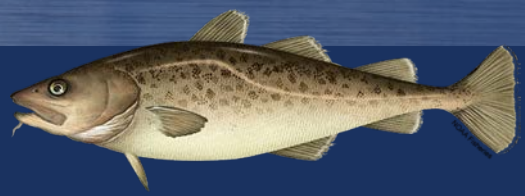
Assessment of the Pacific cod stock in the Aleutian Islands

Ingrid Spies, Steve Barbeaux, Pete Hulson, Ivonne Ortiz

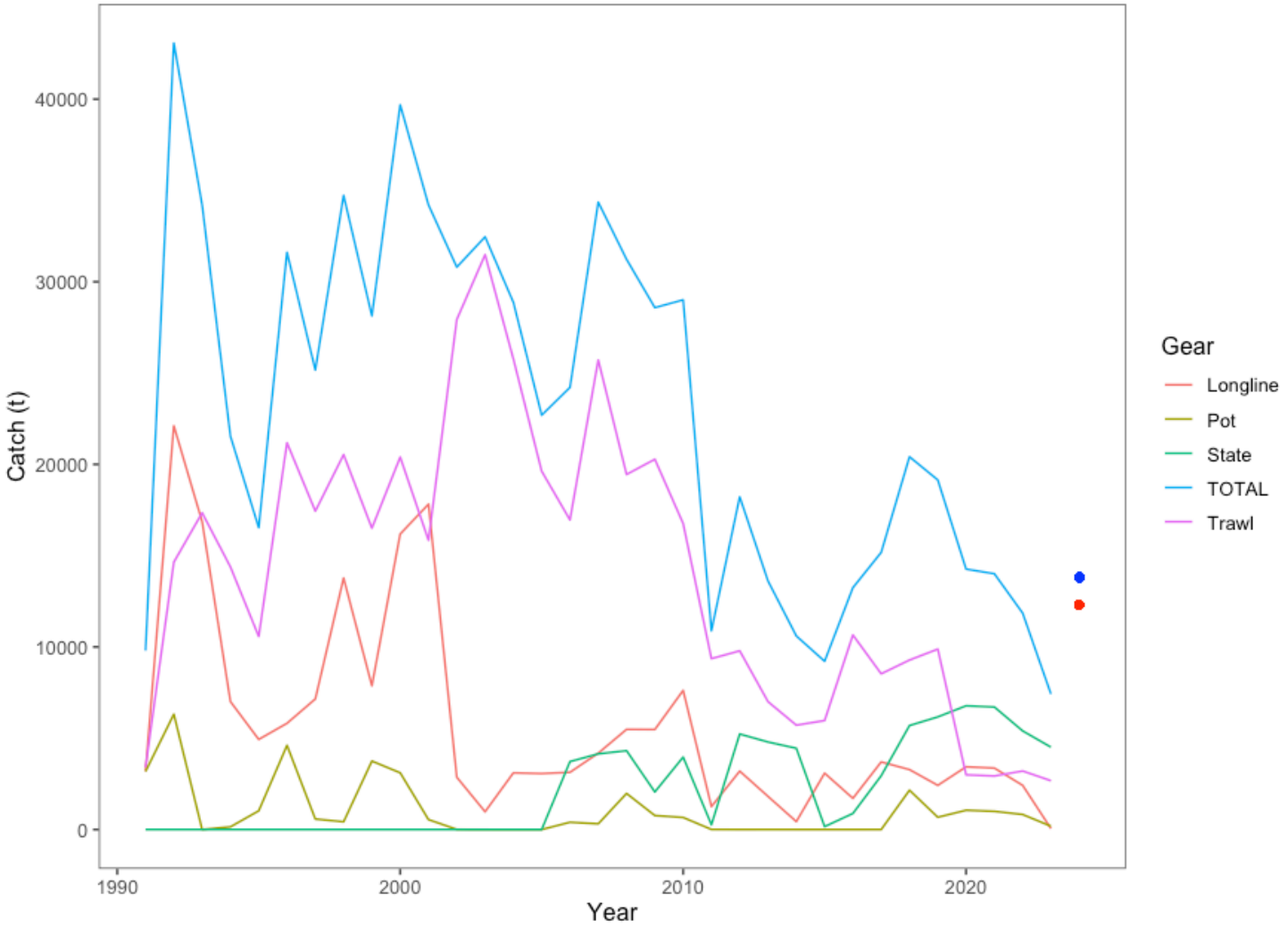
November,2023 Presentation to the Bering Sea and Aleutian Islands Plan Team



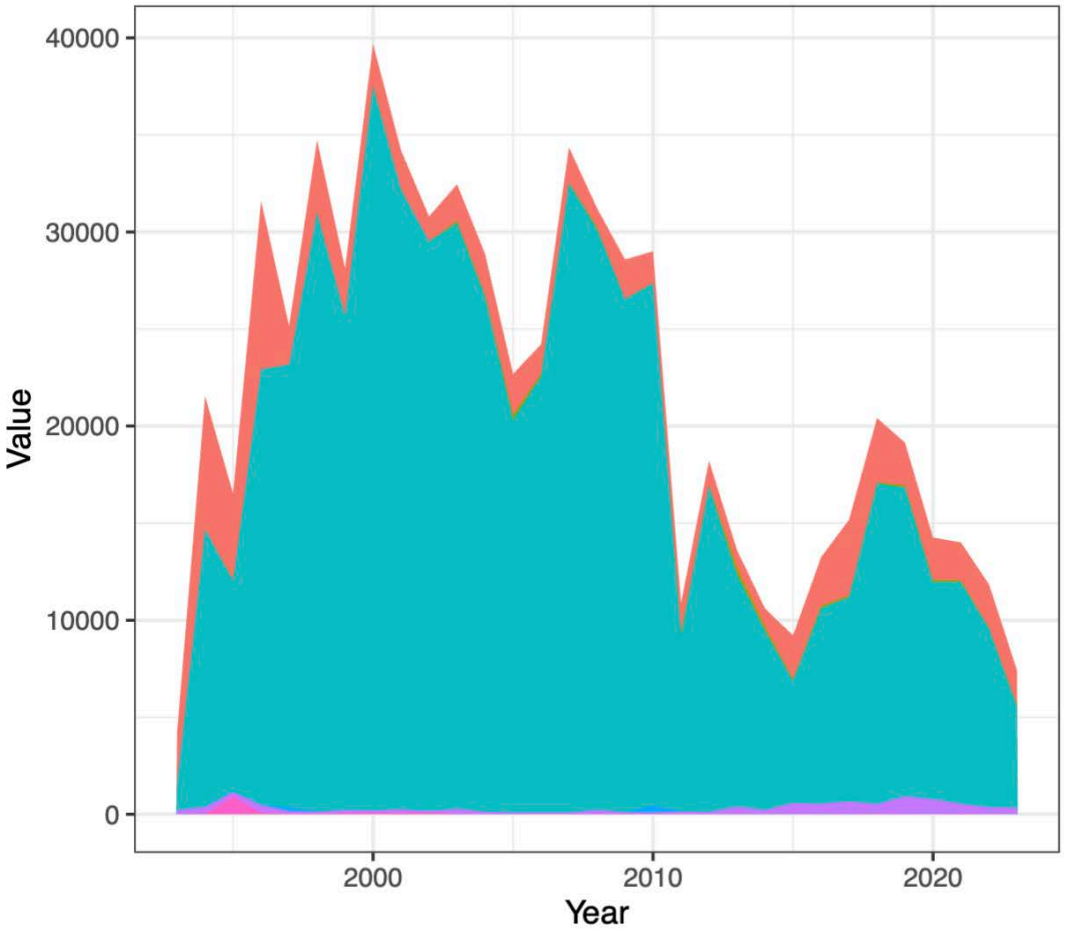
NOAA FISHERIES

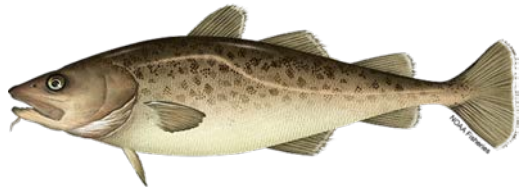
Fishery and catch

Aleutian Islands Pacific cod catch by gear, 1991 – 2023



Proportion of Pacific cod caught in targeted fisheries in the Aleutian Islands (541, 542, and 543), 1991 through October 26, 2023.

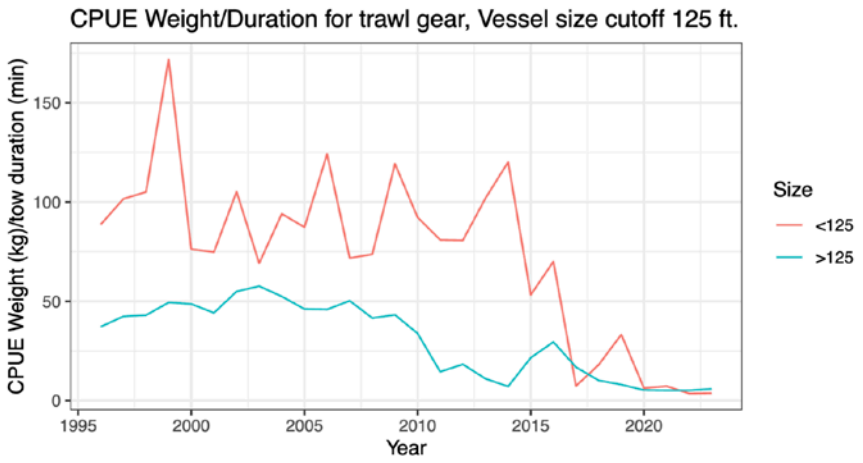


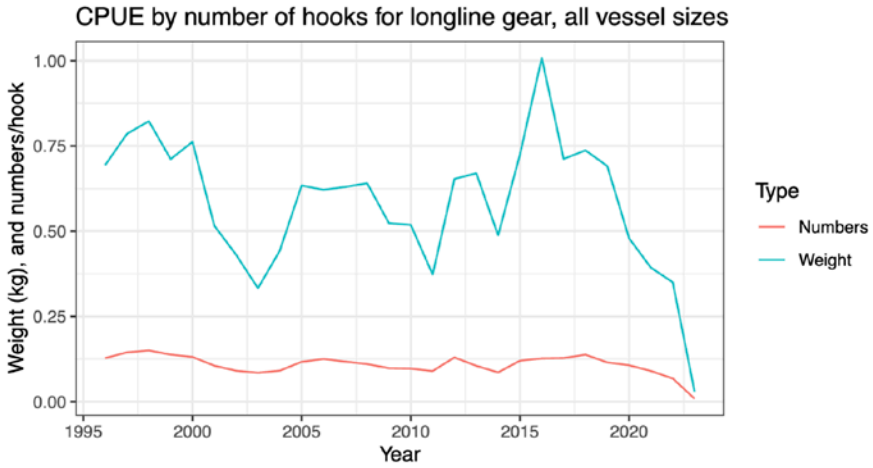


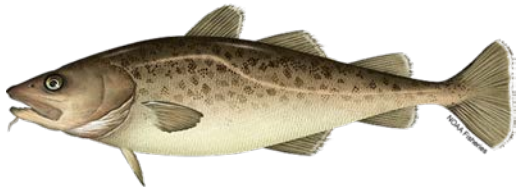
Target

- Atka Mackerel
- Flatfish
- Halibut
- Other
- Pacific Cod
- Pollock
- Rockfish
- Sablefish

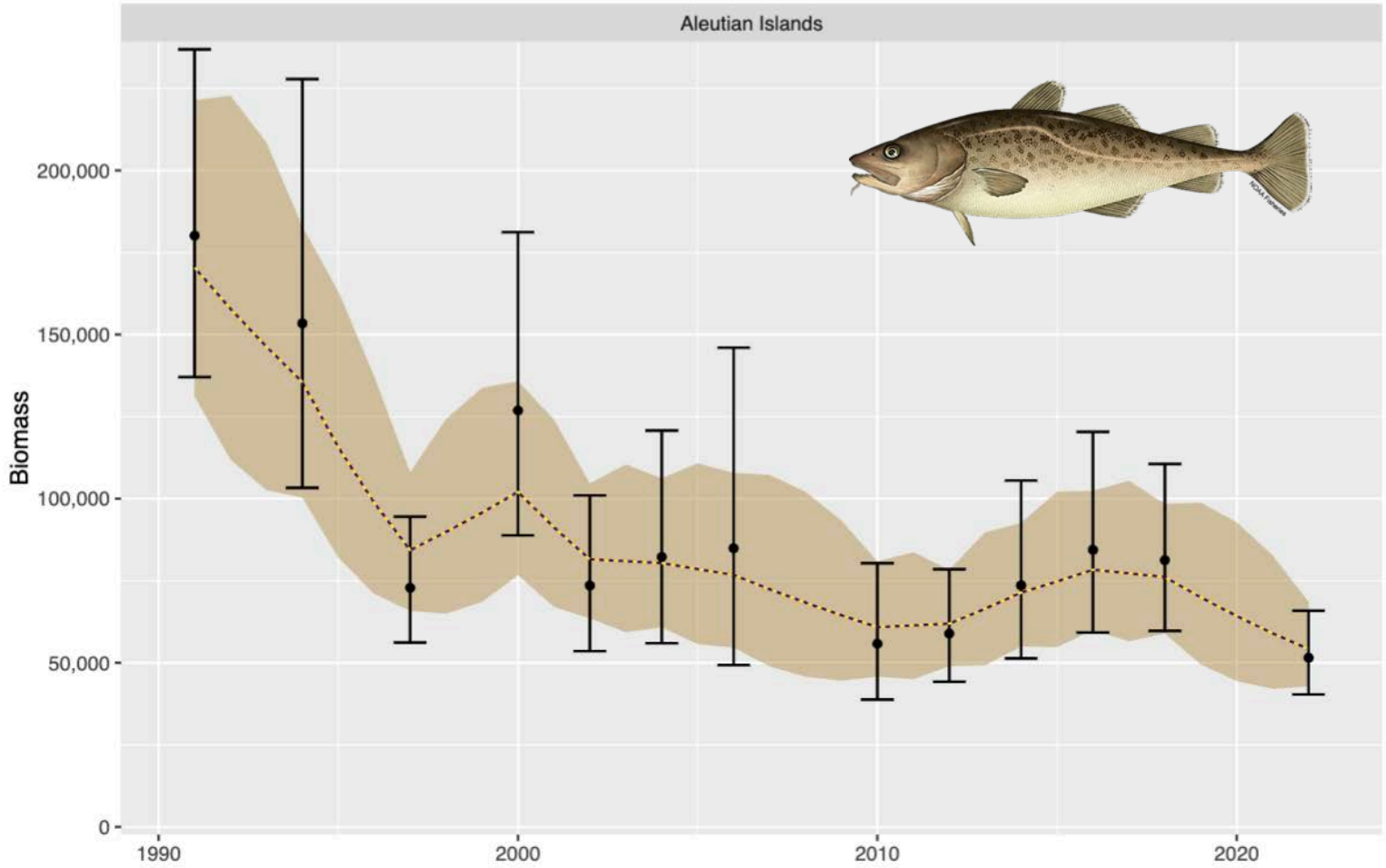
Catch per unit effort appears to have declined by weight and number of hooks.



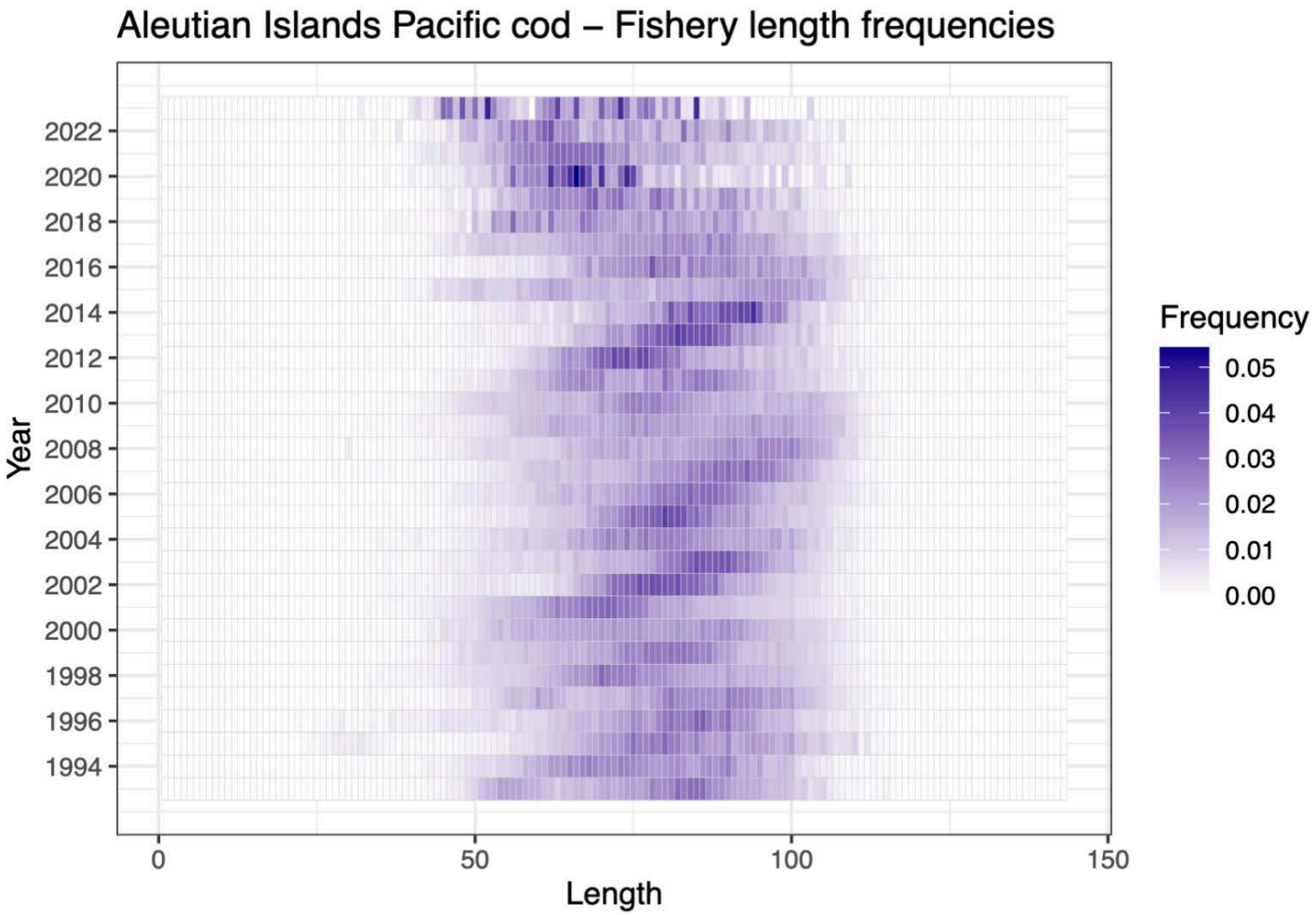




Survey index of biomass and Tier 5 fit using a random effects model.



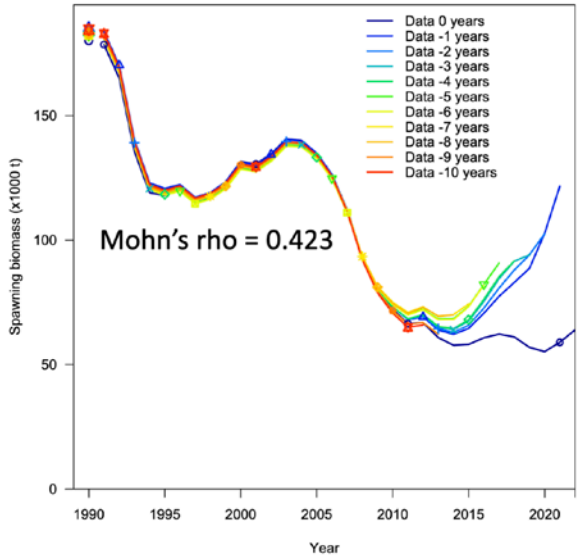
Aleutian Islands fishery length frequencies over all fisheries combined.

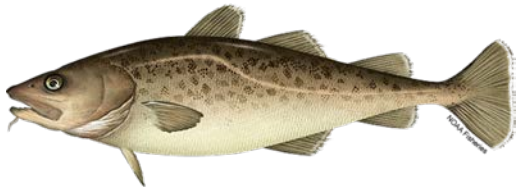


Models

Improvements in age structured models based on previous models

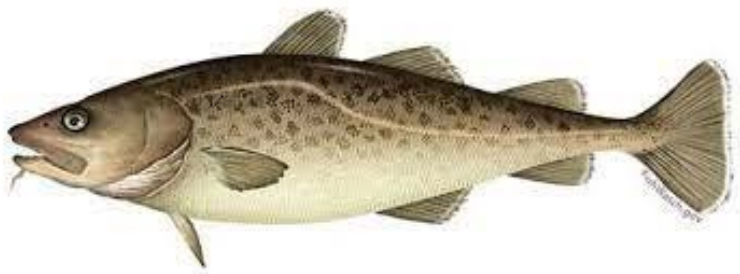
- Retrospective patterns
- Fitting survey and fishery length composition data.
- Inconsistency with EBS and GOA Pacific cod models.



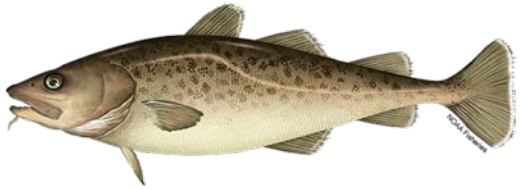


Changes to the Aleutian Islands Pacific cod model presented in September

- Survey conditional age-at-length
- Time varying survey and fishery selectivity
- Input composition sample sizes
- All models consider combined fisheries



Aleutian Islands Pacific cod: Two models recommended by September Plan Team, and 23.2 recommended by the authors



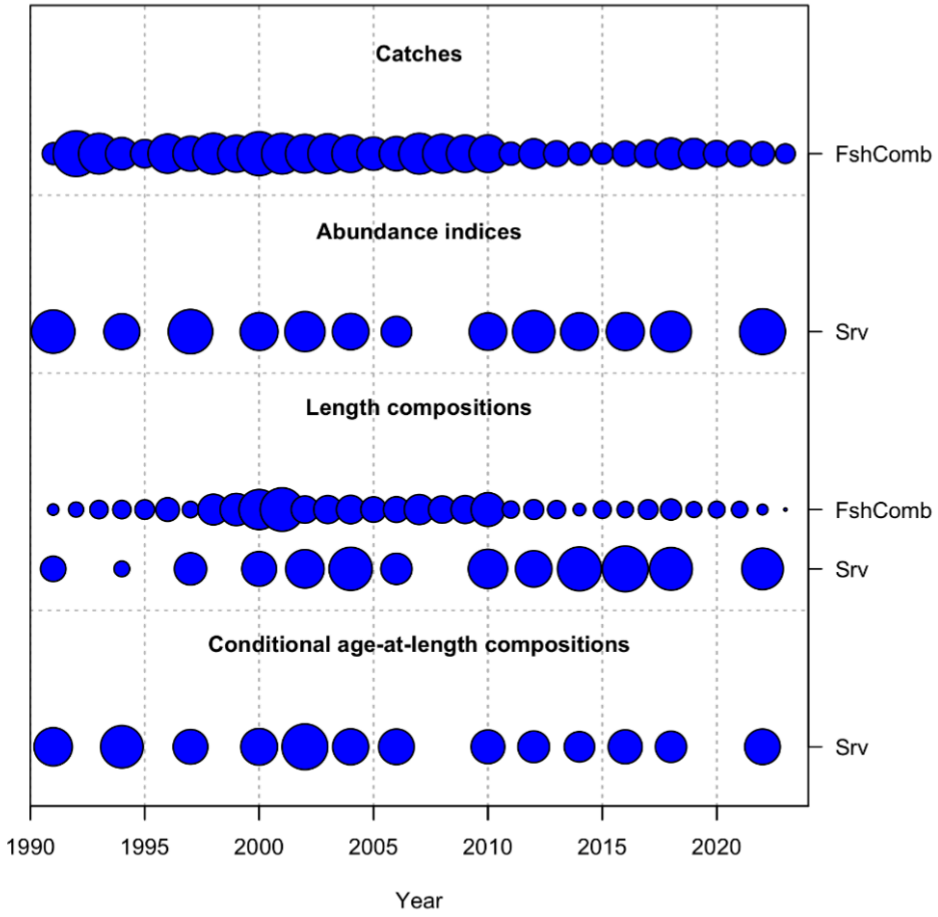
TIER 5 MODEL:

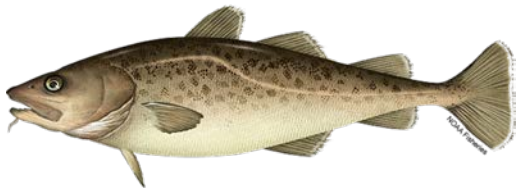
- M13.4 (Tier 5 model)

AGE STRUCTURED MODELS:

- M23.0
  - Time varying growth (3 time blocks)
- M23.1
  - Time varying growth (3 time blocks)
  - Time-varying fishery selectivity (5 time blocks)
- M23.2
  - Time-varying growth (2 time blocks)
  - Time-varying natural mortality (2 time blocks)

Data sources and relative weight used in Models 23.0, Model 23.1, and Model 23.2.



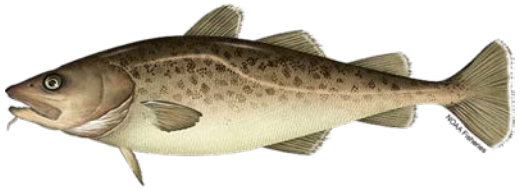


Effective sample sizes generated using methodology of Hulson et al. (2023).

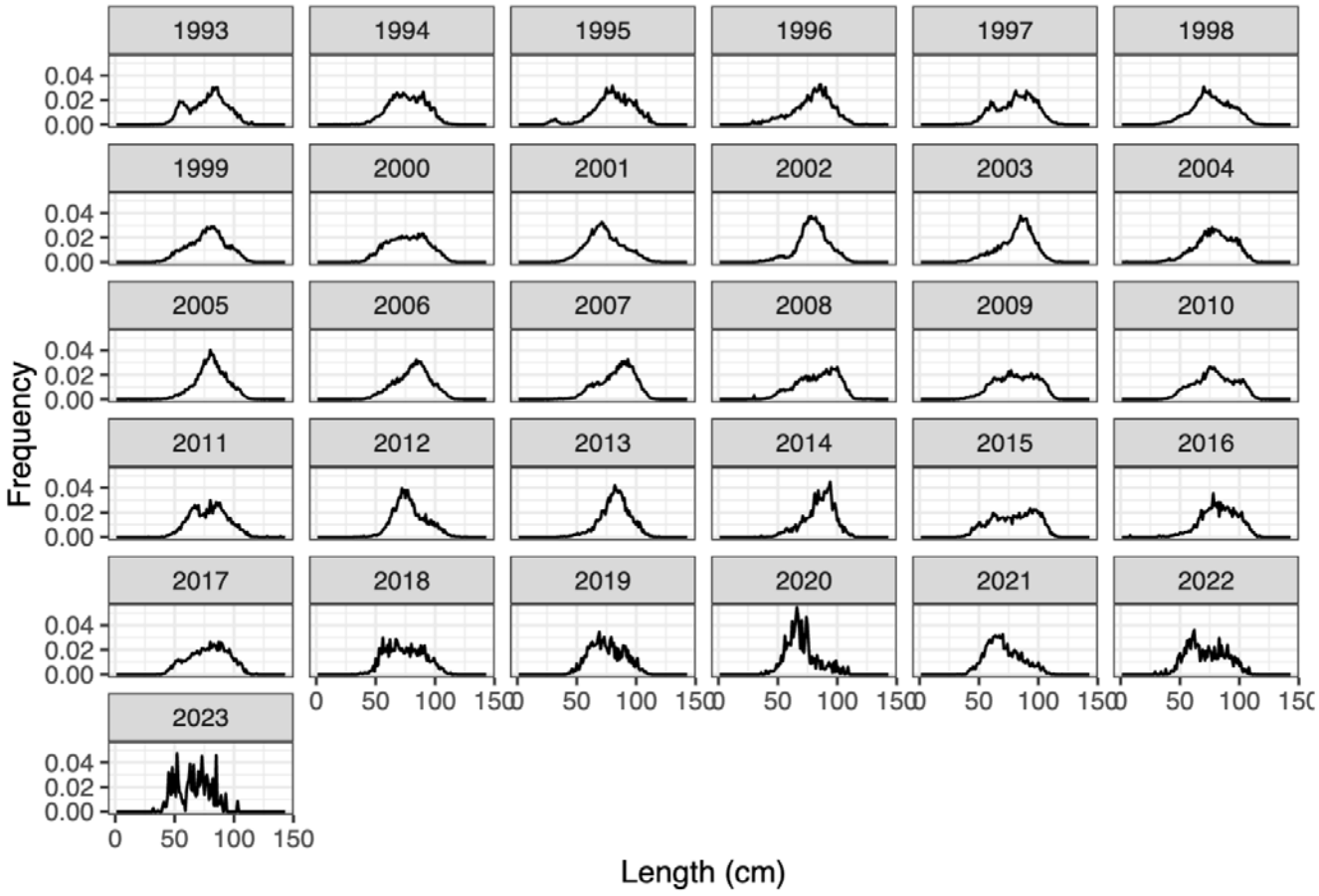
- Survey length and age input sample sizes generated by bootstrapping the number of hauls from which length and age data were taken using the methodology of Hulson et al. (2023).

- Fishery length composition input sample sizes based on number of hauls, scaled to mean *survey* input sample size.

- Data weighting was performed using Francis (2011) methodology for composition data.

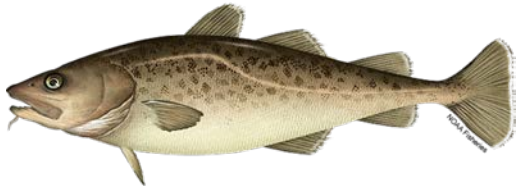


Fishery length frequencies (all fisheries combined) weighted by relative catch by year, area (541, 542, and 543), gear, and quarter.



The combined fishery length compositions were used in Model 23.0, Model 23.1, and Model 23.2.

Aleutian Islands Pacific cod: Two models recommended by September Plan Team, and 23.2 recommended by the authors



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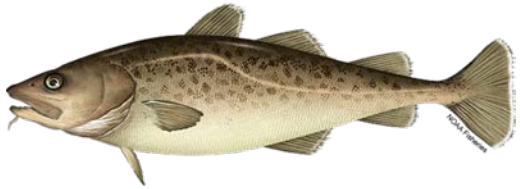
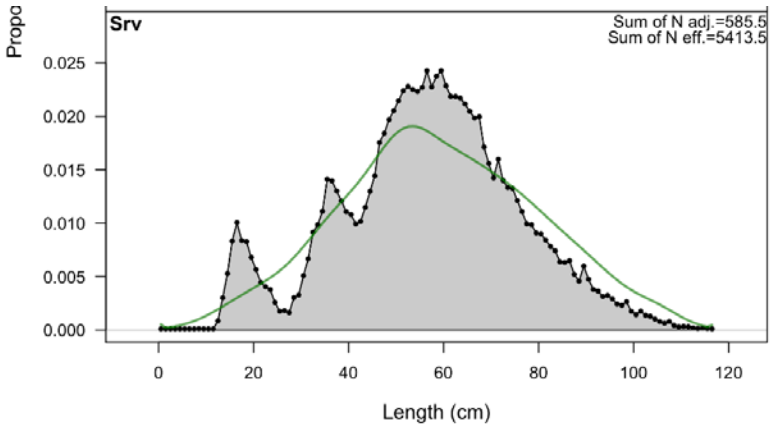


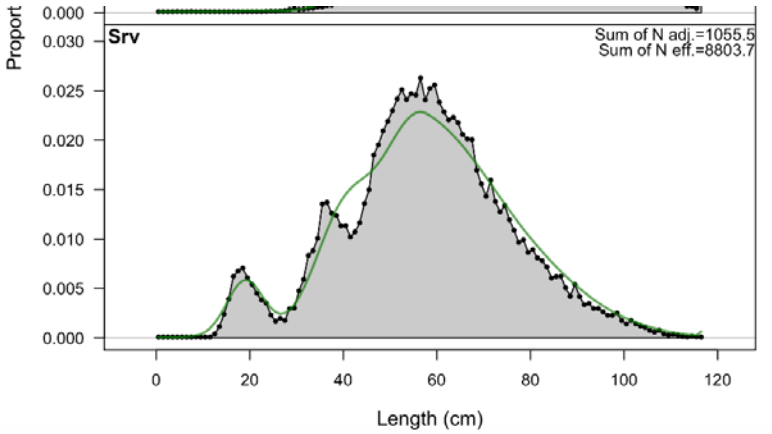
Natural mortality was freely estimated in all models.

Survey catchability used a prior, after check using 'float Q' option.

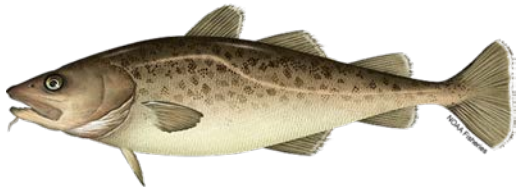
Fit to survey length frequency data



Model 22.0



Model 23.2



Time-varying growth: Was there a biological reason for annually varying growth differences in AI Pacific cod?

Analysis:
Methodology of Kapur et al. (2020) using a generalized additive model; identified potential breakpoints, re-fit the growth curves at the breakpoint (e.g. fit a separate curve for fish through 2002, and 2003+), then checked the degree of overlap among the estimated parameters for each cluster.

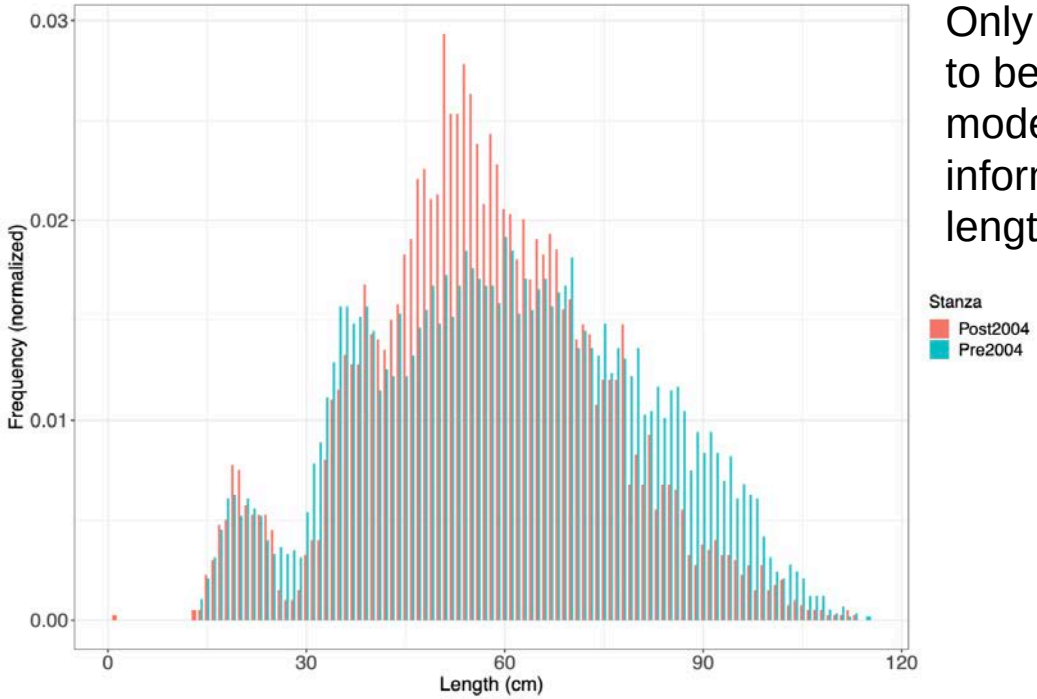
Data:
Aged and lengthed Pacific cod taken from NMFS research surveys (n= 10,134) between 1991 and 2022.

Results:
A shift in growth in 2002.

Kapur, M., Haltuch, M., Connors, B., Rogers, L., Berger, A., Koontz, E., Cope, J., Echave, K., Fenske, K., Hanselman, D. and Punt, A.E., 2020. Oceanographic features delineate growth zonation in Northeast Pacific sablefish. Fisheries Research, 222, p.105414.

Time-varying growth: Was there a biological reason for annually varying growth differences in AI Pacific cod?

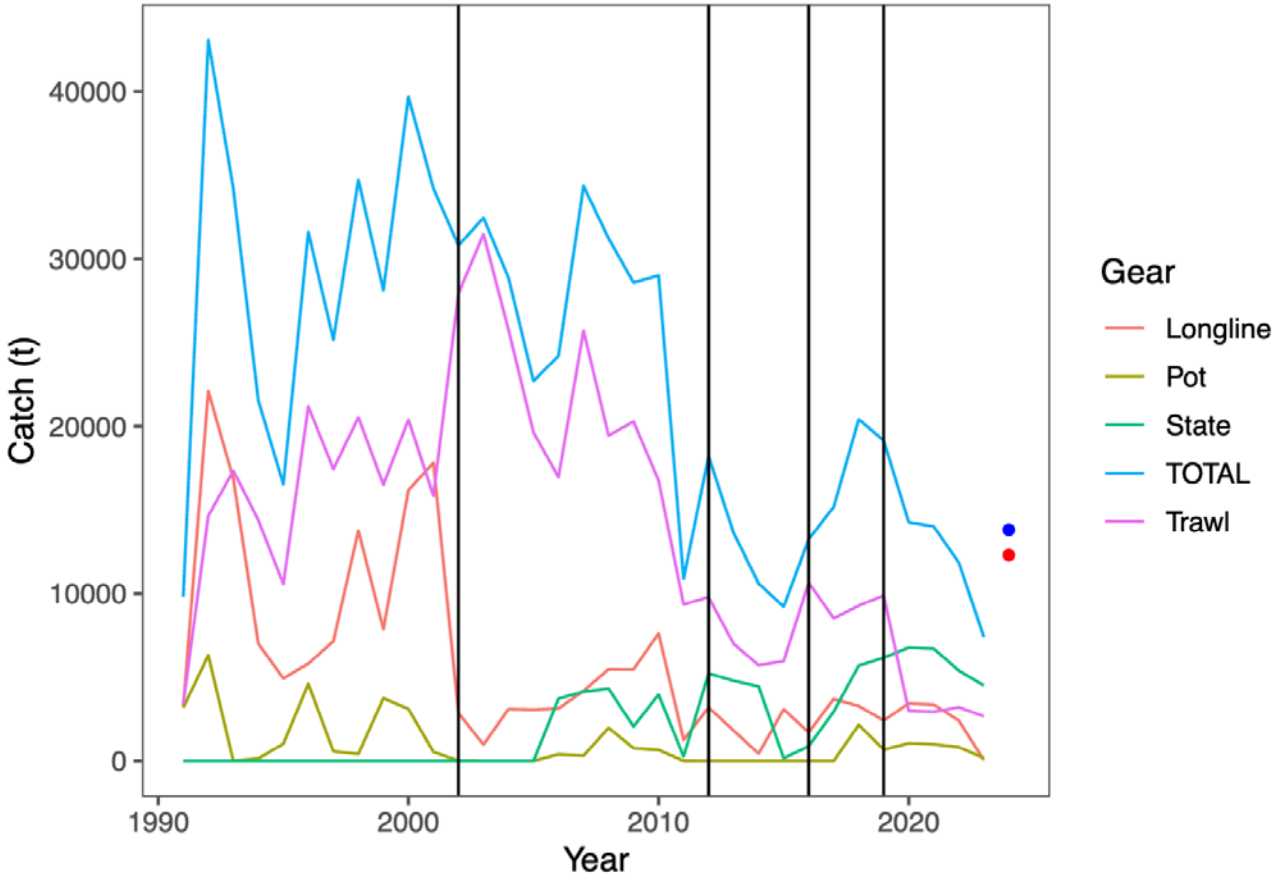
- Age data was split into two sets, pre-2004 and post-2004.
- A series of nested von Bertalanffy growth models applied to determine which parameters changed (=initial length and K).



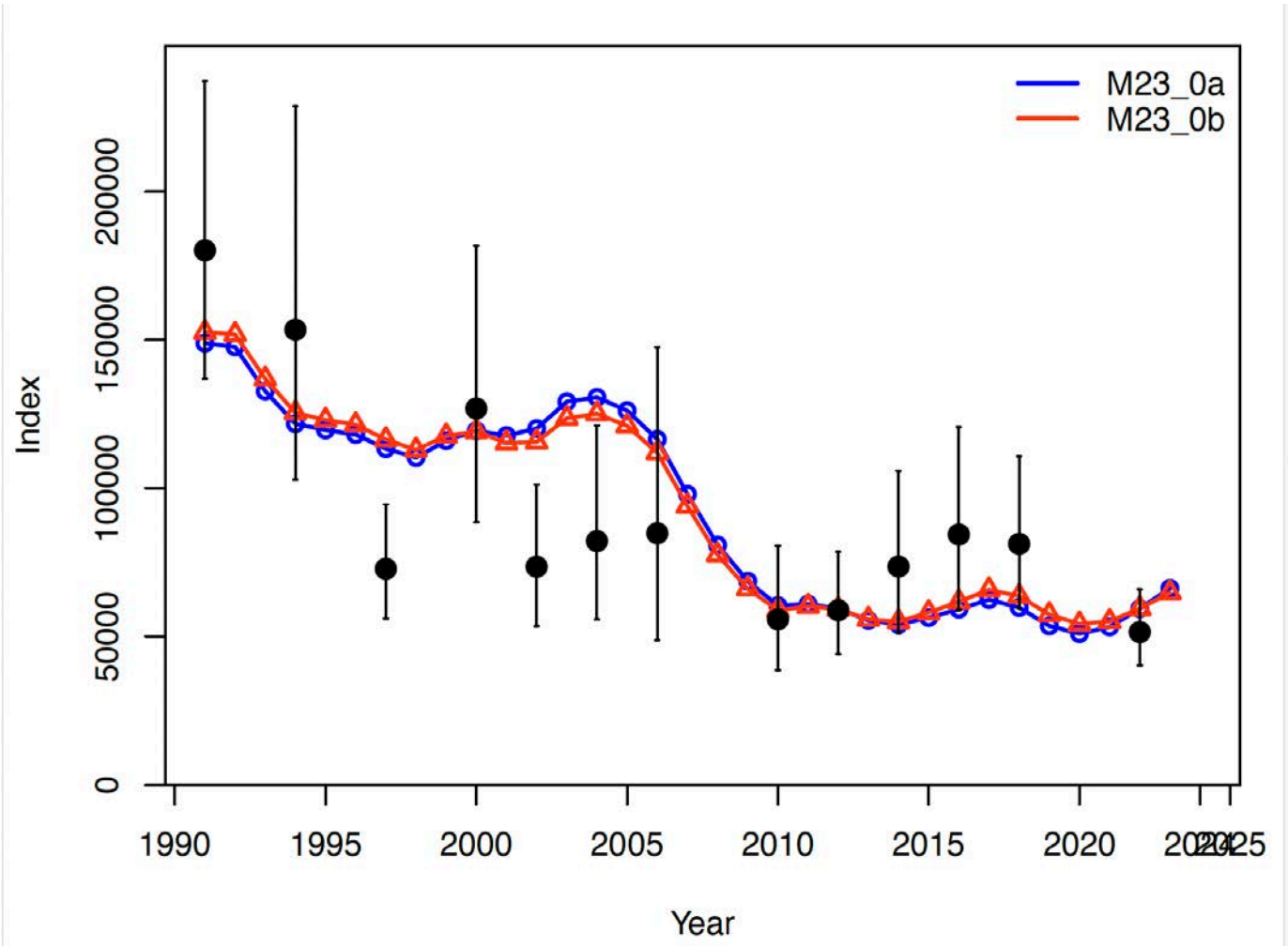
Only K was parameterized to be time-varying in the model because of little information on initial length.

Normalized length frequency for Aleutian Islands Pacific cod aged before and after 2004.

Model 23.1: Time blocks on fishery selectivity were chosen to reflect shifts in gear.



Models 23.0 and 23.1 provide an acceptable fit to the survey index.

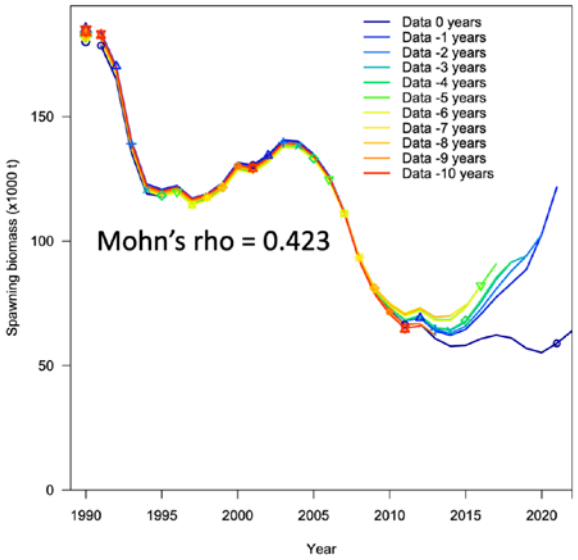


Model 23.0 vs. Model 23.1:
Time-varying growth improves model.
Time-varying fishery selectivity does not (significantly) improve model.

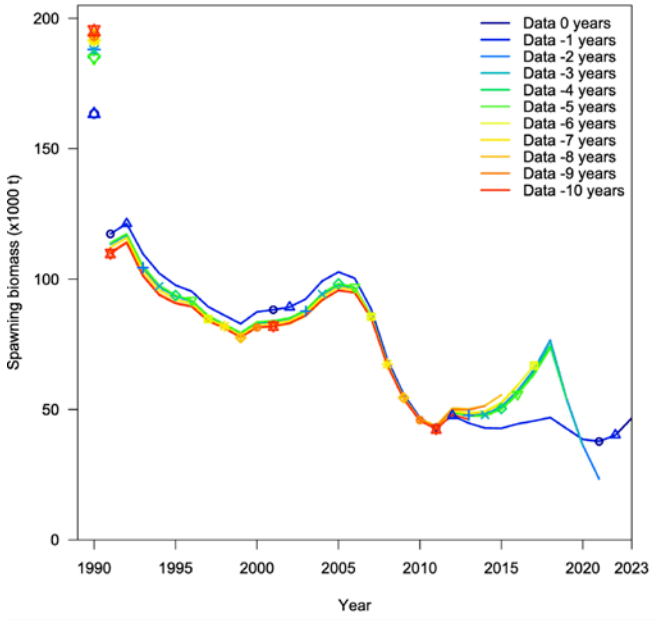
Label	M23_0a	M23.0	M23.1
TOTAL_like	787.899	777.812	772.106
Survey_like	20.548	-1.979	-4.268
Length_comp_like	356.046	141.08	138.871
Age_comp_like	412.195	641.532	640.58
Parm_priors_like	0.378	0.622	0.693
Recr_Virgin_millions	28.892	23.633	24.457
SR_LN(R0)	10.271	10.07	10.105
SR_BH_steep	1	1	1
NatM_uniform_Fem_GP_1	0.35	0.34	0.34
NatM_uniform_Fem_GP_1_BLK2add_1991	NA	NA	NA
NatM_uniform_Fem_GP_1_BLK2add_2016	NA	NA	NA
L_at_Amax_Fem_GP_1	113.157	117.212	117.631
VonBert_K_Fem_GP_1	0.213	0.191	0.19
VonBert_K_Fem_GP_1_BLK1add_1991	NA	0.004	0.004
VonBert_K_Fem_GP_1_BLK1add_2004	NA	0.003	0.002
VonBert_K_Fem_GP_1_BLK1add_2018	NA	-0.007	-0.006
SSB_Virgin_thousand_mt	179.164	163.374	161.961
Bratio_2021	0.19	0.231	0.25
SPRratio_2020	0.656	0.611	0.598
npar	63	71	76
AIC	1701.798	1697.624	1696.212
Rho		0.17	0.14

A time block was applied at 2004 AND at 2017 in Models 23.0 and 23.1.

- M23.0
  - Time varying growth (2004, 2017)
- M23.1
  - Time-varying growth (2004, 2017)
  - Time-varying fishery selectivity



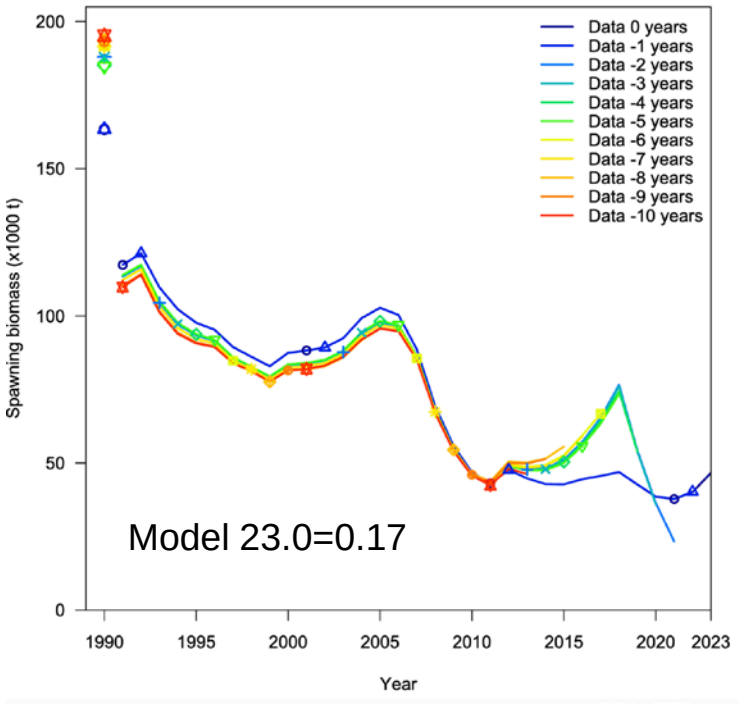
Model 23.0a (presented September 2023)



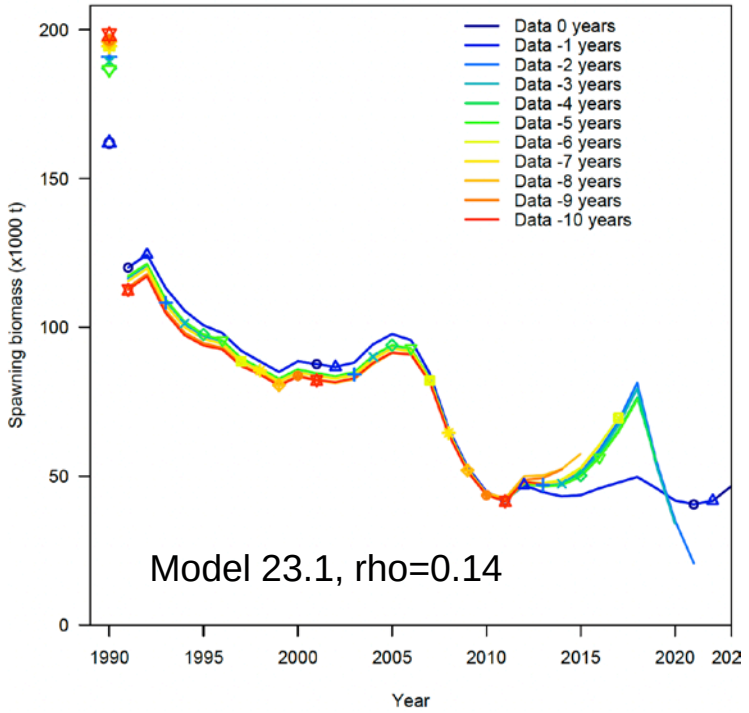
Model 23.0

A time block was applied at 2004 AND at 2017 in Models 23.0 and 23.1.

- M23.0
  - Time varying growth (2004, 2017)



- M23.1
  - Time-varying growth (2004, 2017)
  - Time-varying fishery selectivity



Models 23.0 and 23.1 summary

- Time-varying selectivity does not significantly improve model.
- Time-varying growth improves model.
  - Time-varying growth documented in 2002.
  - Time-varying growth in 2017 not justified.

- There is some extrinsic factor driving the population within the past decade not accounted for my Models 23.0 and 23.1.

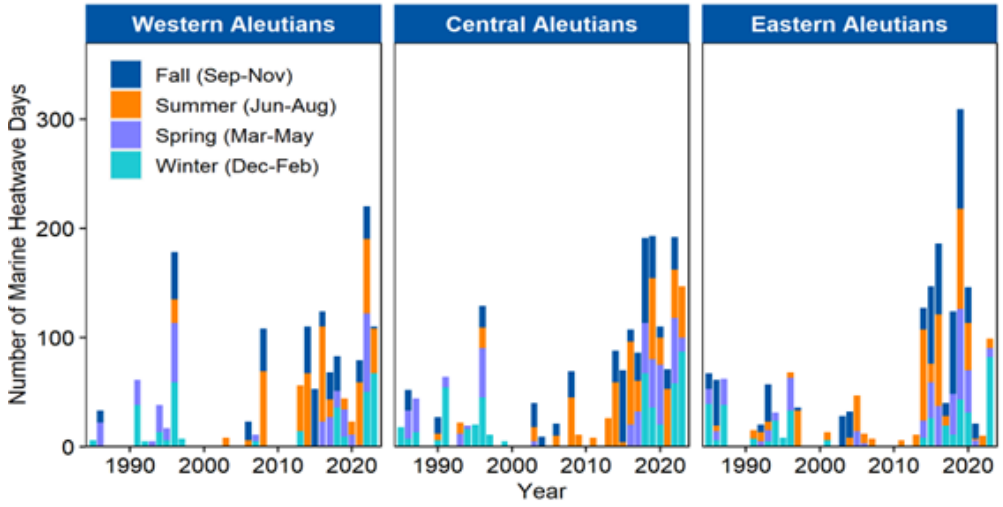
Increased temperatures may have an effect on natural mortality in Pacific cod

Pacific cod are typically found between 3.5–5.7°C (range 2.8 to 6.9◦C).

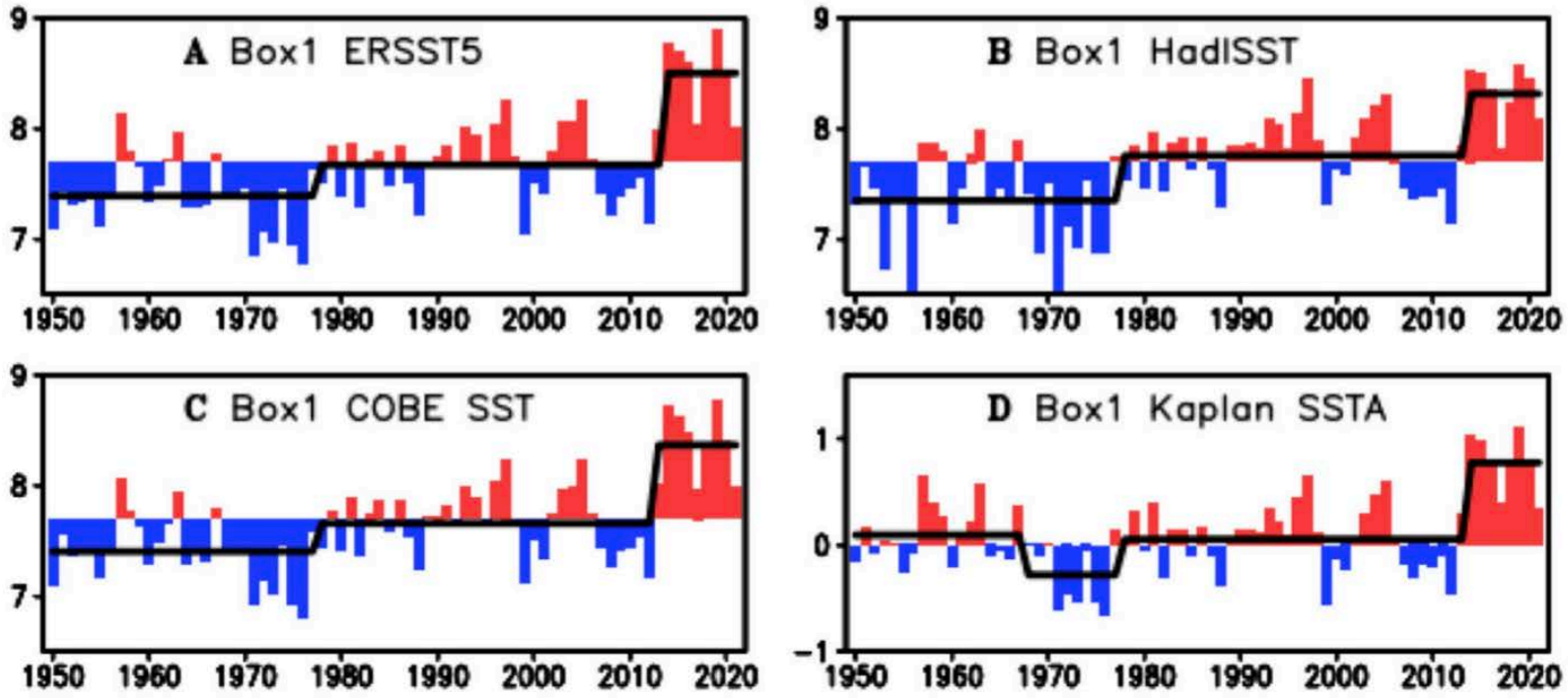
They are sensitive to temperatures outside their preferred range (2-8 C) and have been shown to experience higher natural mortality under higher than optimal temperatures (Barbeaux et al. 2018, Barbeaux et al. 2020).

Higher ambient temperatures incur bioenergetic costs for ectothermic fish (Holsman and Aydin 2015).

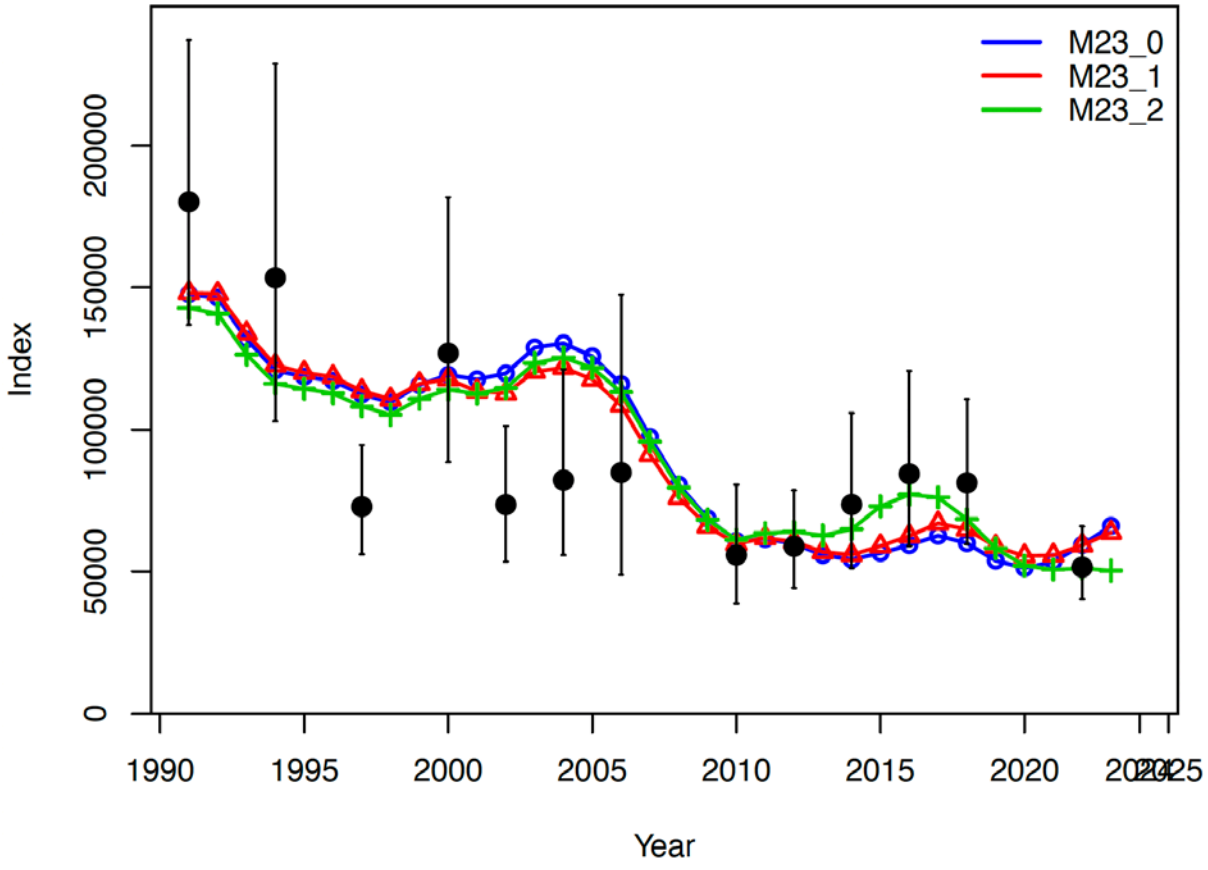
The number of heatwave days in the Aleutian Islands has increased in all three areas since ~2013-2014



Xiao and Ren: Thermal heatwave off Alaska in 2013/2014



Model 23.2 improves the fit to the four most recent trawl survey data points.



Aleutian Island Pacific cod models for 2023

- M23.0
  - Time varying growth (3 time blocks)
- M23.1
  - Time varying growth (3 time blocks)
  - Time-varying fishery selectivity (5 time blocks)
- M23.2
  - Time-varying growth (2 time blocks)
  - Time-varying natural mortality (2 time blocks)

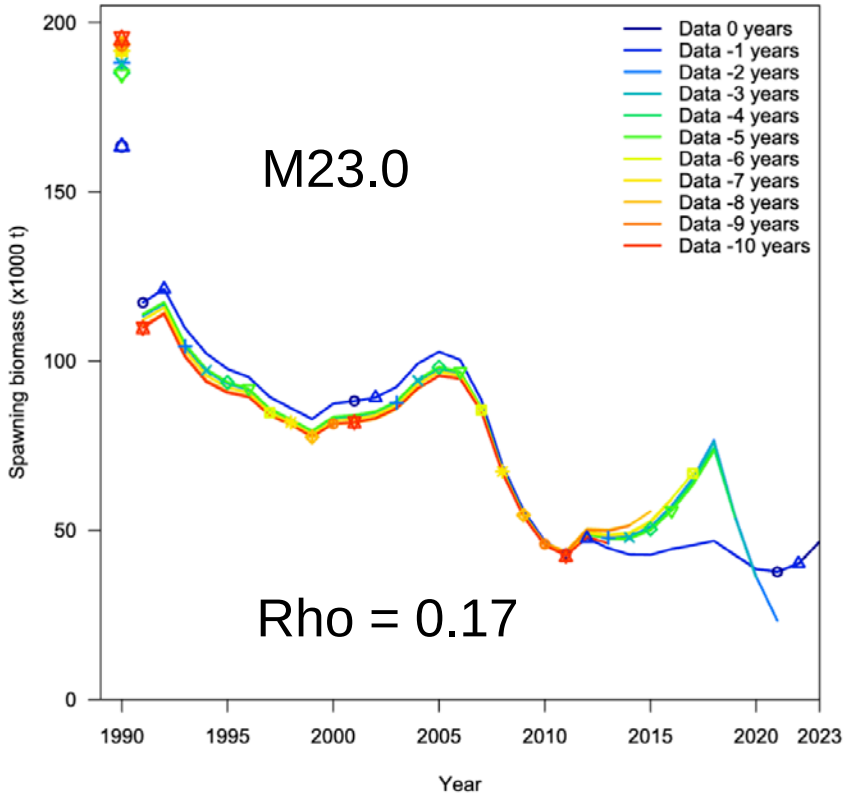
Retrospective patterns

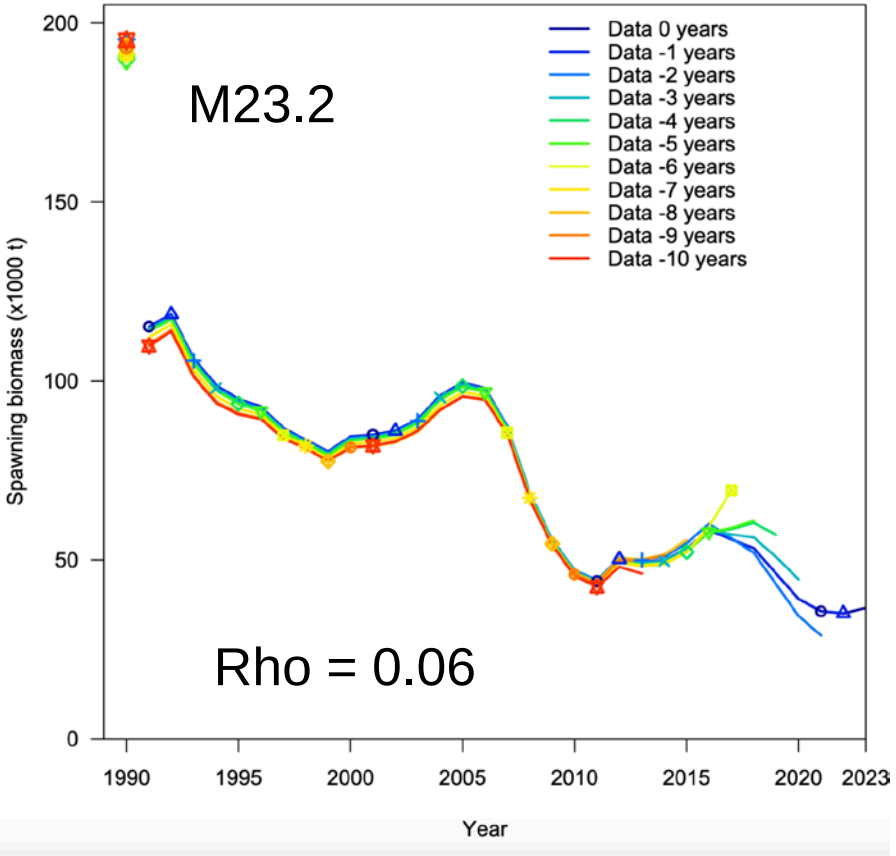
- *Retrospective patterns: systematic changes in estimates of population size … that occur as additional years of data are added to, or removed from, a stock assessment (Hurtado-Ferro et al. 2015).*
- *Can result from time-varying processes unaccounted for in the assessment (e.g. selectivity, natural mortality, and growth), or contradictory (or incomplete) data.*
- *"In general, allowing selectivity, natural mortality, and growth to vary in the model decreased retrospective patterns in estimated spawning biomass, regardless of whether the* ***true*** *time-varying process was allowed to vary." (Szuwalski et al. 2018)*
- *Retrospective patterns can lead to severe errors when providing management advice (particularly when misspecified) (Hurtado-Ferro et al. 2015, Szuwalski et al. 2018).*

Hurtado-Ferro, F., Szuwalski, C. S., Valero, J. L., Anderson, S. C., Cunningham, C. J., Johnson, K. F., Licandeo, R., McGilliard, C. R., Monnahan, C. C., Muradian, M. L., Ono, K., Vert-Pre, K. A., Whitten, A. R., and Punt, A. E. 2015. Looking in the rear-view mirror: bias and retrospective patterns in integrated, age-structured stock assessment models. – ICES, 72: 99–110.

Szuwalski, C.S., Ianelli, J.N. and Punt, A.E., 2018. Reducing retrospective patterns in stock assessment and impacts on management performance. *ICES Journal of Marine Science*, *75*(2), pp.596-609.

Model 23.2 significantly improved retrospective pattern.





Groundtruthing catchability (Q)

The effect of the prior was evaluated by comparing the ‘float’ option in Stock Synthesis rather than estimating a parameter for Q.

The float option calculates an analytical solution for Q.

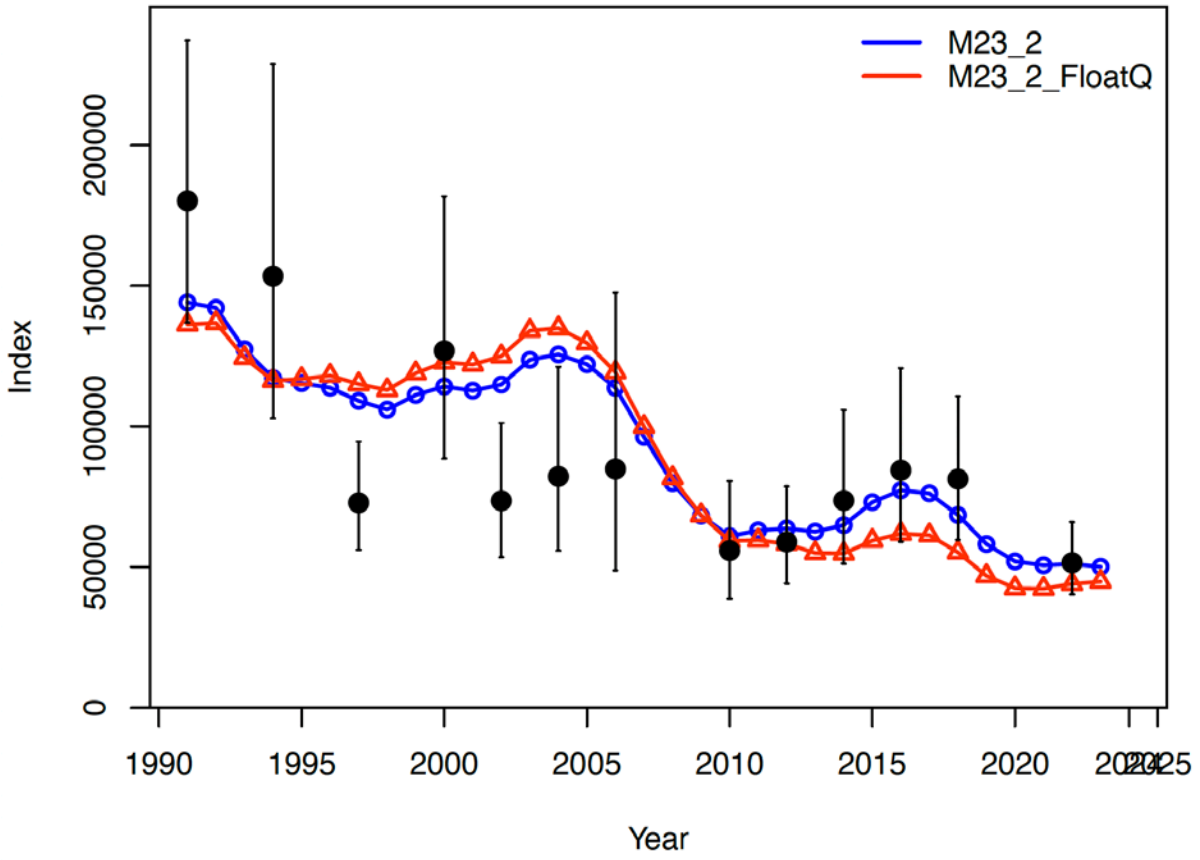
M23.2 with float Q :
Ln Q = -0.0020846. → The analytical Q is 0.9979176.

M23.2 (estimated Q):
Ln Q = -0.002539 → The analytical Q is 0.9974642.

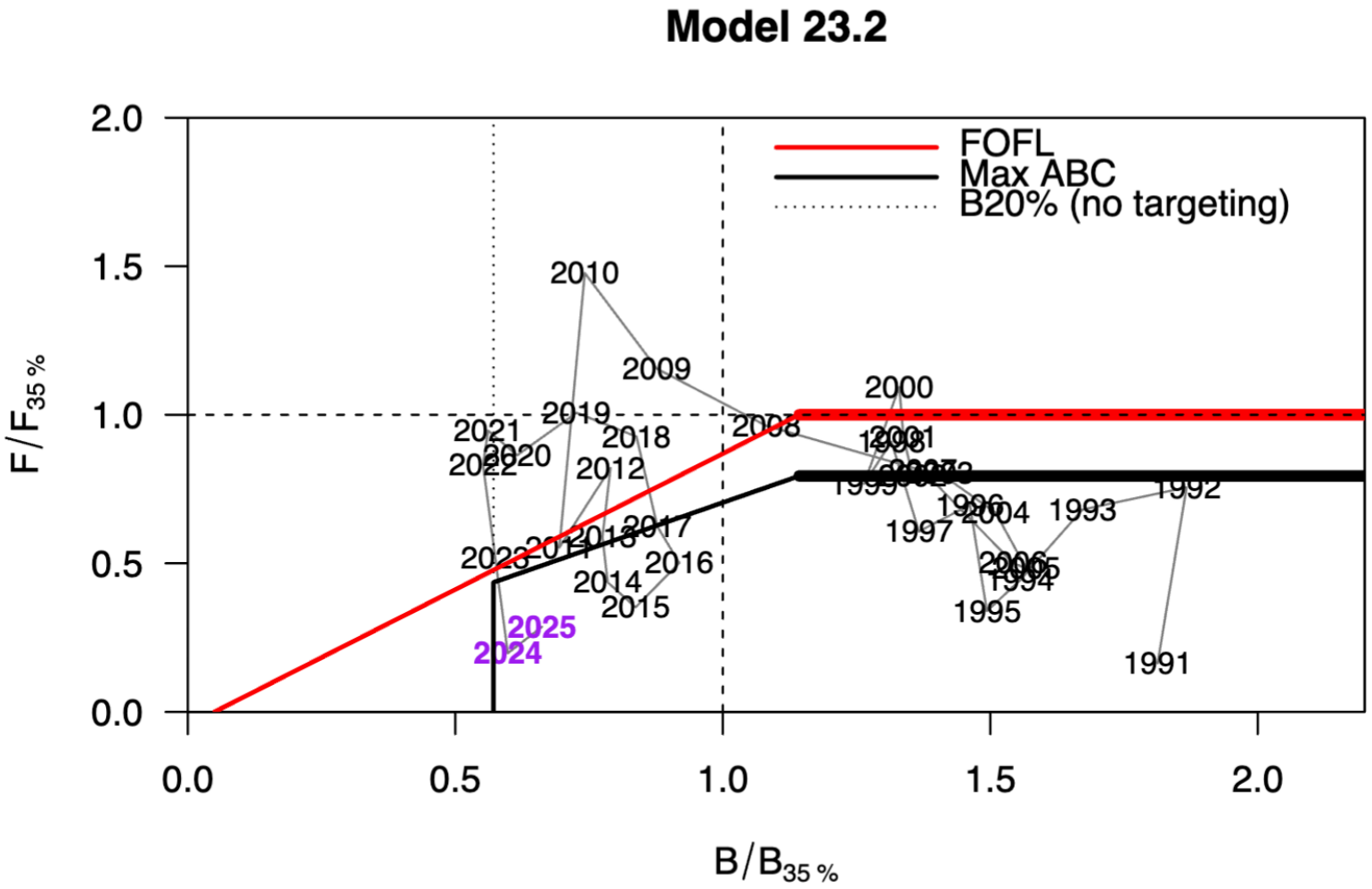
Float Q

Label	M23_2	M23_2_FQ
TOTAL_like	769.871	765.646
Survey_like	-8.21468	-8.02859
Length_comp_like	141.552	136.084
Age_comp_like	639.635	639.76
Parm_priors_like	0.655364	0.599234
Recr_Virgin_millions	24.3493	23.1365
SR_LN(R0)	10.1003	10.0492
SR_BH_steep	1	1
NatM_uniform_Fem_GP_1	0.40351	0.383876
NatM_uniform_Fem_GP_1_BLK2add_1991	-0.083867	-0.0584271
NatM_uniform_Fem_GP_1_BLK2add_2016	0.0838674	0.0584277
L_at_Amax_Fem_GP_1	117.259	116.948
VonBert_K_Fem_GP_1	0.193694	0.194435
VonBert_K_Fem_GP_1_BLK1add_1991	0.00112976	0.00144323
VonBert_K_Fem_GP_1_BLK1add_2004	-0.00112953	-0.001443
SSB_Virgin_thousand_mt	194.596	176.394
Bratio_2021	0.183293	0.16415
SPRratio_2020	0.487824	0.581092

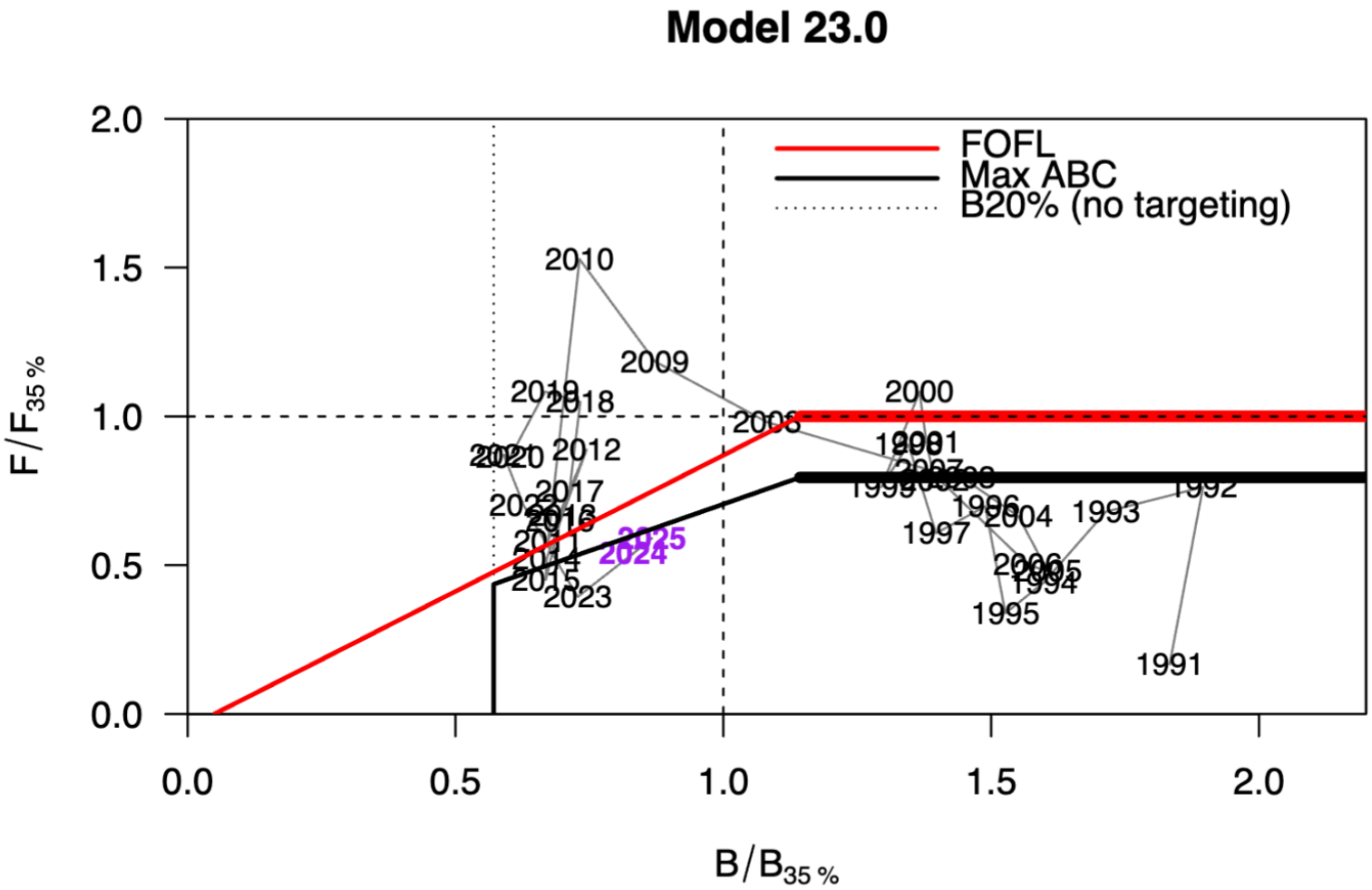
The 'Float Q' model produced slightly lower biomass estimates.



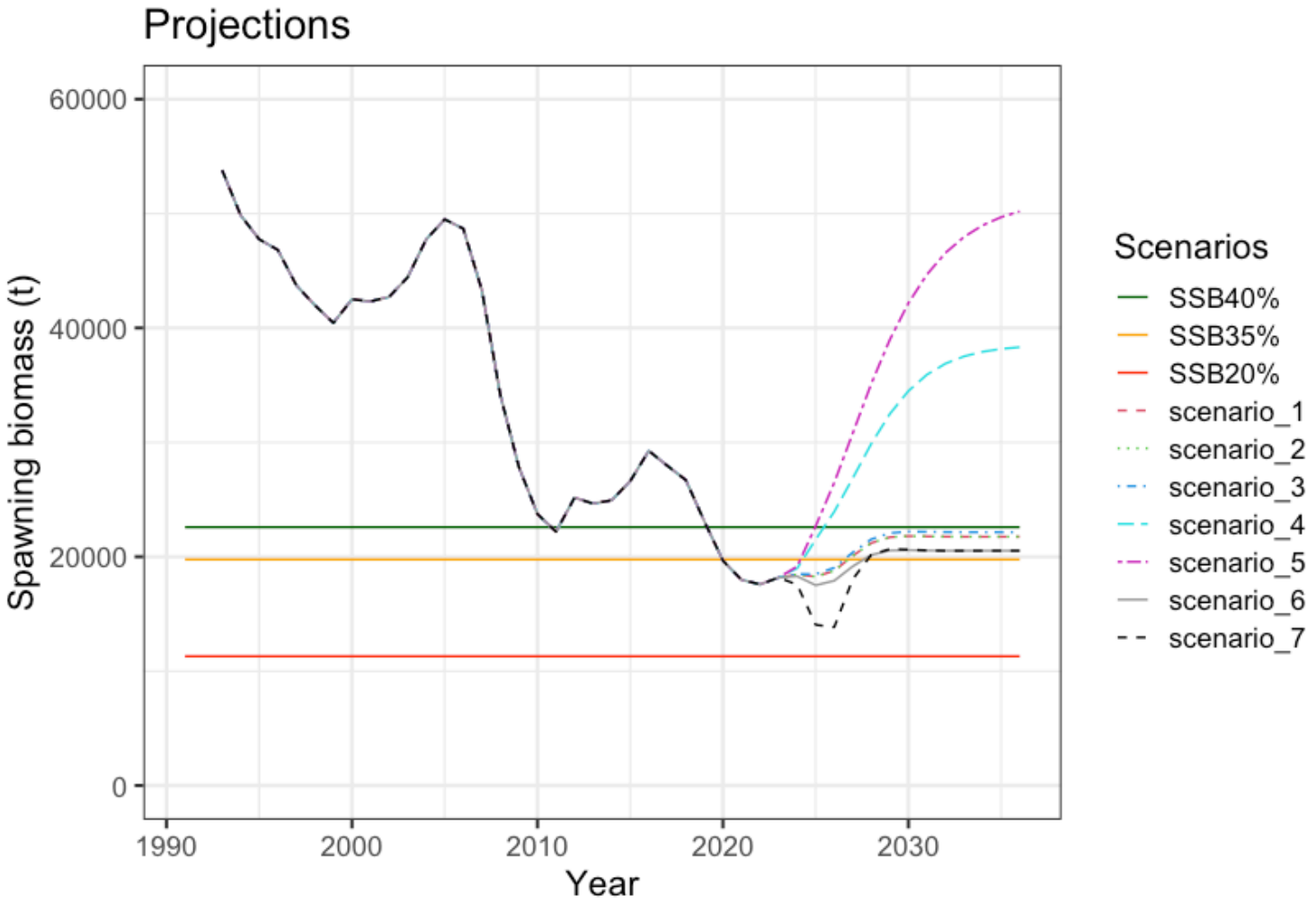
Phase plane for Model 23.2



Phase plane diagram for Model 23.0



Projections for spawning biomass Model 23.2 (2004-2023 biology)



Projections were based on time blocks

1991 - 2023

	Yr	SSB	SSB_PER	SB100	SB40	SB35	F40	F35	C_ABC	C_OFL
1	2024	19027.75	0.27369591	69521.5	27808.6	24332.525	0.237352	0.287902	5991.14	7174.55
2	2025	20161.55	0.29000453	69521.5	27808.6	24332.525	0.279803	0.37641	7717.15	10560.3

2004 - 2023

	Yr	SSB	SSB_PER	SB100	SB40	SB35	F40	F35	C_ABC	C_OFL
1	2024	18687.35	0.33032861	56572	22628.8	19800.2	0.44486	0.5444	10660.3	12732
2	2025	18302.85	0.32353196	56572	22628.8	19800.2	0.421717	0.666244	10214.2	17304.4

2017 - 2023

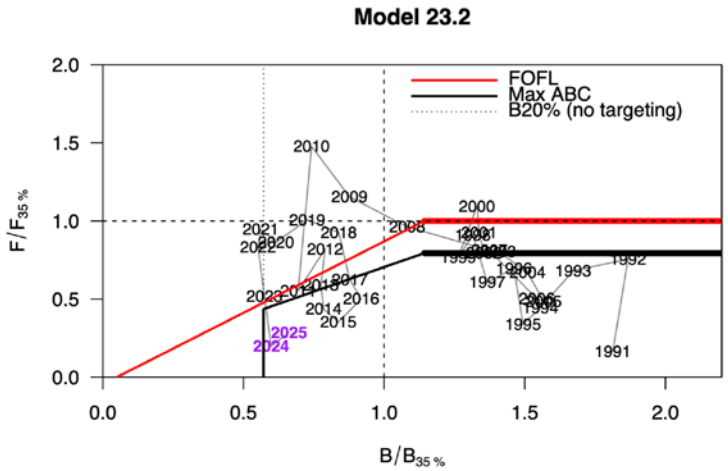
		Yr	SSB	SSB_PER	SB100	SB40	SB35	F40	F35	C_ABC	C_OFL
1											
2	1	2024	17821.9	0.61280706	29082.4	11632.96	10178.84	0.993489	1.26885	20915.5	25133.1
3	2	2025	14164.75	0.48705575	29082.4	11632.96	10178.84	0.993489	1.26885	16712.6	27244.8

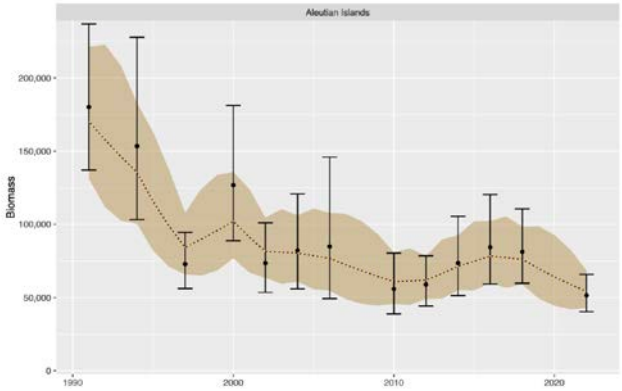
Risk Table

Assessment consideration	Population dynamics	Environmental ecosystem	Fishery performance
Level 1: No concern	Level 2: Major concern	Level 2: Major concern	Level 1: No concern

Risk Table

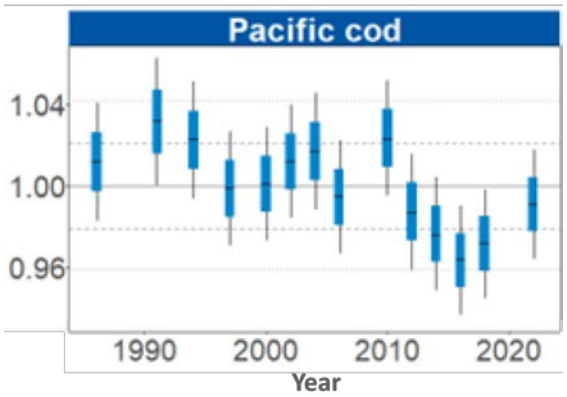
Assessment consideration	Population dynamics	Environmental ecosystem	Fishery performance
Level 1: No concern	Level 2: Major concern	Level 2: Major concern	Level 1: No concern





Risk Table

Assessment consideration	Population dynamics	Environmental ecosystem	Fishery performance
Level 1: No concern	Level 2: Major concern	Level 2: Major concern	Level 1: No concern



Risk Table

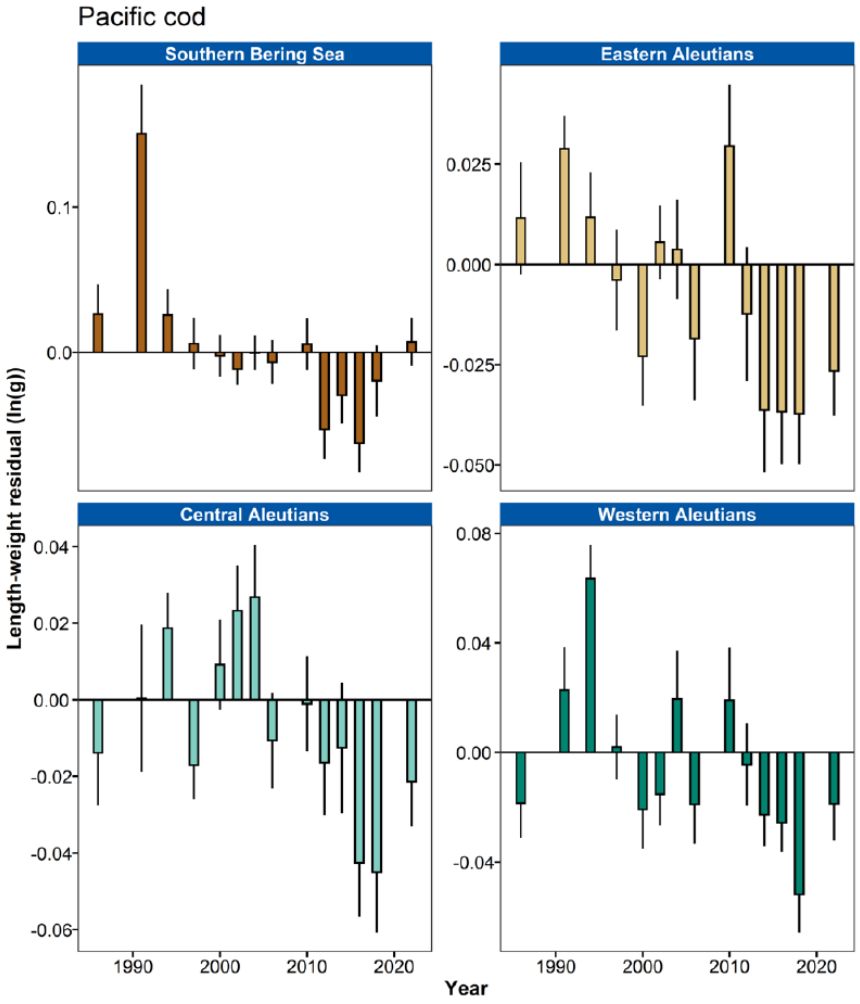
Assessment consideration	Population dynamics	Environmental ecosystem	Fishery performance
Level 1: No concern	Level 2: Major concern	Level 2: Major concern	Level 1: No concern

Risk Assessment – Environmental/Ecosystem

- Lower amount of fish in diet since 2010.
- Lower prey quality -> lower fish condition
- Decreased consumption of Atka mackerel in diet
- Lower body condition seems to be related to diet.
- If consumption rate is increased, would need to eat more to accommodate increased consumption rates.

(O'Leary and Rohan 2022)

Aleutian Islands cod condition has been below average for the past 5 survey years, since 2012



Summary Table for Model 13.4

	As estimated or *specified* *last* year for:		As estimated or *recommended* *this* year for:	
Quantity	2023	2024	2024	2025
M (natural mortality rate)	0.34	0.34	0.34	0.34
Tier	5	5	5	5
Biomass (t)	54,165	54,165	54,166	54,166
F_{OFL}	0.34	0.34	0.34	0.34
$maxF_{ABC}$	0.255	0.255	0.255	0.255
F_{ABC}	0.255	0.255	0.255	0.255
OFL	18,416	18,416	18,416	18,416
$maxABC$	13,812	13,812	13,812	13,812
ABC	13,812	13,812	13,812	13,812
Status	2021	2022	2022	2023
Overfishing	No	n/a	No	n/a

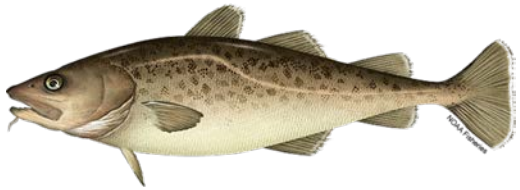
Summary Table for Model 23.2

	As estimated or *specified* *last* year for:		As estimated or *recommended* *this* year for:	
Quantity	2023	2024	2024	2025
M (natural mortality rate)	0.34	0.34	0.32, 0.49	0.32, 0.49
Tier	5	5	3b	3b
Projected total (age 1+) biomass (t)	54,165	54,165	54,611	61,611
Projected female spawning biomass (t)	-	-	18,687	18,302
$B_{100\%}$	-	-	56,572	56,572
$B_{40\%}$	-	-	22,628	22,628
$B_{35\%}$	-	-	19,800	19,800
F_{OFL}	0.34	0.34	0.544	0.666
$maxF_{ABC}$	0.255	0.255	0.445	0.422
F_{ABC}	0.255	0.255	0.445	0.422
OFL	18,416	18,416	12,732	17,304
$maxABC$	13,812	13,812	10,660	10,214
ABC	13,812	13,812	10,660	10,214
Status	2021	2022	2022	2023
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Summary Table for Model 23.0

Quantity	As estimated or *specified last* year for: 2023	2024	As estimated or *recommended this* year for: 2024	2025
M (natural mortality rate)	0.34	0.34	0.34	0.34
Tier	5	5	3b	3b
Projected total (age 1+) biomass (t)	54,165	54,165	75,238	80,120
Projected female spawning biomass (t)	-	-	26,602	27,728
$B_{100\%}$	-	-	79,980	79,980
$B_{40\%}$	-	-	31,992	31,992
$B_{35\%}$	-	-	27,993	27,993
F_{OFL}	0.34	0.34	0.445	0.487
$maxF_{ABC}$	0.255	0.255	0.363	0.398
F_{ABC}	0.255	0.255	0.363	0.398
OFL	18,416	18,416	15,311	17,880
$maxABC$	13,812	13,812	12,757	14,955
ABC	13,812	13,812	12,757	14,955
Status	2021	2022	2022	2023
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Questions?

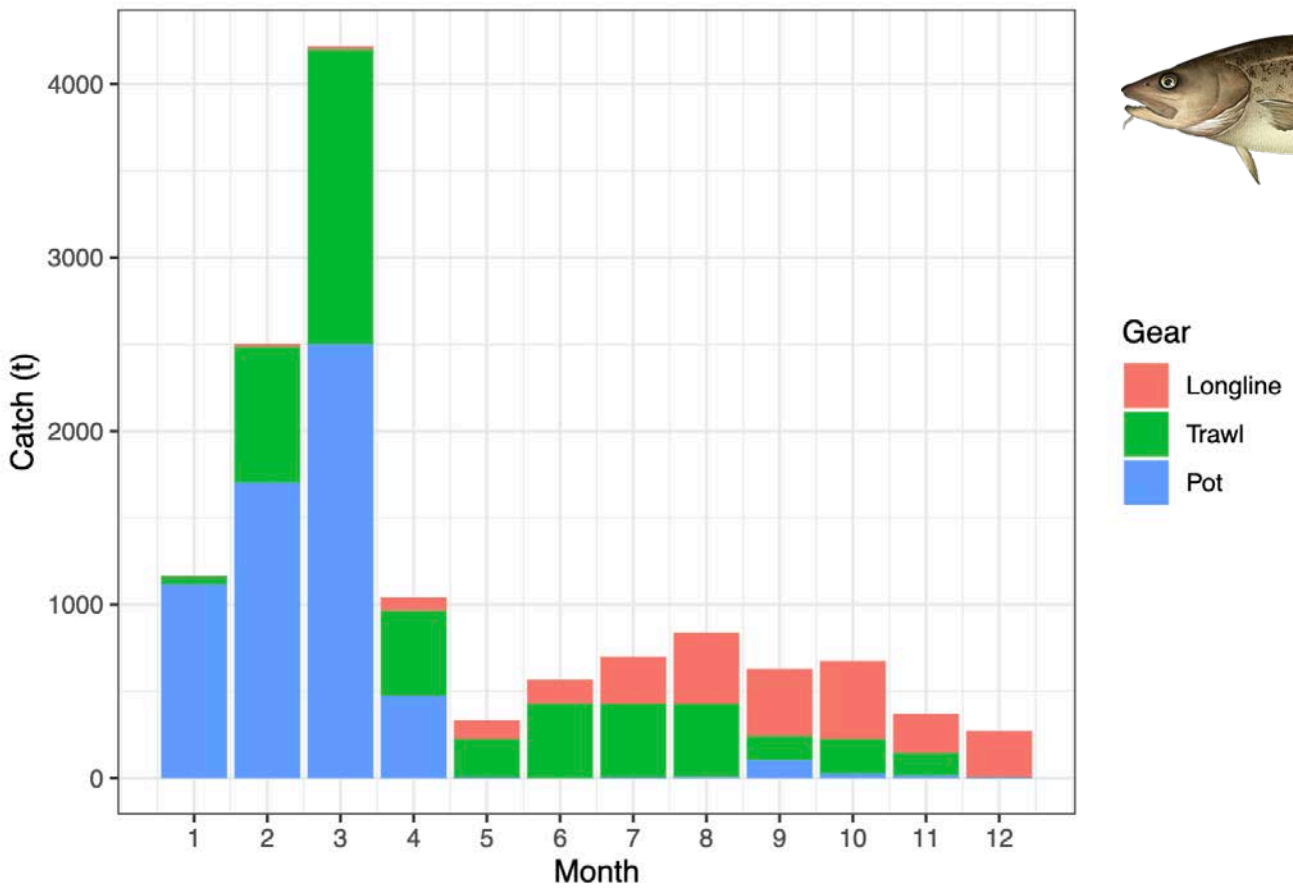


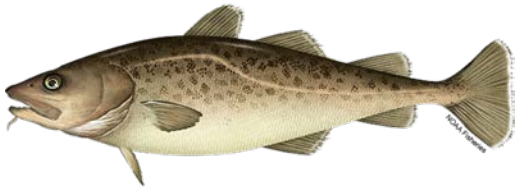
Effective sample size calculated using methodology of Hulson et al. (2022)

Year	Number of aged fish	Number of hauls	Effective sample size
1991	919	121	39
1994	1174	150	25
1997	845	99	67
2000	828	111	153
2002	1270	173	162
2004	775	107	169
2006	754	105	105
2010	673	94	156
2012	599	83	126
2014	557	76	153
2016	681	95	142
2018	575	80	197
2022	765	192	253

*consistent with EBS and GOA Pacific cod assessments.

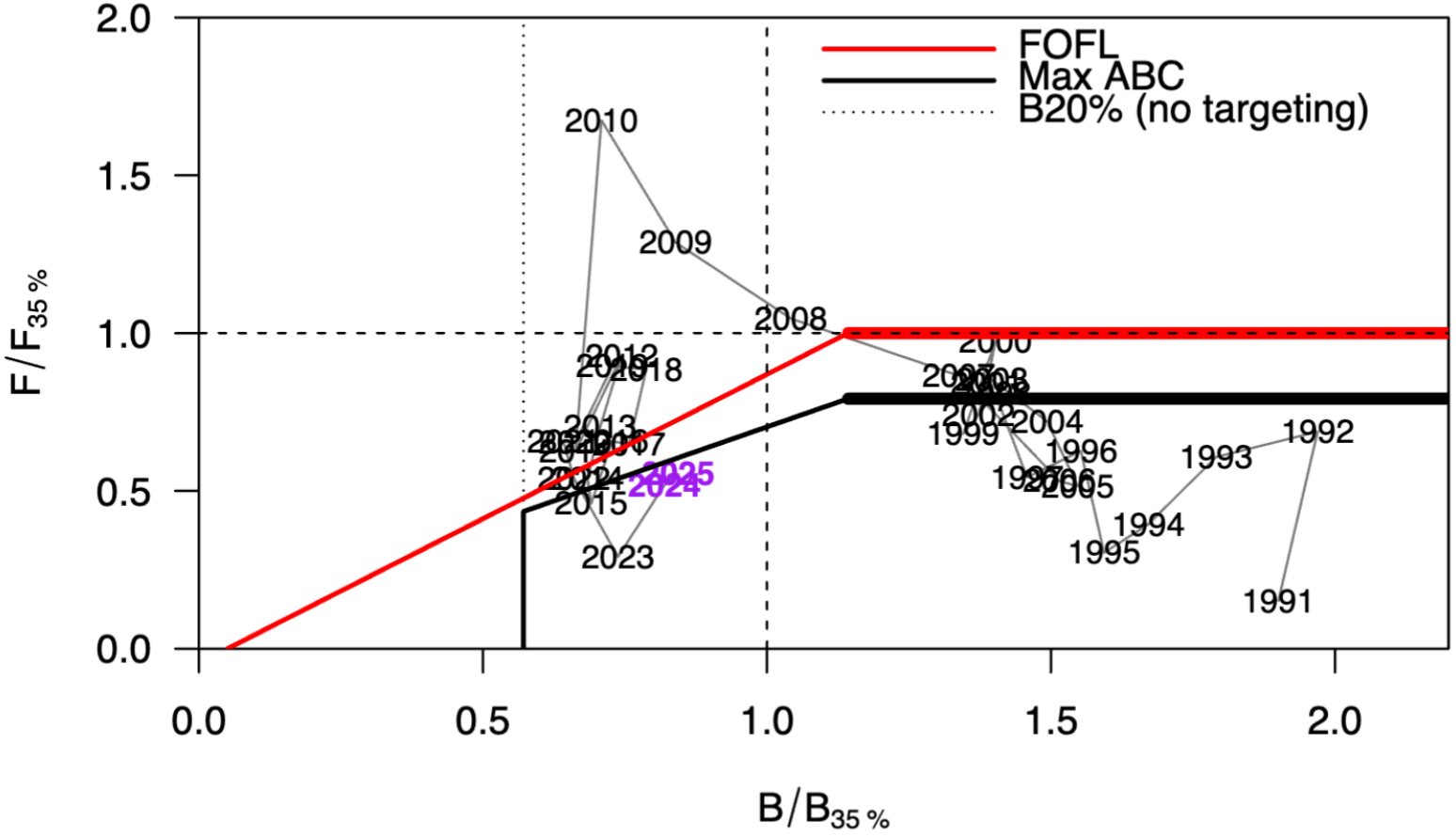
Aleutian Islands Pacific cod average catch (t) by month per year and gear from January 1, 2019 - October 20, 2023.





Gear
Longline
Trawl
Pot

Model 23.1


FOFL
Max ABC
B20% (no targeting)
2010
2009
2008
2012
2018
2013
2015
2023
2024
2025
1999
2004
1996
1992
1993
1994
1995
1991
2005
F/F35 %
B/B35 %
0.0
0.5
1.0
1.5
2.0

Risk Assessment – Environmental/Ecosystem

- Cod condition has now remained below average since 2012.
- Diet includes less Atka mackerel, previously one of their primary prey items, over the past few years.
- Declining biomass and body condition of Atka mackerel in these areas (O'Leary and Rohan 2022), potentially providing lower quality prey for Pacific cod.
- Squid and shrimp have increased in relevance across the board, as have invertebrates in general. Diets seem to now be dominated by invertebrates, as opposed to fish. Walleye pollock remains below average biomass and condition.