Assessment of the Pacific cod stock in the Aleutian Islands

September Plan Team Document

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In 2023, the authors examined multiple sensitivity analyses for the Aleutian Islands (AI) Tier 3 Pacific cod stock assessment model, as well as SSC and Plan Team suggestions based on the 2022 model. The Aleutian Islands Pacific cod assessment has been in the Tier 5 category since 2014. Age structured models have been presented in most years since 2013 but none have been accepted by the Plan Teams or SSC. In 2022, the models were not accepted due to poor retrospective patterns. The goal of sensitivity testing to be presented at the September Plan Team meeting was to consider upgrading to the Tier 3 level by incorporating past comments and suggestions to the 2022 SS3 age structured model(s). Improvements were also implemented with the aim of improving the model fit to the survey length compositions and index and to provide consistency with the eastern Bering Sea and Gulf of Alaska Pacific cod models. The base model was M22.0, a statistical catch at age model presented in 2022 that incorporated various data sources to inform population dynamics and estimated management quantities (Table 1). This work responds to the SSC comment: 'The SSC supports the PT recommendation for continued efforts to develop a viable age-structured assessment model framework for this stock and retaining the annual assessment cycle at this time.'

We examined conditional survey age-at-length, mean survey length-at-age, constant vs. time varying growth, survey and fishery selectivity, and input composition sample sizes, as well as longline survey data. All models described here and accompanying output summaries, likelihood for all data components, and comparative plots can be found at https://github.com/afsc-assessments/AI_Pcod_2023/.

Sensitivity testing

Survey conditional age-at-length vs. Mean length-at-age

We examined whether the addition of conditional age-at-length or mean length-at-age would improve the fit to the survey index and composition data. To this end, three models were explored: only mean length-at-age (M22.0), only conditional age-at-length (M22.0a), and neither conditional age-at-length nor mean length-at-age (marginal age compositions) (M22.0b). M22.0b did not fit the marginal age composition well. Model 22.0a resulted in an improved AIC from 3,479 in M22.0, which used mean length-at-age to 2,469. The largest improvement from M22.0 to M22.0a was in the age and length composition likelihoods (Table 1). Due to these improvements, conditional age-at-length was retained as a feature in the recommended model for the 2023 assessment, M23.0.

Constant survey and fishery selectivity

Model 22.0f changed time-varying length-based survey and fishery selectivity to constant selectivity. While this did not improve the overall likelihood (or the AIC), it reduced the number of parameters from 165 to 61. For simplicity, the base model M23.0 will incorporate no time-varying selectivity. Time-varying fishery selectivity is retained as a feature in Model 23.1 because it was recommended by the SSC as a means to improve the retrospective pattern.

Input sample size
The 2022 model used a constant survey input sample size = 100. This has been improved upon, with survey length and age input sample sizes generated by bootstrapping (Hulson et al. 2023) the number of hauls from which length and age data were taken. Fishery length composition input sample sizes were generated from the number of hauls, and scaled to the mean survey input sample size (so that the mean fishery length comp input sample size was the same as the survey mean input sample size). This did not result in a change in likelihood, but is preferred over a constant sample size approach to weighting compositional data because it considers the number of hauls in each year and therefore the varying informational content in each year.

Changing survey selectivity parameters and phasing
Model 22.0h adopted survey selectivity parameters from the EBS survey as well as a later phase (phase 2 to 3). This improved the fit to the overall survey index, but not the fit to the length compositional data (Table 1).

Incorporating the longline as well as trawl survey data
Model 23.2 incorporates longline survey indices as well as length compositions, in response to an SSC comment encouraging the use of longline survey data as a supplemental data source.

Results

Improving fit to survey index
Model 22.0h improved the fit to the survey index that is reflected in the likelihood, although it did not improve the fit to the survey length frequency (Table 1). Model 23.0 improved the fit to the age- and length-compositional data, as well as to the overall survey index likelihood (Table 1). Improved model fits resulted from changing the input sample sizes from constant to relative to the number of hauls (and bootstrapping). Secondly, changing the phase at which the selectivity was fit in the model from 2 to 3, and finally, Francis weighting in addition to changing the input sample sizes improved the fit (Figures 1, 2 and 3).

Models produced as a result of sensitivity testing
We incorporated lessons from sensitivity testing to produced several new models. The proposed base model M23.0 includes conditional age-at-length survey data, rather than mean length-at-age, bootstrapped input sample sizes based on haul count for survey length and age compositional data, no time varying selectivity for the survey or the fishery, as well as modeling growth in phase 2 and selectivity in phase 3. Model 23.0 improved the AIC and total likelihood over all other models in the M22.x series after Francis weighting was applied to the length and age compositional data (Table 1).

Model 23.1 was based on Model 23.0 except it incorporated annually-varying fishery selectivity for the entire modeled period, 1991-2022 (Figure 3b). This model resulted in a much better retrospective pattern (Figure 4) and a lower Mohn's Rho (0.303), compared with Mohn's Rho = 0.52 for Model 23.0. While this value is lower, it is still considered high, and further work is warranted to understand and reduce this retrospective pattern.

Model 23.2 incorporated longline survey data but did not produce a convincing model. This is likely due to the fact that the longline survey does not accurately sample the biomass of

Aleutian Islands Pacific cod (Figure 5). There has been a long-term decline in the estimated abundance of cod in the Aleutian Islands, due to high fishing mortality rates in the early portion of the time series, likely followed by poor recruitment due to heat wave conditions in the Aleutian Islands since 2016. This is not reflected in the longline survey, partially because the survey is not designed to target cod, and it also does not span the extent of the Aleutian Islands, only the eastern portion. Therefore, Model 23.2 does not appear to be a reasonable alternative model.

Similar to the eastern Bering Sea cod model, time varying growth in Model 23.3 provides a better fit to the data while accounting for changes in growth that are known to exist in Pacific cod under different temperature regimes (Figure 4). This model resulted in the lowest AIC and the best retrospective pattern, Mohn's rho=0.230 (Table 1).

Other issues related to changes in the EBS cod model

A significant recommendation for the EBS Pacific cod model involves transitioning back to a standard multinomial model instead of the Dirichlet multinomial (DM) for length and age composition data. The reason for the change is the eastern Bering Sea (EBS) P. cod DM theta values in all models for the fishery length composition data consistently reached the upper bound. The AI Pacific cod model uses a multinomial model for length- and age-composition data; therefore, transitioning away from the Dirichlet multinomial was not an issue for this assessment.

Secondly, model explorations in the EBS cod model indicated that natural mortality and survey catchability are highly correlated, which results in problems with estimating both quantities simultaneously. Unnecessarily varying catchability can lead to extreme shifts in the magnitude of harvest recommendations depending on the magnitude of catchability. In order to standardize all Alaska Pacific cod models into the future, we propose adopting a fixed natural mortality. This is considered a better alternative to adopting a fixed catchability, because catchability can vary across regions. Over the past decade, the EBS cod model found M=0.4 to be the most commonly estimated value for natural mortality (Barbeaux et al. 2022), and this value was also similar to natural mortality estimates for the Aleutian Islands age structured cod assessment model (Spies et al. 2022). The natural mortality values for GOA P.cod have been somewhat higher (0.47 and 0.48) (Barbeaux et al. 2021). Jim Thorson recently produced an R package for estimating M, and for EBS cod this value was 0.3866. We propose using this tool and fixing M at the recommended value, because we are not able to consistently estimate M. There may be limited information in the data to inform M, and in order to avoid unnecessary swings in harvest recommendations into the future. Fixed M=0.4 was adopted in Model M23.0a and Model 23.1a (Table 1). We recommend retaining one model (M23.0a or M23.1a) for exploratory purposes and for comparison with the EBS cod model.

Retrospective patterns

A consideration from the 2022 Tier 3 Aleutian Islands Pacific cod assessment was poor retrospective patterns. A poor retrospective pattern was also present in M23.0 (Mohn's rho based on 10 SSB peels was 0.52). To improve the retrospective pattern, we incorporated time-varying fishery selectivity into M23.1. This was justified because the fishery for Aleutian Islands Pacific cod has changed significantly over the past 25 years, from high fishing rates in the 1990s when the quota was combined with the EBS Pacific cod stock, to limitations on fishing due to Steller Sea Lion restrictions starting in ~2010. Currently, there is very little targeted cod fishing in the

Aleutian Islands compared with the high fishing mortality rates of the 1990s. The retrospective pattern was further improved in M23.3 with the addition of time-varying growth.

Summary

The two models that the authors plan to move forward are Models 23.1 and 23.3. Model 23.1 is the best model in terms of fitting the survey index and survey composition data. It also has the best retrospective pattern. Model 23.3 improves the AIC as well as the retrospective pattern (Mohn's rho=0.230). We will work with the EBS and GOA cod authors to determine whether fixing M or applying a tight prior will be a good direction as well. Unlike the EBS cod model, M and Q do not appear to vary significantly from M=4, Q~0 regardless of the parameterizations applied. The workplan for the November document includes continuing to identify the factors driving the retrospective pattern, and examine growth spatially and temporally.

Table 1. Likelihood components for the models discussed here. See Table 2 for model details.

Model number	M22.0	M22.0a	M22.0f	M22.0h	M23.0
TOTAL_like	1574.42	1069.51	1695.82	1853.34	773.94
Survey_like	34.4609	33.8004	44.211	7.65055	1.61103
Length_comp_like	394.566	379.307	512.758	513.315	173.403
Age_comp_like	894.256	633.48	900.681	922.546	599.842
Parm_priors_like	1.36279	1.50511	1.30302	0.0630689	0.0996056
Size_at_age_like	226.877	NA	233.397	409.842	NA
Recr_Virgin_millions	32.2864	30.9159	32.5456	76.5333	38.9685
SR_LN(R0)	10.3824	10.339	10.3904	18.1532	10.5705
SR_BH_steep	1	1	1	1	1
NatM_uniform_Fem_GP_1	0.351564	0.331684	0.358298	0.51459	0.41392
L_at_Amax_Fem_GP_1	113.491	114.262	113.476	112.921	115.352
VonBert_K_Fem_GP_1	0.242727	0.215675	0.244616	0.239866	0.199158
SSB_Virgin_thousand_mt	0.002	0.003	0.002	5.444	151.14
Bratio_2021	0.432066	0.477838	0.44286	0.639137	0.268439
SPRratio_2020	2.62E-04	9.33E-05	3.56E-04	7.79E-08	0.54011
Number of parameters	165	165	64	63	61
AIC	3478.84	2469.02	3519.64	3832.68	1669.88
Mohn’s rho AFSC (10yrs)					0.519

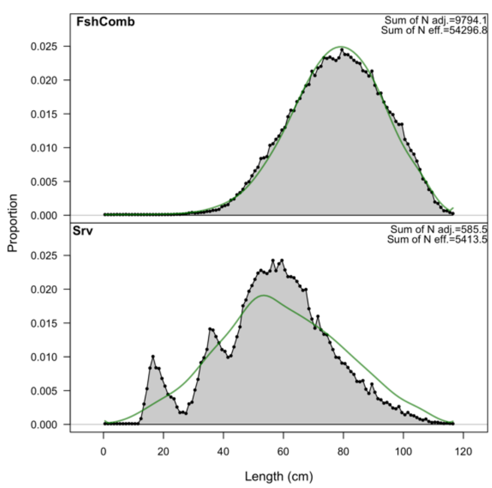
Label	M23.0a	M23.1	M23.1a	M23.2	M23.3
TOTAL_like	774.061	727.186	727.189	943.501	628.675
Survey_like	1.30122	-8.83941	-8.79928	-11.451	-17.5648
Length_comp_like	174.01	138.334	138.275	351.762	114.408
Age_comp_like	599.721	596.335	596.344	600.759	523.373
Parm_priors_like	0.0884051	0.0838087	0.0854849	0.0752557	0.0307601
Size_at_age_like					
Recr_Virgin_millions	35.5337	37.1923	37.707	219.9	36.202
SR_LN(R0)	10.4782	10.5239	10.5376	12.3009	10.4969
SR_BH_steep	1	1	1	1	1
NatM_uniform_Fem_GP_1	0.4	0.39784	0.4	0.669808	0.388569
L_at_Amax_Fem_GP_1	114.775	115.978	116.055	122.054	127.759
VonBert_K_Fem_GP_1	0.201477	0.194652	0.194347	0.161414	0.153315
SSB_Virgin_thousand_mt	151.723	160.548	160.316	161.168	153.338
Bratio_2021	0.264313	0.28327	0.284009	0.568952	0.278623
SPRratio_2020	0.554001	0.553108	0.551007	0.212738	0.584294
Number of parameters	60	158	157	162	254
AIC	1668.122	1770.372	1768.378	2211.002	1765.35
Mohns Rho AFSC (10yrs)	0.423	0.303	0.307	0.185	0.230

Table 2. Models presented here included changes to survey CAAL (conditional age-at-length), survey mean length-at-age, ISS (improved bootstrap input sample size of survey length- and age-compositional data), time varying fishery selectivity (TV), TV survey selectivity, changing size selectivity parameters for survey length composition similar to EBS model M23.0.1.a, phasing (growth in phase 2, selectivity in phase 3), fixing natural mortality (M) to 0.4, and incorporating two surveys; trawl and longline, and adding time varying growth.

					base	4.7	4.6	4.8		
Model number	22.0	22.0a	22.0f	22.0h	23.0	23.0a	23.1	23.1a	23.2	23.3
CAAL		X			X	X	X	X	X	X
Mean length@age	X		X		X	X	X	X	X	X
ISS					X	X	X	X	X	X
Fish. Selectivity TV	X	X					X	X		X
Survey sel. TV	X	X								
Size sel. Params.				X						
Phasing					X	X	X	X	X	X
M fixed at 0.4						X		X		
Longline survey									X	
Growth TV										X

Figure1. Fit to survey length frequencies M23.0 aggregated across time for the fishery and the survey.

a. M22.0



b. M23.0

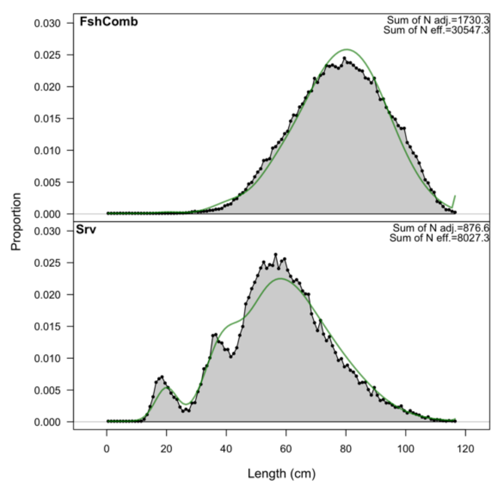
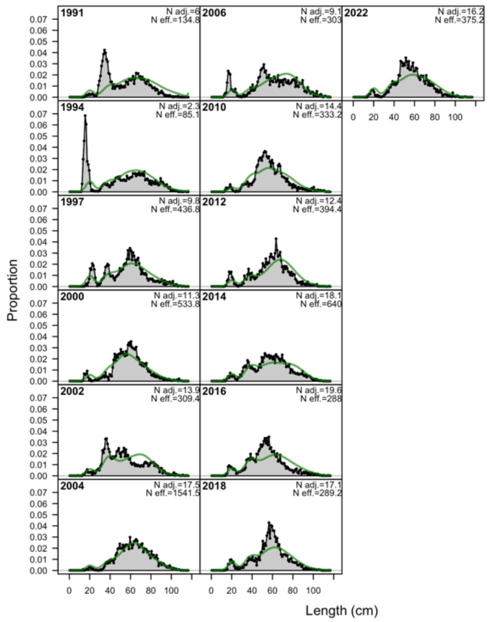
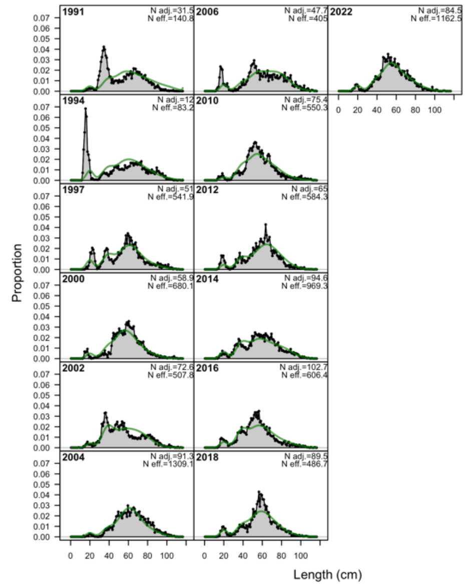


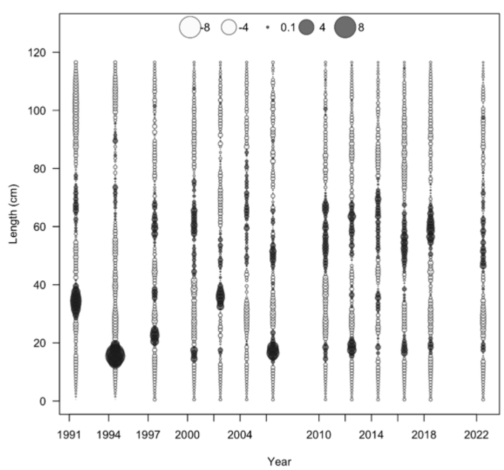
Figure 2. Fit to survey length frequencies M22.0 (panel a.) and M23.0 (panel b.) by year (trawl survey). Lower row shows pearson residuals [Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected)].

a. M22.0



b. M23.0





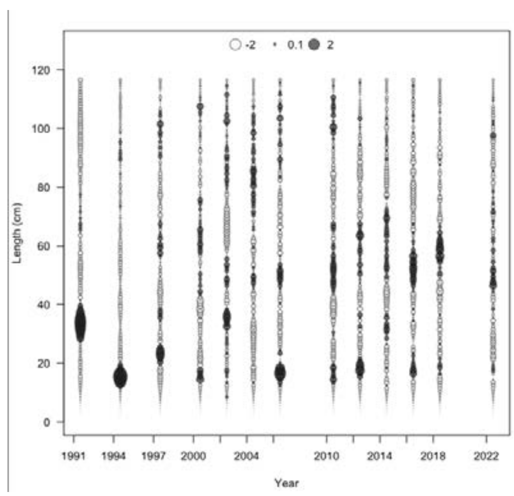
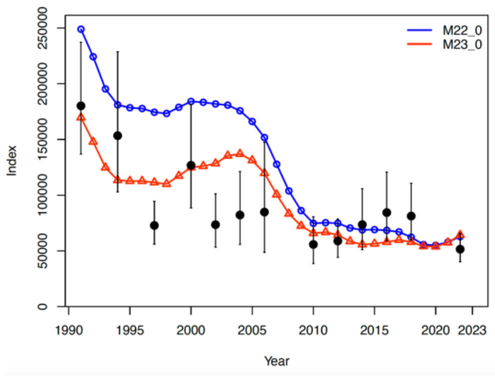
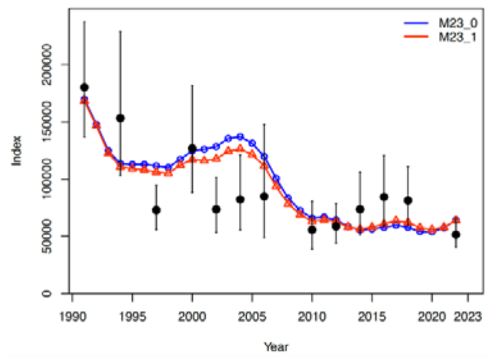


Figure 3. Fit to survey index for Model 23.0 compared to Model 22.0.

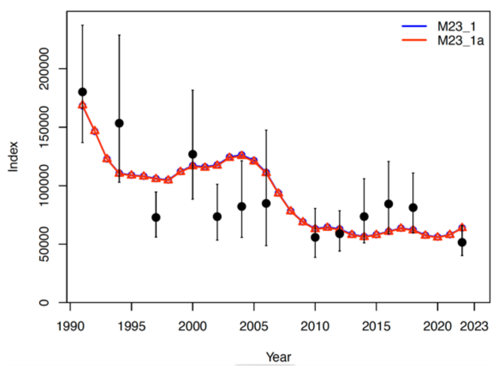
a. M23.0 vs. M22.0



b. M23.0 vs. M23.1



c. . M23.1 vs. M23.1a



d. M23.1 vs. M23.3

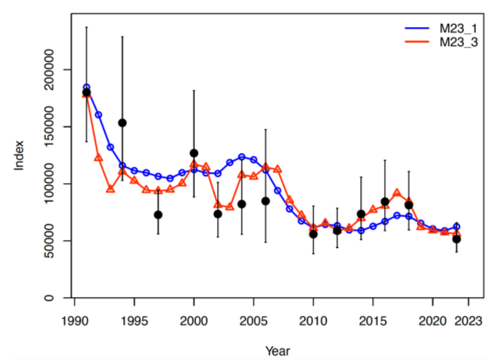
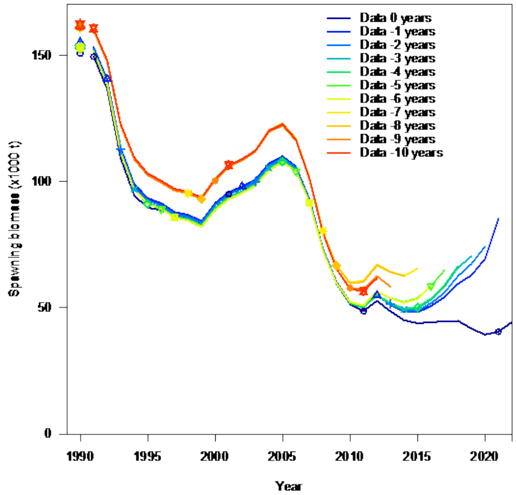
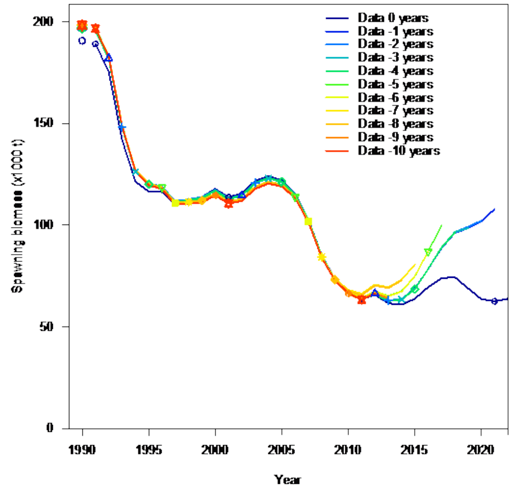


Figure 4. Retrospective plot of spawning biomass for Model 23.0 (panel a.) and 23.1 (panel b.).

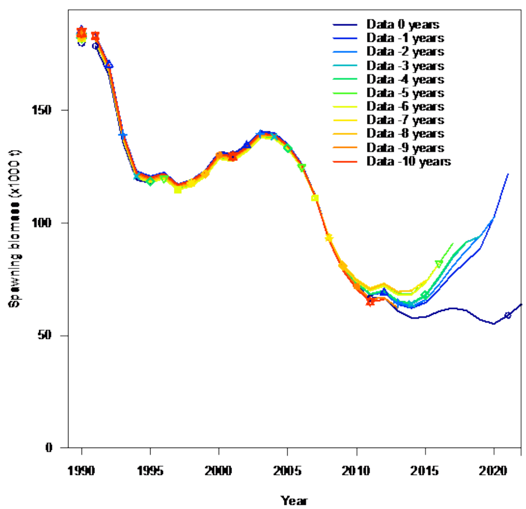
M23.0



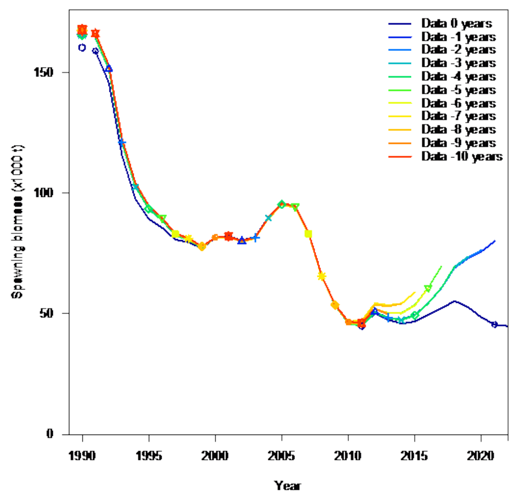
M23.1



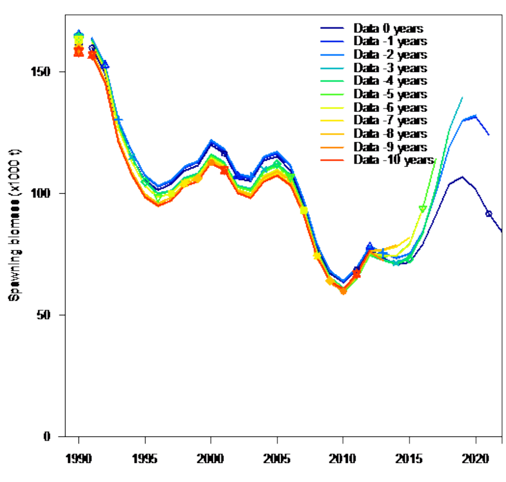
M23.0a



M23.1a



M23.2



M23.3

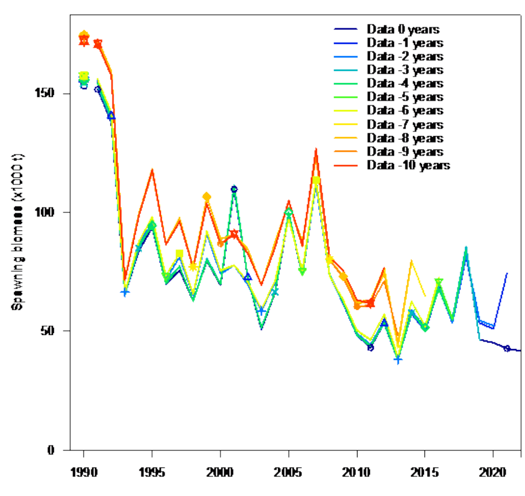
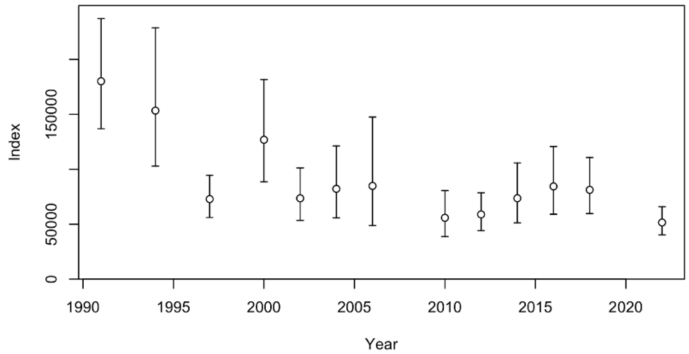
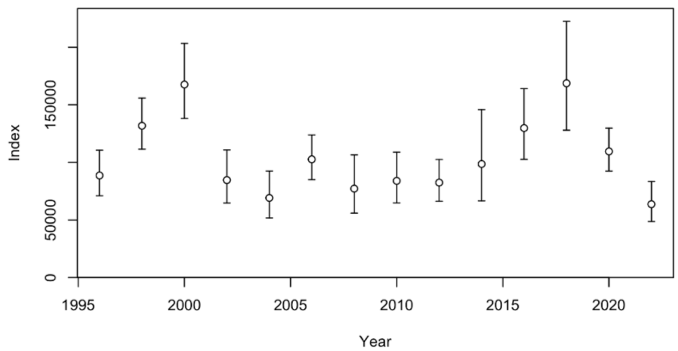


Figure 5. Survey index for the Aleutian Islands trawl survey (left) and longline survey (right).

Trawl survey index



Longline survey index



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Appendix (SSC comments)

This section is provided for reference. Direct responses will be made in the full assessment.

SSC Dec. 2022

The SSC supports the PT and author recommendation for continued use of the Tier 5 assessment approach in 2022, due to strong positive retrospective pattern in both age-structured model variants 22.0 (Mohn's rho: 0.316) and 22.1 (Mohn's rho: 0.252), which highlight a history of overly optimistic projections for increasing abundance. The SSC also notes that both Tier 3 age-structured models exhibit a positive bias in their fit to the AI bottom trawl survey, for the period prior to and including 2014. **The SSC supports the PT and authors' recommendation to use the Tier 5 random effects model for 2023 harvest specification, and associated OFLs and ABCs, with no reduction from the maximum permissible ABC.**

The SSC supports the PT recommendation for continued efforts to develop a viable age-structured assessment model framework for this stock and retaining the annual assessment cycle at this time. However, the SSC encourages the authors and PT to consider whether this stock might be a viable candidate for reduced assessment frequency given the timing of available survey information and the opportunity for more model development in off-cycle years.

The SSC notes that the majority (65.8%) of harvest is taken during the January-April spawning season while fish are aggregated, during which the majority of harvest comes from trawl (40.5%) and pot (58.3%) gears. However, the fishery length composition data are collected primarily from the longline and trawl fleets. The SSC encourages the authors to work with the observer program to identify whether it is possible to collect additional length composition data from the pot fleet to ensure representative composition samples are available to inform continued development of fleet-disaggregated models such as 22.1. Otherwise, the data may not support a fleet-specific model.

The SSC is encouraged by the authors' progress in developing age-structured models for this stock and offers the following suggestions for future development:

- If the fleet disaggregated model 22.1 is pursued in the future, the SSC encourages consideration of dome-shaped selectivity for the HAL fleet, given the observed differences in size compositions among fleets.
- If the fleet-aggregated model 22.0 is pursued in the future, the SSC encourages the authors to explore the potential for time-varying fishery selectivity as one option for addressing the retrospective pattern, and changes in fishing behavior and gear use over time.
- Given the uncertainty of the AI bottom trawl survey, a version of 22.0 that includes the AFSC longline survey and/or IPHC survey data could be a viable alternative

With respect to future use of the Tier 5 assessment method, the SSC supports the PT recommendation to consider a hybrid approach where the natural mortality estimated by a Tier 3 age-structured model is used for Tier 5 harvest specification.