2016 Initial report from the ACLIM Project

Photo: Mark Holsman

Evaluating fishery management strategies under different climate change scenarios in the Bering Sea

Anne Hollowed[1], Al Hermann[2], Kirstin Holsman[1], Alan Haynie[1]

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2. NOAA Office of Oceanic and Atmospheric Research, Pacific Marine Environmental Laboratory
3. Joint Institute for the Study of the Atmosphere and Ocean, University of Washington
4. Institute of Marine Research, Bergen Norway
5. School of Aquatic and Fisheries Science, University of Washington

NOAA FISHERIES

Alaska Climate-change Integrated Modeling Project

The ACLIM team: Speaking Today

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Stephen Kasperski

Cody Szuwalski

Amanda Faig

Jonathan Reum

Michael Dalton

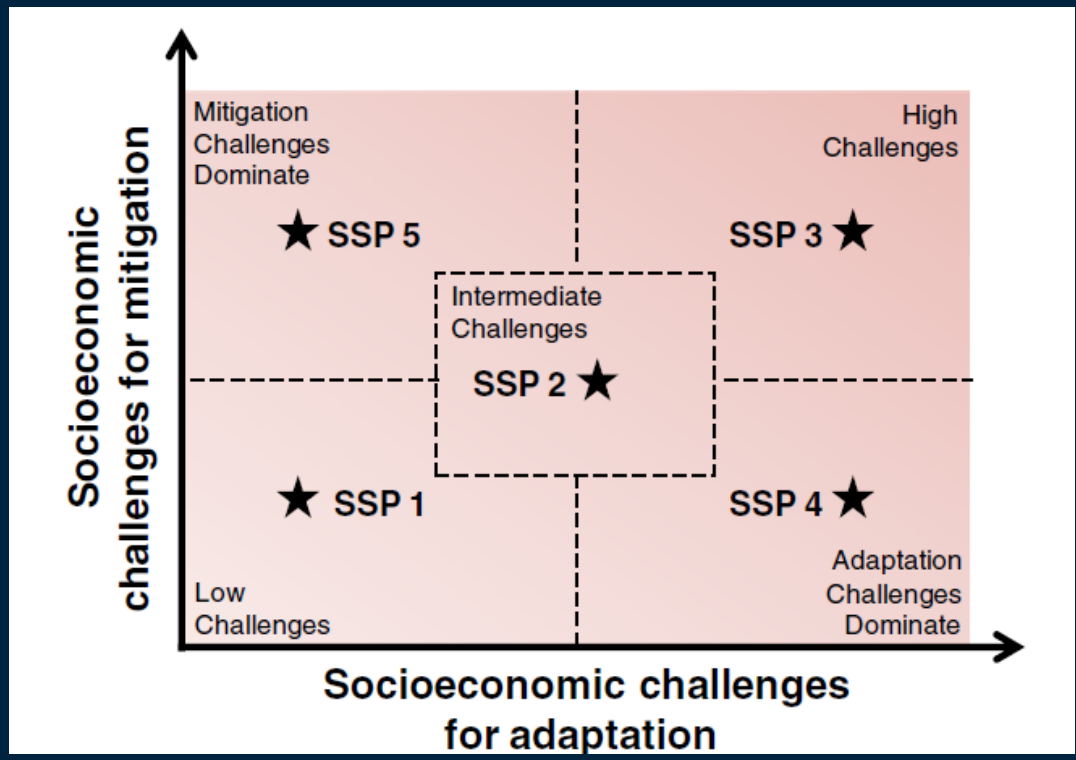
Paul Spencer

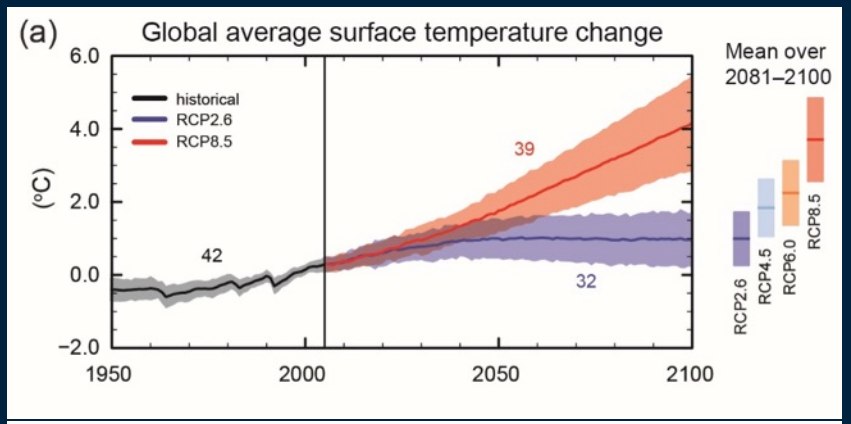
Tom Wilderbuer

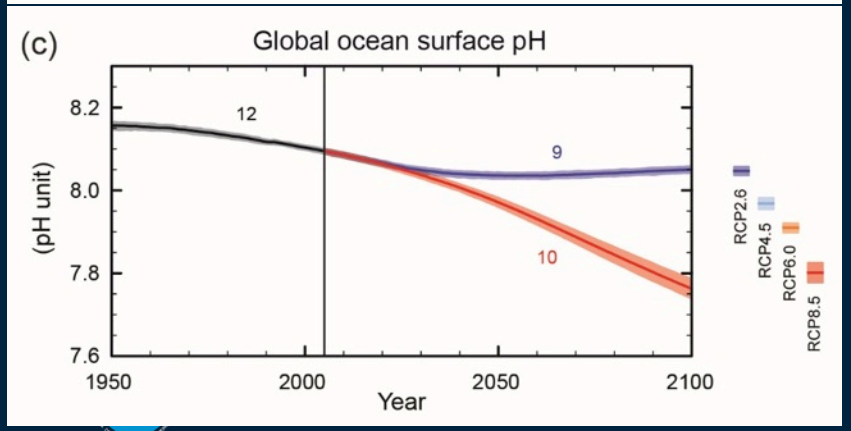
William Stockhausen

Integrating Concepts of IPCC 2014

Management Options
O' Neill et al. 2014. Climate Change 122:387-00







IPCC AR5 WG 1 synthesis report: https://www.ipcc.ch/report/graphics/index.php?t=Assessment%20Reports&r=AR5%20-%20WG1&f=SPM

IPCC 5th Assessment Report

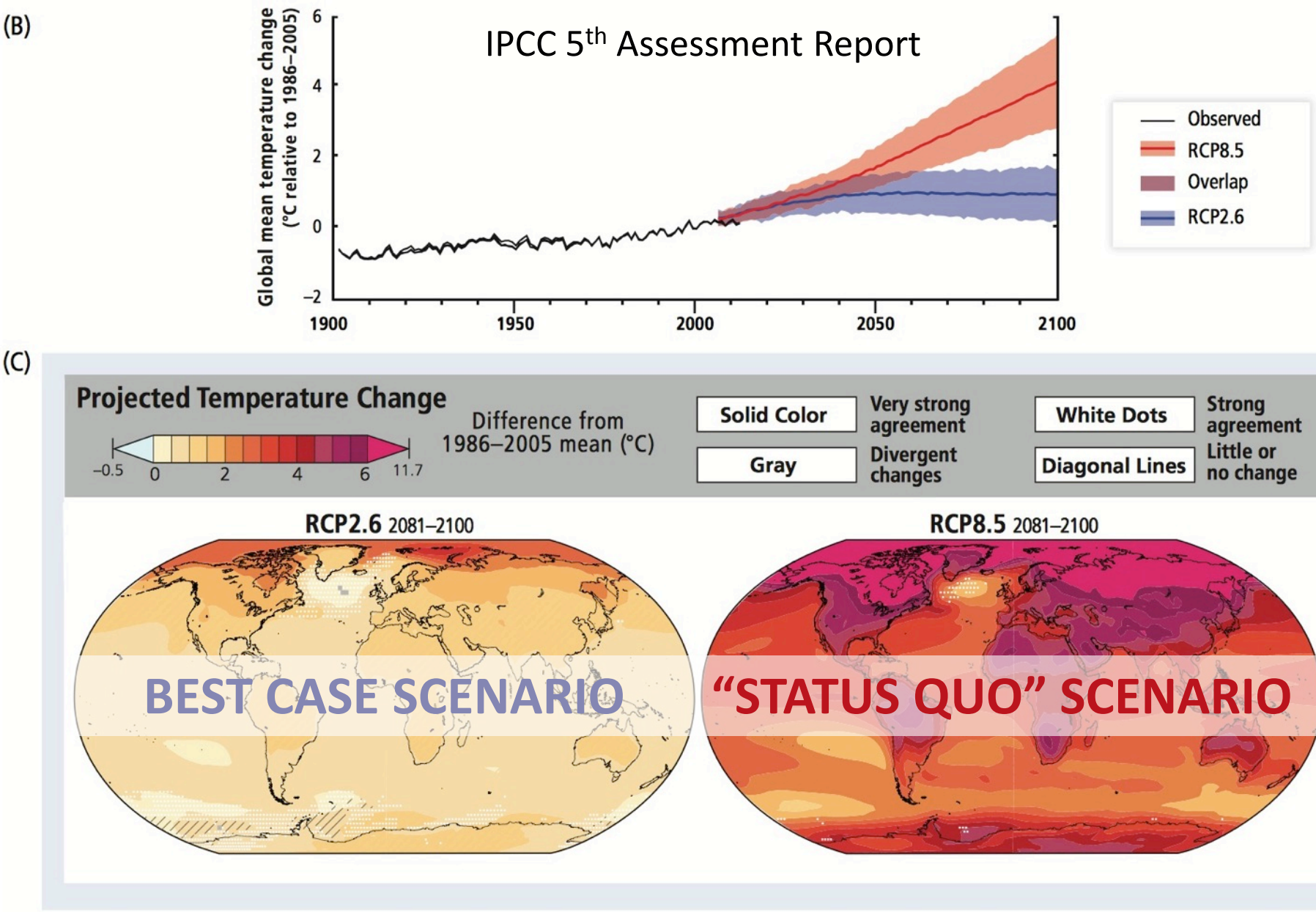
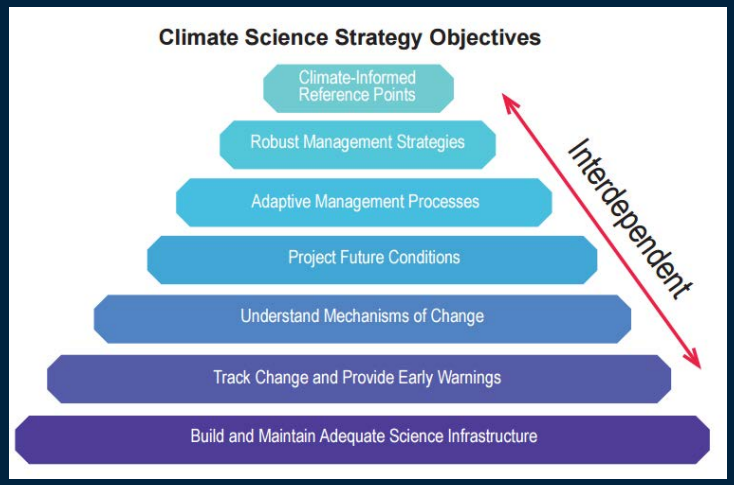


Figure SPM.4 | Observed and projected changes in annual average surface temperature. This figure informs understanding of climate-related risks in the WGII AR5. It illustrates temperature change observed to date and projected warming under continued high emissions and under ambitious mitigation.

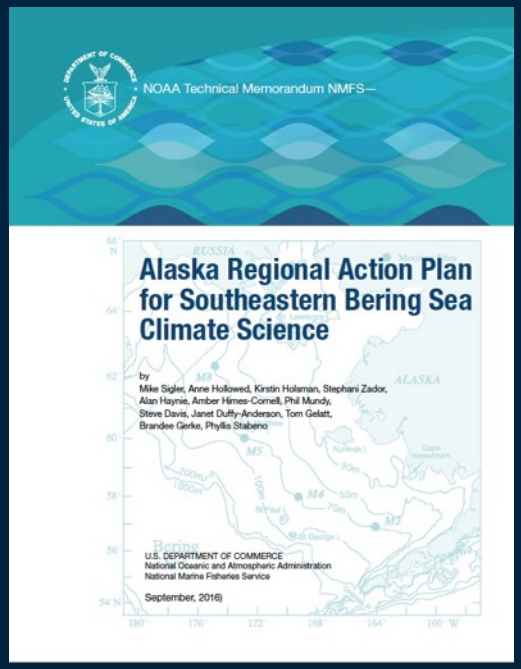
ACLIM Purpose and Need

National and international climate impact assessments 2020-2022

- Scientific advancement



- Operationalization of national climate-ecosystem projection enterprise
- Testing management strategies for climate Informed decision making - NPFMC FEP



http://www.st.nmfs.noaa.gov/ecosystems/climate/national-climate-strategy

The Bering Sea (Alaska)

450 species of fish and shellfish

35 million birds

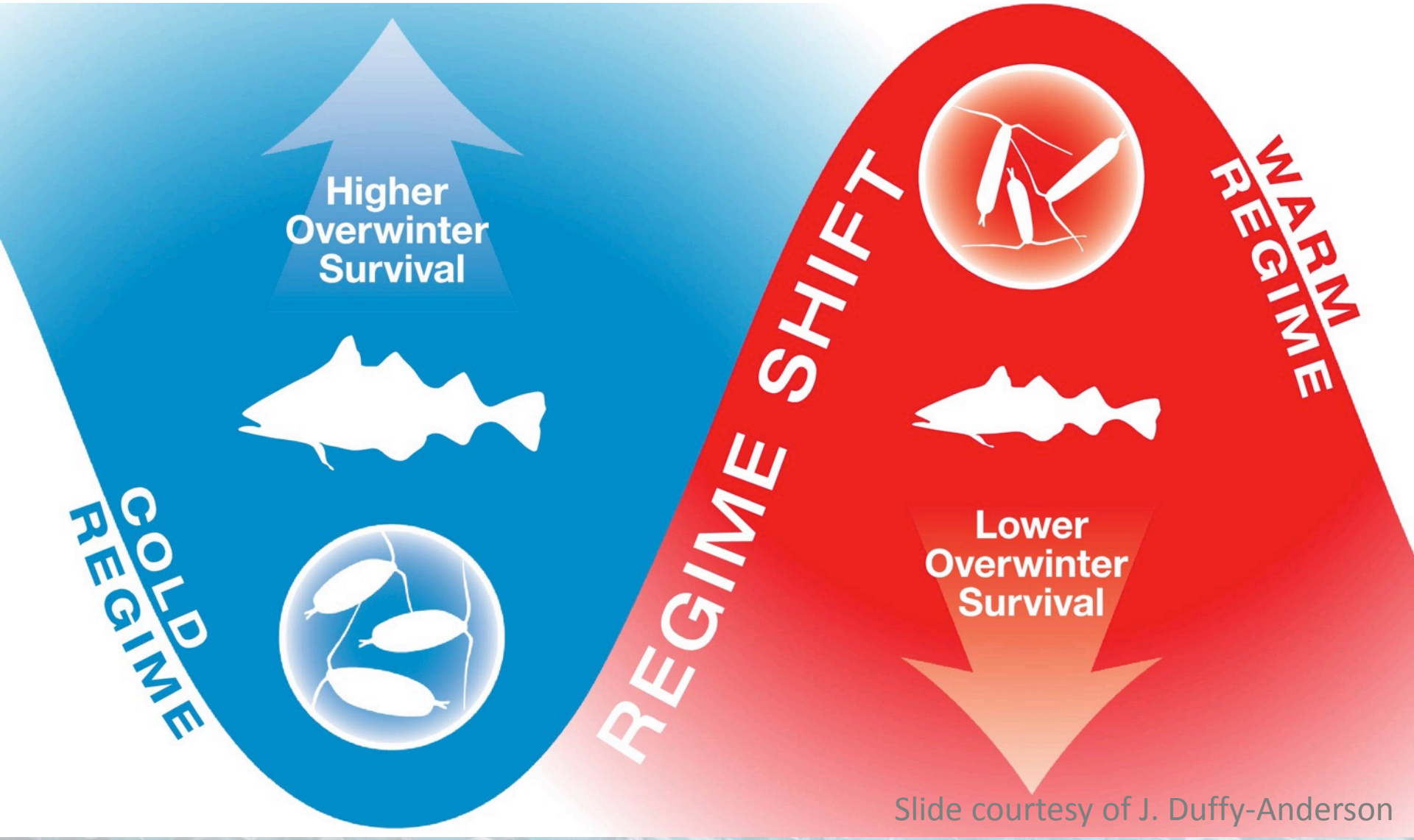
25 species of marine mammals

40% of the total US commercial catch of fish and shellfish

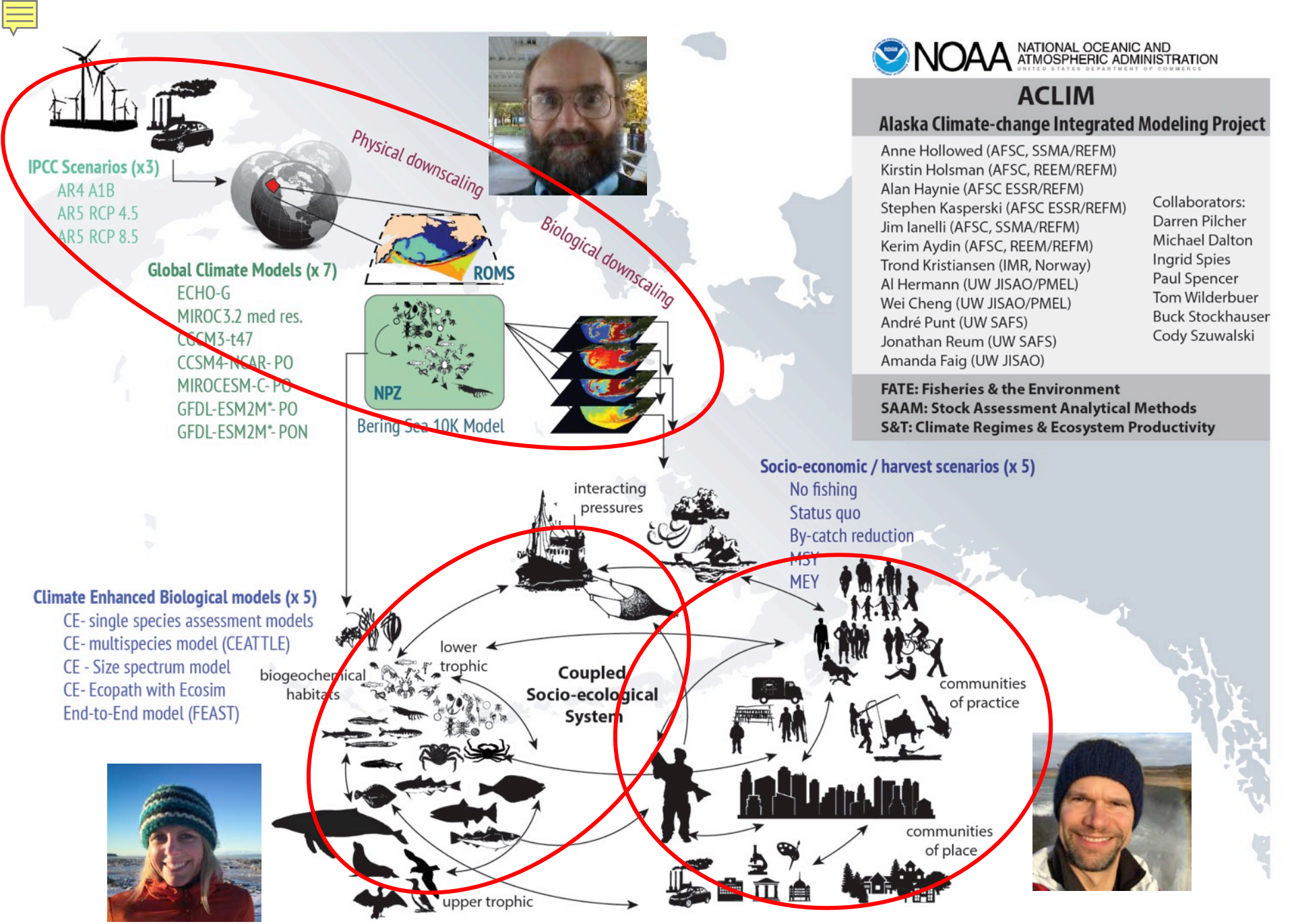
world's largest sockeye salmon fishery

75% of the subsistence harvest for 55,000 Alaskans

Long history of integrated ecosystem research programs- Most recently the Bering Sea Project (NPRB, NSF, NOAA): 90 investigators, $52 M



Slide courtesy of J. Duffy-Anderson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IPCC Scenarios (x3)
AR4 A1B
AR5 RCP 4.5
AR5 RCP 8.5
Physical downscaling
Biological downscaling
ROMS
Global Climate Models (x 7)
ECHO-G
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CE- Ecopath with Ecosim
End-to-End model (FEAST)
lower trophic
biogeochemical habitats
Coupled Socio-ecological System
communities of practice
communities of place
upper trophic

Physical & lower trophic (NPZ) modeling (Al Hermann)

Dr. Albert Hermann
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at JISAO/UW and NOAA/PMEL
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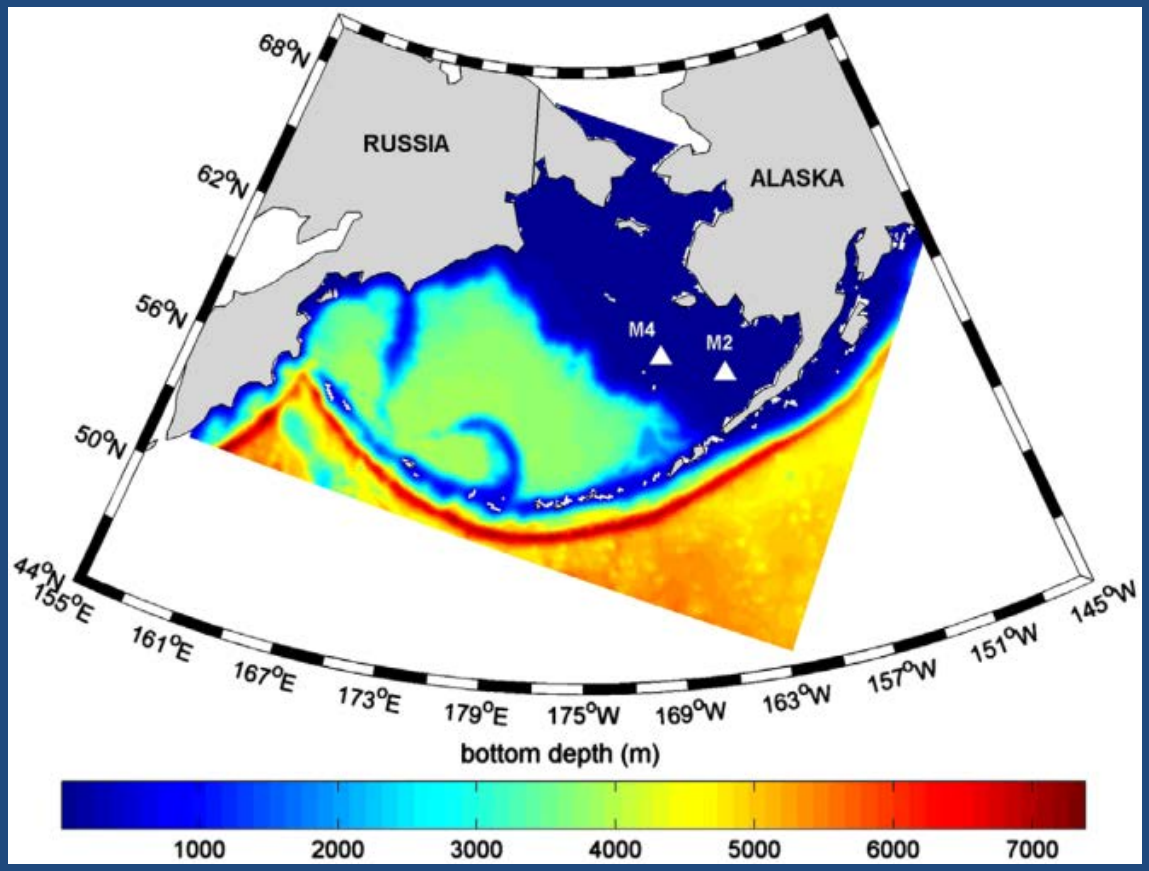
Photo: Mark Holsman

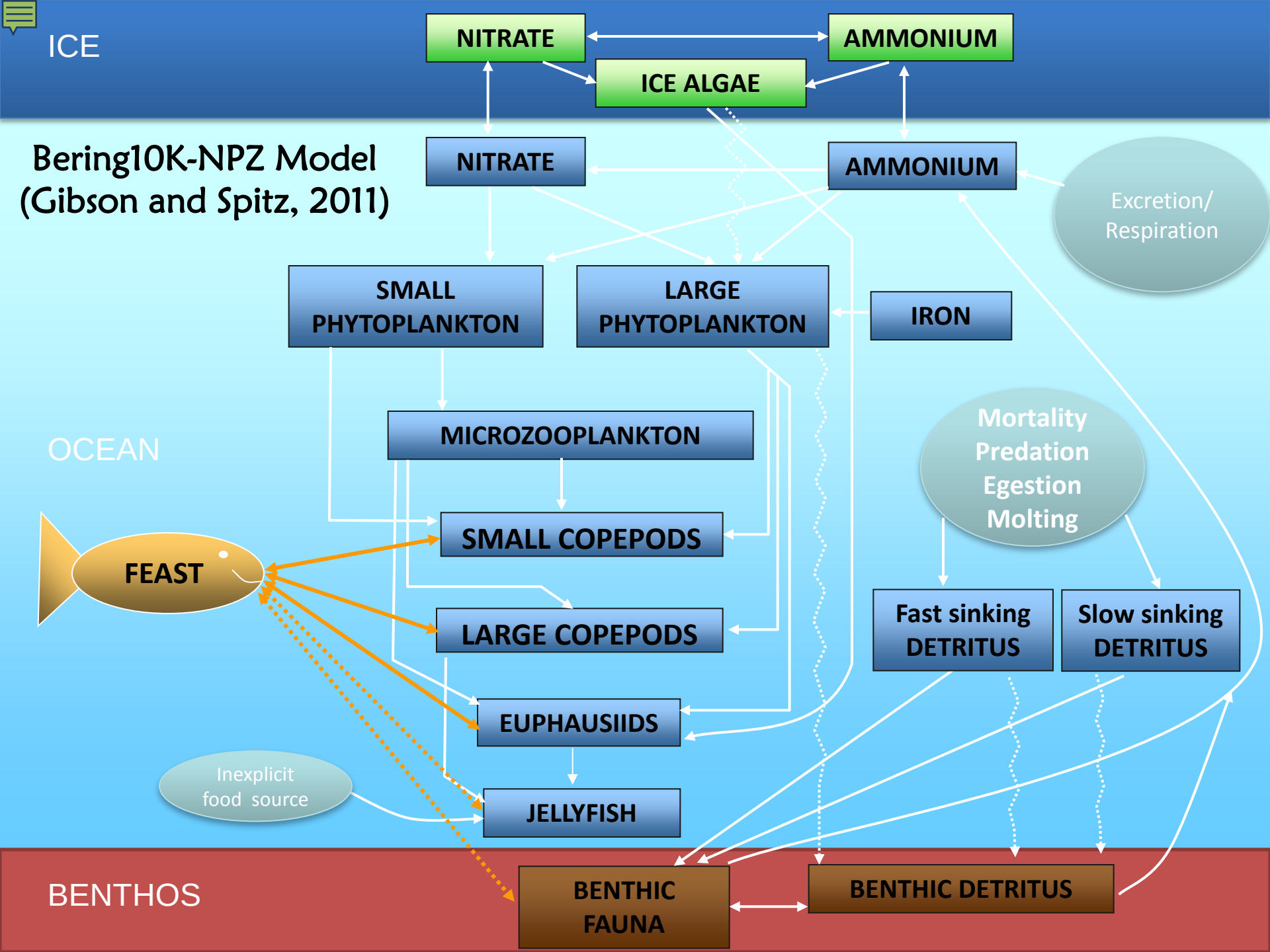
What is unique about the Bering Sea?

- Physical
  - Seasonal ice with advection to the south
  - Tidal mixing sets up distinct biophysical regimes
- Biological
  - Ice plankton may be a major food source to higher trophic levels
  - Benthic food chain is a major player

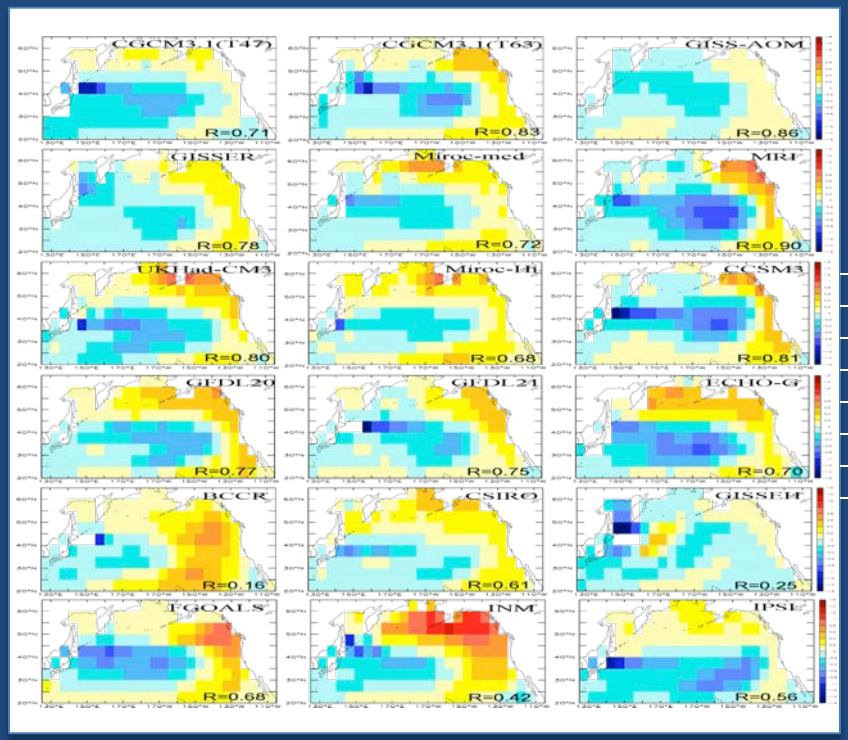
Bering10K model



- Regional Ocean Modeling System (ROMS)
- Descendent of NEP5 (Danielson et al. 2012)
- 10 layers, 10-km grid Includes ice and tides
- CCSM bulk flux
- Details in Hermann et al. (DSR2, 2013, 2016)

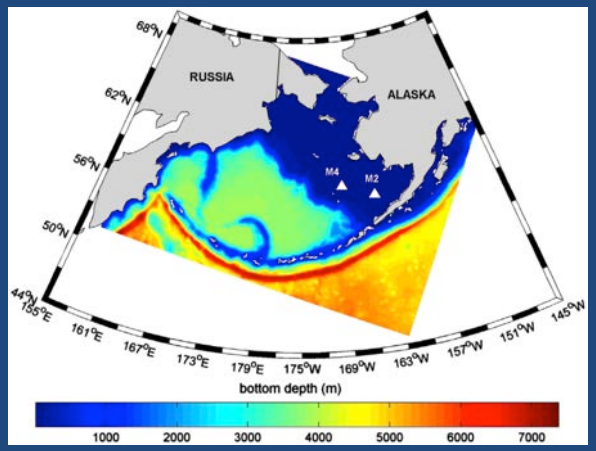

ICE
NITRATE
AMMONIUM
ICE ALGAE
Bering10K-NPZ Model
(Gibson and Spitz, 2011)
NITRATE
AMMONIUM
Excretion/
Respiration
SMALL
PHYTOPLANKTON
LARGE
PHYTOPLANKTON
IRON
OCEAN
MICROZOOPLANKTON
Mortality
Predation
Egestion
Molting
FEAST
SMALL COPEPODS
LARGE COPEPODS
Fast sinking
DETRITUS
Slow sinking
DETRITUS
EUPHAUSIIDS
Inexplicit
food source
JELLYFISH
BENTHOS
BENTHIC
FAUNA
BENTHIC DETRITUS

Climate models provide BCs/ICs to *regional coupled models*

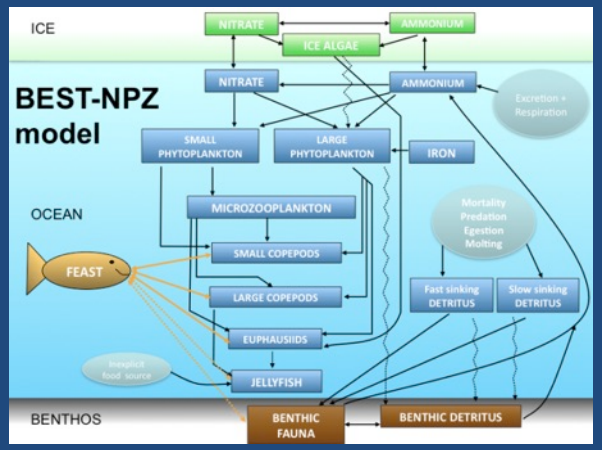


ensemble of runs

Bering10K



NPZ



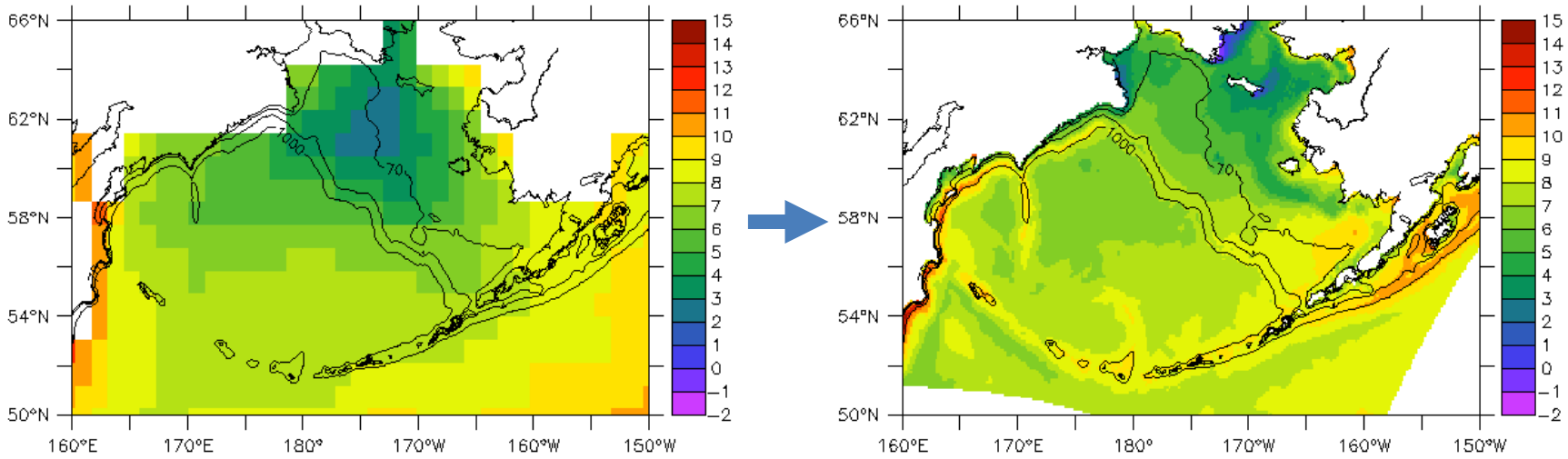
GOAL: ***mutidecadal*** **projections of physics and biology in the Bering Sea**

ensemble of projected futures

IPCC global projections drive regional model (*dynamical downscaling*)

IPCC model (MIROC)

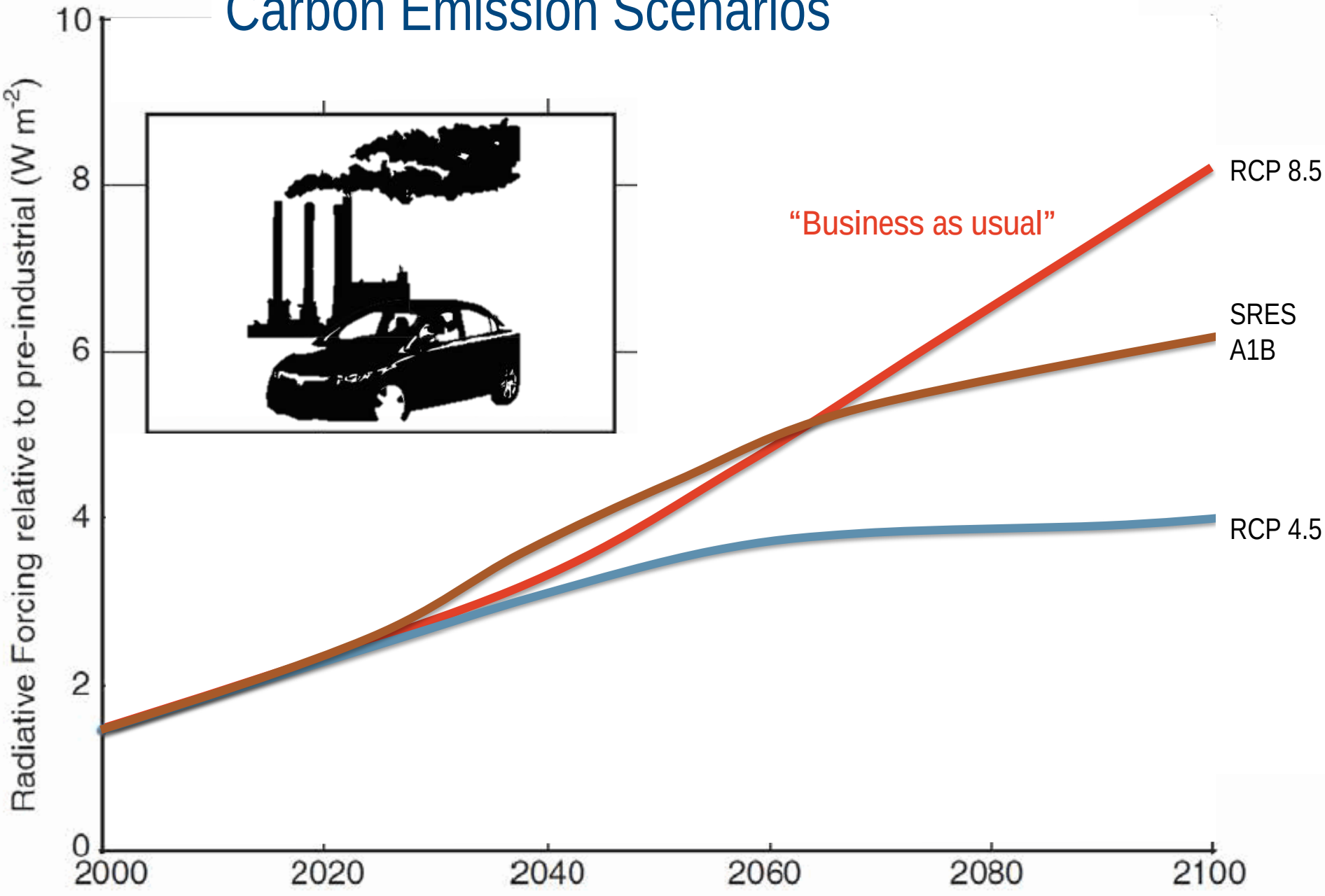
Regional model (Bering10K)



IPCC global atmosphere provides *surface forcing*

IPCC global ocean provides *boundary conditions*

Carbon Emission Scenarios



Downscaling Methods

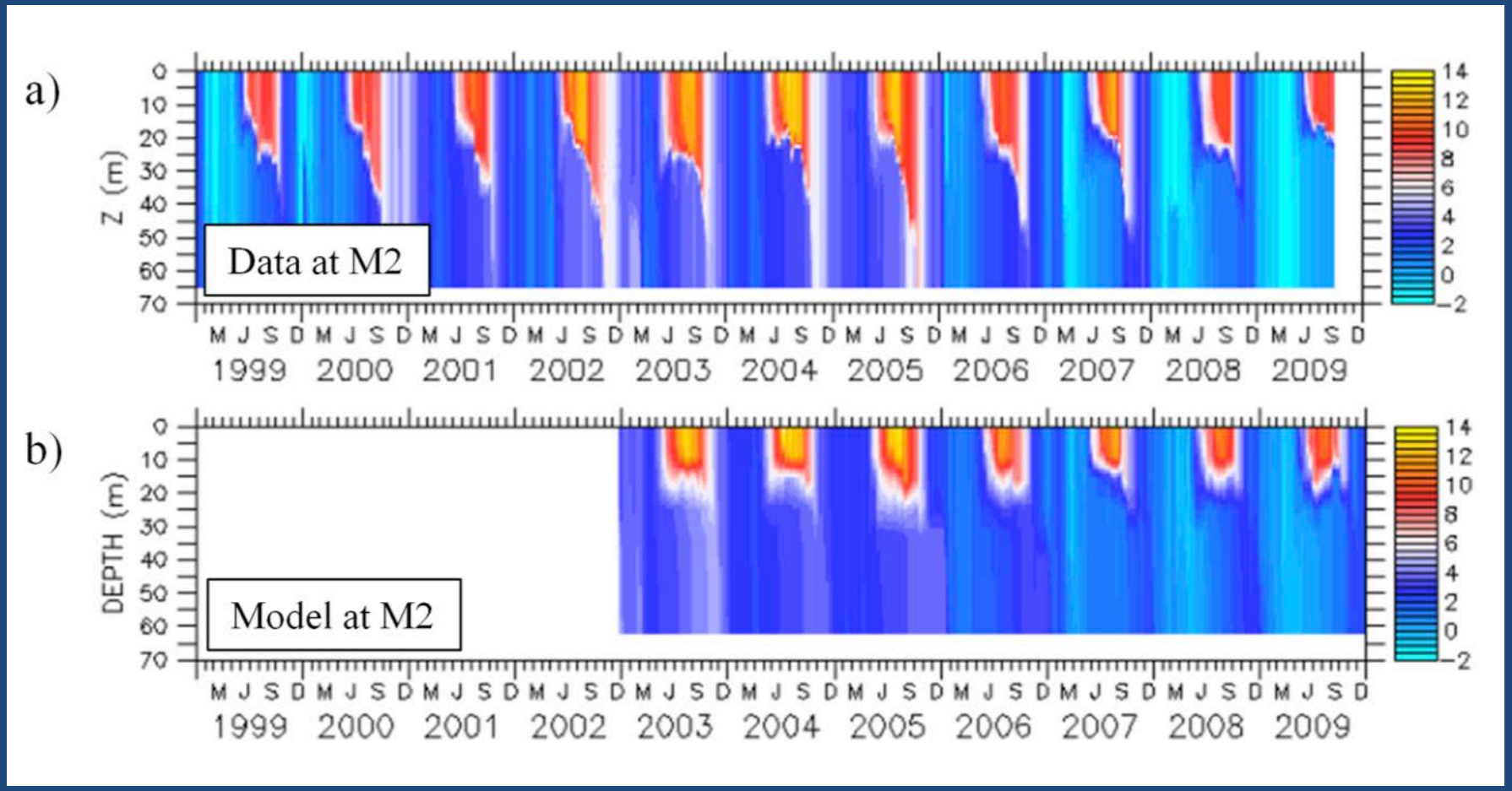
- Choose a subset of IPCC models for atmospheric forcing and oceanic boundary conditions (physical/biological) for our regional model (Bering10K)
- Model choice based on
  - Local validation (replicate present ice cover the Bering Sea)
  - Availability of needed forcing variables
  - Availability of multiple emission scenarios
  - NPZ and OA variable output (not available for all models)
- Ocean Acidification dynamics (e.g. pH, aragonite saturation) are now being added to Bering10K (D. Pilcher)

IPCC scenarios/models used

- A1B
  - CGCM3.1-t47
  - ECHOG
  - MIROC
- rcp4.5
  - GFDL
  - CESM
  - MIROC
- rcp8.5
  - GFDL
  - GFDL w/bio
  - CESM
  - CESM w/bio
  - MIROC

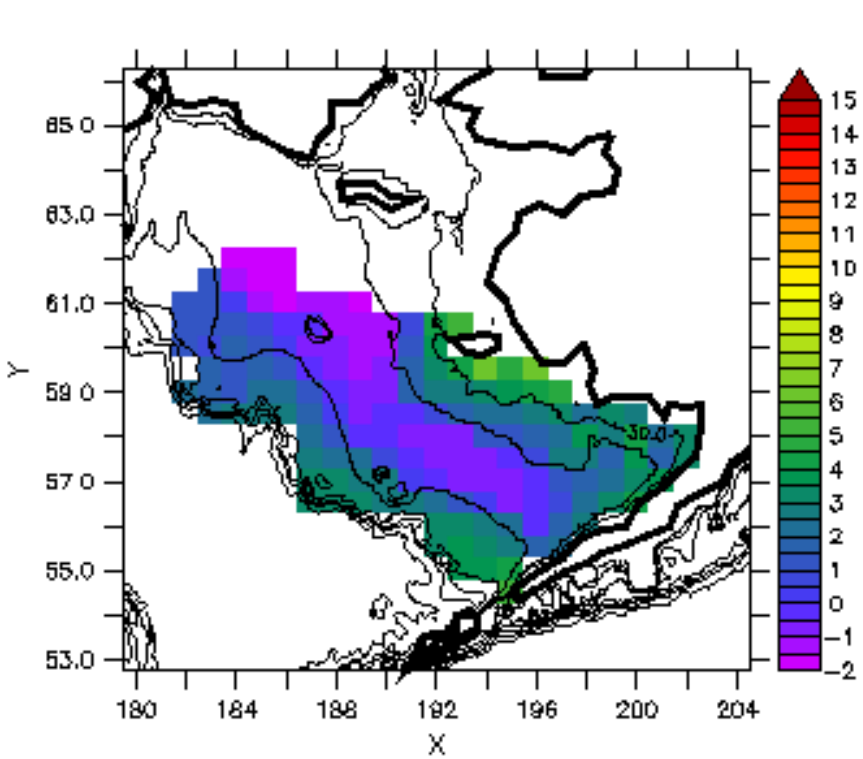
- A1B runs used for 2000-2040
- rcp4.5/rcp8.5 runs used for 2010-2100

Bering10K validation:
Modeled/Observed mid-shelf temperatures (deg C)

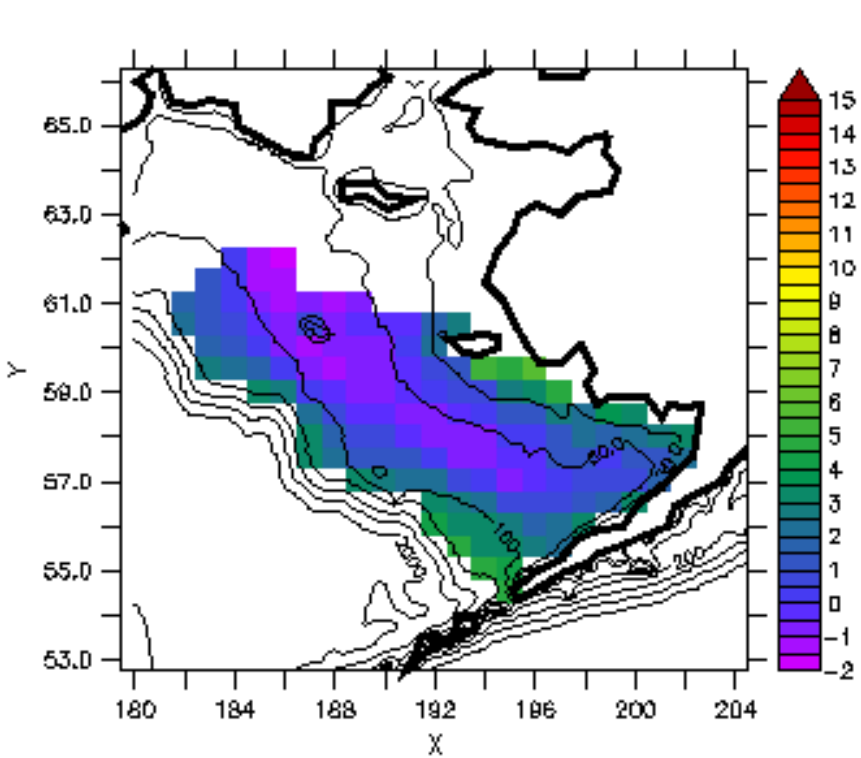


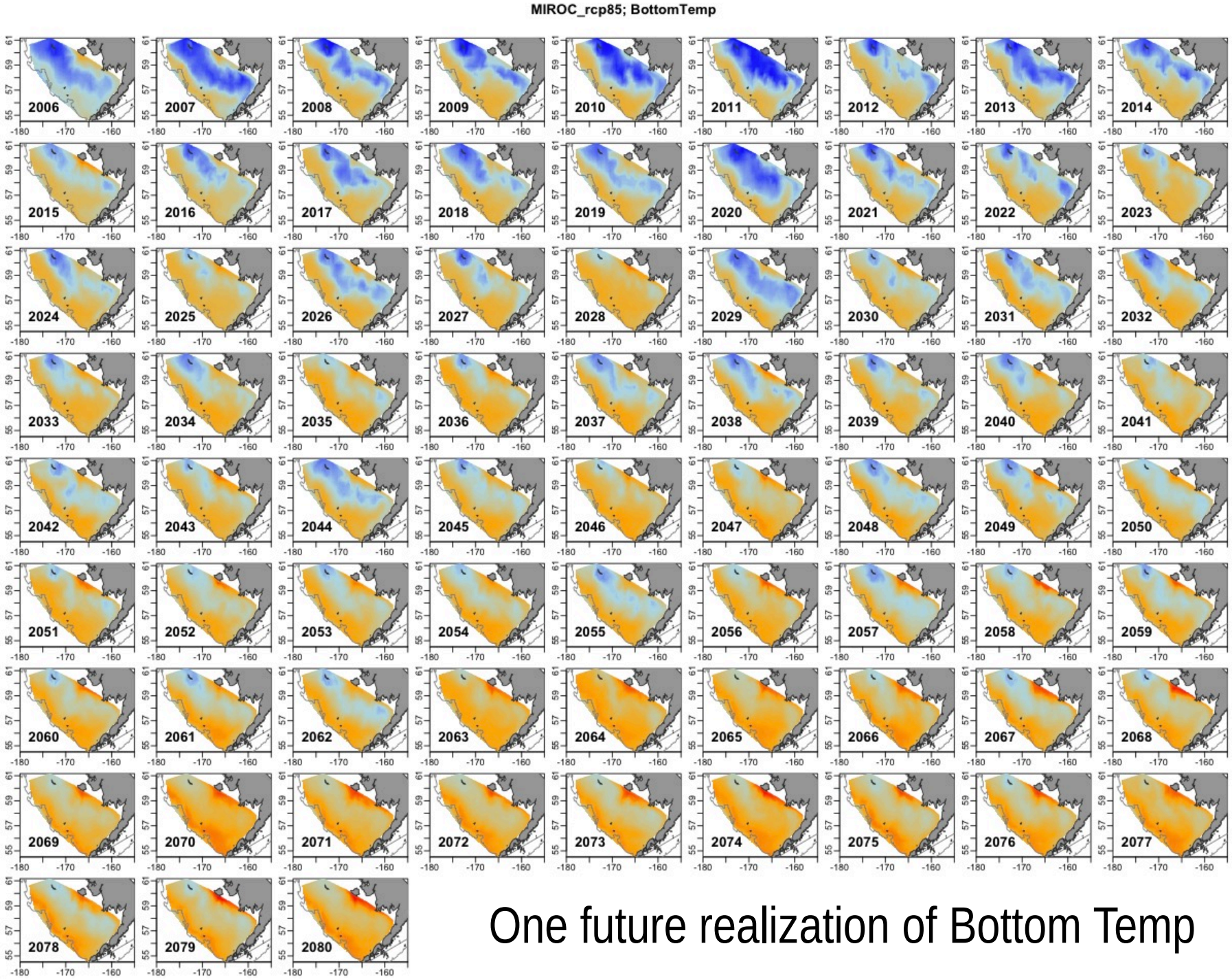
Bering10K validation:
Bottom Temp (deg C) summer 2009

DATA



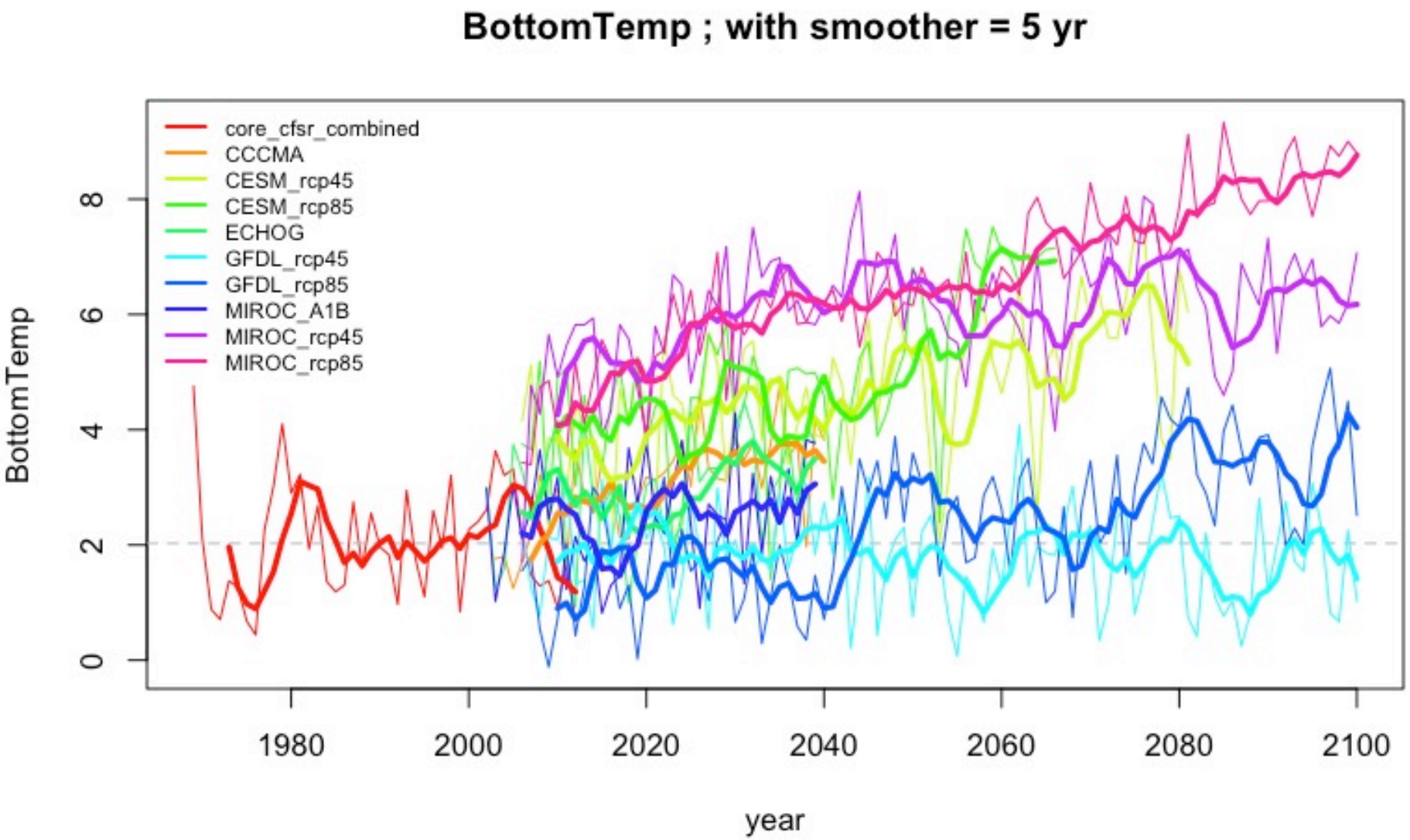
MODEL





One future realization of Bottom Temp

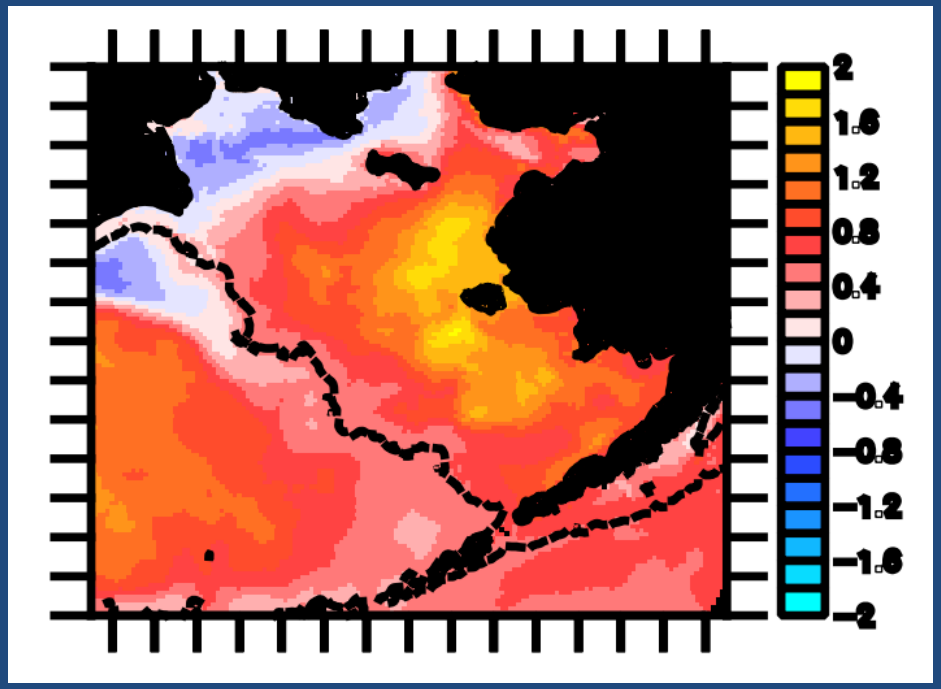
Ensemble of Bering10K output: Bottom Temperature



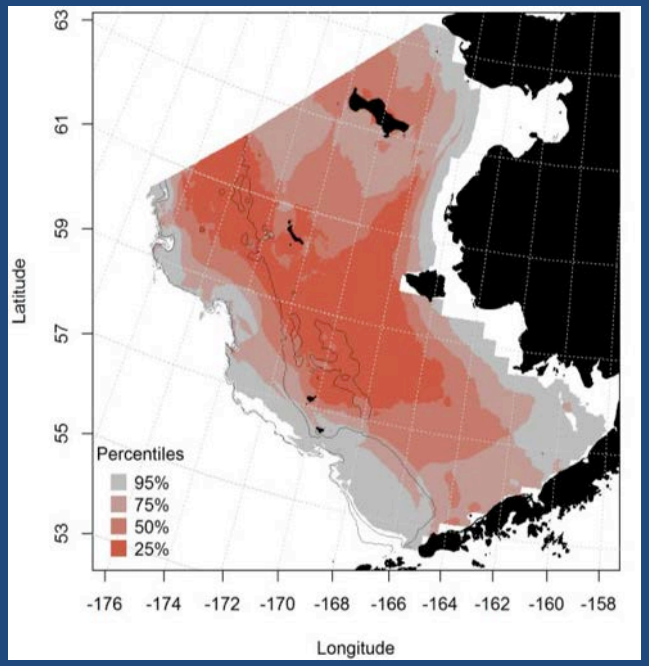
Bering Sea vulnerability analysis:

Compare present time variance and mean anticipated change with present fish distribution

Summer Bottom Temp anticipated change



Walleye pollock Essential Fish Habitat



Biological modeling (Kirstin Holsman)

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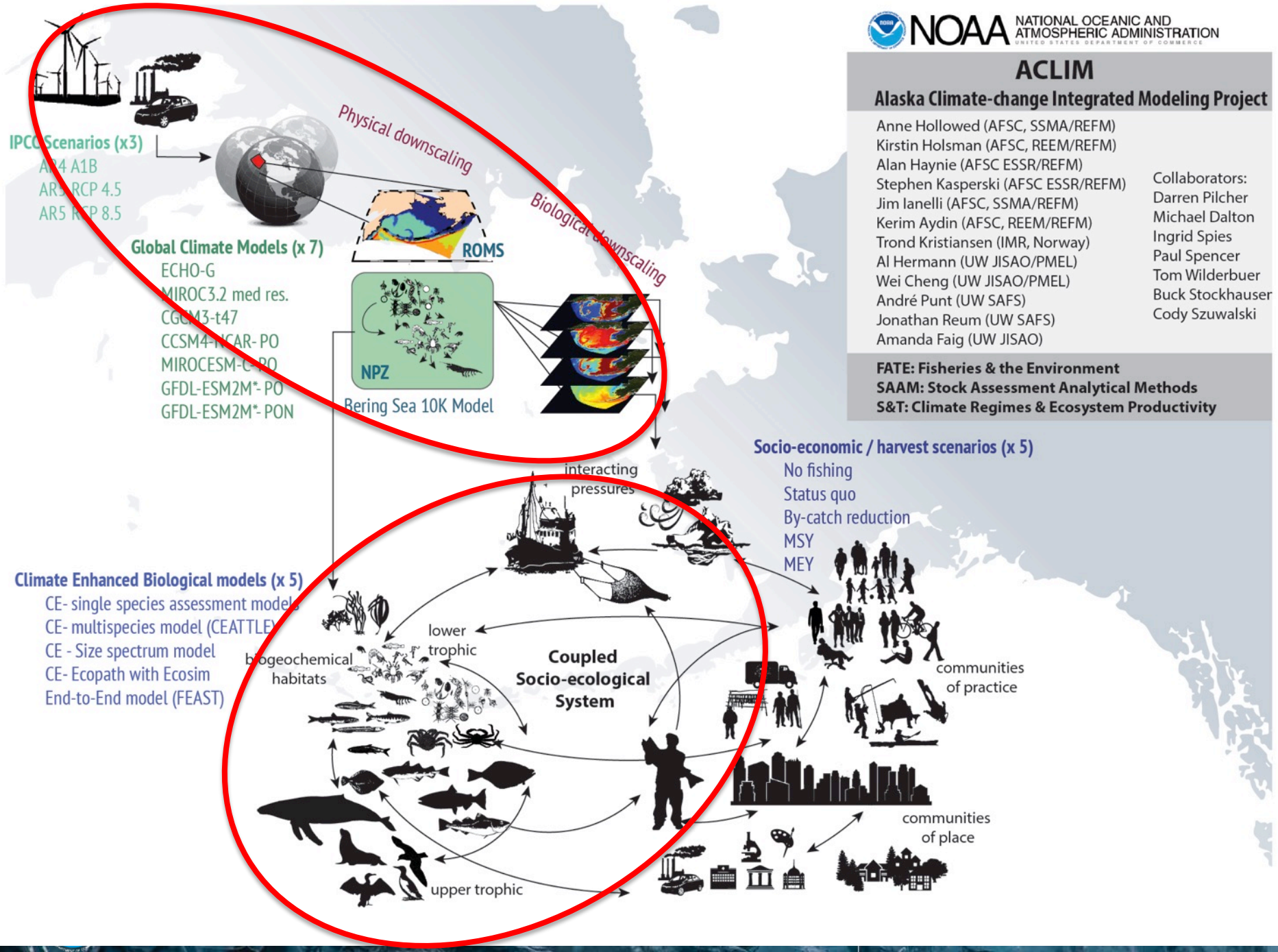
Photo: Mark Holsman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lower trophic
biogeochemical habitats
Coupled Socio-ecological System
communities of practice
communities of place
upper trophic

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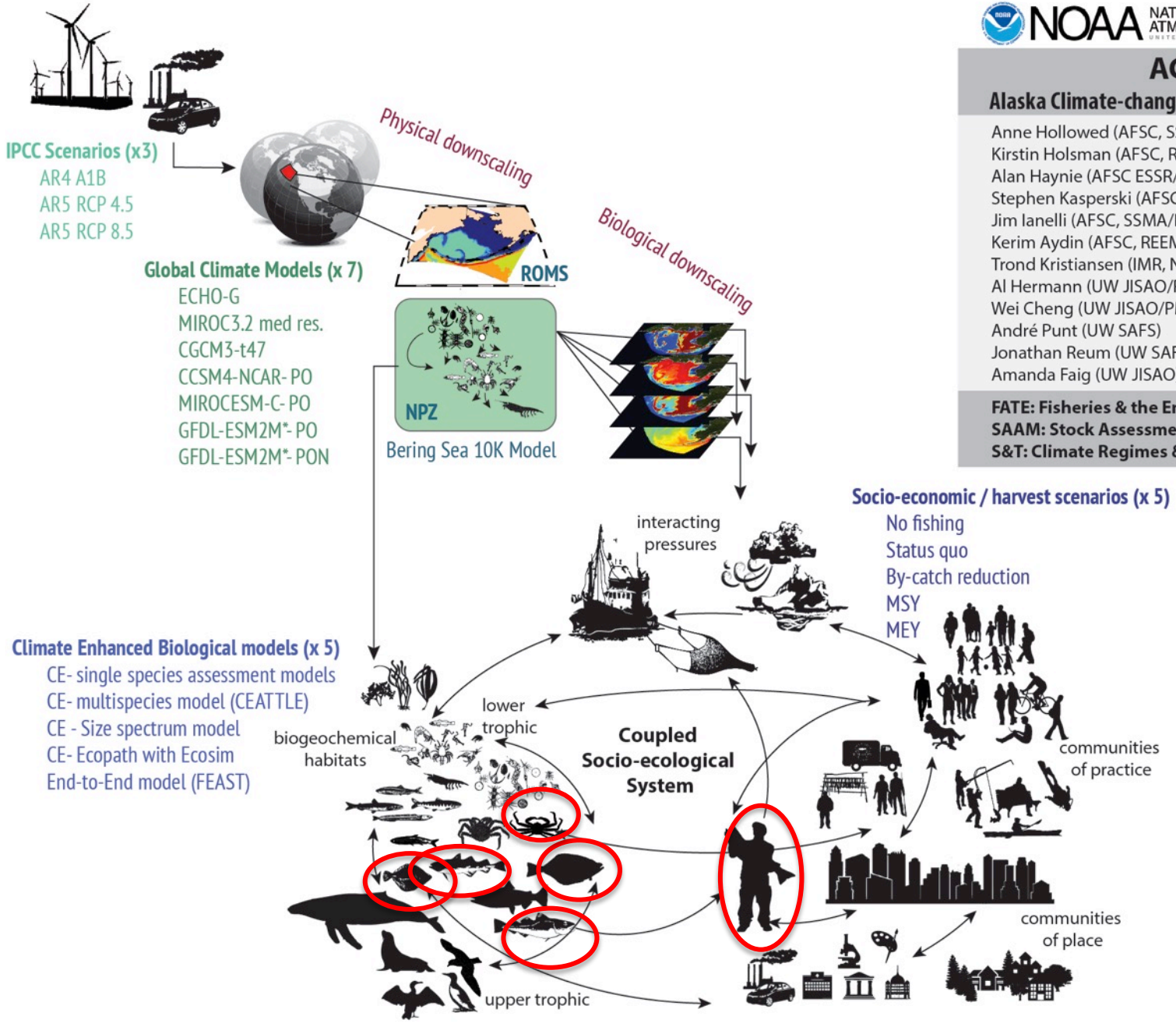
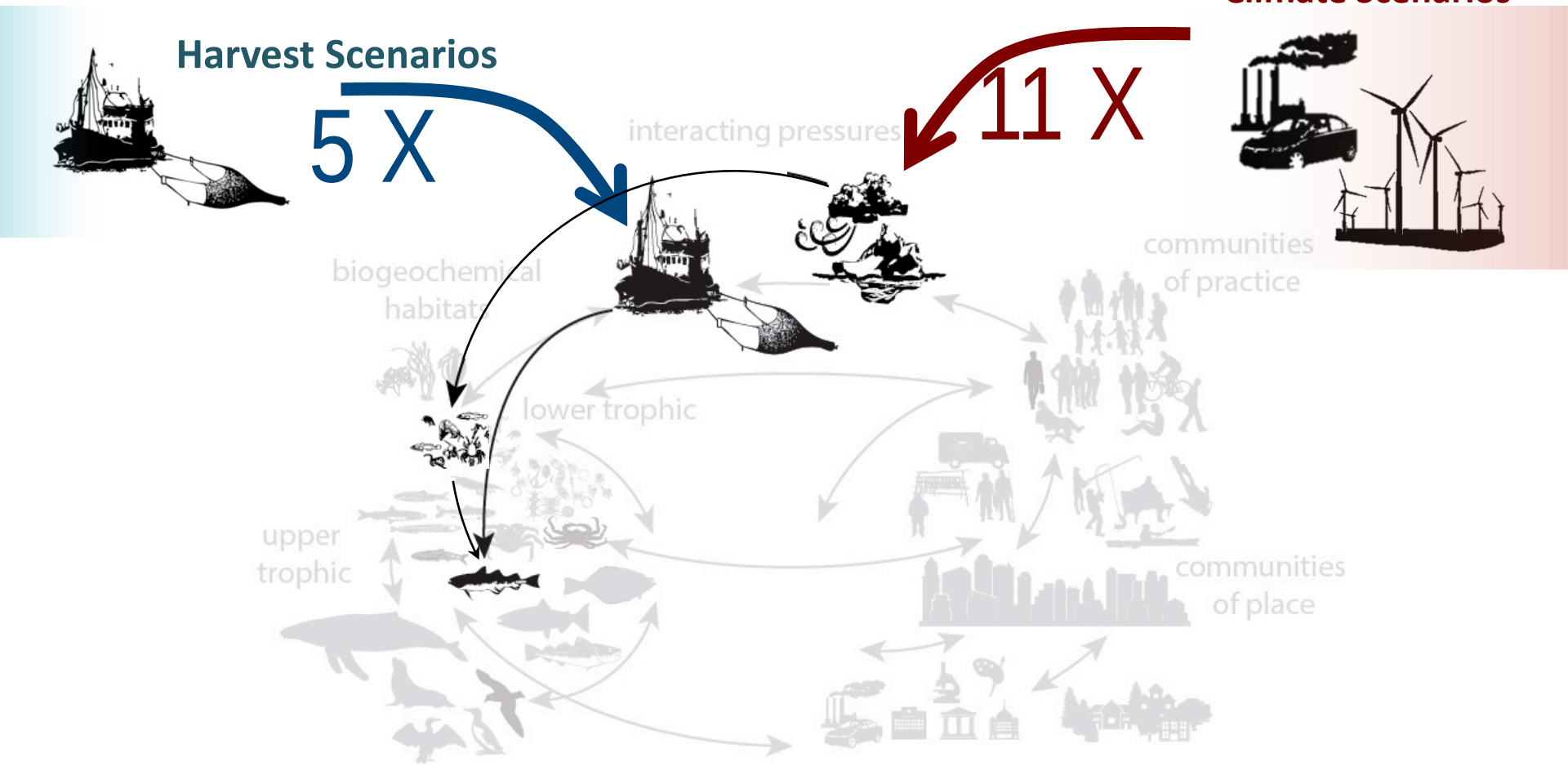


Mark Lovewell

Coupled Socio-Ecological System



Climate-enhanced Single-species Assessment Model

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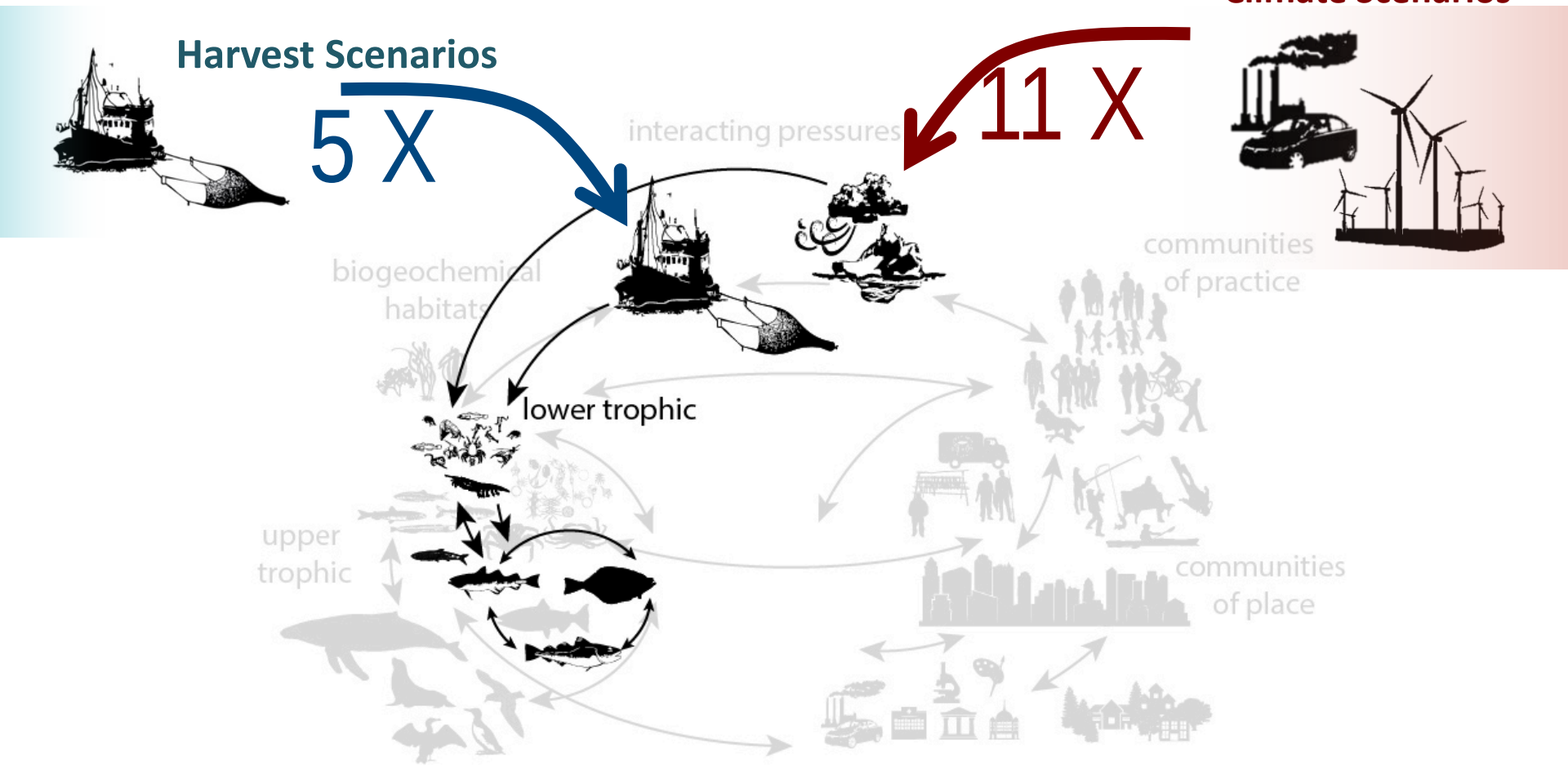
Coupled Socio-Ecological System



Climate-enhanced Multi-species Assessment Model

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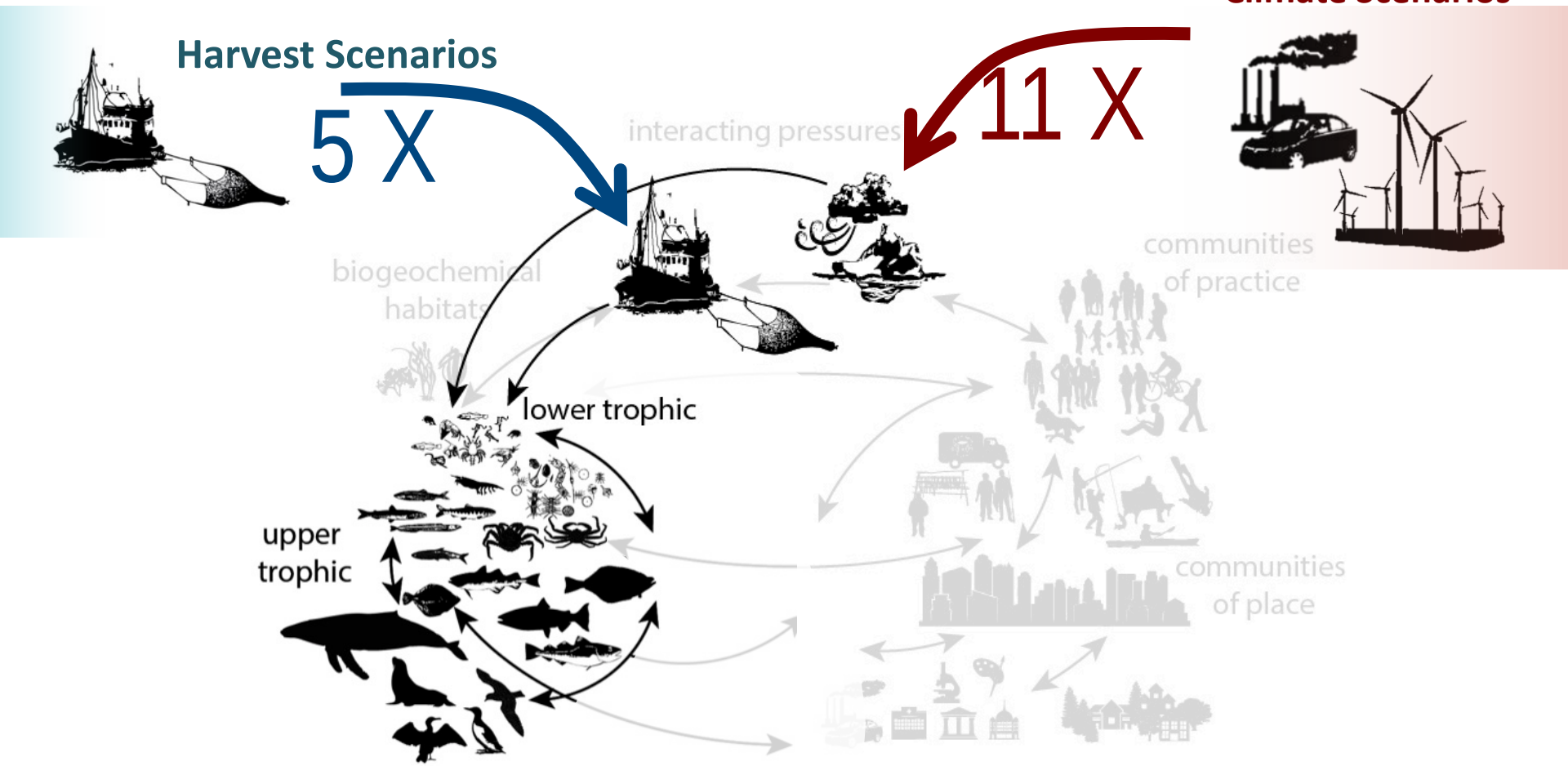
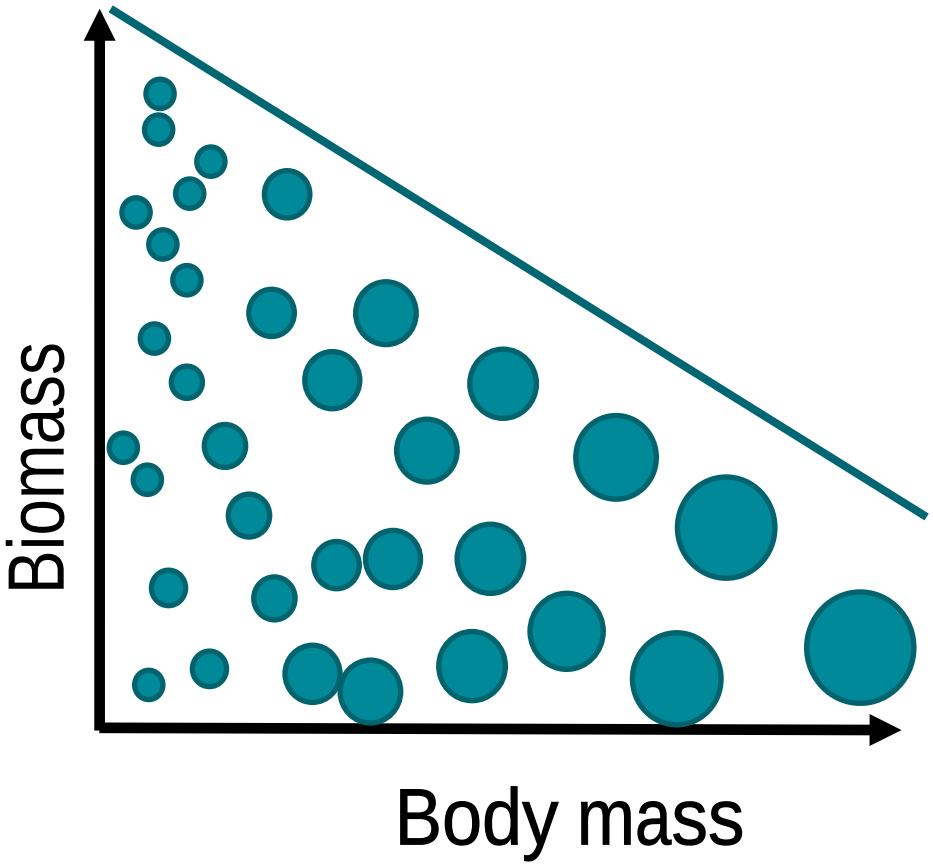
Coupled Socio-Ecological System



Climate-enhanced Size-spectrum Model

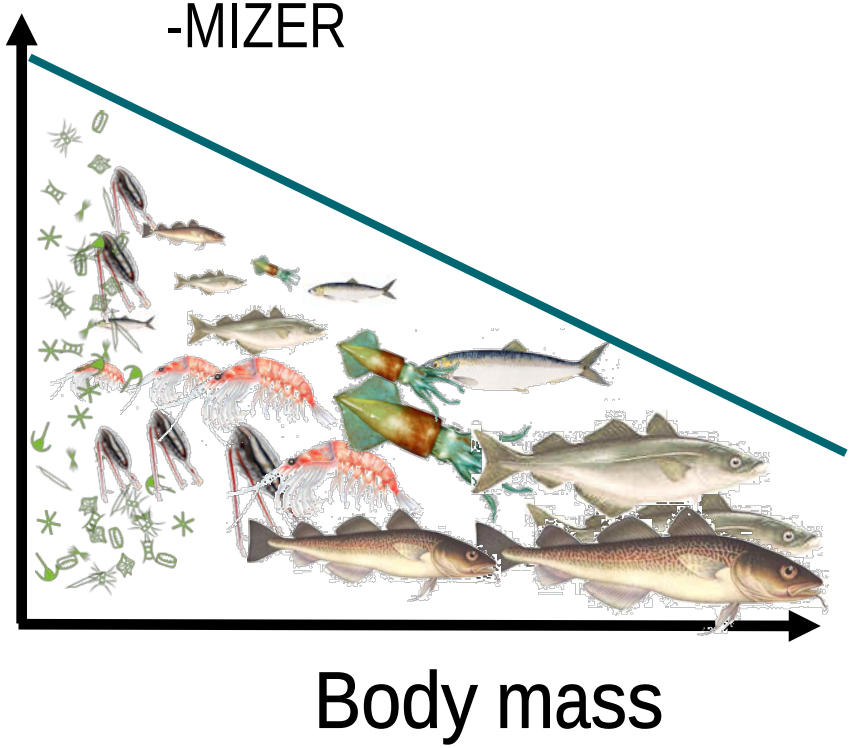
ACLIM: *Alaska Climate-change Integrated Modeling project*

Particles that eat, grow and reproduce



Species level attributes

- -Maximum size
- -Minimum size
- -Size at maturation
- -preferred prey size
- -preferred prey species
- -MIZER



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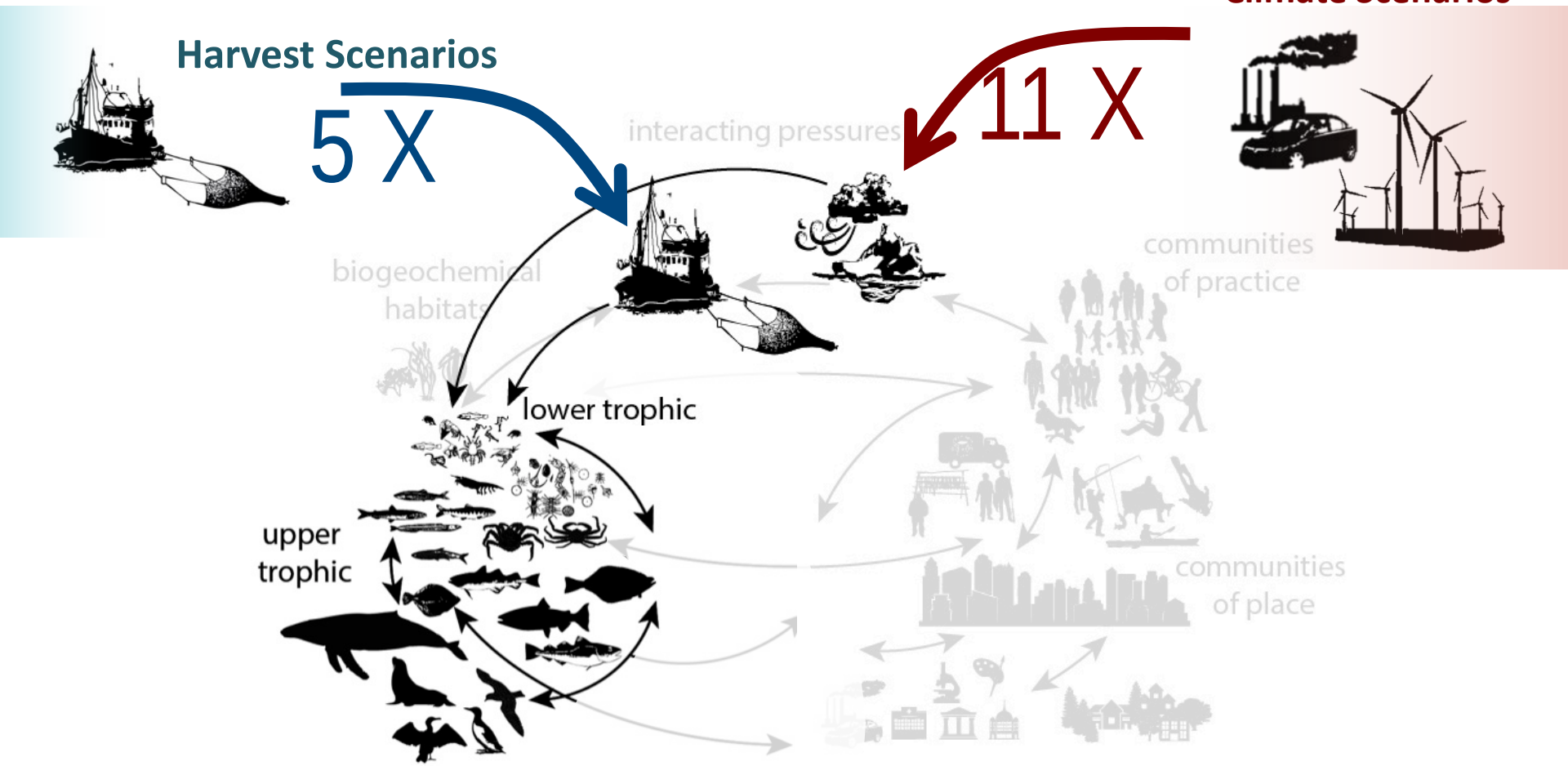

Climate-enhanced Ecosim Model

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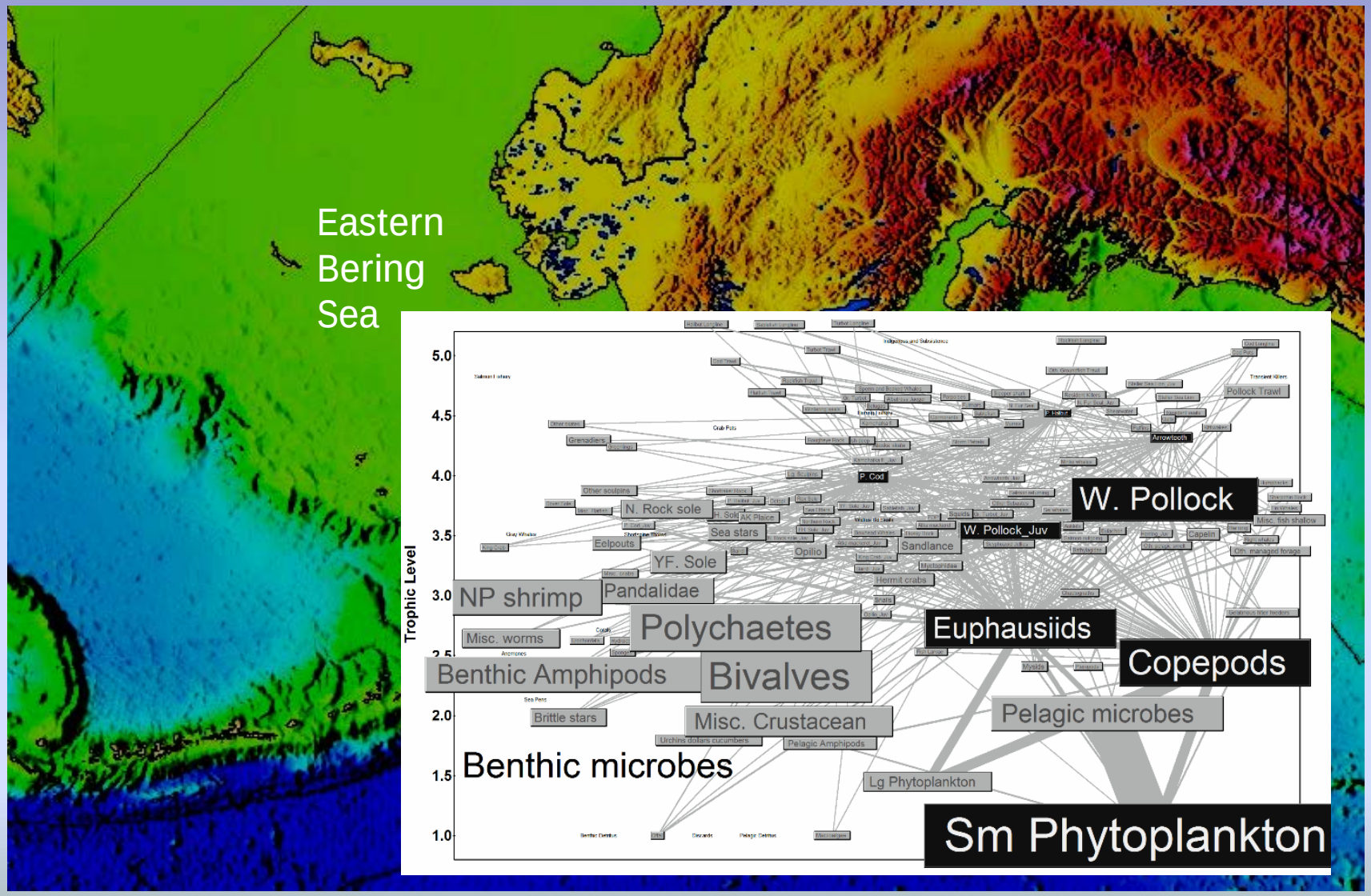
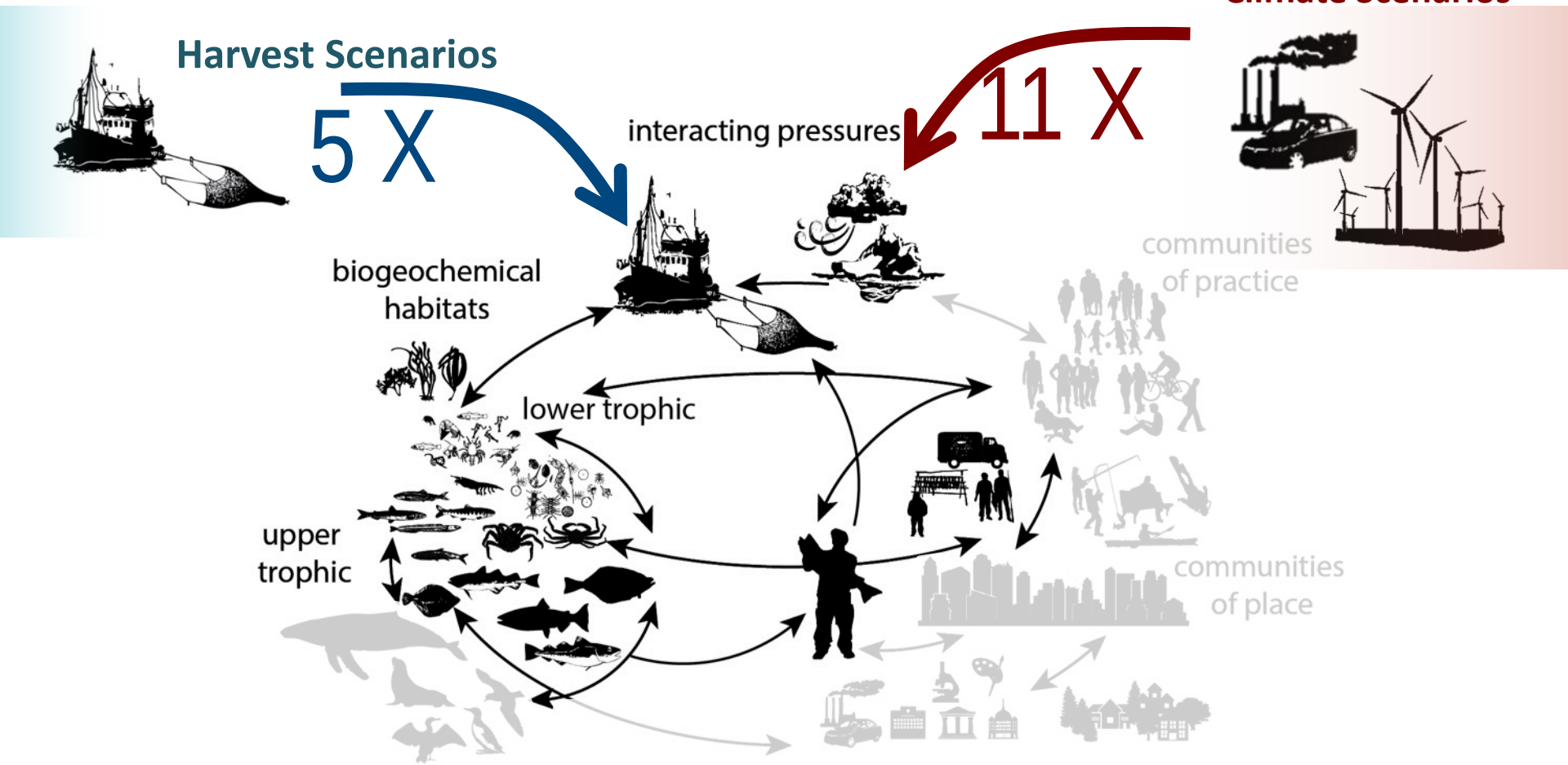
Ecopath food web model (Aydin et al. 2007)



Coupled Socio-Ecological System



FEAST End-to-End Model

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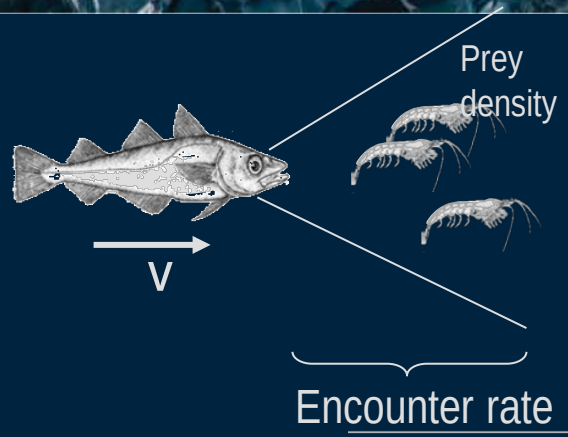
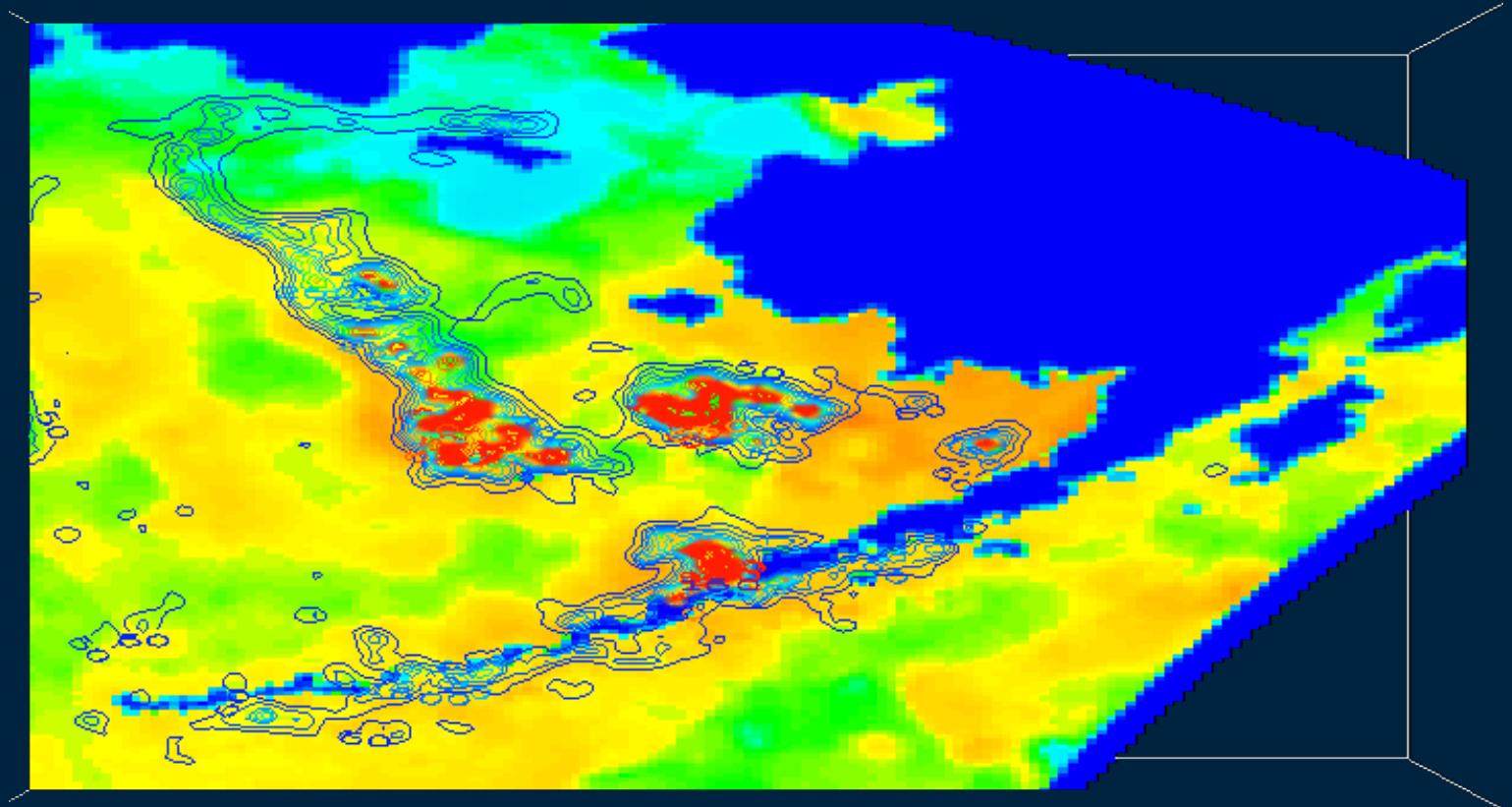


Modeled age 5 pollock biomass (colored contours) and 0-300m integrated euphausiid density (color field) for July, 2004.

FEAST

Ortiz et al. 2016



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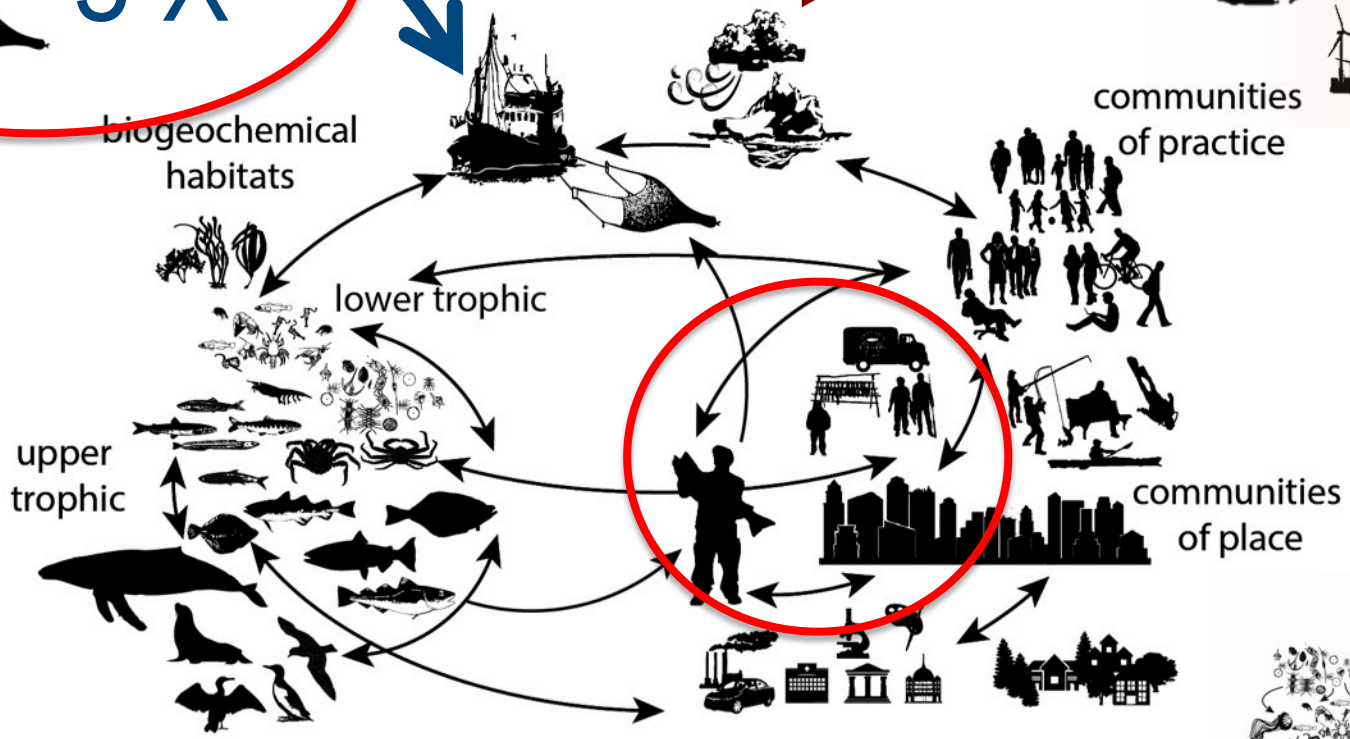
Coupled Socio-Ecological System

Future Climate Scenarios

Harvest Scenarios

5 X

11 X



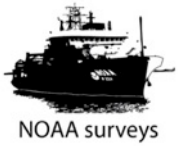
Climate-enhanced Biological Models

5 X

ACLIM: *Alaska Climate-change Integrated Modeling project*

Management Strategy Evaluations

Observation Error



NOAA surveys

Fishery data

Assessment Methods

CE-SSM
CEATTLE
Ecosim

Monitoring data

Assessment outcome

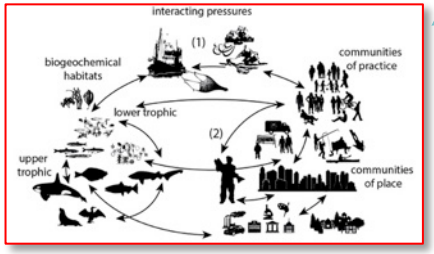
Operating Model

more complex than assessment method

Management Scenarios

e.g control rules

Fisheries Management



Effort by fleet and location

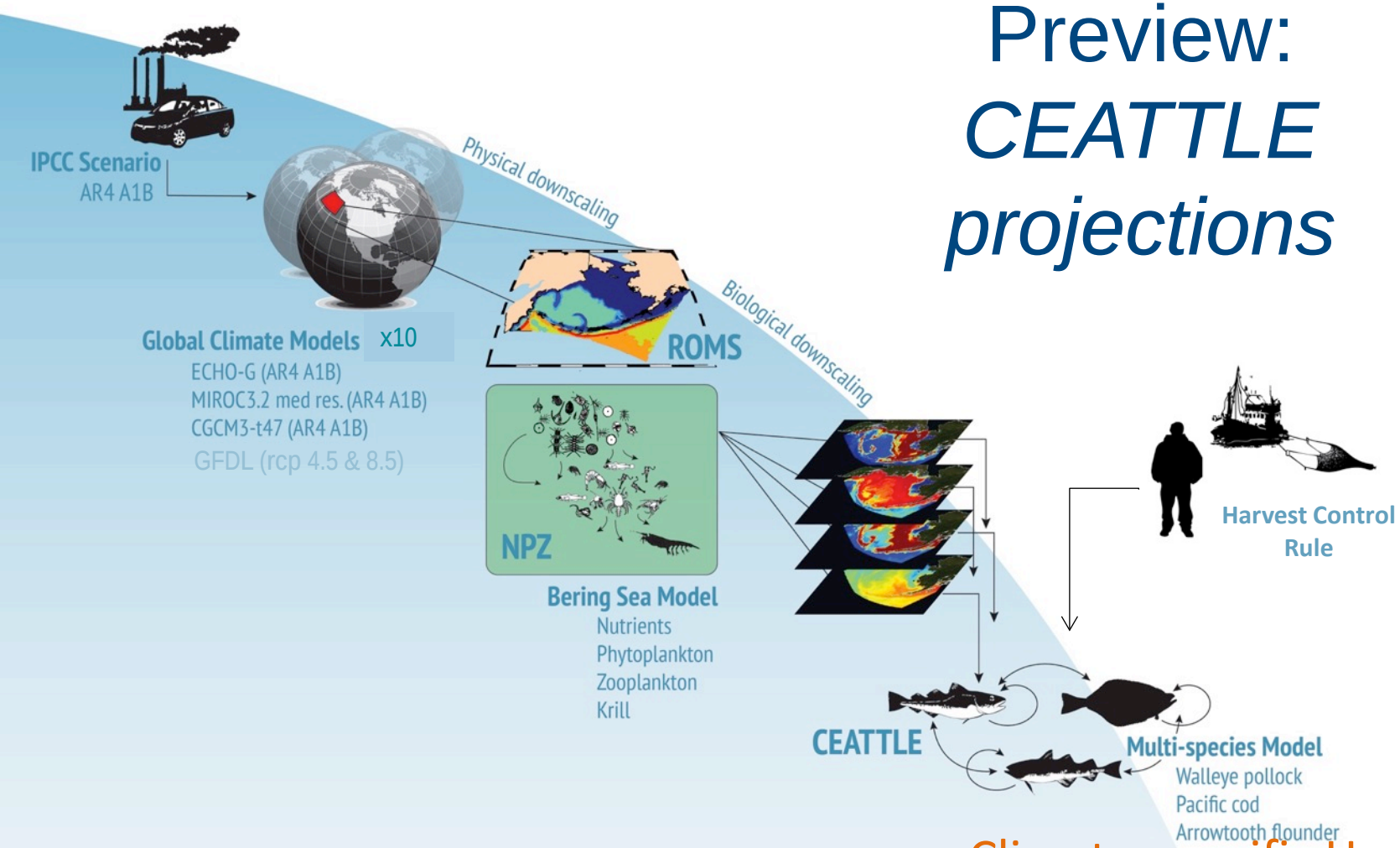
Management Regulations (OFL & ABC)

Socio-Economic Model

FEAST , CEATTLE, Ecosim
Size-spectrum Model

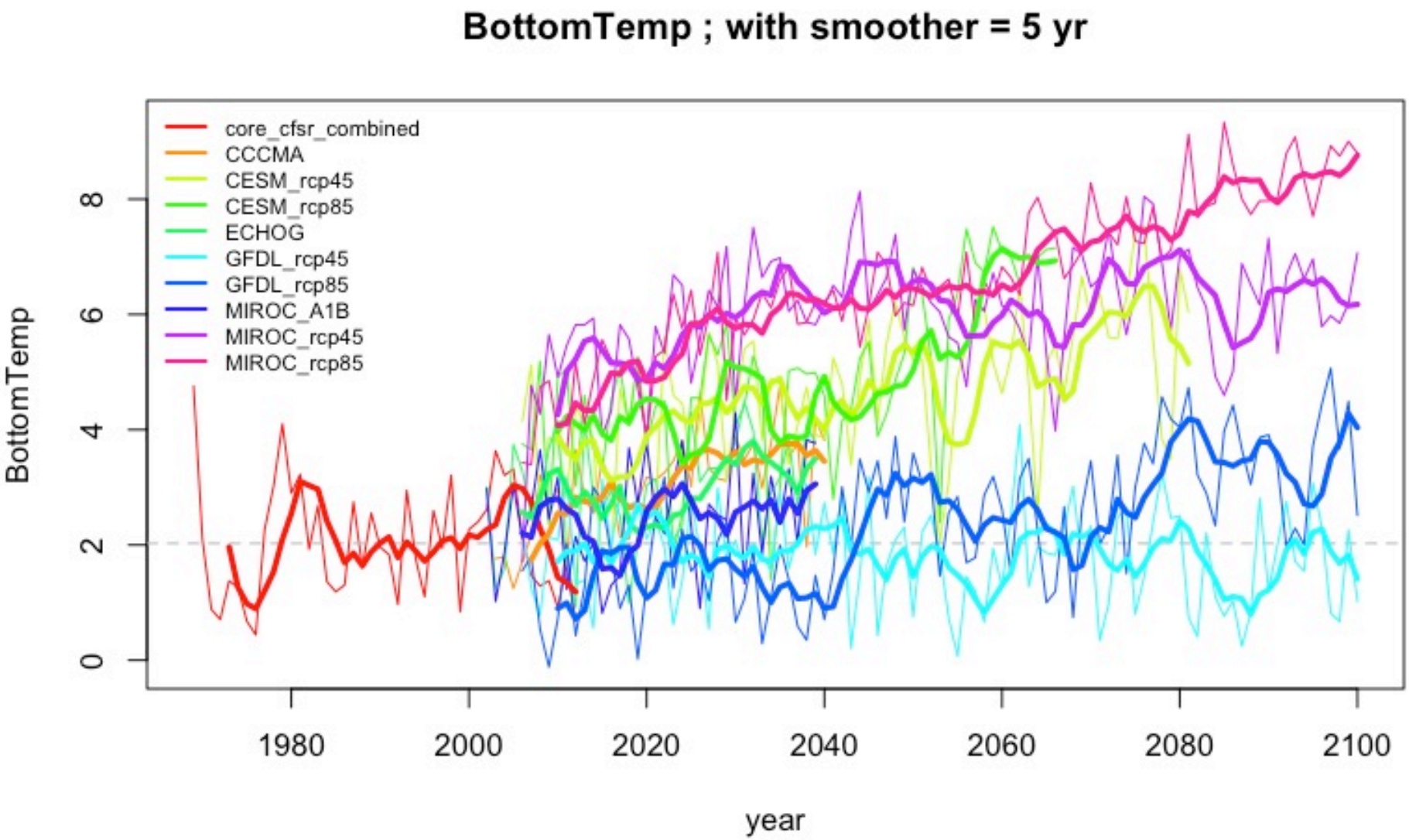
Process Error

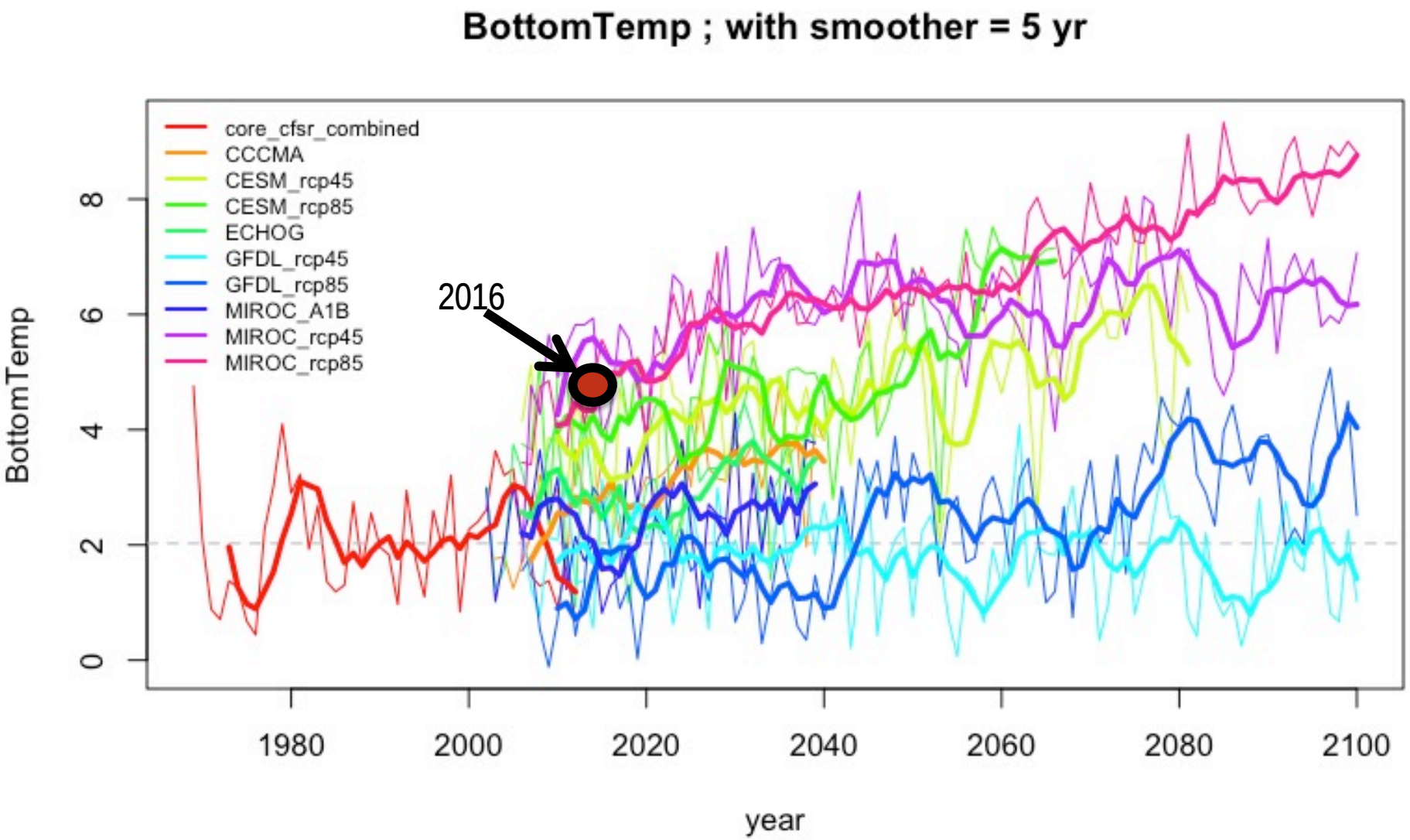
Preview: *CEATTLE projections*



Holsman et al. in prep

Climate-specific Harvest & Population Projections


BottomTemp ; with smoother = 5 yr
core_cfsr_combined
CCCMA
CESM_rcp45
CESM_rcp85
ECHOG
GFDL_rcp45
GFDL_rcp85
MIROC_A1B
MIROC_rcp45
MIROC_rcp85
BottomTemp
0
2
4
6
8
1980
2000
2020
2040
2060
2080
2100
year


BottomTemp ; with smoother = 5 yr
core_cfsr_combined
CCCMA
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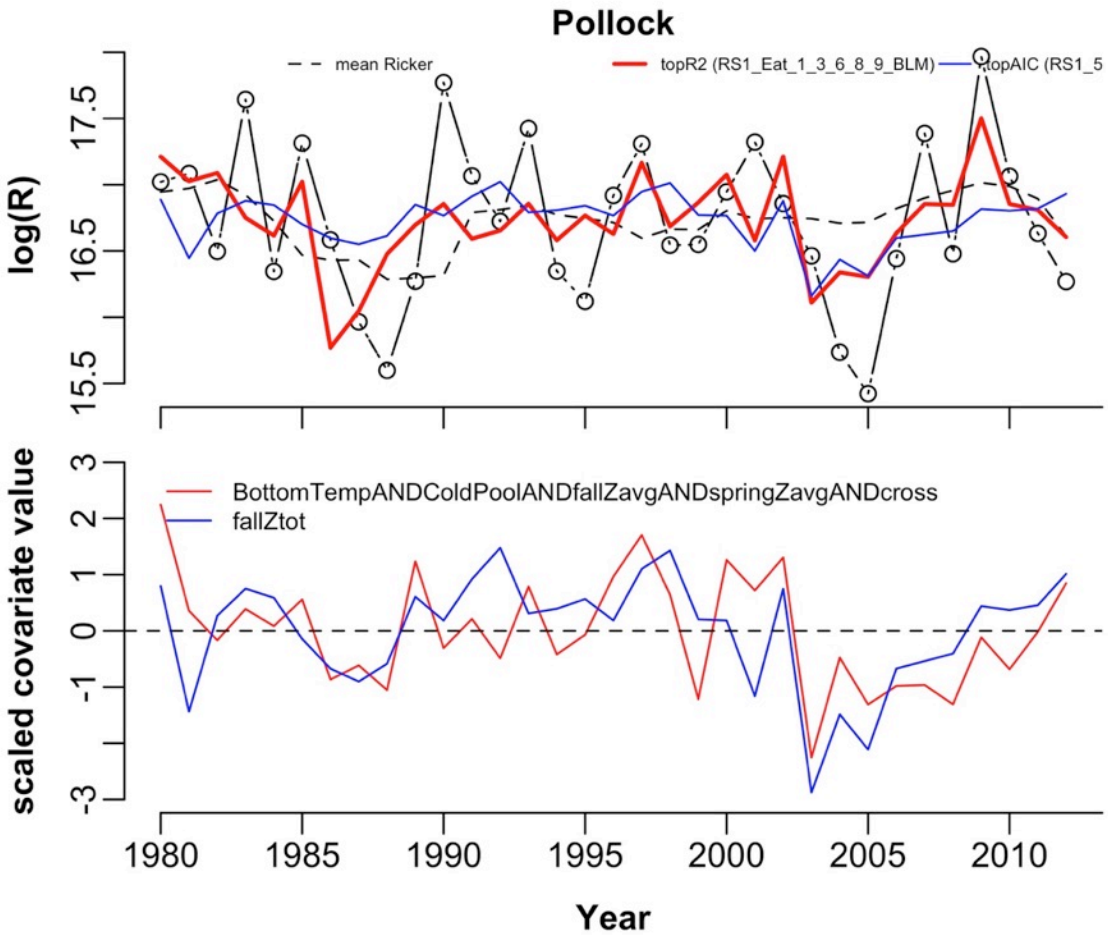
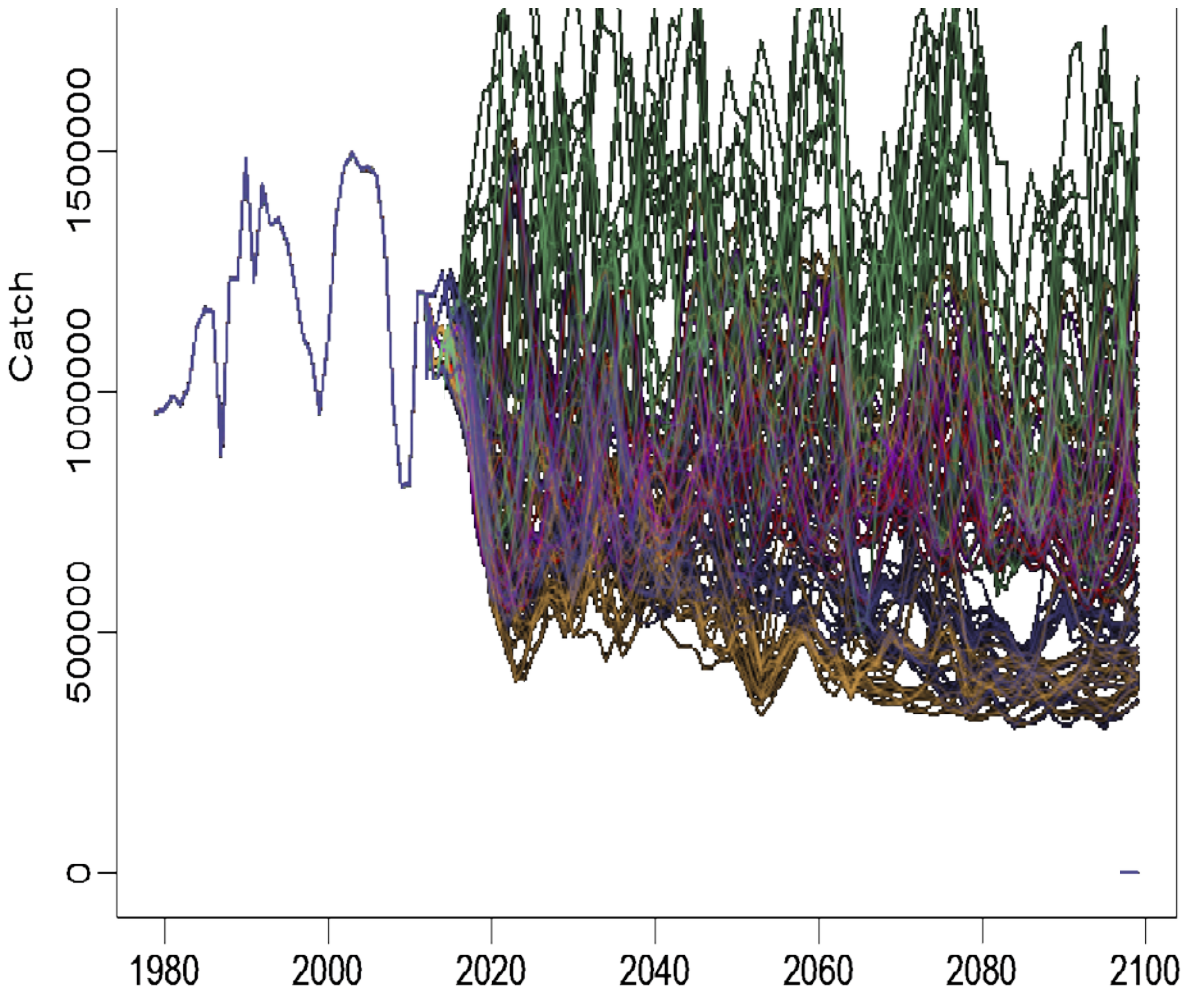
GFDL_rcp85
MIROC_A1B
MIROC_rcp45
MIROC_rcp85
2016
BottomTemp
0
2
4
6
8
1980
2000
2020
2040
2060
2080
2100
year

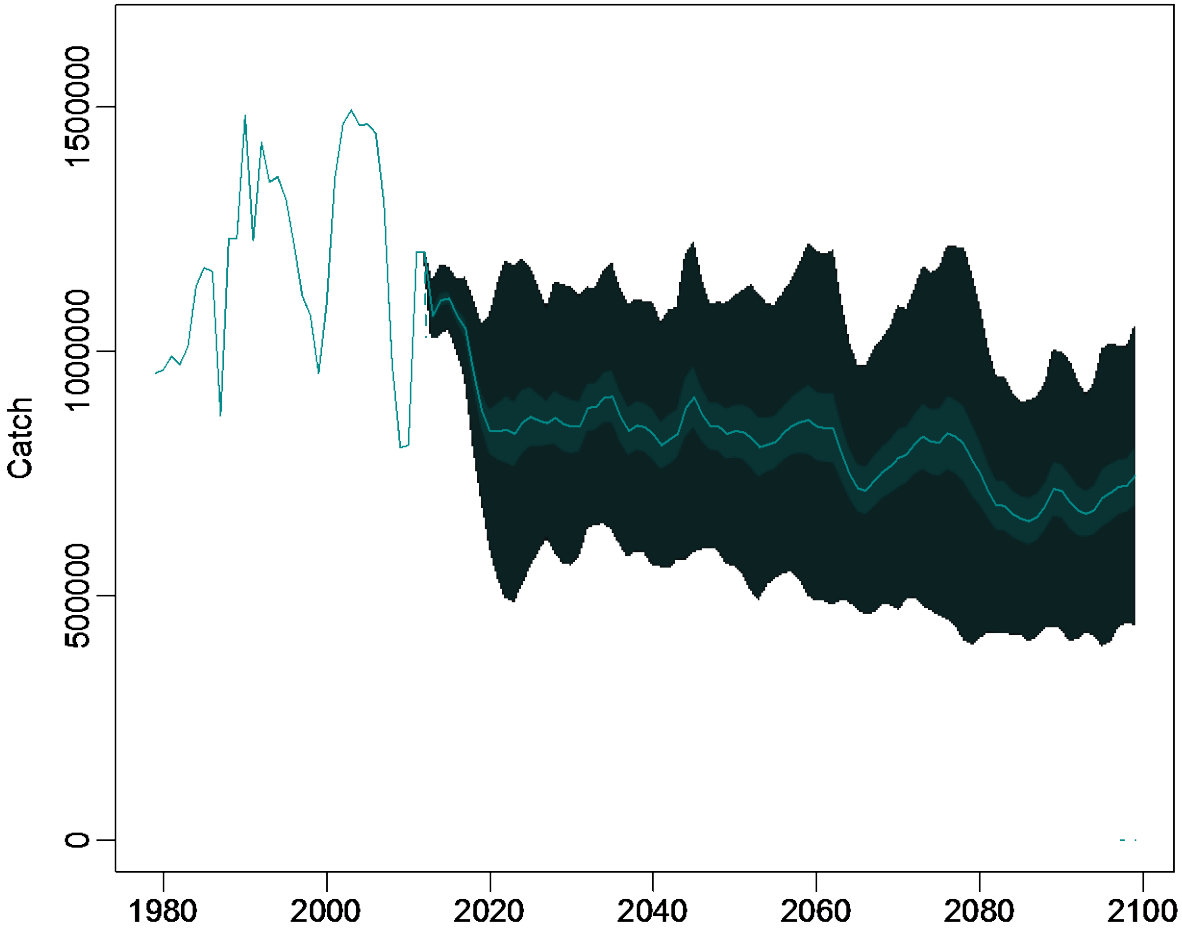
CEATTLE: Recruitment



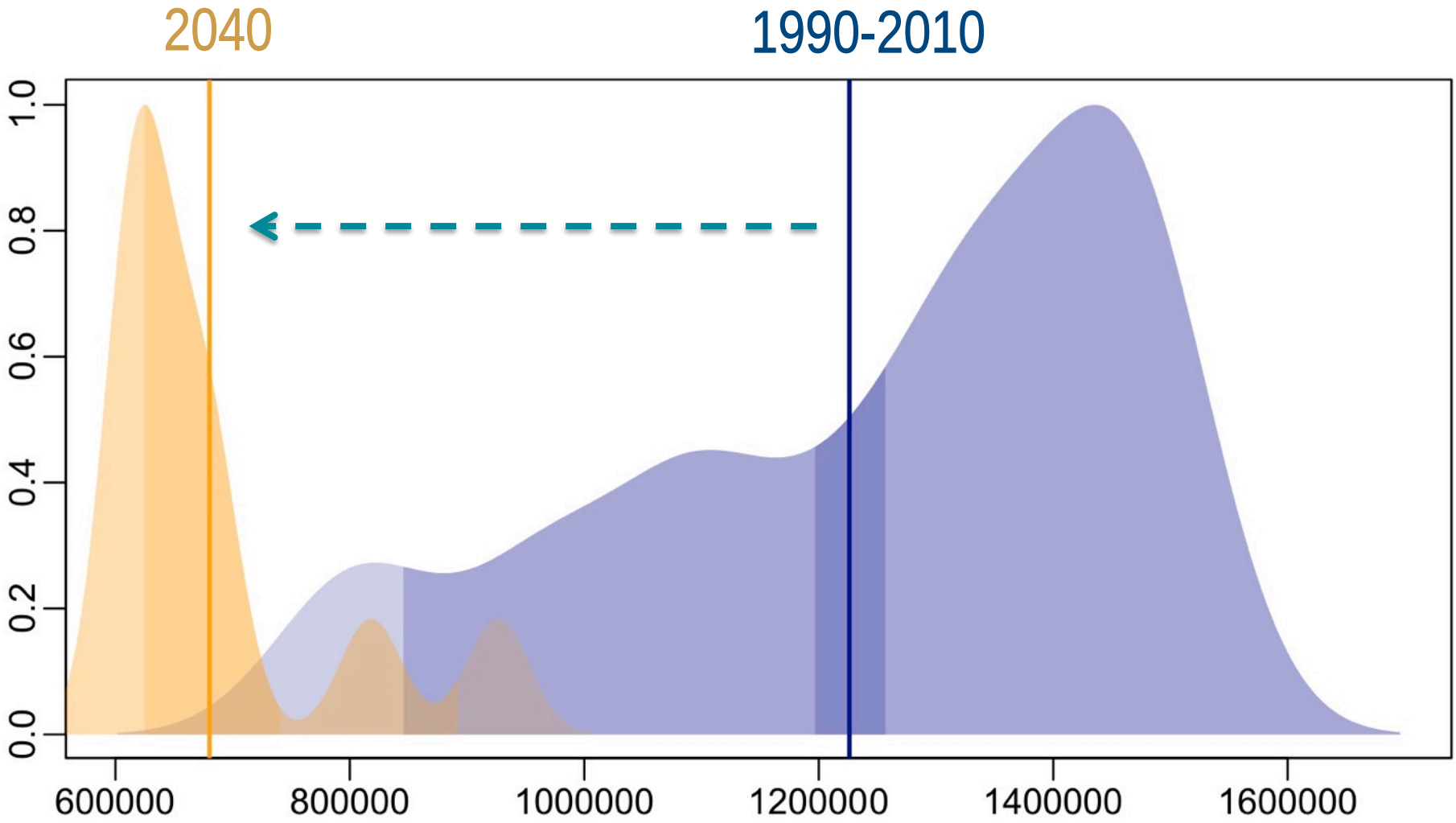
Catch under mean F



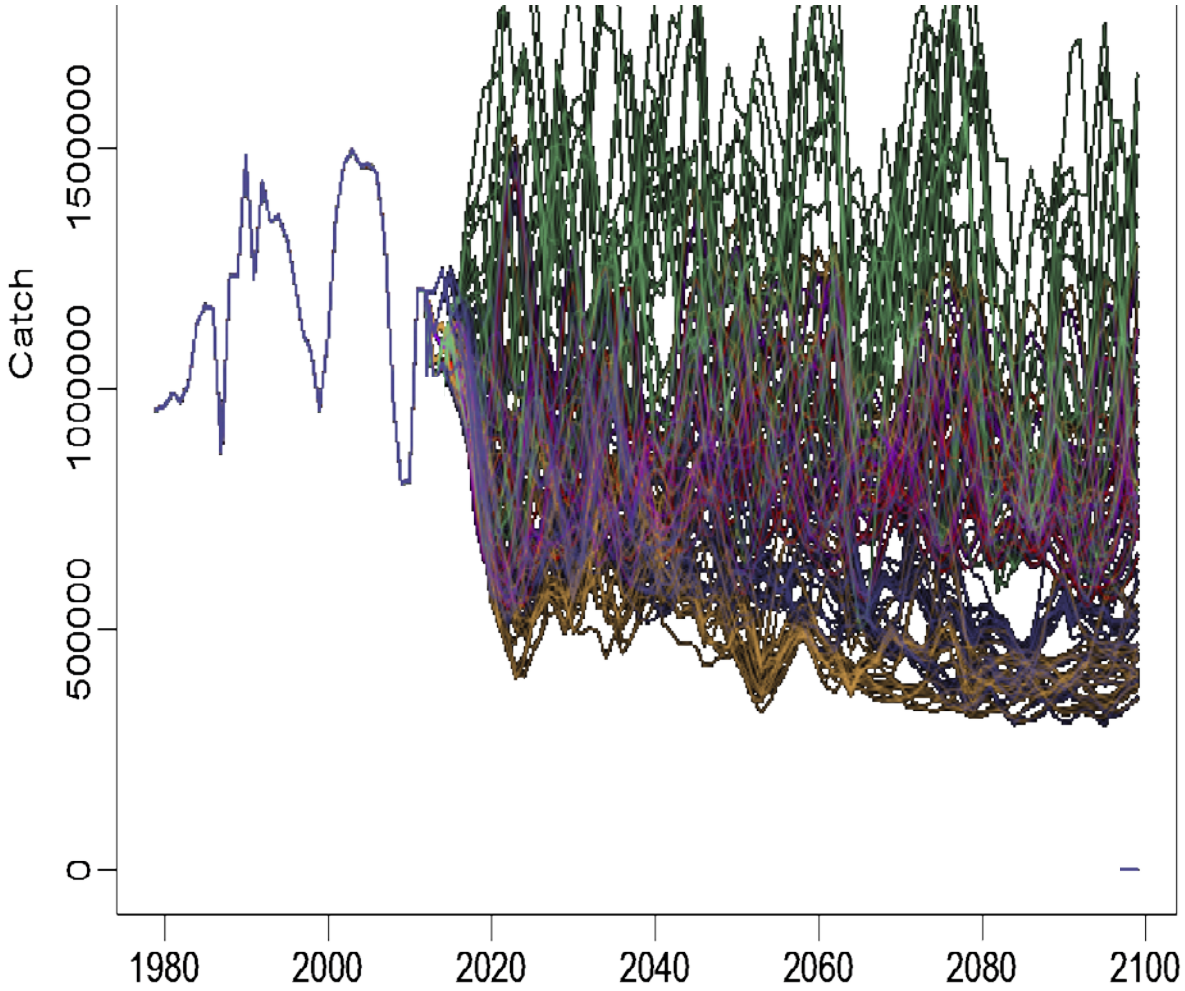
Catch under mean F



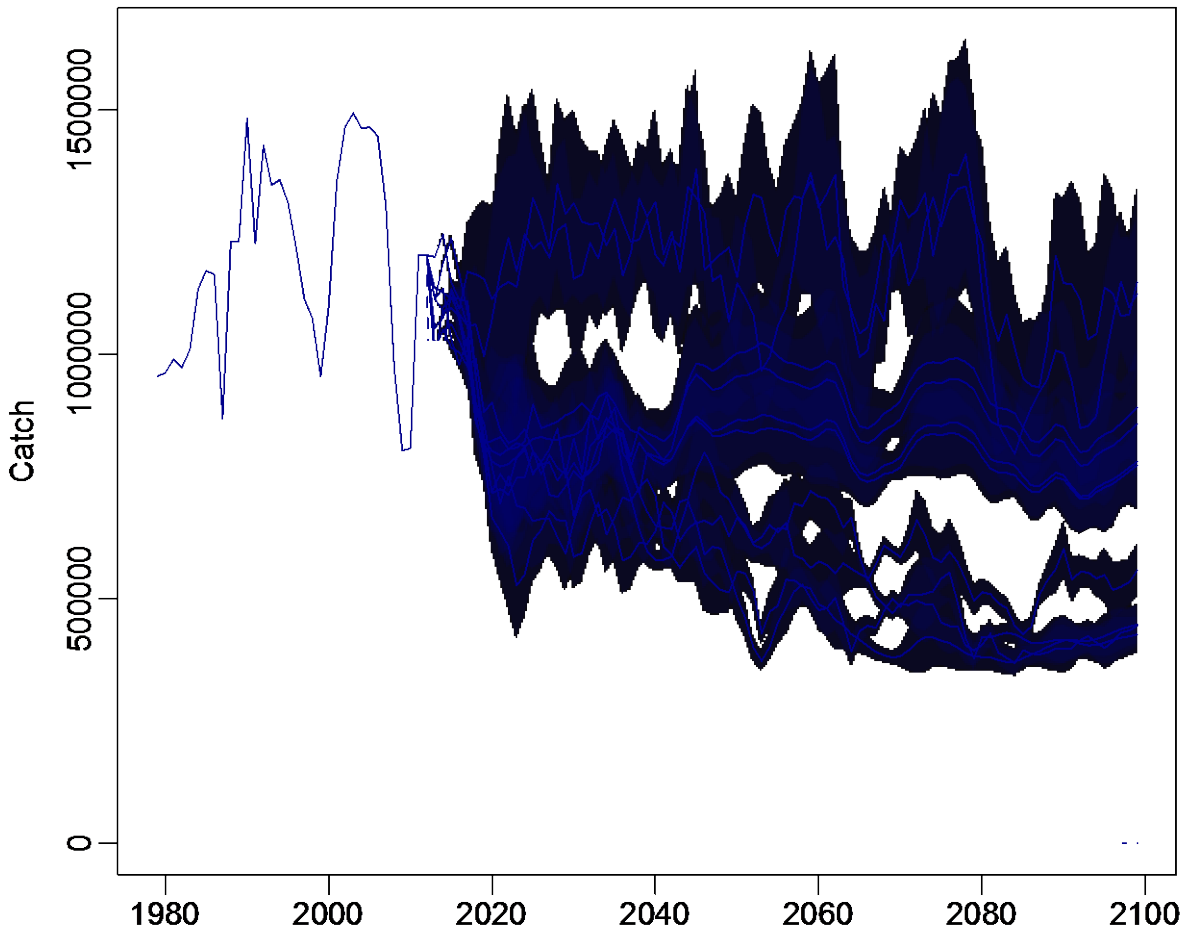
Catch under mean F



Catch under mean F

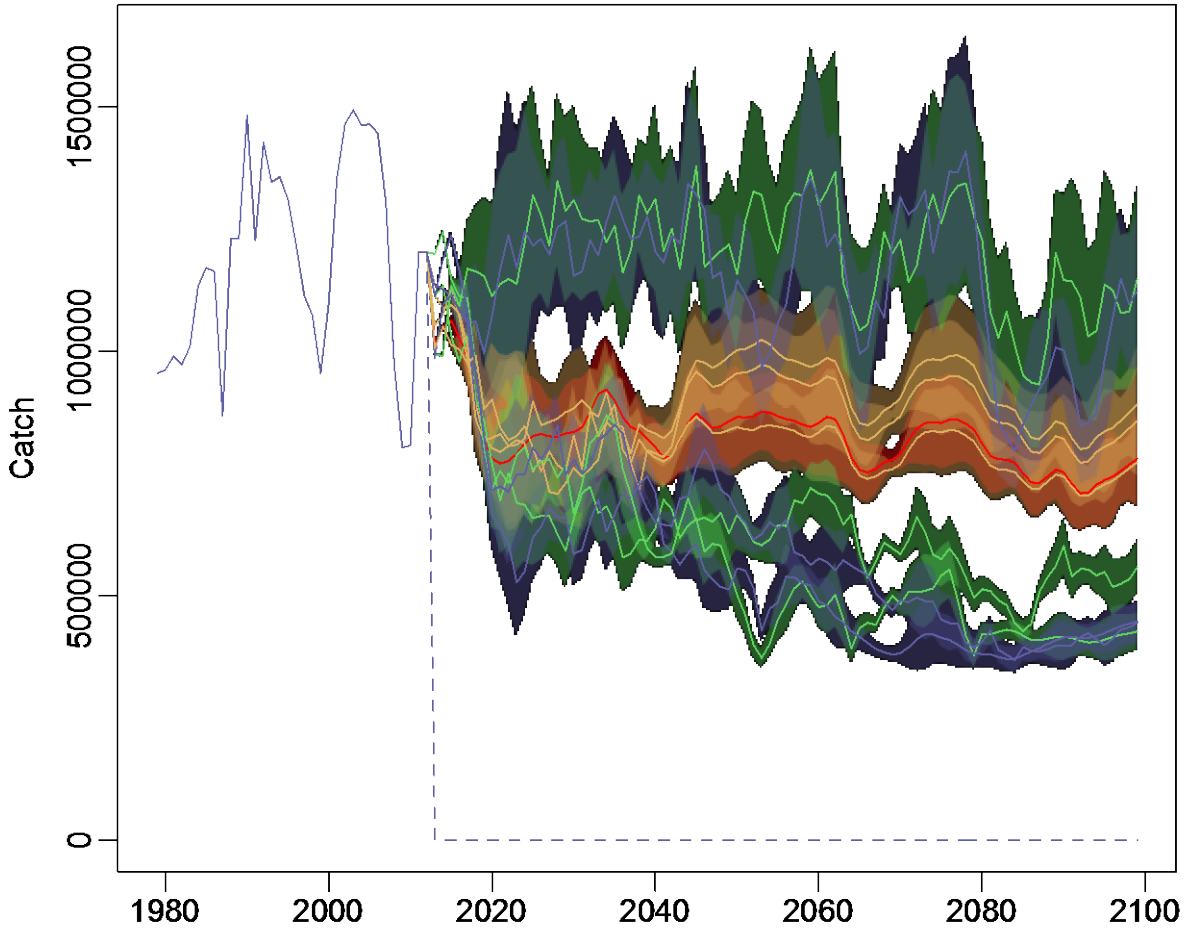


Catch under mean F



Catch under mean F

By climate scenario



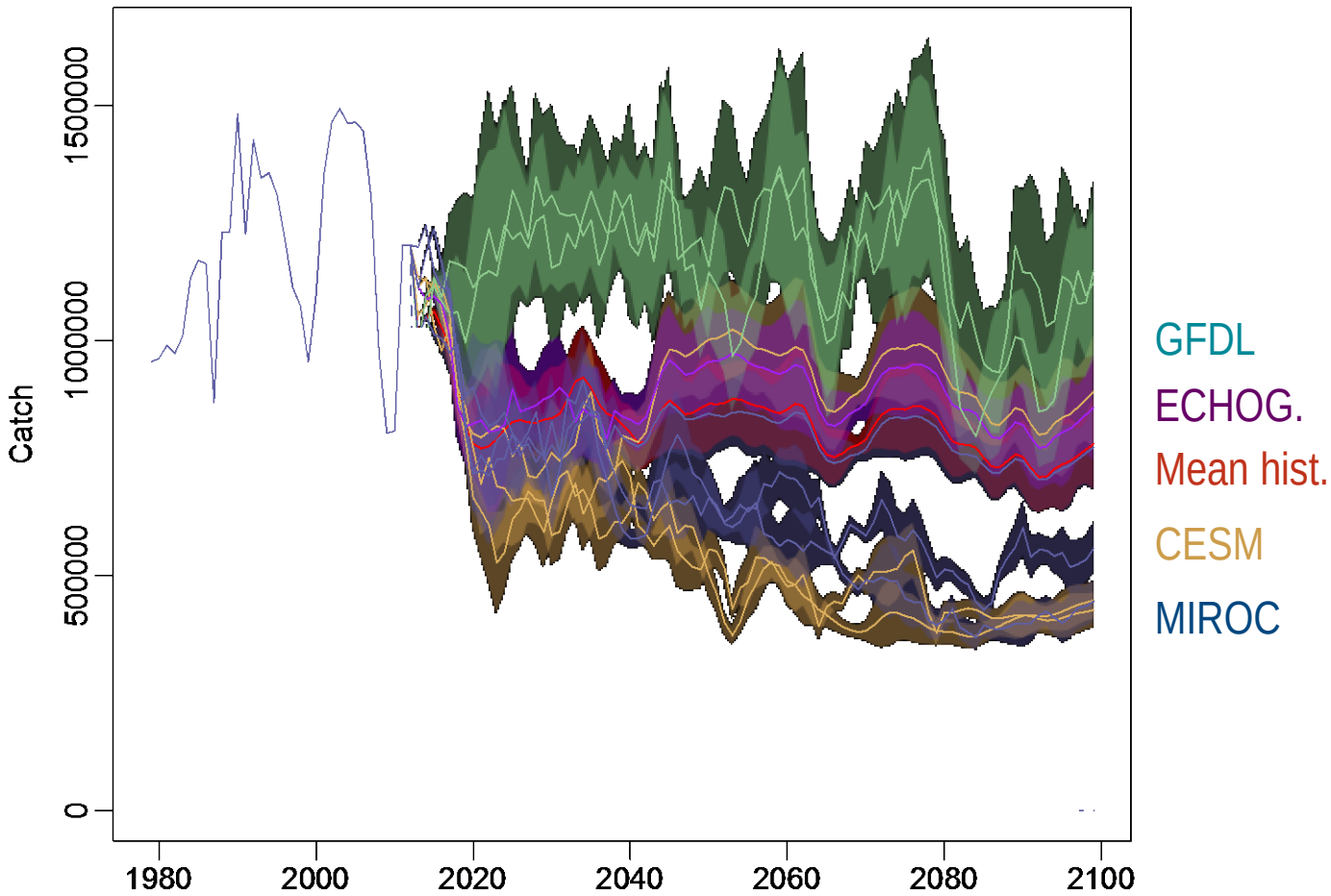
SRES A1B

Mean hist.

RCP 4.5

RCP 8.5

Catch under mean F



Socioeconomic elements (Alan Haynie)

Dr. Alan Haynie
Economist at
NMFS/AFSC/NOAA
alan.haynie@noaa.gov

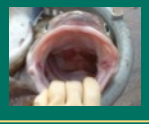
Photo: Mark Holsman

The Human Connection

NOAA FISHERIES

Bering Sea Integrated Ecosystem Study (BSIERP) and Bering Ecosystem Study (BEST)

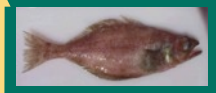
Humans



Humpback and fin whales

Commercial/subsistence fish: Pollock, cod, arrowtooth flounder

Kittiwakes and murres, fur seals, walrus



Forage species: Juvenile pollock, capelin, myctophids

NPZ: Ichthyoplankton, euphausiids, Copepods

Infauna: Bivalves, gastropods, polychaetes

Atmosphere/ocean

Climate Scenarios

Some great parts of the Bering Sea Project

- Parallel project approach
- Multiple exposure to research over a 5-year period
- Comparisons across trophic levels

Great parts of the Bering Sea Project

- Parallel project approach
- Multiple exposure to research over a 5-year period
- Comparisons across trophic levels
- The project created a large group of scientists with strong relationships and experience working with other disciplines.

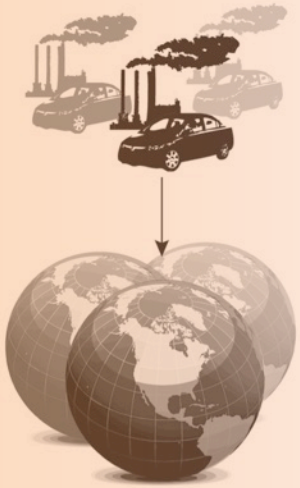
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Alaska CLIMate Project

Anne Hollowed (AFSC, SSMA/REFM)
Kirstin Holsman (AFSC, REEM/REFM)
Alan Haynie (AFSC ESSR/REFM)
Stephen Kasperski (AFSC ESSR/REFM)
Jim Ianelli (AFSC, SSMA/REFM)
Kerim Aydin (AFSC, REEM/REFM)
Trond Kristiansen (IMR, Norway)
Al Hermann (UW JISAO/PMEL)
Wei Cheng (UW JISAO/PMEL)
André Punt (UW SAFS)

FATE: Fisheries & the Environment
SAAM: Stock Assessment Analytical Methods
S&T: Climate Regimes & Ecosystem Productivity

Future Climate Scenarios



IPCC Scenarios (x3)

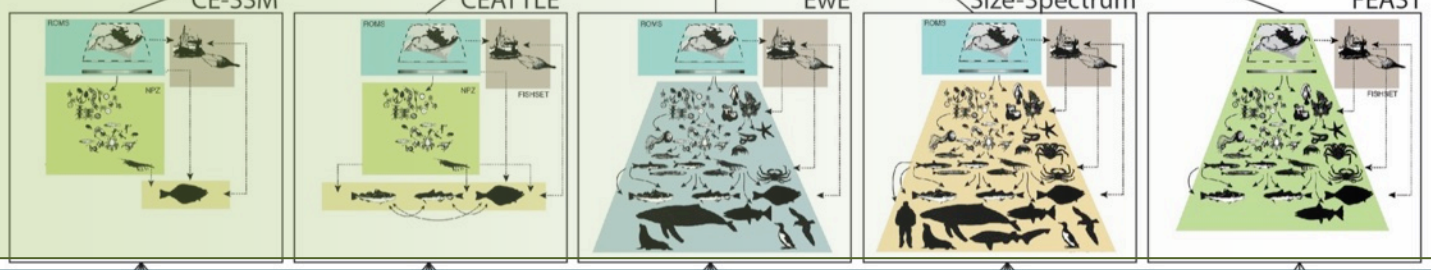
AR4 A1B
AR5 RCP6.0
AR5 RCP8.5

Global Climate Models (x 11)

ECHO-G (AR4 A1B)
MIROC3.2 med res. (AR4 A1B)
CGCM3-t47 (AR4 A1B)
CCSM4-NCAR- PO (AR5 RCP 6.0 & 8.5)
MIROCESM-C- PO (AR5 RCP 6.0 & 8.5)
GFDL-ESM2M*- PO (AR5 RCP 6.0 & 8.5)
GFDL-ESM2M*- PON (AR5 RCP 6.0 & 8.5)

Climate-enhanced Models

Bering Sea Models



Fishing Scenarios

By-catch, MSY, Status quo, MEY, No fishing — **Harvest Control Rules (x5)**

By-catch, MSY, Status quo, MEY, No fishing — **Harvest Control Rules (x5)**

By-catch, MSY, Status quo, MEY, No fishing — **Harvest Control Rules (x5)**

By-catch, MSY, Status quo, MEY, No fishing — **Harvest Control Rules (x5)**

Fleet dynamics, Status quo, No fishing — **Harvest Control Rules (x3)**

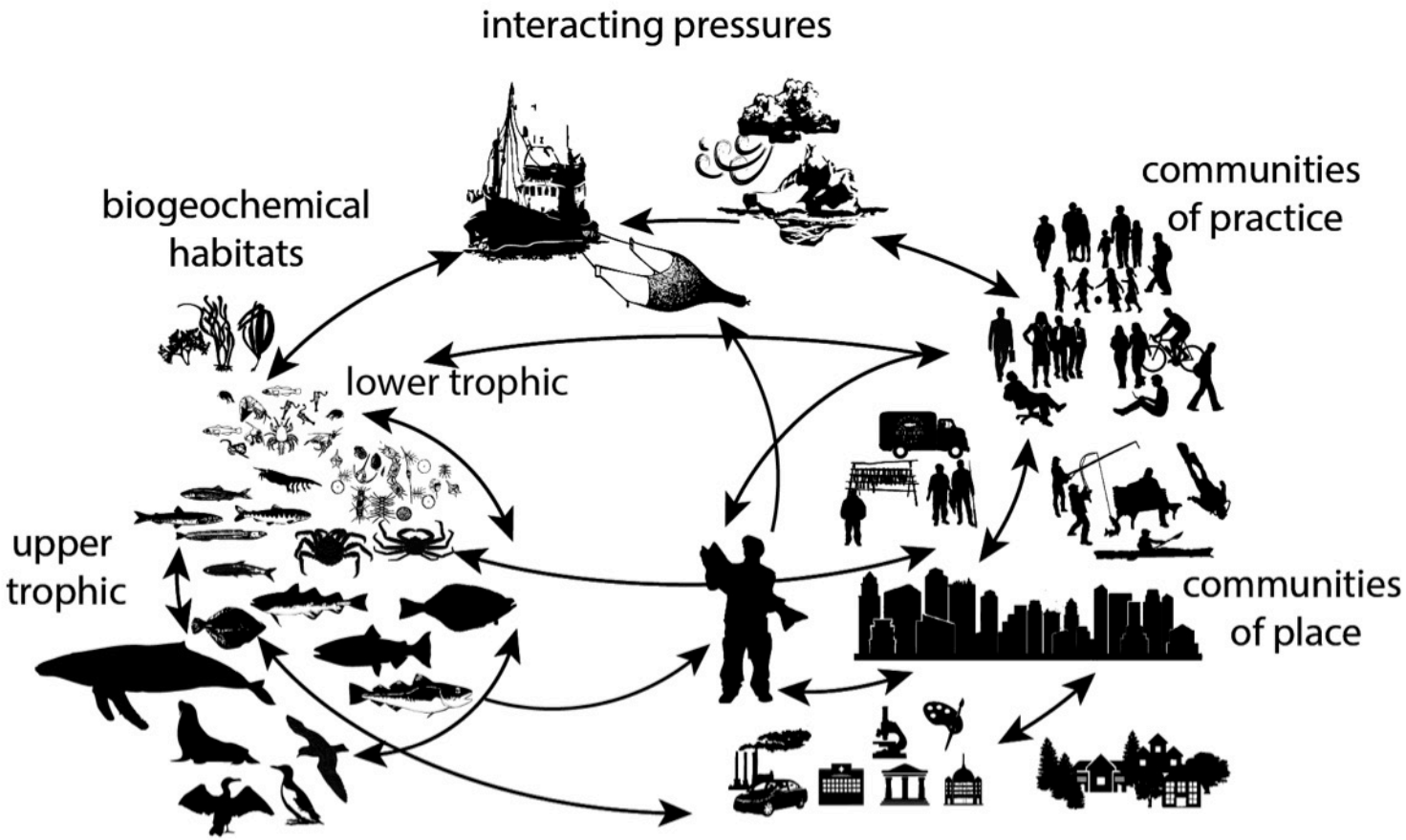
multiple non-linear pressures

multiple non-linear interacting pressures

- How do bottom-up vs. top-down models look different?

- We are approaching the research questions in ACLIM from all directions.

ACLIM utilizes a fully integrated approach



ACLIM: *Alaska Climate-change Integrated Modeling project*

Integration is Hard!

Integration Challenges (among many!)

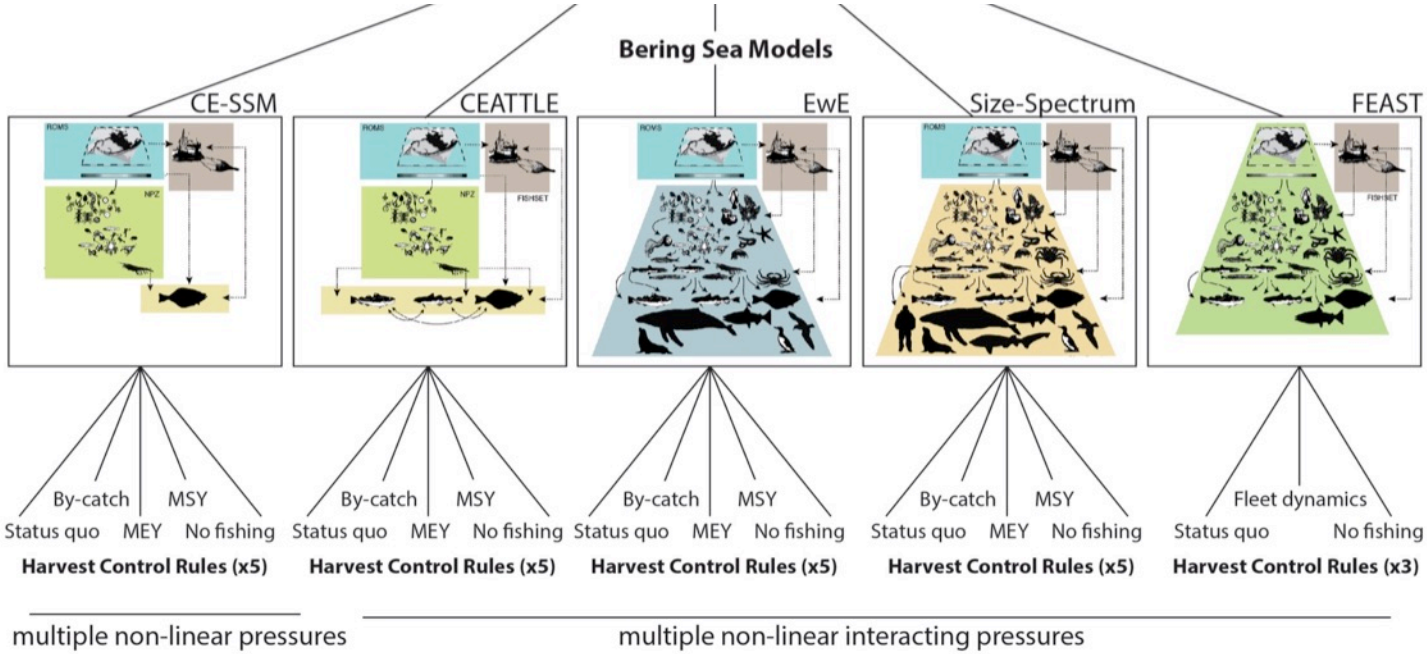
- Model timing - everyone wants their models to be functioning well before integration
- Large integrated models are computationally expensive – you spend time waiting
- It takes time to talk and listen to each other

Don’t Wait

To Integrate !!

Key ACLIM Integration Elements

- Multiple economists involved
- Many integrated collaborations & constant contacts
- Connect now – perfect later!
- Lots of joint scientific meeting participation
- Workshop on economic model integration held recently at AFSC
- Strong existing AFSC & BSIERP relationships.



ACLIM utilizes economic models of different complexity

- Effort response to abundance
- Maximum economic yield (MEY)
- Bycatch-constrained optimizations
- Spatial models of fleets

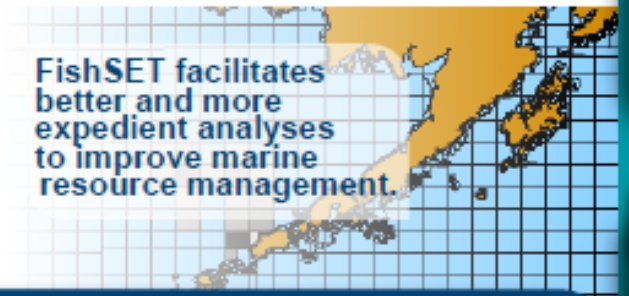
FishSET
Spatial Economics Toolbox for Fisheries

FishSET's goal is to enable NOAA Fisheries economists and social scientists to better inform policy decisions by predicting how a variety of factors might influence fisher behavior.

Many modeling challenges exist. While predictive models are valuable tools for sustainable fisheries management and conservation, challenges to their development include preparing, integrating & updating many data sources, choosing appropriate models, and interpreting results.

FishSET provides:

1. **Superior data organization, analysis, and integration** for spatial models.
2. **Best management practices** for data, modeling, and model comparison.
3. **Many models in a single toolbox** for ease of model comparision and use. Combines several fisheries economics modeling approaches in one toolbox.



FishSET facilitates better and more expedient analyses to improve marine resource management.

To learn more, visit:
www.st.nmfs.noaa.gov/humandimensions/fishset/index

What tools are in the FishSET toolbox?

Data Tools

Data Management & Integration Tool
Facilitates the development and integration of datasets for spatial modeling

Monte Carlo Tool
Simulates real fisheries data while preserving confidentiality, allowing better model testing and comparison.

Data Analysis & Mapping Tool
Enables graphical and geographic data viewing and prepares data for spatial modeling

Model Tools

Model Design & Selection Tool
Enables modeling of different combinations of variables and models

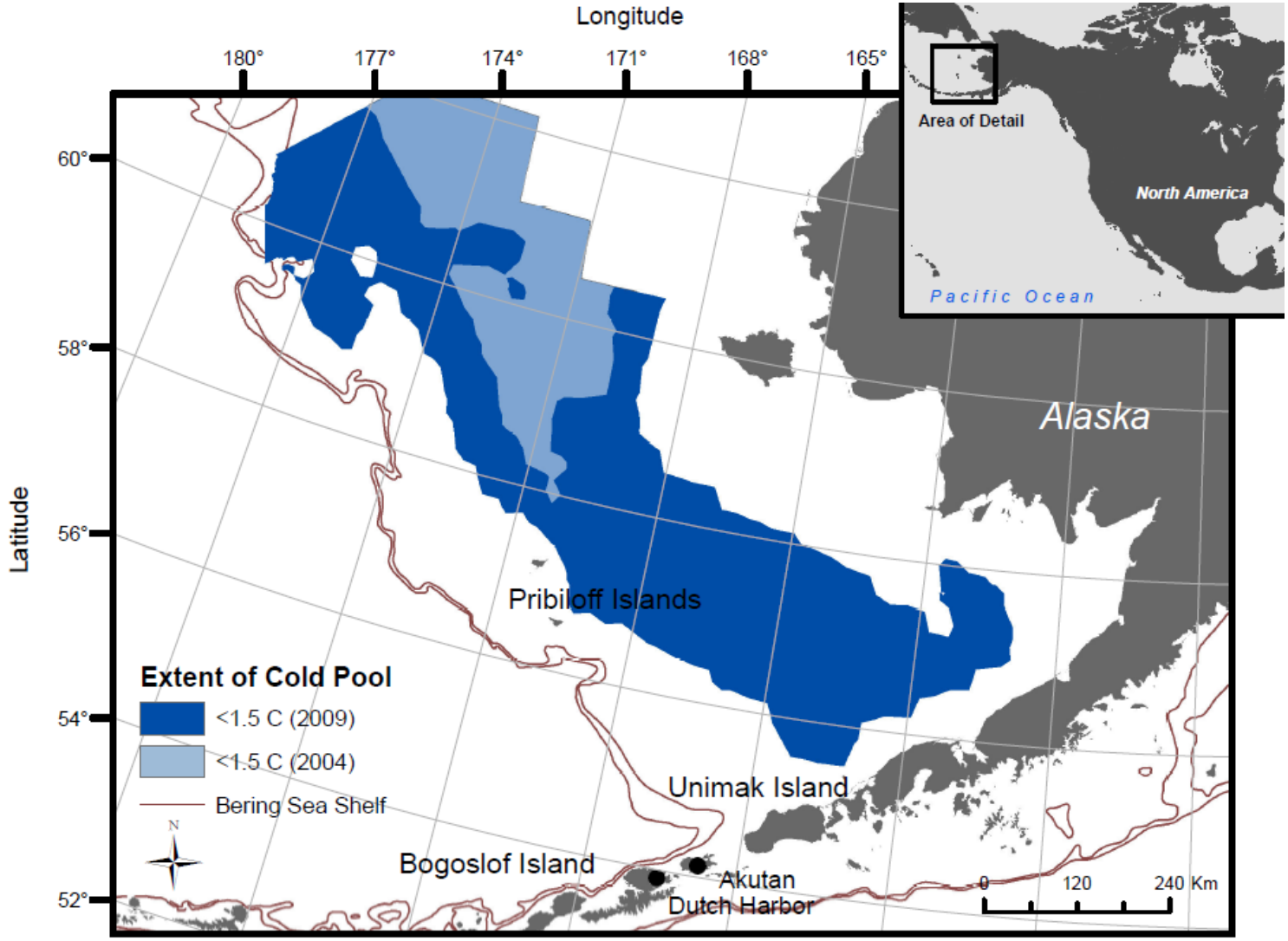
Modeling Tool
Runs standard, cutting-edge, and user-designed models

Model Comparison & Reporting Tool
Provides an extensive comparison of model performance and summarizes data, models, and results

Policy Tools

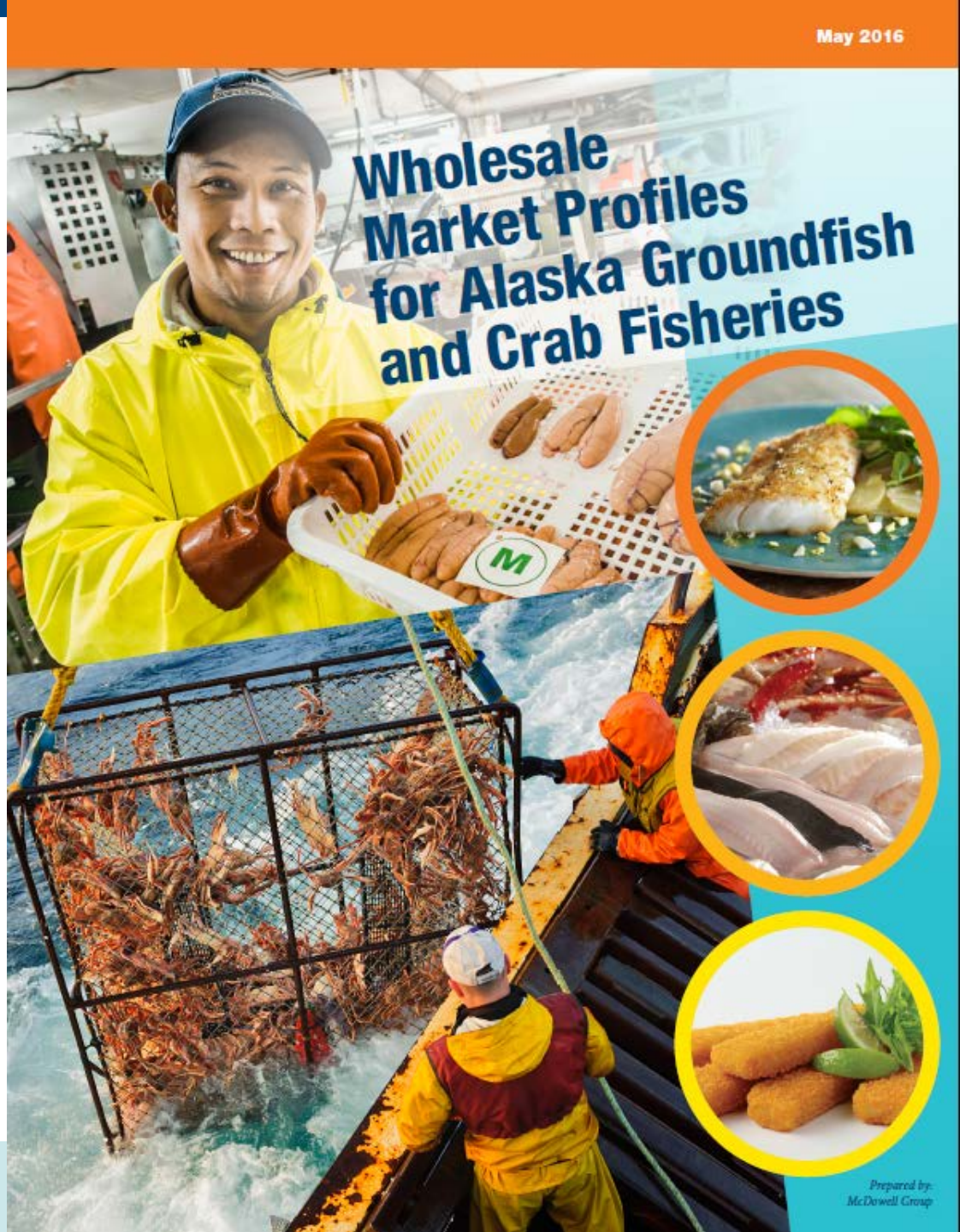
Policy Simulation Tool
Predicts location choices and estimates policy impacts

Water temperature has a big impact on where fishing occurs



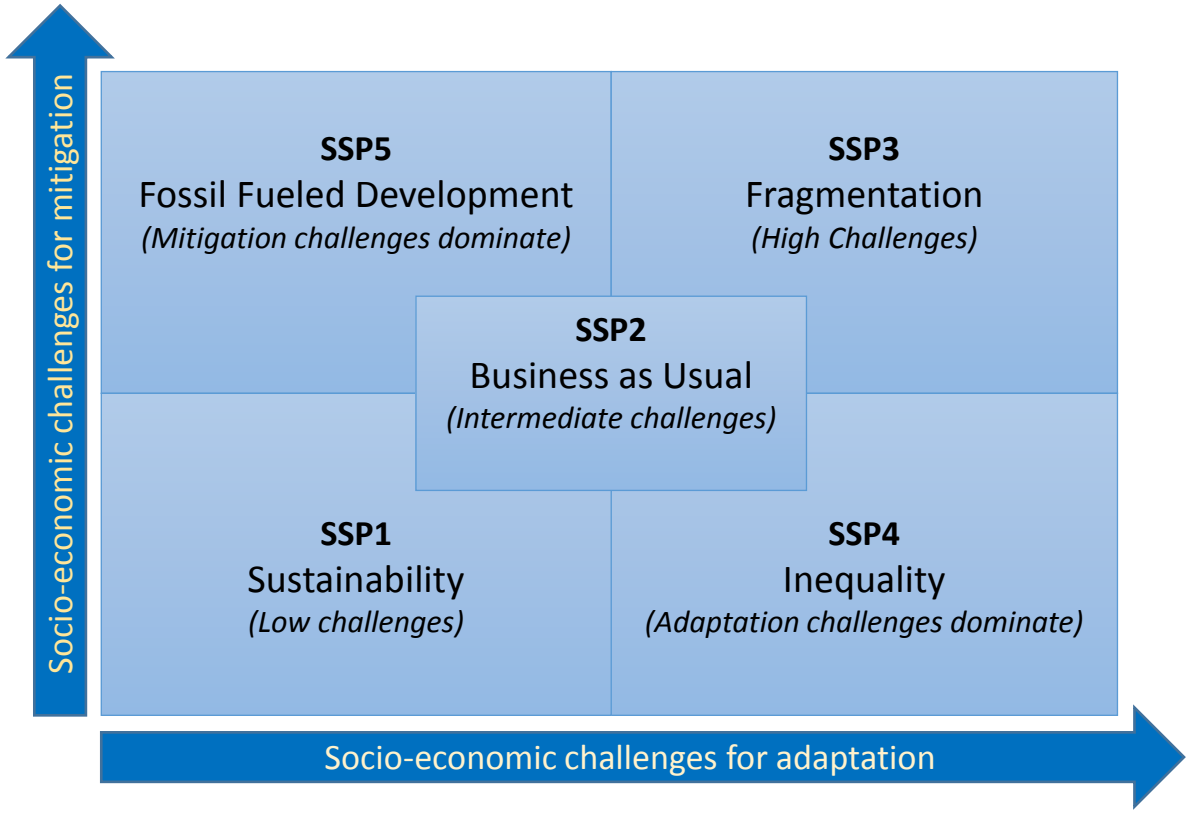
Haynie & Pfeiffer *CJFAS* 2013

Markets may change dramatically with a changing climate

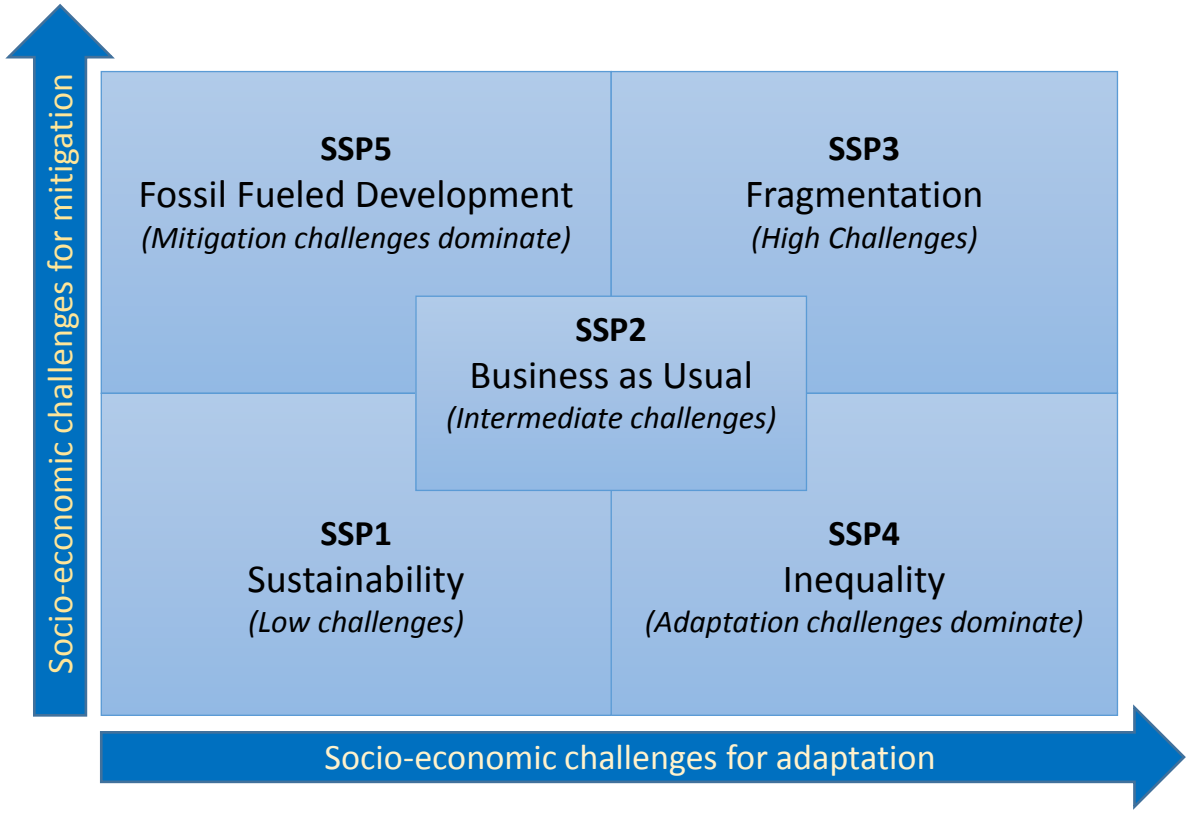


NOAA FISHERIES

ACLIM Socio-Economic Scenarios are being developed based on IPCC Shared Socio-Economic Pathways (SSPs)



ACLIM Socio-Economic Scenarios are being developed based on IPCC Shared Socio-Economic Pathways (SSPs)



What features of these scenarios are most important for North Pacific fisheries management?

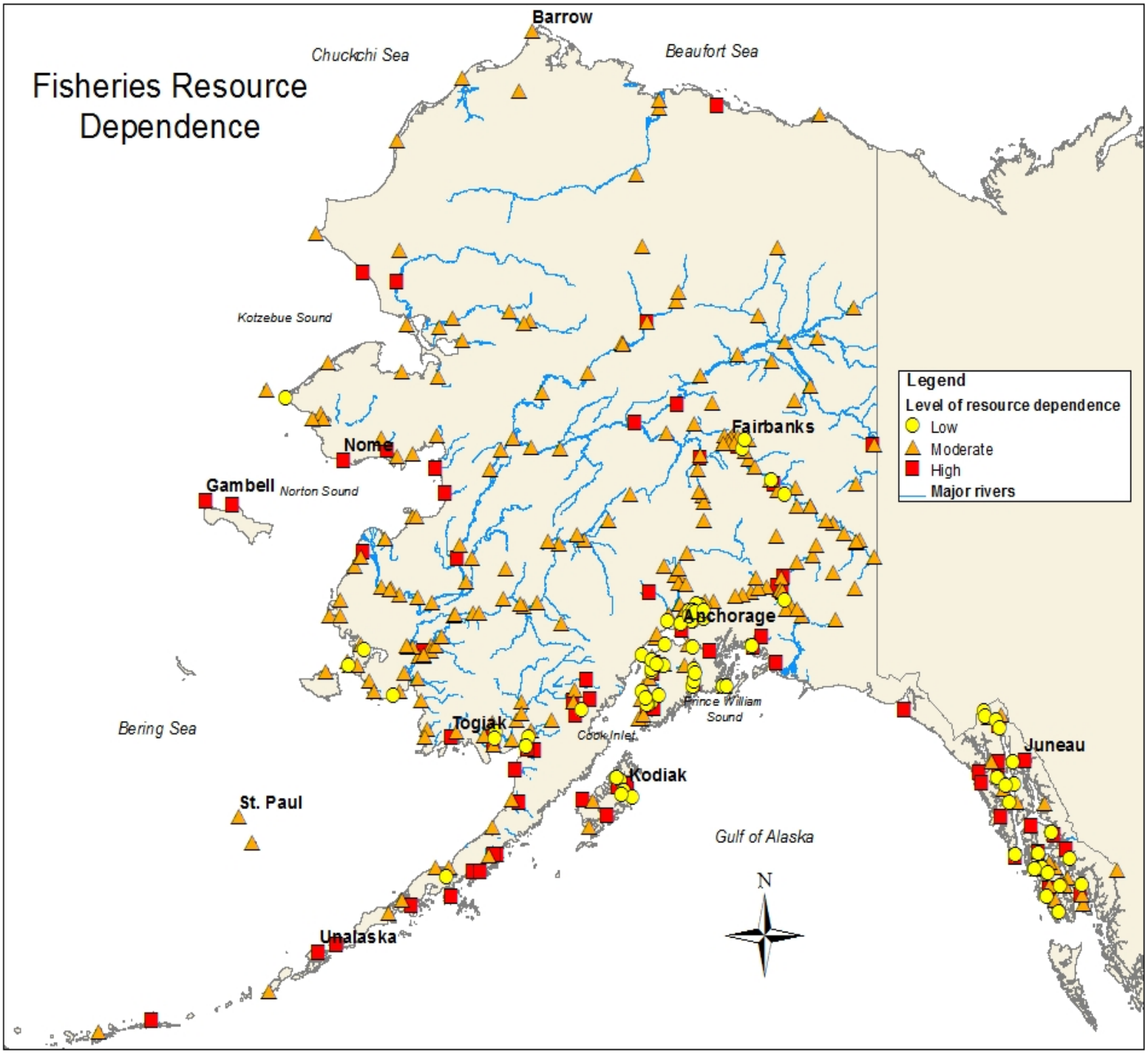
ACLIM Socio-Economic Scenario Elements

- Fish prices increase
- Changes in relative prices
  - Relative change in “premium” vs “protein” fish
- Fishing costs change
  - Increased fuel costs vs. improved technology
- Changes in conservation priorities
  - Change in demand or strength of conservation measures
  - Change in “weak stock” protections
- Changes in priorities/ nature of fishing communities.

Under what conditions are our management tools resilient to changing climate under different socioeconomic scenarios?

- Policies can and will evolve dynamically to adapt to changing environmental, biological, & economic conditions

- Many tools available: catch shares, dynamic area closures, bycatch incentives, community-based quotas, revised harvest control rules, etc.


Fisheries Resource Dependence
Barrow
Chuckchi Sea
Beaufort Sea
Kotzebue Sound
Nome
Gambell
Norton Sound
Fairbanks
Anchorage
Prince William Sound
Cook Inlet
Togiak
Bering Sea
Kodiak
Juneau
St. Paul
Gulf of Alaska
Unalaska
N
Legend
Level of resource dependence
Low
Moderate
High
Major rivers

Stakeholder involvement is central to our climate research approach

- Bering Sea Project - interviews and communication with stakeholders
- Long-term conversations with fishers and others
- Community surveys, workshops, and ongoing collaborations
- Regular model discussions and ecosystem assessments at the Plan Team and Council emphasize climate change.
- Industry, stakeholder, and scientific outreach.

Wrap up
(Anne Hollowed)

Dr. Anne Hollowed
Supervisory fishery biologist at AFSC/NOAA
anne.hollowed@noaa.gov

Photo: Mark Holsman

Challenges

- GCM and scenario selection
- Computing capacity limitations
- Data-sharing/Translating model outputs & inputs
- Models based on current ecological understanding
- Evolution of models to incorporate nascent science

Successes

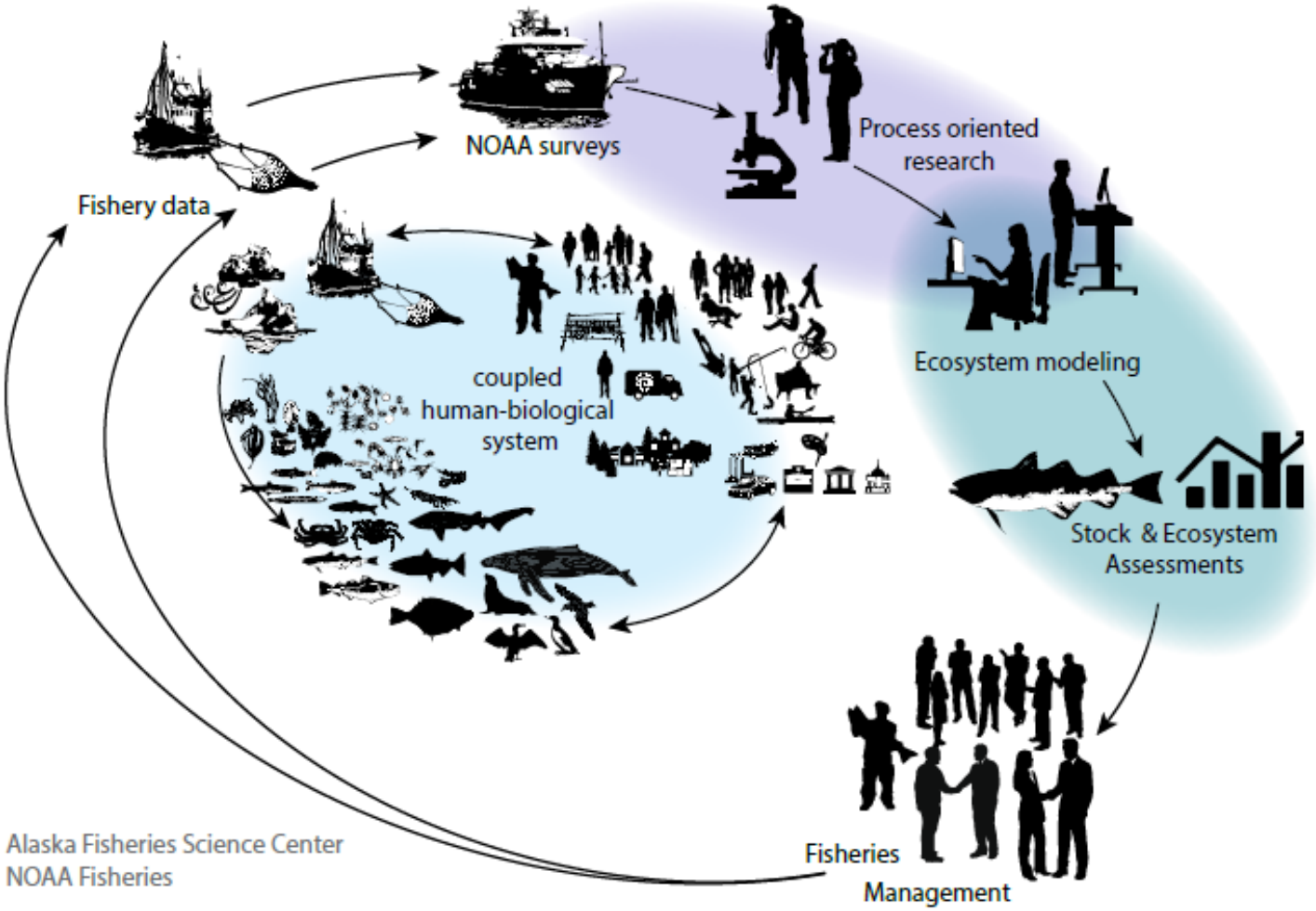
- Strong integrated research program at AFSC
- Right mix of people and tools
- Engagement with Council & stakeholders is iterative
- Long-term analyses can inform short-term forecasts

Closing Remarks

- Integrated modeling teams seeking to quantify implications of different climate and management scenarios.
- Addresses multiple sources of uncertainty
- Projections vary considerably between GCMs
- Phase II: RTAP proposal to rapidly uptake AR6 model results to align IPCC WG 1 & 2
- Coordinated research teams within NMFS SCs and internationally through ICES & PICES - SICCME.

Photo: Mark Holsman

Integrated Research Teams



Alaska Fisheries Science Center
NOAA Fisheries

Thanks!

Photo: Mark Holsman

ACLIM Team

"Behind these numbers lies, of course, an infinity of movements and of destinies."

– von Bertalanffy 1938

…and of people!

FATE: Fisheries & the Environment
SAAM: Stock Assessment Analytical Methods
S&T: Climate Regimes & Ecosystem Productivity
NPRB and the BSIERP Team

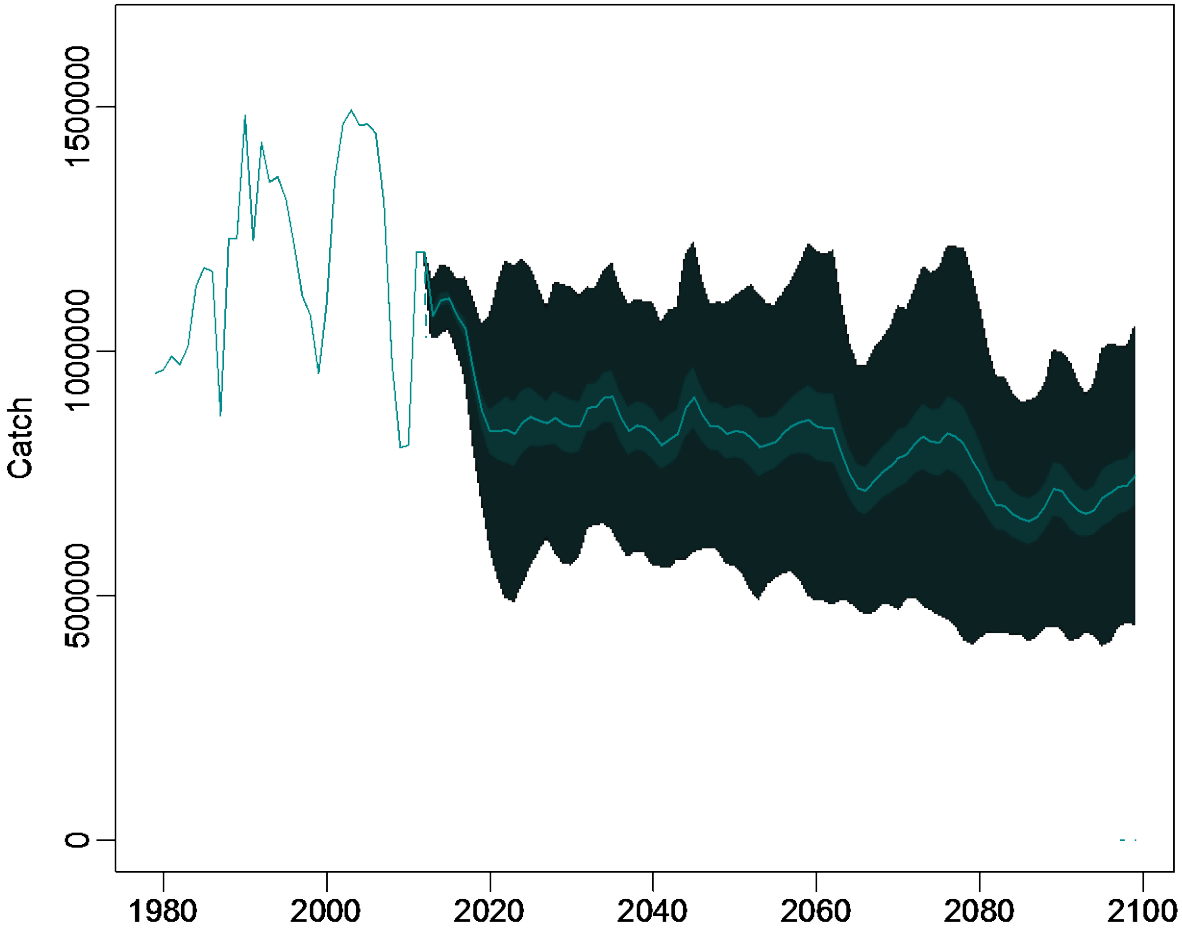
NOAA FISHERIES

EXTRA SLIDES

Photo: Mark Holsman

Part 1 Overview Presenter: Anne Hollowed

Catch under mean F



Ianelli et al. in press: Blended Forecasts

Deep-Sea Research II ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Multi-model inference for incorporating trophic and climate uncertainty into stock assessments

James Ianelli [a,*], Kirstin K. Holsman [b], André E. Punt [c], Kerim Aydin [a]

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

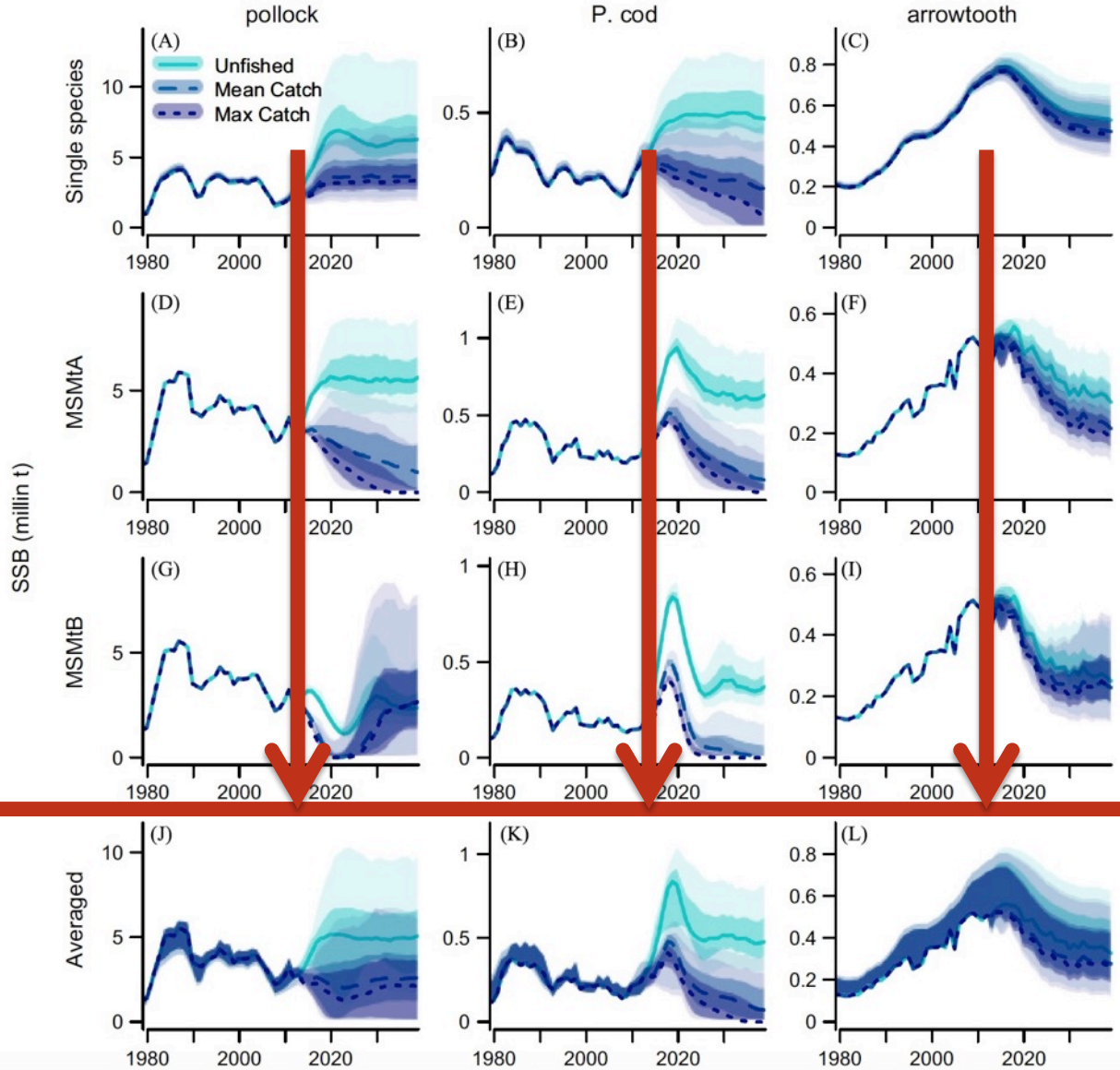
ARTICLE INFO

Keywords:
Model averaging
Model ensemble
Multi-species model

ABSTRACT

Ecosystem-based fisheries management (EBFM) approaches allow a broader and more extensive consideration of objectives than is typically possible with conventional single-species approaches. Ecosystem linkages may include trophic interactions and climate change effects on productivity for the relevant species within the system. Presently, models are evolving to include a comprehensive set of fishery and ecosystem information to address these broader management considerations. The increased

Blended results (three models)



Single spp.
No Temp.

Single spp.
Avg. R_{hist}
Temp. → W@A

Multi spp.
Temp. →Ration
Avg. R_{hist}
Temp.→ W@A

Blended Result

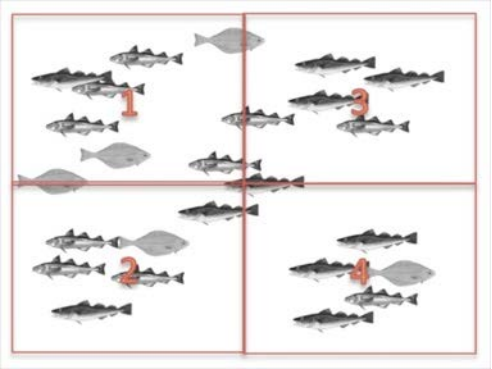
Considerations for MMI:

- Near-term or long-term? → Avg. or indiv.
- Tactical vs strategic? → communication
- Model weighting
- Consider “baseline”→bias correction

Sources of Error

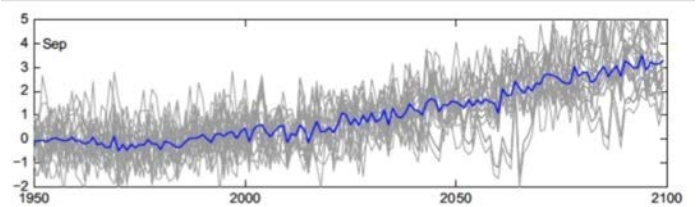
1. Observation error

- Measurement error
- Spatial heterogeneity
- Temporal variability
- Reduce through replication



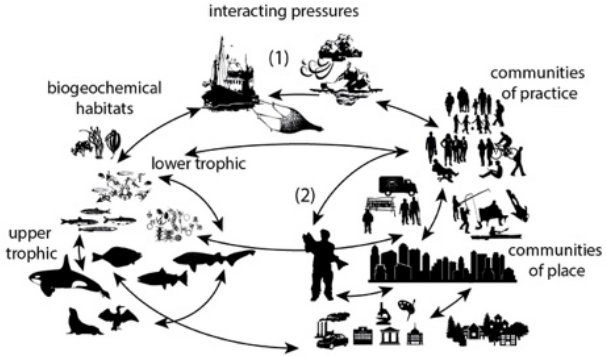
2. Process error

- “Noise” due to environmental variability
- Can be recreated using climate models
- MCMC to get “avg” trend right

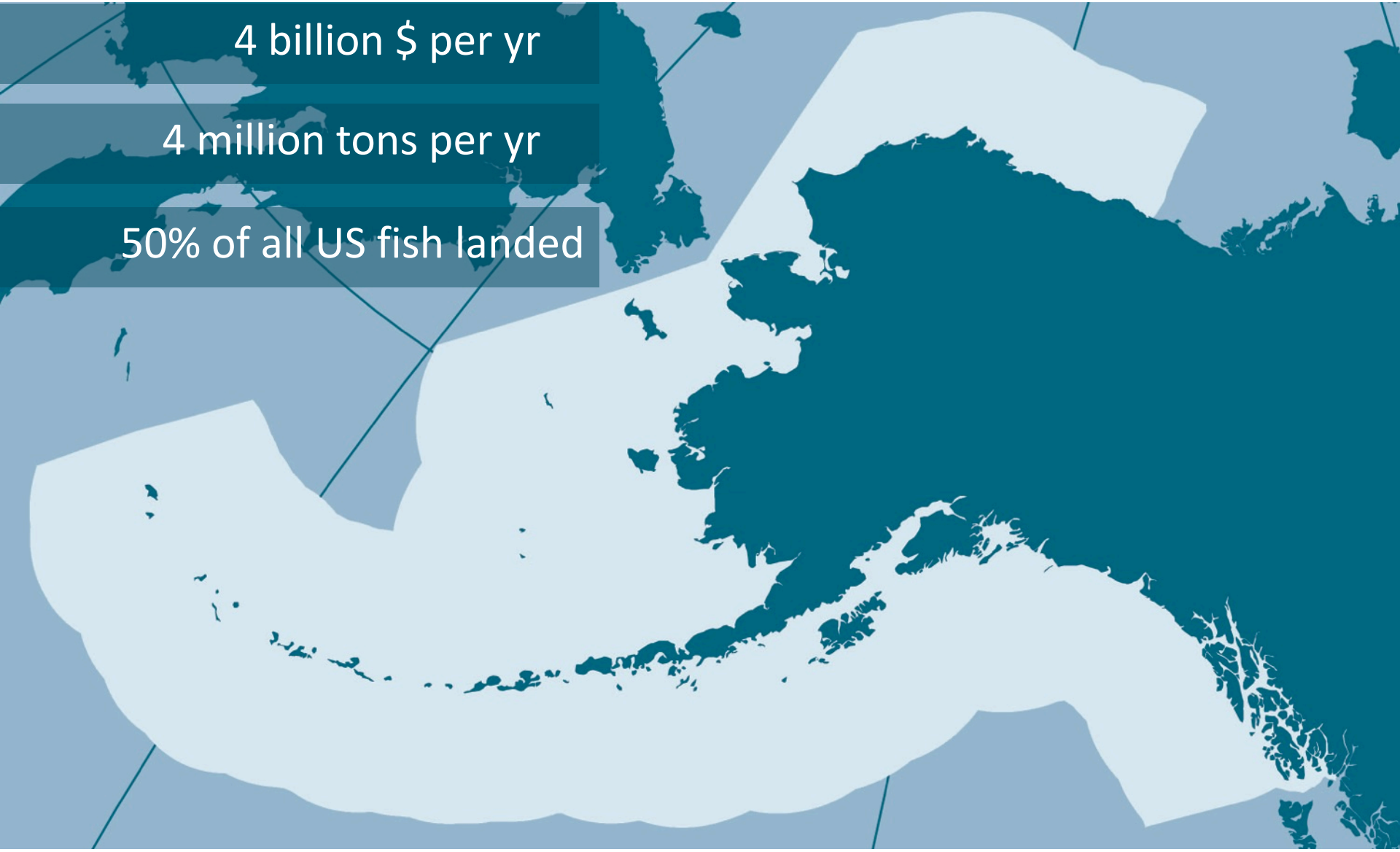


3. Model misspecification error

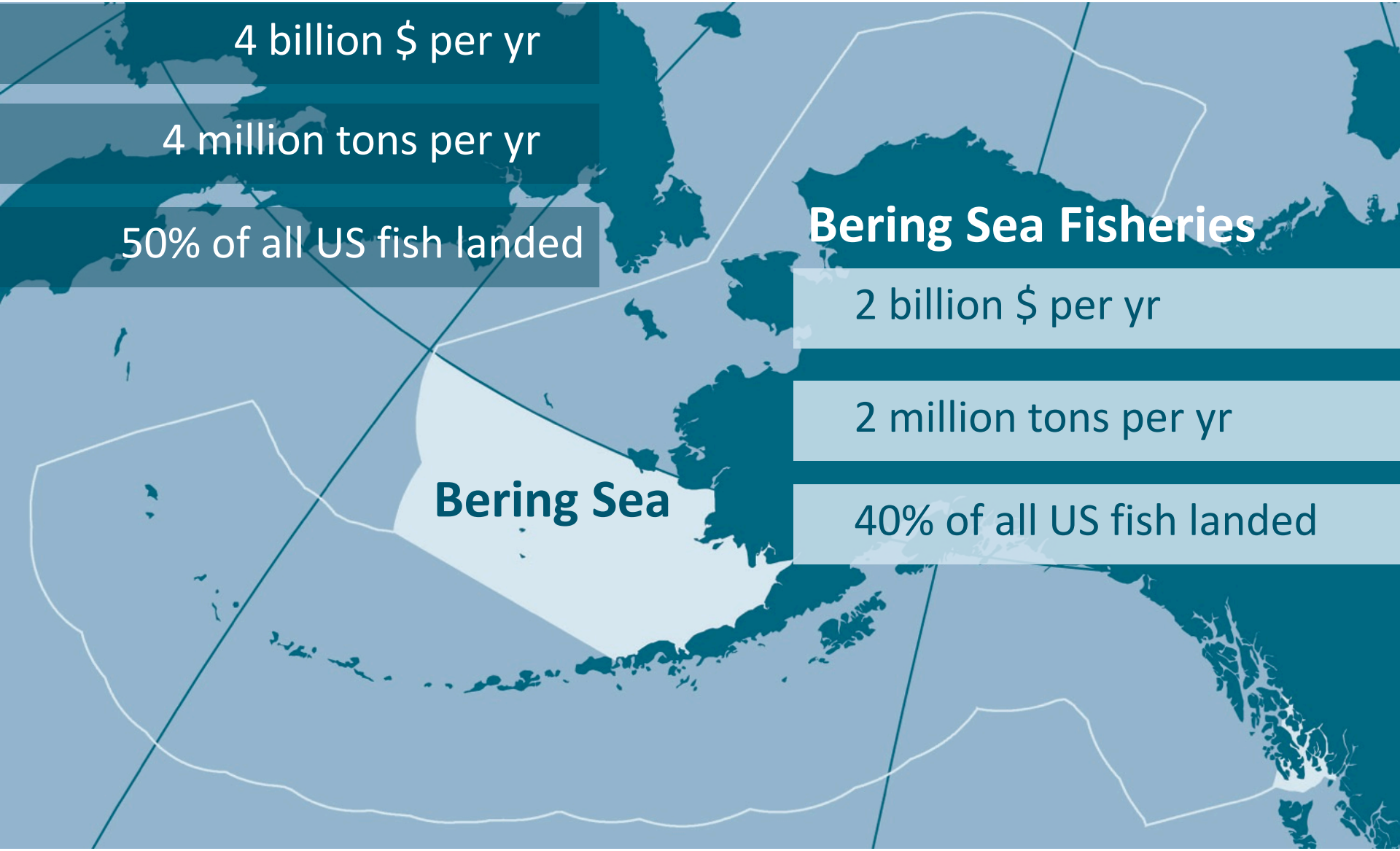
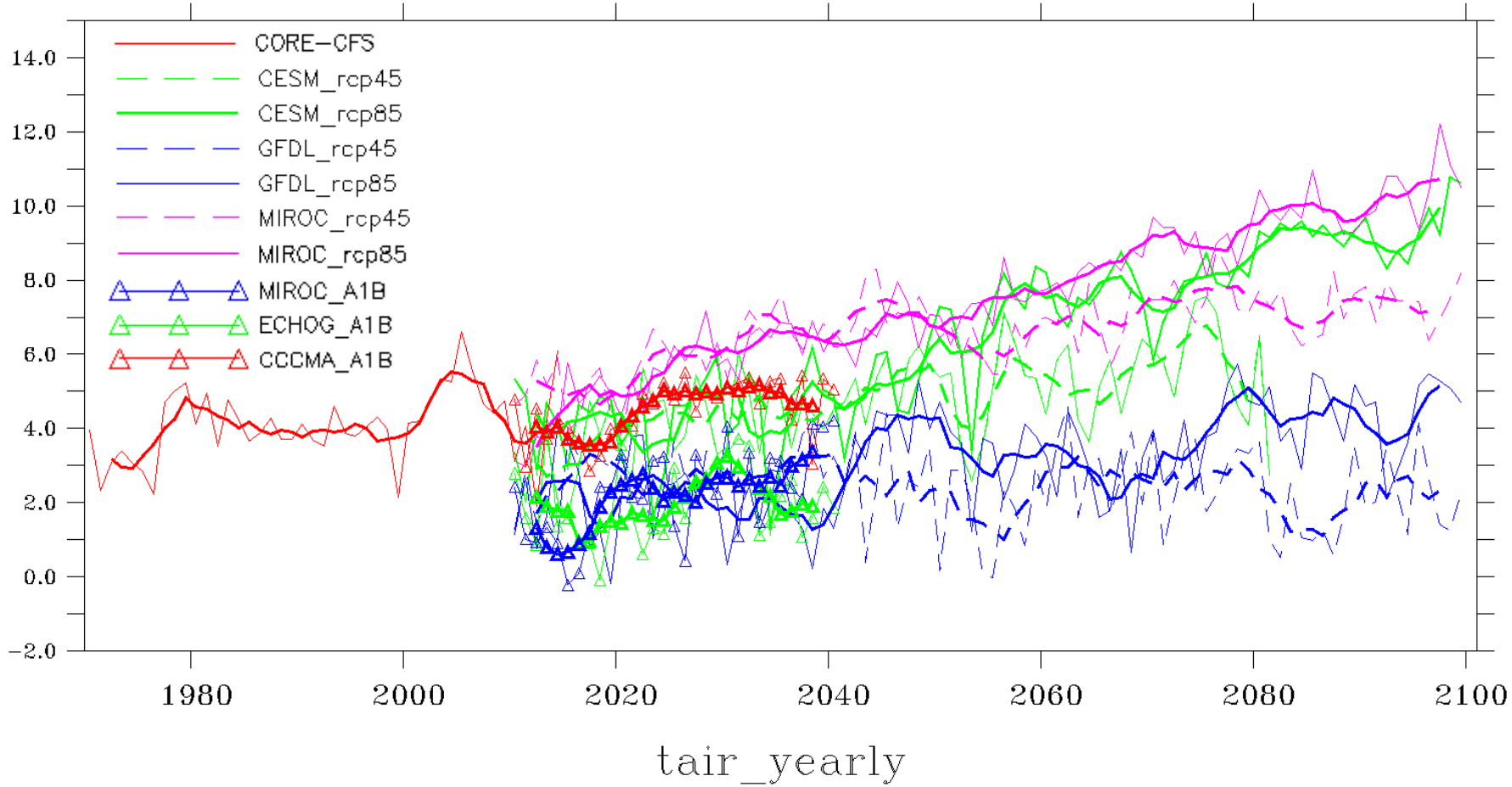
- Can result from spurious correlations
- Under or over estimate interactions
- More likely with indirect effects ?
- Experimental manipulation to reduce error
- Avg. from multiple models can help reduce error (“multi-model inference”)?



Alaska-wide Fisheries



Alaska-wide Fisheries



Ensemble of IPCC output: Air Temperature