ACLIM
The Alaska Climate Integrated Modeling project

Anne Hollowed, NOAA

Kerim Aydin, NOAA

Al Hermann, UW

Jonathan Reum, NOAA

André Punt, UW

+ ACLIM Team

Ecosystem Committee, March 29, 2022

Kirstin Holsman, kirstin.holsman@noaa.gov
Alan Haynie, Alan.Haynie@noaa.gov
NOAA Alaska Fisheries Science Center

ACLIM Team

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

Co-Pis & Collaborators

Wei Cheng
Jim Ianelli
Kelly Kearney
Elizabeth McHuron
Daren Pilcher
Jeremy Sterling
Ingrid Spies
Paul Spencer
William Stockhausen
Cody Szuwalski
Sarah Wise
Ellen Yasumiishi

Andy Whitehouse
James Thorson
Peggy Sullivan
Amanda Faig
Steve Kasperski
Martin Dorn
Diana Evans
Ed Farely
Enrique Curchitser
Elliott Hazen
David Kimmel
Mike Jacox
Adam Hayes

Carol Ladd
Stan Kotwicki
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 advice

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

Model enhancements & scoping of scenarios

Modelers run first set of (HCR+ABC x Fishing x Climate) scenarios

Modelers run phase 2 (HCR+ABC x Fishing x Climate) scenarios

Initial results and findings summarized and synthesized

Papers and synthesis writing; Individual MSEs & follow up papers planned

Draft summary of key findings for Council provided to CCTF, Eco. Comm., AP, SSC, and Council

Final report and recommendations for future actions & priority research

2021 — **December Council Meeting**

Introduction to ACLIM 2.0 and review of findings from ACLIM 1.0.

2022 — **March Ecosystem Committee update**

In depth discussion of ACLIM 1.0 findings and feedback on planned activities leading up to June 2022 fishing scenarios workshop.

2022 — **June Scenarios Workshop (June 8)**

Evening workshop to discuss recent ACLIM management strategy evaluation climate X fishing scenarios and scope June - Oct phase 2 set. Interactive with SSC, Council members and public.

2022 — **October Council Meeting**

ACLIM initial findings presented to Council for feedback.

2023 — **December Council Meeting**

2023 — **April Council Meeting**

2023 — **June Council Meeting**

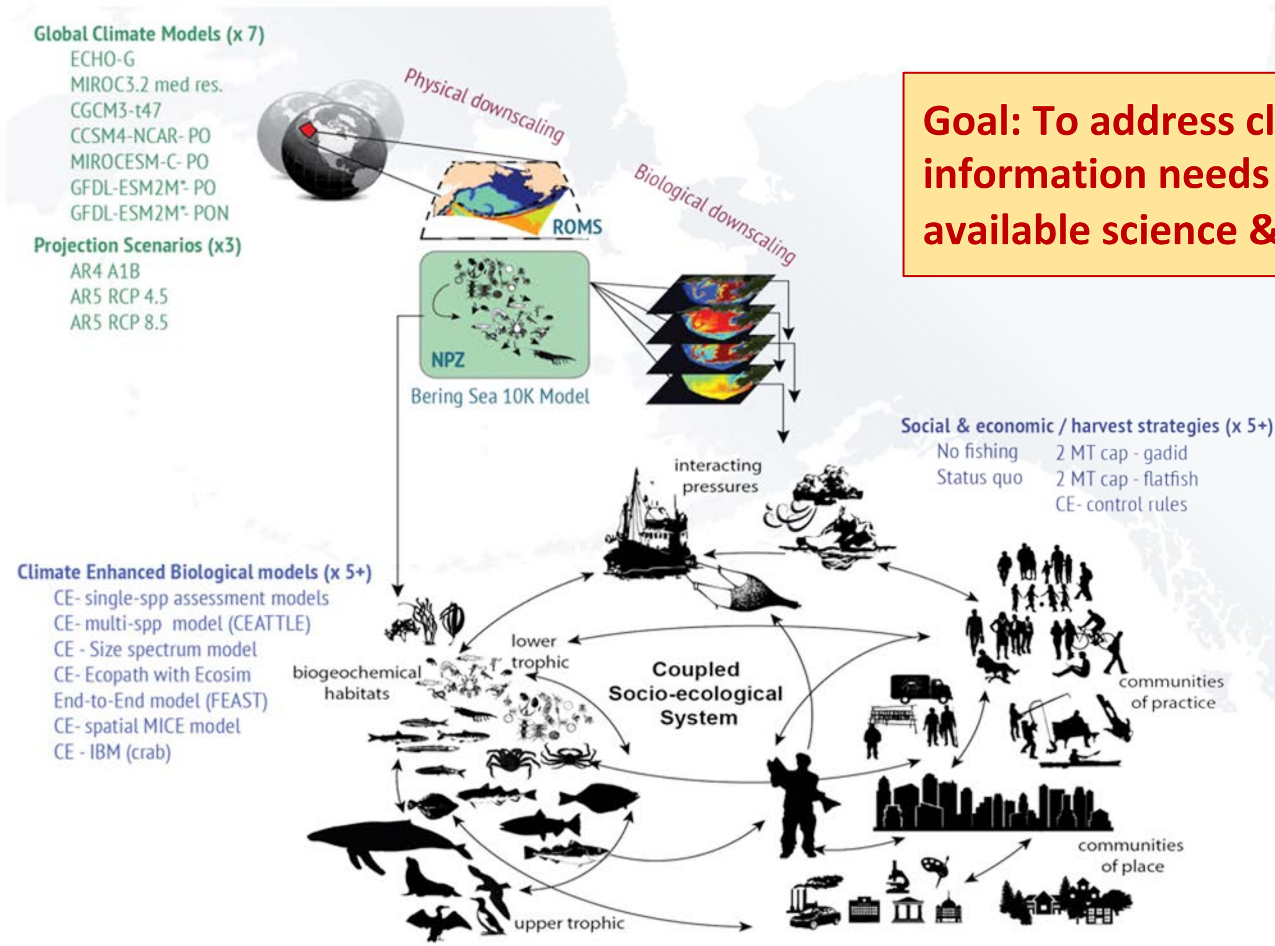
ACLIM

The Alaska Climate Integrated Modeling Project

NOAA Alaska Fisheries Science Center

The Alaska Climate Integrated Modeling Project

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



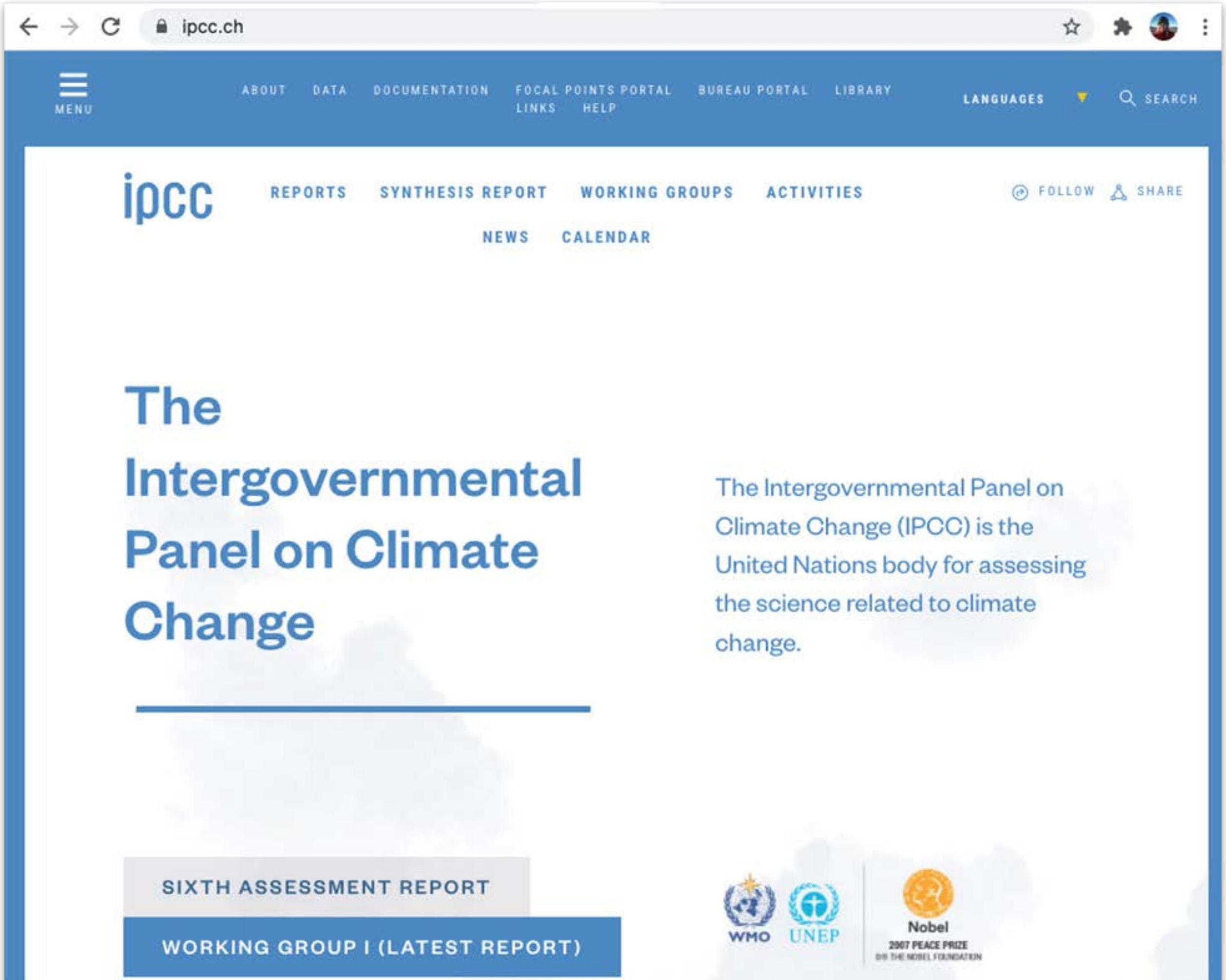
Goal: To address climate information needs with best available science & tools

UNIVERSITY of WASHINGTON
SAFS School of Aquatic and Fishery Sciences
PMEL
JISAO
IEA INTEGRATED ECOSYSTEM ASSESSMENT
NOAA FISHERIES

Outline of Today's Presentation

1. Background on climate change and ACLIM
2. Most recent climate projections for the Bering Sea
3. ACLIM phase 1: Biological projections with fishing scenarios
4. ACLIM phase 2: fishing and harvest control rule (HCR) example scenarios + requests for Council input

IPCC 6th Assessment Report (2021)

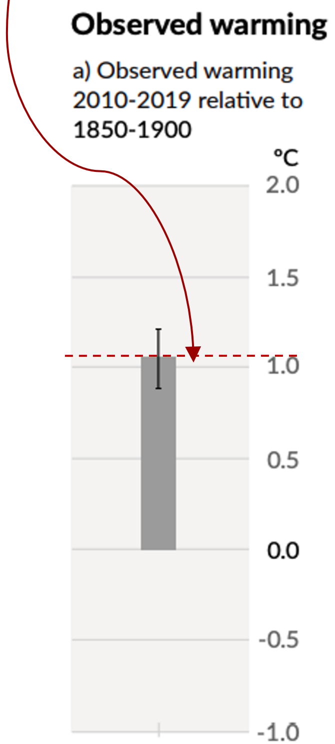


https://www.ipcc.ch/

Part 1

Climate change has already warmed the planet

*"The likely range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019 is **0.8°C to 1.3°C, with a best estimate of 1.07°C.**"*
[IPCC 2021 6th Assessment Report, WG 1, SPM]



Figures from the IPCC AR6 WGI Summary for Policymakers: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

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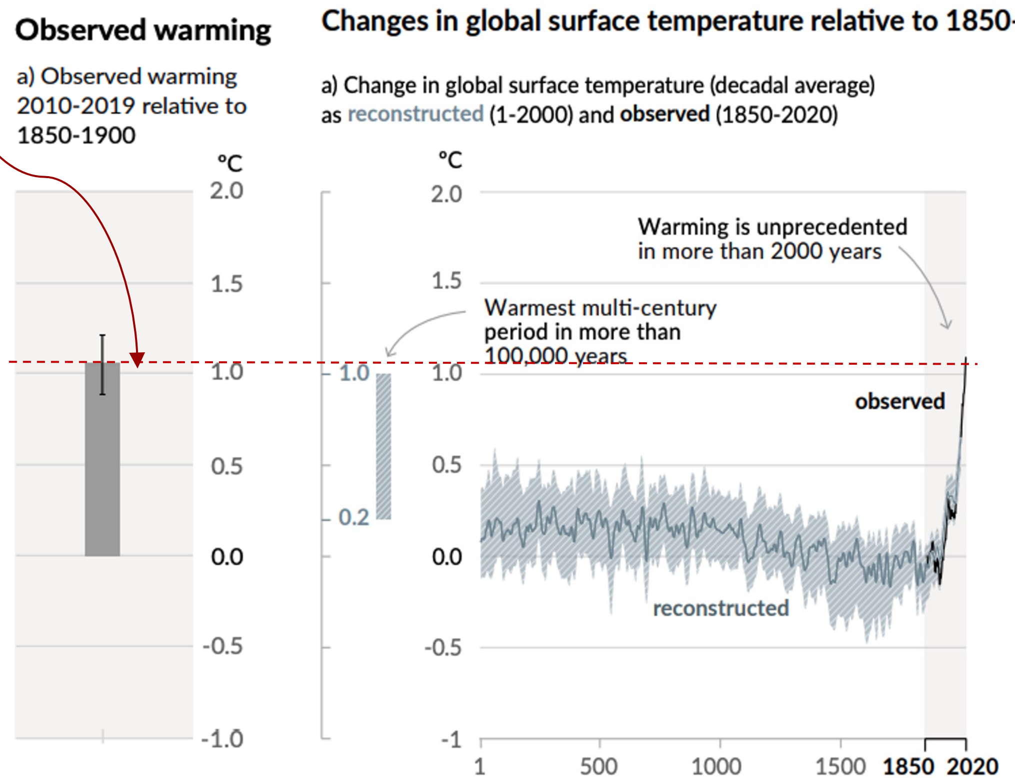

Recent Global Mean Warming is:

- Warmest period in more than 100,000 years
- Unprecedented warming in more than 2,000 years

Figures from the IPCC AR6 WGI Summary for Policymakers: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

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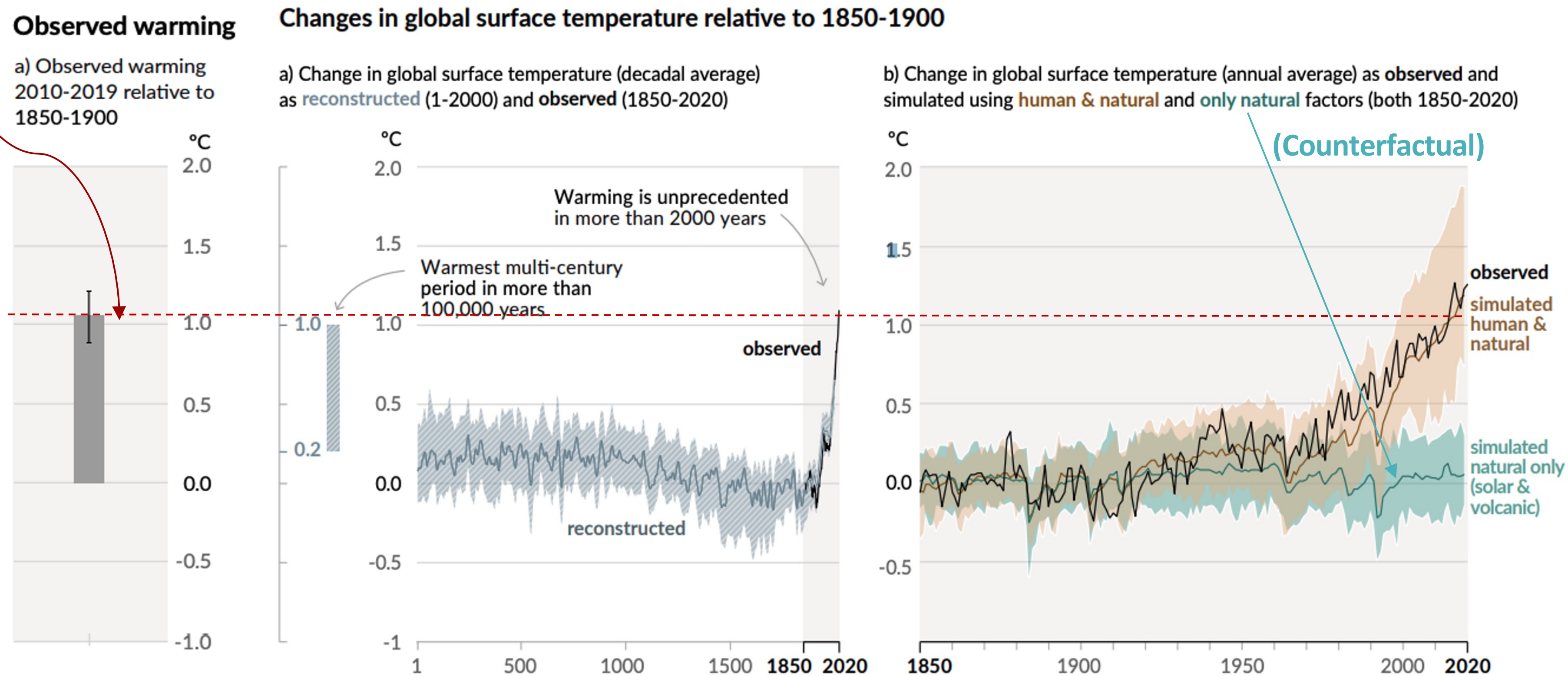


Figures from the IPCC AR6 WGI Summary for Policymakers: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

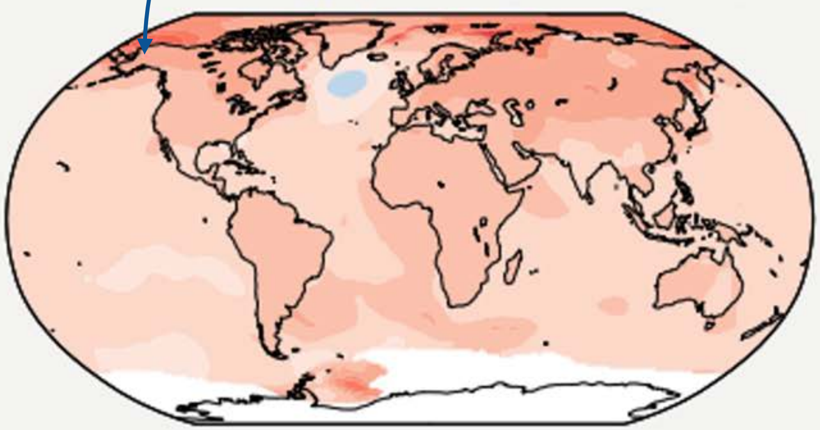
Warming in the Arctic is 2-3 x global average

1.07^{o}C of "Global mean warming" = Warming of 2-3oC in the Arctic

"Polar Amplification"

a) Annual mean temperature change (°C) at 1 °C global warming

Warming at 1 °C affects all continents and is generally larger over land than over the oceans in both observations and models. Across most regions, observed and simulated patterns are consistent.



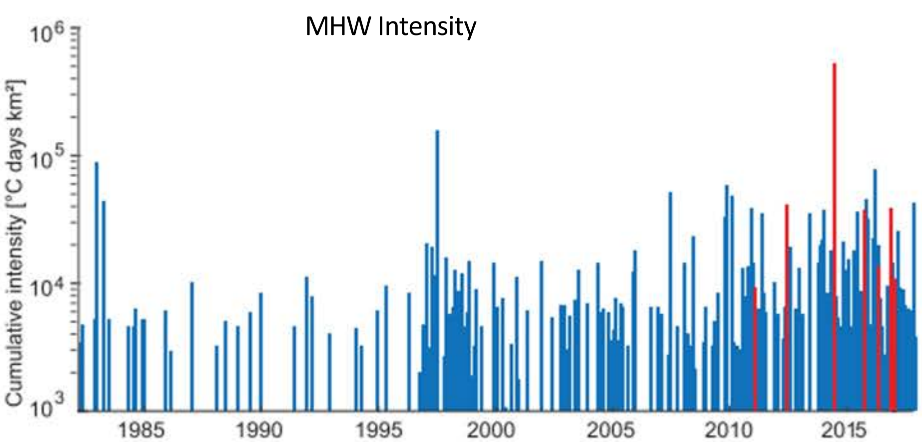
Figures from the IPCC AR6 WGI Summary for Policymakers: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

In Alaska climate change has already caused: Marine Heatwaves

"We show that the occurrence probabilities of the duration, intensity, and cumulative intensity of most documented, large, and **impactful MHWs have increased more than 20-fold as a result of anthropogenic climate change.**"

Pre-industrial (0°C global warming) = once every 100-1,000 y
1.5°C global warming = once every 10 - 100 y
3.0°C global warming = once every 1 - 10 y

E



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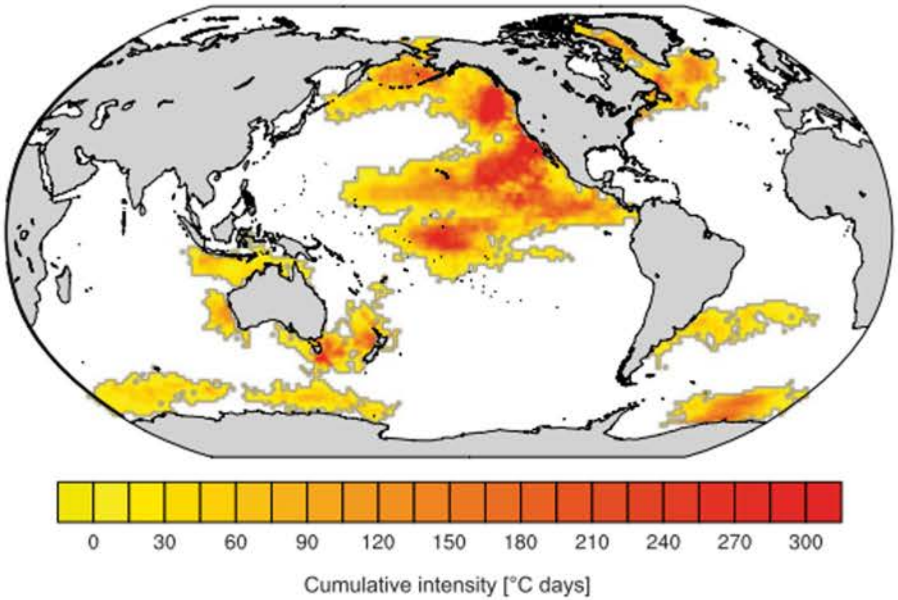
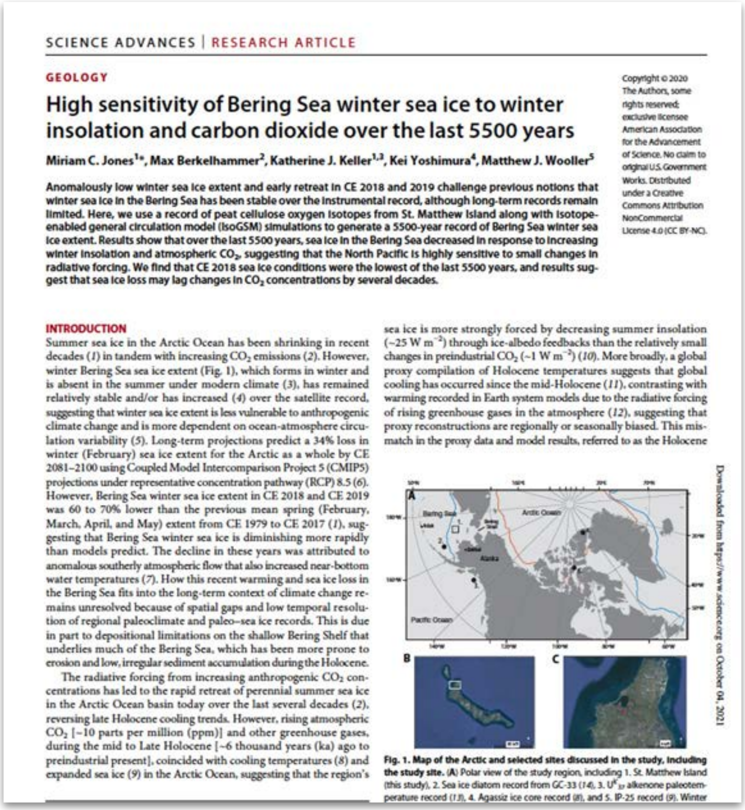


High-impact marine heatwaves attributable to human-induced global warming Laufkötter et al. Science 369 (6511), 1621-1625. DOI: 10.1126/science.aba0690

In Alaska climate change has already caused: Loss of Sea Ice



SCIENCE ADVANCES | RESEARCH ARTICLE

GEOLOGY

High sensitivity of Bering Sea winter sea ice to winter insolation and carbon dioxide over the last 5500 years

Miriam C. Jones[1*], Max Berkelhammer[2], Katherine J. Keller[1,3], Kei Yoshimura[4], Matthew J. Wooller[5]

Anomalously low winter sea ice extent and early retreat in CE 2018 and 2019 challenge previous notions that winter sea ice in the Bering Sea has been stable over the instrumental record, although long-term records remain limited. Here, we use a record of peat cellulose oxygen isotopes from St. Matthew Island along with isotope-enabled general circulation model (IsoGSM) simulations to generate a 5500-year record of Bering Sea winter sea ice extent. Results show that over the last 5500 years, sea ice in the Bering Sea decreased in response to increasing winter insolation and atmospheric CO_2, suggesting that the North Pacific is highly sensitive to small changes in radiative forcing. We find that CE 2018 sea ice conditions were the lowest of the last 5500 years, and results suggest that sea ice loss may lag changes in CO_2 concentrations by several decades.

INTRODUCTION

Summer sea ice in the Arctic Ocean has been shrinking in recent decades (*1*) in tandem with increasing CO_2 emissions (*2*). However, winter Bering Sea sea ice extent (Fig. 1), which forms in winter and is absent in the summer under modern climate (*3*), has remained relatively stable and/or has increased (*4*) over the satellite record, suggesting that winter sea ice extent is less vulnerable to anthropogenic climate change and is more dependent on ocean-atmosphere circulation variability (*5*). Long-term projections predict a 34% loss in winter (February) sea ice extent for the Arctic as a whole by CE 2081–2100 using Coupled Model Intercomparison Project 5 (CMIP5) projections under representative concentration pathway (RCP) 8.5 (*6*). However, Bering Sea winter sea ice extent in CE 2018 and CE 2019 was 60 to 70% lower than the previous mean spring (February, March, April, and May) extent from CE 1979 to CE 2017 (*1*), suggesting that Bering Sea winter sea ice is diminishing more rapidly than models predict. The decline in these years was attributed to anomalous southerly atmospheric flow that also increased near-bottom water temperatures (*7*). How this recent warming and sea ice loss in the Bering Sea fits into the long-term context of climate change remains unresolved because of spatial gaps and low temporal resolution of regional paleoclimate and paleo–sea ice records. This is due in part to depositional limitations on the shallow Bering Shelf that underlies much of the Bering Sea, which has been more prone to erosion and low, irregular sediment accumulation during the Holocene.

The radiative forcing from increasing anthropogenic CO_2 concentrations has led to the rapid retreat of perennial summer sea ice in the Arctic Ocean basin today over the last several decades (*2*), reversing late Holocene cooling trends. However, rising atmospheric CO_2 [~10 parts per million (ppm)] and other greenhouse gases, during the mid to Late Holocene [~6 thousand years (ka) ago to preindustrial present], coincided with cooling temperatures (*8*) and expanded sea ice (*9*) in the Arctic Ocean, suggesting that the region's sea ice is more strongly forced by decreasing summer insolation (~25 W m^{-2}) through ice-albedo feedbacks than the relatively small changes in preindustrial CO_2 (~1 W m^{-2}) (*10*). More broadly, a global proxy compilation of Holocene temperatures suggests that global cooling has occurred since the mid-Holocene (*11*), contrasting with warming recorded in Earth system models due to the radiative forcing of rising greenhouse gases in the atmosphere (*12*), suggesting that proxy reconstructions are regionally or seasonally biased. This mismatch in the proxy data and model results, referred to as the Holocene

Fig. 1. Map of the Arctic and selected sites discussed in the study, including the study site. (**A**) Polar view of the study region, including 1. St. Matthew Island (this study), 2. Sea ice diatom record from GC-33 (*14*), 3. $U^{K'}_{37}$ alkenone paleotemperature record (*13*), 4. Agassiz ice core record (*8*), and 5. IP-25 record (*9*). Winter

- 2018 Bering Sea winter ice extent is **lowest in 5,500 yr record**
- Bering Sea ice extent lags atmospheric carbon concentrations **by ~2 decades**
- Moderate to high global carbon mitigation preserves some winter EBS sea ice

Jones,et al. (2020). High sensitivity of Bering Sea winter sea ice to winter insolation and carbon dioxide over the last 5500 years. *Science Advances*, *6*(36), 1–10. https://doi.org/10.1126/sciadv.aaz9588

https://www.noaa.gov/stories/unprecedented-2018-bering-sea-ice-loss-repeated-in-2019

Part 1

In Alaska climate change has already caused: Fishery impacts

"Nationwide, 84.5% of fishery disasters were either partially or entirely attributed to extreme environmental events."

PeerJ

Table 2 **Total U.S. Congressional fishery disaster assistance (2019 USD) by cause and by federalfisheries management region.** One additional disaster had an allocation amount that was not reported, but the request letter cited economic impacts of $53.8-94.2M. Anthropogenic causes include pollution and overfishing; environmental causes include marine heatwaves, harmful algal blooms, hurricanes, extreme drought, etc.; and a combination includes both anthropogenic and environmental causes. Examples of fisheries being impacted by a combination of causes can be found in some Pacific northwest salmon fishery disasters, which were caused by low returns that resulted from marine heatwaves, drought, disease, habitat impacts, mismanagement, and overfishing.

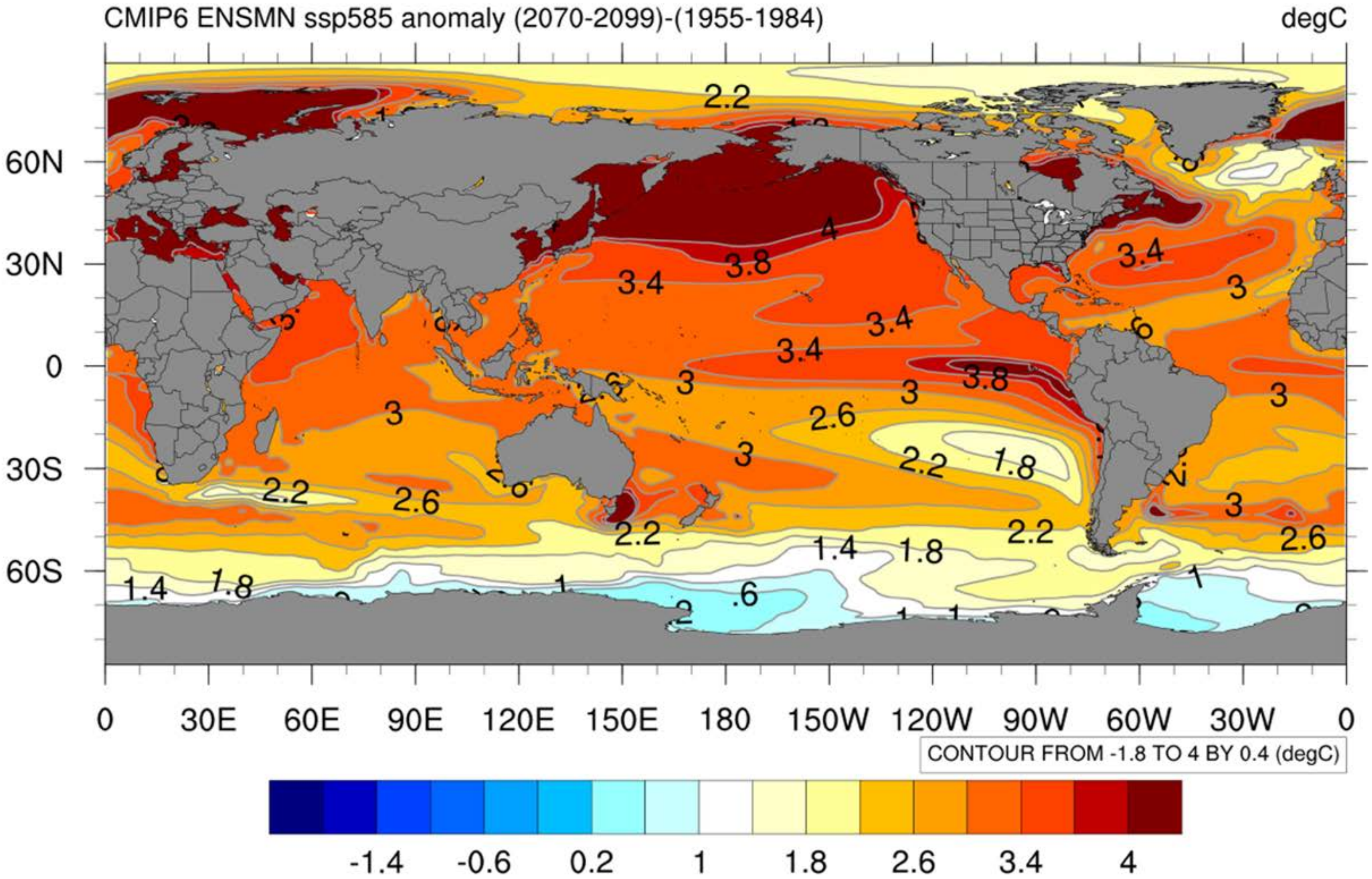
Cause	Alaska	Greater Atlantic	Pacific Islands	Southeast	West Coast	To be determined	Total
Anthropogenic	$82,000,000	$132,996,669		$30,940,000	$7,600,000		$253,536,669
Environmental	$174,292,189	$41,572,622	$1,140,000	$505,938,343	$170,723,211		$893,666,365
Combination of Both	$75,588,349	$36,600,000		$37,098,200	$281,802,589		$431,089,138
To be determined						$414,103,069	$414,103,069
Total	$331,880,538	$211,169,291	$1,140,000	$573,976,543	$460,125,800	$414,103,069	$1,992,395,241

Bellquist et al. 2021. The rise in climate change-induced federal fishery disasters in the United States. https://peerj.com/articles/11186/

ACLIM

Part 1

Climate change is expected to continue to impact AK Ecosystems & Fisheries



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

Part 1

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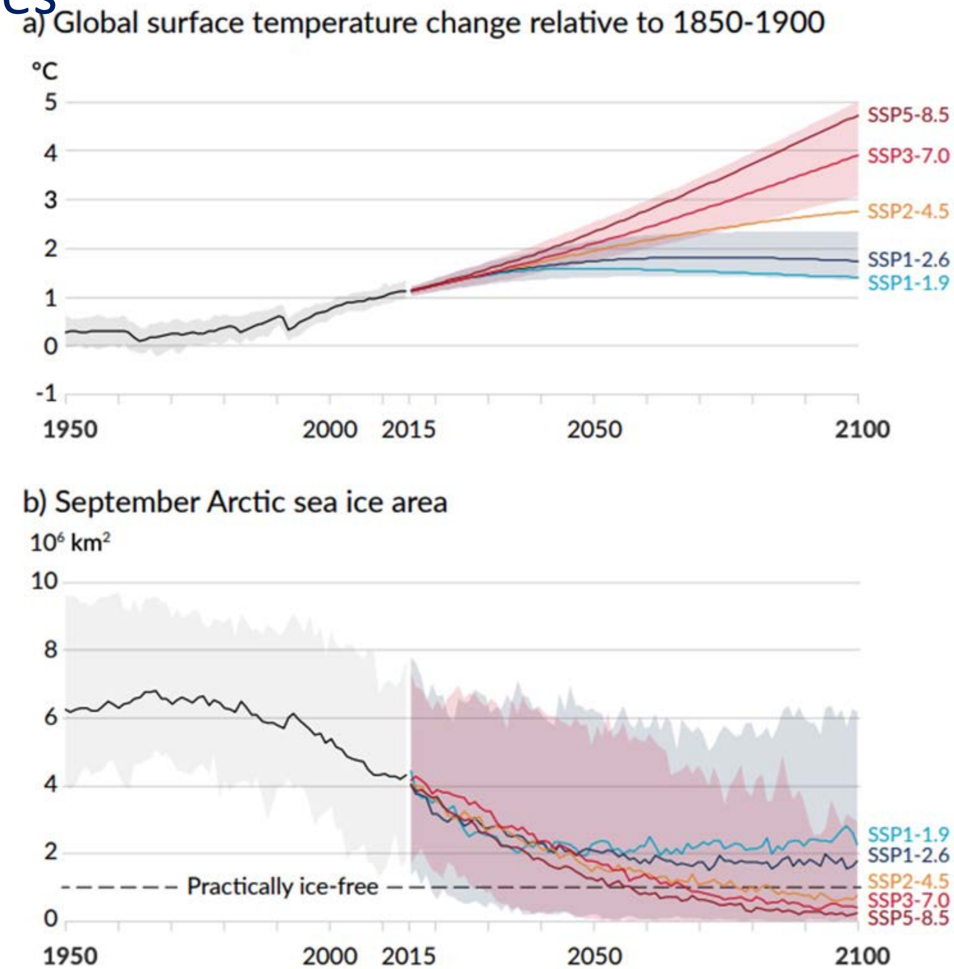

Carbon Emission Scenarios

"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

Figures from the IPCC AR6 WGI Summary for Policymakers: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

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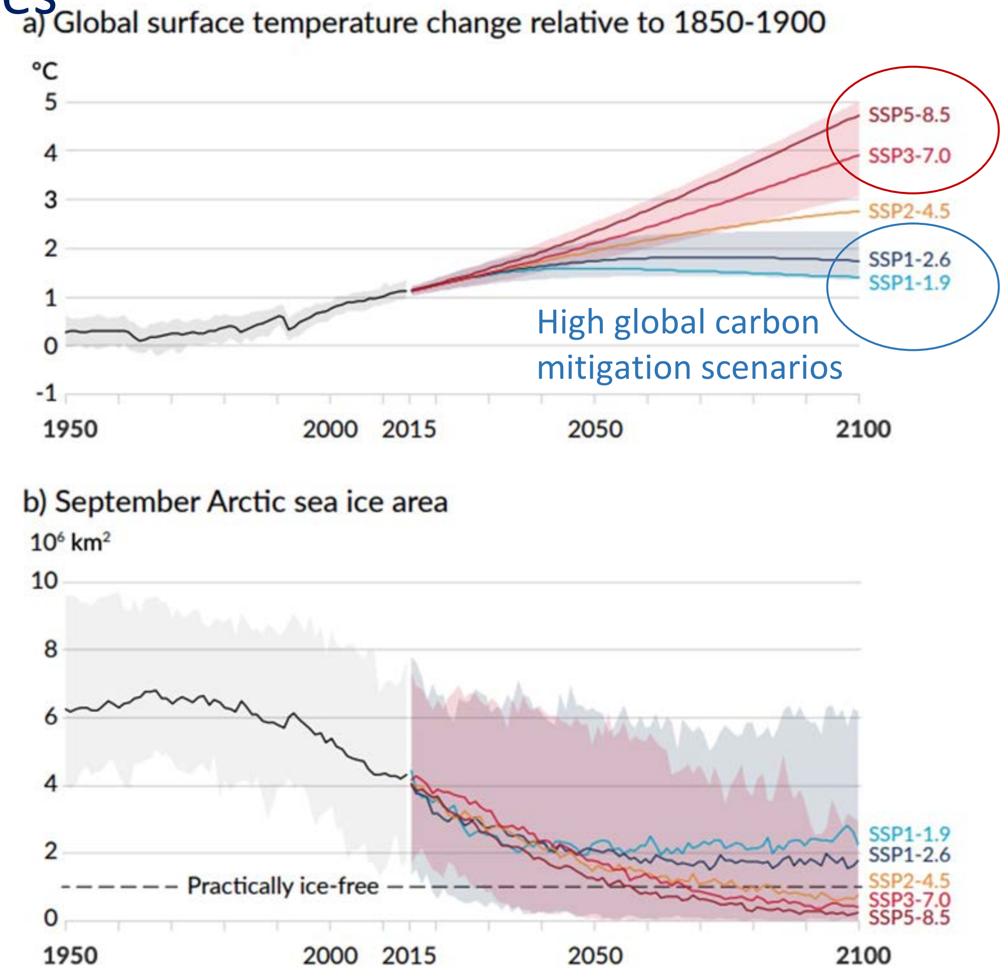

Low carbon mitigation scenarios

Carbon Emission Scenarios

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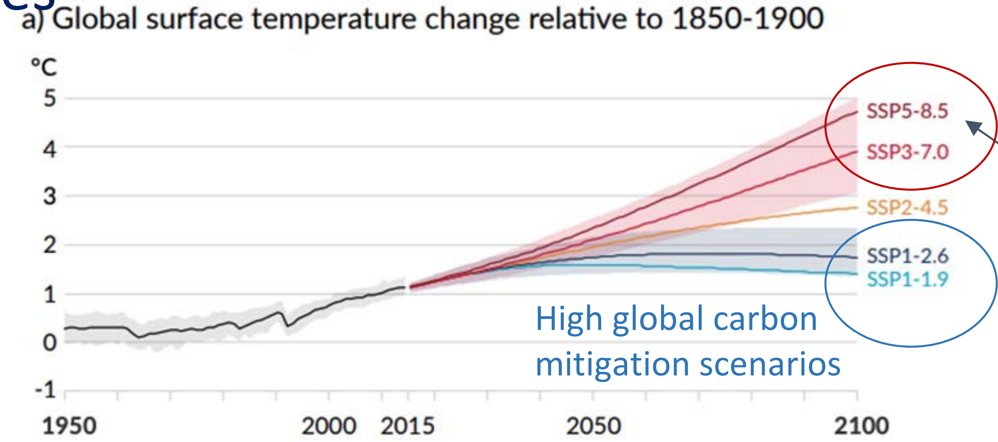
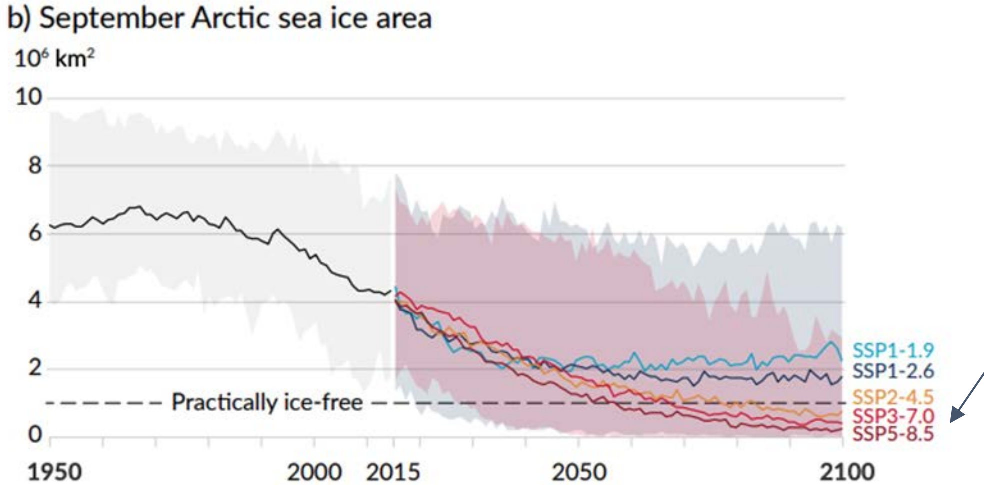


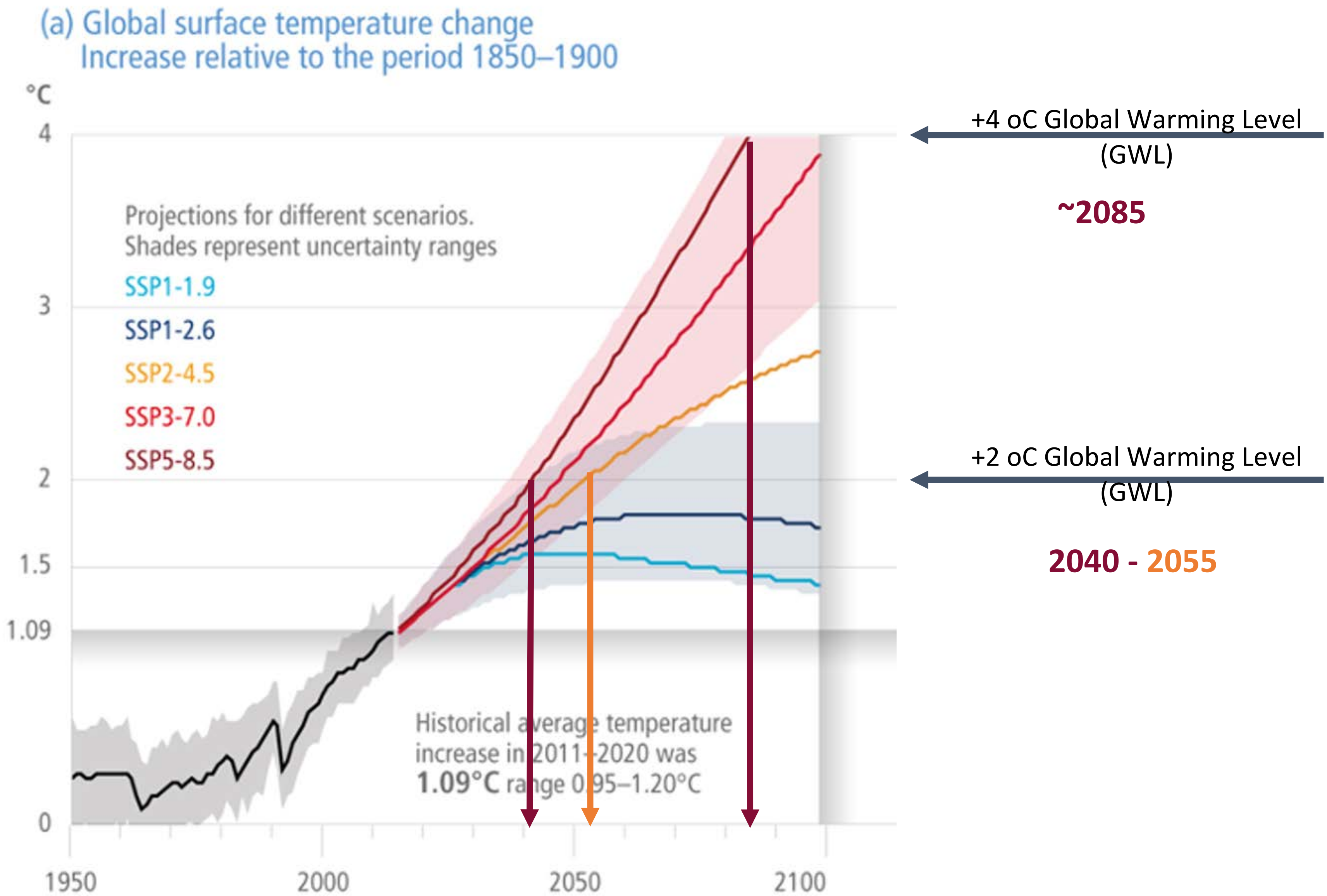
Warming will continue and is greater in scenarios with low carbon mitigation



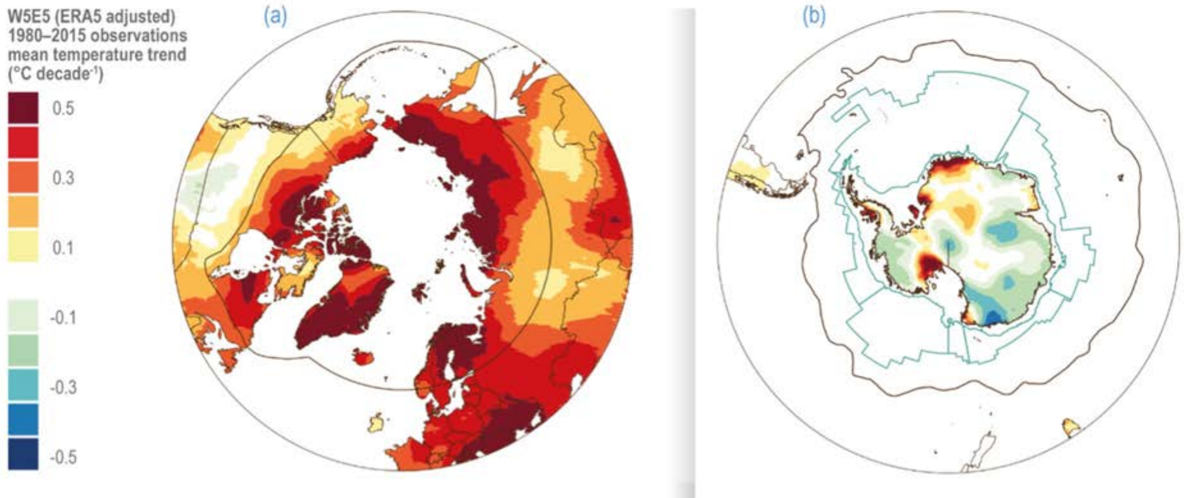
Sea Ice will continue to decline, more so under scenarios with high global warming and low carbon mitigation

Figures from the IPCC AR6 WGI Summary for Policymakers: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

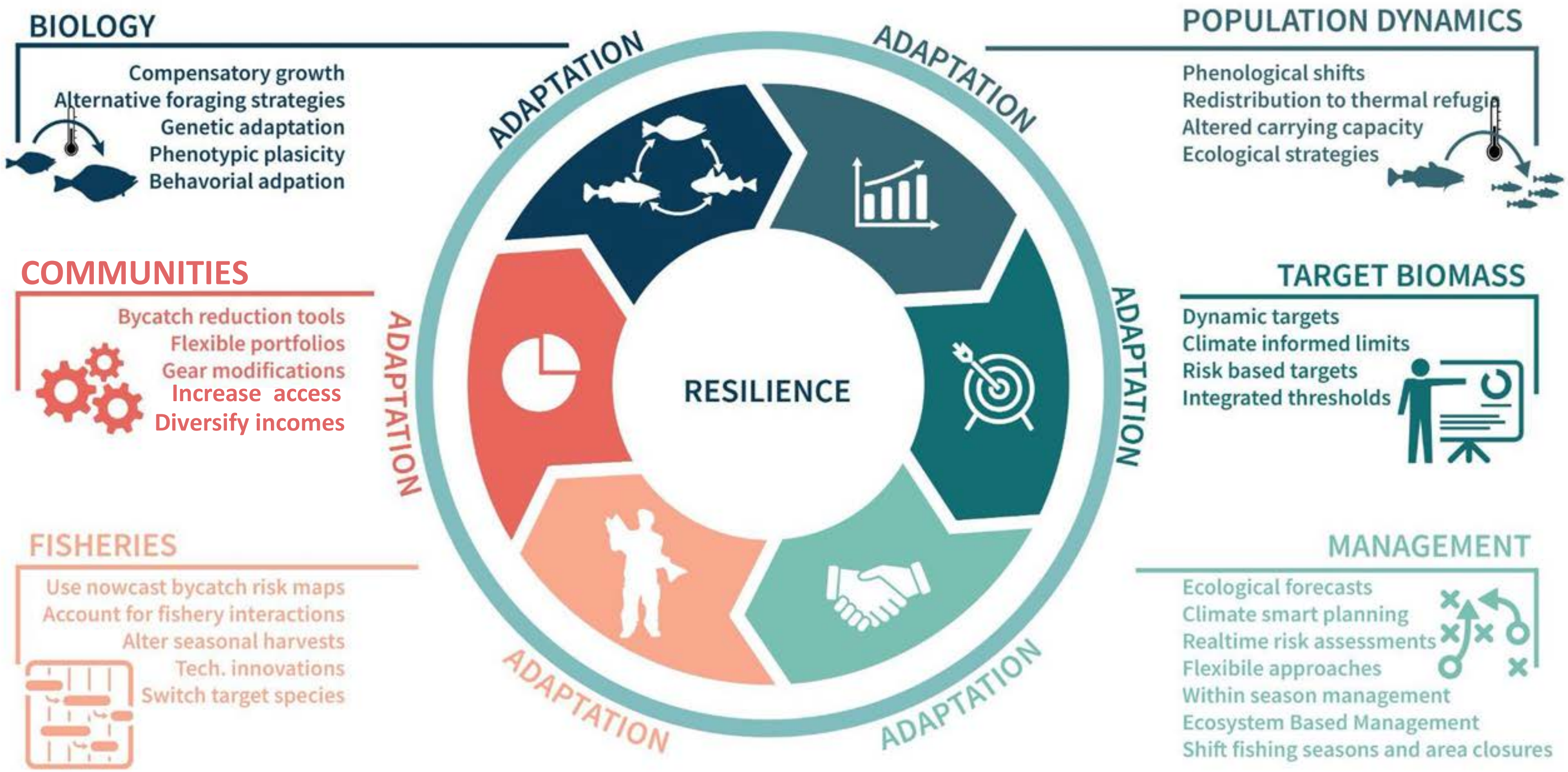
Climate change will increasingly impact polar regions



Observed and projected climate changes across the Arctic and Antarctic



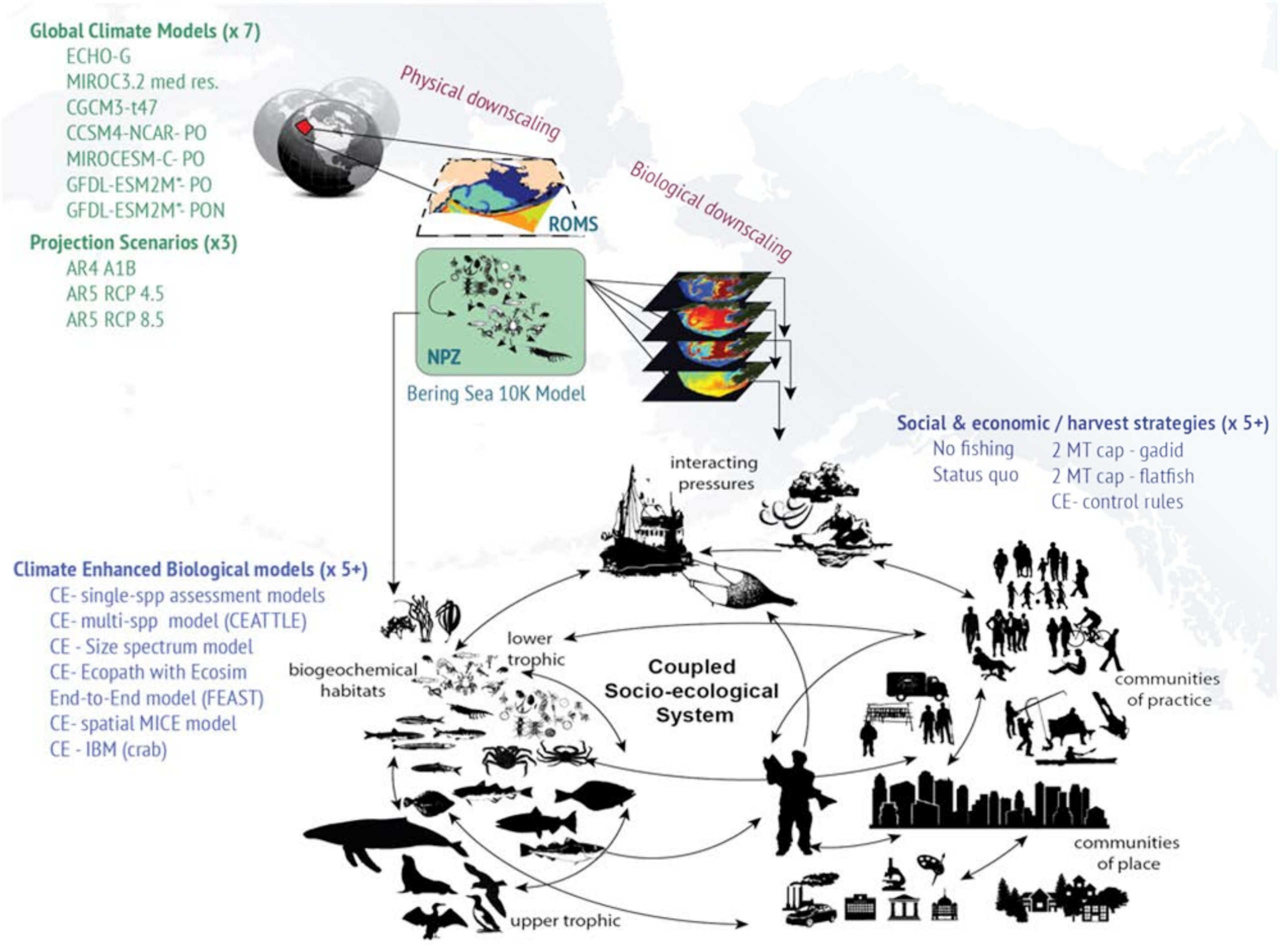
What can be done? Prediction, Planning, Preparing



Holsman et al. (in prep)

The Alaska Climate Integrated Modeling Project

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

Part 1

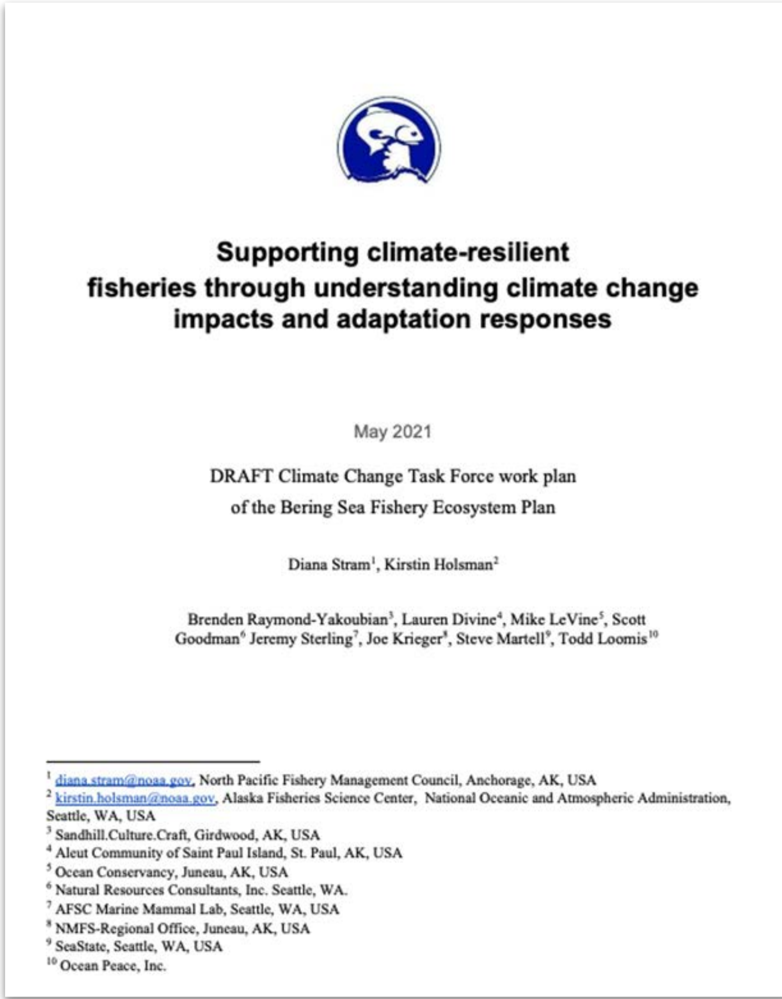
UNIVERSITY of WASHINGTON
School of Aquatic and Fishery Sciences
PMEL
JISAO
Joint Institute for the Study of the Atmosphere and Ocean
IEA INTEGRATED ECOSYSTEM ASSESSMENT
NOAA FISHERIES

ACLIM aims to address:

- **What to expect?**
  Project physical and ecological conditions under levels of climate change (levels of global carbon mitigation)

- **What can be done?**
  Evaluate effectiveness of adaptation actions including those supported by fisheries management

Provide tools and approaches to support climate informed management decisions



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

May 2021

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

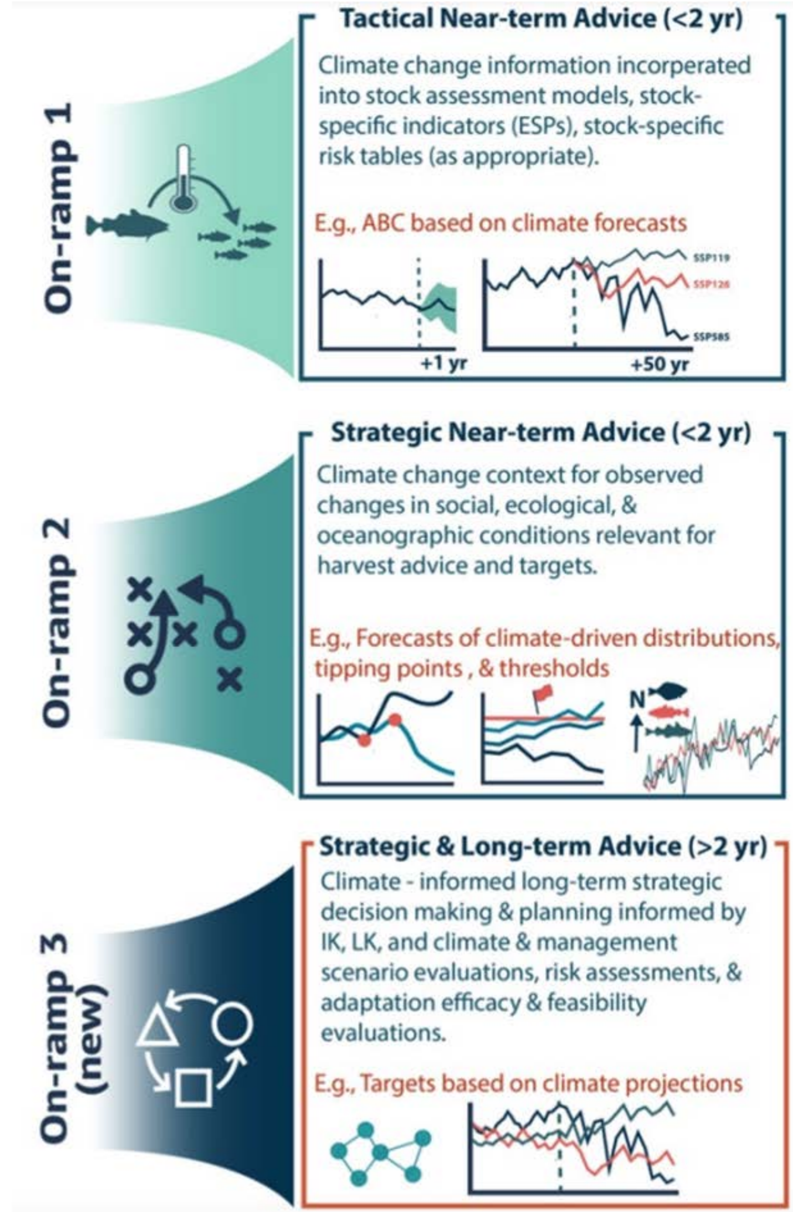
Diana Stram[1], Kirstin Holsman[2]

Brenden Raymond-Yakoubian[3], Lauren Divine[4], Mike LeVine[5], Scott Goodman[6] Jeremy Sterling[7], Joe Krieger[8], Steve Martell[9], Todd Loomis[10]

[1] diana.stram@noaa.gov, North Pacific Fishery Management Council, Anchorage, AK, USA
[2] kirstin.holsman@noaa.gov, Alaska Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, WA, USA
[3] Sandhill.Culture.Craft, Girdwood, AK, USA
[4] Aleut Community of Saint Paul Island, St. Paul, AK, USA
[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, Juneau, AK, USA
[9] SeaState, Seattle, WA, USA
[10] Ocean Peace, Inc.

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

Climate information on ramps for fisheries management



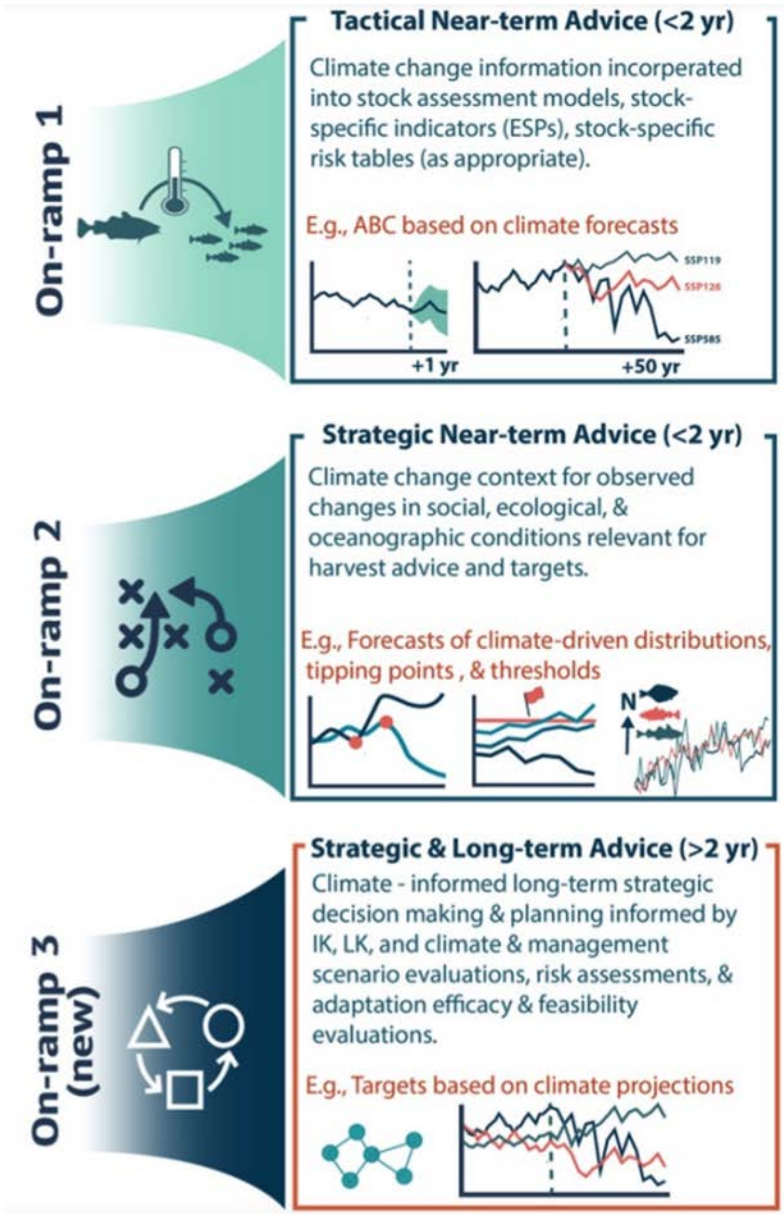
Provide tools and approaches to support climate informed management decisions

Climate informed annual* stock assessments & advice

Climate information in near-term management targets

Climate information in long-term management targets and design

Climate information on ramps for fisheries management

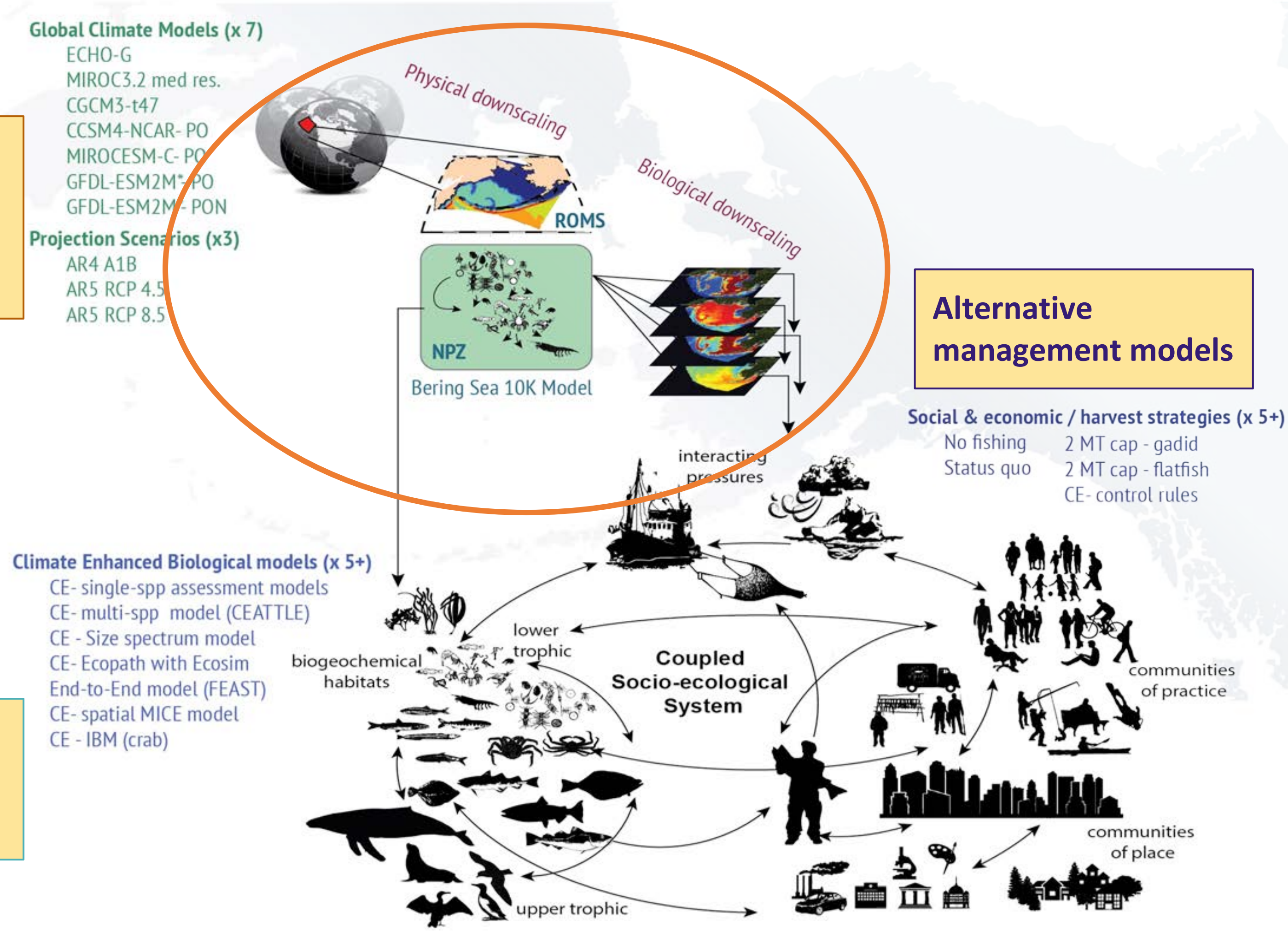


https://www.npfmc.org/climatechangetaskforce/

Bering Sea Oceanographic Projections

The Alaska Climate Integrated Modeling Project

High resolution realistic ocean projections under climate scenarios



Alternative management models

Climate driven changes to species & food-webs

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

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

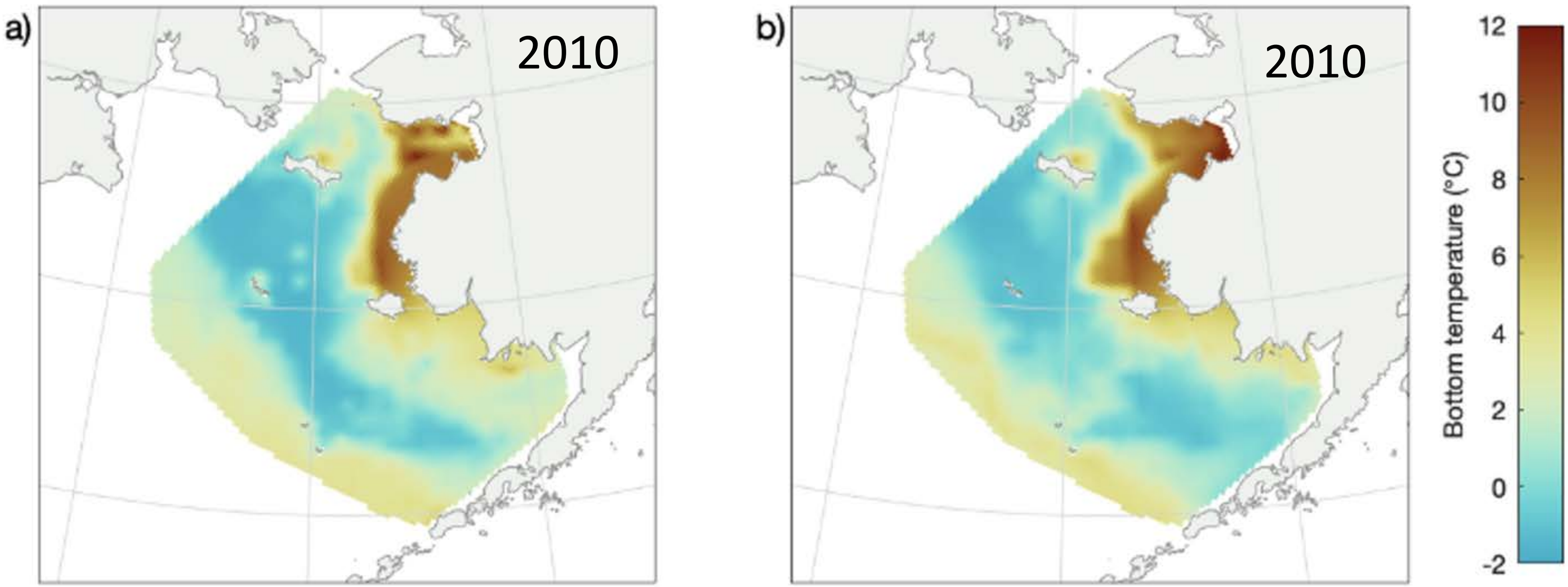
Part 1

Part 2

High-res model reproduces the Bering Sea environment

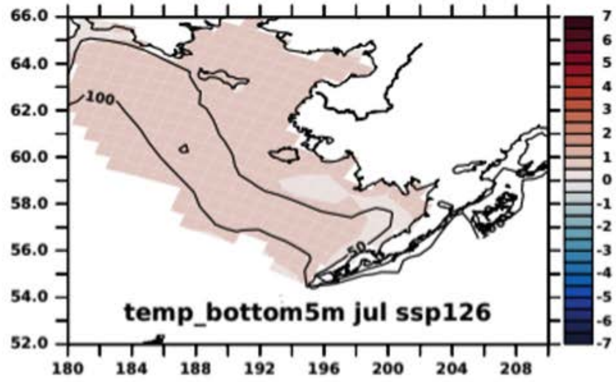
Observed (survey data)

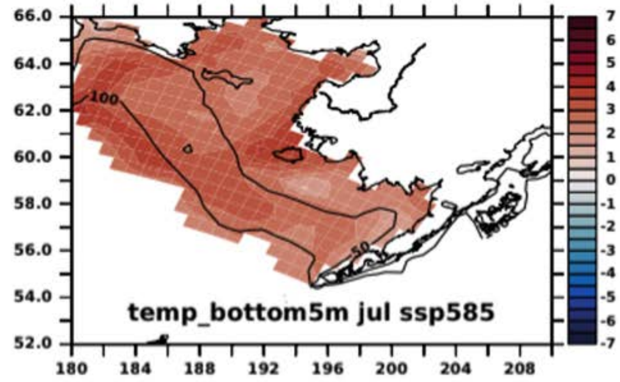
Model (Bering10K ROMSNPZ)



Kearney K (2021). Temperature data from the eastern Bering Sea continental shelf bottom trawl survey as used for hydrodynamic model validation and comparison. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-415, 40 p. link.

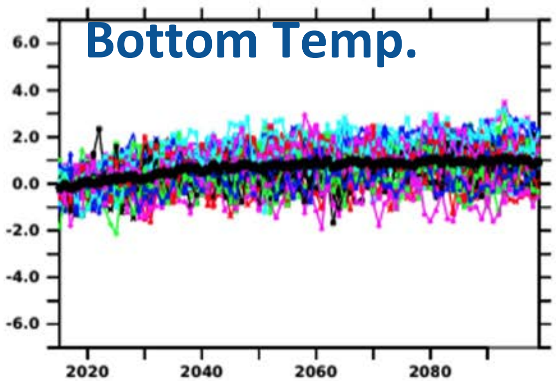
Increased warming expected

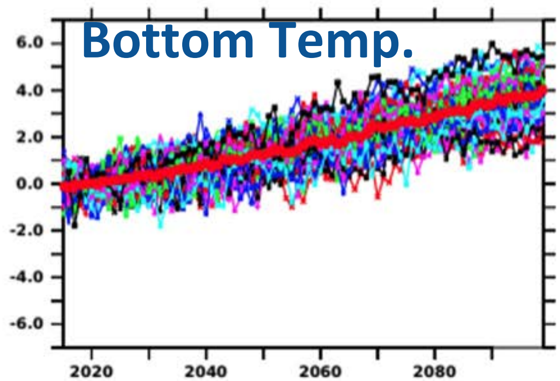




SSP126: High mitigation/ less warming

SSP585: Low mitigation/ more warming

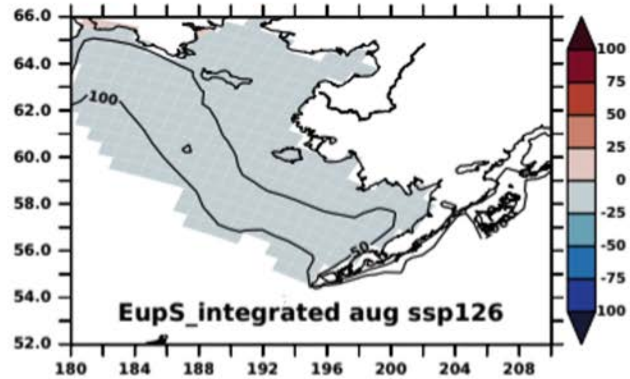


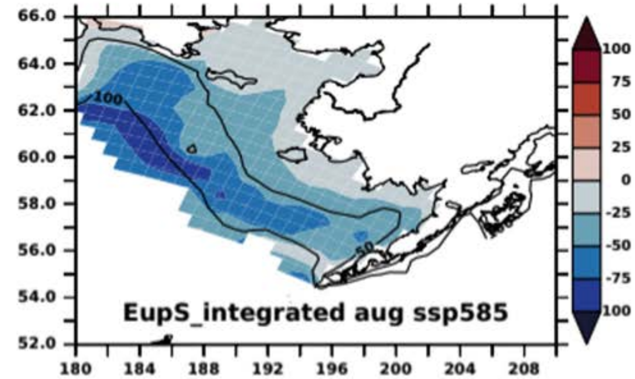


Hermann, et al. (in press)

Declines in Euphausiids expected

Euphausiid biomass

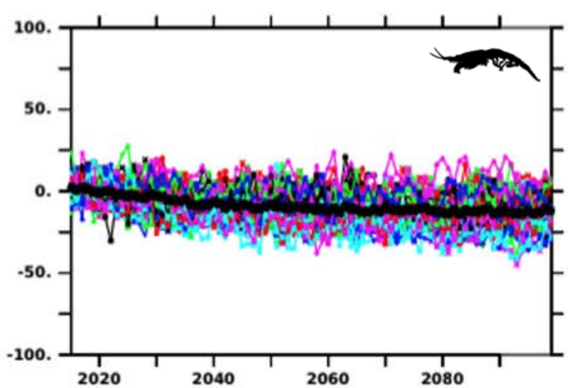


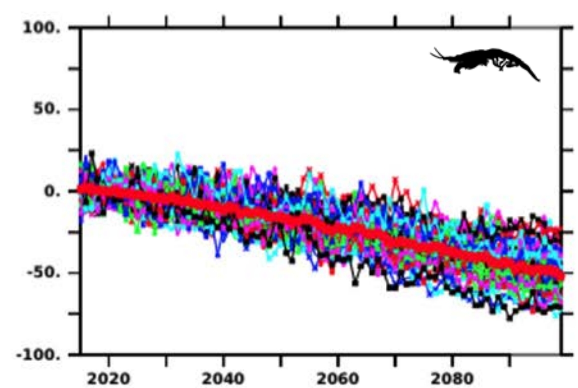


SSP126: High mitigation/ less warming

SSP585: Low mitigation/

more warming



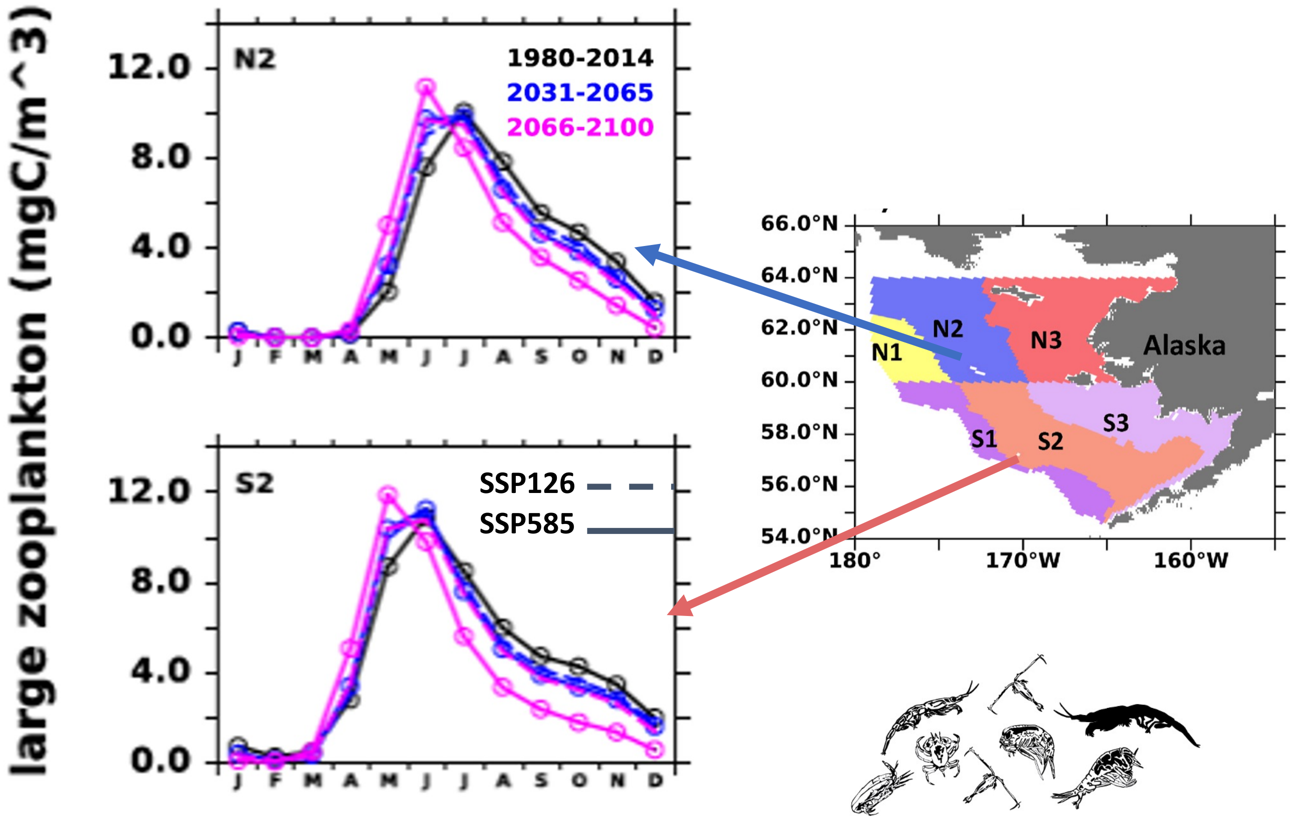


Hermann, et al. (in press)

Part 1

Part 2

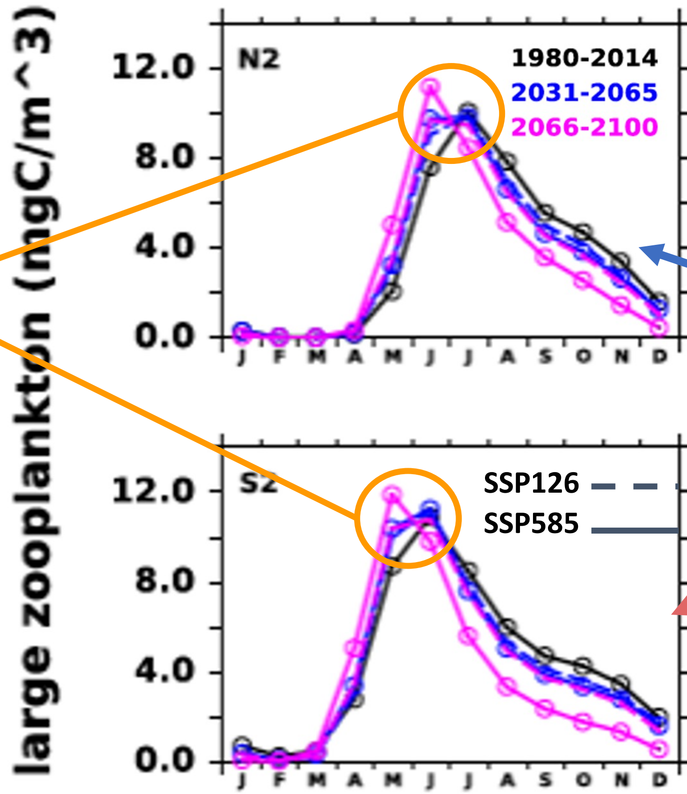
Change in the timing (phenology) of prey resources

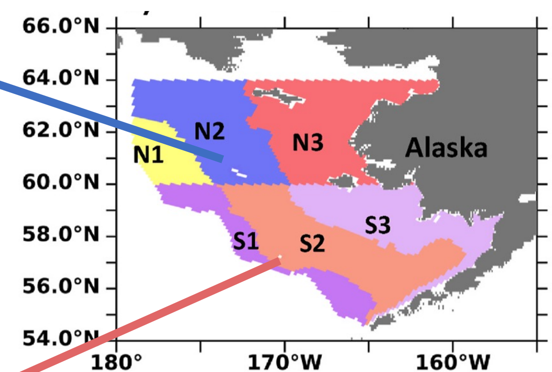


Cheng, et al. (2021) https://www.sciencedirect.com/science/article/pii/S0967064521000515

Change in the timing (phenology) of prey resources

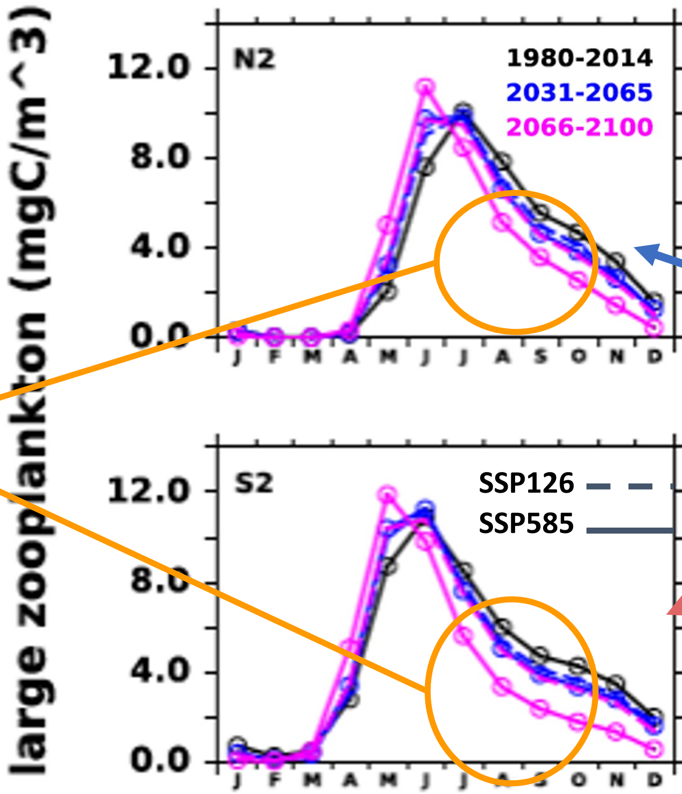
Shift earlier in zooplankton peak under low mitigation (high warming) scenarios



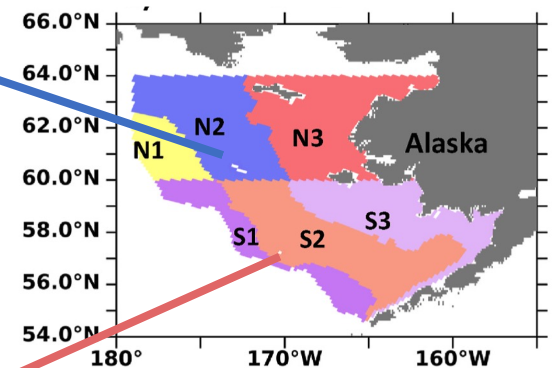


Cheng, et al. (2021) https://www.sciencedirect.com/science/article/pii/S0967064521000515

Change in the timing (phenology) of prey resources



Declines projected during critical bottlenecks for fish overwinter survival

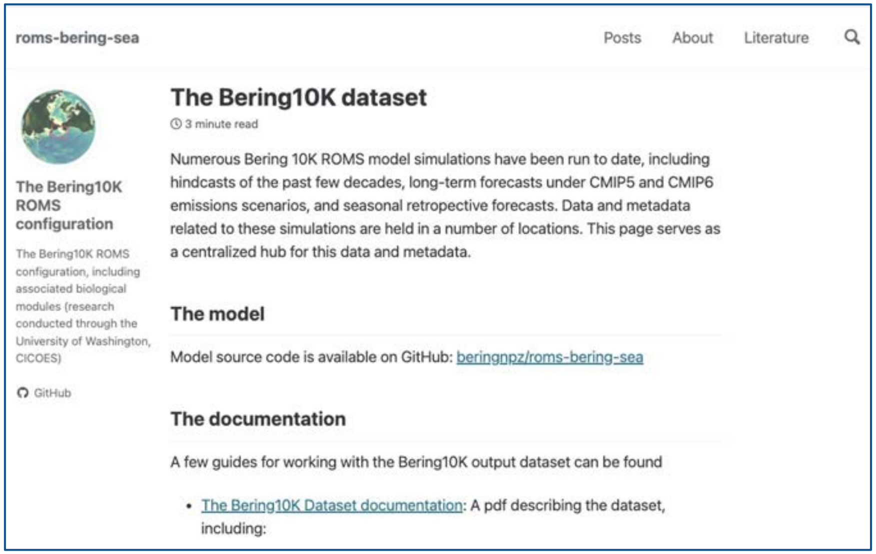


Cheng, et al. (2021) https://www.sciencedirect.com/science/article/pii/S0967064521000515

Learn More: BERING10K Data & Info portals

Learn More:
https://beringnpz.github.io/roms-bering-sea/B10K-dataset-docs/

Explore the Data:
https://github.com/kholsman/ACLIM2



roms-bering-sea   Posts   About   Literature

The Bering10K ROMS configuration

The Bering10K ROMS configuration, including associated biological modules (research conducted through the University of Washington, CICOES)

GitHub

The Bering10K dataset

3 minute read

Numerous Bering 10K ROMS model simulations have been run to date, including hindcasts of the past few decades, long-term forecasts under CMIP5 and CMIP6 emissions scenarios, and seasonal retropective forecasts. Data and metadata related to these simulations are held in a number of locations. This page serves as a centralized hub for this data and metadata.

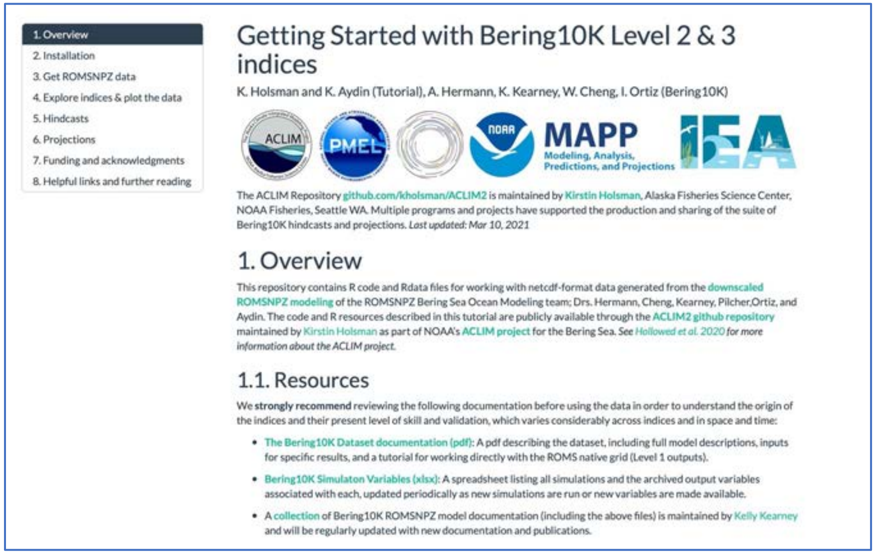
The model

Model source code is available on GitHub: beringnpz/roms-bering-sea

The documentation

A few guides for working with the Bering10K output dataset can be found

- The Bering10K Dataset documentation: A pdf describing the dataset, including:



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

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.

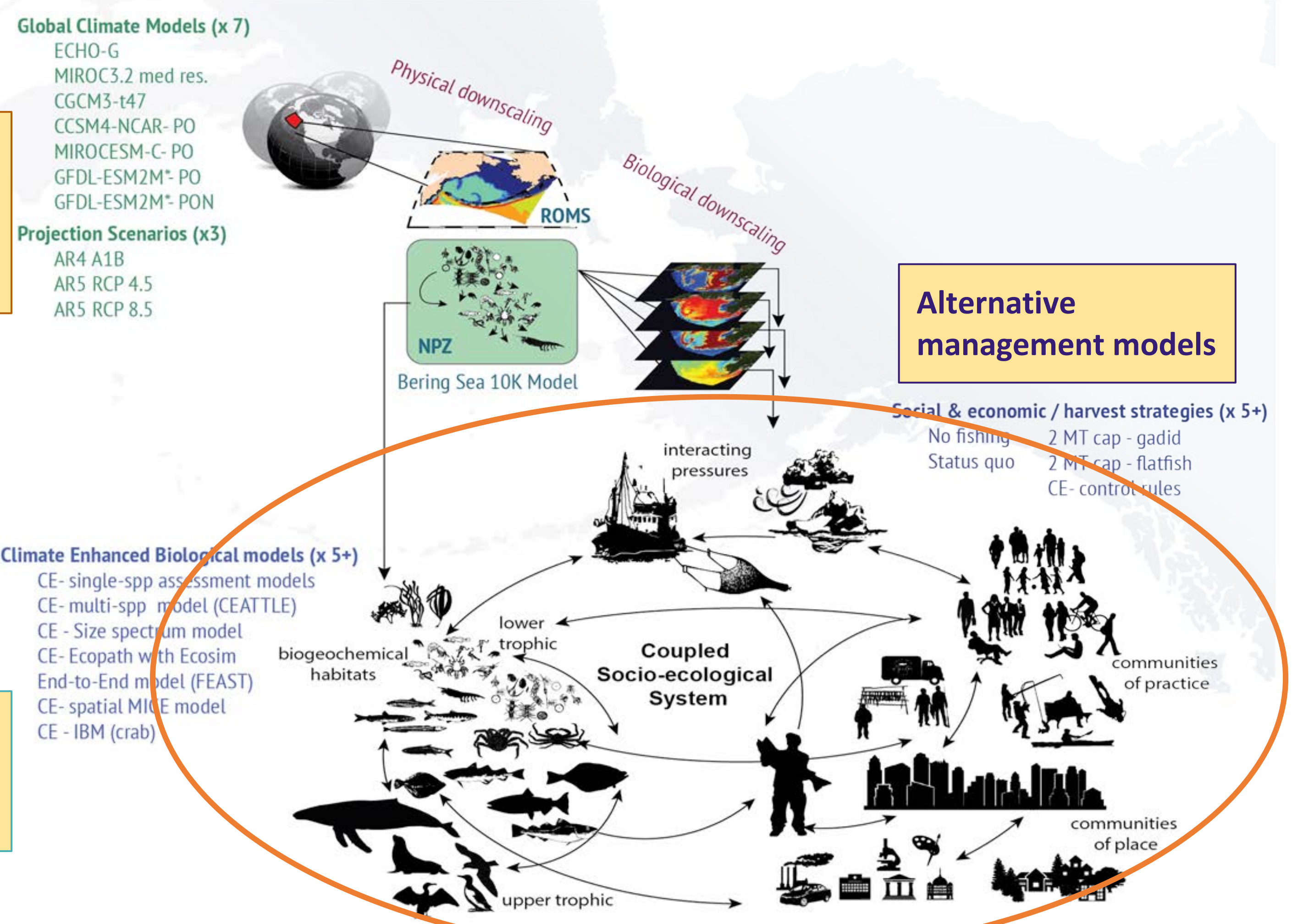
The Alaska Climate Integrated Modeling Project
ACLIM
NOAA Alaska Fisheries Science Center

Part 1   Part 2

Climate + Biological + Management Modeling

The Alaska Climate Integrated Modeling Project

High resolution realistic ocean projections under climate scenarios



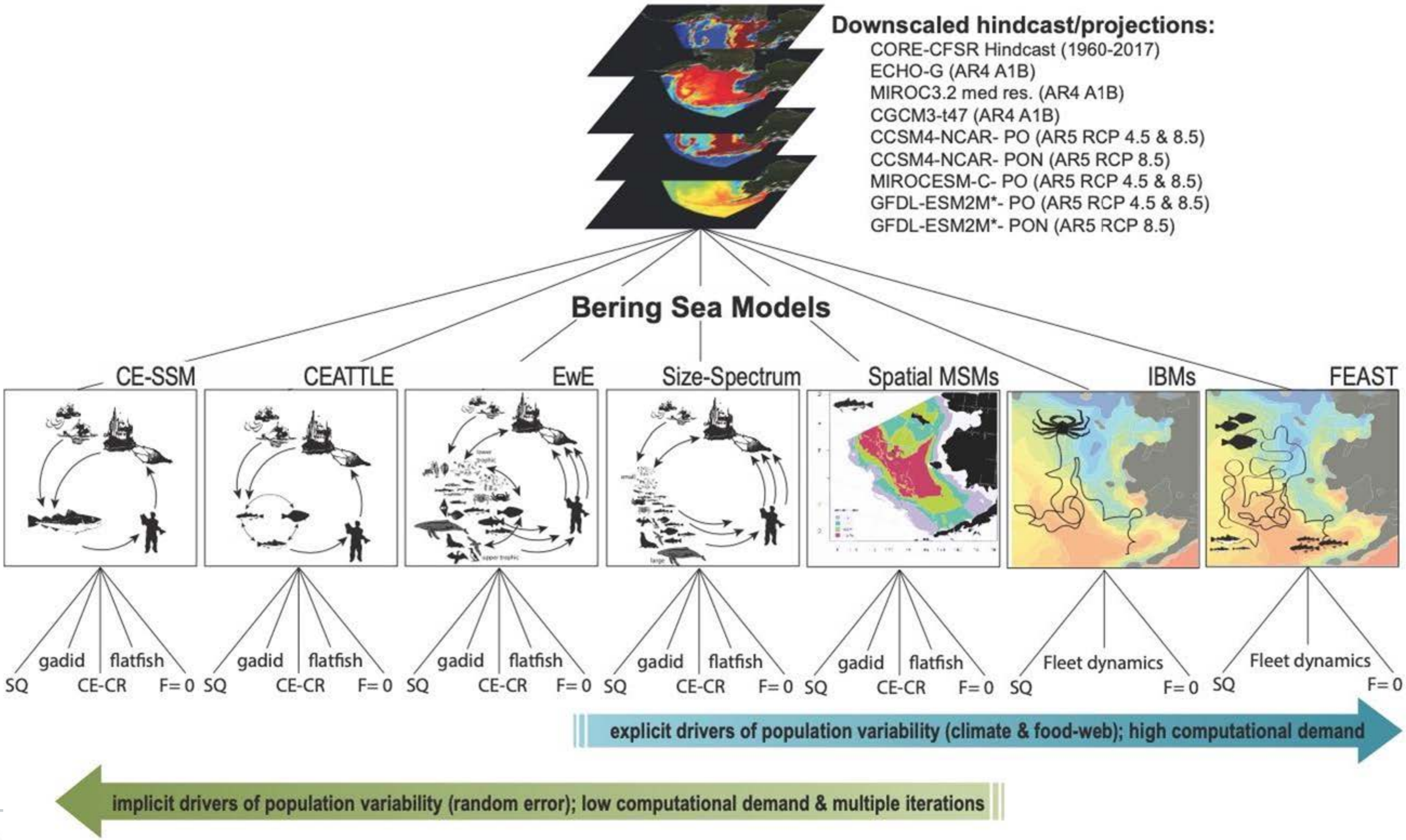
Alternative management models

Climate driven changes to species & food-webs

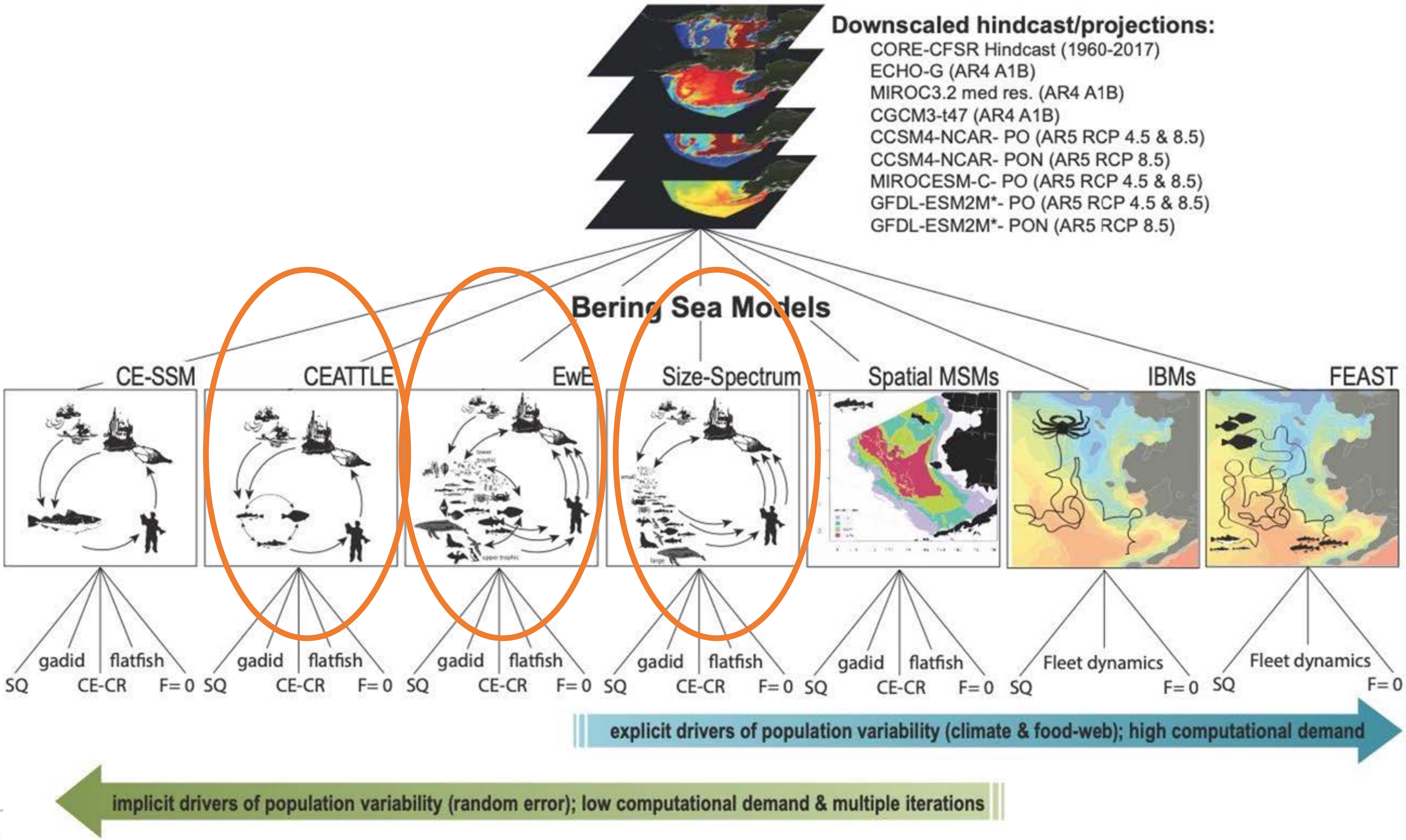
Hollowed et al. 2020. Frontiers in Mar. Sci. doi: 10.3389/fmars.2019.00775

Part 3

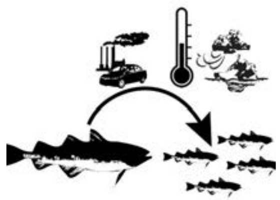
The Alaska Climate Integrated Modeling Project



The Alaska Climate Integrated Modeling Project



The Alaska Climate Integrated Modeling Project



	Climate-effects on food-webs	Sloping HCR	Multispecies effects of 2 MT Cap
No fishing	X		
No-cap	X		
Status quo	X	X	X

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

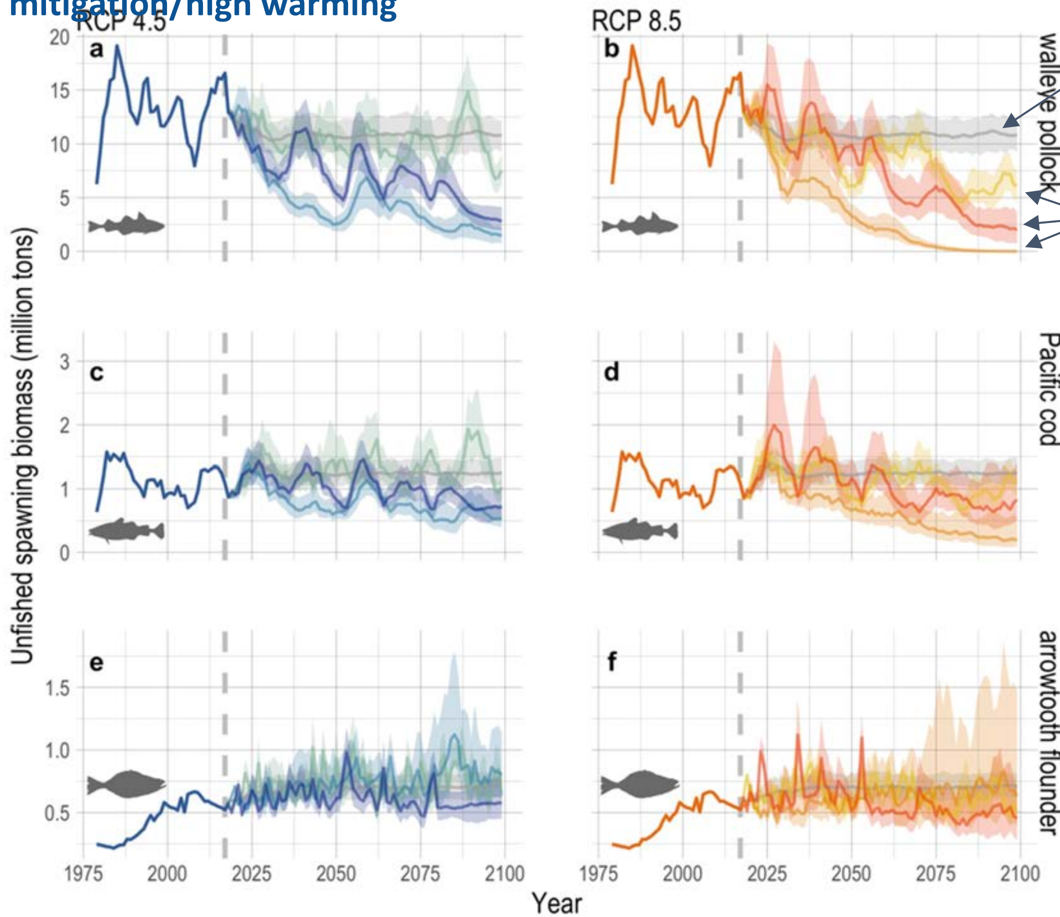
CEATTLE: Unfished biomass (no harvest)

Assumes climate effects on recruitment, growth, & mortality

More warming =

- larger declines
- higher agreement of declines

moderate mitigation/warming **low mitigation/high warming**



No climate change

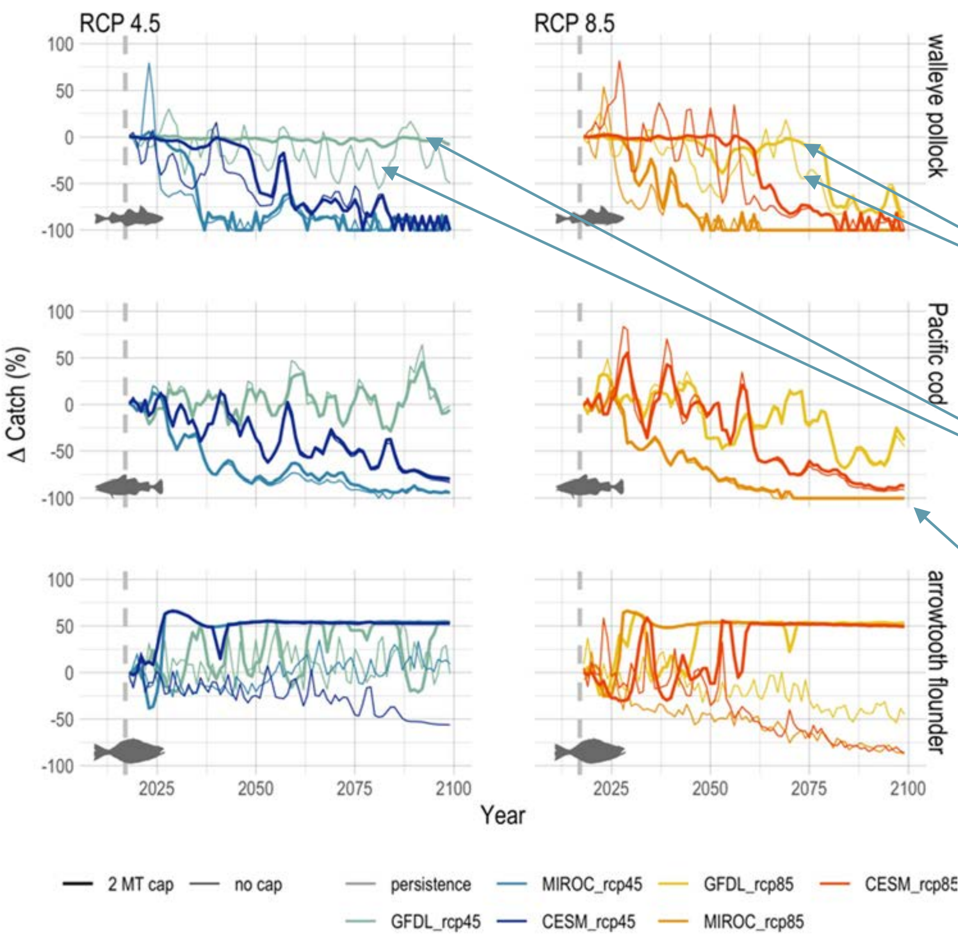
With climate change

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

Part 3

CEATTLE: EBFM vs non-EBFM cap

Assumes climate effects on recruitment, growth, & mortality



EBFM = lower risk of declines & collapse

although risk increases over time & with warming

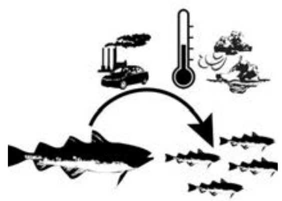
EBFM cap forestalled declines

EBFM cap stabilized catches

EBFM cap had little effect on P. cod

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

The Alaska Climate Integrated Modeling Project

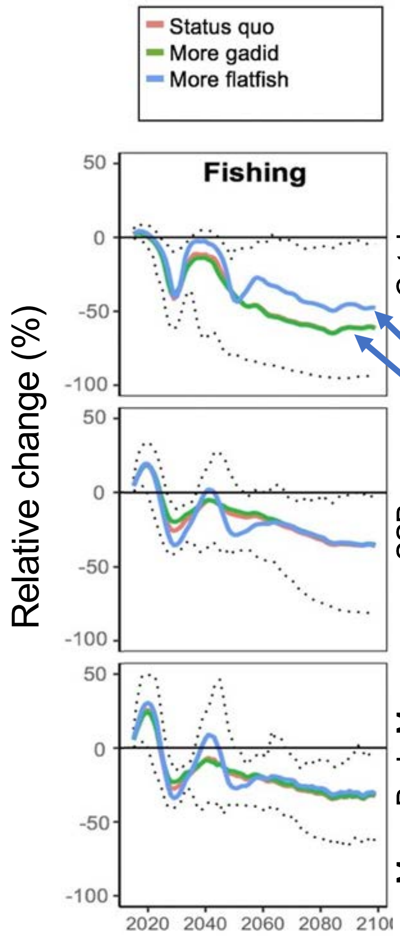
	Climate-effects on food-webs	Sloping HCR	Multispecies effects of 2 MT Cap
			
No fishing	X		
No-cap	X		
Status quo	**X**	**X**	**X** +10% more flatfish +10% more gadid

Flexibility sub-sets:

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

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

Assumes food web dynamics are a function of size



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

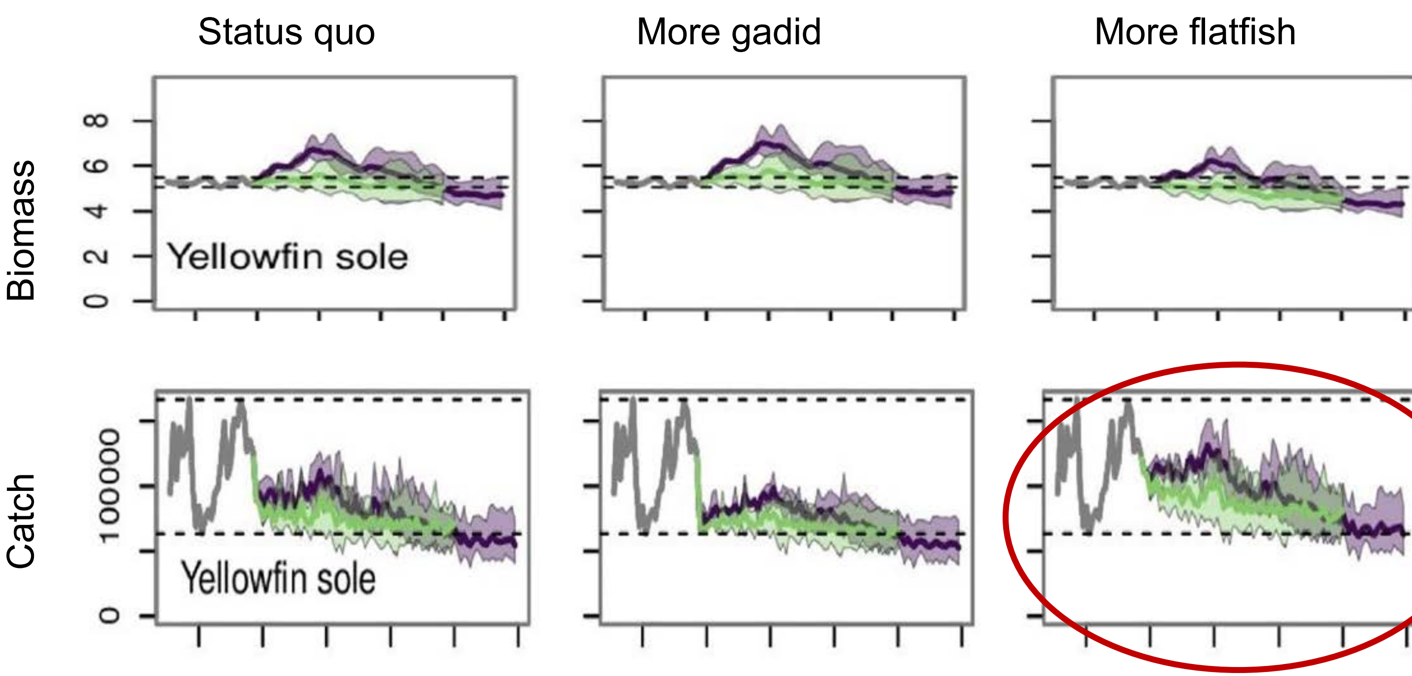
Incremental adjustments/flexibility can increase adaptive scope (slightly)

Reum, et al. 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.

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

Assumes food web dynamics are a function of biomass

YFS fishing scenarios



No difference between fishing scenarios

Higher catch for ‘more flatfish scenario”

Incremental adjustments/flexibility can increase adaptive scope (slightly)

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)

Assumes food web dynamics are a function of biomass

General declines in seabirds

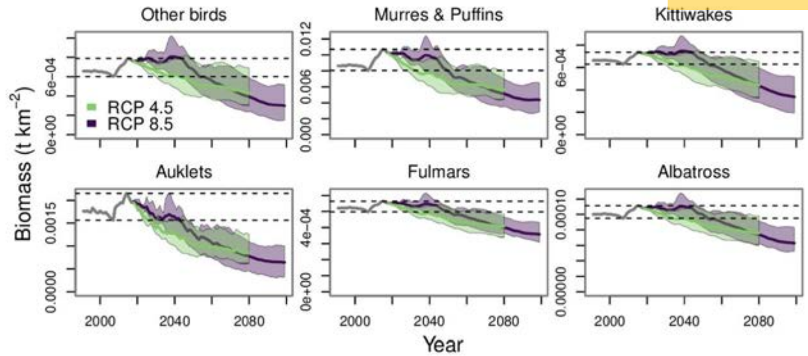


FIGURE 8 | Biomass projections for seabird functional groups. The gray line from 1991 to 2017 indicates the historical period. The purple and green poly indicate the minimum and maximum range for the three earth system models run under each RCP. The purple and green lines indicate the mean of the th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

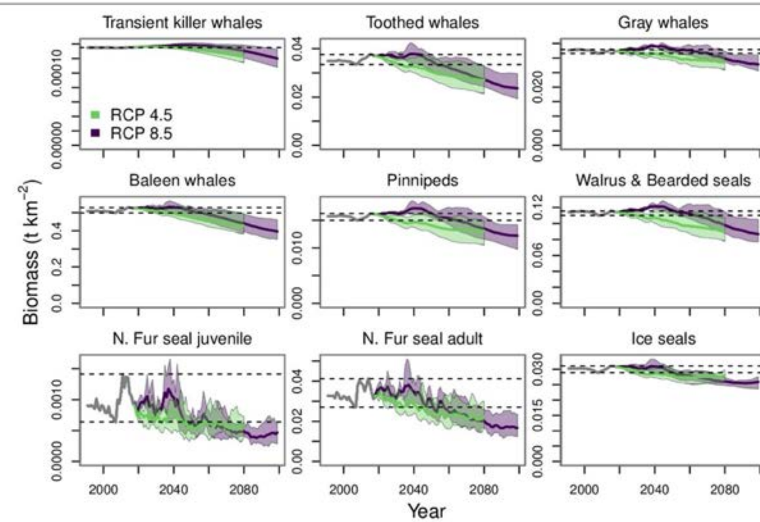


FIGURE 7 | Biomass projections for marine mammal functional groups. The gray line from 1991 to 2017 indicates the historical period. The purple and green polygons indicate the minimum and maximum range for the three earth system models run under each RCP. The purple and green lines indicate the mean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

General declines in marine mammals

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

What we found in ACLIM1.0

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

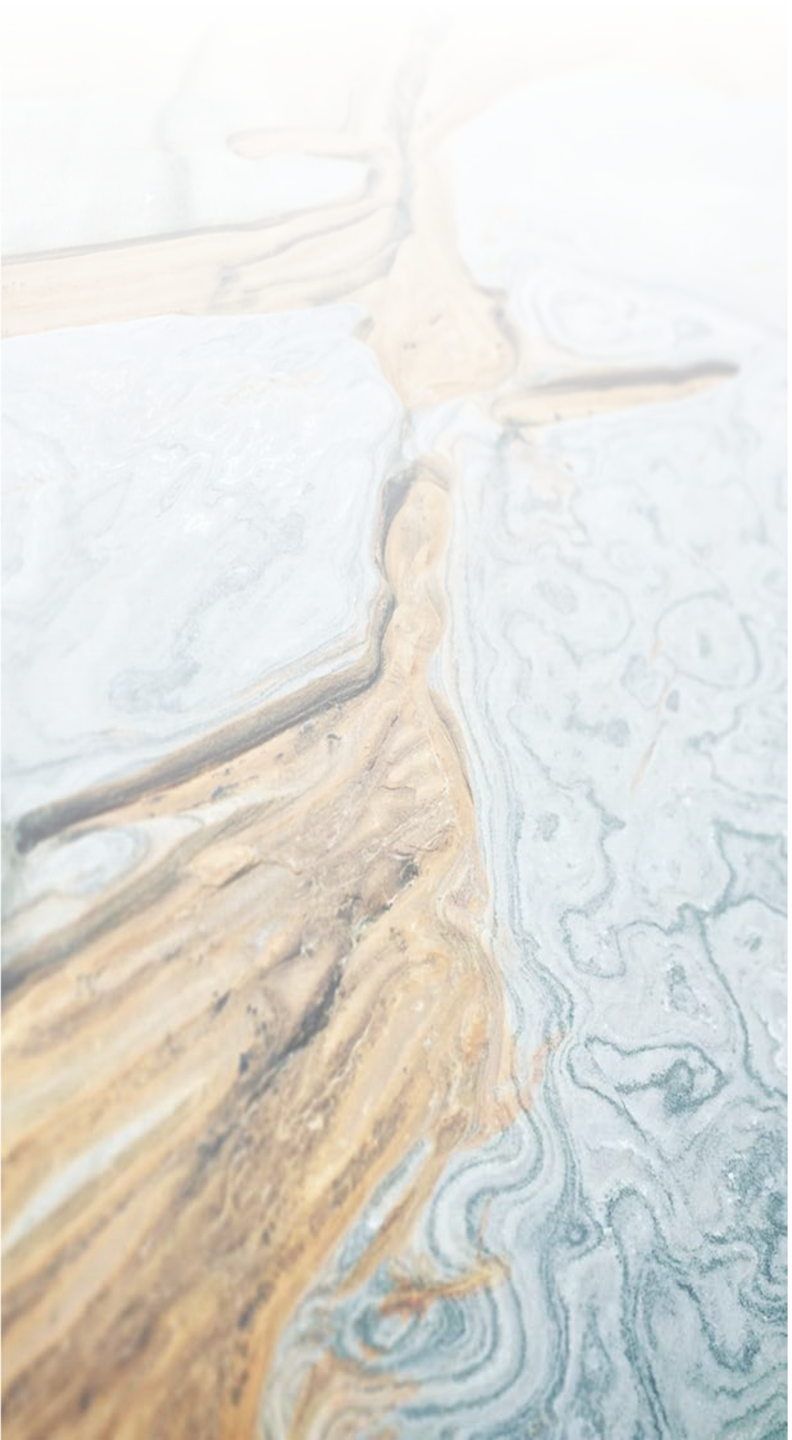
Modeling ecological and social-economic response and adaptation is needed to understand tipping points in the system. Climate impacts are non-additive and dynamics of the social-ecological system may attenuate or amplify impacts. Multiple integrated models are needed to evaluate structural uncertainty.

Mitigation is lower risk

Climate induced changes in productivity caused large declines in fish and crab that are greatest in low mitigation scenarios. Most pollock and cod scenarios declined 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 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 & NEBS

Expanded protected species analyses (marine mammals!)

Expanded Ocean Acidification (OA) and dissolved oxygen modeling

Expanded lower trophic and young of year modeling

GOA through Northern Bering ACLIM via GOA-CLIM

ACLIM 2 Spring Scenarios Climate X Management

Holsman et al. (in prep)

ACLIM 2 Spring Scenarios Climate X Management

Holsman et al. (in prep)

4 ‘Dimensions’ of ACLIM 2.0 Scenarios

1. Climate change scenarios

    → SSP585 vs SSP126

1. Climate enhanced stock assessment & ecosystem models (“biological models”)

2. Climate informed ABC and HCRs (“methods”) that impact harvest ‘Targets’ - the Vertical Axis of the NPSSPs

    → with and without “climate informed” (e.g., forecasts/projections)

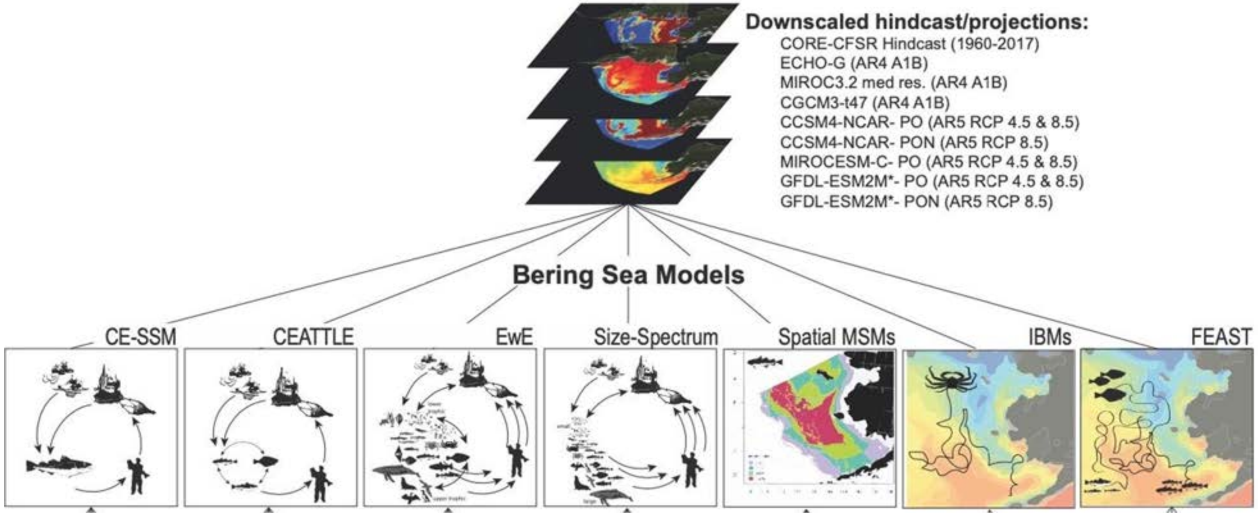
1. Climate informed policy and planning - the Horizontal Axis of the NPSSPs

    → NEBS/SEBS, changes in fishery economics, bycatch, flexibility, emergency response

Part 3

Part 4

Diverse 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

Why ACLIM 2.0 Socioeconomic Scenarios?

- Provide a tractable number of potential management responses to projected climate change
- Evaluate how management strategies interact with environmental changes
  - Estimate the catch, environmental impacts, revenue, profit, and impacts on fishing communities under scenarios
- Are there management changes that would improve the projected future health and productivity of the North Pacific?

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, these 4 scenarios were used in analyses in ACLIM 1.0.

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

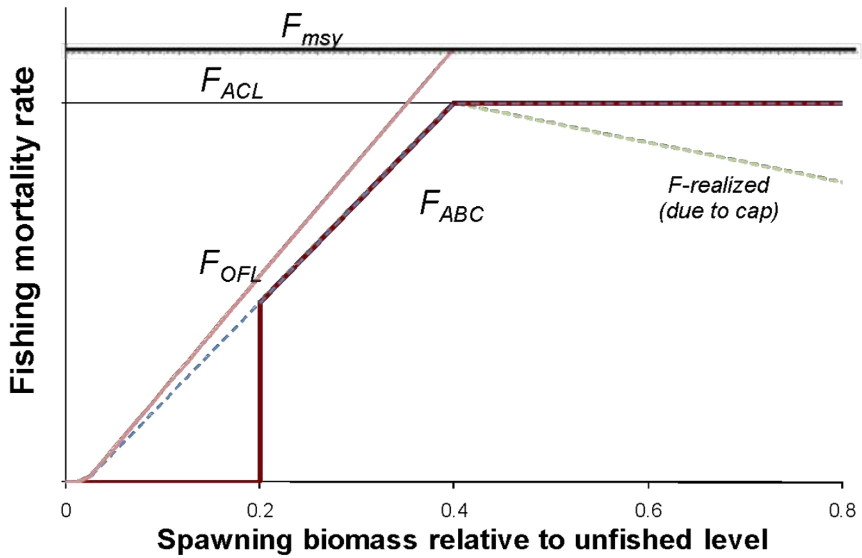
Photo: Alan Haynie

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.
- Boreal species have adapted life history characteristics to sustain populations.
- 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

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

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

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

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

<u>Other dimensions</u>

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

Note: there are additional complexities, too!

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

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

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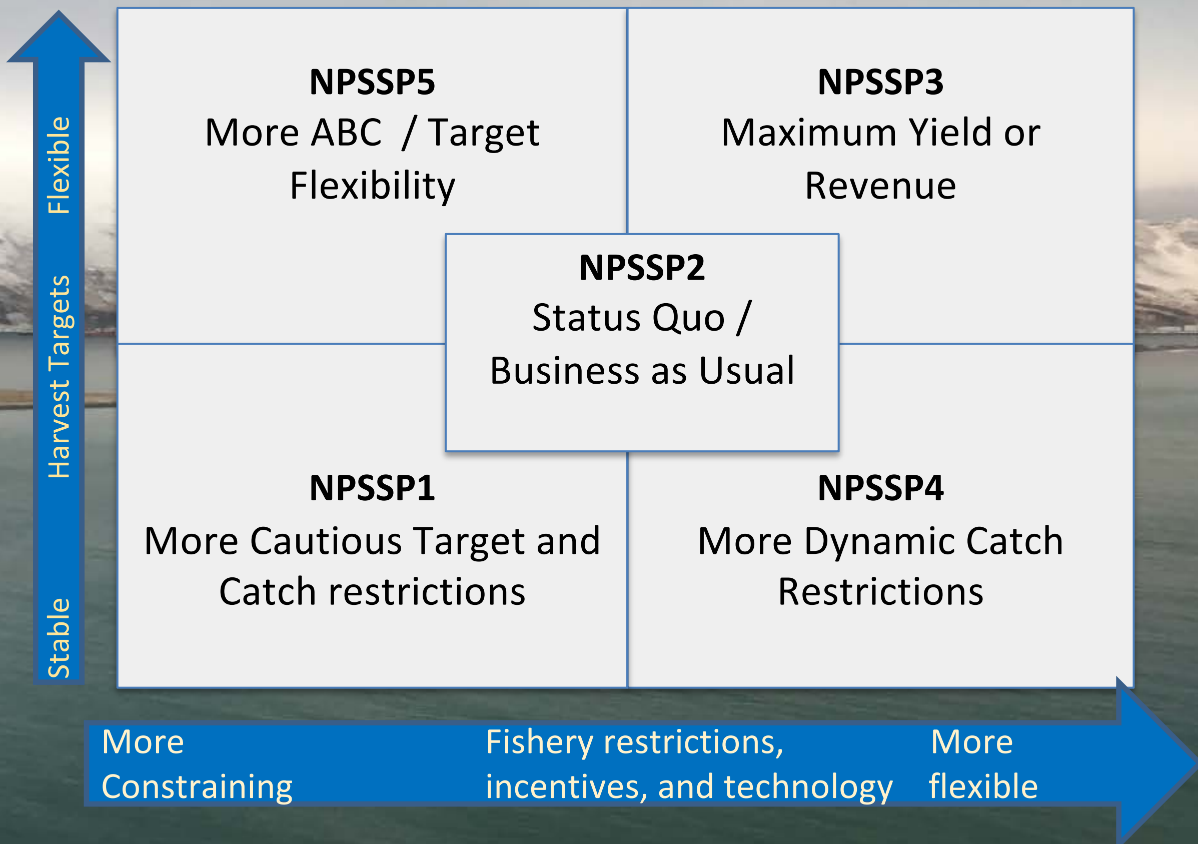


<u>Other dimensions</u>

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

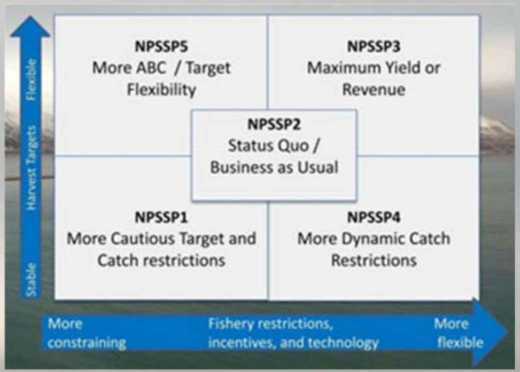
Note: there are additional complexities, too!

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

Caveats on Socioeconomic Scenarios

- Scenarios demonstrate trade-offs - there may be different trade-offs and priorities in the future.
- Some trade-offs may be shown beyond MSA rules - for example, understanding the impacts of loosening single-species annual catch limits in multi-species fisheries.
- Policy trade-offs examined - these are not recommendations.

Examples:



More <u>cautious / stable ABC</u> Measures

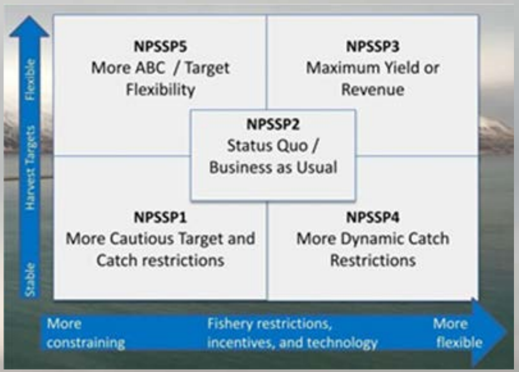
Strategy and Rationale of these measures:
Examine the impacts of scenarios that include more stable ABC policies to adjust ABC / Harvest Control Rules (HCR) with climate.

Example ABC / Harvest Control Rule (HCR) Features:

- **Set harvest targets as a function of climate conditions (e.g., F50 % when temperature is high)**
- **Test regime-specific HCR slopes (warm-period HCR, vs. cold-period HCR).**
- **Include effects of climate on base functions in assessment (e.g., growth, recruitment, or mortality as a function of temperature or zooplankton)**
- **Account for species re-distribution in assessments (e.g., use climate-informed spatial distribution tools to adjust catch-ability).**

Examples:

More <u>flexible ABC </u>Measures

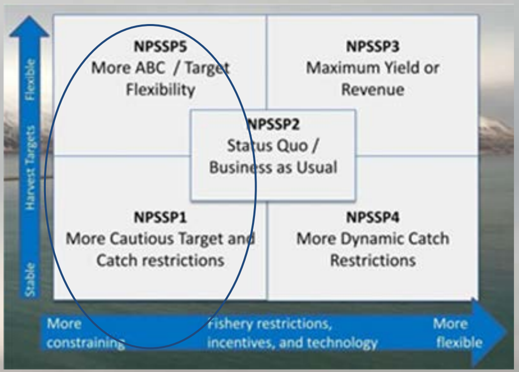


Strategy and Rationale of these measures:
Examine the impacts of scenarios that include more flexible ABC policies to adjust ABC / Harvest Control Rules (HCR) with climate and stock changes.

Example ABC / Harvest Control Rule (HCR) Features:

- **Allow multi-year ABCs.**
- **Evaluate minimum and maximum thresholds (e.g., B20 rule).**
- **Climate- or regime-specific B0 & B40.**
- **Utilize ecosystem and climate forecasts to increase overall sustainable catch and/or revenue.**
- **Explore measures that would increase stability of community access to resources.**

Examples:



Lower OY cap, increased catch restrictions, lower prices / higher costs

Strategy and Rationale of these measures:

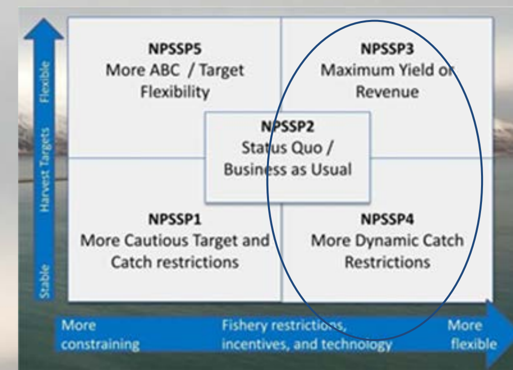
- Examine the impacts of scenarios that include measures that lower the cap or reduce the catch of different species.

Example Fishery Features:

- Impact of 1.7 MMT or climate-linked Ecosystem Cap / Optimum yield.
- Additional spatial management related to protected species.
- Additional bycatch challenges that (further) limit harvest of some species.
- Increases in fishing costs or lack of growth in fish prices, leading to reduced incentives or ability to harvest as much of some species.

Examples:

Higher cap, reduced catch restrictions,higher prices / lower costs, and improved technology leader to higher catch for a given ABC



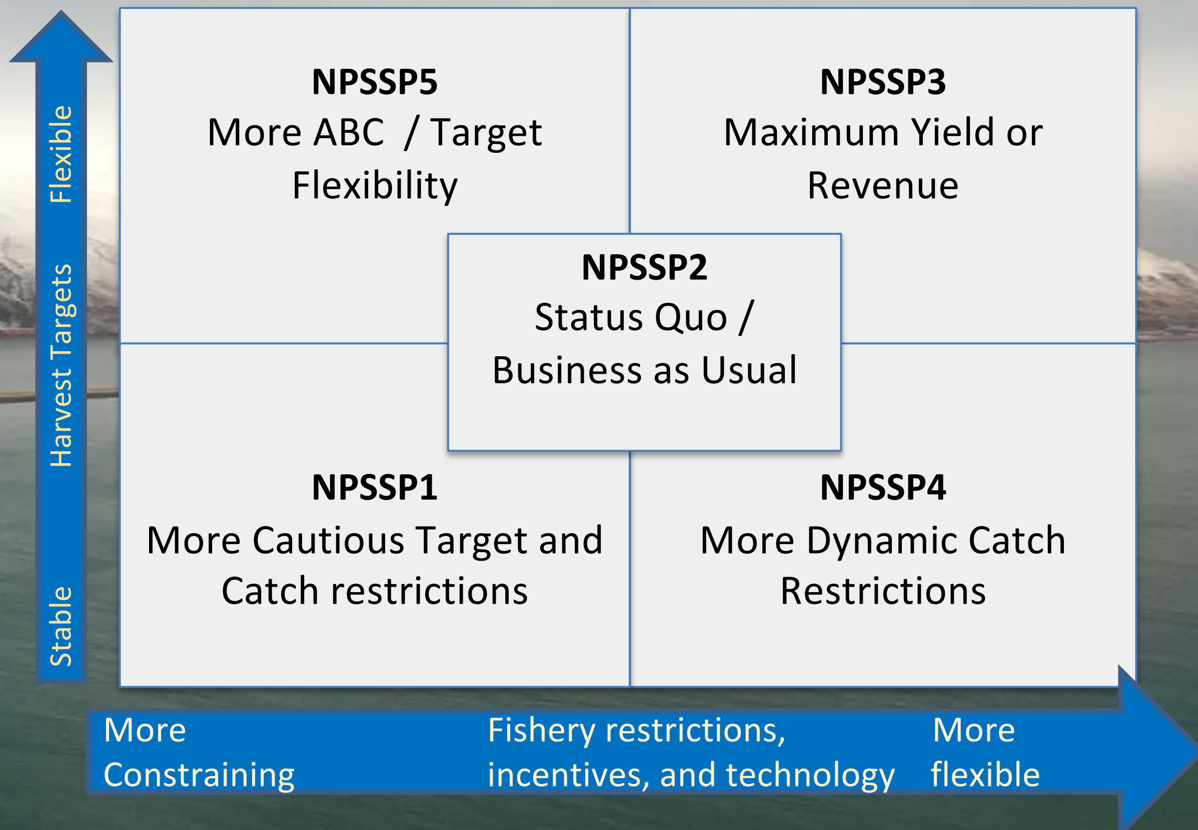
Strategy and Rationale of these measures:

- Examine the impacts and trade-offs of scenarios that include factors that lead to more flexible catch restrictions and/or greater catch.

Example Fishery Features:

- Impact of hypothetical 2.4 MMT Ecosystem Cap / Optimum Yield.
- Reduced spatial management measures when PSC quotas in place.
- Additional fishing flexibility in the Northern Bering Sea.
- Greater quota or bycatch flexibility (e.g., expanded Flatfish flexibility).
- Higher prices or improved fishing technology leading to greater catch.

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



The combinations of Target / ABC / HCR and TAC / Fishery measures will be combined and coupled with different biological models to explore the trade-offs that result under several climate scenarios.

ACLIM 2.0 -- putting it all together

Better and more realistic models

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

= Building on past Council success, use best available science about the trade-offs of management alternatives.

+ An integrated system that will be continuously improved.

How to give input to ACLIM

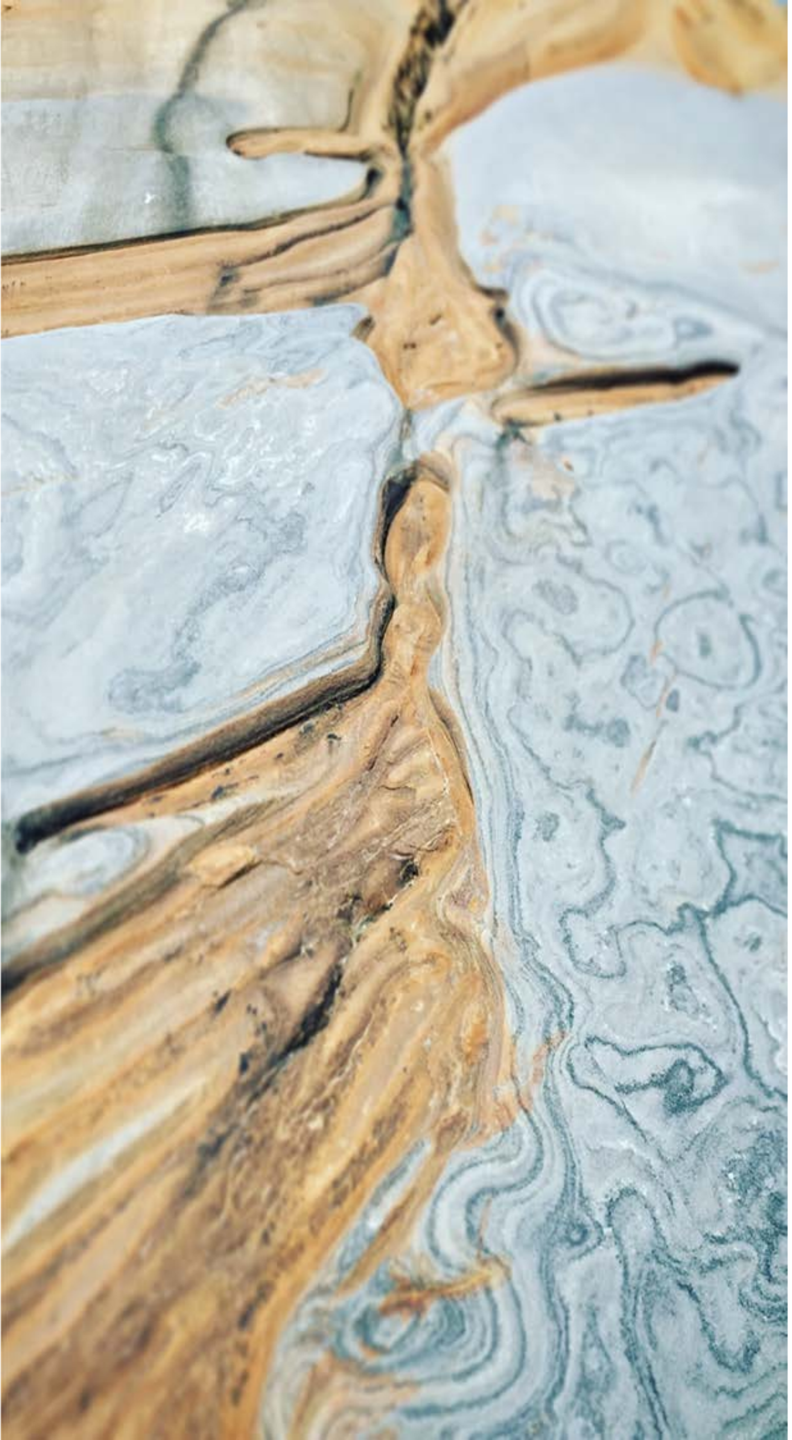
- Opportunities to give input in 2022 and beyond.
  - Council Meeting ACLIM workshop (June 8 Evening - reschedule from April)
  - Bering Sea region community workshop(s) - Summer
  - NPFMC Climate Change Task Force meetings - ongoing
  - Stay tuned for more
- Reach out to us anytime
  - Kirstin Holsman (Kirstin.Holsman@noaa.gov)
  - Alan Haynie (Alan.Haynie@noaa.gov)
  - Email your favorite ACLIM team member.

Part 3 Part 4

Input welcome today or anytime…

- Questions or comments about our work plan?
- What are the most compelling questions or biggest concerns for you?
- How can we best communicate with you and your stakeholders?

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

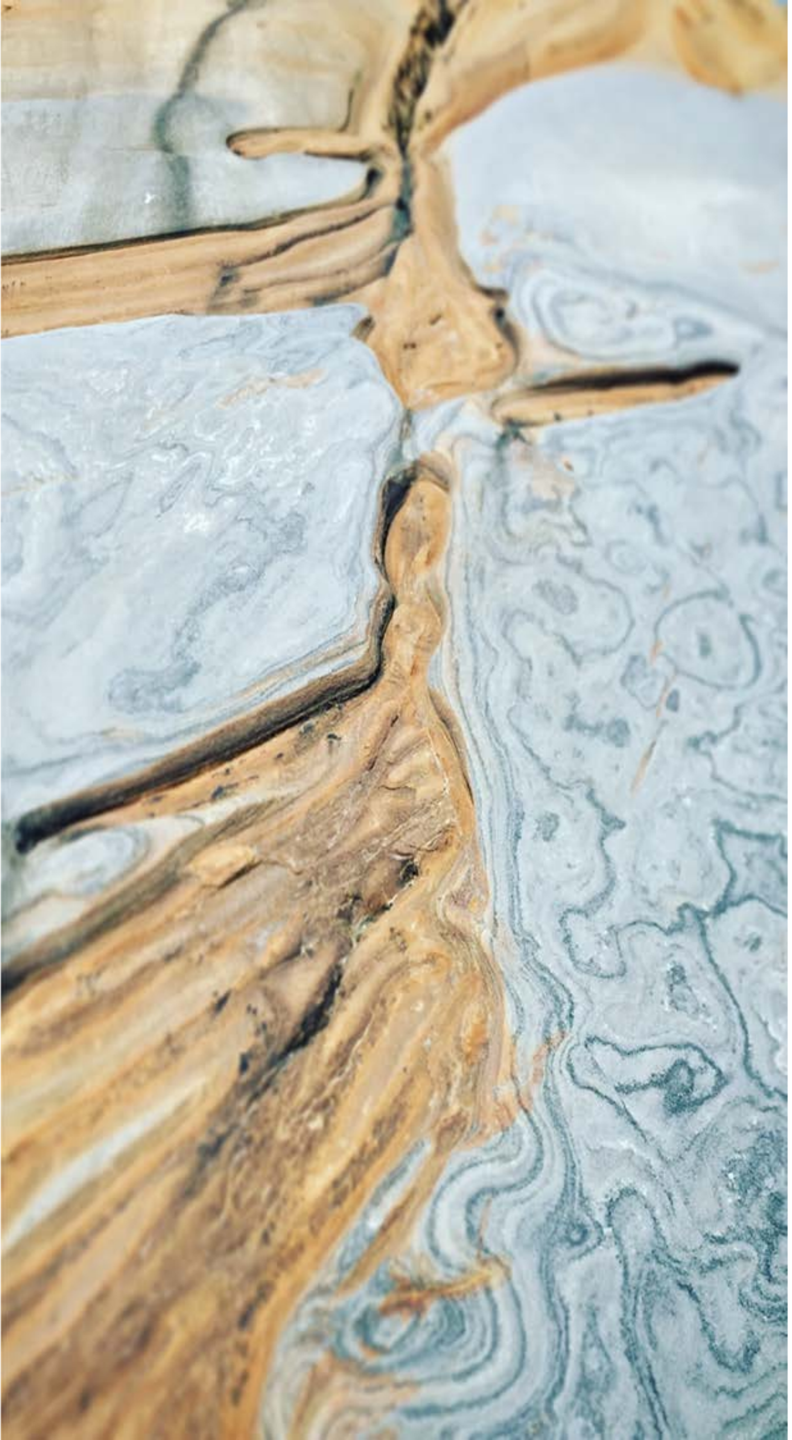
Collaboration support:

- 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?


kirstin.holsman@noaa.gov


Alan.Haynie@noaa.gov



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

ACLIM Publications:

1. (*in press*) Hermann, A., K. Kearney, W. Cheng, D. Pilcher, K. Aydin, K. Holsman, A. Hollowed. Coupled modes of projected regional change in the Bering Sea from a dynamically downscaling model under CMIP6 forcing. Deep Sea Res II.
2. (*in press*) Cheng, W., A. Hermann, A. Hollowed, K. Holsman, K. Kearney, D. Pilcher, C Stock, K Aydin. Bering Sea dynamical downscaling: Environmental and lower trophic level responses to climate forcing in CMIP6. Deep Sea Res II.
3. (in revision) 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.
4. (2021) Punt, A., M G Dalton, W Cheng, A Hermann, K Holsman, T Hurst, J Ianelli, K Kearney, C McGilliard, D Pilcher, M Véron. Evaluating the impact of climate and demographic variation on future prospects for fish stocks: An application for northern rock sole in Alaska. Deep Sea Research Part II: Topical Studies in Oceanography 189–190:104951.
5. (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. Front. Mar. Sci., 03 February 2021 | https://doi.org/10.3389/fmars.2021.624301
6. (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
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8. (2020) 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 J. Mar. Sci fsaa140, https://doi.org/10.1093/icesjms/fsaa140
9. (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.
10. (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
11. (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
12. (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
13. (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
14. (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

EXTRA SLIDES