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Preliminary assessment of the Pacific cod stock in the Aleutian Islands

Ingrid Spies, Maia Kapur, Steve Barbeaux, Melissa Haltuch, Pete Hulson, Ivonne Ortiz, Sandra Lowe

September 19, 2024



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https://github.com/afsc-assessments/AI_PCOD/M24.0

https://github.com/afsc-assessments/AI_PCOD/M24.1

- SSC comments
- Model description
- Data
- Sensitivity testing
- Model diagnostics
- Forecasting
- Models for November



SSC comments



Selected SSC and Plan Team comments - 1

Plan Team September 2023: The Plan Team favors constraining M. They recommend M with a prior based on a reasonable approach.

Authors' response: Based on this suggestion, we have incorporated an externally estimated natural mortality, M, that was based on the same methodology used to calculate M for the eastern Bering Sea Pacific cod assessment model since 2023. We used $M = 0.417$ for Aleutian Islands Pacific cod. This methodology is described below.

SSC December 2023: The SSC recommends a sensitivity analysis and a possible prior on M. It is surprising that estimating M was difficult in the data-rich EBS Pacific cod assessment, but estimating M in the AI cod assessment was successful with fewer data points. The SSC encourages further collaboration among authors of the three cod assessments with regard to the treatment of M.

Authors' response: Based on further collaboration among authors of the three cod assessments with regard to the treatment of M, we have fixed the base value of M in the AI cod assessment at 0.417. A sensitivity was performed (Table 1) and results are discussed below.



Selected SSC and Plan Team comments - 2

SSC December 2023: There were three parameters for natural mortality (M) where only two were required. This is confusing and might have influenced the model results in ambiguous ways that were not fully described in the document. Standard practice would be to estimate two lognormal parameters for the two M blocks.

Authors' response: The M timeblock in Model 24.1 is now estimated as suggested.

SSC December 2023: Similarly, there were three parameters estimated for time varying growth where only two were required. In addition, the author presented a slide showing almost identical growth coefficients for time varying kappa in two periods, suggesting that time-varying growth may not be needed.

Authors' response: Time-varying growth was removed from the model.



Selected SSC and Plan Team comments - 3

SSC December 2023: The SSC recommends that the authors present a simplified version of the original September 23.0 model with minimal time varying parameters alongside a preferred model or set of models in September 2024.

Authors' response: Based on this comment, Model 24.0 is provided which represents a simplified version of the September 23.0 model.



Selected SSC and Plan Team comments - 4

SSC December 2023: In the ESR, the need for an indicator of winter bottom temperature during spawning was noted, possibly derived from winter fisheries data, to assess potential detrimental effects of high temperatures in the AI on spawning and egg survival.

Authors' response: The ESR group indicated that reliable bottom temperatures in the Aleutians in winter is difficult. The ROMS model does not capture the Aleutians, which would require observational data, which is infrequent and may not be properly calibrated.

For the future, the marine mammal laboratory at AFSC has placed a mooring at Unimak Pass for 3 years which could provide bottom temperature throughout the year. This data is not available currently. In addition, bottom temperatures in some regions remain relatively constant year round so that summer data could serve as a potential indicator.



Model description



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Models for 2024

Age structured models (SS3):

- Model 24.0: Base model.
- Model 24.1: Timeblock on natural mortality from 2016 - 2024.

Tier 5 random effects model:

- Model 13.4: Base model.
- Model 24.2: Incorporates $M = 0.417$ estimated externally.



Data



Age structured models - Changes in input data

Catch: Complete data for 2023, 2024 through August 14*.

Fishery size compositions: Complete for 2023, 2024 preliminary through August 14.

Survey: No new survey data, but 2024 data will be added for November assessment.

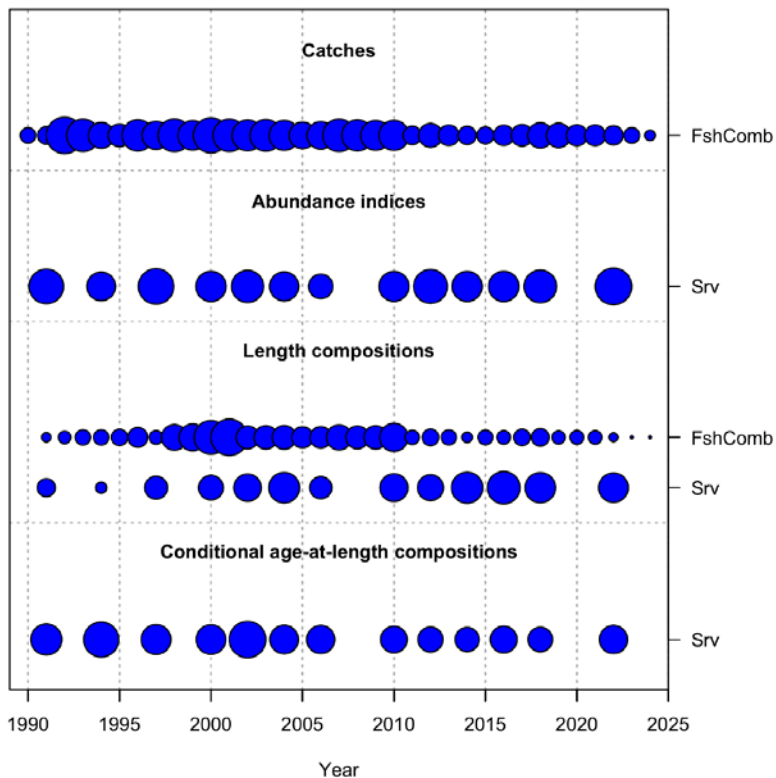
*Current year's catch projected for full year based on proportion caught over past 5 years.



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Age structured models - Data sources and relative weight

Source	Type	Years
Fishery (Trawl, Pot, LL)	Catch biomass	1991-2024*
Fishery (Trawl, Pot, LL)	Length composition	1991-2024
AI bottom trawl survey	Biomass estimate + Length composition	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018, 2022
AI bottom trawl survey	Age composition	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018, 2022

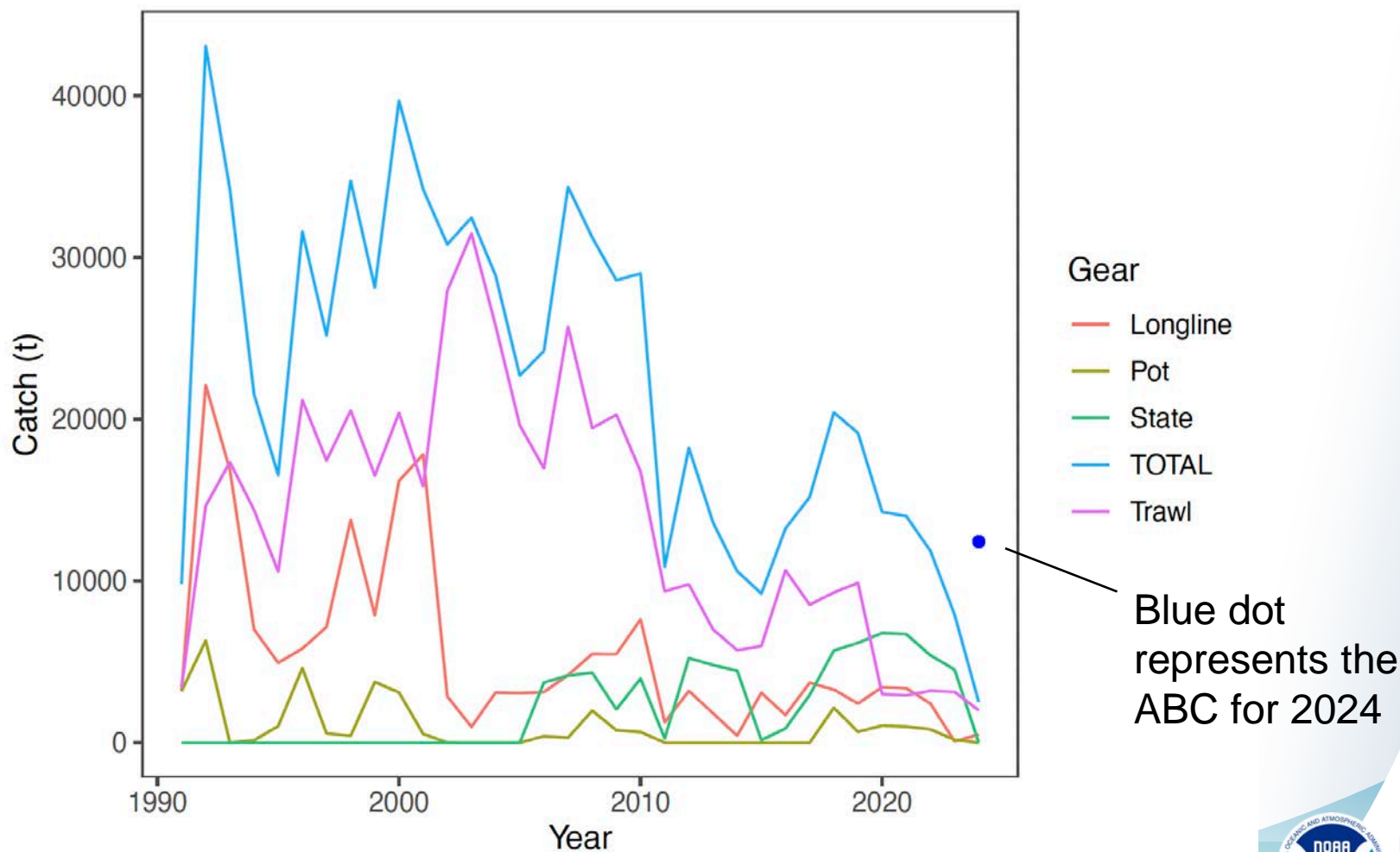


*Data current through August 14, 2024



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Aleutian Islands Pacific cod catch history, with federal catches by gear type, from 1991-2024 (through August 14)



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Tier 5 model - Changes in the input data

Survey: No new survey data, but 2024 data will be added for November assessment.



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Age-structured models - features consistent with the 2023 models:

- Single sex model, 1:1 male female ratio.
- Survey age and length data were input as conditional age-at-length.
- Recruitment estimated as a mean with lognormally distributed deviations.
- Maturity-at-age was estimated externally using observer data, then input into the model.
- Single-fleet fishery that combines trawl, longline, and pot fishery data, weighted by quarter, gear, and NMFS area, from 1991 - current year (through August 14).
- Survey and fishery selectivity were modeled as logistic and constant over time.



Age-structured models - Changes in the assessment methodology

- All parameters were constant over time except for the natural mortality timeblock in Model 24.1.
- The time of settlement was changed: larvae settle as juveniles in the same year as spawning, rather than in the following year.
- Initial fishing mortality was estimated within the model.
- Natural mortality was estimated externally, EXCEPT
- The timeblock on natural mortality from 2016-2024 (Model 24.1) estimated a single value.
- A Richards growth curve was estimated within the model (previously von Bertalanffy).
- Maximum age was changed from 10⁺ to 13 years.
- Fishery length composition extended to max = 143 cm (previously 117⁺ cm).

Sensitivity testing



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Natural mortality

- Based on SSC and Plan Team comments, we calculated M externally using the Then_Im method (<http://barefootecologist.com>).
- Analysis incorporates maximum age
 - EBS max age = 14, AI max age = 13.
- Aleutian Islands $M = 0.417$.
- Eastern Bering Sea $M = 0.387$.
- This M used unless otherwise specified.



Why Then_Im? Uses 'longevity' to estimate 'mortality'
Considered most informative (Cope and Hamel 2022)

Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species

Amy Y. Then^{1,2*}, John M. Hoenig¹, Norman G. Hall^{3,4}, and David A. Hewitt⁵

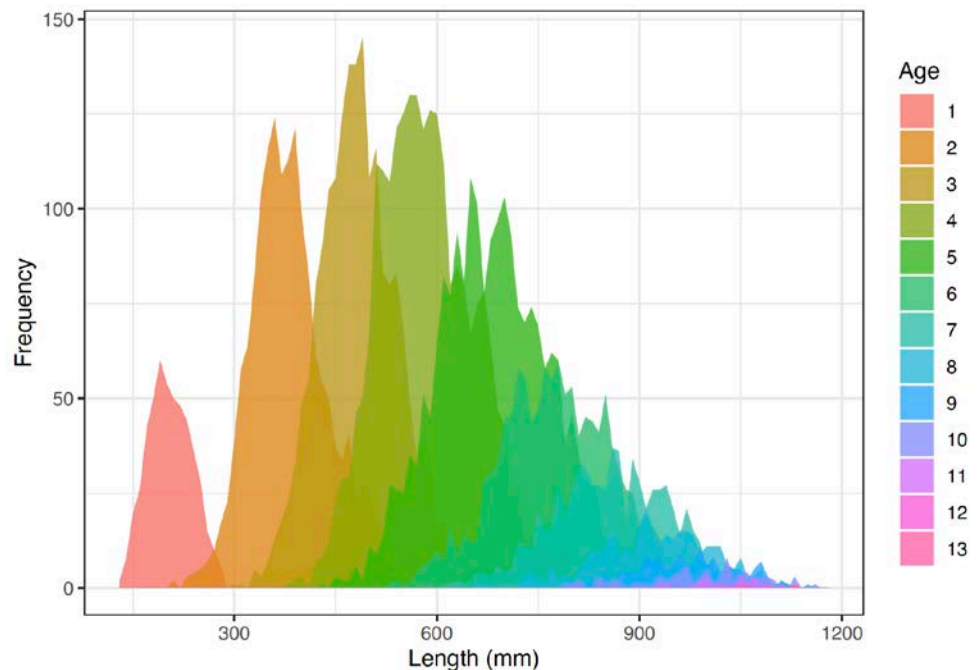


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Improving fit to growth curve

- Incorporated Richards growth curve rather than von Bertalanffy.
- Decreased the CV on the size of younger ages.
- Expanded age and length to represent the full distributions rather than plus groups.

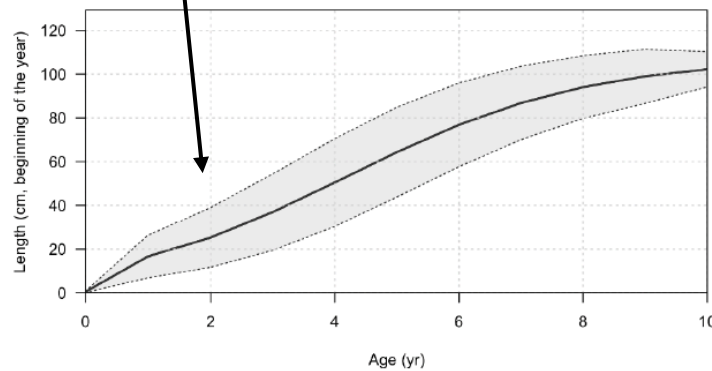
- Cod grow quickly and continue to increase in length.
- Length frequency by age of cod collected from Aleutian Island surveys 1991-2022



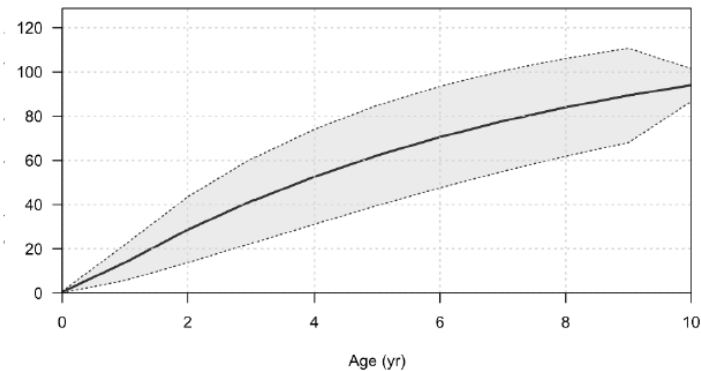
Growth curve

- The Richards growth curve adds an additional parameter.
- This allows for an inflection point between younger (age 2) and older cod (age 4+) that is not available in the von Bertalanffy.

Richards growth curve
Model 24.0F



Von Bertalanffy growth curve
Model 24.0G

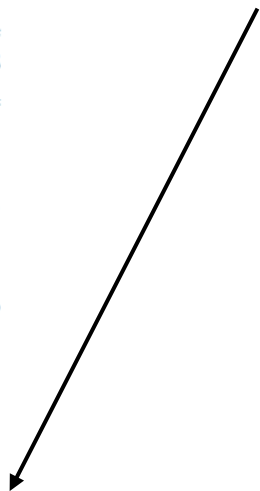
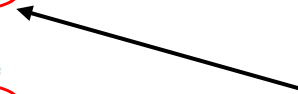


Growth curve

- Past models used the von Bertalanffy growth curve.
- The Richards growth curve improved the fit to the data.

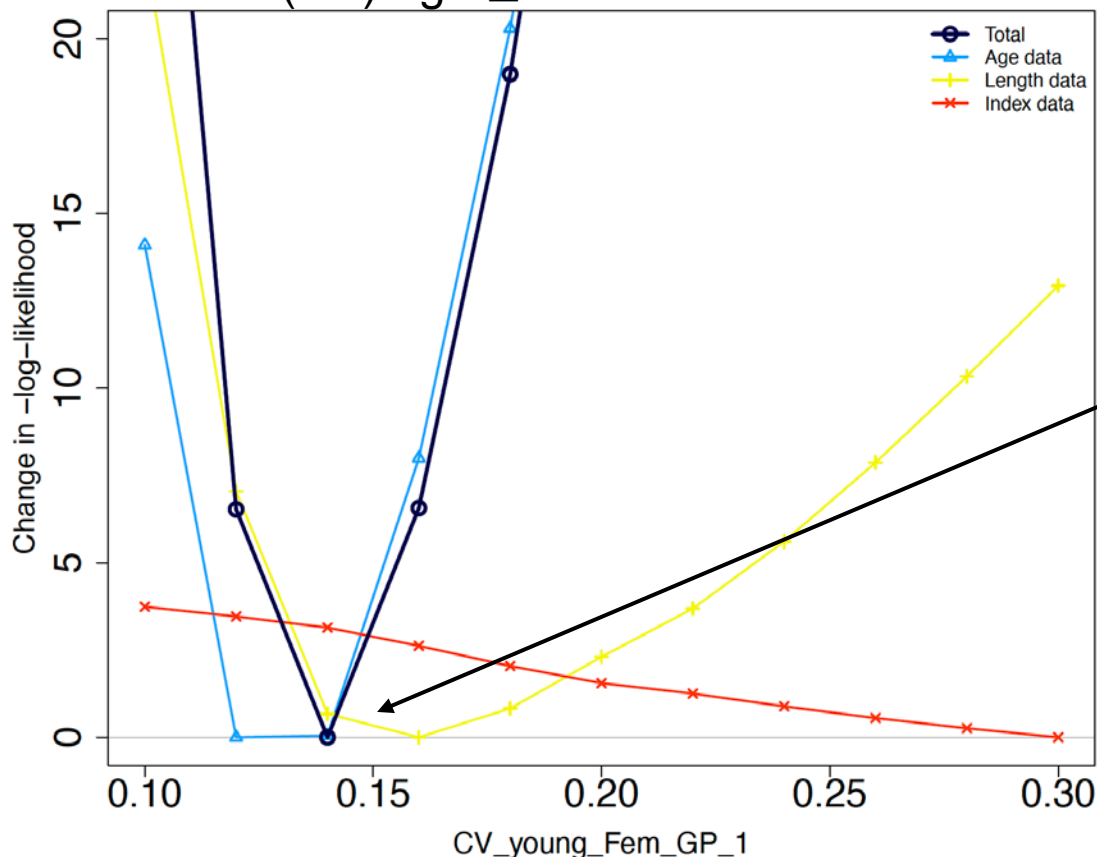
	Richards	Von Bertalanffy
Label	M24_0F	M24_0G
TOTAL_like	628.110	902.625
Survey_like	-9.997	-8.507
Length_comp_like	161.732	154.364
Age_comp_like	470.414	753.548
Recruitment_like_thousands	1.961	-1.182
Forecast_Recruitment_like	0.087	0.069
Recr_Virgin_millions	985.317	609.908
SR_BH_steep	1	1
Natural mortality	0.741	0.674
NatM_BLK2repl_2016	-	-
SmryBio_unfished	511,834	425,054
SSB_Virgin_thousand_mt	321.335	265.358
SSB_2024_thousand_mt	172.101	155.144
Bratio_2024	0.536	0.585
SPRratio_2024	0.031	0.031
Ret_Catch_MS_Y	121,098	120,801
SR_LN(R0)	13.801	13.321
Survey catchability (q)	0.368	0.406
Size_DblN_peak_FshComb(1)	97.635	115.995
Size_DblN_top_logit_FshComb(1)	25.000	25.000
Size_DblN_ascend_se_FshComb(1)	6.445	6.818
Size_DblN_peak_Srv(2)	70.589	76.957
Size_DblN_ascend_se_Srv(2)	6.297	6.641
Number of parameters	69	68
AIC	1394.22	1941.25
SS3 diags Runs test	passed	passed

Note improvements in age comp likelihood, total likelihood, and AIC



Likelihood profile over the coefficient of variation (CV) over growth curve younger ages

Likelihood profile over the coefficient of variation (CV) age ≤ 1



Mean length and CV over all ages

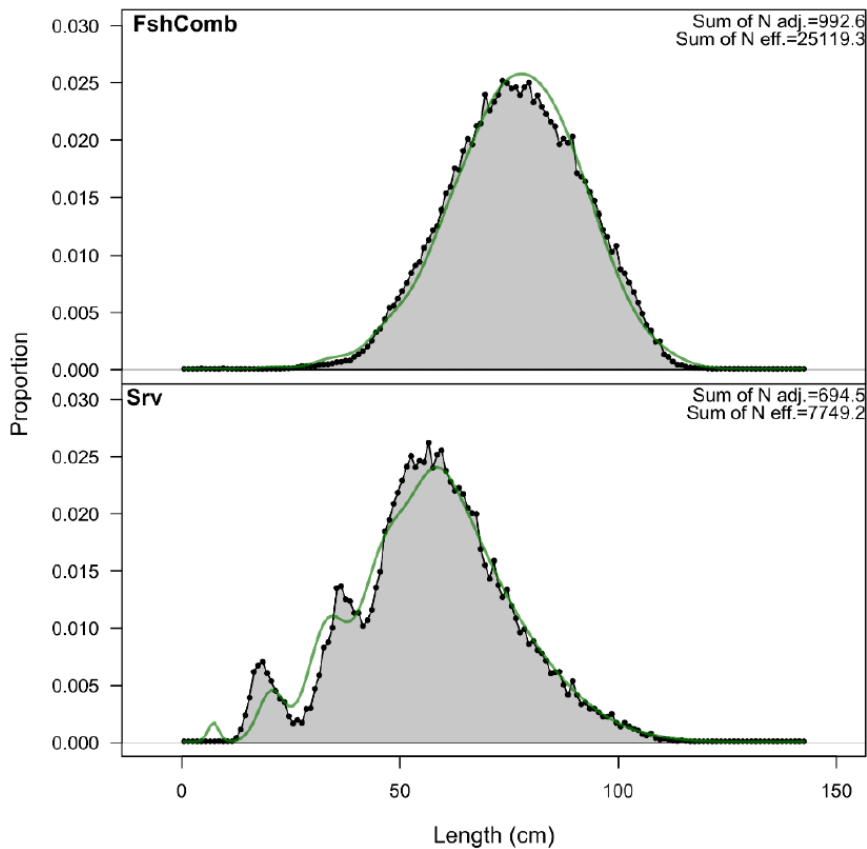
Age	1	2	3	4
Length (cm)	22.1	38.3	48.9	58.7
CV	1.71	1.2	1.2	1.28

Used CV = 0.16 as a compromise between estimates.

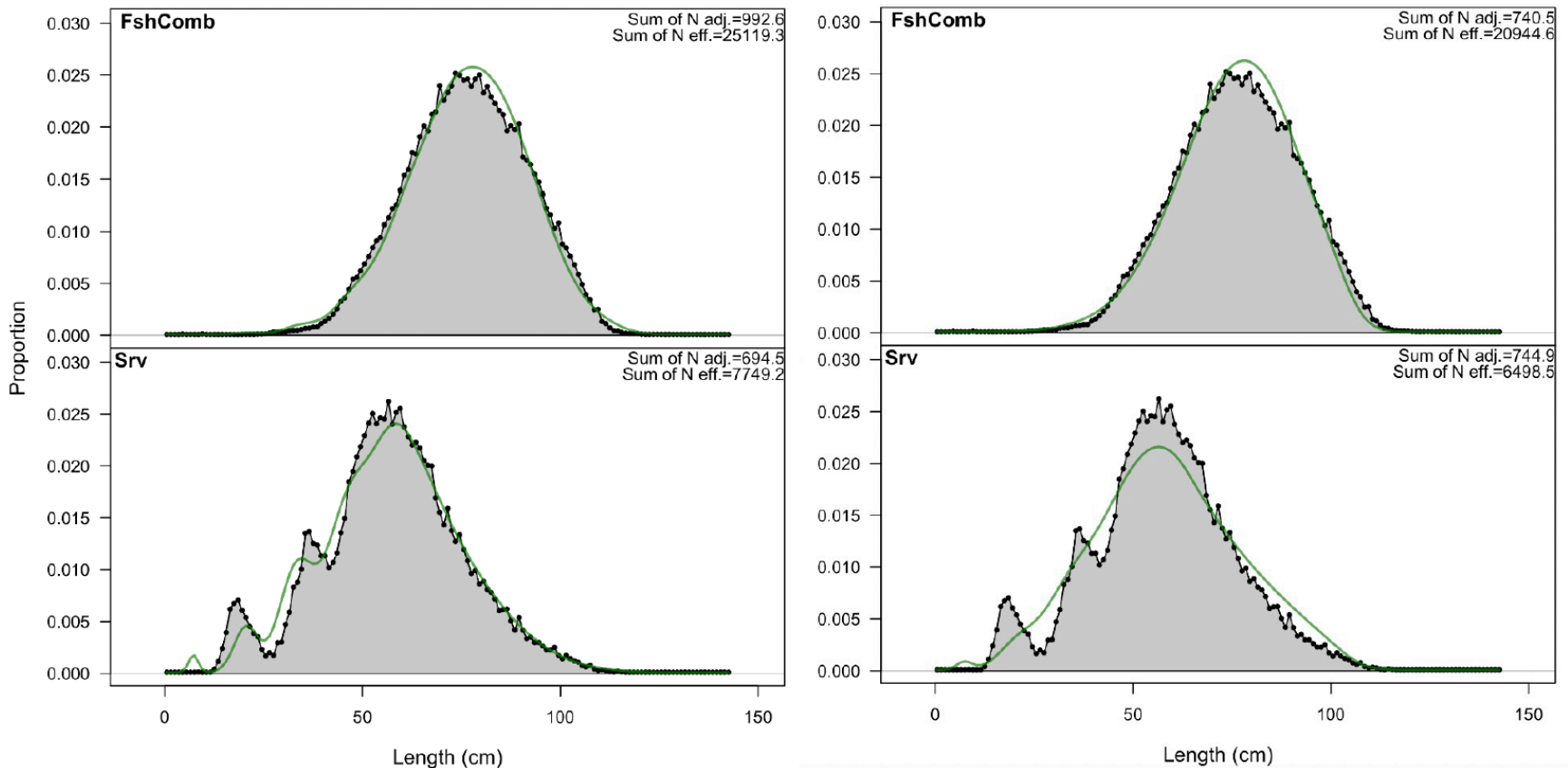
Smaller than 0.30 used previously.

Model fit to observed length frequencies for survey and fishery data, Model 24.1 (left) and 24.0A (right)

Model 24.1



Model 24.0A



Smaller CV age \leq 1 improves fit

CVage \leq 1
=0.16 =0.30

Label	M24_1	M24_0A
TOTAL_like	474.770	733.187
Survey_like	-8.281	-12.415
Length_comp_like	127.206	136.964
Age_comp_like	355.671	609.959
Recruitment_like_thousands	-1.171	-2.696
Forecast_Recruitment_like	0.036	0.015
Recr_Virgin_millions	87.177	94.990
SR_BH_steep	1	1
Natural mortality	0.417	0.417
NatM_BLK2repl_2016	0.579	0.604
SmryBio_unfished	268,675	278,043
SSB_Virgin_thousand_mt	219.259	232.091
SSB_2024_thousand_mt	49.215	54.053
Bratio_2024	0.224	0.233
SPRratio_2024	0.149	0.120
Ret_Catch_MSU	33,966	39,351
SR_LN(R0)	11.376	11.462
Survey catchability (q)	0.872	0.769
Size_DblN_peak_FshComb(1)	101.979	90.127
Size_DblN_top_logit_FshComb(1)	25.000	25.000
Size_DblN_ascend_se_FshComb(1)	6.658	6.378
Size_DblN_peak_Srv(2)	69.435	64.198
Size_DblN_ascend_se_Srv(2)	6.500	6.267
Number of parameters	73	73
AIC	1095.54	1612.374
SS3 diags Runs test	passed	passed

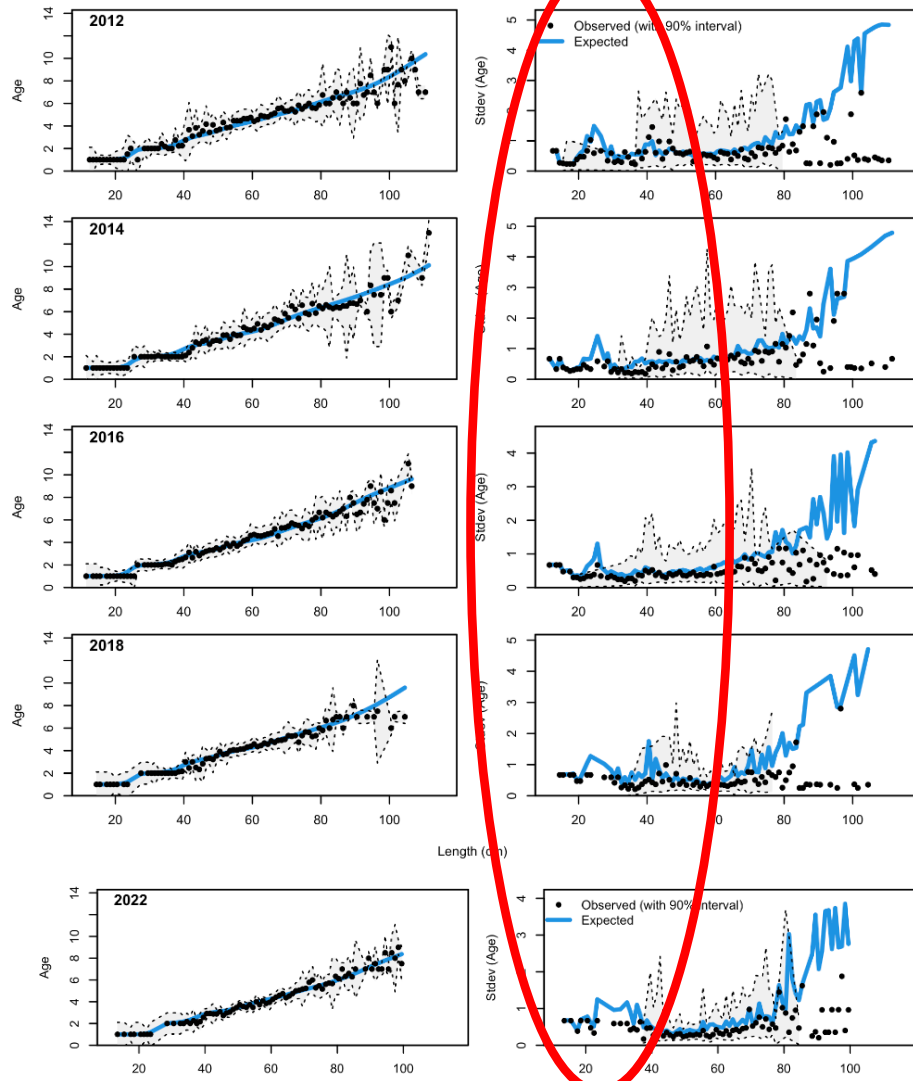
Note improvements in total likelihood, Length & age comp likelihood, and AIC



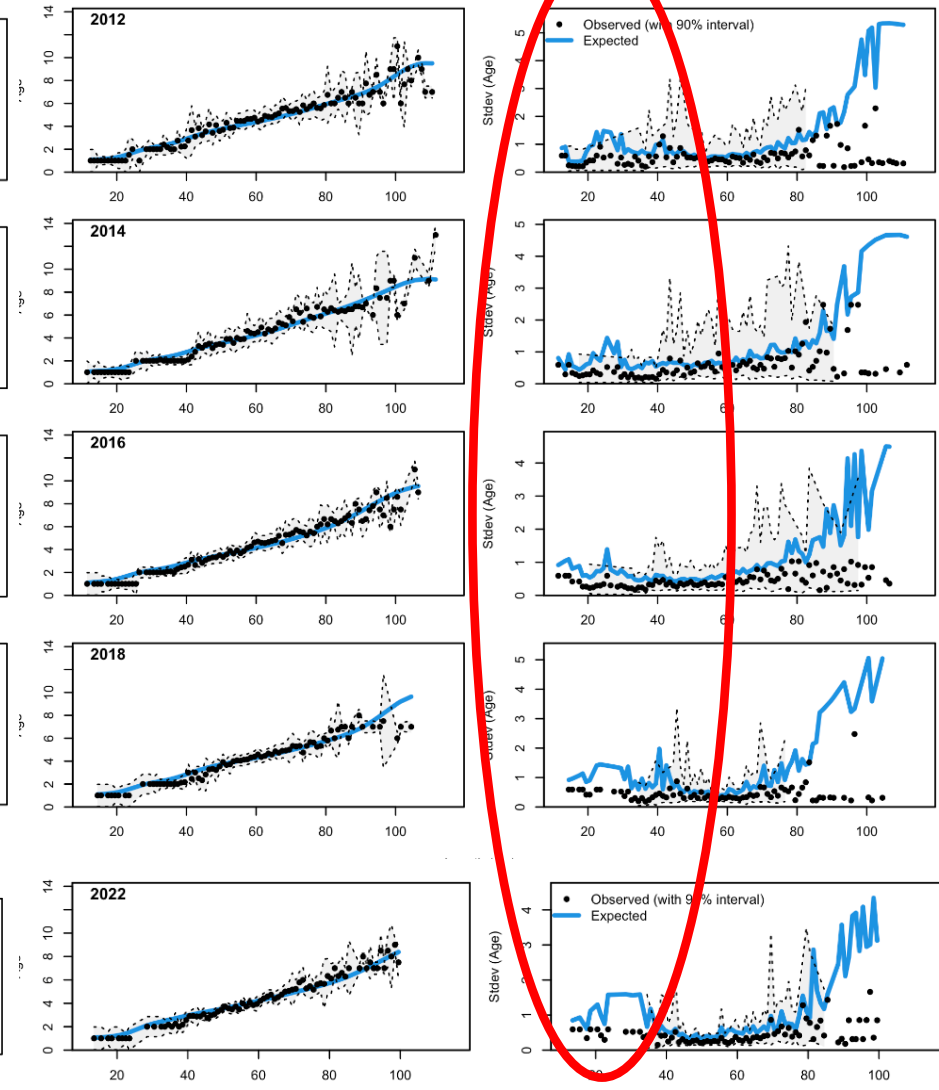
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Fit to conditional age at length improved with smaller CV

Model 24.1 (CV age $\leq 1 = 0.16$)

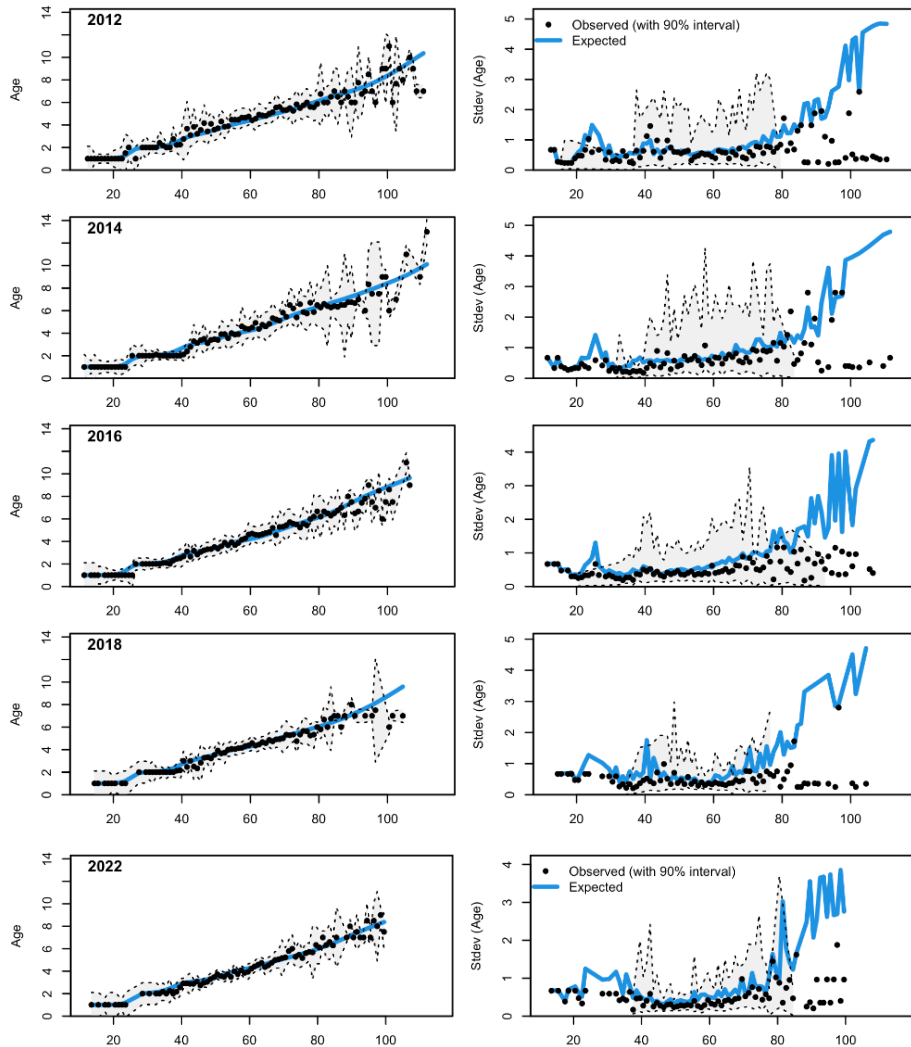


Model 24.0A (CV age $\leq 1 = 0.30$)

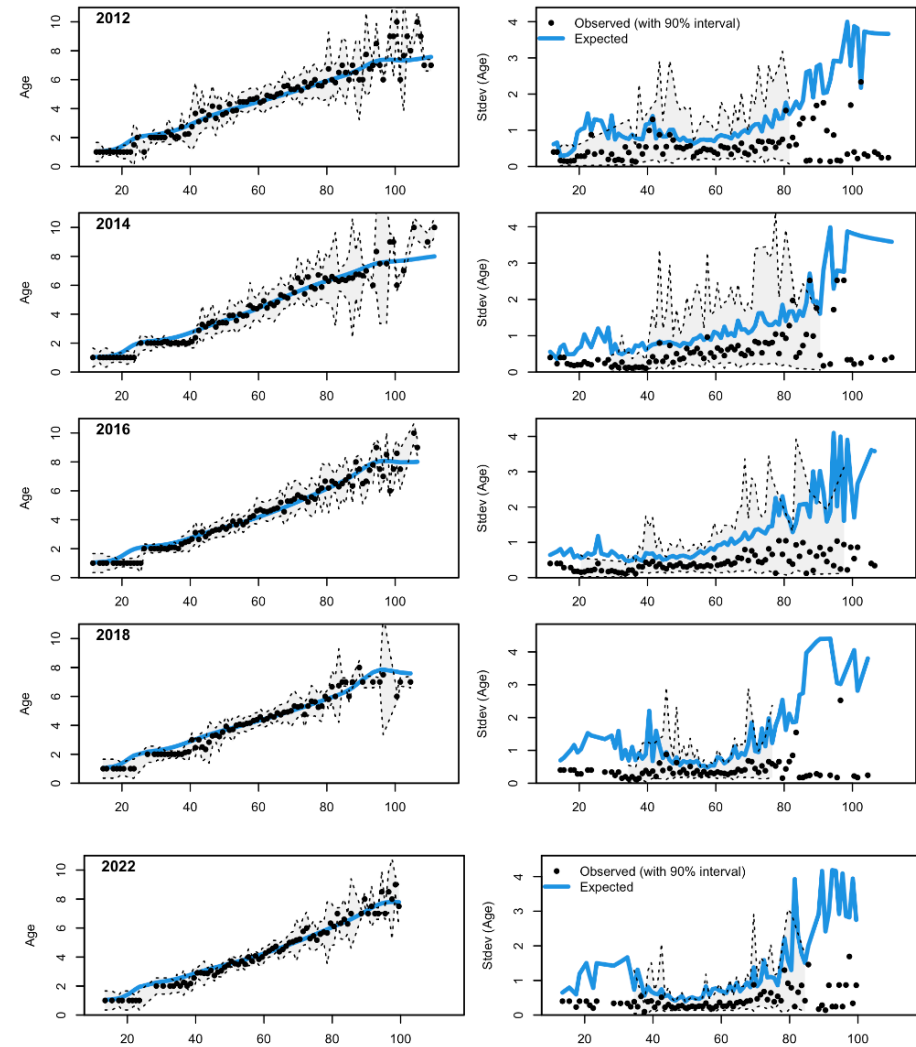


Fit to conditional age at length improved with Richards growth curve, reducing age ≤ 1 CV, full age, length comps

Model 24.1



Model 24.0G



Initial F - estimated based on the average catch from 1981-1990

Init F estimated No Init F

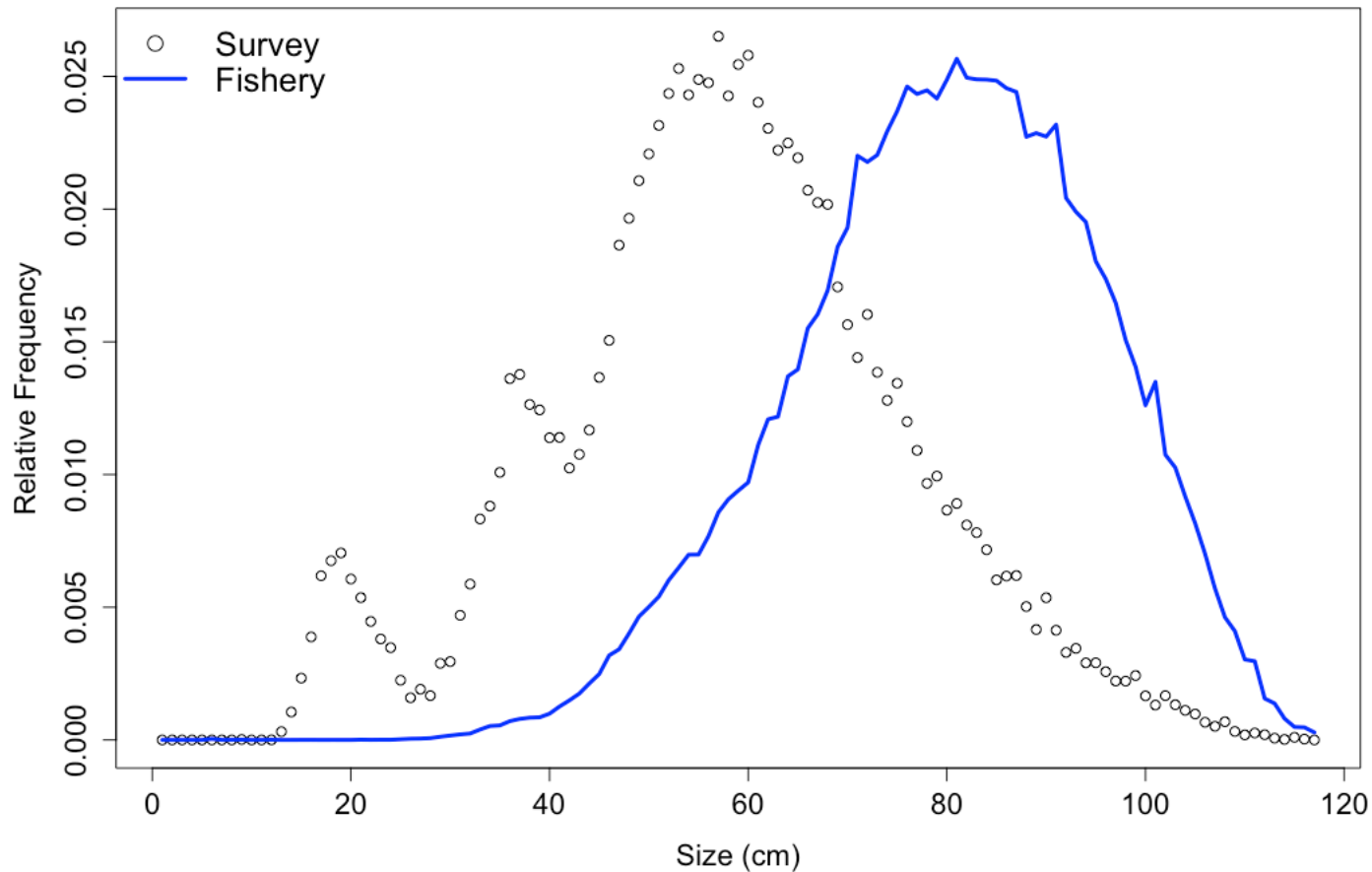
Label	M24_OD	M24_OE
TOTAL_like	735.480	743.955
Survey_like	-3.308	-3.280
Length_comp_like	184.074	184.217
Age_comp_like	550.428	554.867
Recruitment_like_thousands	2.610	2.445
Forecast_Recruitment_like	0.073	0.084
Recr_Virgin_millions	66.416	73.947
SR_BH_steep	1	1
Natural mortality	0.417	0.417
NatM_BLK2repl_2016	-	-
SmryBio_unfished	238,226	265,181
SSB_Virgin_thousand_mt	201.028	223.764
SSB_2024_thousand_mt	76.539	76.212
Bratio_2024	0.381	0.341
SPRratio_2024	0.125	0.125
Ret_Catch_MSU	34,416	38,303
SR_LN(R0)	11.104	11.211
Survey catchability (q)	0.857	0.854
Size_DbIN_peak_FshComb(1)	91.730	91.675
Size_DbIN_top_logit_FshComb(1)	25.000	25.000
Size_DbIN_ascend_se_FshComb(1)	6.441	6.440
Size_DbIN_peak_Srv(2)	63.928	63.905
Size_DbIN_ascend_se_Srv(2)	6.350	6.351
Number of parameters	69	68
AIC	1608.96	1623.91
SS3 diags Runs test	passed	passed

Note improvements in total likelihood, age comp likelihood, recruitment, and AIC



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Survey selectivity: length compositions suggest survey selectivity may be dome shaped



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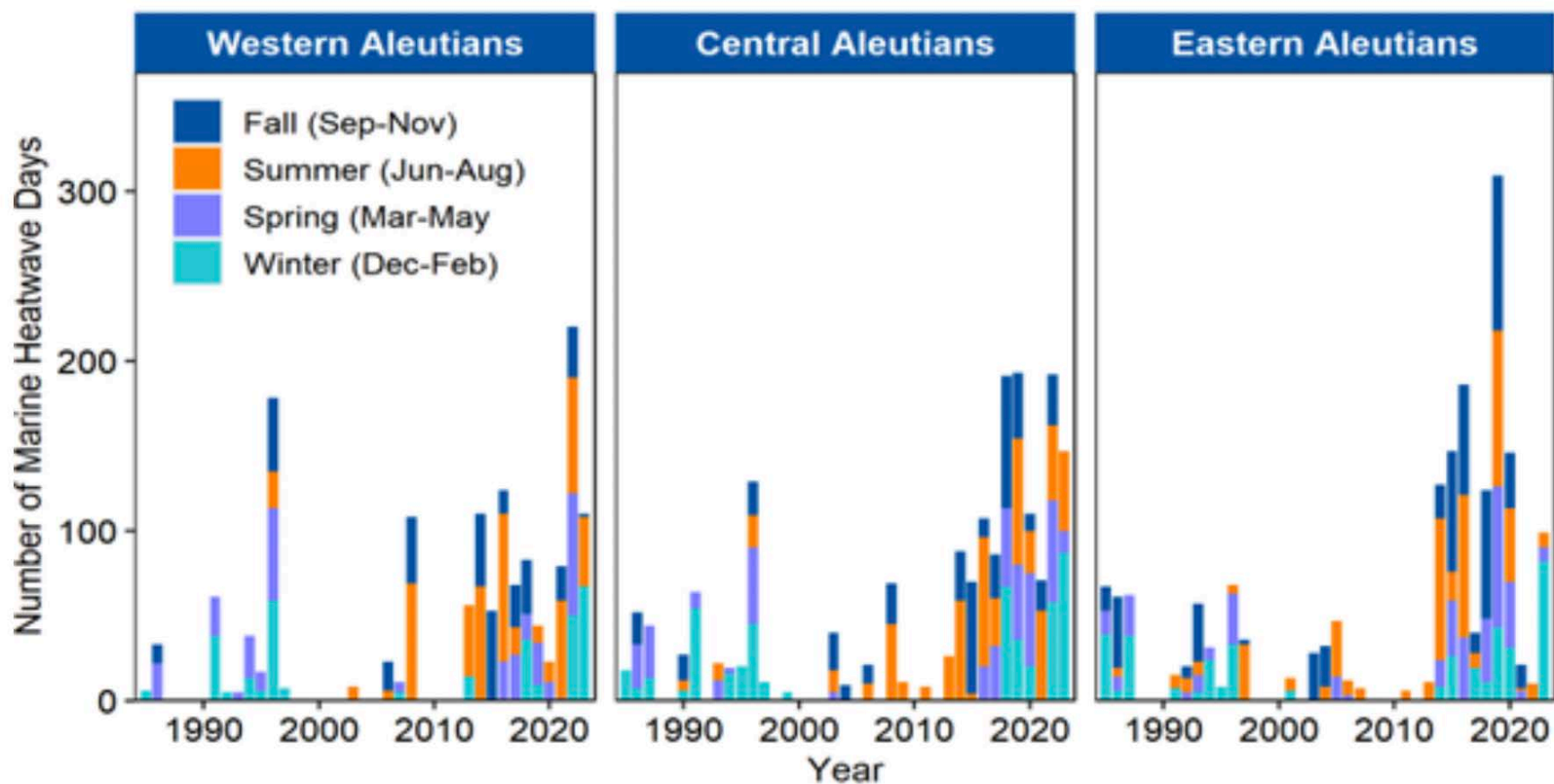
Selectivity – dome shaped is not an improvement

Survey selectivity Logistic | Dome shaped

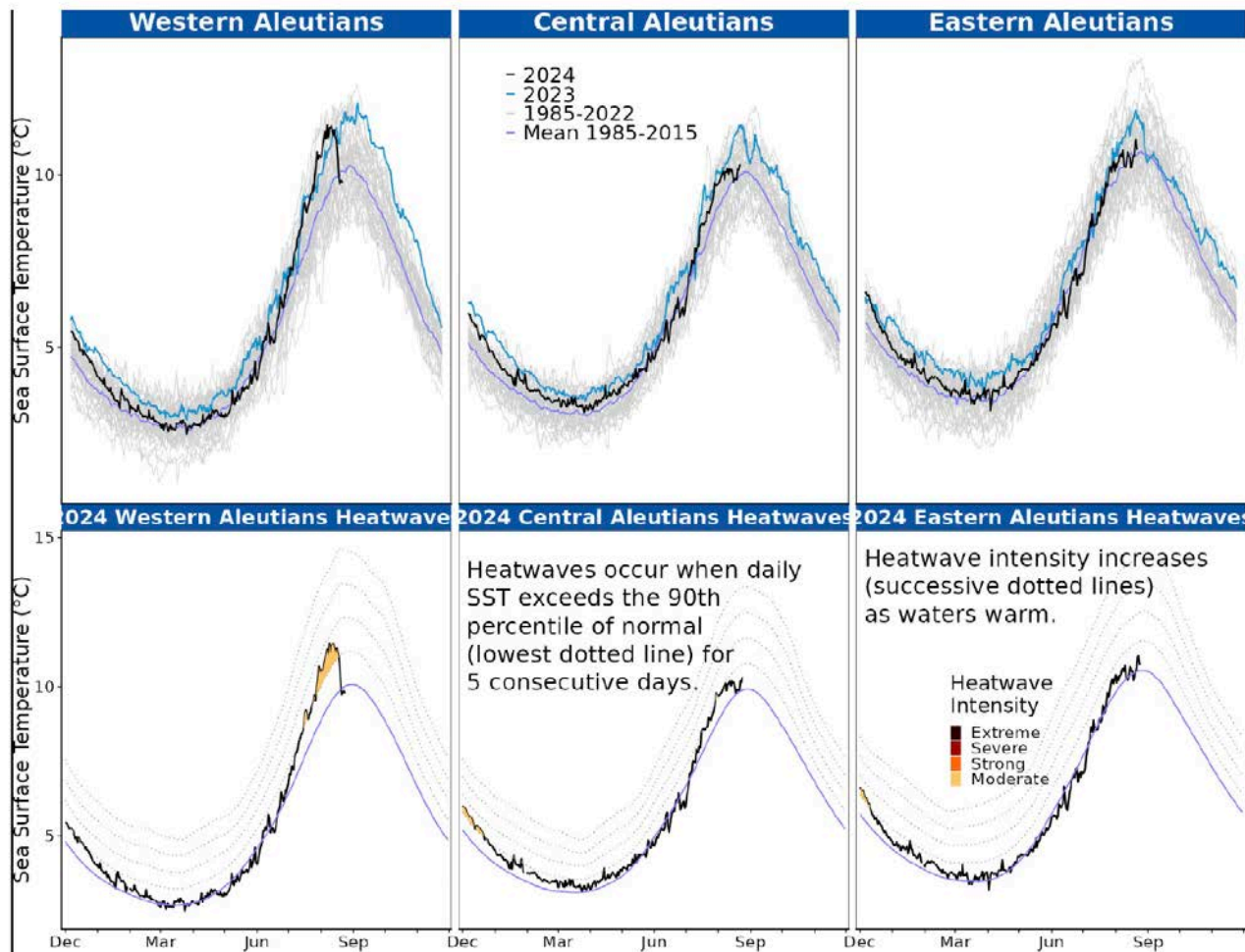
Label	M24_0B	M24_0C
TOTAL_like	696.616	727.079
Survey_like	-3.829	-6.708
Length_comp_like	162.235	146.185
Age_comp_like	537.925	589.337
Recruitment_like_thousands	-1.209	-3.887
Forecast_Recruitment_like	0.030	0.016
Recr_Virgin_millions	79.246	102.465
SR_BH_steep	1	1
Natural mortality	0.417	0.417
NatM_BLK2repl_2016	-	-
SmryBio_unfished	235,989	312,252
SSB_Virgin_thousand_mt	197.524	263.108
SSB_2024_thousand_mt	87.169	139.403
Bratio_2024	0.441	0.530
SPRratio_2024	0.115	0.075
Ret_Catch_MSY	33,647	42,657
SR_LN(R0)	11.280	11.537
Survey catchability (q)	0.743	0.597
Size_DbIN_peak_FshComb(1)	94.813	85.362
Size_DbIN_top_logit_FshComb(1)	25.000	25.000
Size_DbIN_ascend_se_FshComb(1)	6.554	6.252
Size_DbIN_peak_Srv(2)	62.791	60.635
Size_DbIN_ascend_se_Srv(2)	6.289	6.160
Number of parameters	72	73
AIC	1537.232	1600.158
SS3 diags Runs test	passed	passed

Note improvements
in total likelihood,
age comp likelihood,
and AIC

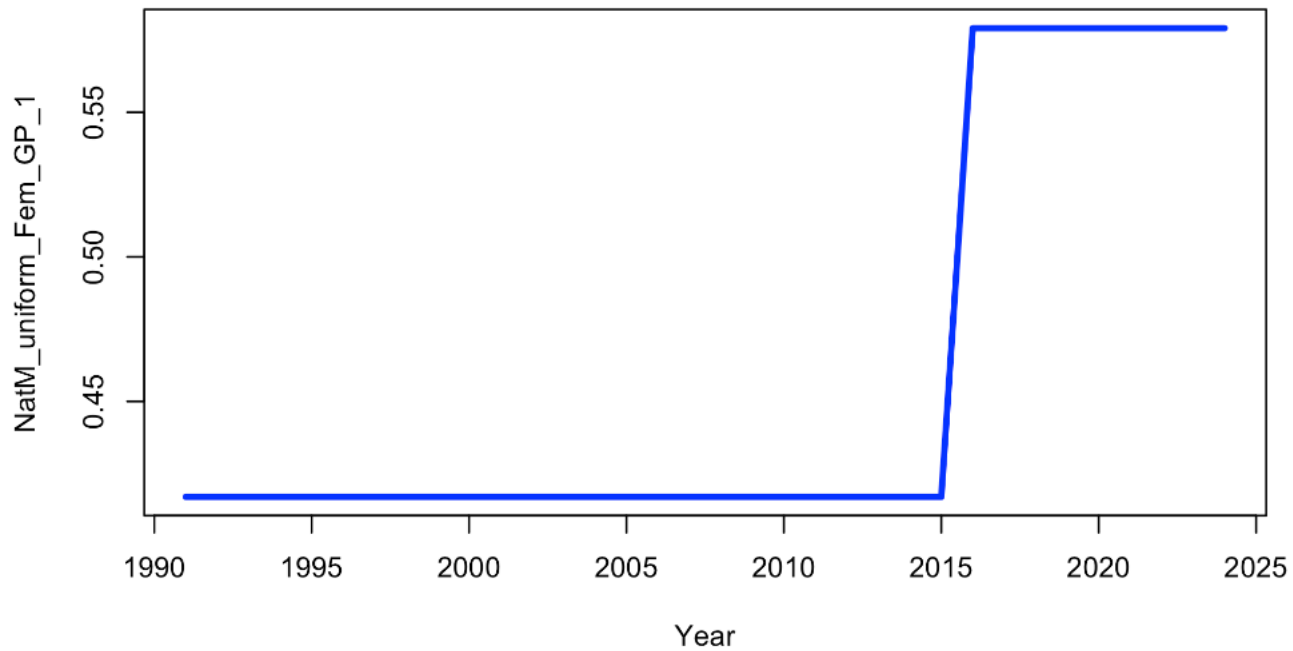
Natural mortality timeblock: The number of days under heatwave conditions for the western, central, and eastern Aleutian Islands has increased since 2014



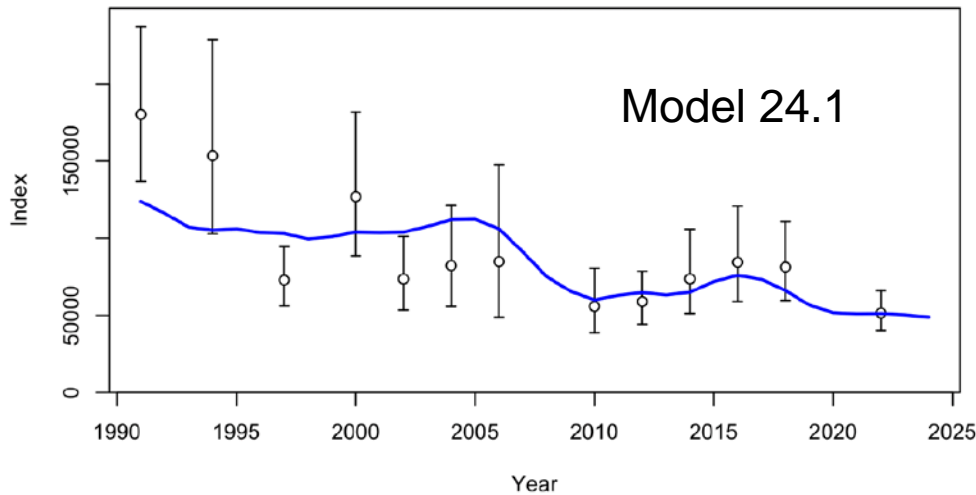
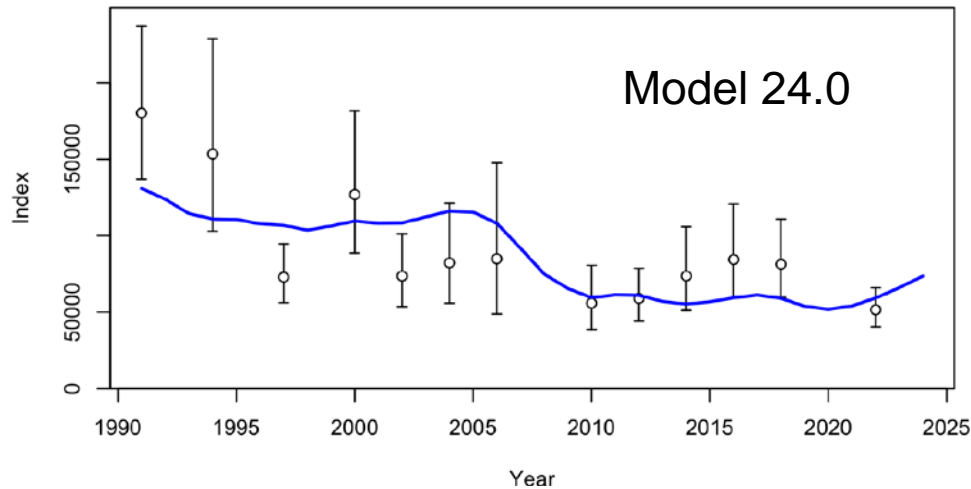
Natural mortality timeblock: In 2024 there were several short periods considered heatwave conditions in the Aleutian Islands, but less than in previous years



Natural mortality timeblock



Model 24.0 (upper panel) and Model 24.1 (lower panel) fit to survey index, 1991 - 2024

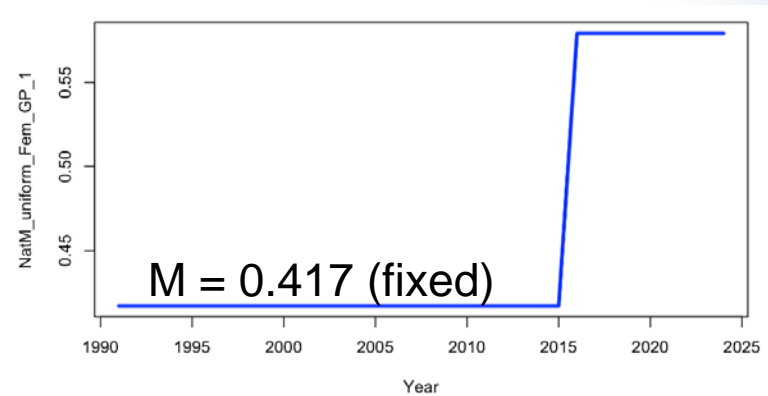


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Natural mortality timeblock improves multiple aspects of the fit to the data

Label	M24_1	M24_0
TOTAL_like	474.770	515.367
Survey_like	8.281	-4.043
Length_comp_like	127.206	122.324
Age_comp_like	355.671	395.581
Recruitment_like_thousands	-1.171	0.225
Forecast_Recruitment_like	0.036	0.060
Recr_Virgin_millions	87.177	73.347
SR_BH_steep	1	1
Natural mortality	0.417	0.417
NatM_BLK2repl_2016	0.579	-
SmryBio_unfished	268,675	226,176
SSB_Virgin_thousand_mt	219.259	184.541
SSB_2024_thousand_mt	49.215	64.959
Bratio_2024	0.224	0.352
SPRratio_2024	0.149	0.173
Ret_Catch_MS_Y	33,966	28,671
SR_LN(R0)	11.376	11.203
Survey catchability (q)	0.872	0.928
Size_DbIN_peak_FshComb(1)	101.979	103.989
Size_DbIN_top_logit_FshComb(1)	25.000	25.000
Size_DbIN_ascend_se_FshComb(1)	6.658	6.719
Size_DbIN_peak_Srv(2)	69.435	68.774
Size_DbIN_ascend_se_Srv(2)	6.500	6.539
Number of parameters	73	72
AIC	1095.54	1174.734
SS3 diags Runs test	passed	passed

M = 0.579 (estimated)



Note improvements in total likelihood, survey likelihood, age comp likelihood, recruitment likelihood age comp likelihood, and AIC



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Maturity curve

We will update the maturity curve with new data and filtered for stomach scan data (which can be mistaken for maturity data in OBSINT).

- $L_{50\%} = 54.9$ cm, and slope = -0.148.
- Reanalysis: $L_{50\%} = 55.5$ cm (95% CI :53.7 - 57.3), slope = -0.155.

There were 1,331 records previously, approximately 1,355 including current data.



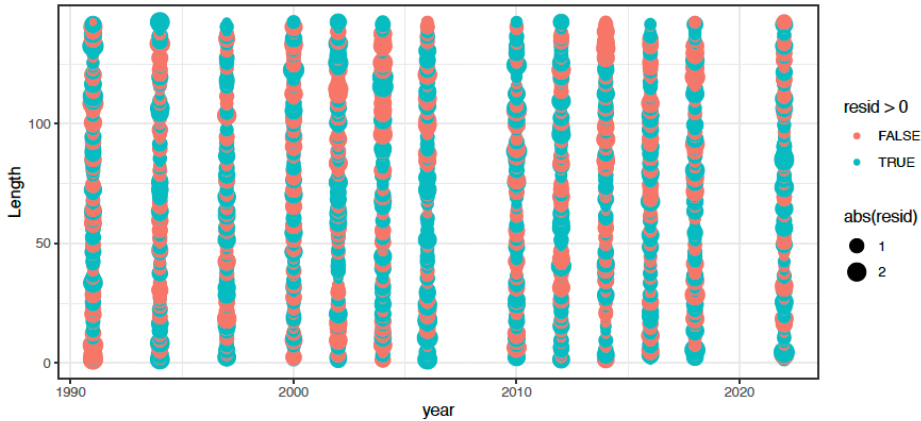
Model diagnostics



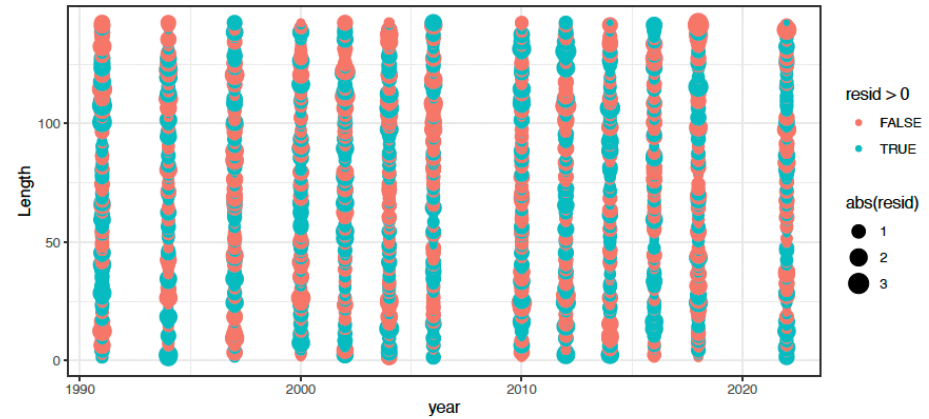
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One step ahead (OSA) and Pearson residuals for Model 24.0 (left) and Model 24.1 (right)

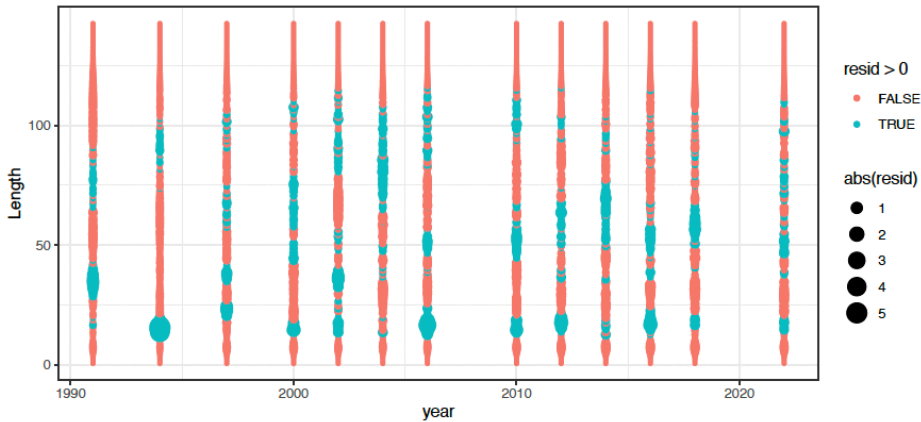
Model 24.0 OSA w/o Length 1



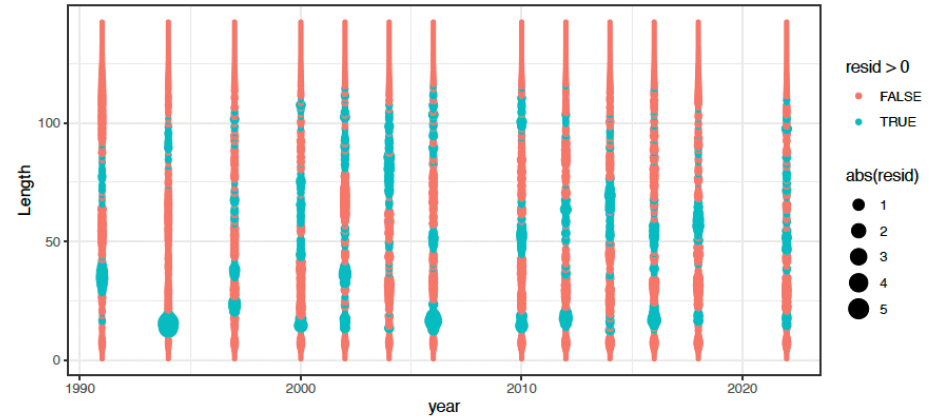
Model 24.1 OSA w/o Length 1



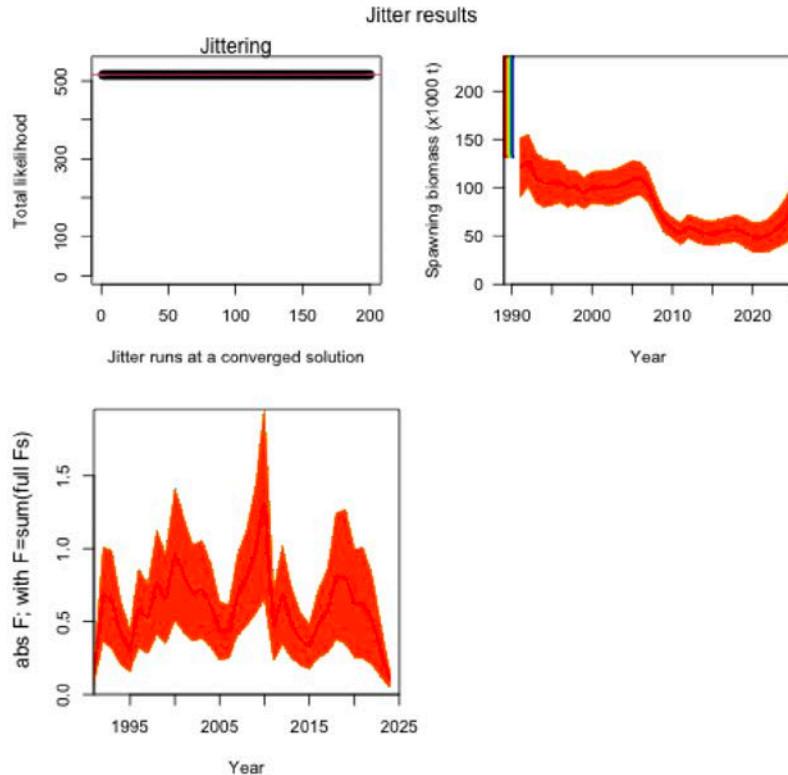
Pearson



Pearson

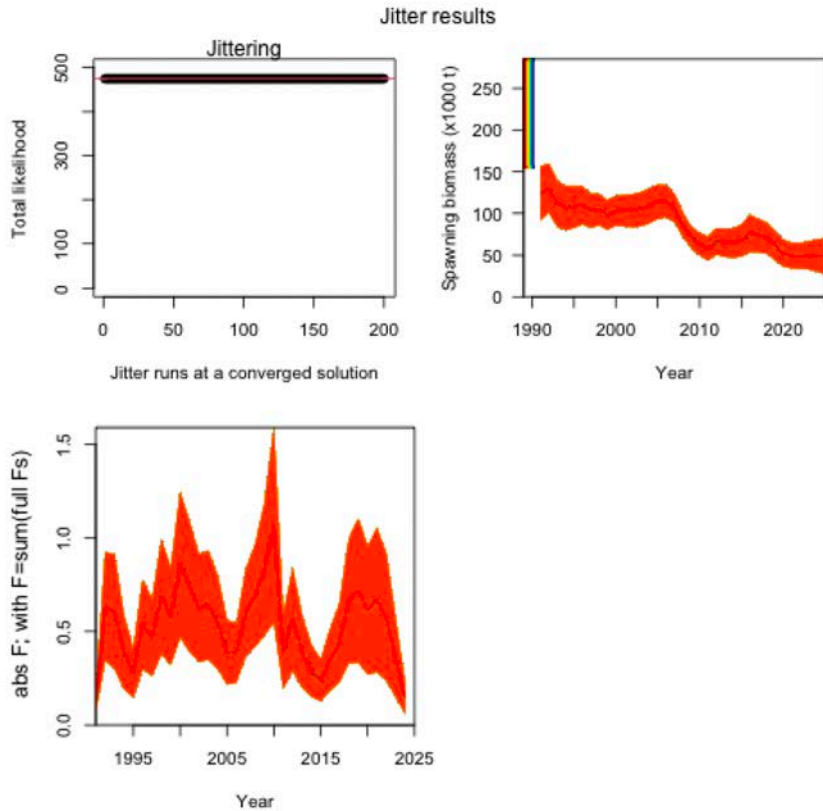


The Model 24.1 jitter diagnostic for global convergence conducted on the Aleutian Islands Pacific cod assessment.



- Upper left: solid black circles represent the total likelihood obtained from 200 jittered model runs and the red horizontal dashed line represents the total likelihood value from the base-case model.
- Upper right: spawning stock biomass (SSB) from jittered model runs.
- Lower panel: the estimate of absolute fishing mortality, F , with $F=\text{sum}(\text{full } F_s)$.

The Model 24.0 jitter diagnostic for global convergence conducted on the Aleutian Islands Pacific cod assessment.



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- Upper right: spawning stock biomass (SSB) from jittered model runs.
- Lower panel: the estimate of absolute fishing mortality, F , with $F = \text{sum}(\text{full } F_s)$.

Forecasting



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Forecasting

- Model 24.1 forecasts performed using the base value of natural mortality from 1991-2015, 0.417.
- Forecasting using the mean natural mortality would result in very high harvest rates.



2024 survey results



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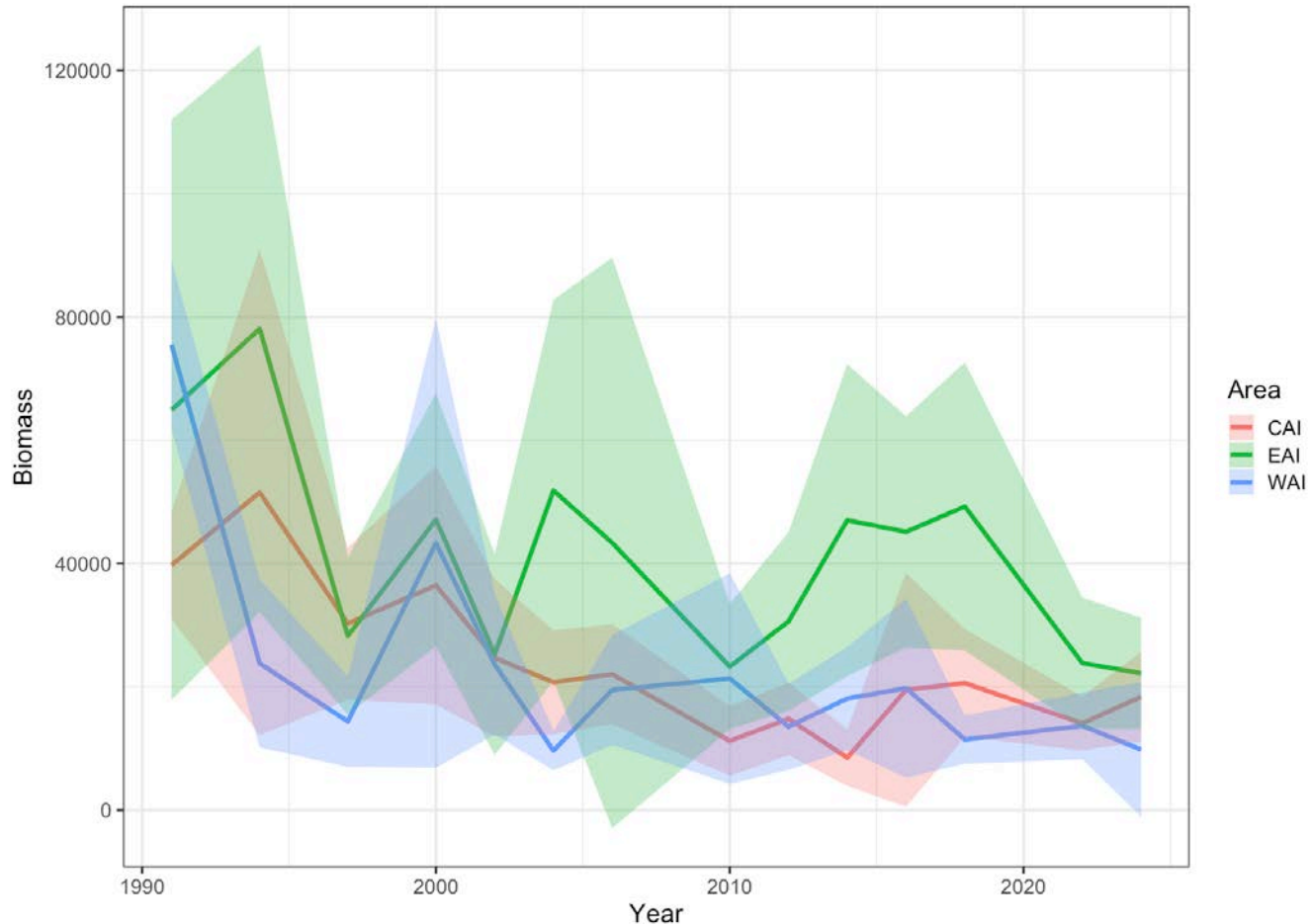
Survey data from 2024 – similar to 2022 estimates

Biomass (t)				
Year	Western	Central	Eastern	Total
1991	75,514	39,729	64,926	180,170
1994	23,797	51,538	78,081	153,416
1997	14,357	30,252	28,239	72,848
2000	43,298	36,456	47,117	126,870
2002	23,623	24,687	25,241	73,551
2004	9,637	20,731	51,851	82,219
2006	19,480	22,033	43,348	84,861
2010	21,341	11,207	23,277	55,826
2012	13,514	14,804	30,592	58,911
2014	18,088	8,488	47,032	73,608
2016	19,775	19,496	45,138	84,409
2018	11,425	20,596	49,251	81,272
2022	13,661	14,041	23,837	51,539
2024	9,817	18,379	22,188	50,384

Proportion by area				
Year	Western	Central	Eastern	Total
1991	0.419	0.221	0.360	1
1994	0.155	0.336	0.509	1
1997	0.197	0.415	0.388	1
2000	0.341	0.287	0.371	1
2002	0.321	0.336	0.343	1
2004	0.117	0.252	0.631	1
2006	0.230	0.260	0.511	1
2010	0.382	0.201	0.417	1
2012	0.229	0.251	0.519	1
2014	0.246	0.115	0.639	1
2016	0.234	0.231	0.535	1
2018	0.141	0.253	0.606	1
2022	0.265	0.272	0.463	1
2024	0.195	0.365	0.440	1



Aleutian Islands Pacific cod survey biomass 1991 - 2024



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November models

- We plan to present age structured models 24.0 and 24.1, and Tier 5 models 13.4 and 24.2.
- We will also use a realistic catch value for projections.
- Update maturity curve. The new maturity curve will include observer visual maturity scans and length through September 2024, represents ~24 more records than previously used.



Extra Slides



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Model results and comparison



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Summary table with a comparison of proposed 2024 Models 24.0 and 24.1

Quantity	Model 24.1		Model 24.0	
	2025	2026	2025	2026
M (natural mortality rate)	0.42, 0.58*	0.42, 0.58*	0.42	0.42
Tier	3	3	3	3
Projected total (age 1+) biomass (t)	71,627	77,671	102,888	92,506
Projected female spawning biomass (t)	24,383	24,401	36,970	29,761
$B_{100\%}$	109,629	109,629	92,270	92,270
$B_{40\%}$	43,851	43,851	36,908	36,908
$B_{35\%}$	38,370	38,370	32,294	32,294
F_{OFL}	0.617	0.618	1.246	0.992
$maxF_{ABC}$	0.471	0.471	0.948	0.755
F_{ABC}	0.255	0.255	0.471	0.471
OFL	15,251	15,079	39,082	25,506
$maxABC$	12,089	11,960	31,926	20,524
ABC	12,089	11,960	31,926	20,524
Status	2023	2024	2023	2024
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

*Asterisk denotes natural mortality estimated in the timeblock 2016-2024.



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Summary table for Models 13.4 and 24.2 proposed for 2024. Model 13.4 (2023) was the tier 5 model used in 2023.

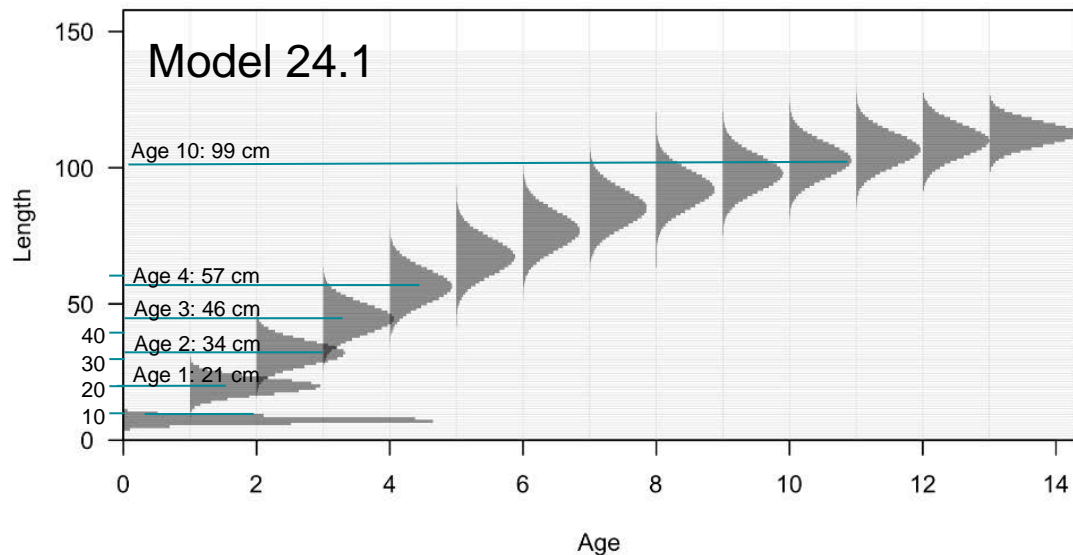
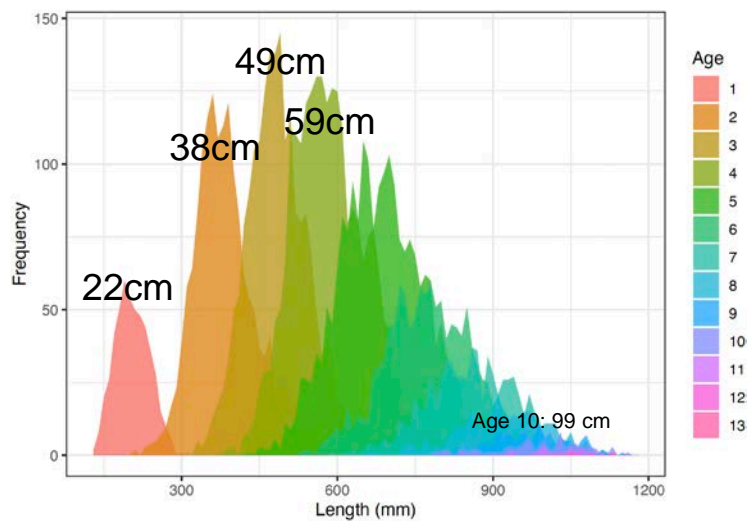
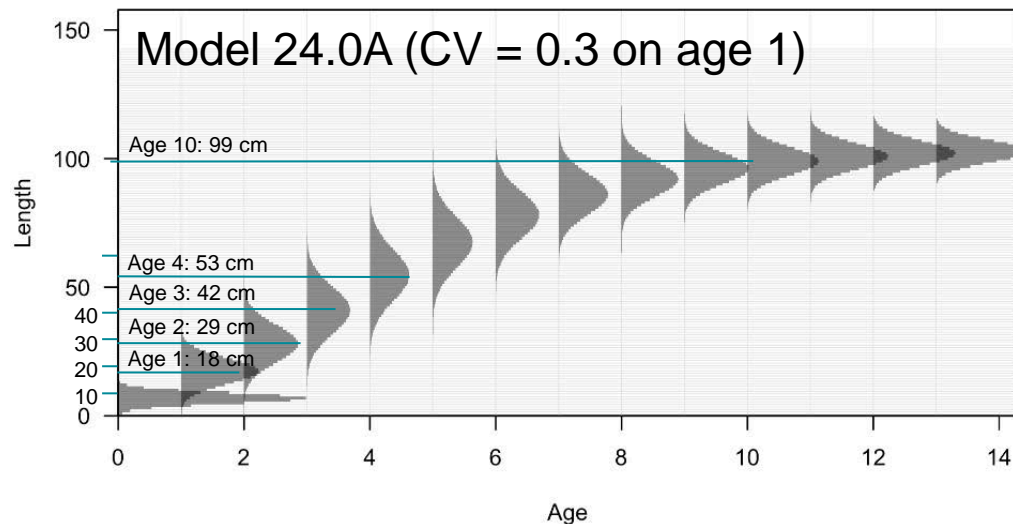
Quantity	Model 13.4 (2023) As estimated or <i>specified</i> <i>last year for:</i>		Model 13.4 As estimated or <i>recommended</i> <i>this year for:</i>		Model 24.2 As estimated or <i>recommended</i> <i>this year for:</i>	
	2024	2025	2025	2026	2025	2026
M	0.34	0.34	0.34	0.34	0.417	0.417
Tier	5	5	5	5	5	5
Biomass (t)	54,165	54,165	54,166	54,166	54,166	54,166
F_{OFL}	0.34	0.34	0.34	0.34	0.417	0.417
$maxF_{ABC}$	0.255	0.255	0.255	0.255	0.313	0.313
F_{ABC}	0.255	0.255	0.255	0.255	0.313	0.313
OFL	18,416	18,416	18,416	18,416	22,587	22,587
$maxABC$	12,431	12,431	13,812	13,812	16,940	16,940
ABC	12,431	12,431	13,812	13,812	16,940	16,940
Status	2022	2023	2023	2024	2023	2024
Overfishing	No	n/a	No	n/a	No	n/a

*Note the 2024 accepted ABC and OFL were adjusted from the 2024 model values for OFL and ABC



Growth

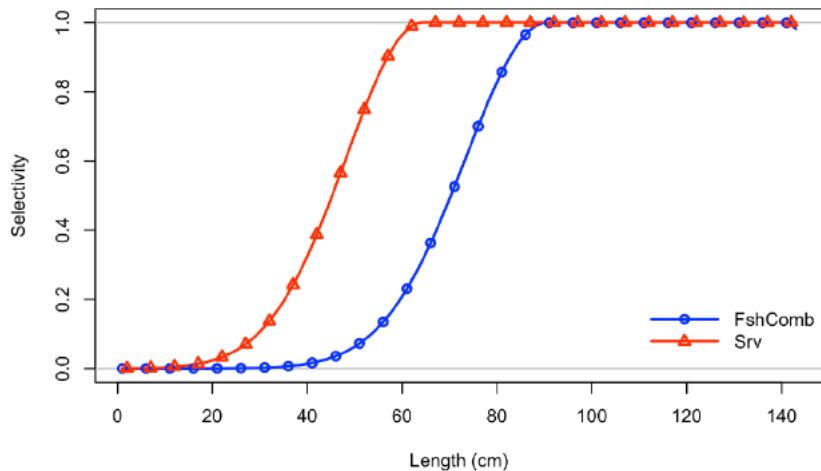
Age	1	2	3	4
Length (cm)	22.1	38.3	48.9	58.7
CV	1.71	1.2	1.2	1.28



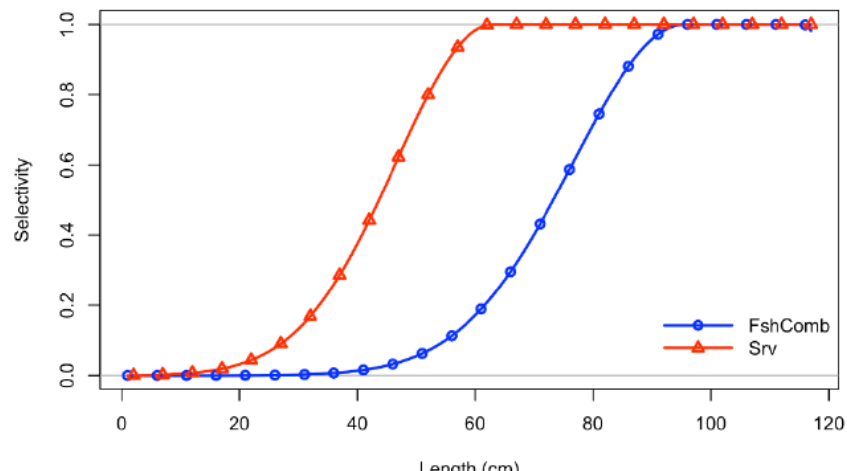
Selection of maximum age & length

Shifts selectivity curves to

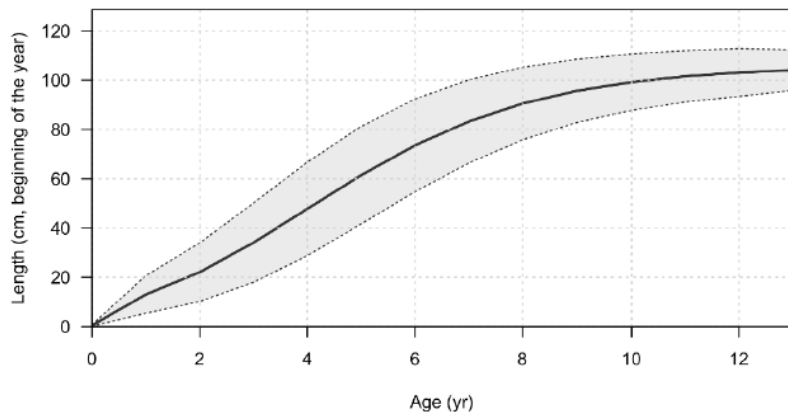
Model 24.0A



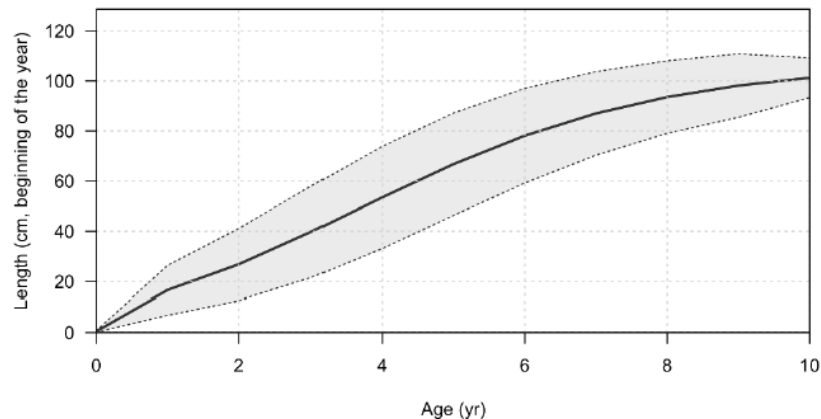
Model 24.0B



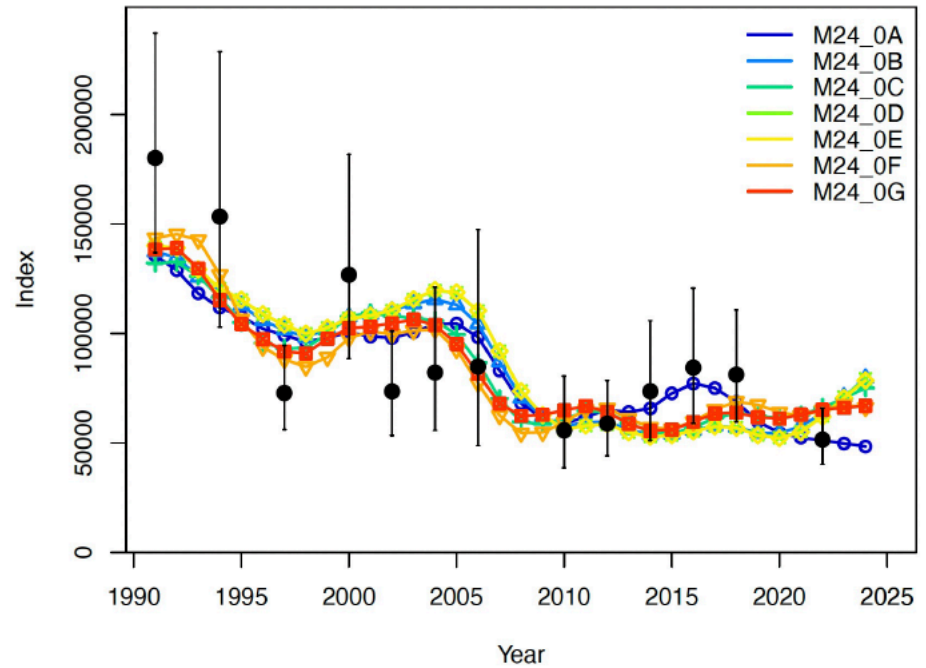
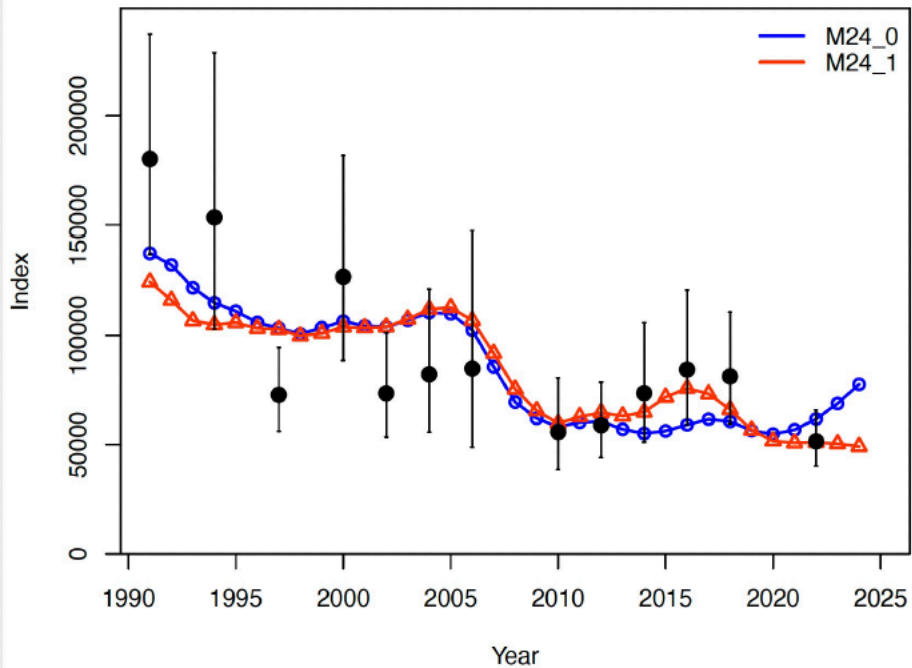
Model 24.0C



Model 24.0D

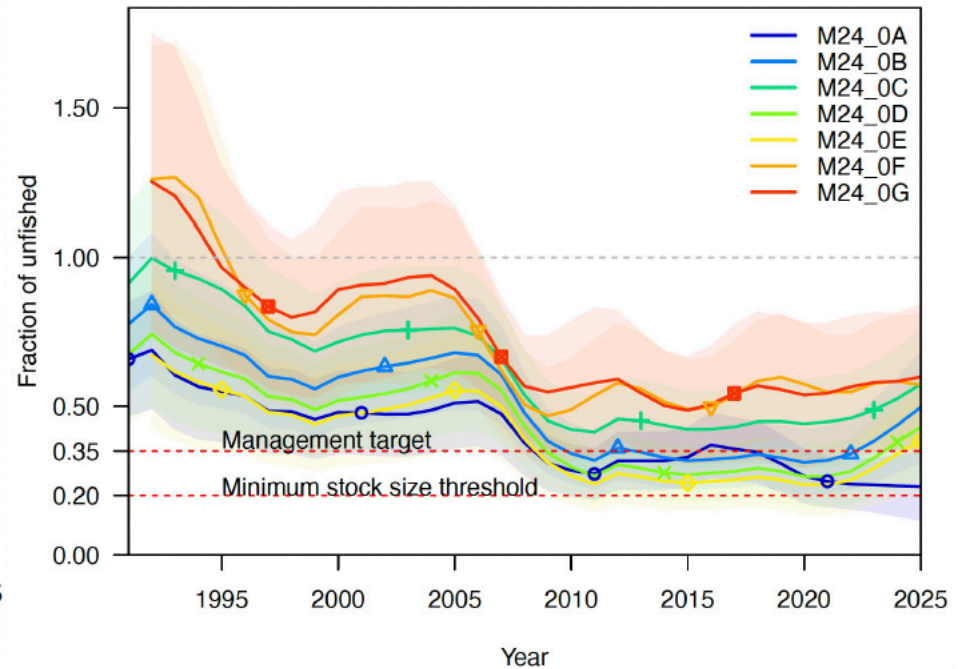
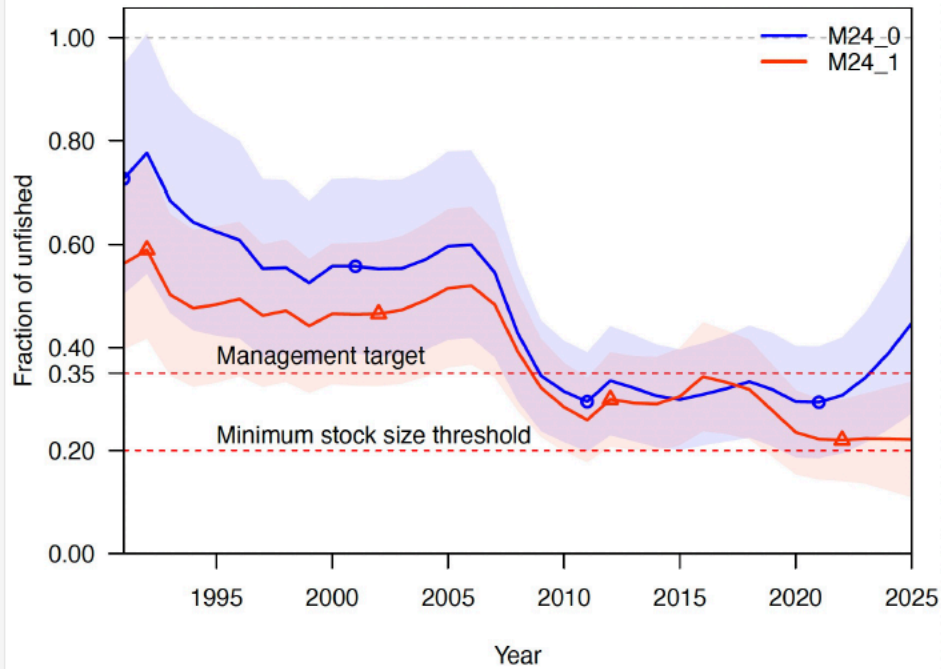


Model fit to survey index for all Models 24.0, 24.1 (left), and seven bridging models, M24.0 A-G (right)

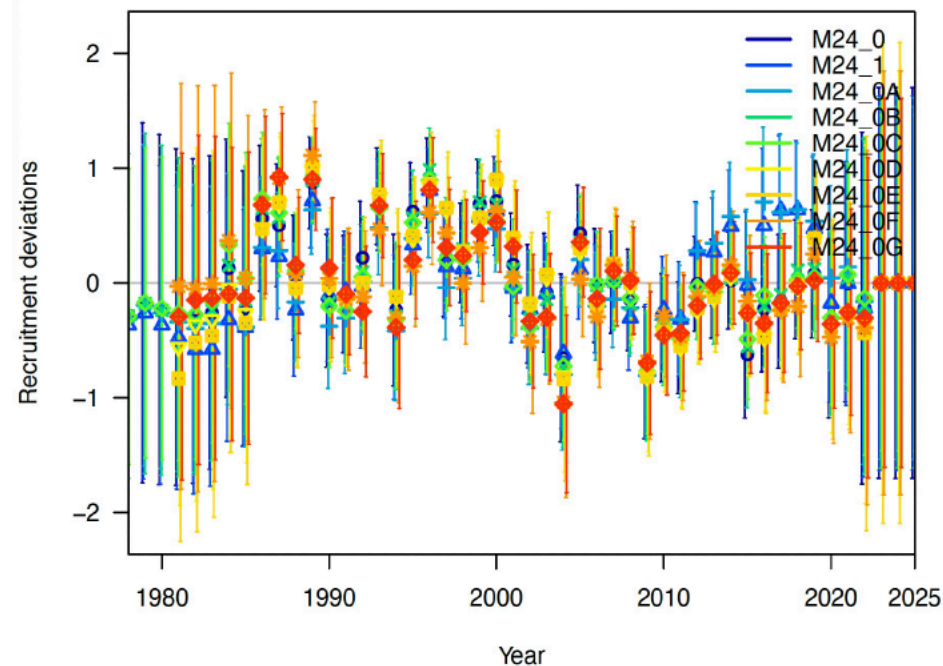
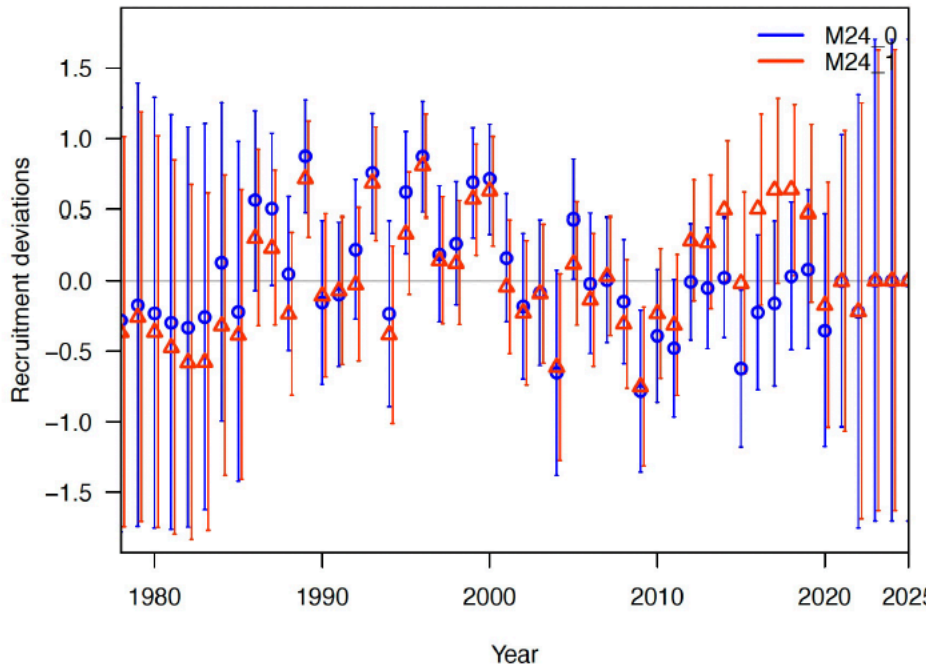


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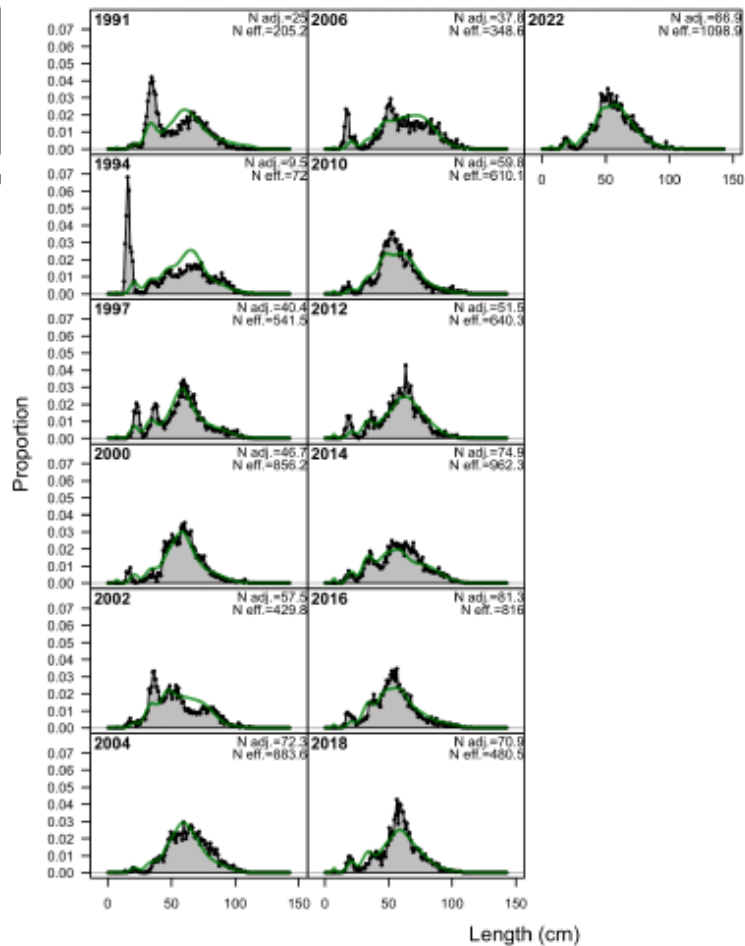
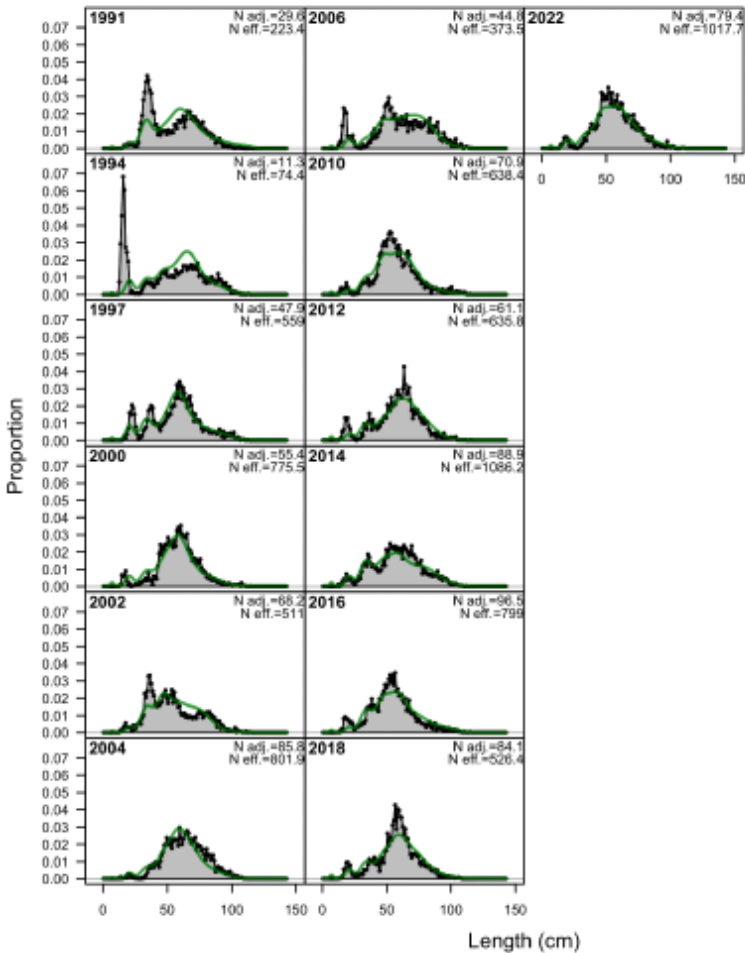
Spawning biomass relative to unfished for all Models 24.0, 24.1 (left), and seven bridging models, M24.0 A-G (right)



Recruitment estimates for all Models 24.0, 24.1 (left), and seven bridging models, Models 24.0 A-G (right)



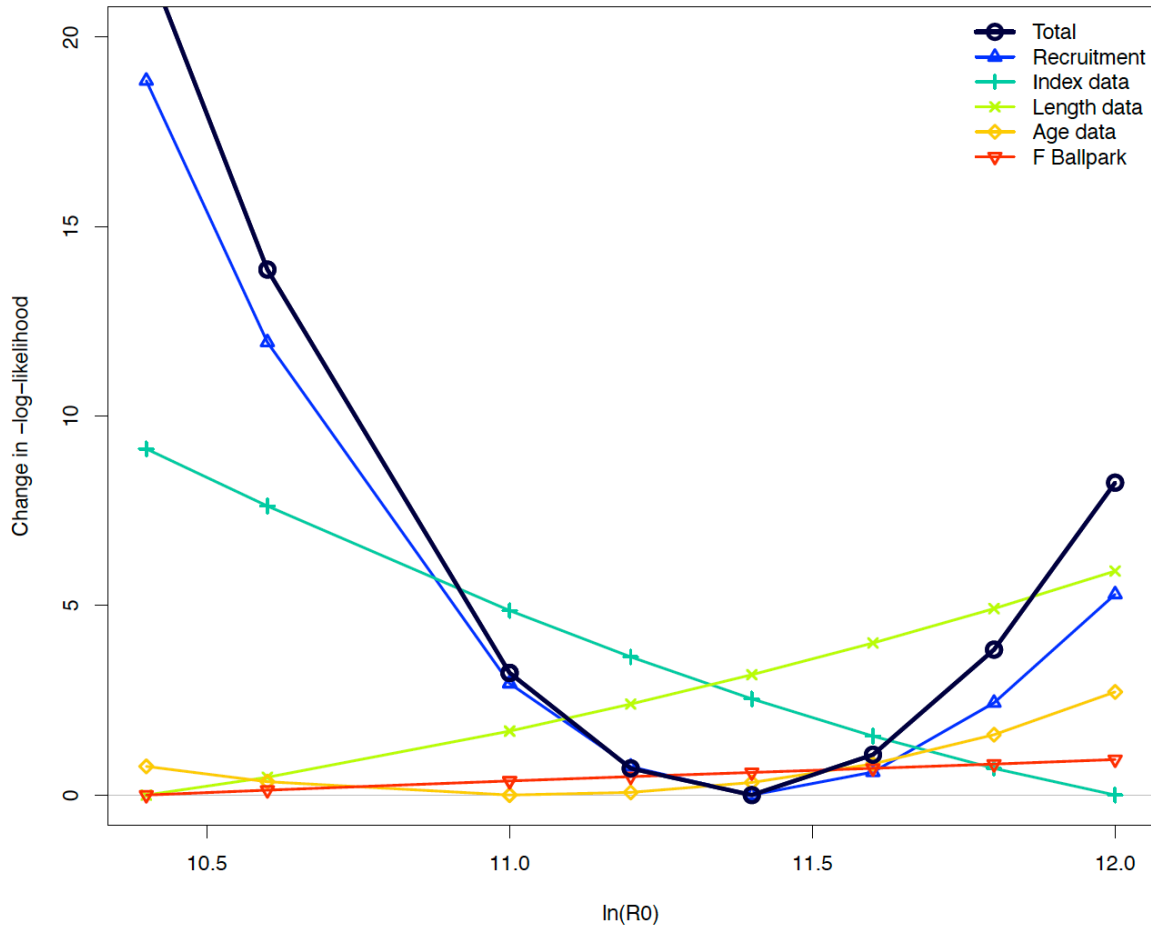
Survey length composition and fit to the length composition, Model 24.0 (left) and Model 24.1 (right)



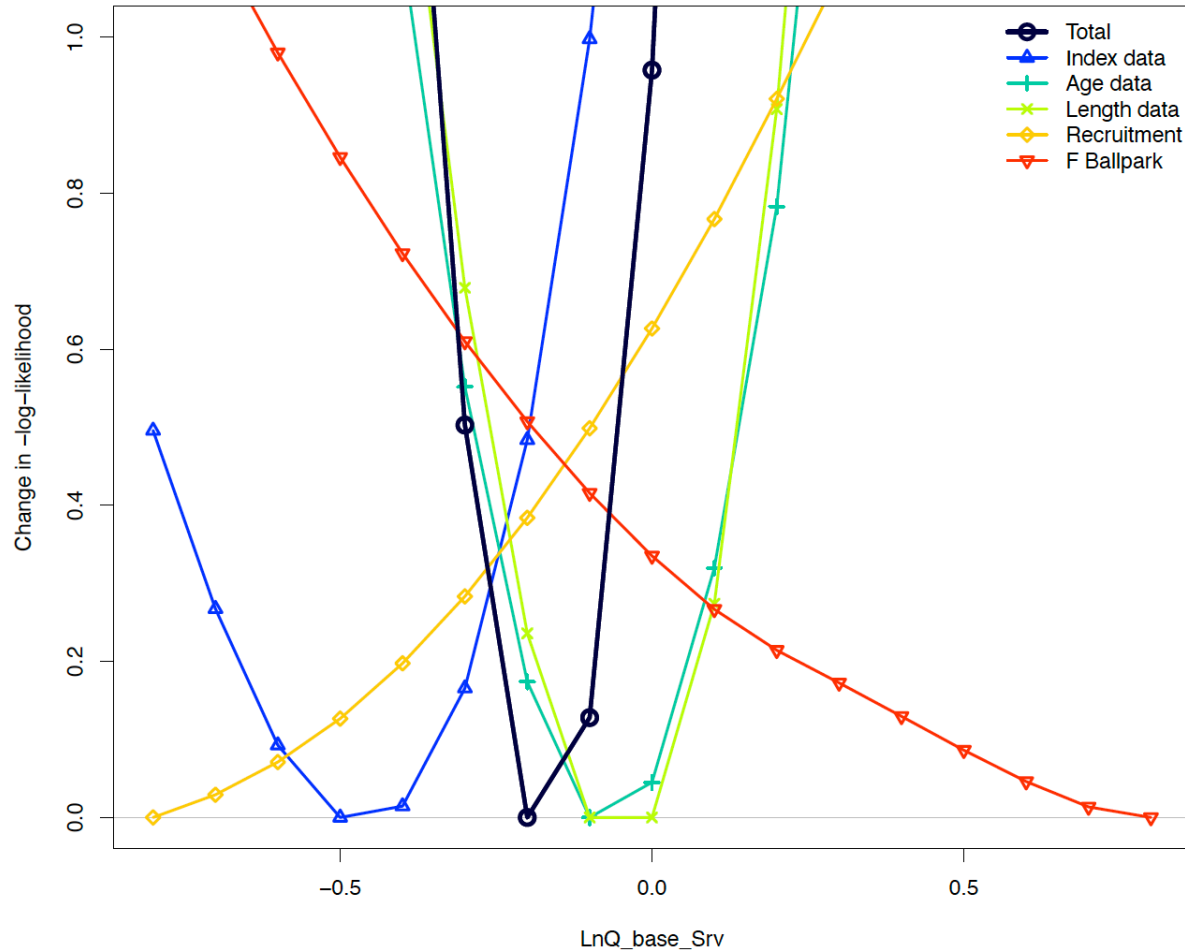
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Likelihood profile over initial recruitment, R0, from 10.4 to 12

Model 24.1 likelihood profile over R0

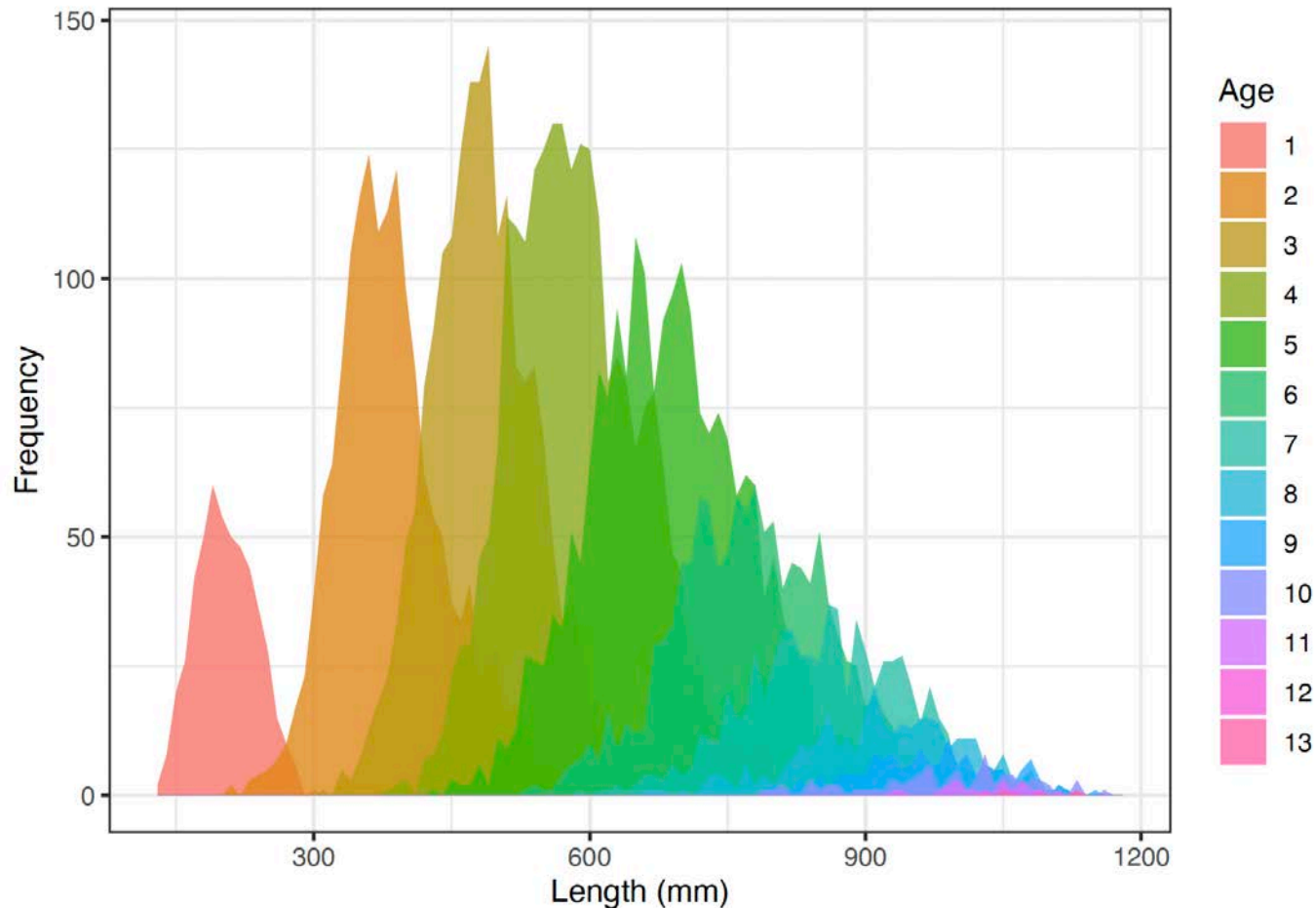


Likelihood profile over the log of catchability (q), from -0.8 to 0.8 in increments of 0.1.



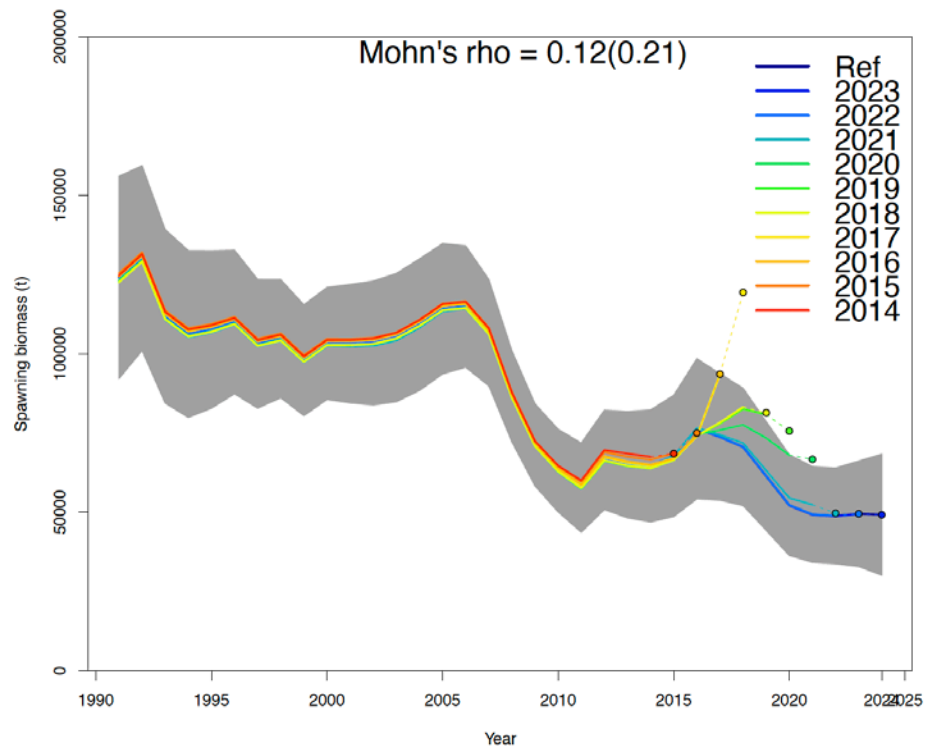
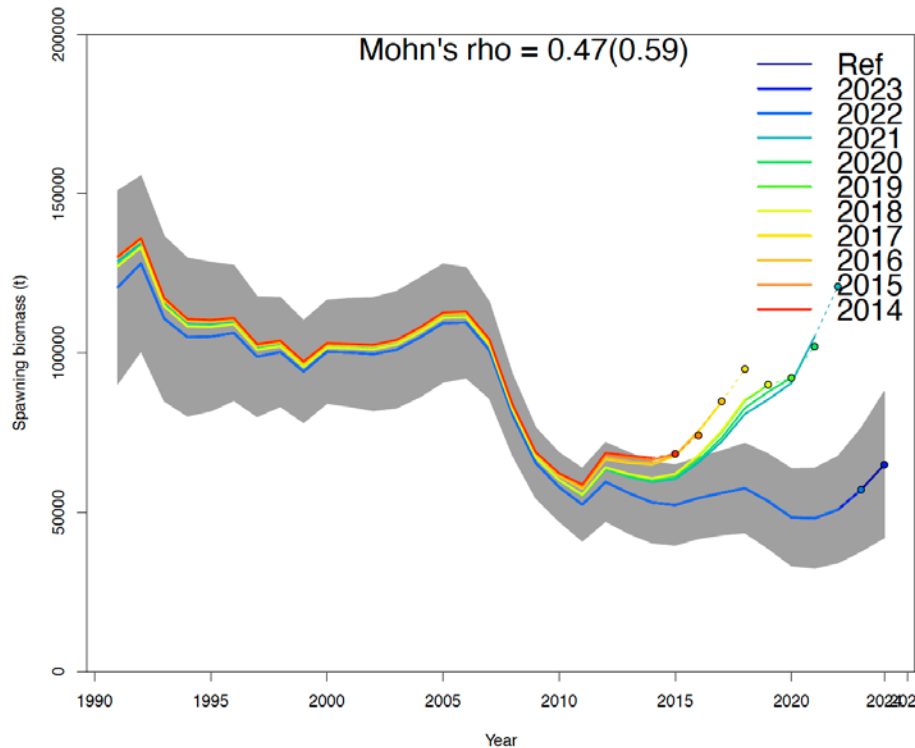
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Length frequency by age of cod collected from surveys 1991-2022

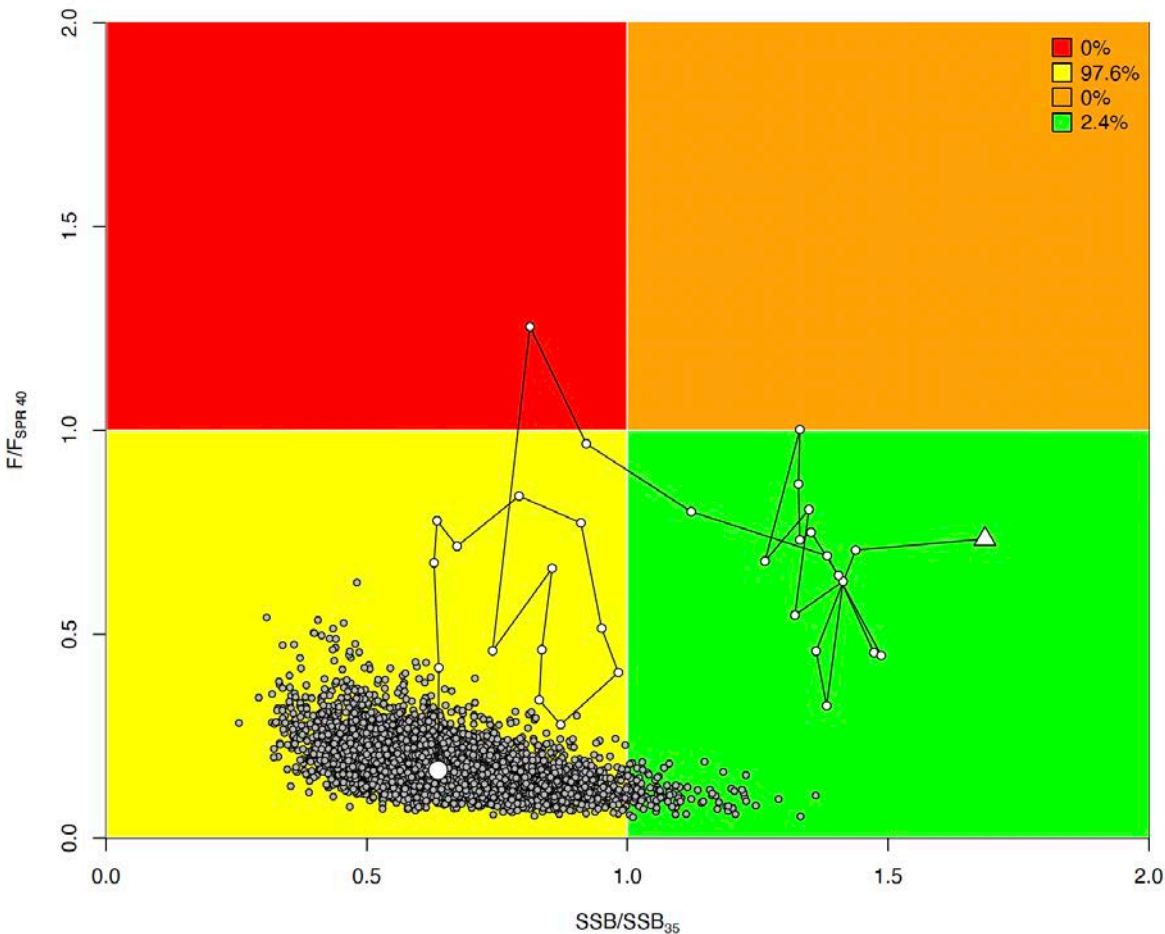


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Retrospective plot of spawning biomass, Model 24.0 (left), and Model 24.1 (right). Mohn's rho is presented for each retrospective, followed by the forecasted estimate of rho in parentheses. The shaded area represents the 95% confidence interval around the mean of the base year (full time series)



A Kobe plot demonstrating the stock status uncertainty over SSB/SSB_{msy} and F/F_{msy} , indicates a 97.6% probability that the stock status is between $SSB_{8\%}$ and $SSB_{35\%}$, and that the fishing mortality rate is below $F_{40\%}$. The triangle represents the first year (1991) and the large circle the final year (2024). Grey dots provide uncertainty among Model 24.1 runs for the stock status in the final year.



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