Ocean Acidification & Rising Ocean Temperatures

Scott Doney
Joe D. and Helen J. Kington Professor
in Environmental Change
University of Virginia

Congress on Ocean Policy
Renewable Natural Resources Foundation
Washington, DC, December 2018
https://www.rnrf.org/2018cong/

UNIVERSITY of VIRGINIA

ENVIRONMENTAL RESILIENCE
INSTITUTE

UNIVERSITY of VIRGINIA
DEPARTMENT of ENVIRONMENTAL SCIENCES

Recent U.S. & International Scientific Assessments

Climate Science Special Report

Fourth National Climate Assessment (NCA4), Volume I

This report is an authoritative assessment of the science of climate change, with a focus on the United States. It represents the first of two volumes of the Fourth National Climate Assessment, mandated by the Global Change Research Act of 1990.

https://science2017.globalchange.gov/

Second State of the Carbon Cycle Report

(SOCCR2)

SOCCR2 is an authoritative decadal assessment of carbon cycle science across North America, developed by over 200 experts from the U.S., Canadian and Mexican governments, national laboratories, universities, private sector, and research institutions.
SOCCR2 is a Sustained Assessment Product of the U.S. Global Change Research Program.

https://carbon2018.globalchange.gov/

FOURTH NATIONAL CLIMATE ASSESSMENT

Volume II: Impacts, Risks, and Adaptation in the United States

The National Climate Assessment (NCA) assesses the science of climate change and variability and its impacts across the United States, now and throughout this century.

https://nca2018.globalchange.gov/

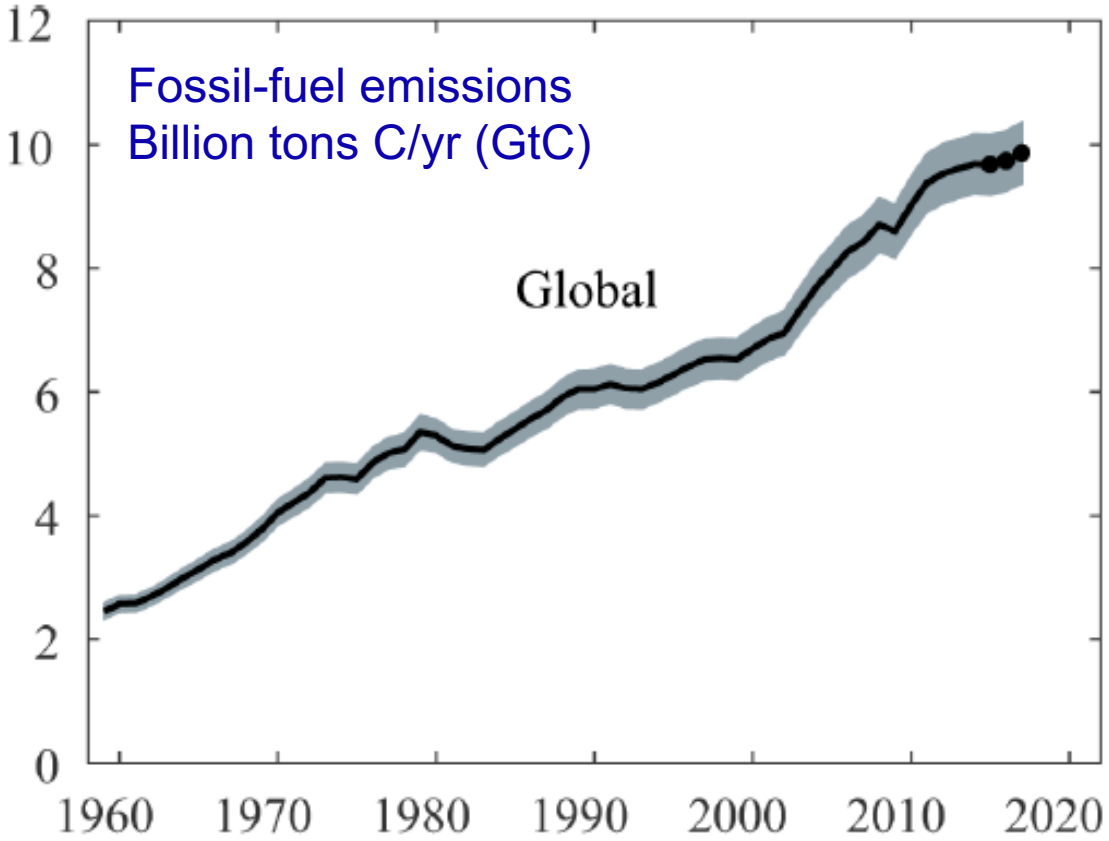
ipcc
INTERGOVERNMENTAL PANEL ON climate change

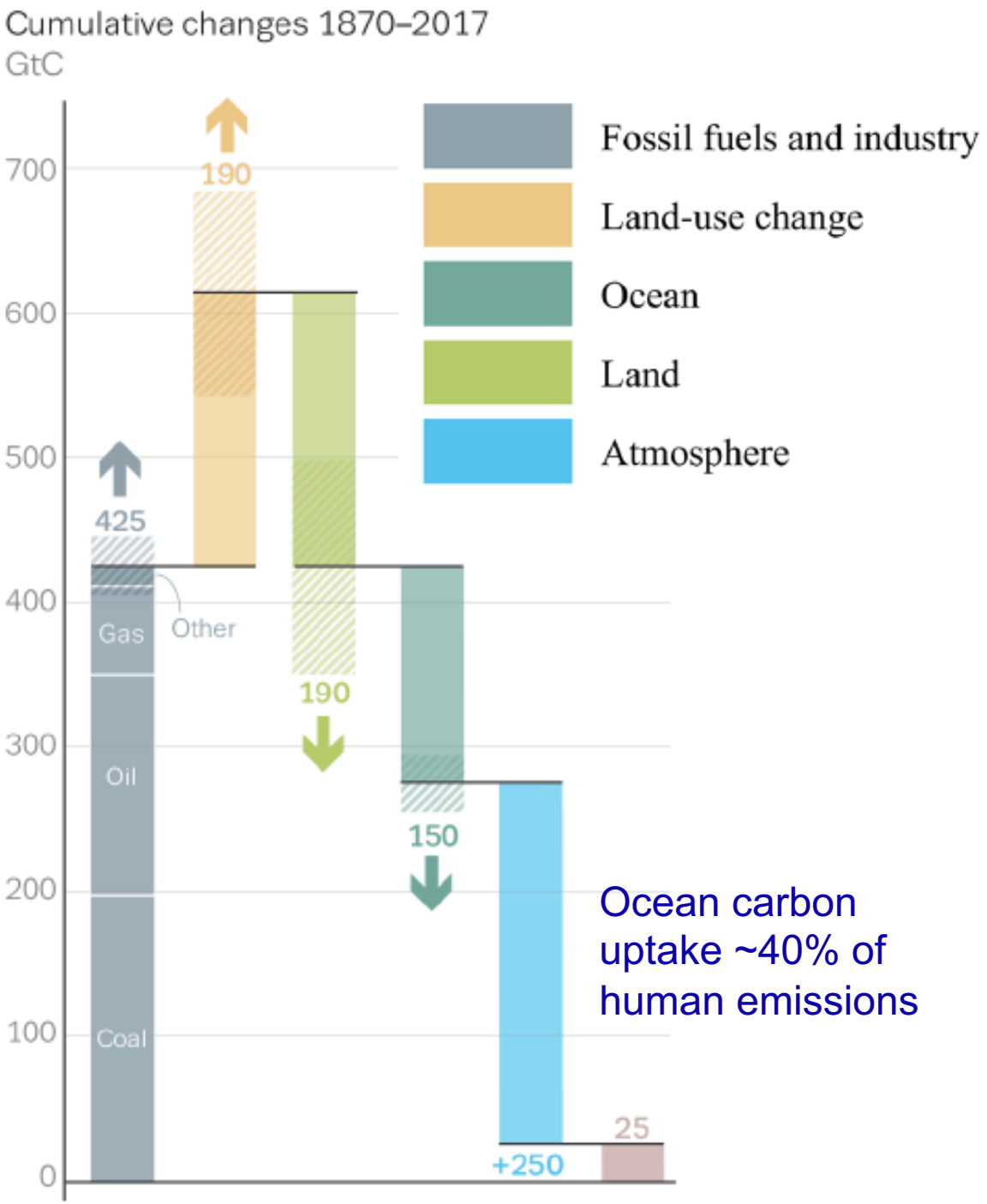
GLOBAL WARMING OF 1.5 °C

an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty

https://www.ipcc.ch/report/sr15/

Human Perturbation to Global Carbon Cycle

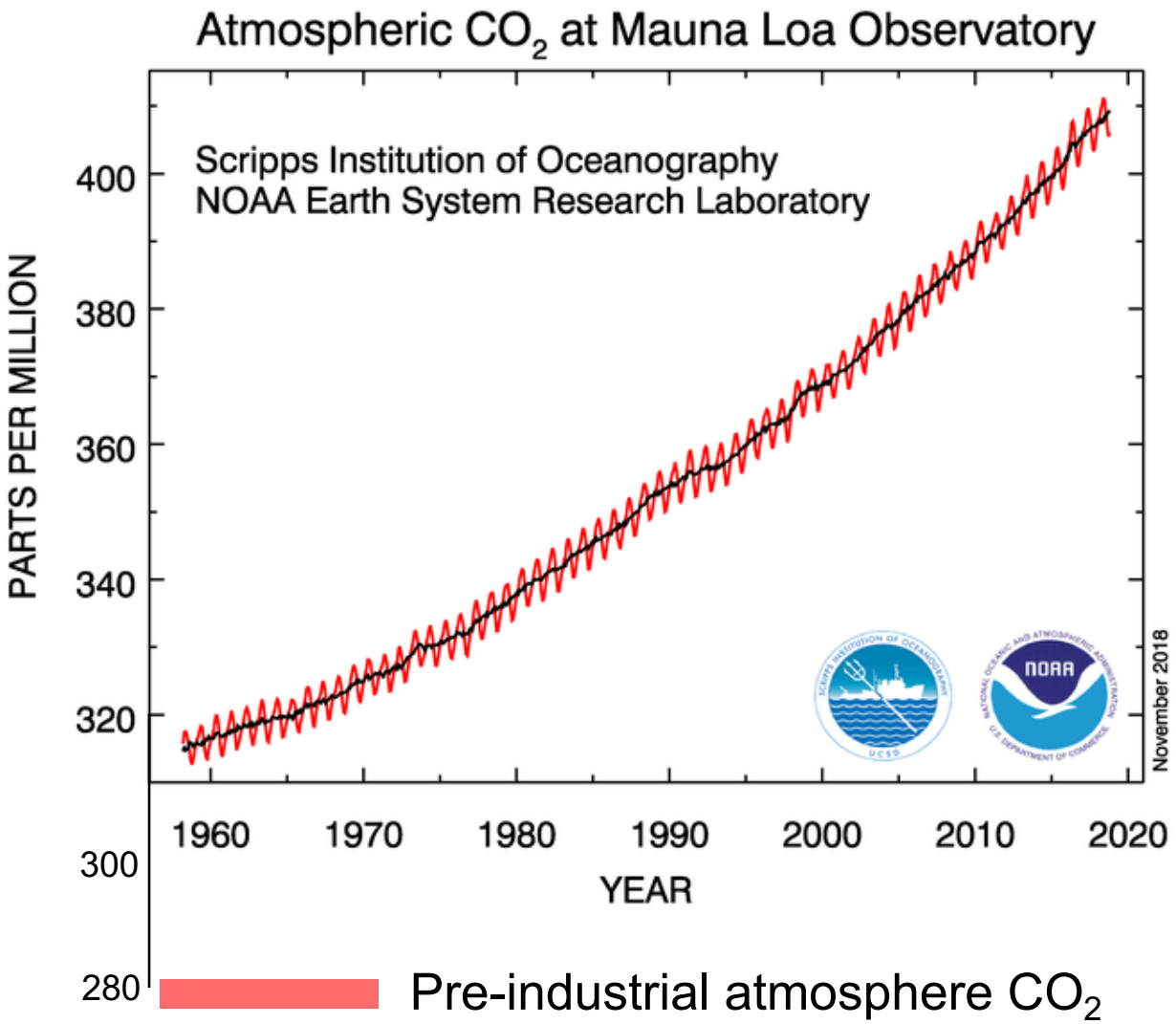




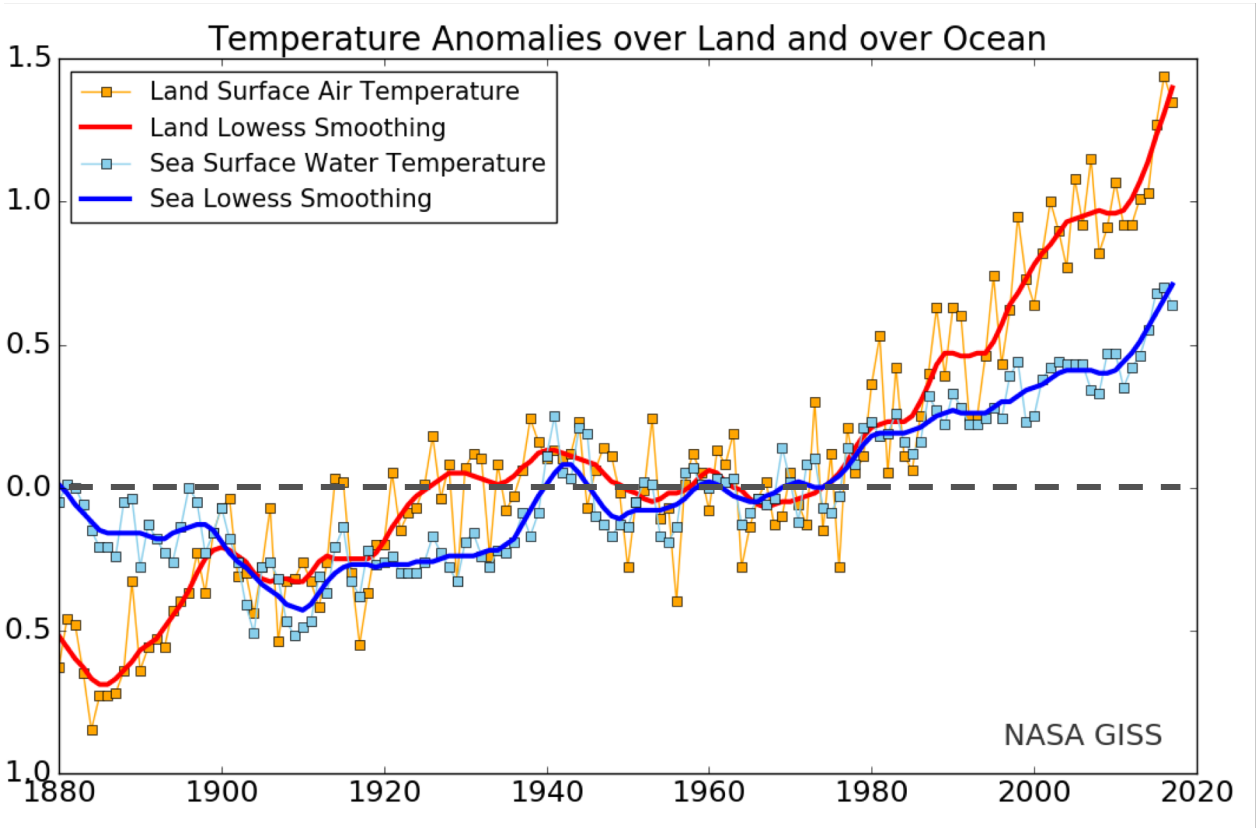
Ocean carbon uptake ~40% of human emissions

Global Carbon Project: Le Quéré et al.
Earth System Science Data 2018

Rising Atmospheric CO_2 & Ocean Warming

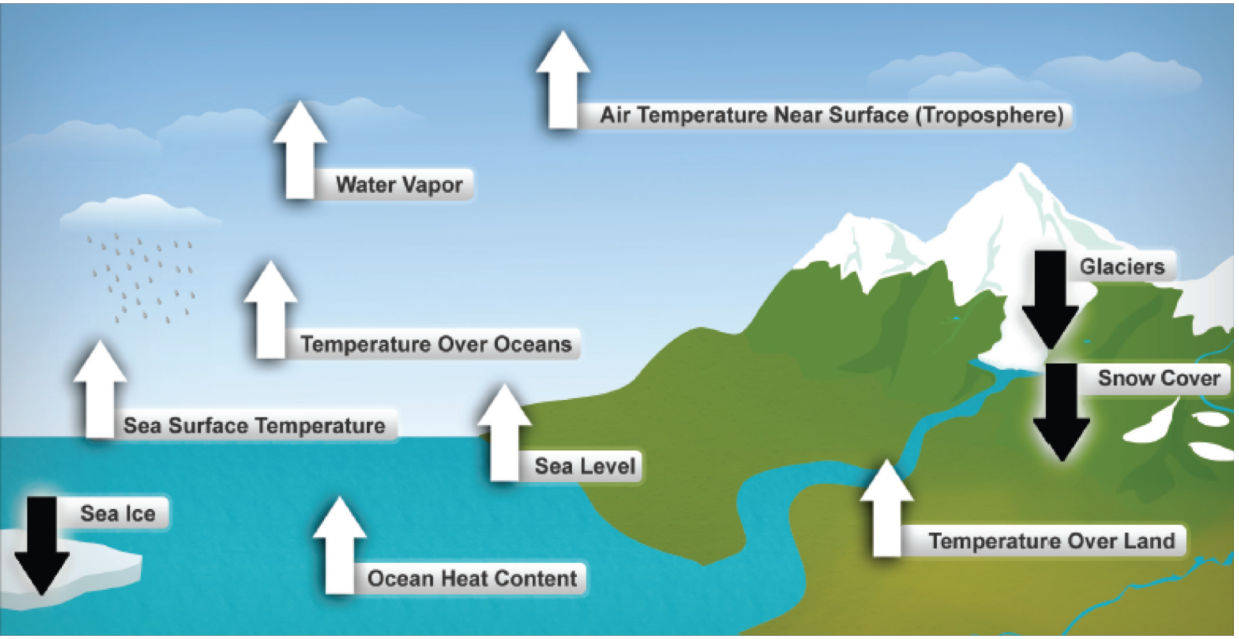


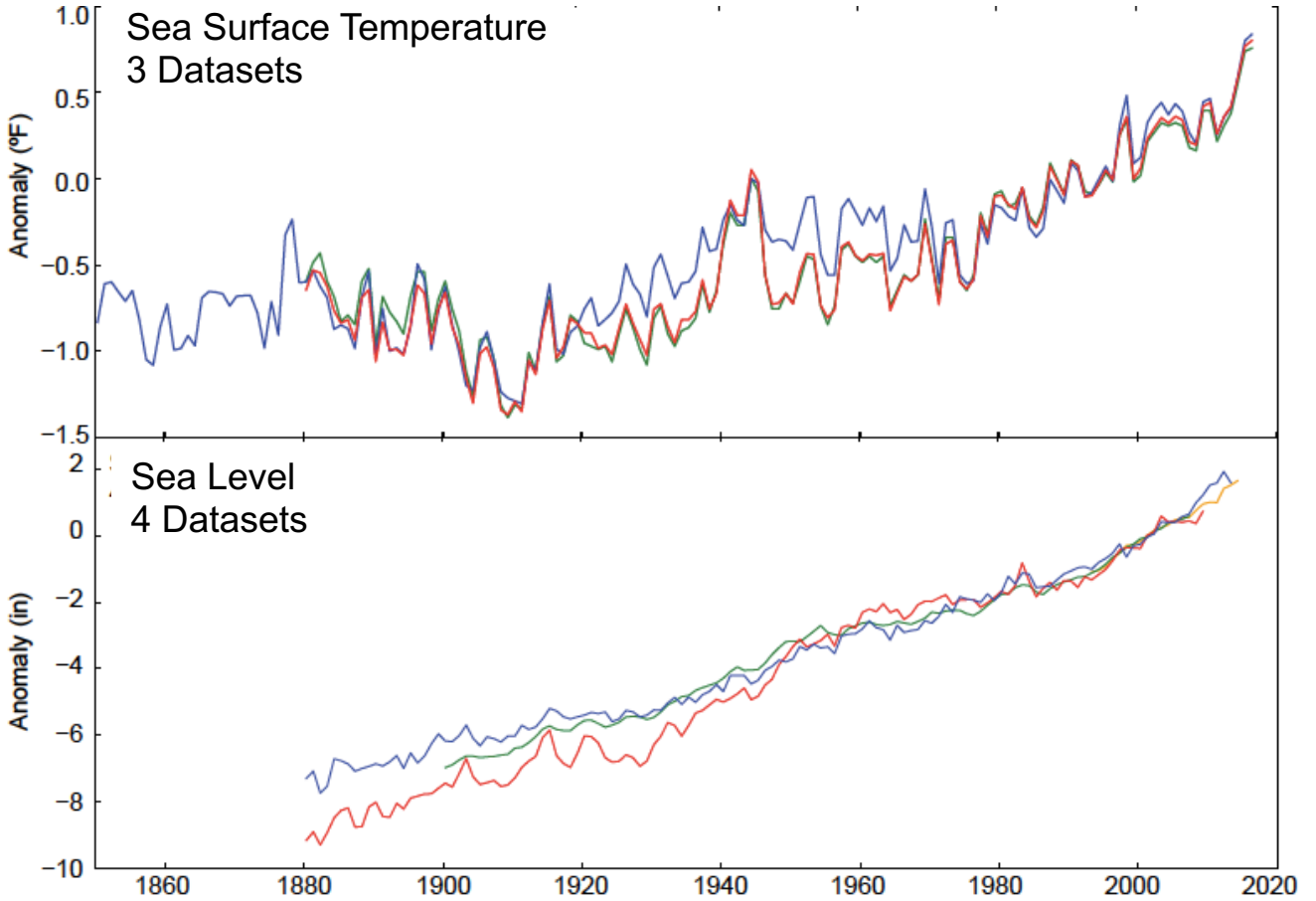
https://www.esrl.noaa.gov/gmd/ccgg/trends/

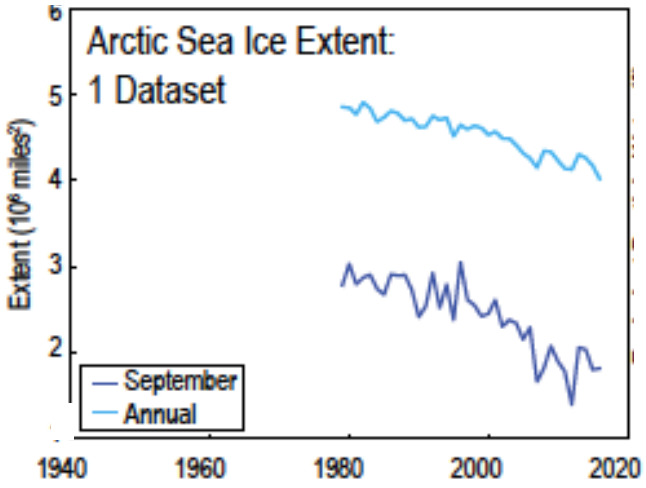


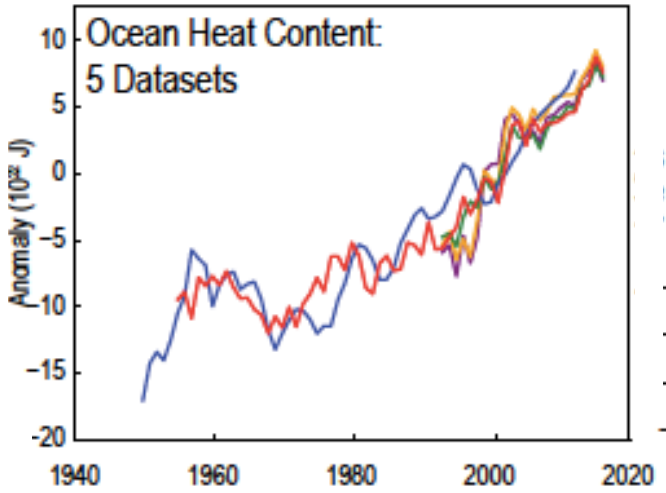
https://data.giss.nasa.gov/gistemp

Ocean Climate Change Signals



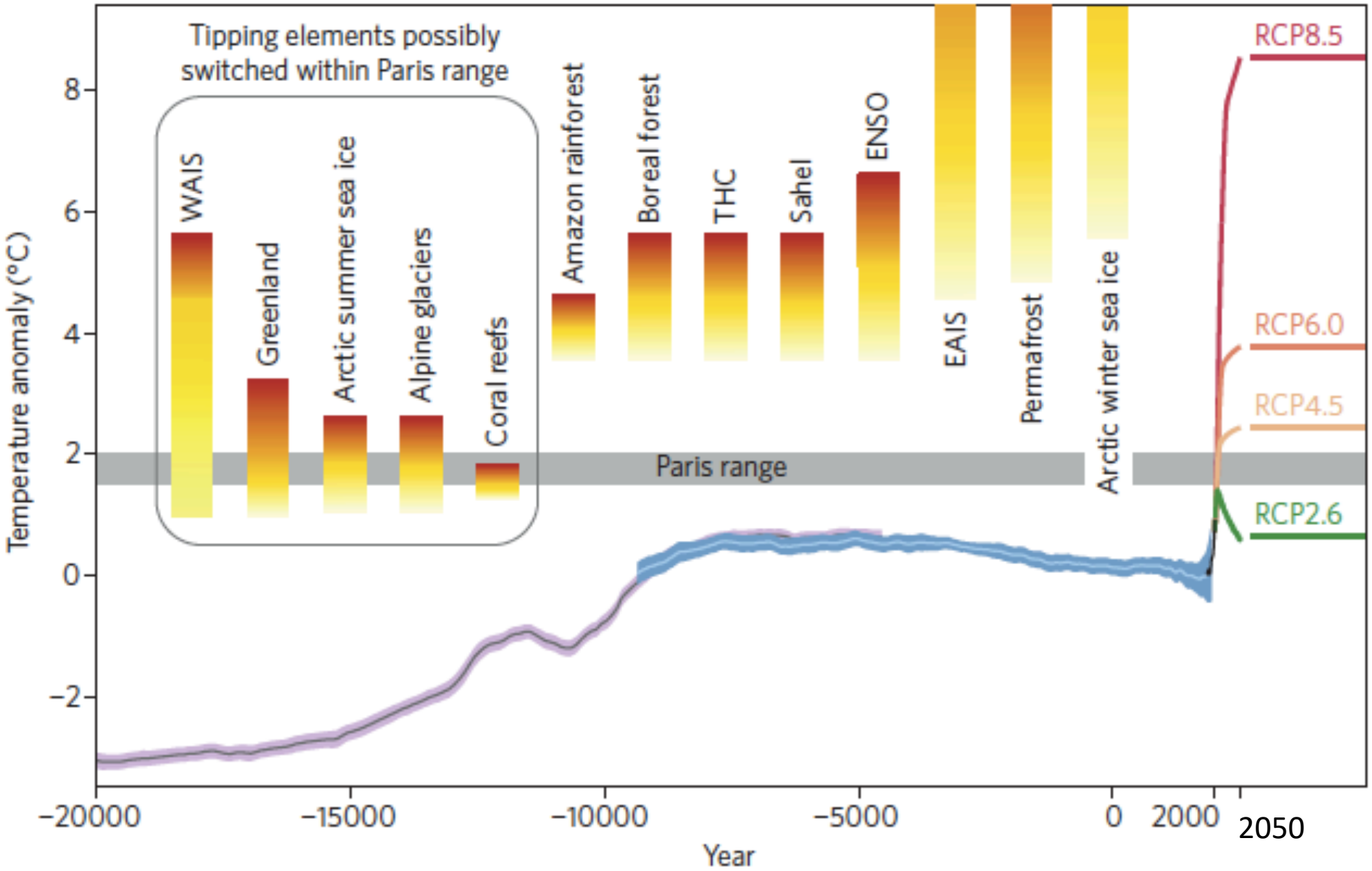






Climate Science Special Report 2017

Climate Thresholds

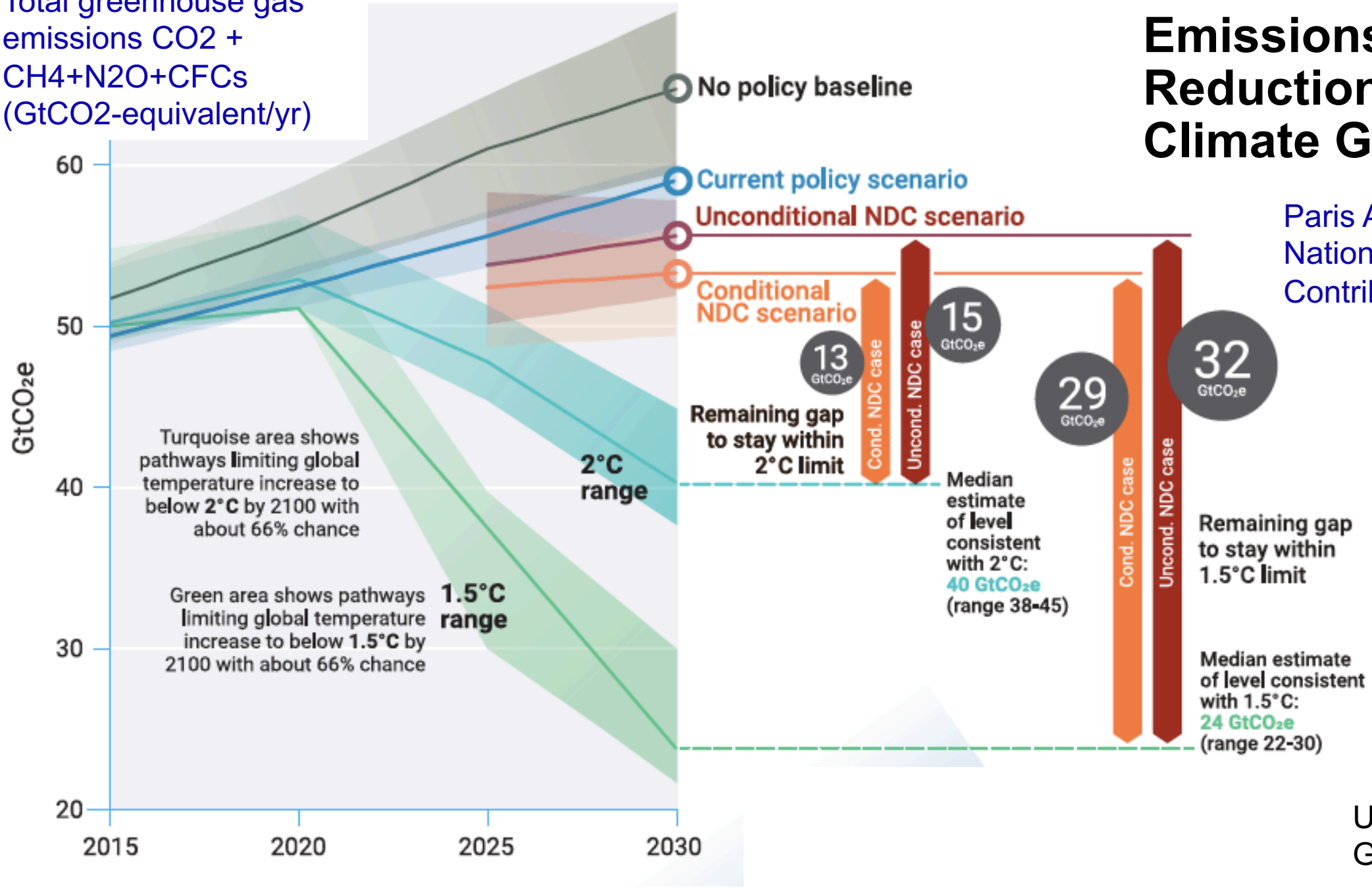


Schellnhuber et al. Nature Climate Change 2016

Emissions Reductions to Meet Climate Goals

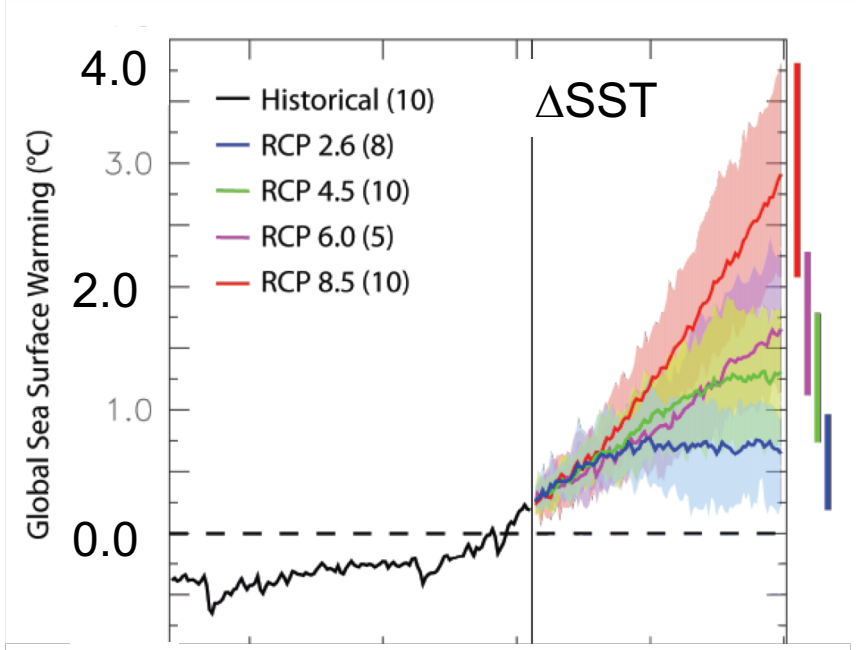
Total greenhouse gas emissions CO2 + CH4+N2O+CFCs (GtCO2-equivalent/yr)

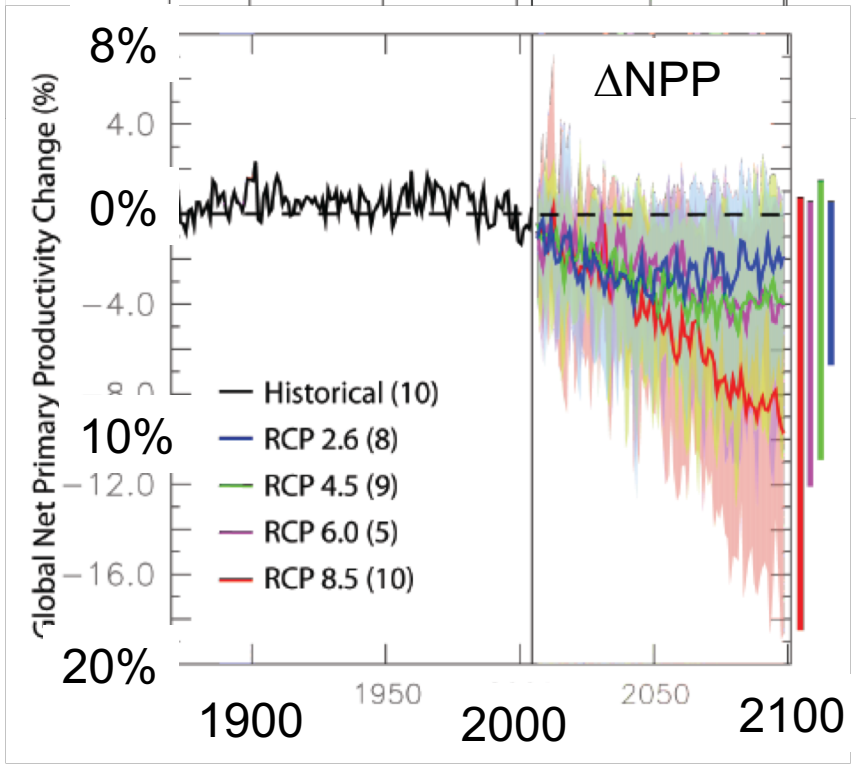
Paris Agreement & Nationally Determined Contributions (NDC)

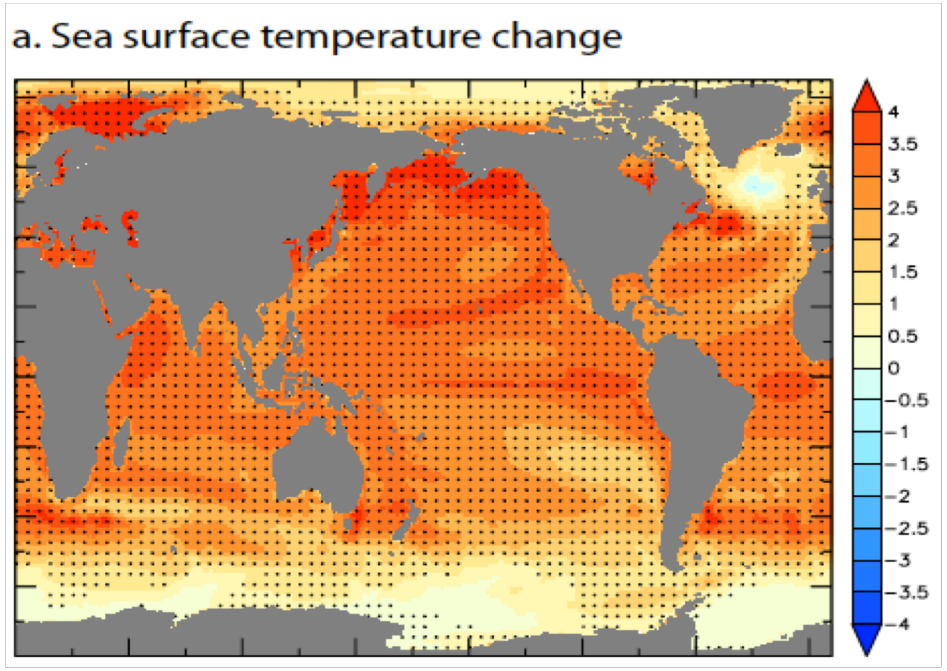


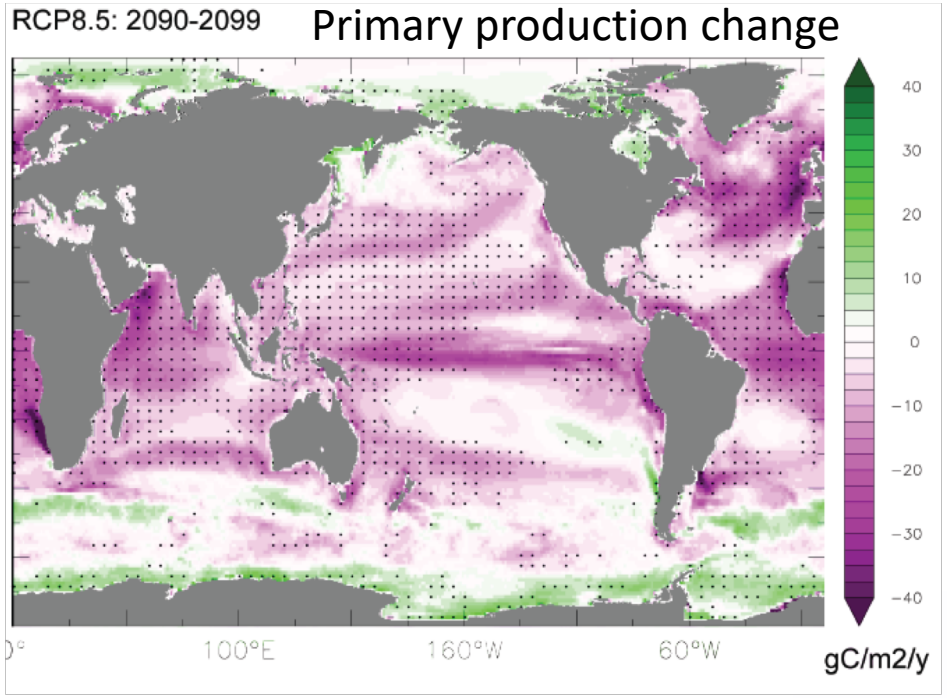
UNEP Emissions Gap Report 2018

Surface Warming & Primary Productivity





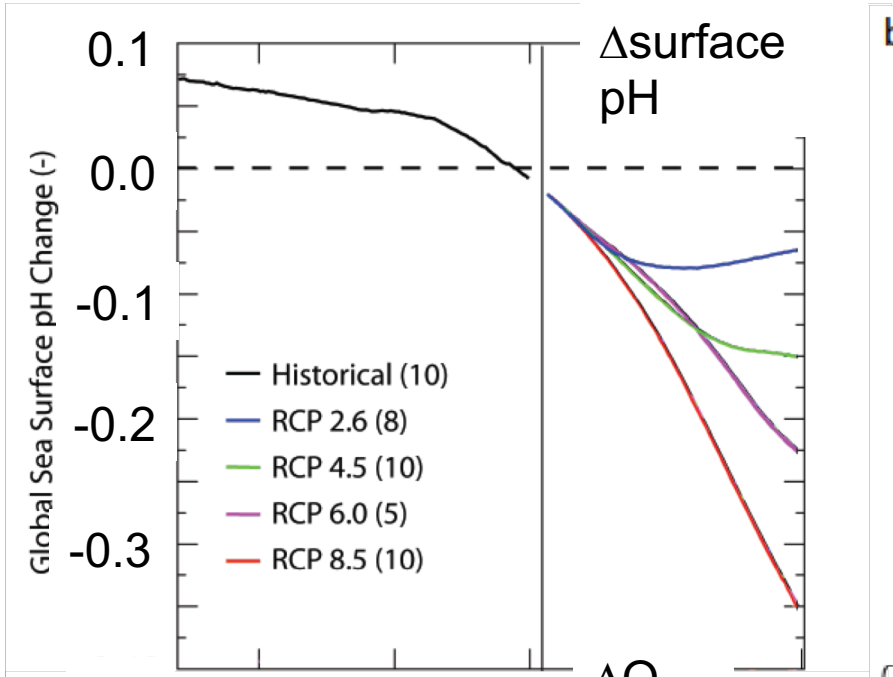


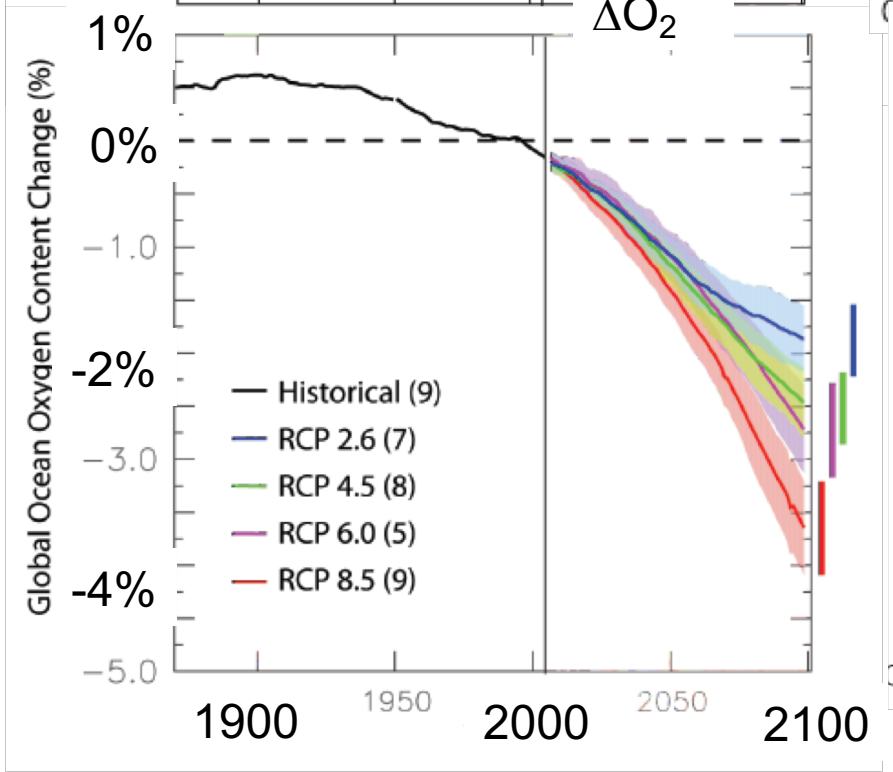


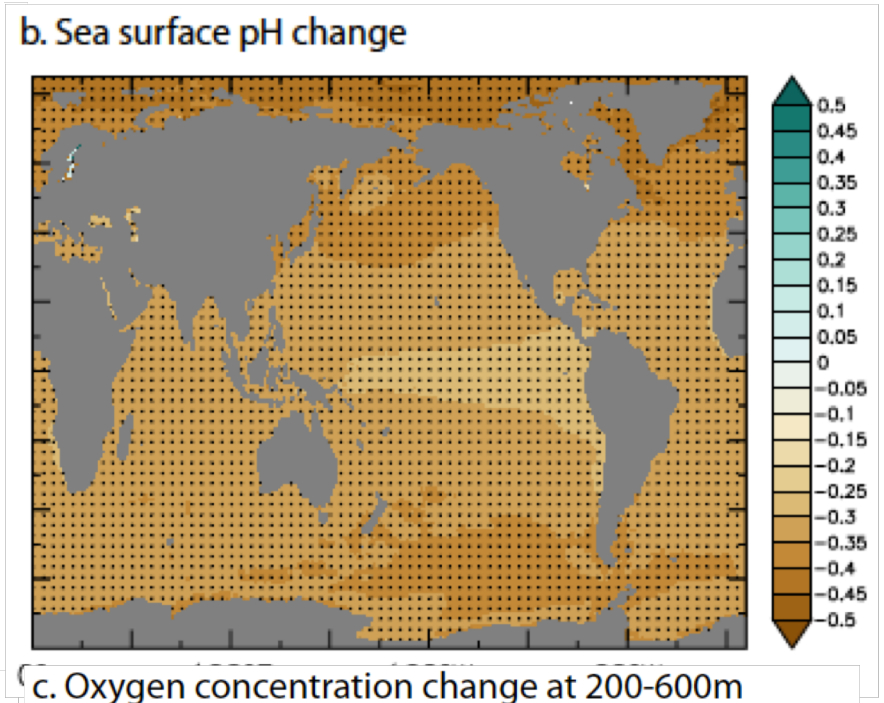
Ensemble of CMIP5 Models

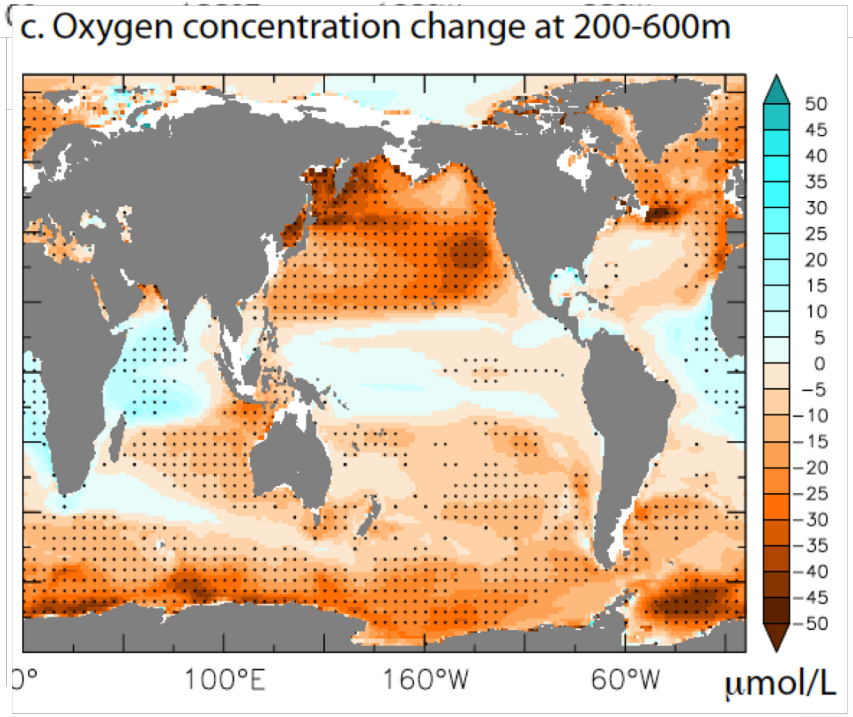
Bopp et al. Biogeosciences 2013

Surface Acidification & Subsurface Deoxygenation







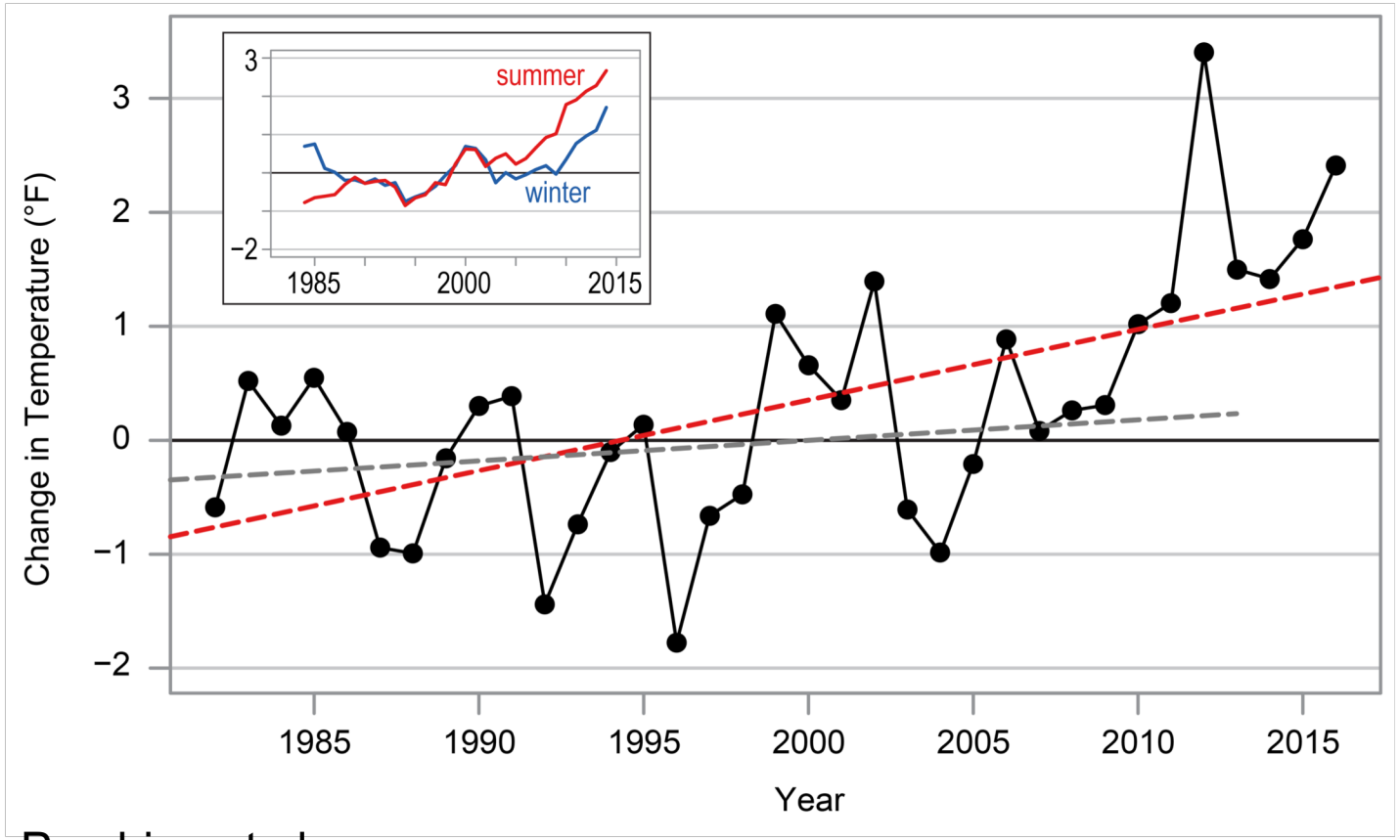


Ensemble of CMIP5 Models

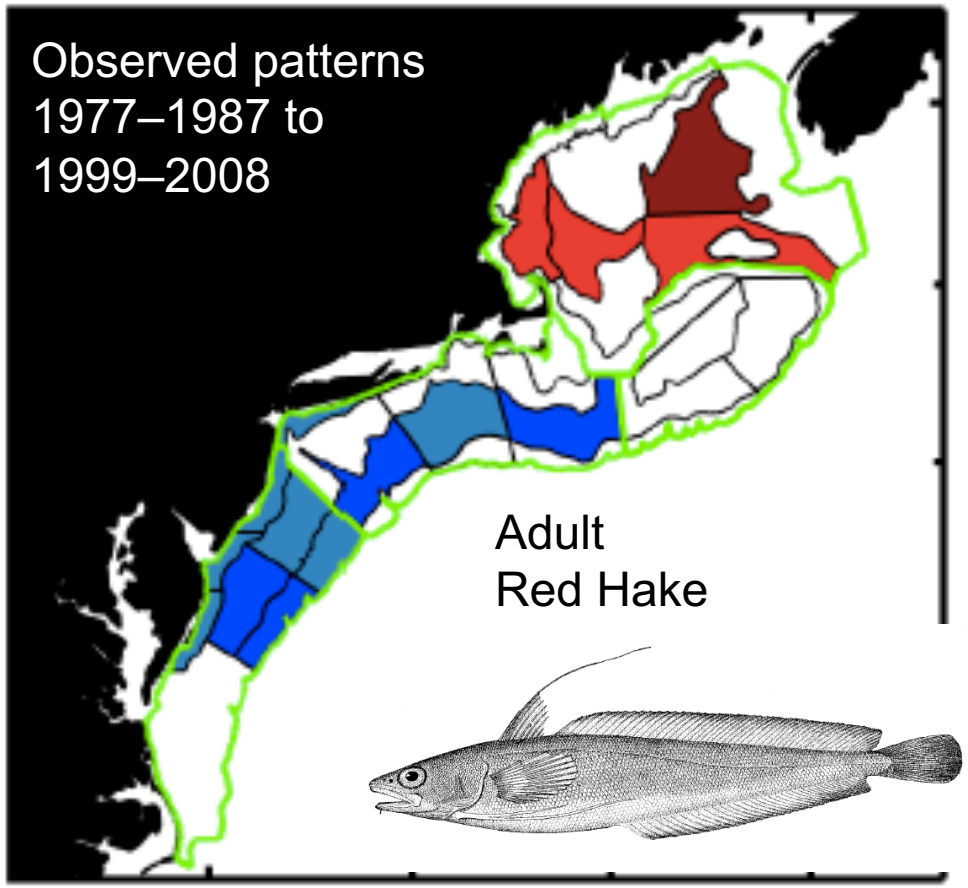
Bopp et al. Biogeosciences 2013

Ocean Warming & Poleward Shifts in Species Distributions

Sea Surface Temperature; Northeast Continental Shelf



Pershing et al.
NCA4 2018

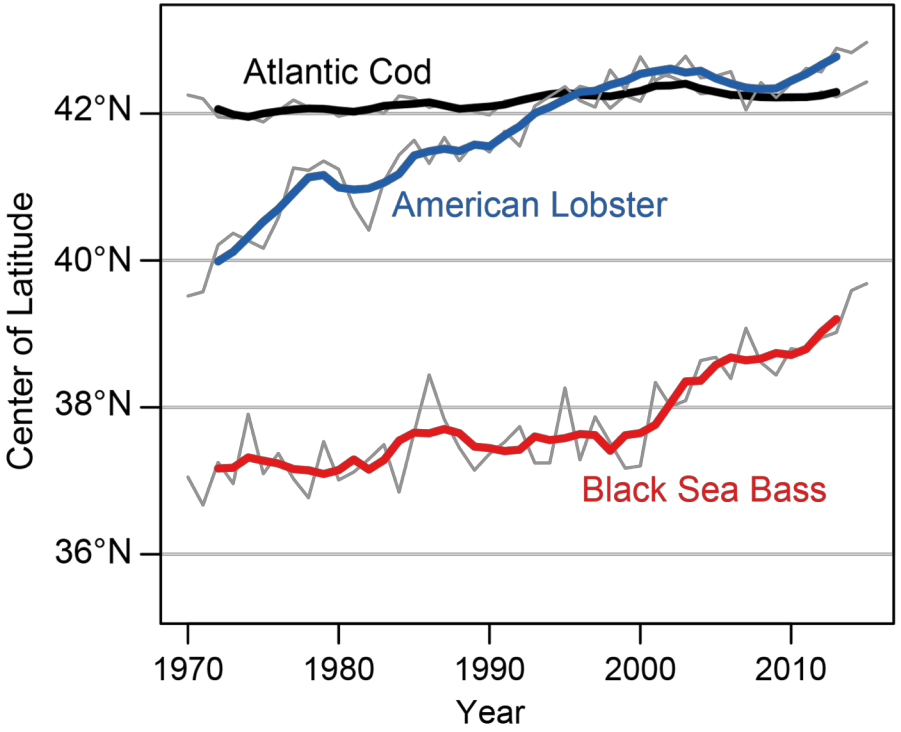


Poleward shifts for many species
from climate (& fishing pressure)

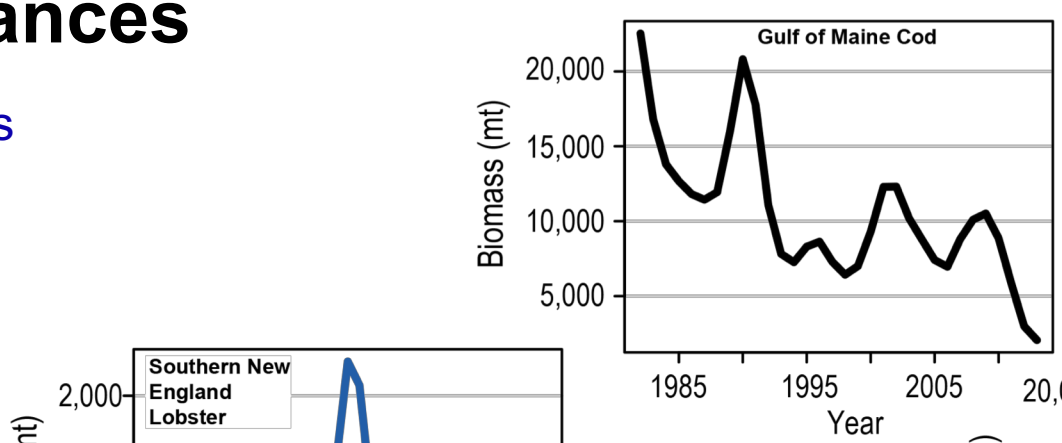
Walsh et al. PLoS ONE 2015

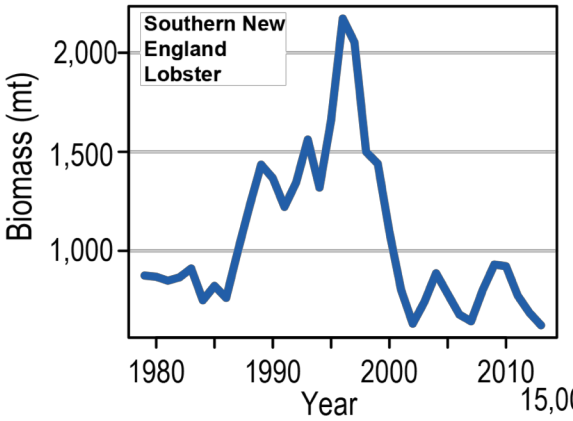
Geographic Shifts in Distributions & Abundances

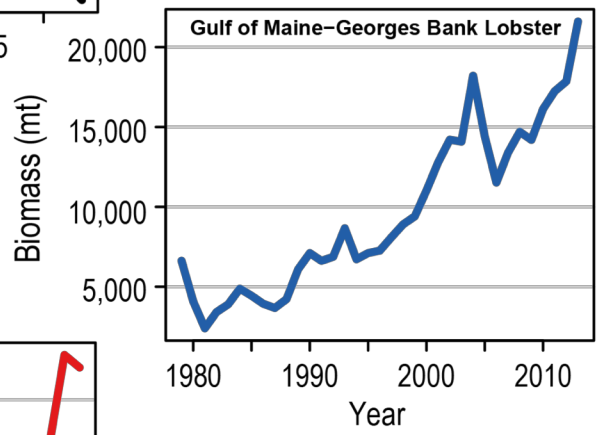
Poleward shifts in species distributions

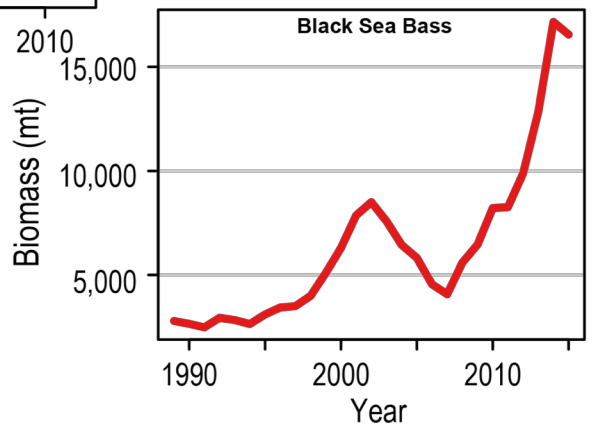


Pershing et al.
NCA4 2018





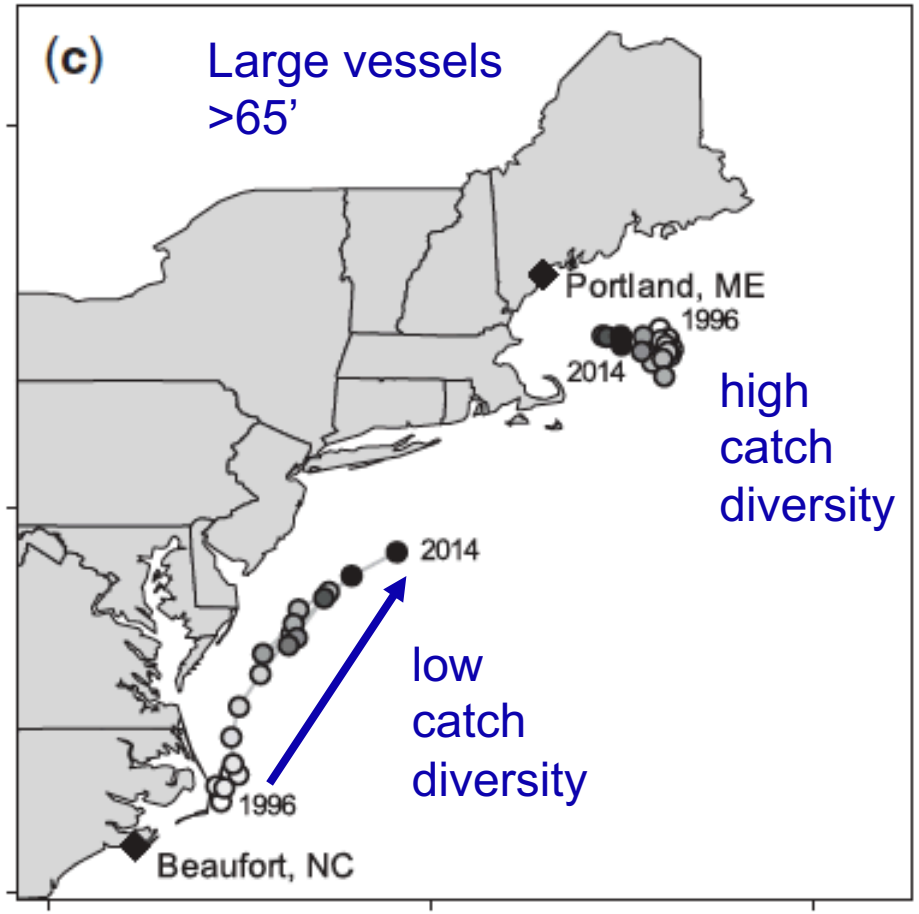


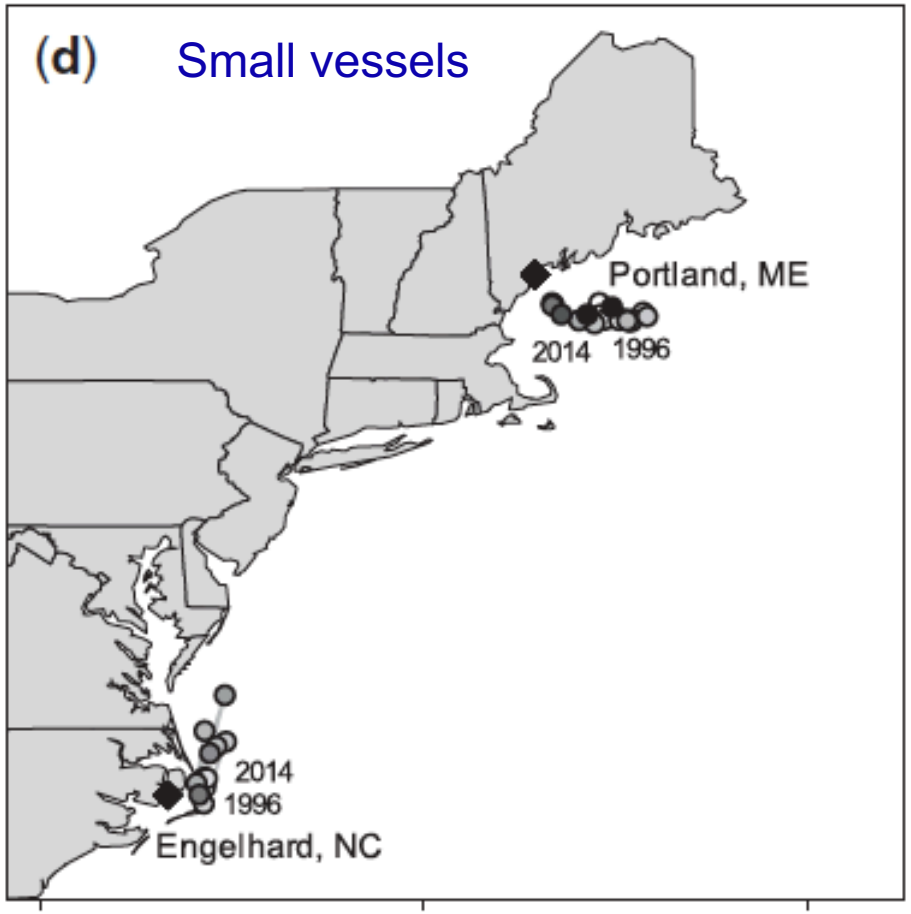


Regional trends in abundance

- physiology
- phenology
- predator-prey mismatch
- disease

Fishing Fleet Responses to Distribution Shifts

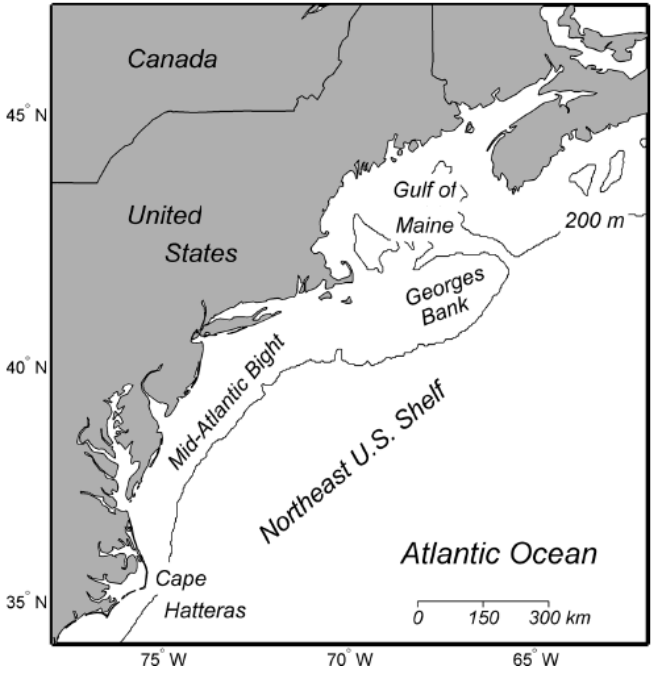




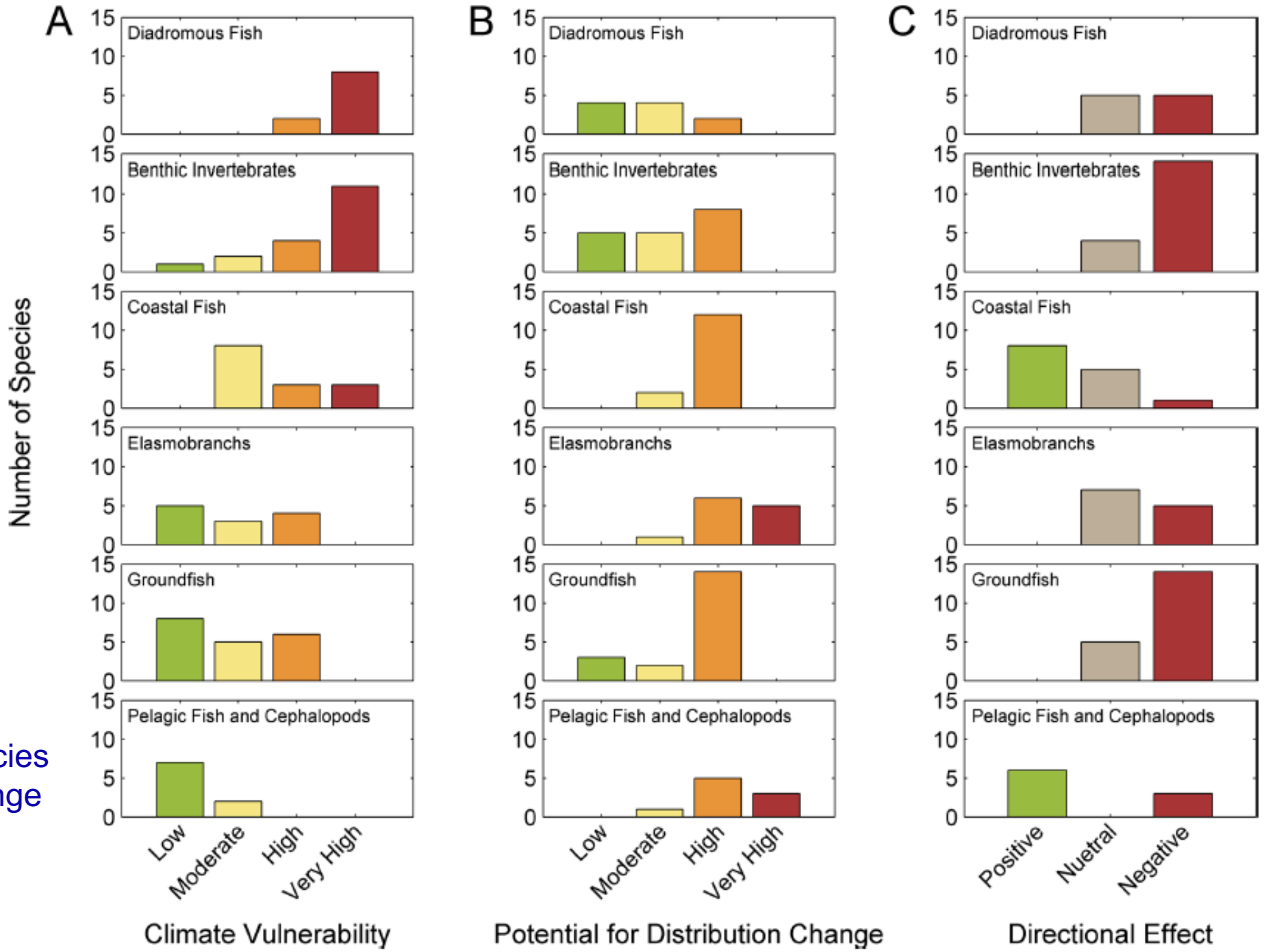
Adaptation strategies:
catch diversity & high mobility may buffer fishing communities from effects of environmental change

Young et al. ICES Journal of Marine Science 2018

Fishery Climate Vulnerability Assessment



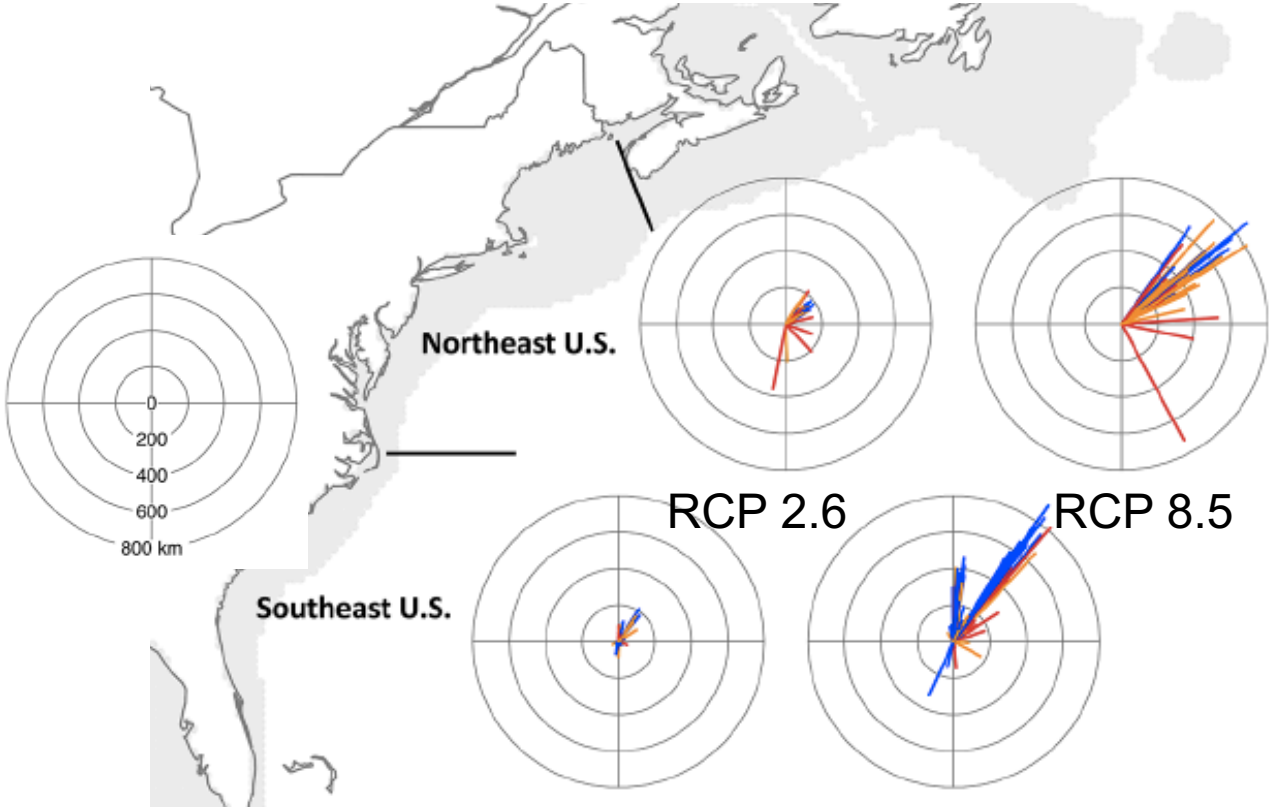
Exposure & sensitivity of species abundance, productivity & range to climate & acidification



Hare et al. PLoS One 2016

Projected Future Effects

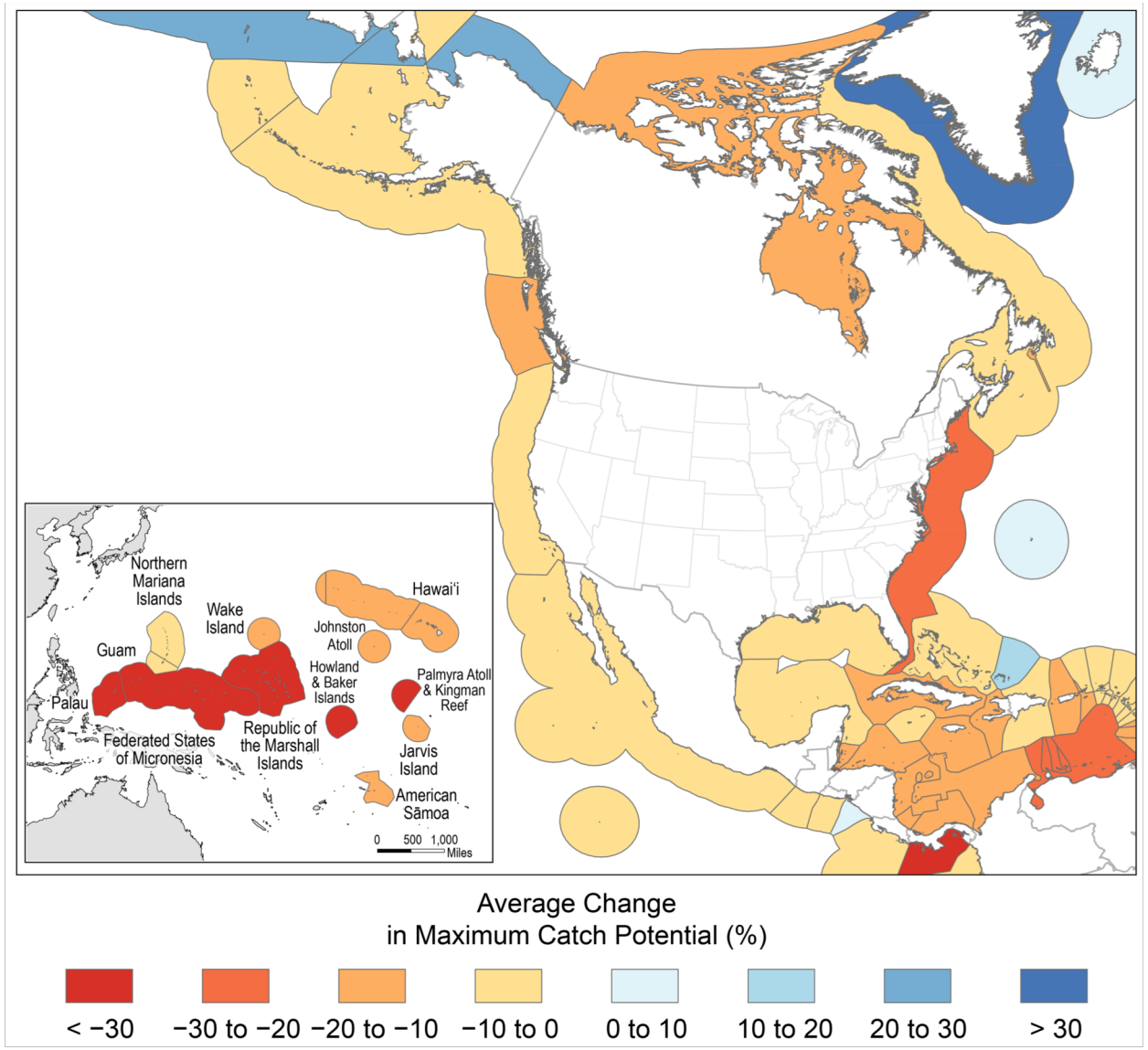
Thermal habitat range shifts



Low uncertainty
High uncertainty

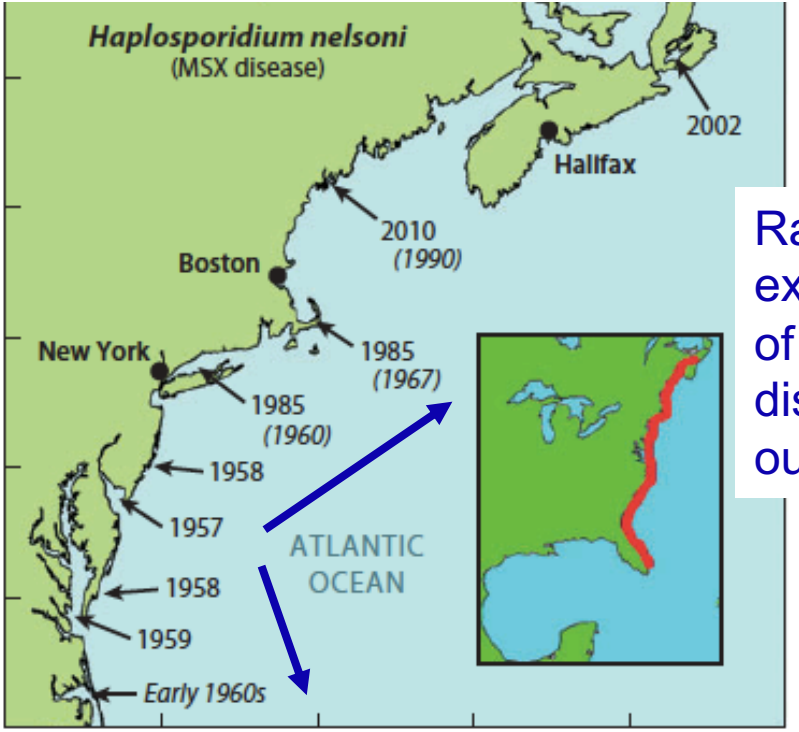
Morley et al. PLoS ONE 2018

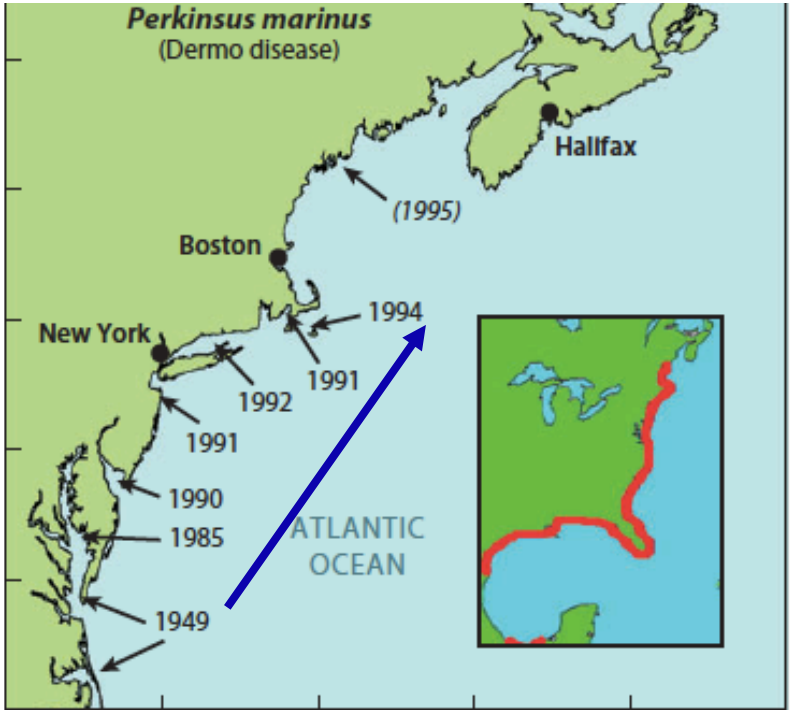
Projected changes in fishery catch potential 2041–2060 relative to 1991–2010 under a higher scenario (RCP8.5)



Pershing et al. 2018 4th National Climate Assessment

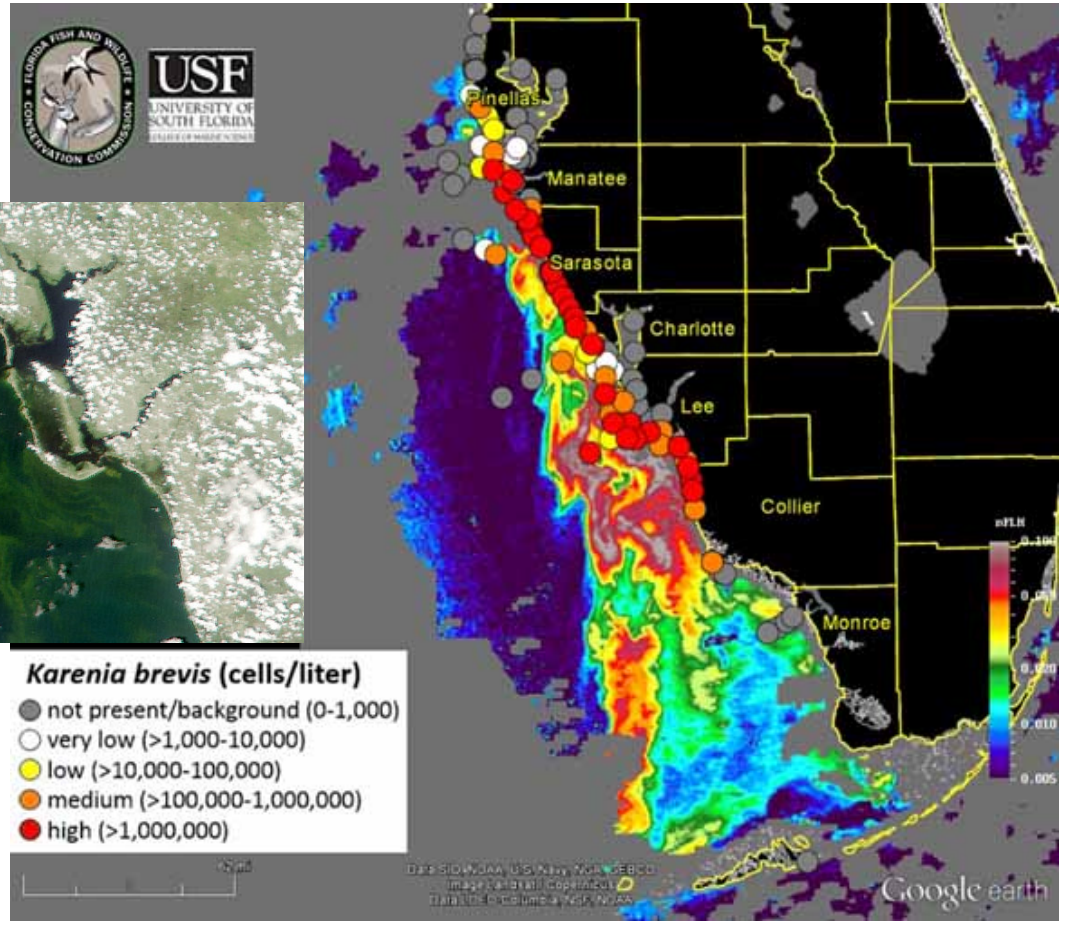
Marine Diseases & Harmful Algal Blooms





Range extension of oyster disease outbreaks

Climate may influence HAB composition & frequency

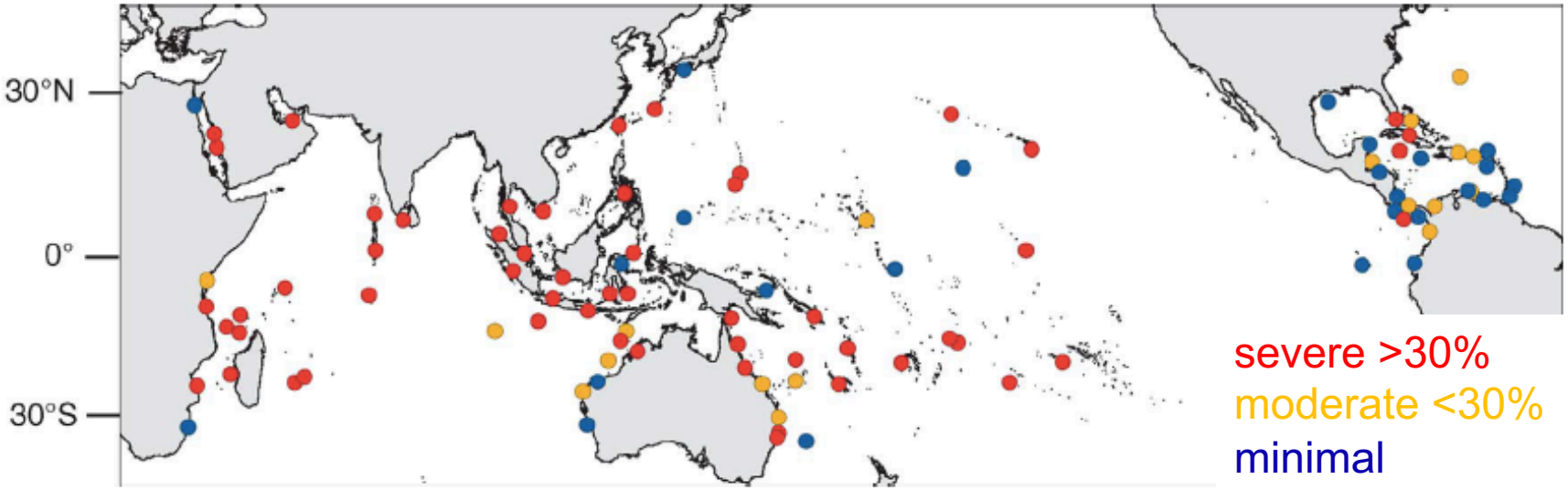


Burge et al.
Annual Review
Marine Science
2014

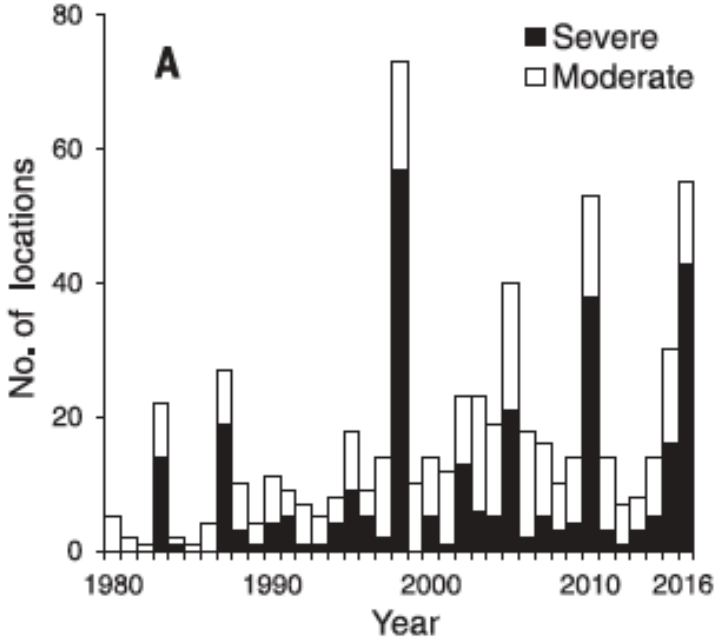
https://earthobservatory.nasa.gov/blogs/earthmatters/2018/08/24/how-scientists-are-tracking-red-tides-with-satellites-and-smartphones/

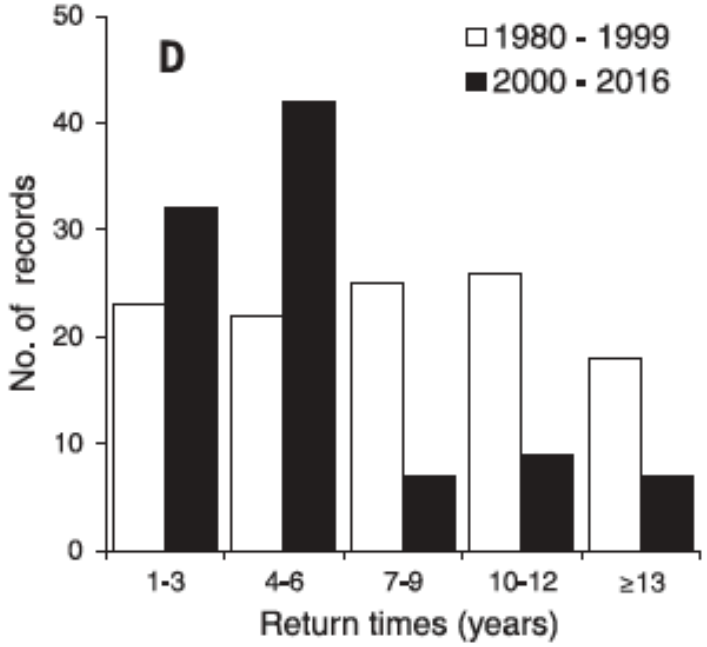
Coral Bleaching

Global extent of mass bleaching of corals in 2015 and 2016



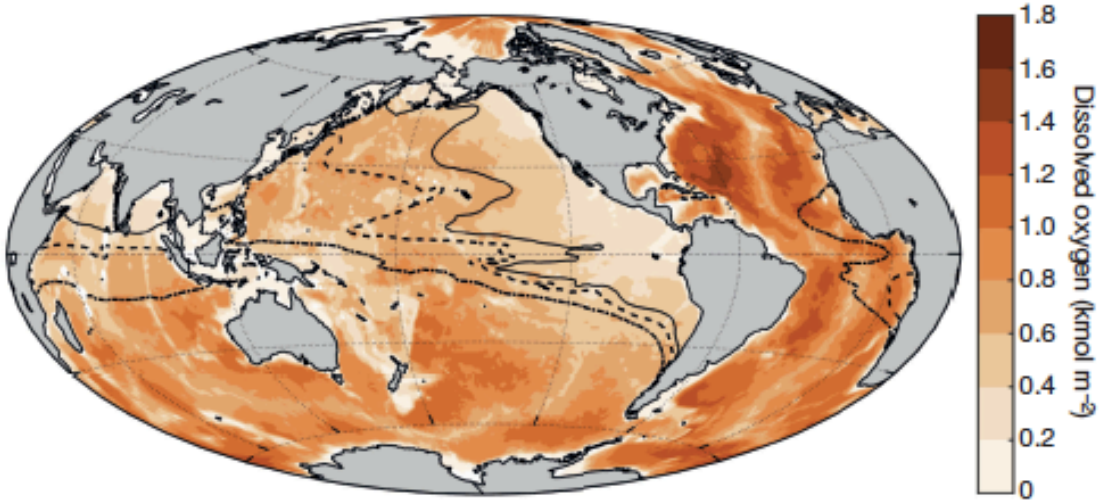
severe >30%
moderate <30%
minimal

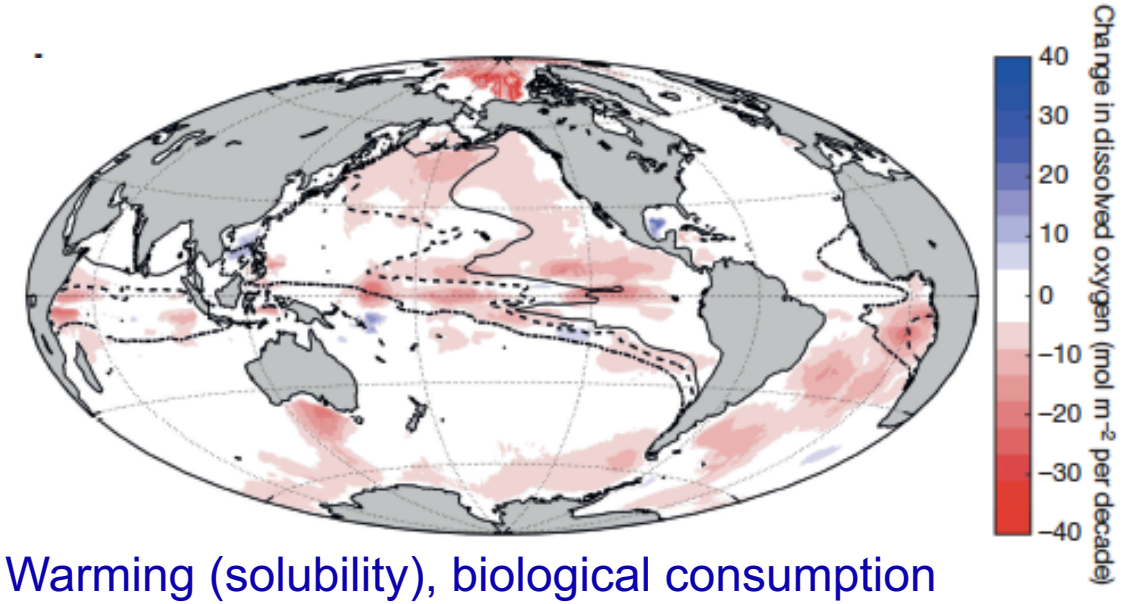




Hughes et al. Science 2018

Ocean & Coastal Oxygen Loss

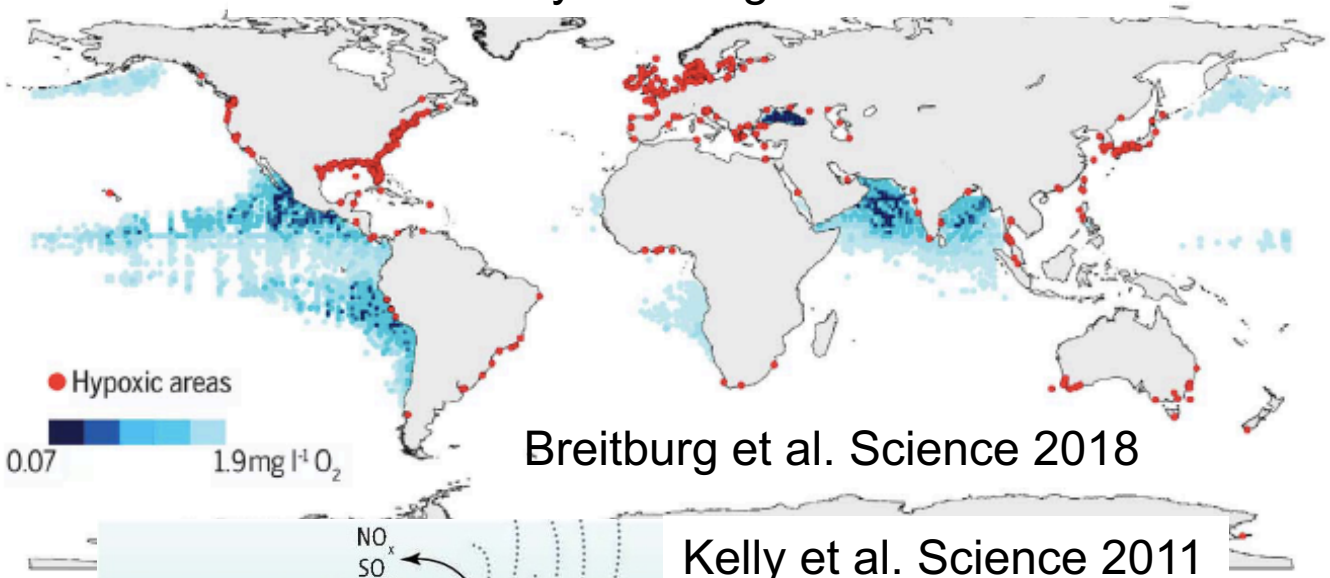




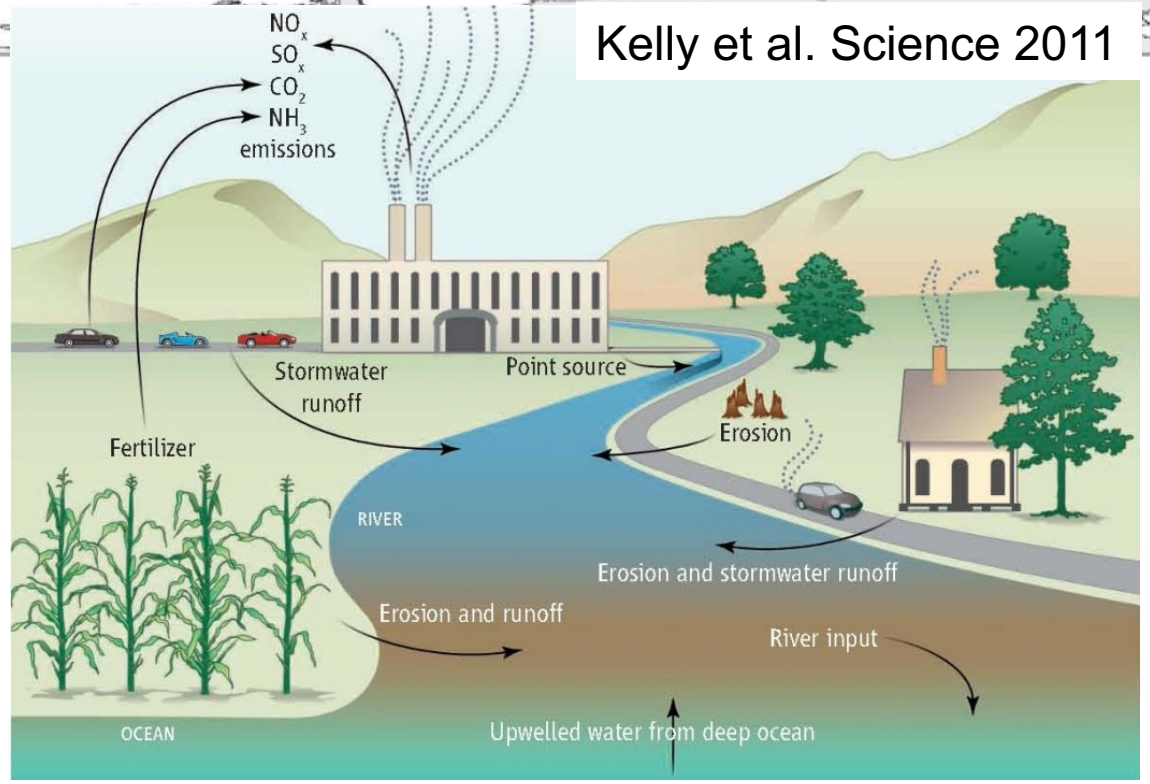
Warming (solubility), biological consumption & reduced ventilation

Schmidtko et al. Nature 2017

- Coastal nutrient eutrophication & hypoxia exacerbated by warming & stratification

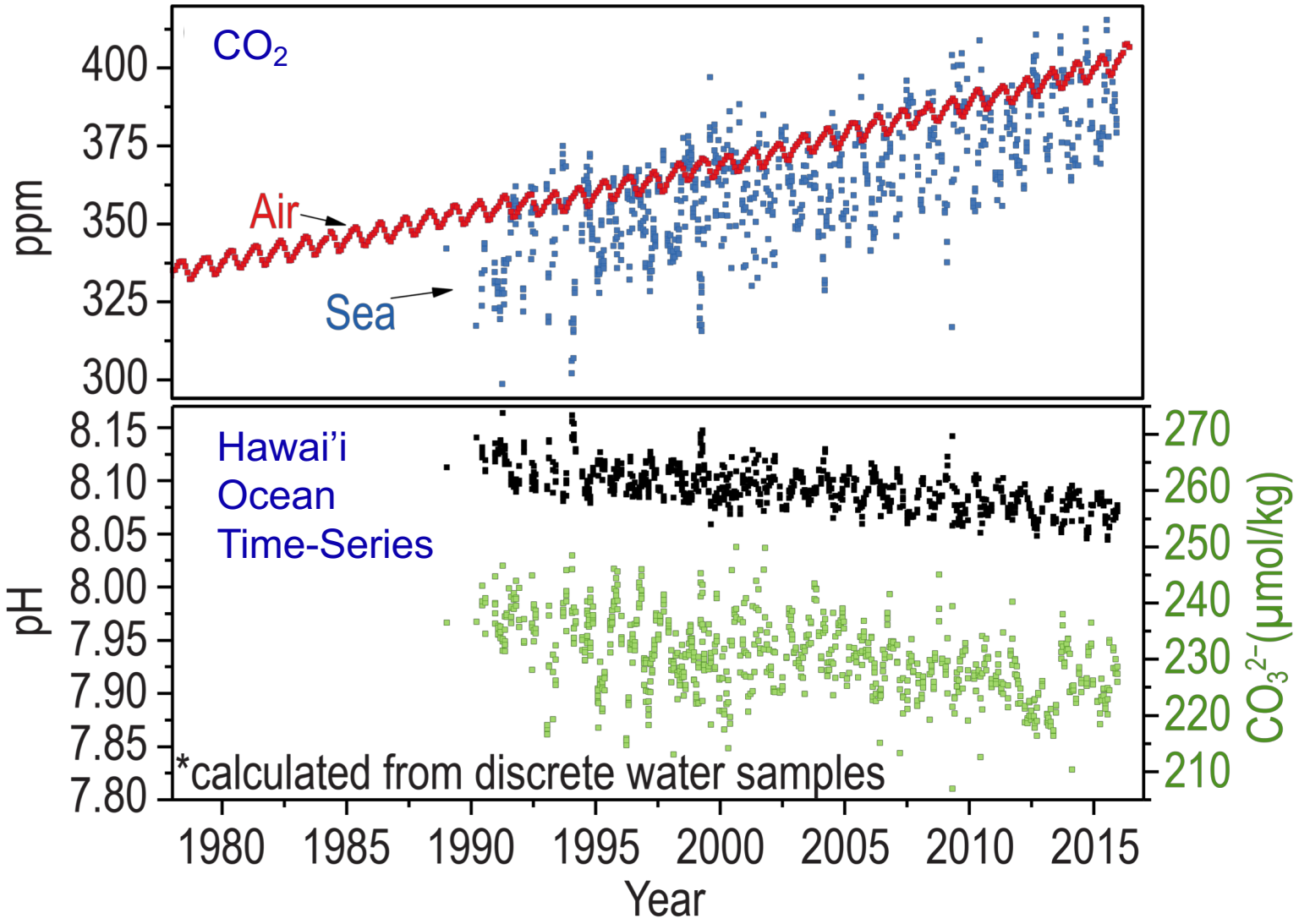


Breitburg et al. Science 2018



Kelly et al. Science 2011

Rising Atmospheric Carbon Dioxide (CO_2) & Ocean Acidification



Jewett & Romanou 2017
Climate Science Special Report

$$CO_2 + H_2O \longrightarrow H^+ + HCO_3^-$$

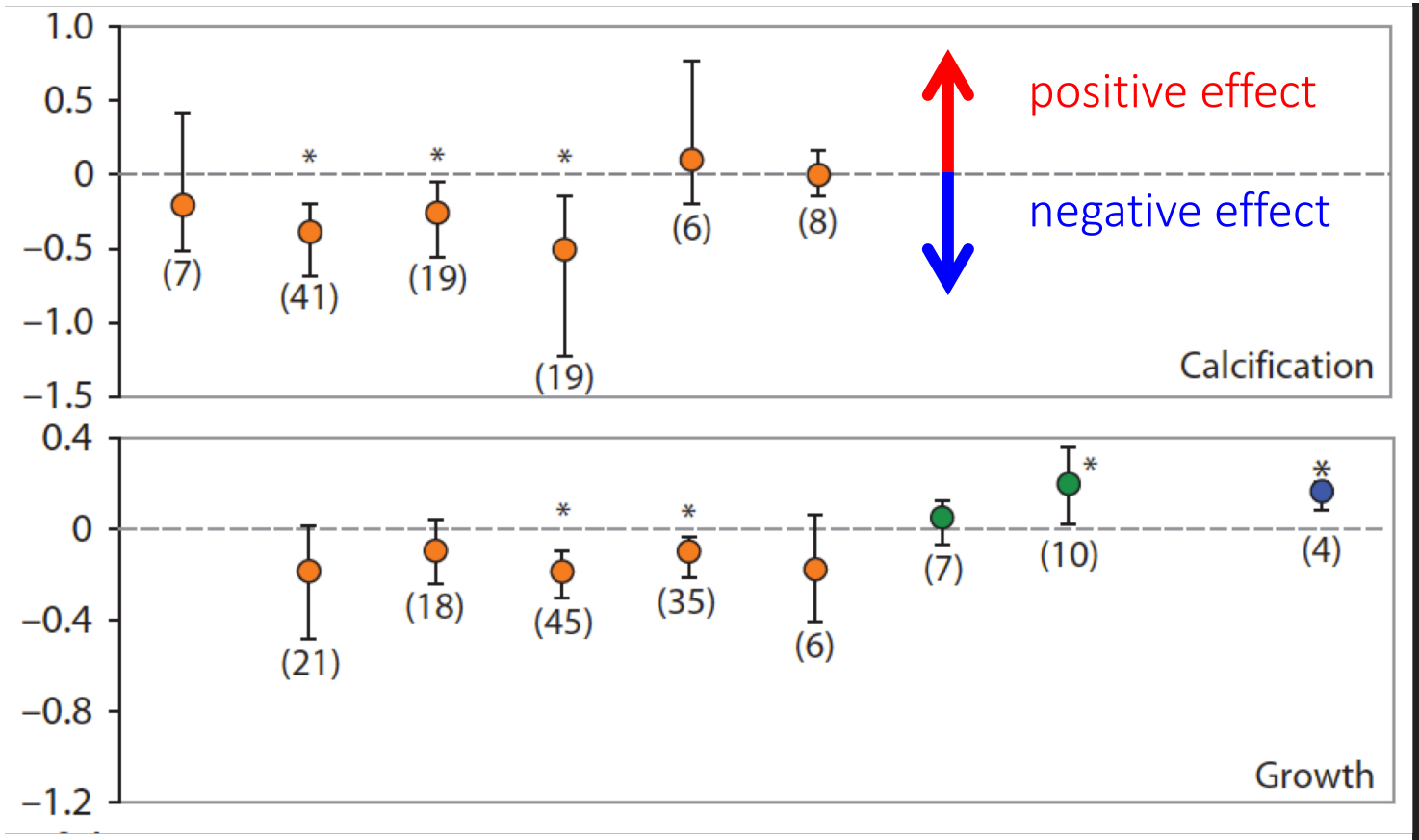
$$H^+ + CO_3^{2-} \longrightarrow HCO_3^-$$

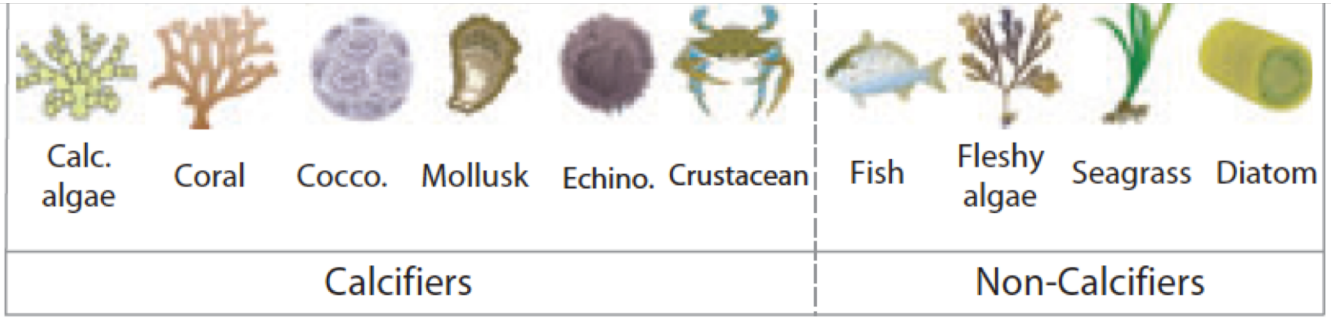
Ocean uptake of CO_2 causes:

- elevated CO_2 & inorganic carbon used by plants & phytoplankton
- acidification (lower pH)
- reduced carbonate ion used to build shells & corals

See also Fennel et al. 2018
2nd State of the Carbon Cycle Report

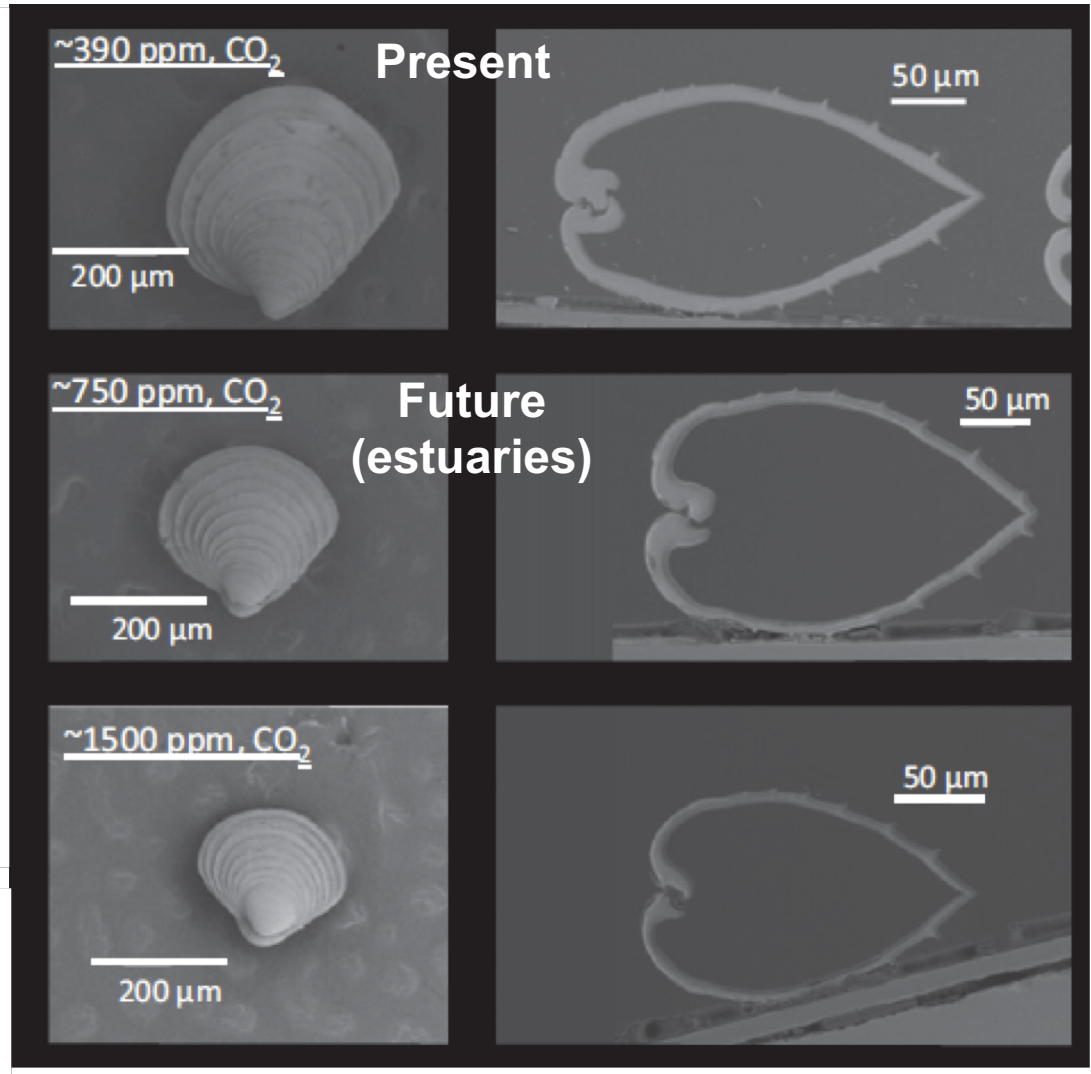
Acidification Biological Impacts





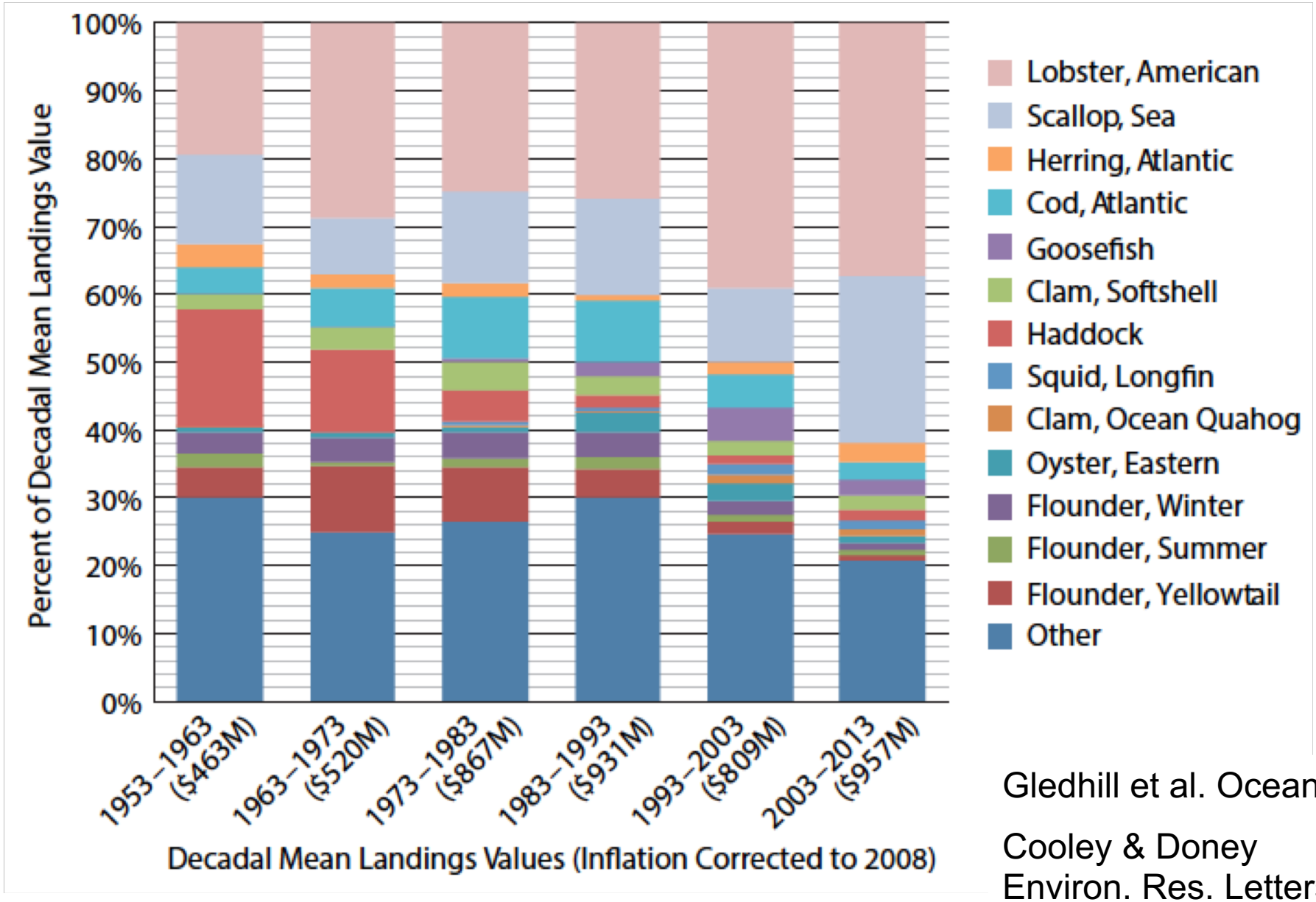
Kroecker et al. Global Change Biology 2013

Negative impacts of CO_2 on mollusks



Talmage et al. PNAS 2010

US Northeast Fisheries (Landings Value)

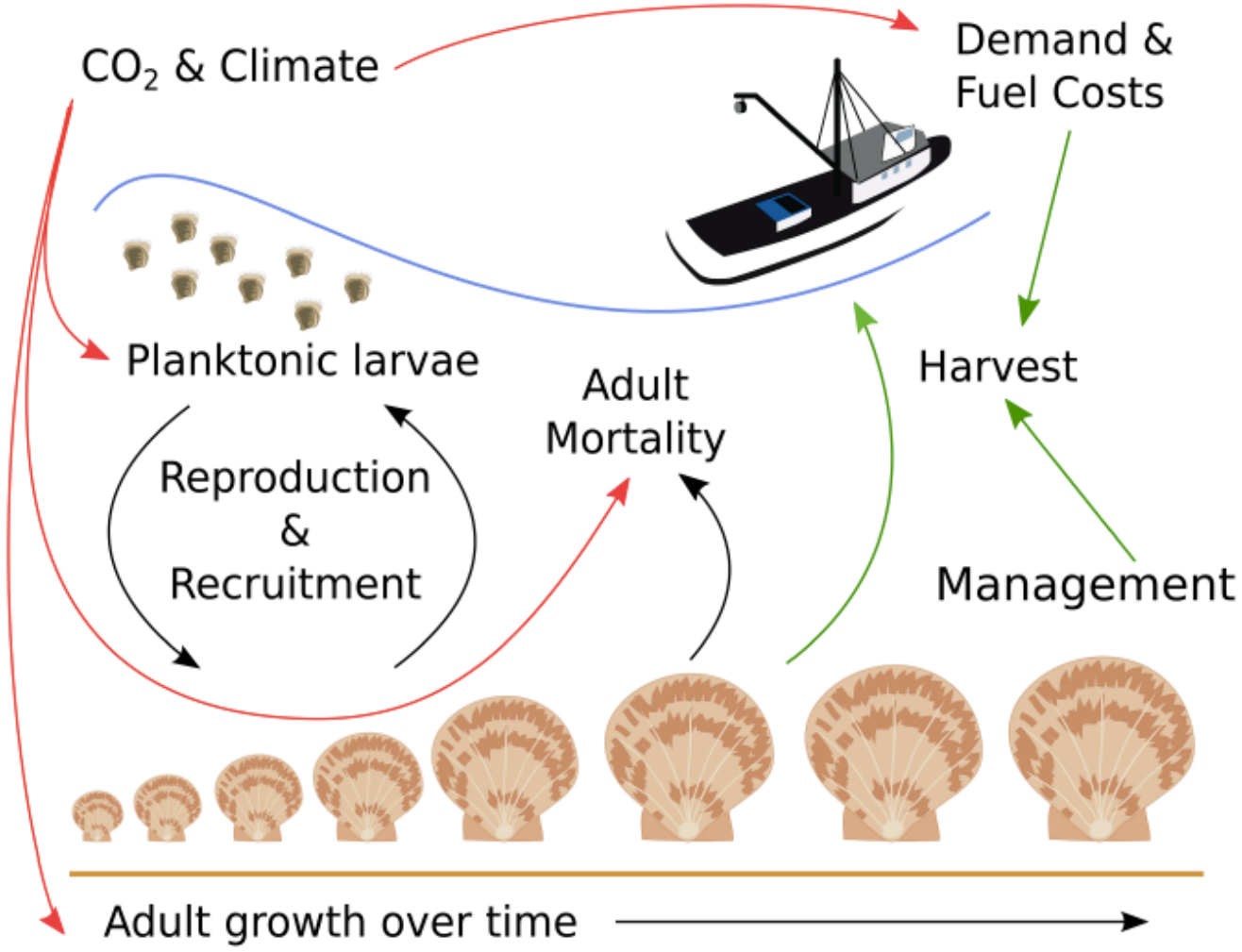


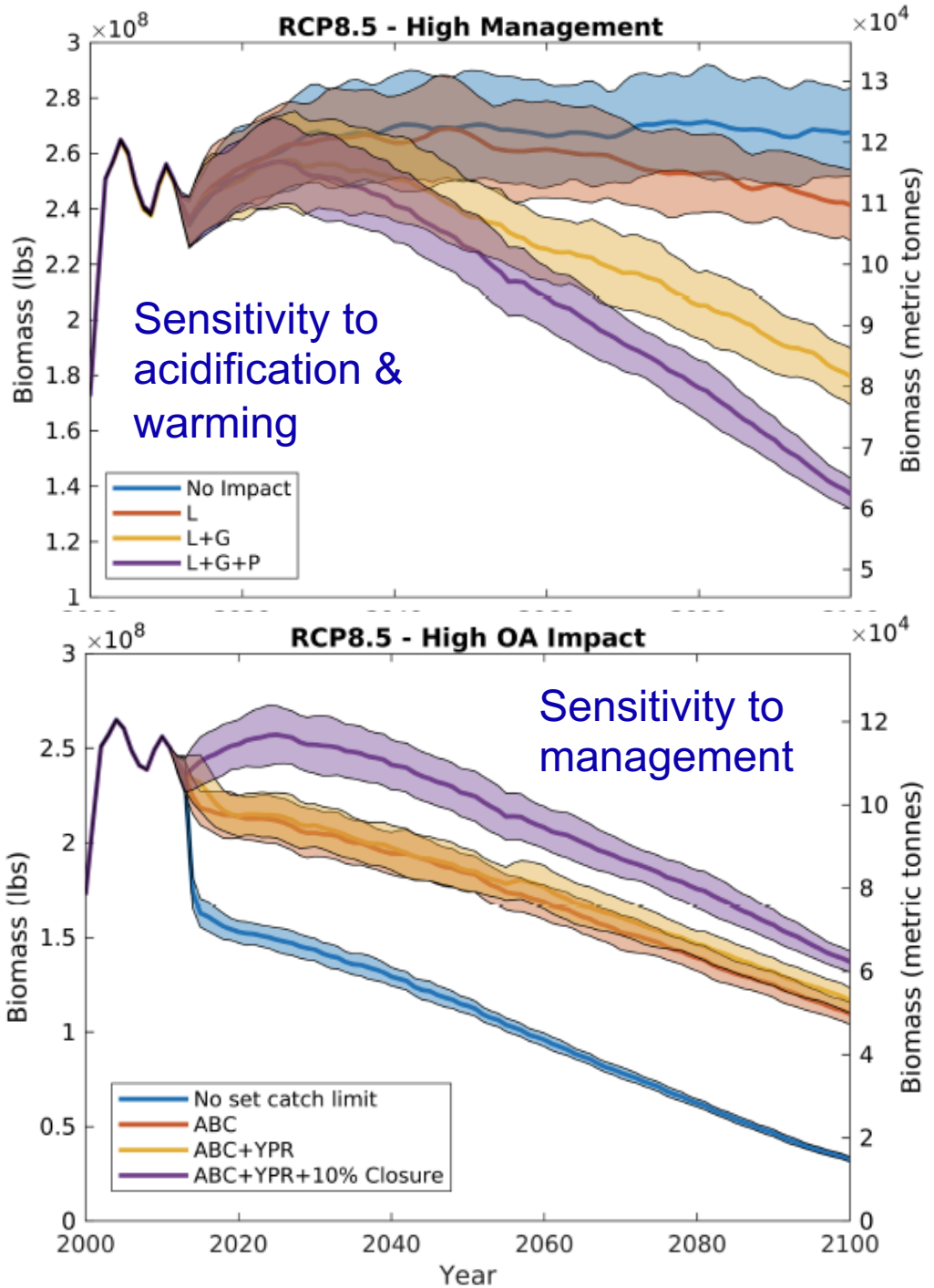
Gledhill et al. Oceanography 2015

Cooley & Doney
Environ. Res. Letters 2009

U.S. Northeast Scallop Fishery

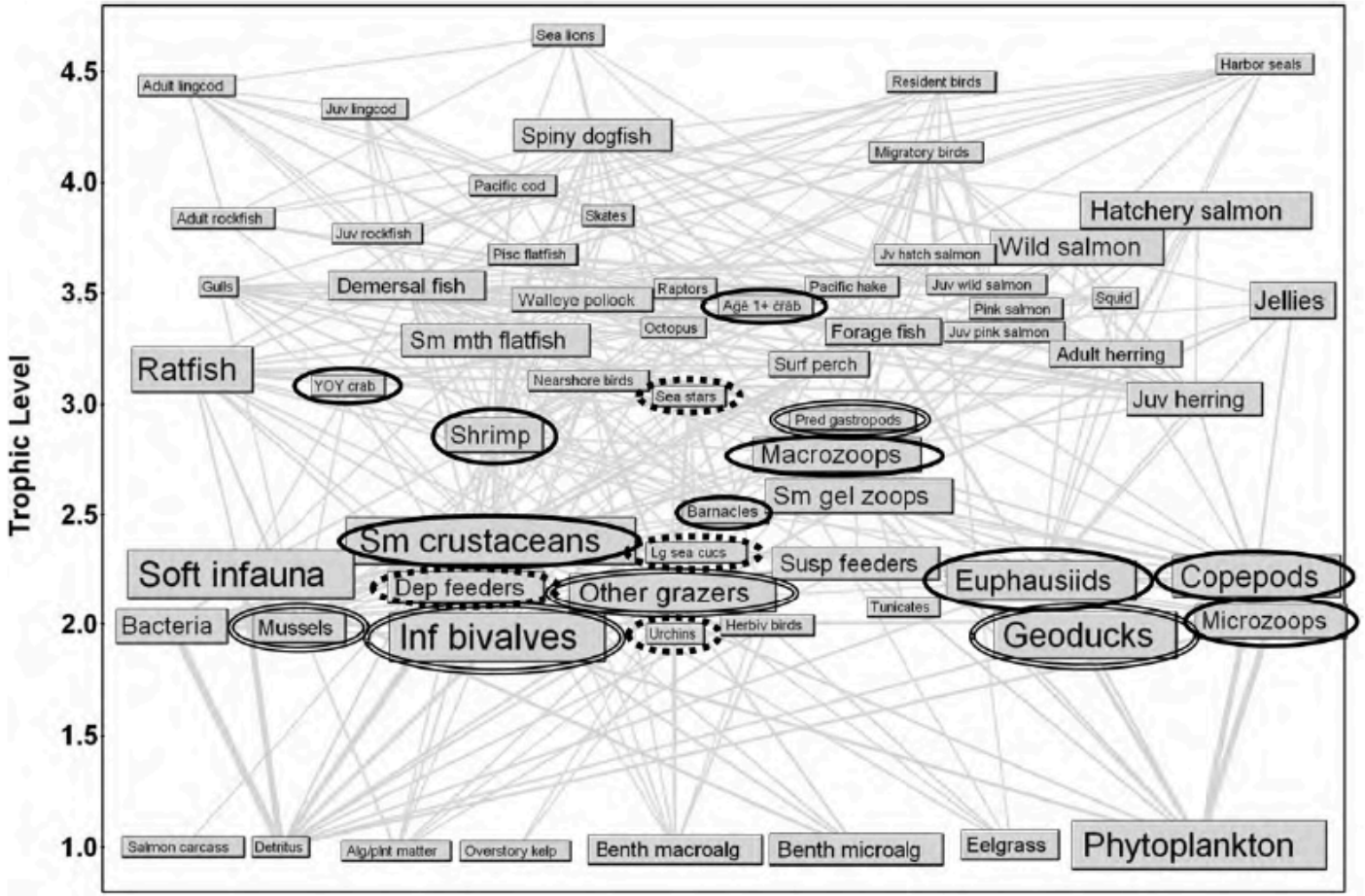
Integrated assessment model: biology, chemistry & socio-economics





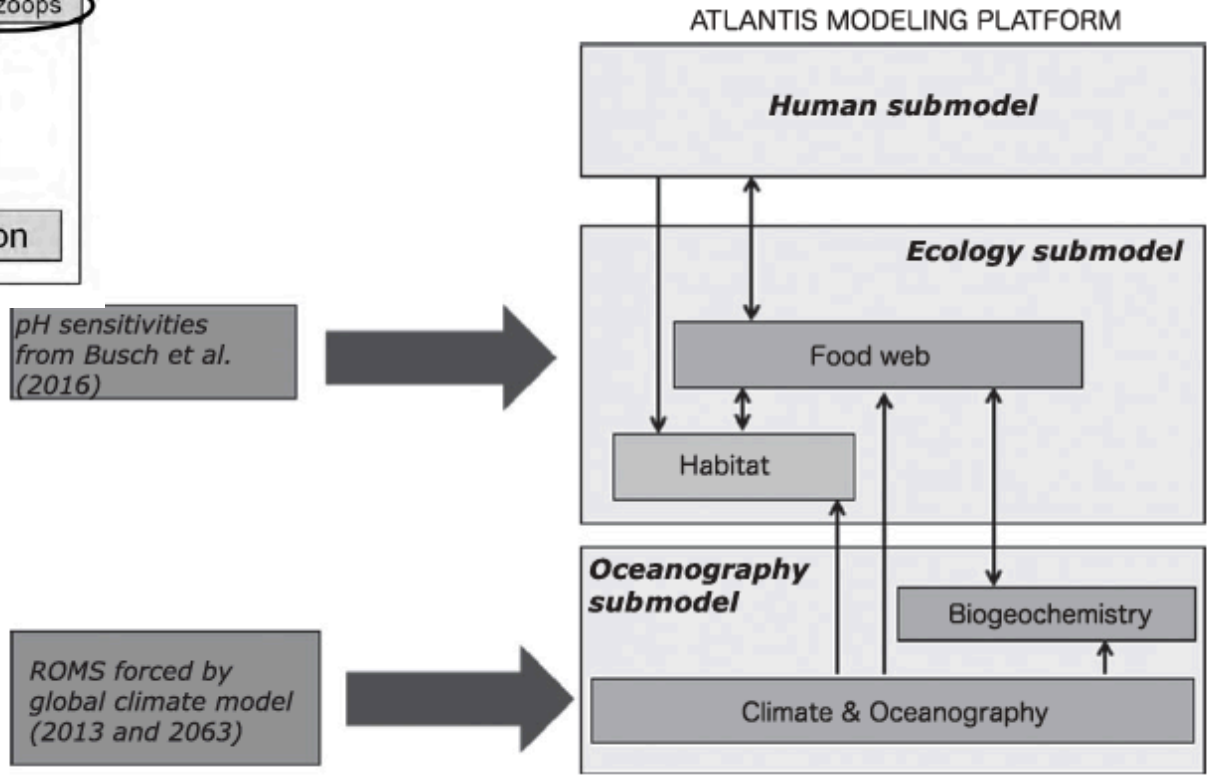
Cooley et al. PLoS One 2015 Rheuban et al. PLoS One 2018

Food-Web Dynamics

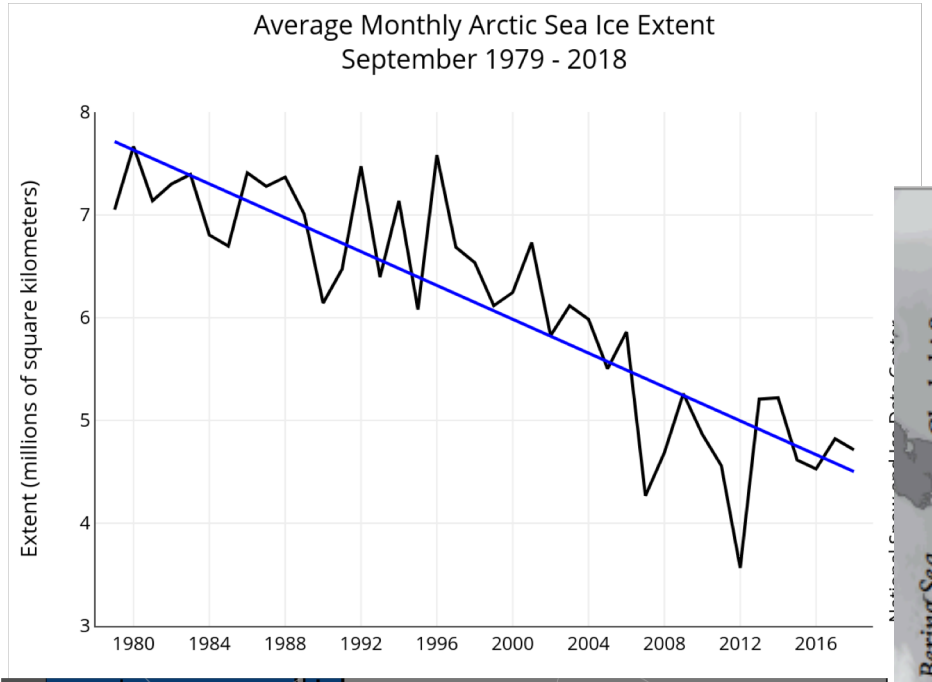


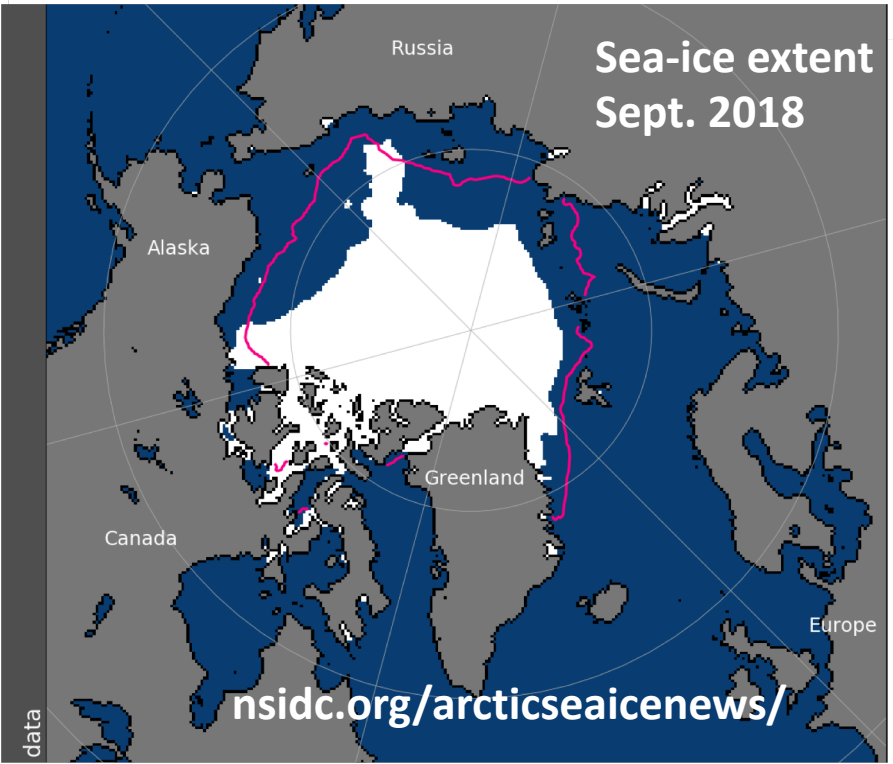
Busch et al.
ICES Journal of Marine Science
2013

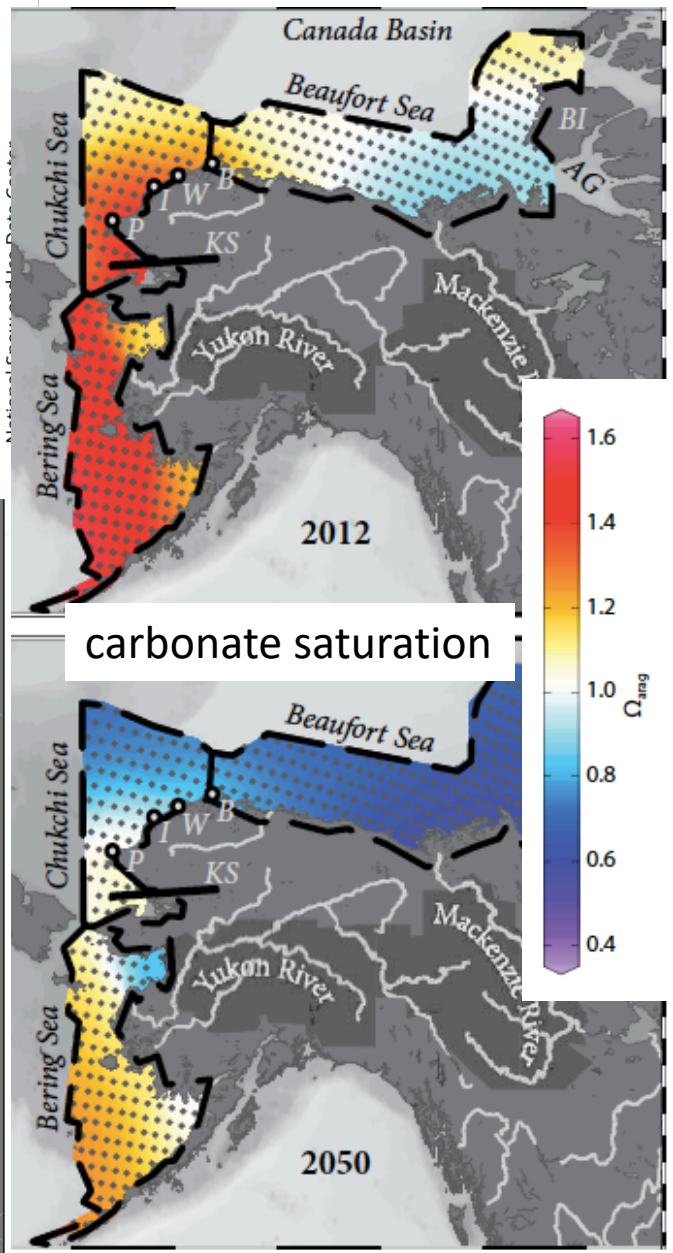
Marshall et al.
Global Change Biology
2017



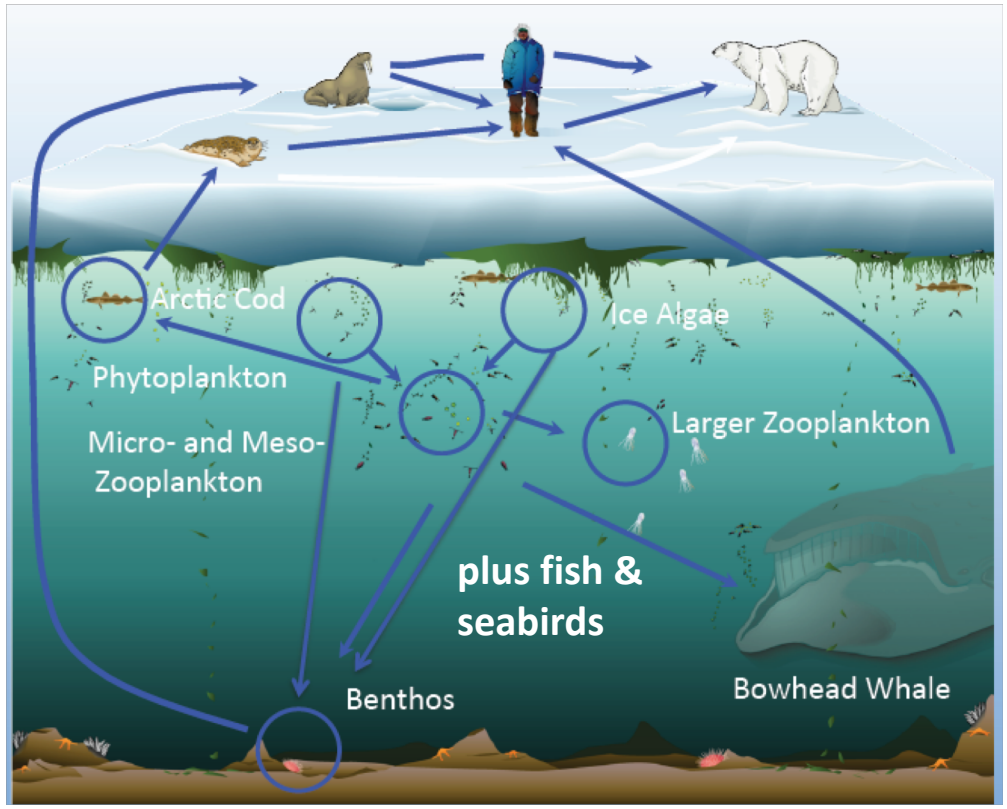
Arctic Climate Change & Acidification





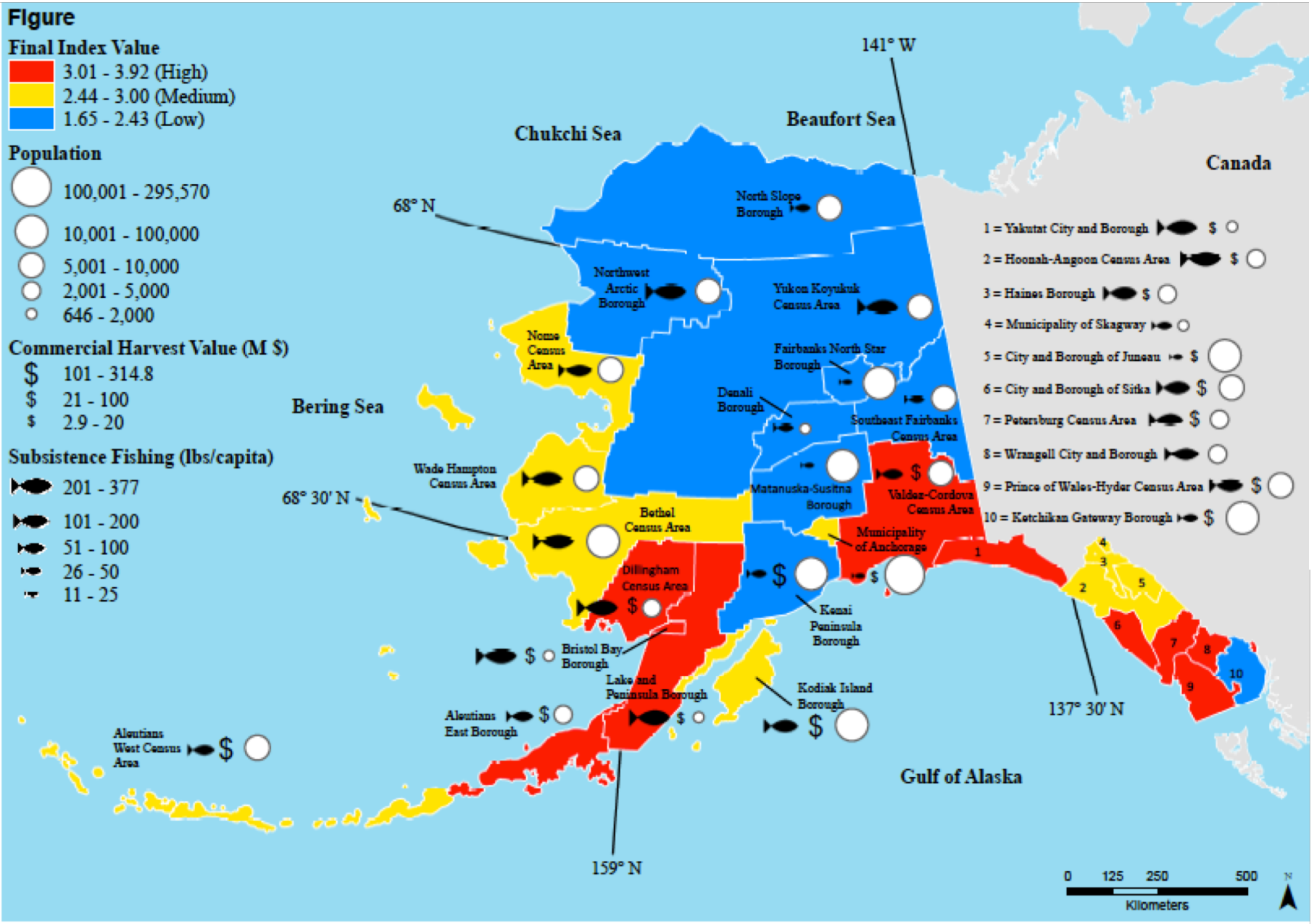


carbonate saturation



Mathis et al. Oceanography 2015

Alaskan Integrated Risk from Ocean Acidification

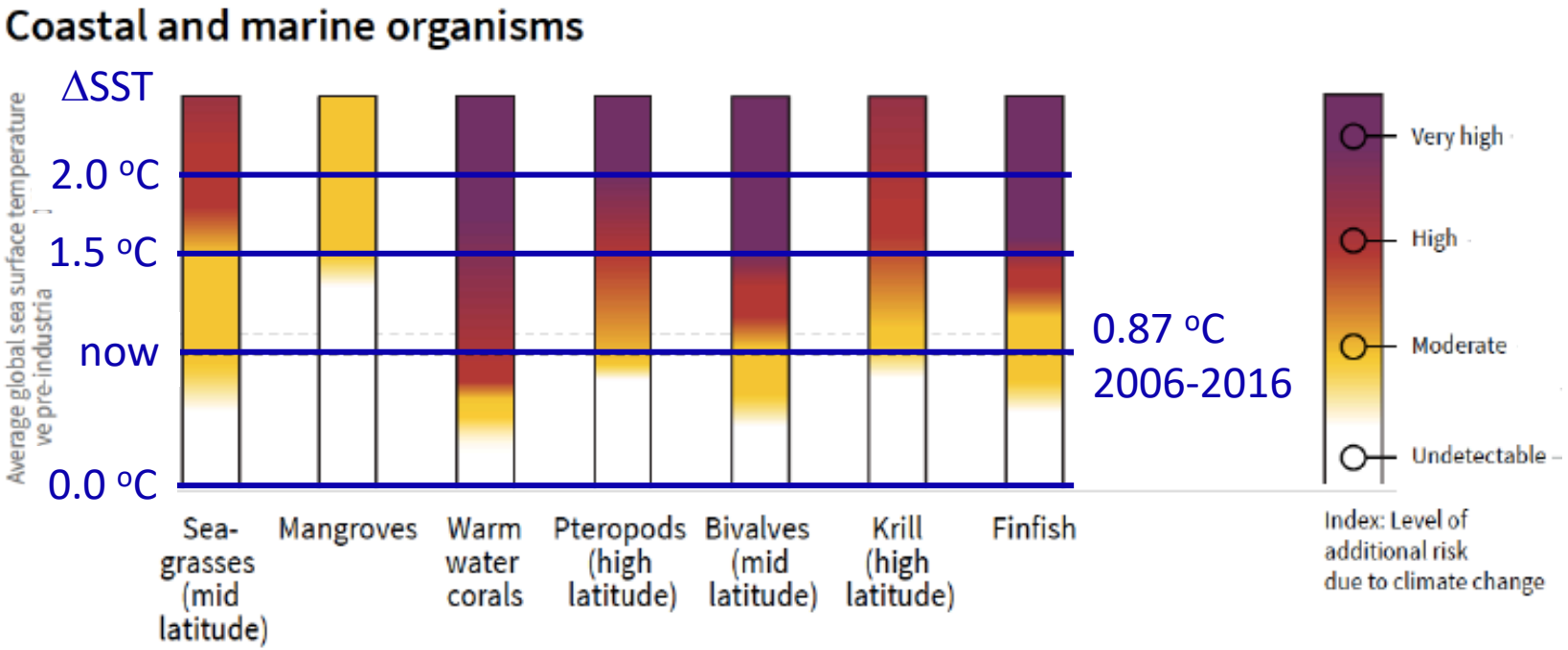


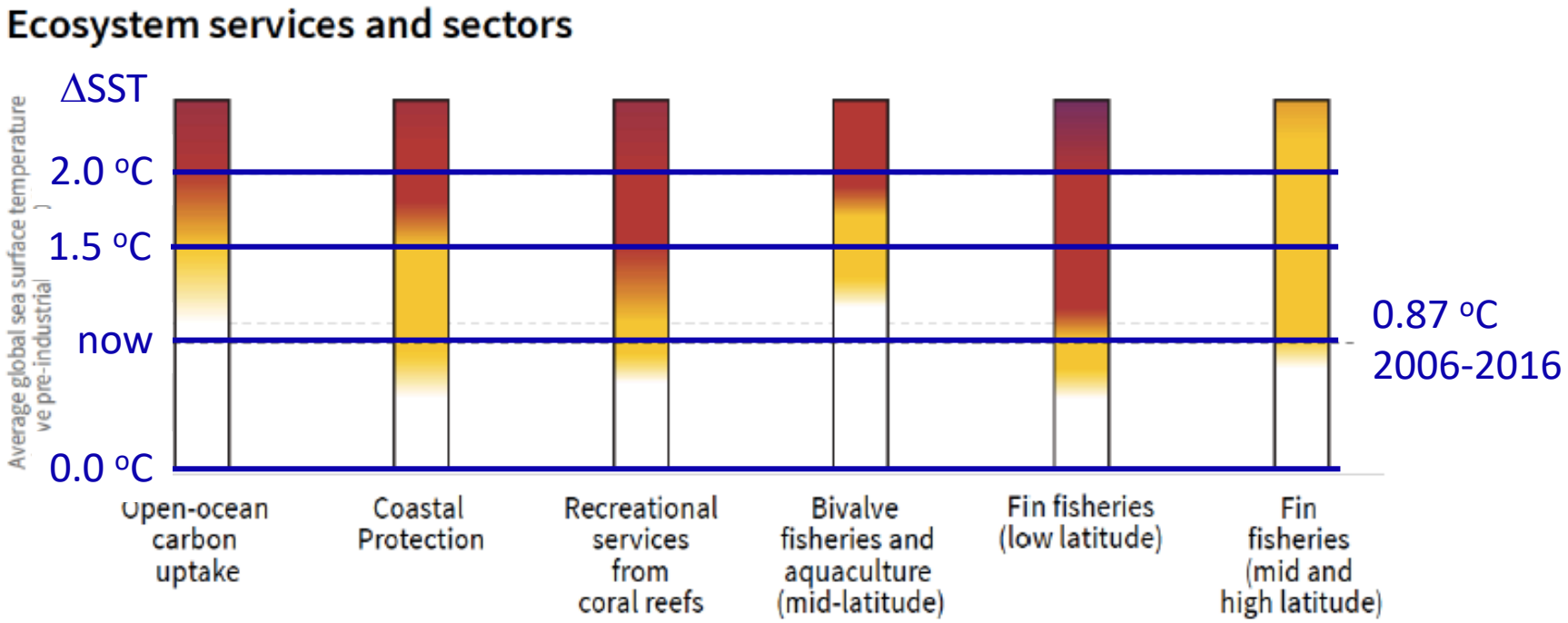
Mathis, Cooley et al.
Prog. Oceanogr. 2015

Ecosystem Services & Public Goods

Ocean Health Index
Halpern et al. Nature 2012

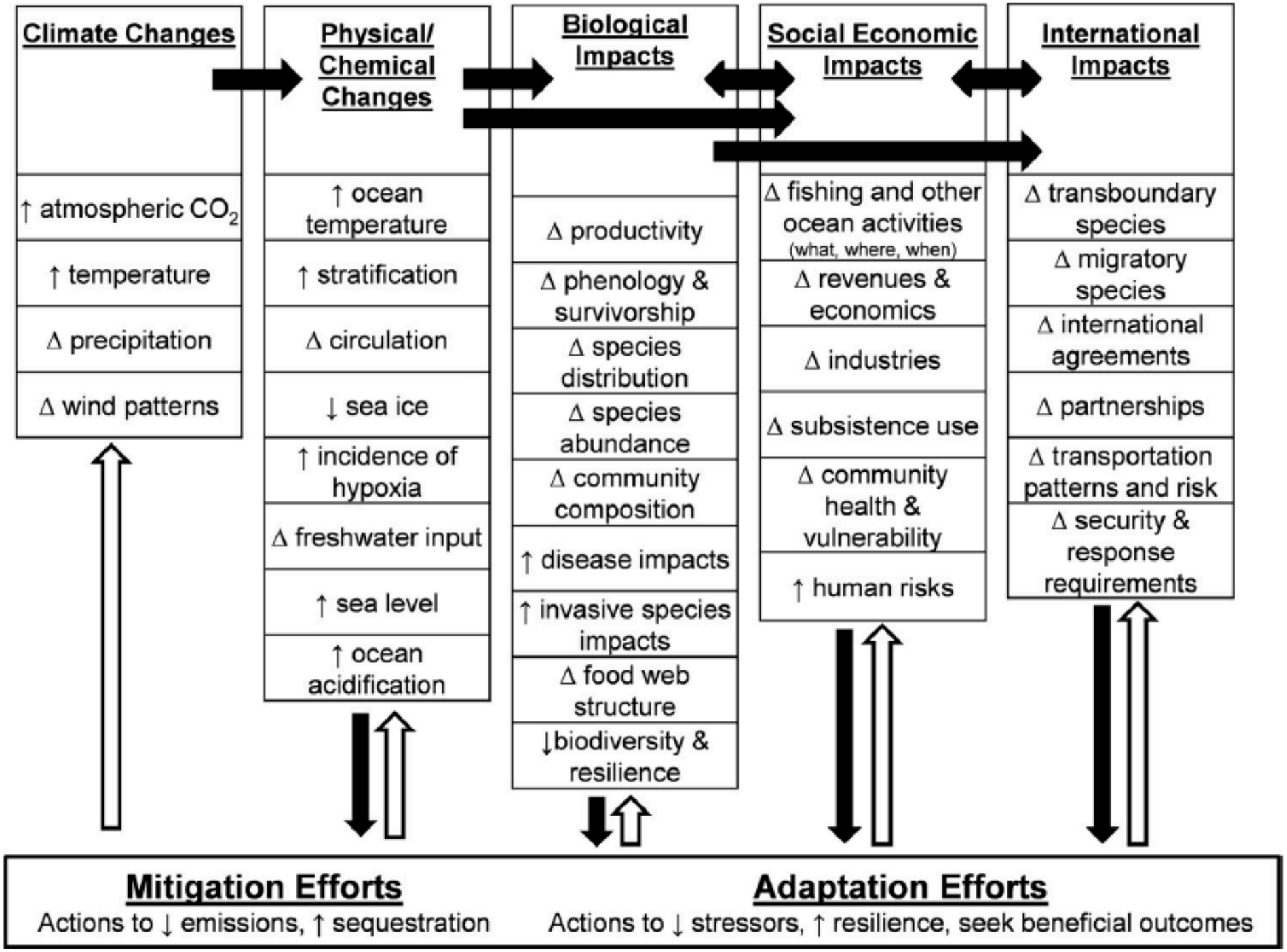
Marine Ecosystem Thresholds





Hoegh-Guldberg et al.
IPCC 1.5 °C Special Report

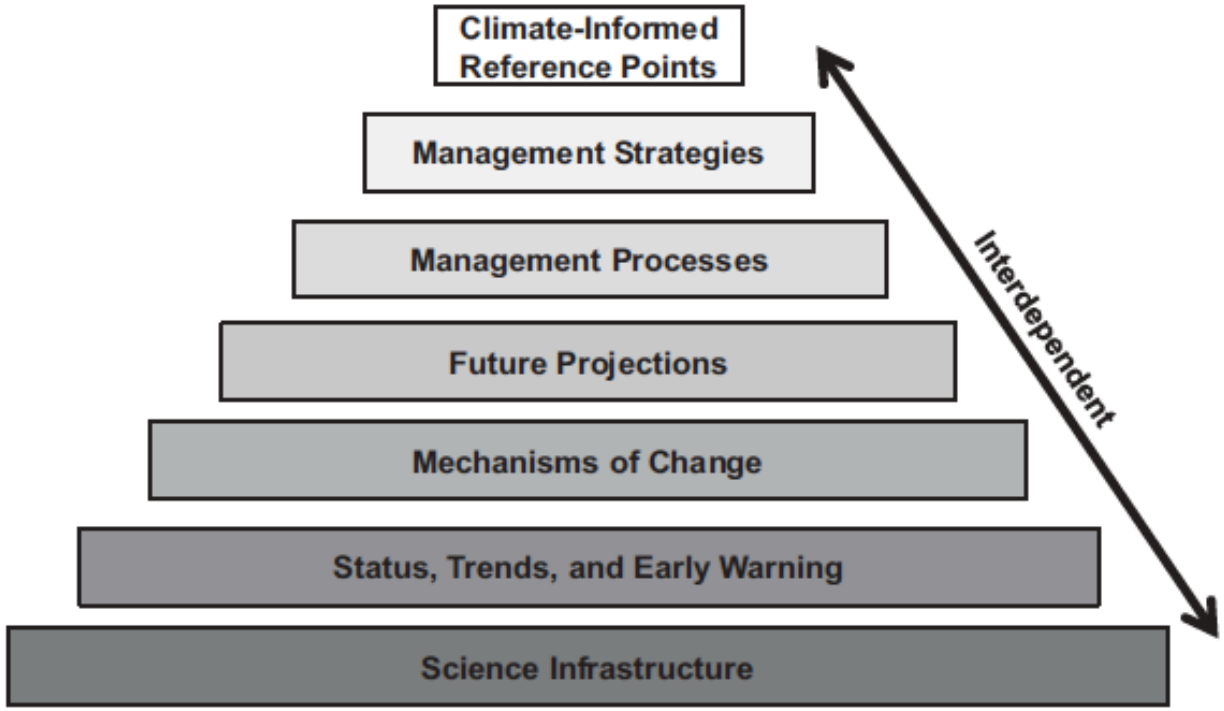
NMFS Climate Science Strategy



Busch et al.
Marine Policy 2016

Applying Principled Flexibility to Resource Management

NOAA Fisheries Climate Vulnerability Assessment



Strategies

- Continuous monitoring
- Fully embrace precautionary principle – instead of MSY use “clearly sustainable”
- Minimize multiple stressors
- Incentivize adaptation and commit to adaptive management
- Preserve ecosystem connectivity
- Increase long term planning and coordination across governments and jurisdictions
- Enable management goals to reflect changing baselines

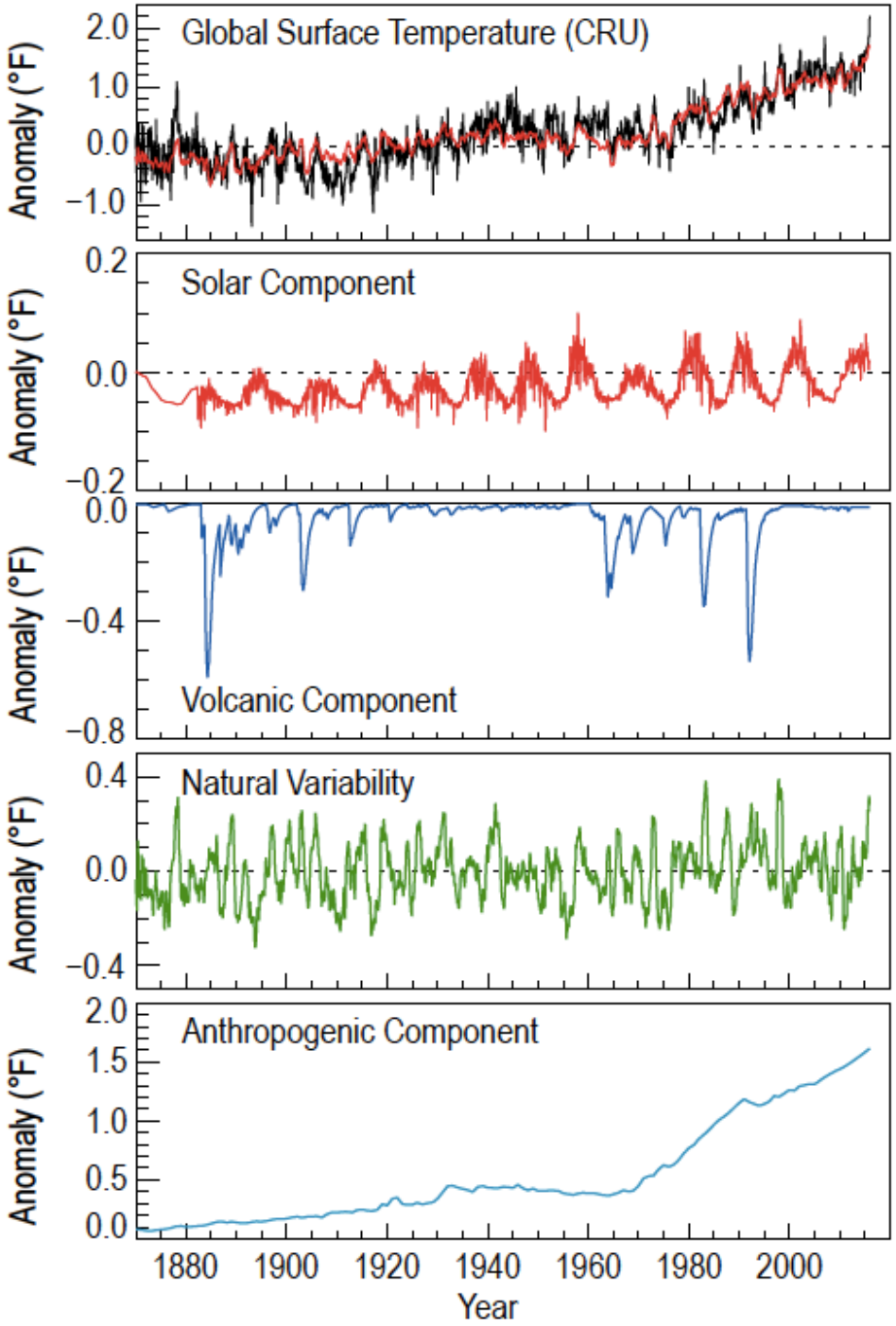
Processes

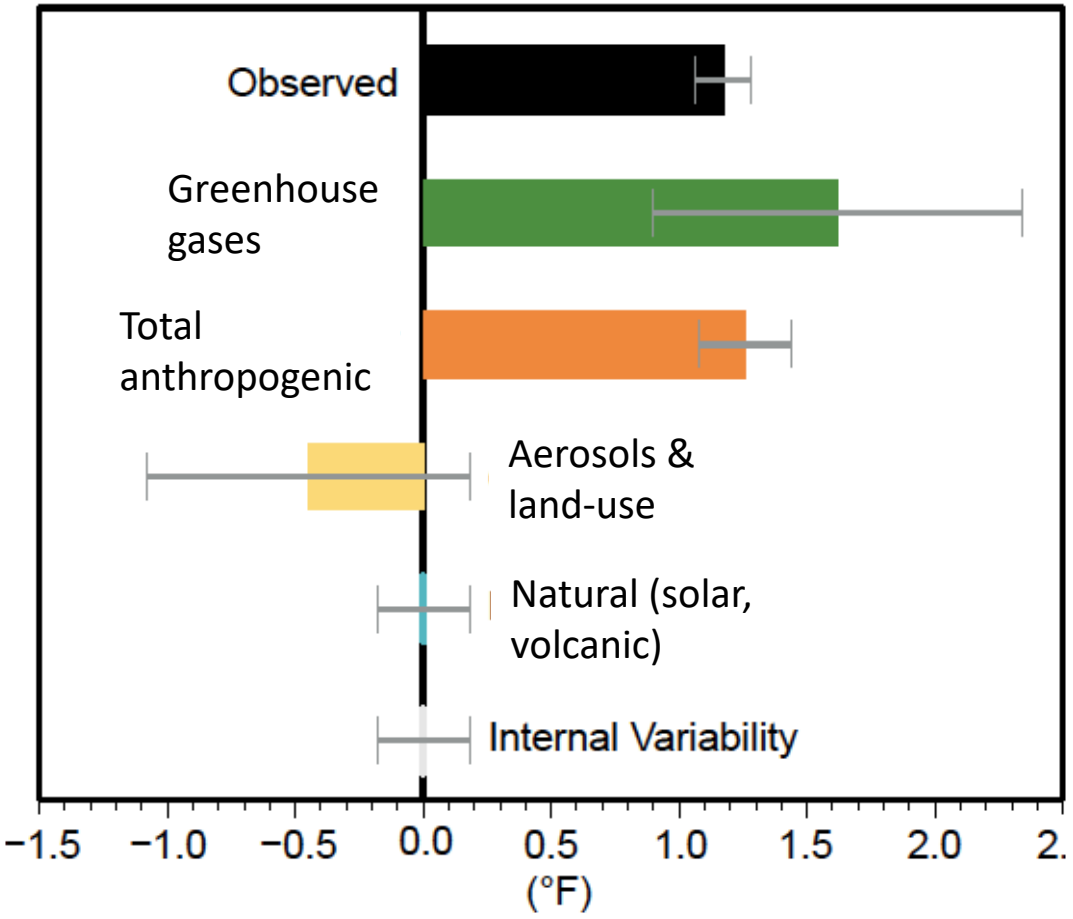
- Science based decision making
- Ecosystem based management
- Marine planning
- Assessing ecosystem services

Whit Saumweber
Center for Strategic and International Studies

Extra Slides

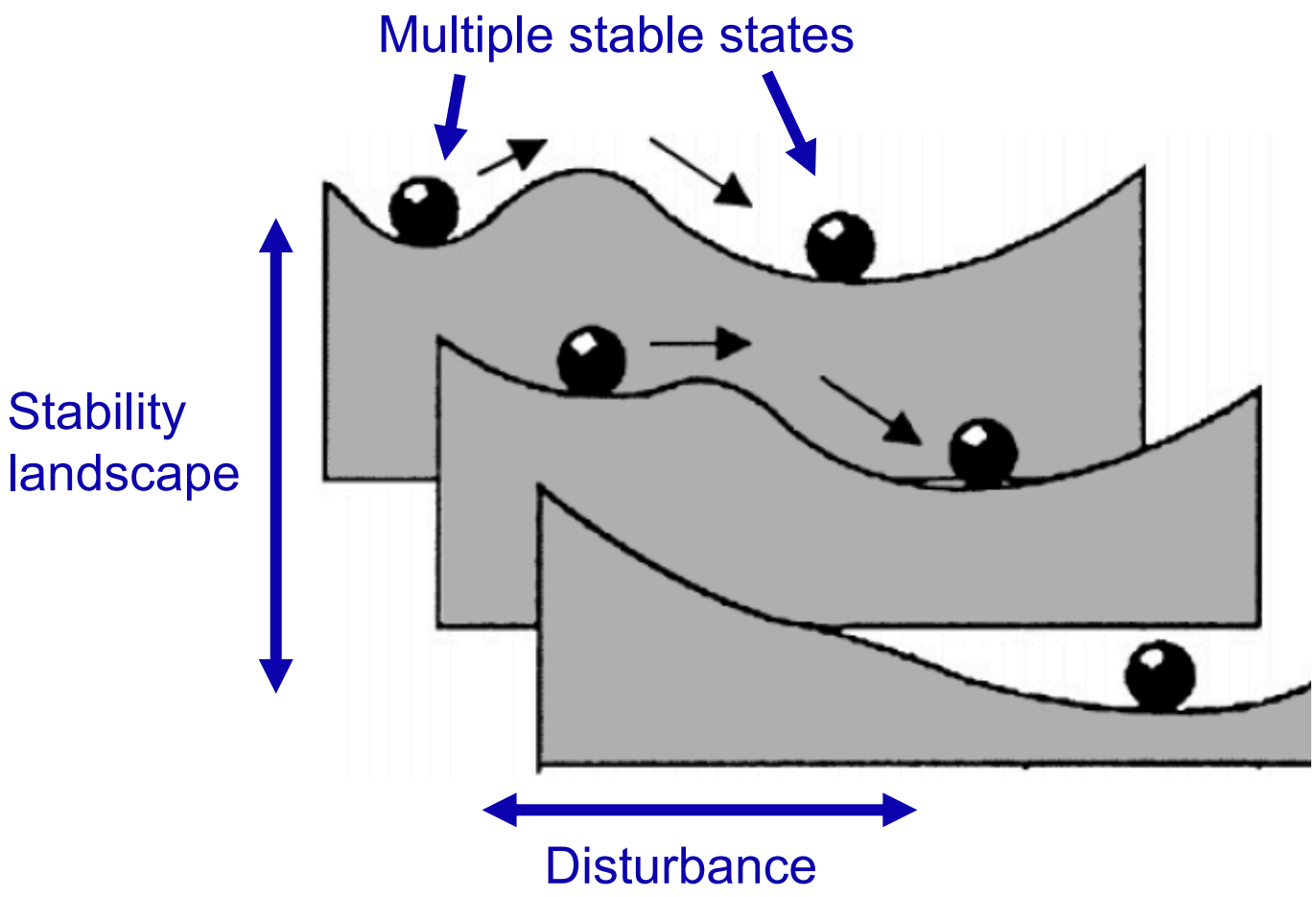
Attribution & Detection of Human Climate Impacts





Climate Science Special Report 2017

Ecological Resilience, Adaptation & System Evolution



Perturbations can alter response of complex social-ecological systems

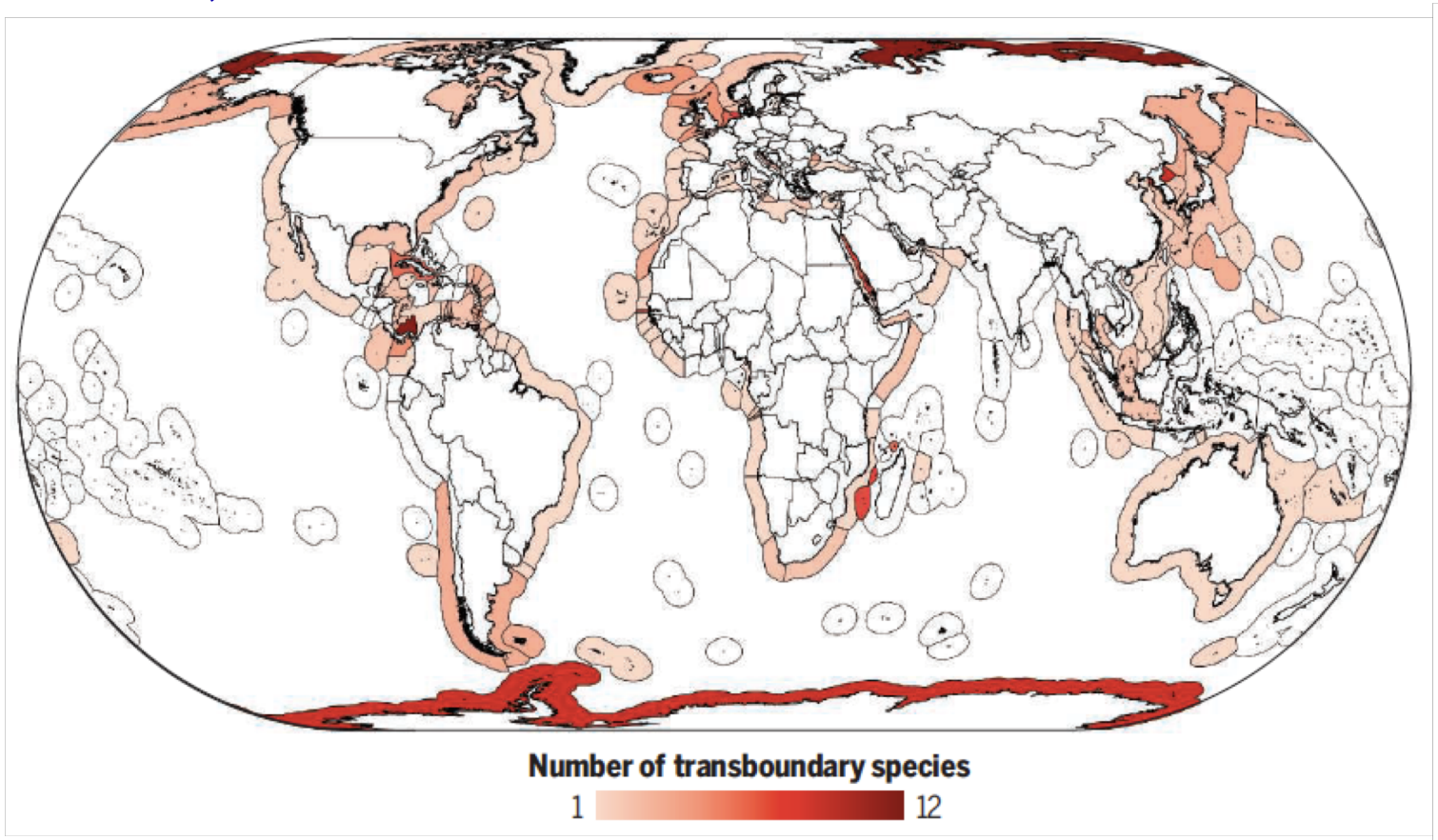
Resilient systems:

- diversity
- connectivity
- adaptive capacity

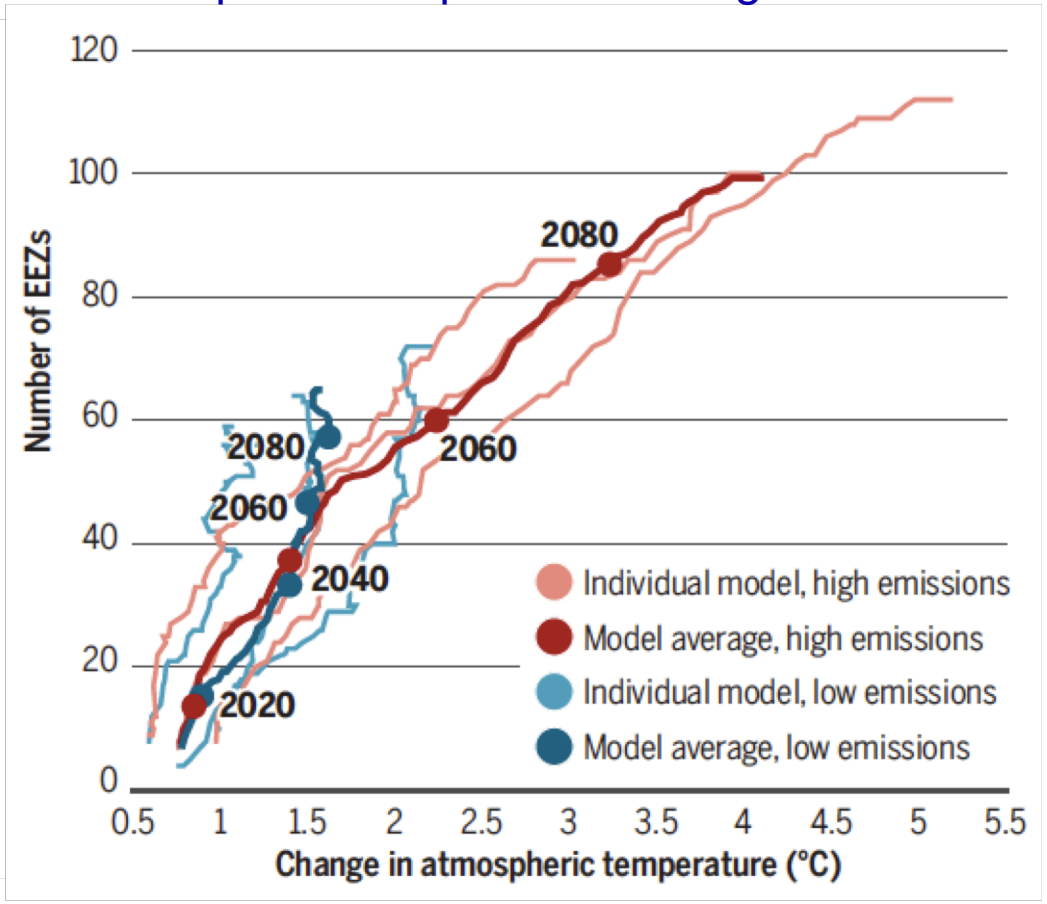
Gunderson Ann. Rev. Ecol. Syst. 2000

Transboundary Stock Shifts

of transboundary species by Exclusive Economic Zones (EEZs)
RCP8.5; 2100 relative to 1950-2014

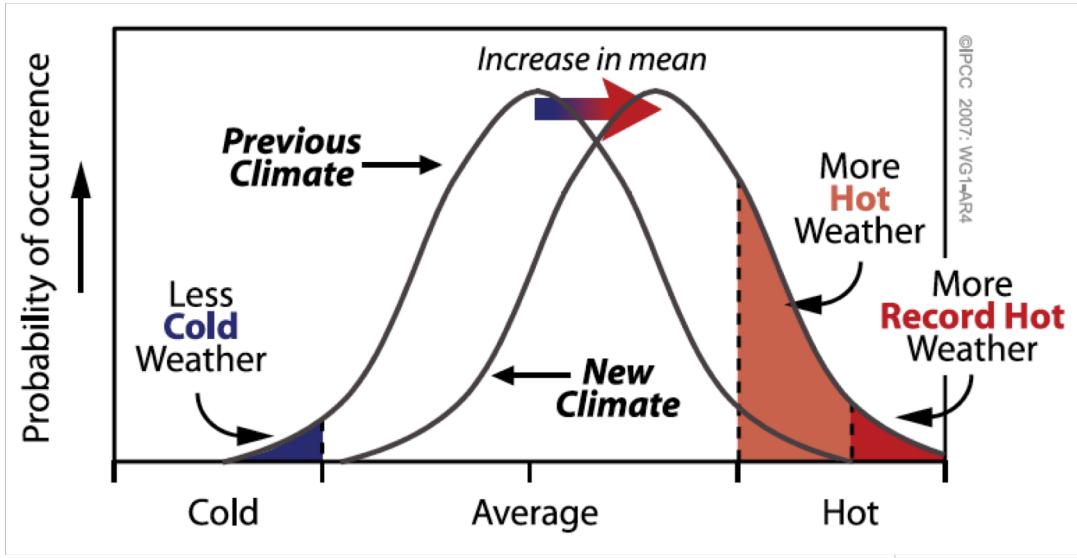


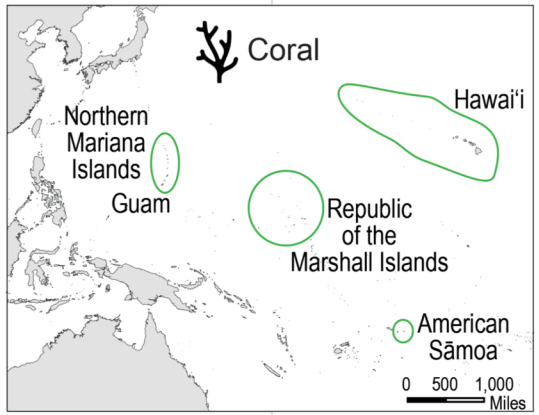
# of EEZs with transboundary species relative to atmospheric temperature change

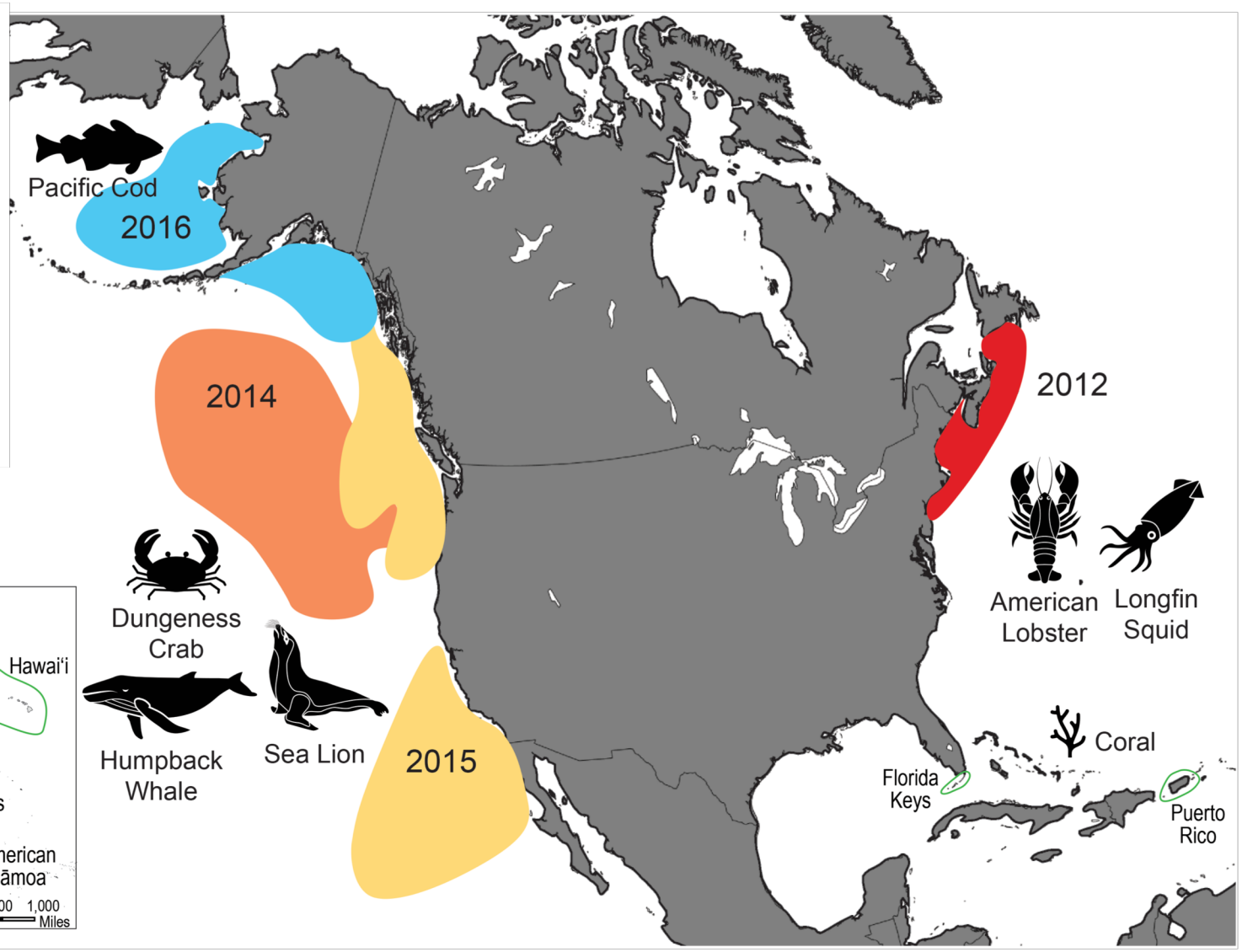


Pinsky et al. Science 2018

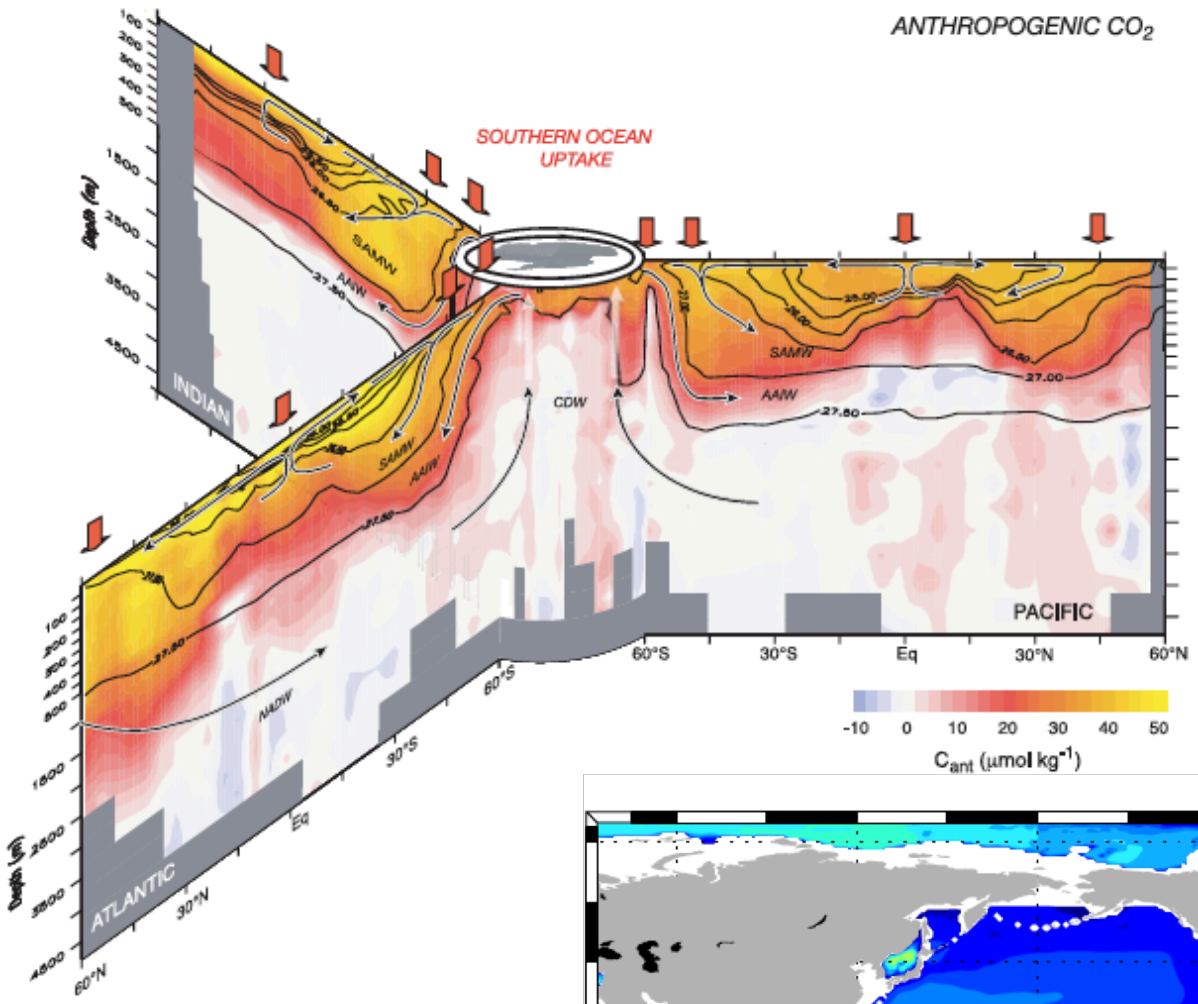
Ocean Climate Extreme Events



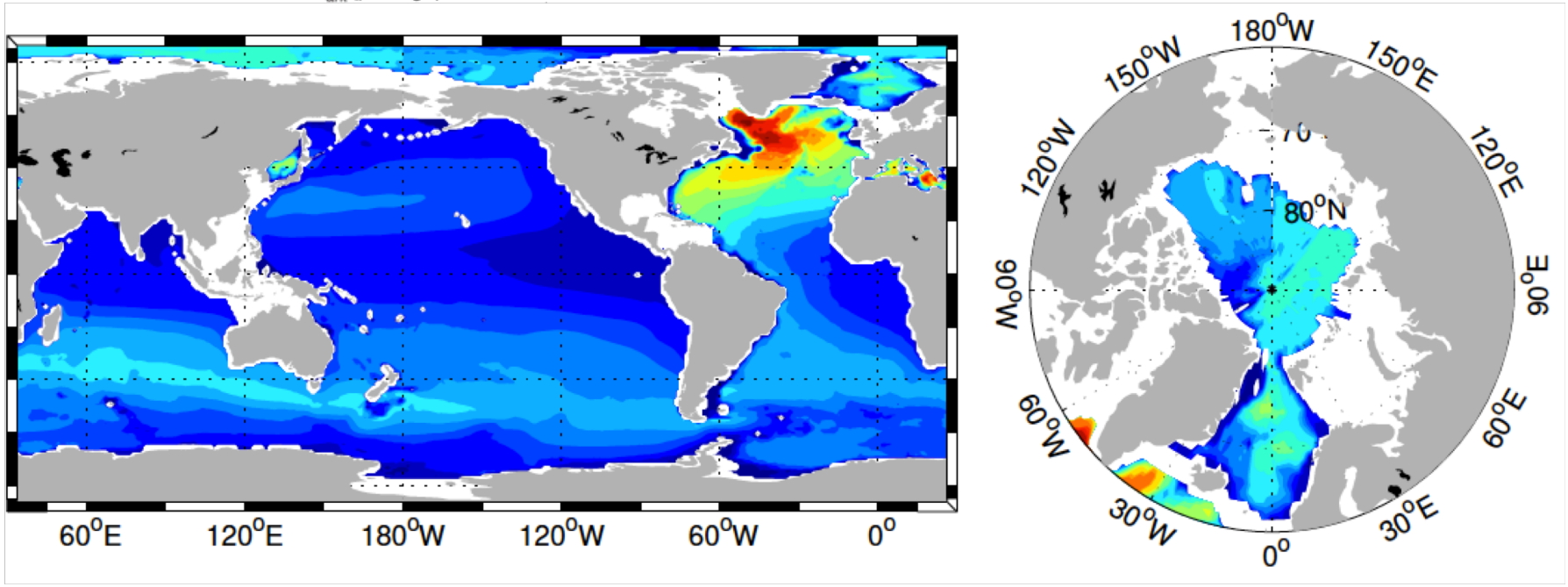




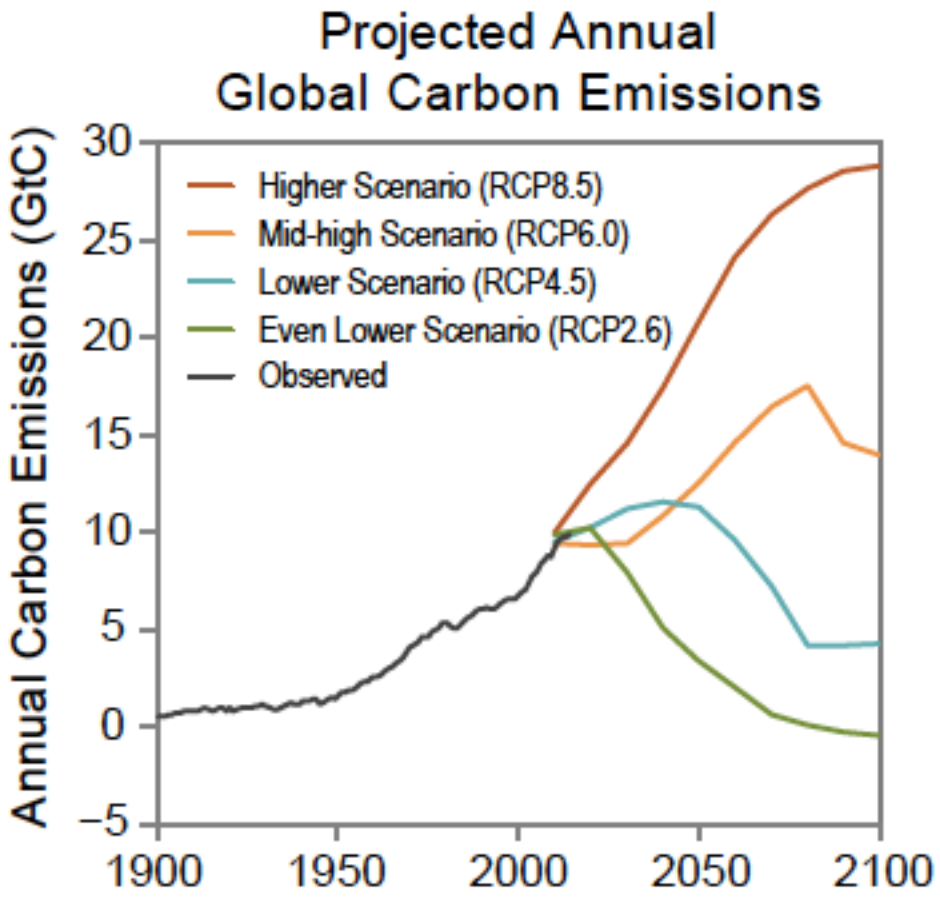
Ocean Anthropogenic CO_2

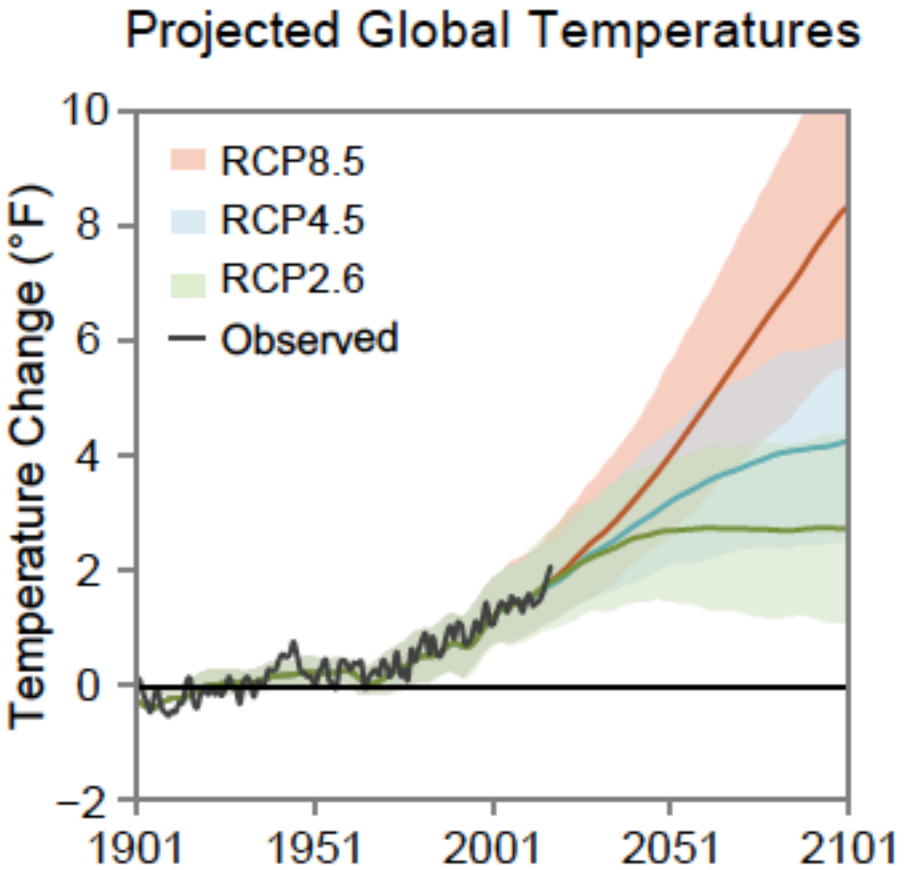


Gruber et al.
Global Biogeochemical Cycles
2009

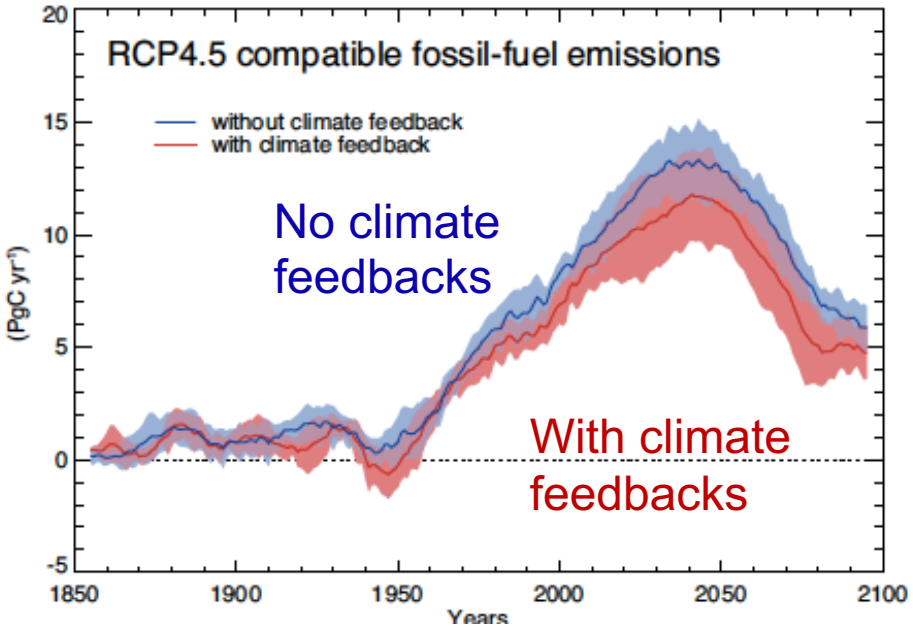


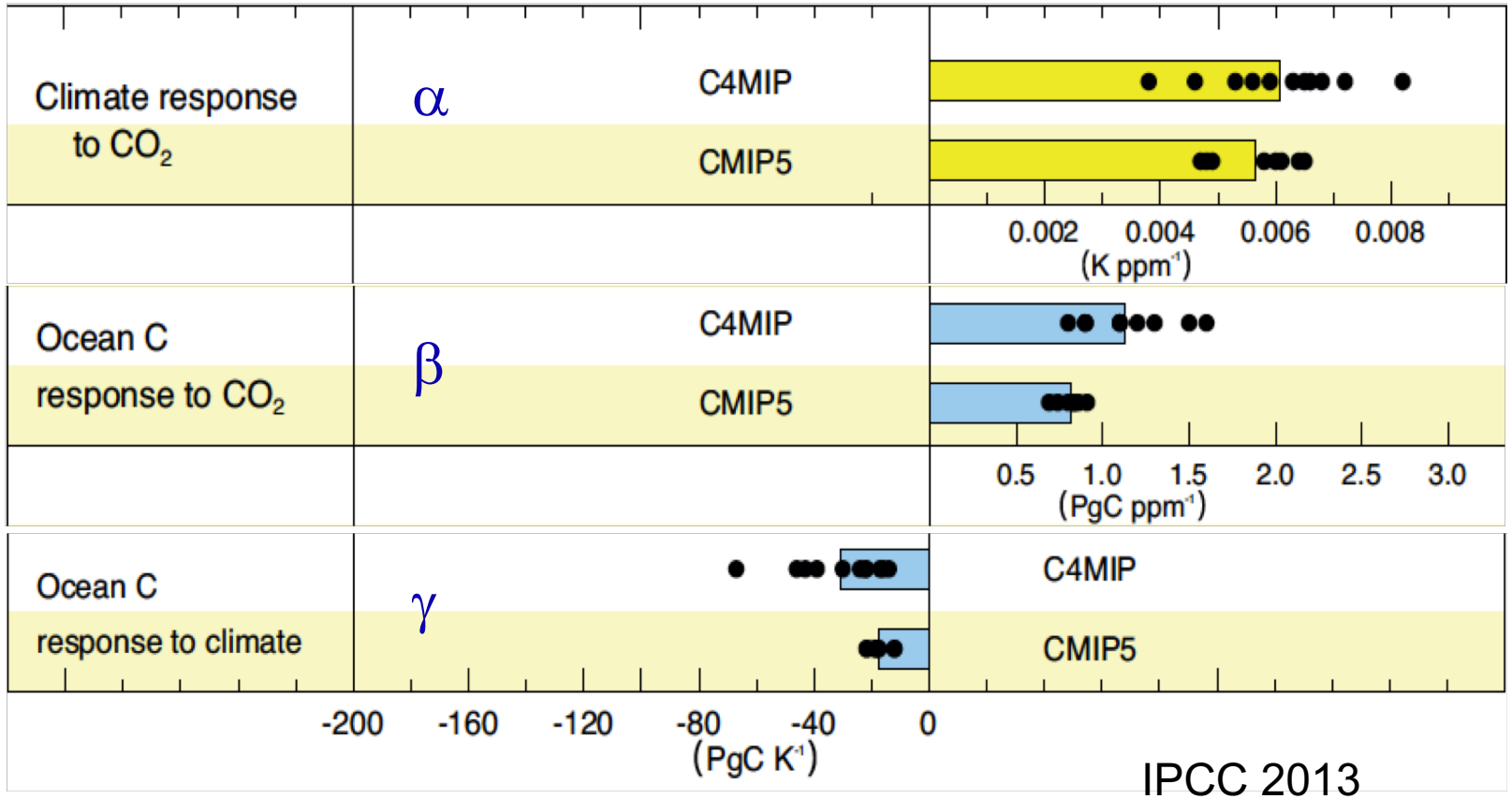
Khatiwala et al.
Biogeosciences 2013


Projected Annual
Global Carbon Emissions
Annual Carbon Emissions (GtC)
30
25
20
15
10
5
0
−5
1900
1950
2000
2050
2100
Higher Scenario (RCP8.5)
Mid-high Scenario (RCP6.0)
Lower Scenario (RCP4.5)
Even Lower Scenario (RCP2.6)
Observed


Projected Global Temperatures
Temperature Change (°F)
10
8
6
4
2
0
−2
1901
1951
2001
2051
2101
RCP8.5
RCP4.5
RCP2.6
Observed

CO_2 & Carbon-Climate Feedbacks





IPCC 2013
WG1 Chapter 6

Climate reduces effectiveness of land and ocean carbon sinks

Results in lower compatible fossil fuel emissions

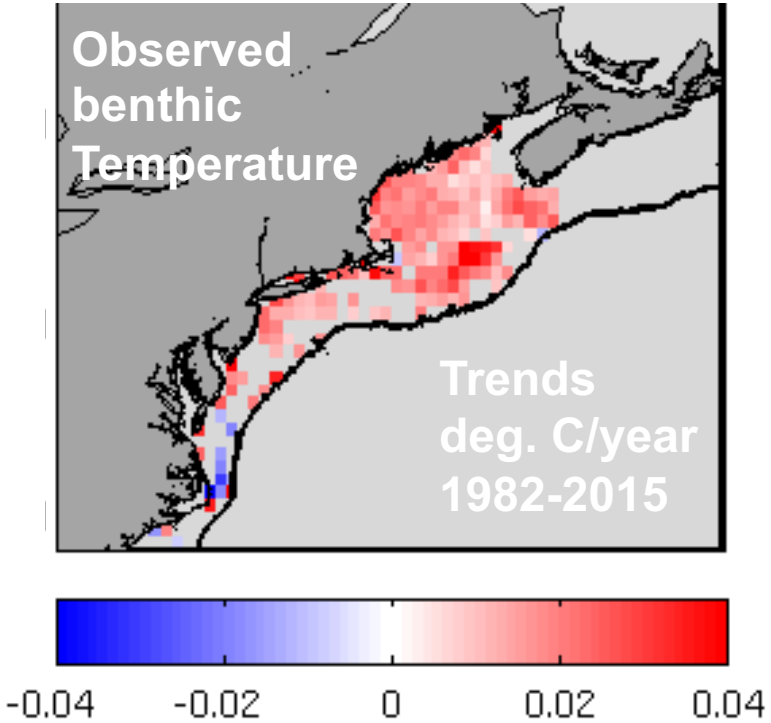
Climate Sensitivity

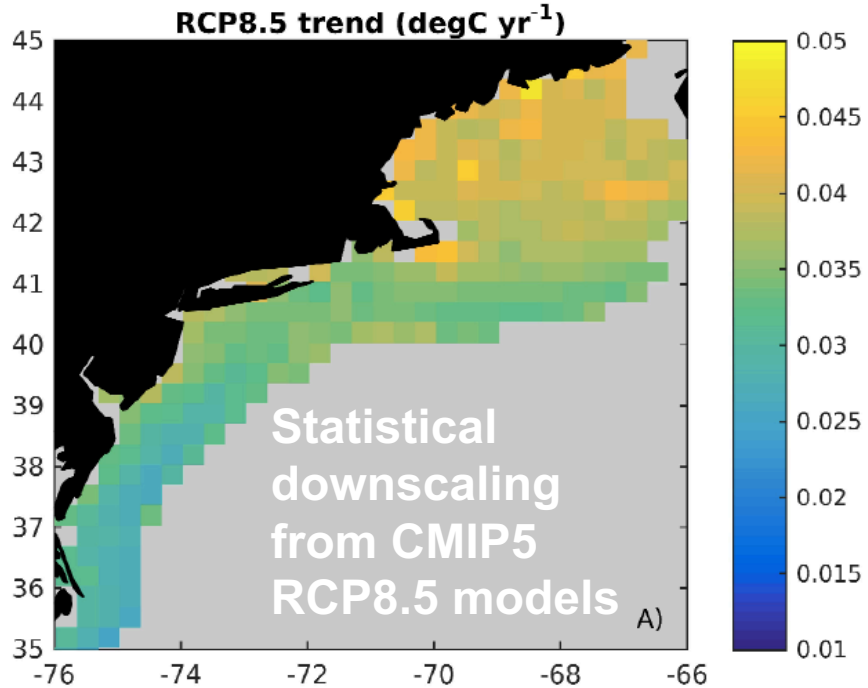
$\Delta T = \alpha \, \Delta CO_2^{atm}$ α (K/ppm)

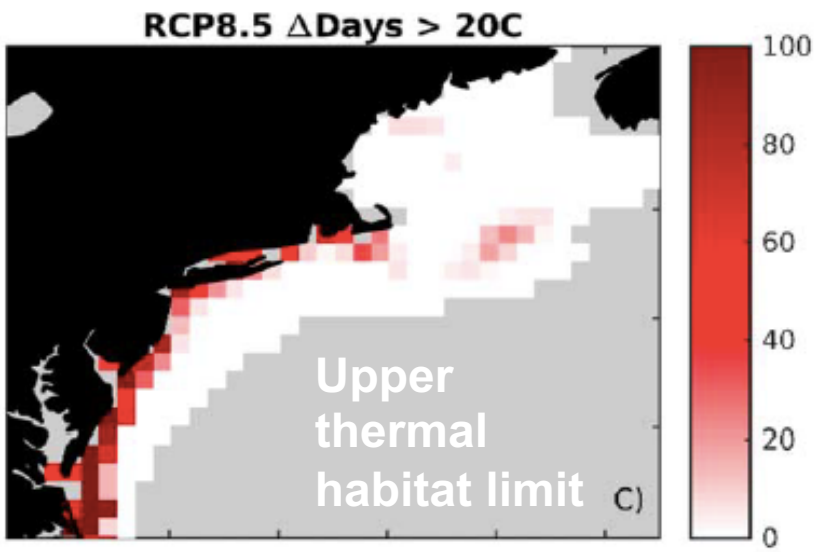
Linear decomposition of cumulative ocean carbon inventory

$\Delta C = \beta \, \Delta CO_2^{atm} + \gamma \, \Delta T$ β (PgC/ppm); γ (Pg C/K)

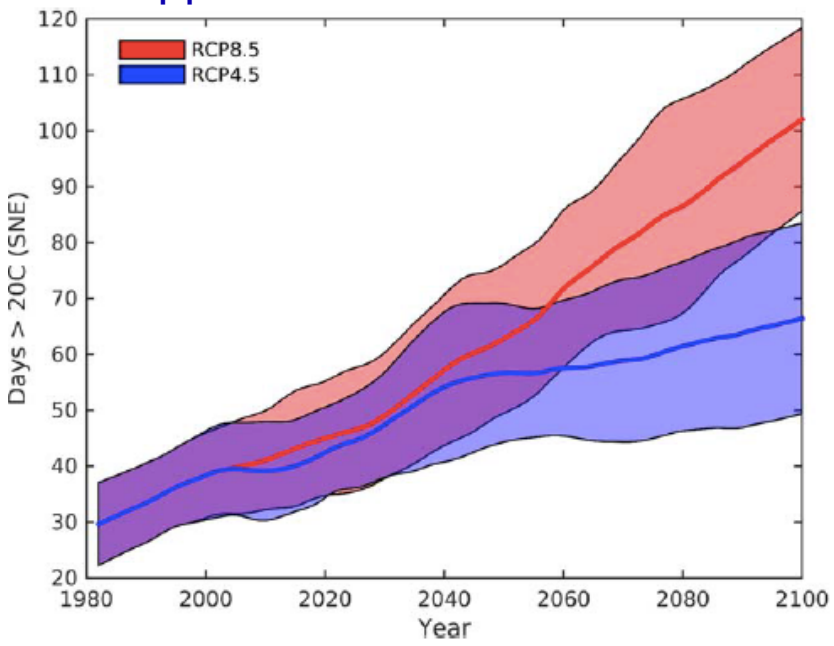
Benthic Warming & Lobsters







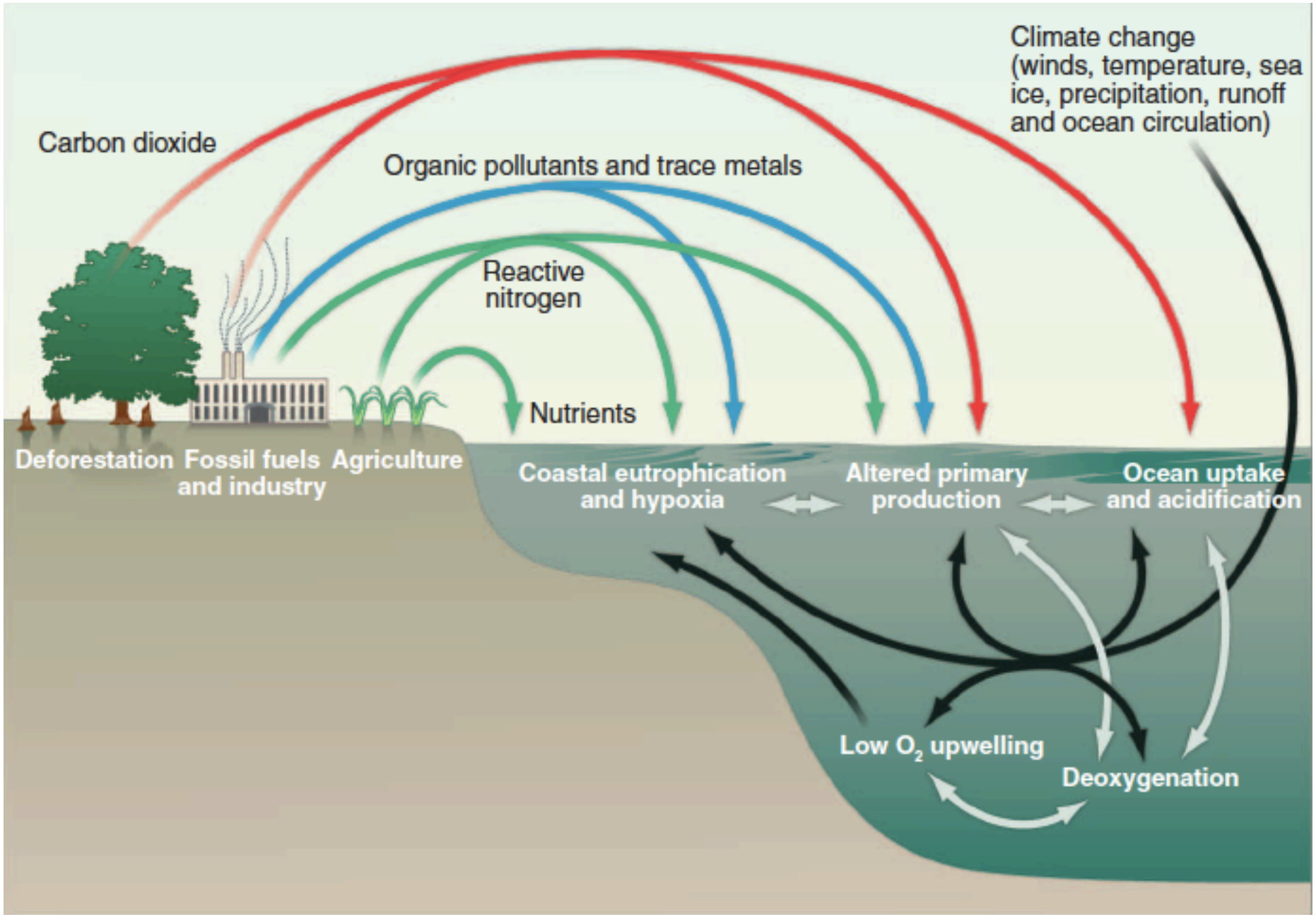
Days > 20 °C
Upper thermal habitat limit



Kavanaugh et al.
JGR Oceans 2017

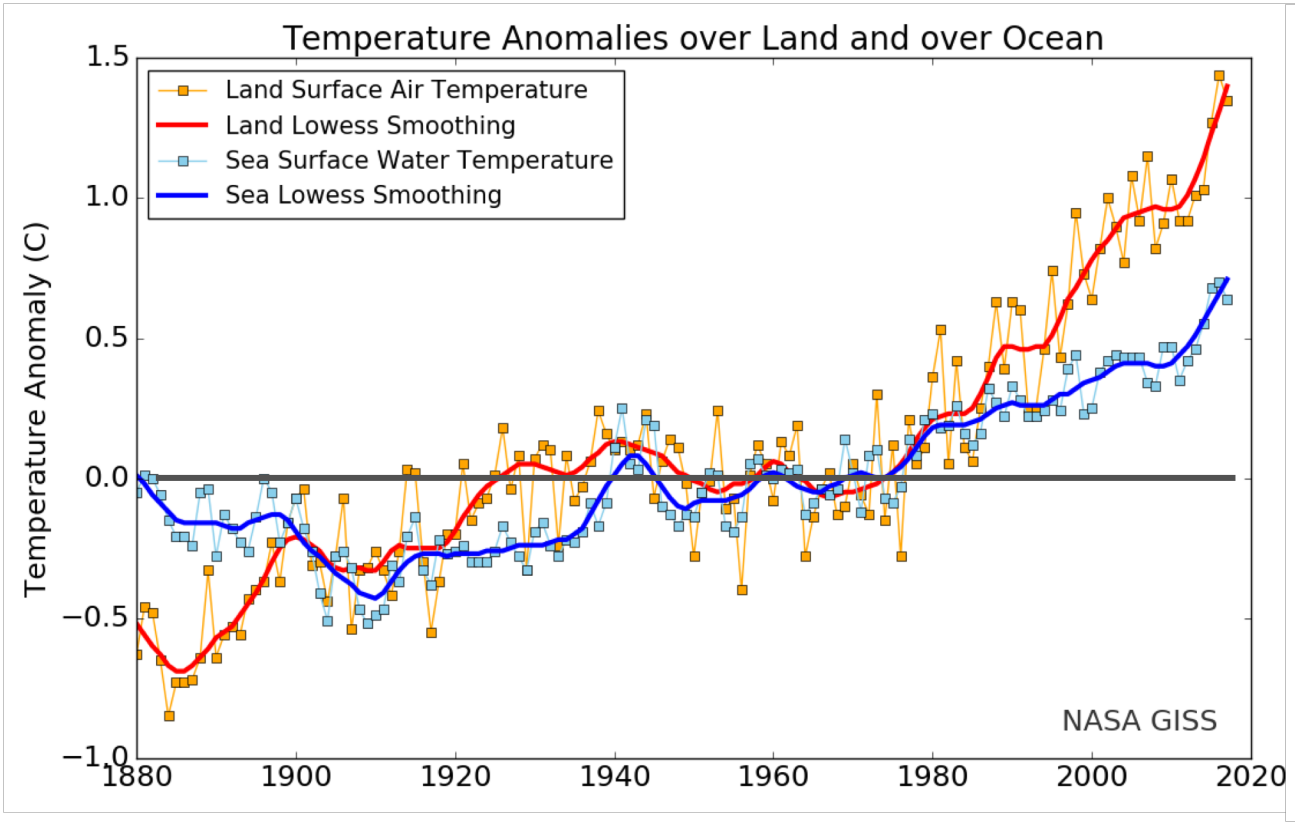
Rheuban et al.
JGR Oceans 2017

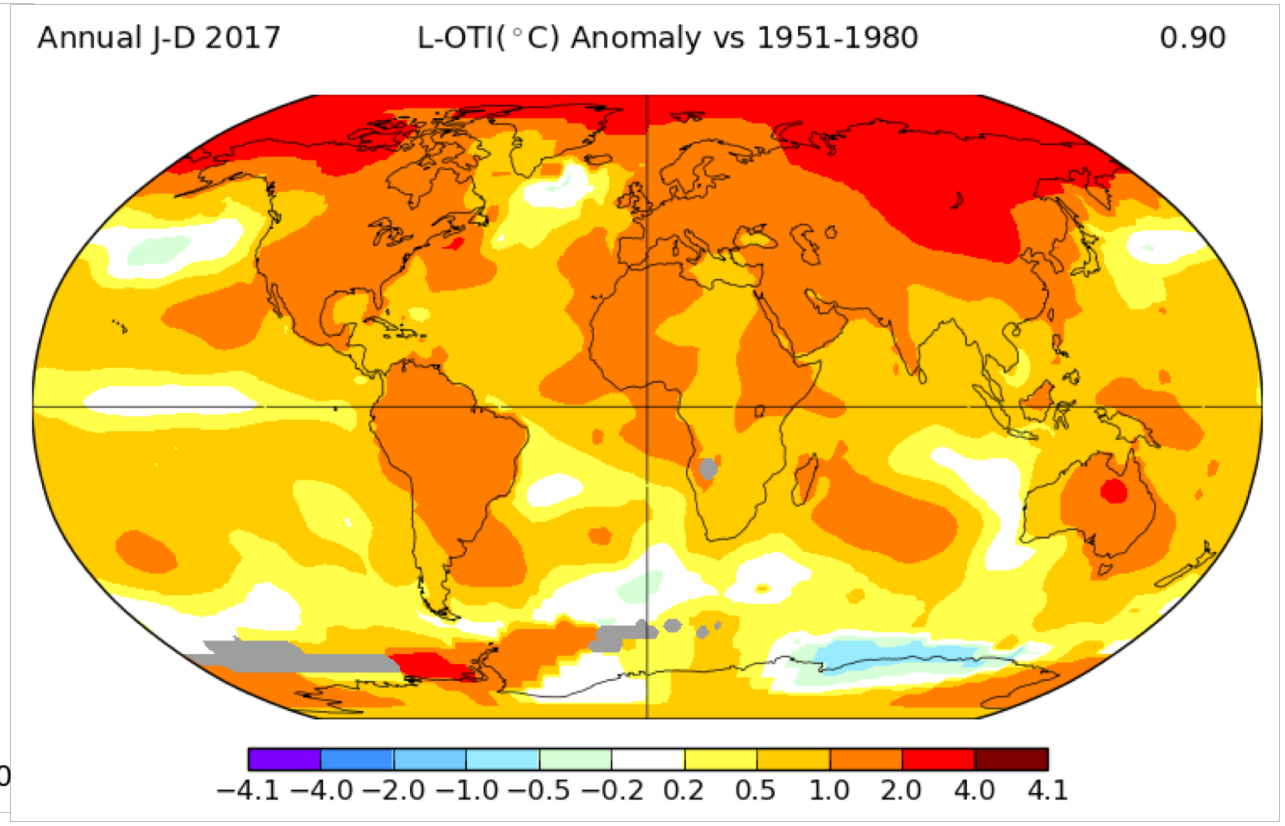
Ocean Warming, Acidification & Deoxygenation



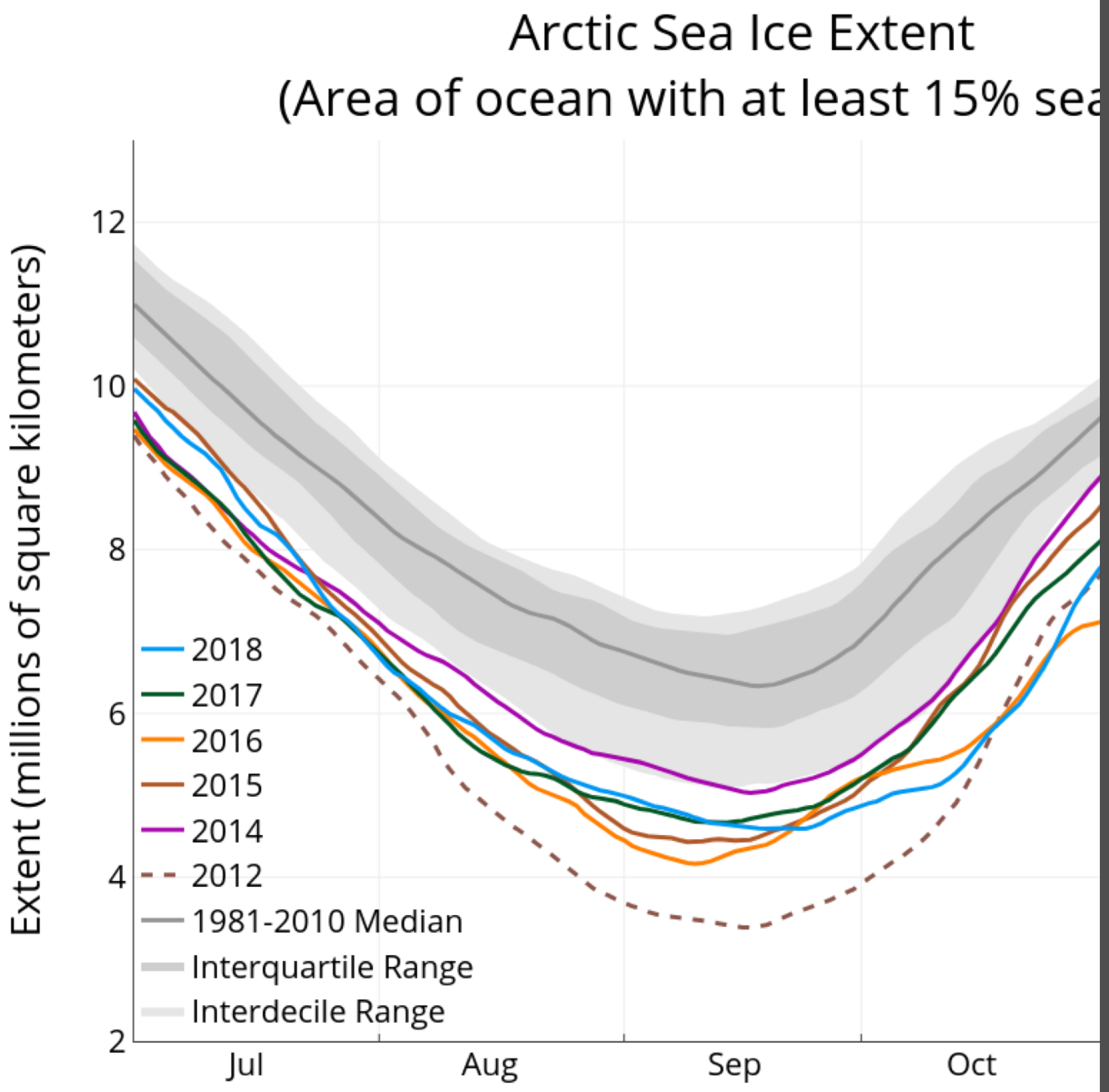
Doney Science 2010

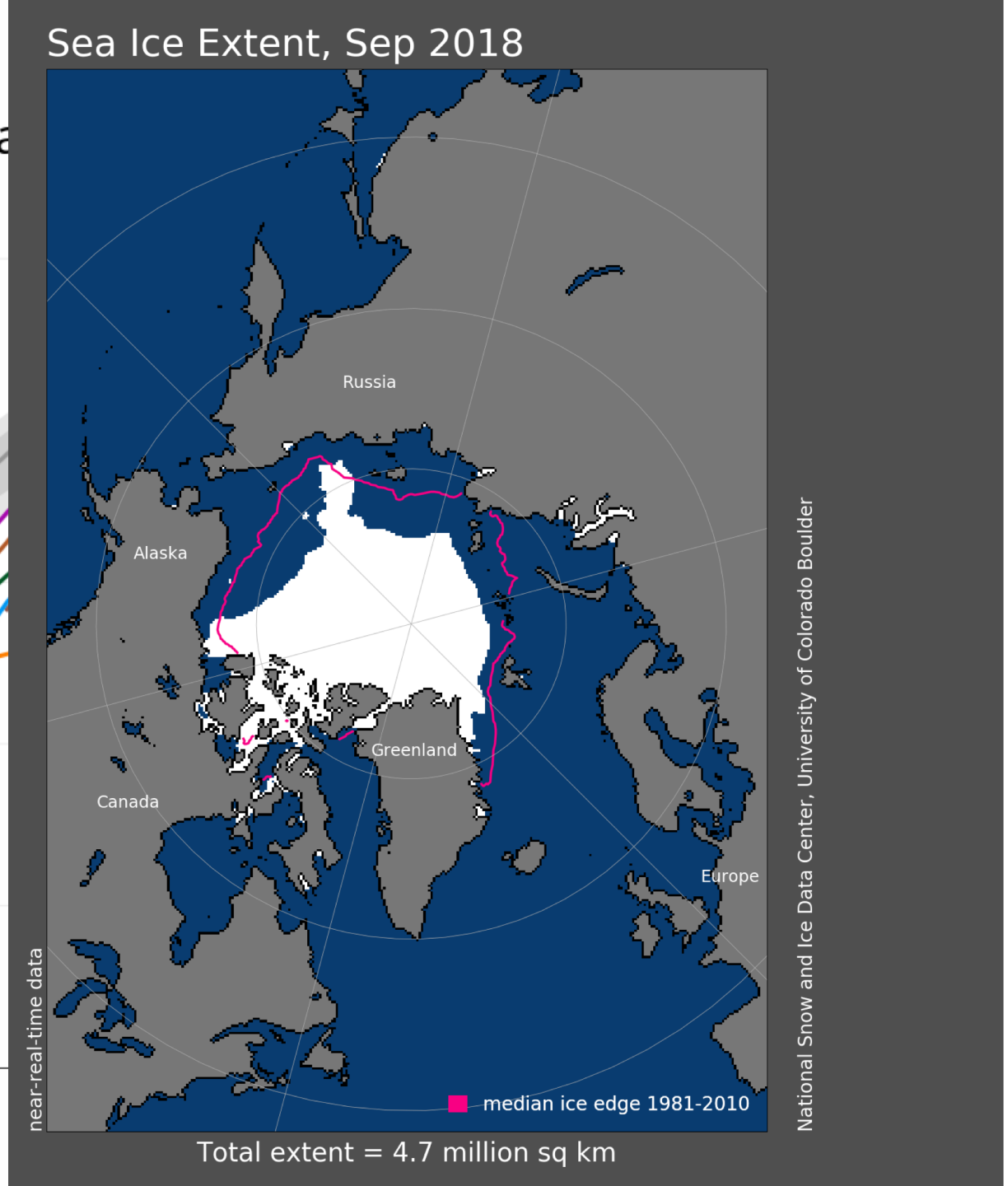
Global & Regional Patterns of Ocean Warming



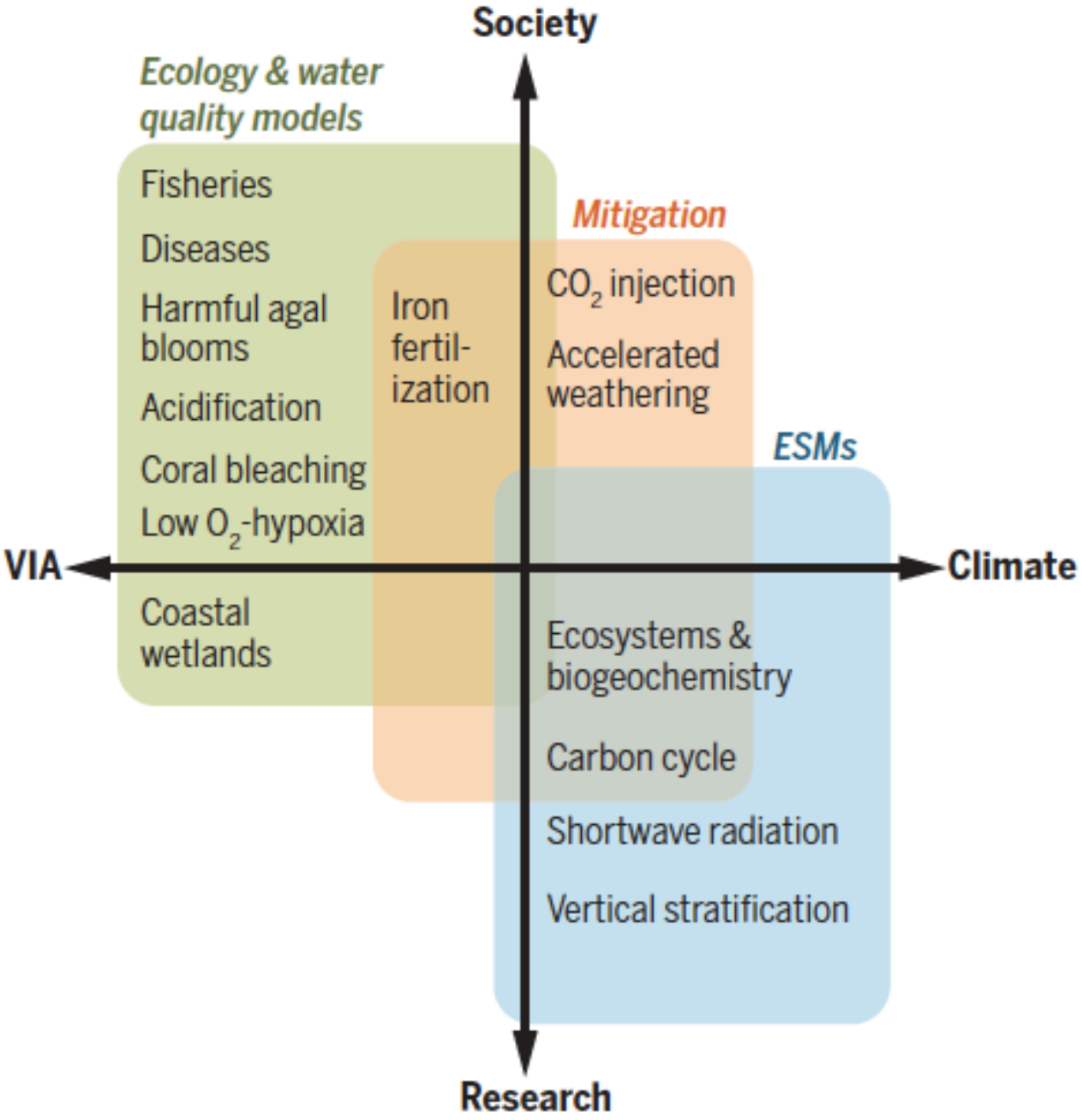


https://data.giss.nasa.gov/gistemp


Arctic Sea Ice Extent
(Area of ocean with at least 15% sea
Extent (millions of square kilometers)
12
10
8
6
4
2
Jul
Aug
Sep
Oct
2018
2017
2016
2015
2014
2012
1981-2010 Median
Interquartile Range
Interdecile Range


Sea Ice Extent, Sep 2018
Russia
Alaska
Greenland
Canada
Europe
median ice edge 1981-2010
near-real-time data
National Snow and Ice Data Center, University of Colorado Boulder
Total extent = 4.7 million sq km

Ocean: Marine ecosystems



Bonan & Doney
Science 2018

Global Mean Temperature Change