Bering Sea climate-enhanced multi-species stock assessment



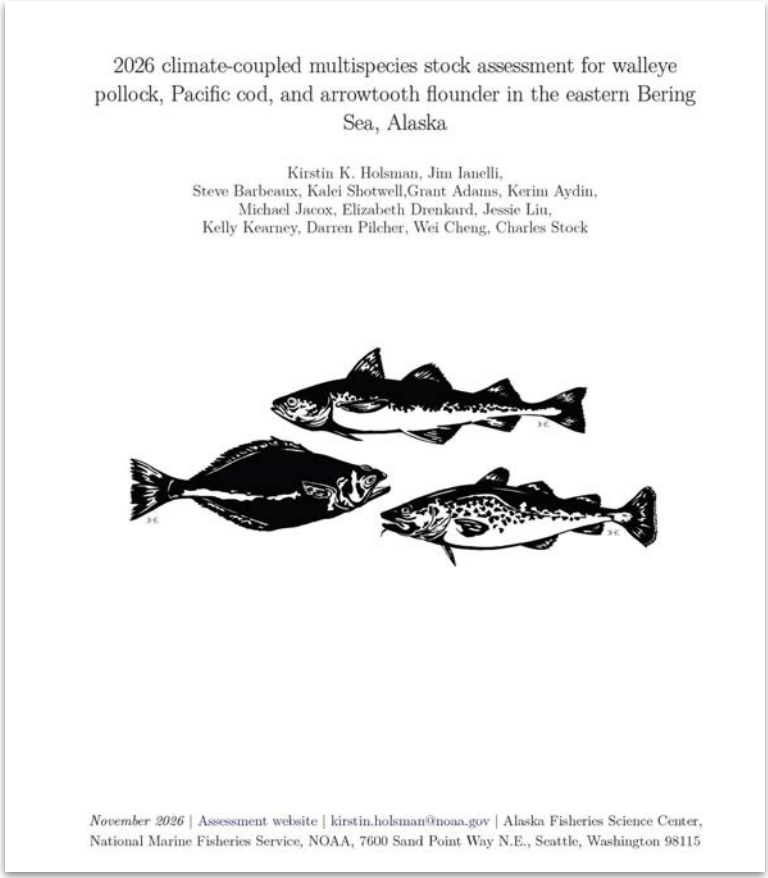
Nov. 2026

Kirstin K. Holsman
Jim Ianelli, Steve Barbeaux, Kalei Shotwell, Grant Adams, Kerim Aydin, Michael Jacox, Elizabeth Drenkard, Jessie Liu, Kelly Kearney, Darren Pilcher, Wei Cheng, Charles Stock

Assessment website: https://kholsman.github.io/EBS-multispecies-assessment/

NOAA FISHERIES

Climate-coupled multispecies stock assessment model

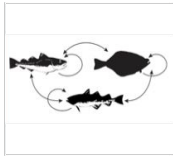
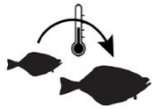
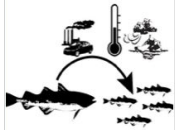


2026 climate-coupled multispecies stock assessment for walleye pollock, Pacific cod, and arrowtooth flounder in the eastern Bering Sea, Alaska

Kirstin K. Holsman, Jim Ianelli,
Steve Barbeaux, Kalei Shotwell,Grant Adams, Kerim Aydin,
Michael Jacox, Elizabeth Drenkard, Jessie Liu,
Kelly Kearney, Darren Pilcher, Wei Cheng, Charles Stock

November 2026 | Assessment website | kirstin.holsman@noaa.gov | Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Seattle, Washington 98115

Produced annually 2016 - present

Mortality	Weight @ Age	Rec	HCRs
			
• Empirical diets • Bioenergetics	• Empirical • VonB with Temp	• Climate-S/R • S/R • mean R	• Climate ABC • MMSY • MEY • SPR • Aggregate MSY

Two models presented each year:

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

Plan Team and SSC comments

(2024 Nov Plan Team) The Team recommended that the authors include a comparison of the single-species mode in CEATTLE to the operational single-species stock assessment models to evaluate differences between model results.

This year a new appendix called "Bridging and comparisons to other assessments" is included that provides comparison to this year's status quo assessment for Pacific cod as a pilot for what this might include in the future. That section provides side-by-side comparisons for biomass, spawning biomass and harvest rate (F). Direct comparisons are for illustrative purposes only and to assess relative agreement between model trends, different mortality rates, base data and model specification decisions will lead to inherent differences in model output. For harvest specifications the status quo stock assessments should be used. As such we added the following text to this year's multispecies assessment:

> *"This multispecies assessment is intended to complement those chapters by providing advice regarding the sensitivity of harvest recommendations to alternative formulations of inclusion (or omission of) climate and trophic interactions. Often the interactions explicitly quantified in this assessment are implicitly or inherently accounted for in the current status quo assessments through estimated parameters such as natural mortality, growth, selectivity, and annual recruitment. This assessment helps provide context for such estimated parameters as well as implications of projections that explicitly account for future conditions and trophic interactions. Results from this assessment are therefore presented from models estimated and projected without trophic interactions (single-species mode, `SSM`) and with trophic interactions (multispecies mode, `MSM`), as well as with ("climate informed") or without ("climate naive") climate effects on growth, recruitment, and predation (natural mortality)."*

Plan Team and SSC comments

(2024 Nov Plan Team) The Team recommended the authors communicate with the ESP teams to explore the duplicative methods.

Significant developments in the ESP and multispecies assessment approaches render complementary but divergent and non-duplicative approaches. The ESP leads have been pursuing covariate development using the Dynamic Structural Equation Modeling (DSEM) package, which shows exceptional promise for development of integrative covariates for use in ESPs. To date most of these evaluations have focused on observational data. The CNRG model similarly explores the relationship between environmental covariates and mortality, recruitment, and growth but uses output of oceanographic models that can be projected in time and space for future scenario simulations. These efforts are complementary; agreement between the ESP indices and multispecies assessment indices could indicate greater support for inclusion of model covariates in projections. Similarly, indices identified through the assessment might provide a basis for model based oceanographic (e.g., MOM6) index inclusion in future ESP efforts. Coordination regarding the complementary efforts is underway via the monthly Alaska Changing Ecosystem and Fisheries Initiative (AK CEFI) decision support team meetings and through the larger National Ecosystem Assessment Program (NEAP) coordination (CEFI is an effort under NEAP).

Plan Team and SSC comments

(2024 Dec SSC) The SSC encourages authors of the pollock, Pacific cod and arrowtooth assessments to explore the use of outputs from the multispecies model.

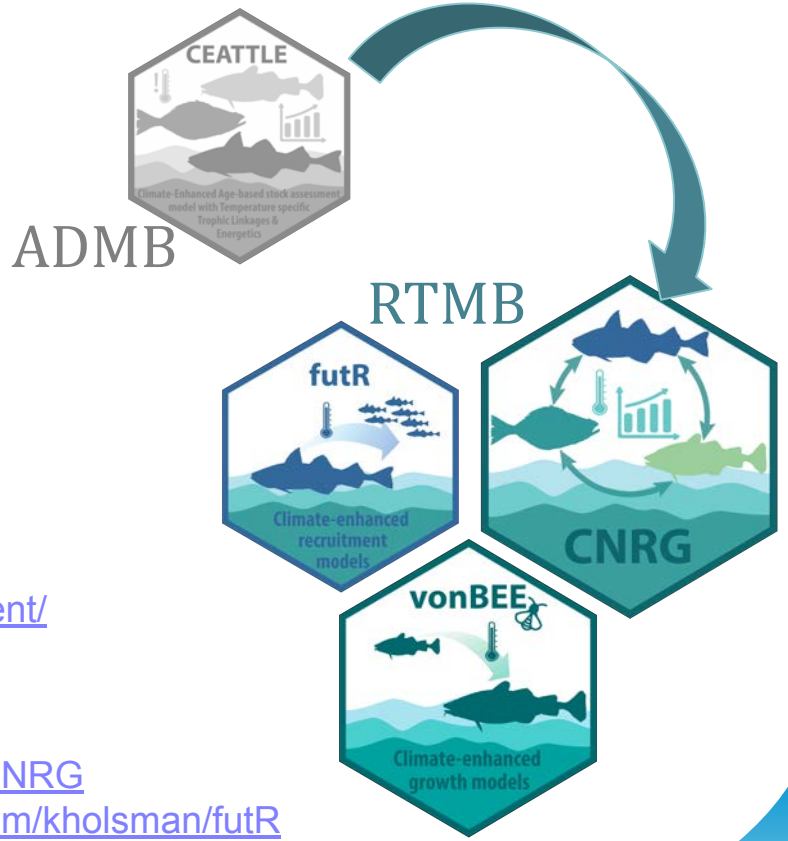
Coordination and evaluation of multispecies output in status quo models has been underway for more than a decade for pollock. Multispecies outputs are also included in ESPs for these stocks. Finally a full assessment is planned for arrowtooth flounder for next year and the authors will be considering ways to include model output from CNRG into that assessment as well. That assessment uses Rceattle as a base, a complementary modeling framework that can readily incorporate CNRG outputs as deemed appropriate. The authors of the status quo assessments are co-authors on the multispecies model. As such we will continue to explore options regarding uptake of model outputs for next year's assessments, options might include MOM6 forecast-linked weight at age, growth, or mortality.

Plan Team and SSC comments

(2024 Dec SSC) The SSC suggests that the focus of annual updates should be on how the multi-species model can help inform the current single-species assessments, such as through the development of indicators that can be incorporated in ESPs or directly in assessments.

We appreciate this comment and have restructured the assessment to provide context for the effects of climate- and trophic interaction on potential future stock productivity. This includes new MOM6-forecast linked trajectories, return to normal time estimates for SSB and yield (following forecasted conditions), and specific index output that can inform external assessments (including base species in this assessment as well as predation impacts on other crab and fish stocks). This information is now summarized in section called "Implications for operational stock assessments". Further, data outputs from the assessment will soon be provided with DOI tags via the Multispecies Assessment website (https://kholsman.github.io/EBS-multispecies-assessment).

CNRG workflow features



R package and vignettes (scripts) run:

- MOM6 Seasonal projections (new this year)
- ROMSNPZ Multi-decadal projections

Regular output includes ESR contribution (R markdown)

- ESP indices (produced annually)
- Assessment written in Rmarkdown using Rdata outputs

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Github repositories

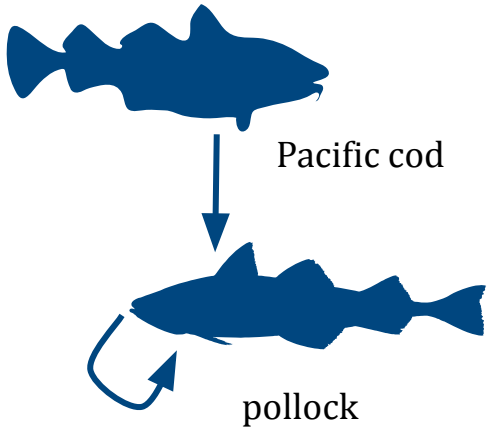
- CNRG R package (RTMB): https://github.com/kholsman/CNRG
- futR() : recruitment fitting model in RTMB: https://github.com/kholsman/futR
- vonBEE(): env. varying vonB model in RTMB: https://github.com/NOAA-REEM/vonBEE

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

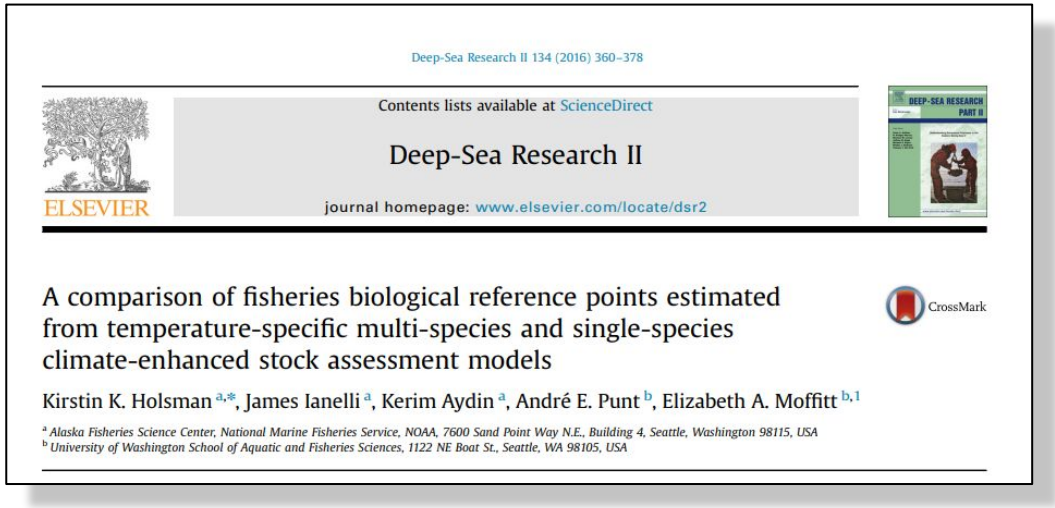
Jesús Jurado-Molina, Patricia A. Livingston, and James N. Ianelli

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

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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]

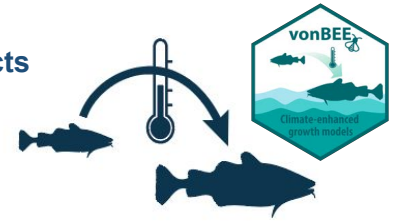
[a] Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Building 4, Seattle, Washington 98115, USA
[b] University of Washington School of Aquatic and Fisheries Sciences, 1122 NE Boat St., Seattle, WA 98105, USA

2010 → 2016
Added arrowtooth, projections, MSE & MSM BRP methods; ACLIM funded

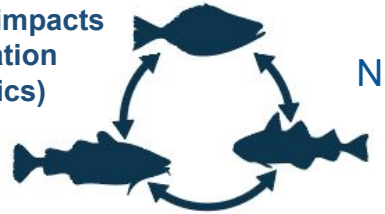
Ianelli et al. 2016
multimodel inference

Holsman et al. 2016

Climate impacts on growth & condition



Climate impacts on predation (energetics)



NRG()

"CEATTLE"

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

NOAA FISHERIES

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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]

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Ianelli et al. 2016
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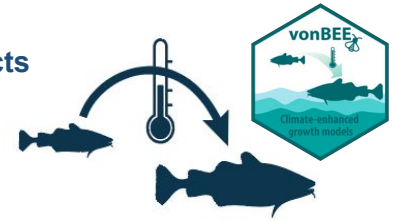
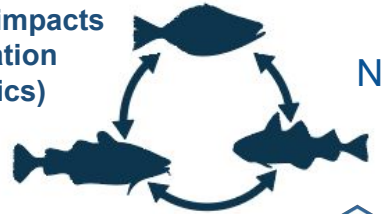
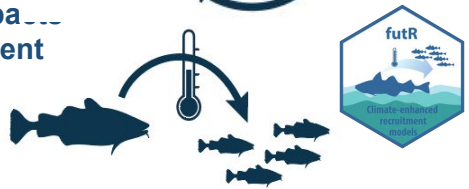


Climate impacts on predation (energetics)

NRG()



Climate impa… on recruitment



Holsman et al. 2020

NOAA FISHERIES

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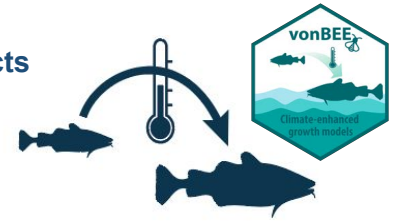


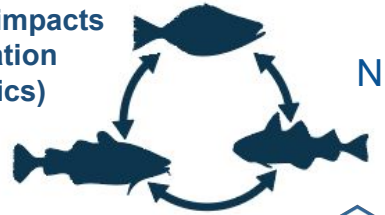


Grant Adams
grantdadams

2017→ FATE GOA CEATTLE project

Port to TMB, add halibut, random effects

Climate impacts on predation (energetics)



NRG()

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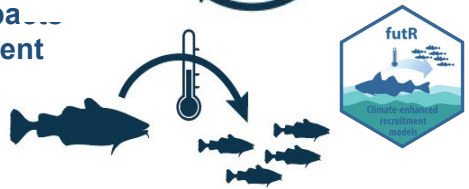

Rceattle

Too much to list!

Holsman et al. 2020



CNRG
RTMB, MOM6

NOAA FISHERIES



https://github.com/grantdadams/Rceattle



Grant Adams
grantdadams

Unfollow

I am a statistician at the NOAA Alaska Fisheries Science Center

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R ☆12 4

antarctic-humpback-2019-assessment/**HumpbackSIR** Public
Use Sample-Importance-Resampling to estimate Bayesian surplus production population dynamics models using the "backward" approach
R ☆1 1

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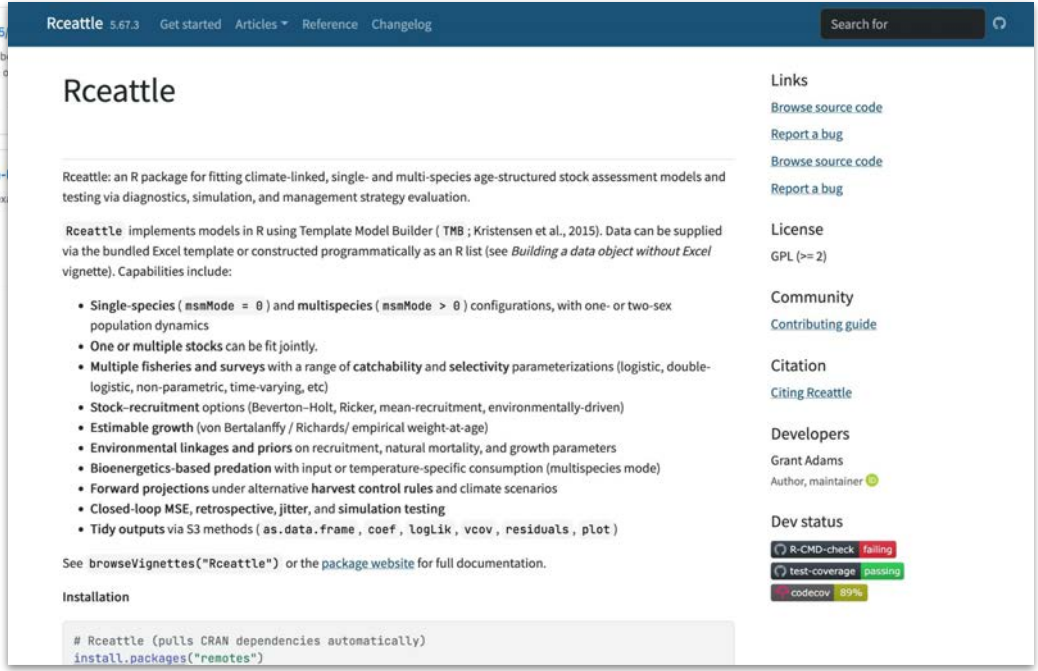
R ☆4

Growth-
Some code ex
R ☆2



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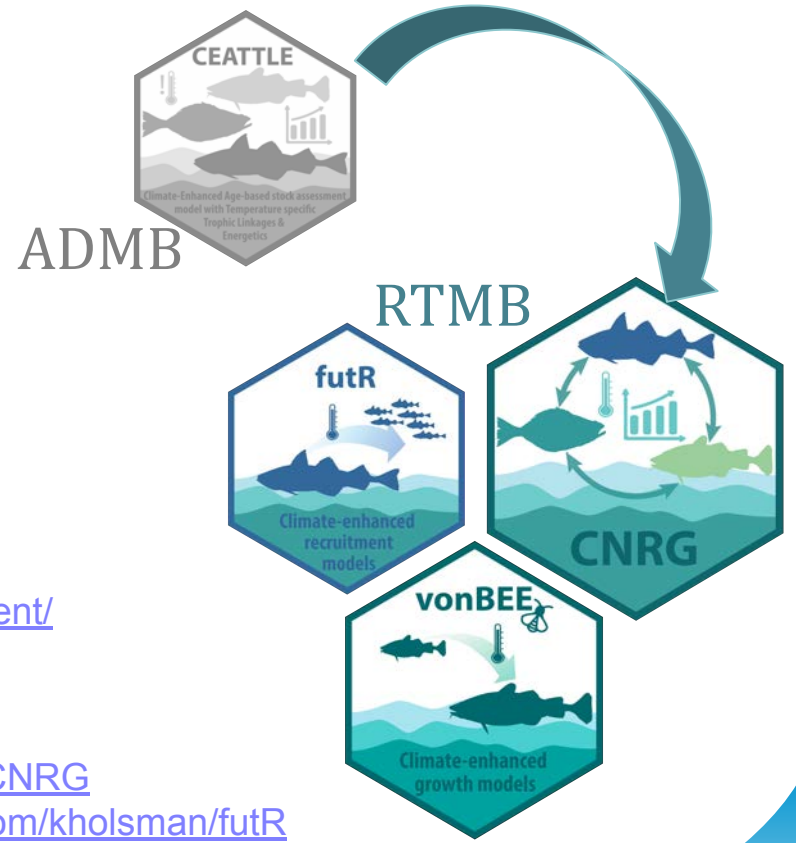
link to bridging figs



Multispecies assessment features

Table 4: Species-specific model configuration and input settings for the 2026 multispecies assessment.

Parameter	Pollock	Pacific cod	Arrowtooth	Units
Fishery composition type	age	length	length	Number
Fishery composition bins	14–61 (3 cm bins)	9–105 (4 cm bins)	10–75 (2.5 cm bins)	
Fishery sample size	200	200	200	Fish
Fishery selectivity	Coefficients	Coefficients	Coefficients	Type
Catch area	EBS	EBS	EBS + AI	Region
Survey composition type	age	length	length	Type
Survey composition bins	14–61 (3 cm bins)	9–105 (4 cm bins)	10–75 (2.5 cm bins)	Number
Survey sample size	100	100	100	Fish
Survey selectivity	Logistic	Logistic	Logistic	Type
Survey area	EBS + NBS	EBS + NBS	EBS + NBS	Region
Number of ages	12	12	21	Number
Foraging days	365	237	365	Days/year
Mean RFR	0.15	0.29	0.27	d^{-1}
Fishery sample-size reweighting	FALSE	FALSE	FALSE	T/F

Multispecies assessment features

- Design-based survey biomass and harvest indices from the NEBS and SEBS are included.
- Predation natural mortality is age specific and annually varying (M2).
- Residual (non-predation) natural mortality (M1) is time-invariant but is age specific
    - Ages 1-4 single-species mode is set to the mean (1979 - 2026) of the multispecies total mortality by age and species (for ages 1-4)
- Pollock fishery numerical composition data is age-based whereas Pacific cod and arrowtooth fishery composition data is based on lengths.
- WAA and ALKs are calculated outside of the model using design based estimates (weighted by survey CPUE at the strata level) from the summer bottom trawl survey and species-specific mean weight at age across years is used to fill in for missing years and for projections.
- Age to length transition keys are based on design based estimates of mean length at age across years for each species from summer bottom trawl surveys.
- Acoustic trawl survey selectivity was set equal to the SAFE report model estimates.
- Fisheries selectivity and survey selectivity are age specific and constant over time.
- Arrowtooth flounder stock is treated as sexes combined (weight at age and proportion mature is calculated separately for males and females and combined using a mortality-based mean).
- Maturity schedules are based on operational assessments

Multispecies assessment features

Multispecies implications

- Predator overlap index is set to 1 for all species (i.e., assumes all prey are available to all predators).
- Prey size preference (suitability) is derived from the model
- Cannibalism and population level annual consumption (ration) is estimated
- Predation mortality emerges from the assessment

Climate BRPs and outlook

- Projections to derive ABC include a sequential method for determining universal climate-naive B0, and include the constraint that SSB>0.35 for all years in the projection.
- A "climate-informed" approach is used to derive biological reference points through projecting the model forward with climate effects
- Evaluation of spawning stock biomass given F_{ABC} is performed using MOM6
- Evaluation of spawning stock biomass given F_{ABC} under ensemble of climate futures is provided at +10, +20 and +50 year slices

Likelihood Components

Table 6: Log-likelihood components of the objective function minimized when fitting the assessment to data sources.

Description	Equation	Data source
GBT survey biomass	$\sum_i \sum_y \frac{(\ln \beta^s_{i,y} - \ln \hat{\beta}^s_{i,y})^2}{2\sigma^2_{\log,s,i}}$	AFSC annual Bering Sea bottom trawl survey (1979–2026), except 1979, 1980, 1981, 2020 for all three species
GBT survey age or length composition	$-\sum_i n_i \sum_y \sum_j (O^s_{i*,y} + v) \ln(\hat{O}^s_{i*,y} + v)$	AFSC annual Bering Sea bottom trawl survey (1979–2026), except 1981, 2020 for pollock and Pacific cod, and 1979, 1980, 1981, 2020 for arrowtooth
AT survey biomass (pollock only)	$\sum_i \sum_y \frac{(\ln \beta^{AT}_{i,y} - \ln \hat{\beta}^{AT}_{i,y})^2}{2\sigma^2_{\log,AT}}, \sigma^2_{\log,AT} = 0.2^2$	Pollock acoustic trawl survey (1979–2026)
AT survey age composition (pollock only)	$-\sum_i n_i \sum_y \sum_j (O^{AT}_{ij,y} + v) \ln(\hat{O}^{AT}_{ij,y} + v), for\ i = 1$	Pollock acoustic trawl survey (1979–2026)
Total catch	$\sum_i \sum_y \frac{[\ln(C_{i,y}) - \ln(\hat{C}_{i,y})]^2}{2\sigma^2_c}, \sigma_c = 0.05$	Fishery observer data (1979–2026)
Fishery age or length composition	$-\sum_i n_i \sum_y \sum_j (O^f_{i*,y} + v) \ln(\hat{O}^f_{i*,y} + v)$	Fishery observer data (1979–2026), except 2024, 2025, 2026 for pollock and 1989, 2015, 2017, 2025, 2026 for arrowtooth
Penalties		
Fishery selectivity	$\sum_i \sum_j^{A_i - 1} x[\ln(\frac{n^f_{ij}}{n^f_{ij+1}}) - ln(\frac{n^f_{ij+1}}{n^f_{ij+2}})]^2,\ x = \begin{cases} 20, if\ \ n^f_{ij} > n^f_{ij+1} \\ 0, if\ \ n^f_{ij} \le n^f_{ij+1} \end{cases}$	
Priors		
	$\sum_i \sum_y (\epsilon^R_{i,y})^2$ $\sum_i \sum_y (N_{0,ij})^2$ $\sum_i \sum_y (\varepsilon_{i,y})^2$	



New this year

- The base model (ADMB CEATTLE) was ported to **RTMB via the CNRG R package suite**
- **Predator-prey suitability is age-specific and varies by time blocks** determined from break point evaluations of diet data collected during summer bottom trawl surveys.
- Survey biomass and harvest from the NEBS and SEBS were updated through 2026
- Survey biomass and age or length composition were updated using design-based methods and data available from the NMFS bottom trawl survey and fishery observer database 2026
- Estimates of annual biomass of key prey species eaten (NEBS and SEBS combined) were updated for species outside of the assessment (e.g., *"Opilio"*) based on model estimates of predator ration (kg eaten/pred) and biomass.
- **More detailed information was included** for empirical design based data methods, temperature specific weight at age, and climate-driven recruitment.
- In past years pollock weight at age (WAA) was based on values from the current SAFE report , in this year we used design based estimates of WAA to be consistent with the approach for P. cod and arrowtooth; missing years were filled using empirical WAA averaged over available years (rather than the temperature linked vonB in the hindcast).

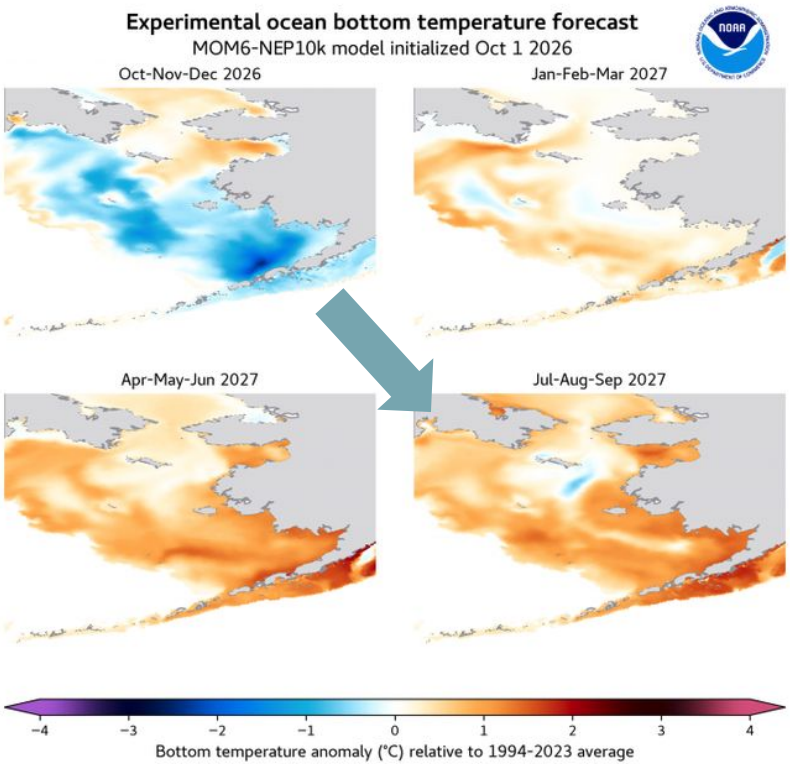
New this year

- A "climate-informed" approach is used to derive biological reference points through projecting the model forward with climate effects
- Bottom temperature and other variables from the MOM6 operational hindcast were updated through 2026 and **newly released MOM6 forecasts were used for 2027 and projections.**
- Environmentally linked vonB models were fit to **MOM6 hindcasts using `vonBEE()`**
- Recruitment was fit to both the **MOM6 and ROMSNPZ hindcasts using `futR()`.**
- The newly released MOM6 forecasts were used to drive forecasts and derive F_{target} and ABC under future climate conditions.
- Climate effects on recruitment (fit to hindcasts of the MOM6 model 1993-2025) were included in the projection model suite of different forecast persistence scenarios for
- Model long-term projections were updated with new CNRG hindcast estimates and ACLIM ROMSNPZ indices were used to drive the model forward for long-term multidecadal outlooks under bounding plausible global scenarios of high (ssp585) and low (ssp126) future warming. These resulted in updates to estimates of F_{target} and ABC under long-term climate effects.

Inputs: MOM6 env. variables



New! NEAP-CEFI MOM6 Forecasts

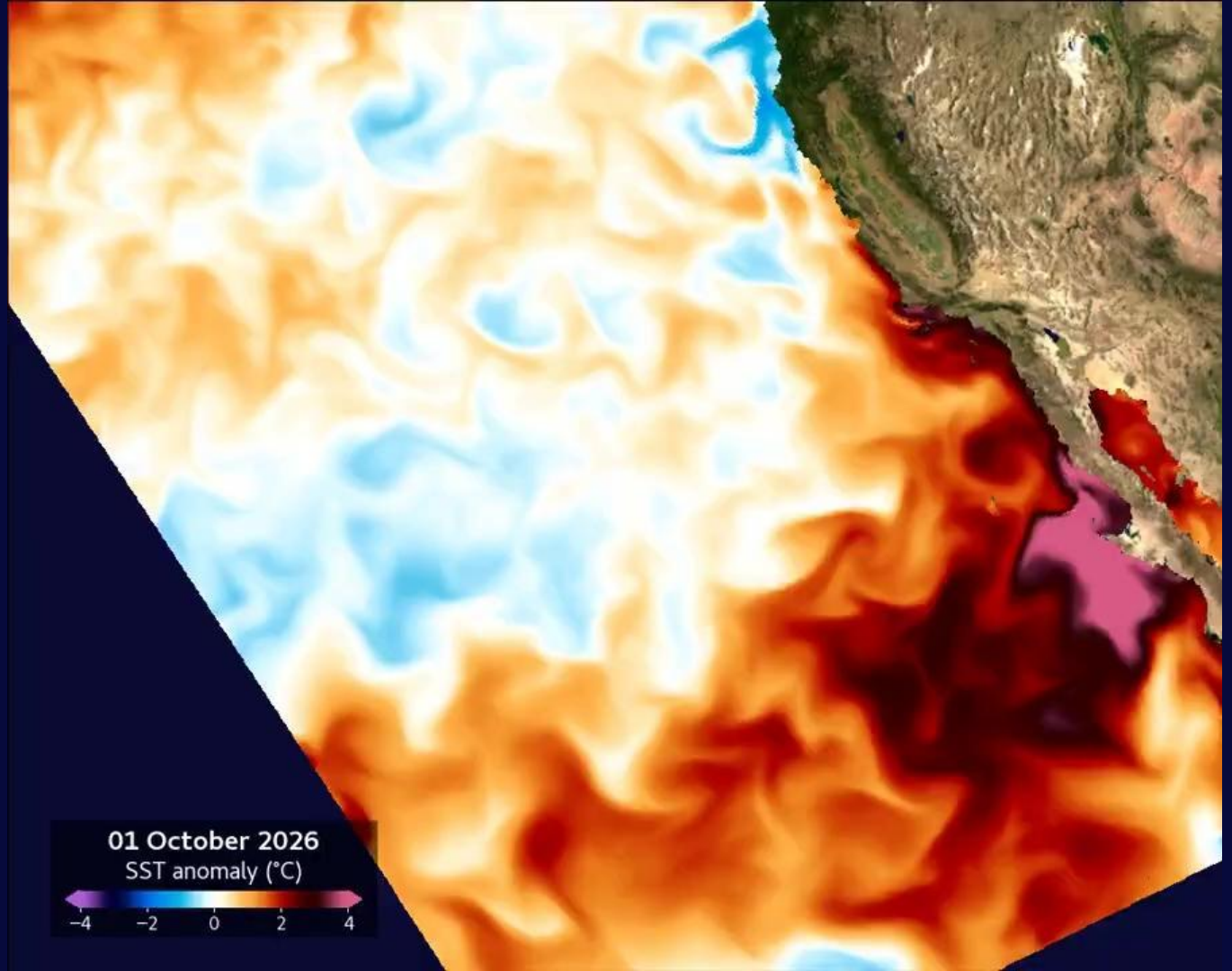


The Eastern Bering Sea is starting off colder than usual in the fall of 2026 due to colder than average conditions from early spring that have persisted throughout the year. While the forecasts predict that the bottom temperatures will gradually increase to above average conditions, there is substantial uncertainty in this region beyond early winter of 2027 due to difficulty in predicting sea ice conditions.

Similar to the Northwest Atlantic model, the Northeast Pacific regional ocean model is run using forcing fields from GFDL's SPEAR global prediction system. An ensemble of 10 simulations is run, using a different ensemble member from SPEAR for each, and the results are averaged for the figures shown here. New seasonal forecasts are run four times per year, in January, April, July, and October. Note that these experimental predictions are not official NOAA forecasts.

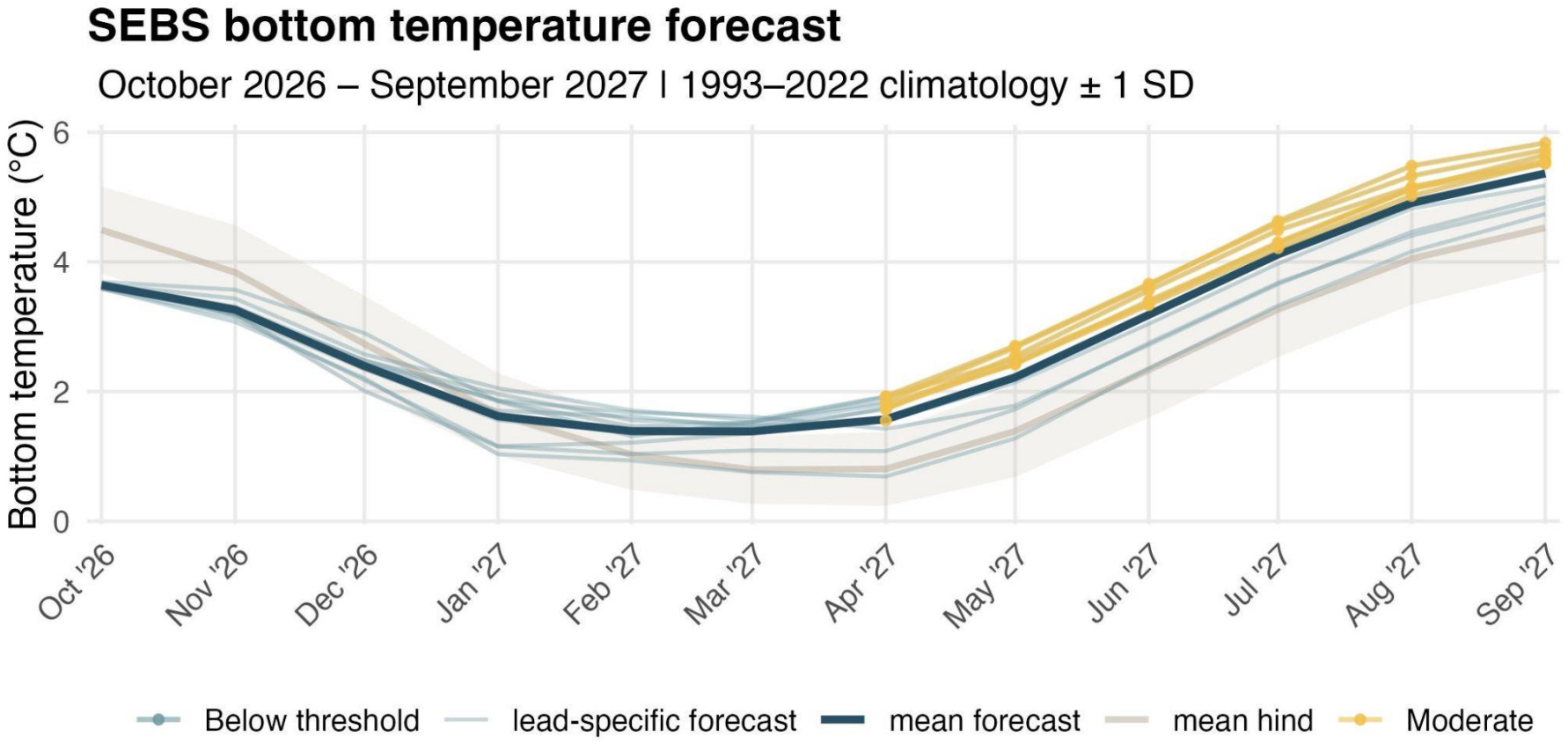
https://www.gfdl.noaa.gov/prediction/october-2026-northeast-pacific-predictions

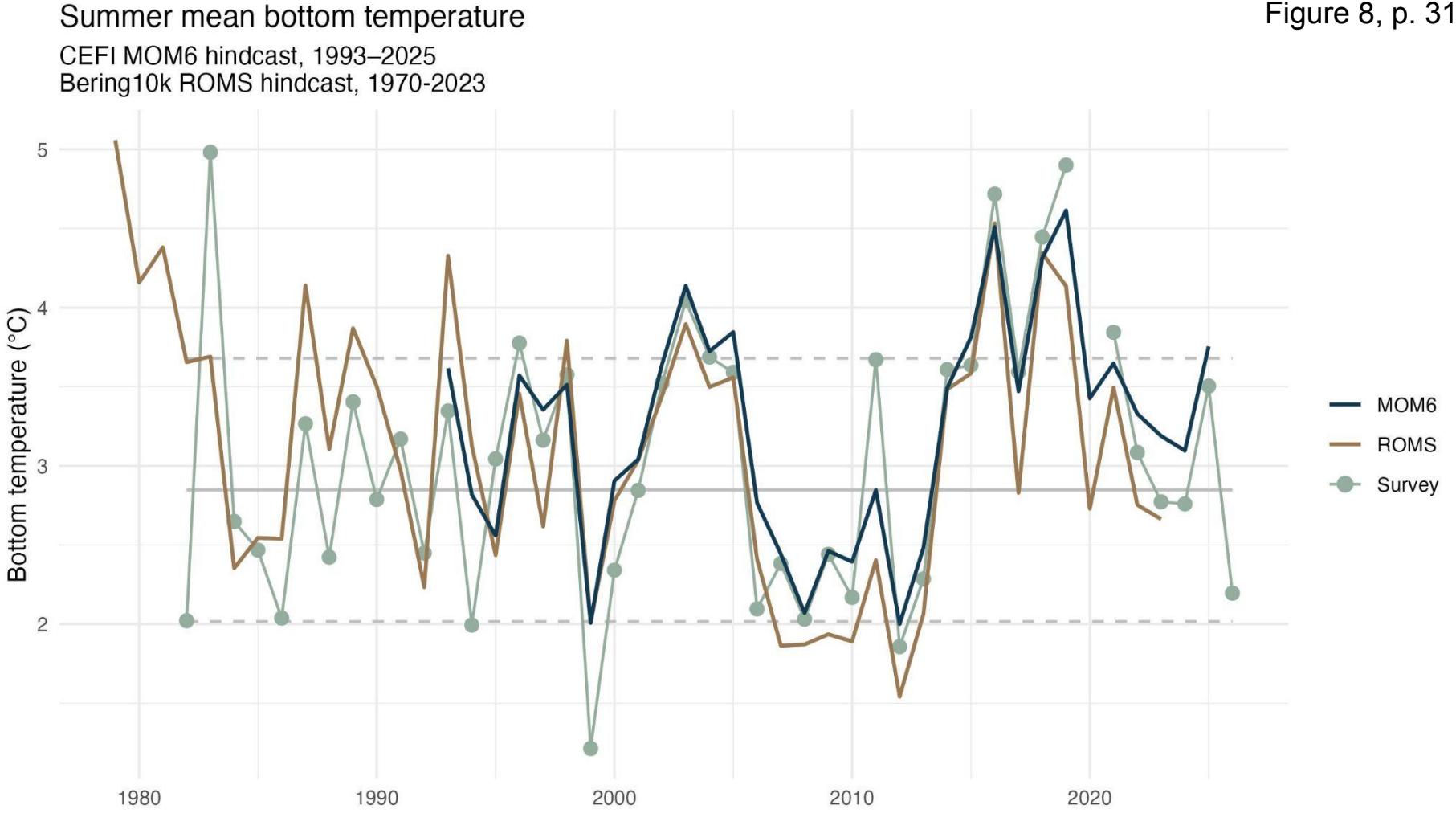
MOM6 NEP 12 Mo Forecast (Oct 2027)

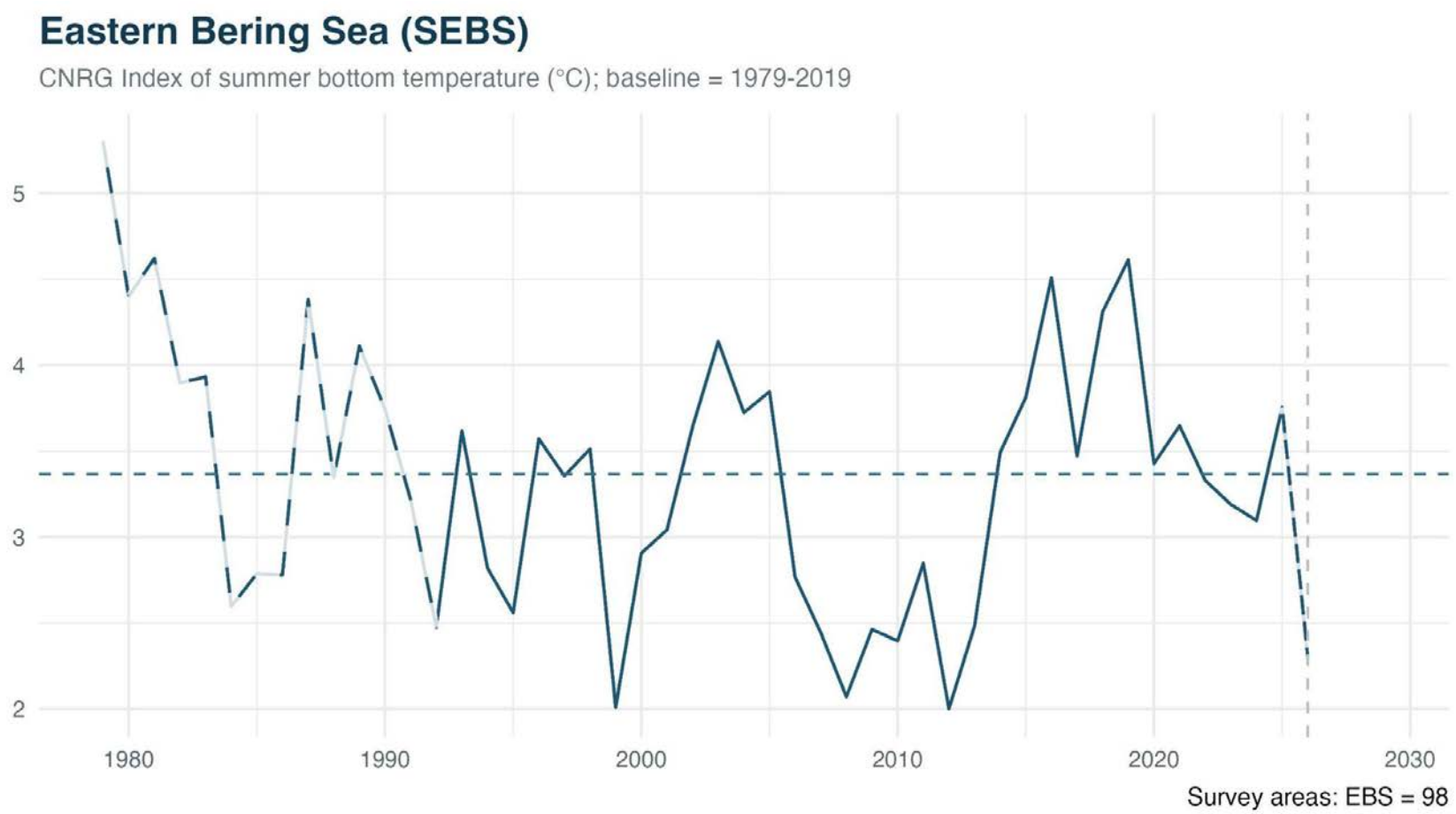


Video:
Andrew Ross

MOM6 Oct 2026 Forecast



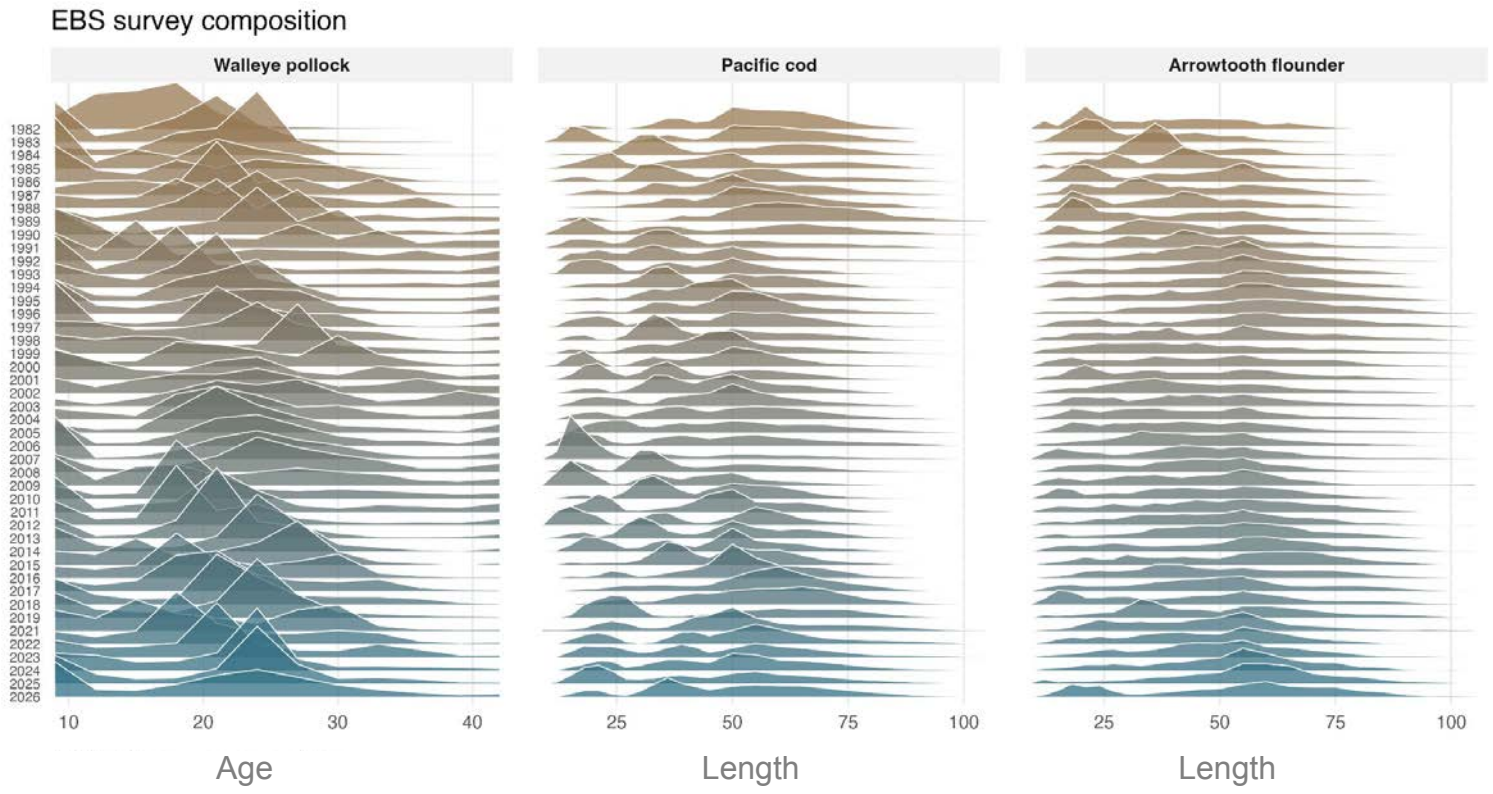

Summer mean bottom temperature
CEFI MOM6 hindcast, 1993–2025
Bering10k ROMS hindcast, 1970-2023
Bottom temperature (°C)
5
4
3
2
1980
1990
2000
2010
2020
MOM6
ROMS
Survey


Eastern Bering Sea (SEBS)
CNRG Index of summer bottom temperature (°C); baseline = 1979-2019
5
4
3
2
1980
1990
2000
2010
2020
2030
Survey areas: EBS = 98

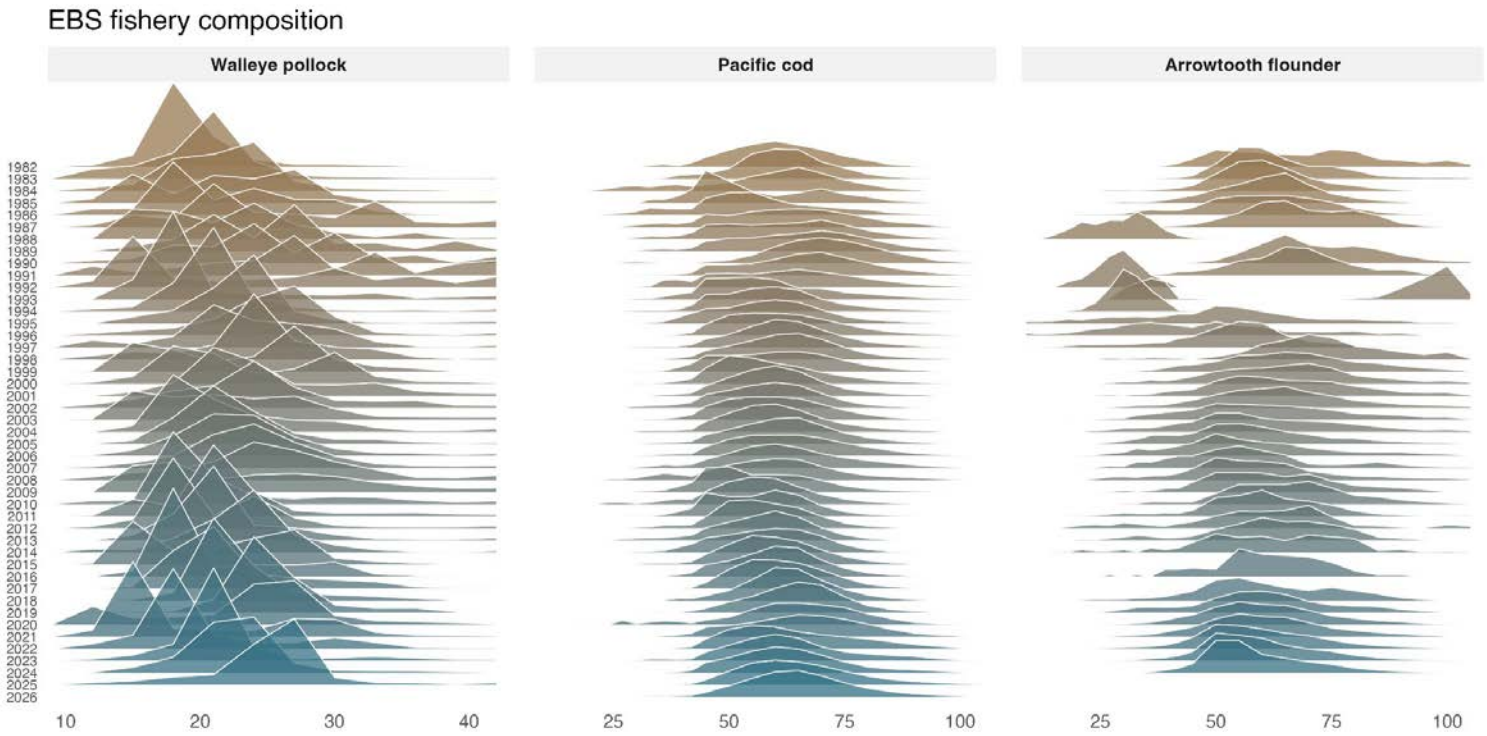
Inputs



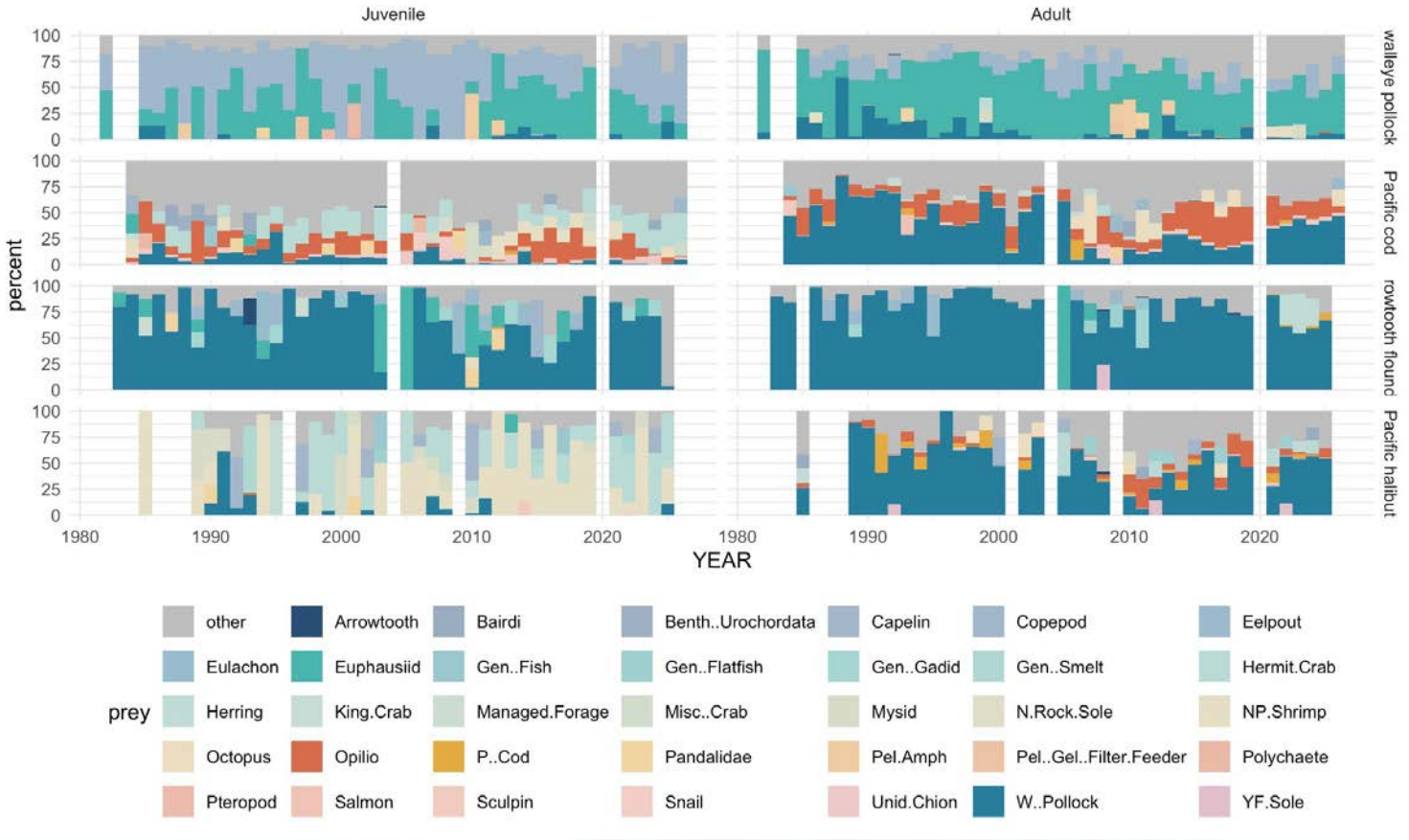
Comp. data: survey



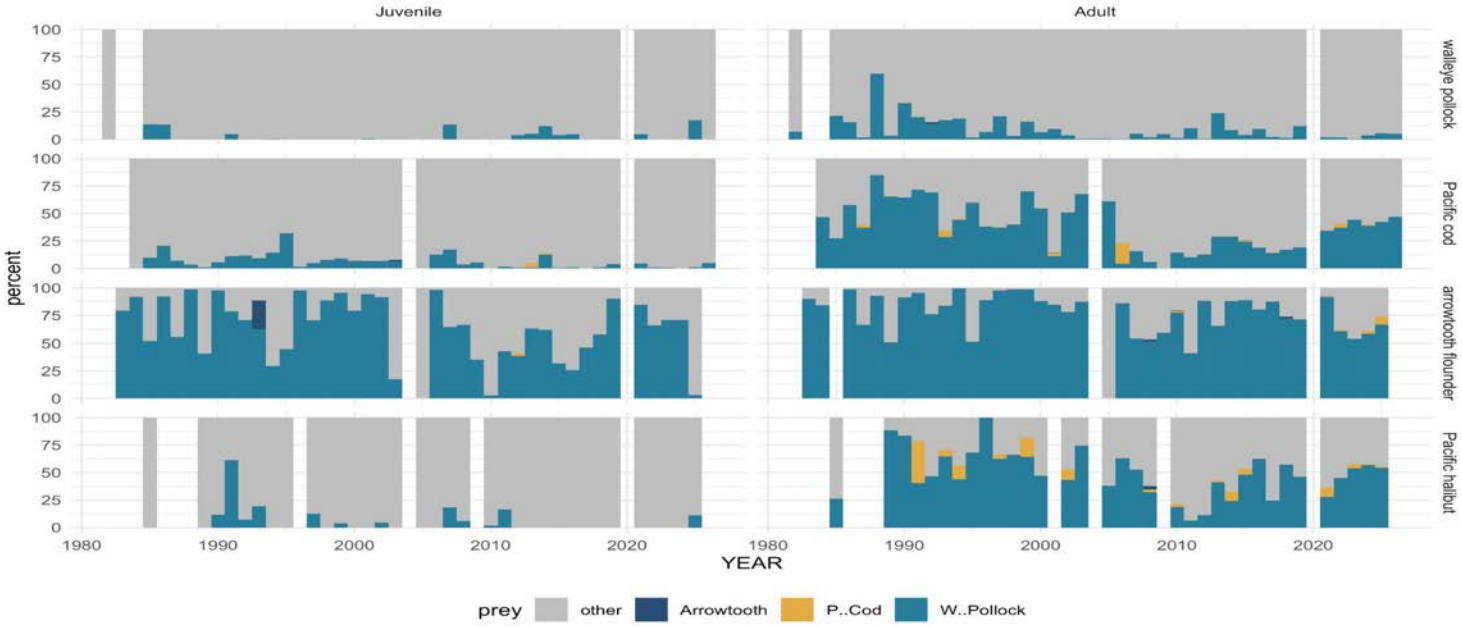
Comp. data: Fishery



Inputs: Diet data



Inputs: Diet data

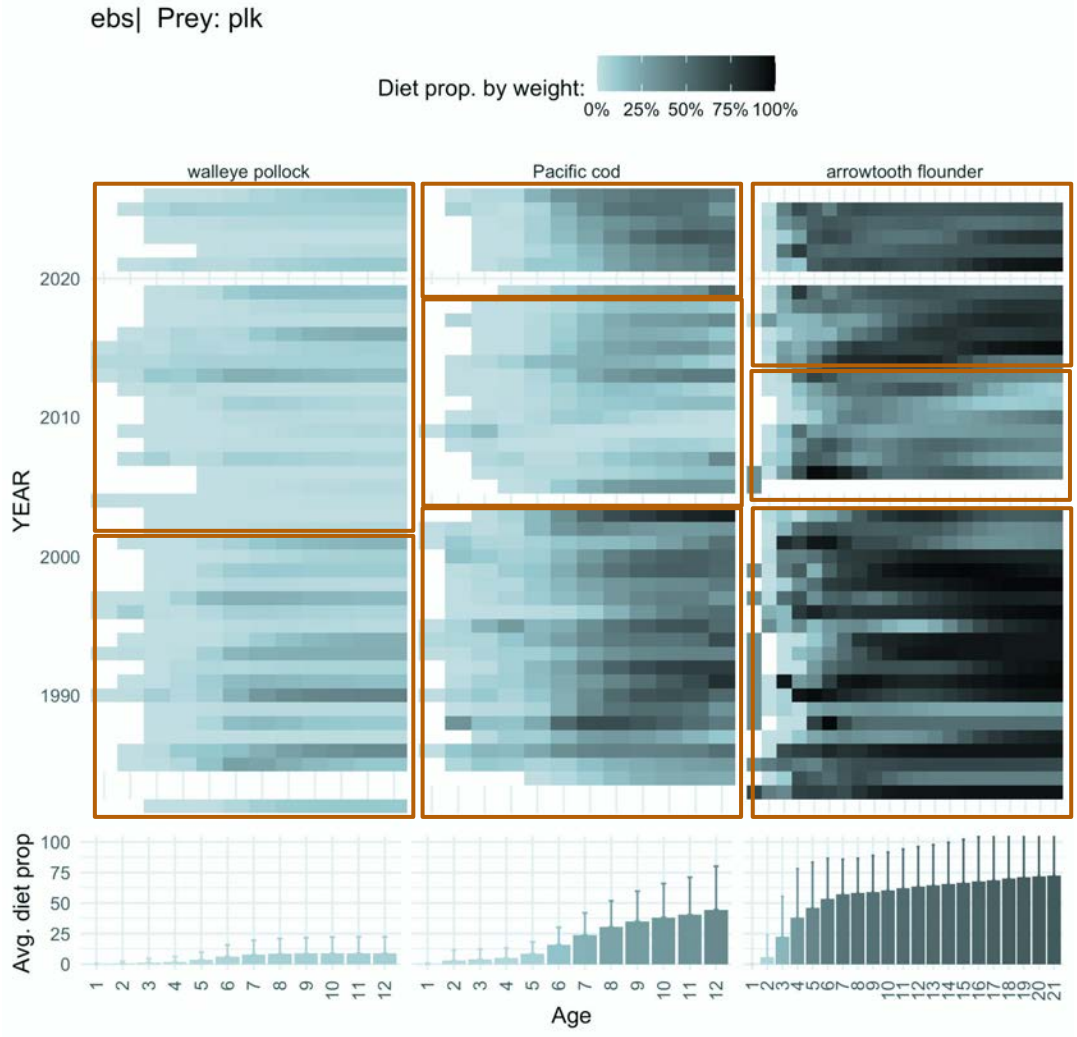


Inputs: Diet data

- nonparametric multiple change point analysis
- e.divisive() function of the `ecp` R package
- This method evaluates shifts in the multivariate distribution of age-specific diet compositions without assuming a parametric distribution.
- max number of blocks = 5
- Min number of years within a block = 4

Species	Block 1	Block 2	Block 3
plk	1979–2001	2002–2026	
pcod	1979–2003	2004–2018	2019–2026
atf	1979–2003	2004–2013	2014–2025

Table 3, p. 29



Predation mortality

Table 2: Predation mortality ($M2$) equations for predators p of age a and prey i of age j in year y or time block $\tau_{p(y)}$.

Definition	Equation	ID
Predation mortality	$\mathrm{M2}_{ij,y} = \sum_{pa}\left(\frac{N_{pa,y}\delta_{pa,y}\bar{S}_{paij,\tau_{p(y)}}}{\left(\sum_{ij}\bar{S}_{paij,\tau_{p(y)}}B_{ij,y}\right)+B_p^{other}\left(1-\sum_{ij}\left(\bar{S}_{paij,\tau_{p(y)}}\right)\right)}\right)$	T2.1
Predator-prey suitability	$\bar{S}_{paij,\tau_{p(y)}} = \frac{\frac{\overline{U}_{paij,\tau_{p(y)}}}{V_{pi,\tau_{p(y)}}\overline{B}_{ij,\tau_{p(y)}}}}{\sum_{ij}\left(\frac{\overline{U}_{paij,\tau_{p(y)}}}{V_{pi,\tau_{p(y)}}\overline{B}_{ij,\tau_{p(y)}}}\right)+\frac{1-\sum_{ij}\overline{U}_{paij,\tau_{p(y)}}}{V_{p,\mathrm{other},\tau_{p(y)}}B_p^{other}}}$	T2.2
Mean gravimetric diet proportion	$\overline{U}_{paij,\tau_{p(y)}} = \frac{1}{n_{\tau_{p(y)}}}\sum_{y\in y_{\tau_{p(y)}}}U_{paij,y}$	T2.3
Individual specific ration (kg yr^{-1})	$\delta_{pa,y} = \hat{\varphi}_{pa,y}\alpha_\delta W_{pa,y}^{(1+\beta_\delta)}f\left(T_y\right)_p$	T2.4
Temperature scaling consumption algorithm	$f\left(T_y\right)_p = V^X e^{(X(1-V))}$	T2.5
	$V = \left(T_p^{cm}-T_y\right)/\left(T_p^{cm}-T_p^{co}\right)$	T2.5a
	$X = \left(Z^2\left(1+\left(1+40/Y\right)^{0.5}\right)^2\right)/400$	T2.5b
	$Z = ln\left(Q_p^c\right)\left(T_p^{cm}-T_p^{co}\right)$	T2.5c
	$Y = ln\left(Q_p^c\right)\left(T_p^{cm}-T_p^{co}+2\right)$	T2.5d

Inputs: Diet composition ($U_{paij,b}$)

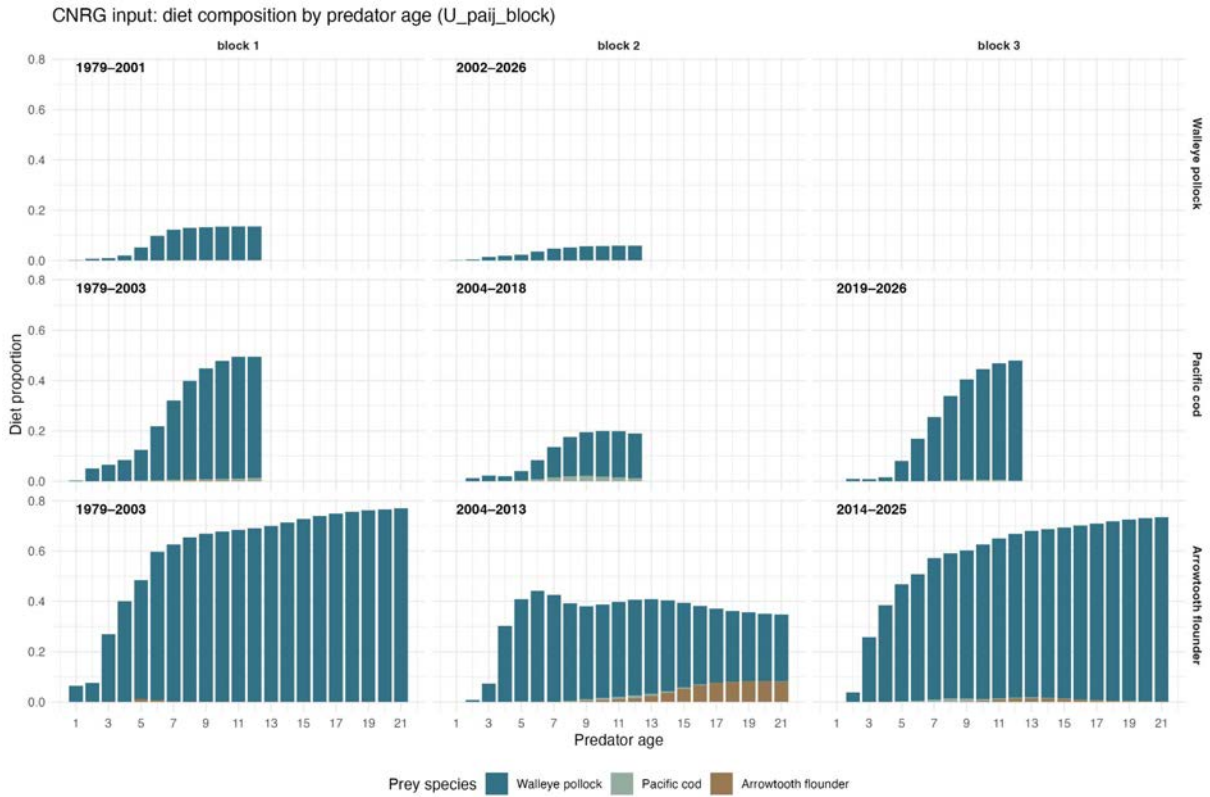


Figure 3, p. 20

Inputs: Relative foraging rate

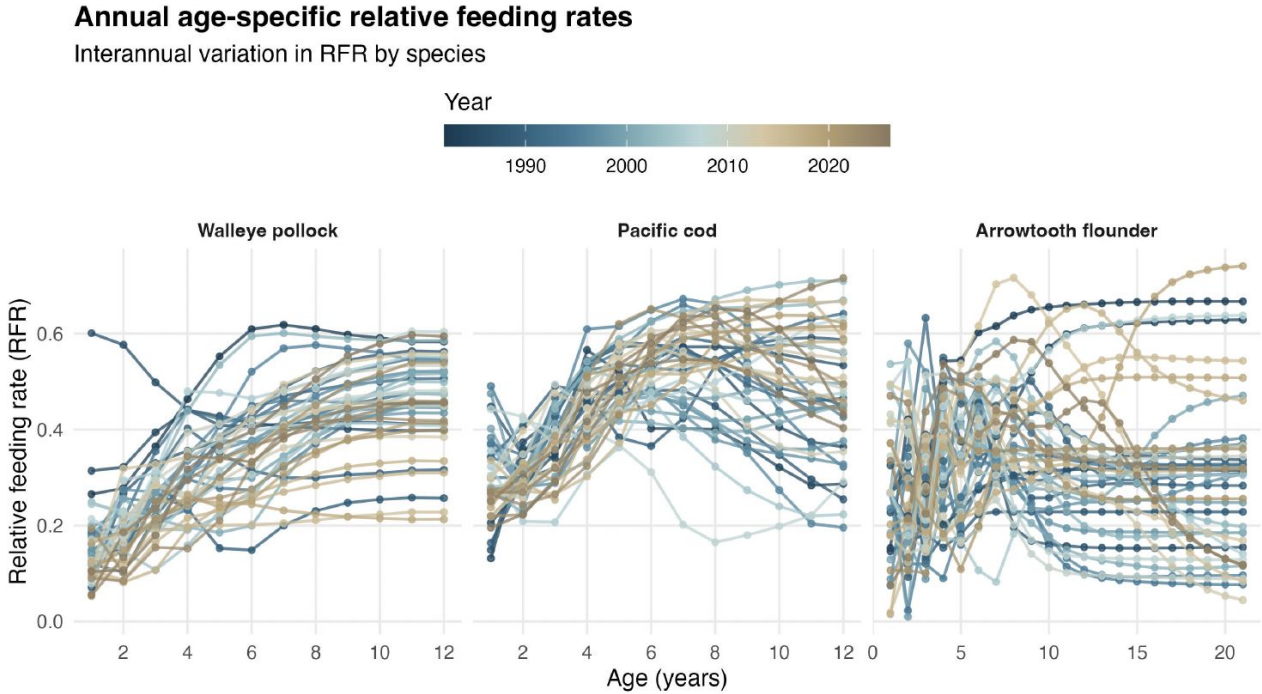


Figure 6: Annual age-specific biomass weighted average RFR for each species.

Inputs: Relative foraging rate

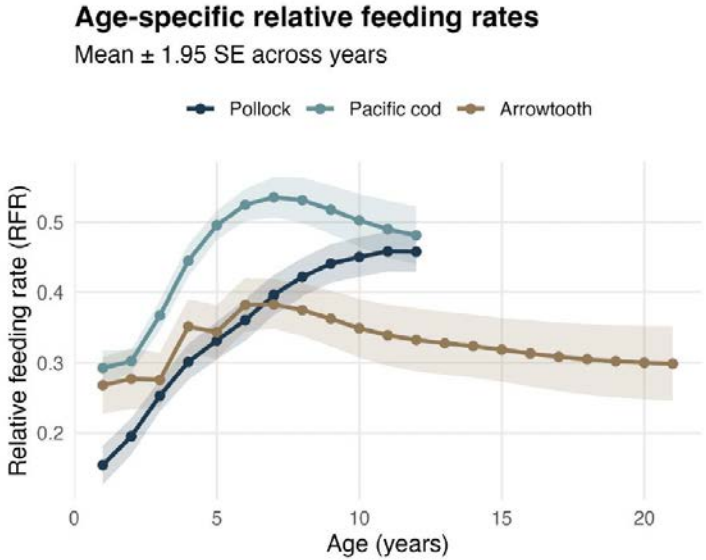


Figure 7: Average (across years) age-specific biomass weighted RFR for each species.

Model results



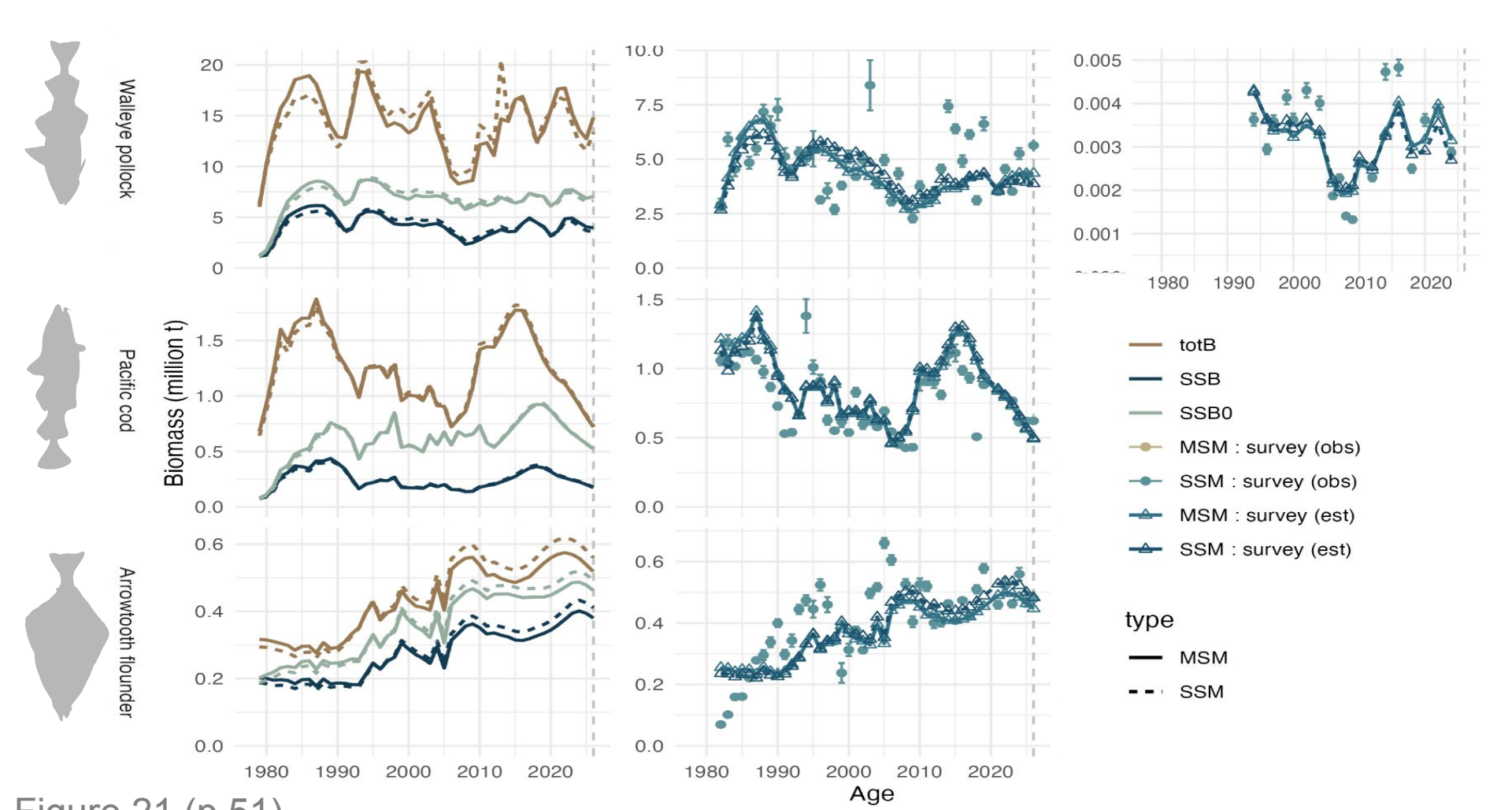
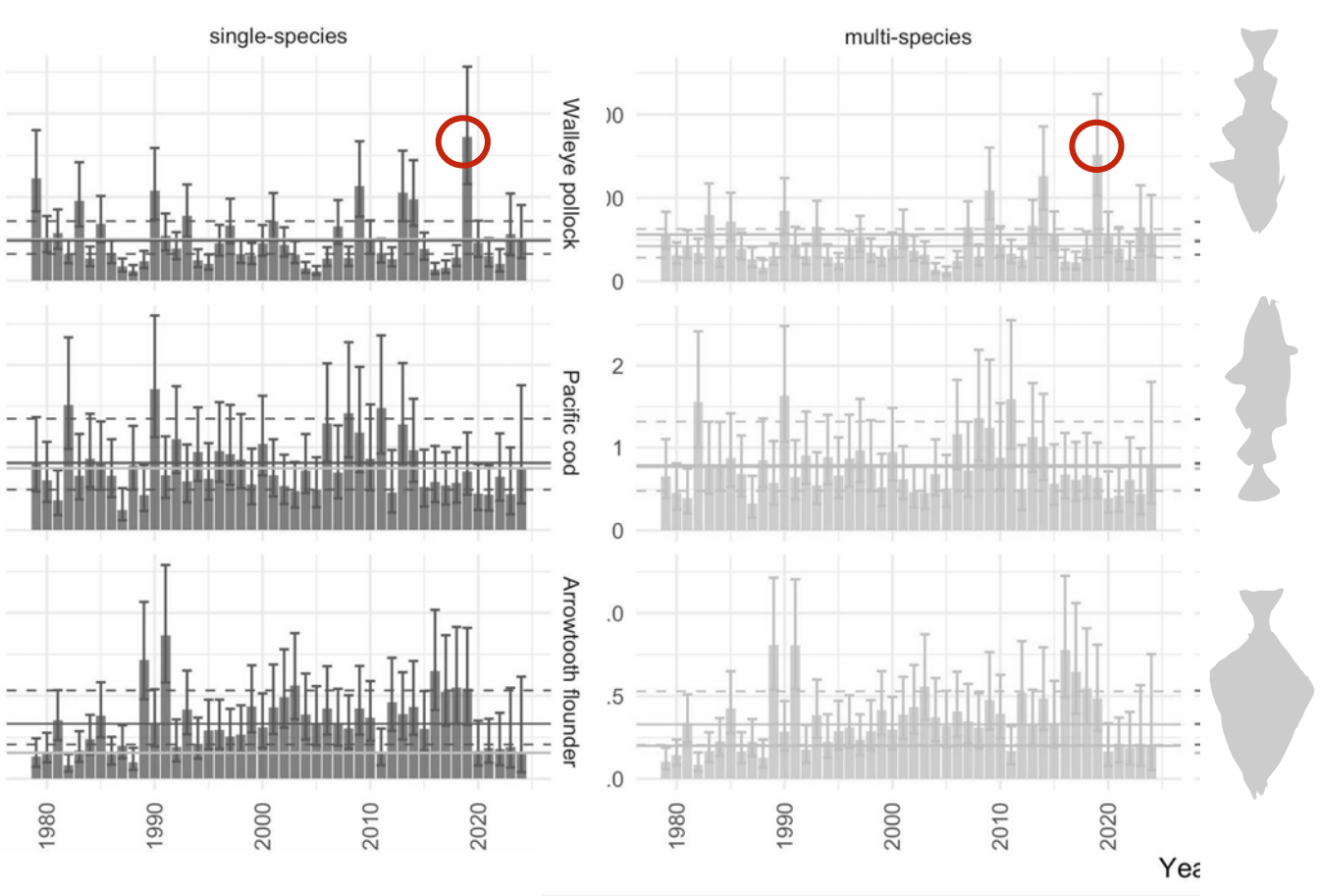


Figure 21 (p 51)

Recruitment

2024 assessment



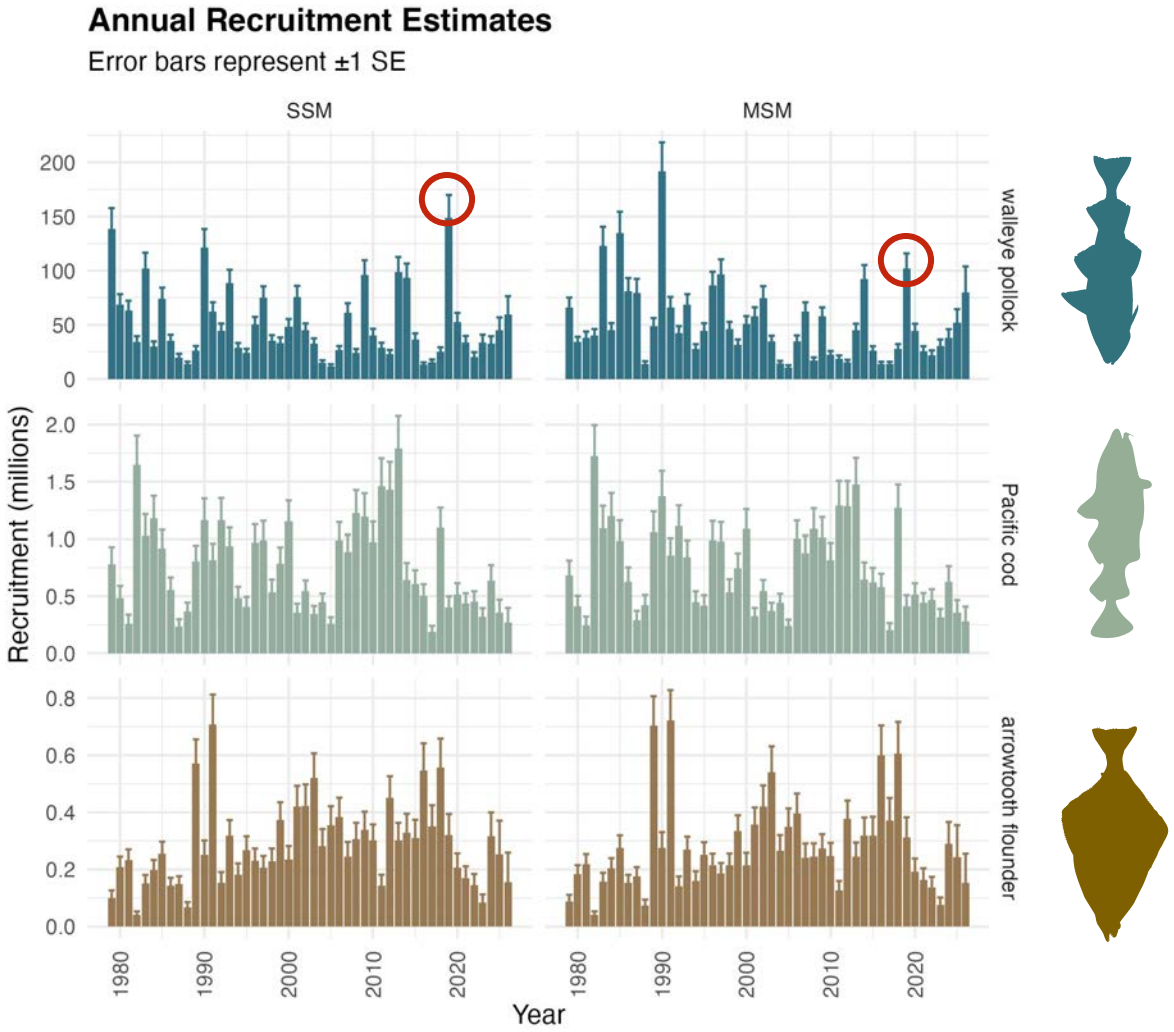
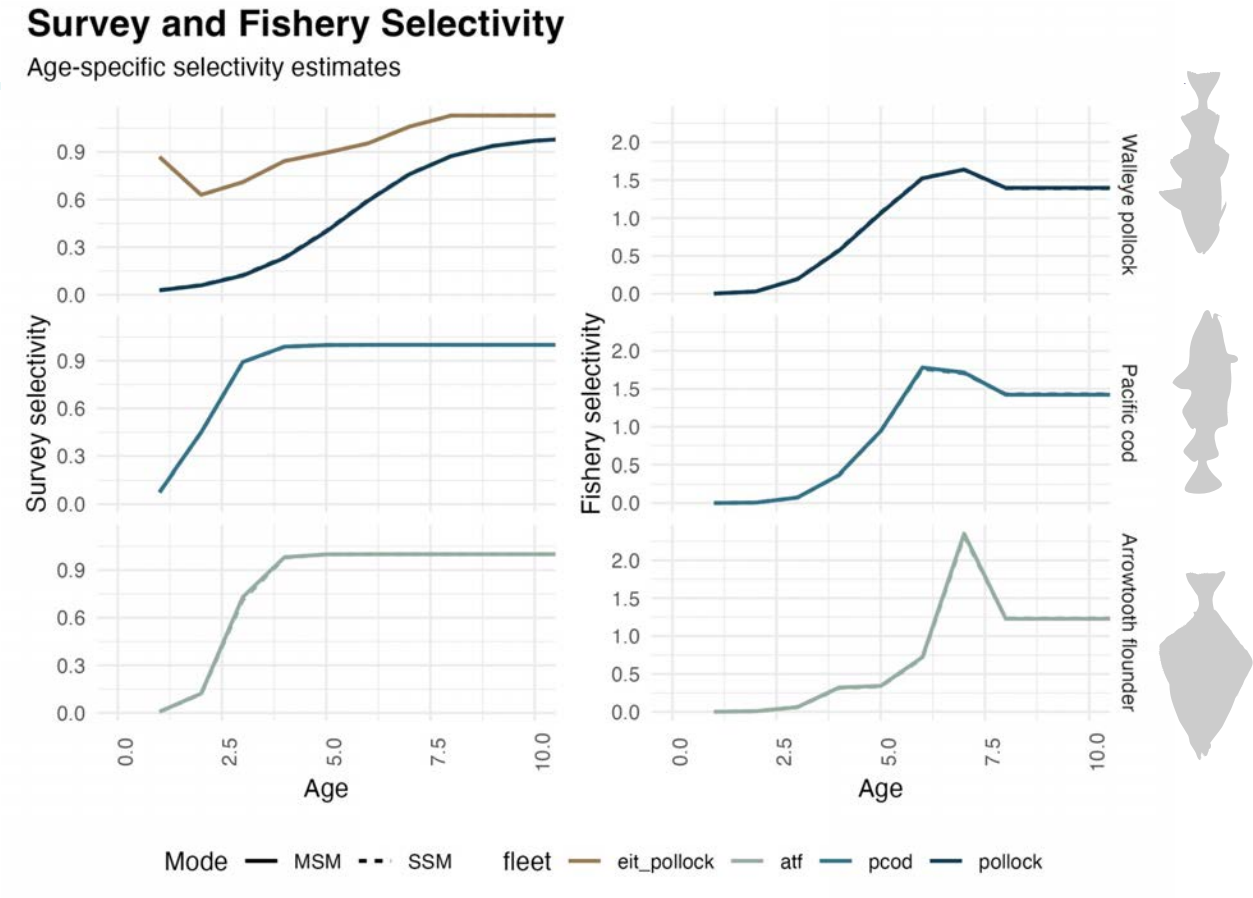
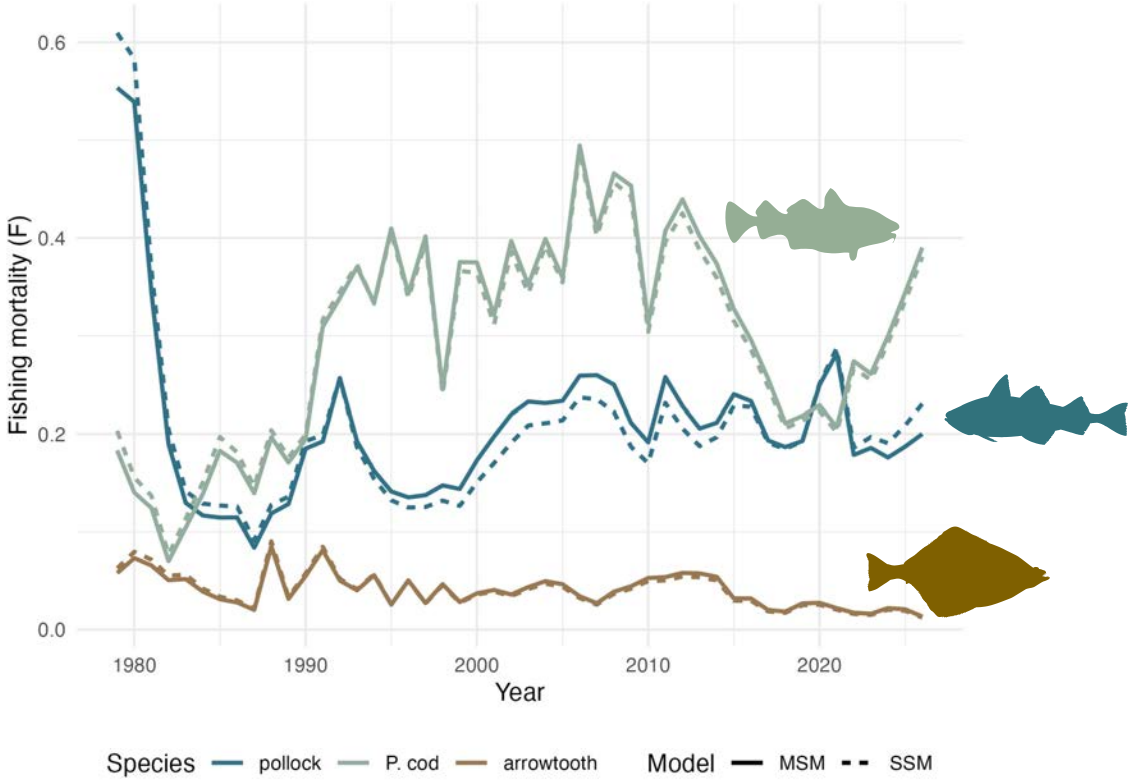


Figure 22 (p 53)

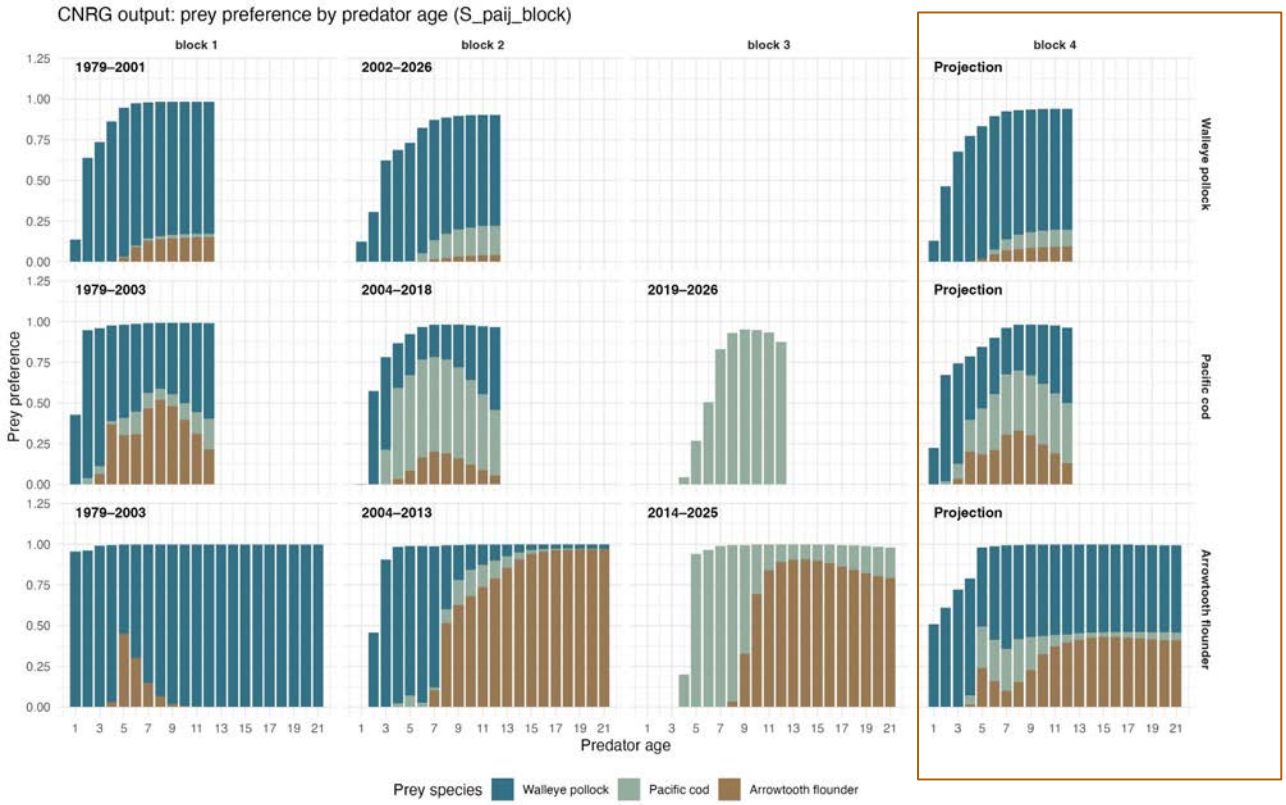


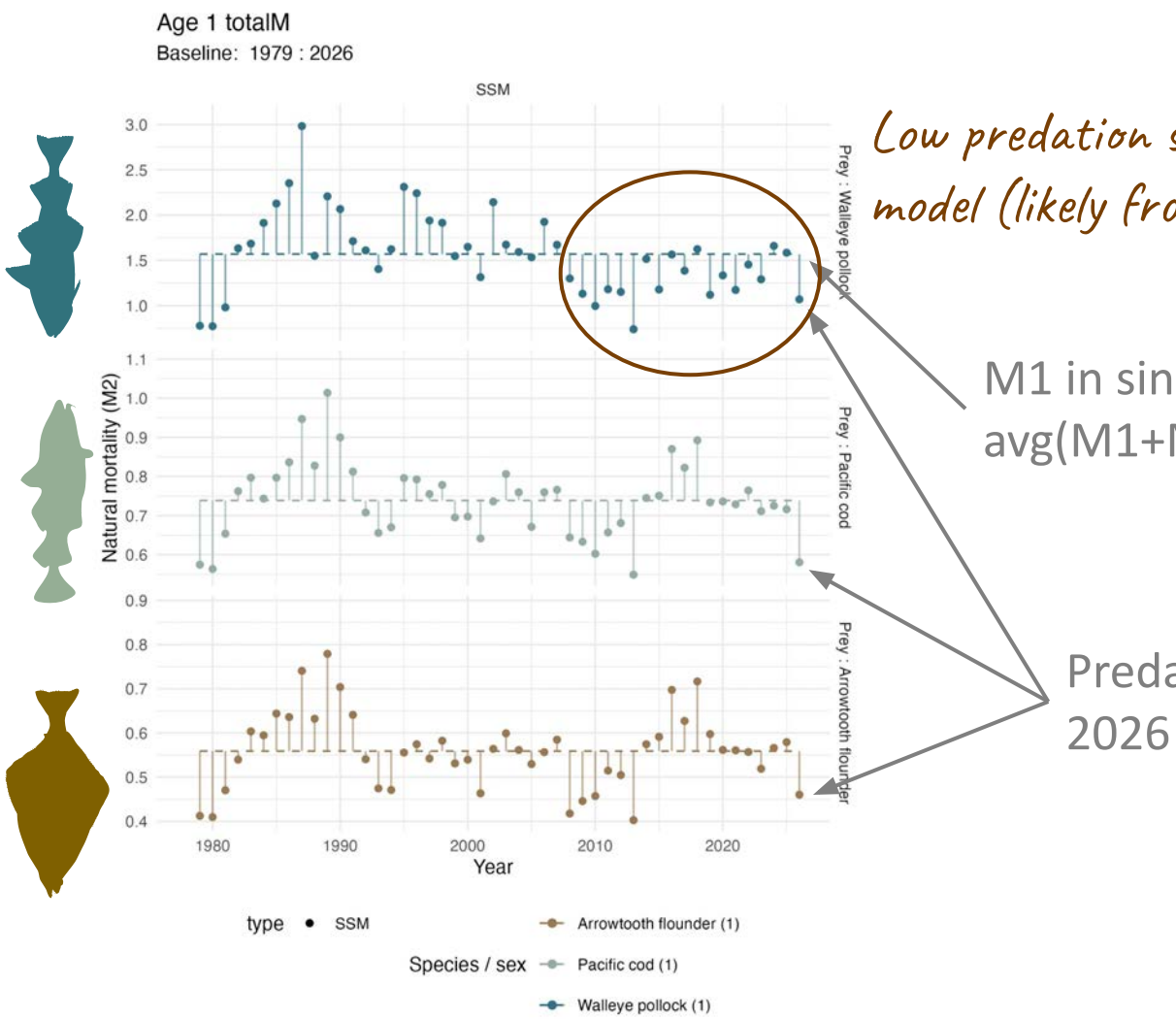
[Jump to comp. fits]

Fishing mortality



Output: Pred-prey preference ($S_{paij,b}$)

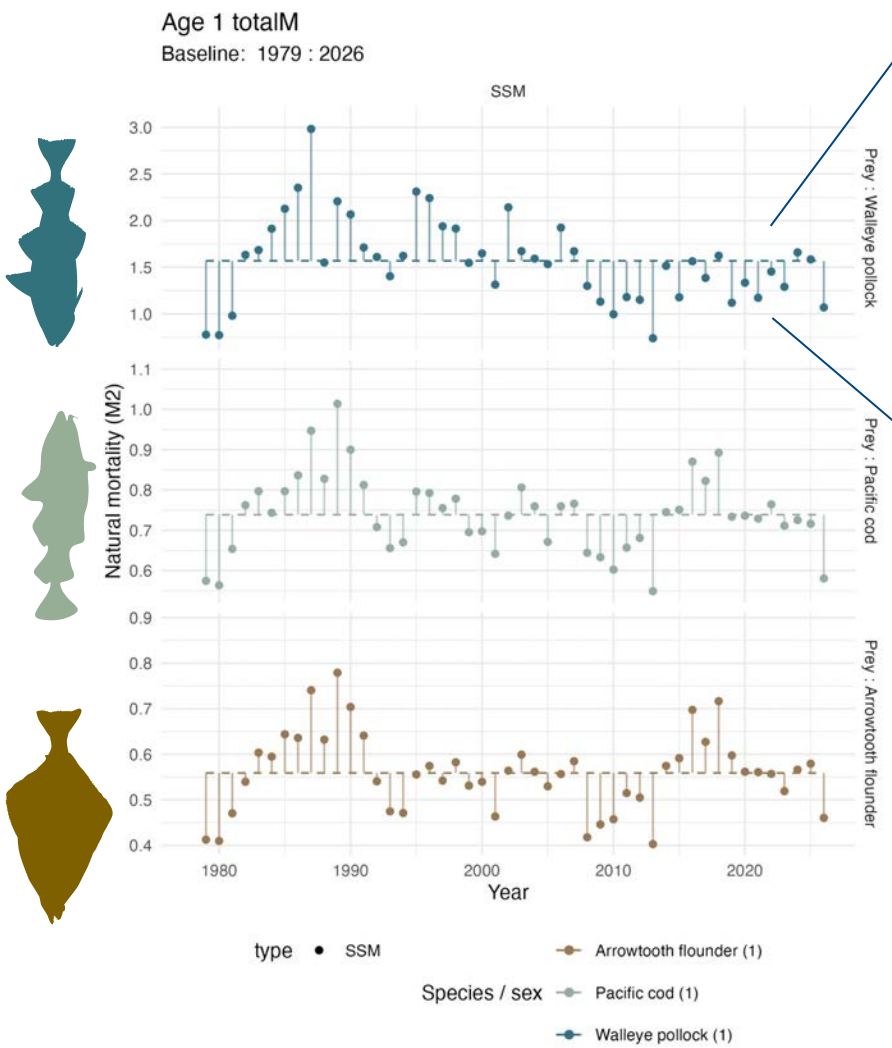


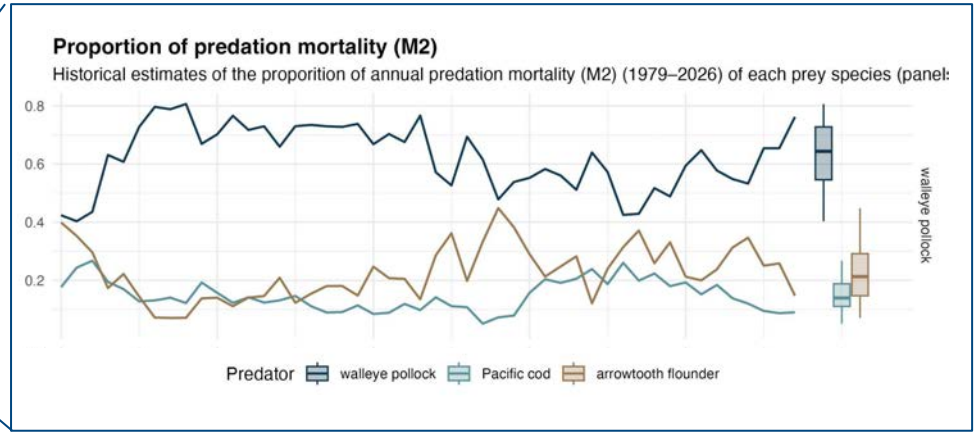


Low predation since 2008, new in this updated model (likely from updated diet inputs)

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

Predation mortality decreased in 2026



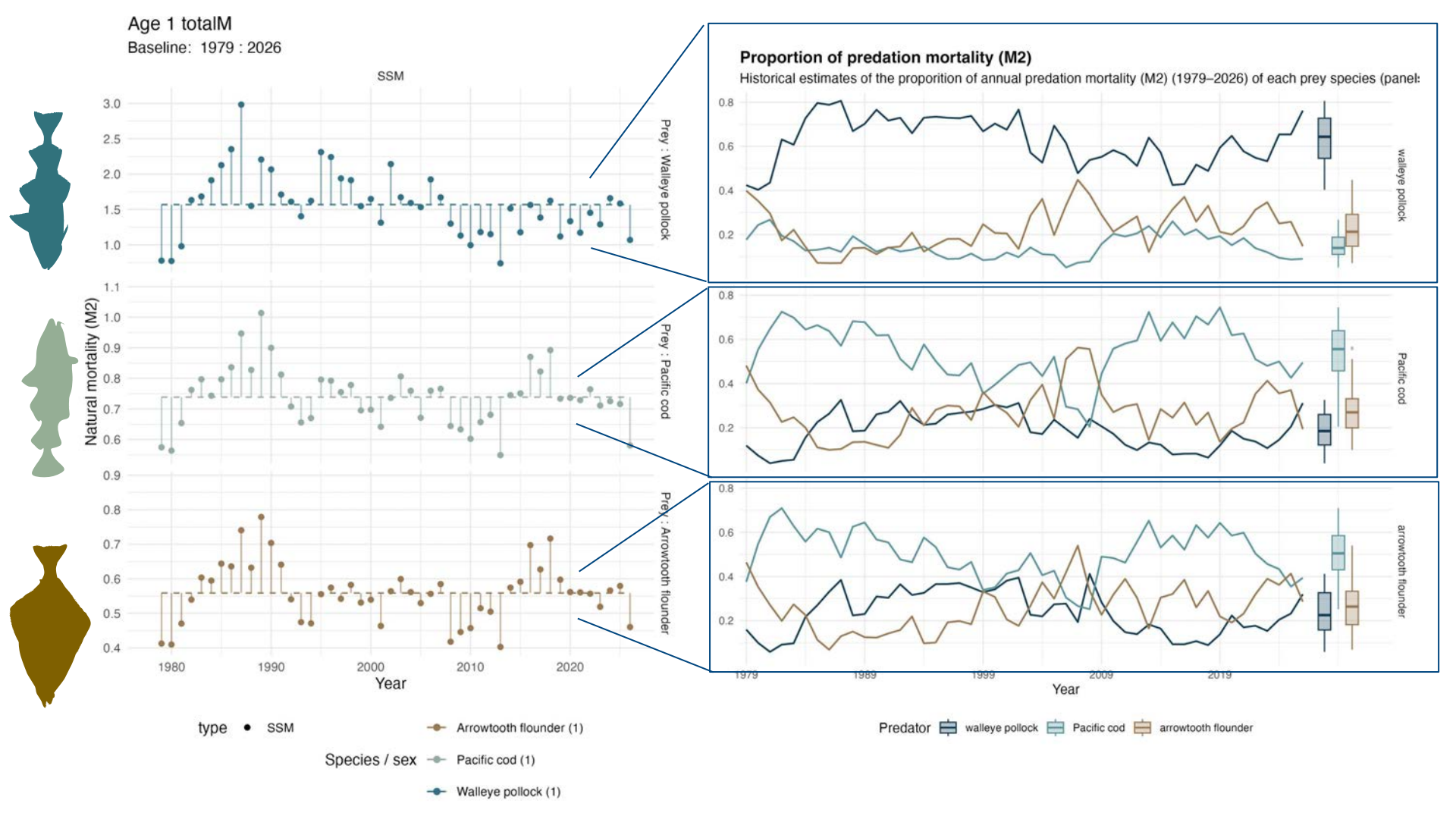


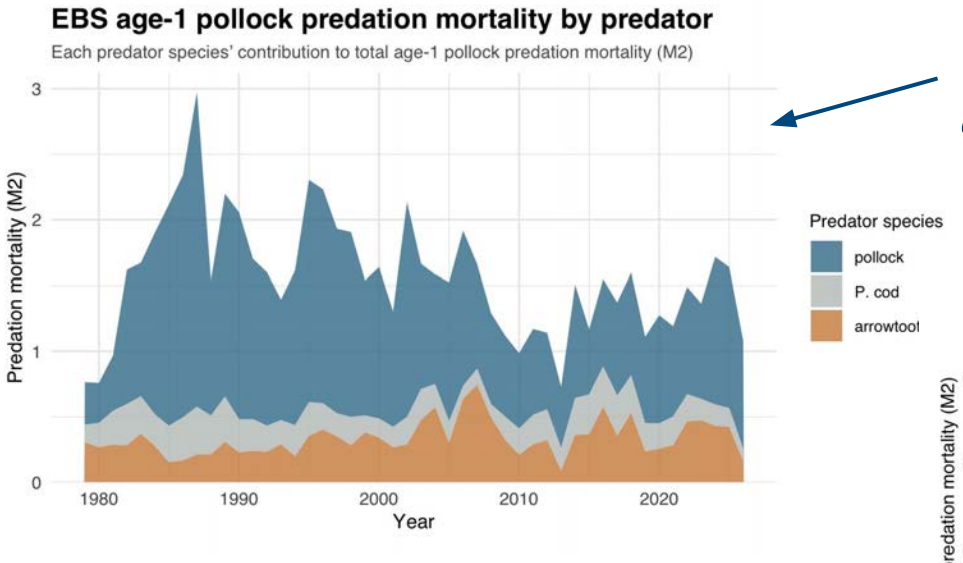
Annual predator ration

Pref for prey ij

$$M2_{ij,y} = \sum_{pa} \left(\frac{N_{pa,y}\delta_{pa,y}\bar{S}_{paij,\tau_{p(y)}}}{\left(\sum_{ij}\bar{S}_{paij,\tau_{p(y)}}B_{ij,y}\right)+B_p^{other}\left(1-\sum_{ij}\left(\bar{S}_{paij,\tau_{p(y)}}\right)\right)} \right)$$

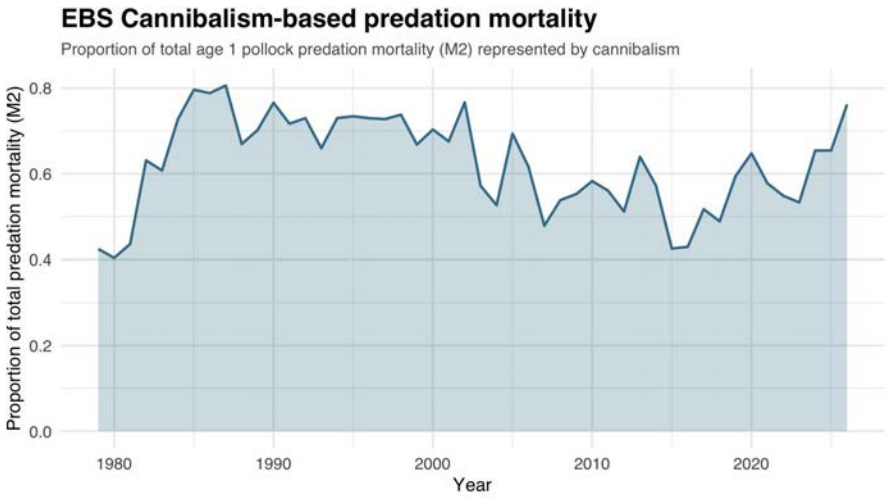
All prey eaten by pred p


Age 1 totalM
Baseline: 1979 : 2026
SSM
Natural mortality (M2)
Year
Prey : Walleye pollock
Prey : Pacific cod
Prey : Arrowtooth flounder
Proportion of predation mortality (M2)
Historical estimates of the proportion of annual predation mortality (M2) (1979–2026) of each prey species (panels)
walleye pollock
Pacific cod
arrowtooth flounder
type
SSM
Species / sex
Arrowtooth flounder (1)
Pacific cod (1)
Walleye pollock (1)
Predator
walleye pollock
Pacific cod
arrowtooth flounder

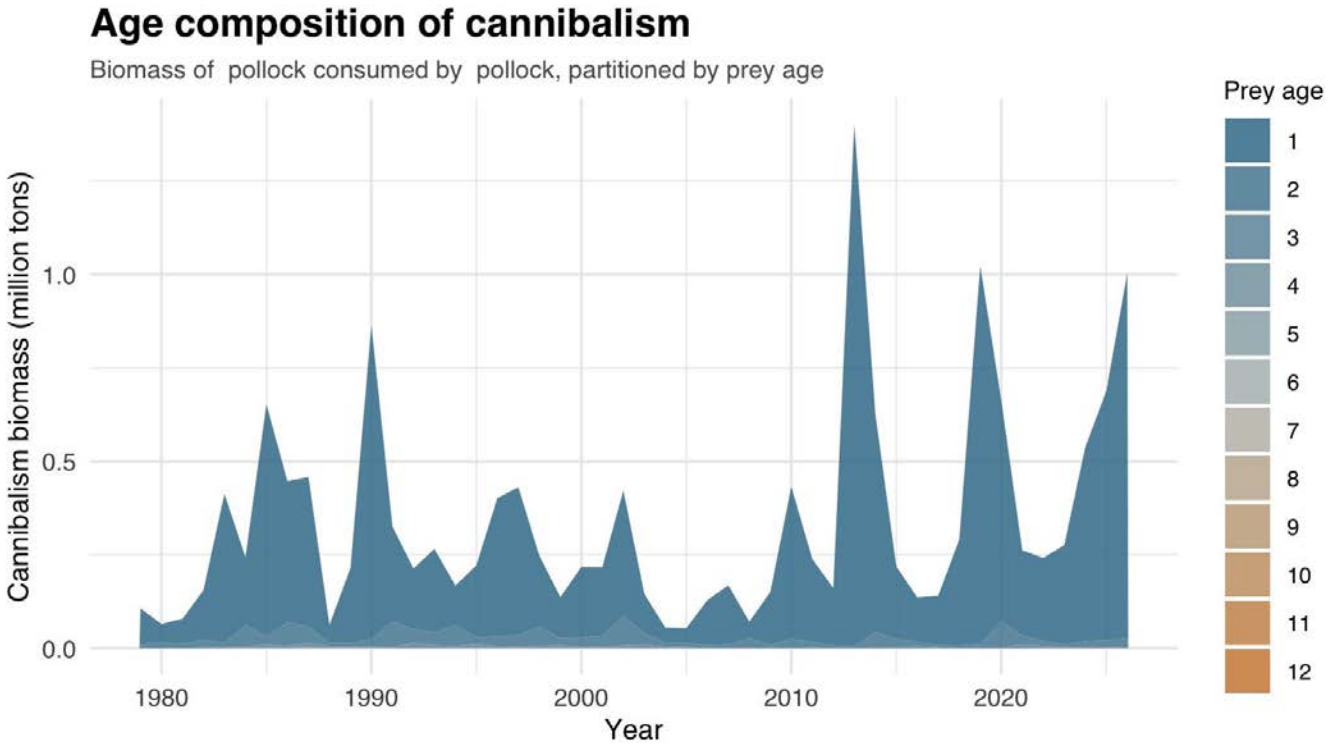


Which predators cause annual changes in M?

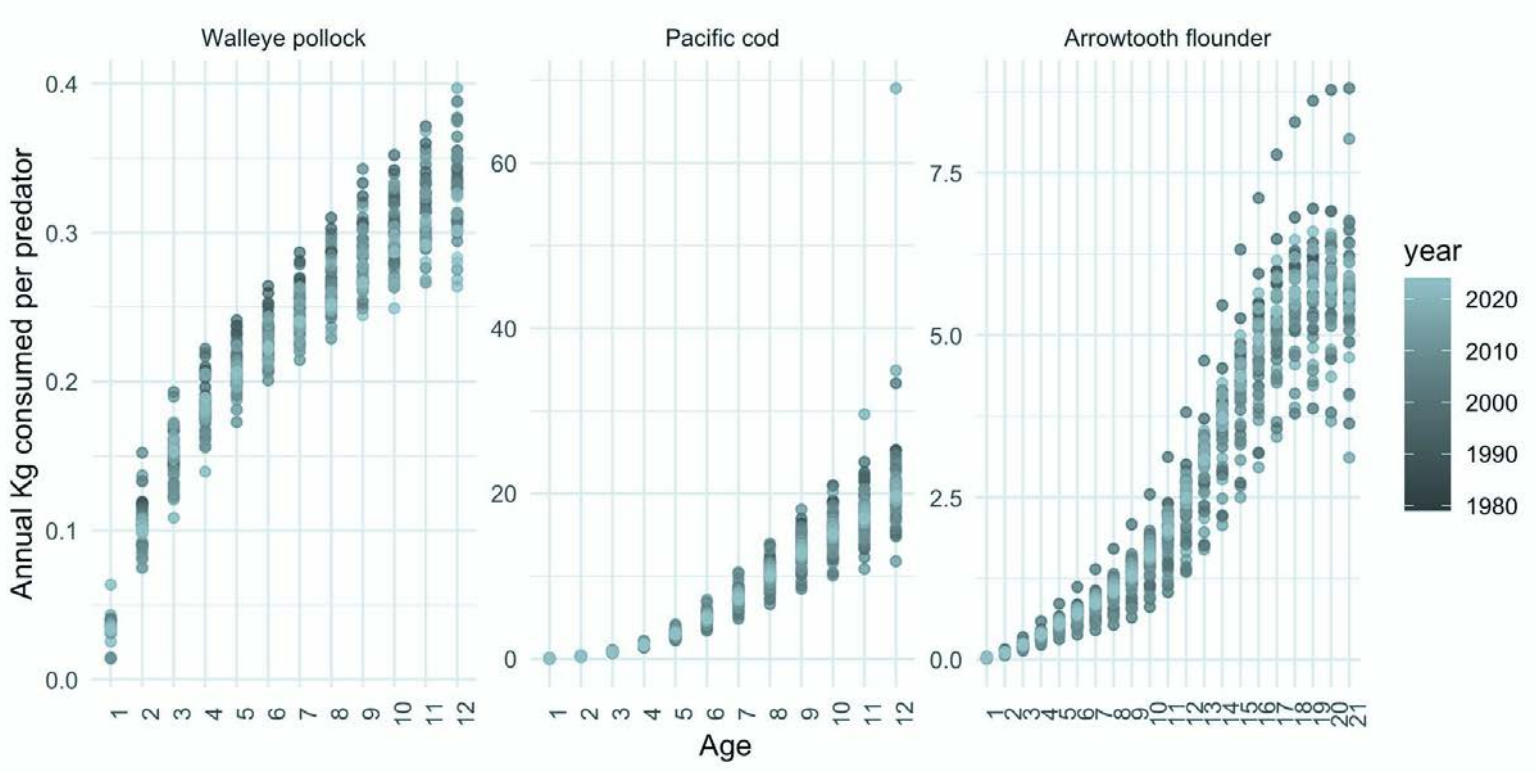
What proportion of annual M is due to cannibalism?

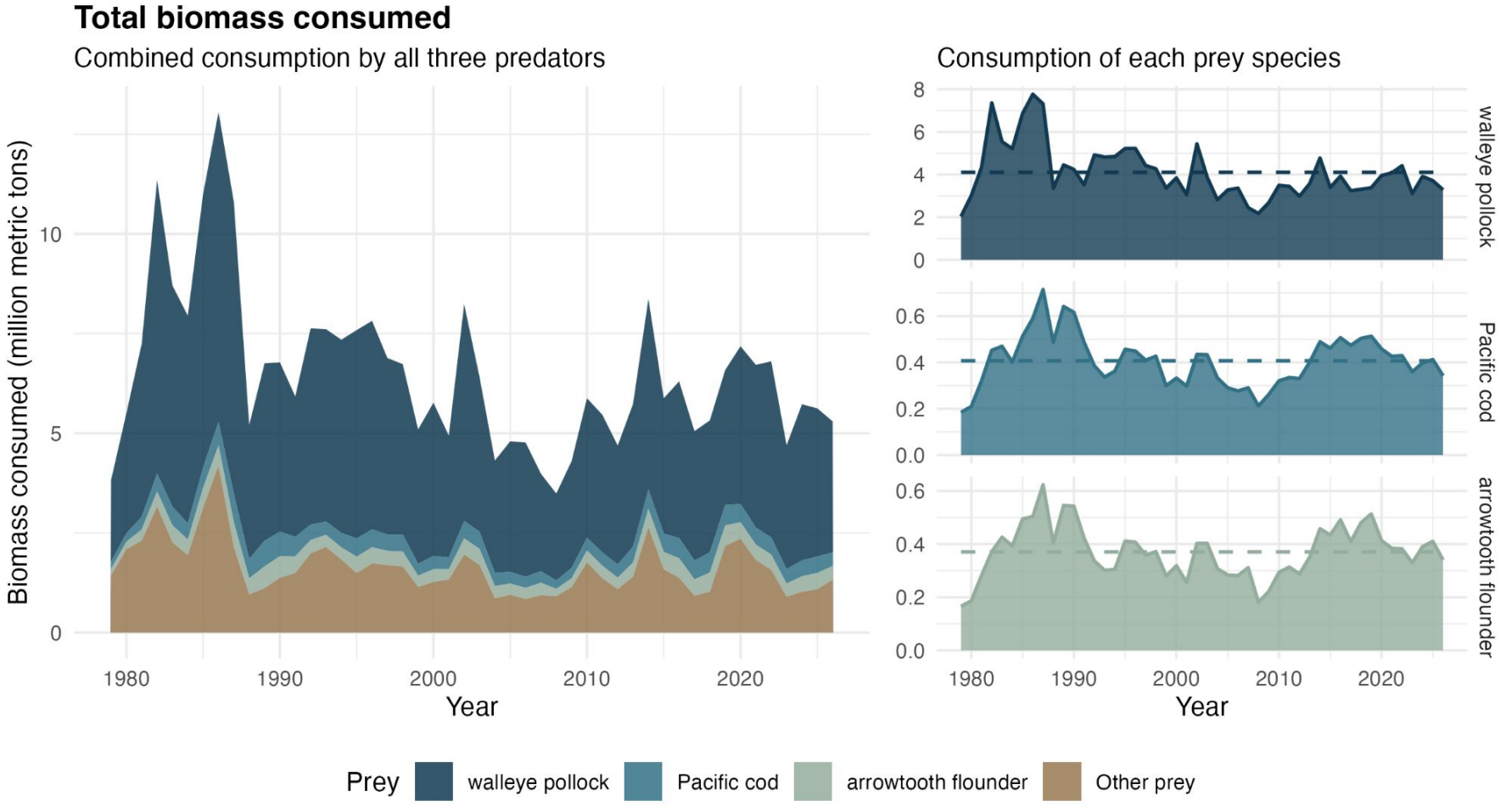


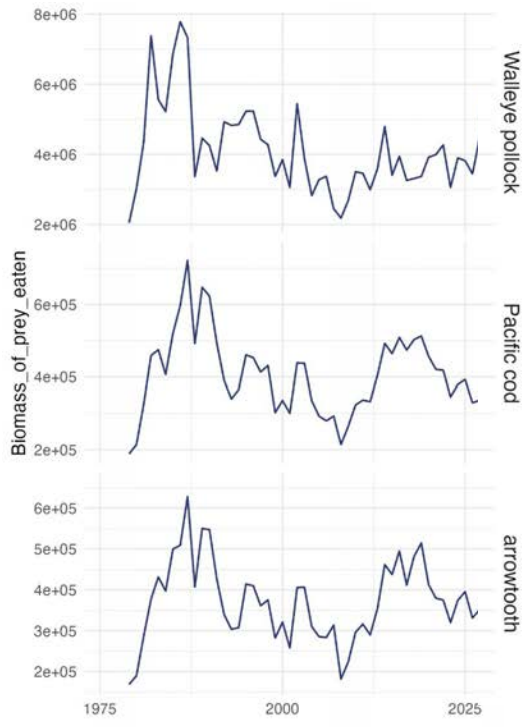
How many tons (and which ages) are eaten each year by cannibalistic con-specifics?

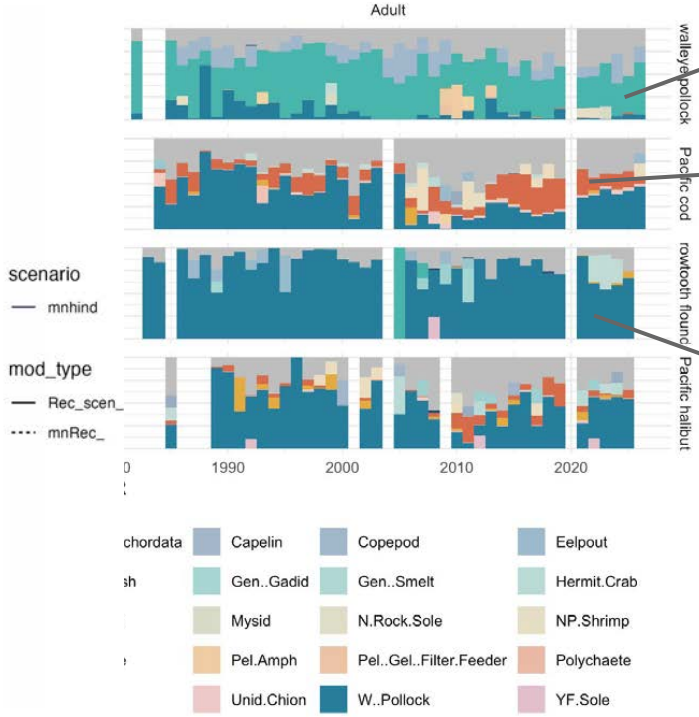


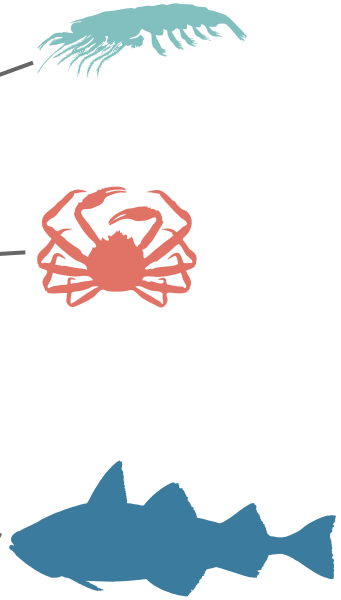
Annual prey consumed per predator (per capita)




Total biomass consumed
Combined consumption by all three predators
Biomass consumed (million metric tons)
0
5
10
1980
1990
2000
2010
2020
Year
Consumption of each prey species
walleye pollock
Pacific cod
arrowtooth flounder
0
2
4
6
0.0
0.2
0.4
0.6
1980
1990
2000
2010
2020
Year
Prey
walleye pollock
Pacific cod
arrowtooth flounder
Other prey


Biomass_of_prey_eaten
8e+06
6e+06
4e+06
2e+06
6e+05
4e+05
2e+05
6e+05
5e+05
4e+05
3e+05
2e+05
1975
2000
2025
Walleye pollock
Pacific cod
arrowtooth


Adult
walleye pollock
Pacific cod
rowtooth flound
Pacific halibut
scenario
mnhind
mod_type
Rec_scen_
mnRec_
1990
2000
2010
2020
chordata
Capelin
Copepod
Eelpout
Gen..Gadid
Gen..Smelt
Hermit.Crab
Mysid
N.Rock.Sole
NP.Shrimp
Pel.Amph
Pel..Gel..Filter.Feeder
Polychaete
Unid.Chion
W..Pollock
YF.Sole



Population estimates of predation

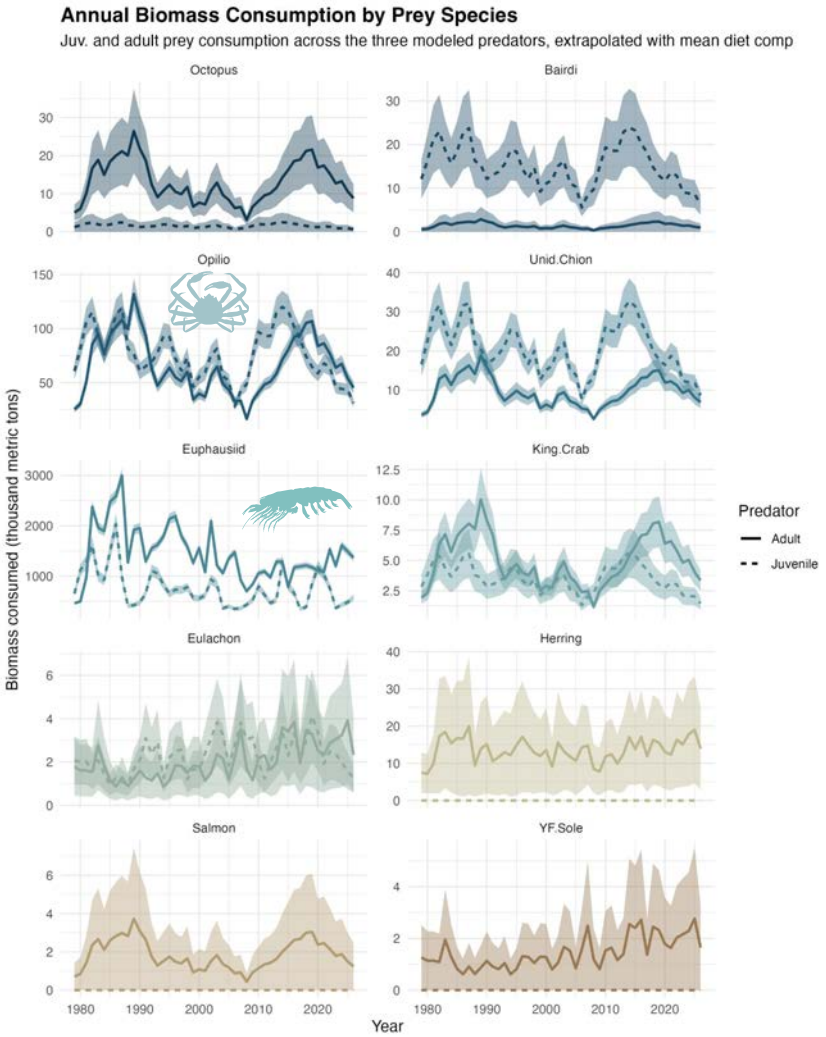
Diet database & survey CPUE

CNRG outputs

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

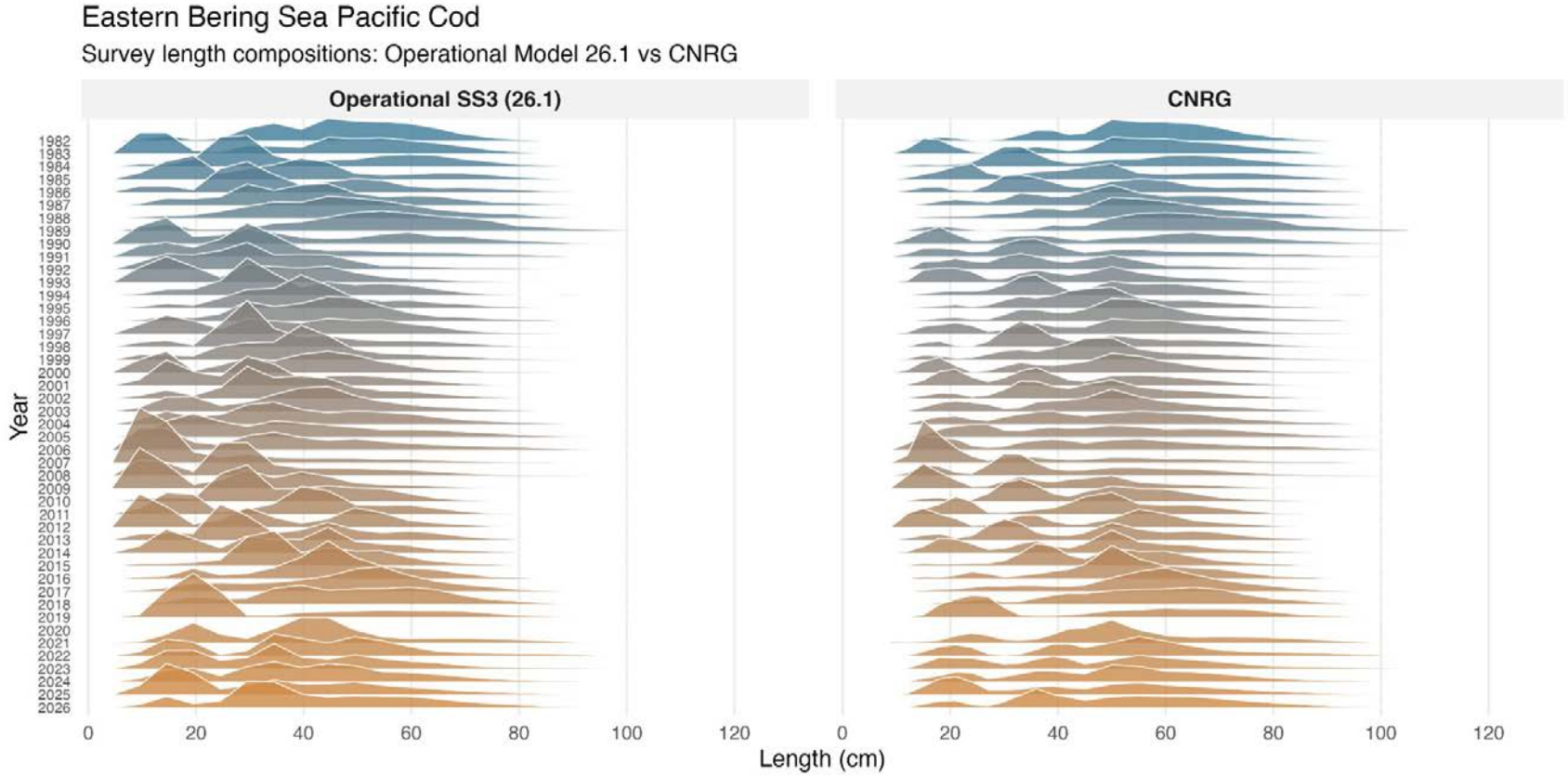
Biomass weighted avg prop of prey i in diet of pred size j

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



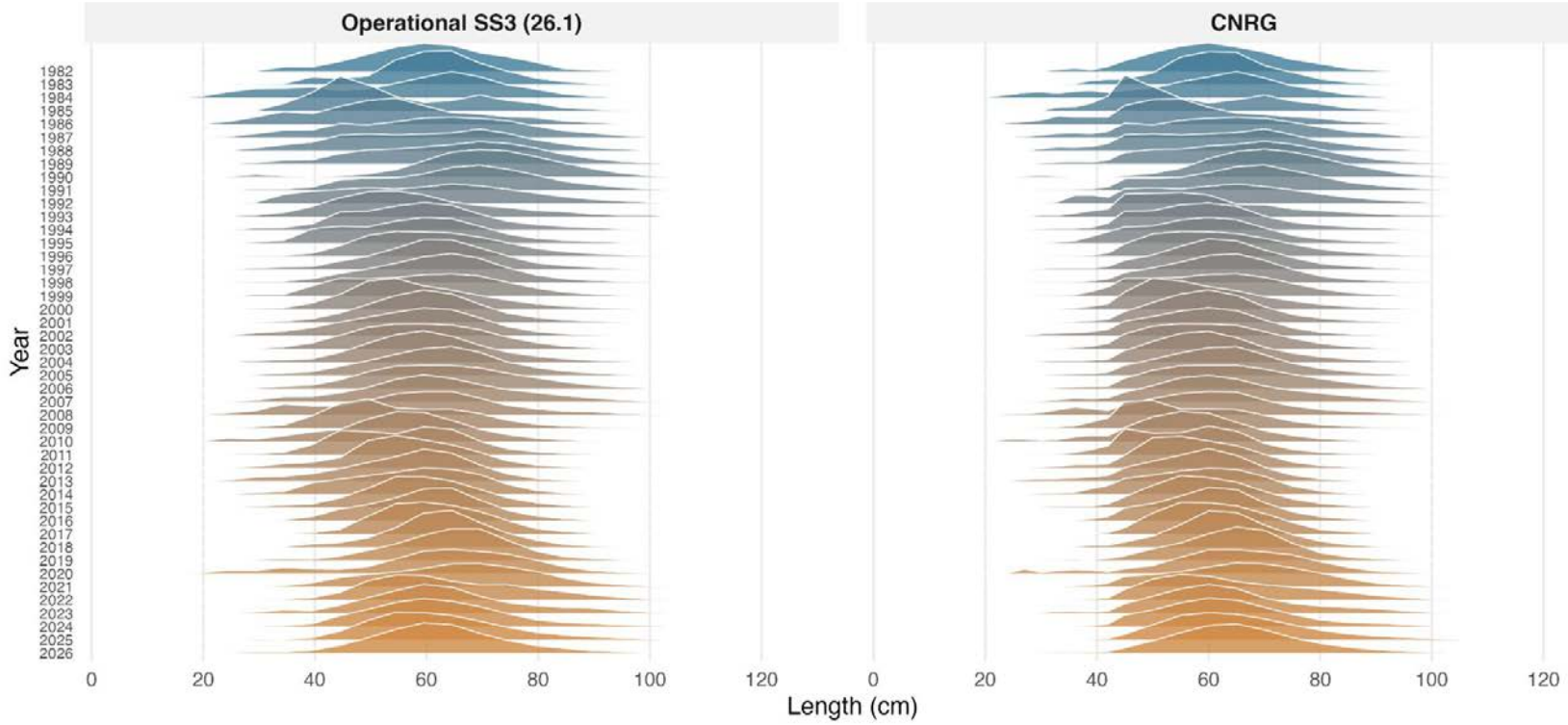
Comparison to SAFE assessments: P. cod



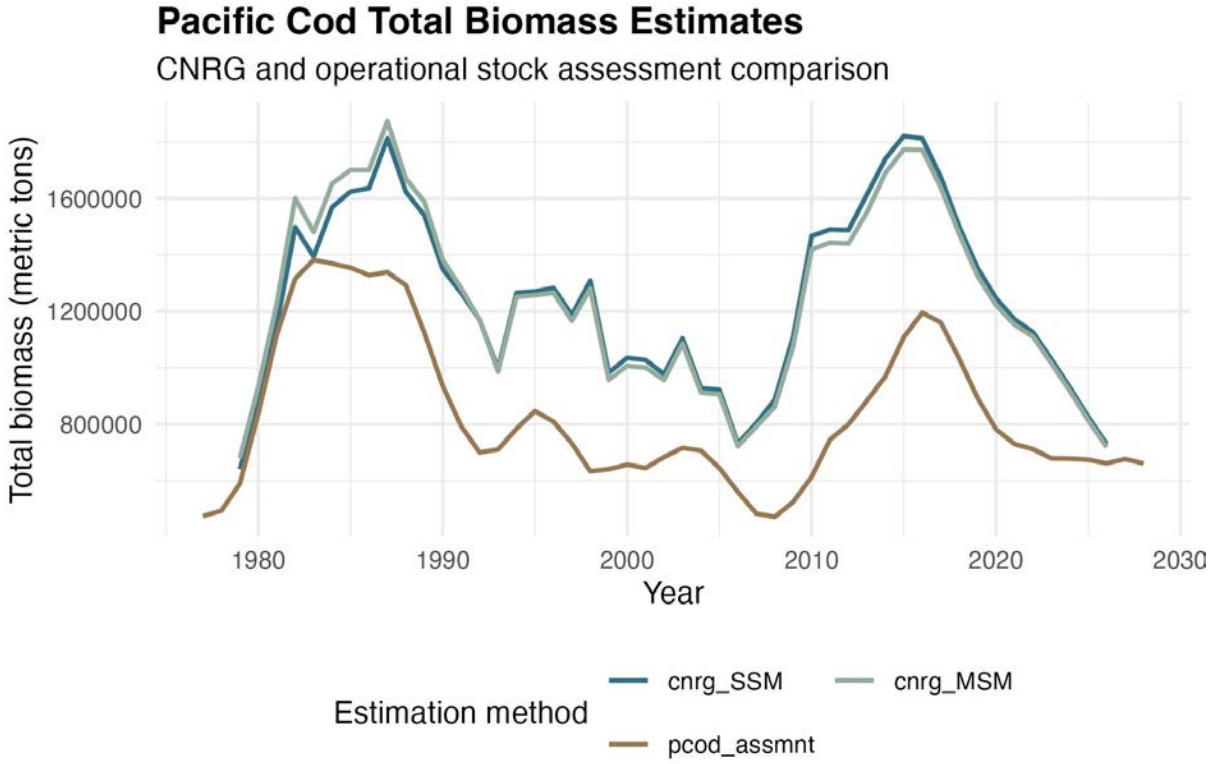

Eastern Bering Sea Pacific Cod
Survey length compositions: Operational Model 26.1 vs CNRG
Operational SS3 (26.1)
CNRG
Year
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
0
20
40
60
80
100
120
Length (cm)

Eastern Bering Sea Pacific Cod

Fishery length compositions: Operational Model 26.1 vs CNRG

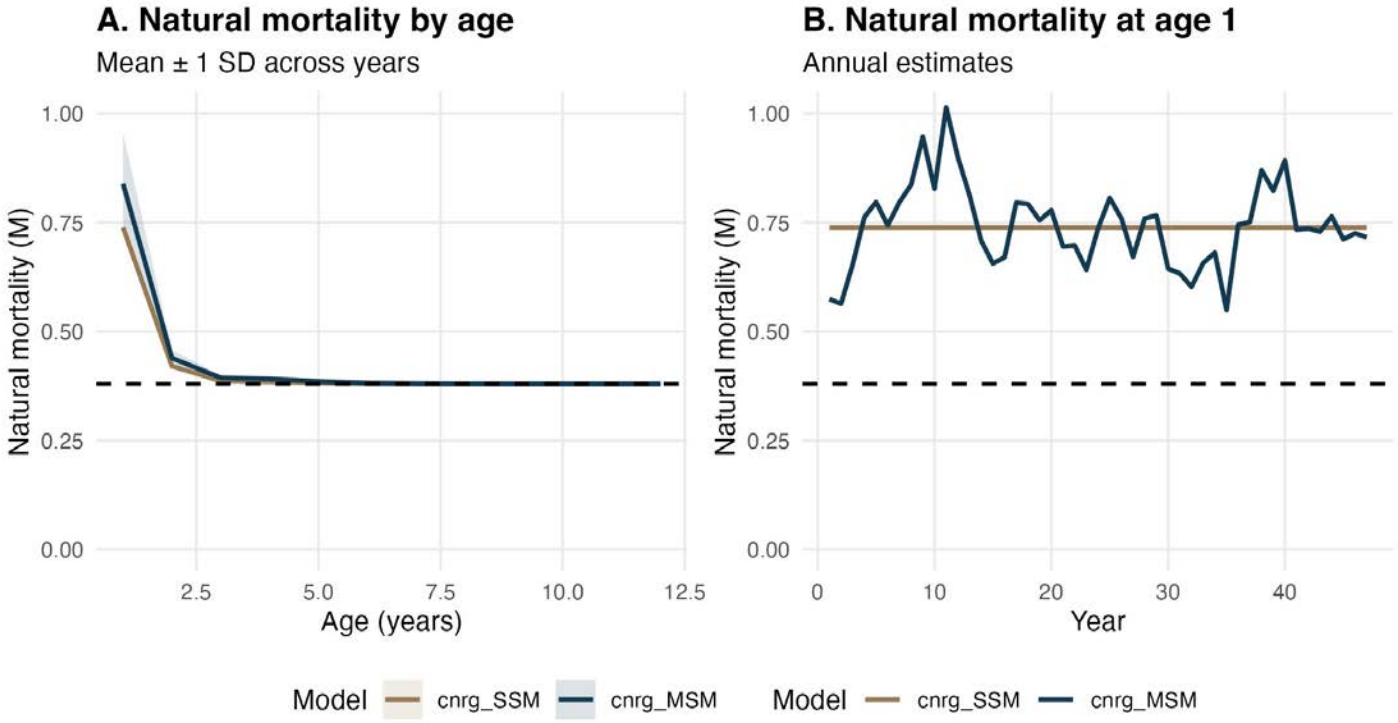


Total biomass



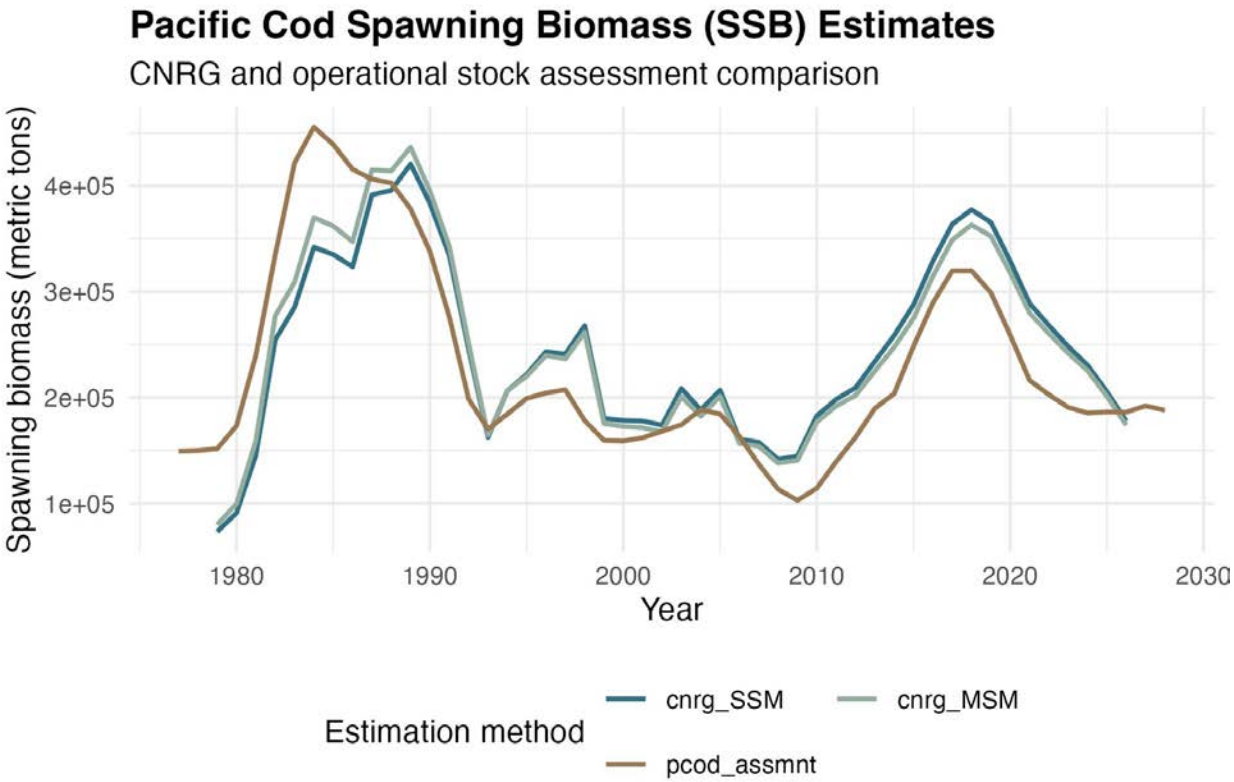
Eastern Bering Sea Pacific Cod: Natural Mortality

CNRG model estimates compared with operational assessment

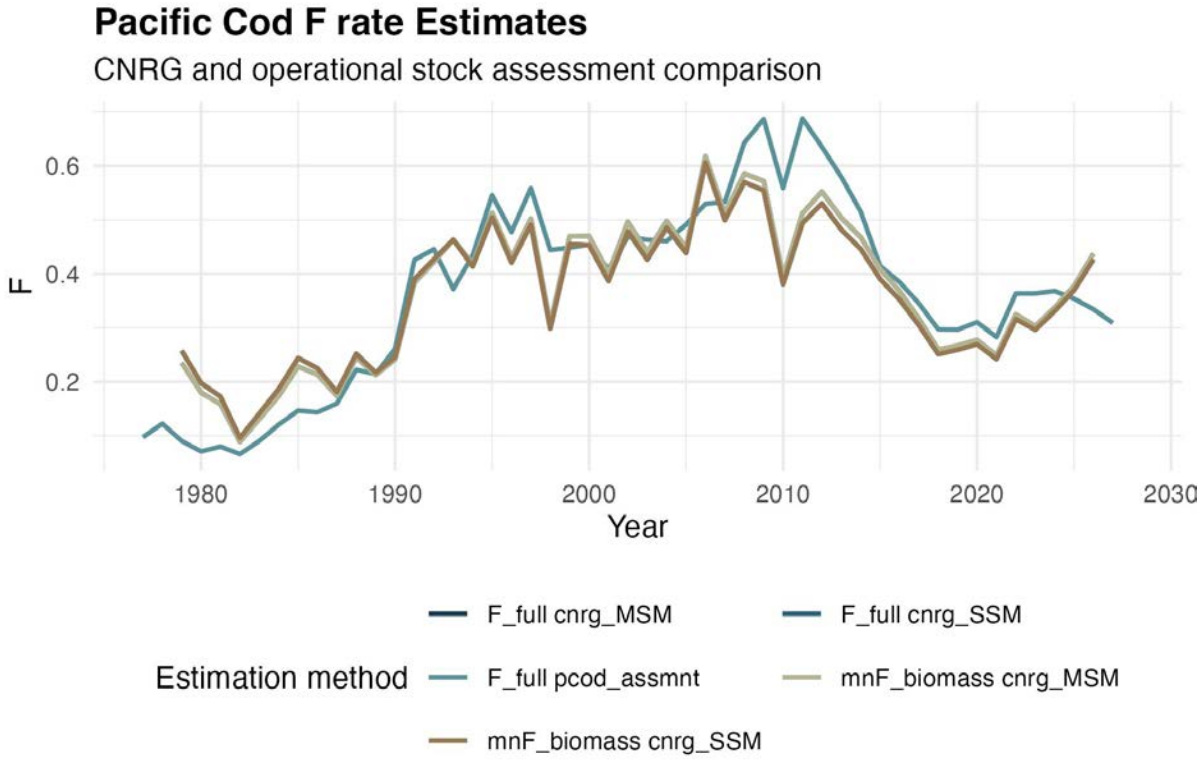


Dashed line indicates operational assessment M = 0.38.

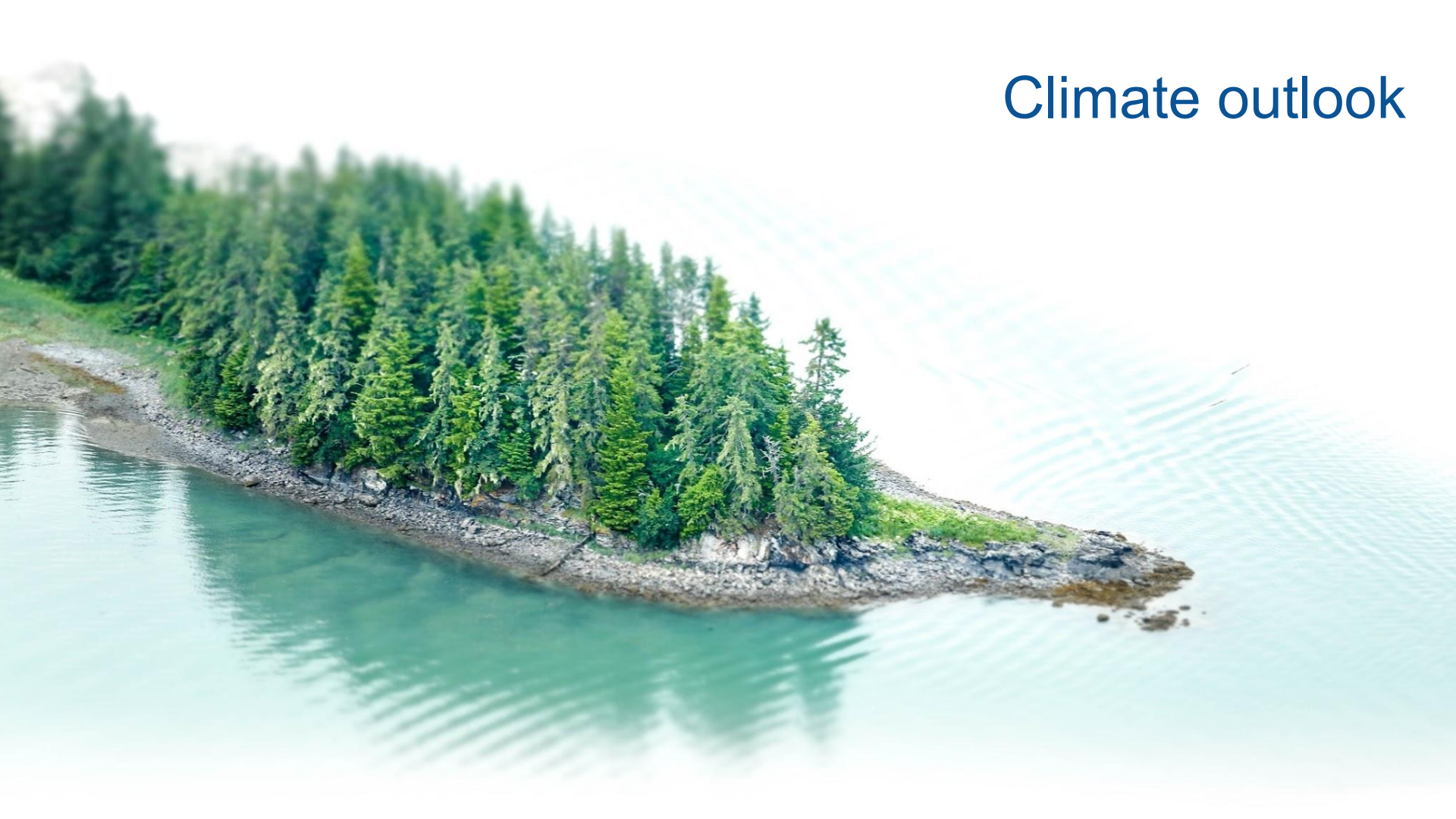
Female spawning biomass



Fishing mortality

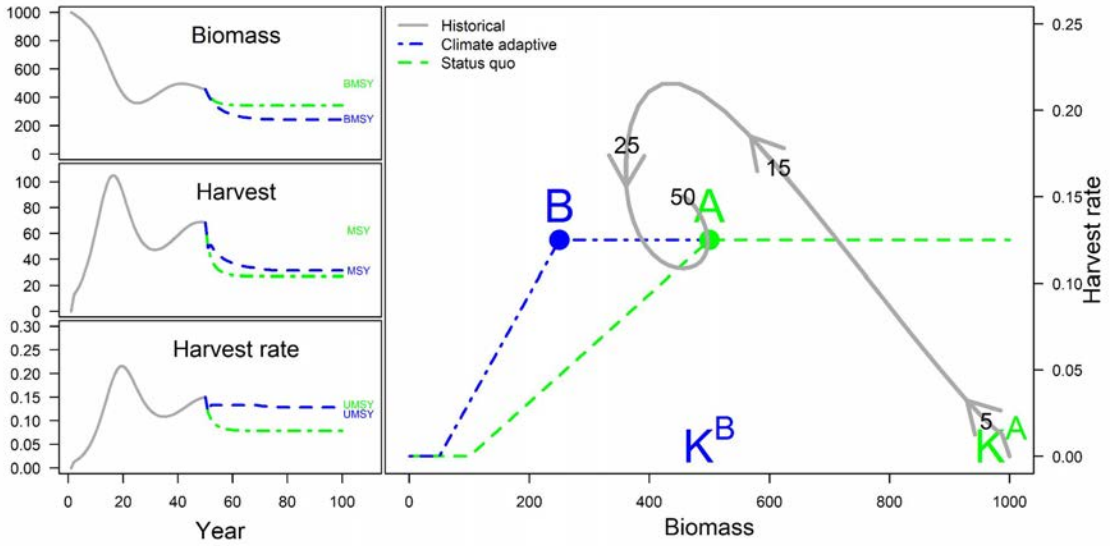


Climate outlook

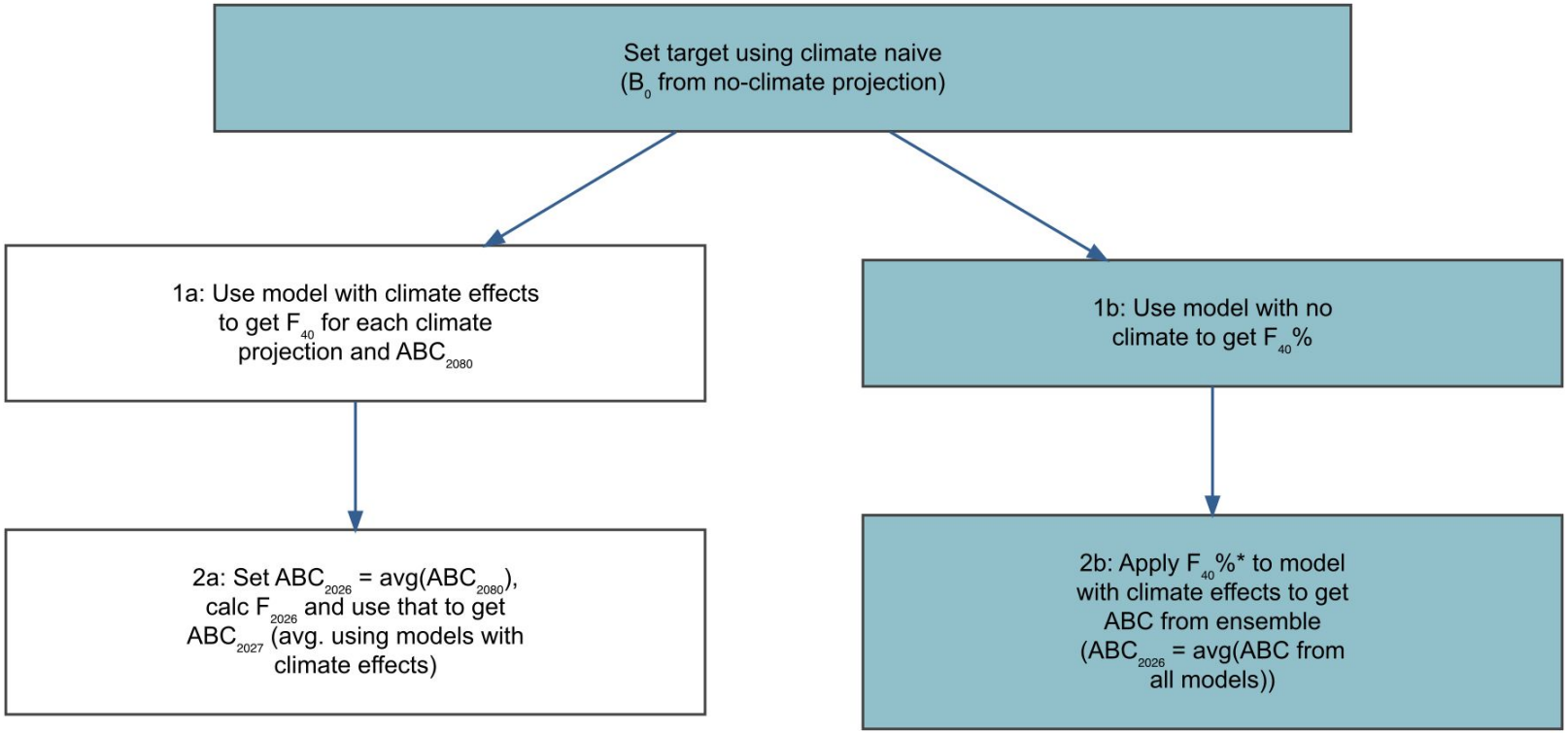


Adapting reference points to reflect changes in productivity

- 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


Set target using climate naive
(B_0 from no-climate projection)
1a: Use model with climate effects to get F_{40} for each climate projection and ABC_{2080}
1b: Use model with no climate to get F_{40}%
2a: Set ABC_{2026} = avg(ABC_{2080}), calc F_{2026} and use that to get ABC_{2027} (avg. using models with climate effects)
2b: Apply F_{40}%* to model with climate effects to get ABC from ensemble (ABC_{2026} = avg(ABC from all models))

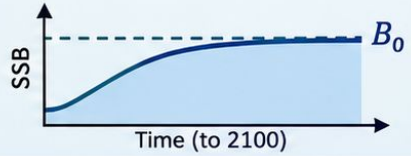
Climate informed biological reference points

Climate-Informed ABC: A Hybrid Approach

A practical way to incorporate climate effects while keeping consistent, intuitive harvest targets

1 Climate-naive reference

Project the model with historical climate and no fishing to estimate the unfished spawning biomass (B_0).



2 Set the target

Use a climate-naive target biomass (B_{target}) as a fixed reference (e.g., 40% of B_0 for ABC; 35% of B_0 for OFL).

$B_{target} = x\%$ of B_0

ABC: $B_{40} = 0.40\,B_0$

OFL: $B_{35} = 0.35\,B_0$

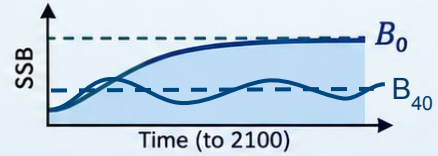
3 Find a climate-informed harvest rate

Project the model with climate effects and iteratively solve for F_{target} that achieves the target (e.g., B_{40}) over the projection period, with a constraint SSB ≥ 35% of B_0.



4 Calculate ABC and OFL

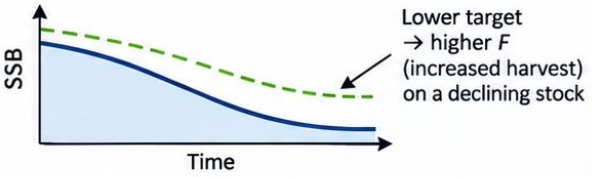
Apply F_{target} to the model to derive near-term harvest specifications (ABC, OFL) for the next 1–2 years under each climate scenario.



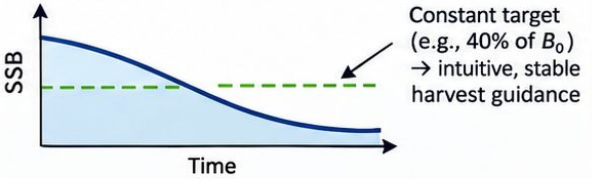
Why a hybrid approach?

Using a climate-informed target that shifts with climate can lead to non-intuitive harvest guidance, such as higher (lower) harvest rates on declining (increasing) populations.

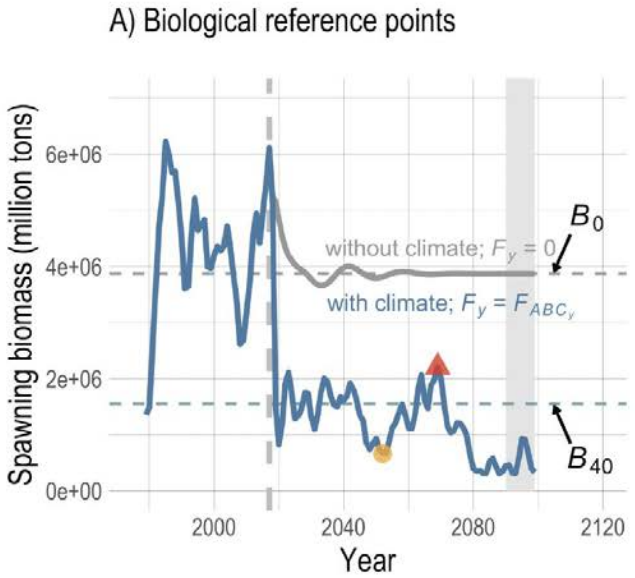
Climate-informed target *(potential issue)*

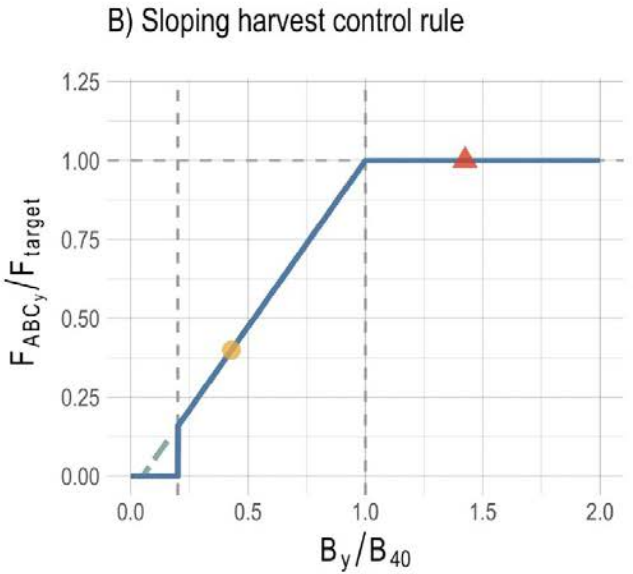


Hybrid approach (this study)



Climate informed biological reference points





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

NOAA FISHERIES

2026 Climate informed targets & reference points

Table 11: Biological reference point (BRP) summary for the 2026 assessment. Values are provided for single-species (SSM) and multispecies (MSM) model configurations under the historical-climate reference scenario.

	Walleye pollock		Pacific cod		Arrowtooth flounder	
Quantity	SSM	MSM	SSM	MSM	SSM	MSM
Current SSB (t)	3,856,379	3,810,401	148,432	139,595	350,661	360,268
Unfished SSB (t)	7,670,124	7,065,215	500,871	479,964	418,457	436,103
Target SSB (t)	6,276,556	4,333,528	812,969	559,828	359,527	299,410
Current SSB / SSB0	0.503	0.539	0.296	0.291	0.838	0.826
Current SSB / Btarget	0.614	0.879	0.183	0.249	0.975	1.203
F ABC max	0.308	0.752	0.100	0.126	0.117	0.181
F ABC	0.308	0.752	0.073	0.090	0.117	0.181
F ABC target	0.308	0.752	0.000	0.076	0.117	0.181
2027 ABC	2,234,280	4,383,574	38,261	44,395	53,690	82,180
2028 ABC	1,977,174	3,177,712	43,749	50,567	44,649	63,576

CNRG

RELATIVE CONTEXT ONLY

* $SSB0,2100$ and $SSBtarget,2100$ are based on climate-naive model projections of SSB at 2100 (equilibrium) given $F = 0$ and $F = Ftarget$, respectively.

** Target ratios in 2100 are based on $B/B0$=0.4, given that $B/B0 > 0.35$ for all future yr.

*** Projected $SSB2025$ (t) refers to SSB at the start of 2025 and Projected $SSB2026$ (t) refers to SSB at the start of 2026 using $FABC,2025$ for 2025

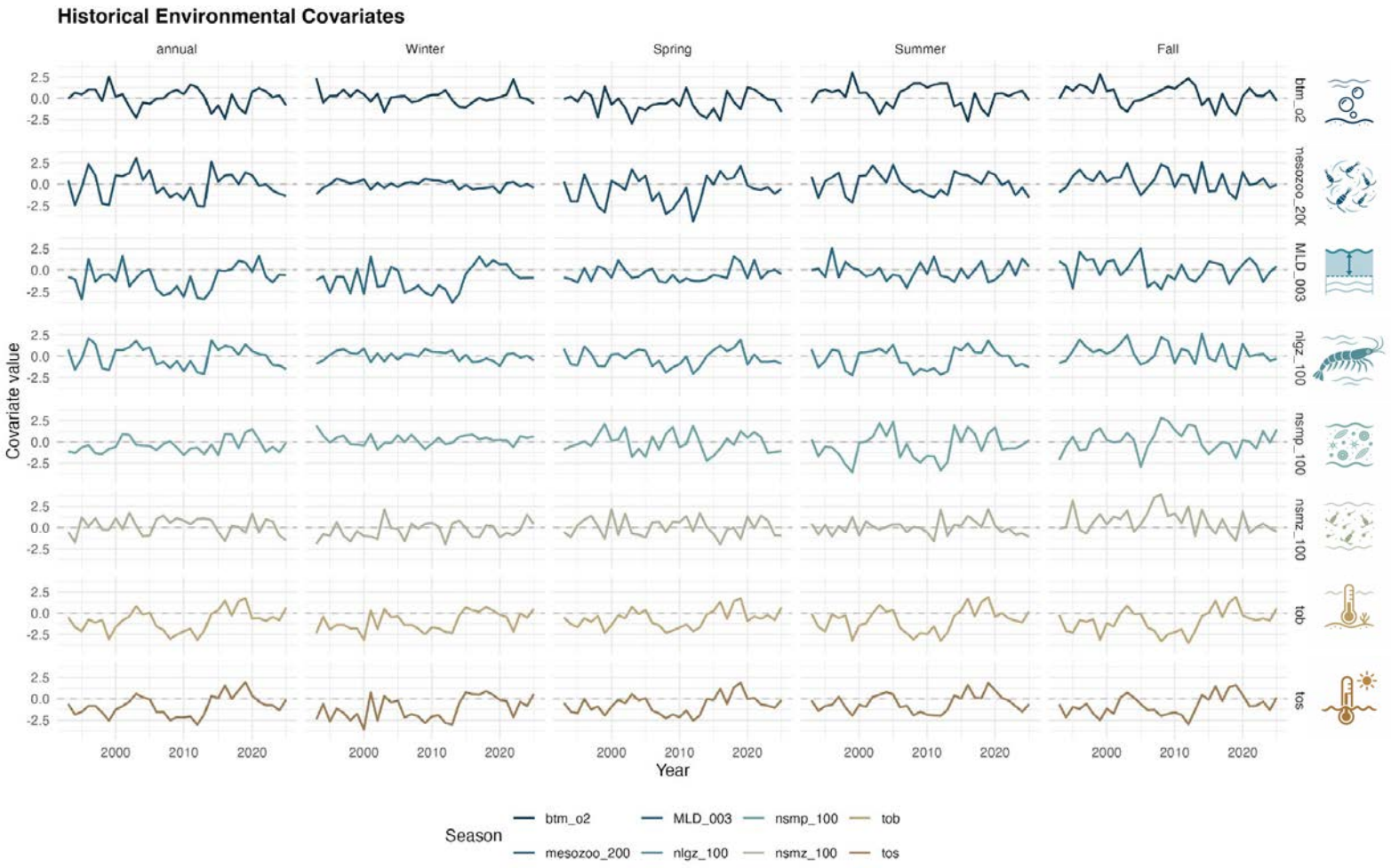


Figure 11: Recruitment covariates from the MOM6 hindcast for the Bering Sea

Output: Climate linked VonB growth

$$W_{ij,y} = W_{\infty,iy}(1 - e^{(-K_i(1-d_{i,y})(j-t_{0,i}))})^{1/(1-d_{i,y})}e^{\varepsilon}$$

$$d_{i,y} = e^{(\alpha_{d,i,y}+\alpha 0_{d,i}+\beta_{d,i}T_y)}$$



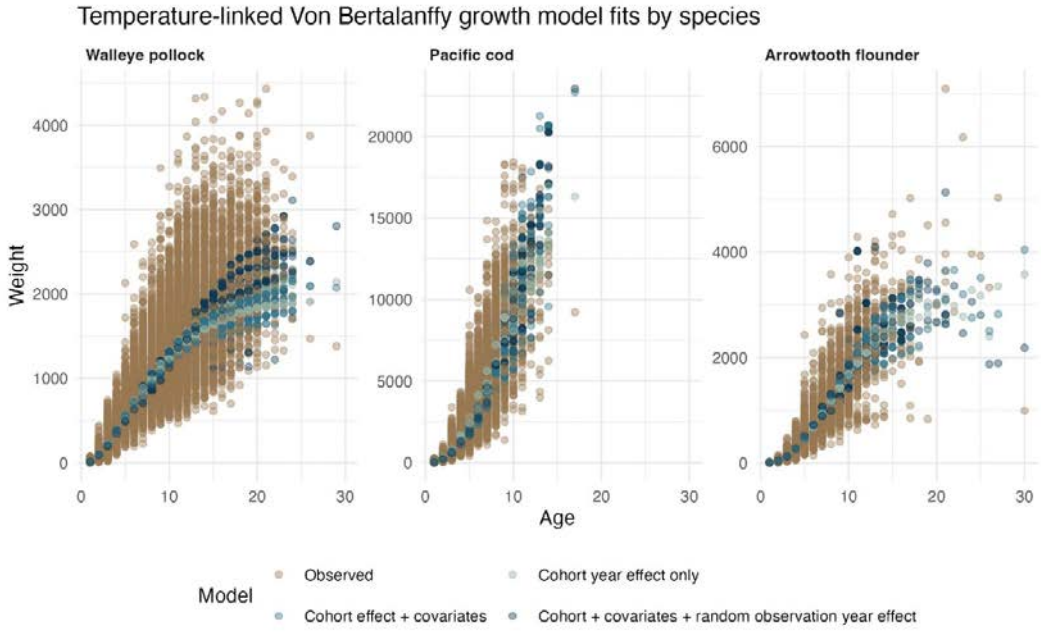
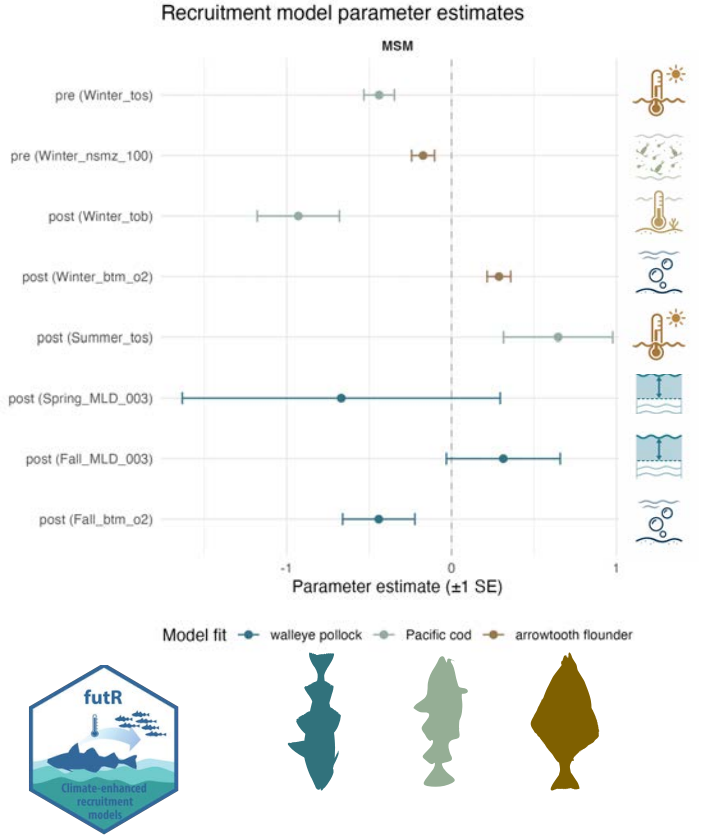


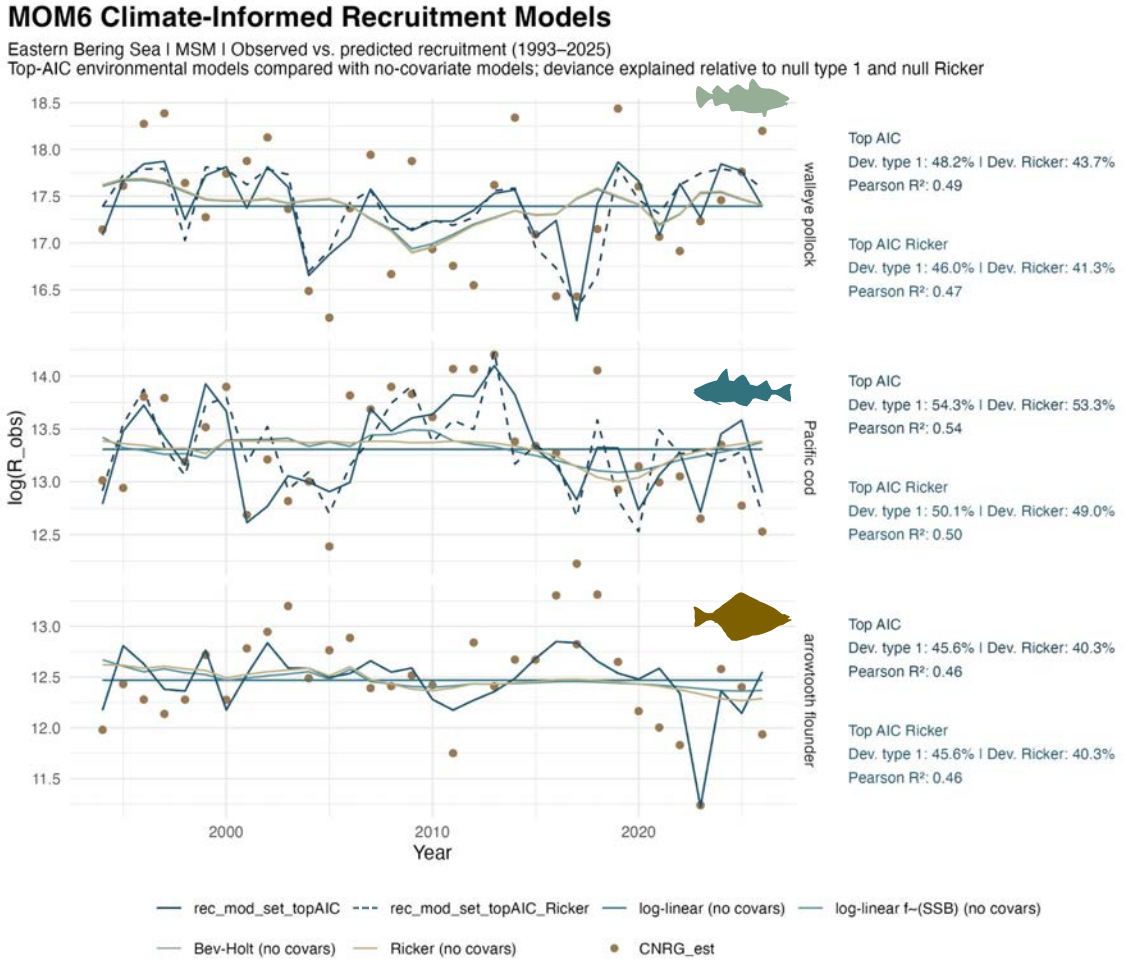
Figure 4: Fit of the von Bertalanffy growth model (vonBEE) with MOM6 annual mean bottom temperature and mesozooplankton indices for EBS pollock, where bottom temperature (Temp) and temperature squared (Temp²) are predictor variables.

Figure 4, p. 22

Holsman et al. in prep

MOM6 recruitment

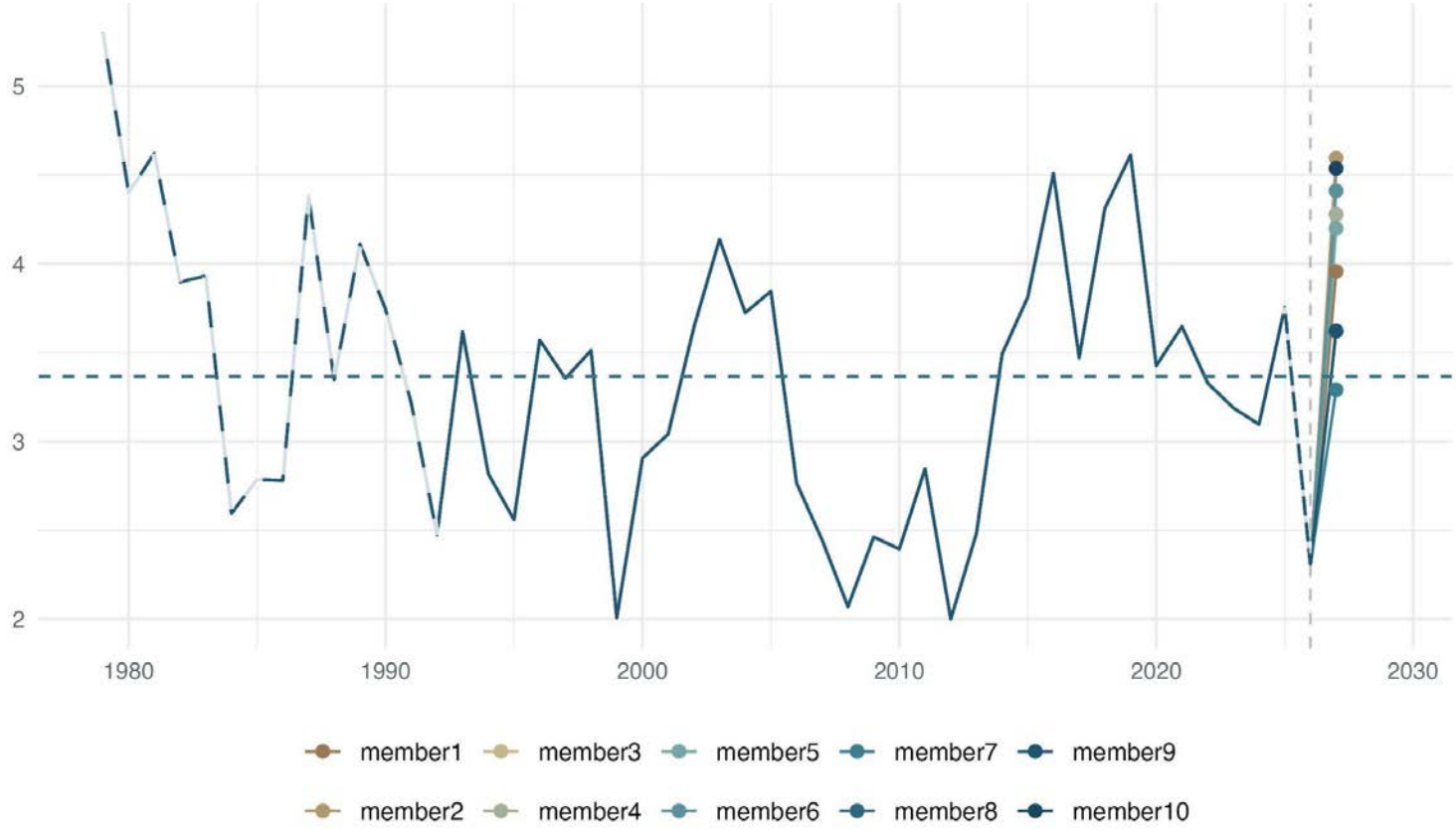




Holsman et al. in prep.

Eastern Bering Sea (SEBS)

CNRG Index of summer bottom temperature (°C); baseline = 1979-2019



Survey areas: EBS = 98

Future Sensitivity runs

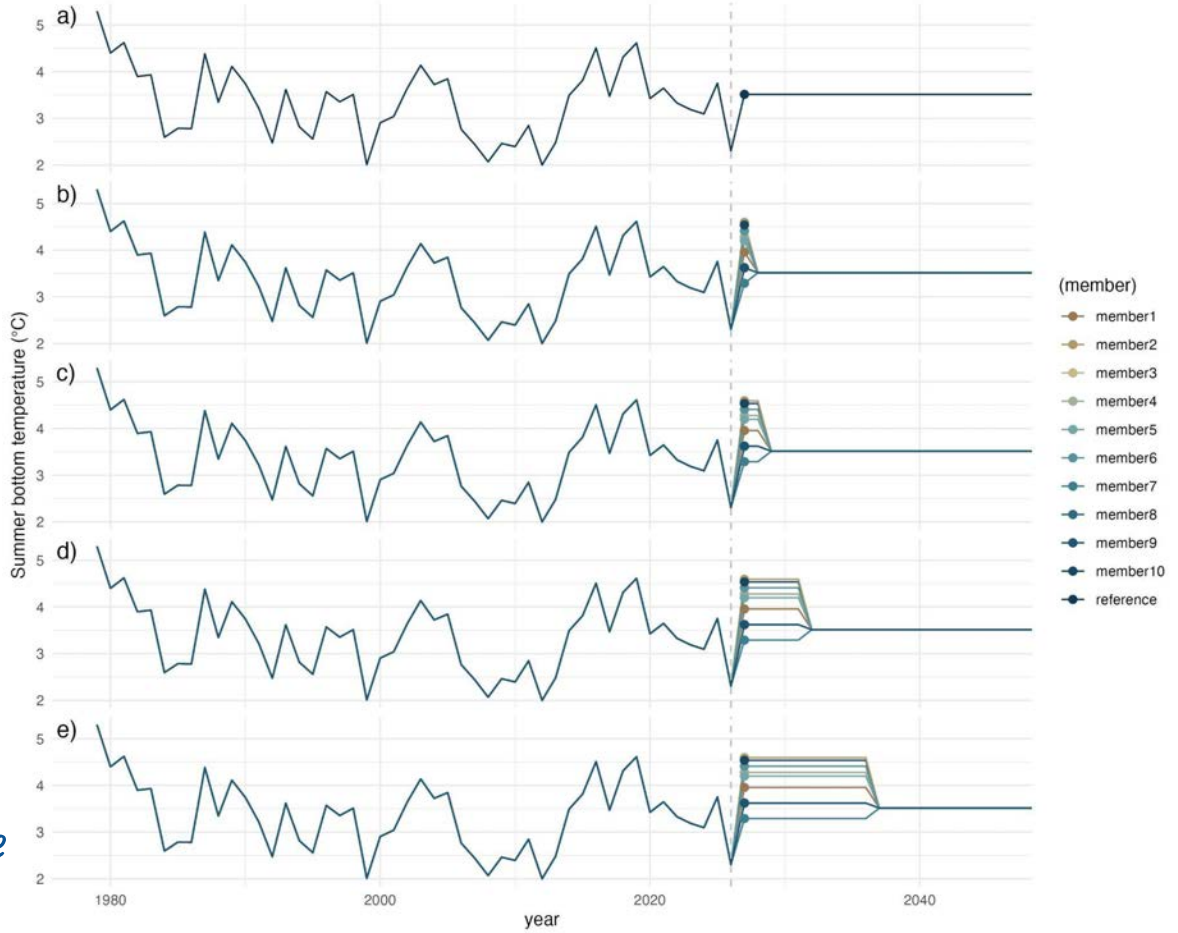
Future = mean of last 10 yrs

forecast (10 member esm), lasts 1 year, then returns to average

forecast (10 member esm), lasts 2 year,2 then returns to average

forecast (10 member esm), lasts 5 years,2 then returns to average

forecast (10 member esm), lasts 10 years,2 then returns to average



Change induced by future condition



What year does it return to average?

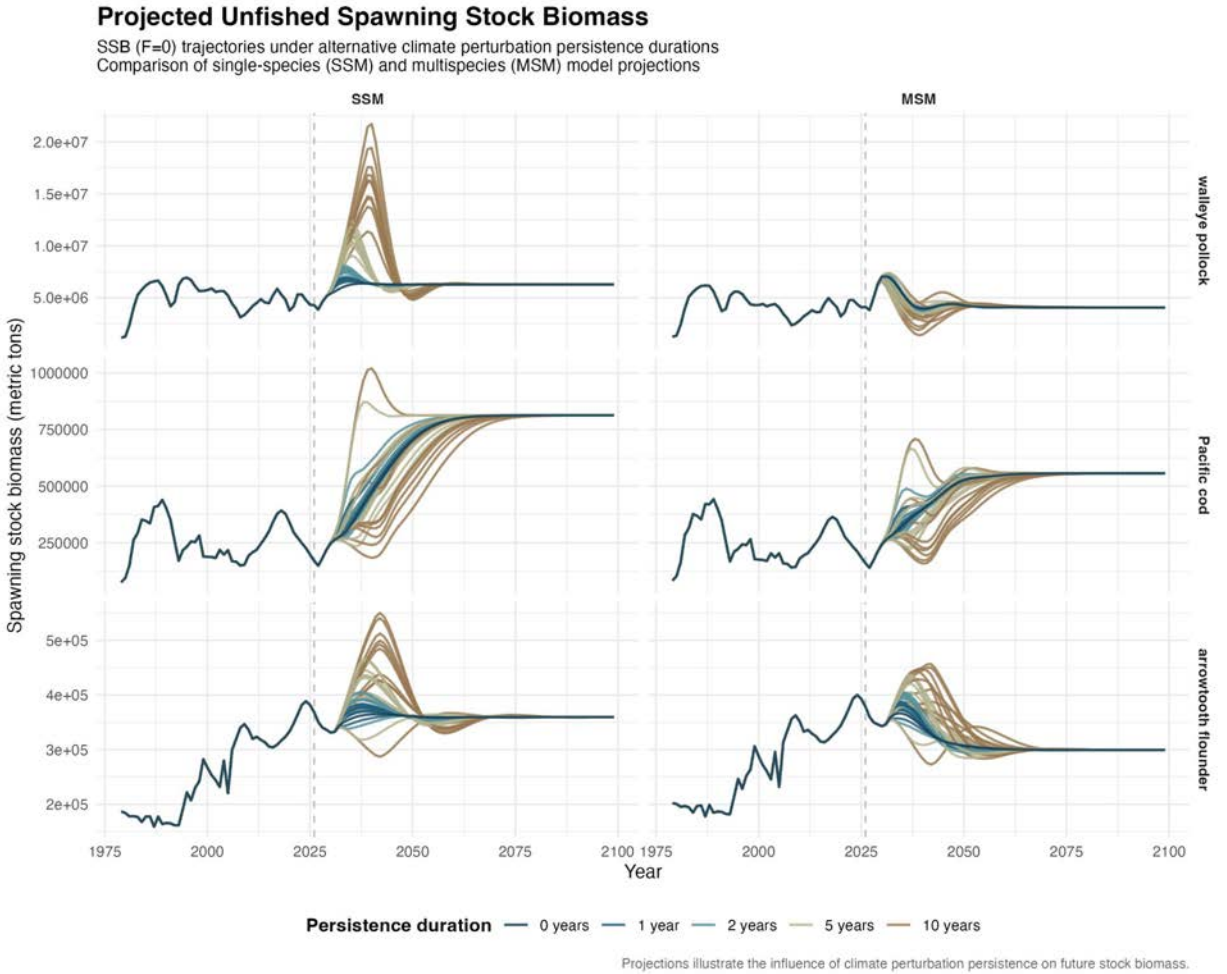
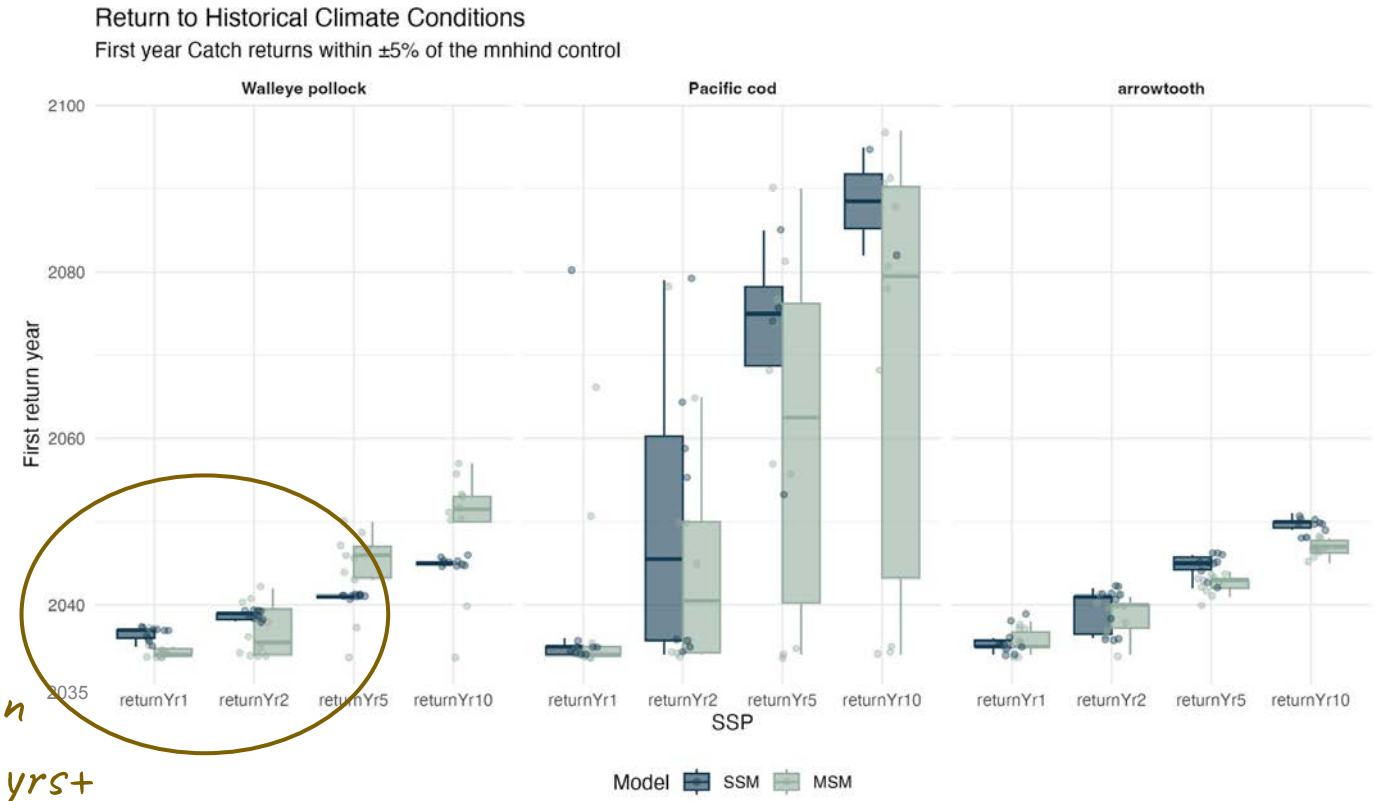


Fig. 33, p.65

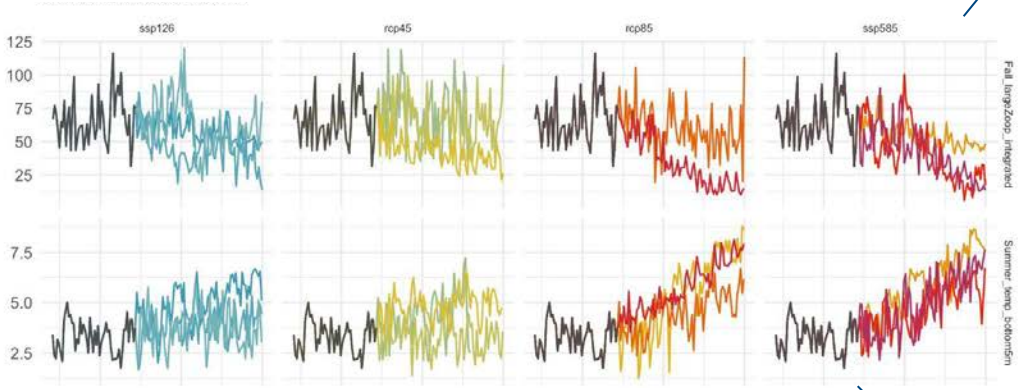
Forecast sensitivity

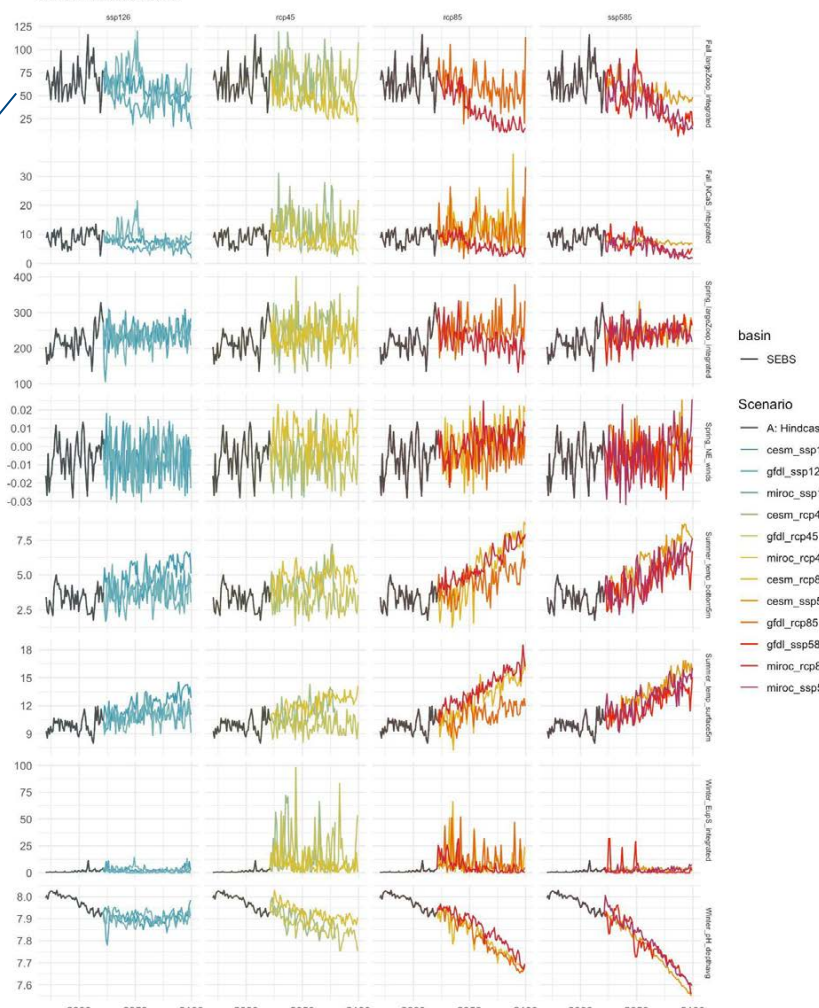


Effects can last 5-10 yrs+

Fig. 34, p.66

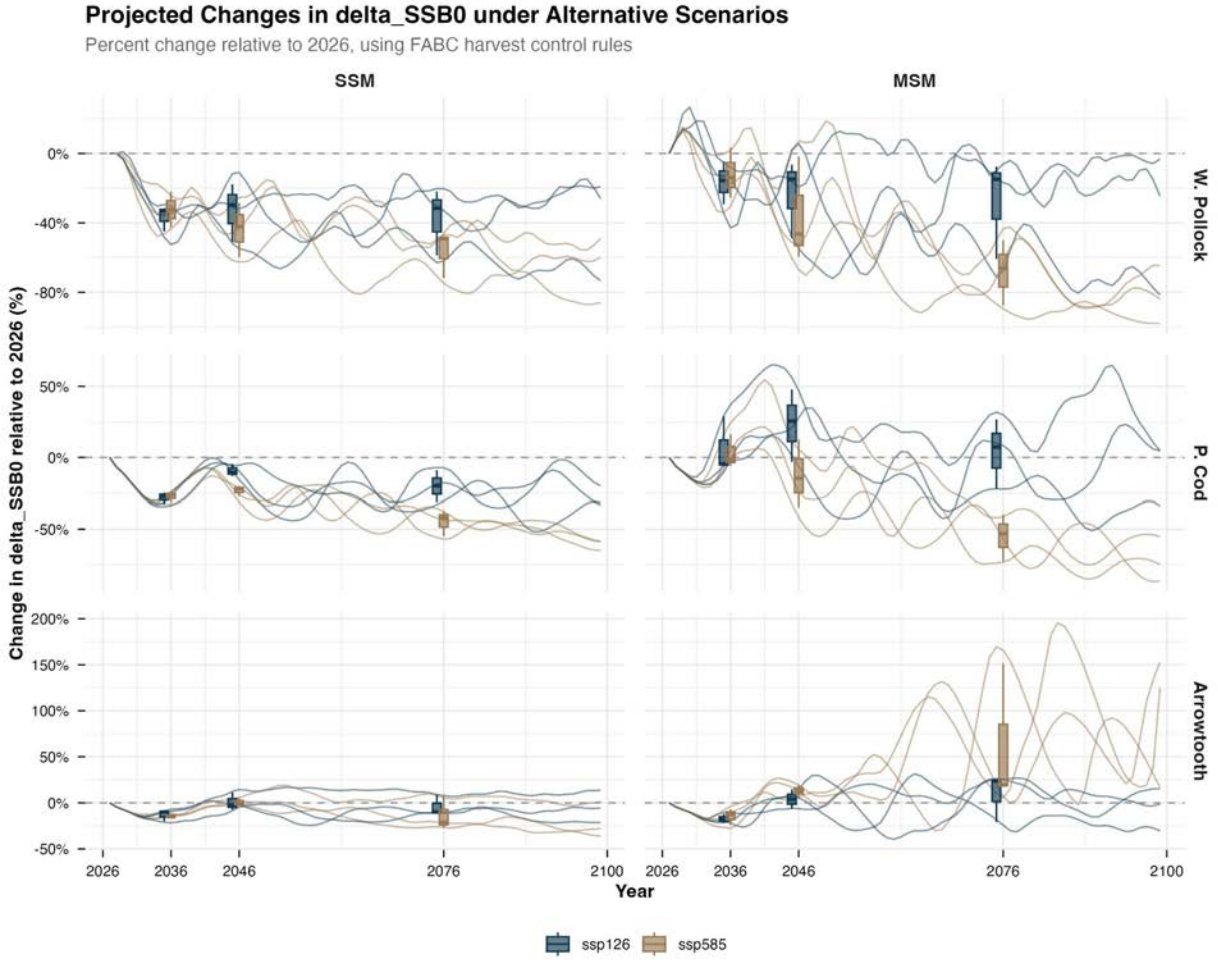
ROMSNPZ Recruitment covariates



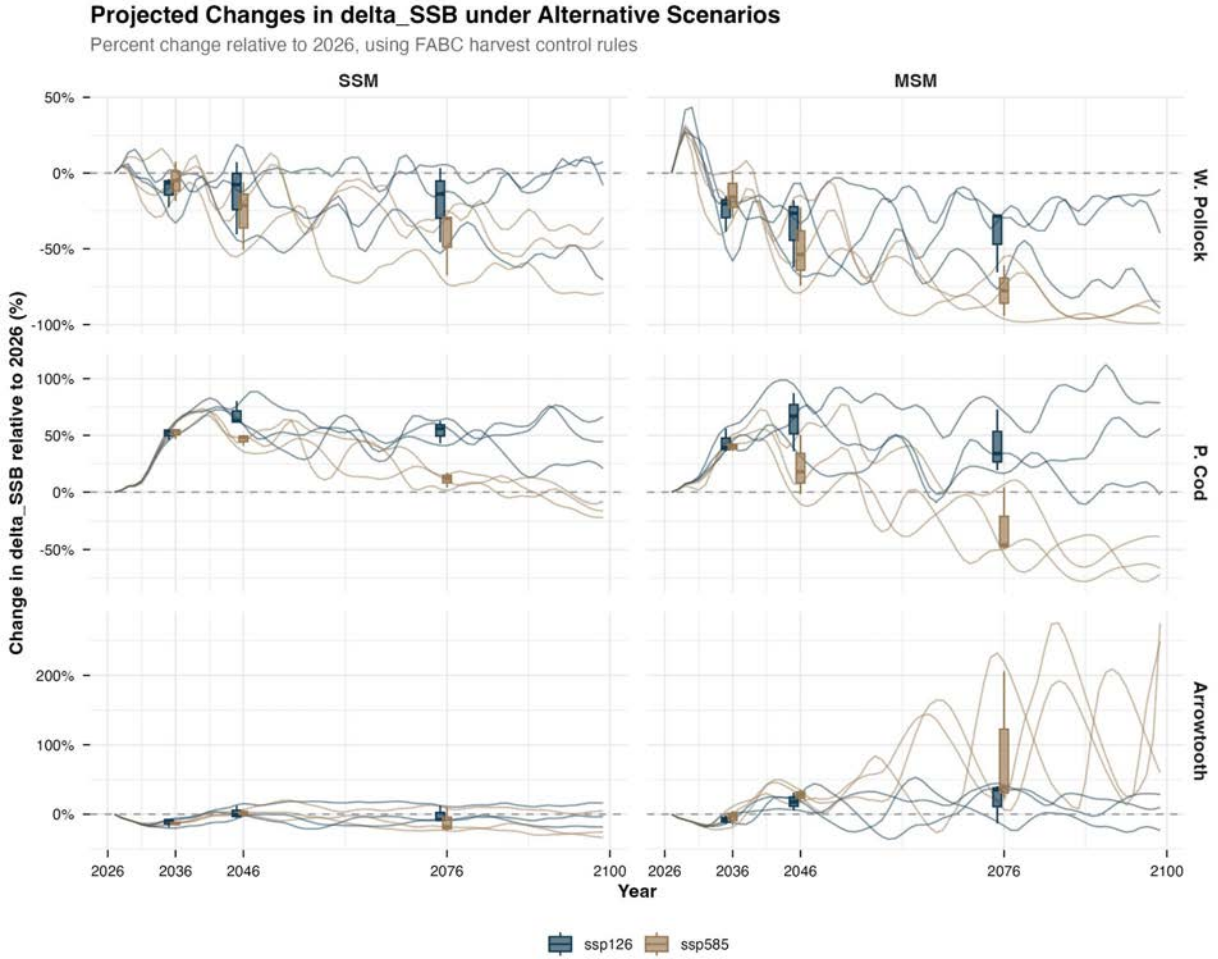


ACLIM indices

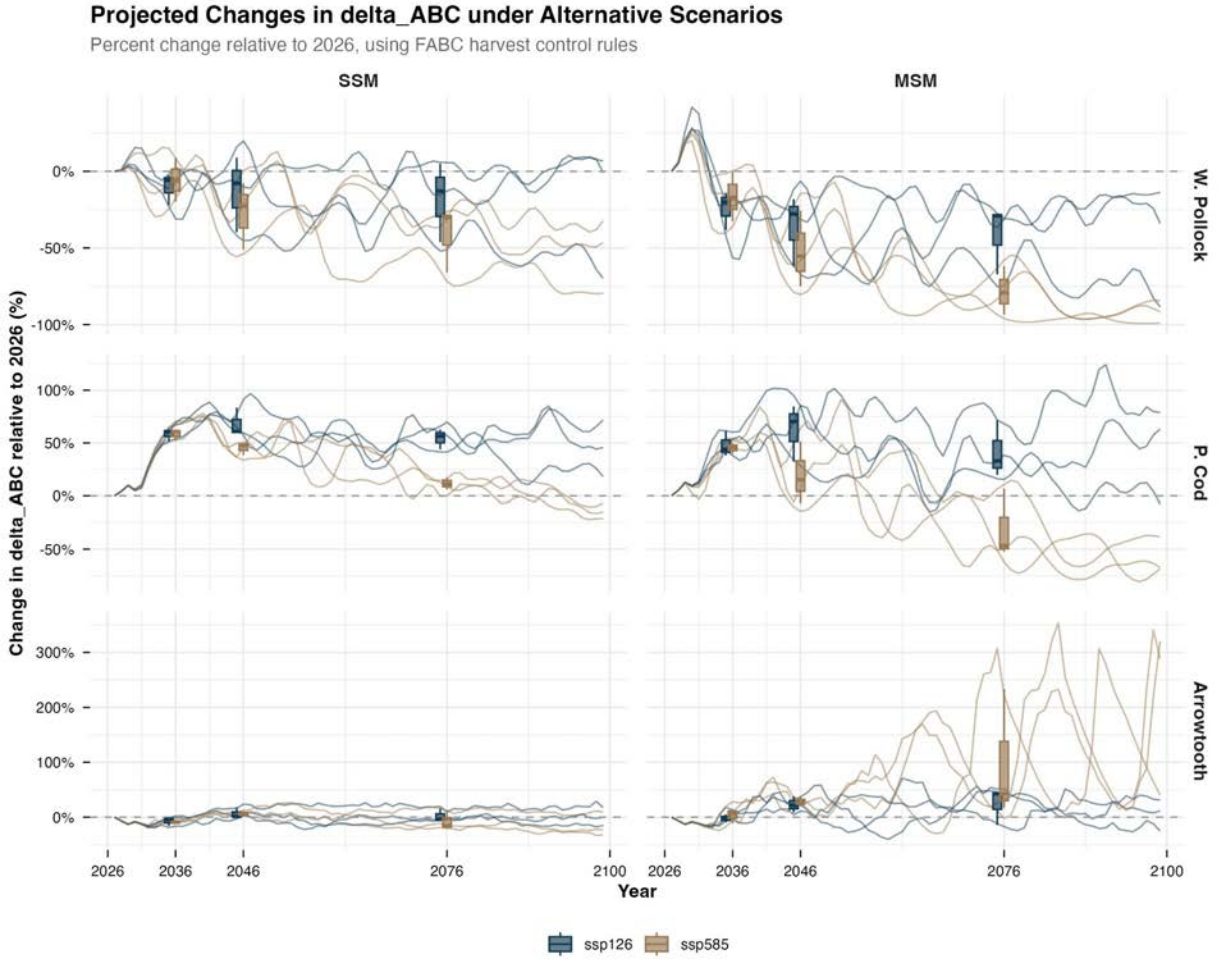
Multispecies multidecadal projections (ROMSNPZ)



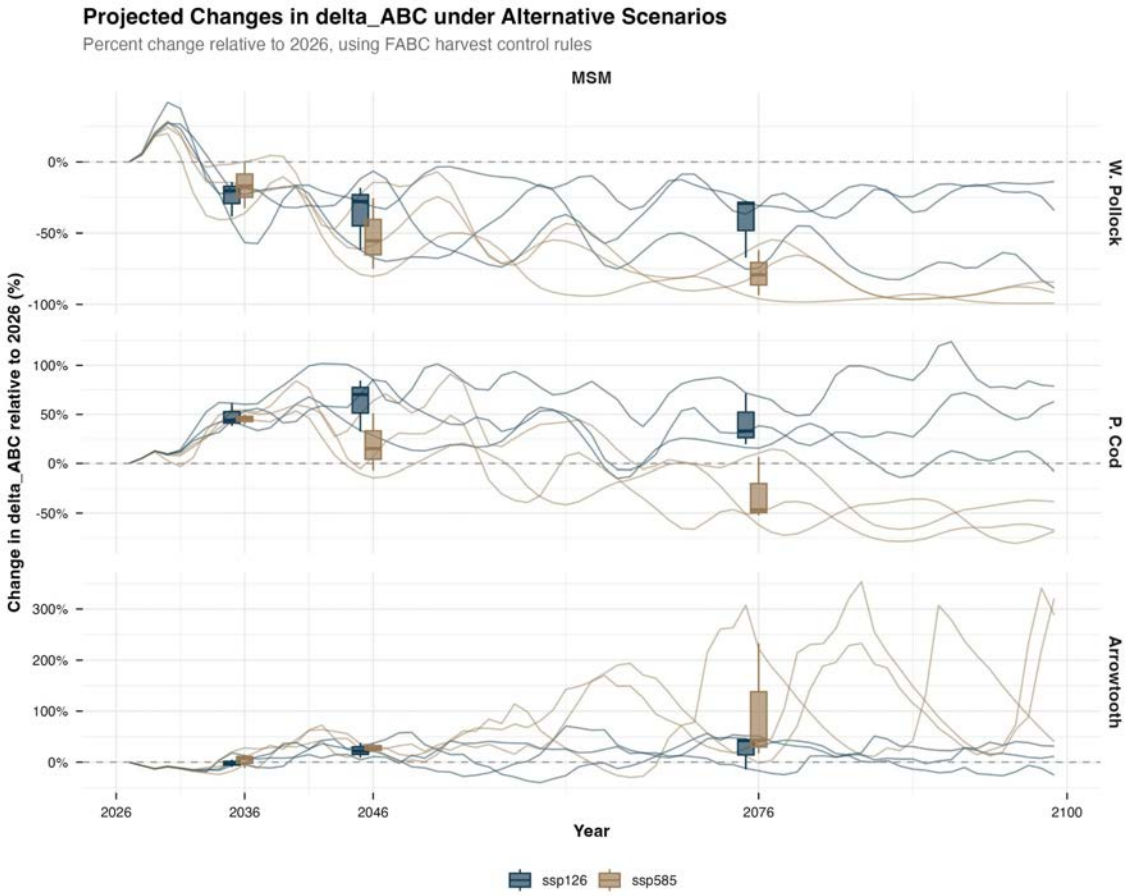
Multispecies multidecadal projections (ROMSNPZ)



Multispecies multidecadal projections (ROMSNPZ)



Multispecies multidecadal projections (ROMSNPZ)



Next year…



Broader MICE Applications

Operational Climate informed EBM advice:

- Individual chapters (GOA and EBS)
- M2 index for EBS ecosystem status report (2016 to now)
- M2 index for ESP (2020 to now)
- 2010-2015 BSIERP MSE
- 2016- now ACLIM - climate MSE
- MSE work for halibut + core
- G. Adams:
  - M2 index for GOA Ecosystem Status Report (2021-now)
  - Climate MSE underway for GOA
- CaliCurrent Hake (S. Wassermann, R. Diaz)



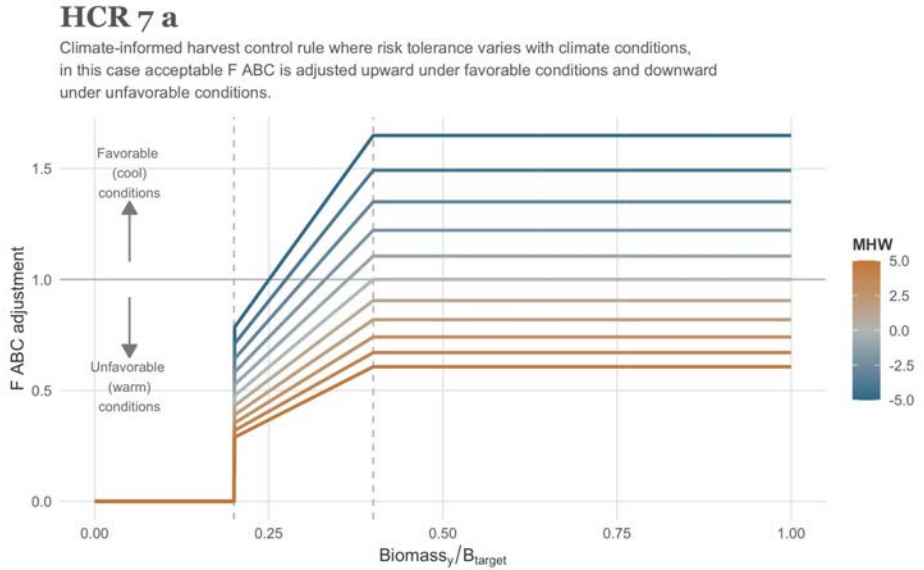
Multi-mandate advice

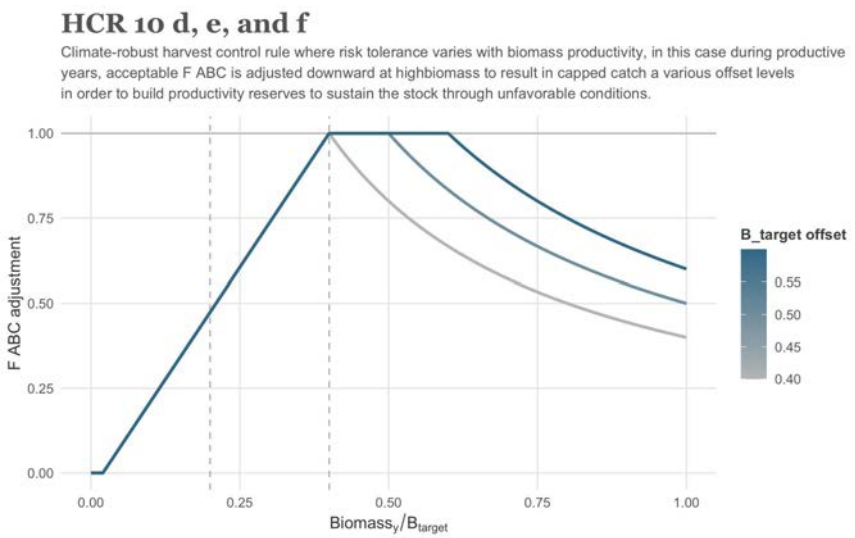
Marine Mammal Linked MICE

- 2019- 2023 Lenfest NFS
- CNRG ongoing work with DEB and NFS (A. Sulc)
- Cali current: R. Ruiz Diaz Rceattle hake and california sea lions



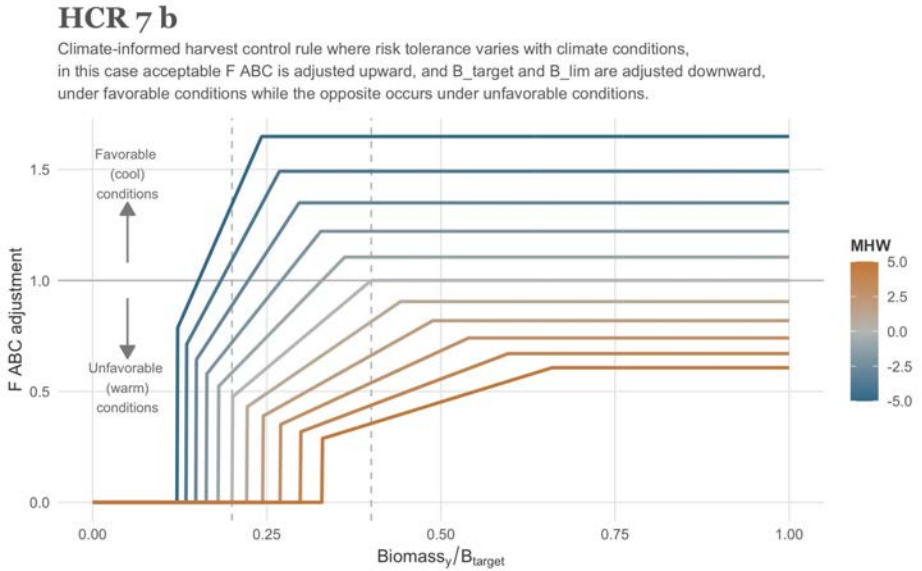
(A)CLIM HCR evaluations underway

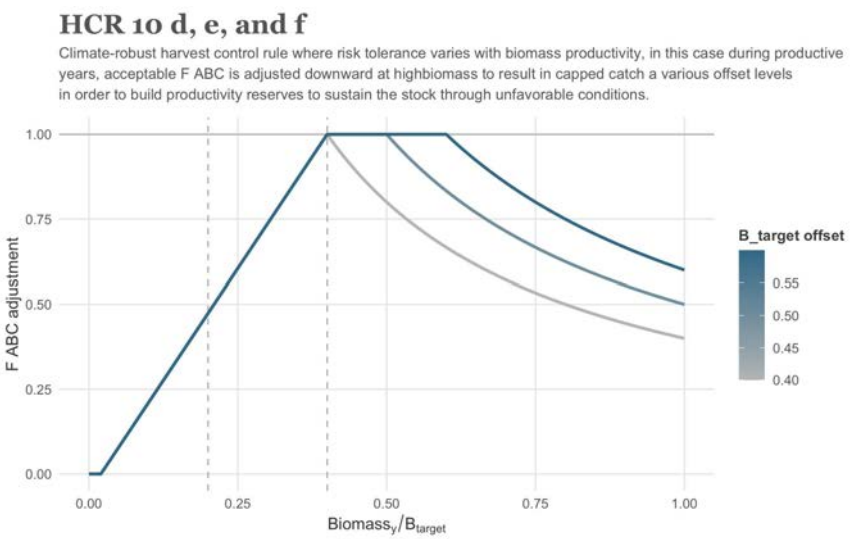




Holsman et al. in prep

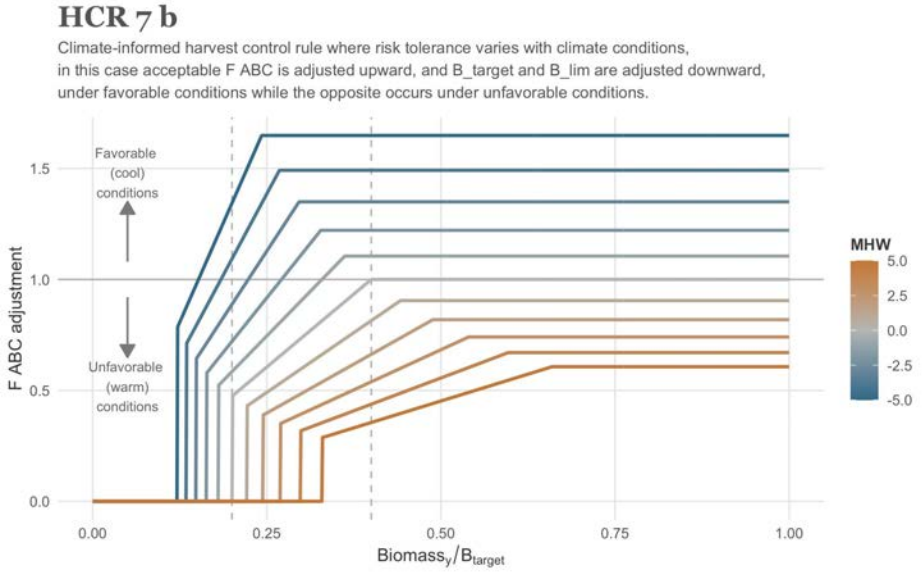
(A)CLIM HCR evaluations underway

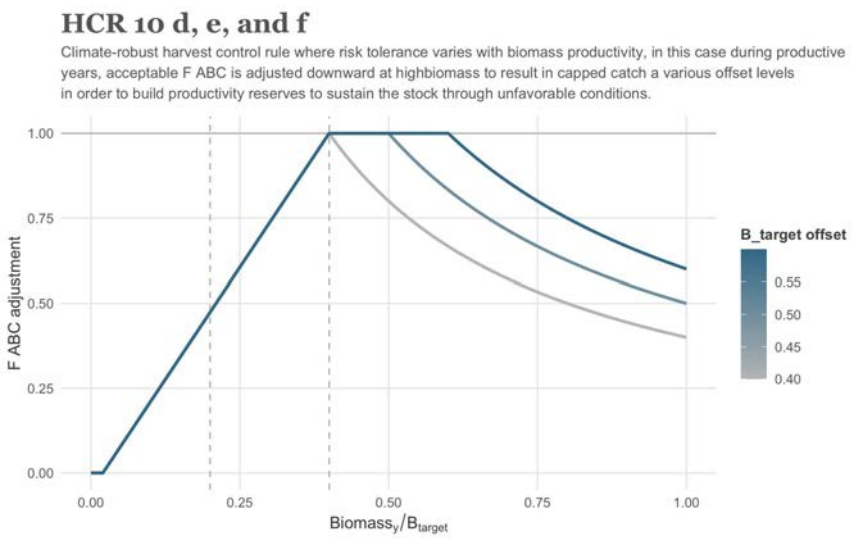


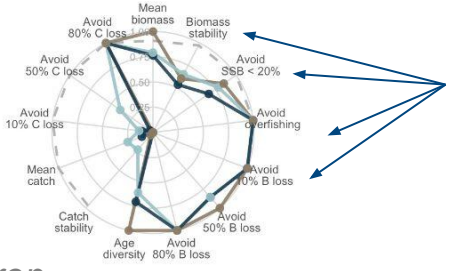


Holsman et al. in prep

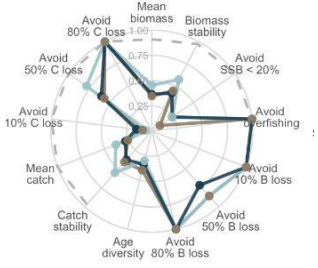
(A)CLIM HCR evaluations underway







Performance criteria



Holsman et al. in prep

Climate Ready Advice

How ACLIM & GOACLIM support actionable advice

Any advice goes through the Council process

1 Research & modeling

Two complementary projects study Alaska's changing ocean & ecosystems

ACLIM

The Alaska Climate Integrated Modeling Project.

Studies how climate and responses may impact Bering sea ecosystems, fisheries, & communities.

GOACLIM

The Gulf of Alaska Integrated Modeling Project.

Examines climate & ecosystem dynamics in the Gulf of Alaska & what it could mean for fisheries.

Iterative feedback, refinement, shared learning

2 CEFI Operational Advice

NEAP- CEFI Science & tools help us understand the changing ocean & inform fishery decisions

- **Climate & ocean foresight**
  Temperature, sea ice, ocean conditions & future projections.
- **Food-web & ecosystem models**
  How climate change affects species & ecosystem connections.
- **Species & stock assessment support**
  Information to help asses fish stocks, their status, and harvest and biological reference points.
- **Future scenarios & harvest strategies**
  Explore "what could happen" and test management approaches.
- **Climate-informed advice**
  Clear, actionable guidance for decision-makers, fisheries, & communities



Informal HCR research discussion sessions planned for Spring 2027

(1) *Tentatively* : April 14th, Kodiak

(2) *Tentatively* : April, Seattle

sign up to stay in the loop

- *Touch base and discuss progress on CLIM HCR evaluation tools*
- *Informal discussions to co-explore results*
- *Hear ideas, priorities, and questions from the public*
- *Co-identify next steps and engagement ideas*

Discussion sessions are pending funding & logistics support

