# 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

# 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

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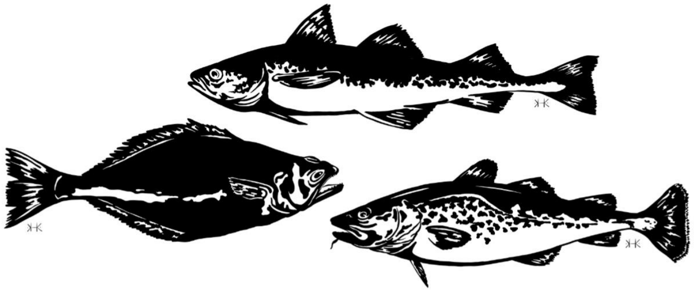

*November 2023* | kirstin.holsman@noaa.gov Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Seattle, Washington 98115

**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

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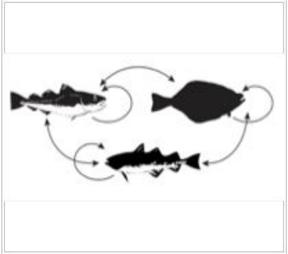
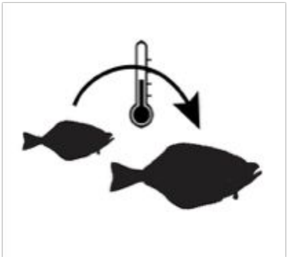
# EBS CEATTLE

## Mortality



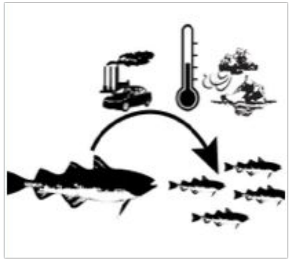
- Empirical diets
- Bioenergetics

## Weight @ Age



- Empirical
- VonB with Temp

## Rec



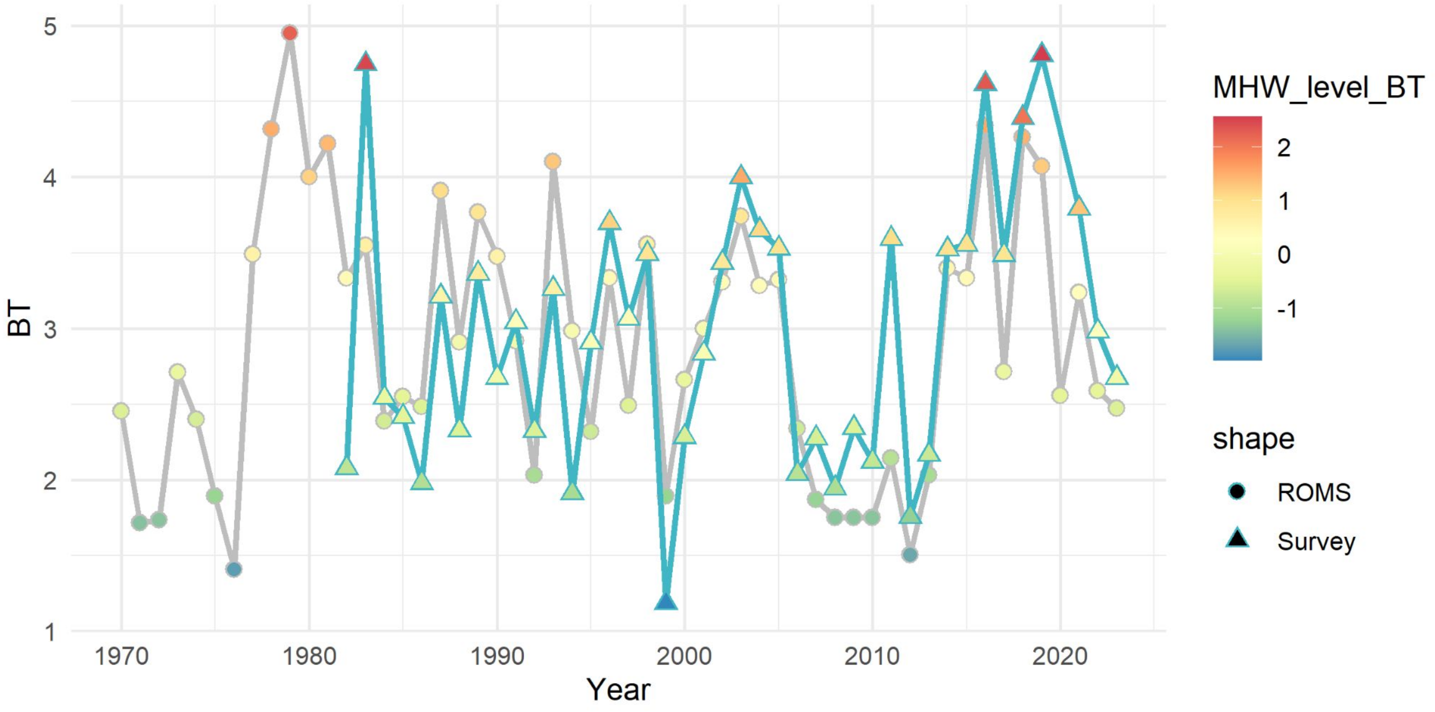
- Climate-S/R
- S/R
- mean R

## HCRs

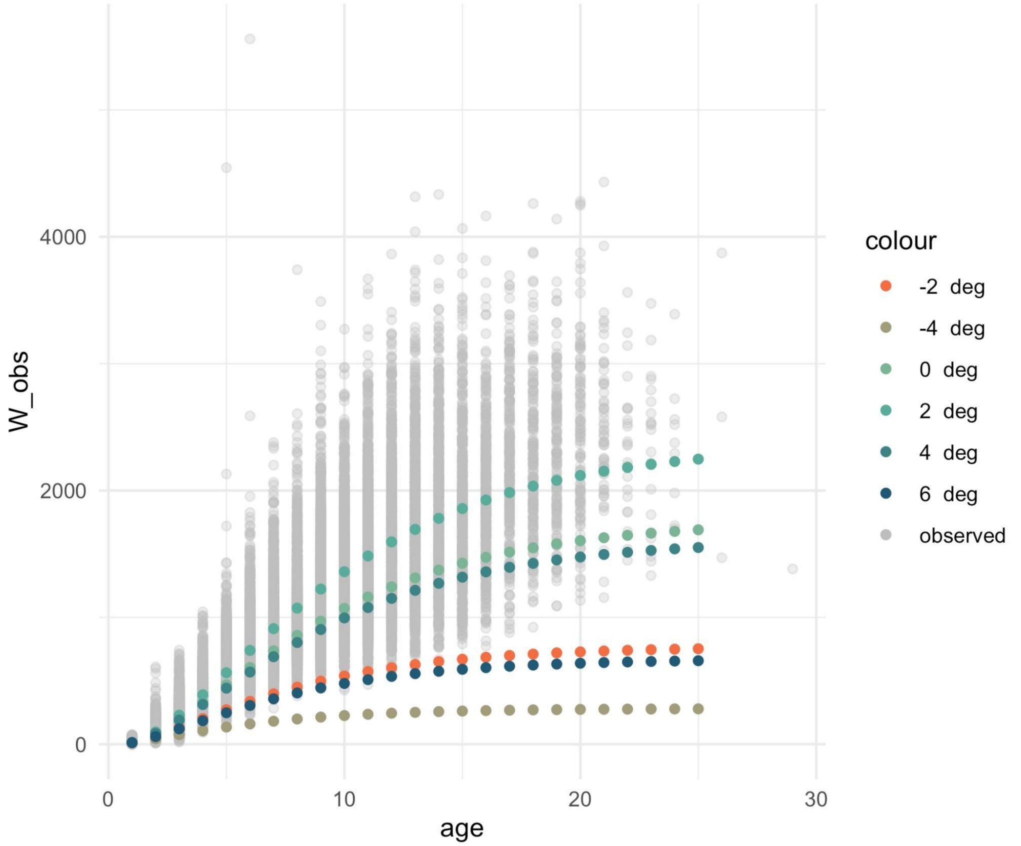
- Climate ABC
- MMSY
- MEY
- SPR
- Aggregate MSY

Holsman; CEATTLE

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



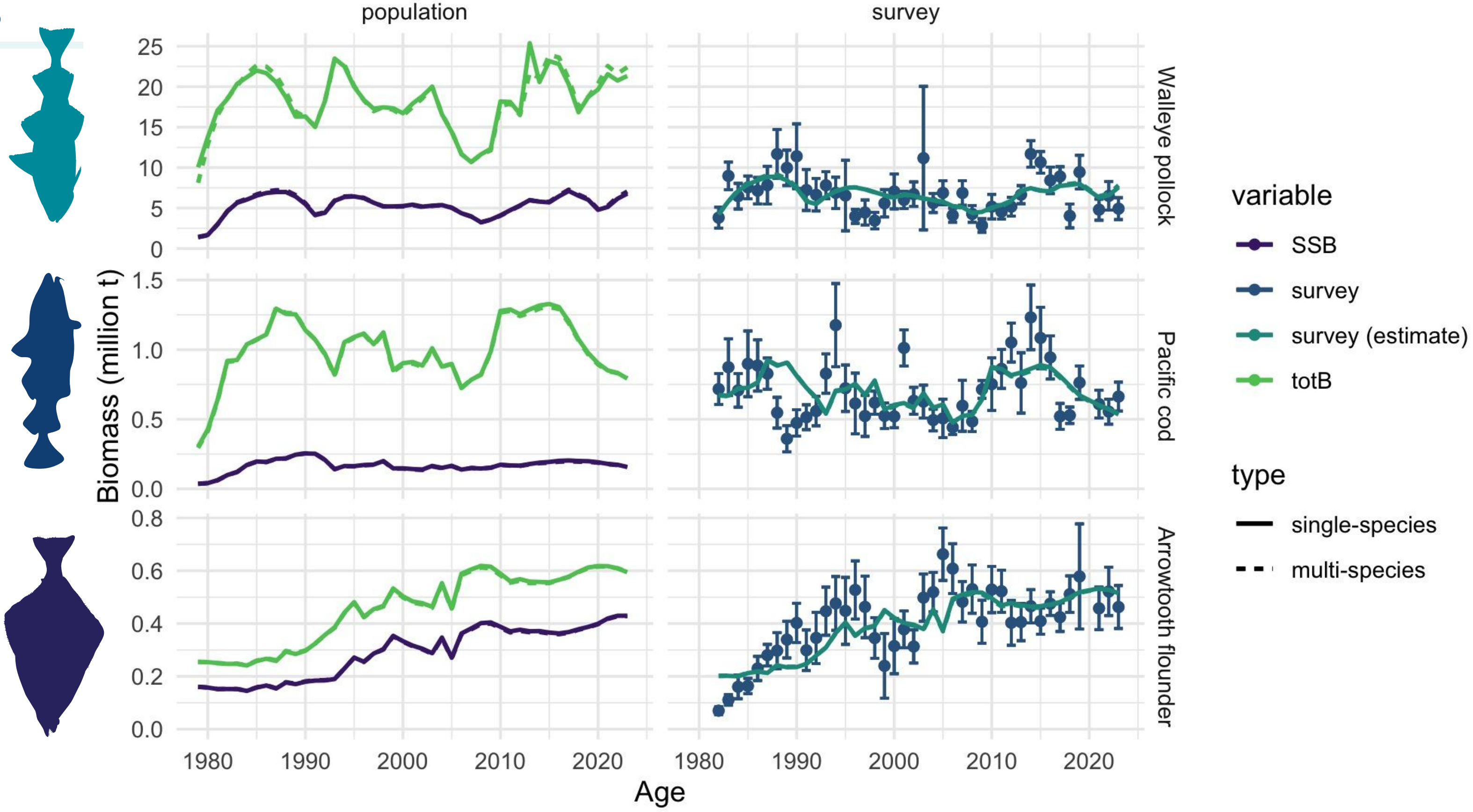
# Weight at Age



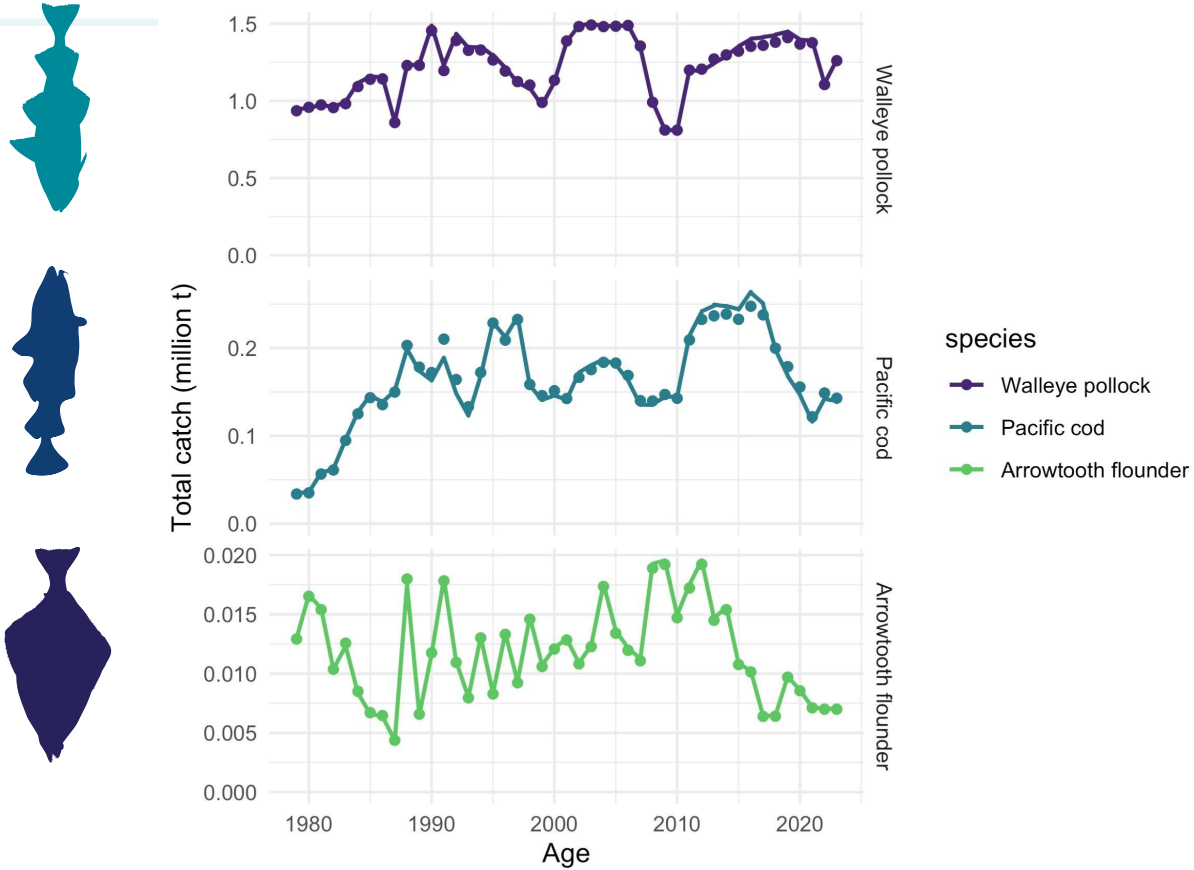

- Hist: Empirical used when avail; missing yrs have vonBT (currently updating with new TMB version of *vonBT()* )
- Projections: VonBT

*Holsman & Aydin 2015*

# Biomass

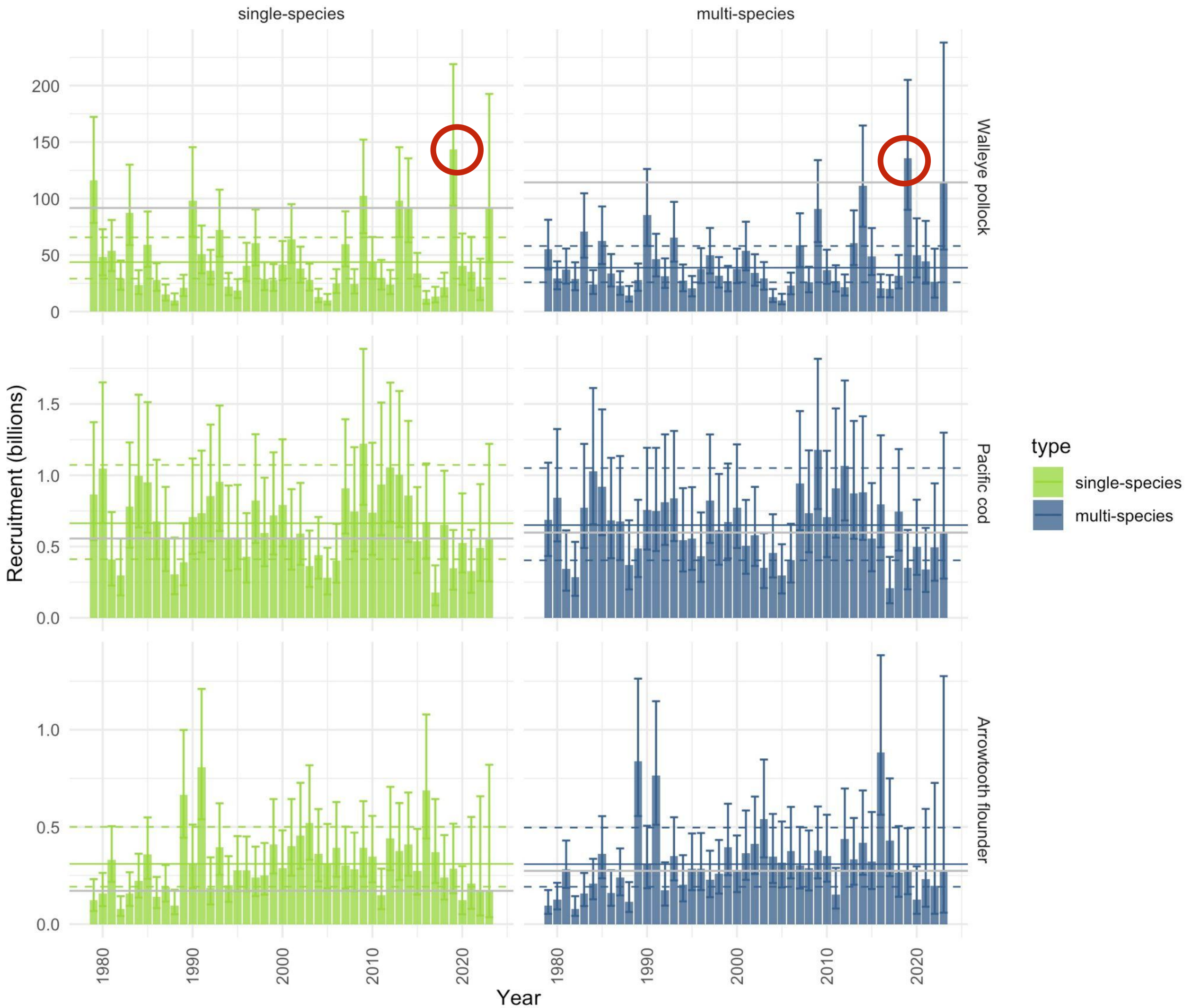

population
survey
Biomass (million t)
Age
Walleye pollock
Pacific cod
Arrowtooth flounder
variable
SSB
survey
survey (estimate)
totB
type
single-species
multi-species
1980
1990
2000
2010
2020

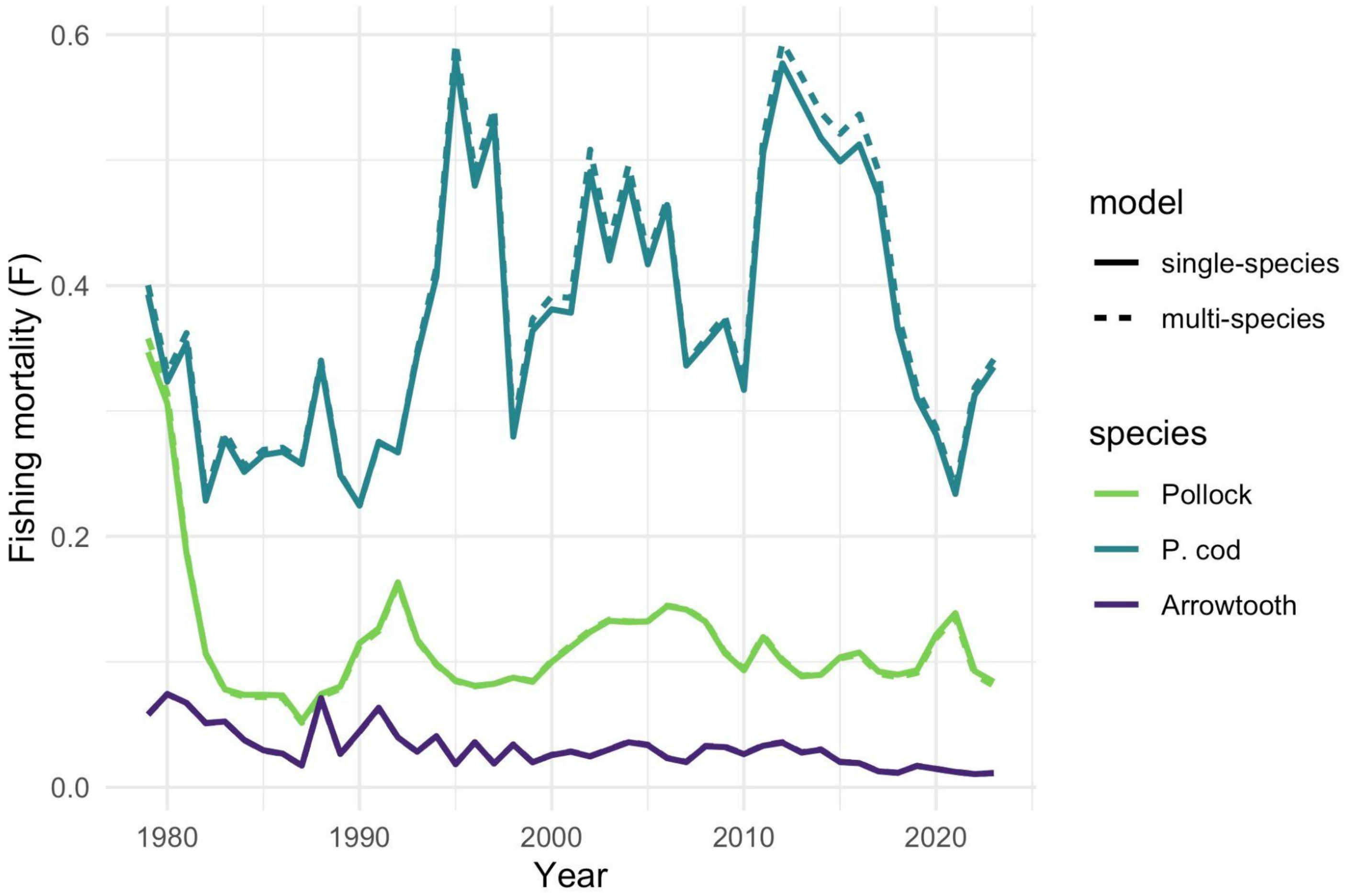
# Catch



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

# Recruitment





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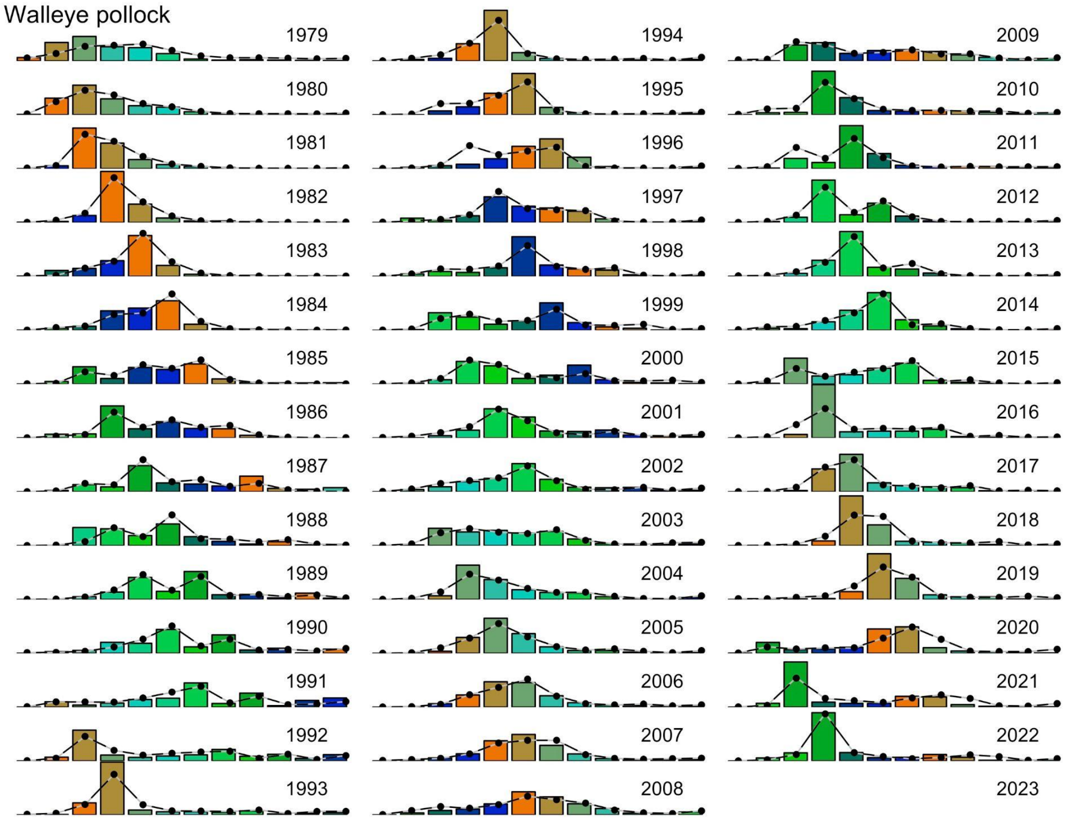
# Fishery age comp.




walleye pollock

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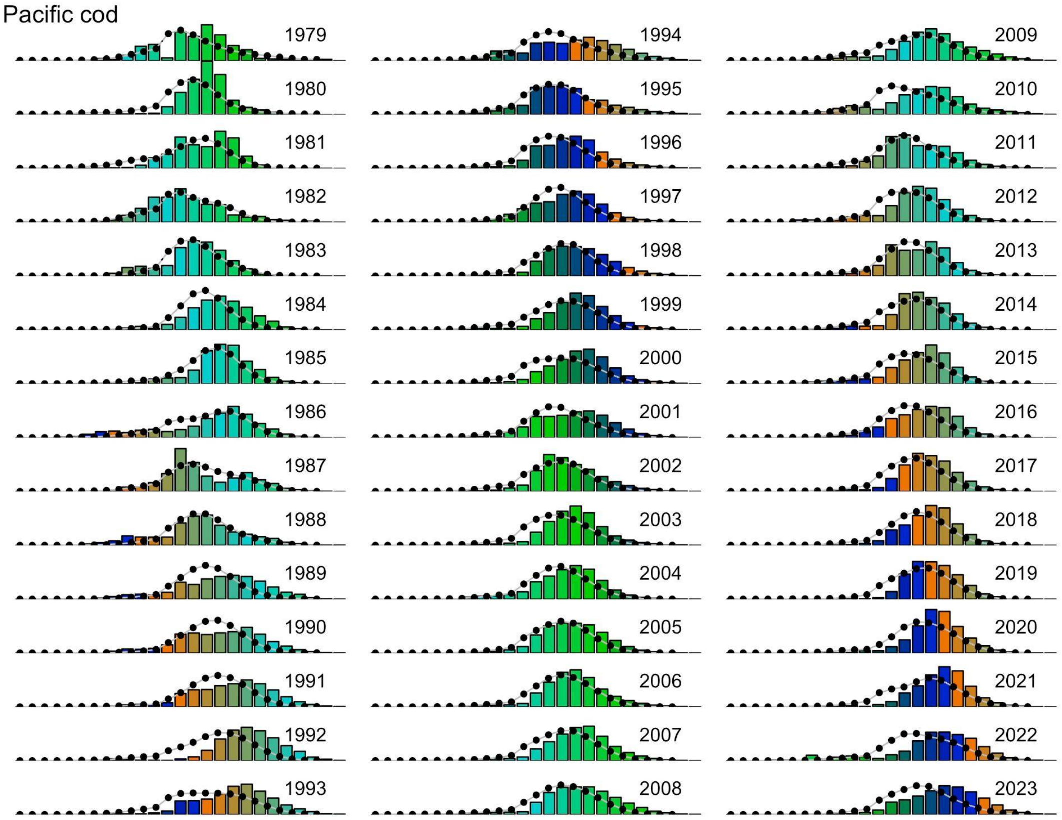
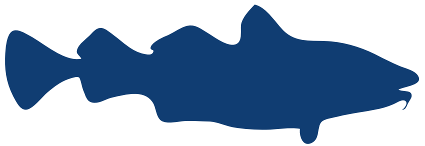
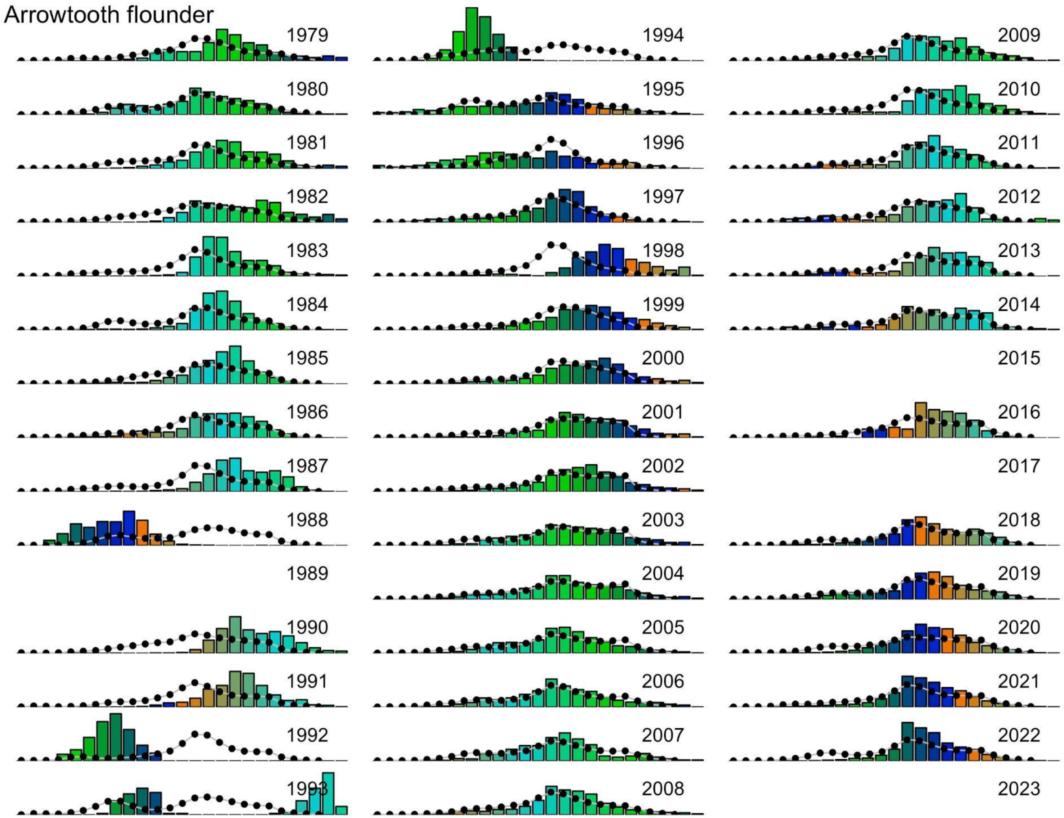
# Fishery length comp.

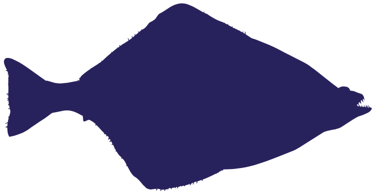


Pacific cod

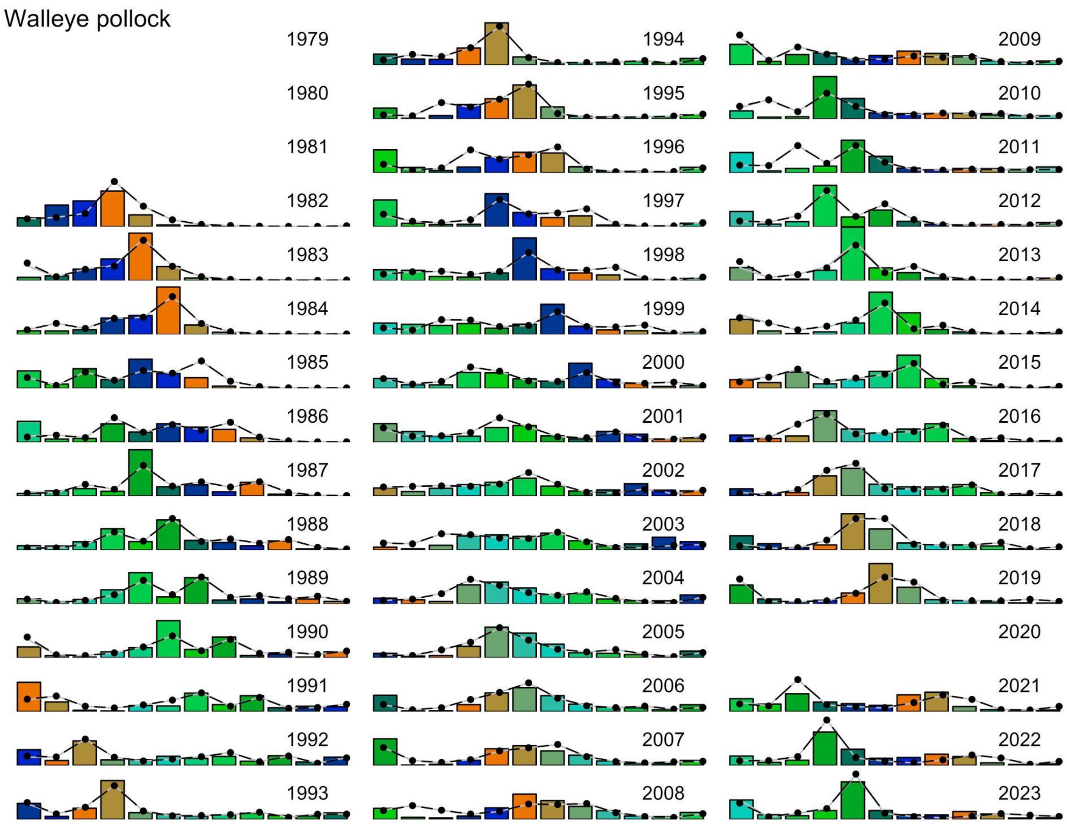
# Fishery length comp.



Arrowtooth flounder

# Survey age comp.




walleye pollock

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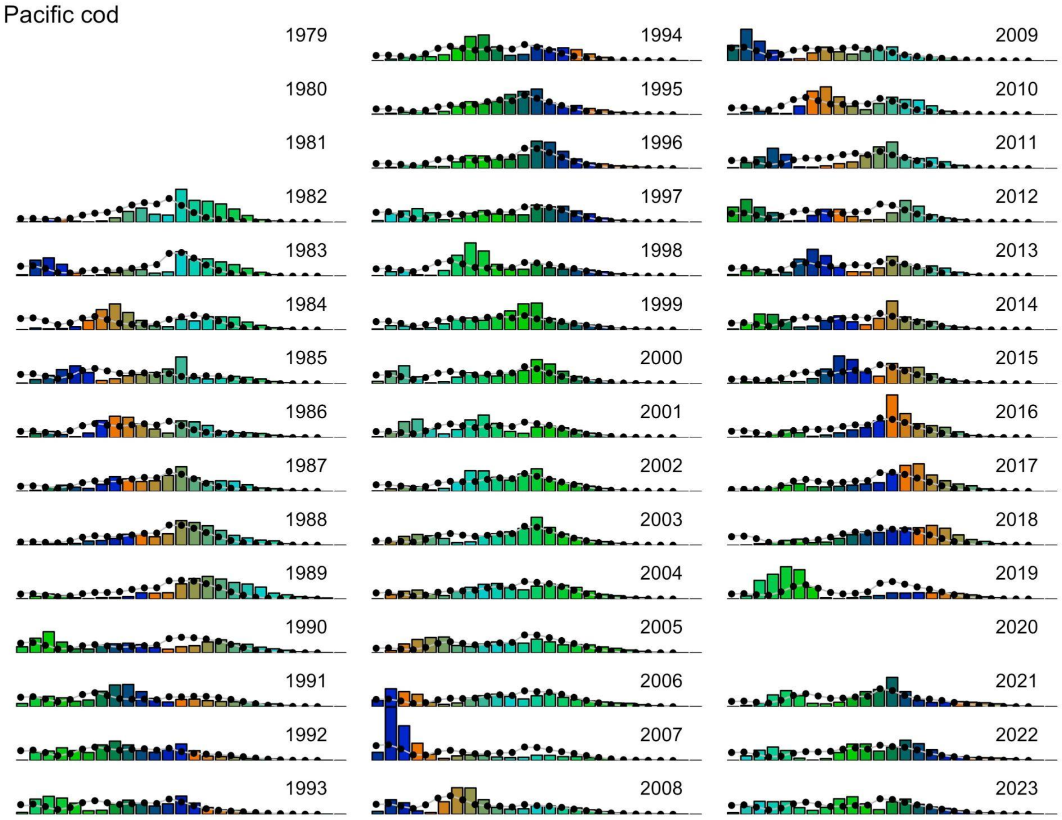
# Survey length comp.




Pacific cod

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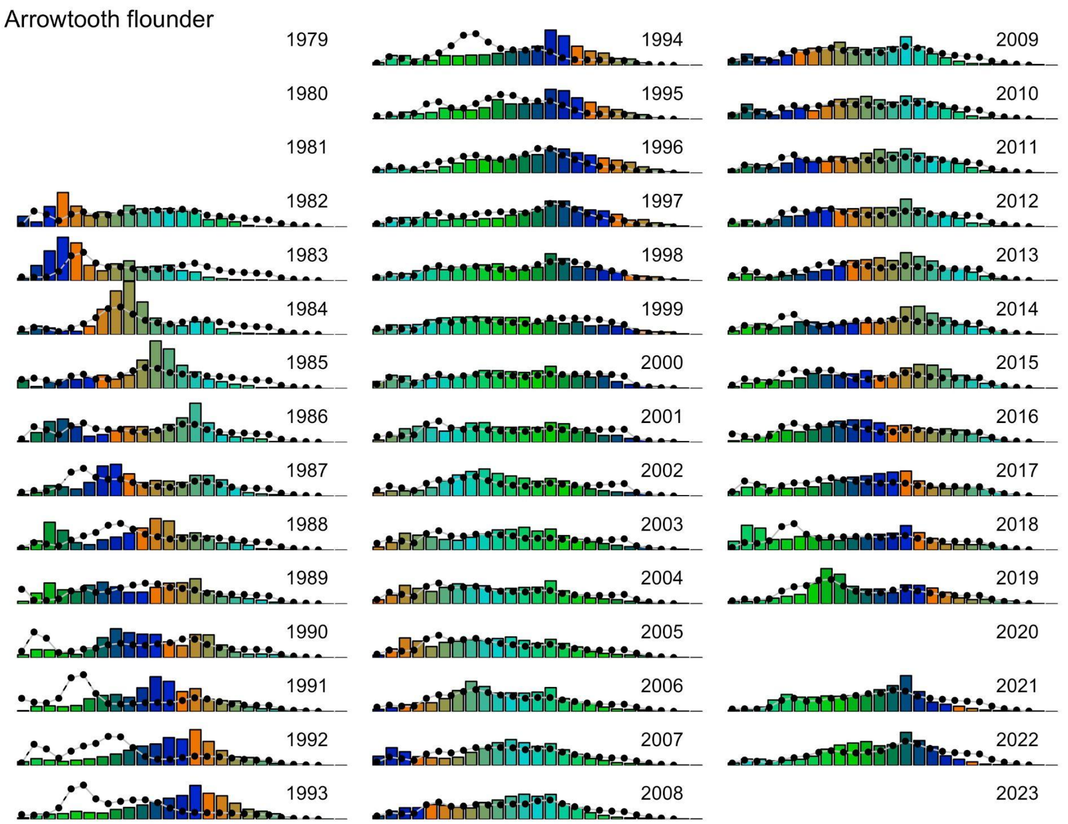
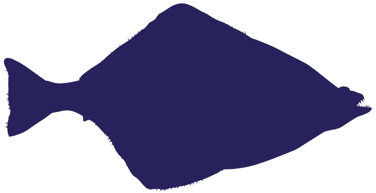
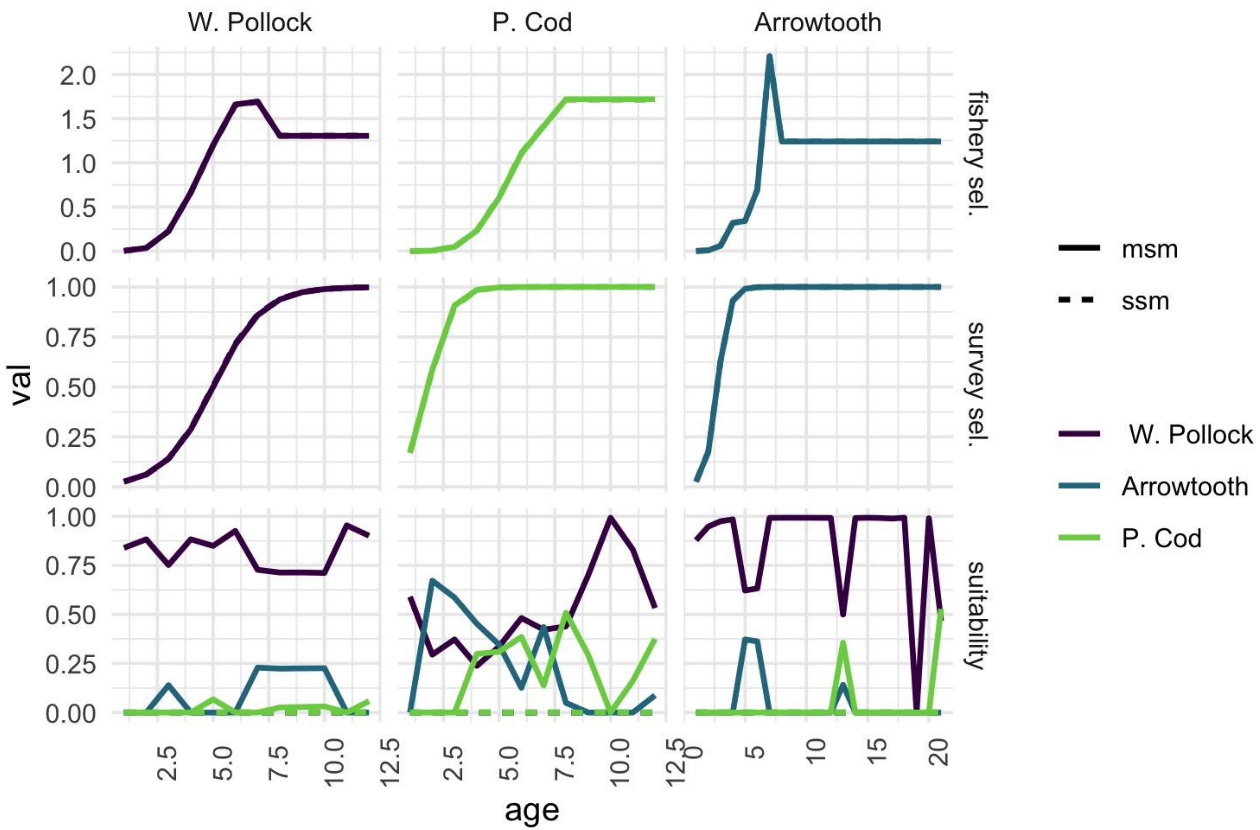
# Survey length comp.

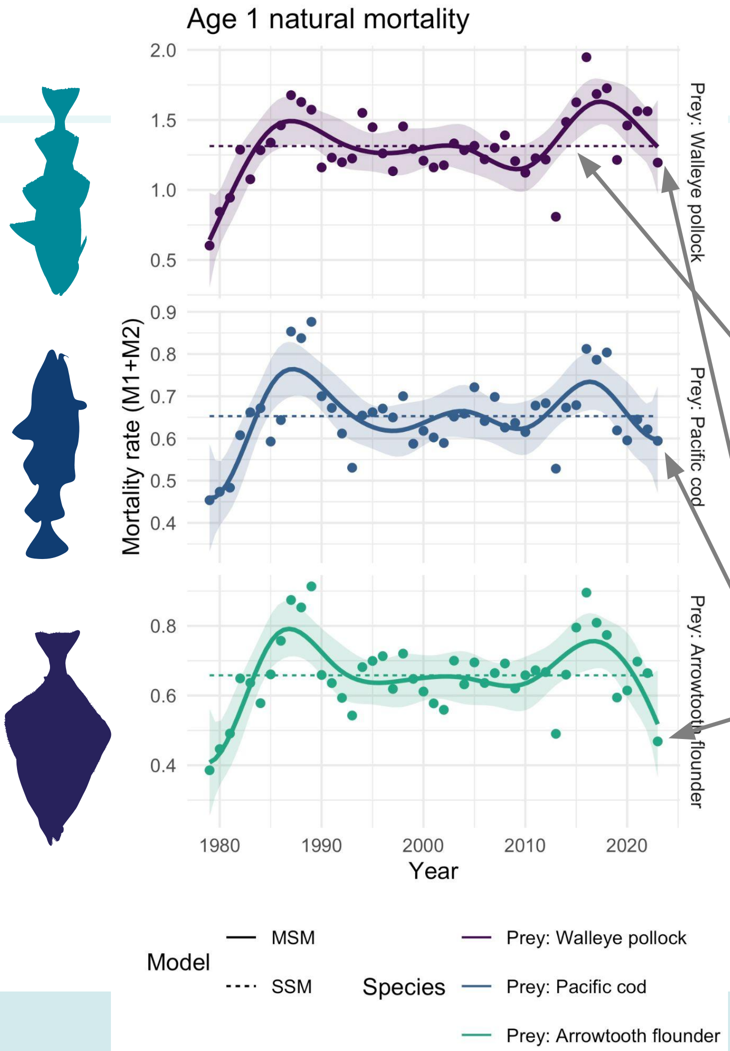


Arrowtooth flounder

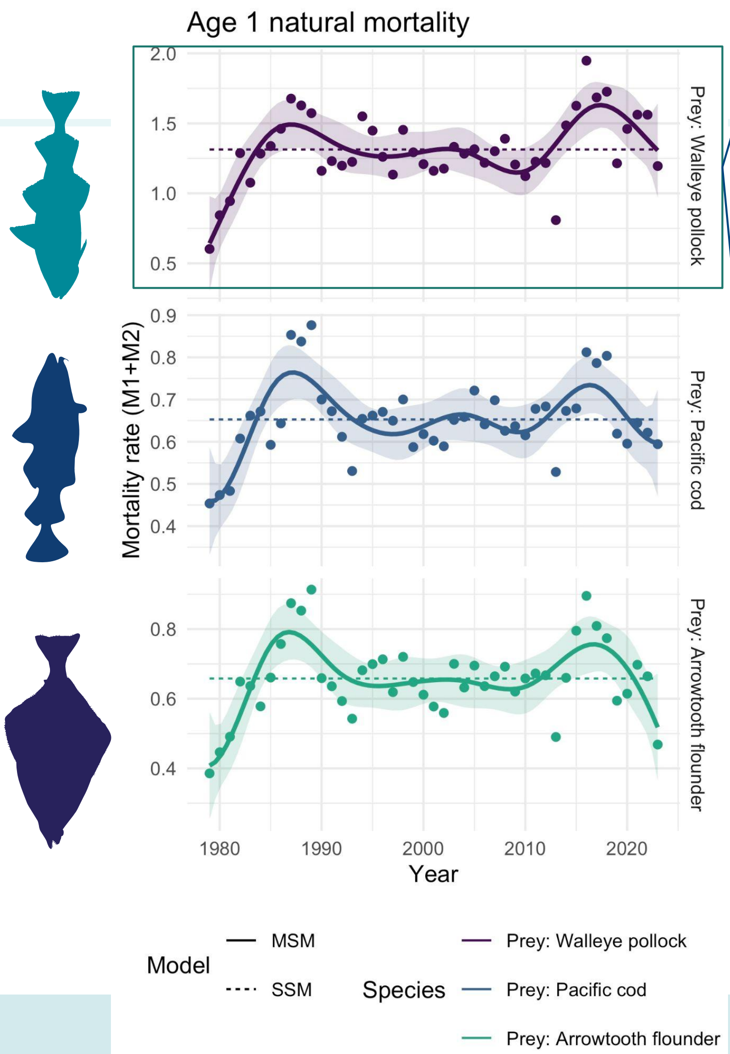


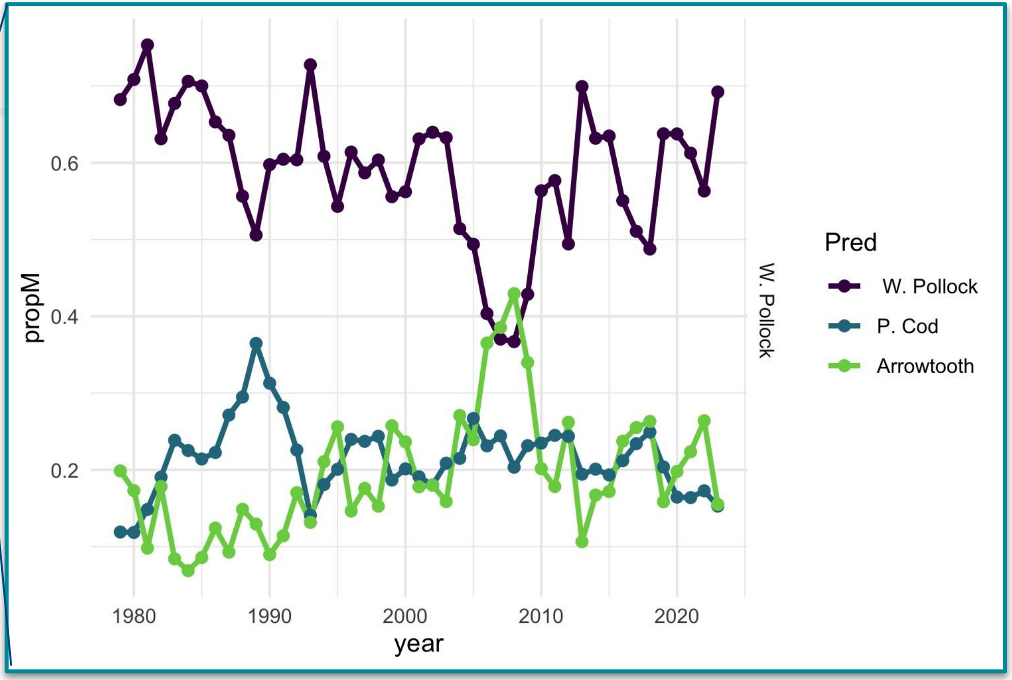
W. Pollock
P. Cod
Arrowtooth
fishery sel.
survey sel.
suitability
val
age
msm
ssm
W. Pollock
Arrowtooth
P. Cod

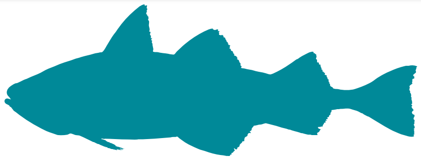



M1 in single species (CEATTLE) model = avg(M1+M2) from multispecies model

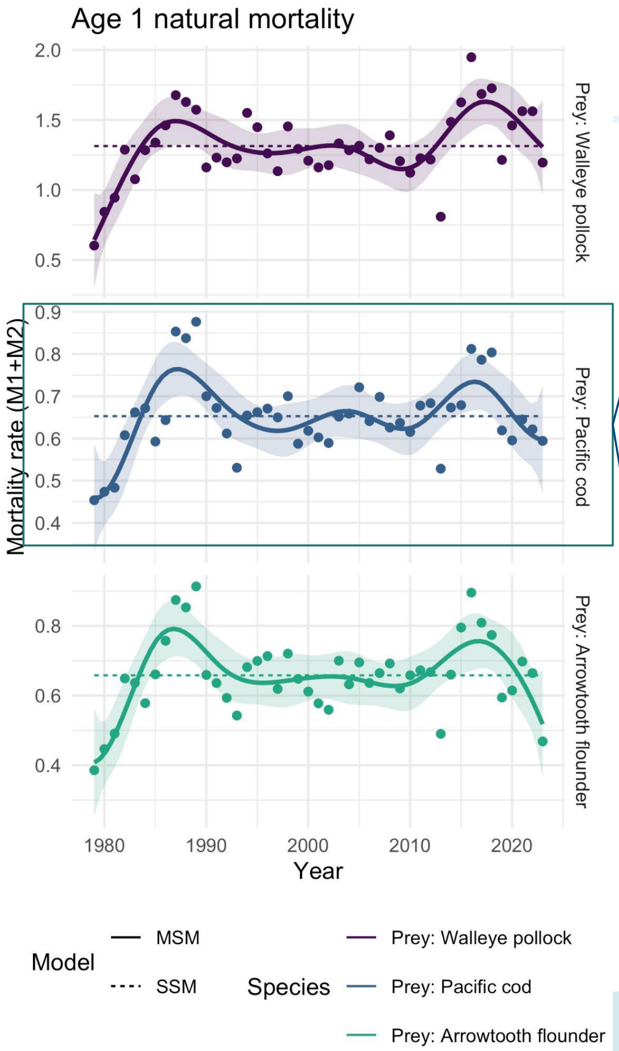
Predation mortality decreased in 2023

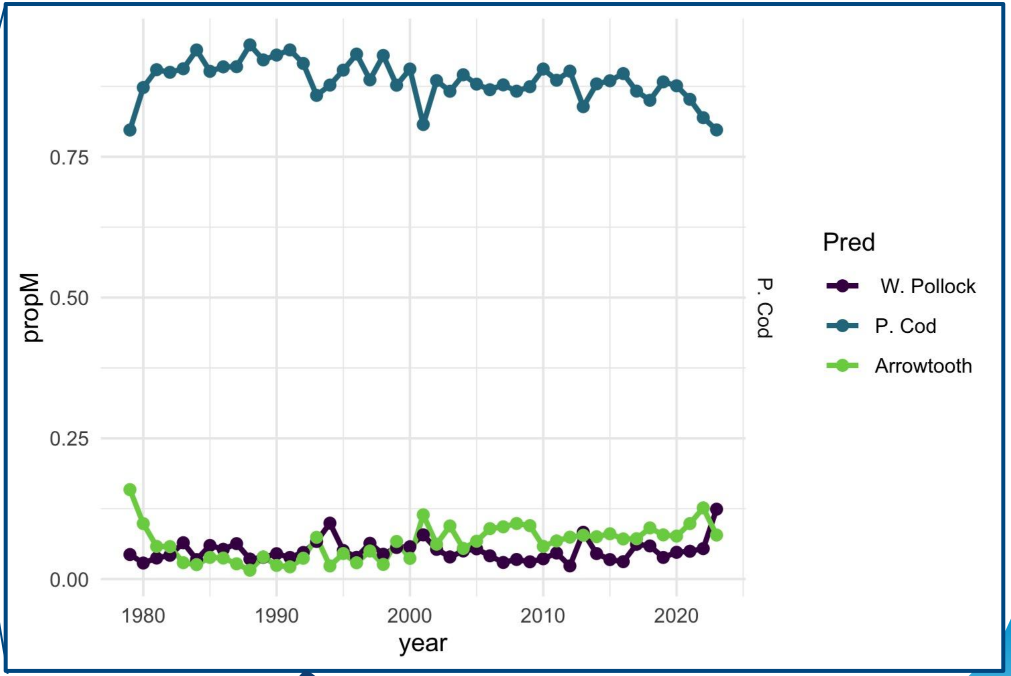


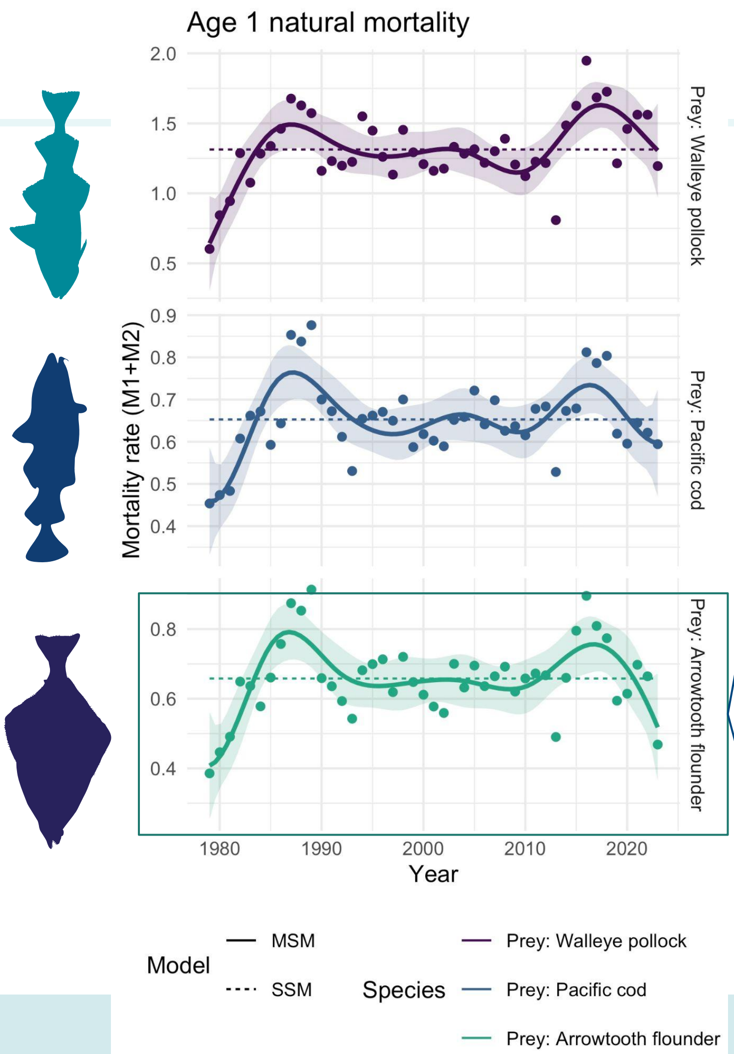



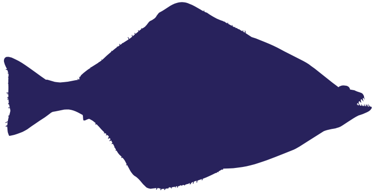
walleye pollock


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

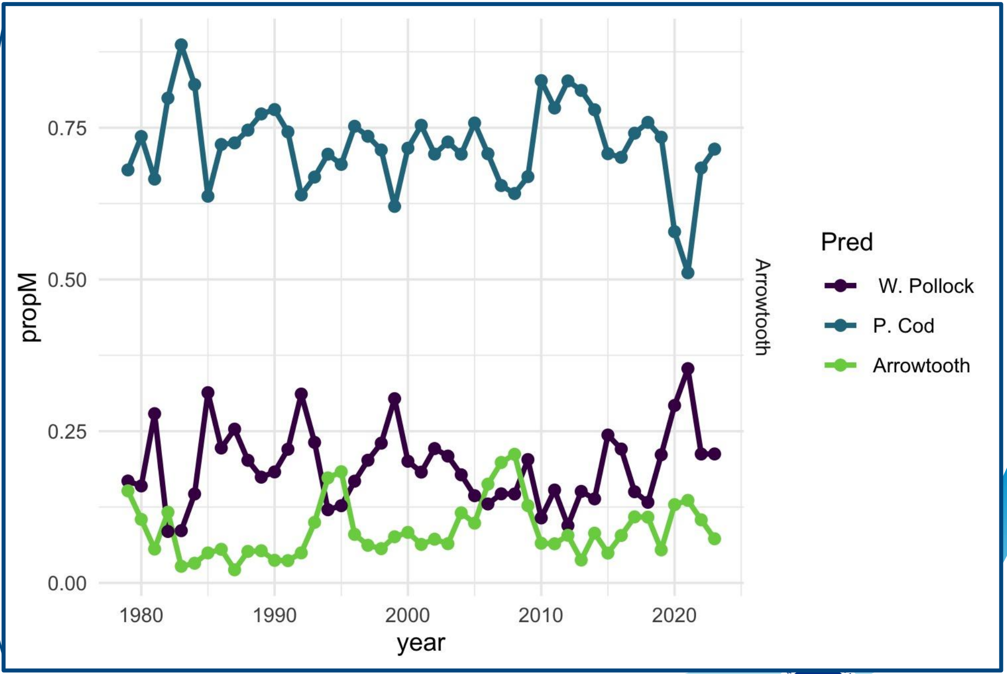

propM
0.75
0.50
0.25
0.00
1980
1990
2000
2010
2020
year
P. Cod
Pred
W. Pollock
P. Cod
Arrowtooth

# Pacific cod



# Arrowtooth flounder

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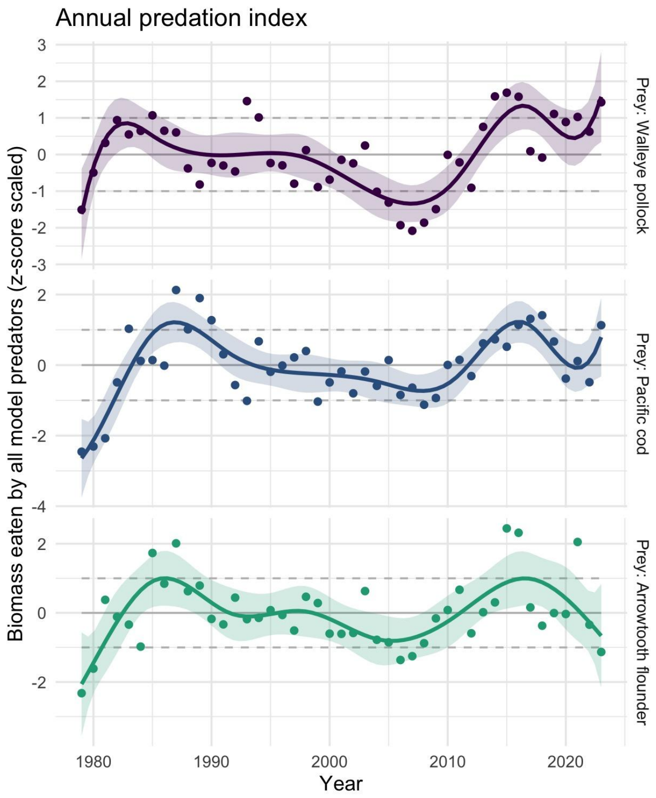
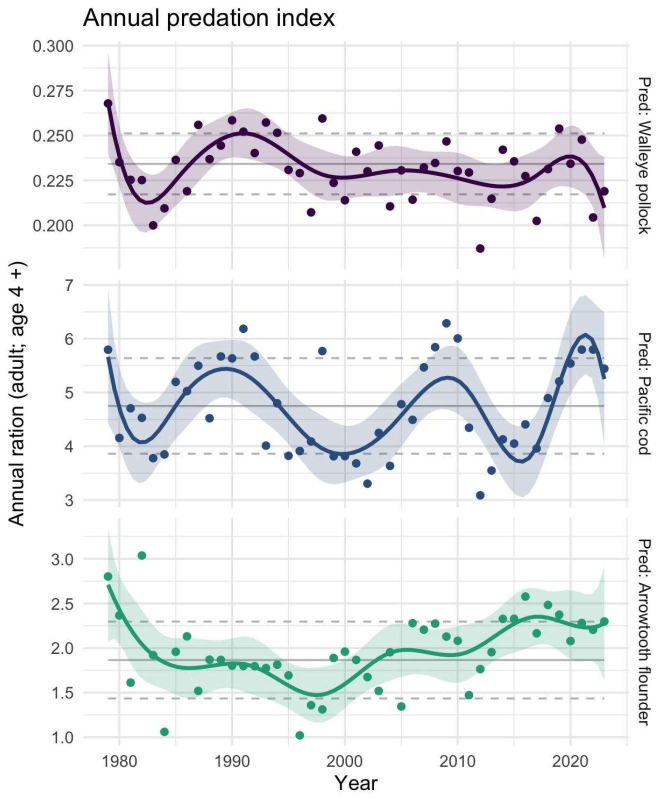
# ESPs

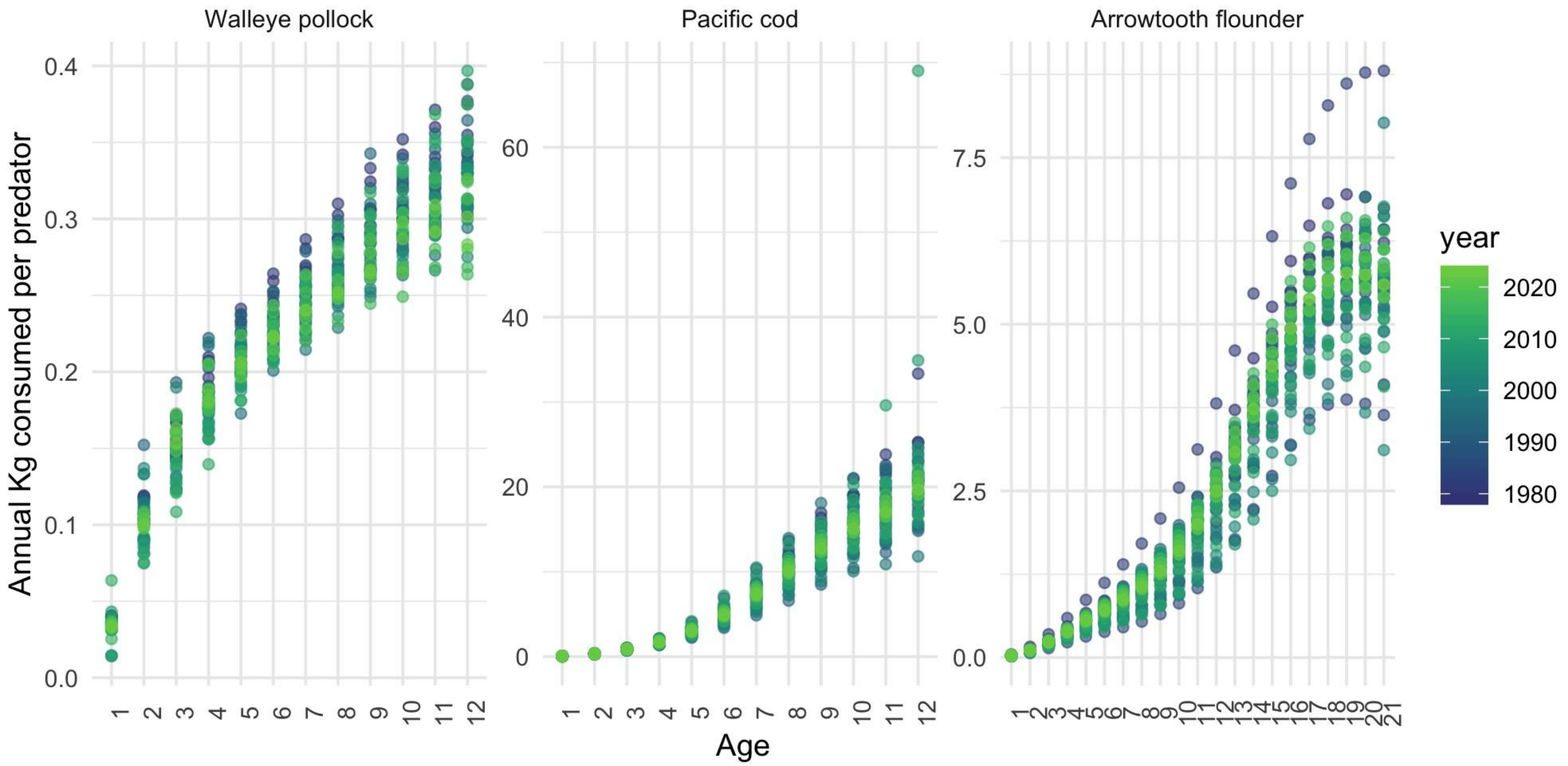
Use this if: need index of mortality for plk, pcod, or atf




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



# Annual estimates of prey consumed per fish

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# Data from food habits lab

# ESP indices expanded

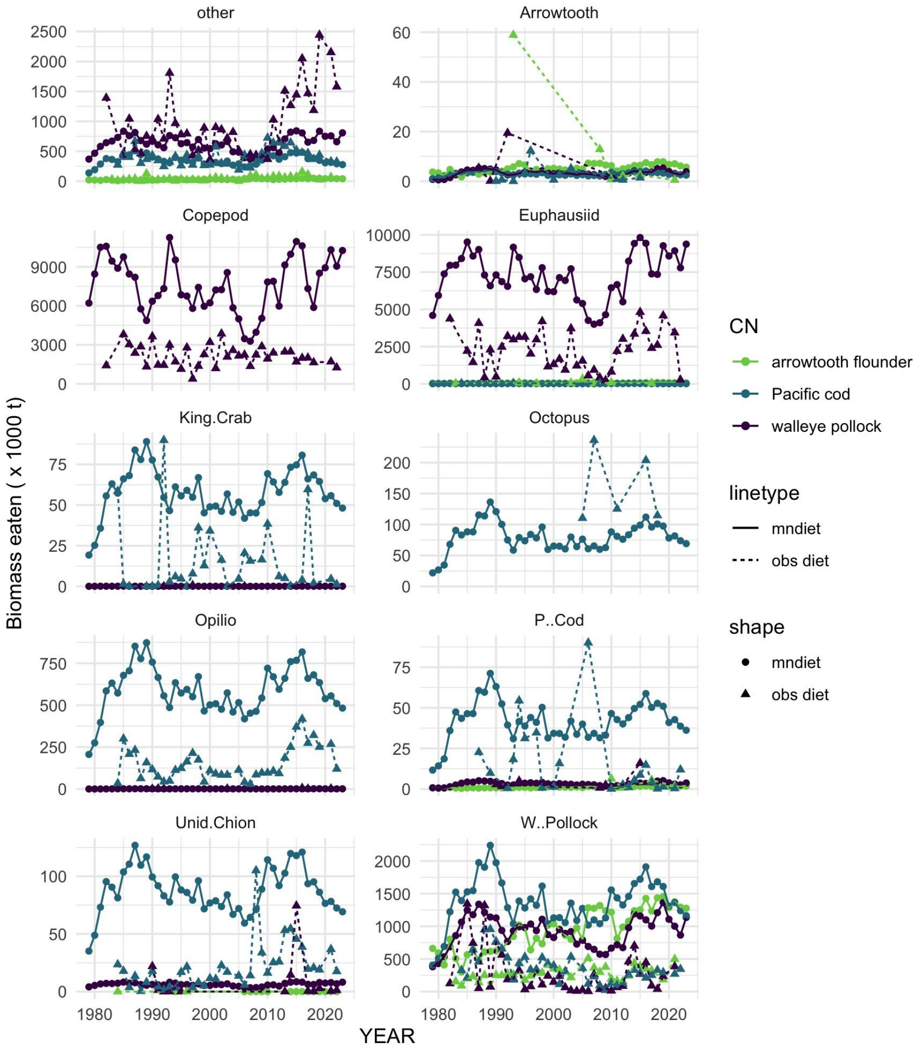
Diet database & survey CPUE

CEATTLE outputs

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

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

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

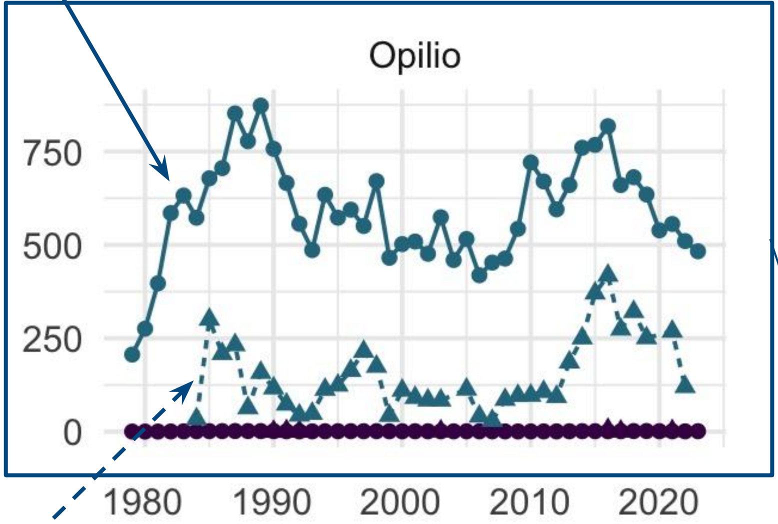



*Holsman et al. in prep*

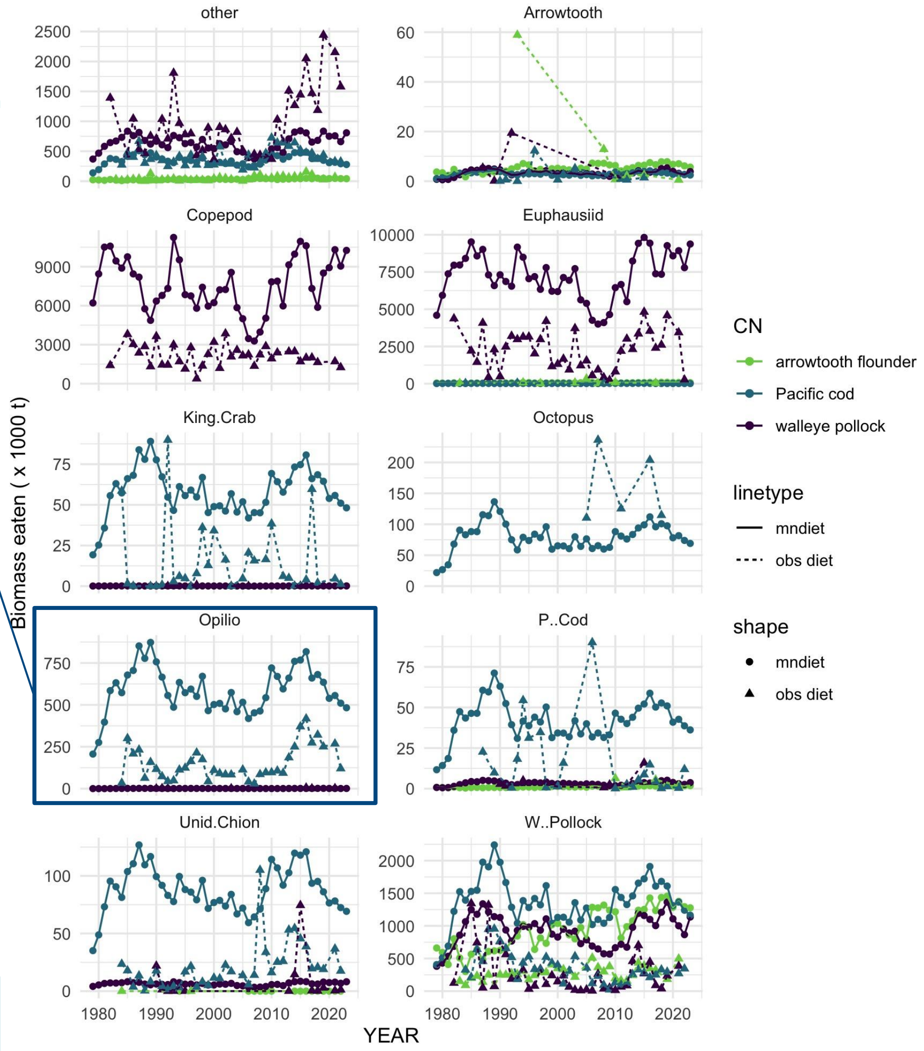
# ESP indices expanded

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

*A = cold, warm, avg T years*



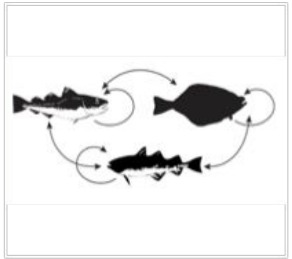

$sum(avgP_{i,j,k,y}*L2A)*AvgN_{a,k,y}*C_{a,k,y}$




Output available as .Rdata

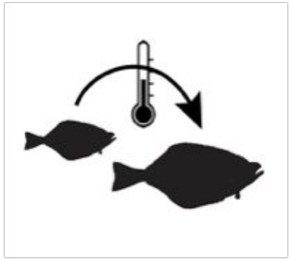
# EBS CEATTLE

## Mortality



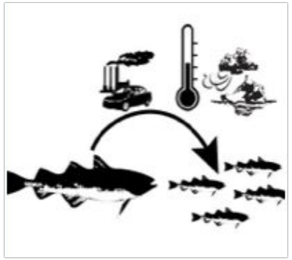
- Empirical diets
- Bioenergetics

## Weight @ Age



- Empirical
- VonB with Temp

## Rec



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

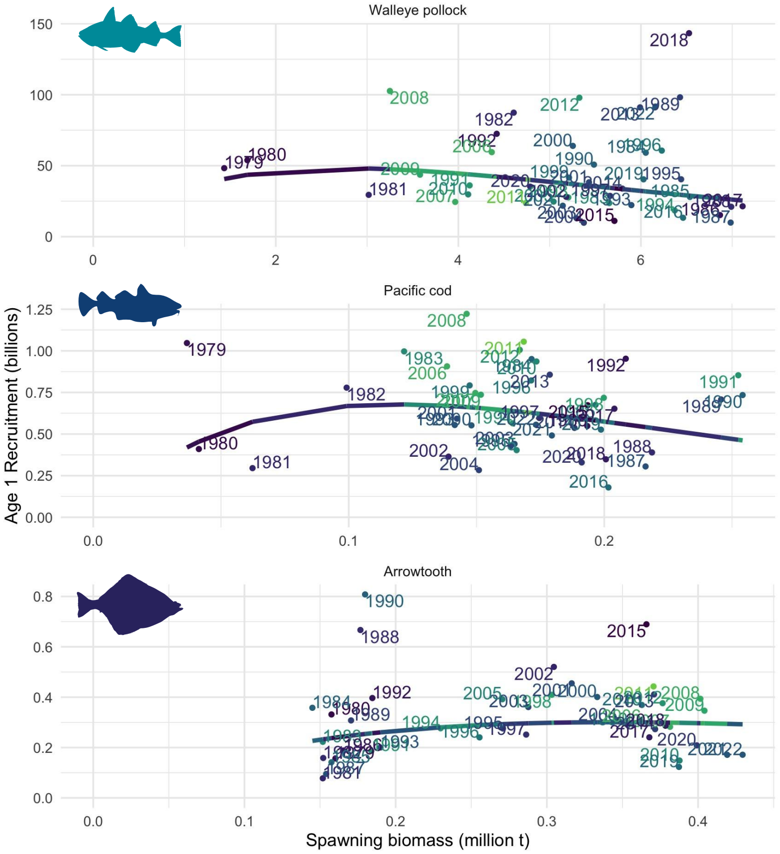
## HCRs

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

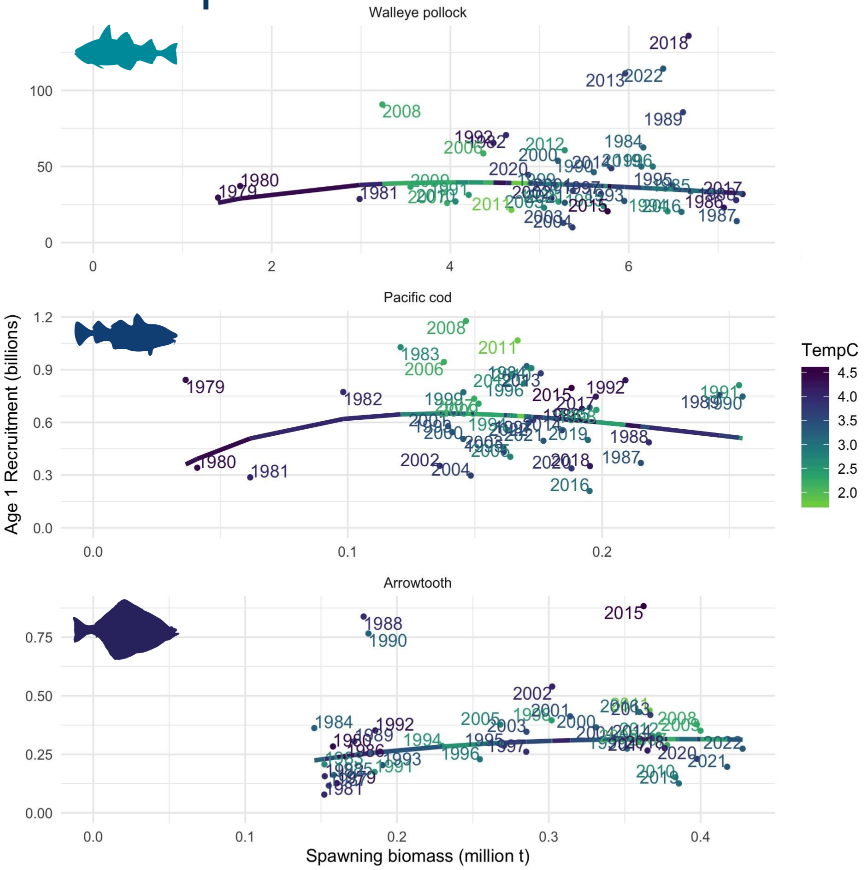
Holsman; CEATTLE

# Recruitment (note: scales vary)

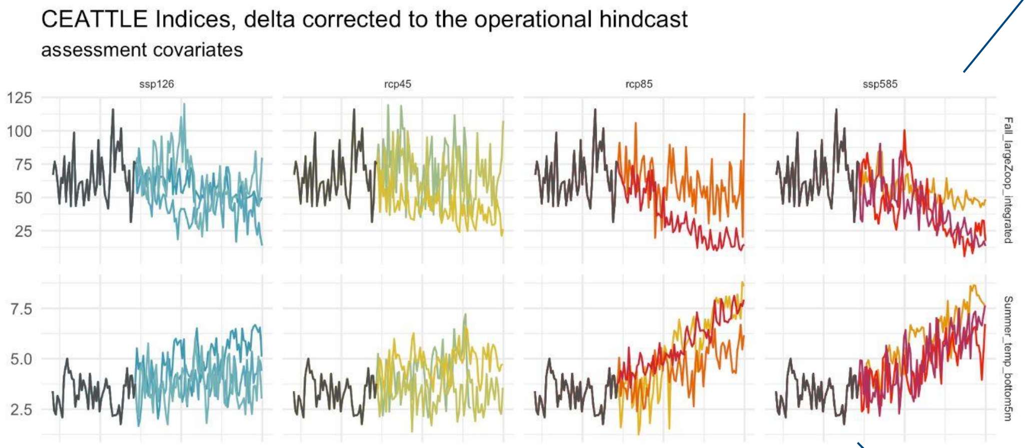
## Single-species

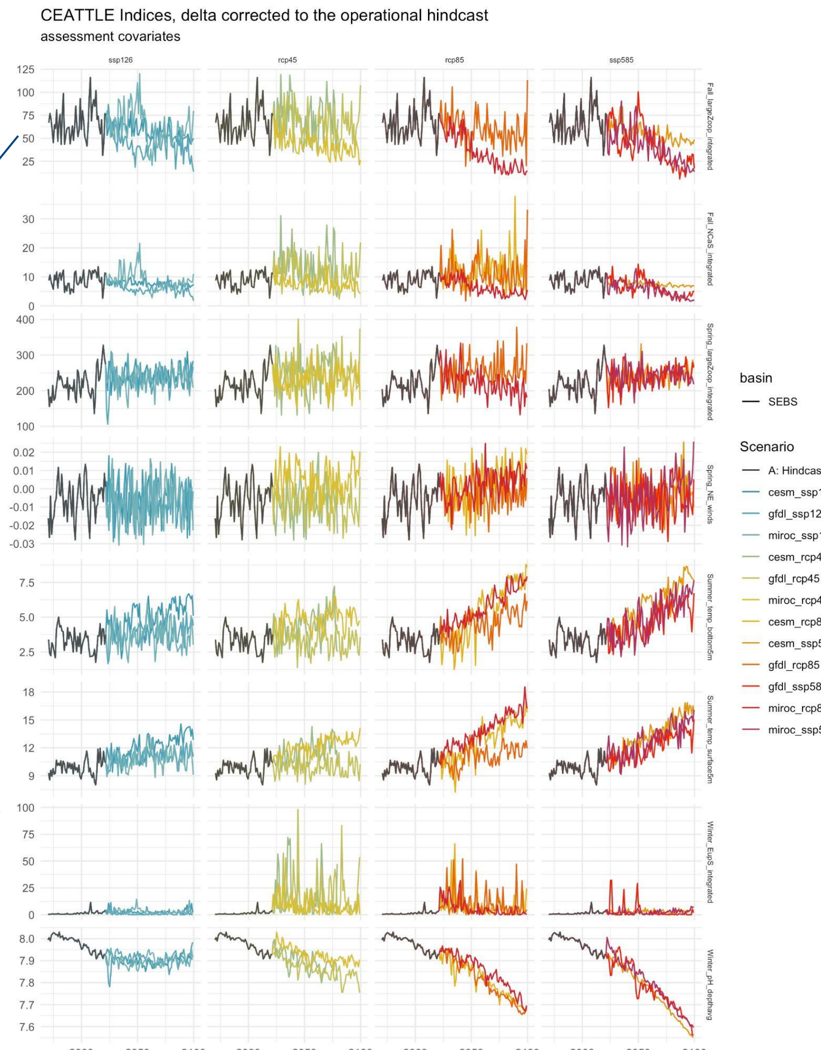



## Multispecies



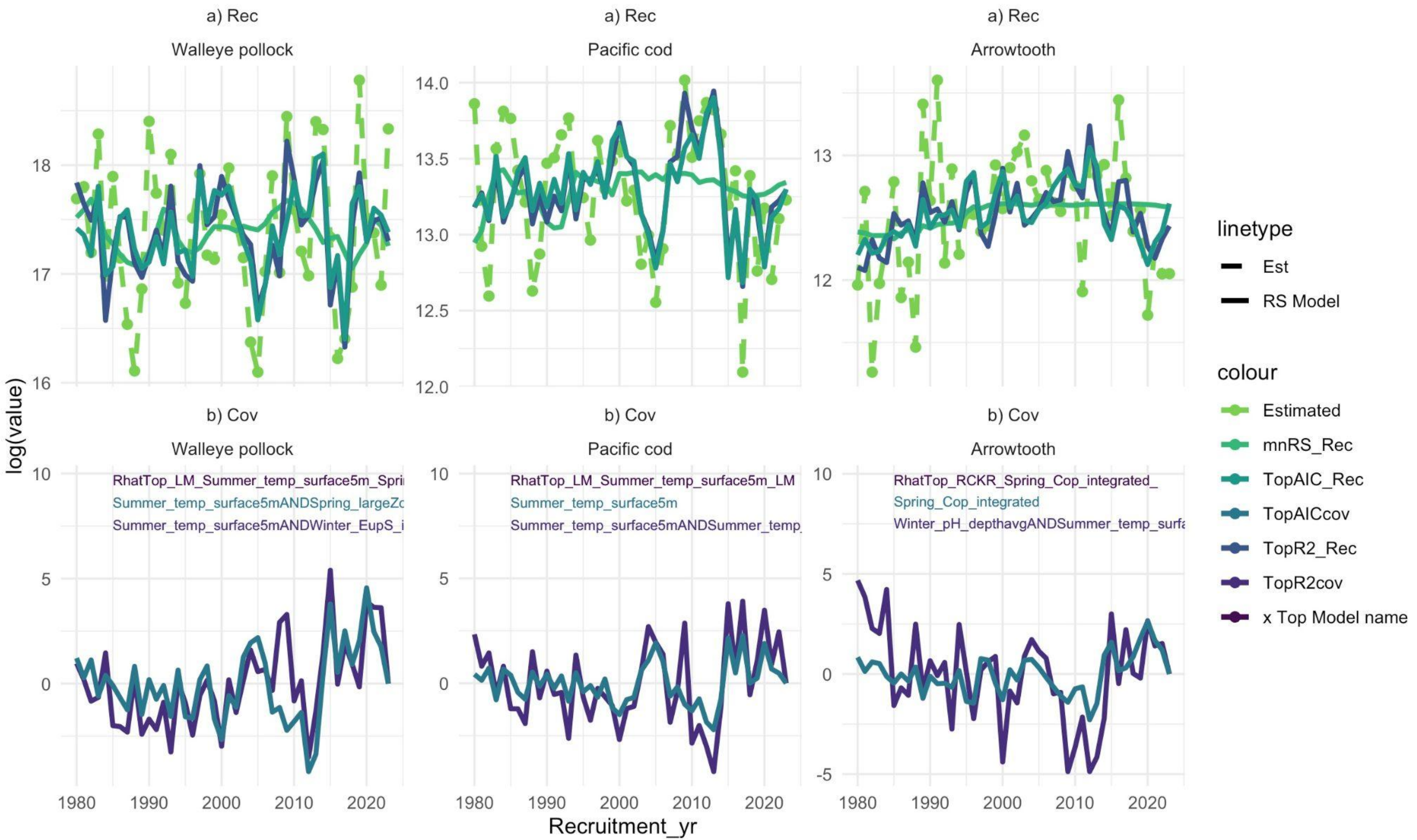
# Recruitment covariates



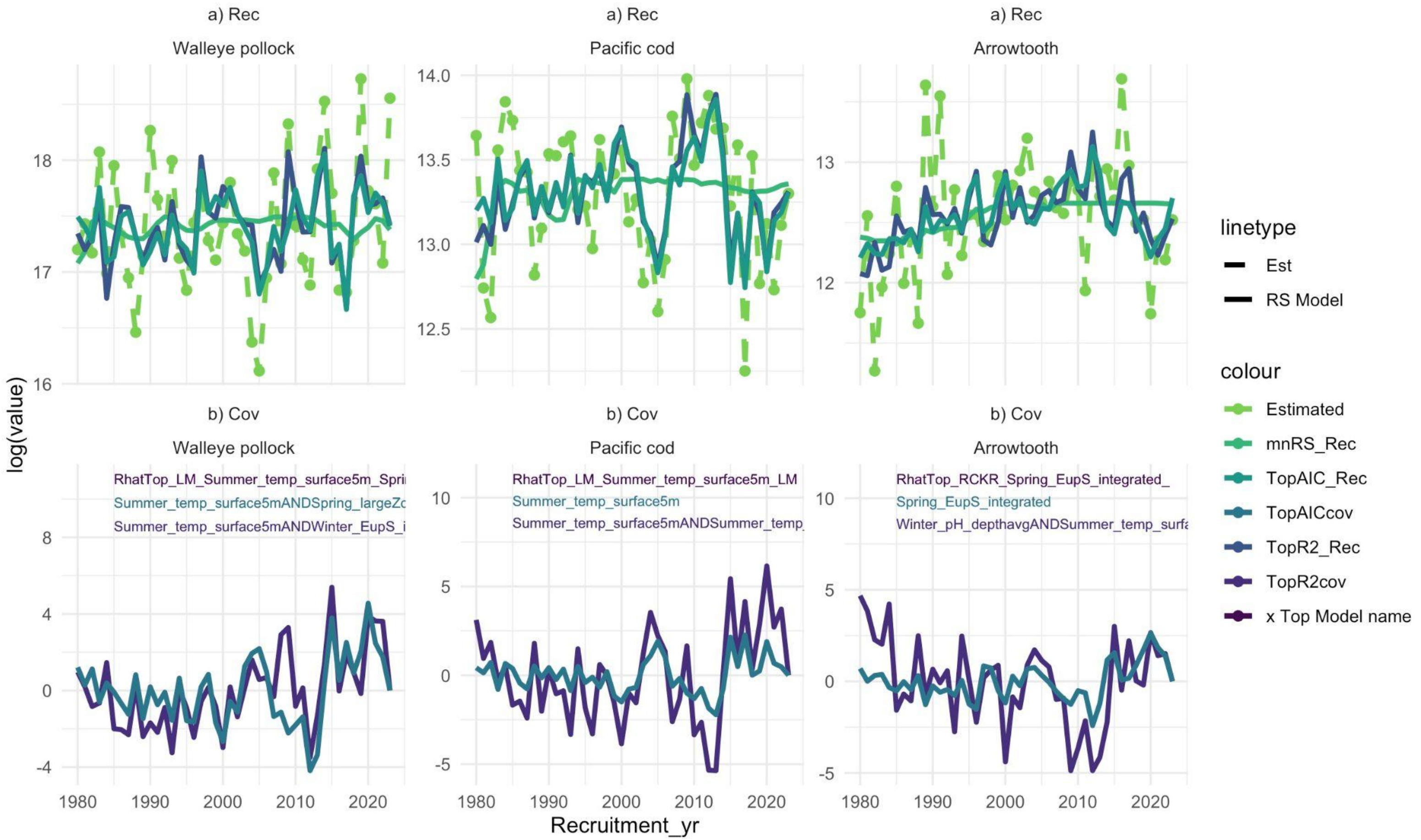




ACLIM indices

# Single species model



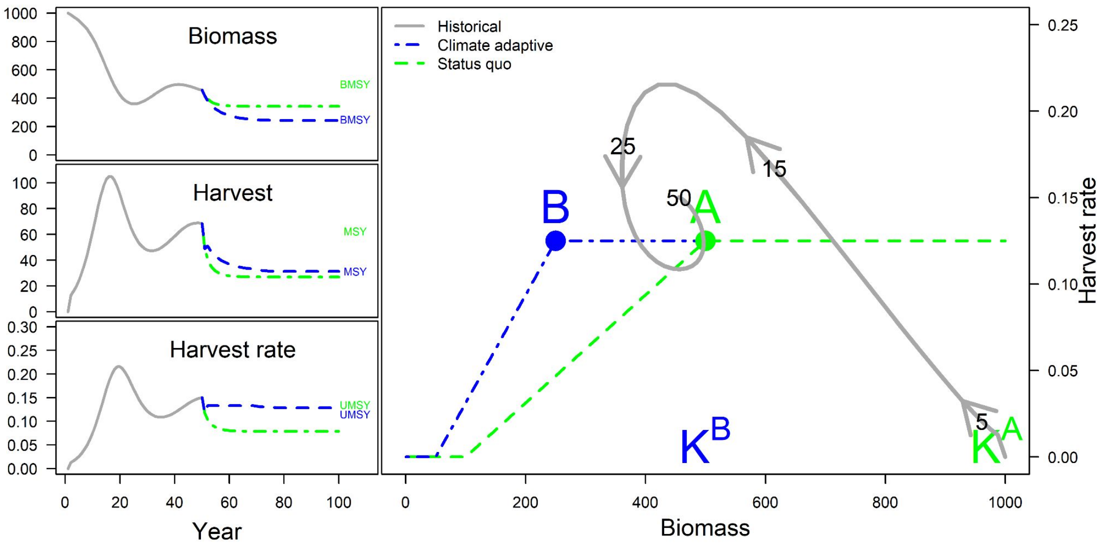
# Multispecies model



# 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)

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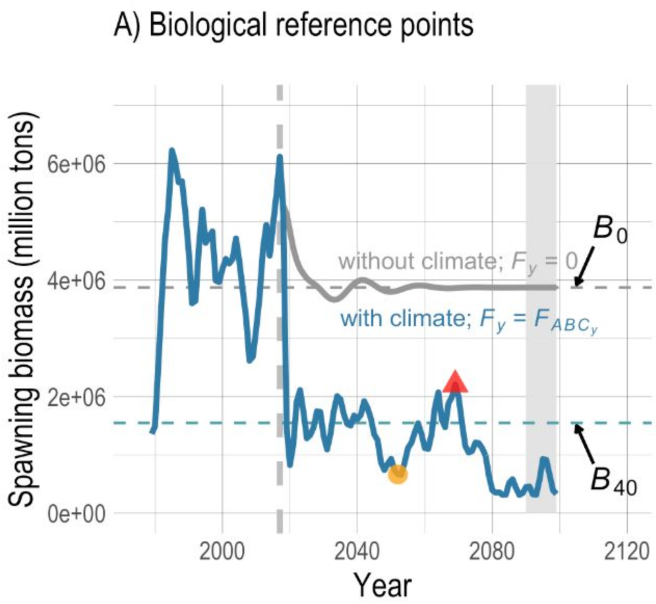
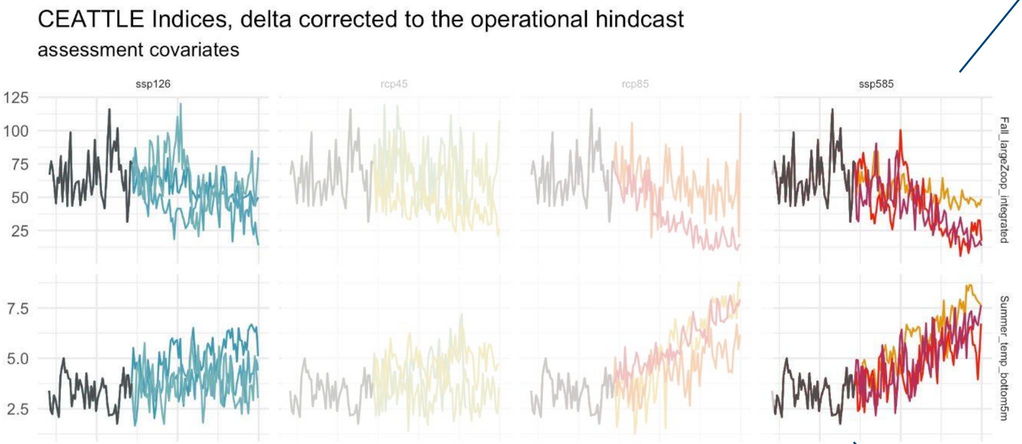
# Climate informed biological reference points




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

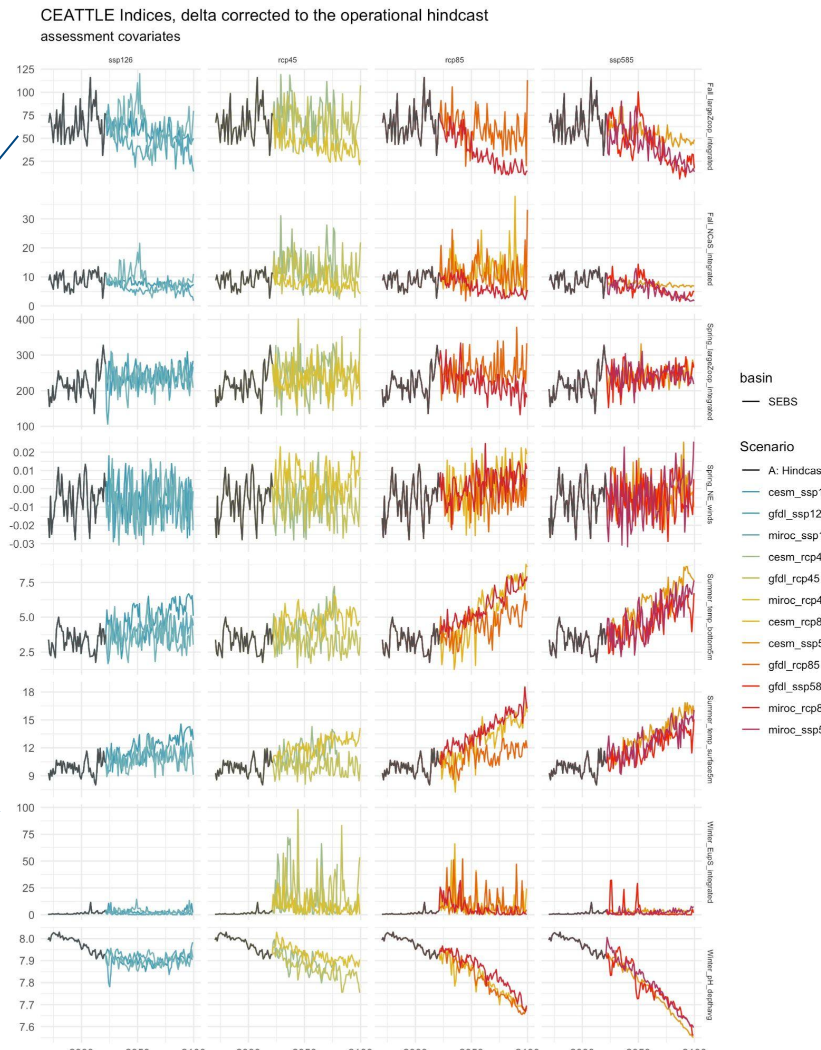
# Recruitment covariates



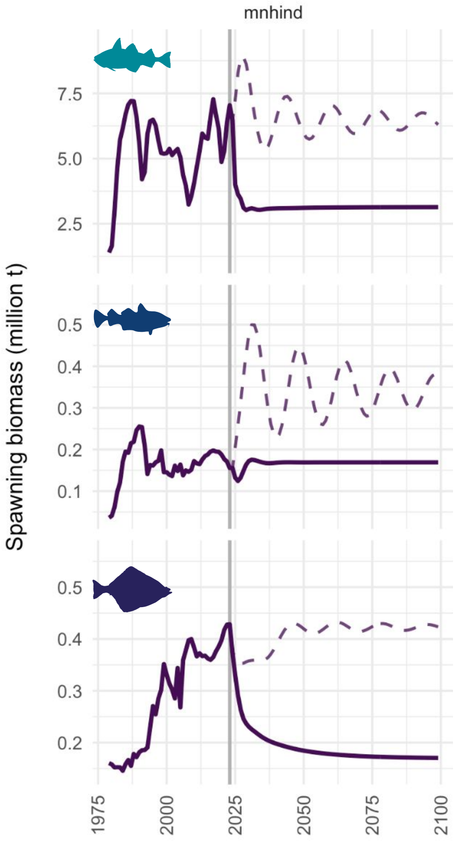

High

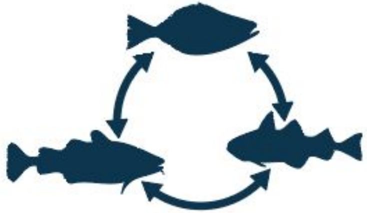
carbon mitigation

Low



# Biomass (multispecies)



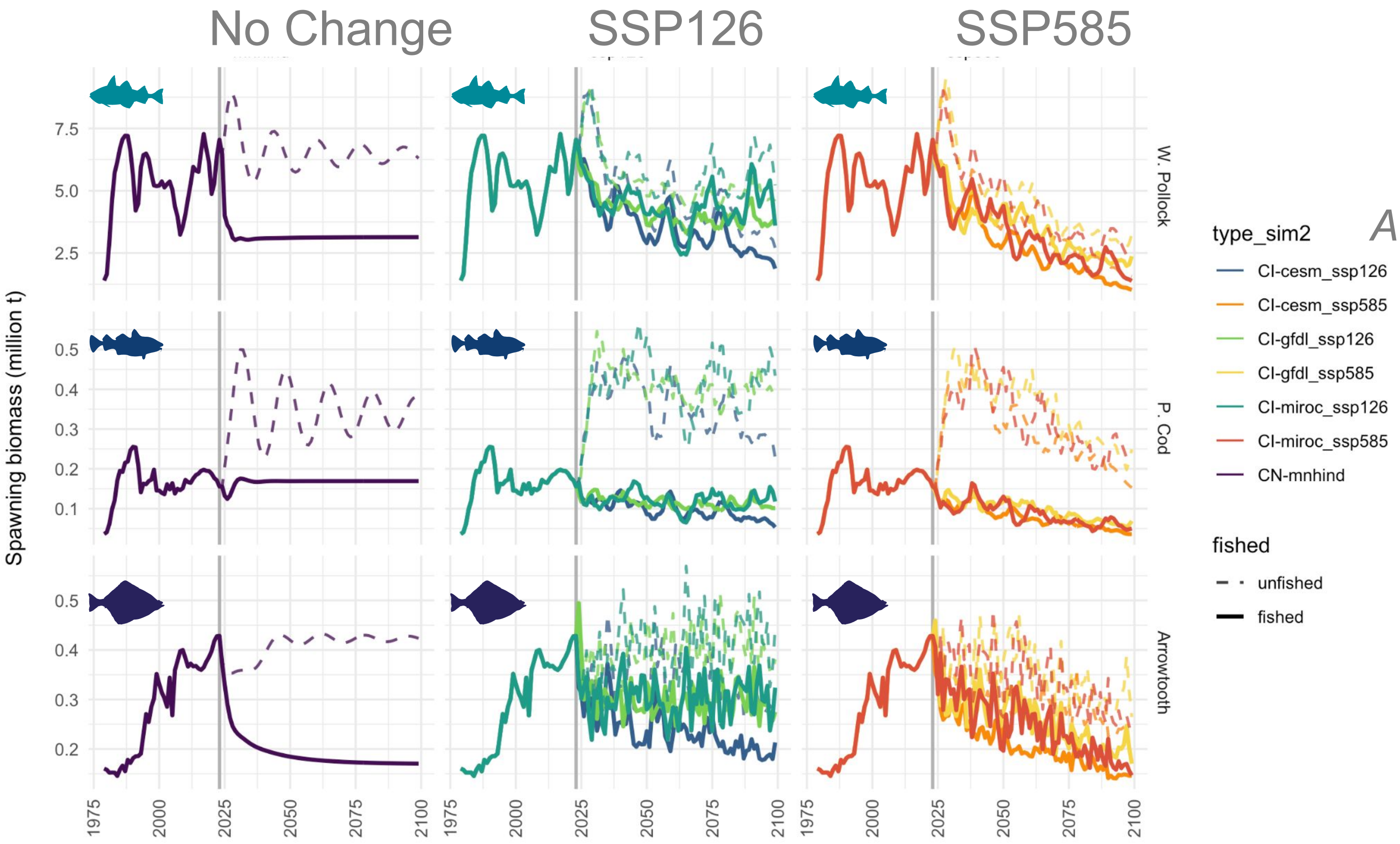



Project to 2099 such that
F that results in $B_{2095\text{-}2099} \sim 0.4\ B_{100\%}$
AND $B_y > 0.35\ B_{100\%}$

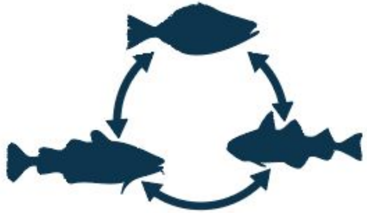
Pollock & P. cod first, then arrowtooth

*(Holsman et al. 2016)*

# Biomass (multispecies)




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



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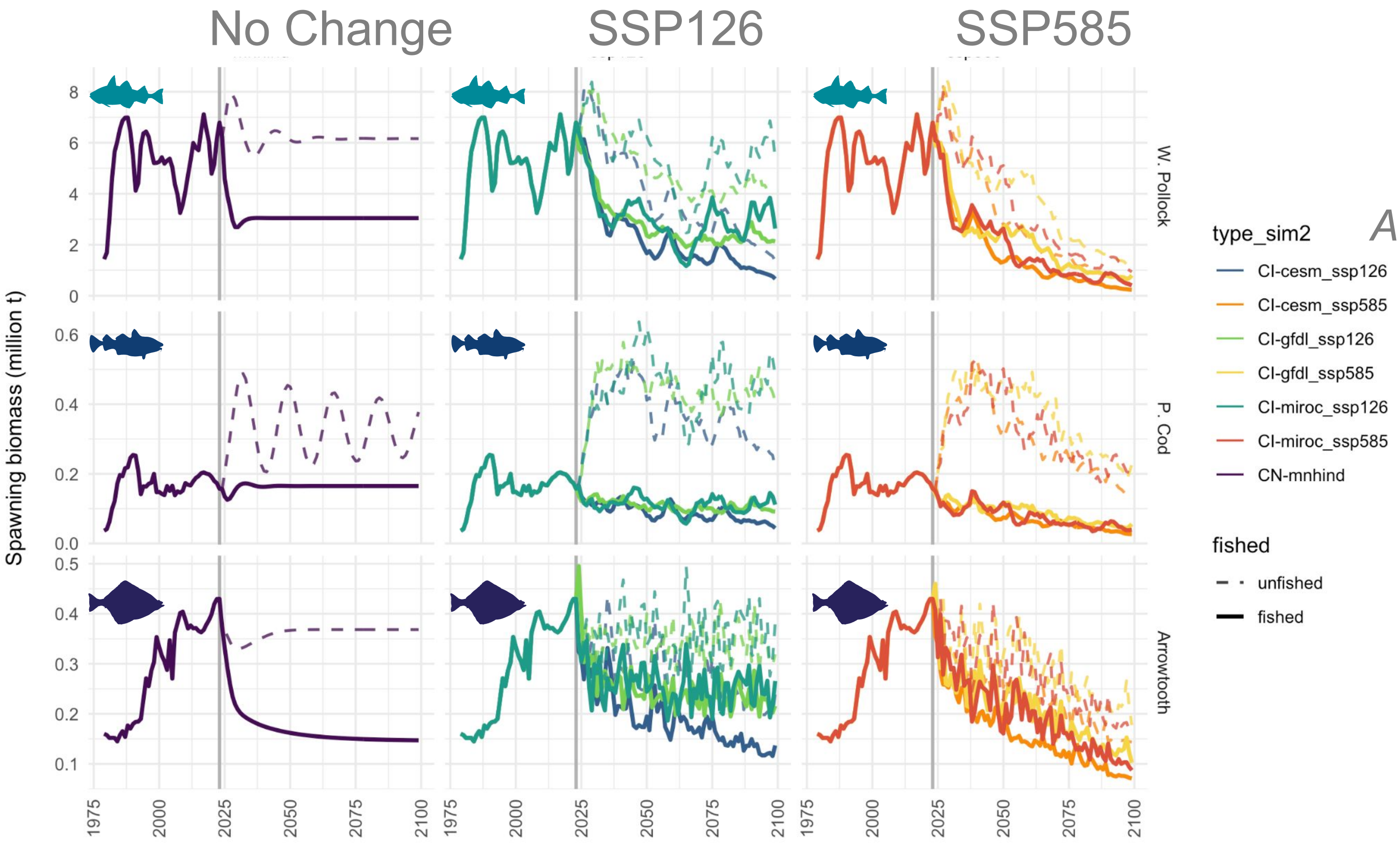
# Biomass (Single species)




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

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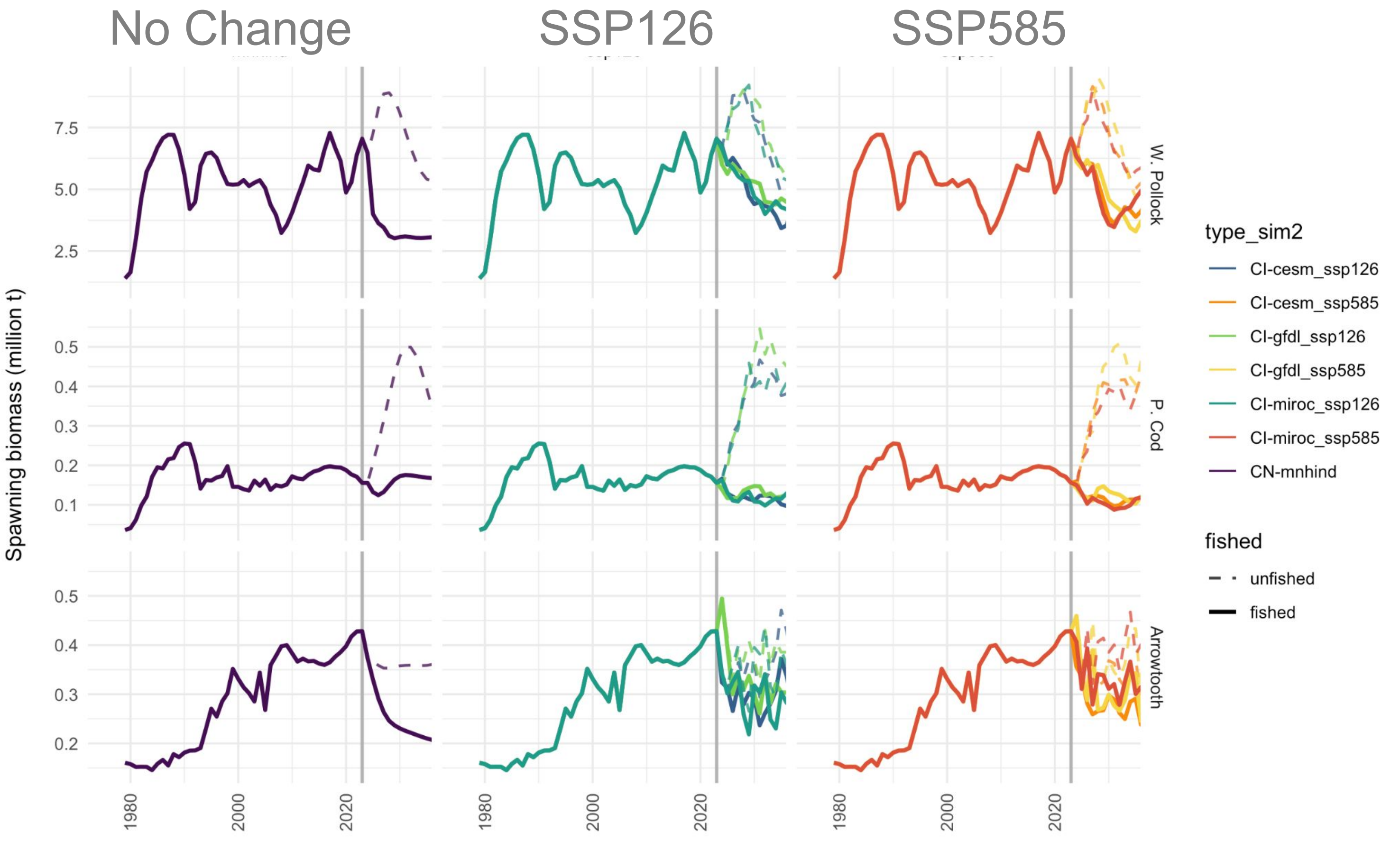
# Biomass



No Change
SSP126
SSP585
Spawning biomass (million t)
7.5
5.0
2.5
0.5
0.4
0.3
0.2
0.1
0.5
0.4
0.3
0.2
1980
2000
2020
W. Pollock
P. Cod
Arrowtooth
type_sim2
CI-cesm_ssp126
CI-cesm_ssp585
CI-gfdl_ssp126
CI-gfdl_ssp585
CI-miroc_ssp126
CI-miroc_ssp585
CN-mnhind
fished
unfished
fished

# 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

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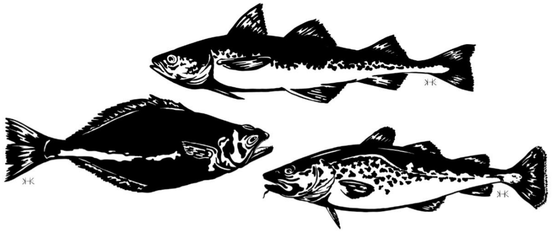
# Multispecies assessment

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

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# 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

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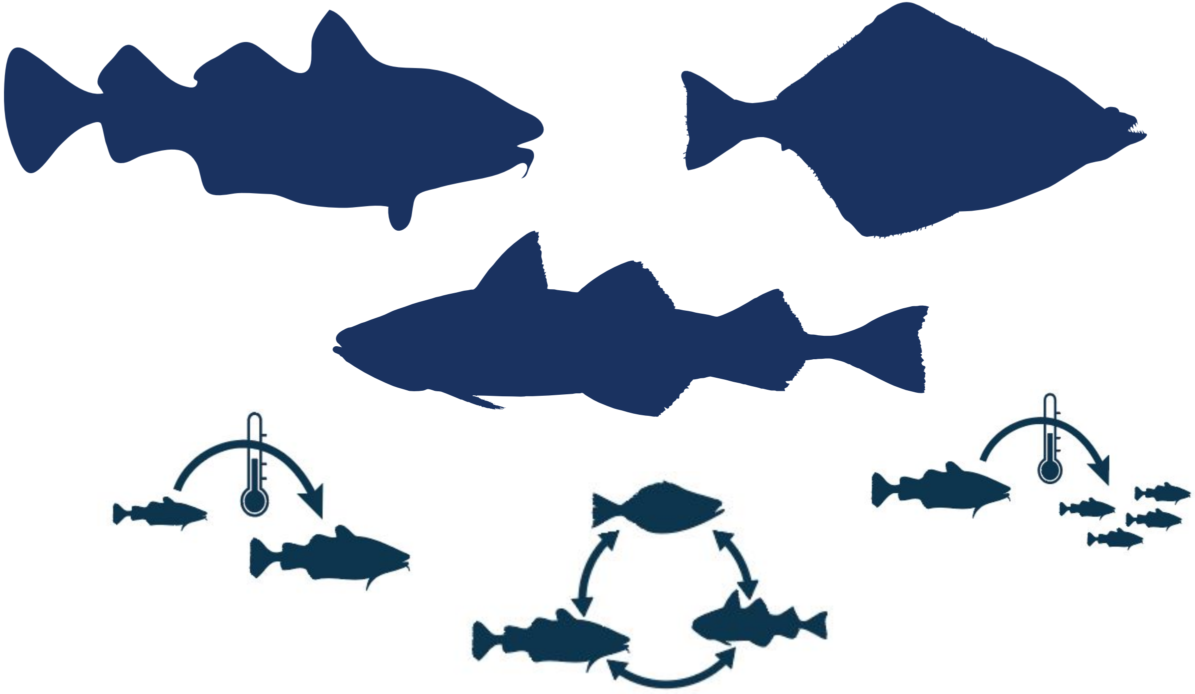
# EXTRA SLIDES



1865

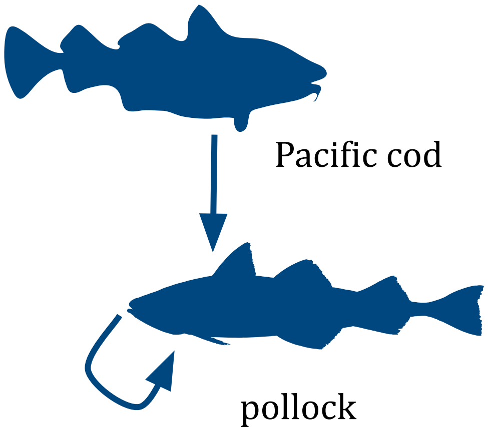
# Incorporating predation interactions in a statistical catch-at-age model for a predator–prey system in the eastern Bering Sea

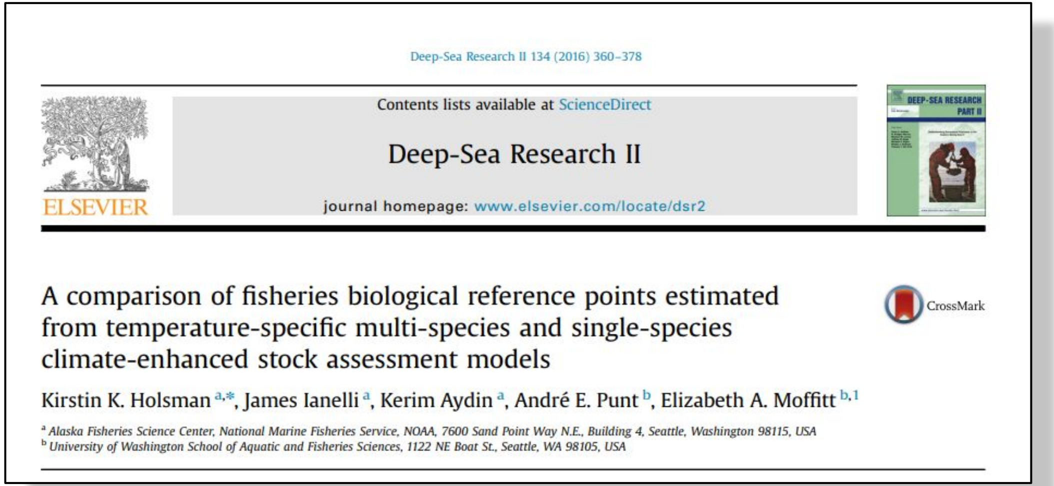
**Jesús Jurado-Molina, Patricia A. Livingston, and James N. Ianelli**

**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

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





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

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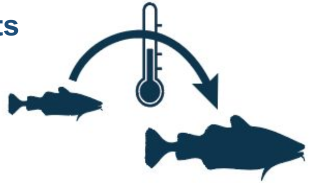
A comparison of fisheries biological reference points estimated from temperature-specific multi-species and single-species climate-enhanced stock assessment models

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

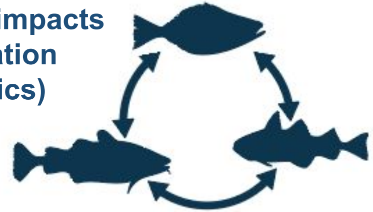
[a] Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Building 4, Seattle, Washington 98115, USA
[b] University of Washington School of Aquatic and Fisheries Sciences, 1122 NE Boat St., Seattle, WA 98105, USA

Holsman et al. 2016

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

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nature COMMUNICATIONS

ARTICLE

Check for updates

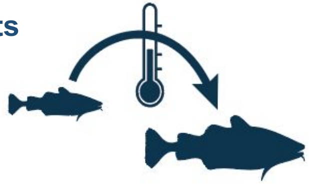
https://doi.org/10.1038/s41467-020-18300-3 OPEN

Ecosystem-based fisheries management forestalls climate-driven collapse

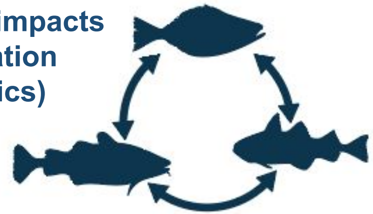
K. K. Holsman[1,2✉], A. C. Haynie[1], A. B. Hollowed[1,2], J. C. P. Reum[1,2,3], K. Aydin[1,2], A. J. Hermann[4,5], W. Cheng[4,5], A. Faig[2], J. N. Ianelli[1,2], K. A. Kearney[1,4] & A. E. Punt[2]

**Holsman et al. 2016**

Climate impacts on growth & condition

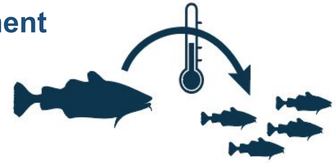


Climate impacts on predation (energetics)



**Holsman et al. 2020**

Climate impacts on recruitment



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# Rceattle

https://github.com/grantdadams/Rceattle

Fisheries Research 251 (2022) 106303

Contents lists available at ScienceDirect

Fisheries Research

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

ELSEVIER

## 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

A R T I C L E I N F O

Handled by: Mark Nicholas Maunder

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

A B S T R A C T

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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**Grant Adams**

grantdadams

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I am a PhD student at the University of Washington School of Aquatic and Fisheries Science.

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# 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

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# Discussion : Climate informed BRPs

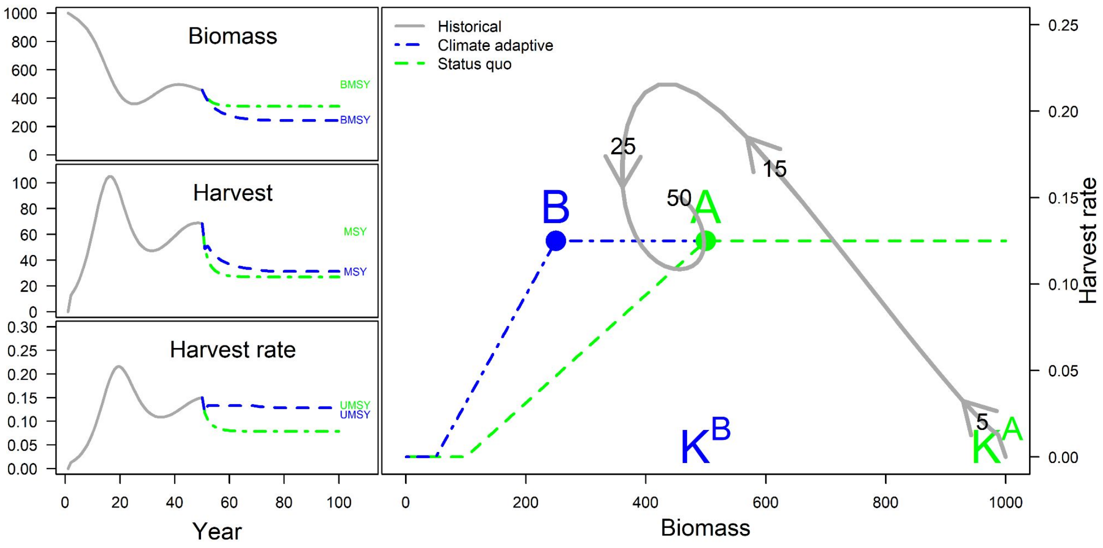
Set B0 and B40 target using climate informed models

NO!

# Adapting reference points to reflect changes in productivity

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

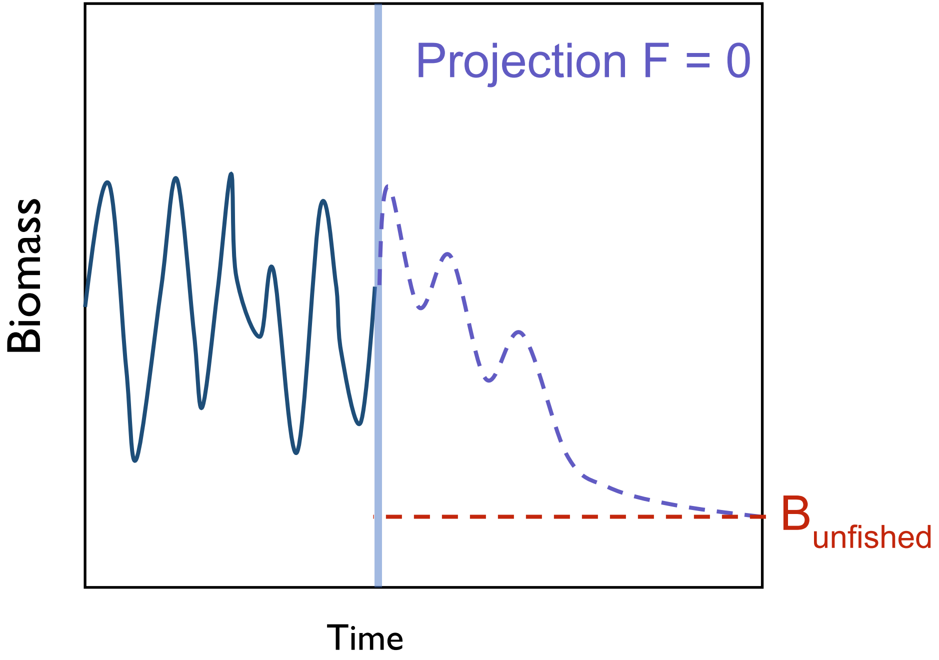
- Changing reference points for stocks undergoing climate-related productivity shifts can result in counter-intuitive management actions:
  - Declining stocks could be fished harder
  - Flourishing stocks could be fished more conservatively



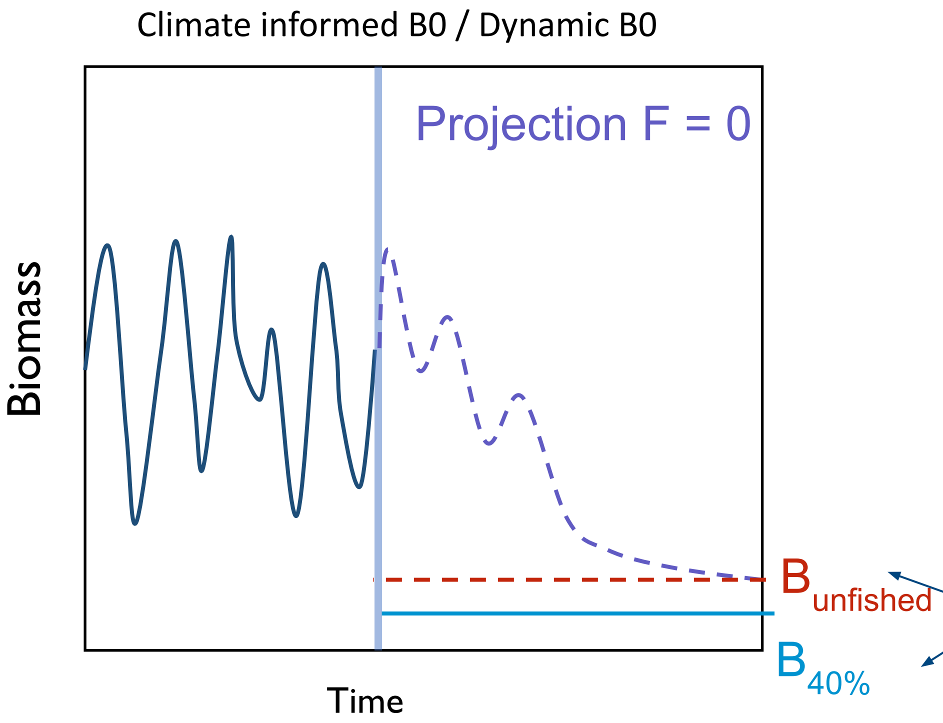

Szuwalski et al. 2023

# First: Set Target / reference points

Climate informed B0 / Dynamic B0

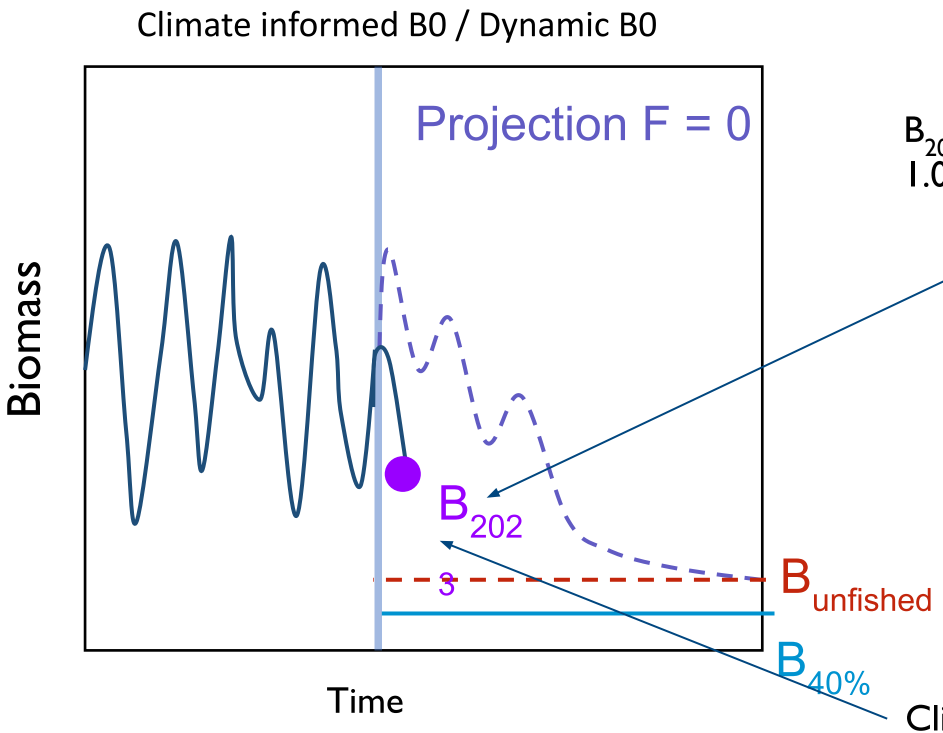


# First: Set Target / reference points




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

# First: Set Target / reference points

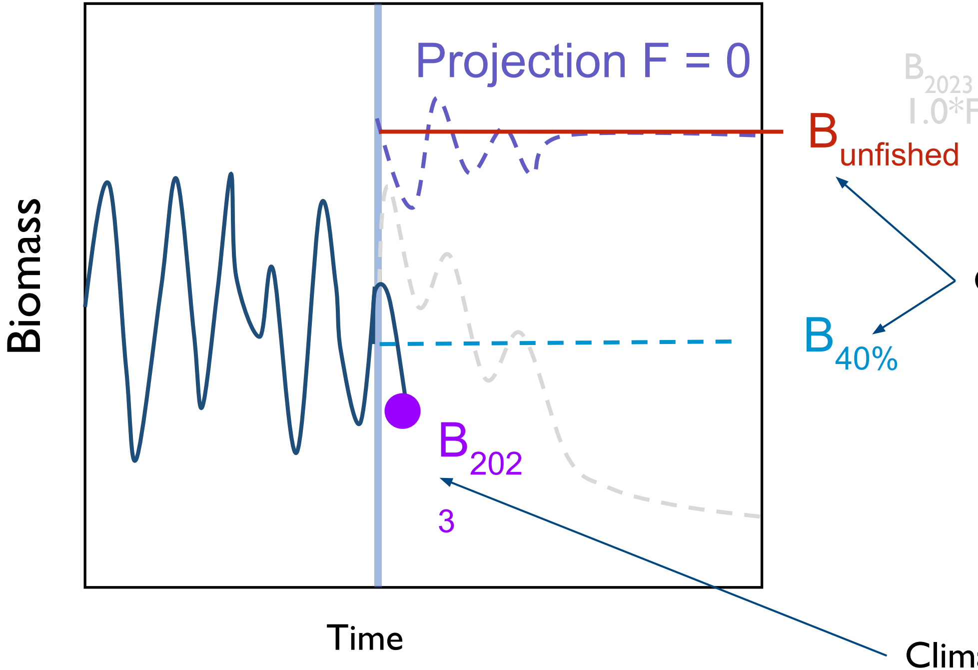



$B_{2023}$ >> $B_{40\%}$ so set $F_{ABC}$ = 1.0*$F_{ACL}$

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

# “hybrid” climate- naive & climate informed approach

Climate naive B0 + climate informed By



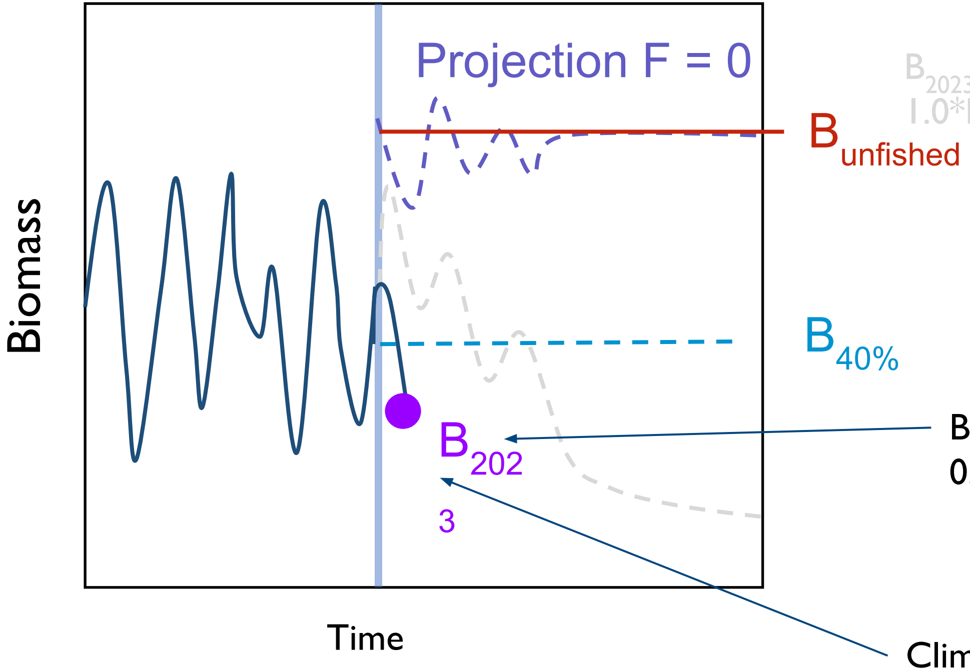

$B_{2023}$ >> $B_{40\%}$ so set $F_{ABC}$ = $1.0{*}F_{ACL}$

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

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

# “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 $B_y$ / $B_{40\%}$ ($B_{2023}$)