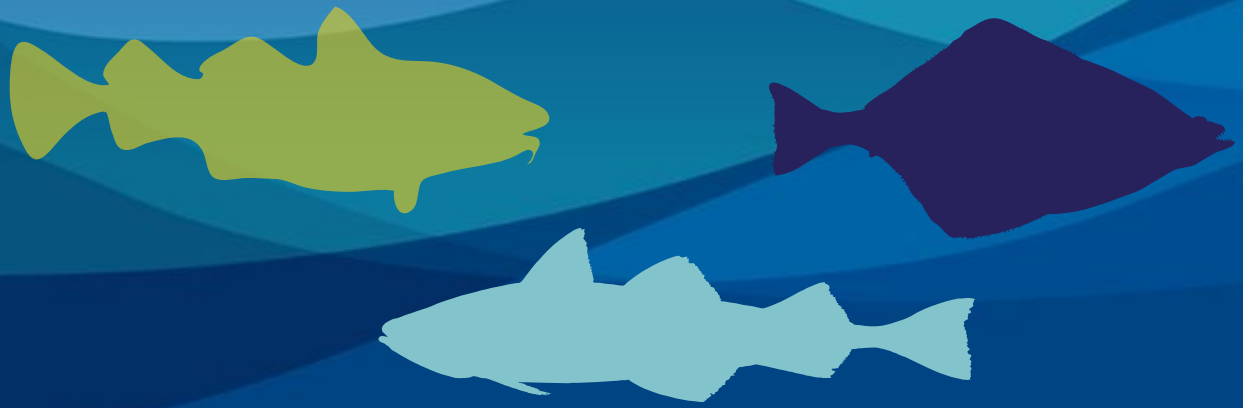
Bering Sea climate-enhanced multi-species stock assessment



Nov. 2024

Kirstin K. Holsman
Jim Ianelli, Kerim Aydin, Grant Adams, Kalei Shotwell, Steve Barbeaux, Kelly Kearney, Anna Sulc

https://github.com/kholsman/2024_Multispp_assessment

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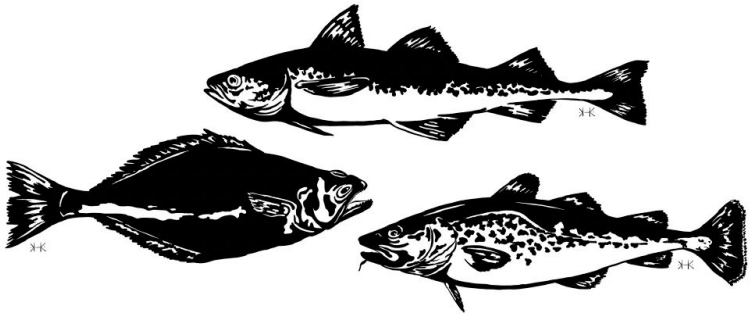
2024 Climate-enhanced multispecies stock assessment for walleye pollock, Pacific cod, and arrowtooth flounder in the eastern Bering Sea

Kirstin K. Holsman, Jim Ianelli, Kalei Shotwell, Steve Barbeaux,
Kerim Aydin, Grant Adams, Kelly Kearney, Anna Sulc, Sophia Wassermann



November 2024 | kirstin.holsman@noaa.gov Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Seattle, Washington 98115

Suggested citation: *Holsman, K. K., J. Ianelli, K. Shotwell, S. Barbeaux, K. Aydin, G. Adams, K. Kearney, A. Sulc, S Wassermann (2024) Climate-enhanced multispecies stock assessment for walleye pollock, Pacific cod, and arrowtooth flounder in the eastern Bering Sea. North Pacific Fishery Management Council, Anchorage, AK.*

Two models presented each year:

- SSM : without trophic interactions (single-species mode)
- MSM : with trophic interactions (multi-species mode)

Produced annually 2016 - present

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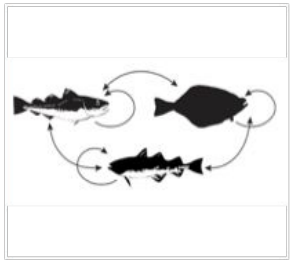
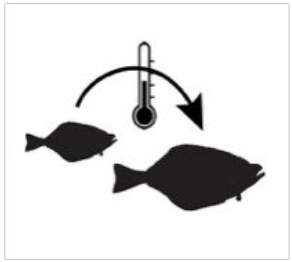
EBS CEATTLE

Mortality



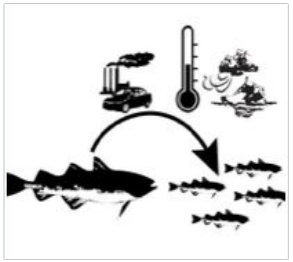
- Empirical diets
- Bioenergetics

Weight @ Age



- Empirical
- VonB with Temp

Rec



- Climate-S/R
- S/R
- mean R

HCRs

- Climate ABC
- MMSY
- MEY
- SPR
- Aggregate MSY

Plan Team and SSC comments

Plan Team recommendations from Nov. 2023 included 'the author intends to communicate with stock assessment authors earlier in next year's assessment cycle to help facilitate risk assessment, which is further recommended by the Team".

- *CEATTLE team members have been working to improve the flow of advice to the risk table teams, in this year that included providing early results to Ebbett Siddon to provide context for discussions. Additional workflow and streamlining approaches are being discussed as part of operationalizing the Multispp assessment*

Plan Team and SSC comments

The SSC agrees with the BSAI GPT's proposal in their presentation to move the multi-species model out of the pollock stock assessment, where it has been included as an appendix since it was first developed. Instead, they suggested it would be a separate chapter listed in parallel with the ESR, as it applies to multiple stocks and informs the ESRs.

- *Done this year (2024); further advancements plan for 2025*

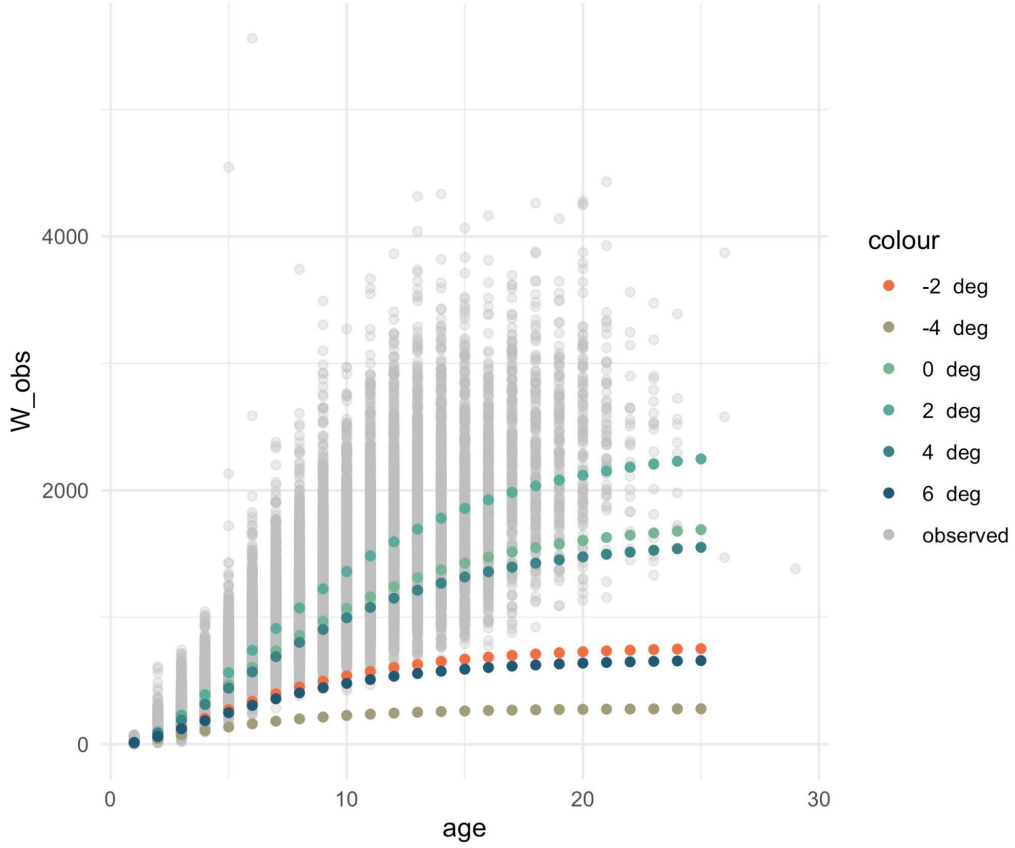
The SSC recognizes the multi-species model as a 'research model' and therefore recommends placing information that appears comparable to a stock assessment specifications table in a regular table (at the end of the document) in order to avoid confusion.

- *Table moved to further into the document*

The SSC supports the multi-species model authors' plan to work with individual assessment authors early in the process to facilitate incorporation of those results into stock assessments.

- *Ongoing efforts to do this include a CEATTLE team approach*

Weight at Age



- Hist: Empirical used when avail; missing yrs have vonBT (currently updating with new TMB version of *vonBT()*)
- Projections: VonBT
- https://github.com/NOAA-REEM/vonBEE

Holsman & Aydin 2015

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Plan Team and SSC comments

Weight-at-age in the multi-species model is temperature driven based on a bioenergetic model. It would be useful to compare these estimates to empirical weights-at-age or the random effects model estimates of weight-at-age in the main pollock assessment.

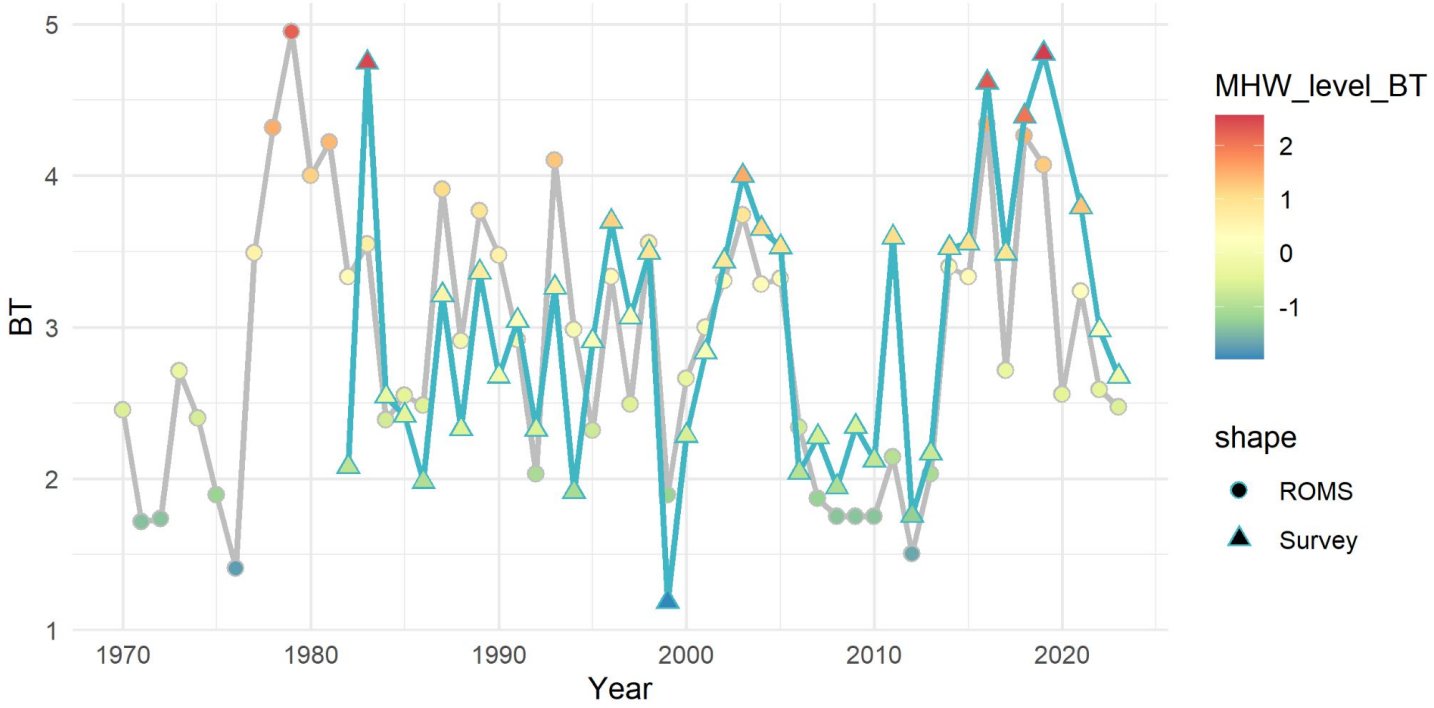
- This work is planned for 2025 under CEFI and in coordination with development of a climate-enhanced TMB standalone model (vonBEE) available here: https://github.com/NOAA-REEM/vonBEE

Consider how output from the multispecies model may best be interpreted independently from results of the actual stock assessment without drawing inference from the same data twice.

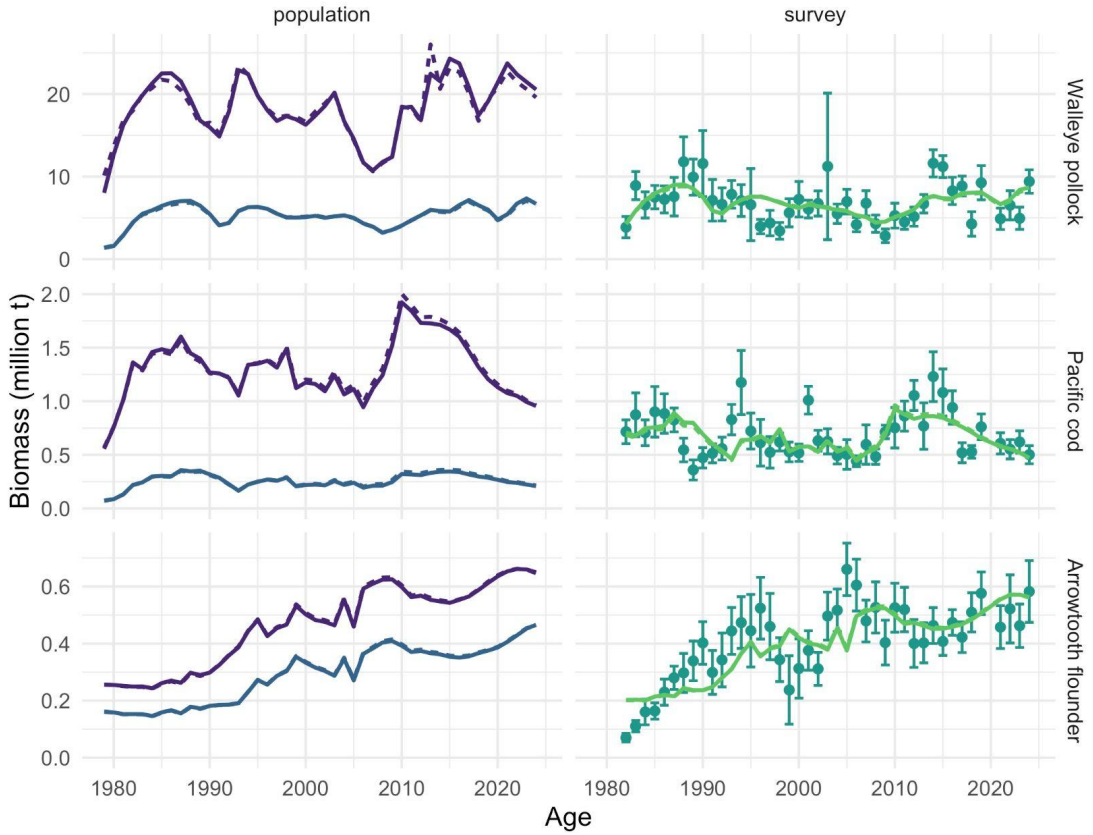
- Continued effort to focus on capturing climate and other ecosystem driven changes in the multispecies assessment to compliment status quo stock assessments in the EBS and GOA. This includes aligning data inputs and structure as much as possible.

ROMS output

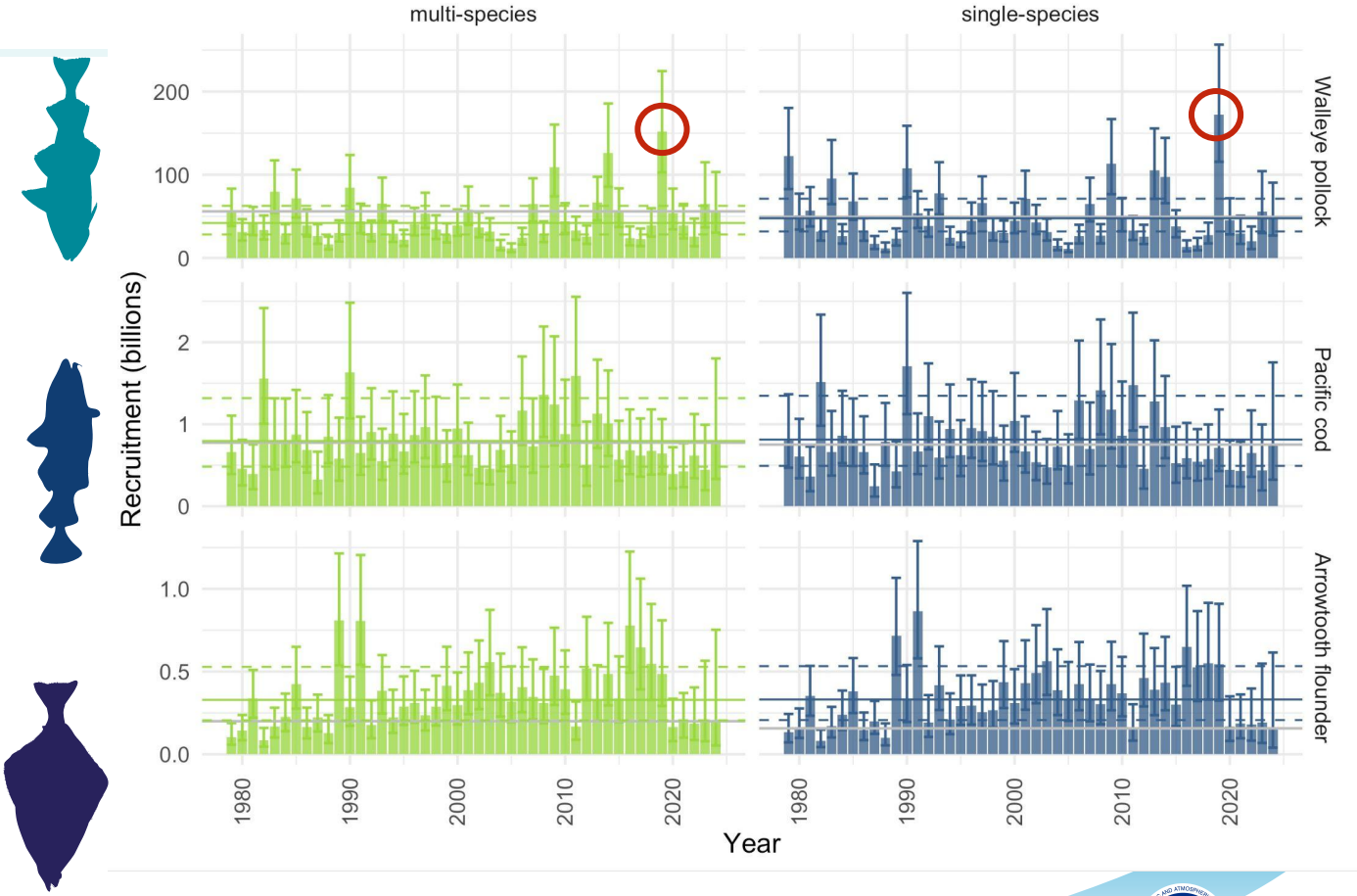
https://data.pmel.noaa.gov/aclim/thredds/catalog/files.html

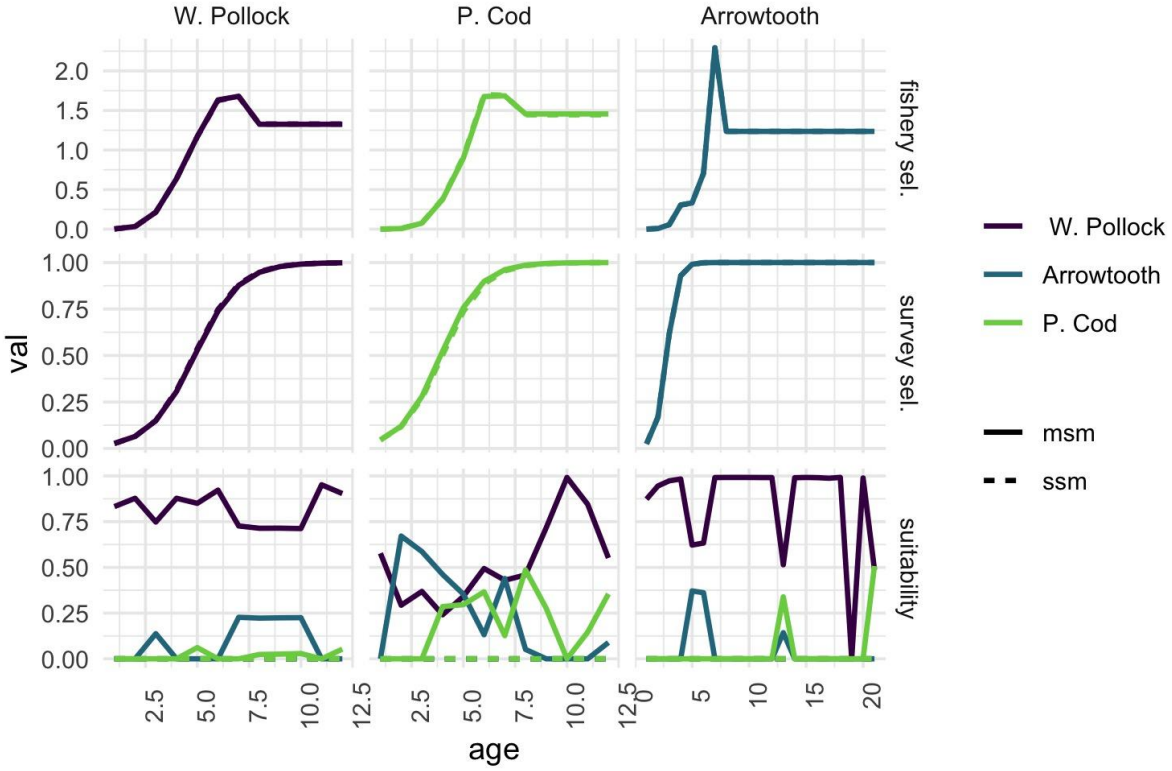


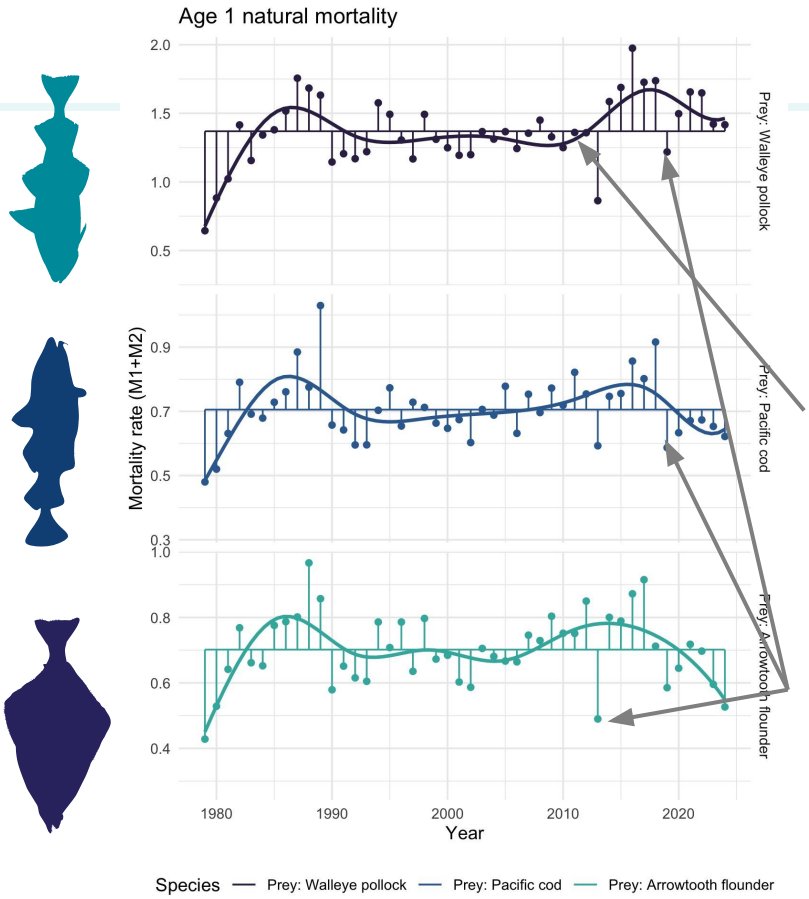
Biomass


population
survey
Walleye pollock
Pacific cod
Arrowtooth flounder
Biomass (million t)
Age
variable
totB
SSB
survey
survey (estimate)
type
multi-species
single-species

Recruitment

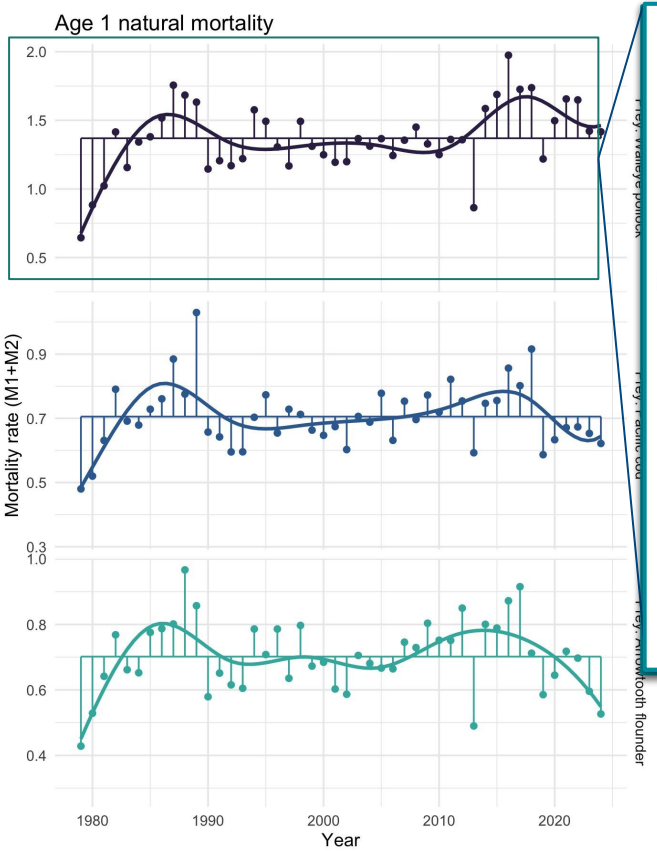


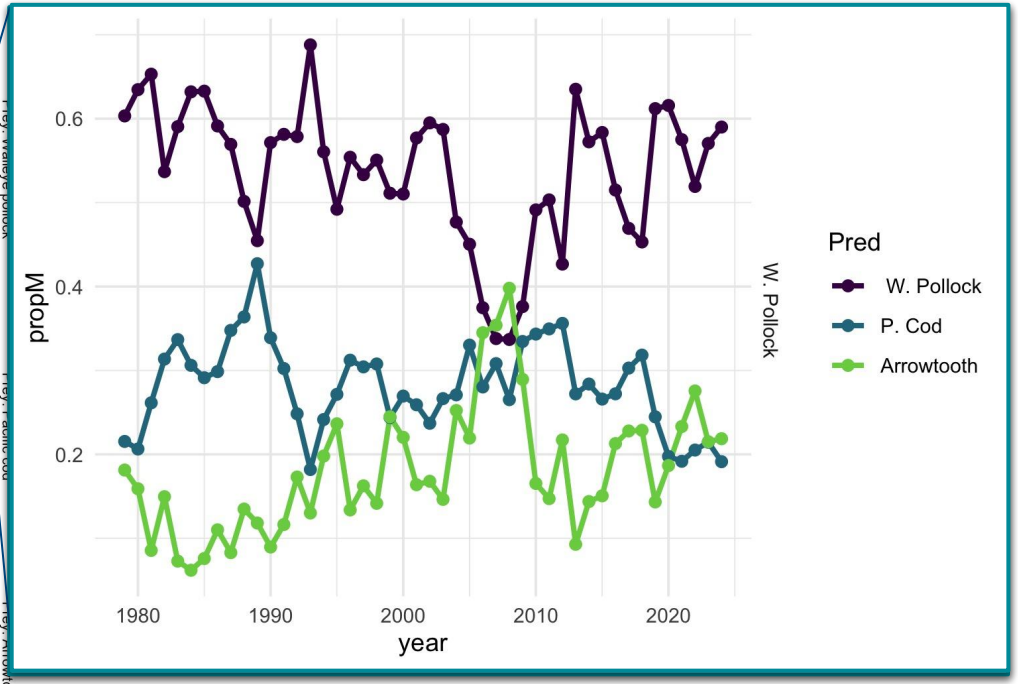

W. Pollock
P. Cod
Arrowtooth
fishery sel.
survey sel.
suitability
val
age
W. Pollock
Arrowtooth
P. Cod
msm
ssm



M1 in single species (CEATTLE) model = avg(M1+M2) from multispecies model

Predation mortality decreased in 2023

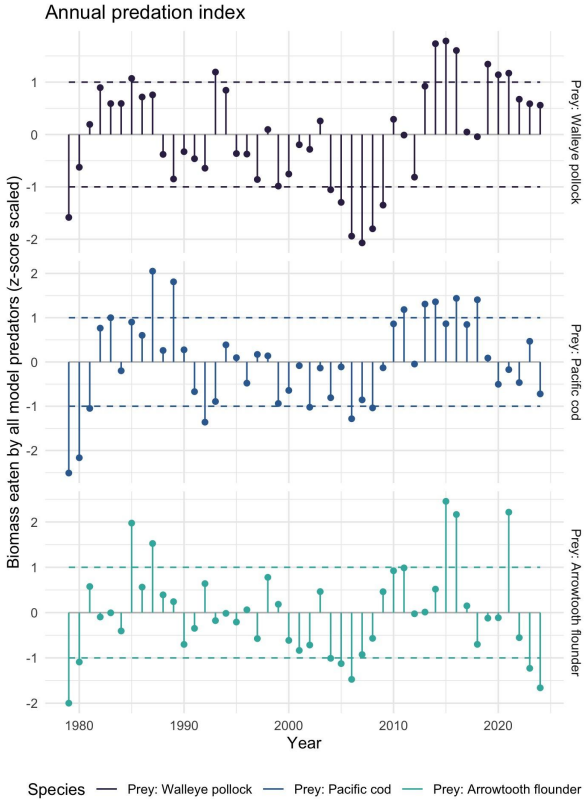




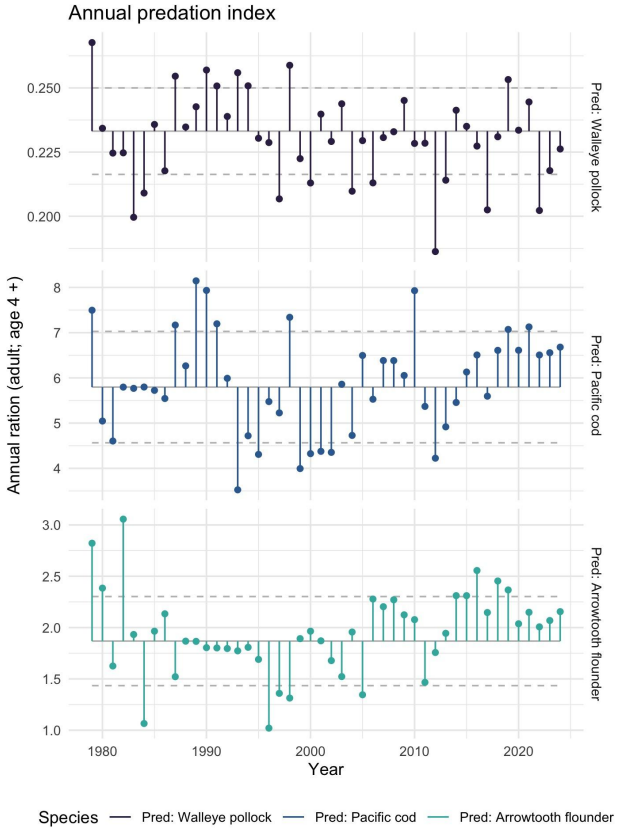
walleye pollock

ESPs

Use this if: need index of mortality for plk, pcod, or atf



Use this if: need index of plk, pcod, atf eating other prey



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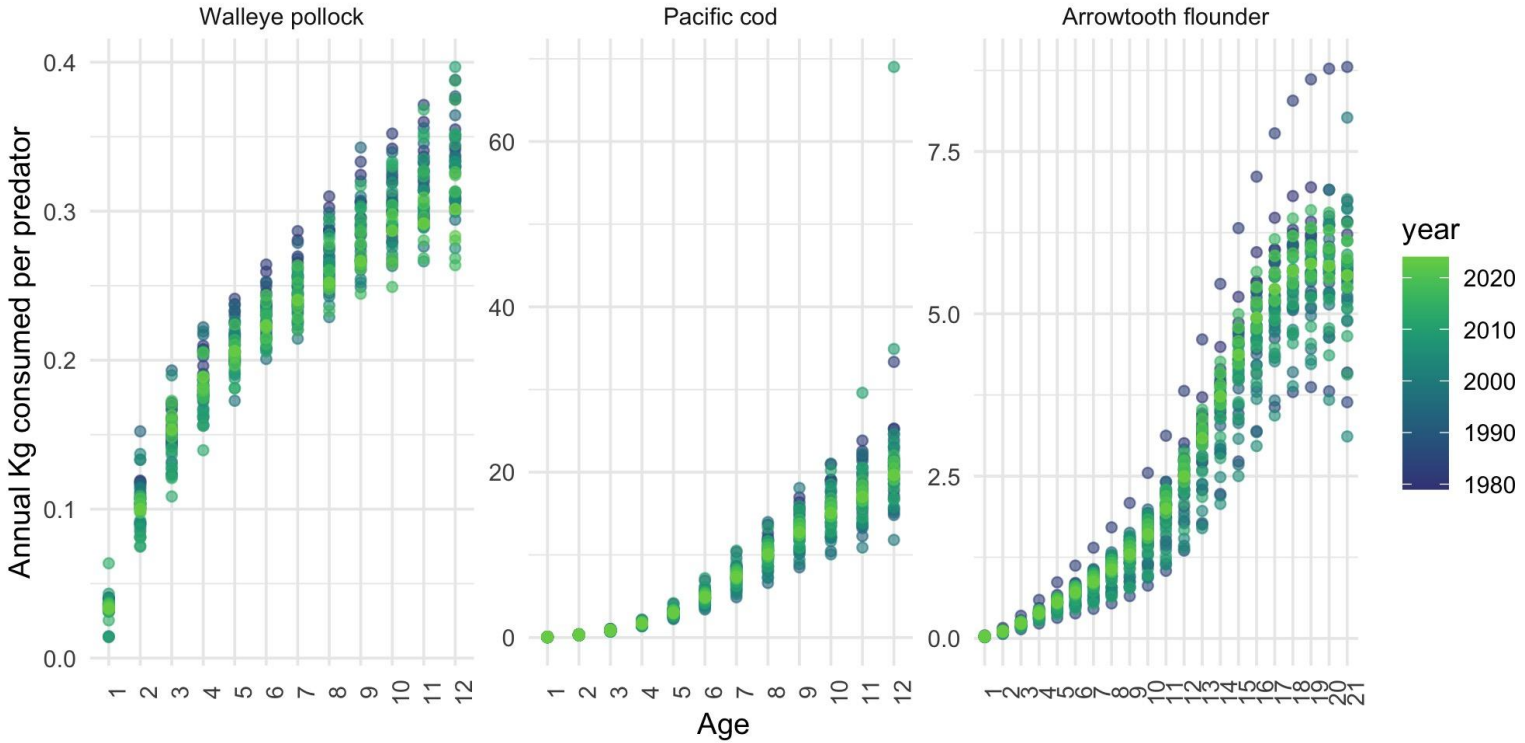
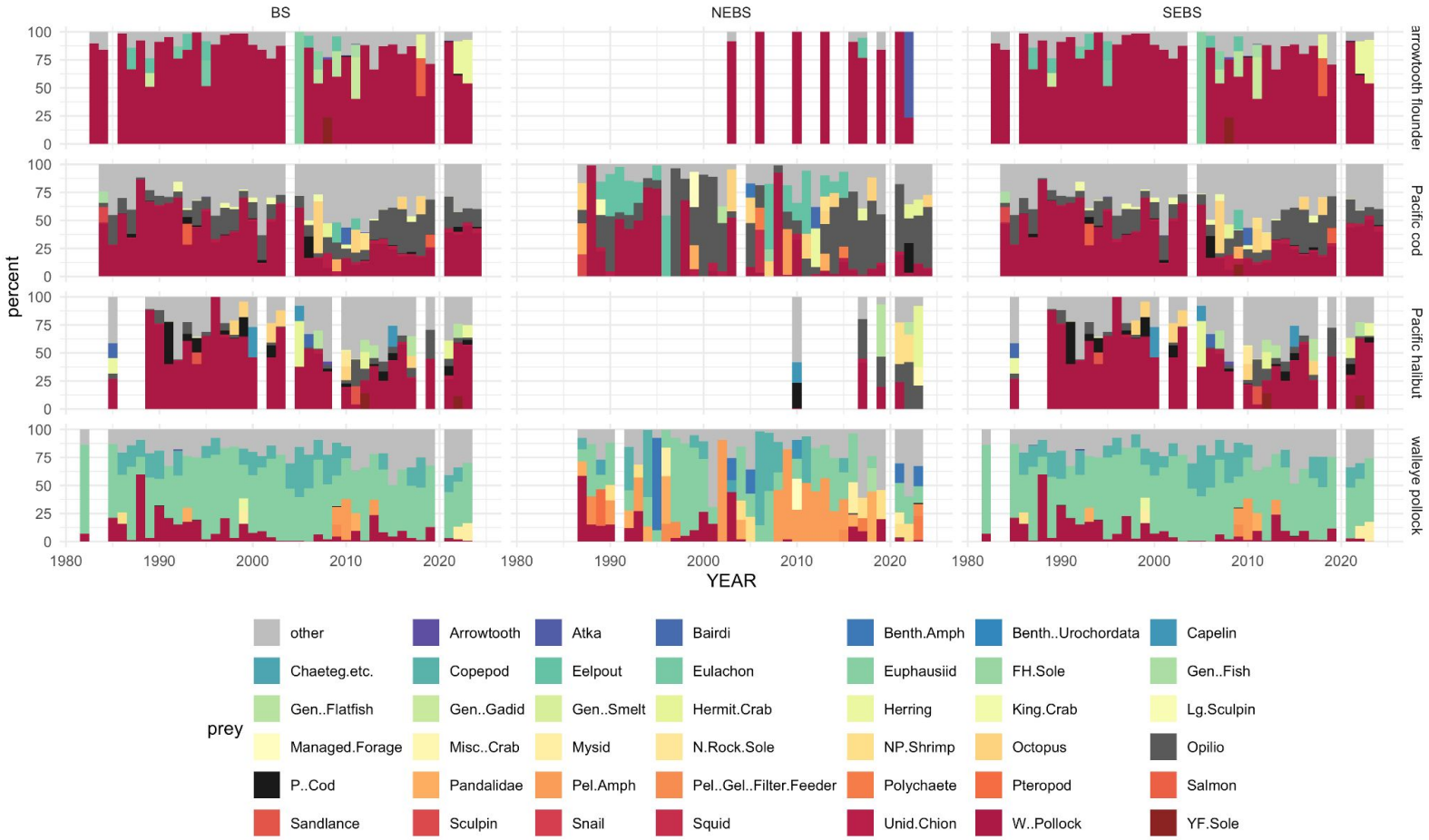
Annual estimates of prey consumed per fish





Data from food habits lab

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ESP indices expanded

Diet database & survey CPUE

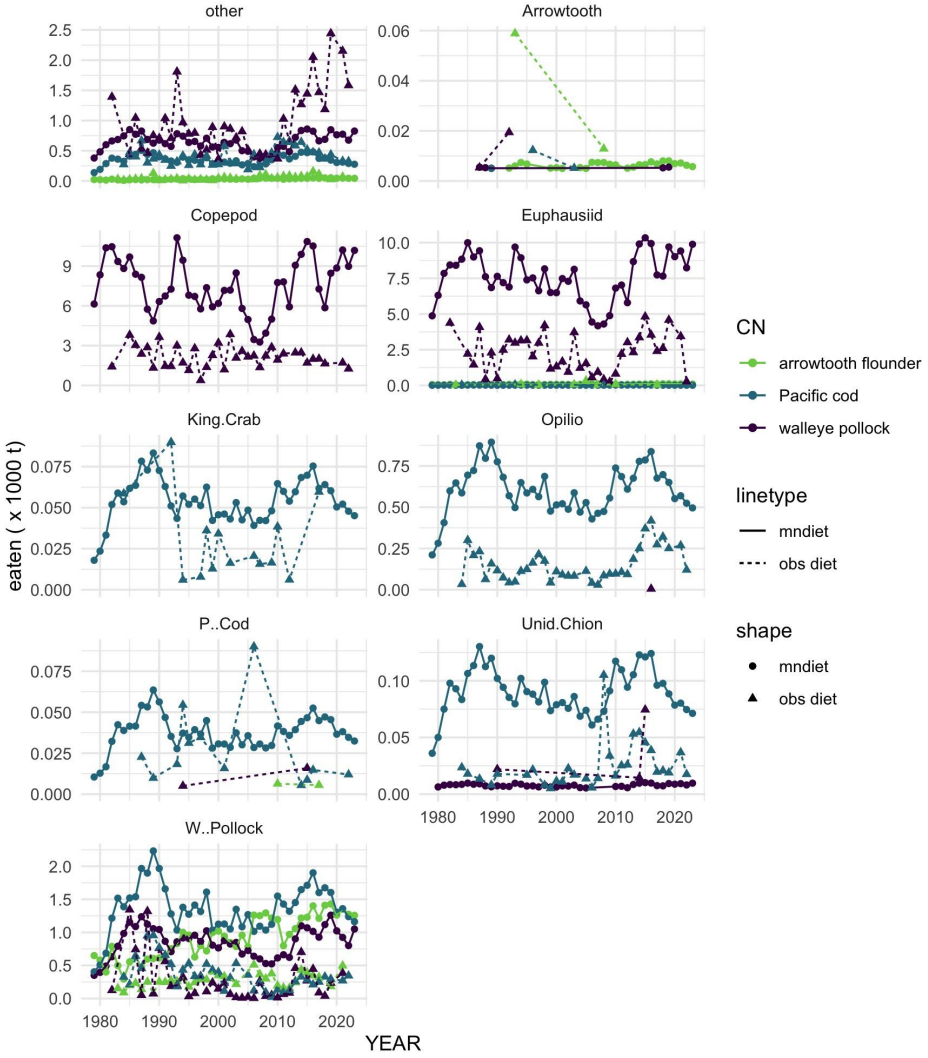
CEATTLE outputs

$$\text{sum}(\text{avgP}_{i,j,k,y} * \text{L2A}) * \text{AvgN}_{a,k,y} * C_{a,k,y}$$

Biomass weighted avg prop of prey i in diet of pred size j

Ration (kg pred^{-1} yr^{-1})

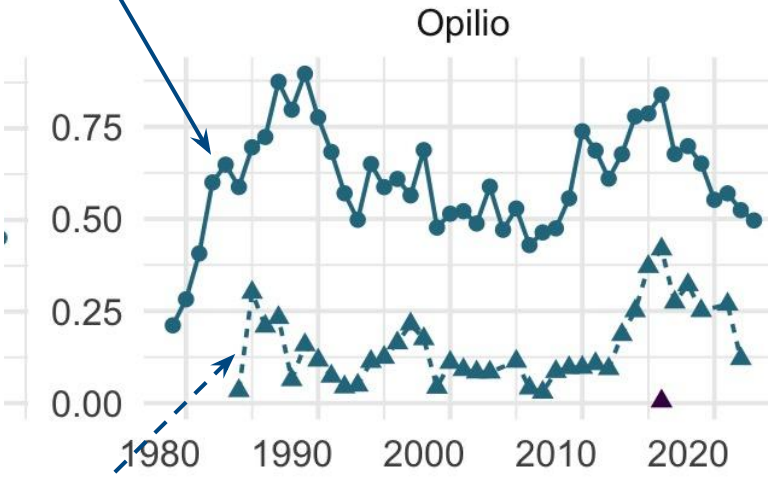
Holsman et al. in prep



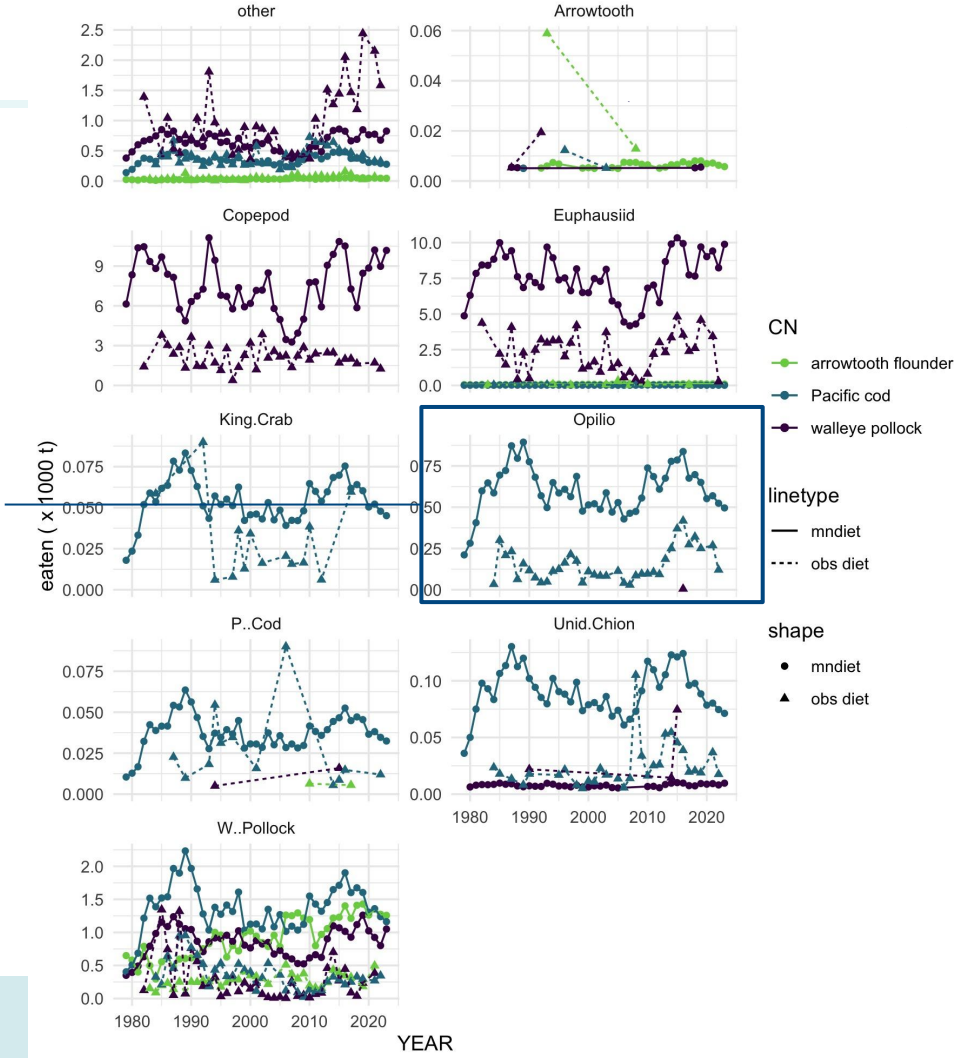
ESP indices expanded

$sum(avgP_{i,j,k,A} * L2A) * AvgN_{a,k,y} * C_{a,k,y}$

A = cold, warm, avg T years



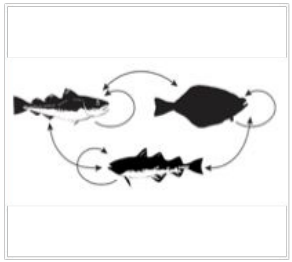
$sum(avgP_{i,j,k,y} * L2A) * AvgN_{a,k,y} * C_{a,k,y}$



Output available as .Rdata

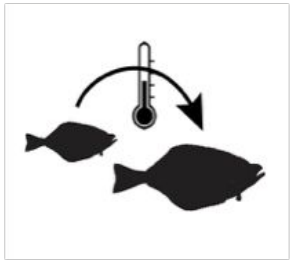
EBS CEATTLE

Mortality



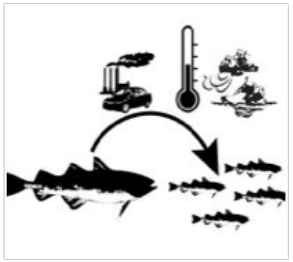
- Empirical diets
- Bioenergetics

Weight @ Age



- Empirical
- VonB with Temp

Rec



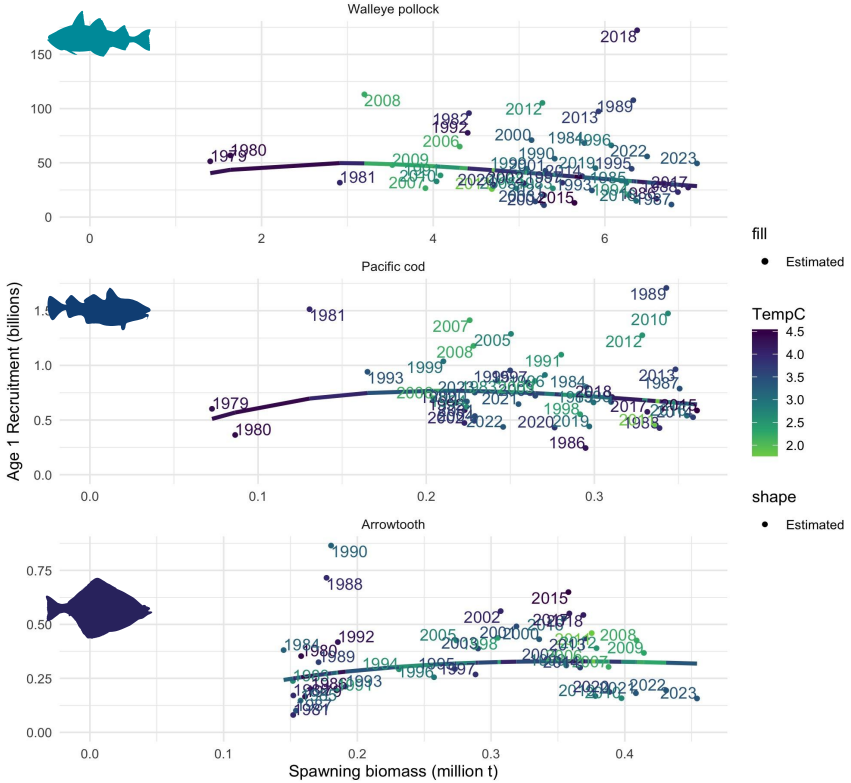
- Climate-S/R
- S/R
- mean R

HCRs

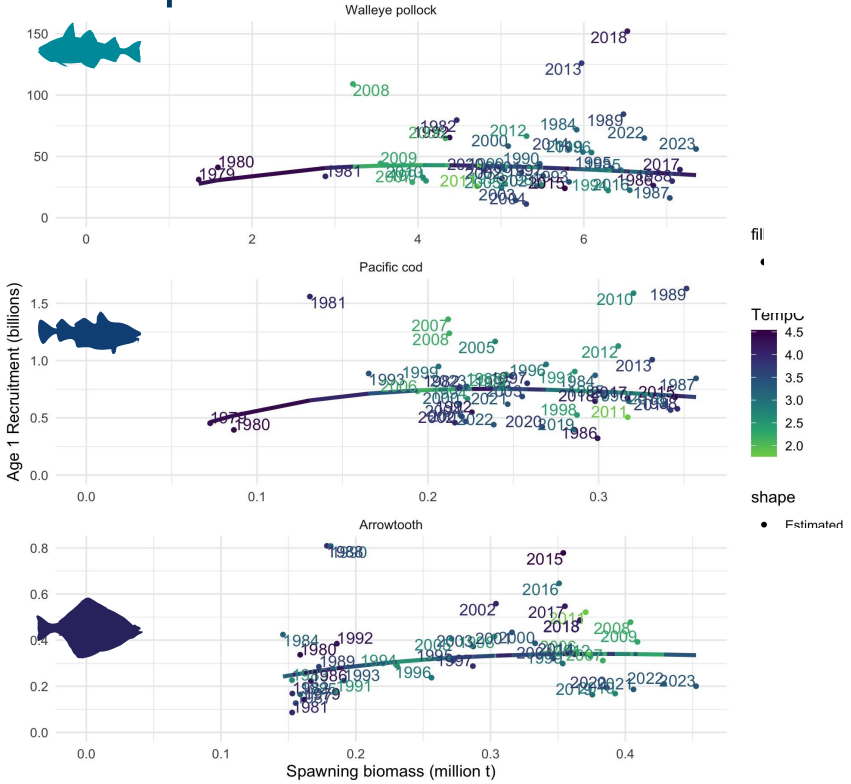
- Climate ABC
- MMSY
- MEY
- SPR
- Aggregate MSY

Recruitment (note: scales vary)

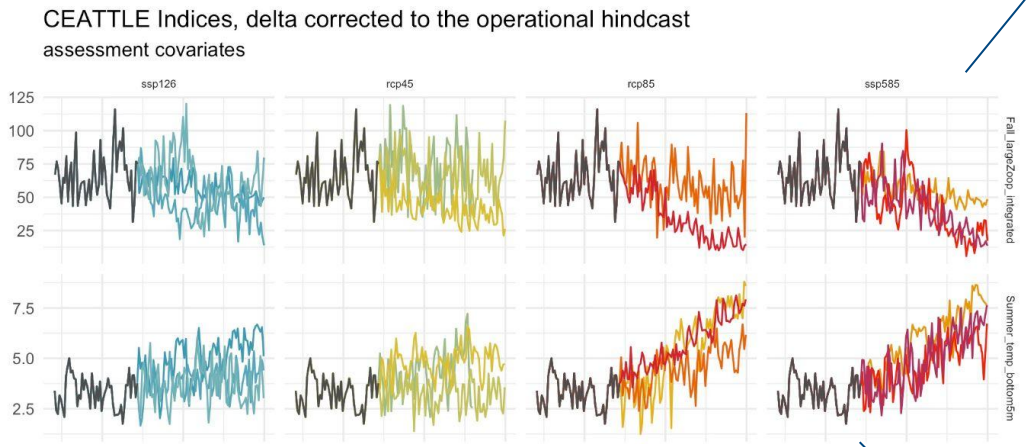
Single-species

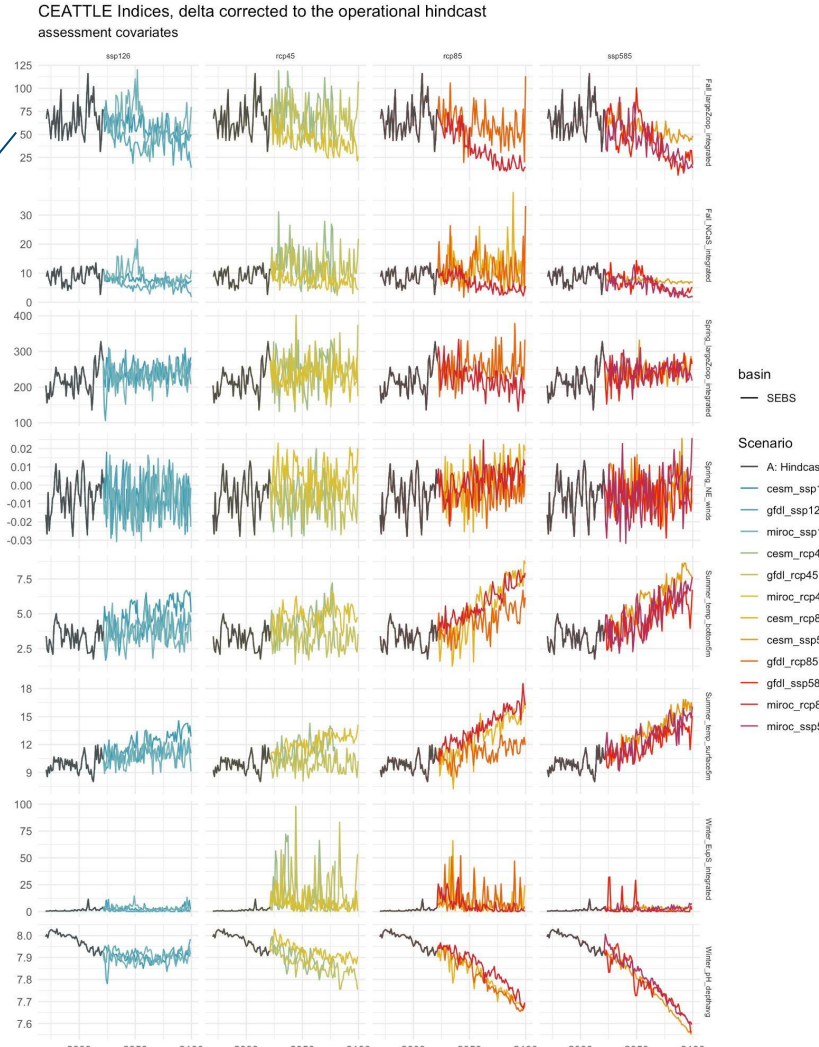


Multispecies



Recruitment covariates



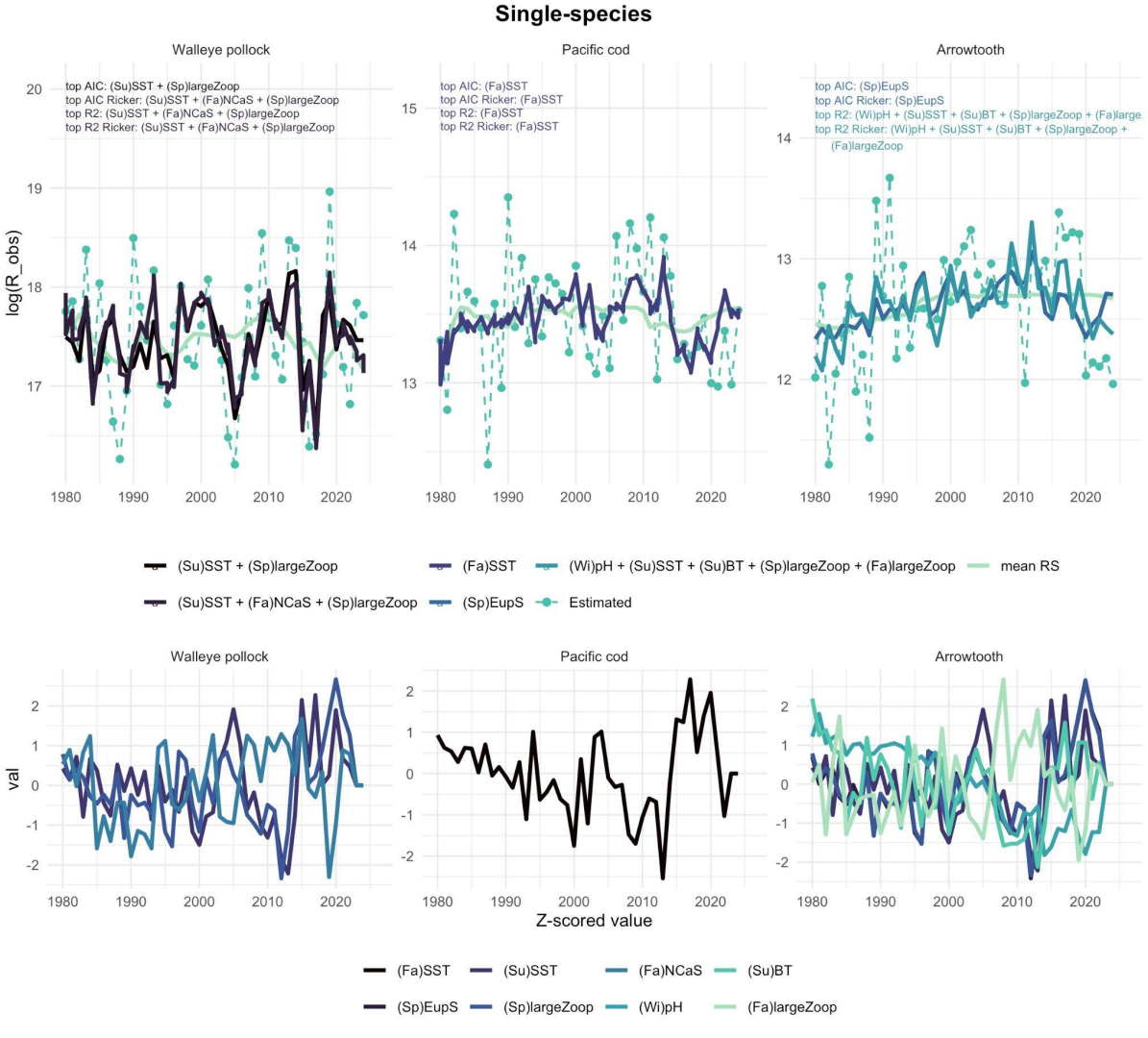


ACLIM indices

Single sp mode

AICc used to select top set of models

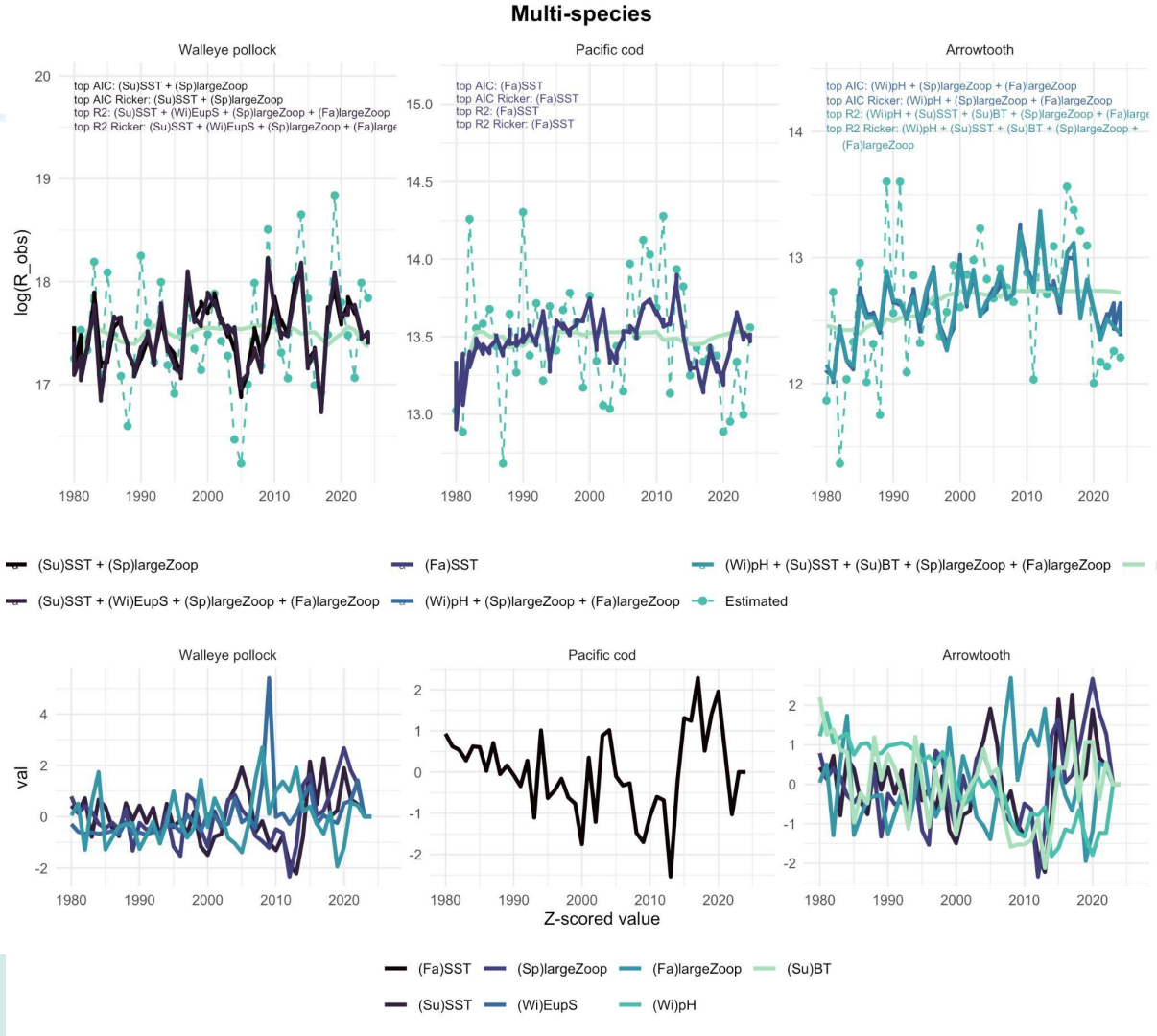
Top set and top R2 reported in the Assessment



Multi-sp mode

AICc used to select top set of models

Top set and top R2 reported in the Assessment



Multi-sp mode

AICc used to select top set of models

Top set and top R2 reported in the Assessment

Table 7: Top selected Ricker recruitment models for each species and mode.

Species	Covariates	Type	R2	deltaAIC	cumlAIC
a) Single-species					
W. Pollock	(Su)SST + (Fa)NCaS + (Sp)largeZoop	Ricker	0.4	2.476	0.3
P. Cod	(Fa)SST	Ricker	0.11	3.647	0.31
Arrowtooth	(Sp)EupS	Ricker	0.09	0	0.02
Arrowtooth	(Wi)pH + (Su)SST + (Su)BT + (Sp)largeZoop + (Fa)largeZoop	Ricker	0.25	6.631	0.92
b) Multi-species					
W. Pollock	(Su)SST + (Sp)largeZoop	Ricker	0.26	3.734	0.5
W. Pollock	(Su)SST + (Wi)EupS + (Sp)largeZoop + (Fa)largeZoop	Ricker	0.42	6.149	0.79
P. Cod	(Fa)SST	Ricker	0.1	3.149	0.35
Arrowtooth	(Wi)pH + (Sp)largeZoop + (Fa)largeZoop	Ricker	0.3	0.033	0.04
Arrowtooth	(Wi)pH + (Su)SST + (Su)BT + (Sp)largeZoop + (Fa)largeZoop	Ricker	0.31	5.635	0.82

Table 8: Top selected (all) recruitment models for each species and mode.

Species	Covariates	Type	R2	deltaAIC	cumlAIC
a) Single-species					
W. Pollock	(Su)SST + (Sp)largeZoop	Linear	0.27	0	0.03
W. Pollock	(Su)SST + (Fa)NCaS + (Sp)largeZoop	Linear, SSB(y-1)	0.42	1.389	0.14
P. Cod	(Fa)SST	Linear	0.16	0	0.07
P. Cod	(Fa)SST	Linear, SSB(y-1)	0.16	2.398	0.12
Arrowtooth	(Sp)EupS	Ricker	0.09	0	0.02
Arrowtooth	(Wi)pH + (Su)SST + (Su)BT + (Sp)largeZoop + (Fa)largeZoop	Ricker	0.25	6.631	0.92
b) Multi-species					
W. Pollock	(Su)SST + (Sp)largeZoop	Linear	0.28	0	0.03
W. Pollock	(Su)SST + (Wi)EupS + (Sp)largeZoop + (Fa)largeZoop	Linear, SSB(y-1)	0.46	4.456	0.62
P. Cod	(Fa)SST	Linear	0.13	0	0.04
P. Cod	(Fa)SST	Linear, SSB(y-1)	0.14	1.886	0.19
Arrowtooth	(Wi)pH + (Sp)largeZoop + (Fa)largeZoop	Linear	0.23	0	0.02
Arrowtooth	(Wi)pH + (Su)SST + (Su)BT + (Sp)largeZoop + (Fa)largeZoop	Ricker	0.31	5.635	0.82

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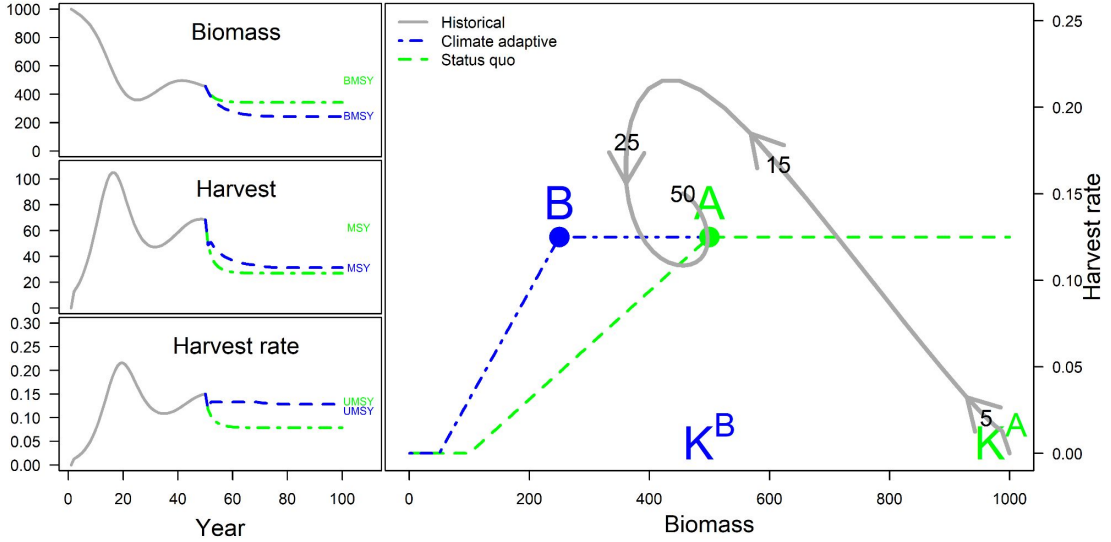
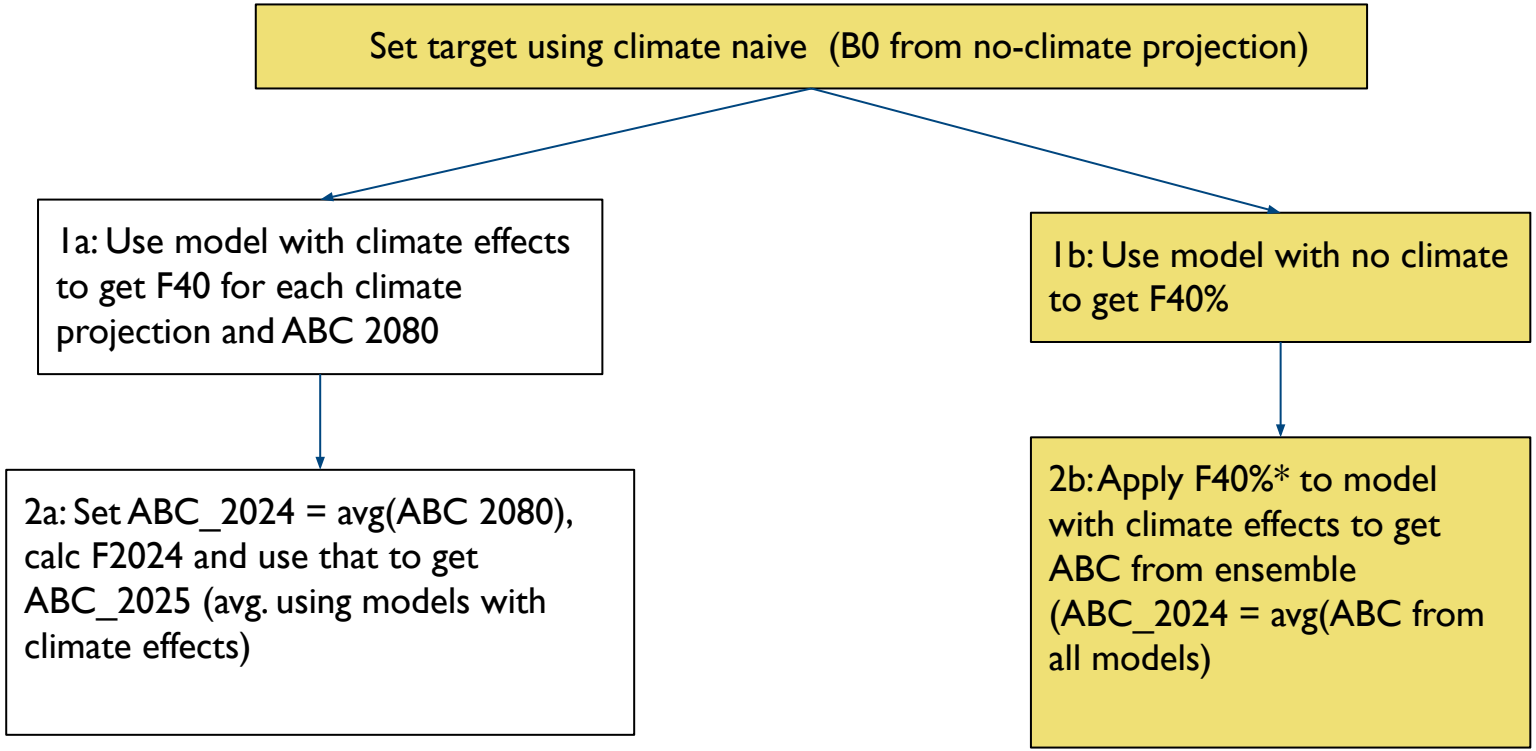
Adapting reference points to reflect changes in productivity

- MSA directs reference points to reflect current and probable future environmental conditions
- Changing reference points for stocks undergoing climate-related productivity shifts can result in counter-intuitive management actions:
  - Declining stocks fished harder
  - Flourishing stocks fished more conservatively

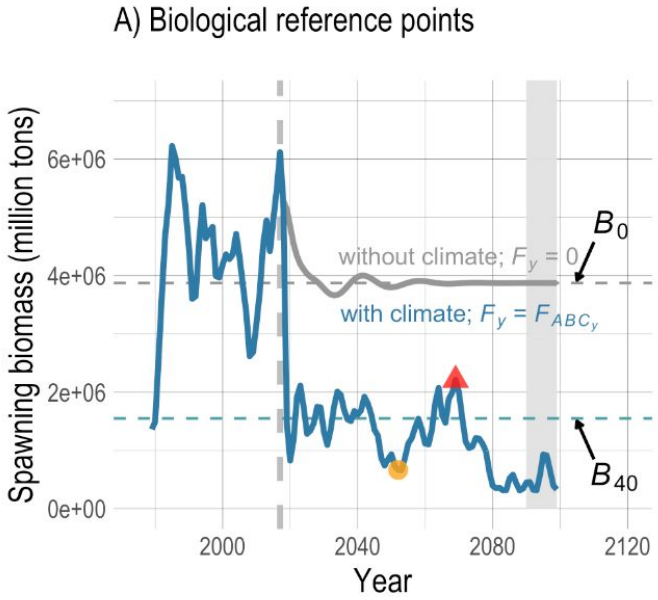


Szuwalski et al. 2023

Climate informed BRPs



Climate informed biological reference points



Holsman, K. K. et al. Climate-informed multispecies assessment model methods for determining biological references points and Acceptable Biological Catch. *Protoc. Exch.* https://doi.org/10.21203/rs.3.pex-1084/v1 (2020).

Holsman et al. 2020. https://www.nature.com/articles/s41467-020-18300-3

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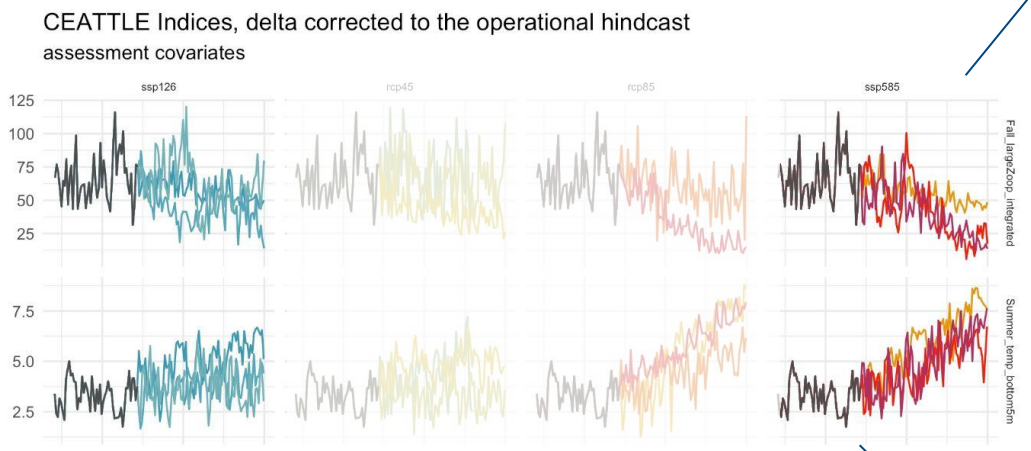
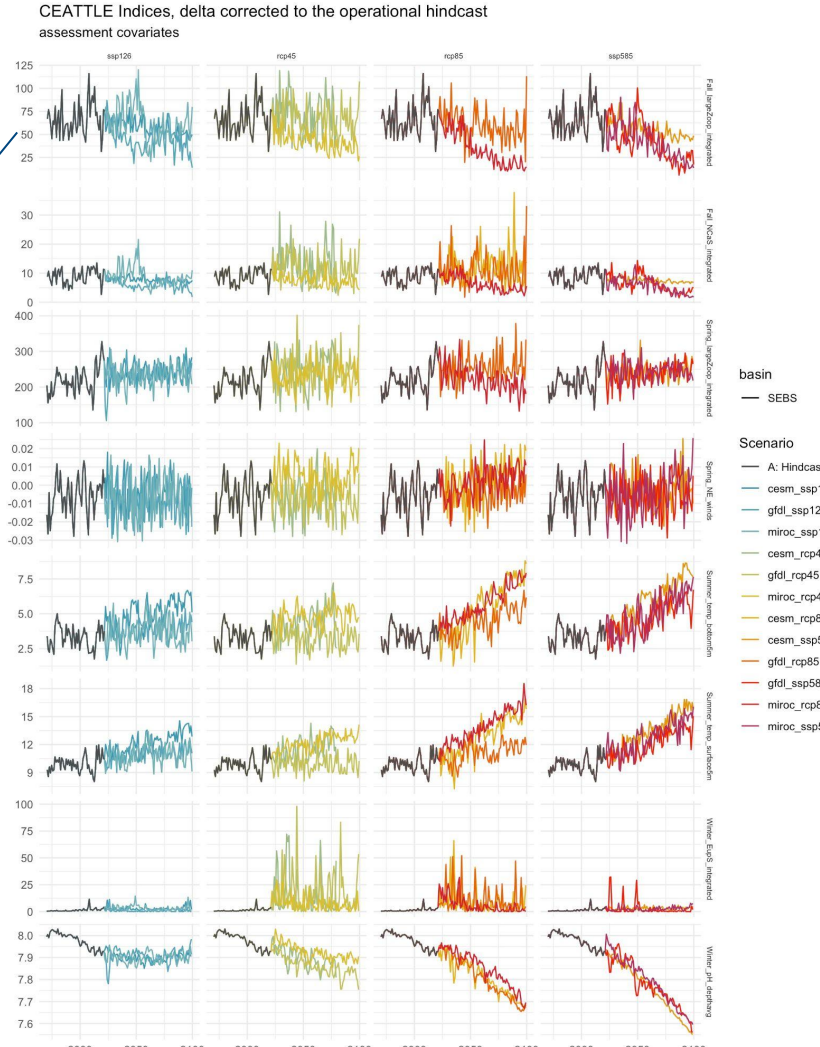
Recruitment covariates



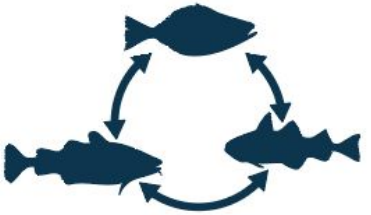
High

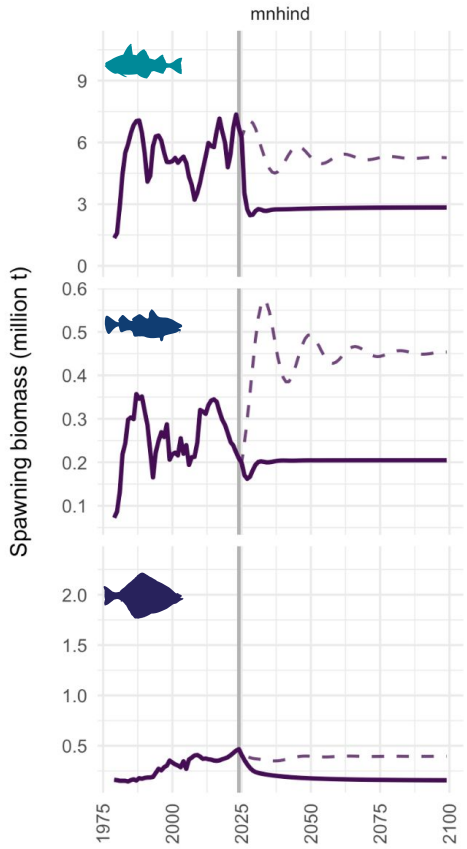
carbon mitigation

Low



Biomass (multispecies)





Project to 2099 such that
F that results in $B_{2095\text{-}2099} \sim 0.4\ B_{100\%}$
AND $B_y > 0.35\ B_{100\%}$

Pollock & P. cod first, then arrowtooth

(Holsman et al. 2016)

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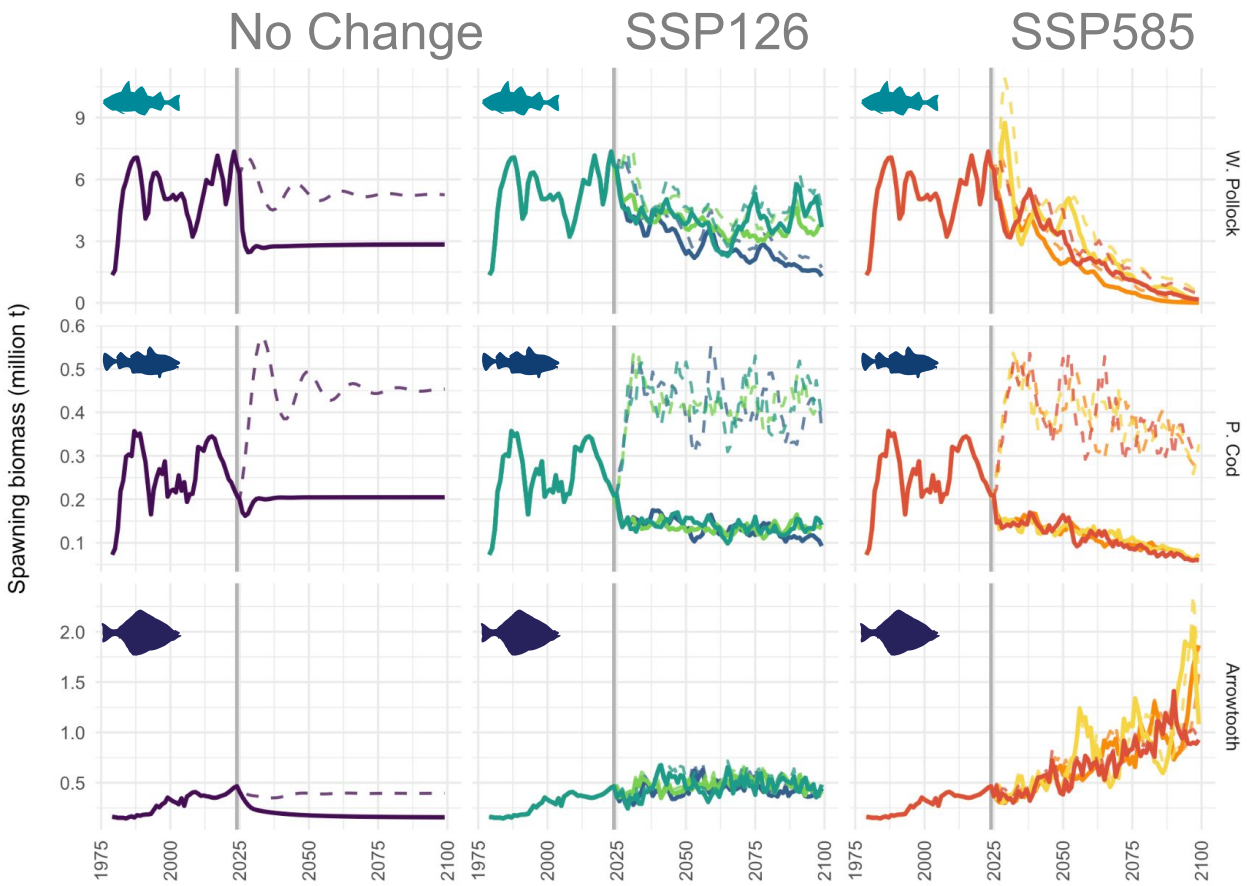
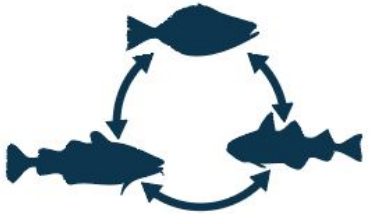
Biomass (multispecies)





fished
- unfished
- fished

type_sim2
- CI-cesm_ssp126
- CI-cesm_ssp585
- CI-gfdl_ssp126
- CI-gfdl_ssp585
- CI-miroc_ssp126
- CI-miroc_ssp585
- CN-mnhind

Assumes no climate adaptation (in fish, fishery or fisheries management)

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Climate informed BRPs and ABC evaluations

5 Climate-informed outlook

5.1 Probability of near-term (+ 1-2 yr) biomass decline or increase

- Relative to 2024 levels, the model projects SSB of pollock will decline in 2025 (projected based on 2024 catch) followed by a decline in SSB in 2026 (projected with F_{ABC}). For Pacific cod, the model projects a decline (slightly) in SSB in both 2025 and 2026.
- Ensemble projections using climate-enhanced recruitment models and projected future warming scenarios (including high (ssp126), moderate(RCP45), and low (ssp585) carbon mitigation scenarios, as well as a persistence scenario and assuming 2024 catch for 2025 and F_{ABC} for 2026, estimate a 95% probability that pollock SSB will remain between 92-95% of 2024 SSB in 2025 and will be between 79-82% of 2024 SSB levels in 2026.
- Ensemble projections using climate-enhanced recruitment models based on long-term projections estimate a 95% chance that Pacific cod SSB will continue to decline to between 93-98% of 2024 SSB in 2025 and between 75-78% of 2024 SSB levels in 2026.
- Ensemble projections using climate-enhanced recruitment models based on long-term projections estimate a 95% chance that arrowtooth SSB will be between 82 and 93% of 2024 SSB in 2025 and will be between 77 and 87% of 2024 SSB levels in 2026.

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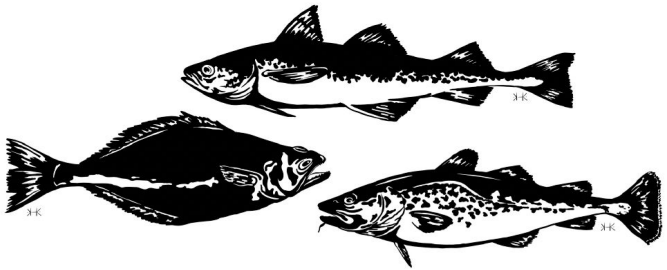
Multispecies assessment

2024 Climate-enhanced multispecies stock assessment for walleye pollock, Pacific cod, and arrowtooth flounder in the eastern Bering Sea

Kirstin K. Holsman, Jim Ianelli, Kalei Shotwell, Steve Barbeaux, Kerim Aydin, Grant Adams, Kelly Kearney, Anna Sulc, Sophia Wassermann



November 2024 | kirstin.holsman@noaa.gov Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Seattle, Washington 98115

Suggested citation: *Holsman, K. K., J. Ianelli, K. Shotwell, S. Barbeaux, K. Aydin, G. Adams, K. Kearney, A. Sulc, S Wassermann (2024) Climate-enhanced multispecies stock assessment for walleye pollock, Pacific cod, and arrowtooth flounder in the eastern Bering Sea. North Pacific Fishery Management Council, Anchorage, AK.*

Climate-informed outlook

Probability of near-term (+ 1-2 yr) biomass decline or increase

- Relative to 2023 levels, the model projects SSB of pollock will decline in 2024 (projected based on 2023 catch) followed by a decline in SSB in 2025 (projected with F_{ABC}). For Pacific cod the model projects

Use climate informed model to characterize risk in +1 & +2 years

2024 and between 78-82% of 2023 SSB levels in 2025.

- Ensemble projections using climate-enhanced recruitment models based on long-term projections estimate a 95% chance that arrowtooth SSB will be between 84 and 98% of 2023 SSB in 2024 and will be between 76 and 86% of 2023 SSB levels in 2025.

Low warming scenarios (SSP126): probability of long-term (2033, 2050, 2080) biomass decline or increase

- Trends in biomass and recruitment under high carbon mitigation (low warming; SSP126) scenarios are very similar to near-present day. *Note that projections assume no adaptation by the species, fishery, or*

Use climate informed model to characterize risk in 10 + years with low warming

- Ensemble projections using climate-enhanced recruitment models based on long-term projections estimate a 95% chance that arrowtooth SSB will be between 62-74% of 2023 SSB in 2033, between 63-68% of 2023 SSB levels in 2050, and between 59-66% of 2023 SSB levels in 2080.

High warming scenarios (SSP585): probability of long-term (2033, 2050, 2080) biomass decline or increase

- Trends in biomass and recruitment under low carbon mitigation (high warming; SSP585) scenarios

Use climate informed model to characterize risk in 10 + years with high warming

and 69% of 2023 SSB levels in 2050, and between 37 and 42% of 2023 SSB levels in 2080.

- Ensemble projections using climate-enhanced recruitment models based on long-term projections estimate a 95% chance that arrowtooth SSB will be between 64 and 74% of 2023 SSB in 2033, between 58 and 61% of 2023 SSB levels in 2050, and between 40 and 43% of 2023 SSB levels in 2080.

https://apps-afsc.fisheries.noaa.gov/Plan_Team/2022/EBSmultispp.pdf

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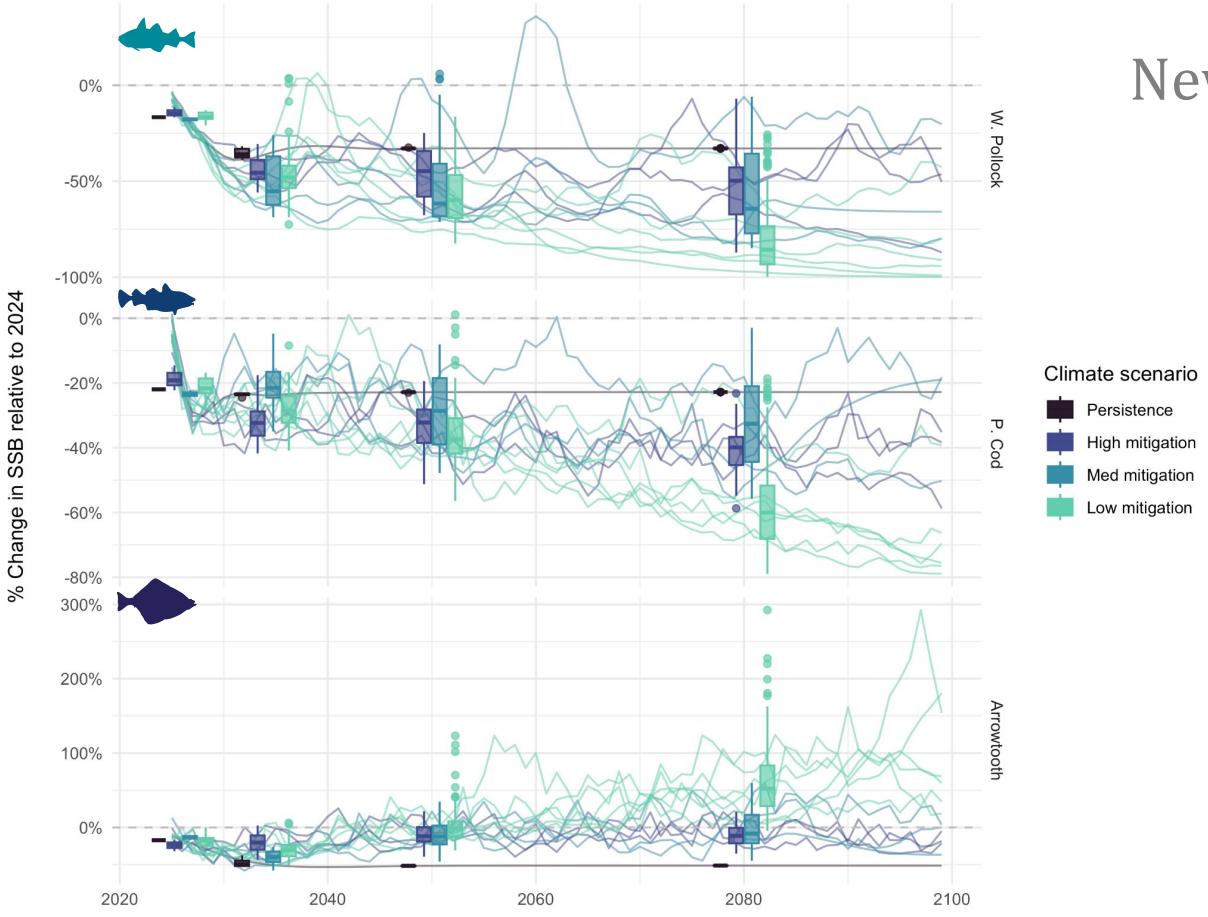
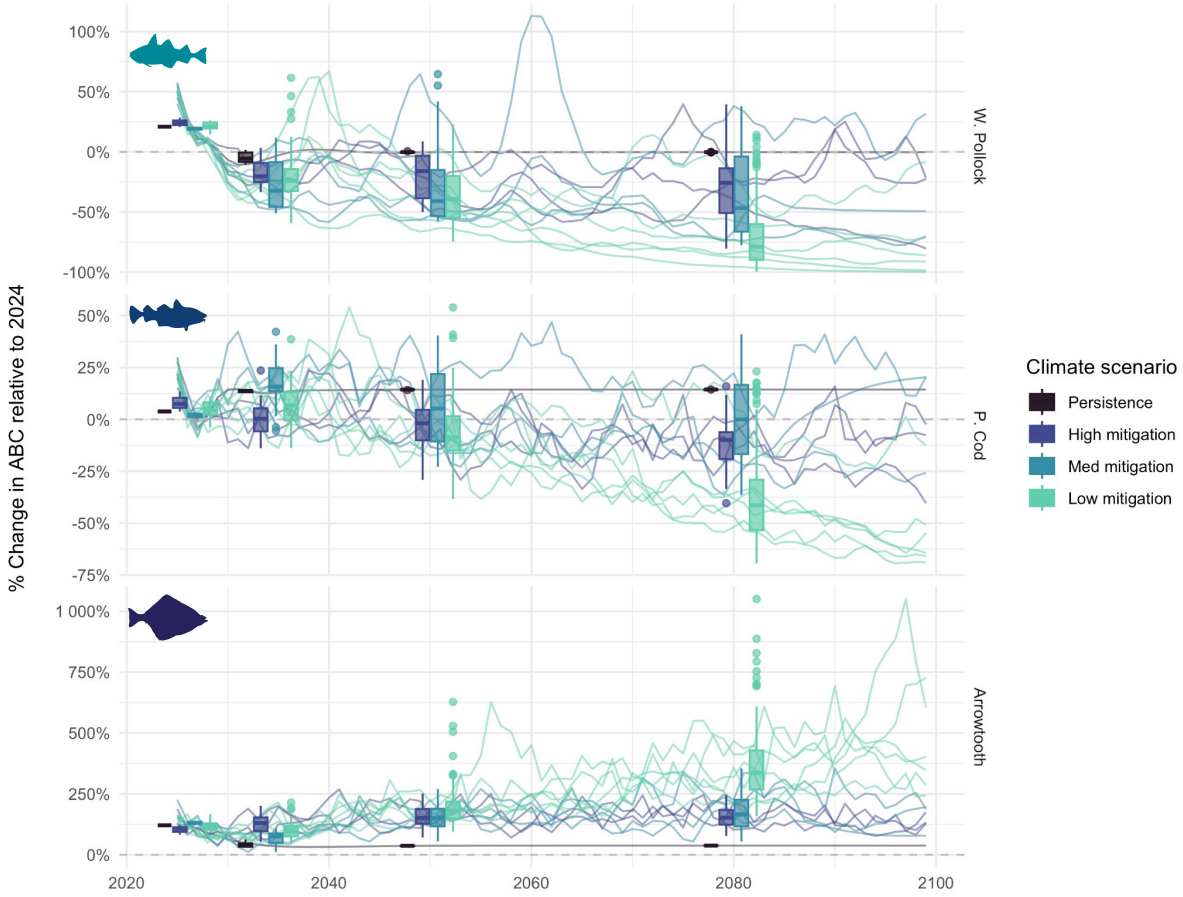
New this year




% Change in ABC relative to 2024
100%
50%
0%
-50%
-100%
W. Pollock
50%
25%
0%
-25%
-50%
-75%
P. Cod
1 000%
750%
500%
250%
0%
Arrowtooth
2020
2040
2060
2080
2100
Climate scenario
Persistence
High mitigation
Med mitigation
Low mitigation

2023 Climate informed targets & reference points

Quantity	Walleye pollock		Pacific cod		Arrowtooth flounder	
	SSM	MSM	SSM	MSM	SSM	MSM
2023 M (age 1)	1.313	1.195	0.653	0.594	0.658	0.468
2023 Average 3+ M	0.306	0.306	0.38	0.38	0.227	0.227
Projected (age 3+) B_{2024} (t)	15,860,694	16,265,727	679,301	686,562	566,160	569,909
SSB_{2023} (t)	6,790,160	7,044,480	157,340	155,597	429,700	428,256
% change in SSB (t) from 2022	10.3	10.3	-9.2	-9.0	0.1	0.2
Projected SSB_{2024} (t)	6,239,390	6,475,040	156,408	155,652	374,227	373,806
Projected SSB_{2025} (t)	5,828,060	5,819,550	128,478	123,214	351,317	348,509
*Projected $SSB_{0,2100}$ (t)	6,164,698	6,504,694	322,907	372,244	368,306	426,212
*Projected $SSB_{target,2100}$ (t)	3,044,850	3,136,376	164,934	169,131	147,286	170,536
**Target 2100 B/B_0	0.494	0.482	0.511	0.454	0.4	0.4
$F_{target,2100}$	0.345	0.547	0.443	0.481	0.08	0.086
$F_{ABC,2024}$	0.134	0.192	0.498	0.566	0.033	0.042
ABC_{2024}	2,054,020	2,965,510	188,498	205,756	17,411	21,741
ABC_{2025}	1,853,370	2,521,900	156,934	165,274	16,533	20,573

Climate informed BRPs and ABC evaluations

5.2 Low warming scenarios (SSP126): probability of long-term (2034, 2050, 2080) biomass decline or increase

- Trends in biomass and recruitment under high carbon mitigation (low warming; SSP126) scenarios are very similar to near-present day. *Note that projections assume no adaptation by the species, fishery, or fishery management.* See Figures 32 and 33 for more information.

- Ensemble projections using climate-enhanced recruitment models and projected future warming scenarios and assuming F_{ABC} for 2026 - 2100) estimate a 95% chance that pollock SSB will be between 58-66% of 2024 SSB in 2034, between 54-58% of 2024 SSB levels in 2050, and between 44-53% of 2024 SSB levels in 2080 (Fig. 24). Projections also estimate a 95% chance that the ABC for pollock will be between 118-131% of 2024 ABC in 2034, between 109-119% of 2024 ABC levels in 2050, and between 89-107% of 2024 ABC levels in 2080 (Fig.25).

- Ensemble projections using climate-enhanced recruitment models based on long-term projections estimate a 95% chance that Pacific cod SSB will be between 66-71% of 2024 SSB in 2034, between 66-70% of 2024 SSB levels in 2050, and between 60-63% of 2024 SSB levels in 2080. Projections also estimate a 95% chance that the ABC for Pacific cod will be between 106-116% of 2024 ABC in 2034, between 107-113% of 2024 ABC levels in 2050, and between 96-103% of 2024 ABC levels in 2080.

- Ensemble projections using climate-enhanced recruitment models based on long-term projections estimate a 95% chance that arrowtooth SSB will be between 78-106% of 2024 SSB in 2034, between 95-103% of 2024 SSB levels in 2050, and between 92-99% of 2024 SSB levels in 2080. Projections also estimate a 95% chance that the ABC for arrowtooth will be between 260-358% of 2024 ABC in 2034, between 310-339% of 2024 ABC levels in 2050, and between 300-324% of 2024 ABC levels in 2080.

Climate informed BRPs and ABC evaluations

5.3 High warming scenarios (SSP585): probability of long-term (2034, 2050, 2080) biomass decline or increase

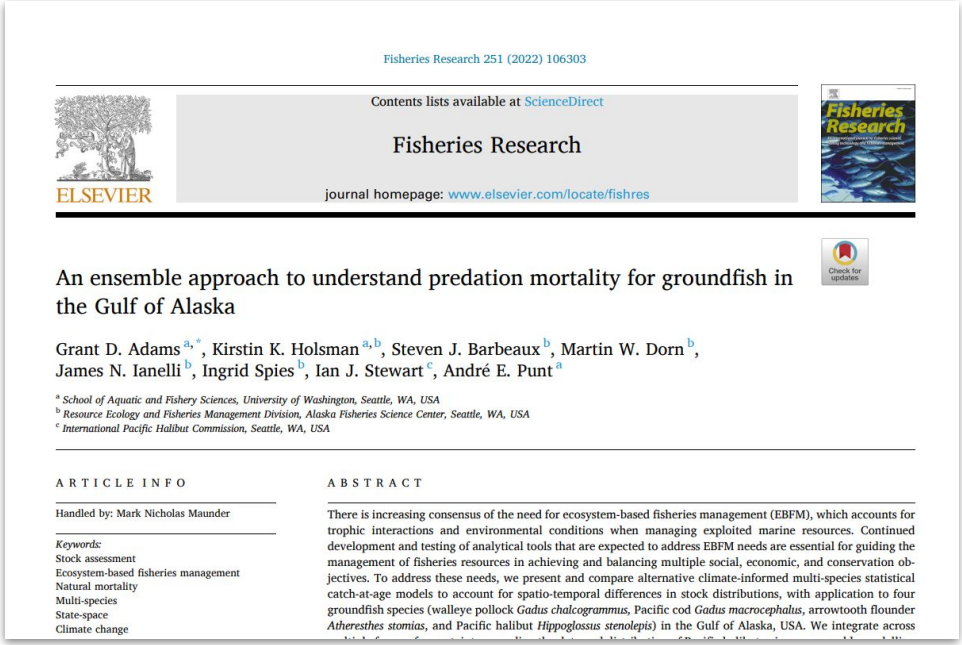
- Trends in biomass and recruitment under low carbon mitigation (high warming; SSP585) scenarios are markedly different than historical or present day productivity. *Note that projections assume no adaptation by the species, fishery, or fishery management.*
- Ensemble projections using climate-enhanced recruitment models and projected future warming scenarios and assuming F_{ABC} for 2026 - 2100) estimate a 95% chance that pollock SSB will be between 70 and 105% of 2024 SSB in 2034, between 53 and 63% of 2024 SSB levels in 2050, and between 11 and 19% of 2024 SSB levels in 2080. Projections also estimate a 95% chance that the ABC for pollock will be between 140 and 212% of 2024 ABC in 2034, between 106 and 129% of 2024 ABC levels in 2050, and between 22 and 39% of 2024 ABC levels in 2080 (Figs. 24, 25).
- Ensemble projections using climate-enhanced recruitment models based on long-term projections estimate a 95% chance that Pacific cod SSB will be between 68 and 73% of 2024 SSB in 2034, between 64 and 67% of 2024 SSB levels in 2050, and between 38 and 42% of 2024 SSB levels in 2080. Projections also estimate a 95% chance that the ABC for Pacific cod will be between 111 and 120% of 2024 ABC in 2034, between 103 and 108% of 2024 ABC levels in 2050, and between 62 and 68% of 2024 ABC levels in 2080.
- Ensemble projections using climate-enhanced recruitment models based on long-term projections estimate a 95% chance that arrowtooth SSB will be between 73 and 91% of 2024 SSB in 2034, between 110 and 122% of 2024 SSB levels in 2050, and between 190 and 215% of 2024 SSB levels in 2080. Projections also estimate a 95% chance that the ABC for arrowtooth will be between 241 and 305% of 2024 ABC in 2034, between 369 and 409% of 2024 ABC levels in 2050, and between 636 and 721% of 2024 ABC levels in 2080.

Next year

1. Bridge CEATTLE classic (ADMB) to TMB Rceattle (with G. Adams)
2. Update diet matrices to include new REEM methods
3. Revist likelihood weighting
4. Update weight at age (Holsman et al. in prep); vonBEE
5. Add in pred/prey overlap (Goodman et al. in prep)
6. NSF conditioned ABC andn NFS pop. dynamics (2025-2027)
    a. building on Lenfest
    b. Anna Sulc
7. Include ACLIM MSE results and CI features
8. Share output via AKFIN

Rceattle

https://github.com/grantdadams/Rceattle



Fisheries Research 251 (2022) 106303

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

An ensemble approach to understand predation mortality for groundfish in the Gulf of Alaska

Grant D. Adams [a,*], Kirstin K. Holsman [a,b], Steven J. Barbeaux [b], Martin W. Dorn [b], James N. Ianelli [b], Ingrid Spies [b], Ian J. Stewart [c], André E. Punt [a]

[a] School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA, USA
[b] Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, Seattle, WA, USA
[c] International Pacific Halibut Commission, Seattle, WA, USA

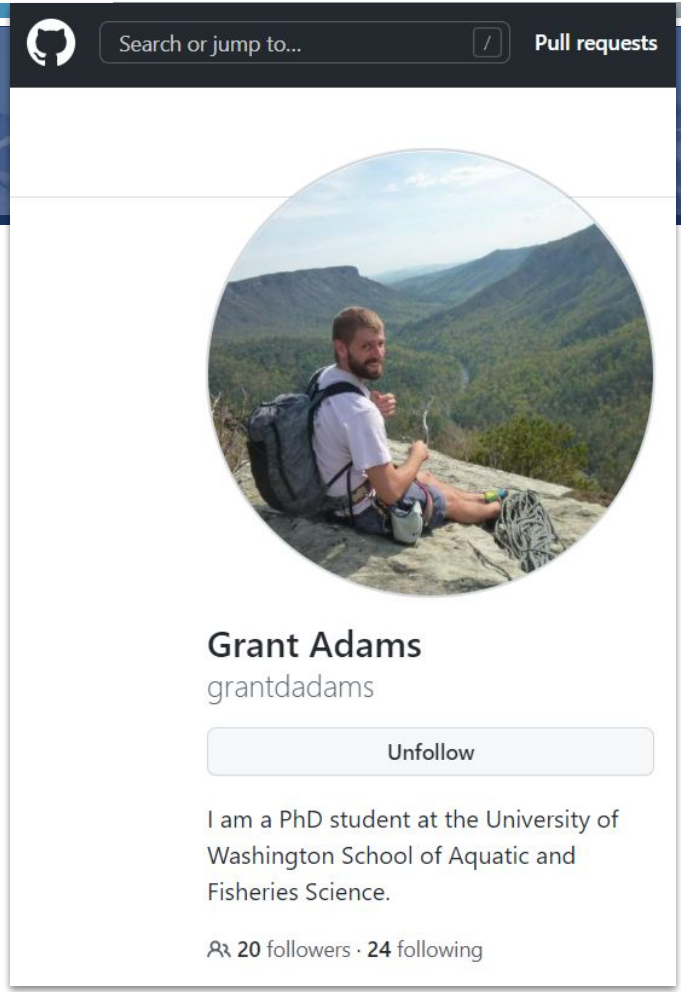
ARTICLE INFO

Handled by: Mark Nicholas Maunder

Keywords:
Stock assessment
Ecosystem-based fisheries management
Natural mortality
Multi-species
State-space
Climate change

ABSTRACT

There is increasing consensus of the need for ecosystem-based fisheries management (EBFM), which accounts for trophic interactions and environmental conditions when managing exploited marine resources. Continued development and testing of analytical tools that are expected to address EBFM needs are essential for guiding the management of fisheries resources in achieving and balancing multiple social, economic, and conservation objectives. To address these needs, we present and compare alternative climate-informed multi-species statistical catch-at-age models to account for spatio-temporal differences in stock distributions, with application to four groundfish species (walleye pollock *Gadus chalcogrammus*, Pacific cod *Gadus macrocephalus*, arrowtooth flounder *Atheresthes stomias*, and Pacific halibut *Hippoglossus stenolepis*) in the Gulf of Alaska, USA. We integrate across



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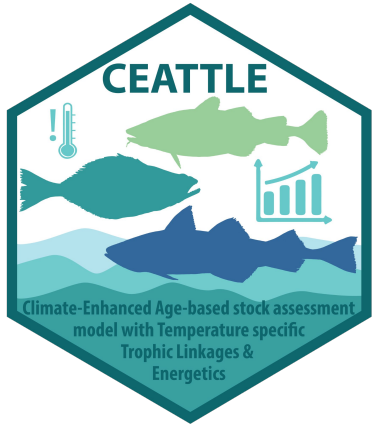
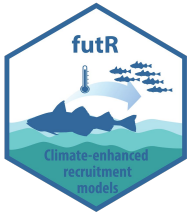
    a. building on Lenfest
    b. Anna Sulc
7. Include ACLIM MSE results and CI features
8. Share output via AKFIN

CEATTLE workflow features

- R and shell scripts used to run the model through projections:
  - Regular output includes ESR contribution (R markdown)
  - ESP indices (produced annually)
  - Assessment written in Rmarkdown using Rdata outputs
    https://github.com/kholsman/2024_Multispp_assessment
- Github repositories (* private)
  - *CEATTLE (ADMB):
    https://github.com/kholsman/CEATTLE
  - *futR() : recruitment fitting model in TMB:
    https://github.com/kholsman/futR
  - * vonBEE(): env. varying vonB model in TMB:
    https://github.com/NOAA-REEM/vonBEE
  - Rceattle (G. Adams; R/TMB):
    https://github.com/grantdadams/Rceattle





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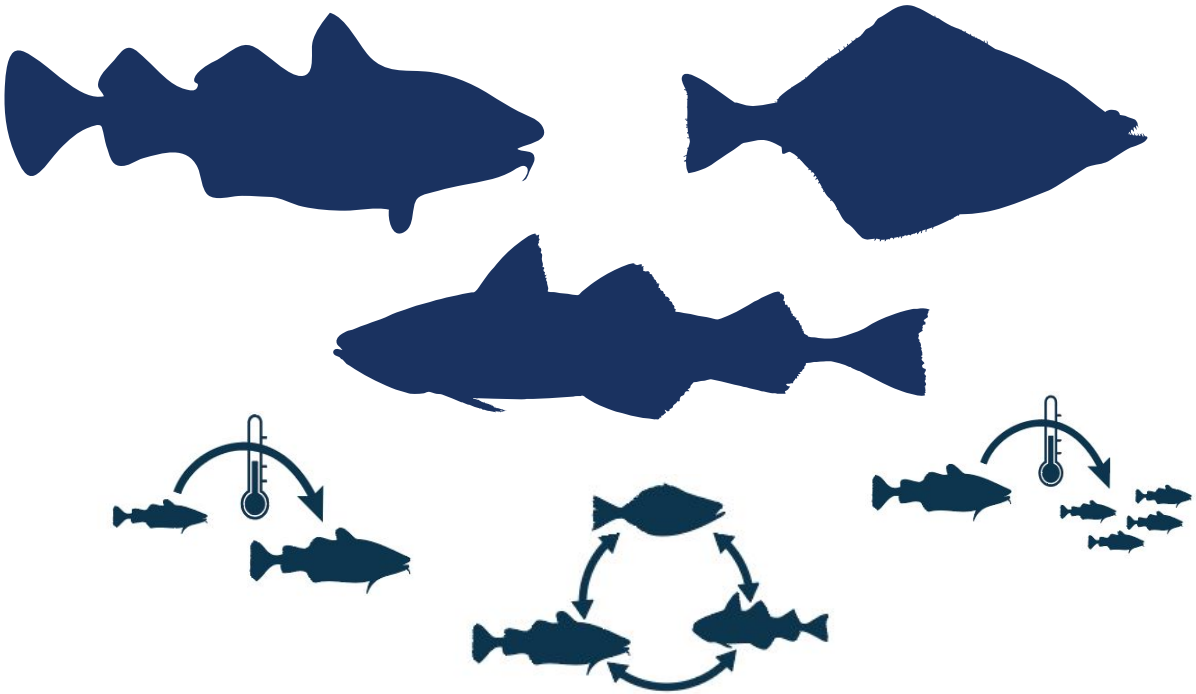
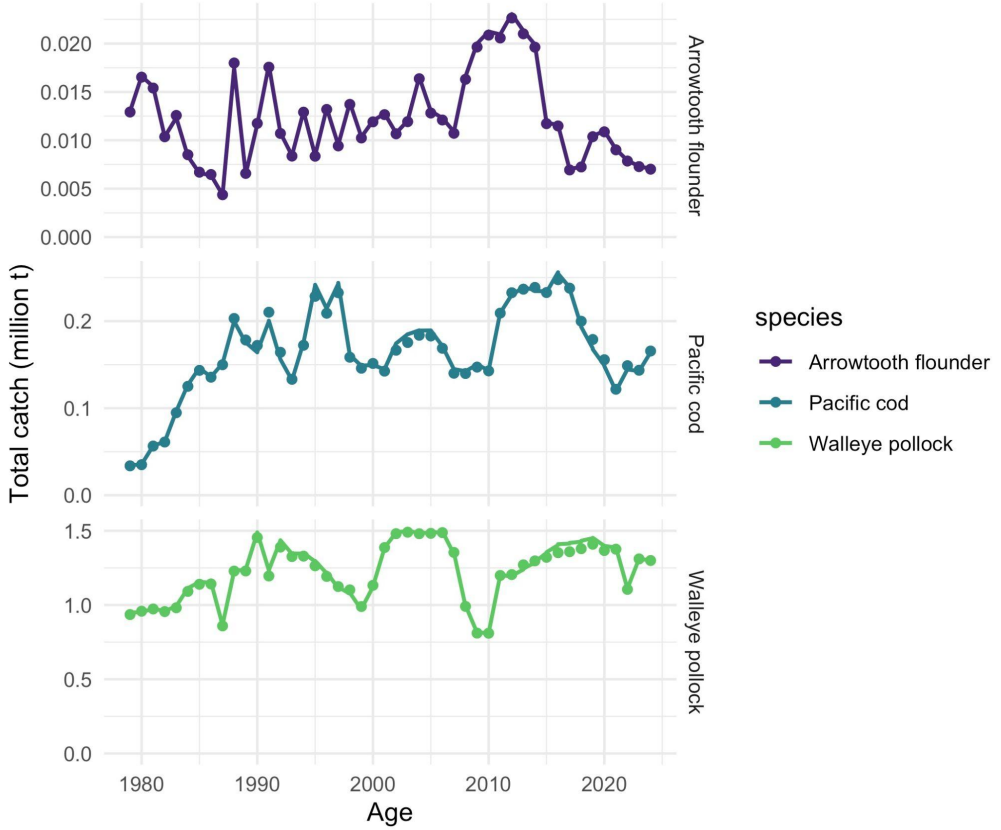
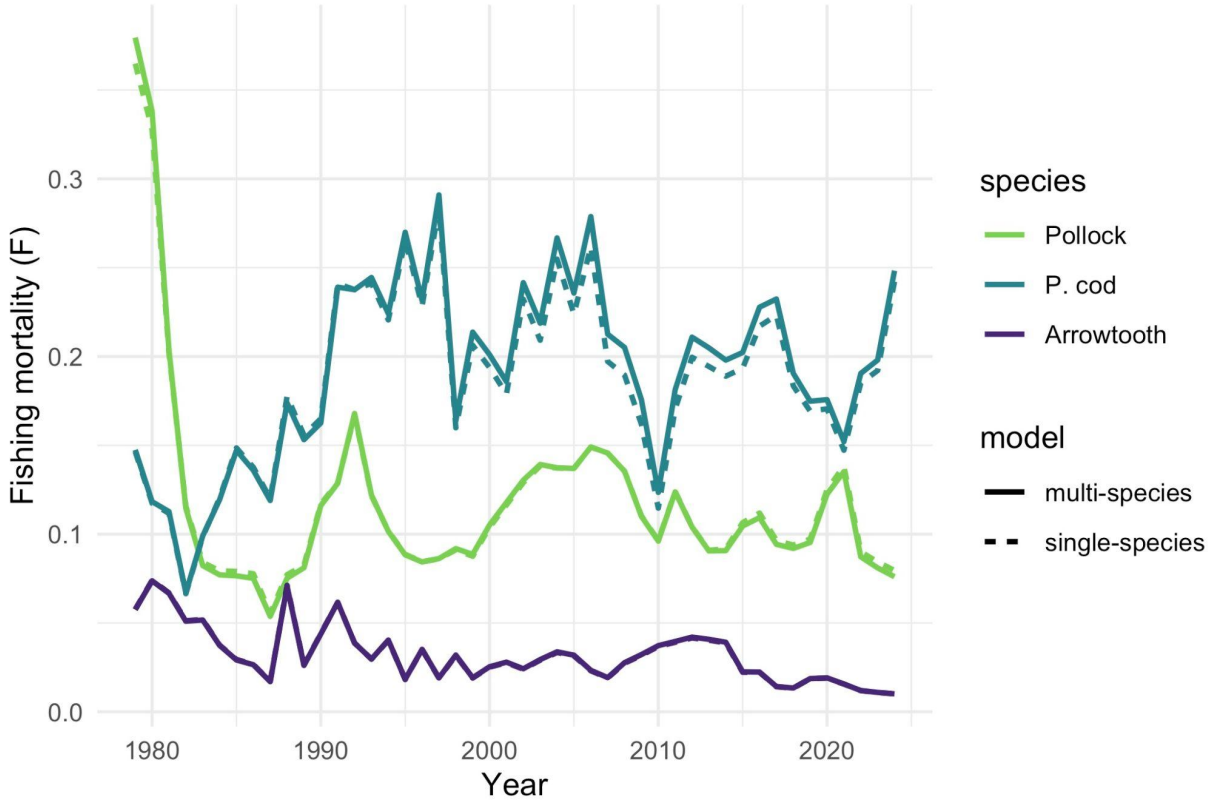
EXTRA SLIDES

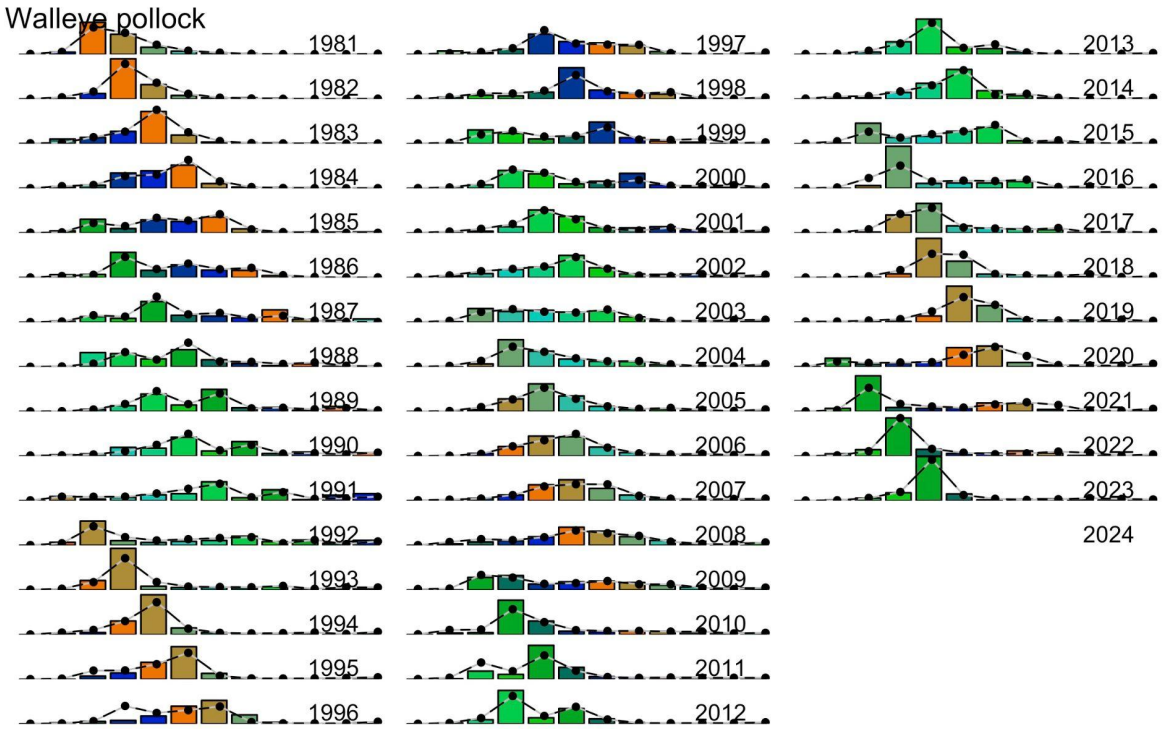


Catch


Arrowtooth flounder
Pacific cod
Walleye pollock
Total catch (million t)
0.020
0.015
0.010
0.005
0.000
0.2
0.1
0.0
1.5
1.0
0.5
0.0
1980
1990
2000
2010
2020
Age
species
Arrowtooth flounder
Pacific cod
Walleye pollock


Fishing mortality (F)
0.3
0.2
0.1
0.0
1980
1990
2000
2010
2020
Year
species
Pollock
P. cod
Arrowtooth
model
multi-species
single-species

Fishery age comp.



walleye pollock

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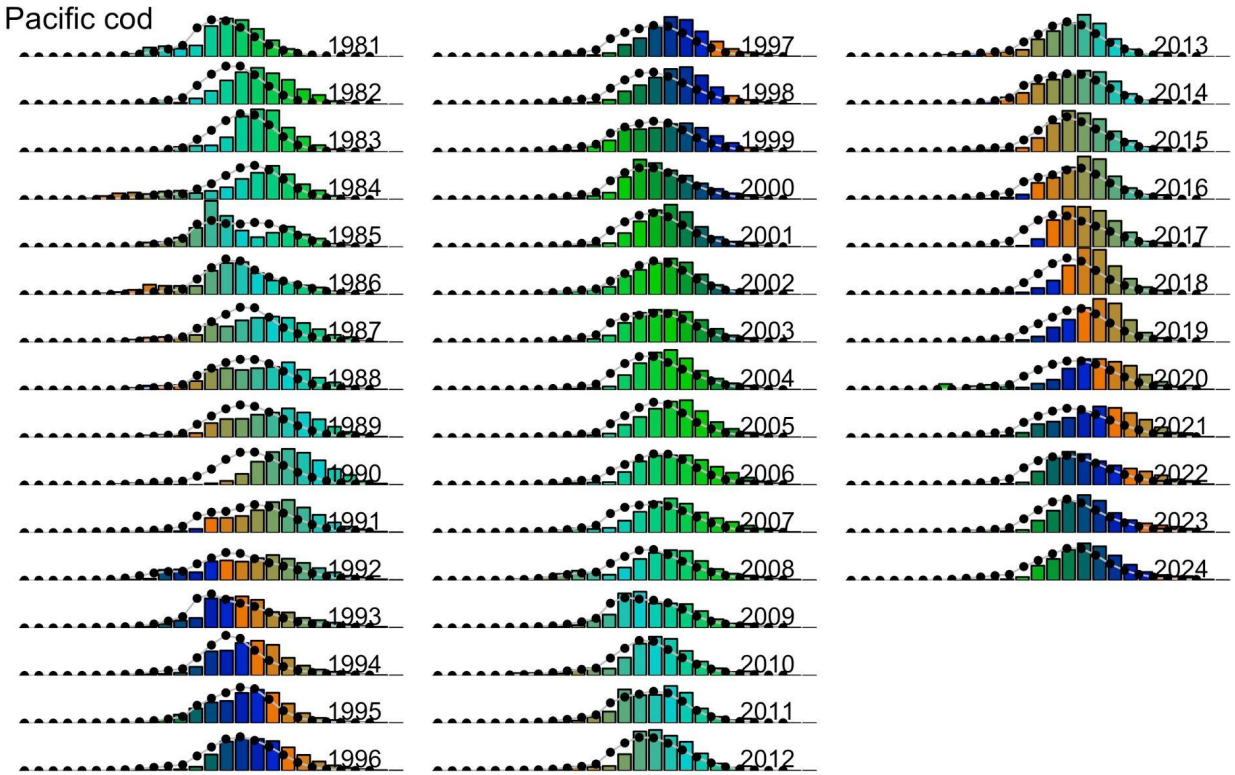
Fishery length comp.



Pacific cod

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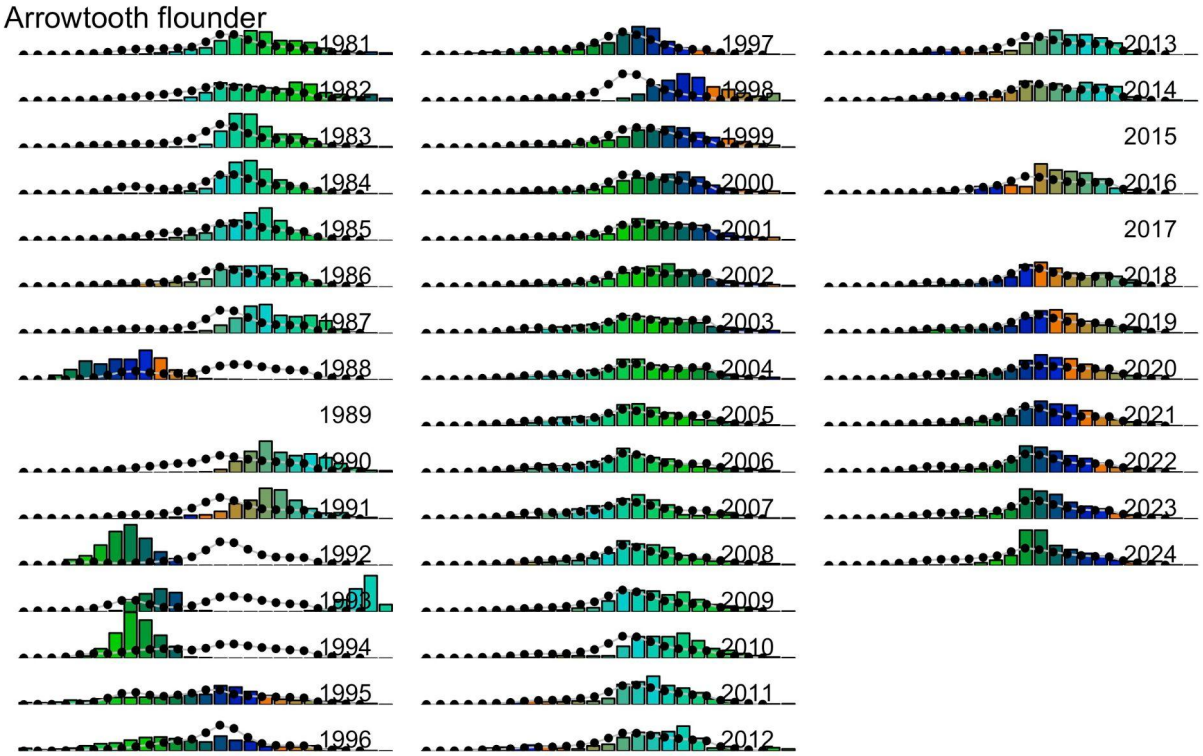
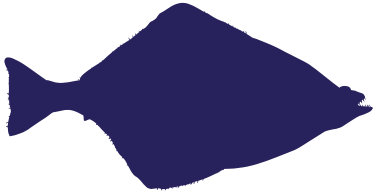
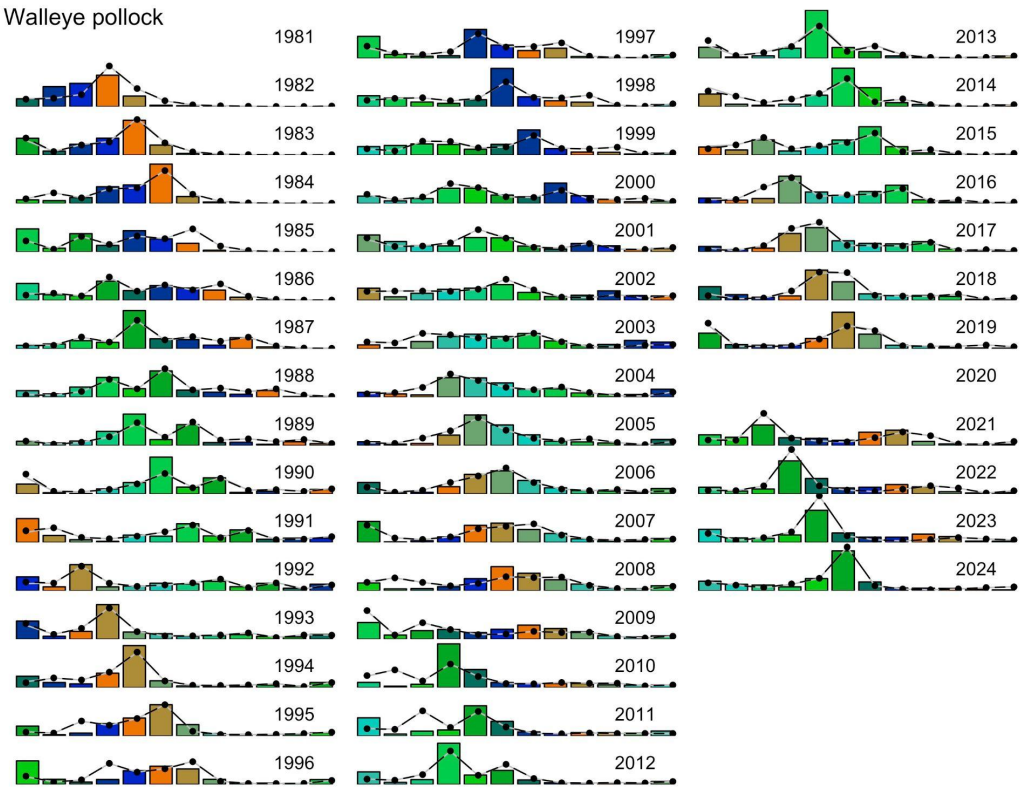
Fishery length comp.





Arrowtooth flounder

Survey age comp.



walleye pollock

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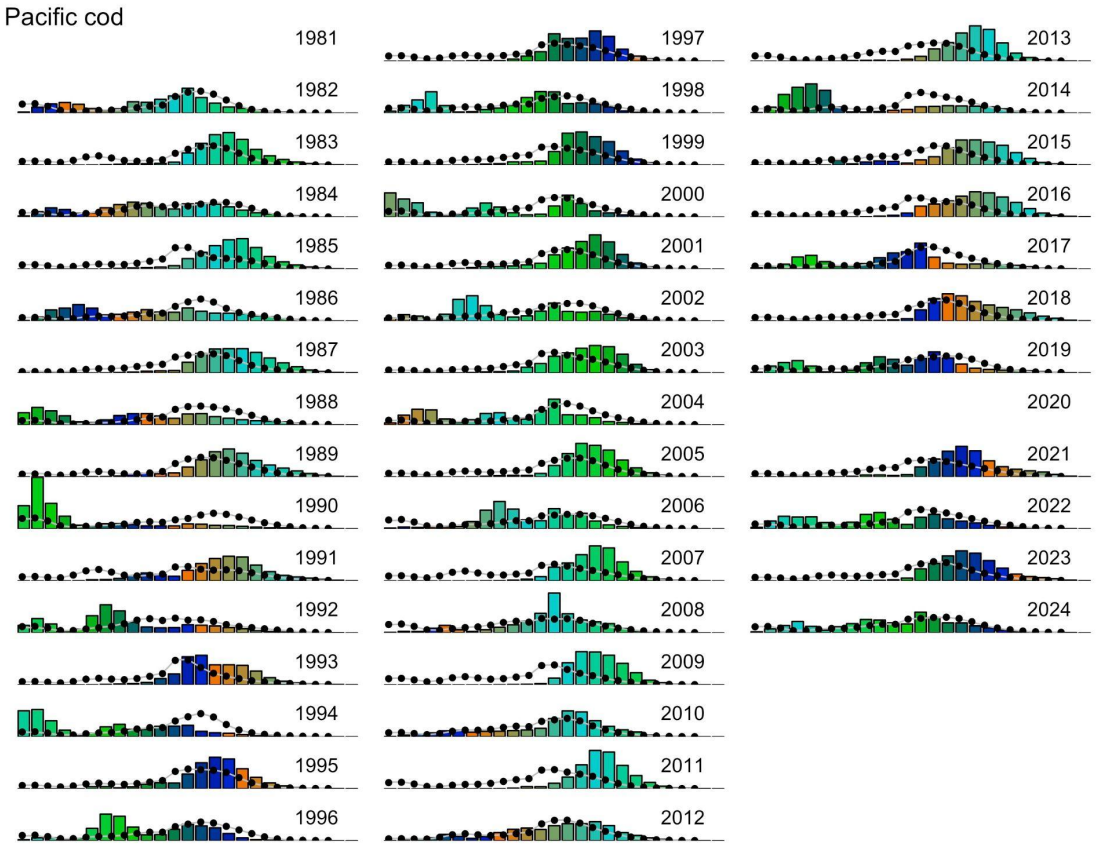
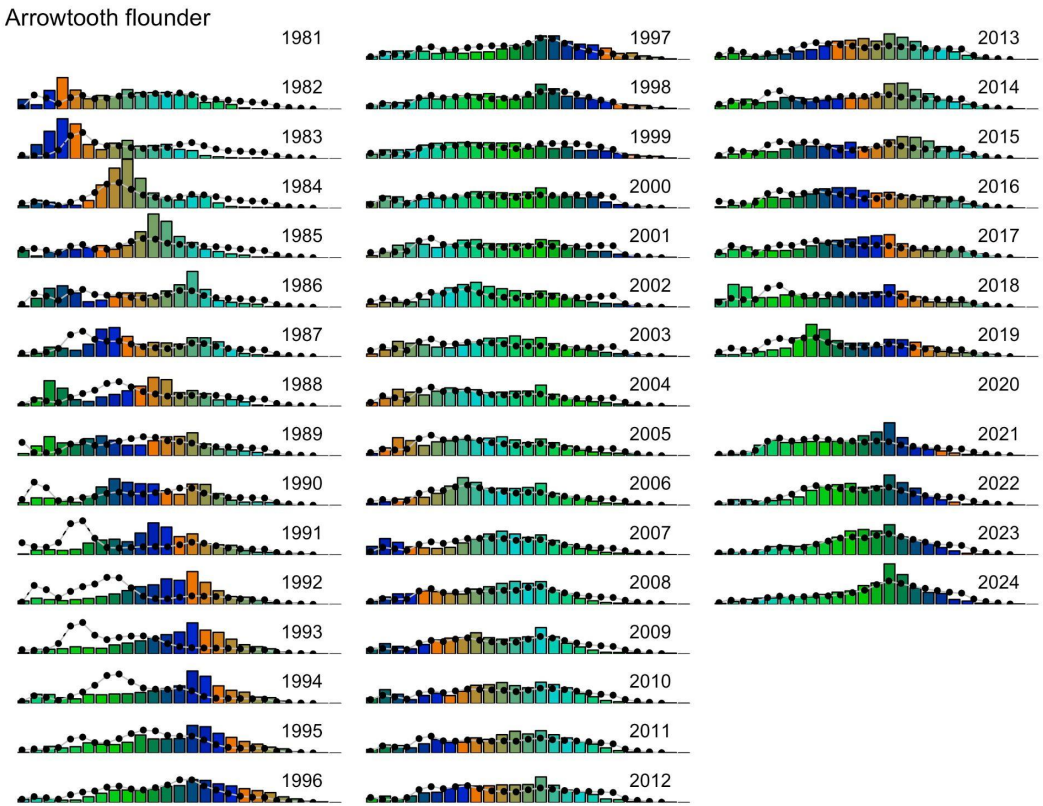
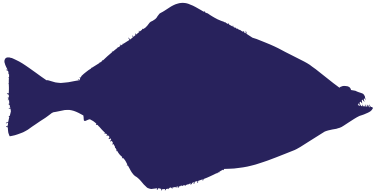
Survey length comp.



Pacific cod

Survey length comp.





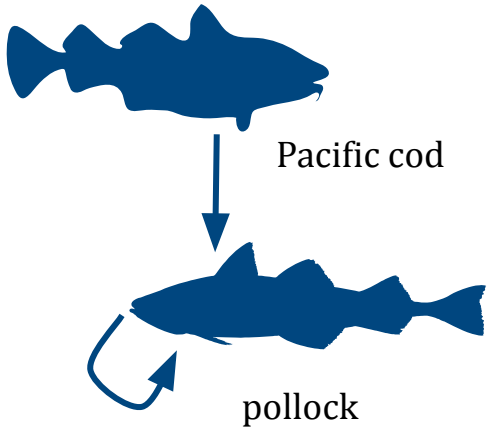
Arrowtooth flounder

Incorporating predation interactions in a statistical catch-at-age model for a predator–prey system in the eastern Bering Sea

Jesús Jurado-Molina, Patricia A. Livingston, and James N. Ianelli

Abstract: Virtual population analysis and the statistical catch-at-age methods are common stock assessment models used for management advice. The difference between them is the statistical assumptions allowing the fitting of parameters by considering how errors enter into the models and the data sources for the estimation. Fishery managers are being asked to consider multispecies interactions in their decisions. One option to achieve this goal is the multispecies virtual population analysis (MSVPA); however, its lack of statistical assumptions does not allow the use of tools used in single-species stock assessment. We chose to use a two-species system, walleye pollock (*Theragra chalcogramma*) and Pacific cod (*Gadus macrocephalus*), to incorporate the predation equations from MSVPA into an age-structured multispecies statistical model (MSM). Results suggest that both models produced similar estimates of suitability coefficients and predation mortalities. The adult population estimates from the single-species stock assessment and MSM were also comparable. MSM provides a measure of parameter uncertainty, which is not available with the MSVPA technologies. MSM is an important advancement in providing advice to fisheries managers because it incorporates the standard tools such as Bayesian methods and decision analysis into a multispecies context, helping to establish useful scenarios for management in the Bering Sea.

Jurado-Molina et al. 2005 doi: 10.1139/F05-110



MSVPA ⟶ Statistical MSM

Deep-Sea Research II 134 (2016) 360–378

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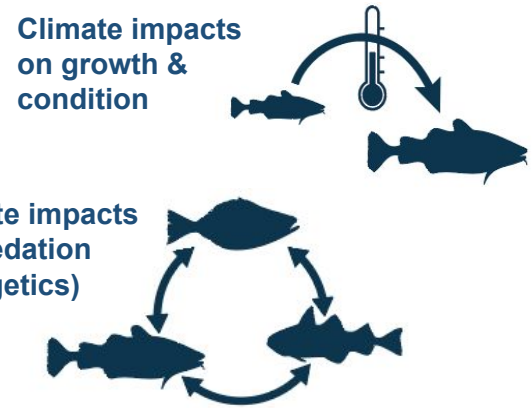
A comparison of fisheries biological reference points estimated from temperature-specific multi-species and single-species climate-enhanced stock assessment models

Kirstin K. Holsman [a,*], James Ianelli [a], Kerim Aydin [a], André E. Punt [b], Elizabeth A. Moffitt [b,1]

[a] Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Building 4, Seattle, Washington 98115, USA
[b] University of Washington School of Aquatic and Fisheries Sciences, 1122 NE Boat St., Seattle, WA 98105, USA

Holsman et al. 2016



"CEATTLE"

Climate Enhanced Age-structured model with Temperature-specific Trophic Linkages and Energetics

NOAA FISHERIES

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[a] Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Building 4, Seattle, Washington 98115, USA
[b] University of Washington School of Aquatic and Fisheries Sciences, 1122 NE Boat St., Seattle, WA 98105, USA

nature COMMUNICATIONS

ARTICLE

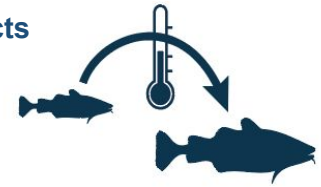
https://doi.org/10.1038/s41467-020-18300-3 OPEN

Ecosystem-based fisheries management forestalls climate-driven collapse

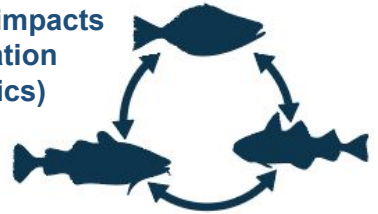
K. K. Holsman [1,2✉], A. C. Haynie[1], A. B. Hollowed[1,2], J. C. P. Reum[1,2,3], K. Aydin[1,2], A. J. Hermann [4,5], W. Cheng [4,5], A. Faig [2], J. N. Ianelli[1,2], K. A. Kearney [1,4] & A. E. Punt [2]

Holsman et al. 2016

Climate impacts on growth & condition

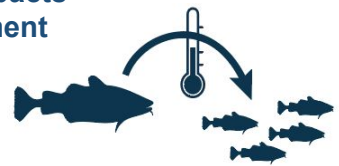


Climate impacts on predation (energetics)



Holsman et al. 2020

Climate impacts on recruitment



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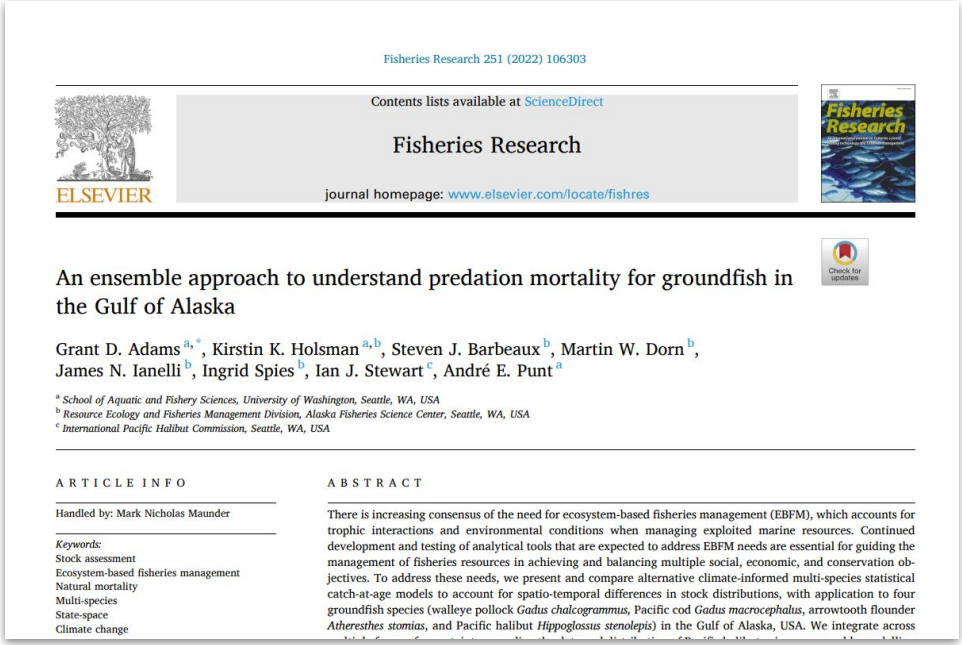
Rceattle

https://github.com/grantdadams/Rceattle



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An ensemble approach to understand predation mortality for groundfish in the Gulf of Alaska

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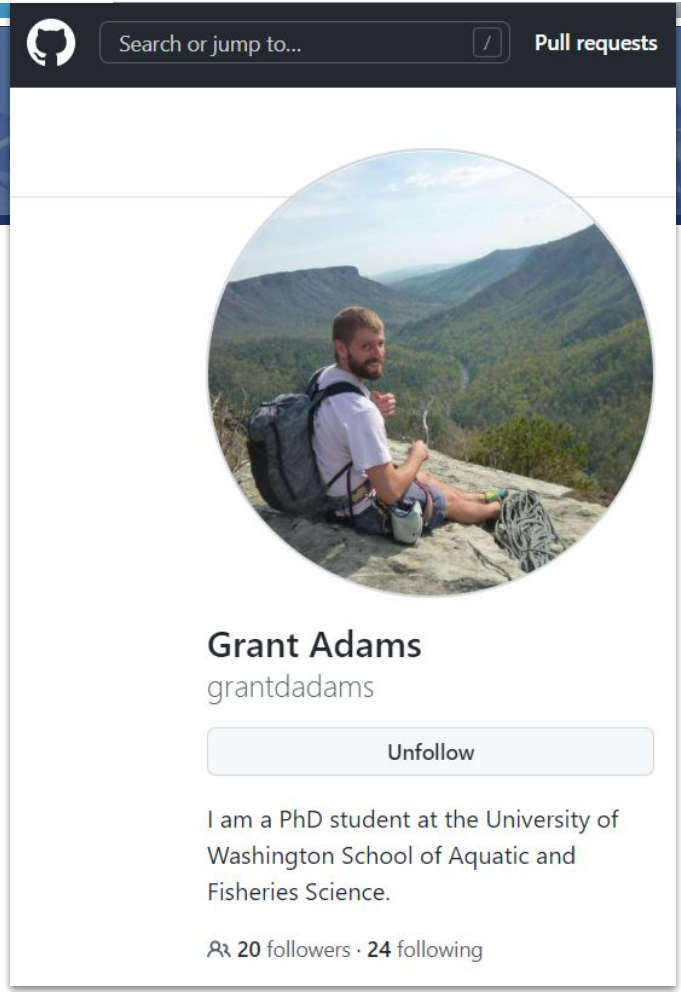
ABSTRACT

There is increasing consensus of the need for ecosystem-based fisheries management (EBFM), which accounts for trophic interactions and environmental conditions when managing exploited marine resources. Continued development and testing of analytical tools that are expected to address EBFM needs are essential for guiding the management of fisheries resources in achieving and balancing multiple social, economic, and conservation objectives. To address these needs, we present and compare alternative climate-informed multi-species statistical catch-at-age models to account for spatio-temporal differences in stock distributions, with application to four groundfish species (walleye pollock *Gadus chalcogrammus*, Pacific cod *Gadus macrocephalus*, arrowtooth flounder *Atheresthes stomias*, and Pacific halibut *Hippoglossus stenolepis*) in the Gulf of Alaska, USA. We integrate across



CEATTLE Applications

Operational advice:

- Appendix to BSAI pollock assessment (2016 to now)
- M2 index for EBS ecosystem status report (2016 to now)
- M2 index for ESP (2020 to now)

ACLIM/Bering Sea:

- 2010-2015 BSIERP MSE
- 2016- now ACLIM - climate MSE
- 2019- 2023 Lenfest NFS
- Lenfest ocean wealth

Bering Seasons

- Forecasts under 9mo

GOA

- G. Adams (UW) : 3 and 4 species model for GOA (Adams et al, in review)
- G. Adams (UW) : M2 index for GOA Ecosystem Status Report (2021-now)
- Climate MSE underway for GOA

Hake (S. Wassermann)

Holsman, K. K. et al. Climate-informed multispecies assessment model methods for determining biological references points and Acceptable Biological Catch. *Protoc. Exch.* https://doi.org/10.21203/rs.3.pex-1084/v1 (2020).

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Model Summary

CEATTLE (Holsman et al. 2016)

- NEBS+EBS
- Age or Length based
- Multi- or single-species
- ADMB
- Climate (energetics) effects on
  - Growth
  - Mortality (if in MSM)
  - Recruitment
- Used to derive climate-inform. ABC
- Pollock, Pcod, ATF
- Operational 2016 - now (annually)
- Climate naive targets; climate informed reference points

Rceattle (Adams et al. 2022)

- GOA
- Age or Length based
- Multi- or single-species
- TMB
- Random effects
- Data weighting
- Climate (energetics) effects on
  - Growth*
  - Mortality (if in MSM)
  - Recruitment
- Used in EBS, GOA, and Cali Current (hake)
- Pollock, Pcod, ATF, Halibut, and Hake

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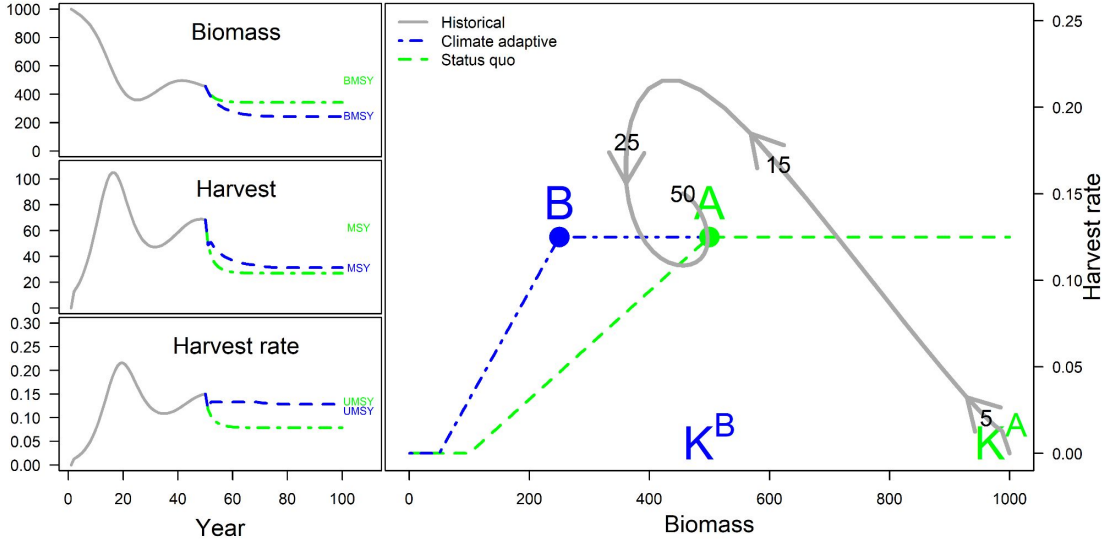
Discussion : Climate informed BRPs

Set B0 and B40 target using climate informed models

NO!

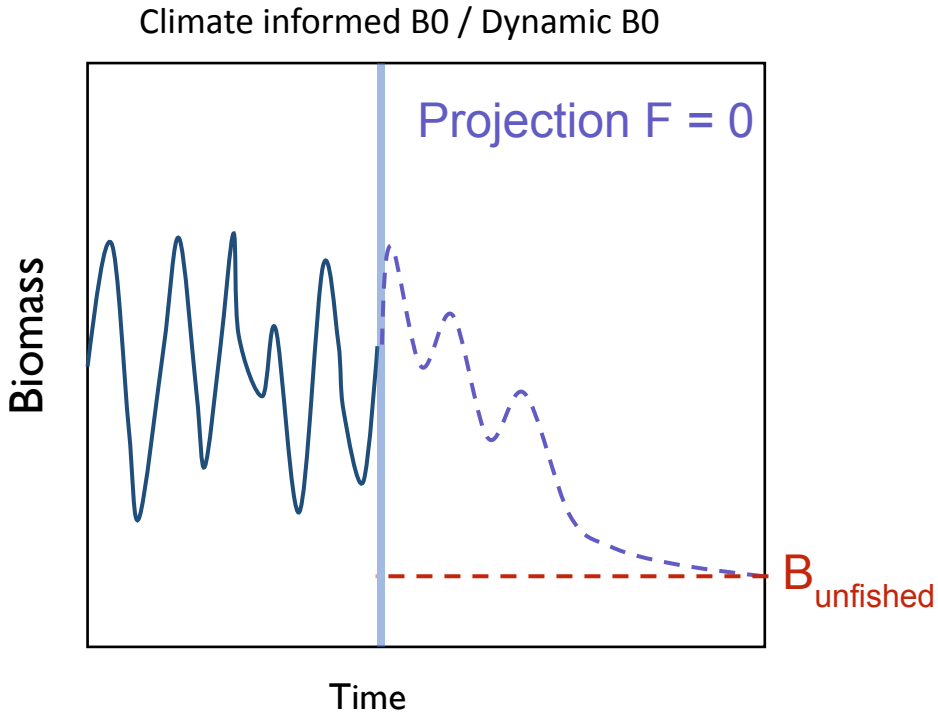
Adapting reference points to reflect changes in productivity

- MSA directs reference points to reflect current and probable future environmental conditions
- Changing reference points for stocks undergoing climate-related productivity shifts can result in counter-intuitive management actions:
  - Declining stocks could be fished harder
  - Flourishing stocks could be fished more conservatively

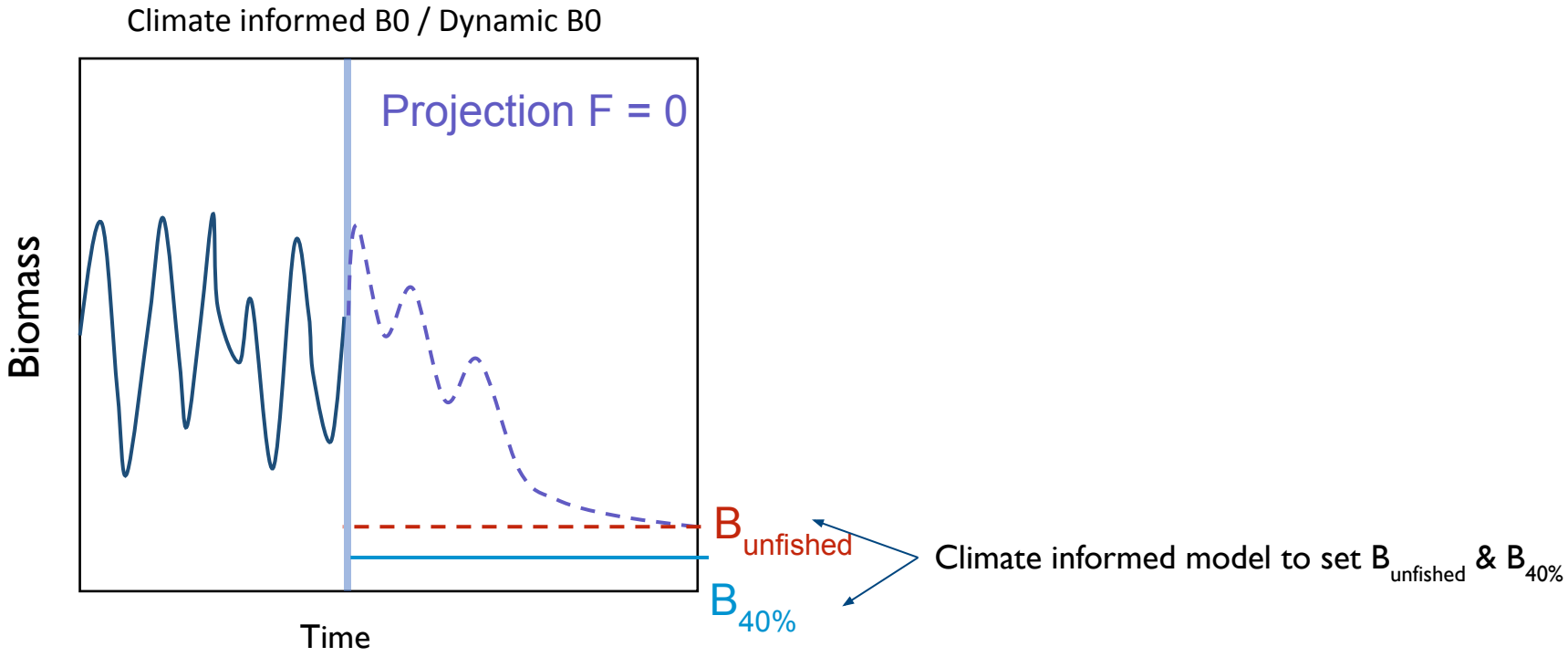


Szuwalski et al. 2023

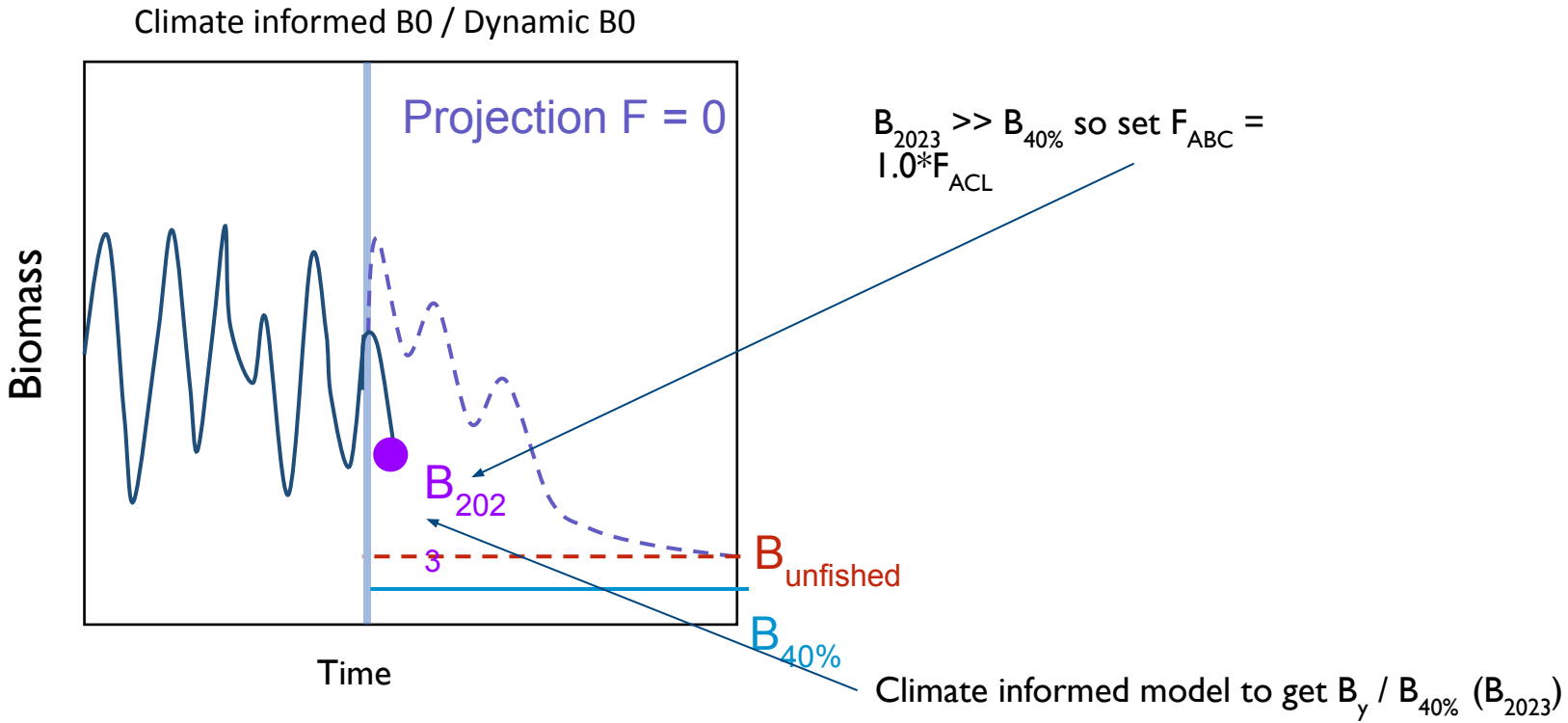
First: Set Target / reference points



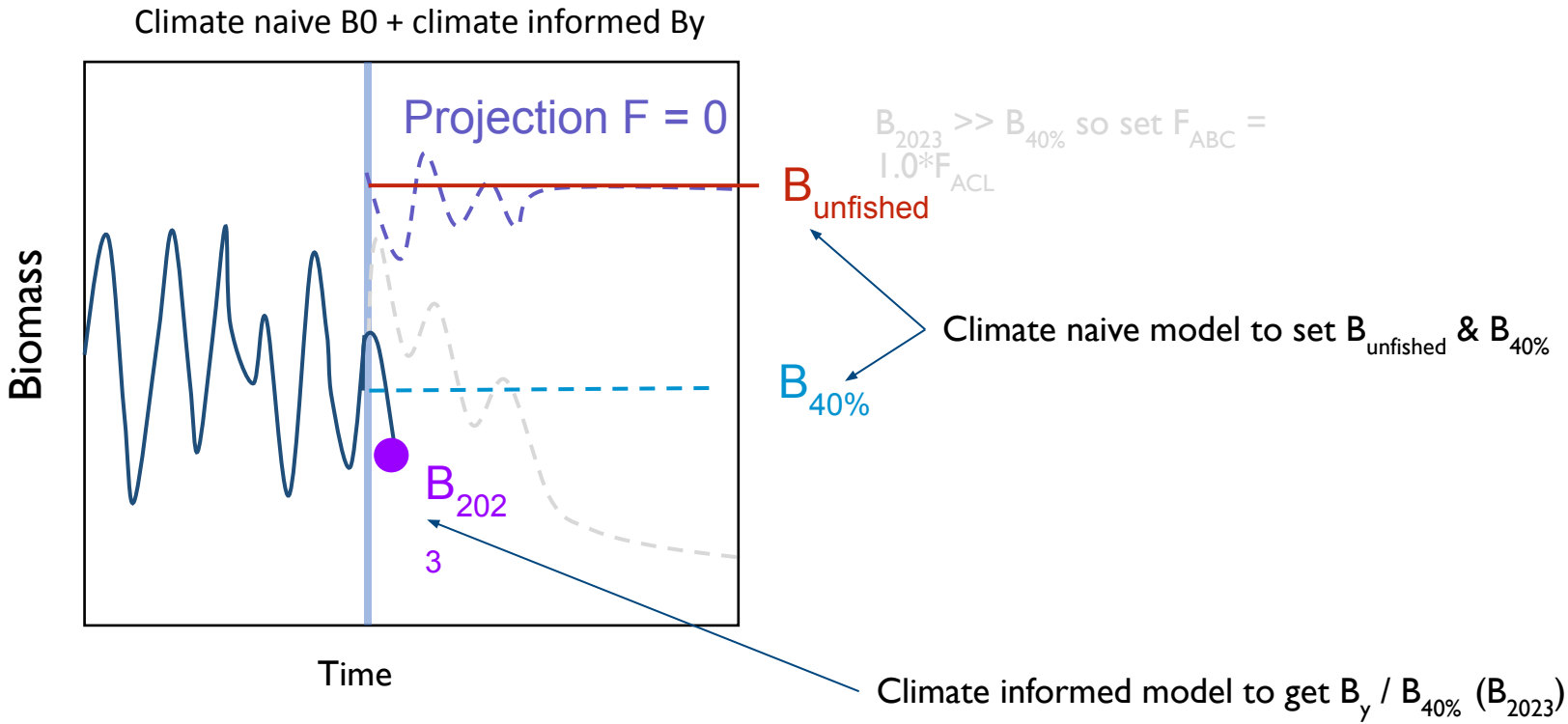
First: Set Target / reference points



First: Set Target / reference points



“hybrid” climate- naive & climate informed approach



“hybrid” climate- naive & climate informed approach