Bering Sea climate-enhanced multi-species stock assessment

Sept., 2023

Kirstin K. Holsman

Jim Ianelli, Kerim Aydin, Grant Adams, Kalei Shotwell, Steve Barbeaux, Kelly Kearney

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

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2022 Climate-enhanced multi-species Stock Assessment for walleye pollock, Pacific cod, and arrowtooth flounder in the South Eastern Bering Sea

Kirstin K. Holsman, Jim Ianelli, Kerim Aydin, Grant Adams, Kelly Kearney, Kalei Shotwell, Grant Thompson, and Ingrid Spies

kirstin.holsman@noaa.gov *November 2022*
Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA,
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https://apps-afsc.fisheries.noaa.gov/Plan_Team/2022/EBSmultispp.pdf

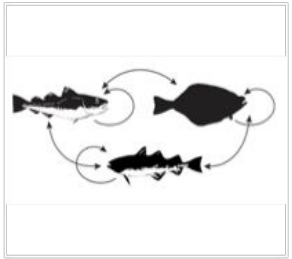
Two models presented each year:

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

Produced annually 2016 - present

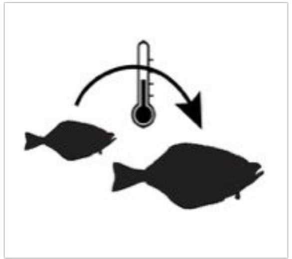
EBS CEATTLE

Mortality



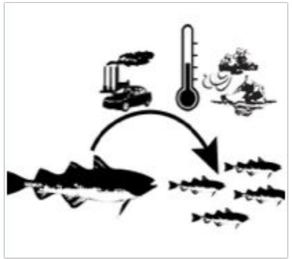
- Empirical diets
- Bioenergetics

Weight @ Age



- Empirical
- VonB with Temp

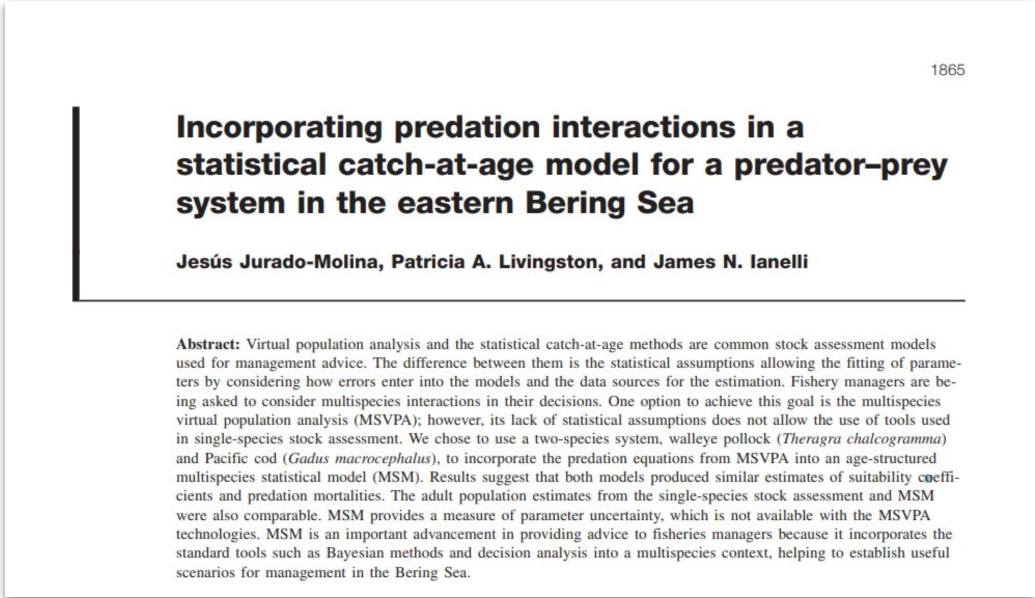
Rec



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

HCRs

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



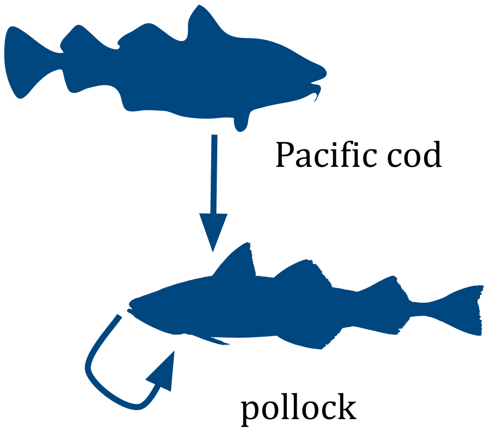
1865

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.

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



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

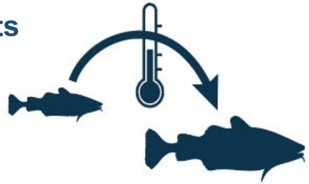
A comparison of fisheries biological reference points estimated from temperature-specific multi-species and single-species climate-enhanced stock assessment models

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

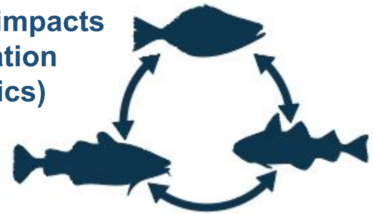
[a] Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Building 4, Seattle, Washington 98115, USA
[b] University of Washington School of Aquatic and Fisheries Sciences, 1122 NE Boat St., Seattle, WA 98105, USA

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

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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

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nature COMMUNICATIONS

ARTICLE

Check for updates

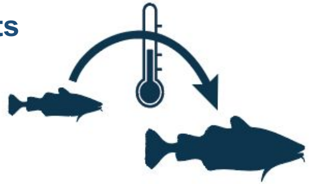
https://doi.org/10.1038/s41467-020-18300-3 OPEN

Ecosystem-based fisheries management forestalls climate-driven collapse

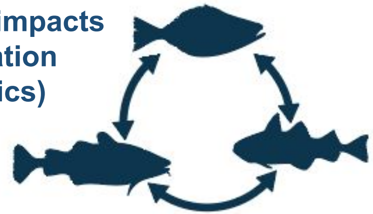
K. K. Holsman[1,2✉], A. C. Haynie[1], A. B. Hollowed[1,2], J. C. P. Reum[1,2,3], K. Aydin[1,2], A. J. Hermann[4,5], W. Cheng[4,5], A. Faig[2], J. N. Ianelli[1,2], K. A. Kearney[1,4] & A. E. Punt[2]

Holsman et al. 2016

Climate impacts on growth & condition

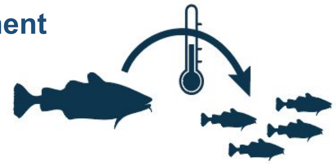


Climate impacts on predation (energetics)



Holsman et al. 2020

Climate impacts on recruitment



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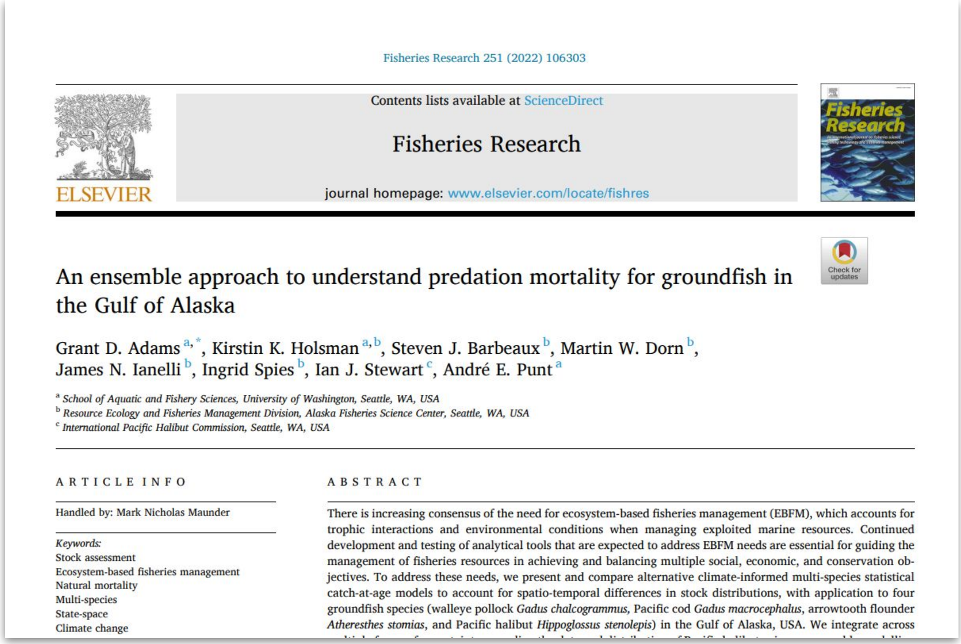
Rceattle

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

Check for updates

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]

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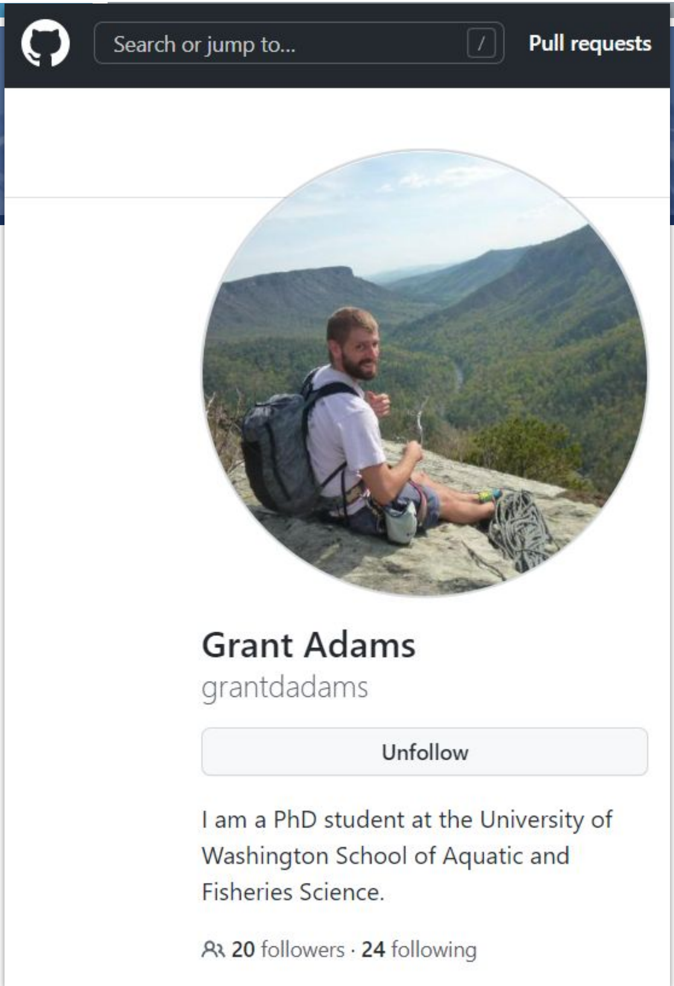
ARTICLE INFO

Handled by: Mark Nicholas Maunder

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

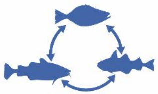
ABSTRACT

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



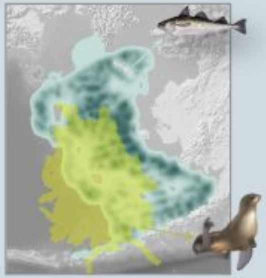
CEATTLE Applications

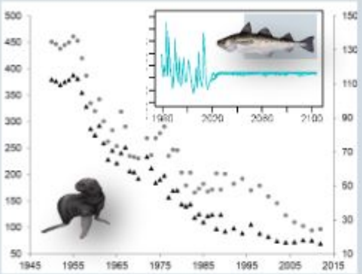
- Operational advice:
  - Appendix to BSAI pollock assessment (2016 to now)
  - M2 index for EBS ecosystem status report (2016 to now)
  - M2 index for ESP (2020 to now)
- Research:
  - 2010-2015 BSIERP MSE
  - 2016- now ACLIM - climate MSE
  - 2019- 2023 Lenfest NFS
  - Lenfest ocean wealth
- Bering 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*. In press https://doi.org/10.21203/rs.3.pex-1084/v1 (2020).

An integrative bioenergetics and spatial approach for quantifying relationships between northern fur seals, their prey, fisheries and climate





a collaboration between the COOPERATIVE INSTITUTE FOR CLIMATE, OCEAN AND ECOSYSTEM STUDIES AT THE UNIVERSITY OF WASHINGTON and the RESOURCE ECOLOGY AND FISHERIES MANAGEMENT AND MARINE MAMMAL LABORATORY AT THE ALASKA FISHERIES SCIENCE CENTER with support from THE LENFEST OCEAN PROGRAM

CICOES NOAA FISHERIES LENFEST OCEAN PROGRAM

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Jeremy Sterling
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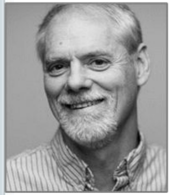
Fur seal ecology

Kerim Aydin
REFM/AFSC
Resource ecology and ecosystem modeling
FEAST



Nick Bond
UW/JISAO
Variability in climate and atmospheric forcing

Kirstin Holsman
REFM/AFSC
Climate specific multispecies stock assessments
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ACLIM

Elizabeth McHuron
UW/JISAO
Marine mammal bioenergetics and population dynamics modeling

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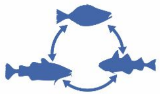

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CEATTLE workflow features

- R and shell scripts used to run the model through projections:
  - Regular output includes ESR contribution (R markdown)
  - ESP indices (produced annually but not yet used)?
  - Assessment written in Rmarkdown using Rdata outputs

- Github repositories (* private)
  - *CEATTLE (ADMB):
    https://github.com/kholsman/CEATTLE
  - Rceattle (G. Adams; R/TMB):
    https://github.com/grantdadams/Rceattle

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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

Discussion : Climate informed BRPs

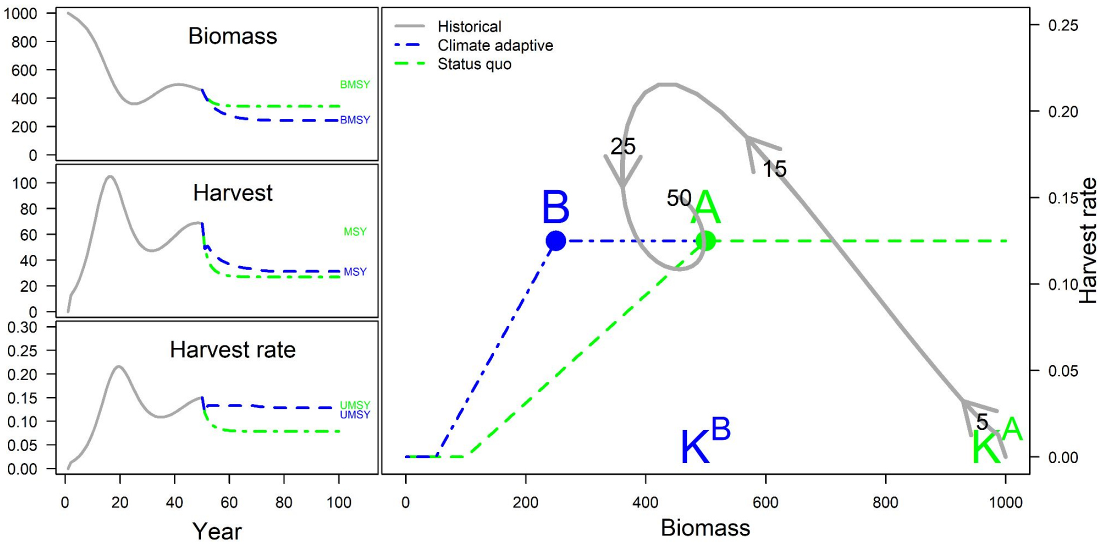
Set B0 and B40 target using climate informed models

NO!

Adapting reference points to reflect changes in productivity

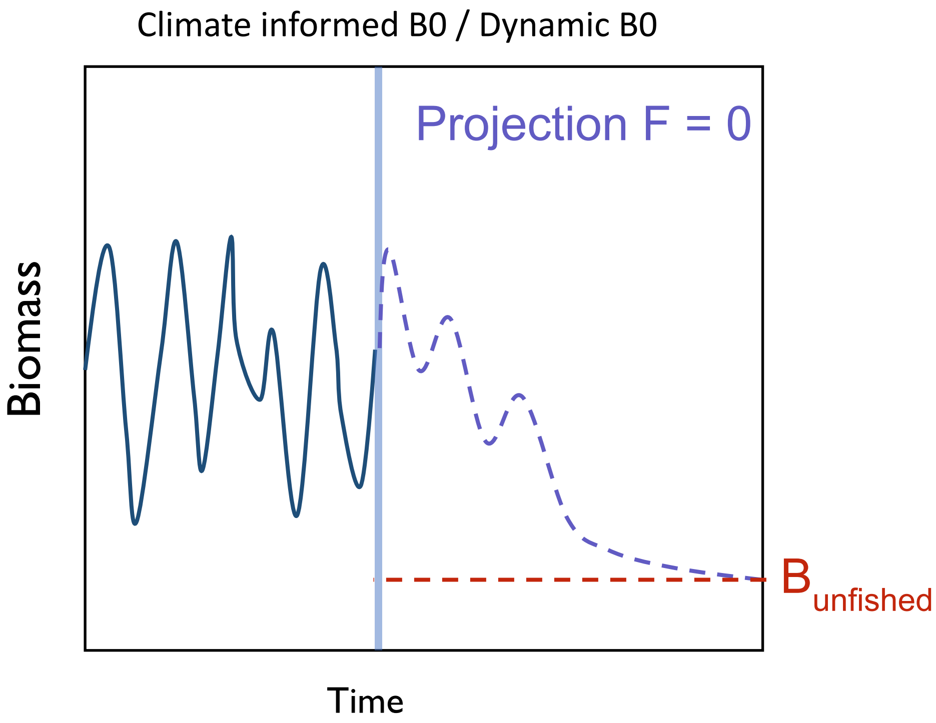
- MSA directs reference points to reflect current and probable future environmental conditions

- 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

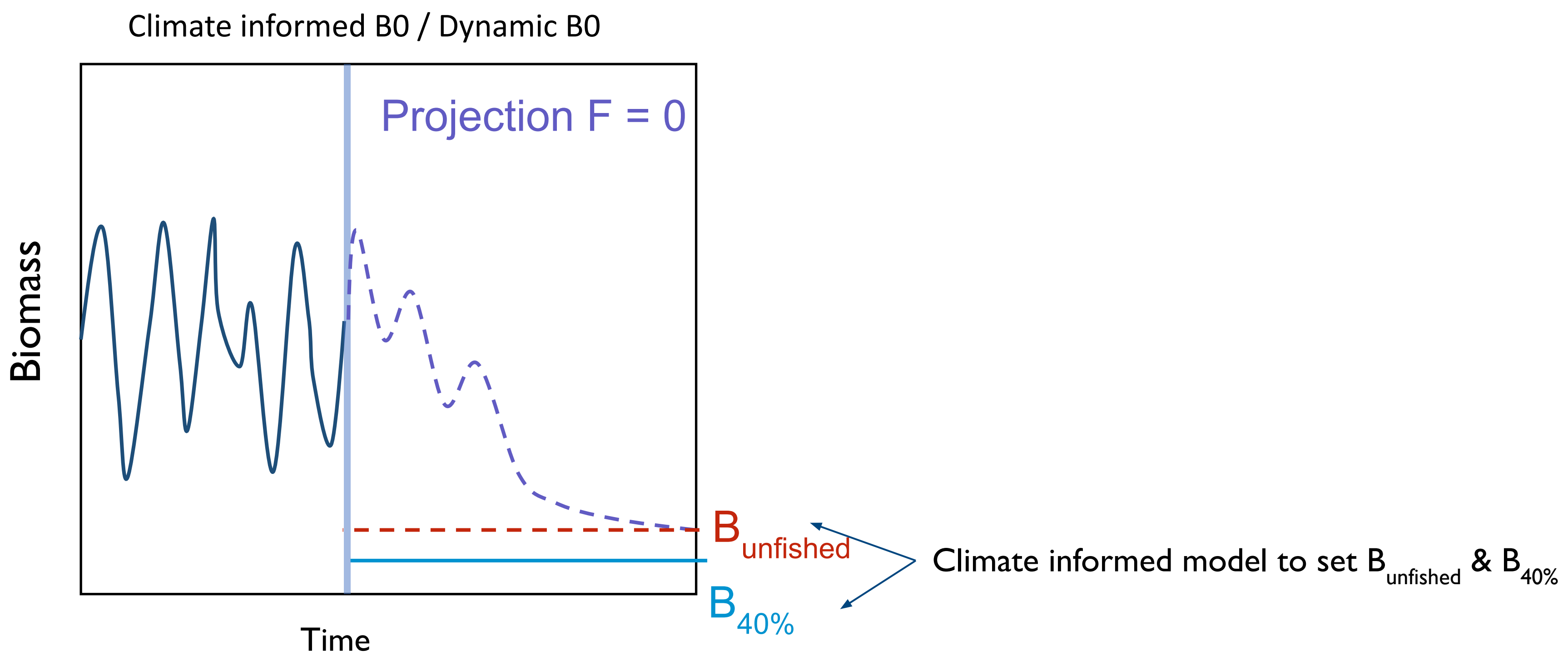


Szuwalski et al. 2023

First: Set Target / reference points

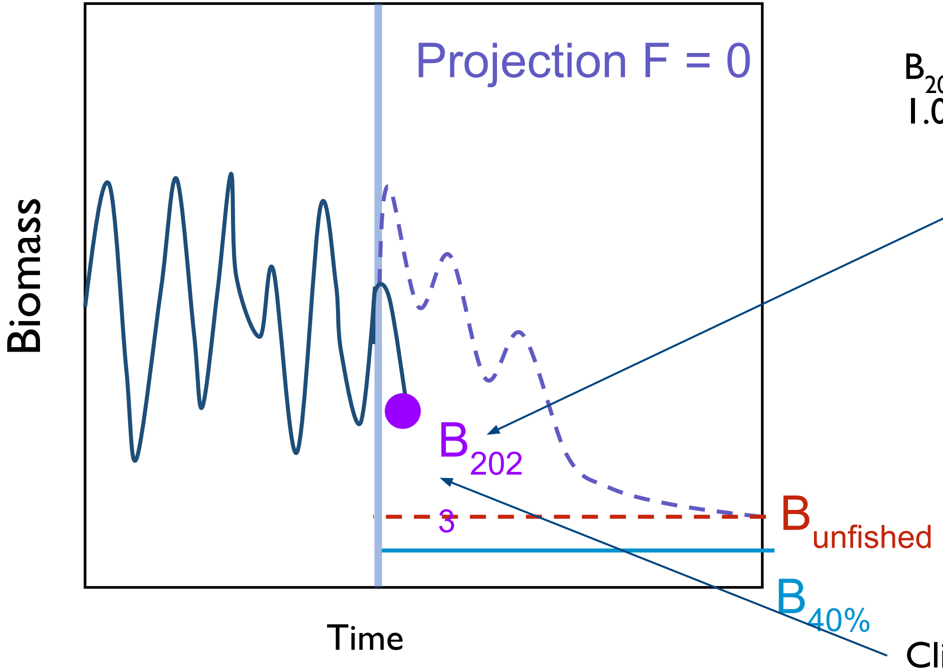


First: Set Target / reference points



First: Set Target / reference points

Climate informed B0 / Dynamic B0

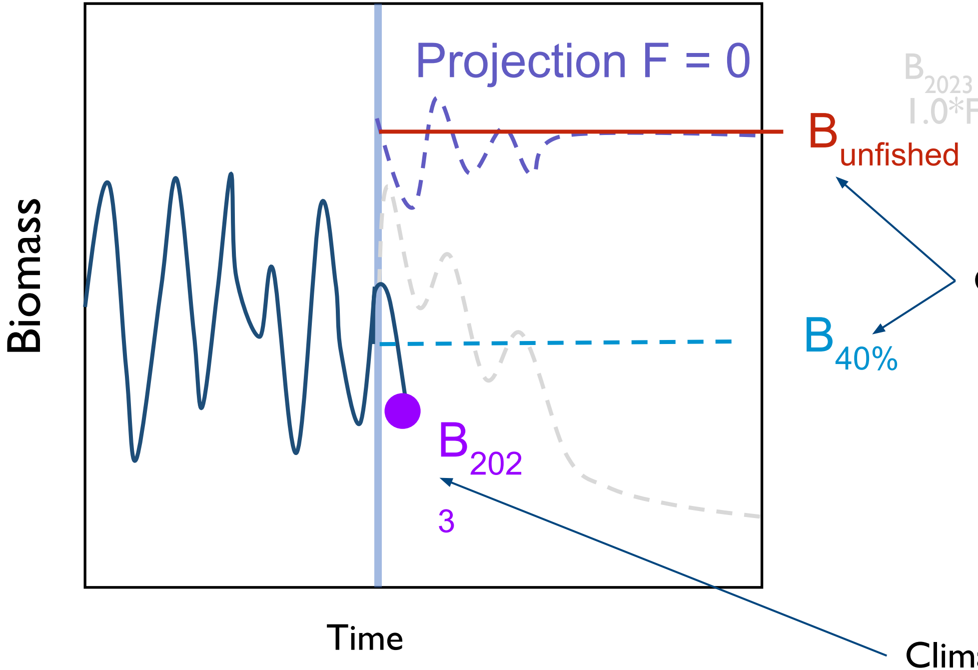


$B_{2023} >> B_{40\%}$ so set $F_{ABC} = 1.0*F_{ACL}$

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

"hybrid" climate- naive & climate informed approach

Climate naive B0 + climate informed By



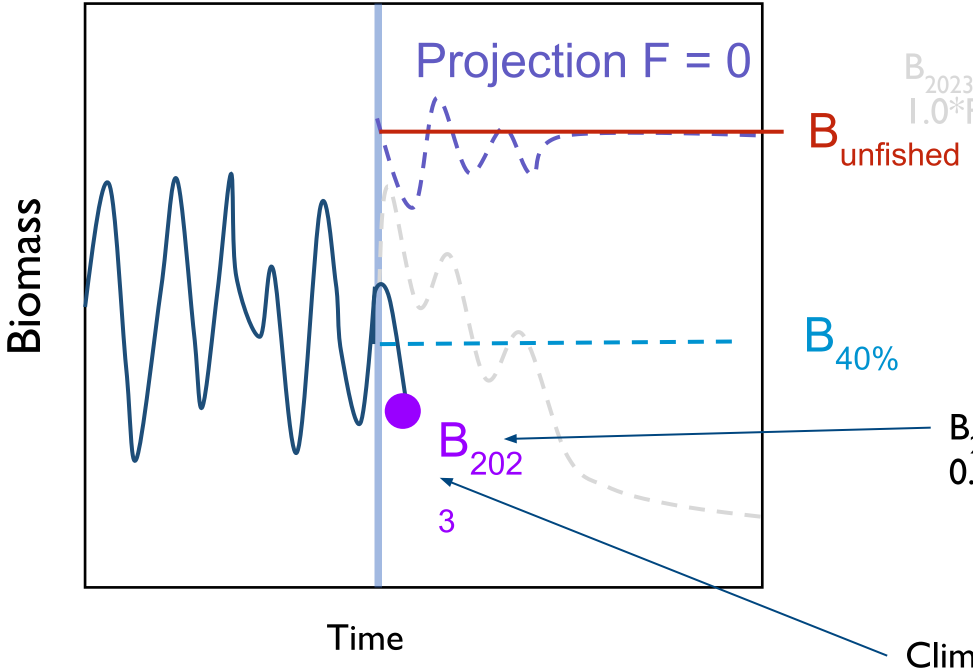
$B_{2023} >> B_{40\%}$ so set $F_{ABC} = 1.0*F_{ACL}$

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

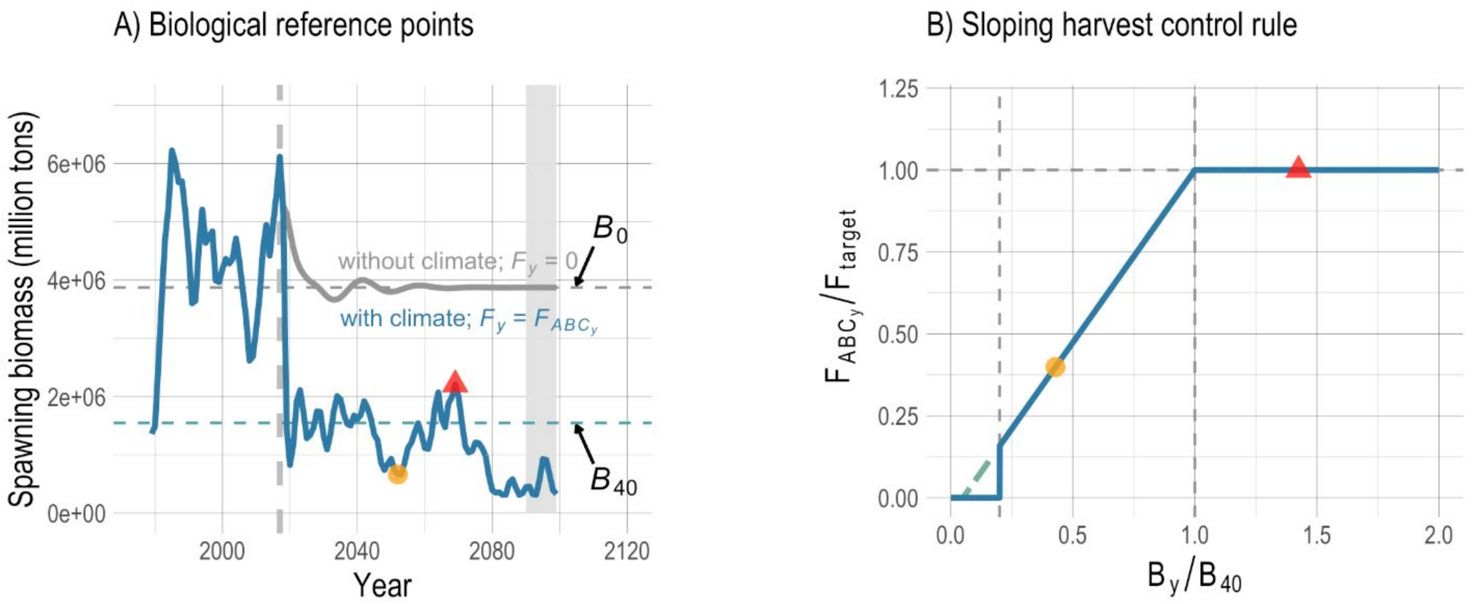


B_{2023} >> $B_{40\%}$ so set F_{ABC} = 1.0*F_{ACL}

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})

Climate informed biological reference points



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

Discussion : Climate informed BRPs

Set target at climate naive (B0* from historical or B0 from no-climate projection)

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

2a: Set ABC_2023 = avg(ABC2080), calc F2023 and use that to get ABC_2024 (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 (ABC2023 = avg(ABC from all models)

Multispp Assessment

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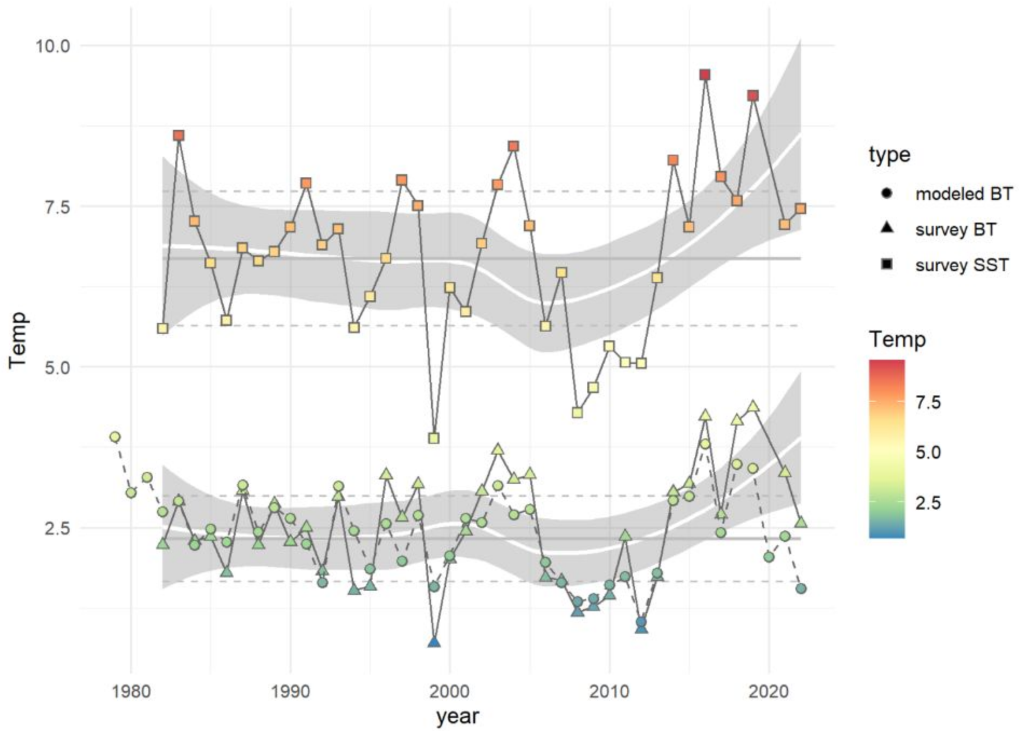
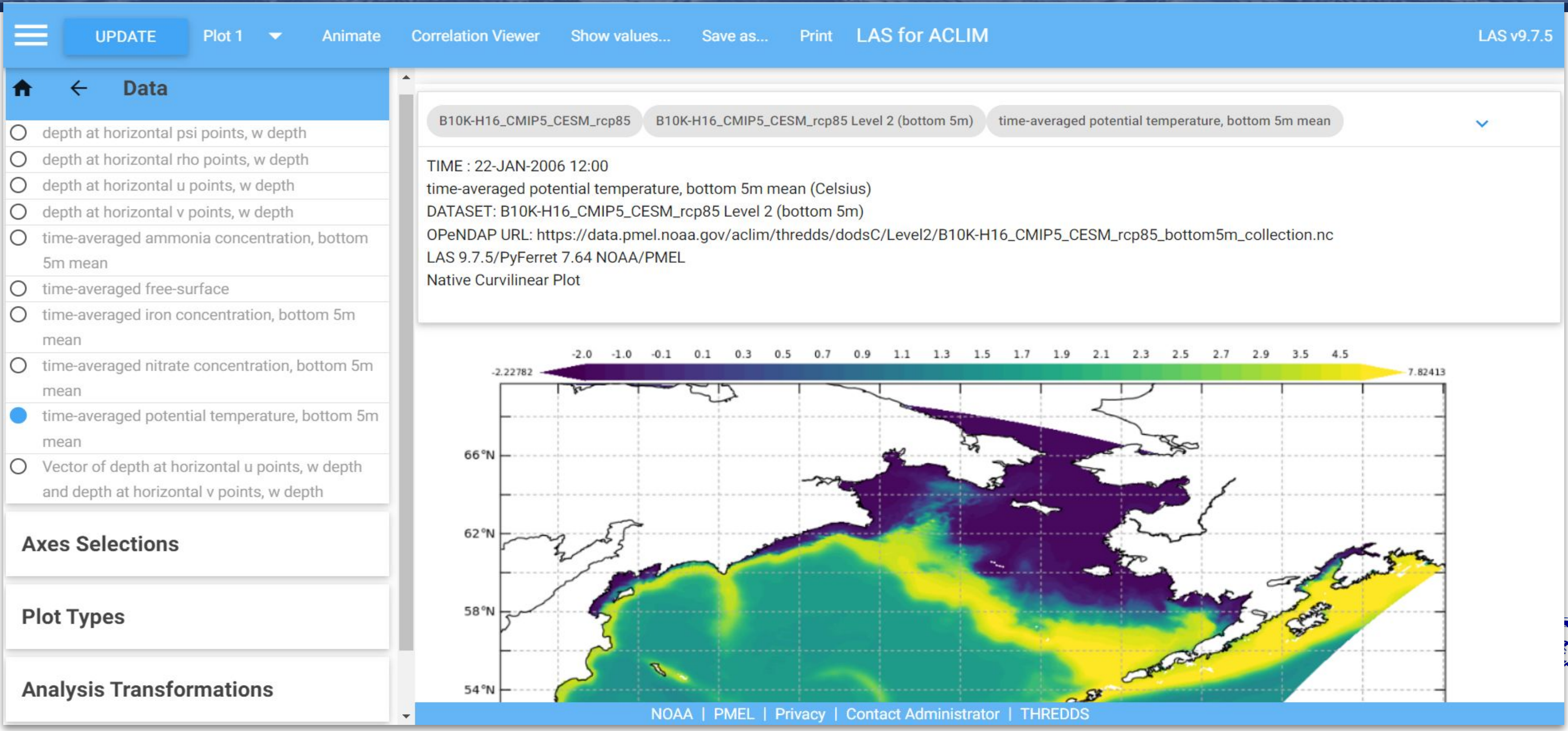
7600 Sand Point Way N.E., Seattle, Washington 98115

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

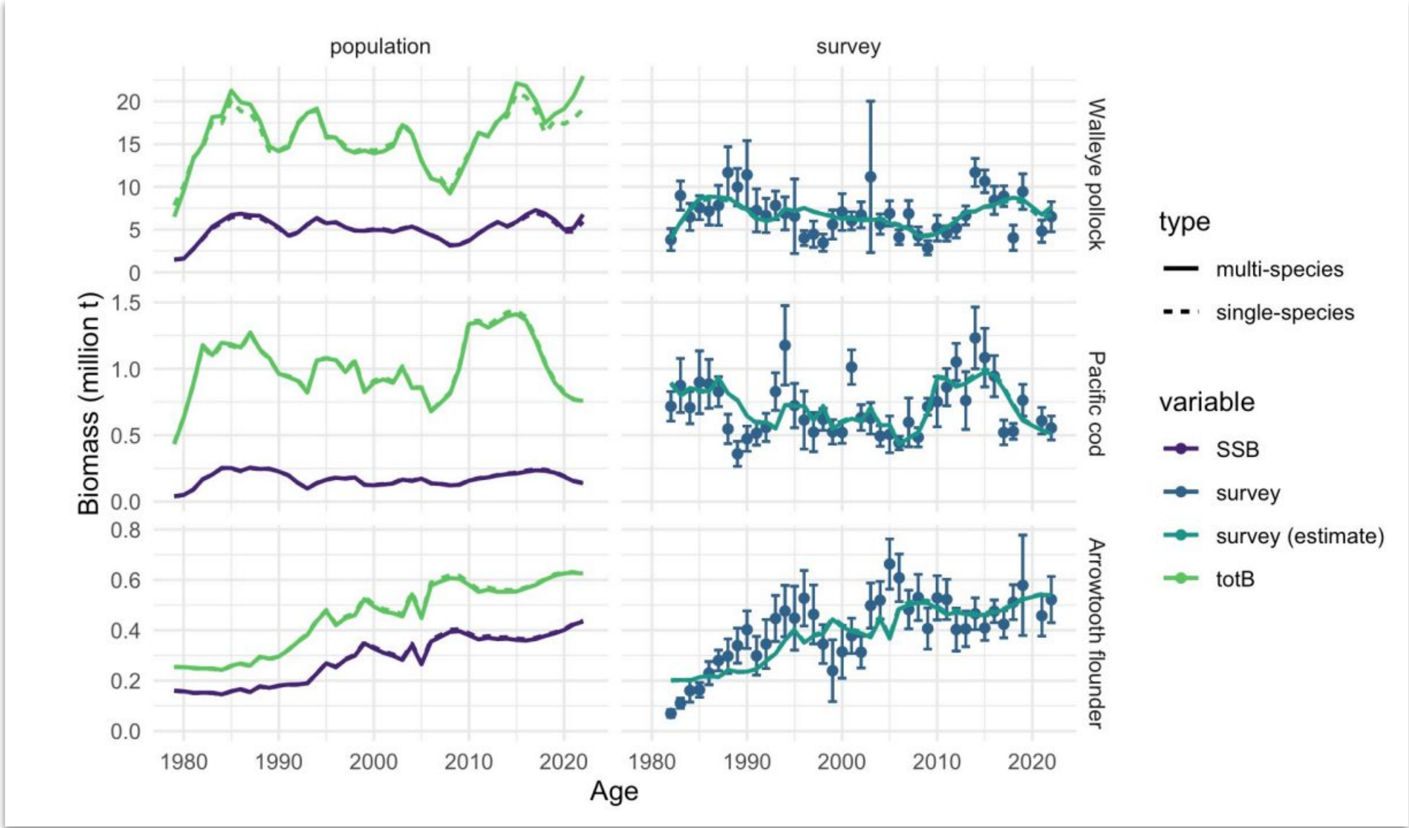


ROMS output

https://data.pmel.noaa.gov/aclim/las/UI.html

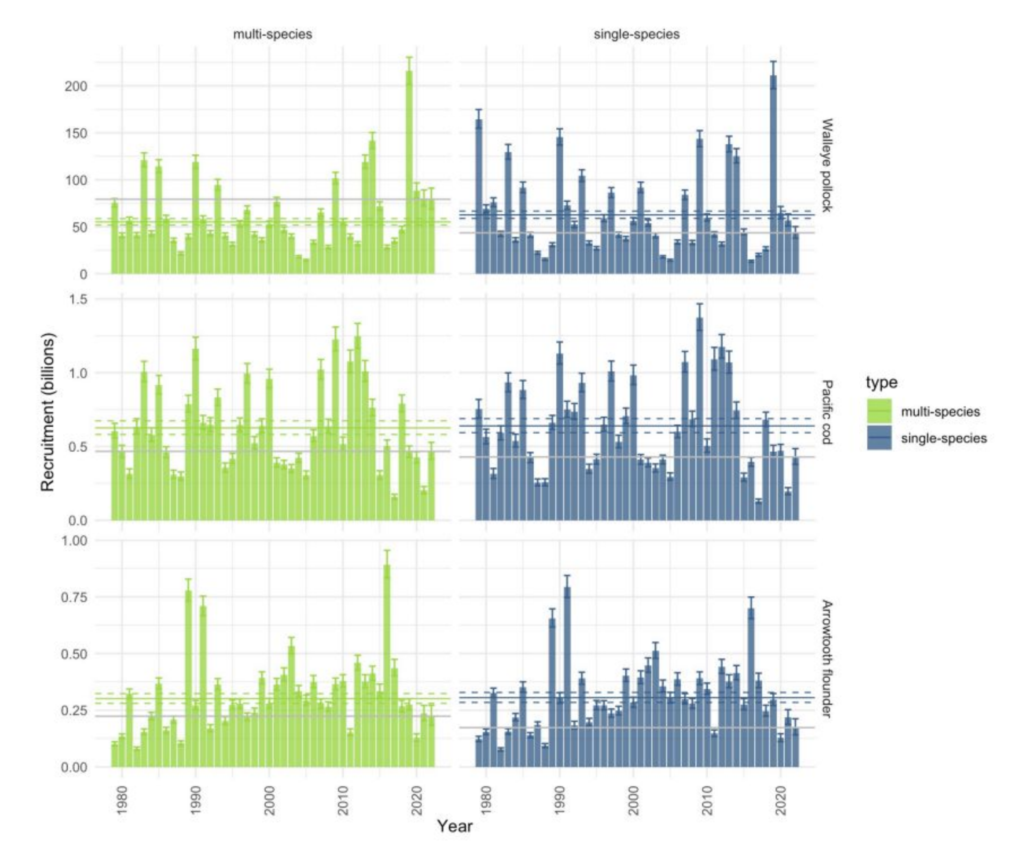


Biomass



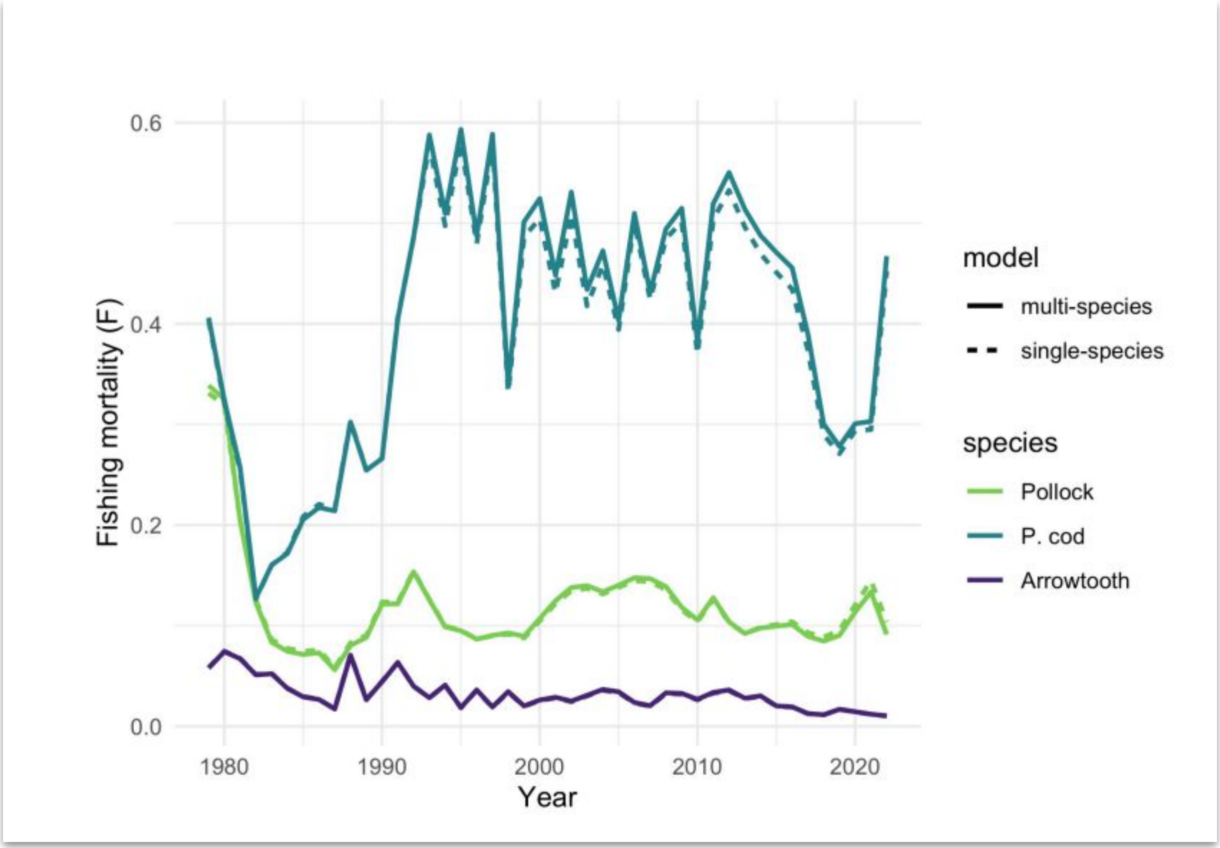
population
survey
Walleye pollock
Pacific cod
Arrowtooth flounder
Biomass (million t)
20
15
10
5
0
1.5
1.0
0.5
0.0
0.8
0.6
0.4
0.2
0.0
1980
1990
2000
2010
2020
Age
type
multi-species
single-species
variable
SSB
survey
survey (estimate)
totB

Biomass



multi-species
single-species
Walleye pollock
Pacific cod
Arrowtooth flounder
Recruitment (billions)
Year
type
multi-species
single-species
200
150
100
50
0
1.5
1.0
0.5
0.0
1.00
0.75
0.50
0.25
0.00
1980
1990
2000
2010
2020

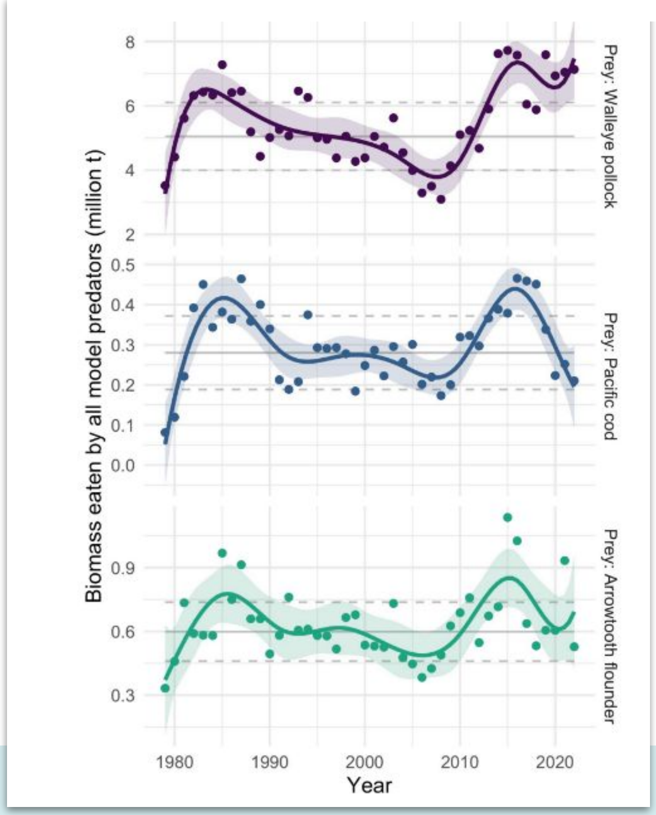
Biomass



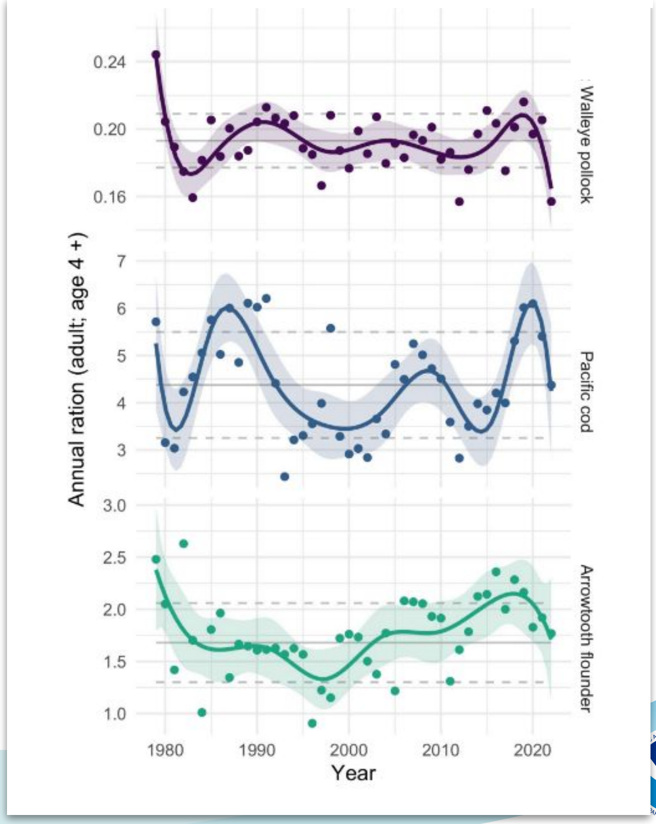
Fishing mortality (F)
0.6
0.4
0.2
0.0
1980
1990
2000
2010
2020
Year
model
multi-species
single-species
species
Pollock
P. cod
Arrowtooth

ESP indices

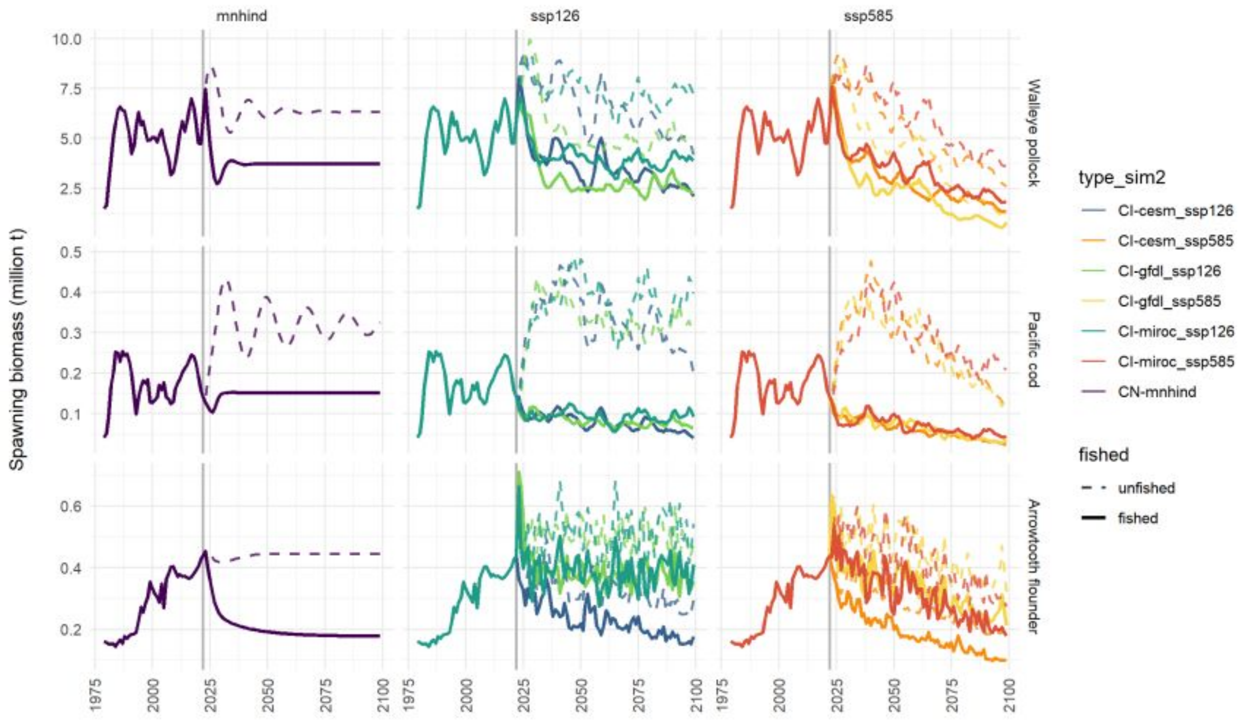
Use this if: need index of mortality for plk, pcod, or atf



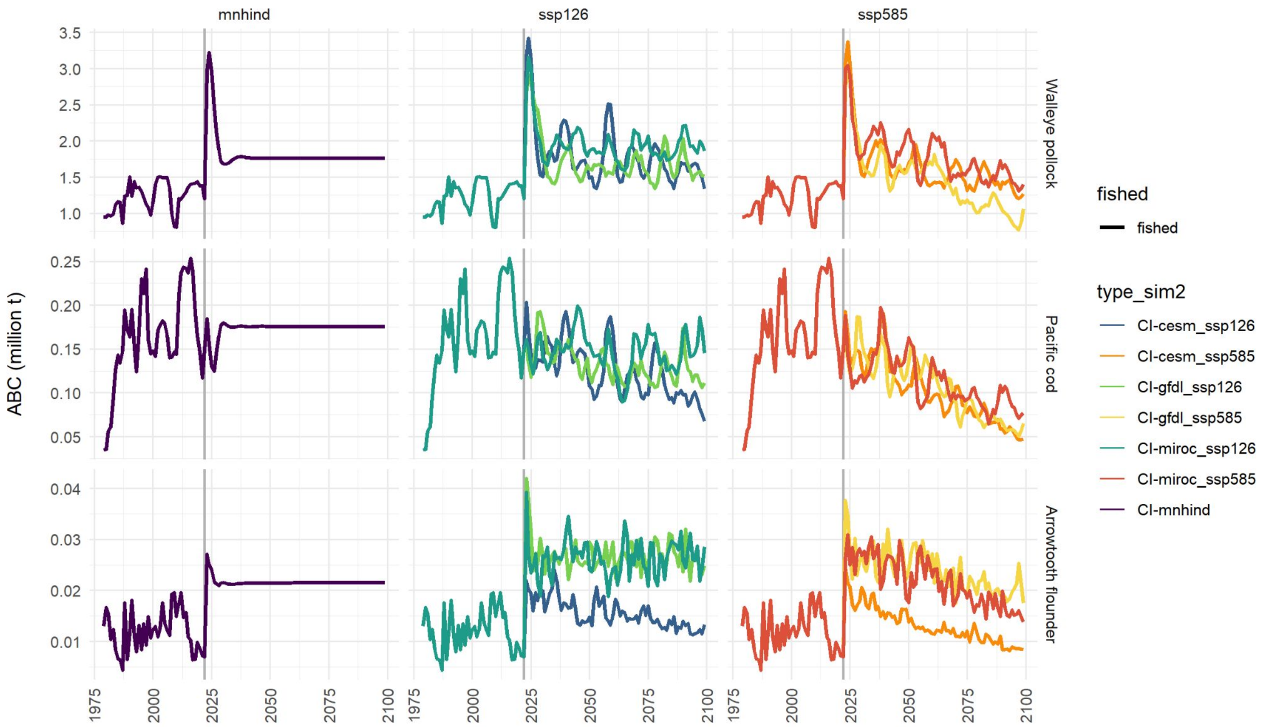
Use this if: need index of plk, pcod, atf eating other prey (eg snow crab)



Biomass (climate projections)



Catch (climate projections)



Climate informed BRPs and ABC evaluations

Improve with ROMS forecasts

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

- Relative to 2022 levels, the model projects SSB of pollock will increase in 2023 (pr… 2022 catch) followed by an increase in SSB in 2024 (projected with F_{ABC}). For Pacific cod … projects a decline in SSB in both 2023 and 2024.
- Ensemble projections using climate-enhanced recruitment models and projected future warming scenarios (including high carbon mitigation (ssp126), low carbon mitigation (ssp585), as well as persistence scenarios and assuming 2022 catch for 2023 and F_{ABC} for 2024) estimate a 95% chance that pollock SSB will remain between 125-138% of 2022 SSB in 2023 and will be between 123-134% of 2022 SSB levels in 2024.
- 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 86-99% of 2022 SSB in 2023 and between 73-83% of 2022 SSB levels in 2024.
- Ensemble projections using climate-enhanced recruitment models based on long-term projections estimate a 95% chance that arrowtooth SSB will be between 92 and 130% of 2022 SSB in 2023 and will be between 87 and 117% of 2022 SSB levels in 2024.

Multispecies assessment

2022 Climate-enhanced multi-species Stock Assessment for walleye pollock, Pacific cod, and arrowtooth flounder in the South Eastern Bering Sea

Kirstin K. Holsman, Jim Ianelli, Kerim Aydin, Grant Adams, Kelly Kearney, Kalei Shotwell, Grant Thompson, and Ingrid Spies

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Summary of assessment results for 2022:

Biomass

- At 6.8 million tons, the 2022 SEBS pollock spawning biomass from the multispecies model is above the long-term (1979-2015) average of 4.9 million tons and represents a 31% change from 2021 and 35% change from 2020 spawning biomass levels. Similarly, the downward trend in total biomass observed in the past few years has continued through 2022, with recent declines placing the total 2022 biomass (23 million t) above the 1979-2015 average of 15.4 million tons. However it is important to note that because there was no Alaska Fisheries Science Center summer bottom trawl survey in 2020, estimates of, and differences relative to the 2020 biomass should be interpreted cautiously.
- The 2022 SEBS Pacific cod female spawning biomass has declined -10% since 2021 and -26% since 2020. 2022 estimates are approximately -17% below the 1979-2015 average. Total biomass in the SEBS has declined -45% since 2016, and at approximately 758 thousand tons, is 26% below the long-term 1979-2015 average of 1 million tons. These patterns are driven in part by continued low survey indices in 2021 and warm bottom temperatures that have induced northward redistribution of the P. cod stock (Spies et al. 2020, Stevenson et al. 2019). This assessment does not include Northern Bering Sea survey data collected in 2017, 2018, and 2019.
- Arrowtooth total and spawning biomass estimates are 48% and 65% greater than the long-term 1979-2015 average (respectively), and trends suggest relatively stable biomass since 2012.
- The multispecies model estimates of a 31% and -10% change in spawning biomass (SSB) between 2021 and 2022 for pollock and Pacific cod (respectively) agree with CEATTLE single species model patterns of decline (25% and -10%, respectively). Both models predict an increase (slightly) in spawning biomass for arrowtooth flounder relative to 2021.

Recruitment

- While pollock age 1 recruitment estimates for this year are 35% above the 1979-2015 average, estimated recruitment has decreased (slightly) in 2022 relative to 2021(note that the most recent estimates have the highest uncertainty).

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

- Relative to 2022 levels, the model projects SSB of pollock will increase in 2023 (projected based on 2022 catch) followed by an increase in SSB in 2024 (projected with F_{ABC}). For Pacific cod the model projects a decline in SSB in both 2023 and 2024.
- Ensemble projections using climate-enhanced recruitment models and projected future warming scenarios (including high carbon mitigation (ssp126), low carbon mitigation (ssp585), as well as persistence scenarios and assuming 2022 catch for 2023 and F_{ABC} for 2024) estimate a 95% chance that pollock ... of 2022 SSB ... ojections esti- ... f 2022 SSB in ... ojections esti-mate a 95% chance that arrowtooth SSB will be between 92 and 130% of 2022 SSB in 2023 and will be between 87 and 117% of 2022 SSB levels in 2024.

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

Probability of long-term (2032, 2050, 2080) biomass decline or increase under high mitigation (low warming) scenarios:

Note that projections assume no adaptation by the species, fishery, or fishery management.

- Ensemble projections using climate-enhanced recruitment models and projected future warming sce- ... will be between ... 71-75% of 2022 ... rojections esti- ... etween 69-74%
- Ensemble projections using climate-enhanced recruitment models based on long-term projections estimate a 95% chance that arrowtooth SSB will be between 76-100% of 2022 SSB in 2032, between 81-92% of 2022 SSB levels in 2050, and between 76-90% of 2022 SSB levels in 2080.

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

Probability of long-term (2032, 2050, 2080) biomass decline or increase under low carbon mitigation scenarios (high warming):

Note that projections assume no adaptation by the species, fishery, or fishery management.

- ... e warming sce- ... will be between ... between 48 and
- ... rojections esti-mate a 95% chance that Pacific cod SSB will be between 55 and 90% of 2022 SSB in 2032, between 61 and 75% of 2022 SSB levels in 2050, and between 36 and 48% of 2022 SSB levels in 2080.

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

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

Climate informed BRPs and ABC evaluations

Improve with graphics

Probability of long-term (2032, 2050, 2080) biomass decline or increase under high mitigation (low warming) scenarios:

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 2024 - 2100) estimate a 95% chance that pollock SSB will be between 69-76% of 2022 SSB in 2032, between 73-78% of 2022 SSB levels in 2050, and between 71-75% of 2022 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 69-78% of 2022 SSB in 2032, between 69-74% of 2022 SSB levels in 2050, and between 58-64% of 2022 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 76-100% of 2022 SSB in 2032, between 81-92% of 2022 SSB levels in 2050, and between 76-90% of 2022 SSB levels in 2080.

Probability of long-term (2032, 2050, 2080) biomass decline or increase under low carbon mitigation scenarios (high warming):

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 2024 - 2100) estimate a 95% chance that pollock SSB will be between 62 and 73% of 2022 SSB in 2032, between 65 and 69% of 2022 SSB levels in 2050, and between 48 and 53% of 2022 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 55 and 90% of 2022 SSB in 2032, between 61 and 75% of 2022 SSB levels in 2050, and between 36 and 48% of 2022 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 67 and 91% of 2022 SSB in 2032, between 63 and 72% of 2022 SSB levels in 2050, and between 42 and 50% of 2022 SSB levels in 2080.

Climate informed BRPs and ABC evaluations

Improve with graphics

Probability of long-term (2032, 2050, 2080) biomass decline or increase under high mitigation (low warming) scenarios:

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 2024 - 2100) estimate a 95% chance that pollock SSB will be between 69-76% of 2022 SSB in 2032, between 73-78% of 2022 SSB levels in 2050, and between 71-75% of 2022 S
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Probability of long-term (2032, 2050, 2080) biomass decline or increase under high mitigation (low warming) scenarios:

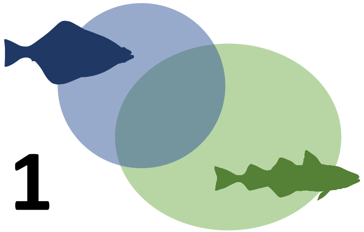
Note that projections assume no adaptation by the species, fishery, or fishery management.

- Ensemble projections using climate-enhanced recruitment models and projected future warming scenarios and assuming F_{ABC} for 2024 - 2100) estimate a 95% chance that pollock SSB will be between 69-76% of 2022 SSB in 2032, between 73-78% of 2022 SSB levels in 2050, and between 71-75% of 2022 SSB levels in 2080.

Climate impacts on spatial predator-prey interactions in the Eastern Bering Sea

ACLIM Spatial Subgroup
October 4th, 2022

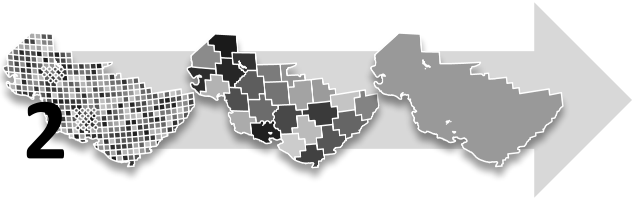
https://mgoodman.shinyapps.io/aclim2_sdms_explorer/



1

Shifting fish distributions drive changes in predation intensity in the Eastern Bering Sea

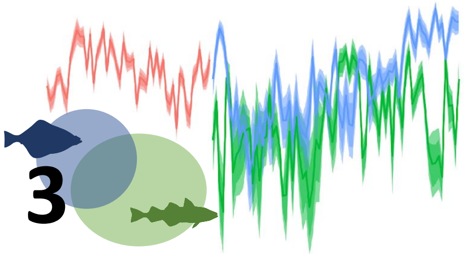
Gemma Carroll, Steph Brodie, Arnaud Gruss, Jim Thorson, Stan Kotwicki, Kirstin Holsman, Becca Selden, Elliott Hazen



2

Climate effects on groundfish trophic interactions: scaling from individuals to shelf communities

Jim Thorson



3

Projecting changes in predator-prey overlap and implications for management

Kirstin Holsman, Andre Punt, Cheryl Barnes, John Reum, Maxime Olmos

Slide: Maurice Goodman

Discussion : Climate informed BRPs

1. Methods to explore for setting climate-informed ABCs
2. Feedback on how long-term outlooks are communicated
3. Transition to TMB via merging CEATTLE and Rceattle
4. NSF conditioned ABC (2024)
5. Include ACLIM MSE results and CI features
6. Share output via AKFIN
7. Push to align more closely with other stocks?