The Alaska Climate Integrated Modeling (ACLIM) project

BSAI Groundfish Plan Team, September 22, 2021

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+ ACLIM Team

ACLIM TEAM

Lead PIs: Anne Hollowed, Kirstin Holsman, Alan Haynie, Jon Reum, Andre Punt, Kerim Aydin, Al Hermann

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- Jim Ianelli
- Kelly Kearney
- Elizabeth McHuron
- Daren Pilcher
- Jeremy Sterling
- Ingrid Spies
- Paul Spencer
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Adam Hayes

Carol Ladd
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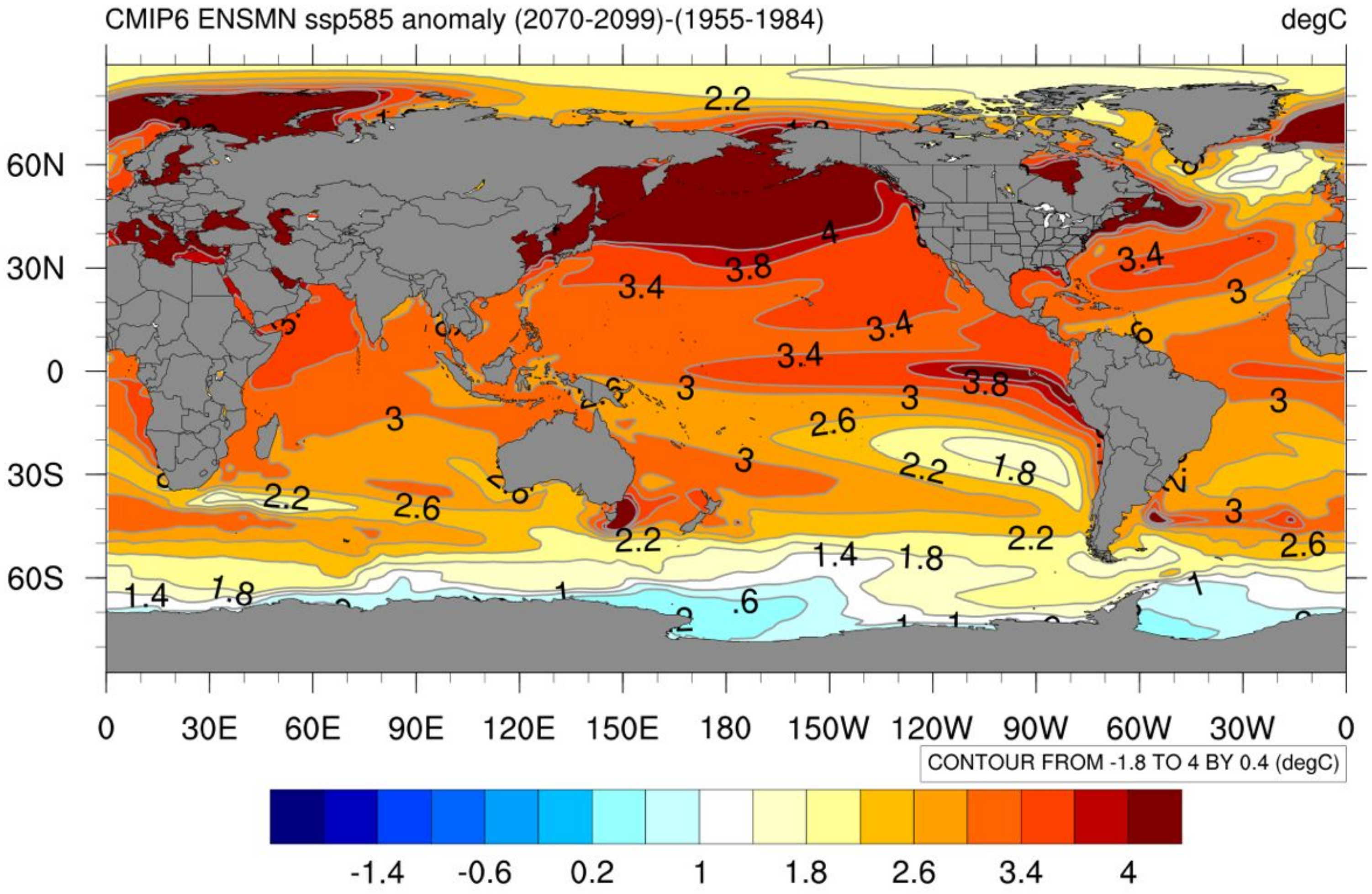
Ivonne Ortiz
Kalei Shotwell
Rolf Ream
Elizabeth Siddon
Phyllis Stabeno
Charlie Stock
Chris Rooper
Jordan Watson
Diana Stram
Lauren Rogers
Ben Laurel

Building climate resilience through climate-informed Ecosystem Based Management

www.fisheries.noaa.gov/alaska/ecosystems/alaska-climate-integrated-modeling-project

CMIP6: SST Anomaly from 1955-1984 climatology

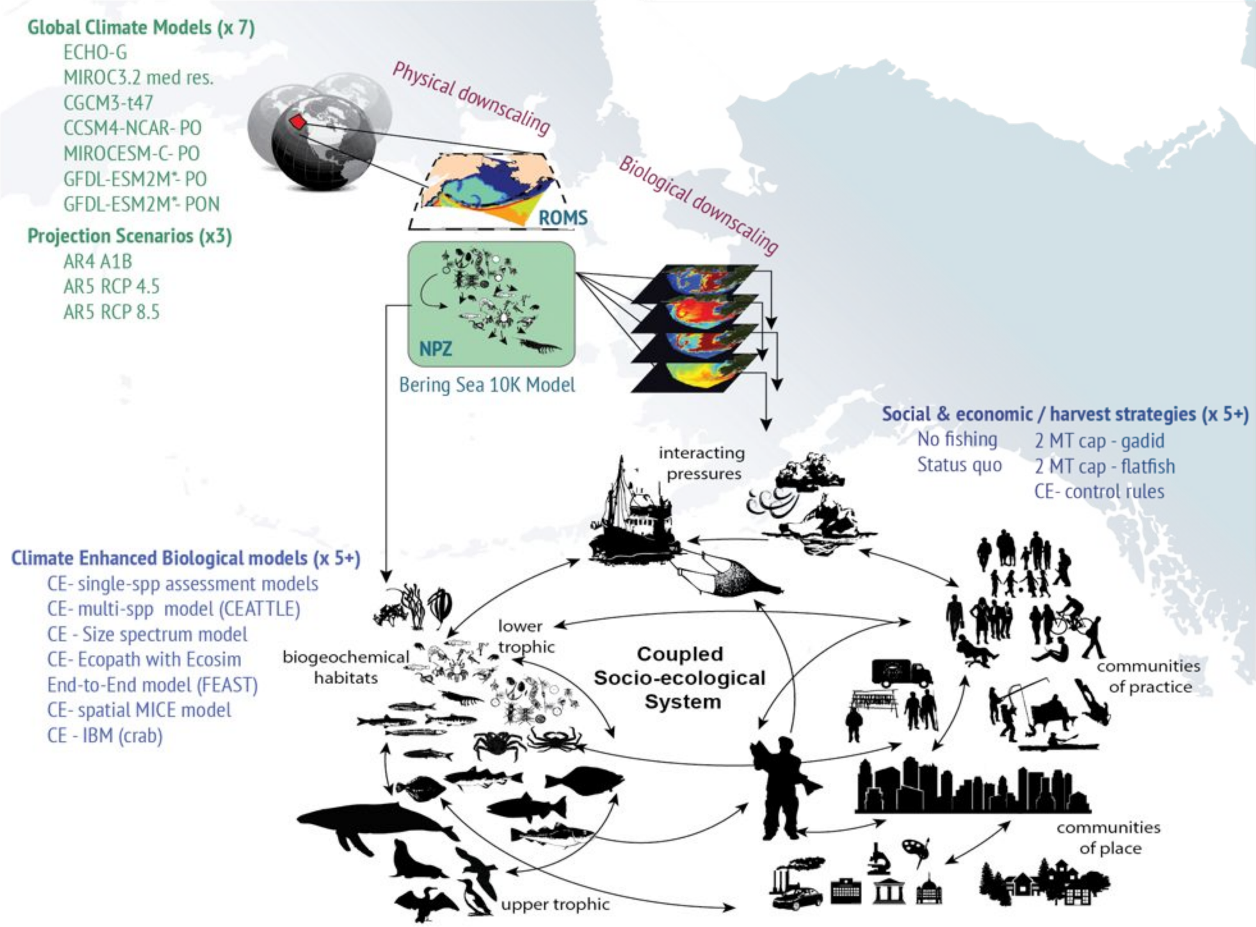


https://psl.noaa.gov/ipcc/cmip6/

The Alaska Climate Integrated Modeling Project

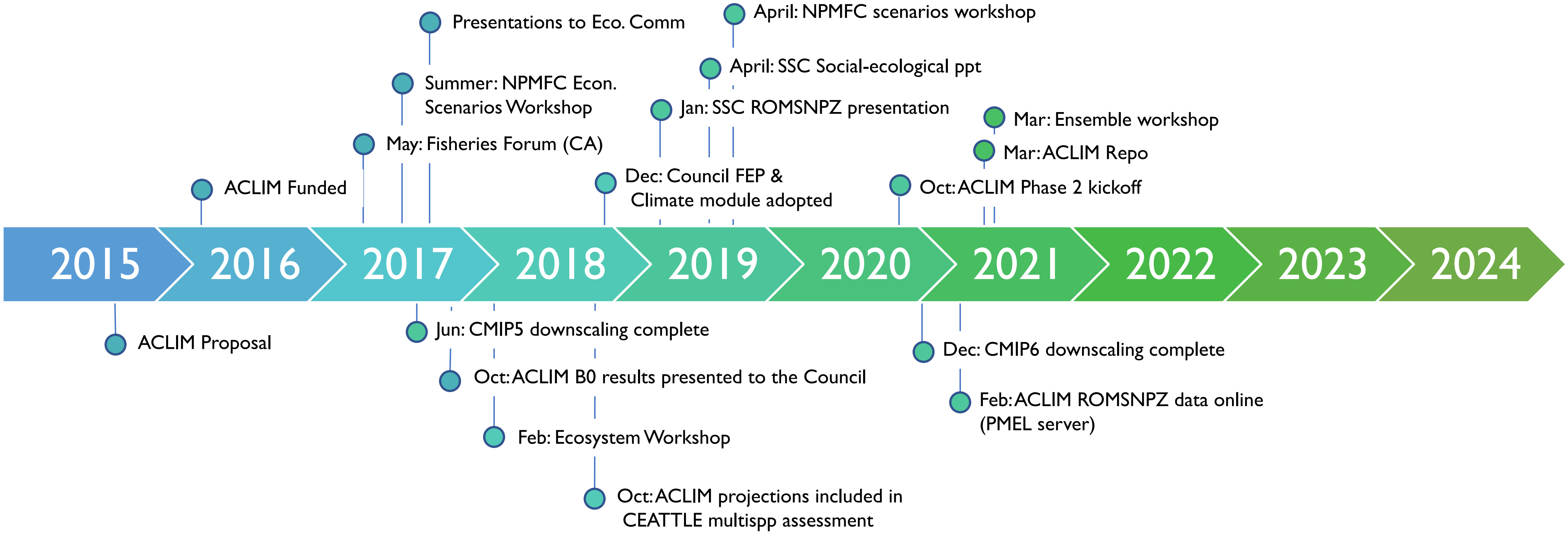
- Southeast Bering Sea
- Funding: NMFS S&T (FATE+SAAM+NPCREP), IEA, RTAP, Economic and Human Dimensions Program, AFSC, OAR)
- Operational suite of coupled socio-ecological models for climate fisheries hindcasts, forecasts, projections and Management Strategy Evaluation

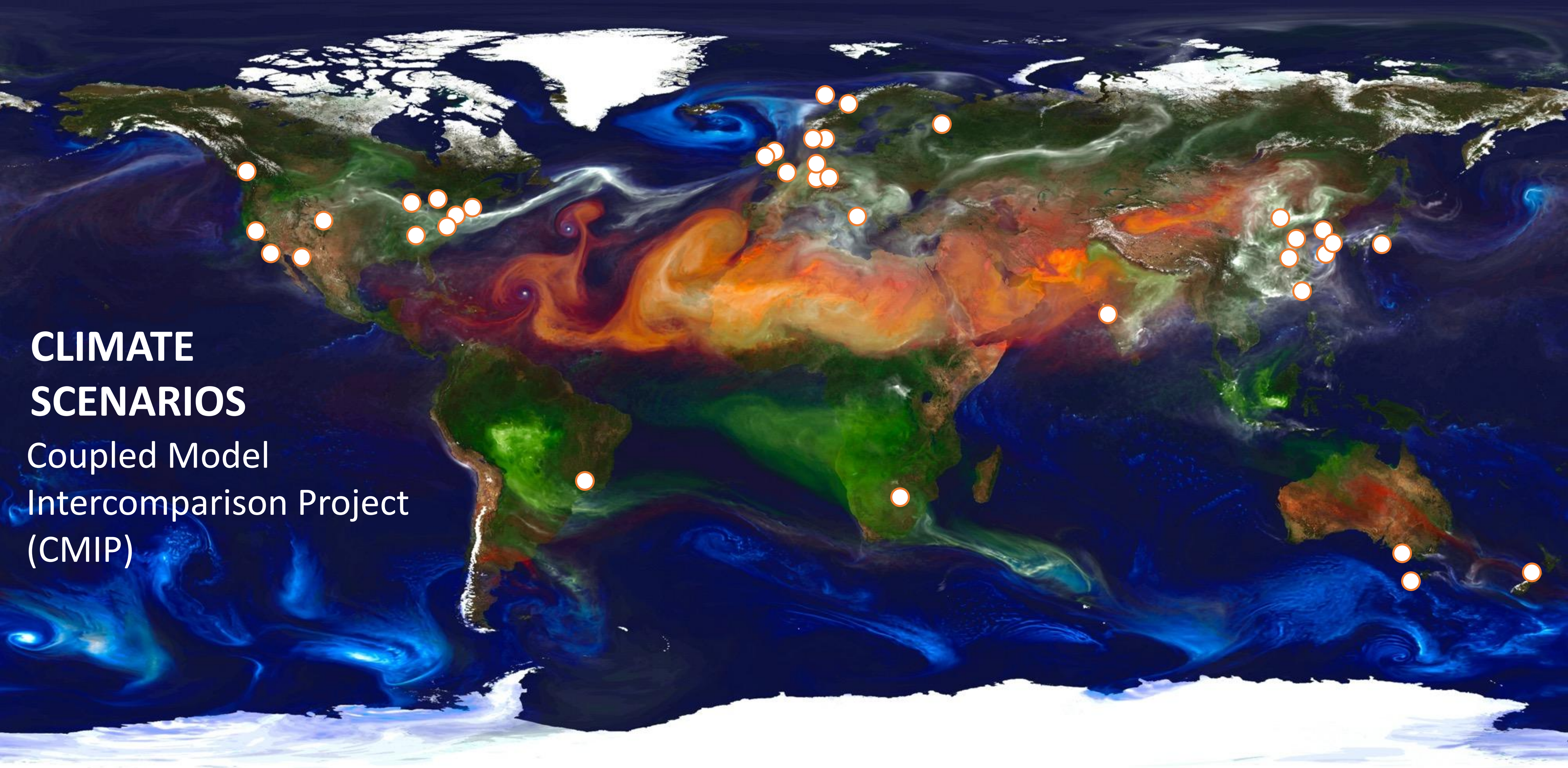
www.fisheries.noaa.gov/alaska/ecosystems/alaska-climate-integrated-modeling-project



Hollowed et al. 2020. Frontiers in Mar. Sci. doi: 10.3389/fmars.2019.00775

The Alaska Climate Integrated Modeling Project (Phase 2)





CLIMATE SCENARIOS

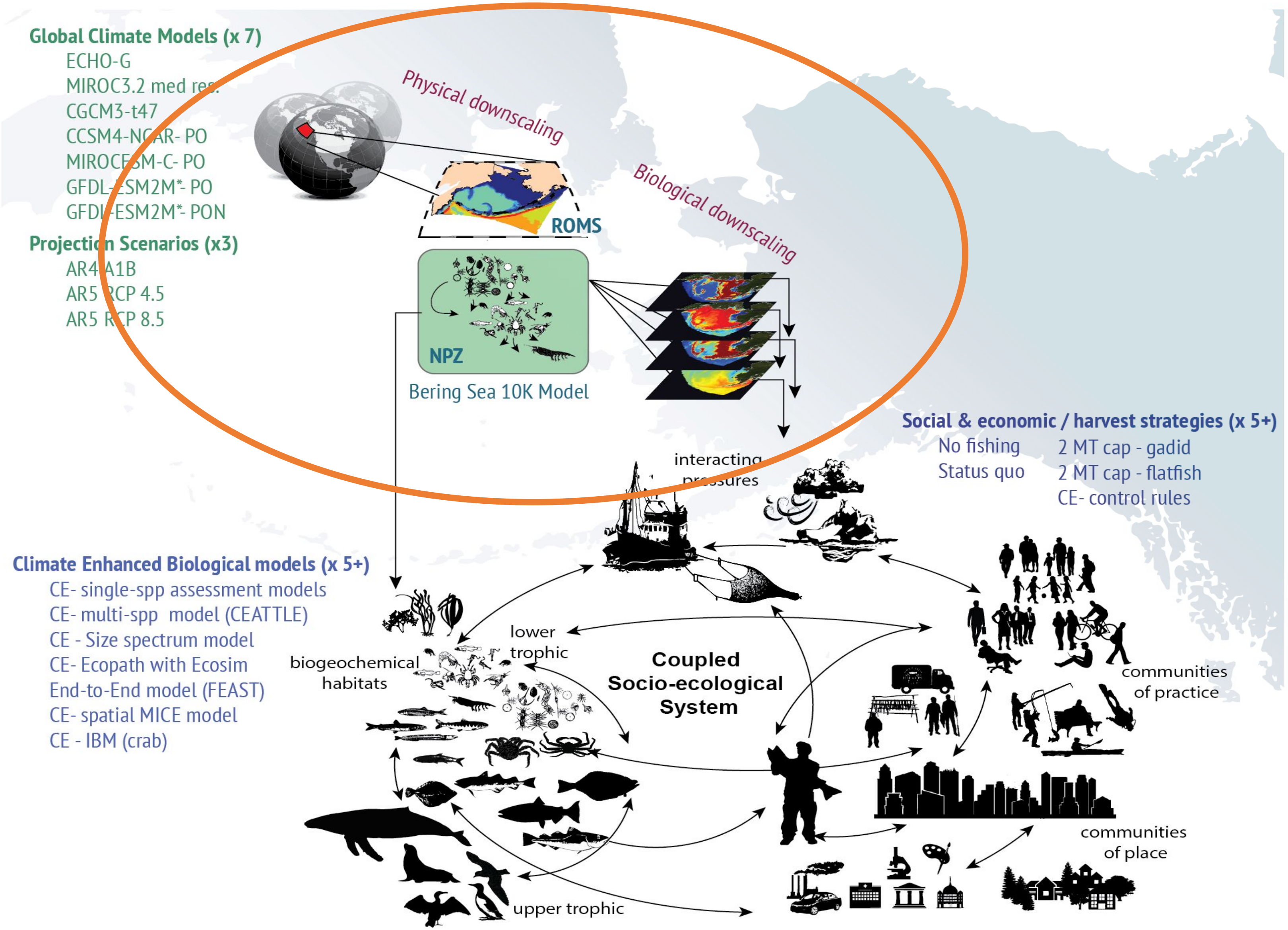
Coupled Model Intercomparison Project (CMIP)

This portrait of global aerosols was produced by a GEOS-5 simulation at a 10-kilometer resolution. Dust (red) is lifted from the surface, sea salt (blue) swirls inside cyclones, smoke (green) rises from fires, and sulfate particles (white) stream from volcanoes and fossil fuel emissions.

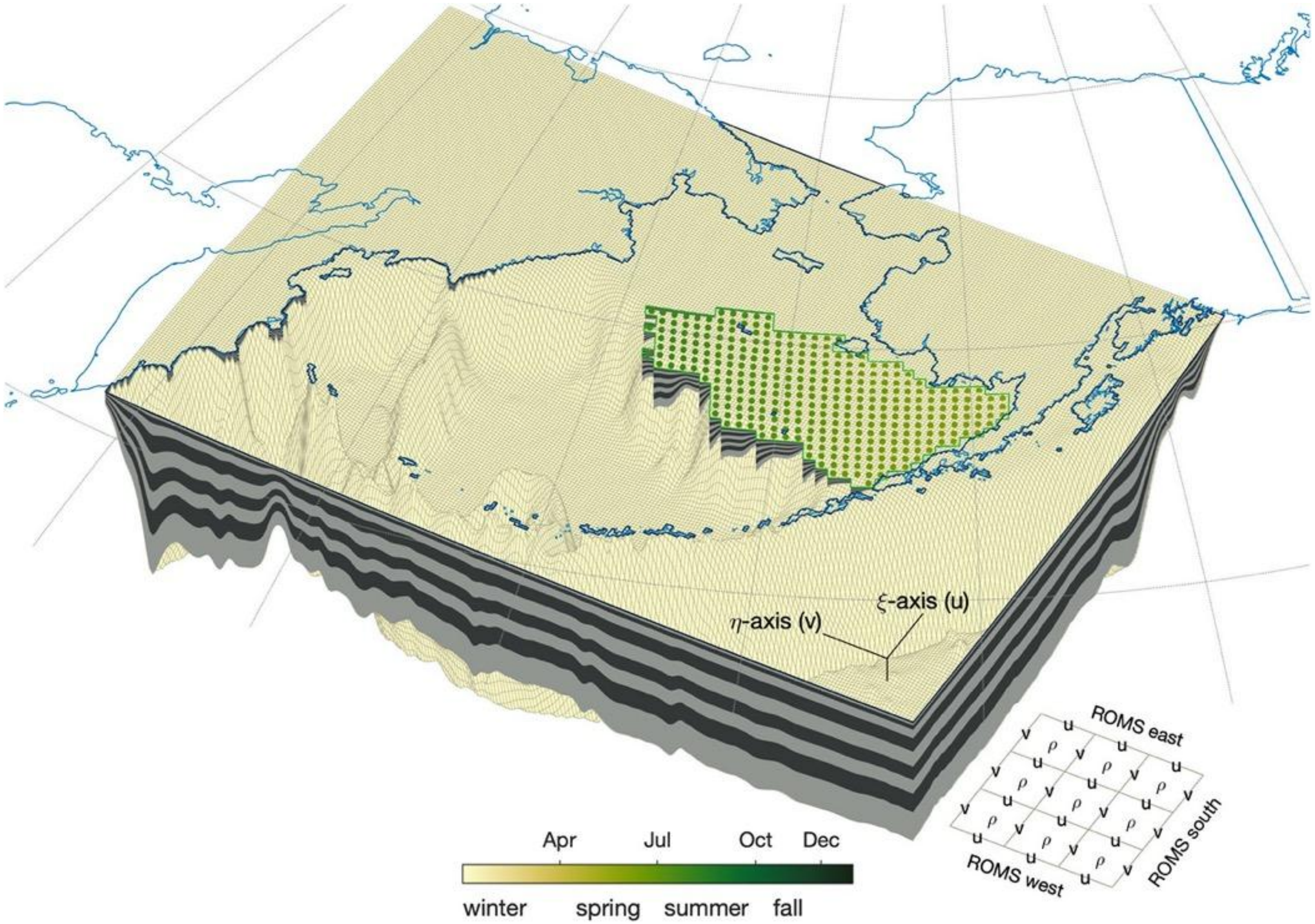
Image credit: William Putman, NASA/Goddard https://www.nasa.gov/multimedia/imagegallery/image_feature_2393.html

The Alaska Climate Integrated Modeling Project

Hollowed et al. 2020. Frontiers in Mar. Sci. doi: 10.3389/fmars.2019.00775



Bering 10K ROMSNPZ model



Hermann et al. 2013,2016, 2019; Kearney et al. 2020; Hollowed et al. 2020. Frontiers in Mar. Sci. doi: 10.3389/fmars.2019.00775

OBSERVATIONS

ROMSNPZ (downscaled)

GLOBAL MODEL

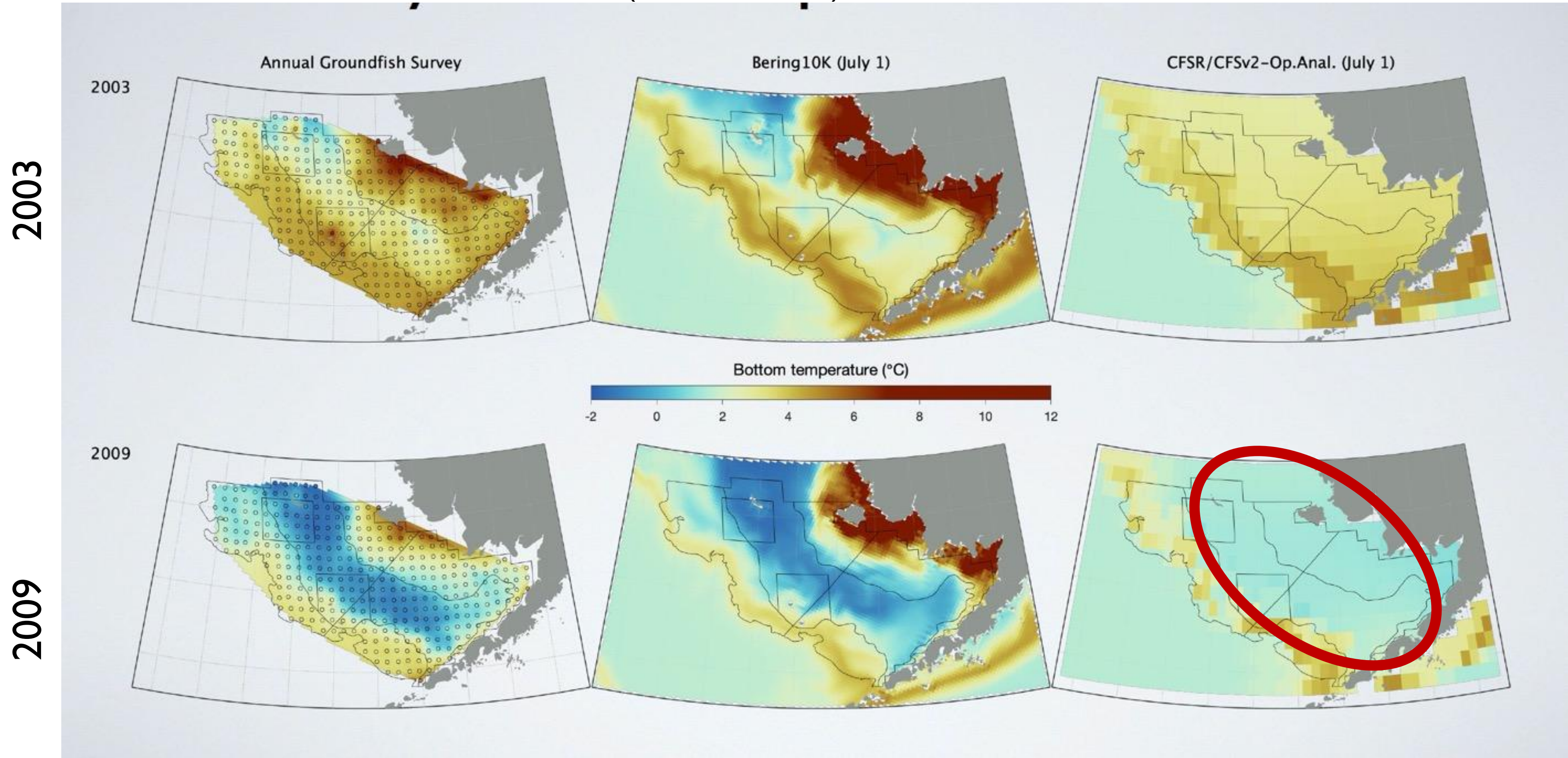
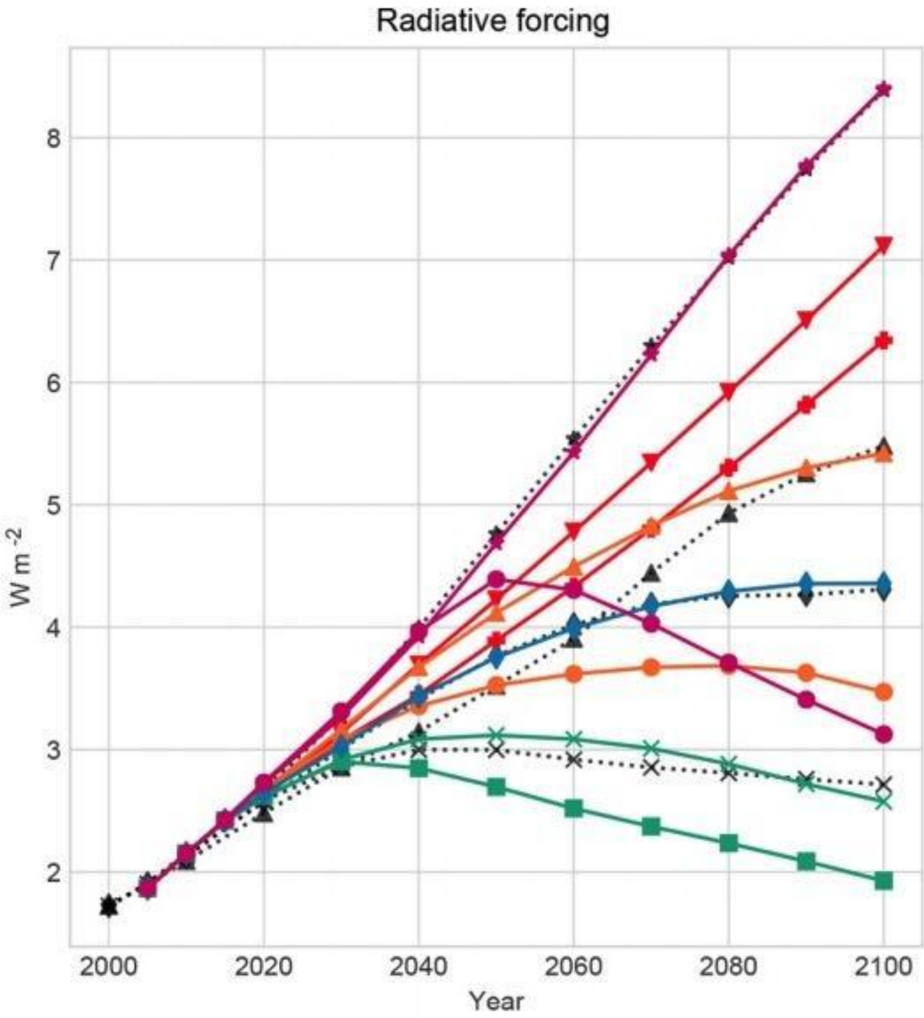


Image: Kelly Kearney

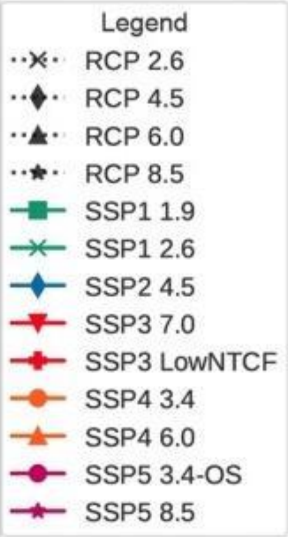
Kearney et al. 2020. A coupled pelagic–benthic–sympagic biogeochemical model for the Bering Sea: documentation and validation of the BESTNPZ model (v2019.08.23) within a high-resolution regional ocean model. Geosci. Model Dev., 13, 597–650, 2020 https://doi.org/10.5194/gmd-13-597-2020

Carbon Emission Scenarios

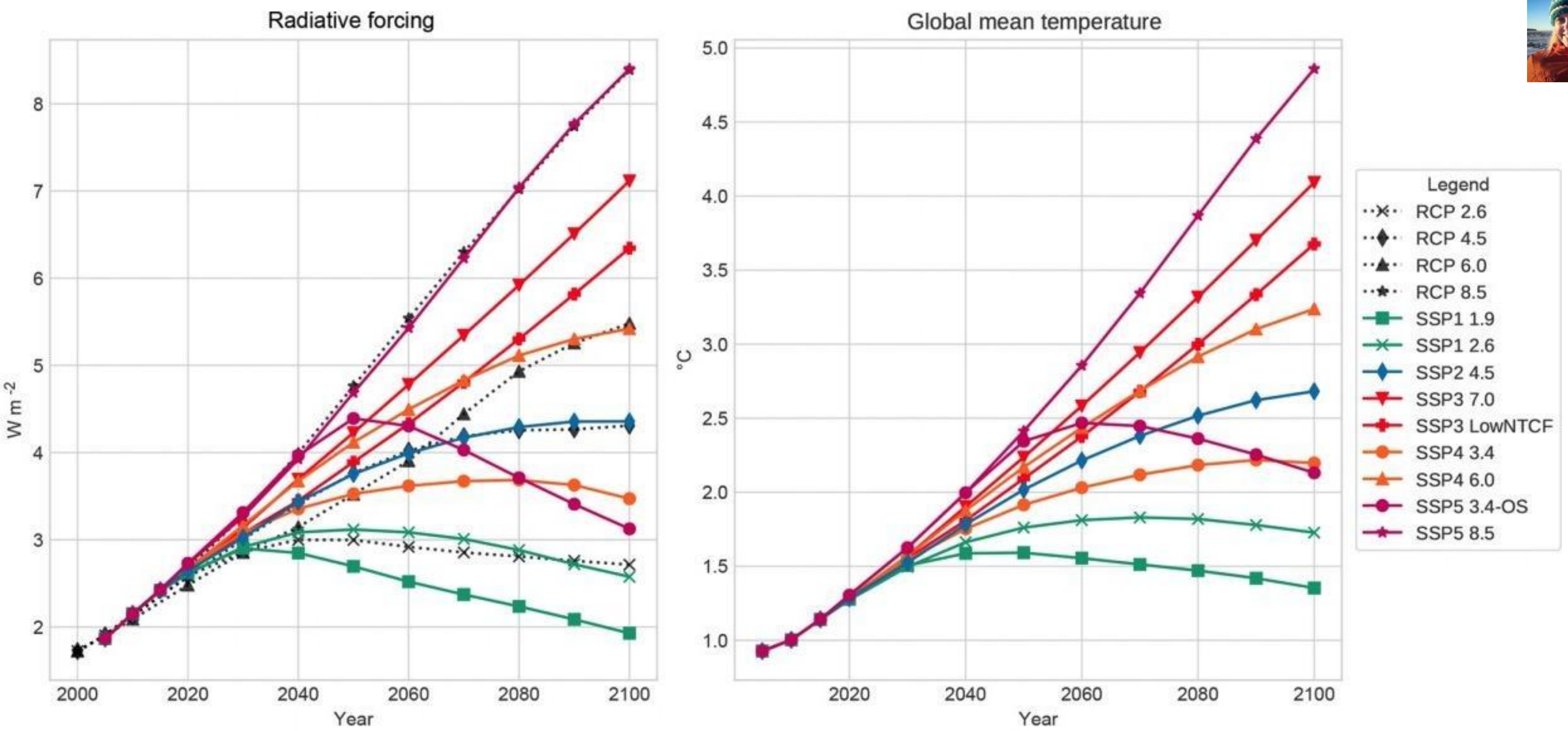


"***plausible descriptions*** *of how the future may evolve with respect to a range of variables…they are not meant to be policy prescriptive, (i.e.* ***no likelihood or preference is attached*** *to any of the individual scenarios of the set)"*

van Vuuren et al. 2011

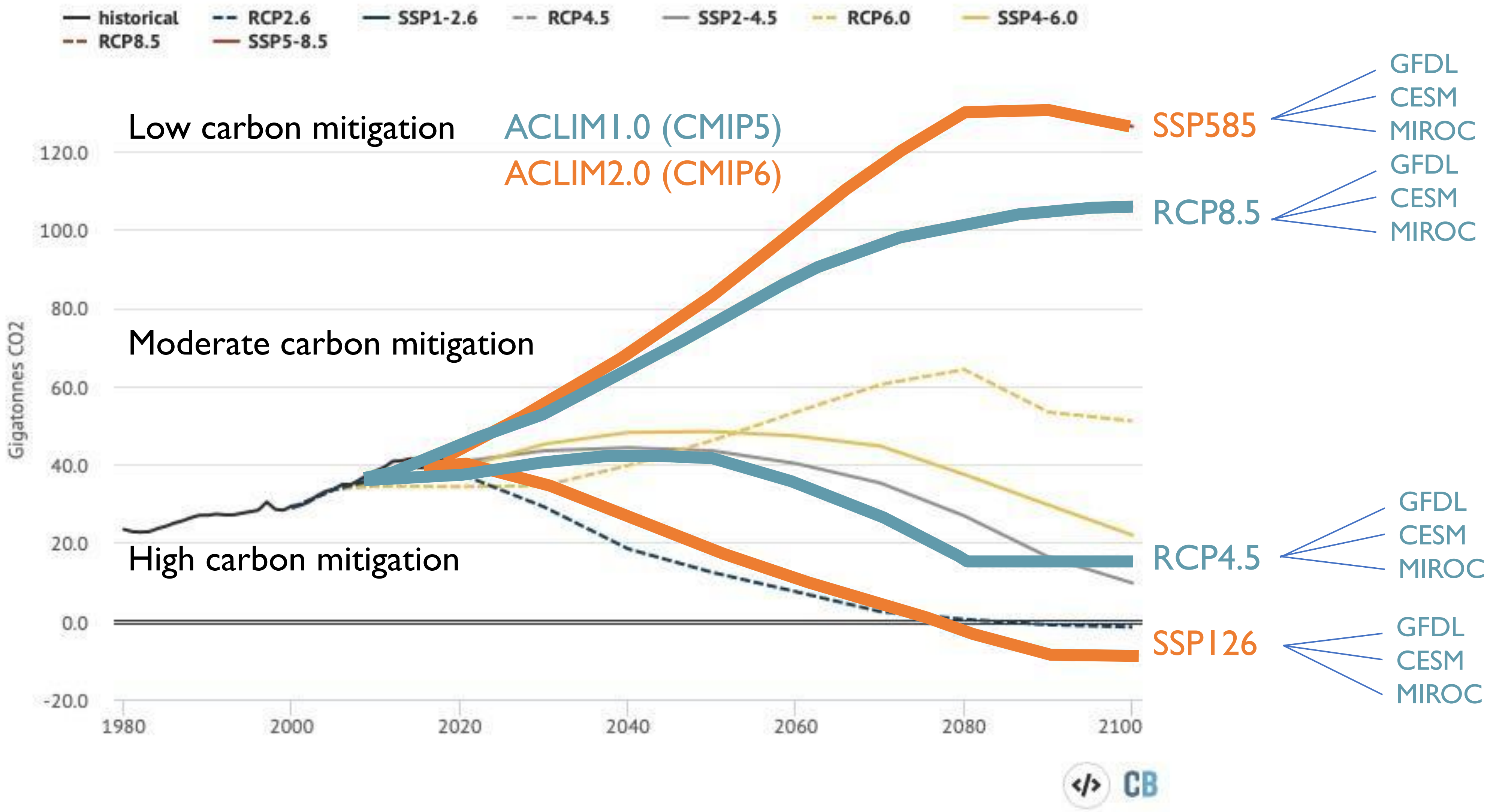


Gidden et al. (2019). Global emissions pathways under different socioeconomic scenarios for use in CMIP6: a dataset of harmonized emissions trajectories through the end of the century. Geosci. Model Dev., 12, 1443–1475, 2019 https://doi.org/10.5194/gmd-12-1443-2019



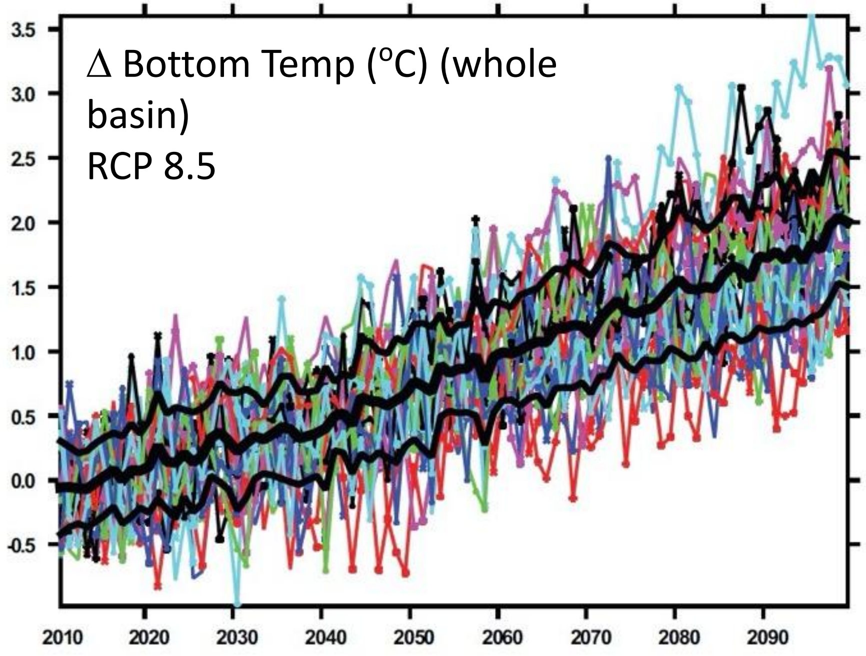
Gidden et al. (2019). Global emissions pathways under different socioeconomic scenarios for use in CMIP6: a dataset of harmonized emissions trajectories through the end of the century. Geosci. Model Dev., 12, 1443–1475, 2019 https://doi.org/10.5194/gmd-12-1443-2019

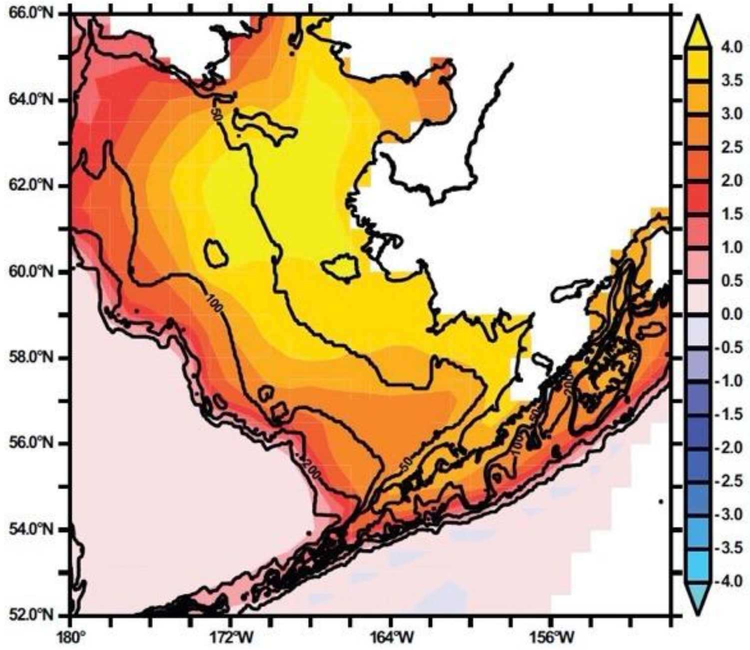
CO2 emissions in comparable CMIP5 and CMIP6 scenarios



Future RCP CO2 emissions scenarios featured in CMIP5 and their CMIP6 counterparts, as well as historical CO2 emissions (in black). Data from the SSP database; chart by Carbon Brief using Highcharts.

Results: Downscaled Bering10K ROMSNPZ high-resolution model (H16)





INCREASED WARMING (2090-2099)-(2010-2019)

The Alaska Climate Integrated Modeling Project
ACLIM
NOAA Alaska Fisheries Science Center

Hermann, A. J., G.A. Gibson, W. Cheng, I. Ortiz1,K. Aydin, M. Wang, A. B. Hollowed, and K. K. Holsman. (2019) Projected biophysical conditions of the Bering Sea to 2100 under multiple emission scenarios. ICES. doi: 10.1093/ices/fsz043

1. Overview
2. Installation
3. Get ROMSNPZ data
4. Explore indices & plot the data
5. Hindcasts
6. Projections
7. Funding and acknowledgments
8. Helpful links and further reading

https://github.com/kholsman/ACLIM2

Getting Started with Bering10K Level 2 & 3 indices

K. Holsman and K. Aydin (Tutorial), A. Hermann, K. Kearney, W. Cheng, I. Ortiz (Bering10K)

The ACLIM Repository github.com/kholsman/ACLIM2 is maintained by Kirstin Holsman, Alaska Fisheries Science Center, NOAA Fisheries, Seattle WA. Multiple programs and projects have supported the production and sharing of the suite of Bering10K hindcasts and projections. *Last updated: Mar 10, 2021*

1. Overview

This repository contains R code and Rdata files for working with netcdf-format data generated from the downscaled ROMSNPZ modeling of the ROMSNPZ Bering Sea Ocean Modeling team; Drs. Hermann, Cheng, Kearney, Pilcher,Ortiz, and Aydin. The code and R resources described in this tutorial are publicly available through the ACLIM2 github repository maintained by Kirstin Holsman as part of NOAA's ACLIM project for the Bering Sea. *See Hollowed et al. 2020 for more information about the ACLIM project.*

1.1. Resources

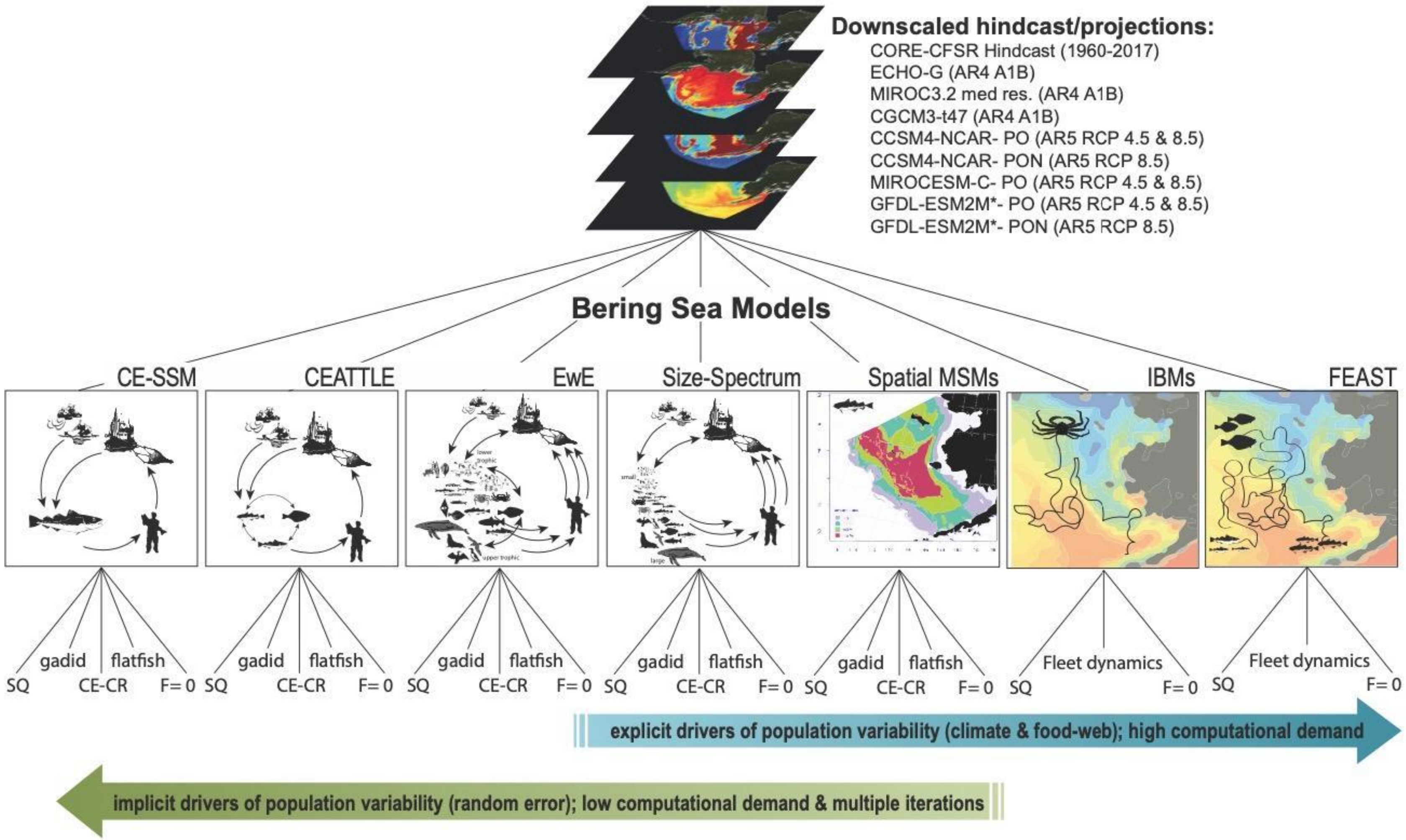
We **strongly recommend** reviewing the following documentation before using the data in order to understand the origin of the indices and their present level of skill and validation, which varies considerably across indices and in space and time:

- The Bering10K Dataset documentation (pdf): A pdf describing the dataset, including full model descriptions, inputs for specific results, and a tutorial for working directly with the ROMS native grid (Level 1 outputs).
- Bering10K Simulaton Variables (xlsx): A spreadsheet listing all simulations and the archived output variables associated with each, updated periodically as new simulations are run or new variables are made available.
- A collection of Bering10K ROMSNPZ model documentation (including the above files) is maintained by Kelly Kearney and will be regularly updated with new documentation and publications.

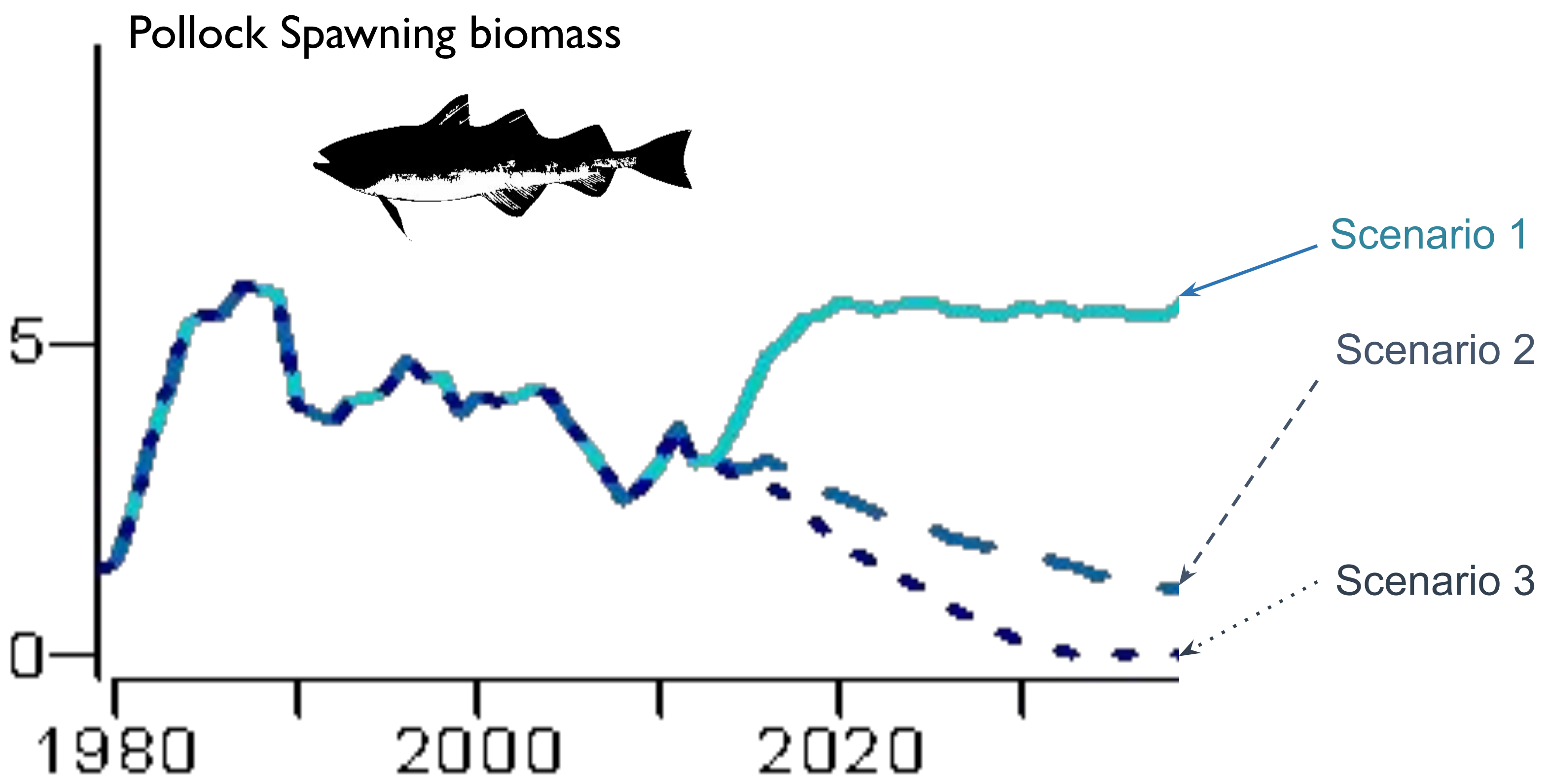
1.2 Guildlines for use and citation of the data

The data described here are published and publicly available for use, except as explicitly noted. However, for novel uses of the data, it is **strongly recommended** that you consult with and consider including at least one author from the ROMSNPZ team (Drs. Hermann, Cheng, Kearney, Pilcher, Aydin, Ortiz). There are multiple spatial and temporal caveats that are best

The Alaska Climate Integrated Modeling Project

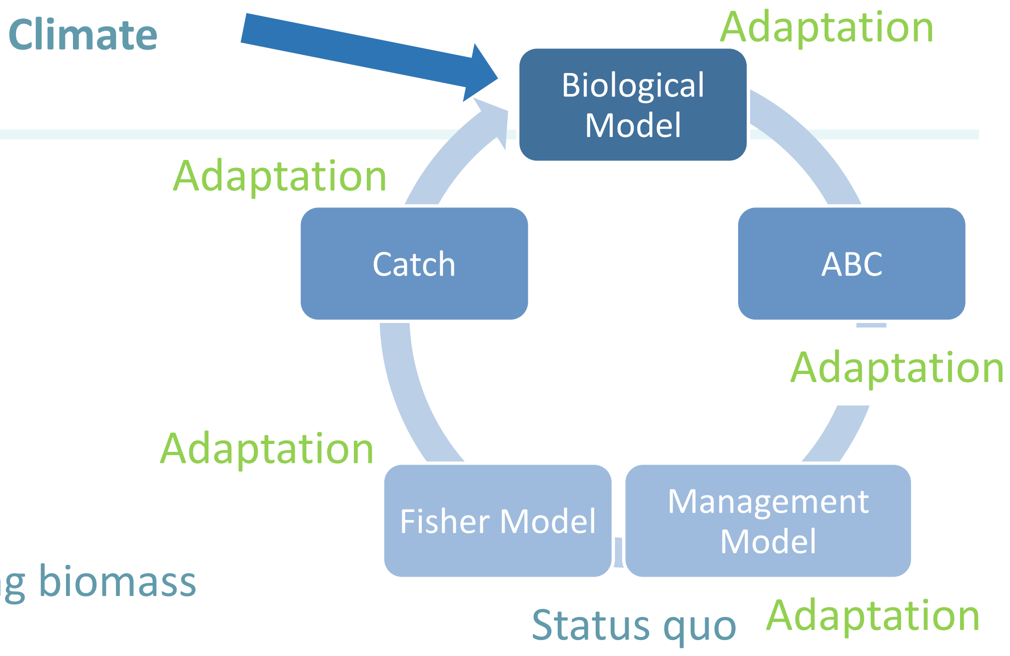


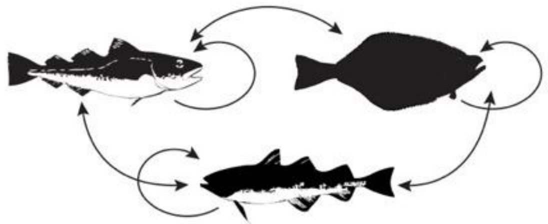
QUANTIFY RISK AND UNCERTAINTY



Ianelli, J KK Holsman, AE Punt, K Aydin (2016). Multi-model inference for incorporating trophic and climate uncertainty into stock assessment estimates of fishery biological reference points. Deep Sea Res II. 134: 379-389 DOI: 10.1016/j.dsr2.2015.04.002

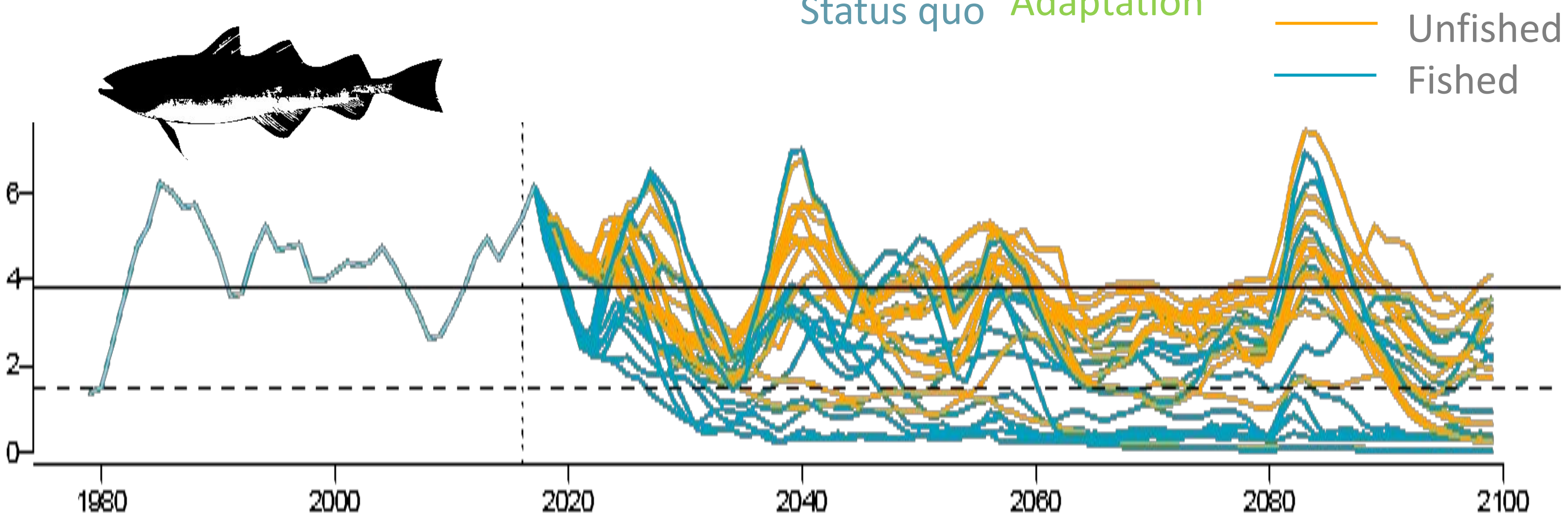
Climate X management dynamic interaction



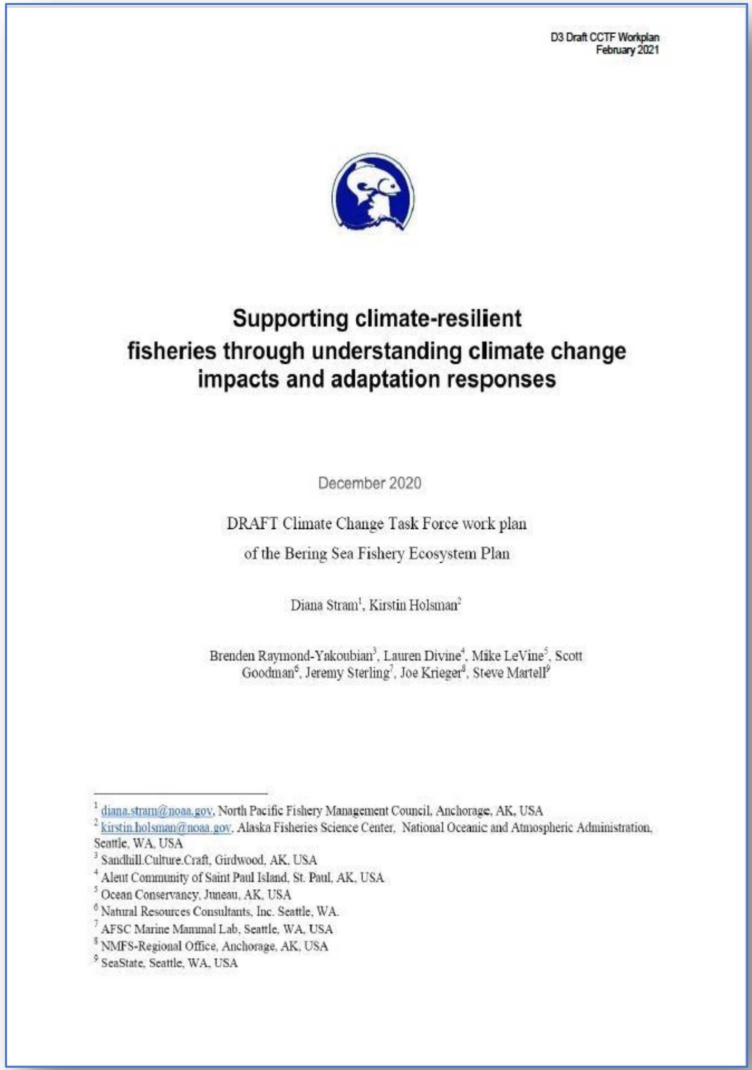


CEATTLE model
Holsman et al. 2016

Pollock Spawning biomass



NPFMC: Climate Change Task Force


D3 Draft CCTF Workplan
February 2021

Supporting climate-resilient fisheries through understanding climate change impacts and adaptation responses

December 2020

DRAFT Climate Change Task Force work plan of the Bering Sea Fishery Ecosystem Plan

Diana Stram[1], Kirstin Holsman[2]

Brenden Raymond-Yakoubian[3], Lauren Divine[4], Mike LeVine[5], Scott Goodman[6], Jeremy Sterling[7], Joe Krieger[8], Steve Martell[9]

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[2] kirstin.holsman@noaa.gov, Alaska Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, WA, USA
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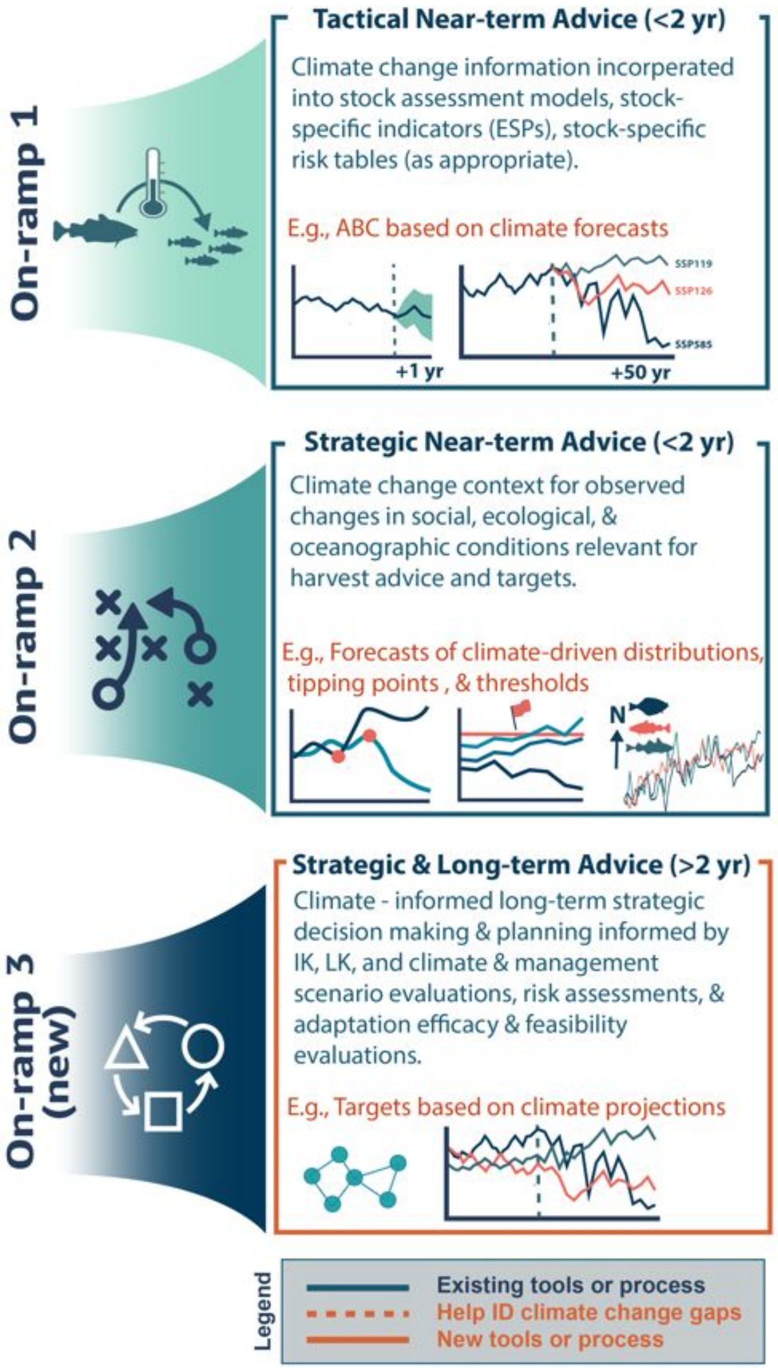
[5] Ocean Conservancy, Juneau, AK, USA
[6] Natural Resources Consultants, Inc. Seattle, WA.
[7] AFSC Marine Mammal Lab, Seattle, WA, USA
[8] NMFS-Regional Office, Anchorage, AK, USA
[9] SeaState, Seattle, WA, USA



Climate information on ramps for fisheries management

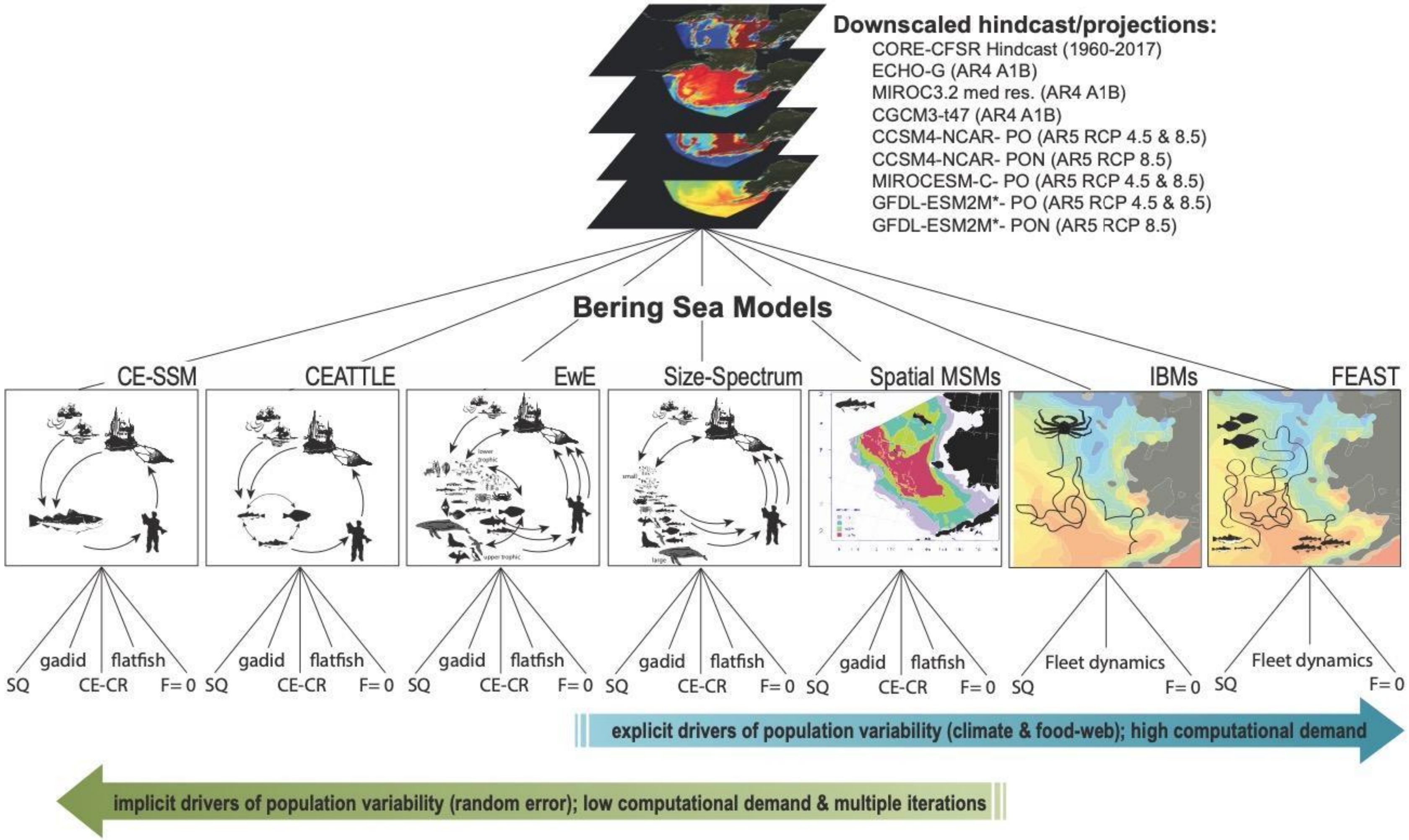
https://www.npfmc.org/climatechangetaskforce/
Stram et al. 2021

Climate x management

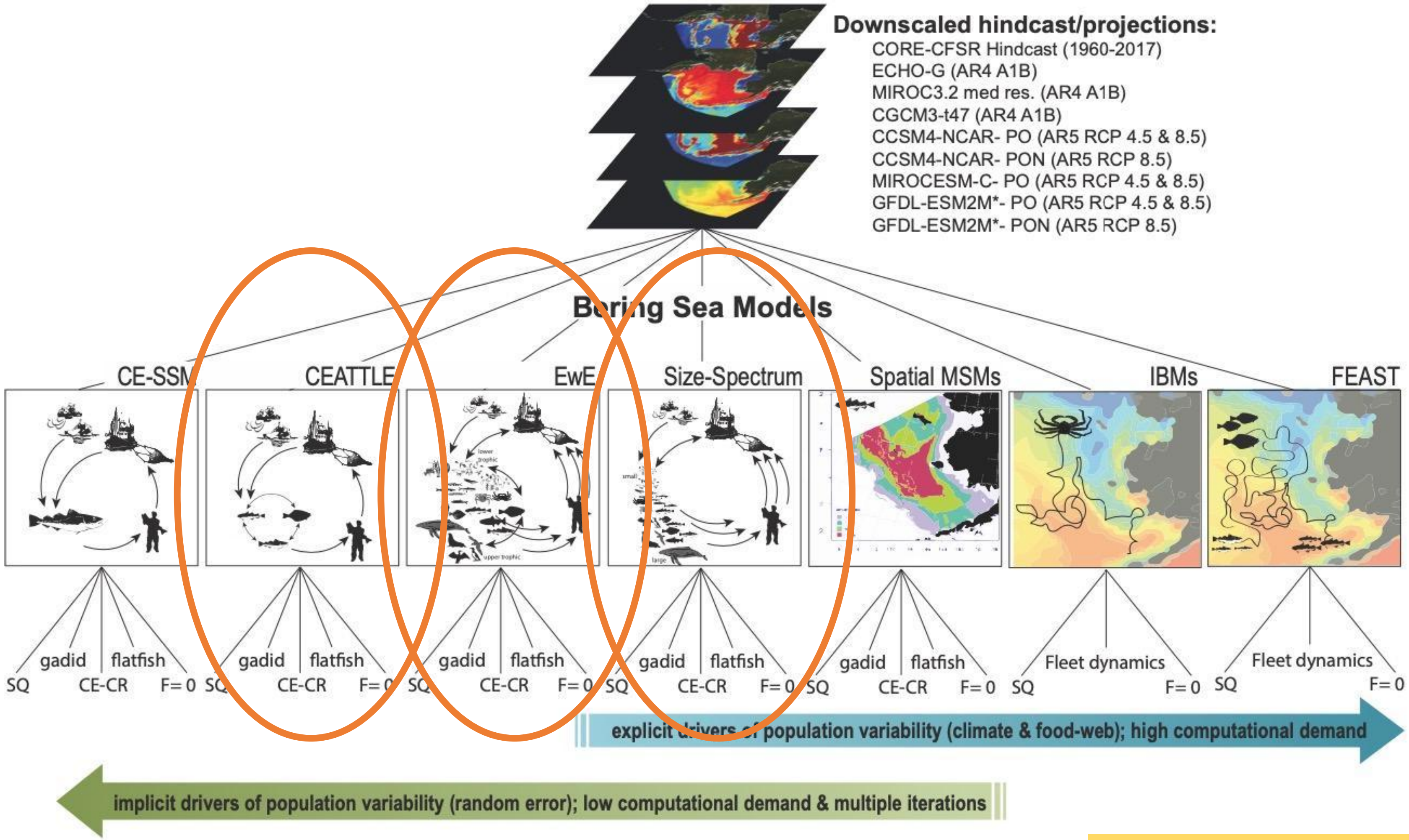
ACLIM Publications:

1. (in review) Torre, M. , W. T. Stockhausen, A. J. Hermann, W. Cheng, R. Foy, C. Stawitz, K. Holsman, C. Szuwalski, A. B. Hollowed. (In Review). Early life stage connectivity for snow crab, Chionoecetes opilio, in the eastern Bering Sea: evaluating the effects of temperature-dependent intermolt duration and vertical migration. Deep Sea Research II.
2. (2021) Whitehouse, G. A., K. Y. Aydin, A. B. Hollowed, K. K. Holsman, W Cheng, A. Faig, A. C. Haynie, A. J. Hermann, K. A. Kearney, A. E. Punt, and T. E. Essington. Bottom-up impacts of forecasted climate change on the eastern Bering Sea food web. Frontiers in Mar. Sci.
3. (2020) Holsman, K.K., A. Haynie, A. Hollowed, J. Reum, K. Aydin, A. Hermann, W. Cheng, A. Faig, J. Ianelli, K. Kearney, A. Punt. (2020) Ecosystem-based fisheries management forestalls climate-driven collapse. Nature Communications. DOI:10.1038/s41467-020-18300-3
4. (in review) Thorson, J., M. Arimitsu, L. Barnett, W. Cheng, L. Eisner, A. Haynie, A. Hermann, K. Holsman, D. Kimmel, M. Lomas, J. Richar, E. Siddon. Forecasting community reassembly using climate-linked spatio-temporal ecosystem models. Ecosphere
5. (Accepted) Szuwalski, W. Cheng, R. Foy, A. Hermann, A. Hollowed, K. Holsman, J. Lee, W. Stockhausen, J. Zheng. Climate change and the future productivity and distribution of crab in the Bering Sea. ICES JMS
6. (2020) Reum, J. C. P., J. L. Blanchard, K. K. Holsman, K. Aydin, A. B. Hollowed, A. J. Hermann, W. Cheng, A. Faig, A. C. Haynie, and A. E. Punt. 2020. Ensemble Projections of Future Climate Change Impacts on the Eastern Bering Sea Food Web Using a Multispecies Size Spectrum Model. Frontiers in Marine Science 7:1–17.
7. (2020) Hollowed, A. B., K. K. Holsman, A. C. Haynie, A. J. Hermann, A. E. Punt, K. Aydin, J. N. Ianelli, S. Kasperski, W. Cheng, A. Faig, K. A. Kearney, J. C. P. Reum, P. Spencer, I. Spies, W. Stockhausen, C. S. Szuwalski, G. A. Whitehouse, and T. K. Wilderbuer. 2020. Integrated Modeling to Evaluate Climate Change Impacts on Coupled Social-Ecological Systems in Alaska. Frontiers in Marine Science 6. https://doi.org/10.3389/fmars.2019.00775
8. (2019) Holsman, KK, EL Hazen, A Haynie, S Gourguet, A Hollowed, S Bograd, JF Samhouri, K Aydin, Toward climate-resiliency in fisheries management. ICES Journal of Marine Science. 10.1093/icesjms/fsz031
9. (2019) Hermann, A. J., G.A. Gibson, W. Cheng, I. Ortiz1, K. Aydin, M. Wang, A. B. Hollowed, and K. K. Holsman. Projected biophysical conditions of the Bering Sea to 2100 under multiple emission scenarios. ICES Journal of Marine Science, fsz043, https://doi.org/10.1093/icesjms/fsz043
10. (2019) Reum, J., JL Blanchard, KK Holsman, K Aydin, AE Punt. Species-specific ontogenetic diet shifts attenuate trophic cascades and lengthen food chains in exploited ecosystems. Okios DOI: 10.1111/oik.05630
11. (2019) Reum, J., K. Holsman, KK, Aydin, J. Blanchard, S. Jennings. Energetically relevant predator to prey body mass ratios and their relationship with predator body size. Ecology and Evolution (9):201–211 DOI: 10.1002/ece3.4715

The Alaska Climate Integrated Modeling Project



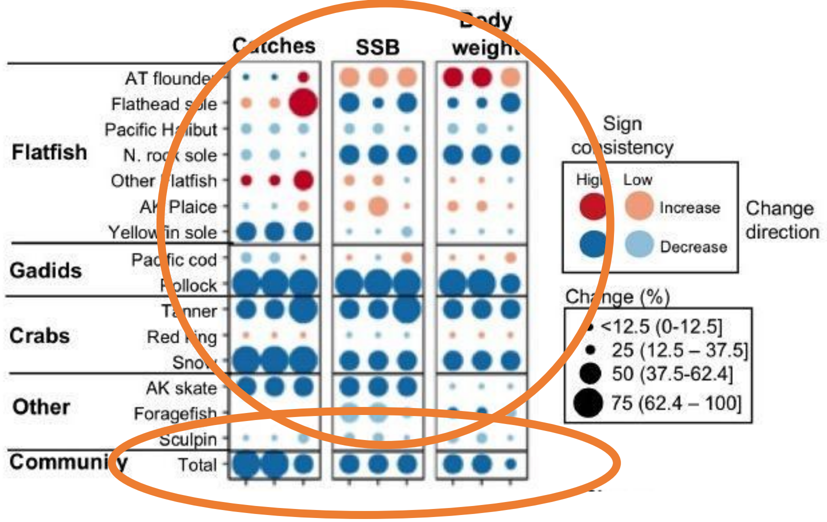
The Alaska Climate Integrated Modeling Project



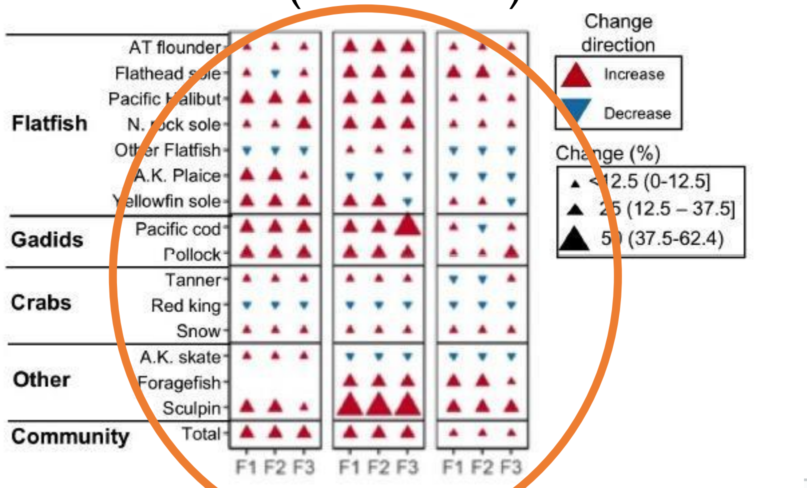
ATTACH Model (Faig & Haynie 2020): http://doi.org/10.5281/zenodo.3966545

Size-spectrum foodweb model (Reum et al. 2020)

RCP8.5 (2080-2100) – (1995-2014)



RCP4.5 - 8.5 (2080-2100)



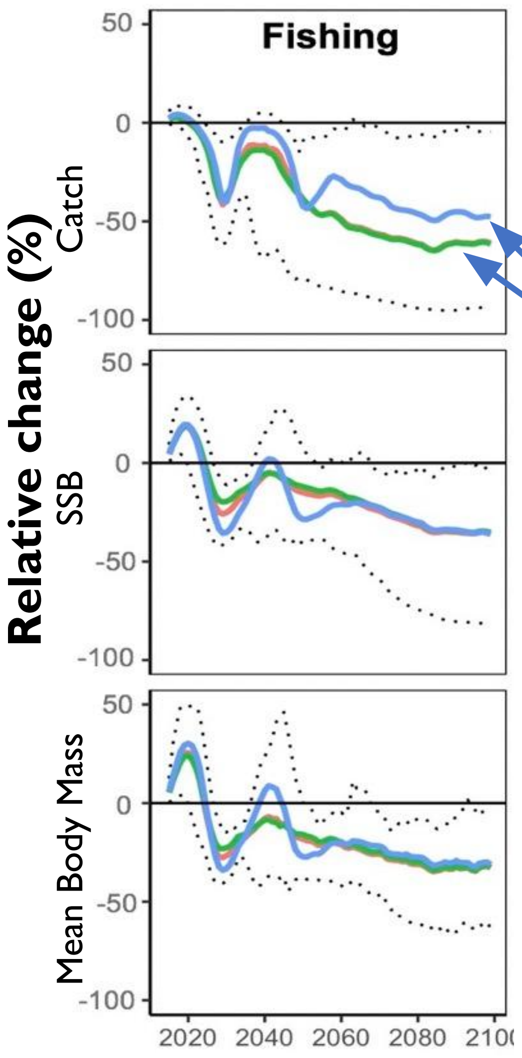
Key Findings:

- Aggregate catch, SSB, and W decline with warming
- Species show mixed response
- Global carbon mitigation reduces declines
- Cumulative effects of Temperature on M and G are not additive

"This highlights a critical aspect of structural uncertainty in climate-driven food web projections and the importance of frameworks such as MSSMs for scaling temperature dependencies in individual-level processes to populations and communities."

Reum, J. C. P., J. L. Blanchard, K. K. Holsman, K. Aydin, A. B. Hollowed, A. J. Hermann, W. Cheng, A. Faig, A. C. Haynie, and A. E. Punt. 2020. Ensemble Projections of Future Climate Change Impacts on the Eastern Bering Sea Food Web Using a Multispecies Size Spectrum Model. Frontiers in Marine Science 7:1–17.

Size-spectrum foodweb model (Reum et al. 2020)



MANAGEMENT SCENARIOS

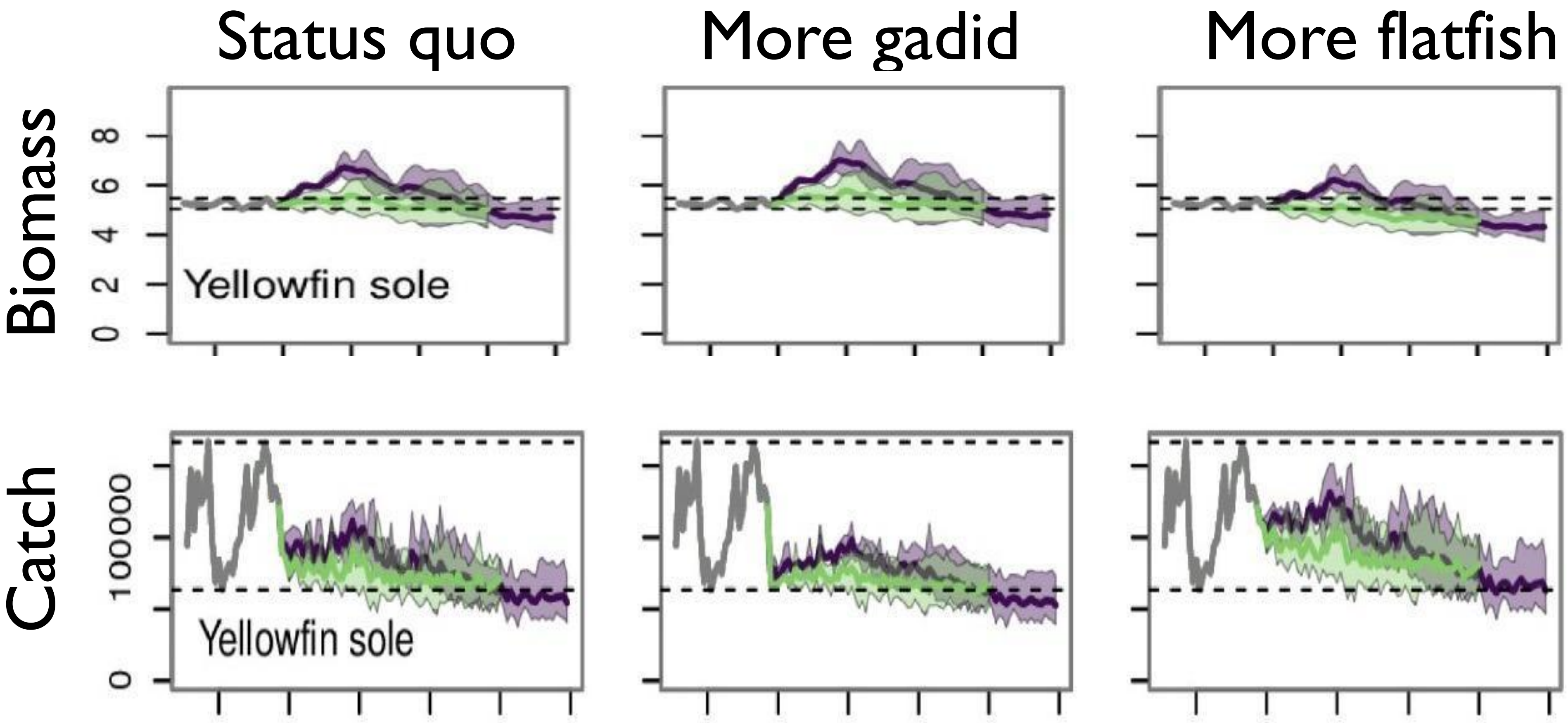
(1) TAC = recent historical patterns ("status quo")
(2) pollock and Pacific cod TAC </= status quo + 10% (at the cost of lower flatfish TAC)
(3) flatfish TAC TAC </= status quo + 10% (at the cost of lower pollock and Pacific cod TAC)

Slight change in management flexibility can result in ~10% increase in catch over status quo

Incremental adjustments can increase adaptive scope (slightly)

Reum, J. C. P., J. L. Blanchard, K. K. Holsman, K. Aydin, A. B. Hollowed, A. J. Hermann, W. Cheng, A. Faig, A. C. Haynie, and A. E. Punt. 2020. Ensemble Projections of Future Climate Change Impacts on the Eastern Bering Sea Food Web Using a Multispecies Size Spectrum Model. Frontiers in Marine Science 7:1–17.

YFS fishing scenarios



No difference between fishing scenarios

Higher catch for 'more flatfish scenario"

Whitehouse, et al. 2021. Bottom-up impacts of forecasted climate change on the eastern Bering Sea food web. Front. Mar. Sci., 03 February 2021 | https://doi.org/10.3389/fmars.2021.624301

Incremental adjustments can increase adaptive scope (slightly)

Rpath() / EwE (Whitehouse et al. 2021)

General declines in seabirds

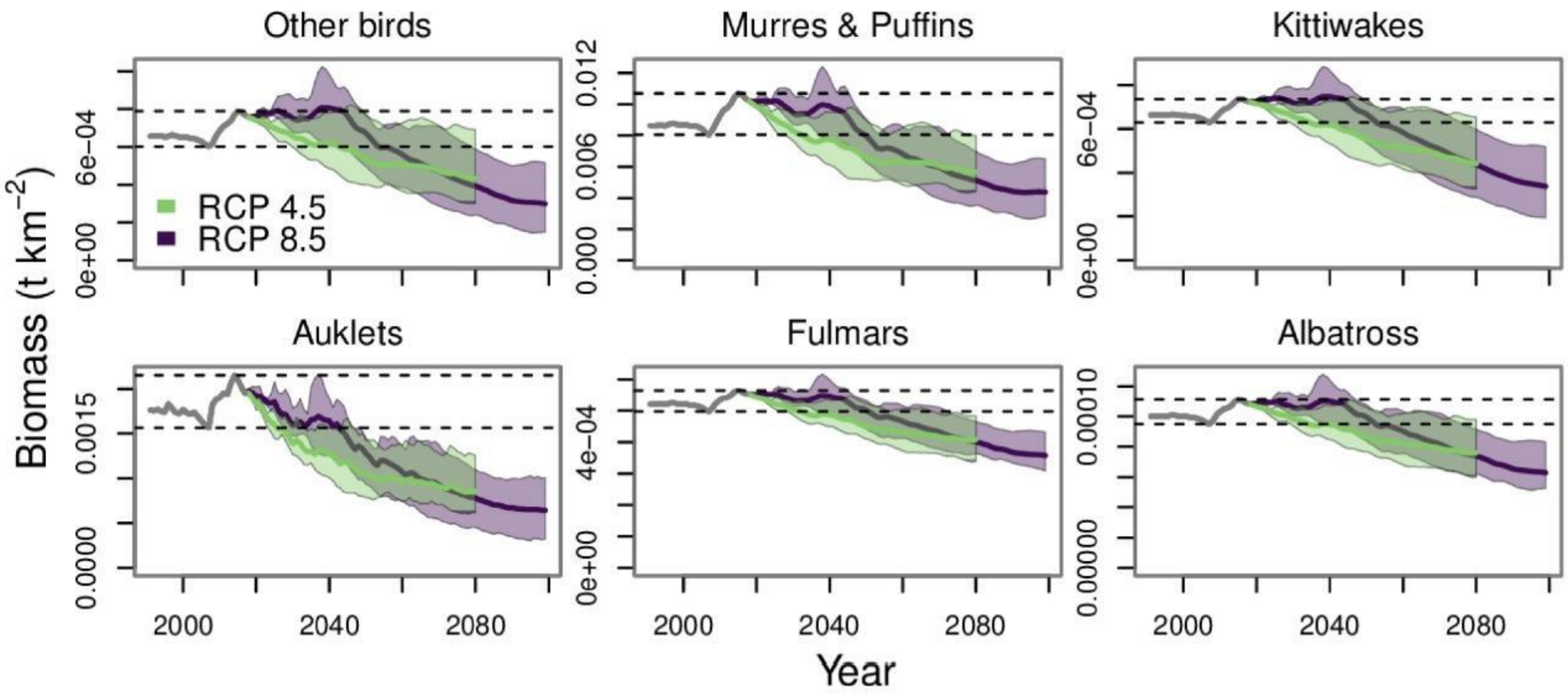


FIGURE 8 | Biomass projections for seabird functional groups. The gray line from 1991 to 2017 indicates the historical period. The purple and green polygons indicate the minimum and maximum range for the three earth system models run under each RCP. The purple and green lines indicate the mean of the three runs for each RCP. The dashed lines indicate the minimum and maximum values from the historical period.

Whitehouse, et al. 2021. Bottom-up impacts of forecasted climate change on the eastern Bering Sea food web. Front. Mar. Sci., 03 February 2021 | https://doi.org/10.3389/fmars.2021.624301

Rpath() / EwE (Whitehouse et al. 2021)

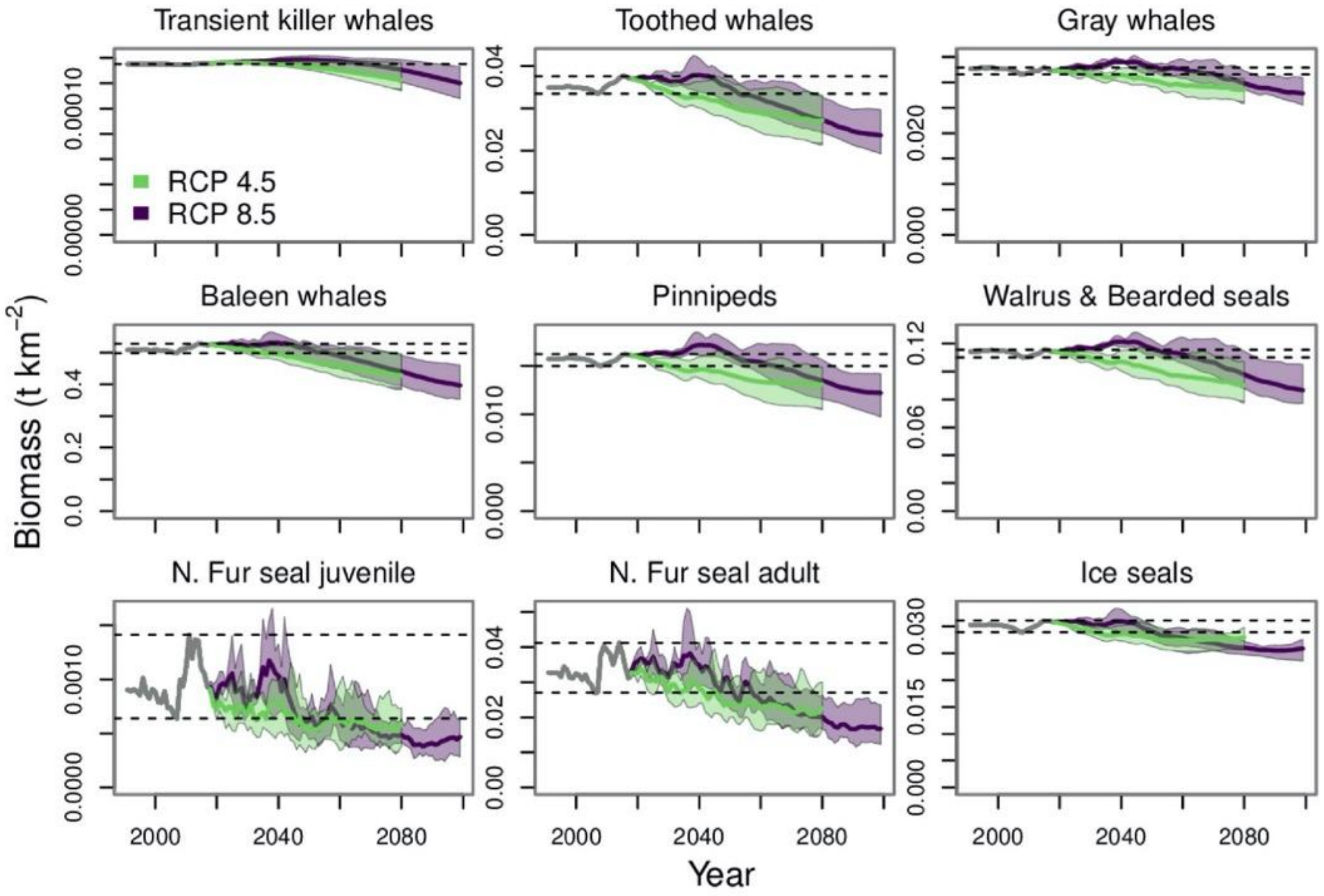
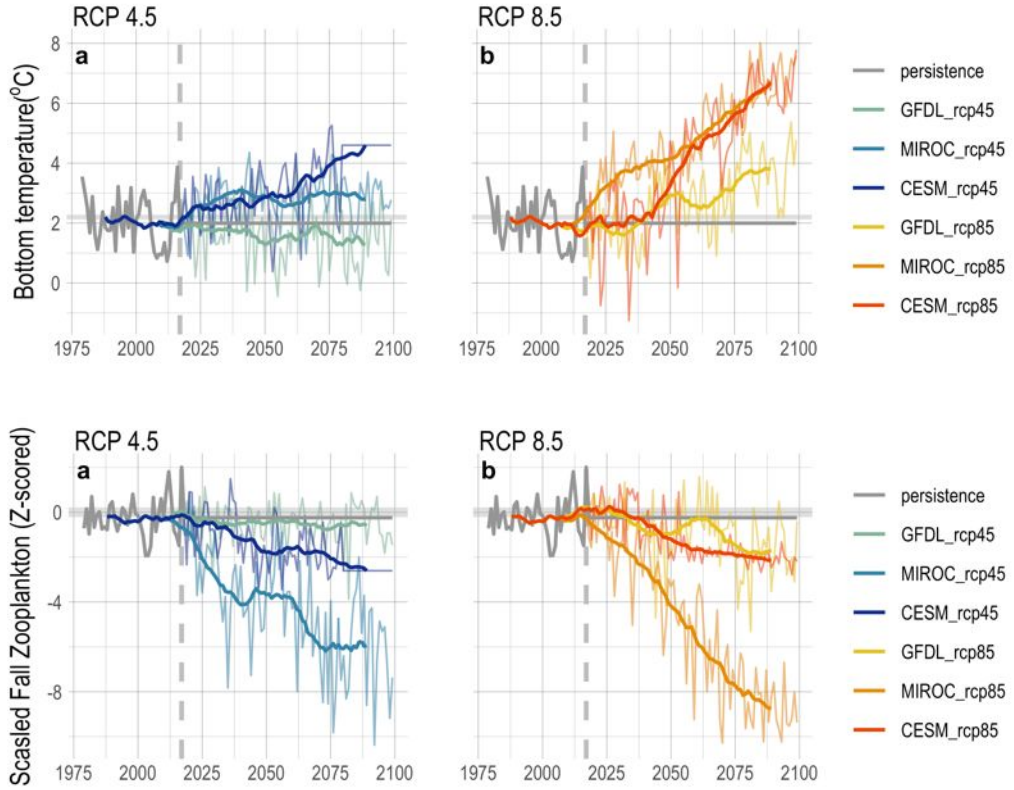


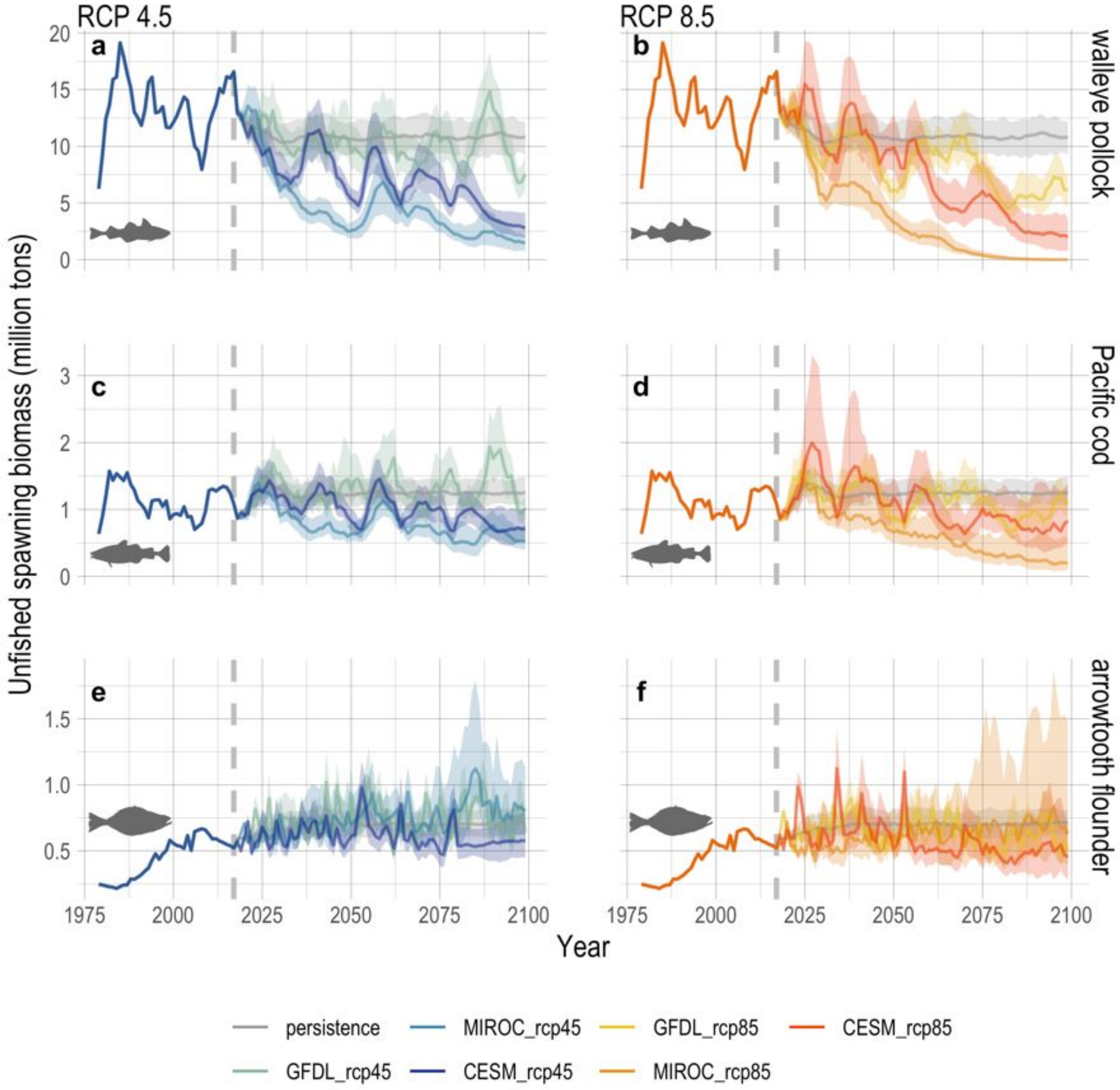
FIGURE 7 | Biomass projections for marine mammal functional groups. The gray line from 1991 to 2017 indicates the historical period. The purple and green polygons indicate the minimum and maximum range for the three earth system models run under each RCP. The purple and green lines indicate the mean of the three runs for each RCP. The dashed lines indicate the minimum and maximum values from the historical period.

Whitehouse, et al. 2021. Bottom-up impacts of forecasted climate change on the eastern Bering Sea food web. Front. Mar. Sci., 03 February 2021 | https://doi.org/10.3389/fmars.2021.624301

General declines in marine mammals

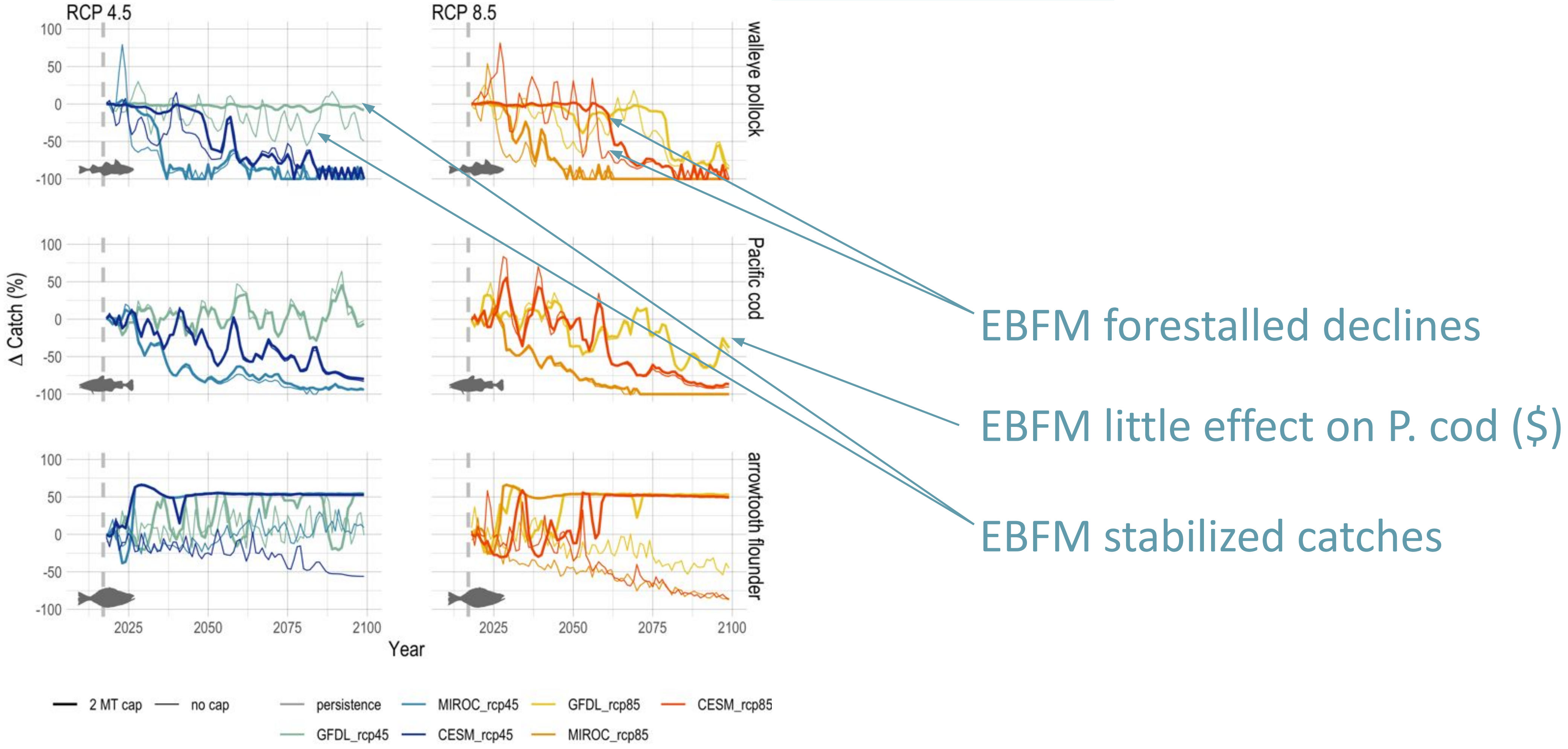
Unfished biomass (no harvest)





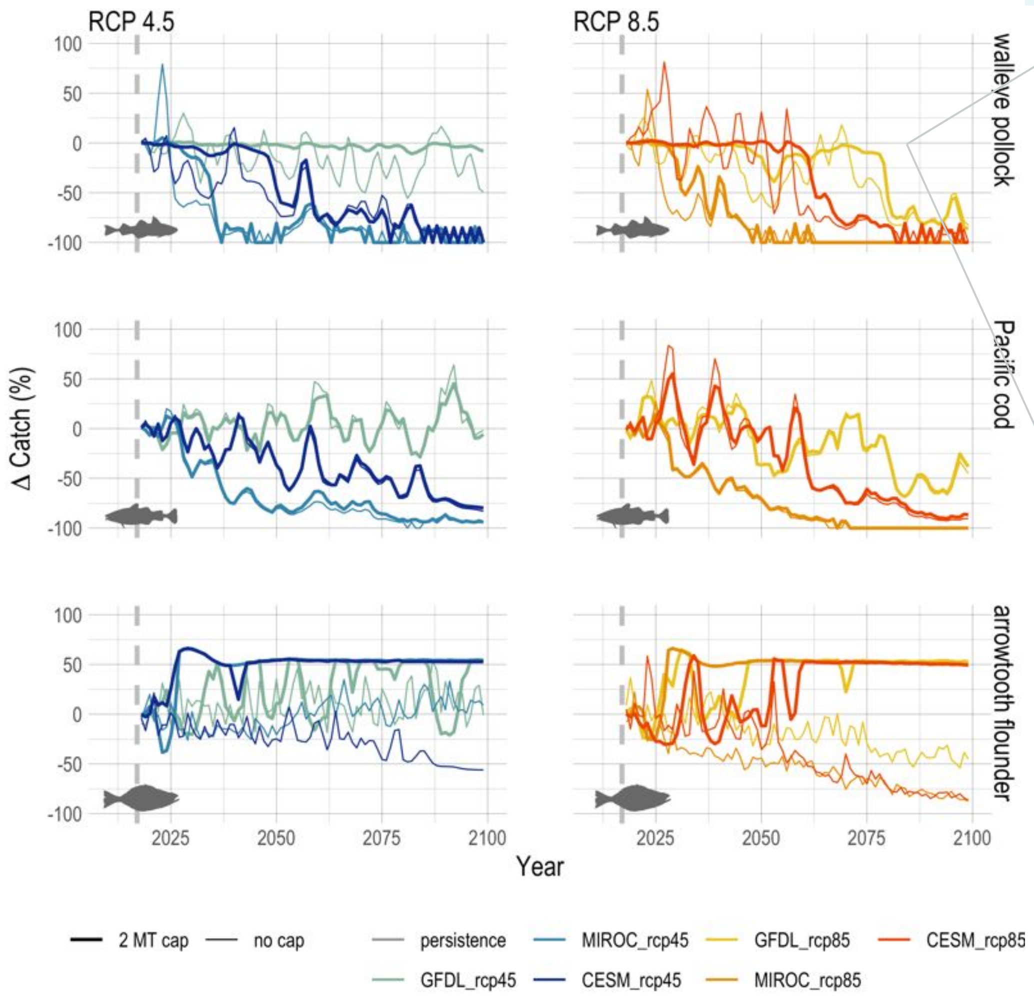
Holsman, K.K., Haynie, A.C., Hollowed, A.B. et al. Ecosystem-based fisheries management forestalls climate-driven collapse. Nat Commun 11, 4579 (2020). https://doi.org/10.1038/s41467-020-18300-3

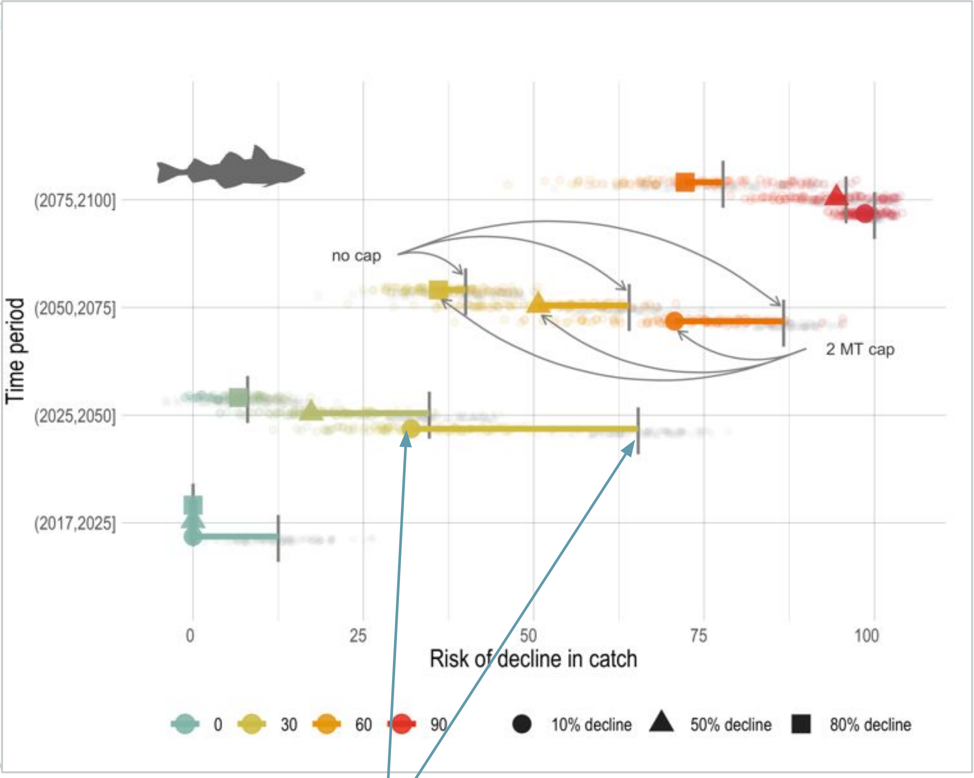
EBFM vs non-EBFM cap



Holsman, K.K., Haynie, A.C., Hollowed, A.B. et al. Ecosystem-based fisheries management forestalls climate-driven collapse. Nat Commun 11, 4579 (2020). https://doi.org/10.1038/s41467-020-18300-3

EBFM vs non-EBFM cap





Risk is lower for EBFM

Holsman, K.K., Haynie, A.C., Hollowed, A.B. et al. Ecosystem-based fisheries management forestalls climate-driven collapse. Nat Commun 11, 4579 (2020). https://doi.org/10.1038/s41467-020-18300-3

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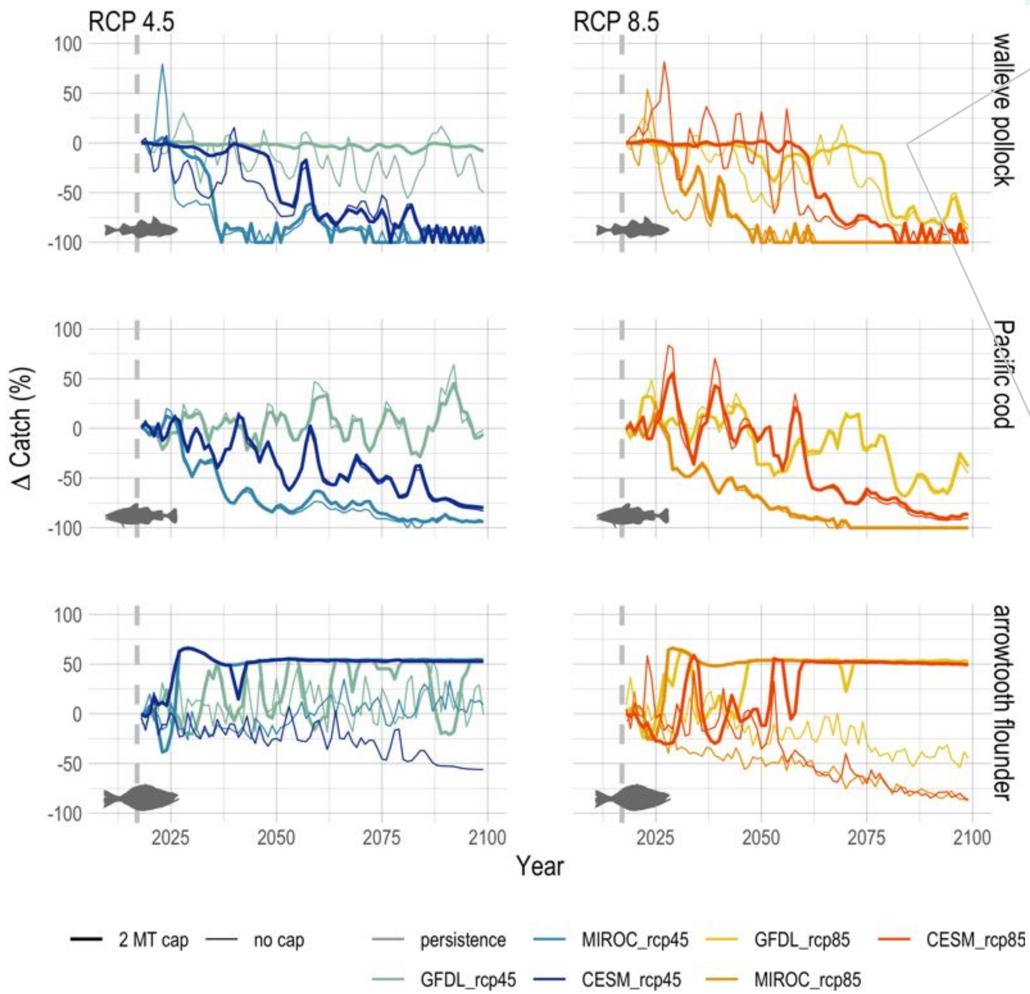

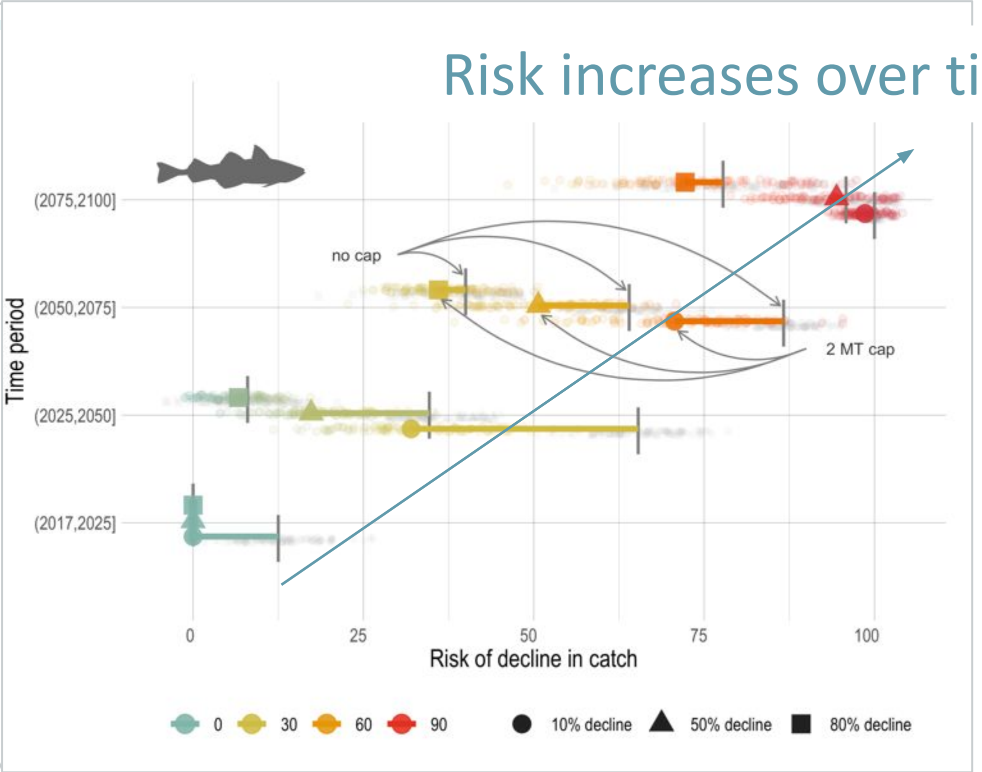

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Downscaling is needed

Projections based on global climate models may underestimate future variance. Variability among GCMs is large so select multiple scenarios to downscale.

Multiple models of biological & socioeconomic dynamics are needed

Accounting for predation changed the direction of projections from increases (single-sp model) to declines (multi-sp). Modeling management response and adaptation is needed to understand tipping points in the system. Climate impacts are non-additive and dynamics of the social-ecological system may attenuate or amplify impacts. Multiple integrated models are needed to evaluate structural uncertainty.

Mitigation is lower risk

Changes in productivity may induce large declines in fish and crab. Most pollock and cod scenarios crashed under business as usual (RCP8.5) by 2100; carbon mitigation (RCP 4.5) represents a lower risk scenario.

Adaptation through fisheries management

Changing harvest rates through management can help lessen climate impacts, to a point. EBFM can forestall climate declines and provide critical time to adapt.

ACLIM 2.0

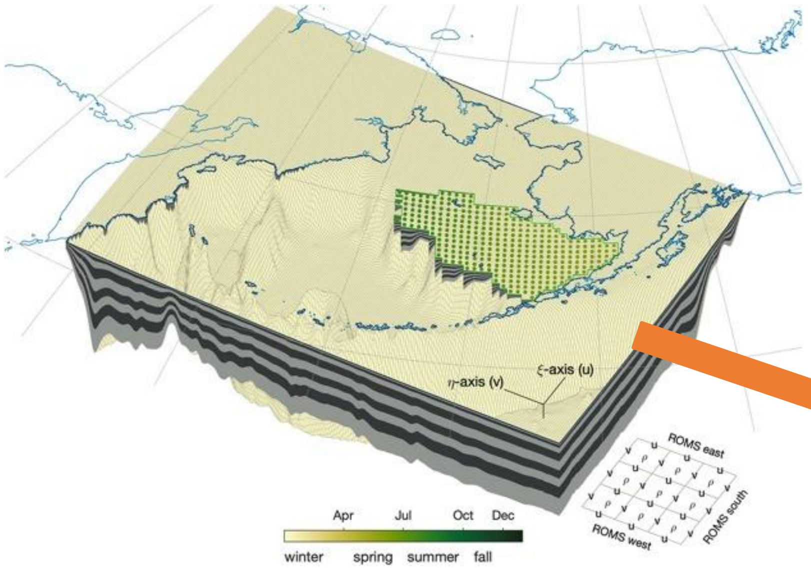
BUILDING PATHWAYS TO RESILIENCE THROUGH EVALUATION OF CLIMATE IMPACTS, RISK, & ADAPTATION RESPONSES OF MARINE ECOSYSTEMS, FISHERIES, & EBS COASTAL COMMUNITIES

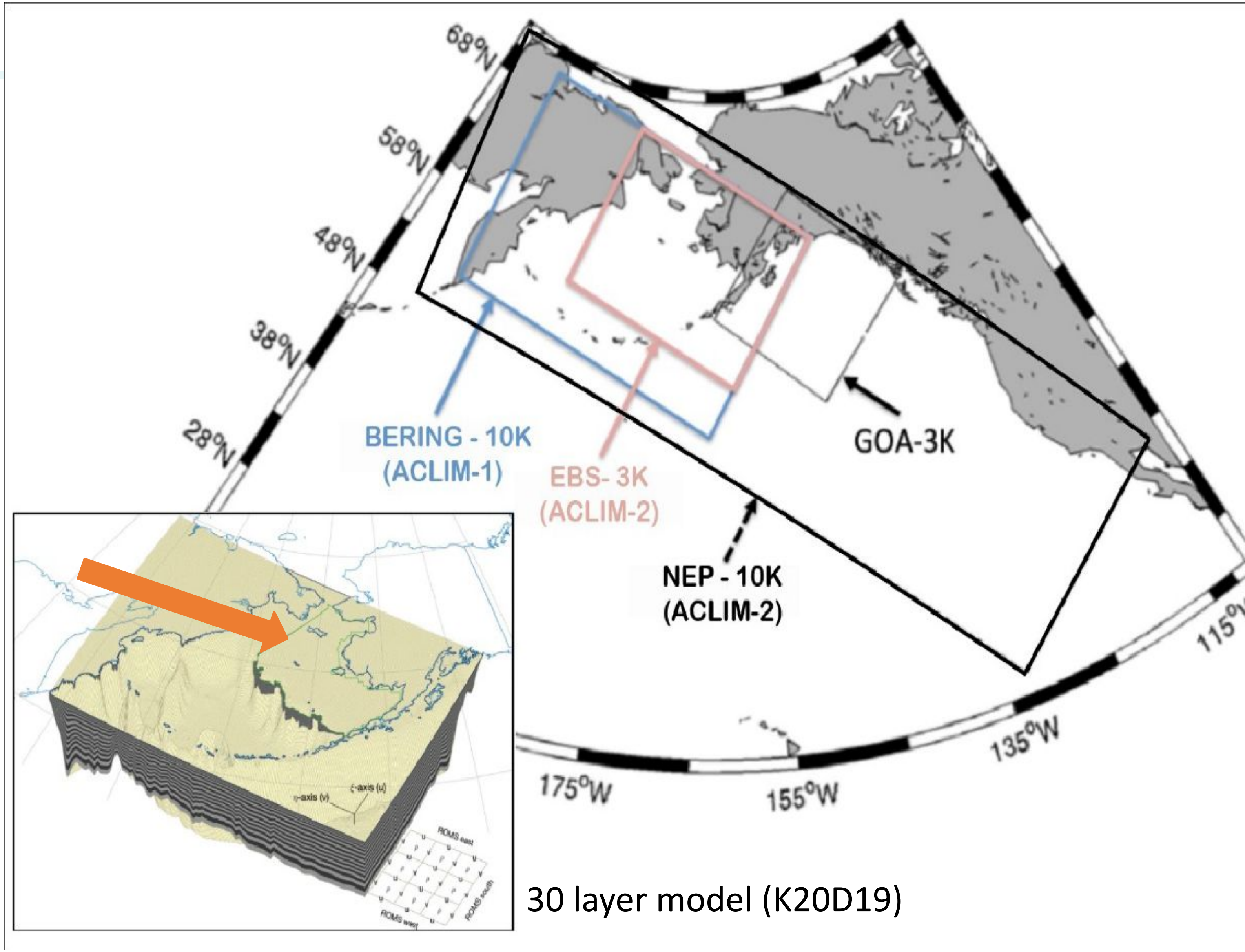
ACLIM 2.0 Next Directions

- EBS Social- ecological system climate risk analysis
- Expanded management scenarios
- Co-production of knowledge, community workshops, and social network modeling.
- Spatial distribution models & EBS
- Expanded protected species analyses (marine mammals!)
- Expanded OA and O2 modeling
- Expanded lower trophic and YOY modeling
- *GOA through Northern Bering ACLIM via GOA-CLIM*

ACLIM Phase 2

ACLIM 1 : 10layer model (H16)



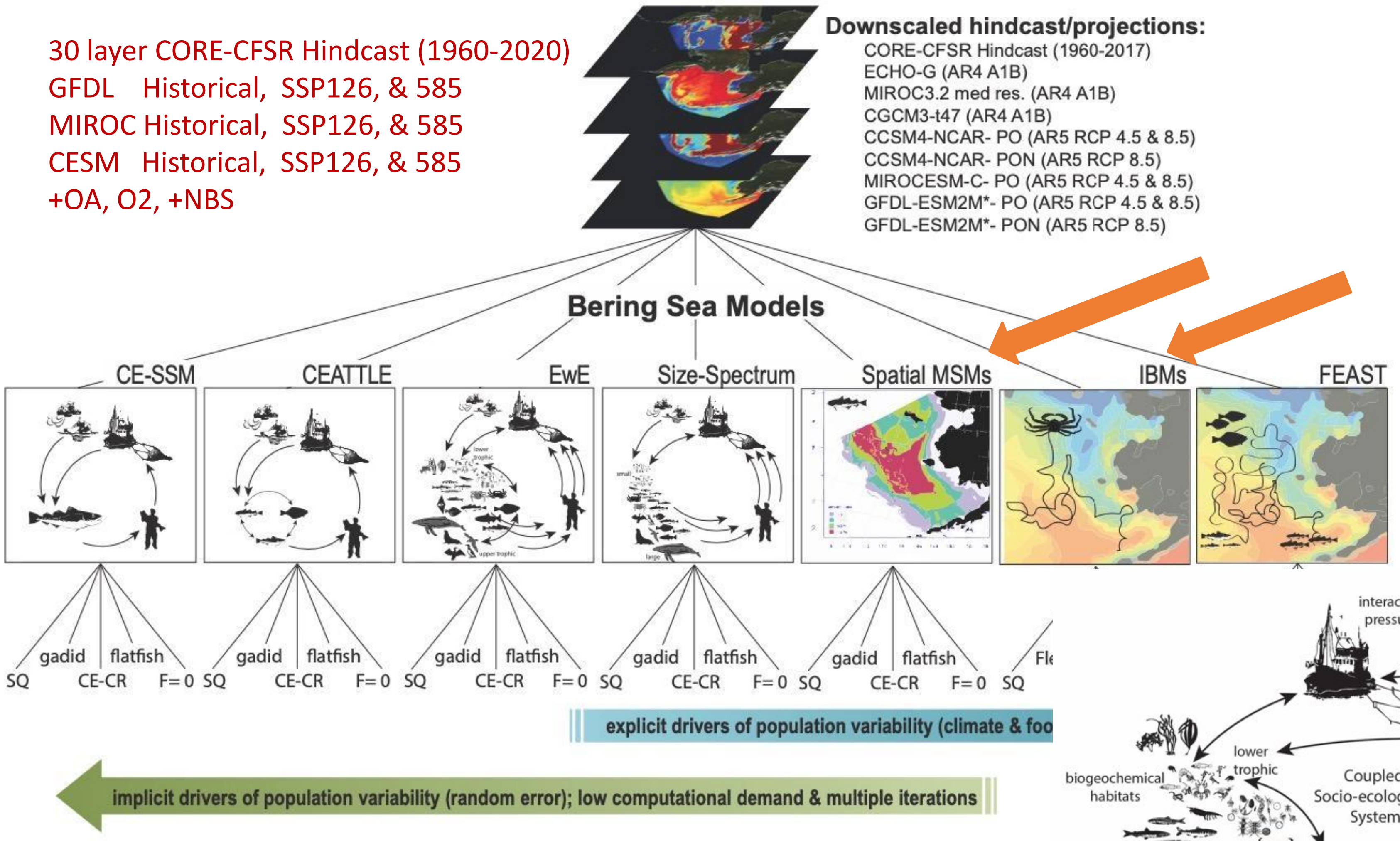


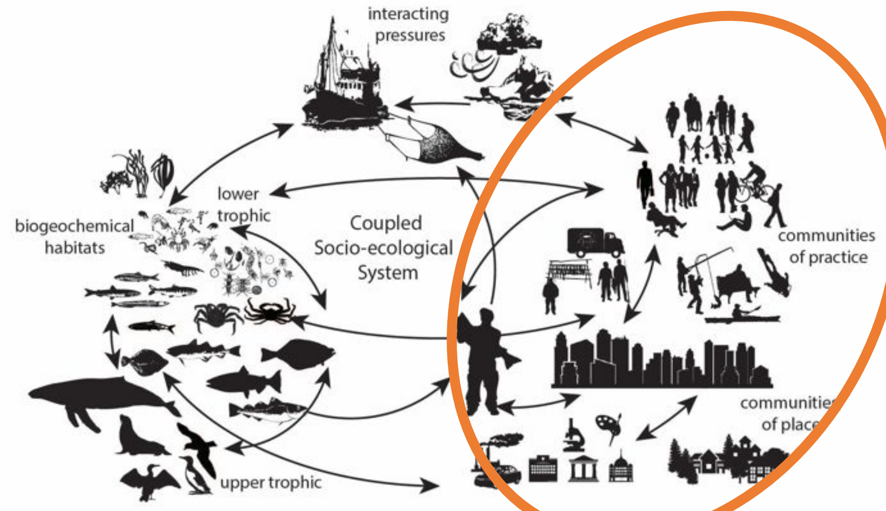
30 layer model (K20D19)

Hermann et al. 2013,2016, 2019; Kearney et al. 2020; Hollowed et al. 2020. Frontiers in Mar. Sci. doi: 10.3389/fmars.2019.00775

The Alaska Climate Integrated Modeling Project Phase 2

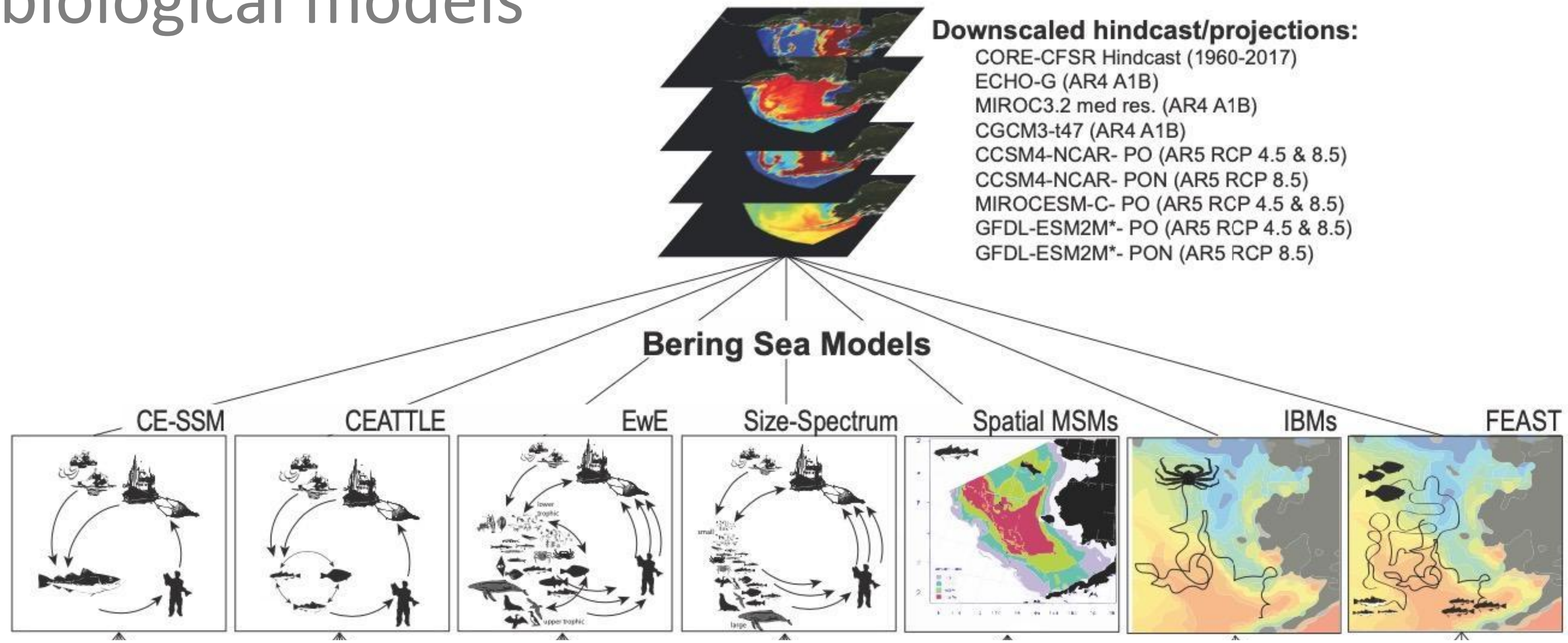
30 layer CORE-CFSR Hindcast (1960-2020)
GFDL Historical, SSP126, & 585
MIROC Historical, SSP126, & 585
CESM Historical, SSP126, & 585
+OA, O2, +NBS





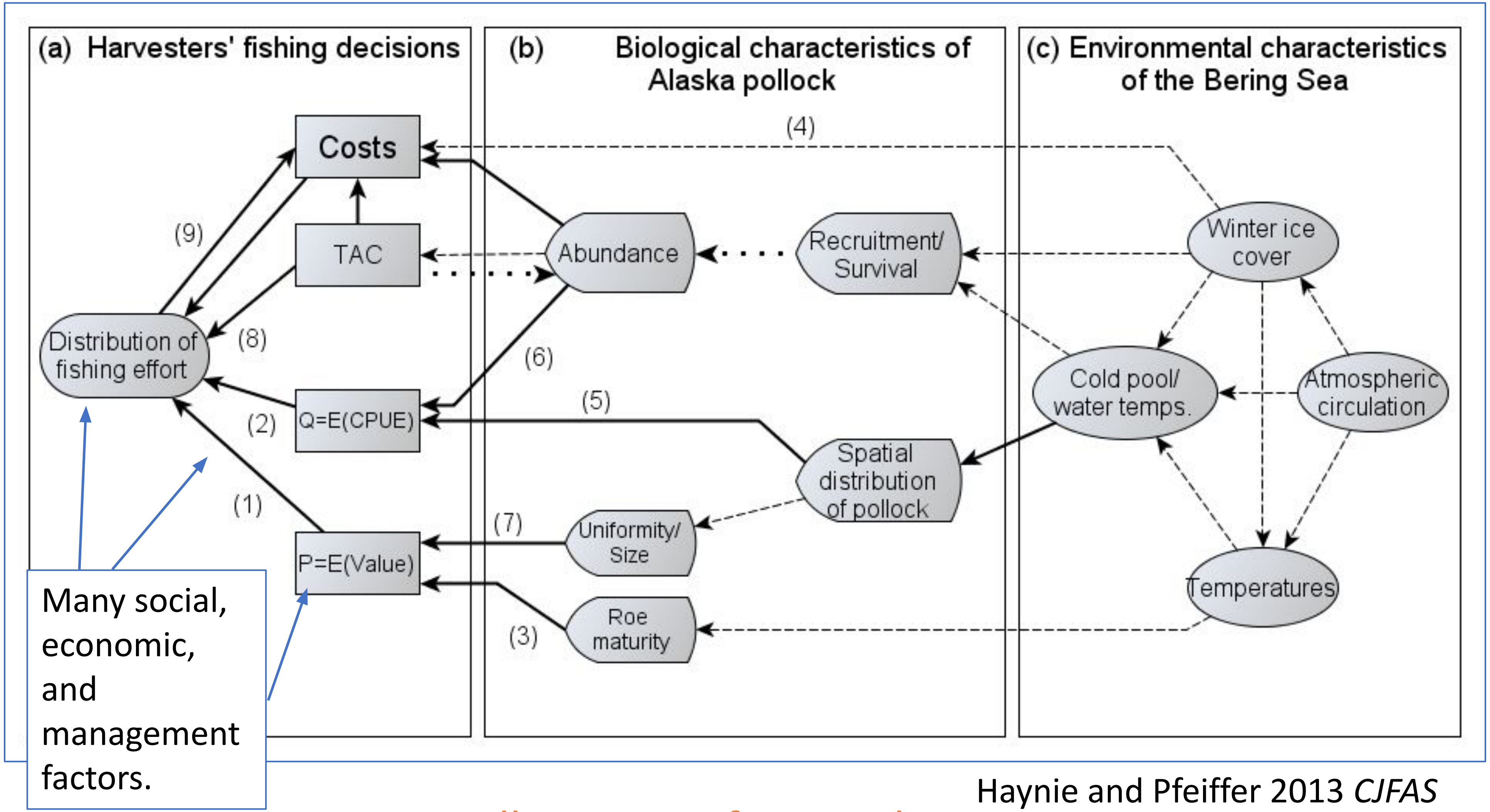
Actionable advice

Different socioeconomic models are being coupled with the integrated physical / biological models



ACLIM 2.0 uses economic / management models of different complexity to match the needs of biological models.

- Council TAC-setting
- Effort response to abundance
- Bycatch & price sensitivities
- Spatial models of fleets



Haynie and Pfeiffer 2013 *CJFAS*

Dynamically account for social and economic responses

How will we use Socioeconomic Scenarios?

- Provide tractable number of variations in the fisheries in response to a project changes in the ecosystem
- Evaluate how management strategies interact with environmental changes
  - Catch, Env impacts, revenue, profit, impacts on communities
- Are there management changes that would improve the projected future health and productivity of the North Pacific?
- What are the trade-offs across management objectives?

The Context for Tradeoffs:U.S. National Standards

1. **Optimum Yield**
2. **Scientific Information**
3. **Management Units**
4. **Allocations**
5. **Efficiency**
6. **Variations and Contingencies**
7. **Costs and Benefits**
8. **Communities**
9. **Bycatch**
10. **Safety of Life at Sea**

U.S. marine fisheries are scientifically monitored, regionally managed, and legally enforced under a number of requirements, including ten national standards.

The National Standards are principles that must be followed in any fishery management plan (FMP) to ensure sustainable and responsible fishery management.

As mandated by the Magnuson-Stevens Fishery Conservation and Management Act, NOAA Fisheries has developed guidelines for each National Standard.

When reviewing FMPs, FMP amendments, and regulations, the Secretary of Commerce must ensure that they are consistent with the National Standard guidelines.

Photo: Alan Haynie

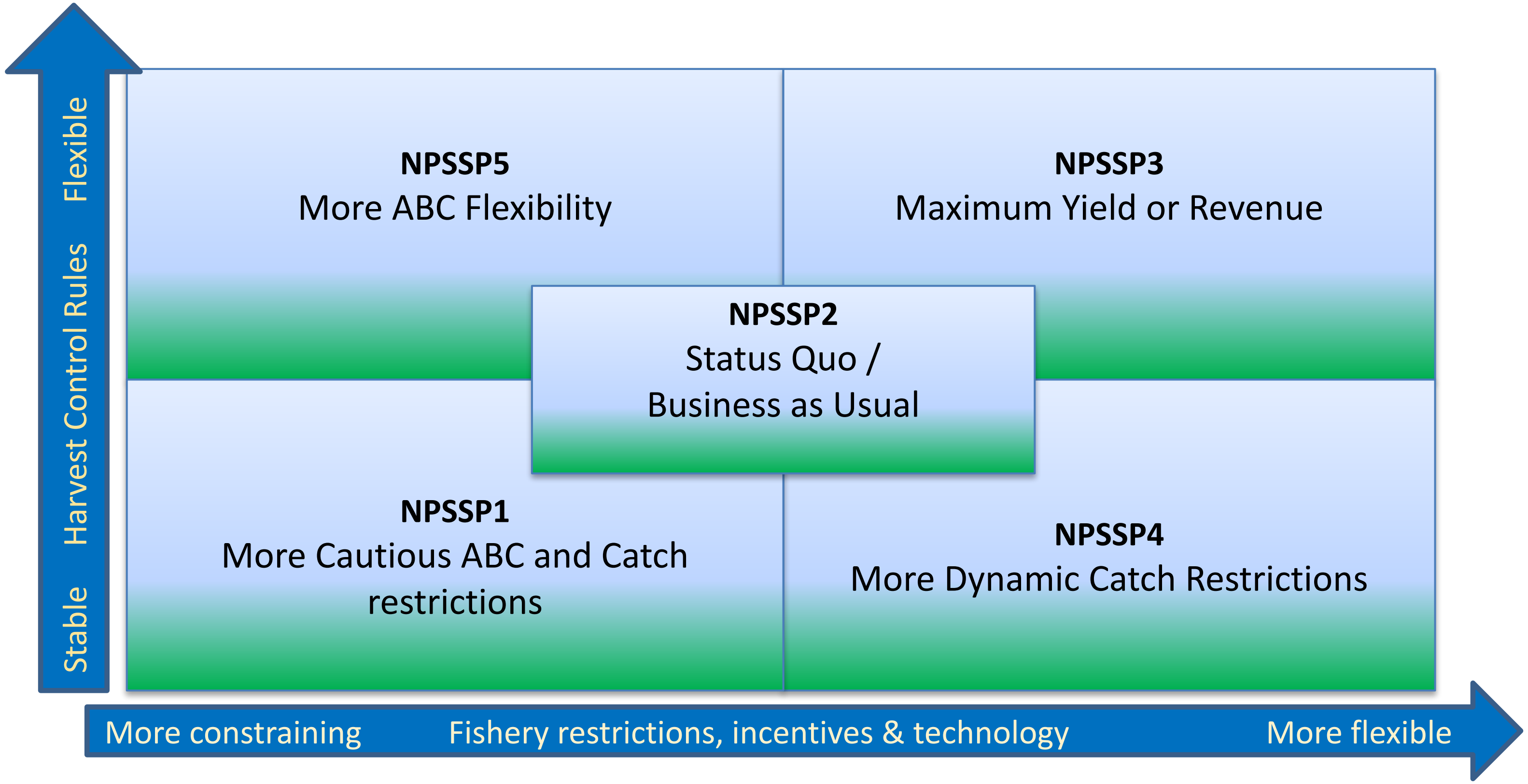
ACLIM 1.0 Four- Scenario Comparison Based on Council input on the challenges of setting TACs under the 2 million ton cap

1. No Fishing
2. Current Ecosystem Management (Status Quo)
3. Increased Pollock-cod share of total allowable catch– max 10% increase under the cap
4. Increased Flatfish share of total allowable catch (Flatfish Dominated) – Lg. flatfish increase

Photo: Alan Haynie

Photo: Alan Haynie

ACLIM 2.0: North Pacific Socio-Economic Pathways (NPSSPs)



<u>Other dimensions</u>

- Monitoring impacts
- Ecosystem models
- Emissions scenarios / models
- Diverse regulations

Note: there are additional complexities, too!

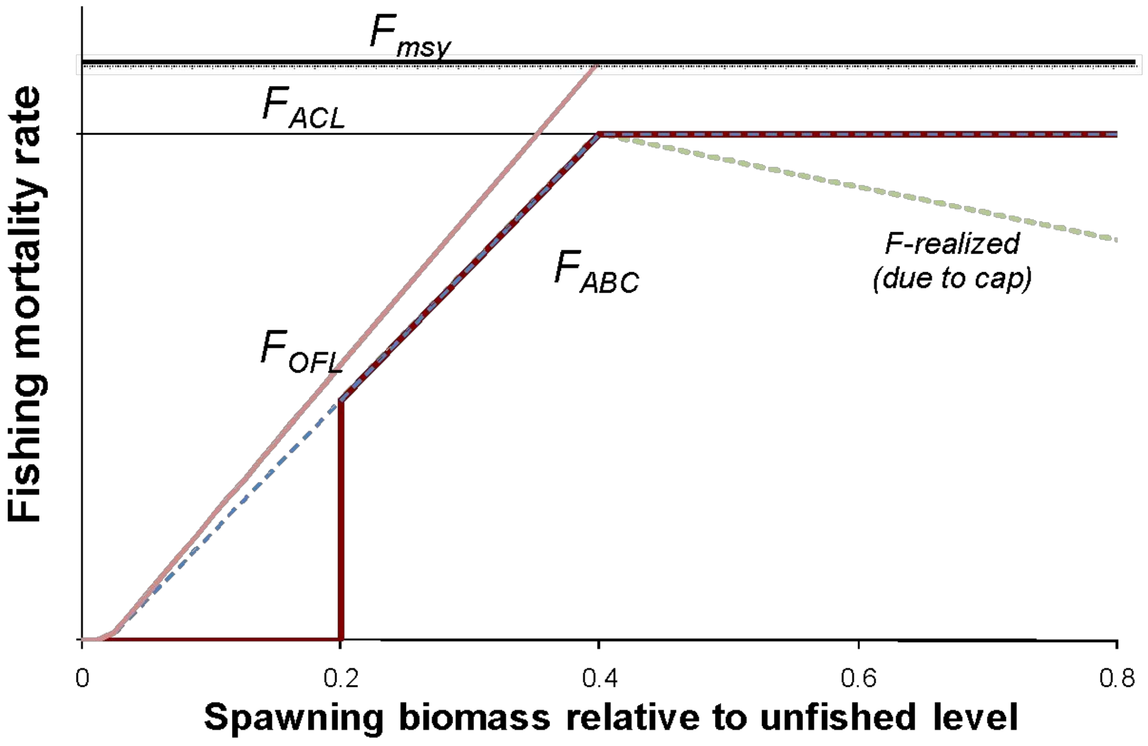
Different models will use simulations that assess the impacts - ecological, economic, and allocational - of different changes in harvest control rules that impact ABC and in regulations and economic drivers that impact catch of different species.

In light of climate change, what are the trade-offs of different Harvest Control Rules (HCRs)?

Boreal ecosystems are exposed to highly variable environmental conditions (seasonal, interannual and decadal).

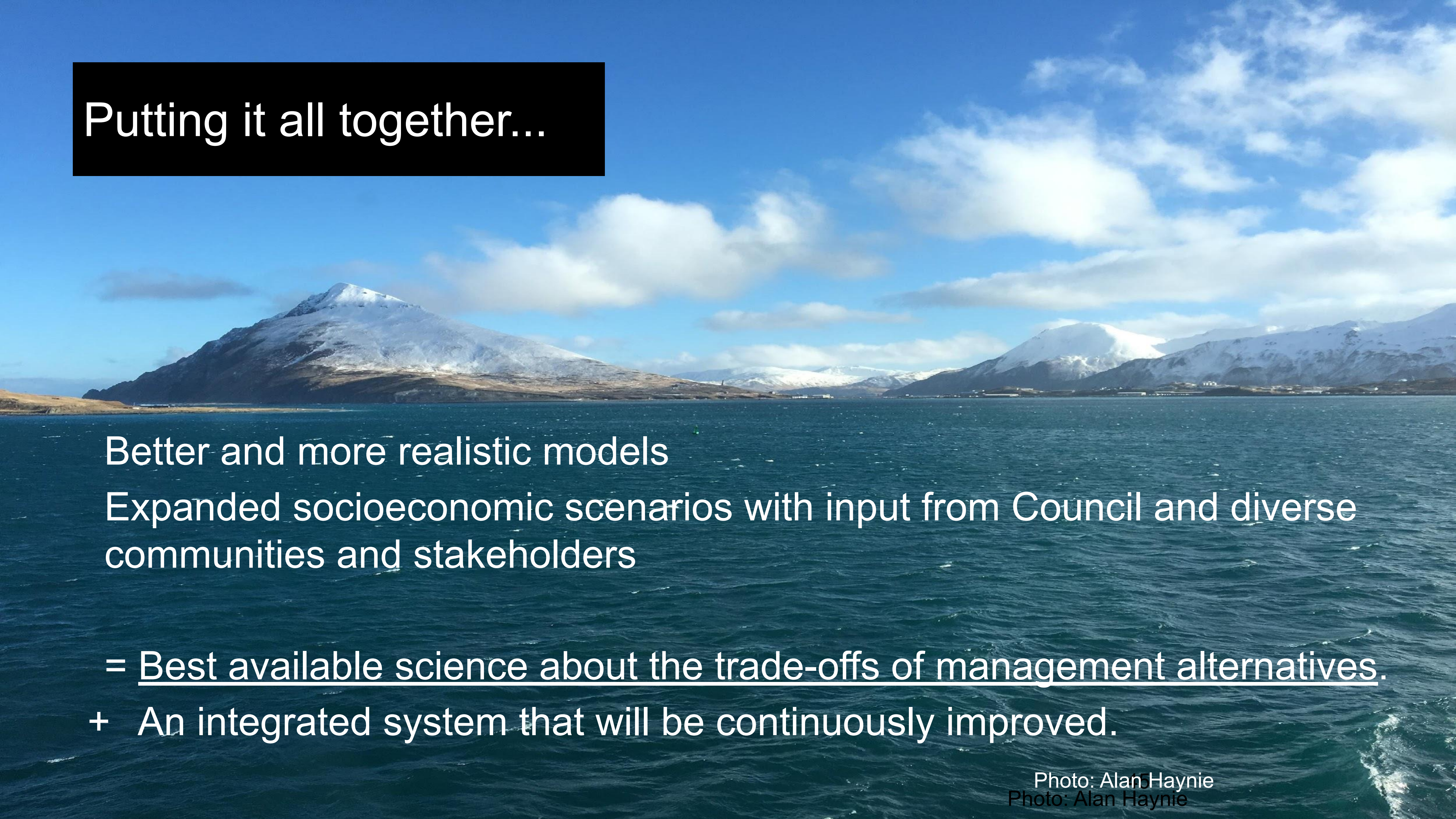
- Over evolutionary time boreal species have adapted life history characteristics to sustain populations through perturbations.
- Sustainable fisheries policies are designed to estimate the average production necessary to replace spawners over time. Assumes some fraction of the surplus production can be harvested sustainably.
- If characteristics of emerging climate impacted ecosystem differ from those experienced in evolutionary time then knowledge of the range of reproductive potential of the population informs actions to sustain populations.

North Pacific Fishery Management Council - Pollock



Punt et al. 2010

Putting it all together...



Better and more realistic models

Expanded socioeconomic scenarios with input from Council and diverse communities and stakeholders

= Best available science about the trade-offs of management alternatives.

\+ An integrated system that will be continuously improved.

Photo: Alan Haynie

Photo: Alan Haynie

Thanks!

- ACLIM 1.0 funding:
  - Fisheries & the Environment (FATE)
  - Stock Assessment Analytical Methods (SAAM)
  - Climate Regimes & Ecosystem Productivity (CREP)
  - NMFS Economics and Human Dimensions Program
  - NOAA Integrated Ecosystem Assessment Program (IEA)
  - NOAA Research Transition Acceleration Program (RTAP)
  - Alaska Fisheries Science Center
- ACLIM 2.0 funding:
  - NOAA's Coastal and Ocean Climate Applications (COCA) Climate and Fisheries Program
  - NOAA Integrated Ecosystem Assessment Program (IEA)
  - Alaska Fisheries Science Center

Collaboration support:

- NPRB & BSIERP Team
- GOA-CLIM Team
- AFSC REEM, REFM, RACE
- ICES PICES Strategic Initiative on climate change and marine ecosystems (SICCME/S-CCME)
- NPFMC Climate change task force, the Ecosystem Committee of the NPFMC
- FAO
- MAPP

QUESTIONS?

Glossary of Terms

- IPCC : United Nations Intergovernmental Panel on Climate Change
- NOAA : National Oceanic and Atmospheric Administration
- NMFS : National Marine Fisheries Service
- Council : North Pacific Fisheries Management Council
- CE - : “Climate Enhanced” -
- GCM : General Circulation Model (Global in scale)
- RCP : Representative (carbon) Concentration Pathway
- FEP : Fisheries Ecosystem Plan
- ROMS : Regional Ocean Modeling System
- NPZ : Nutrient Phytoplankton Zooplankton Model
- CEATTLE : Climate Enhanced Assessment with Temperature and Trophic Linkages & Energetics Model
- FEAST : Forage and Euphausiid Assessment in Space and Time model
- SES : coupled Social-Ecological System