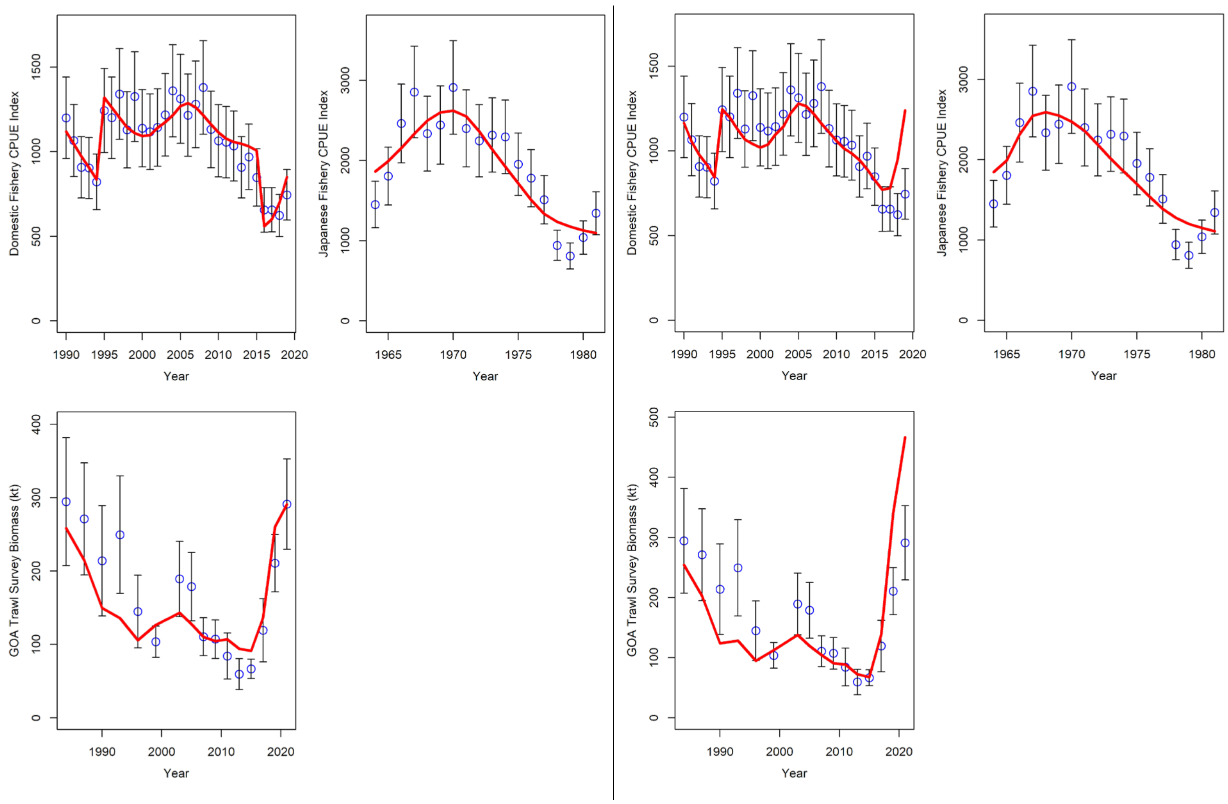


Figure 3I.10. Fits of the new proposed model (*21.12_Proposed_No_Skip_Spawn*; left two columns) and the Continuity model (*16.5_Cont*; right two columns) to abundance indices. Fishery CPUE indices are on top two panels. GOA trawl survey is on the bottom left panel. Points are observed values with approximate 95% confidence intervals, while solid red lines are model predictions.

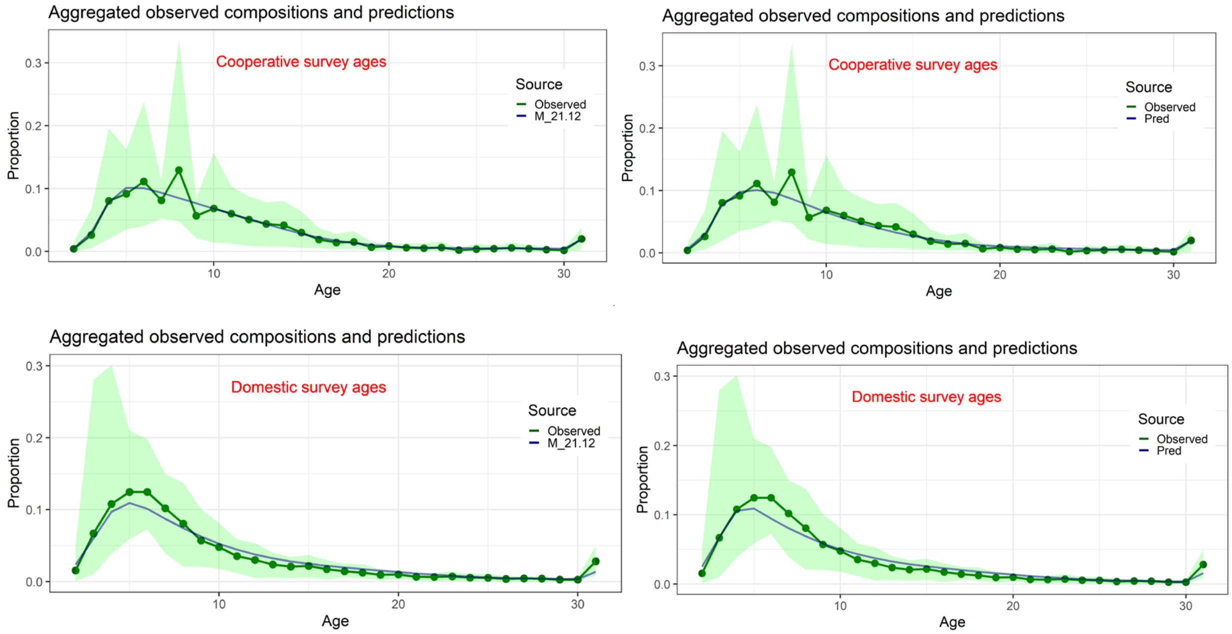


Figure 3I.11. Fits of the new proposed model (*21.12_Proposed_No_Skip_Spawn*; left panel) and the Continuity model (*16.5_Cont*; right panel) to aggregated compositional data. Mean observed (green line) cooperative (top panel) and domestic (bottom panel) longline survey age compositions aggregated across years along with the average fit of the model (blue line). The green bands are the 90% empirical confidence intervals.

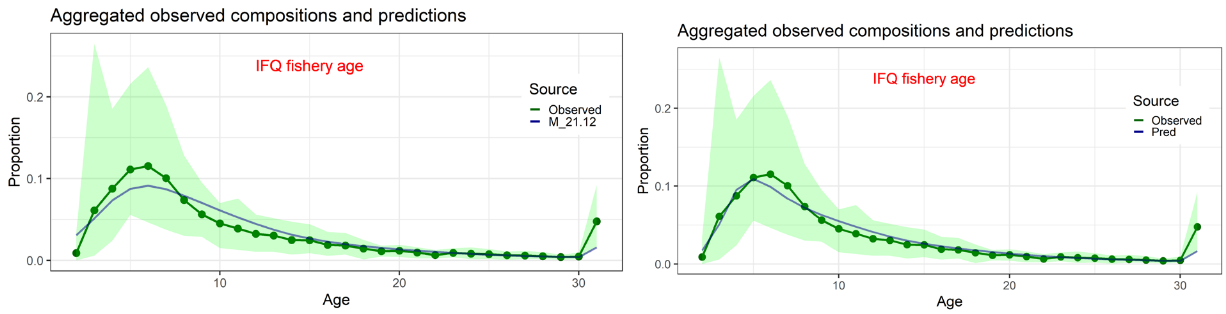


Figure 3I.12. Fits of the new proposed model (*21.12_Proposed_No_Skip_Spawn*; left panel) and the Continuity model (*16.5_Cont*; right panel) to aggregated compositional data. Mean observed (green line) domestic fixed gear fishery age compositions aggregated across years along with the average fit of the model (blue line). The green bands are the 90% empirical confidence intervals. Note the perceptibly worse fits of the *21.12_Proposed_No_Skip_Spawn* model for ages two through five.

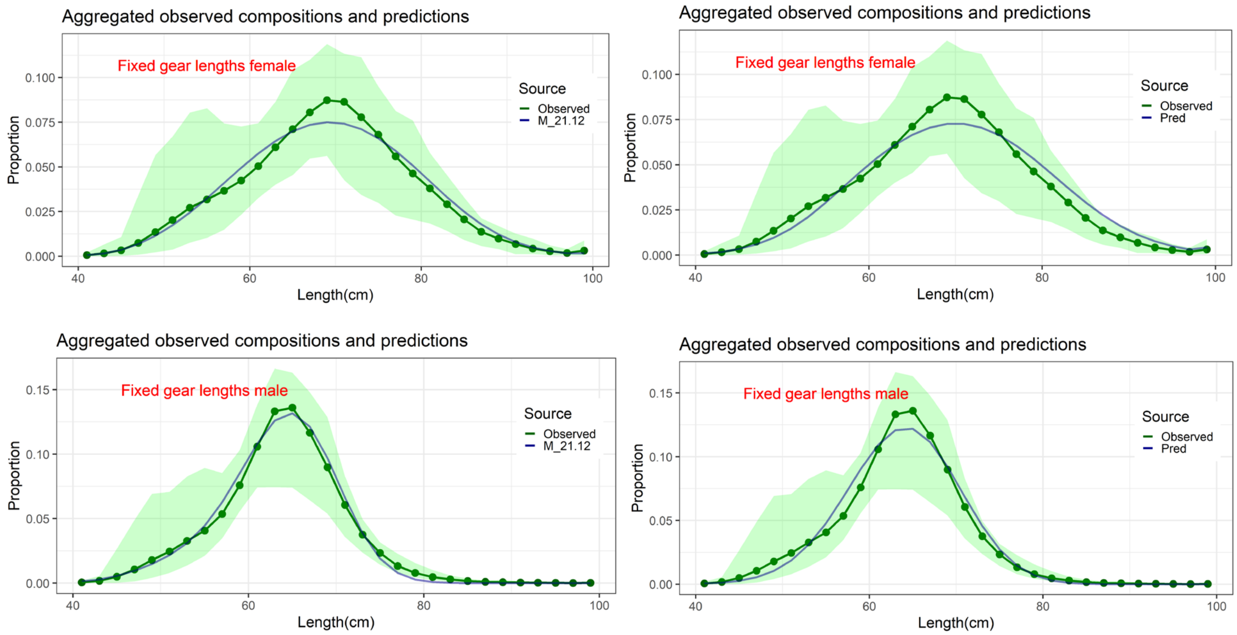


Figure 3I.13. Fits of the new proposed model (*21.12_Proposed_No_Skip_Spawn*; left panel) and the Continuity model (*16.5_Cont*; right panel) to aggregated compositional data. Mean observed (green line) domestic fixed gear fishery length compositions aggregated across years along with the average fit of the 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.

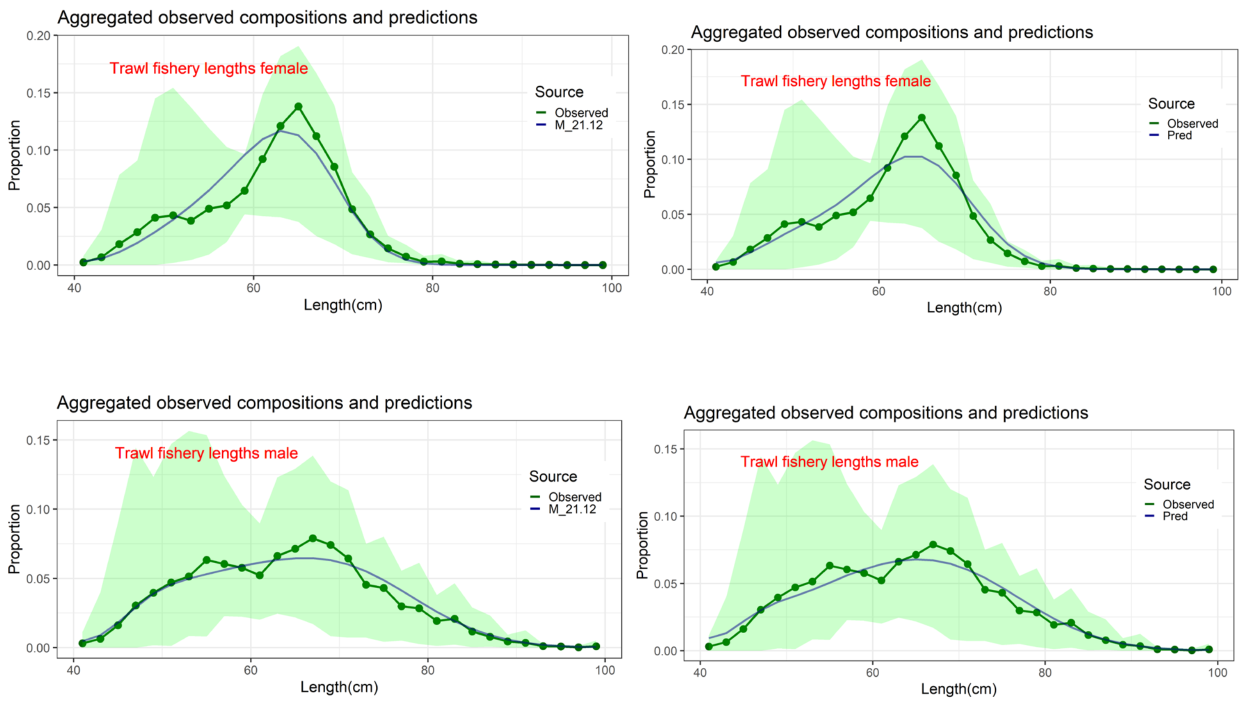


Figure 3I.14. Fits of the new proposed model (*21.12_Proposed_No_Skip_Spawn*; left panel) and the Continuity model (*16.5_Cont*; right panel) to aggregated compositional data. Mean observed (green line) domestic trawl fishery length compositions aggregated across years along with the average fit of the 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.

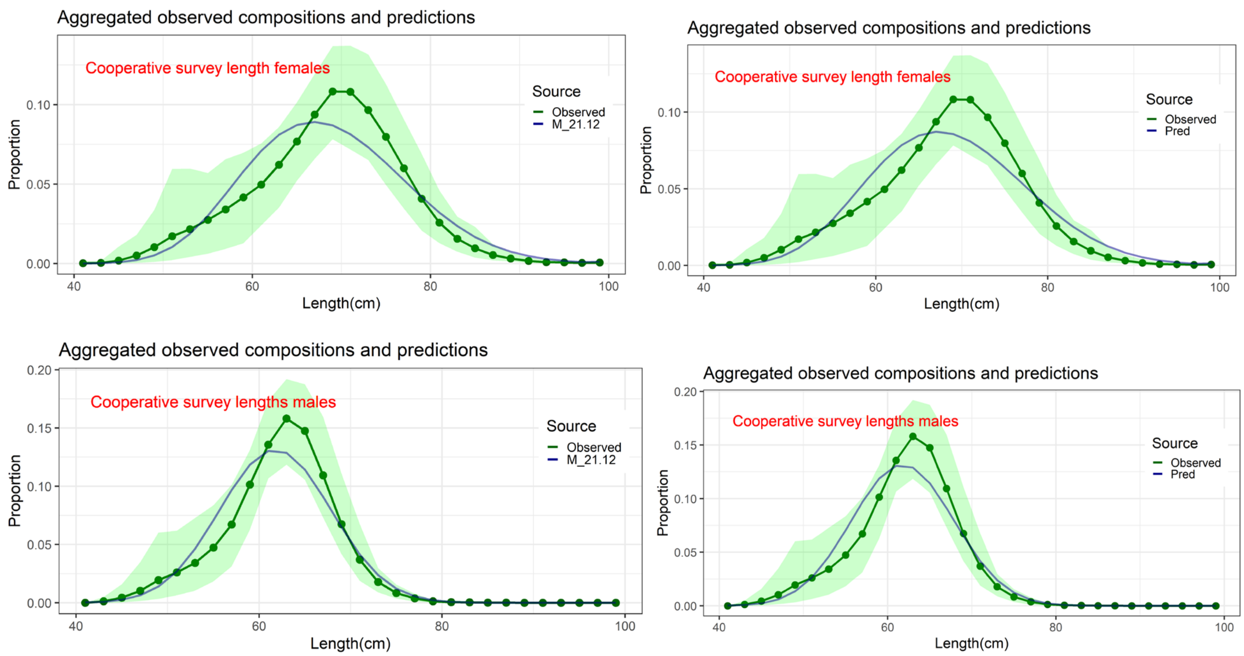


Figure 3I.15. Fits of the new proposed model (*21.12_Proposed_No_Skip_Spawn*; left panel) and the Continuity model (*16.5_Cont*; right panel) to aggregated compositional data. Mean observed (green line) cooperative longline survey length compositions aggregated across years along with the average fit of the 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.

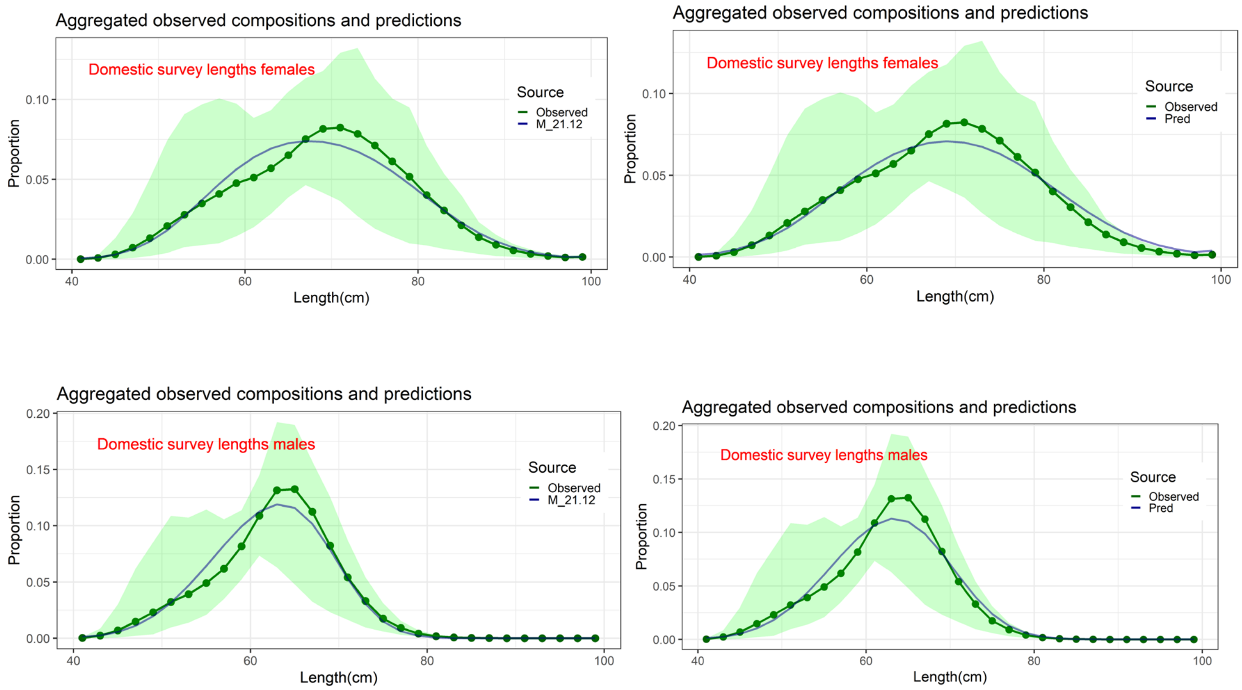


Figure 3I.16. Fits of the new proposed model (*21.12_Proposed_No_Skip_Spawn*; left panel) and the Continuity model (*16.5_Cont*; right panel) to aggregated compositional data. Mean observed (green line) domestic longline survey length compositions aggregated across years along with the average fit of the 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.

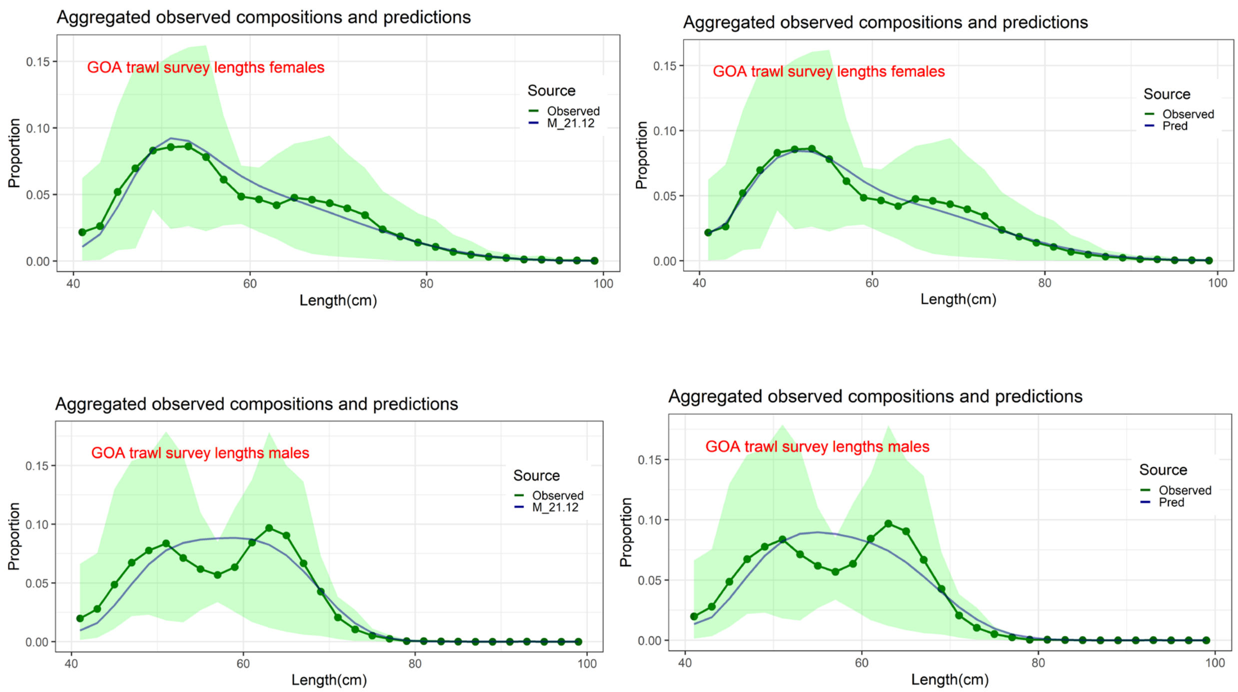


Figure 3I.17. Fits of the new proposed model (*21.12_Proposed_No_Skip_Spawn*; left panel) and the Continuity model (*16.5_Cont*; right panel) to aggregated compositional data. Mean observed (green line) Gulf of Alaska trawl survey length compositions aggregated across years along with the average fit of the 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.

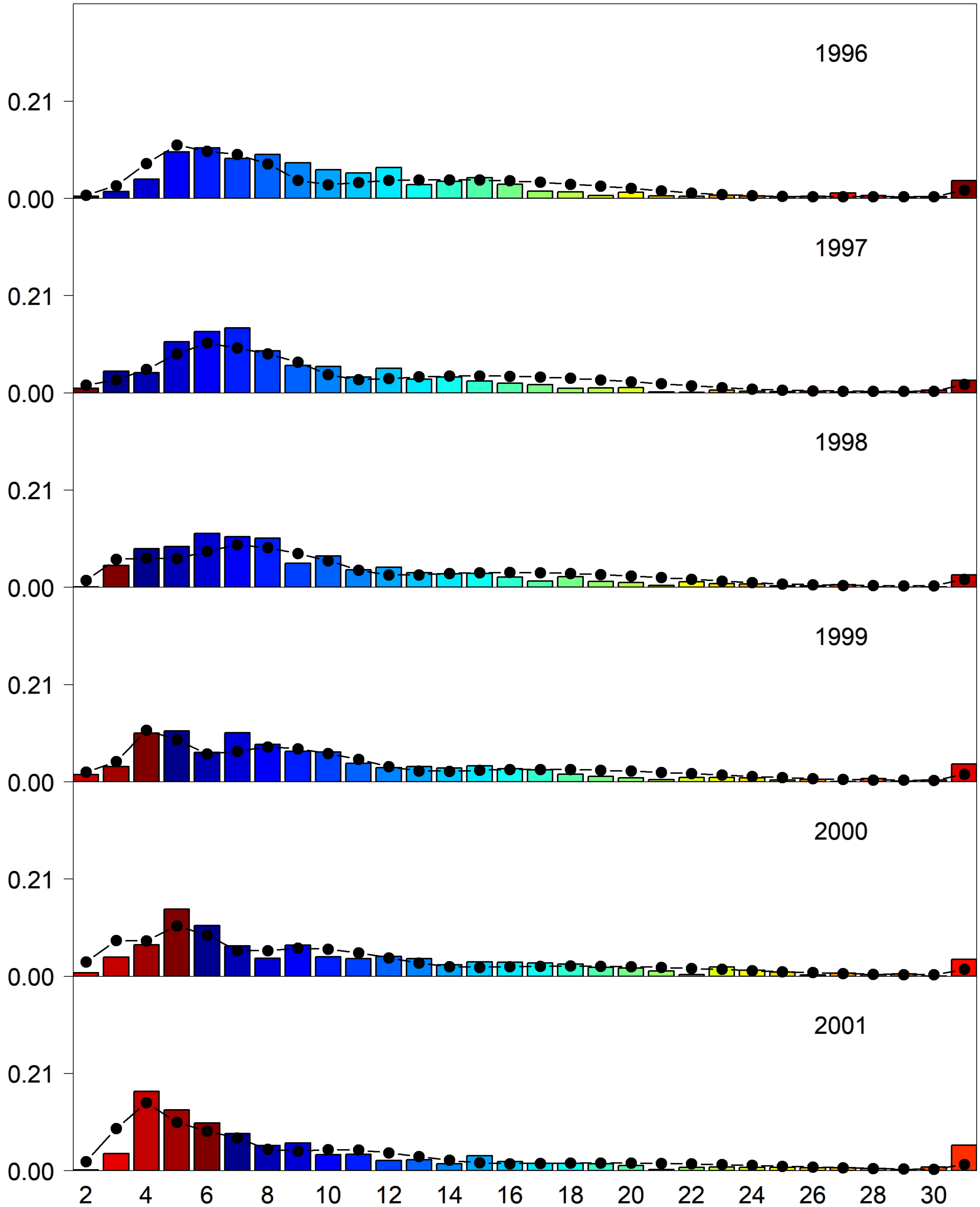


Figure 3I.18. Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies from model *16.5_Cont*.

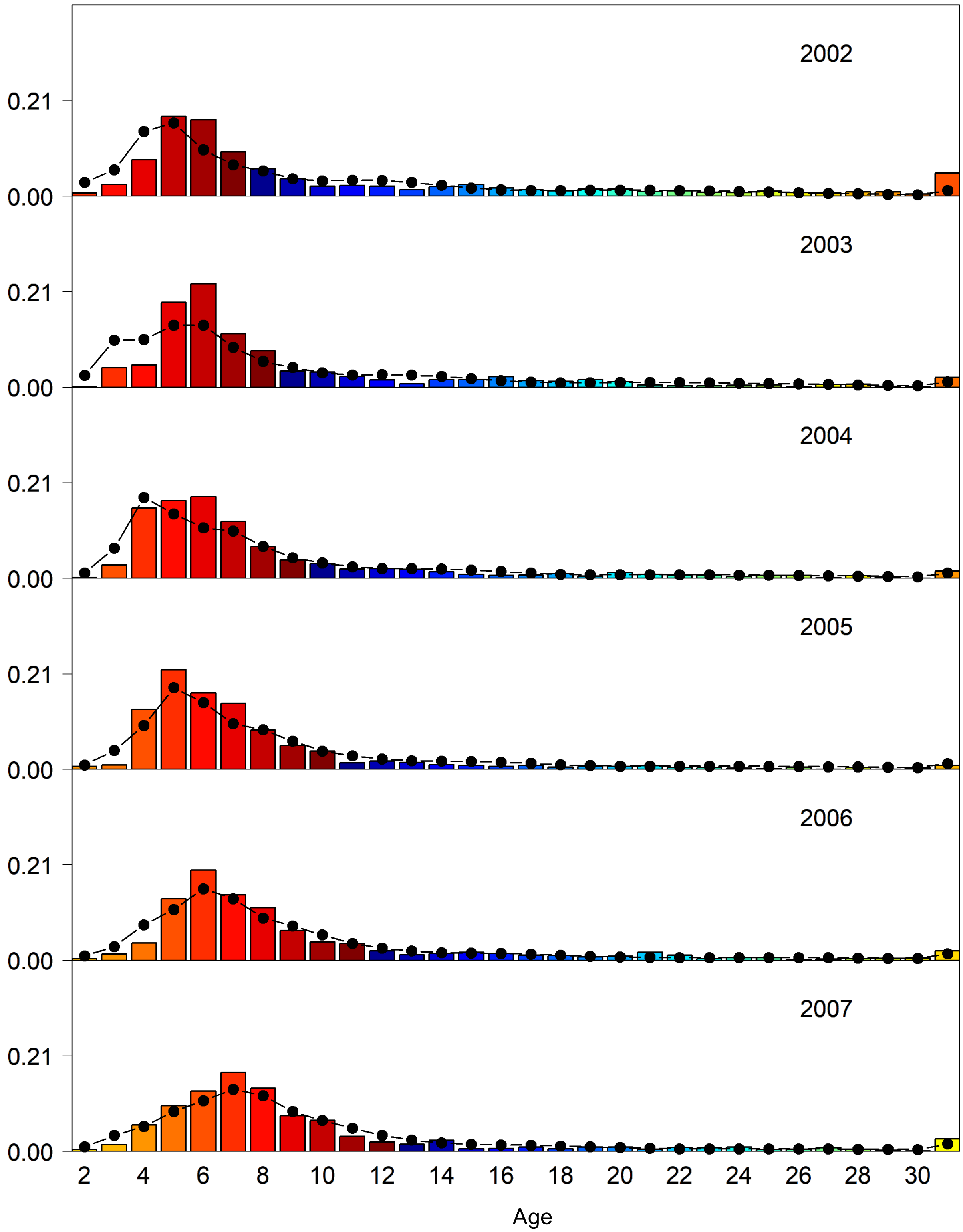


Figure 3I.18 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies from model *16.5_Cont*.

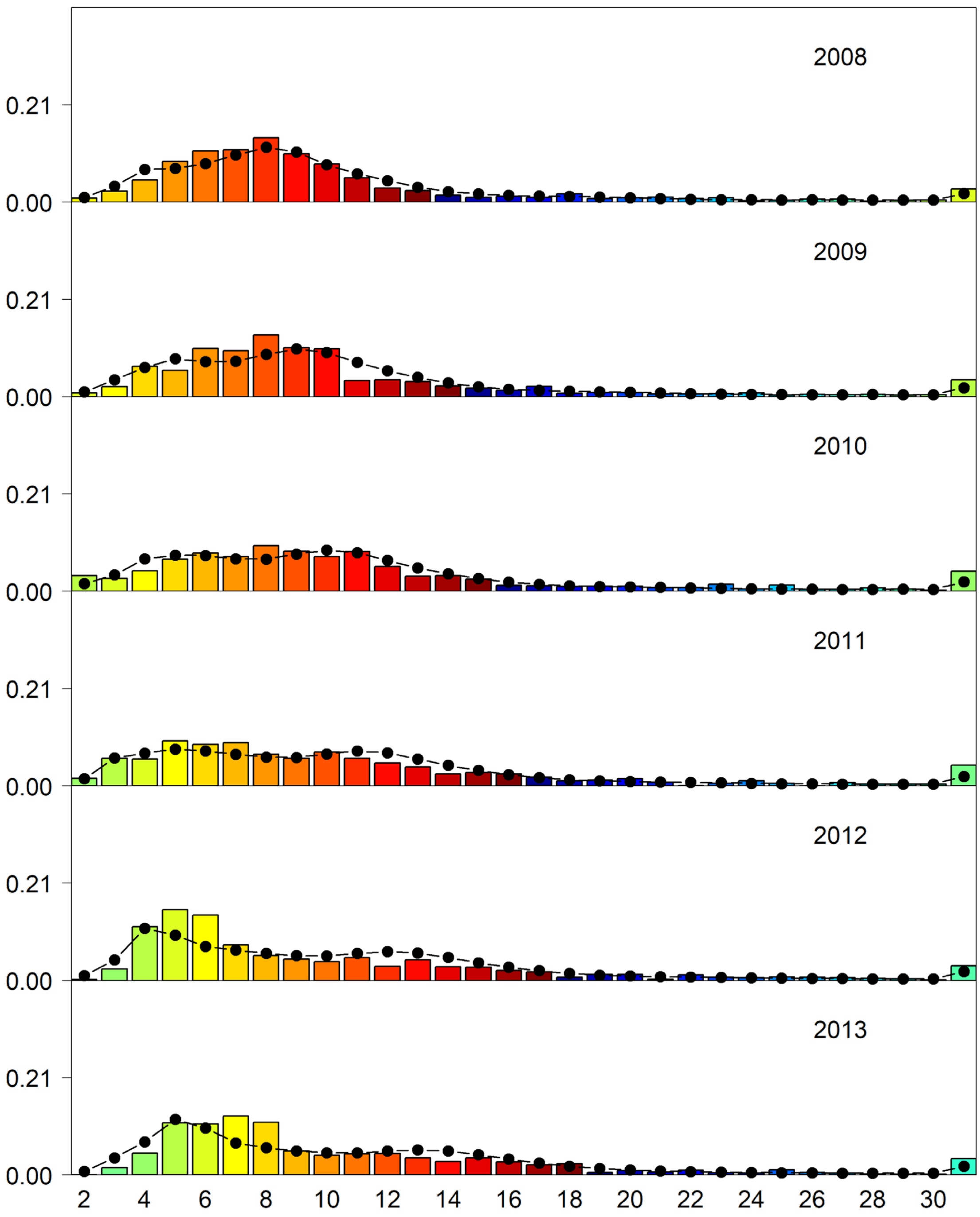
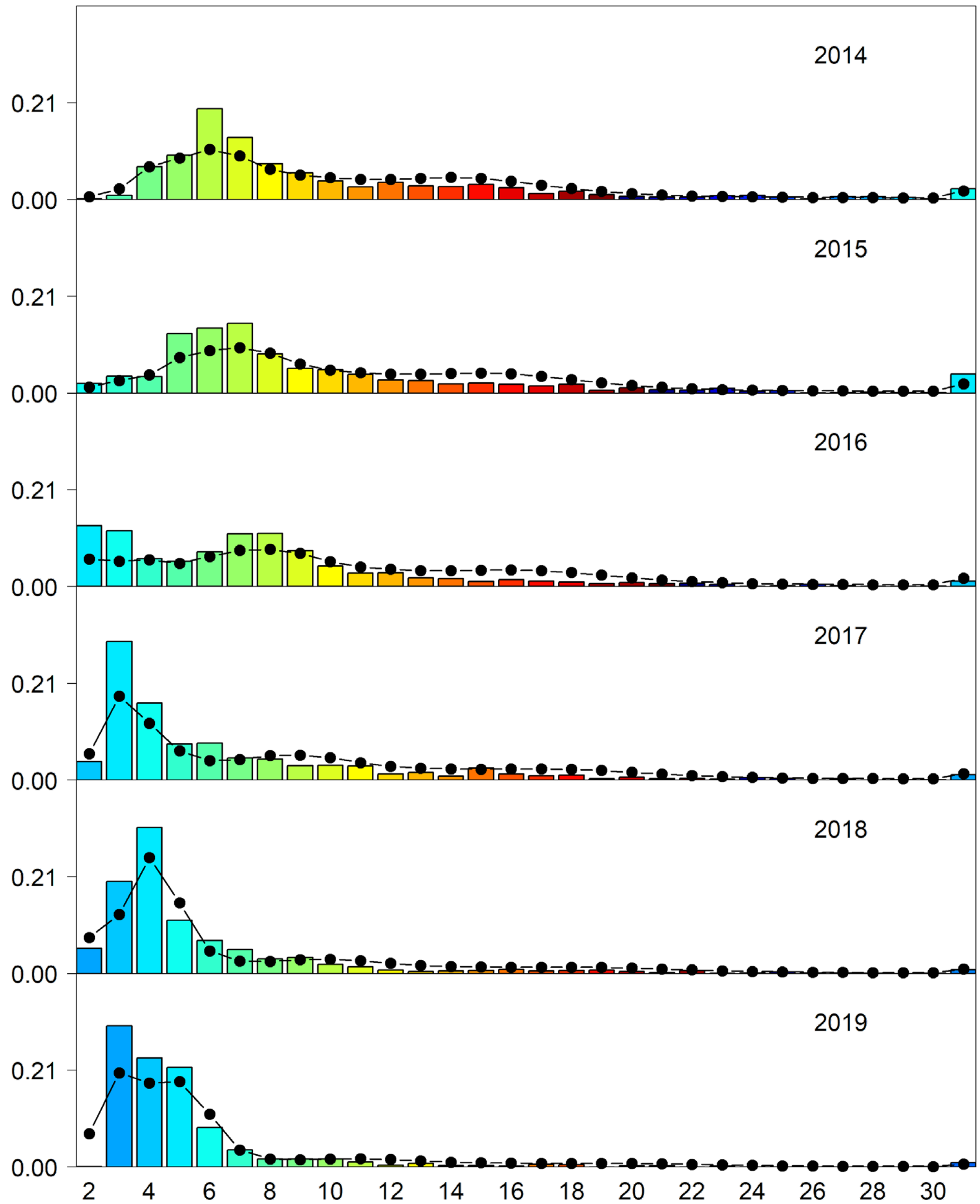


Figure 3I.18 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies from model *16.5_Cont*.



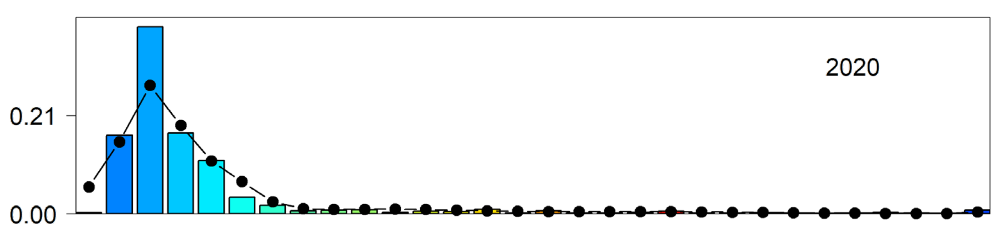


Figure 3I.18 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies from model *16.5_Cont*.

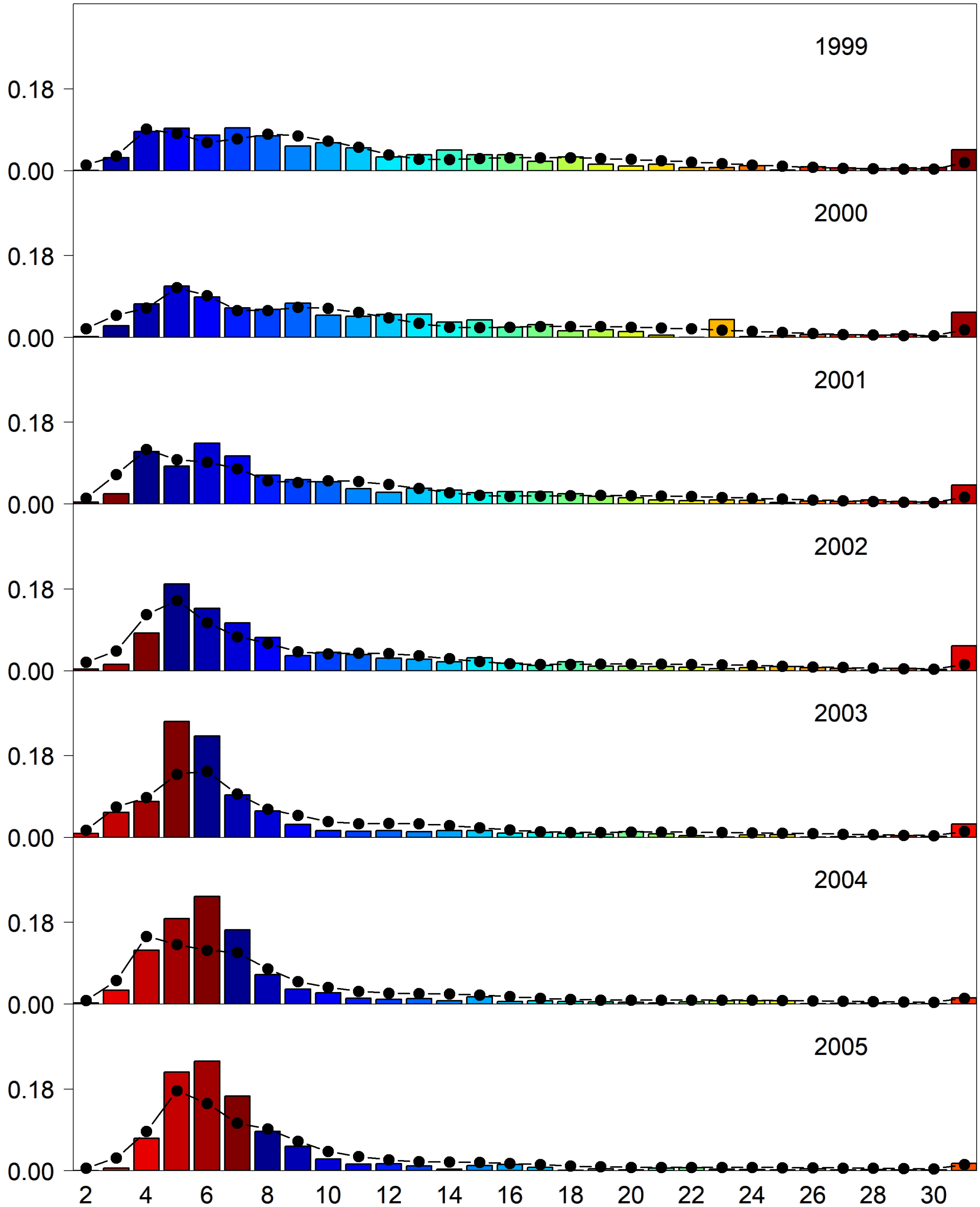


Figure 3I.19. Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies from model *16.5_Cont*.

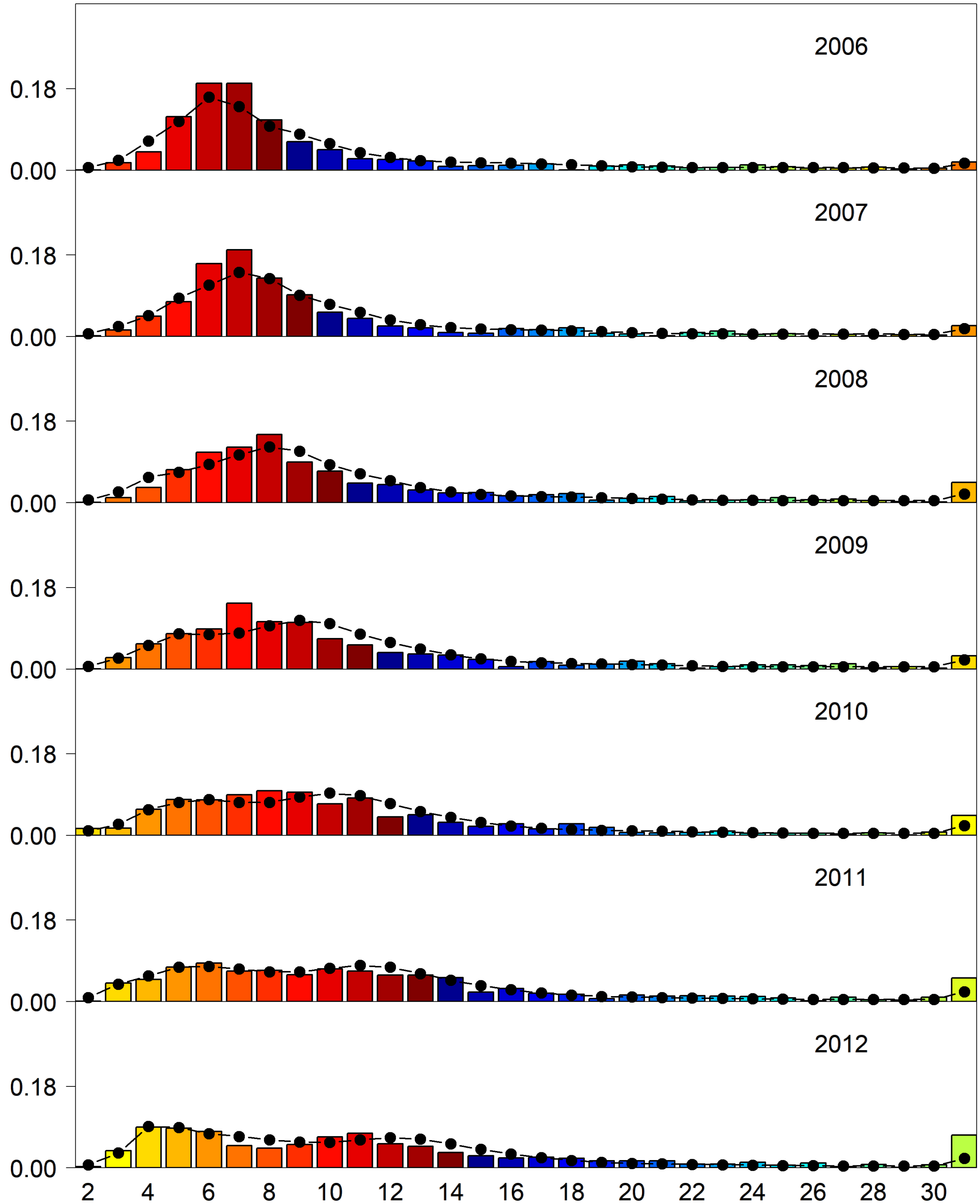


Figure 3I.19 (cont.). Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies from model *16.5_Cont*.

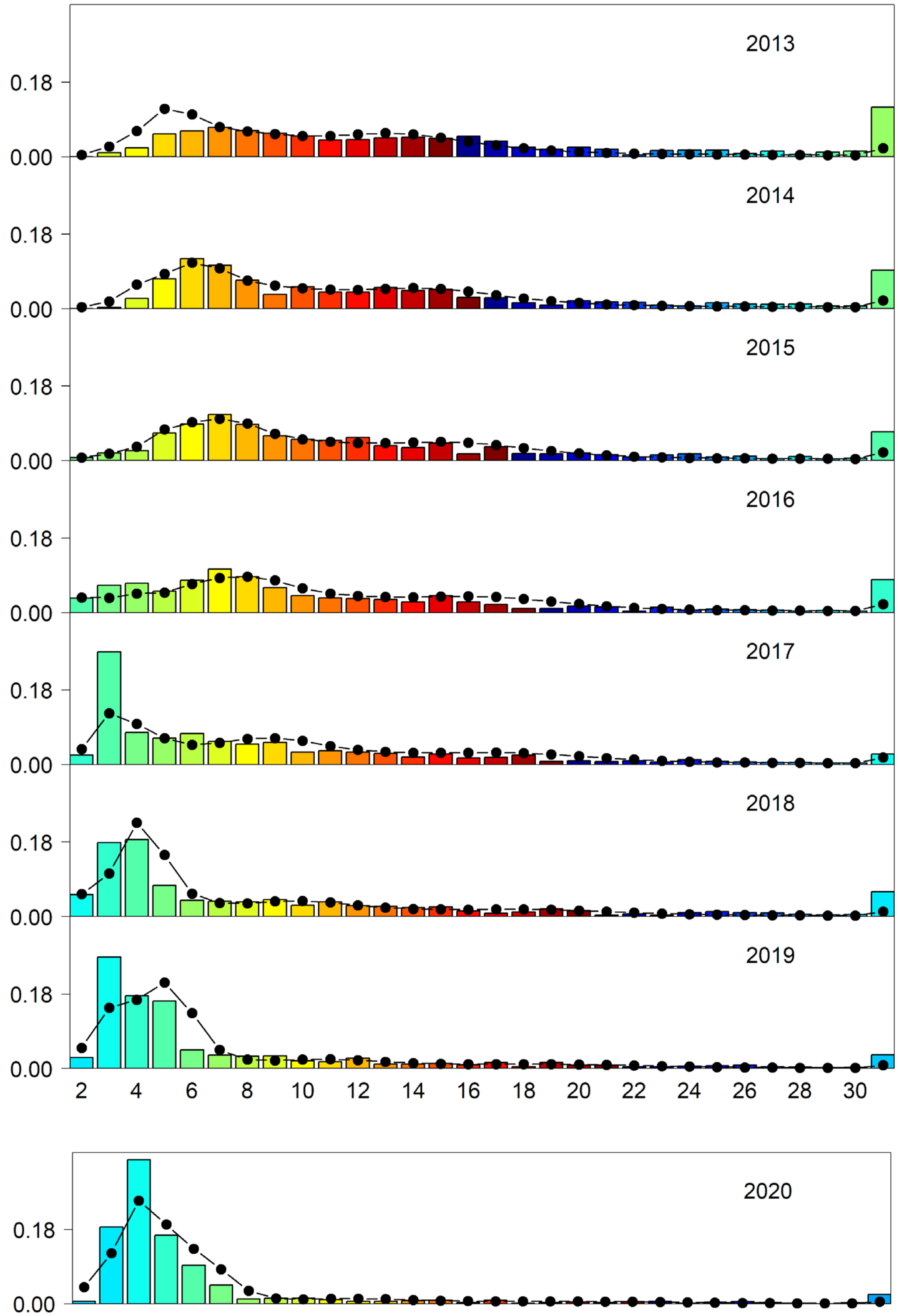


Figure 3I.19 (cont.). Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies from model *16.5_Cont*.

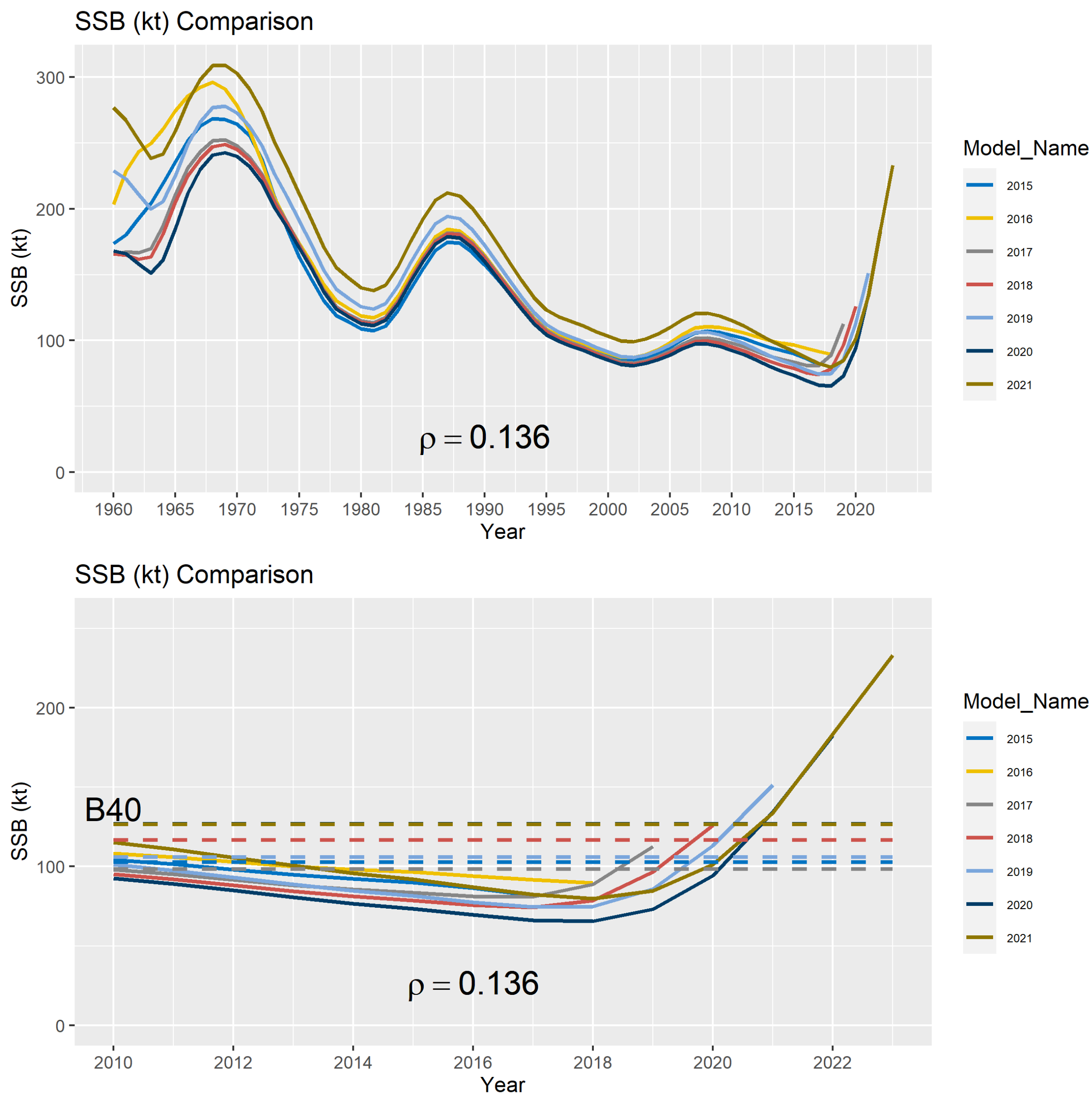


Figure 3I.20. Results of the 'all model' historical retrospective illustrating estimated and projected (terminal year + 2 year) spawning stock biomass (in kilotons). Results are based on the accepted model in each terminal model year and includes application of the *16.5_Cont* model for the 2021 model year. 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 for two year SSB projections is provided below the lines in each plot.