Bering Sea climate-enhanced multi-species stock assessment

Nov., 2023

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

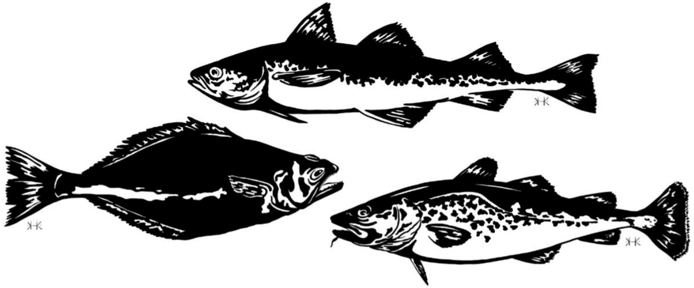
https://apps-afsc.fisheries.noaa.gov/Plan_Team/2023/EBSmultispp.pdf

NOAA FISHERIES

2023 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

Contents



November 2023 | 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, K. Shotwell (2023) Climate-enhanced multispecies stock assessment for walleye pollock, Pacific cod, and arrowtooth flounder in the eastern Bering Sea. In: Ianelli, J. et al. 2023. Assessment of the eastern Bering Sea walleye pollock. North Pacific Fishery Management Council, Anchorage, AK.*

Two models presented each year:

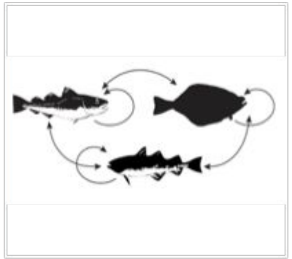
- SSM : without trophic interactions (single-species mode)
- MSM : with trophic interactions (multi-species mode)

Produced annually 2016 - present

NOAA FISHERIES

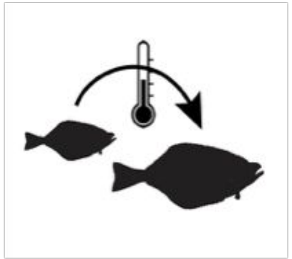
EBS CEATTLE

Mortality



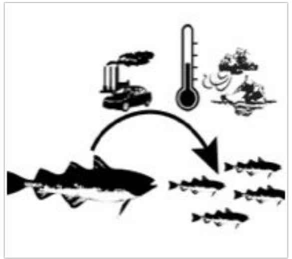
- Empirical diets
- Bioenergetics

Weight @ Age



- Empirical
- VonB with Temp

Rec

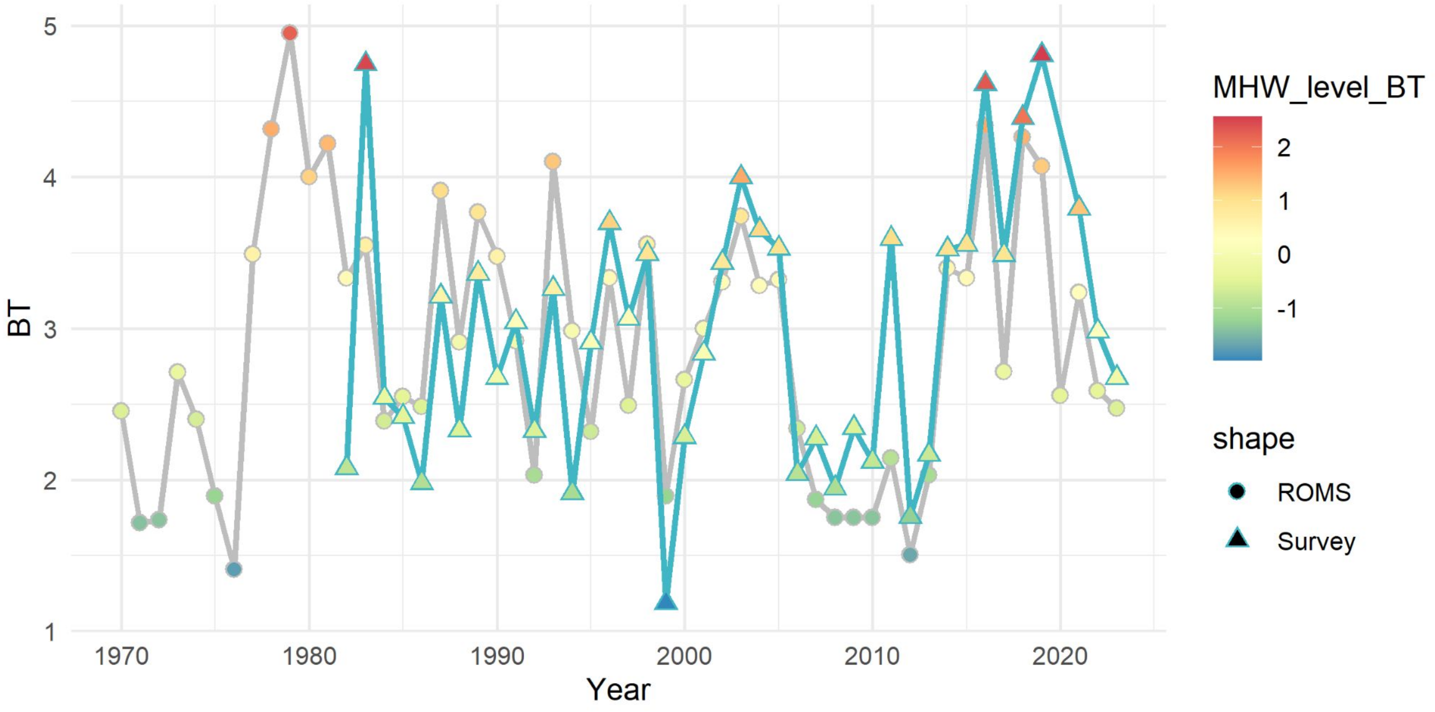


- Climate-S/R
- S/R
- mean R

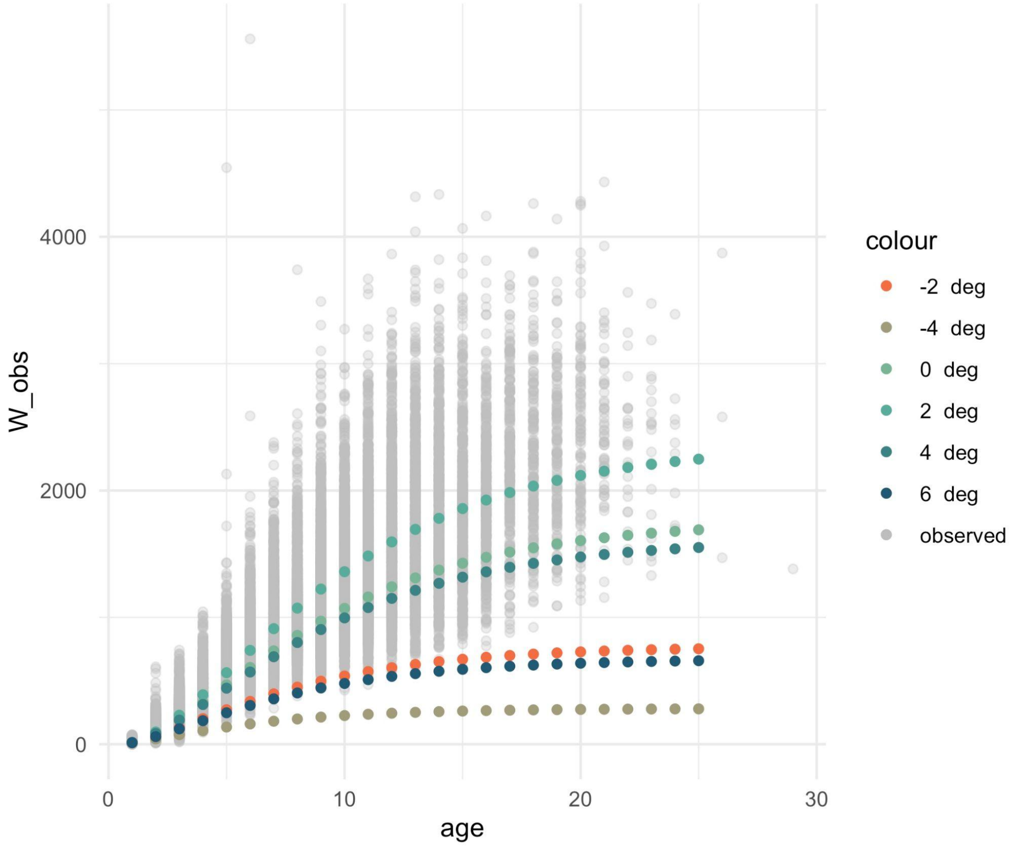
HCRs

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

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



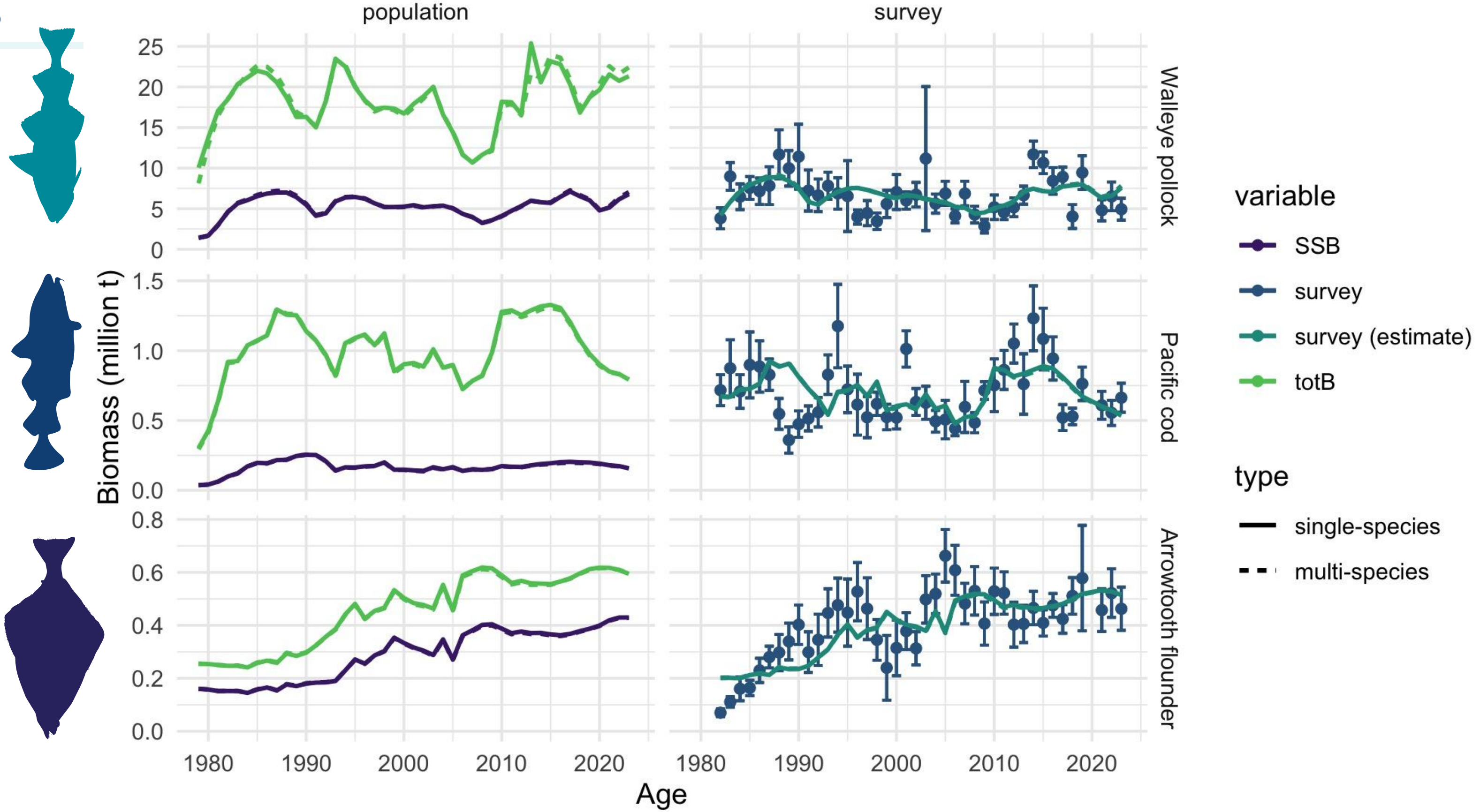
Weight at Age



- Hist: Empirical used when avail; missing yrs have vonBT (currently updating with new TMB version of *vonBT()*)
- Projections: VonBT

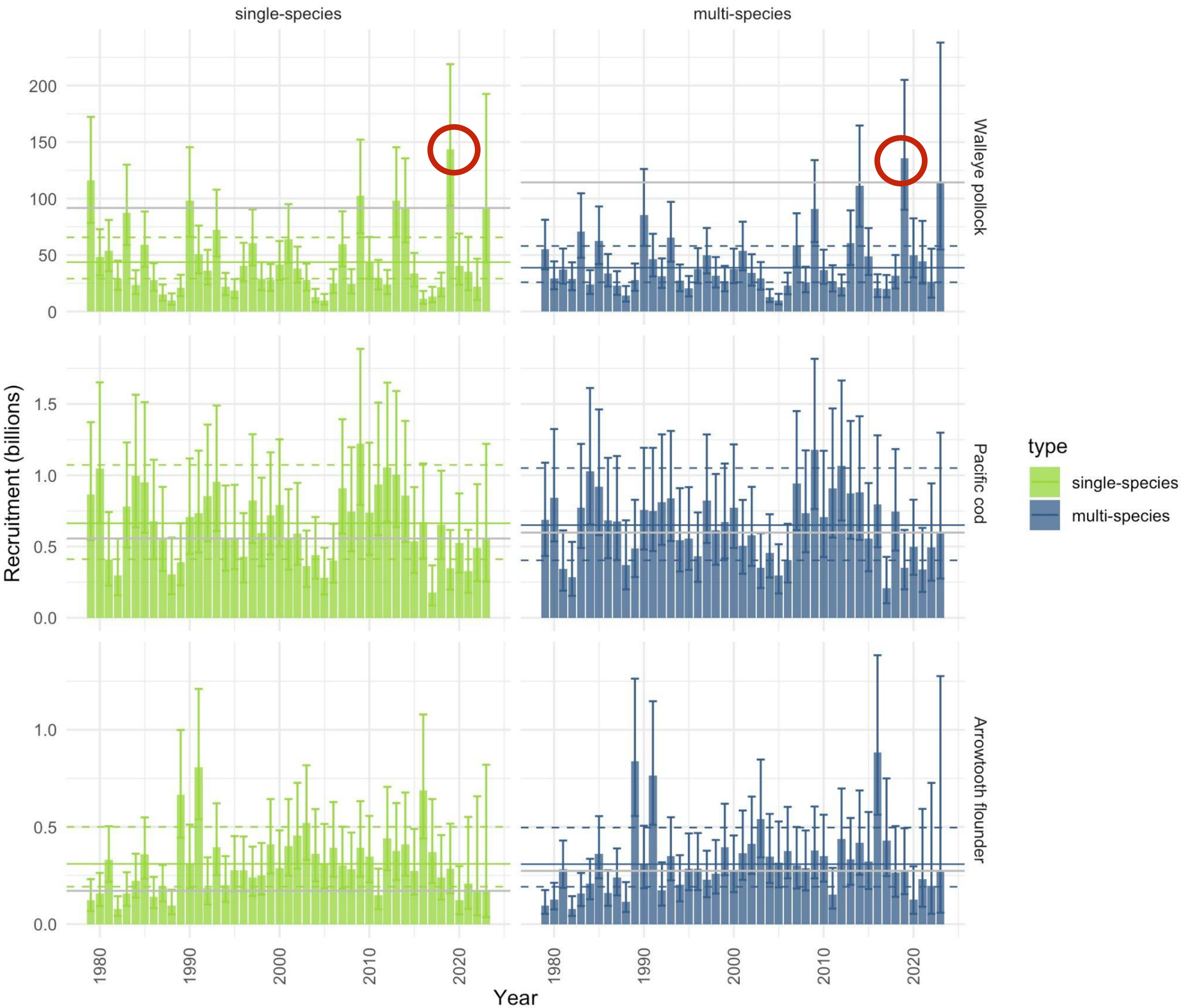
Holsman & Aydin 2015

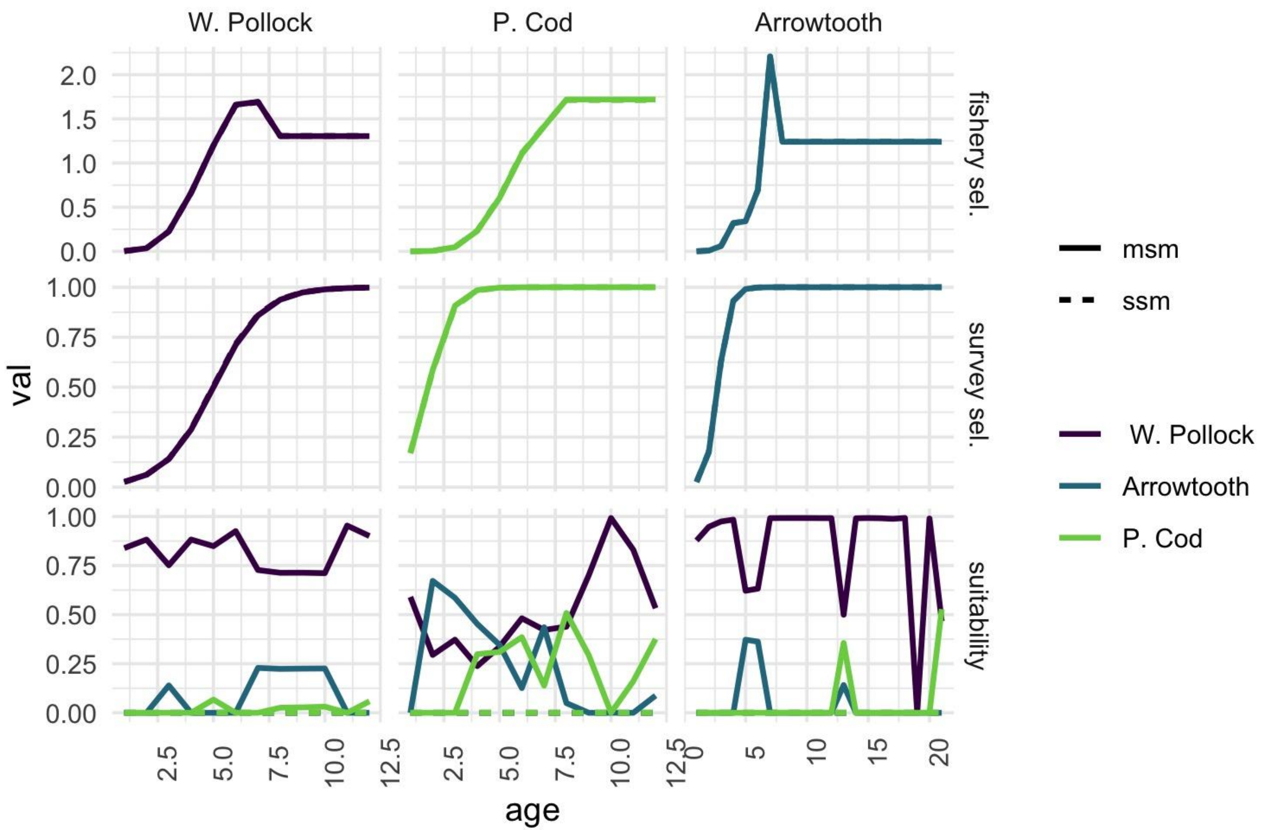
Biomass



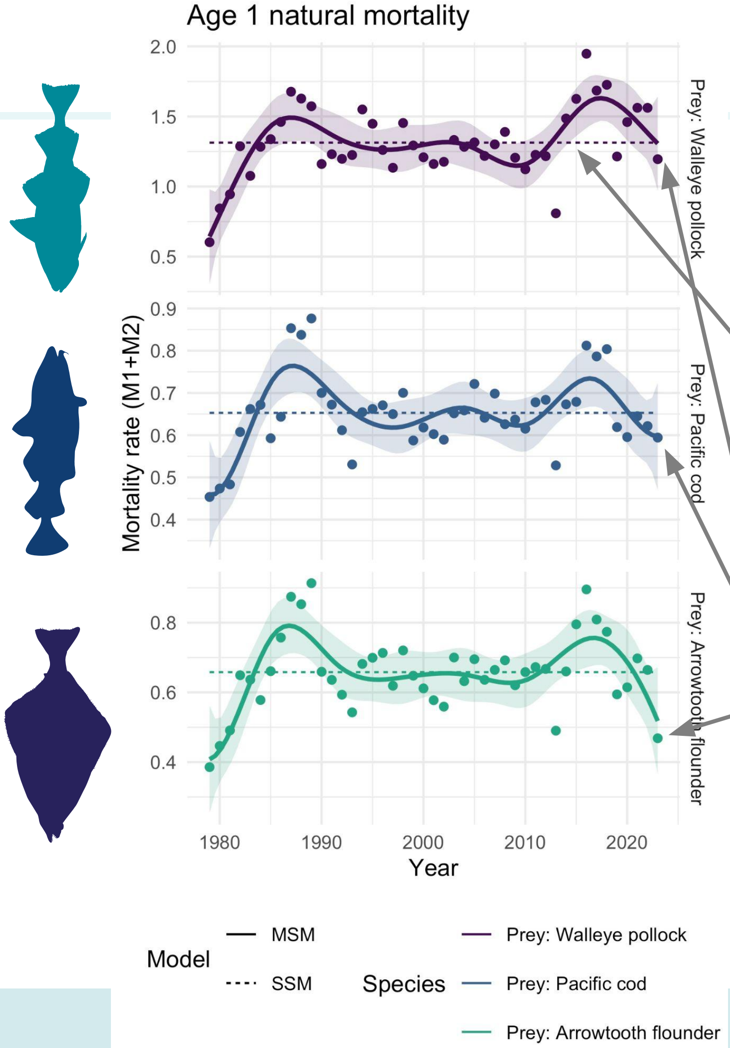
population
survey
Biomass (million t)
Walleye pollock
Pacific cod
Arrowtooth flounder
Age
variable
SSB
survey
survey (estimate)
totB
type
single-species
multi-species

Recruitment



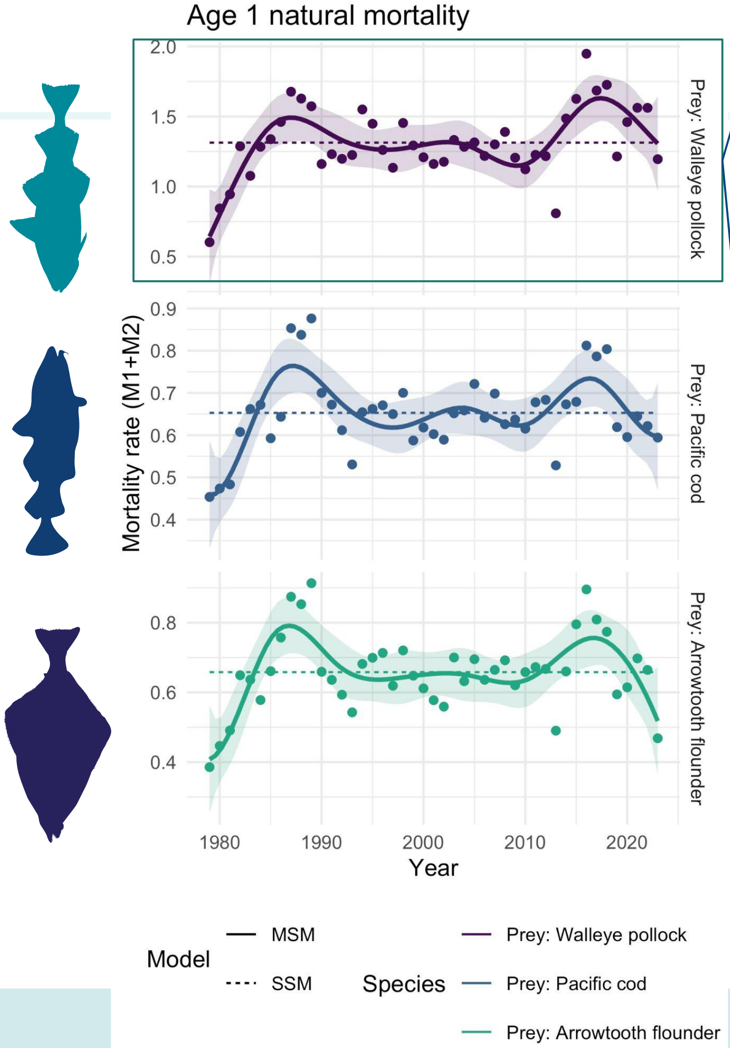


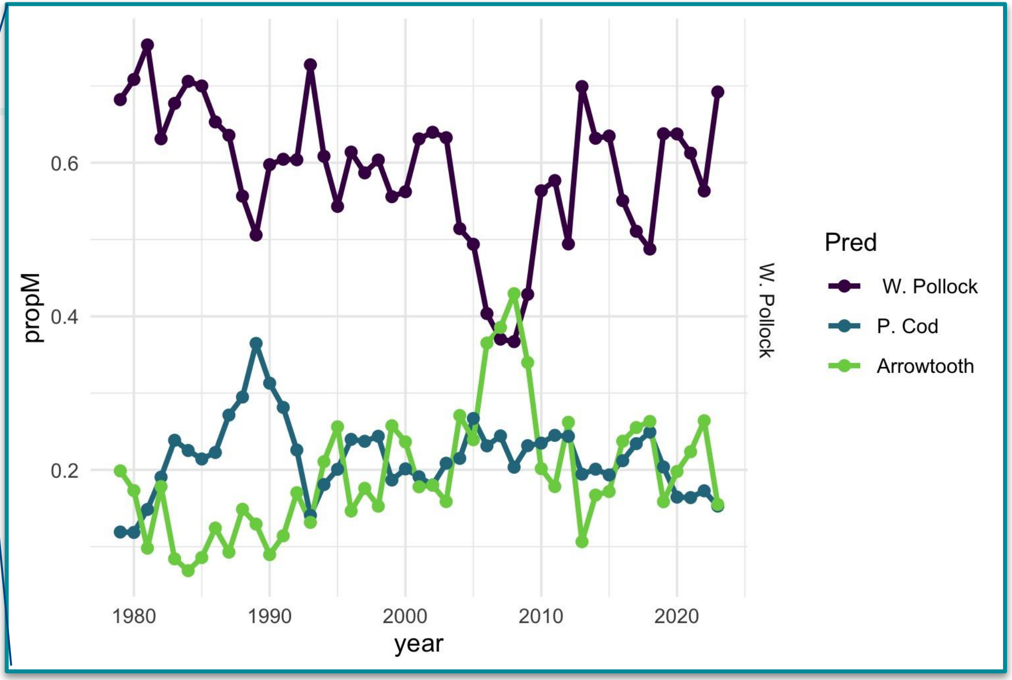
NOAA FISHERIES

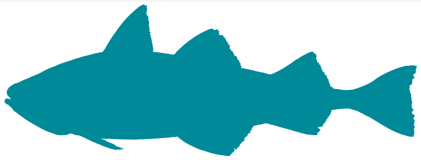


M1 in single species (CEATTLE) model = avg(M1+M2) from multispecies model

Predation mortality decreased in 2023





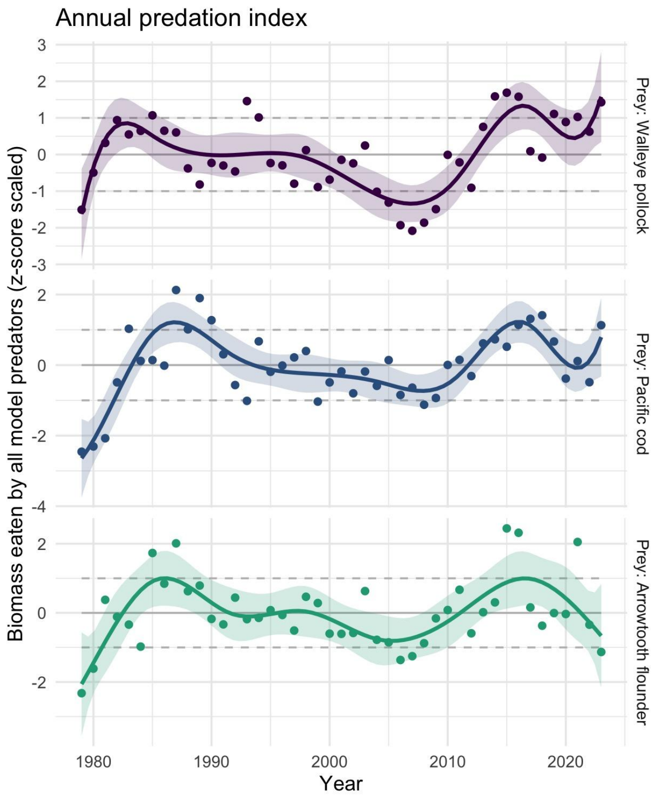


walleye pollock

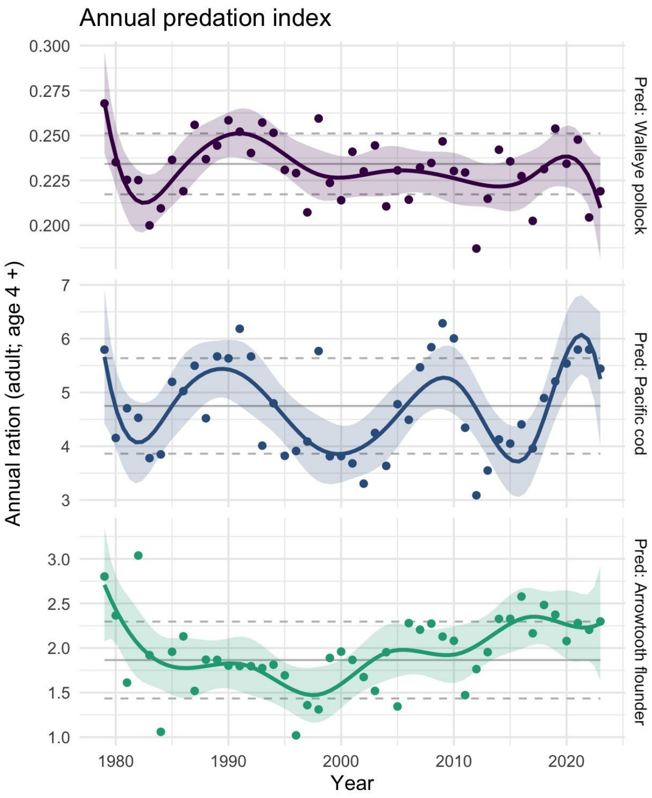
NOAA FISHERIES

ESPs

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

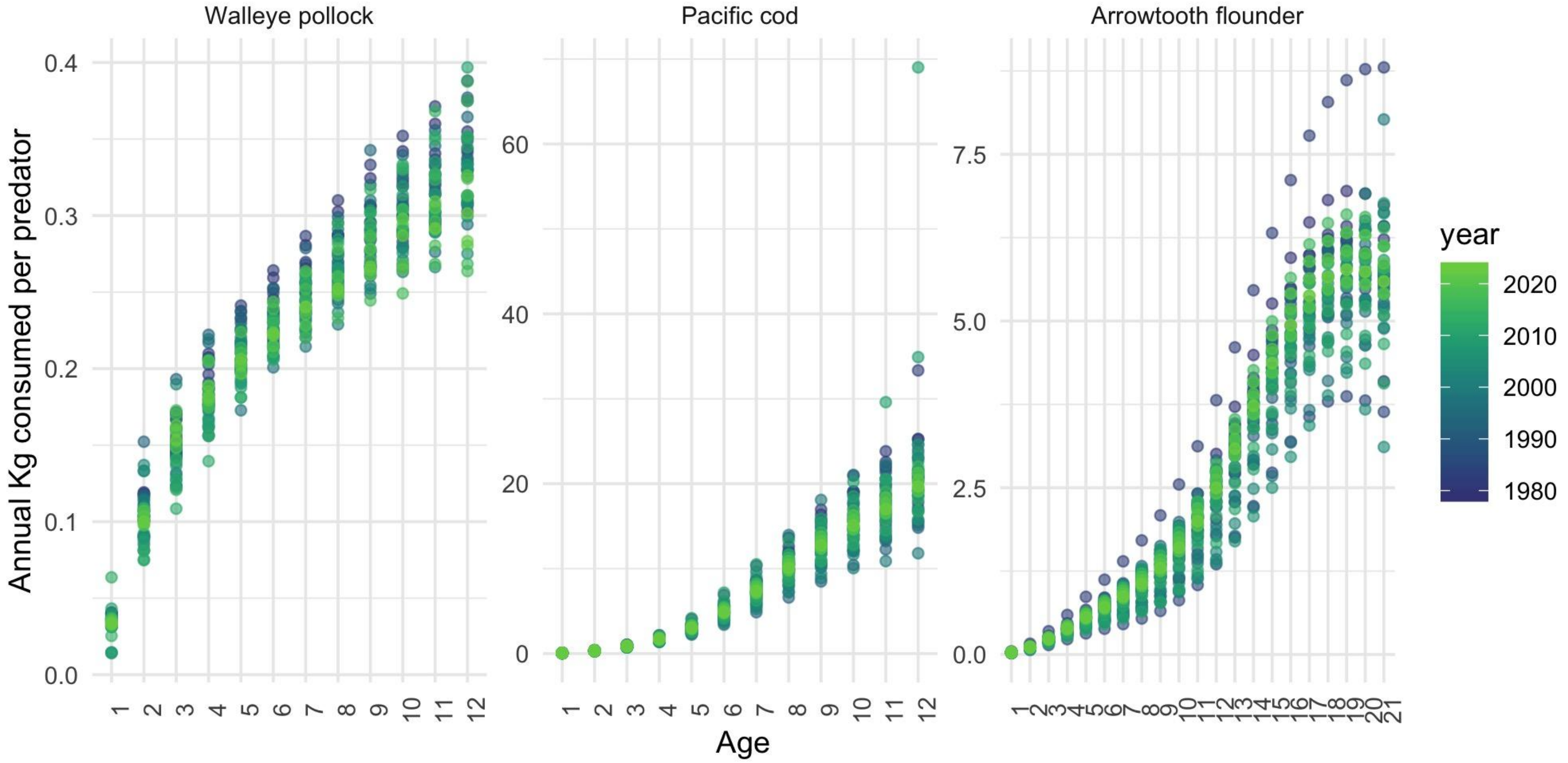


Use this if: need index of plk, pcod, atf eating other prey



NOAA FISHERIES

Annual estimates of prey consumed per fish



NOAA FISHERIES

Data from food habits lab

ESP indices expanded

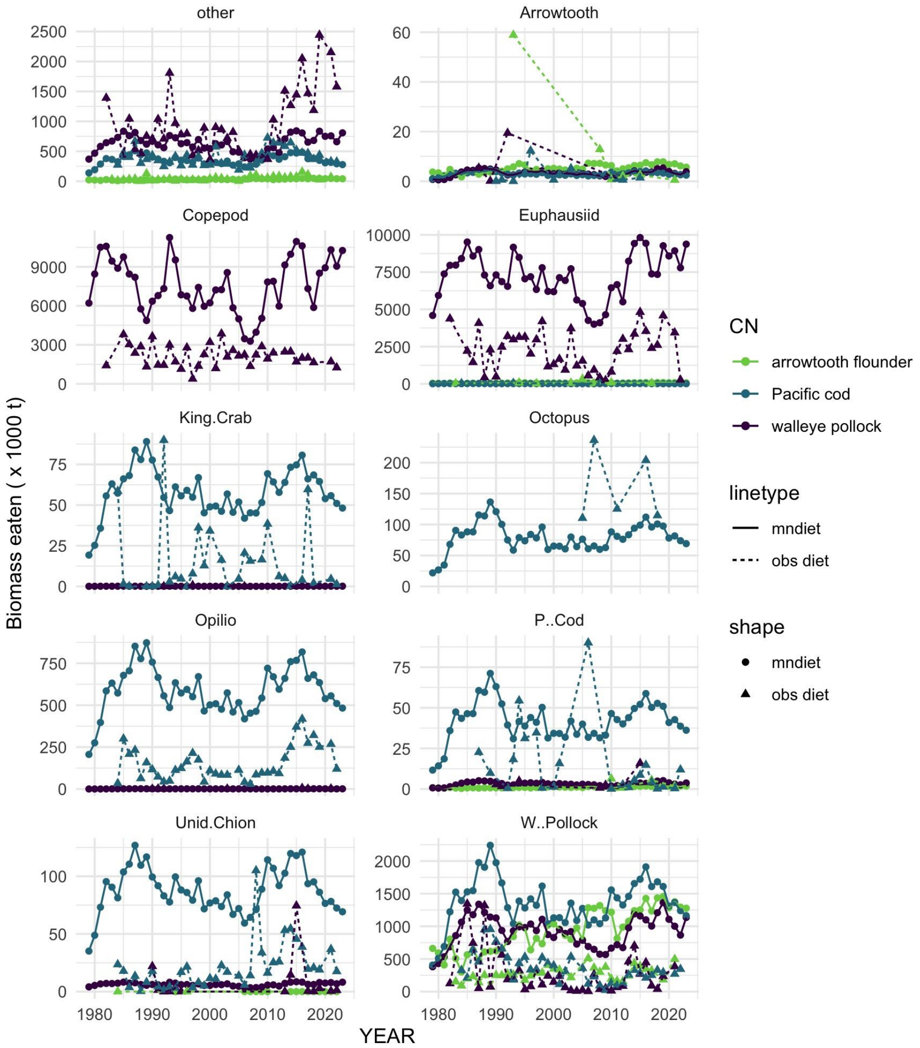
Diet database & survey CPUE

CEATTLE outputs

$$\mathrm{sum}(\overline{avgP}_{i,j,k,y}*L2A)*\overline{AvgN_{a,k,y}*C_{a,k,y}}$$

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

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

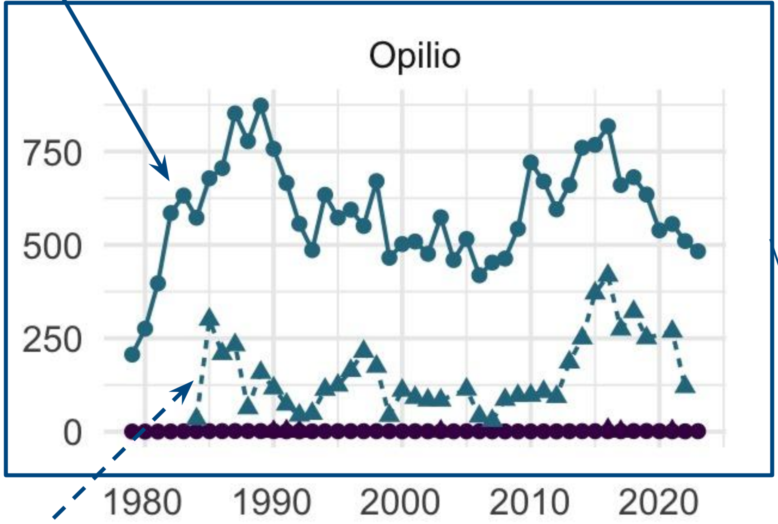


Holsman et al. in prep

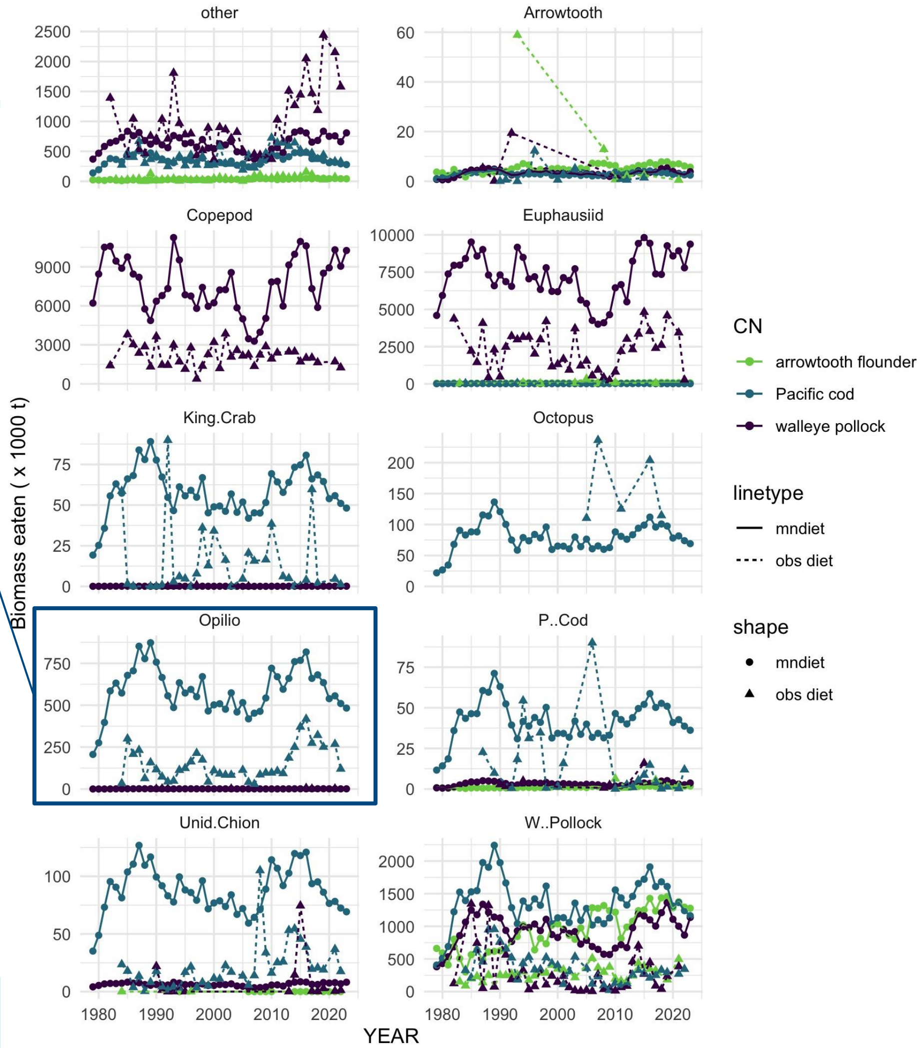
ESP indices expanded

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

A = cold, warm, avg T years



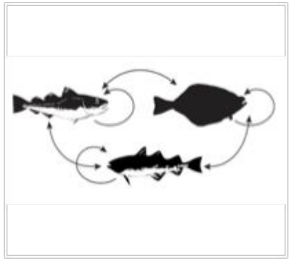
$\text{sum}(avgP_{i,j,k,y} * L2A) * AvgN_{a,k,y} * C_{a,k,y}$



Output available as .Rdata

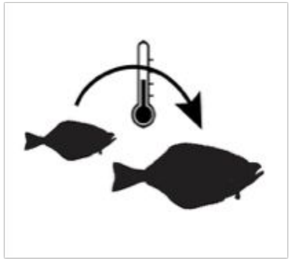
EBS CEATTLE

Mortality



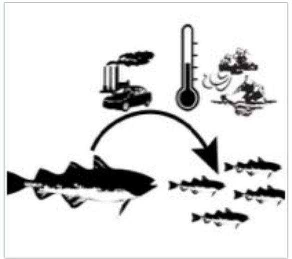
- Empirical diets
- Bioenergetics

Weight @ Age



- Empirical
- VonB with Temp

Rec



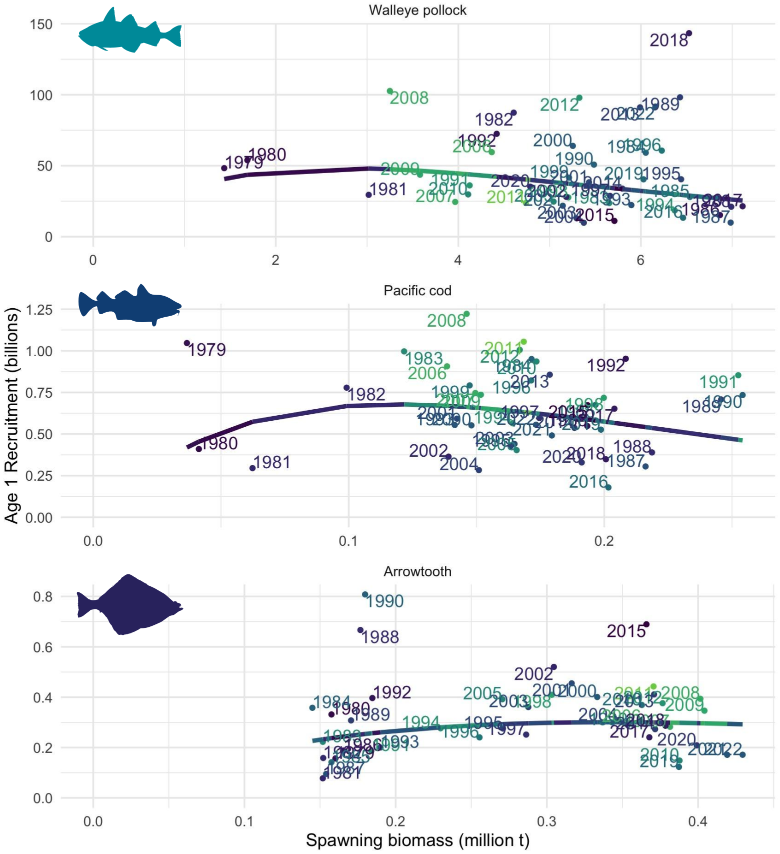
- Climate-S/R
- S/R
- mean R

HCRs

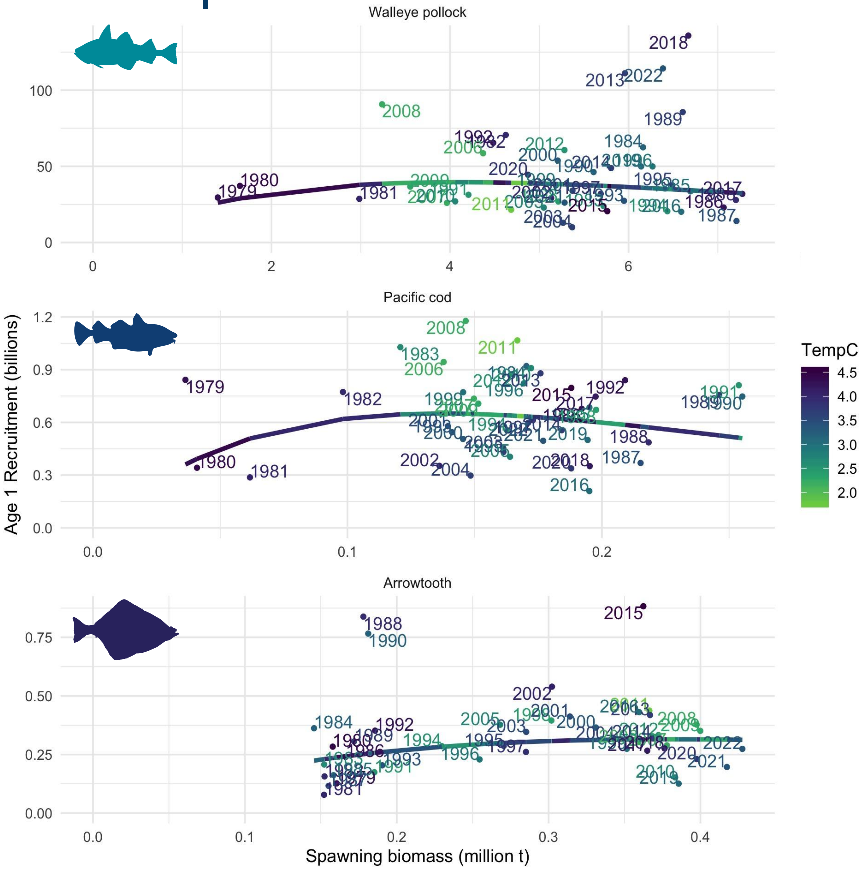
- Climate ABC
- MMSY
- MEY
- SPR
- Aggregate MSY

Recruitment (note: scales vary)

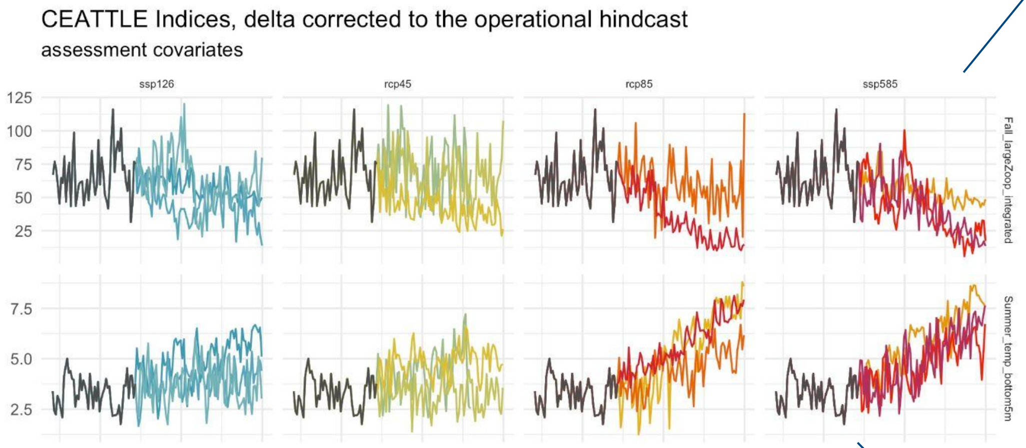
Single-species

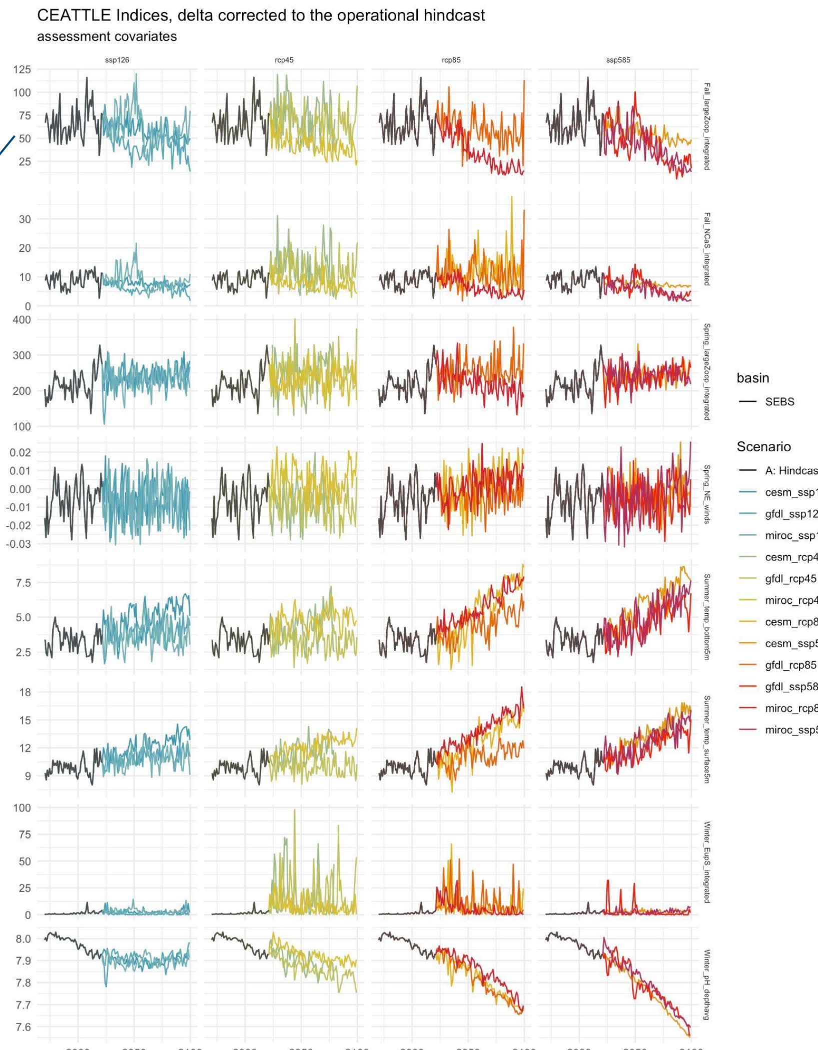


Multispecies



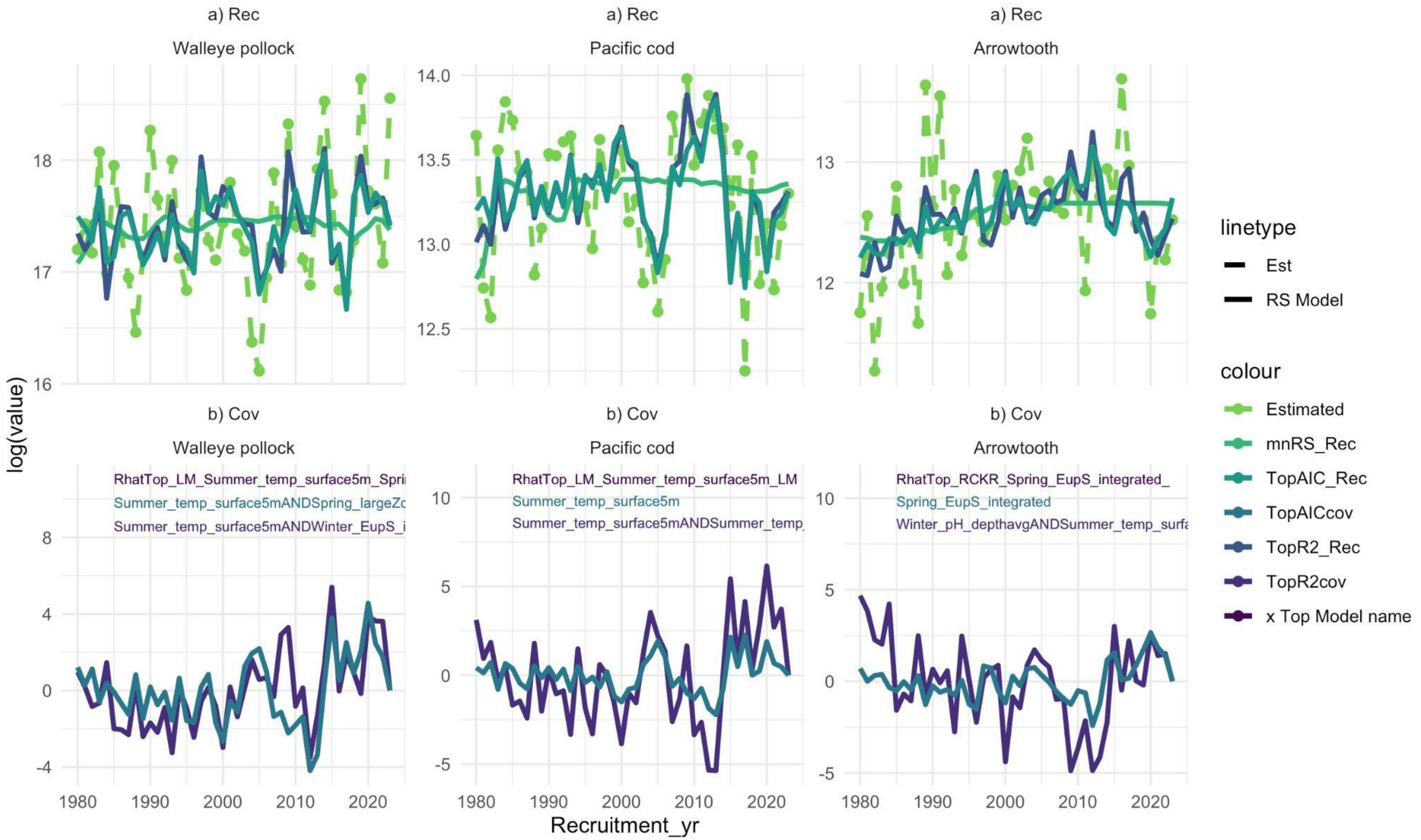
Recruitment covariates





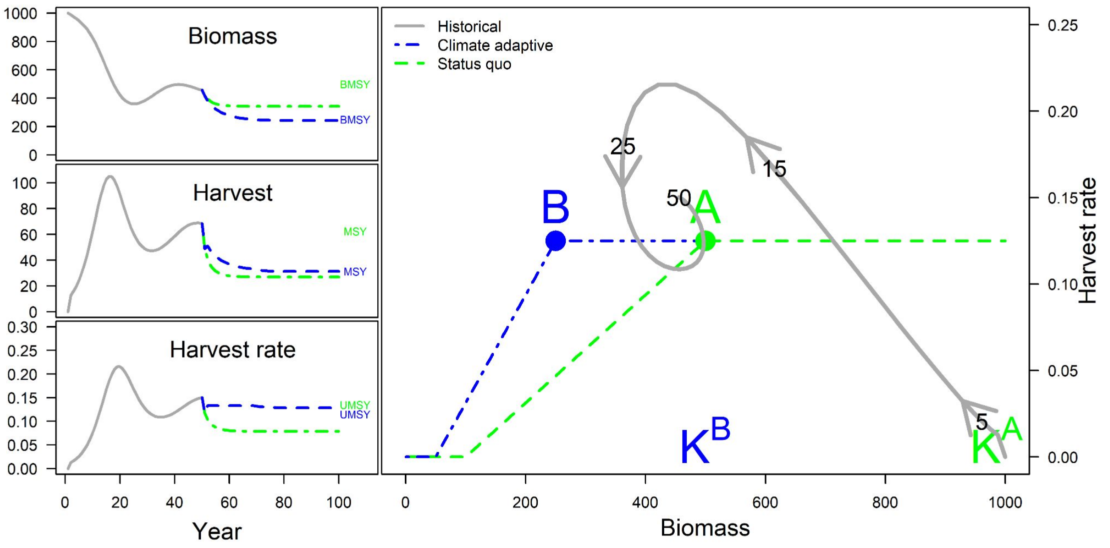
ACLIM indices

Multispecies model



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

Set target using climate naive (B0 from no-climate projection)

1a: Use model with climate effects to get F40 for each climate projection and ABC 2080

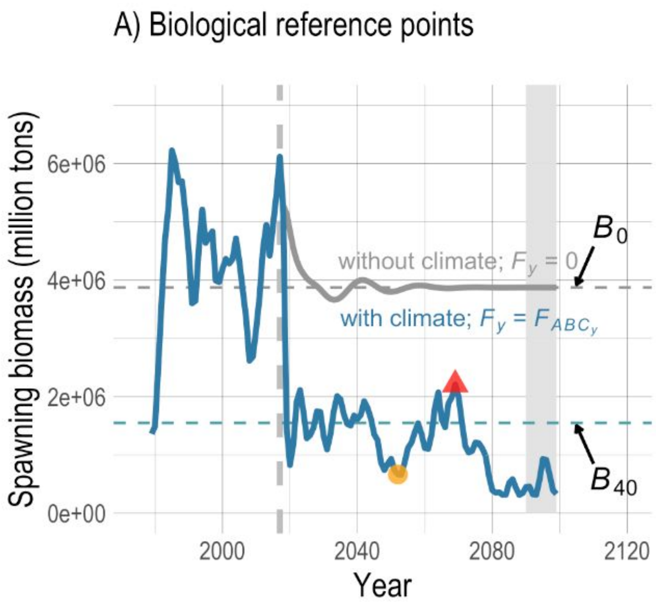
2a: Set ABC_2024 = avg(ABC 2080), calc F2024 and use that to get ABC_2025 (avg. using models with climate effects)

1b: Use model with no climate to get F40%

2b: Apply F40%* to model with climate effects to get ABC from ensemble (ABC_2024 = avg(ABC from all models)

NOAA FISHERIES

Climate informed biological reference points

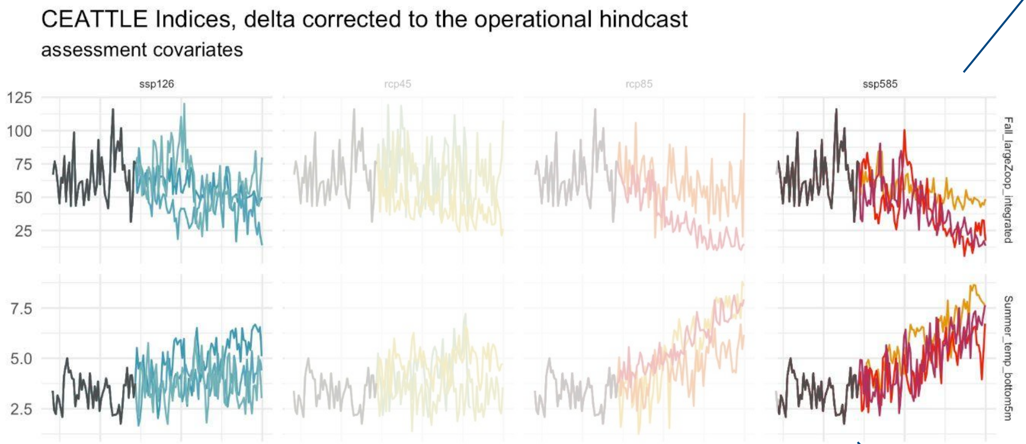


Holsman, K. K. et al. Climate-informed multispecies assessment model methods for determining biological references points and Acceptable Biological Catch. *Protoc. Exch*. https://doi.org/10.21203/rs.3.pex-1084/v1 (2020).

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

NOAA FISHERIES

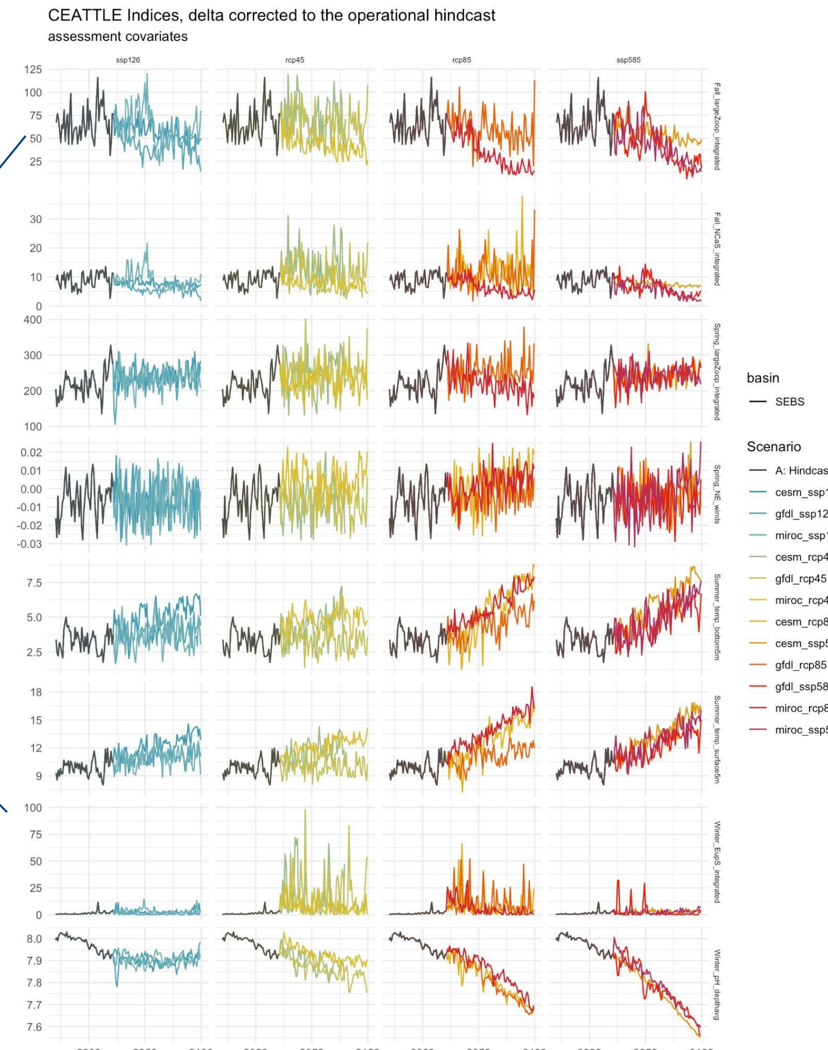
Recruitment covariates



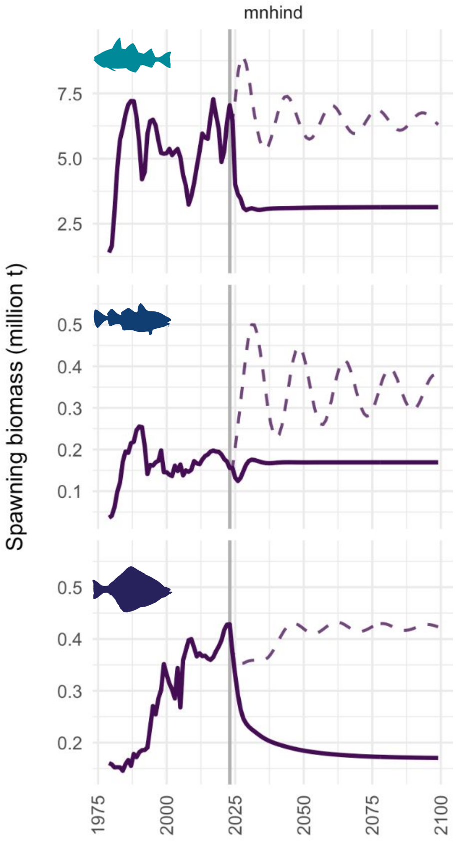
High

carbon mitigation

Low



Biomass (multispecies)



Project to 2099 such that

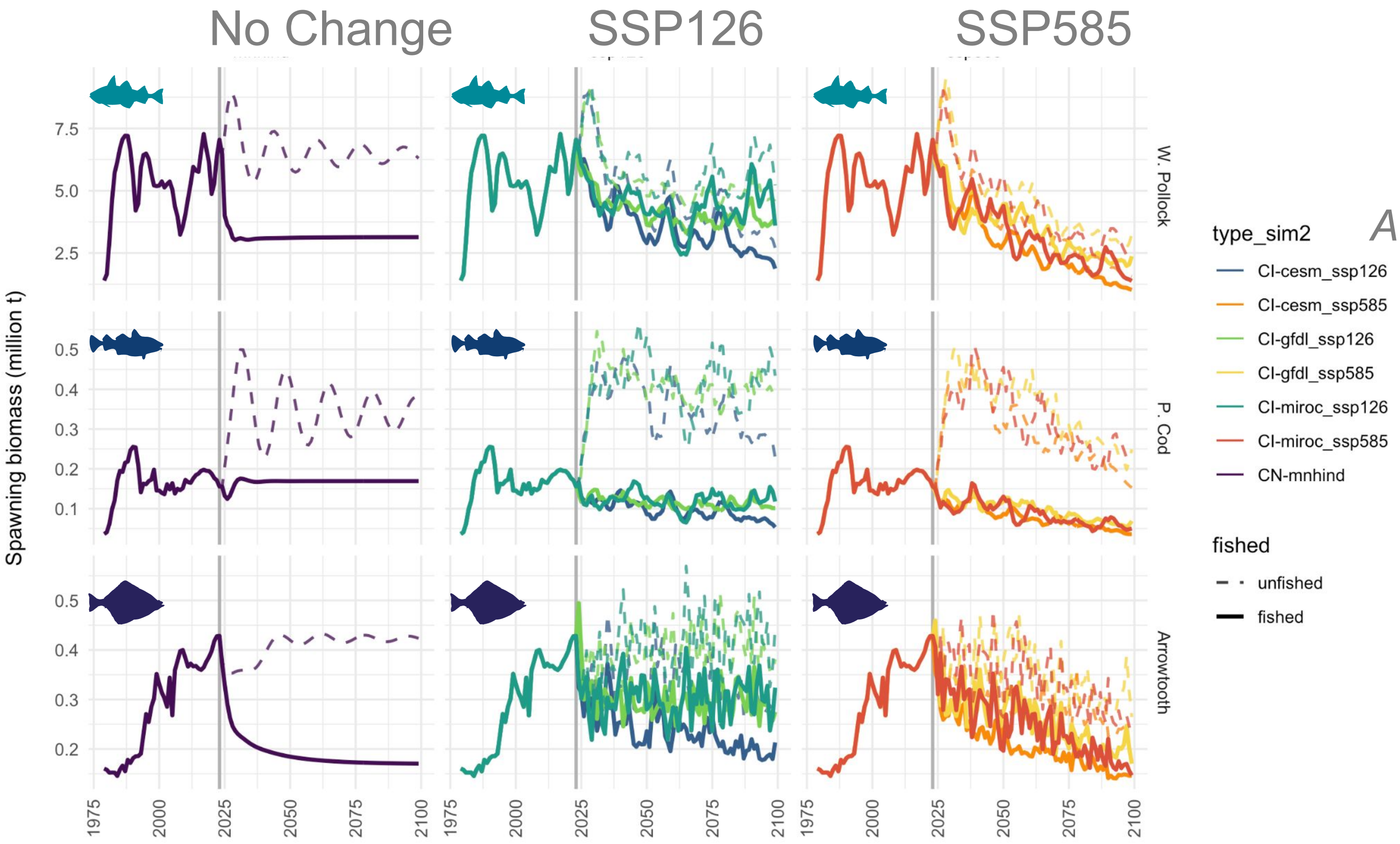
F that results in $B_{2095\text{-}2099} \sim 0.4\ B_{100\%}$

AND $B_y > 0.35\ B_{100\%}$

Pollock & P. cod first, then arrowtooth

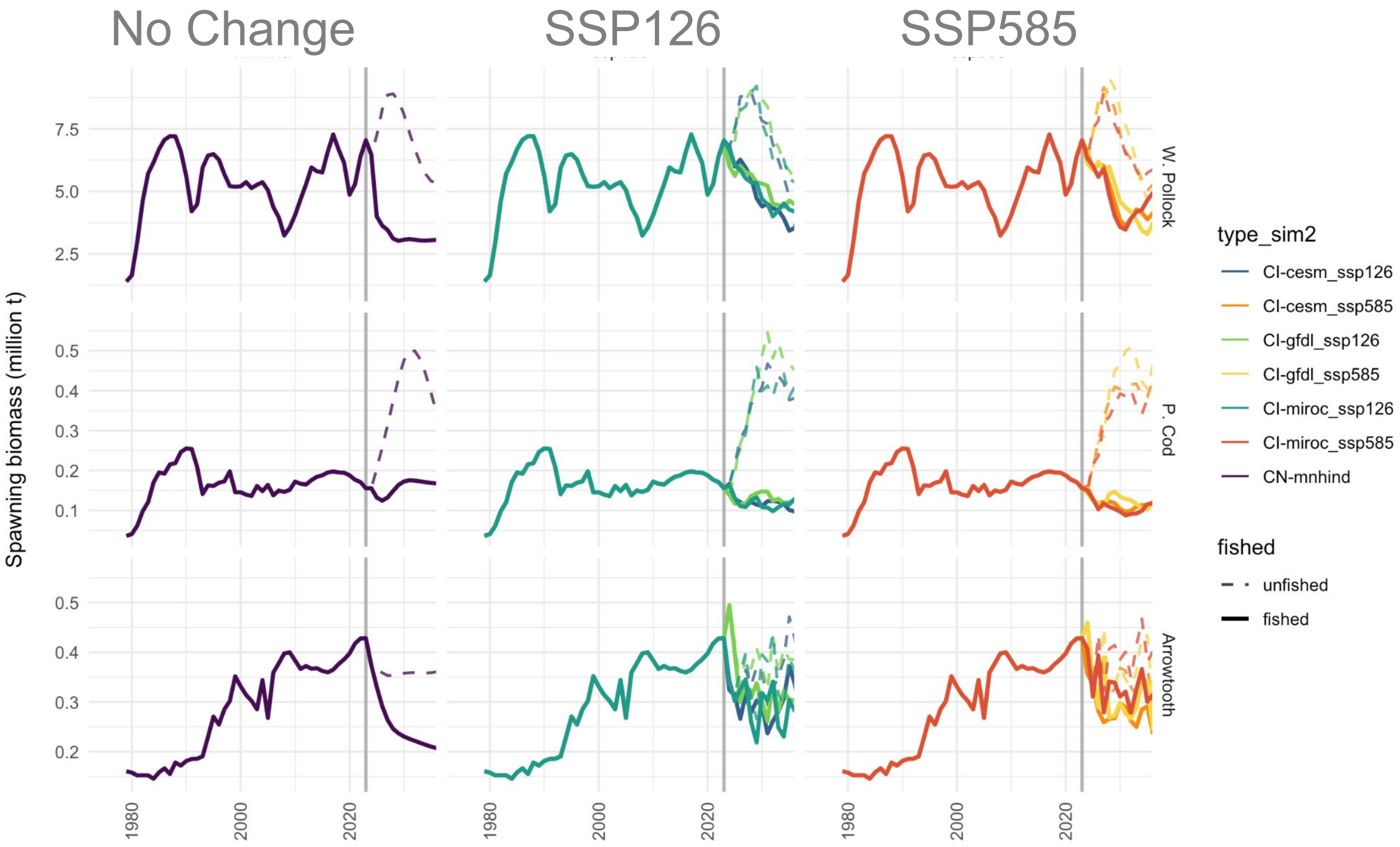
(Holsman et al. 2016)

Biomass (multispecies)



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

Biomass



NOAA FISHERIES

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

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 a decline (slightly) in SSB in both 2024 and 2025.
- 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 2023 catch for 2024 and F_{ABC} for 2025) estimate a 95% probability that pollock SSB will remain between 89-93% of 2023 SSB in 2024 and will be between 81-84% of 2023 SSB levels in 2025.
- 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 96-102% of 2023 SSB in 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.

Climate informed BRPs and ABC evaluations

Climate-informed outlook

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

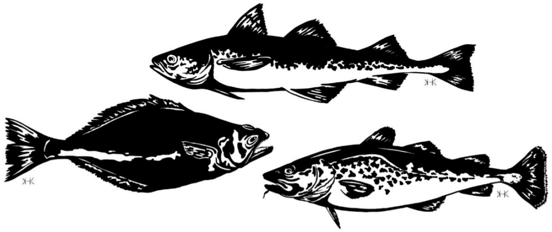
- Relative to 2023 levels, the model projects SSB of pollock will decline in 2024 (projected based on 2023 catch) followed by a decline in SSB in 2025 (projected with F_{ABC}). For Pacific cod the model projects a decline (slightly) in SSB in both 2024 and 2025.
- Ensemble projections using climate-enhanced 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 2023 catch for 2024 and F_{ABC} for 2025) estimate a 95% probability that pollock SSB will remain between 89-93% of 2023 SSB in 2024 and will be between 81-84% of 2023 SSB levels in 2025.
- 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 96-102% of 2023 SSB in 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.

Multispecies assessment

2023 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

Contents



November 2023 | 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, K. Shotwell (2023) Climate-enhanced multispecies stock assessment for walleye pollock, Pacific cod, and arrowtooth flounder in the eastern Bering Sea. In: Ianelli, J. et al. 2023. Assessment of the eastern Bering Sea walleye pollock. 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

NOAA FISHERIES

Climate informed BRPs and ABC evaluations

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 fishery management.* See figures 22 and 23 for more information.
- Ensemble projections using climate-enhanced recruitment models and projected future warming scenarios and assuming F_{ABC} for 2025 - 2100) estimate a 95% chance that pollock SSB will be between 59-63% of 2023 SSB in 2033, between 57-61% of 2023 SSB levels in 2050, and between 48-55% of 2023 SSB levels in 2080.
- Ensemble projections using climate-enhanced recruitment models based on long-term projections estimate a 95% chance that Pacific cod SSB will be between 71-79% of 2023 SSB in 2033, between 73-79% of 2023 SSB levels in 2050, and between 62-69% 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 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.

Cooler future

Climate informed BRPs and ABC evaluations

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 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 2025 - 2100) estimate a 95% chance that pollock SSB will be between 57 and 64% of 2023 SSB in 2033, between 50 and 55% of 2023 SSB levels in 2050, and between 29 and 34% of 2023 SSB levels in 2080.
- Ensemble projections using climate-enhanced recruitment models based on long-term projections estimate a 95% chance that Pacific cod SSB will be between 65 and 75% of 2023 SSB in 2033, between 64 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.

Warmer future

Next year

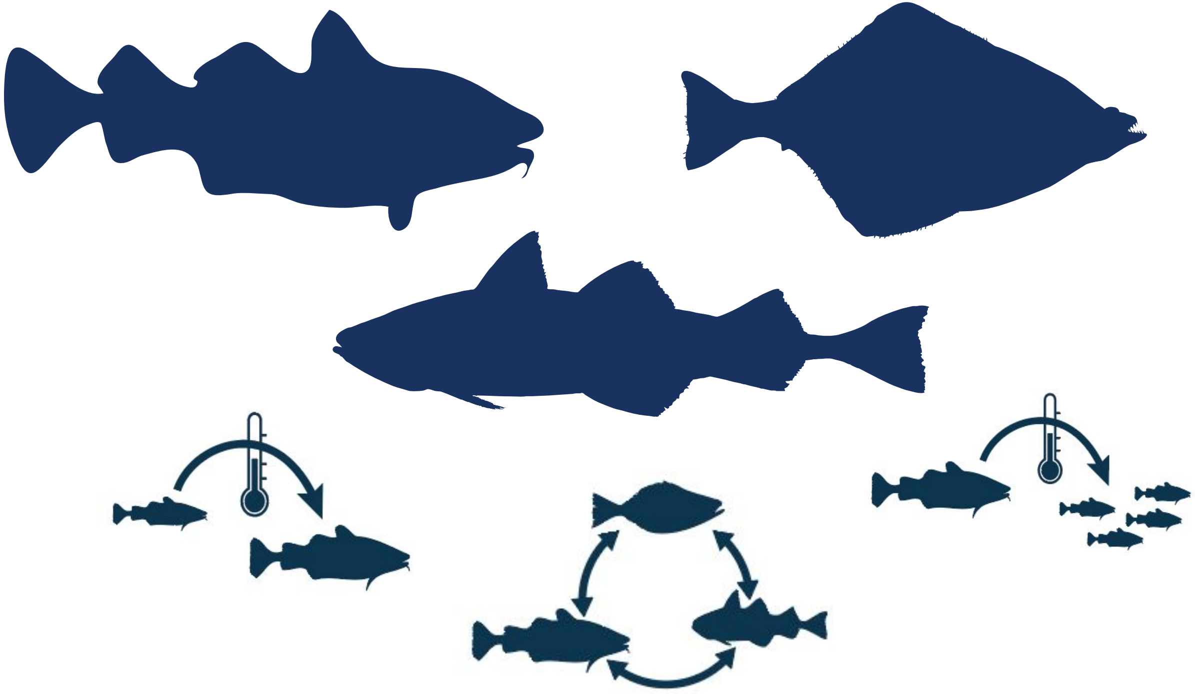
1. Revist likelihood weighting
2. Update weight at age (Holsman et al. in prep)
3. Add in pred/prey overlap (Goodman et al. in prep)
4. Transition to TMB via merging CEATTLE and Rceattle
5. NSF conditioned ABC (2024)
6. Include ACLIM MSE results and CI features
7. Share output via AKFIN

CEATTLE workflow features

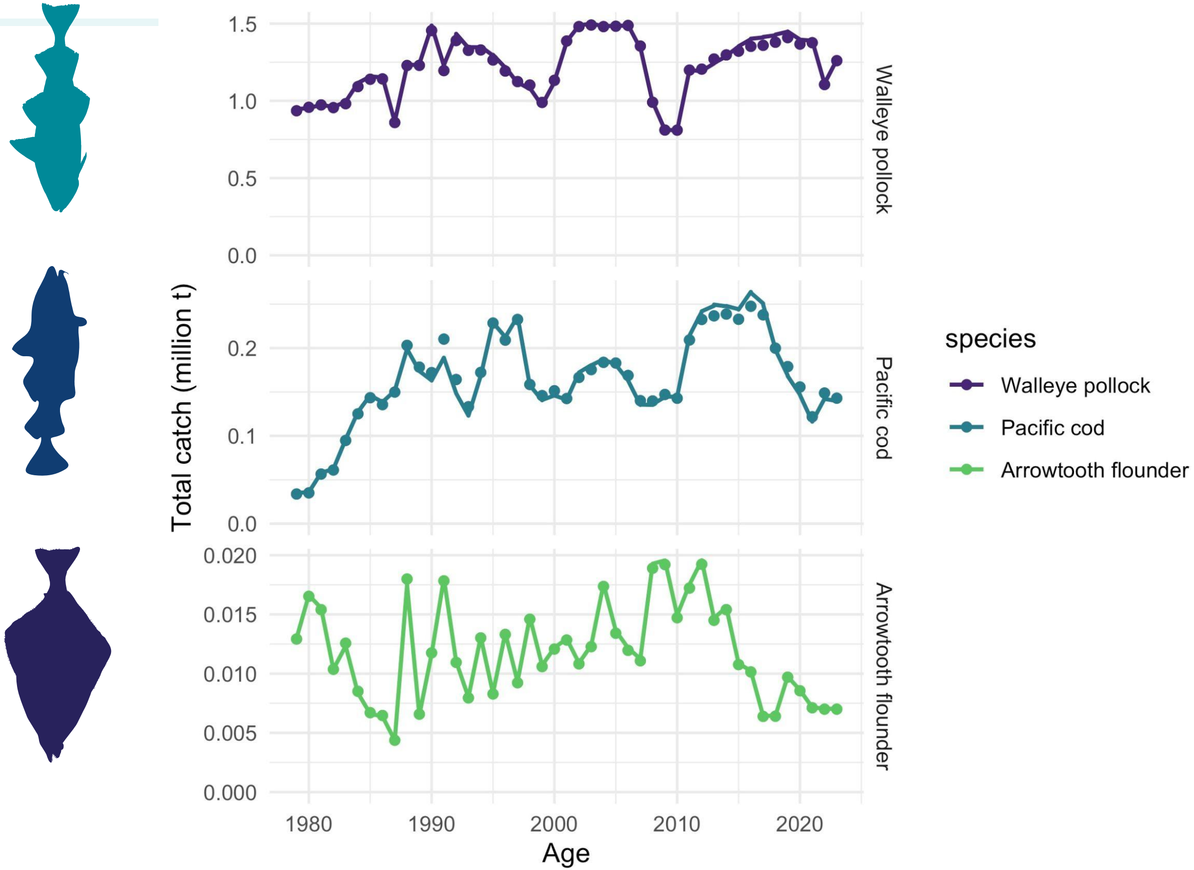
- R and shell scripts used to run the model through projections:
  - Regular output includes ESR contribution (R markdown)
  - ESP indices (produced annually)
  - Assessment written in Rmarkdown using Rdata outputs
    https://apps-afsc.fisheries.noaa.gov/Plan_Team/2023/EBSmultispp.pdf
- Github repositories (* private)
  - *CEATTLE (ADMB):
    https://github.com/kholsman/CEATTLE
  - *futR() : recruitment fitting model in TMB:
    https://github.com/kholsman/futR
  - * vonBT(): temp. varying vonB model in TMB:
    https://github.com/kholsman/vonBT
  - Rceattle (G. Adams; R/TMB):
    https://github.com/grantdadams/Rceattle

NOAA FISHERIES

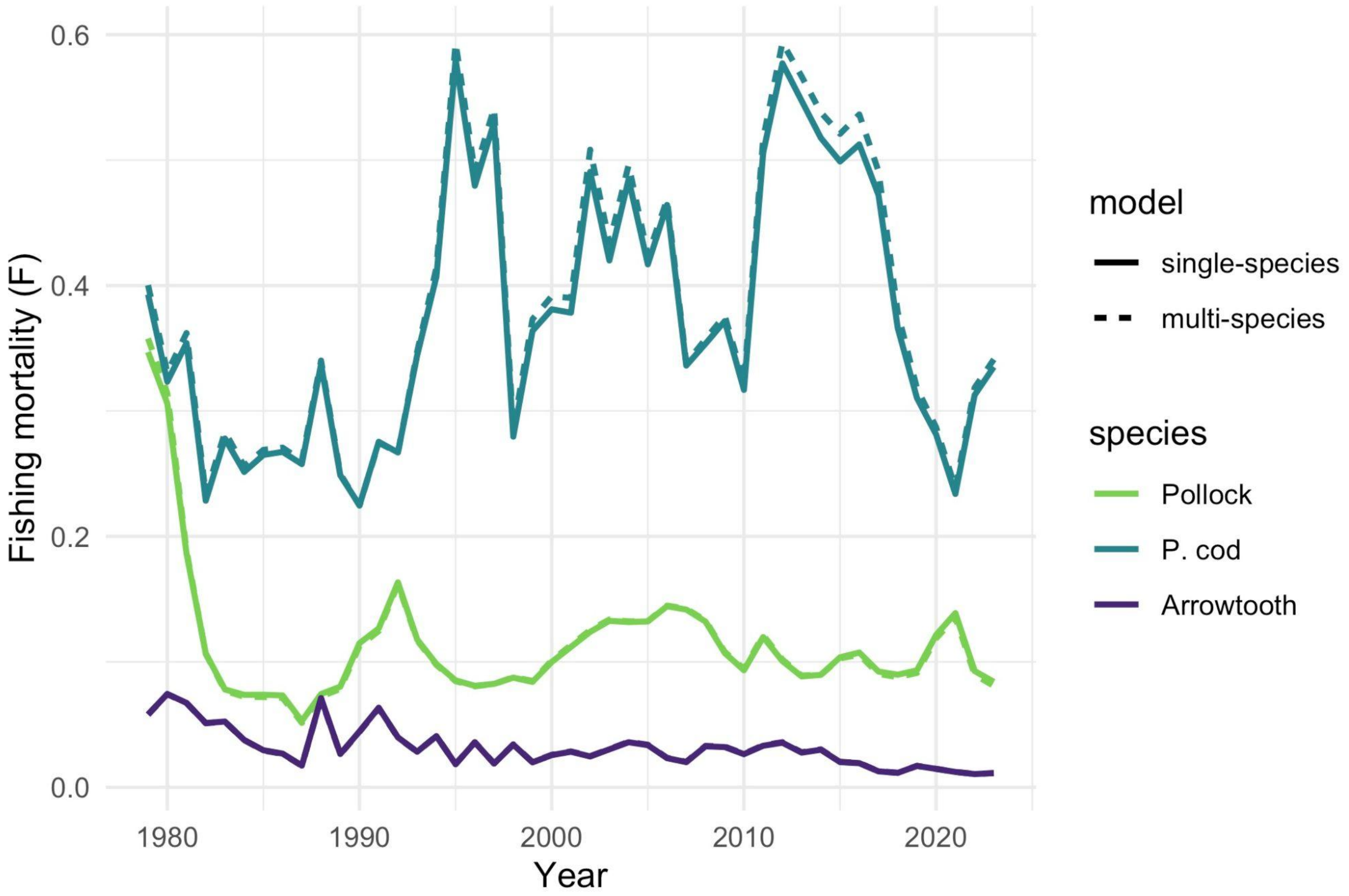
EXTRA SLIDES



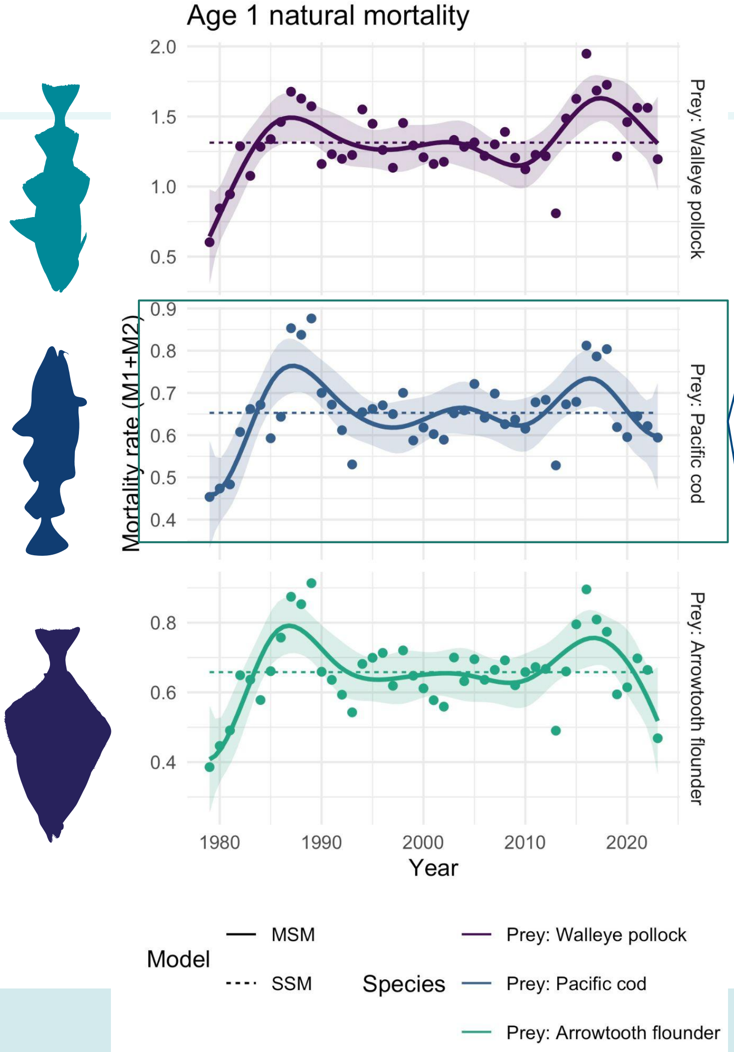
Catch

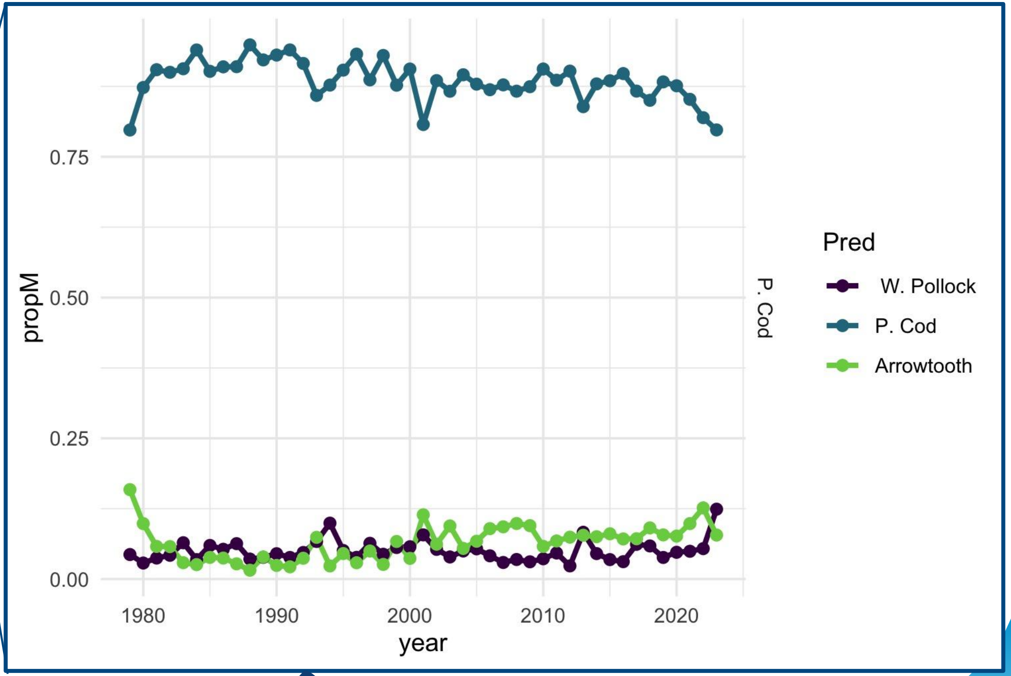


NOAA FISHERIES

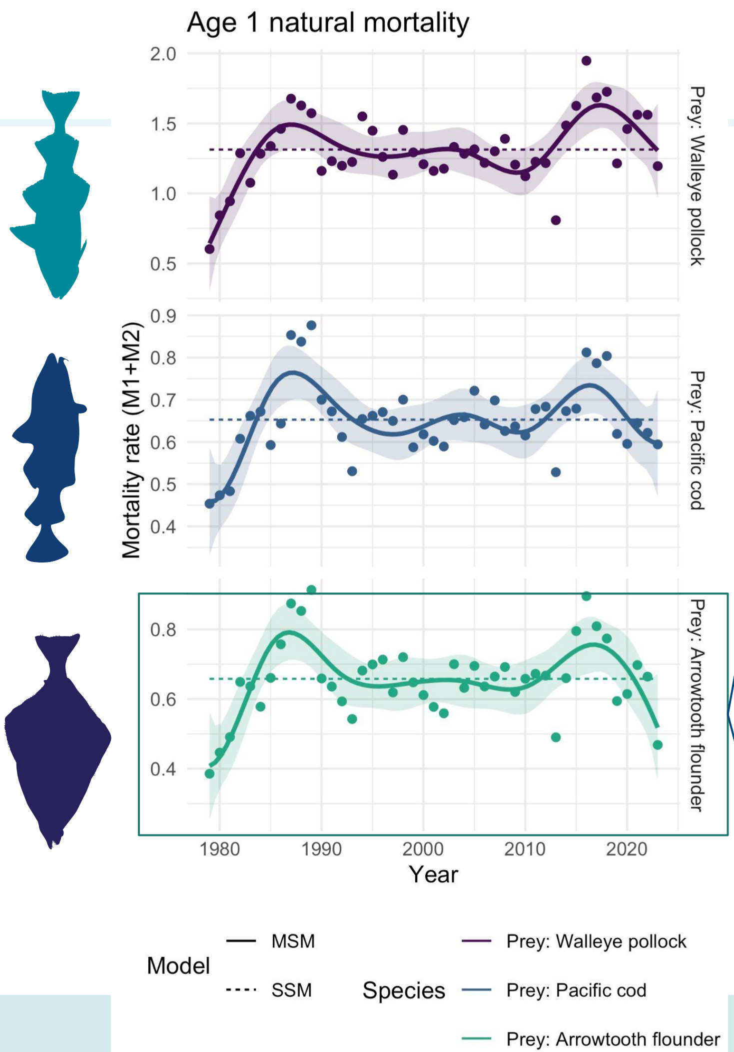


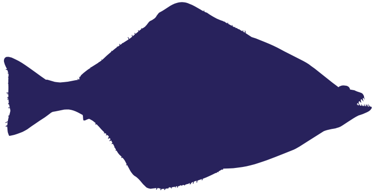
NOAA FISHERIES


Age 1 natural mortality
Mortality rate (M1+M2)
Prey: Walleye pollock
Prey: Pacific cod
Prey: Arrowtooth flounder
2.0
1.5
1.0
0.5
0.9
0.8
0.7
0.6
0.5
0.4
0.8
0.6
0.4
1980
1990
2000
2010
2020
Year
Model
MSM
SSM
Species
Prey: Walleye pollock
Prey: Pacific cod
Prey: Arrowtooth flounder

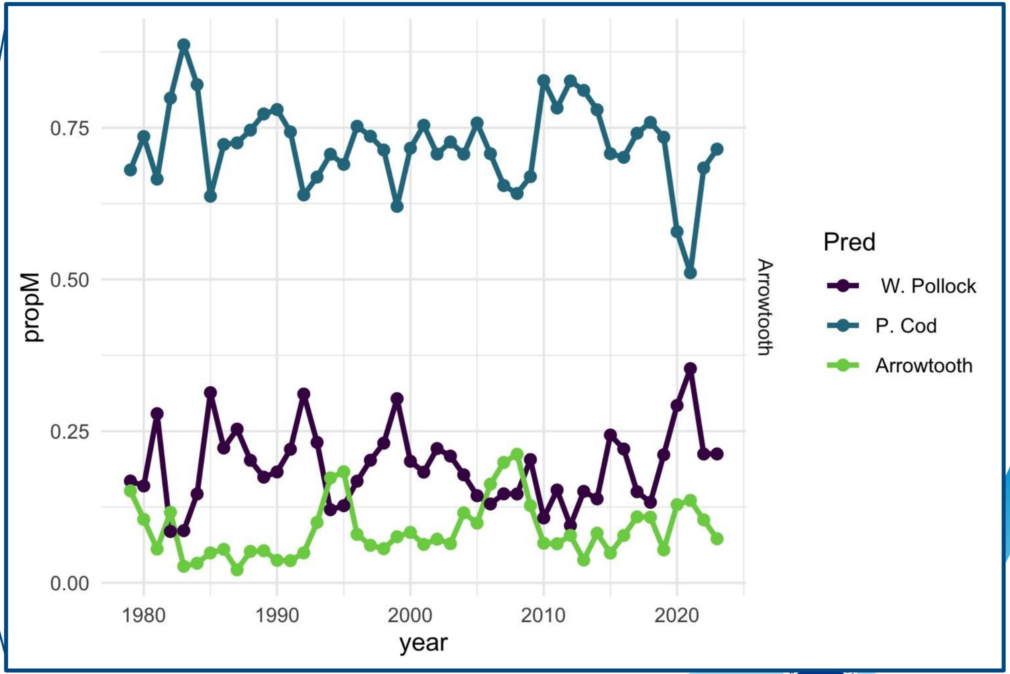

propM
0.75
0.50
0.25
0.00
1980
1990
2000
2010
2020
year
P. Cod
Pred
W. Pollock
P. Cod
Arrowtooth

Pacific cod



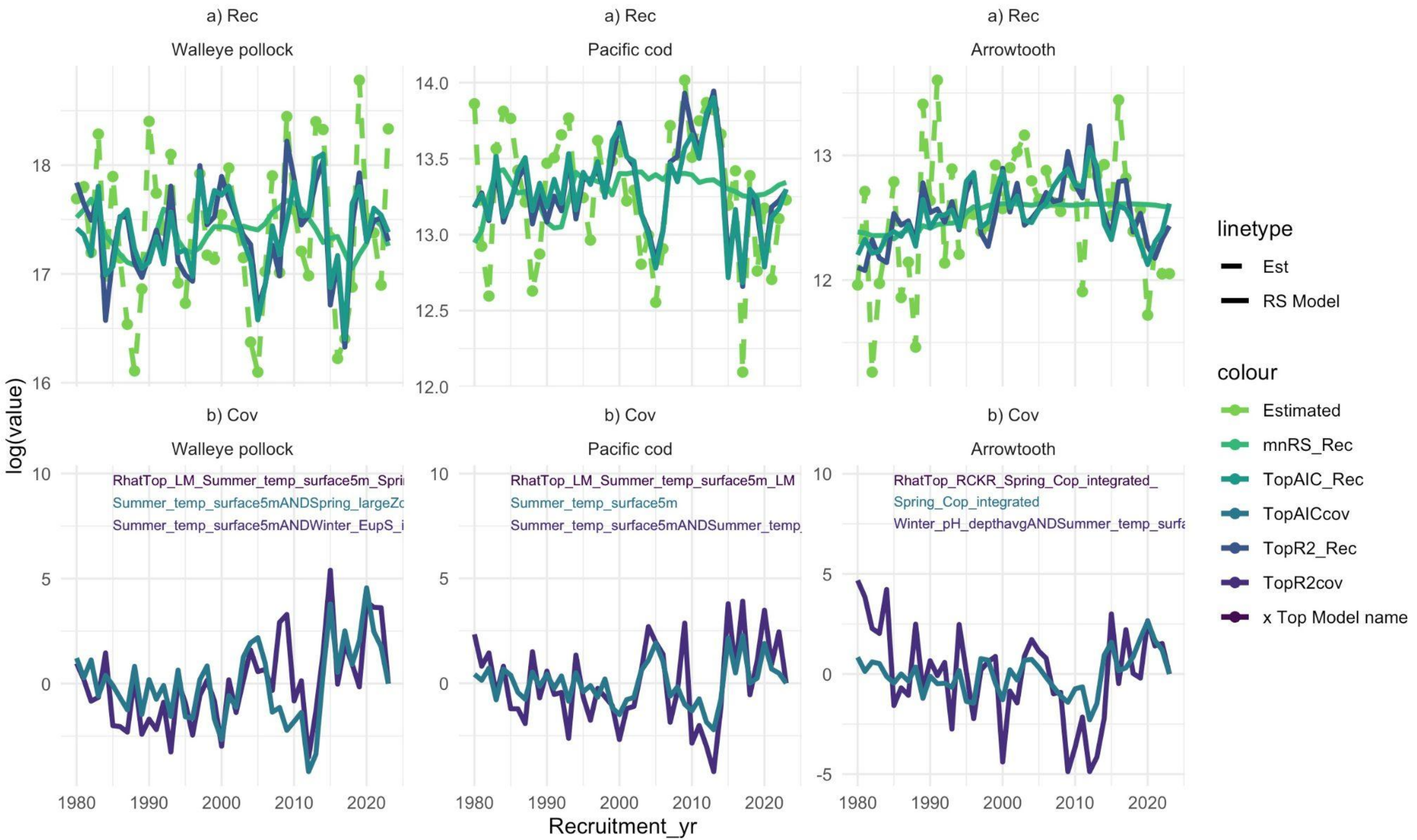


Arrowtooth flounder



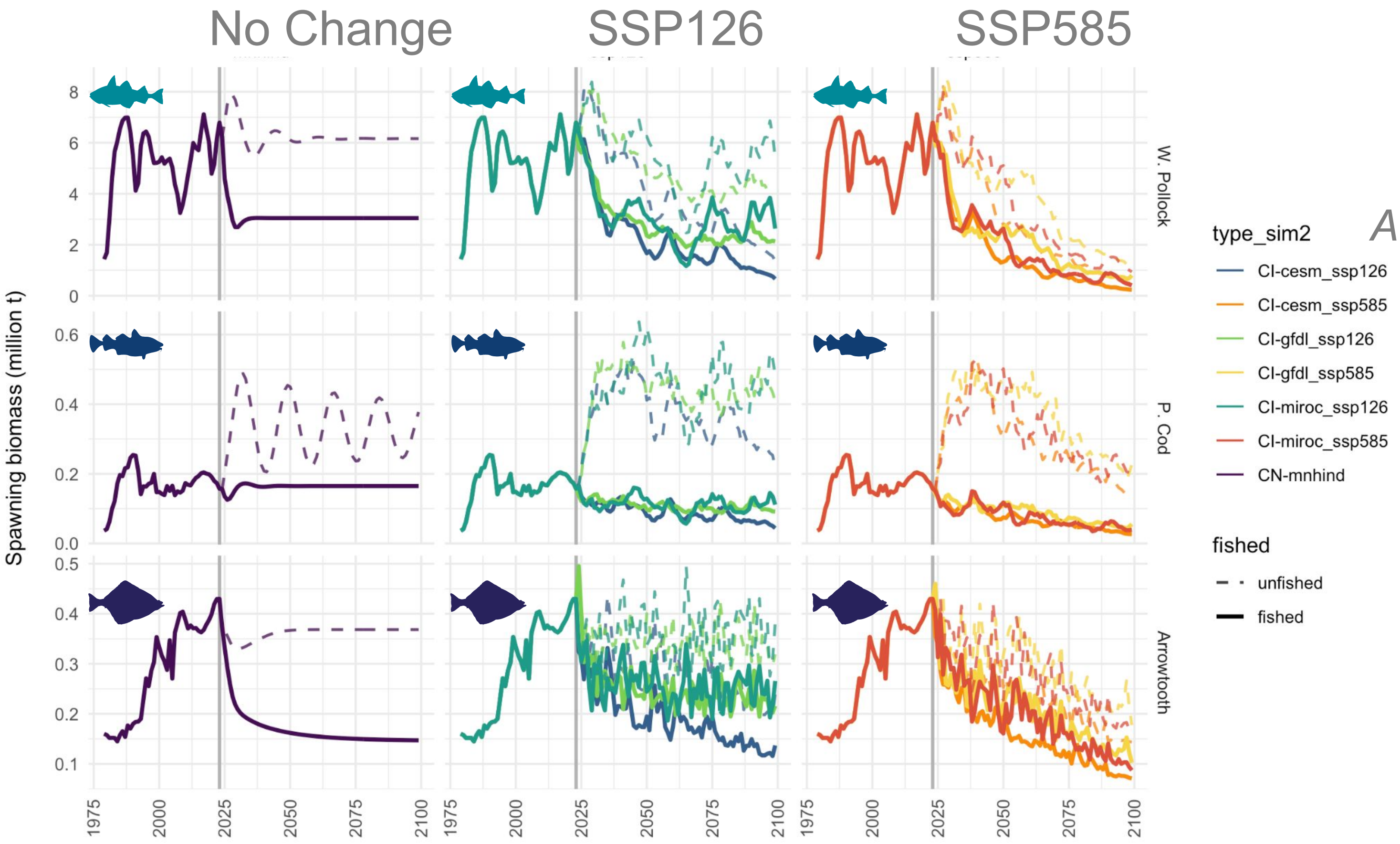
NOAA FISHERIES

Single species model



NOAA FISHERIES

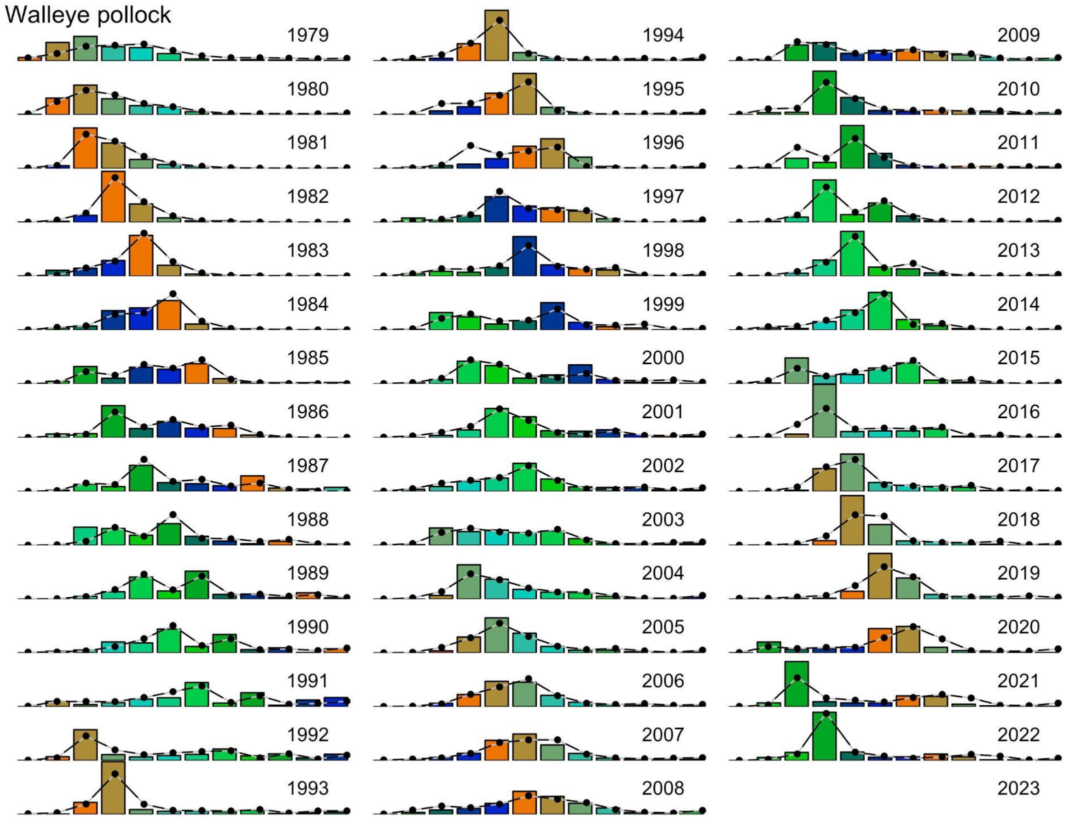
Biomass (Single species)



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

NOAA FISHERIES

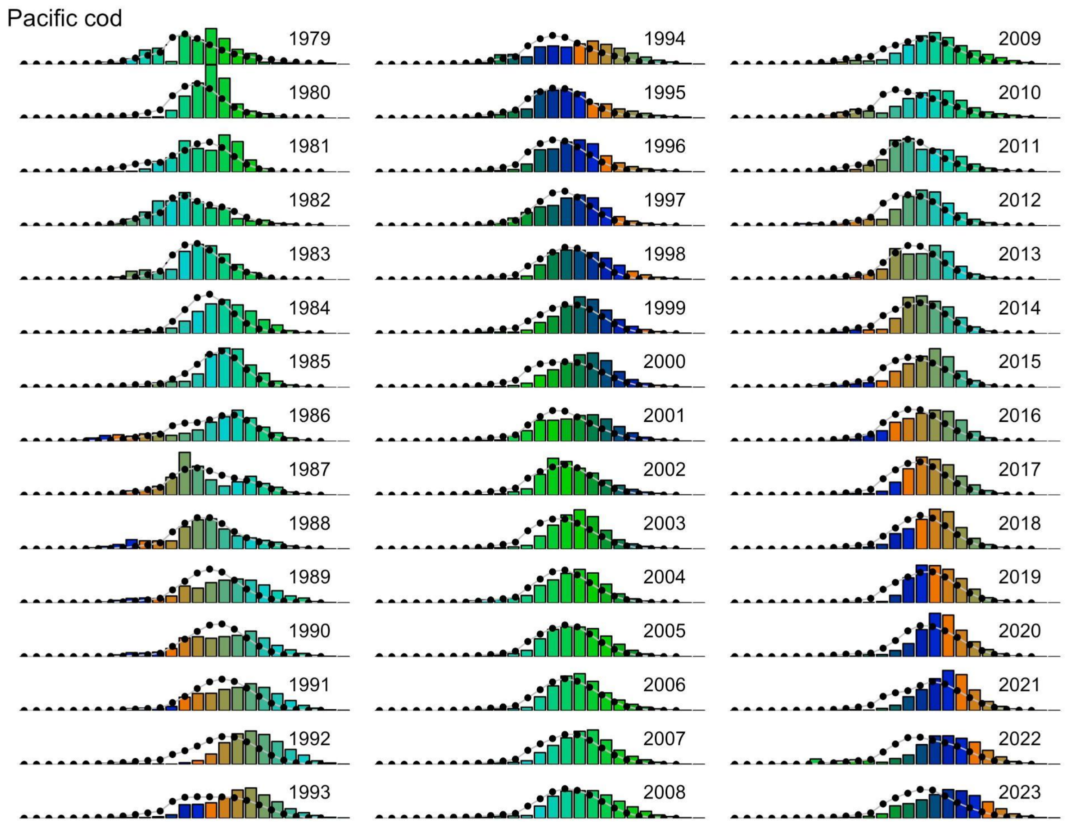
Fishery age comp.

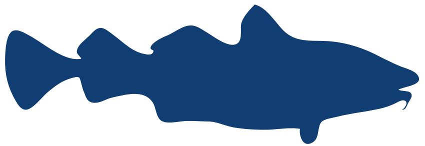


walleye pollock

NOAA FISHERIES

Fishery length comp.

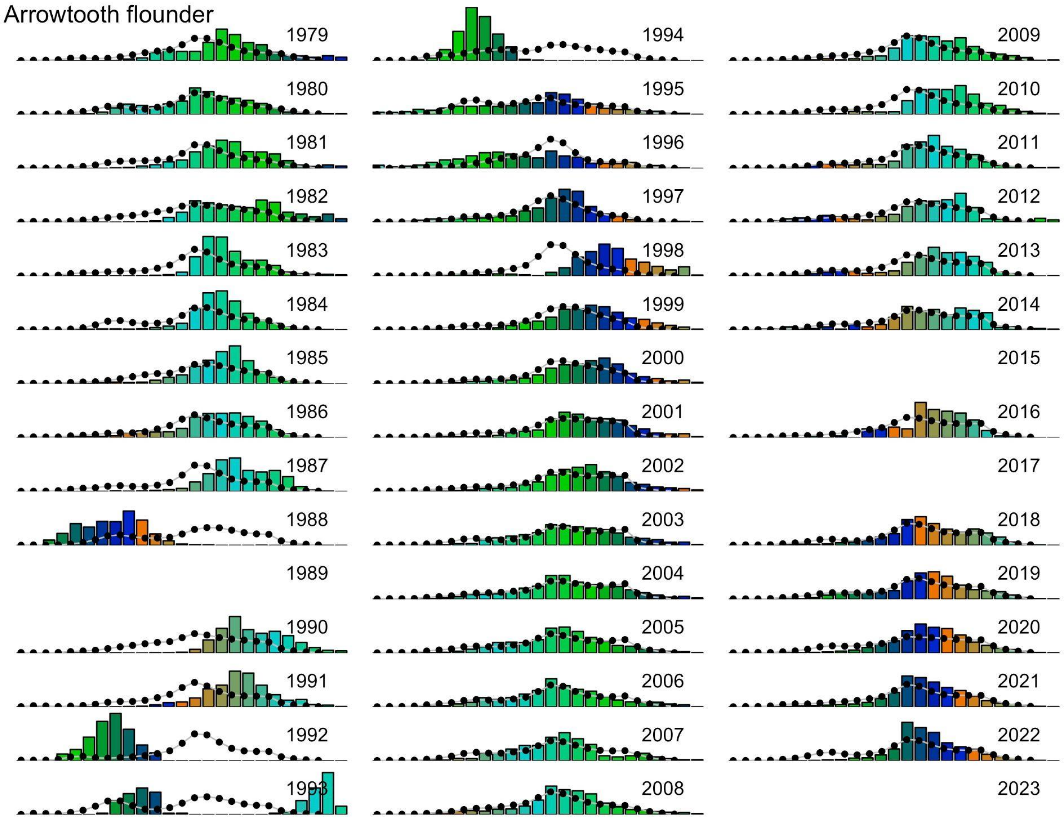


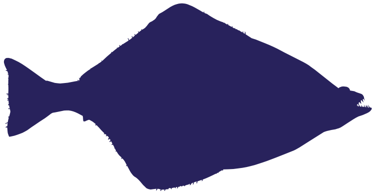


Pacific cod

NOAA FISHERIES

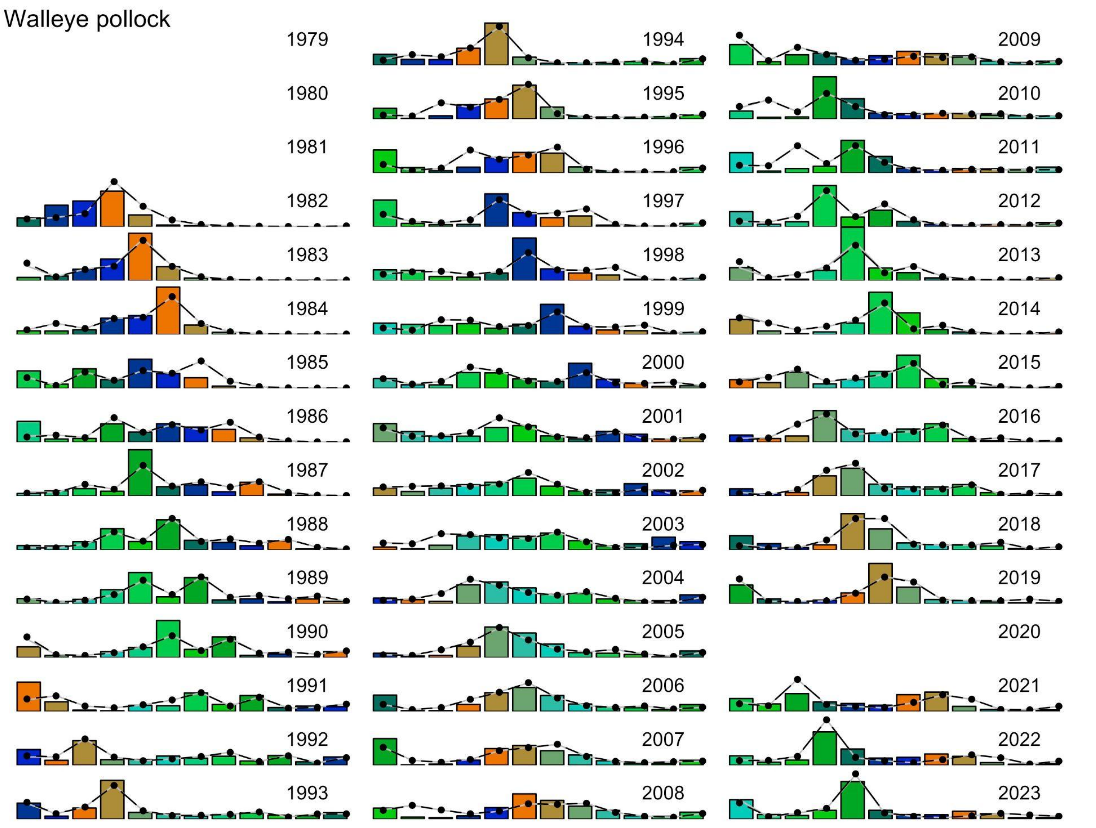
Fishery length comp.

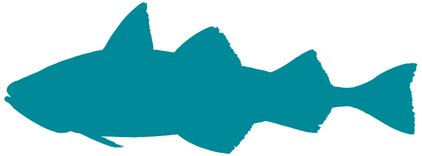




Arrowtooth flounder

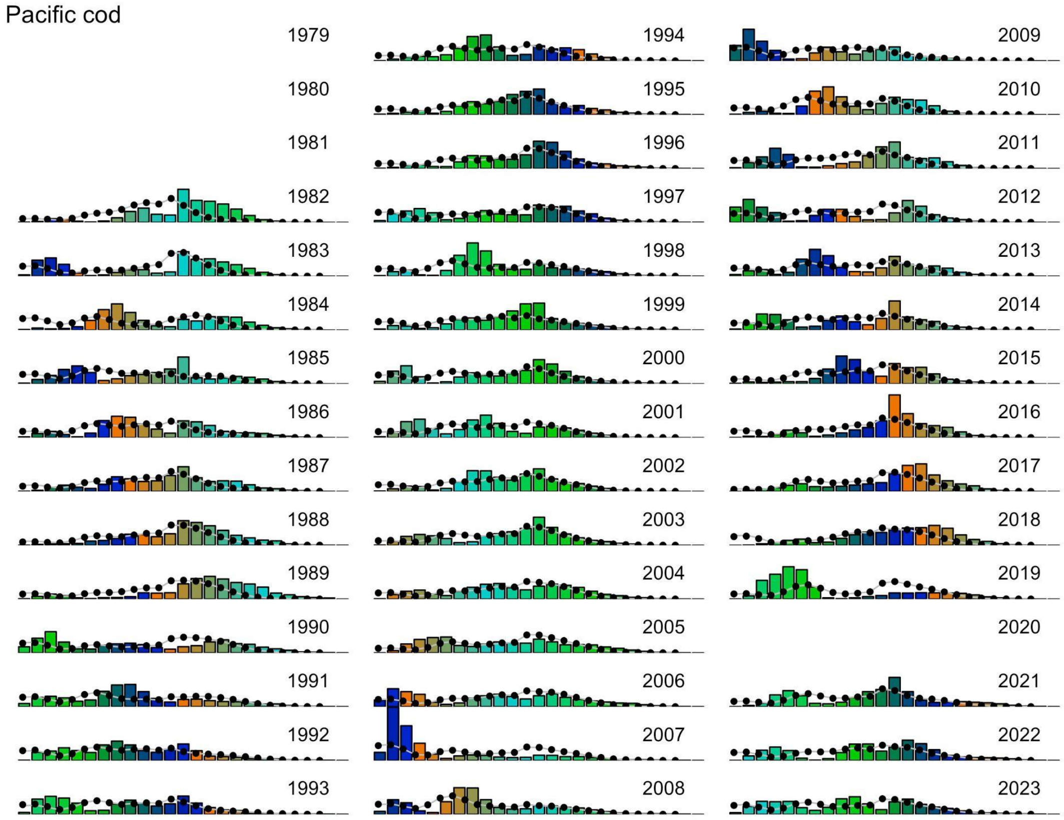
Survey age comp.

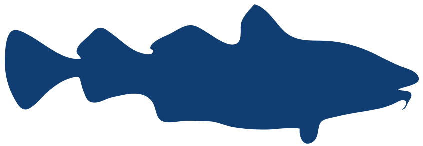




NOAA FISHERIES

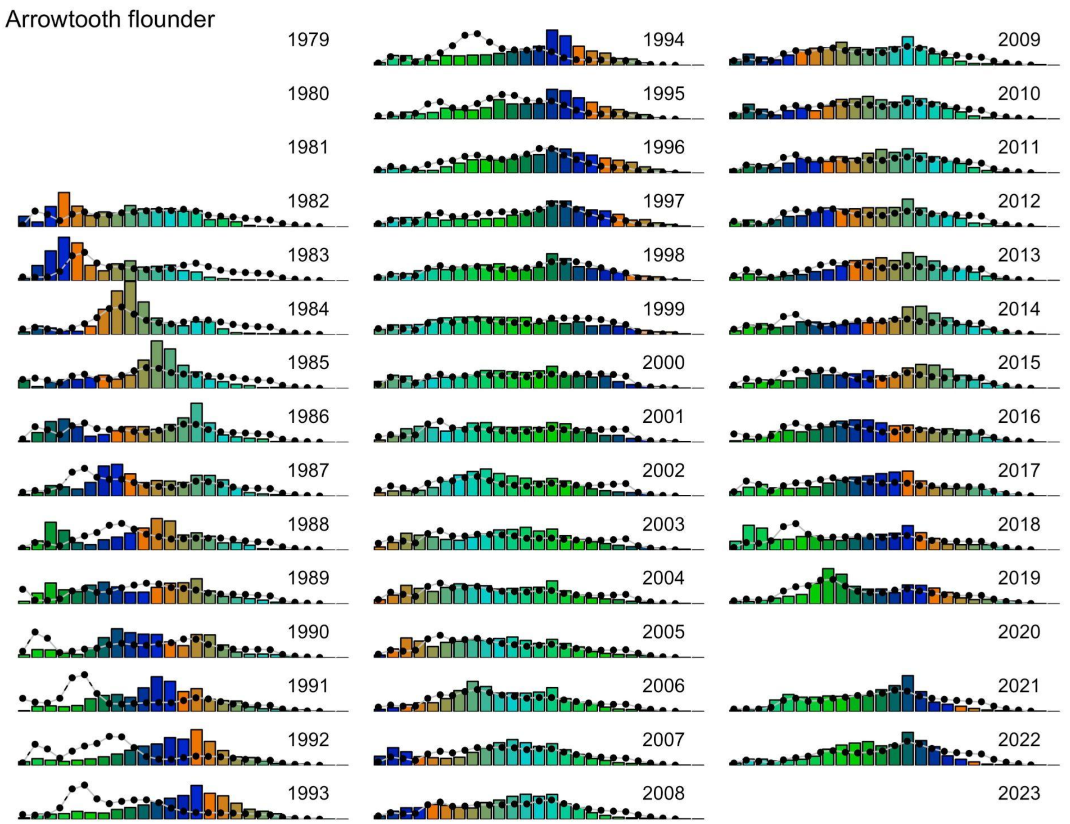
Survey length comp.





NOAA FISHERIES

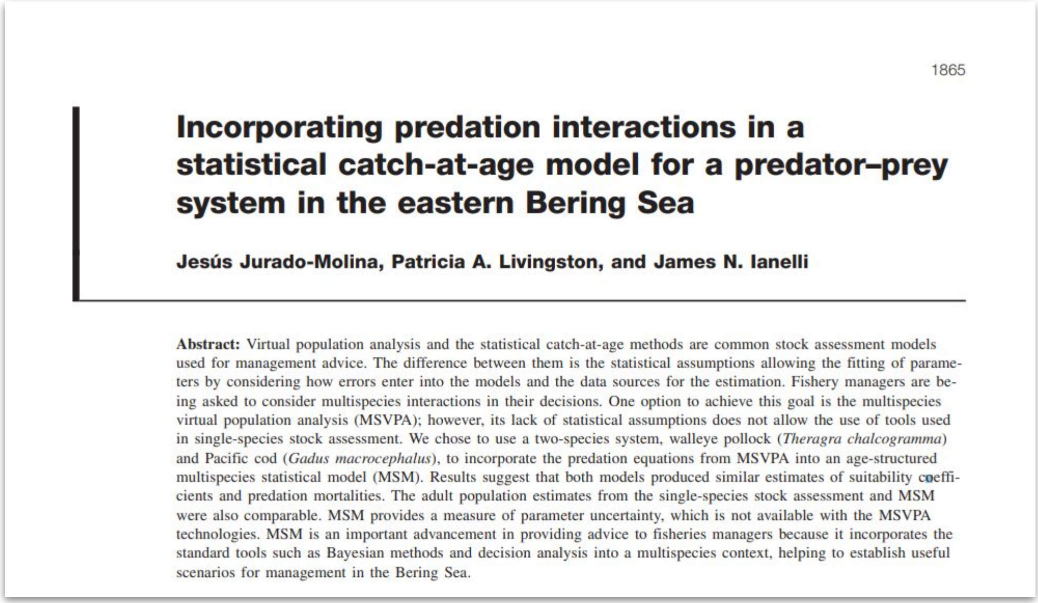
Survey length comp.



Arrowtooth flounder

NOAA FISHERIES

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

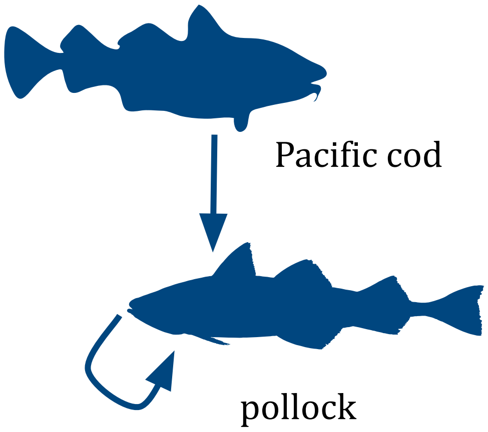


1865

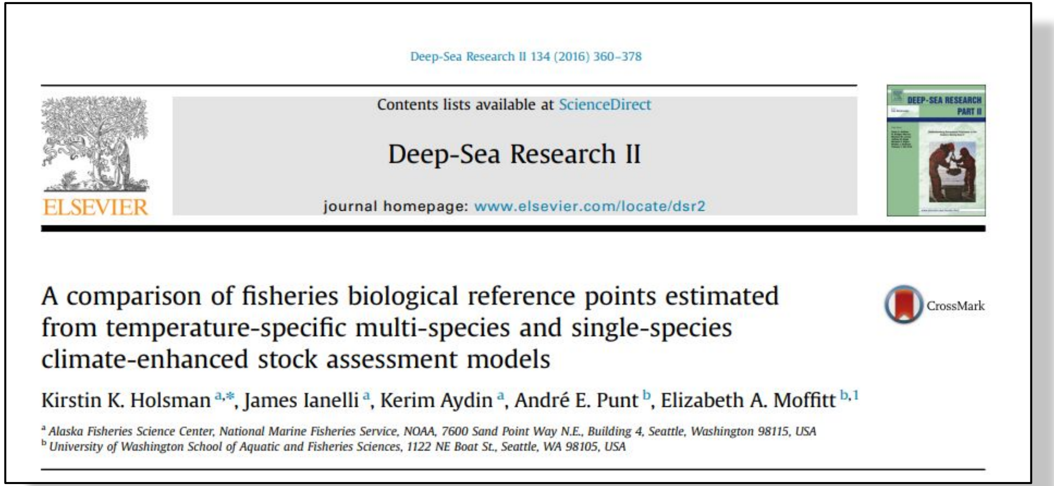
Incorporating predation interactions in a statistical catch-at-age model for a predator–prey system in the eastern Bering Sea

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.



MSVPA ⟶ Statistical MSM


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

Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

ELSEVIER

DEEP-SEA RESEARCH PART II

CrossMark

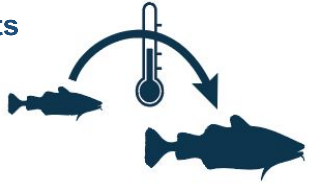
A comparison of fisheries biological reference points estimated from temperature-specific multi-species and single-species climate-enhanced stock assessment models

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

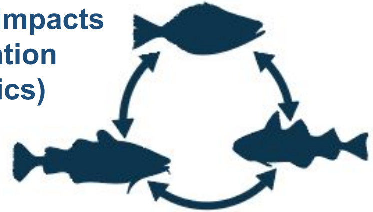
[a] Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Building 4, Seattle, Washington 98115, USA
[b] University of Washington School of Aquatic and Fisheries Sciences, 1122 NE Boat St., Seattle, WA 98105, USA

Holsman et al. 2016

Climate impacts on growth & condition



Climate impacts on predation (energetics)



"CEATTLE"

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

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

Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

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

nature COMMUNICATIONS

ARTICLE

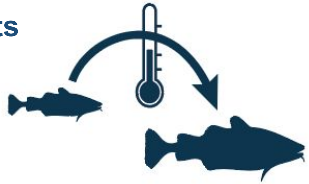
https://doi.org/10.1038/s41467-020-18300-3 OPEN

Ecosystem-based fisheries management forestalls climate-driven collapse

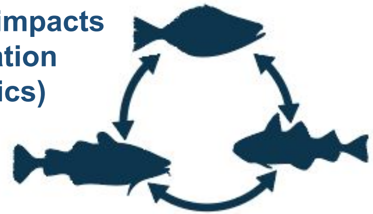
K. K. Holsman [1,2✉], A. C. Haynie[1], A. B. Hollowed[1,2], J. C. P. Reum[1,2,3], K. Aydin[1,2], A. J. Hermann [4,5], W. Cheng [4,5], A. Faig [2], J. N. Ianelli[1,2], K. A. Kearney [1,4] & A. E. Punt [2]

Holsman et al. 2016

Climate impacts on growth & condition

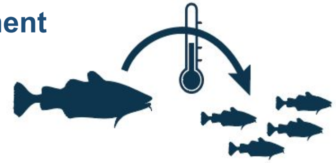


Climate impacts on predation (energetics)



Holsman et al. 2020

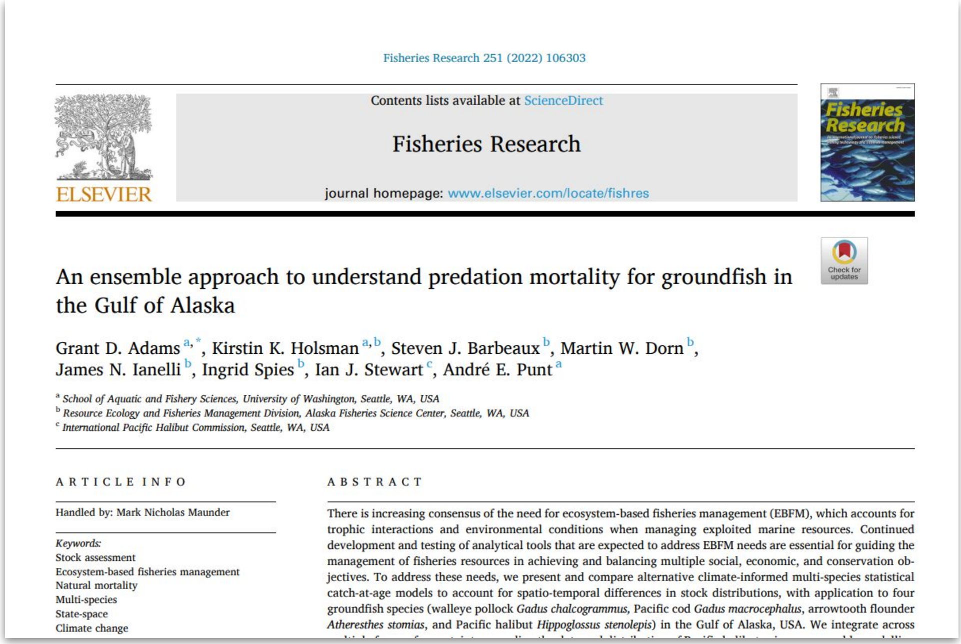
Climate impacts on recruitment



NOAA FISHERIES

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

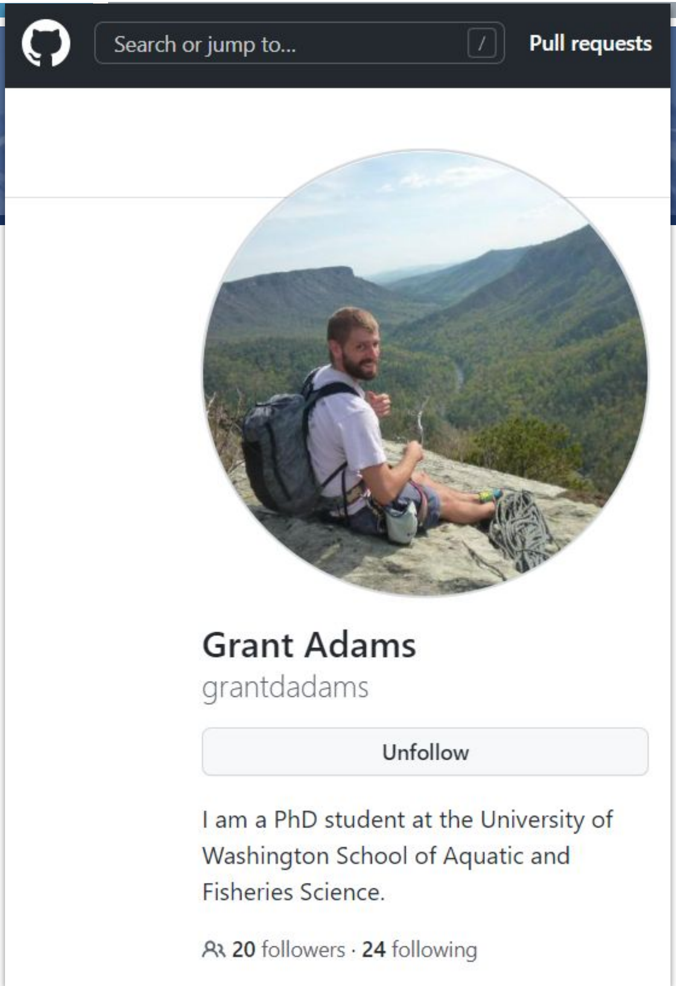
ARTICLE INFO

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



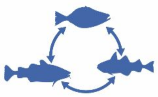
CEATTLE Applications

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



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).

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)

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

Discussion : Climate informed BRPs

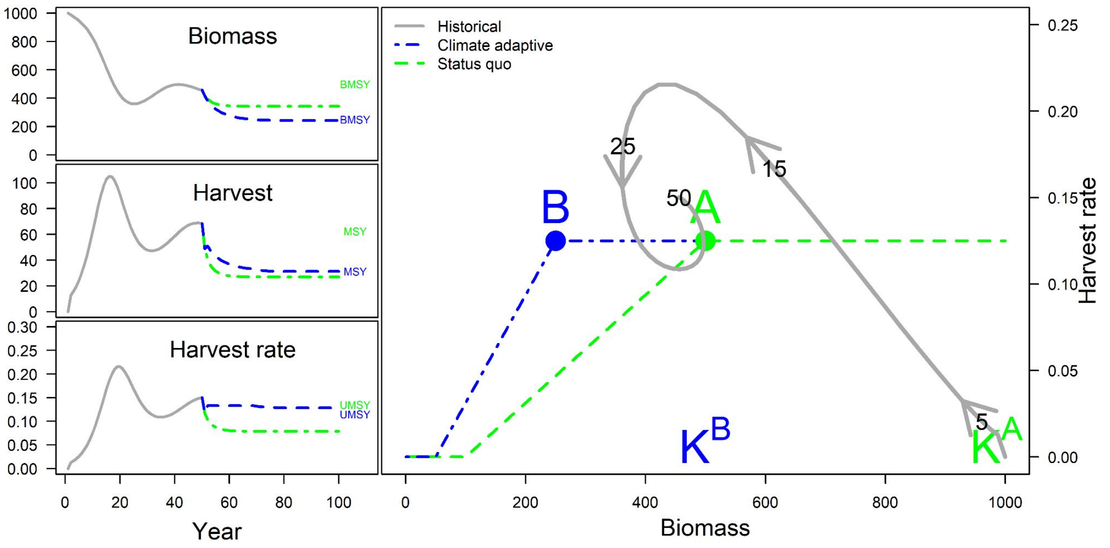
Set B0 and B40 target using climate informed models

NO!

Adapting reference points to reflect changes in productivity

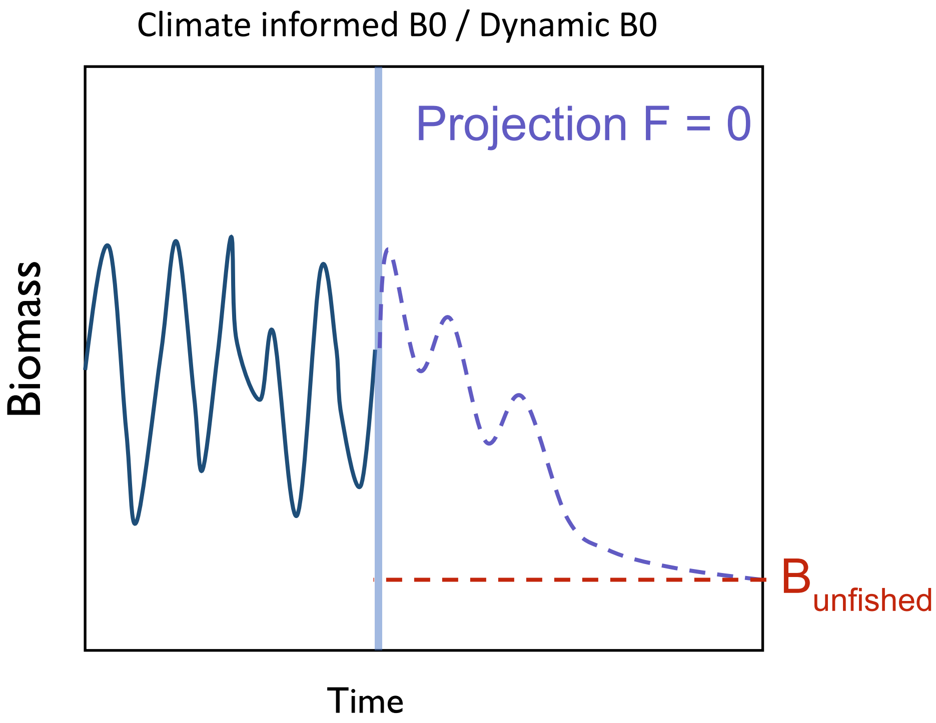
- MSA directs reference points to reflect current and probable future environmental conditions

- 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



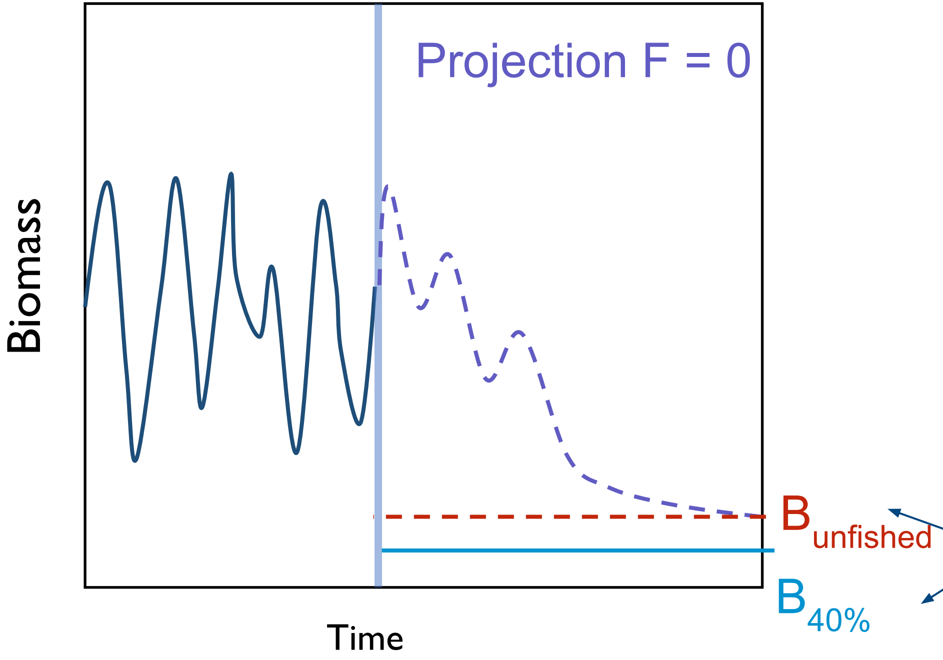
Szuwalski et al. 2023

First: Set Target / reference points



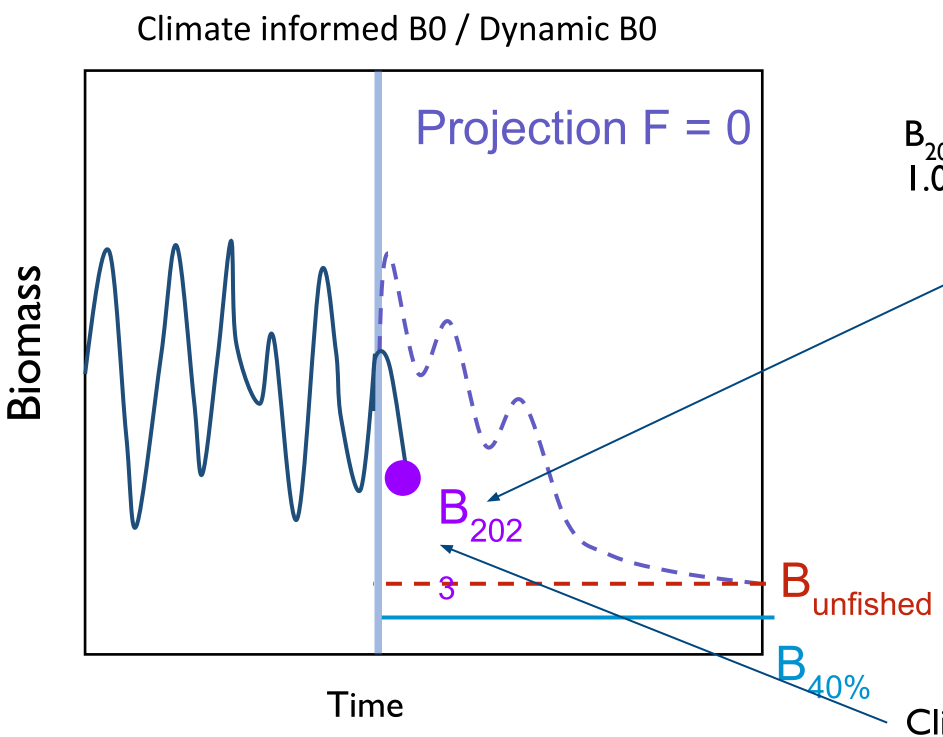
First: Set Target / reference points

Climate informed B0 / Dynamic B0



Climate informed model to set $B_{unfished}$ & $B_{40\%}$

First: Set Target / reference points

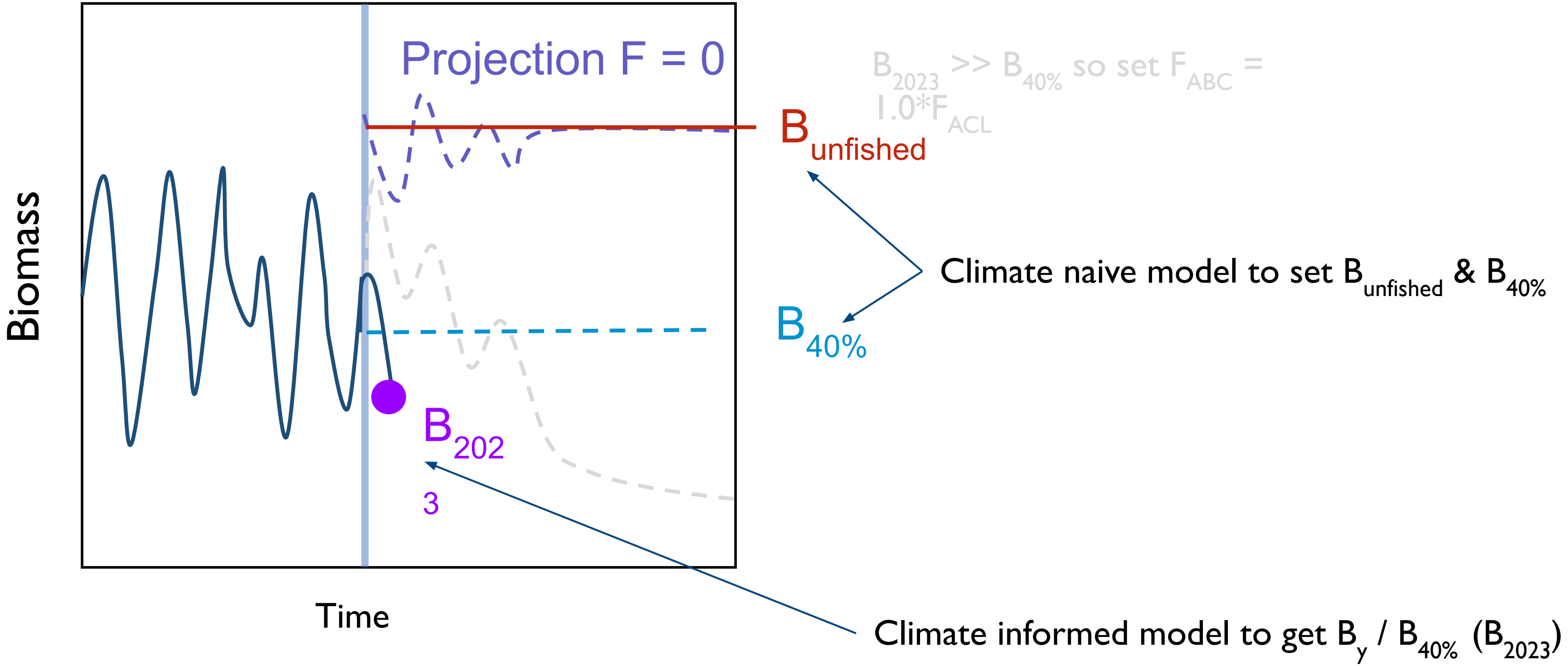


B_{2023} >> $B_{40\%}$ so set F_{ABC} = 1.0*F_{ACL}

Climate informed model to get B_y / $B_{40\%}$ (B_{2023})

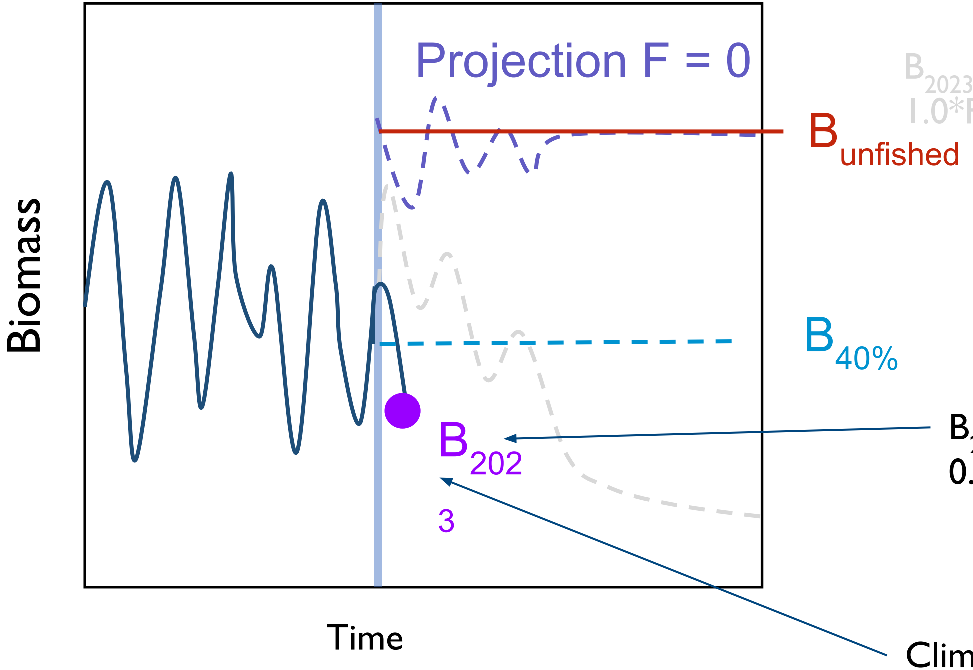
“hybrid” climate- naive & climate informed approach

Climate naive B0 + climate informed By



“hybrid” climate- naive & climate informed approach

Climate naive B0 + climate informed By



$B_{2023} >> B_{40\%}$ so set $F_{ABC} = 1.0*F_{ACL}$

$B_{2023} < B_{40\%}$ invoke sloping HCR and set $F_{ABC} = 0.7*F_{ACL}$

Climate informed model to get B_y / $B_{40\%}$ (B_{2023})