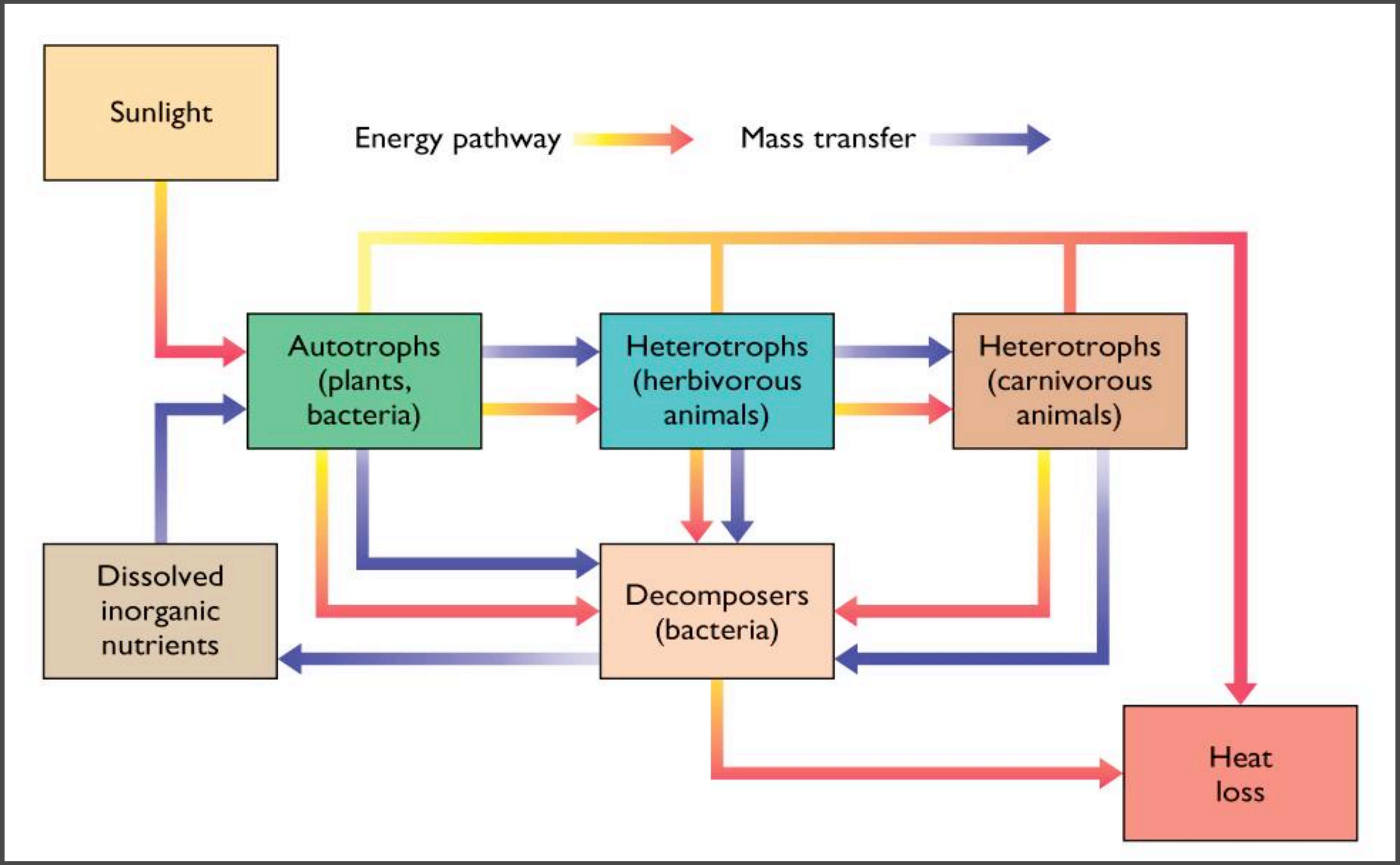
Climate Change Impacts on Marine Ecosystems

Energy Flow & Ecosystem Functions

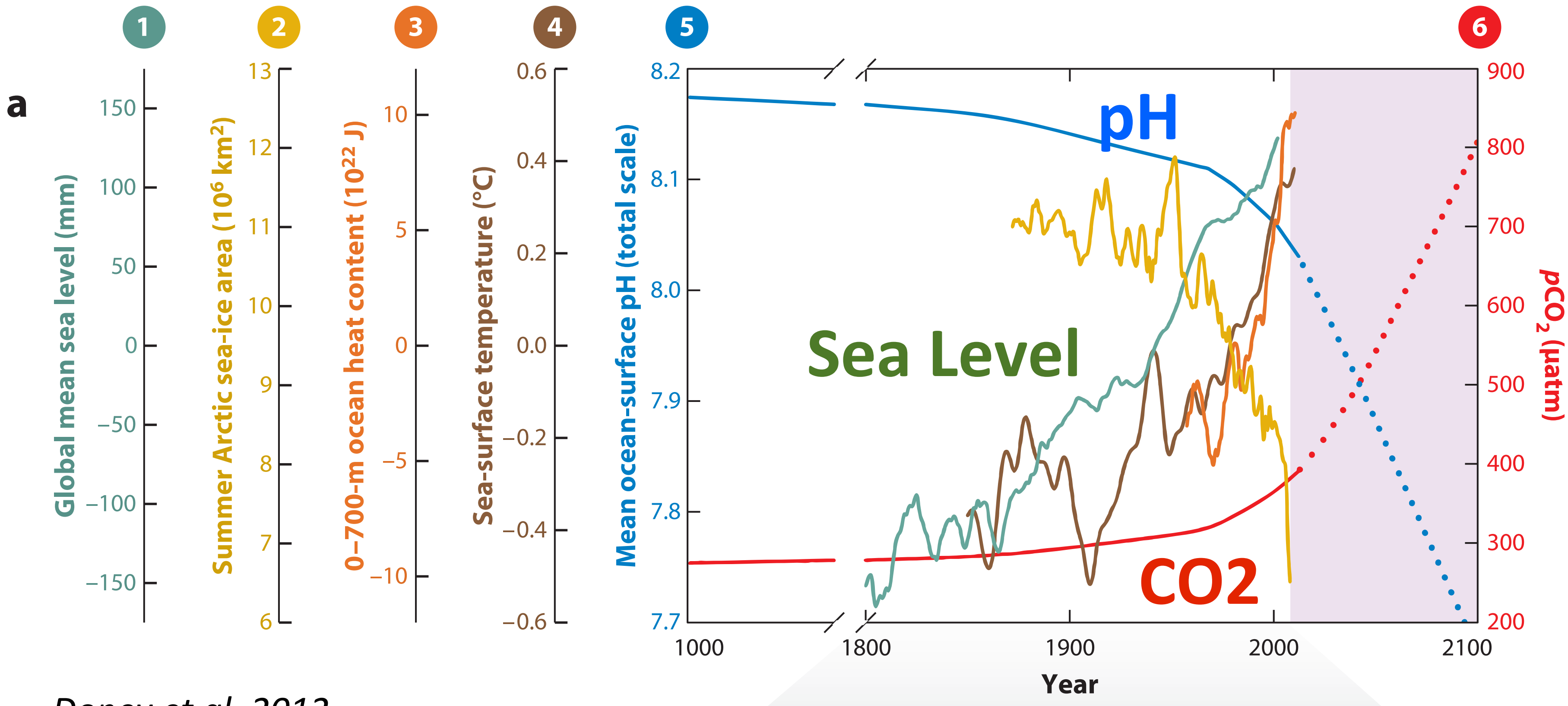
Marine ecosystems are maintained by the flow of energy



Ecosystem function (e.g., nutrient cycling, primary and secondary productivity)

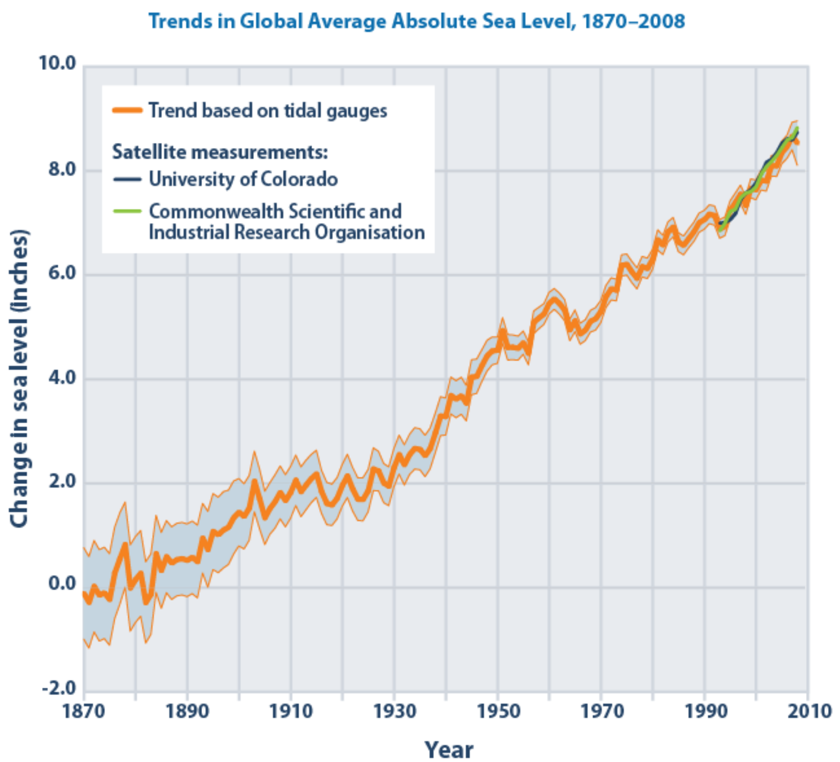
Climate Changes and Rising CO2

The physical environment

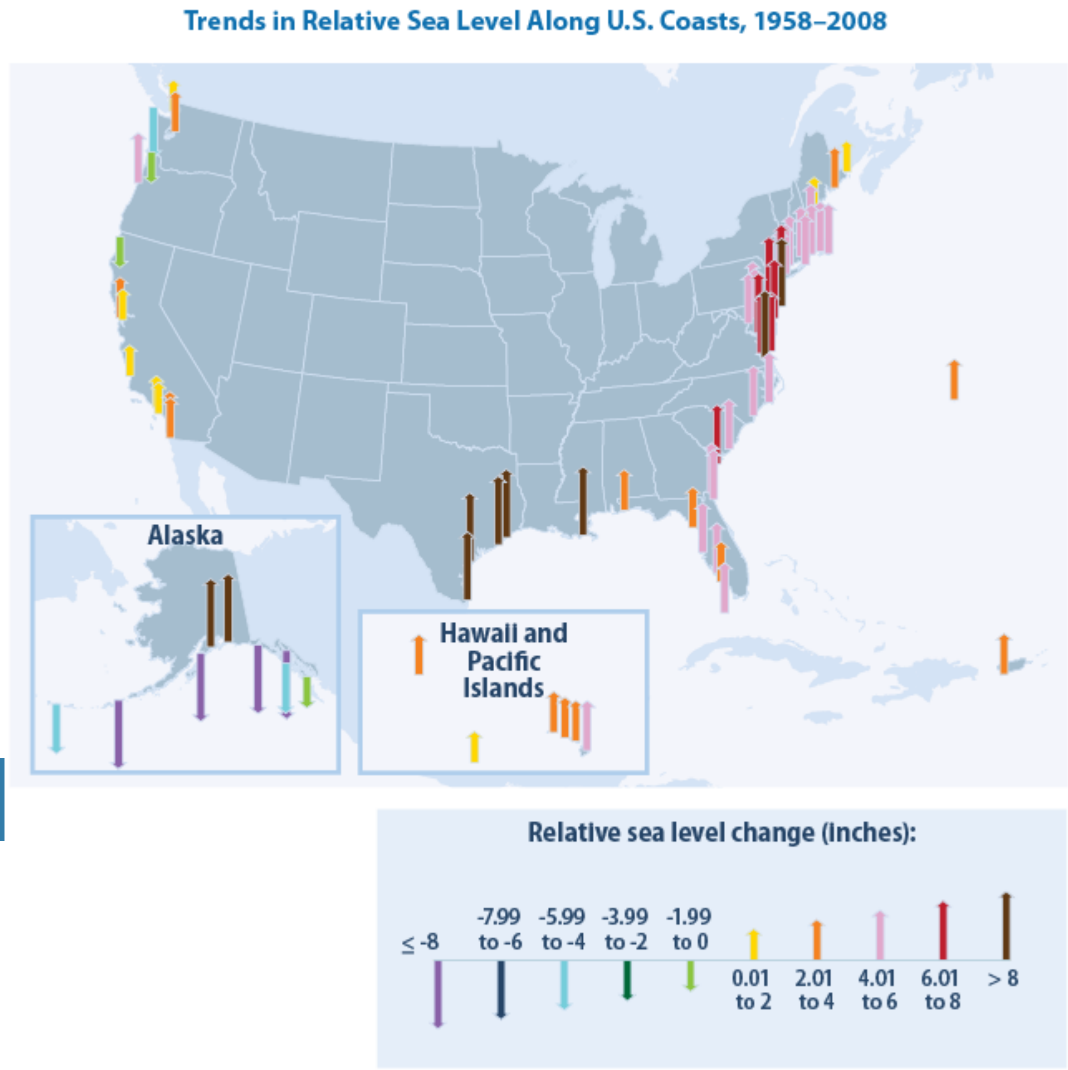


Doney et al. 2012

Rising Sea Level



EPA United States Environmental Protection Agency



Rising Upper Ocean Temperature

nature climate change

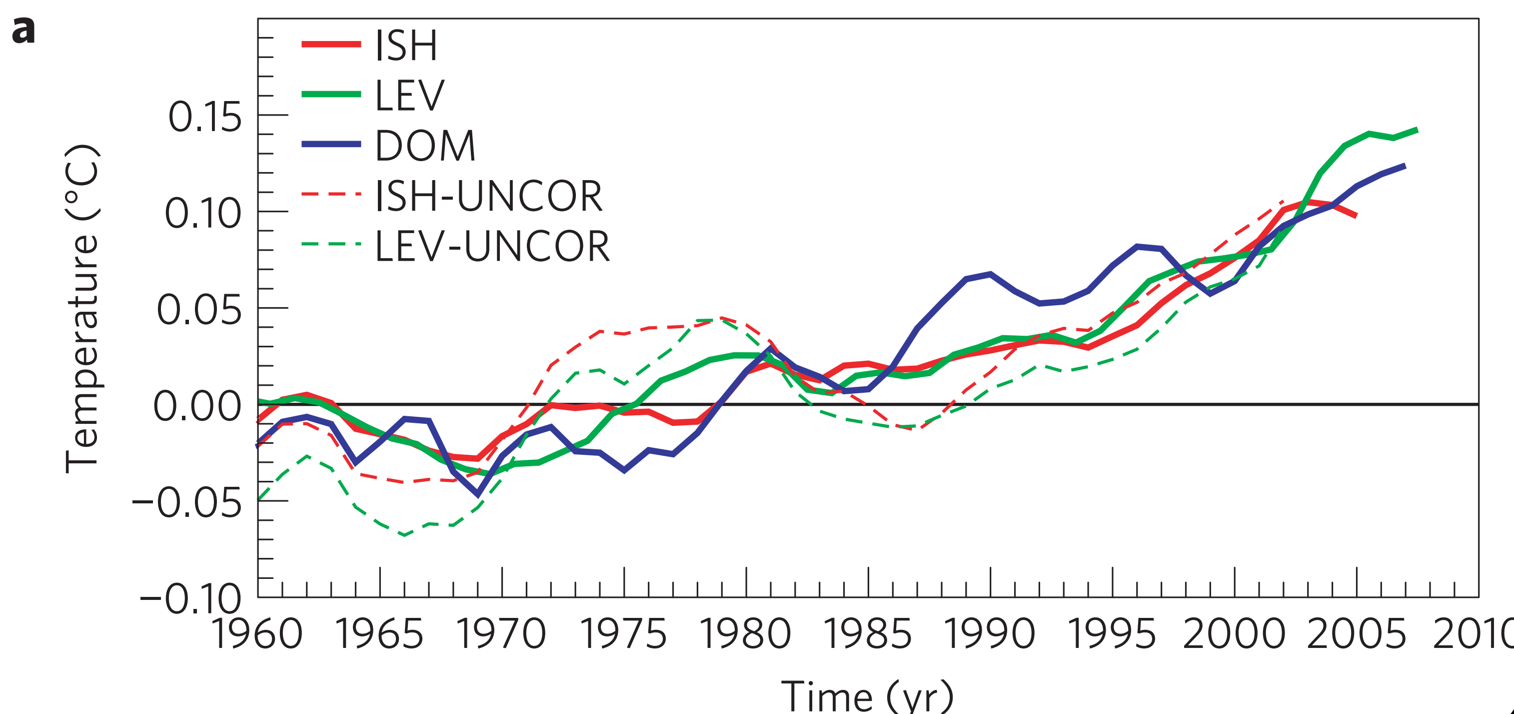
LETTERS

PUBLISHED ONLINE: 10 JUNE 2012 | DOI: 10.1038/NCLIMATE1553

Human-induced global ocean warming on multidecadal timescales

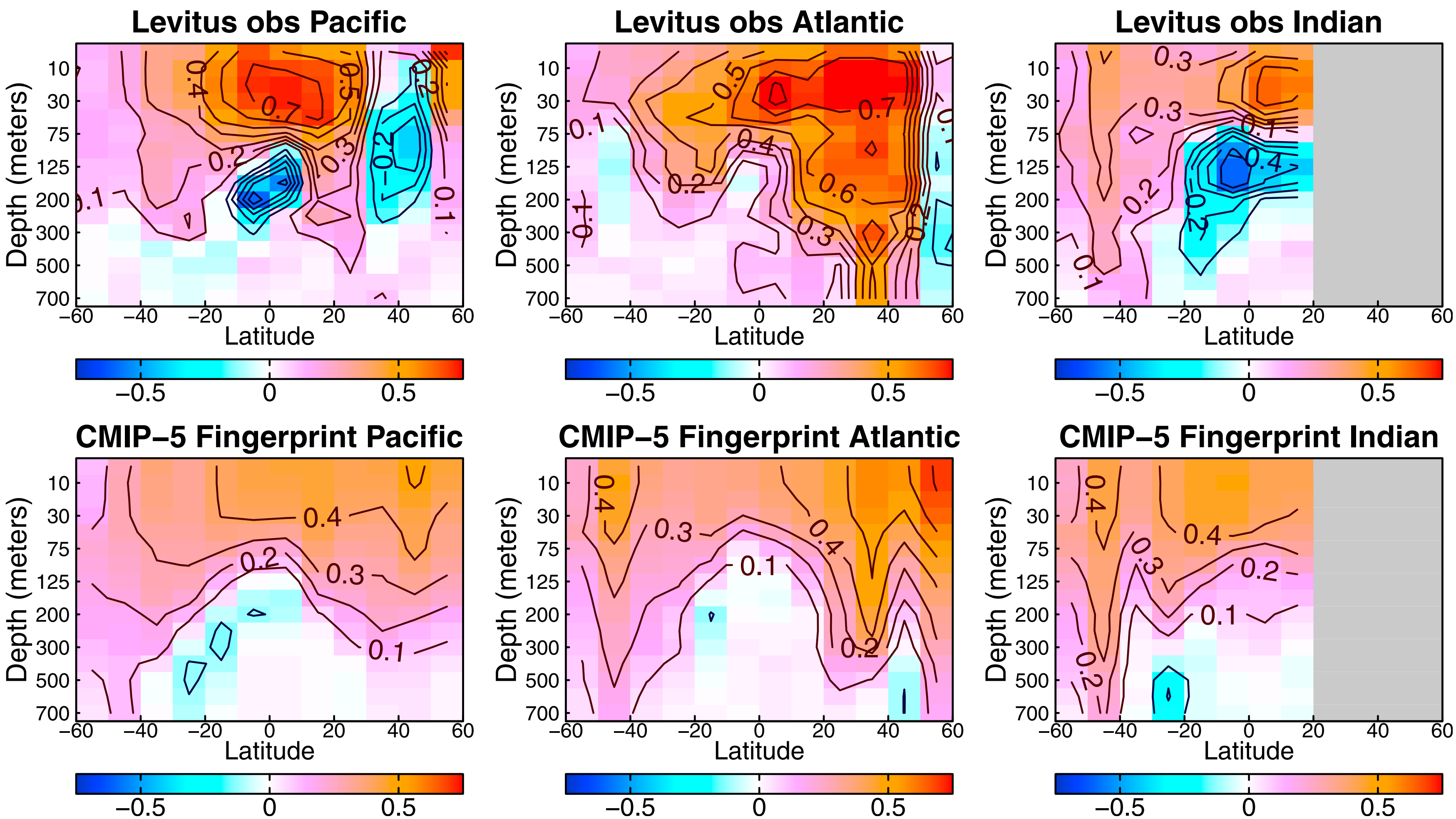
P. J. Gleckler[1]*, B. D. Santer[1], C. M. Domingues[2,3], D. W. Pierce[4], T. P. Barnett[4], K. E. Taylor[1], K. M. AchutaRao[5], T. P. Boyer[6], M. Ishii[7] and P. M. Caldwell[1]

Figure 1 | Global mean ΔT (0–700 m) with respect to a 1957–1990 climatology. a, Estimates of Domingues *et al.*[7] (DOM), Ishii *et al.*[8] (ISH) and Levitus *et al.*[9] (LEV), all of which have been corrected for XBT biases. Earlier (uncorrected) estimates of Ishii *et al.*[10] (ISH-UNCOR) and Levitus *et al.*[11] (LEV-UNCOR) are also shown. **b**, ISH and LEV ΔT_{IF} (solid



Rising Upper Ocean Temperature

OBSERVATIONS: *Trends in degrees over 50 years* ***Pierce et al. 2012***

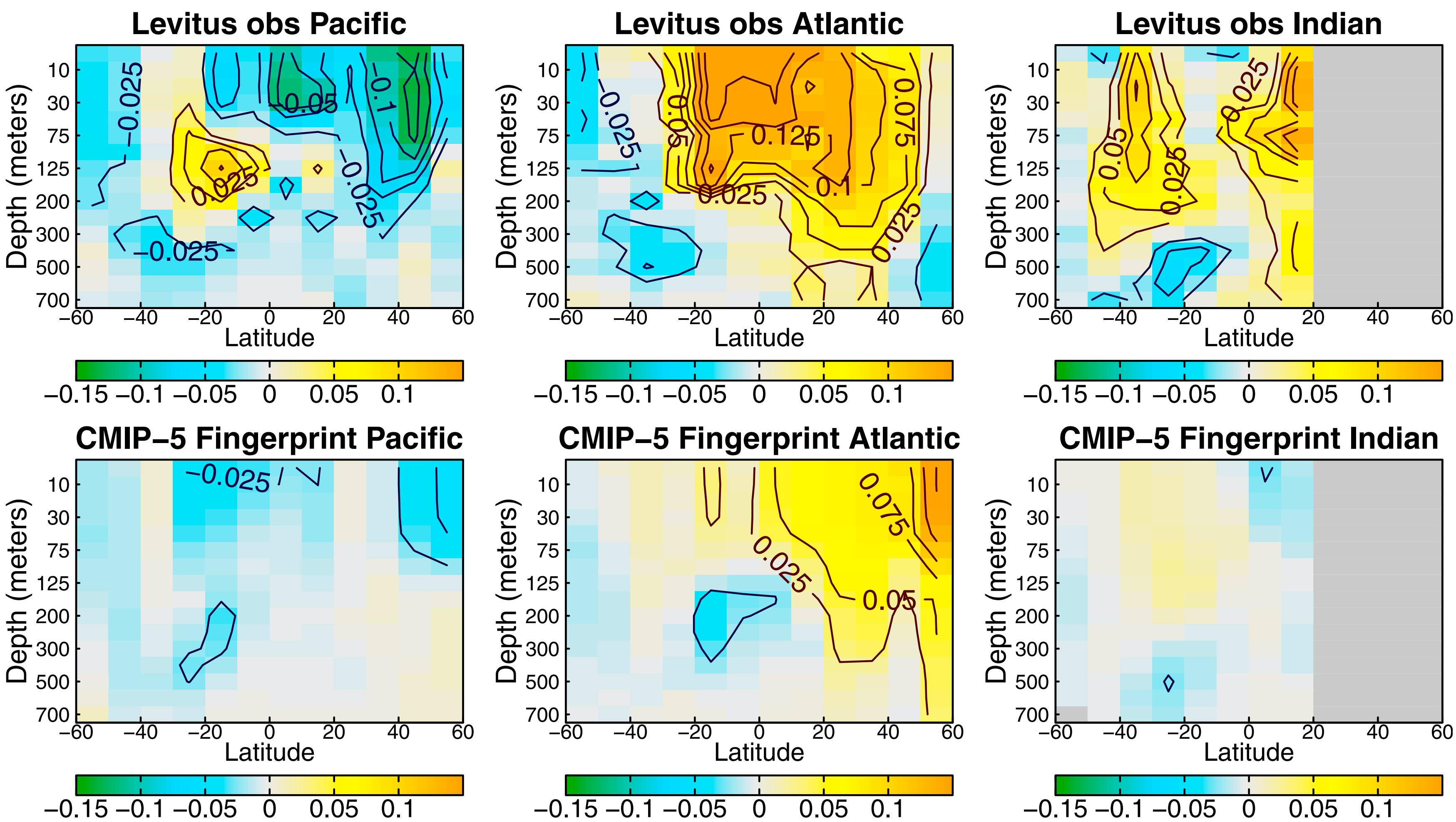


CLIMATE MODELS: *Attribution of anthropogenic signature*

Changes in Upper Ocean Salinity

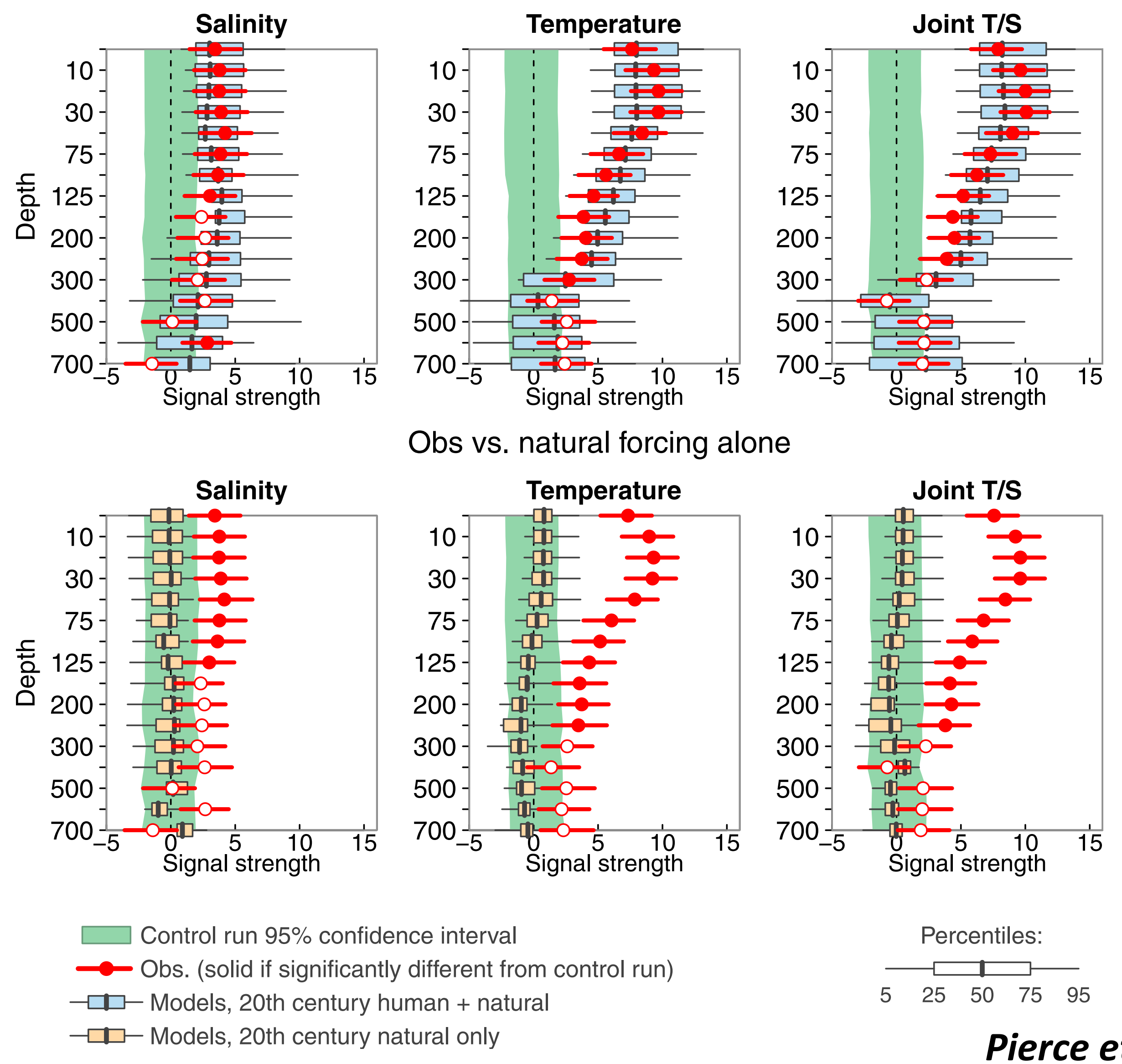
OBSERVATIONS: *Trends in PSU over 50 years*

Pierce et al. 2012



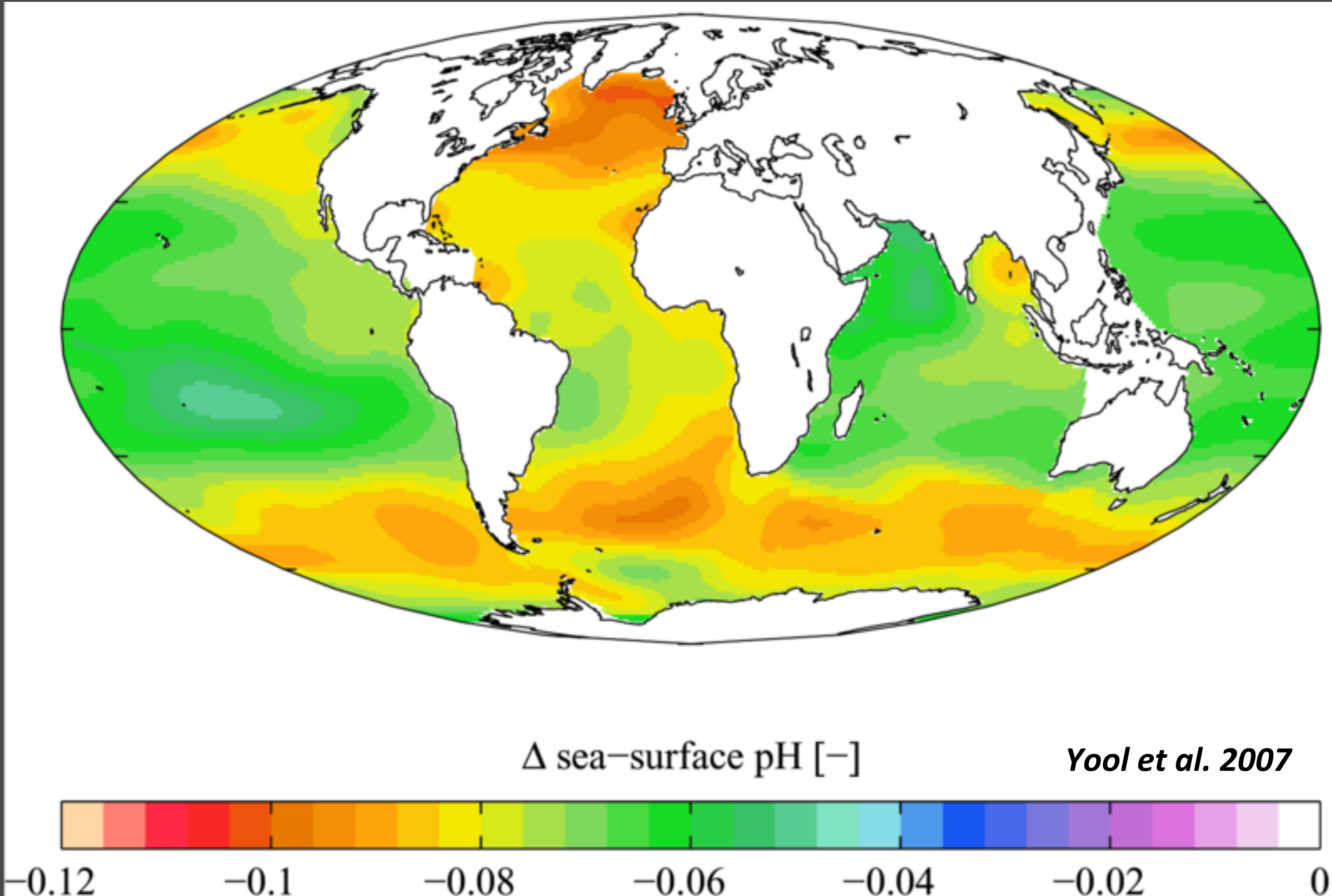
CLIMATE MODELS: *Attribution of anthropogenic signature*

Fingerprinting Human Induced Changes



Pierce et al. 2012

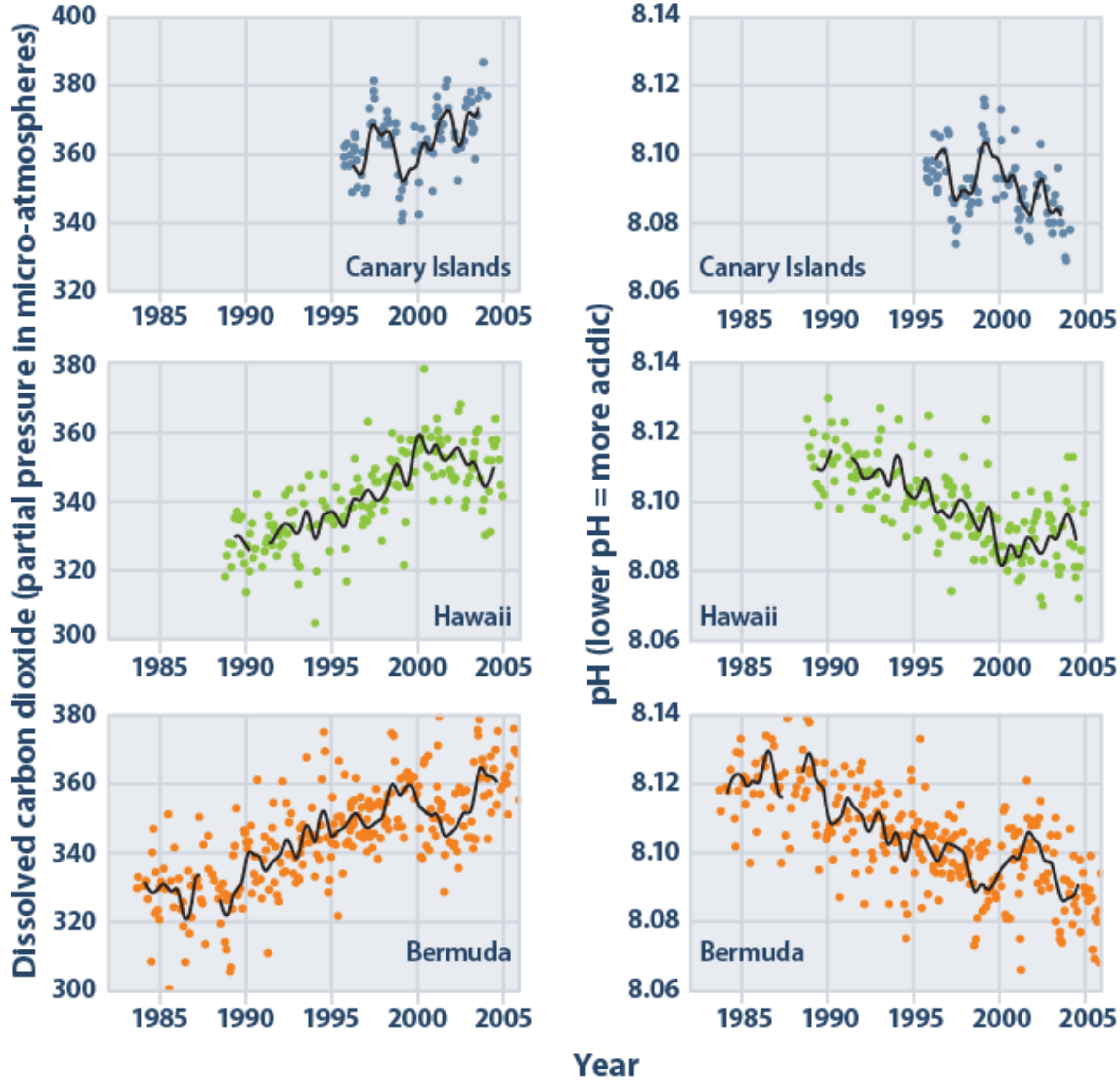
Human Induced Changes in Ocean pH



Yool et al. 2007

EPA United States Environmental Protection Agency

Ocean Carbon Dioxide Levels and Acidity, 1983–2005

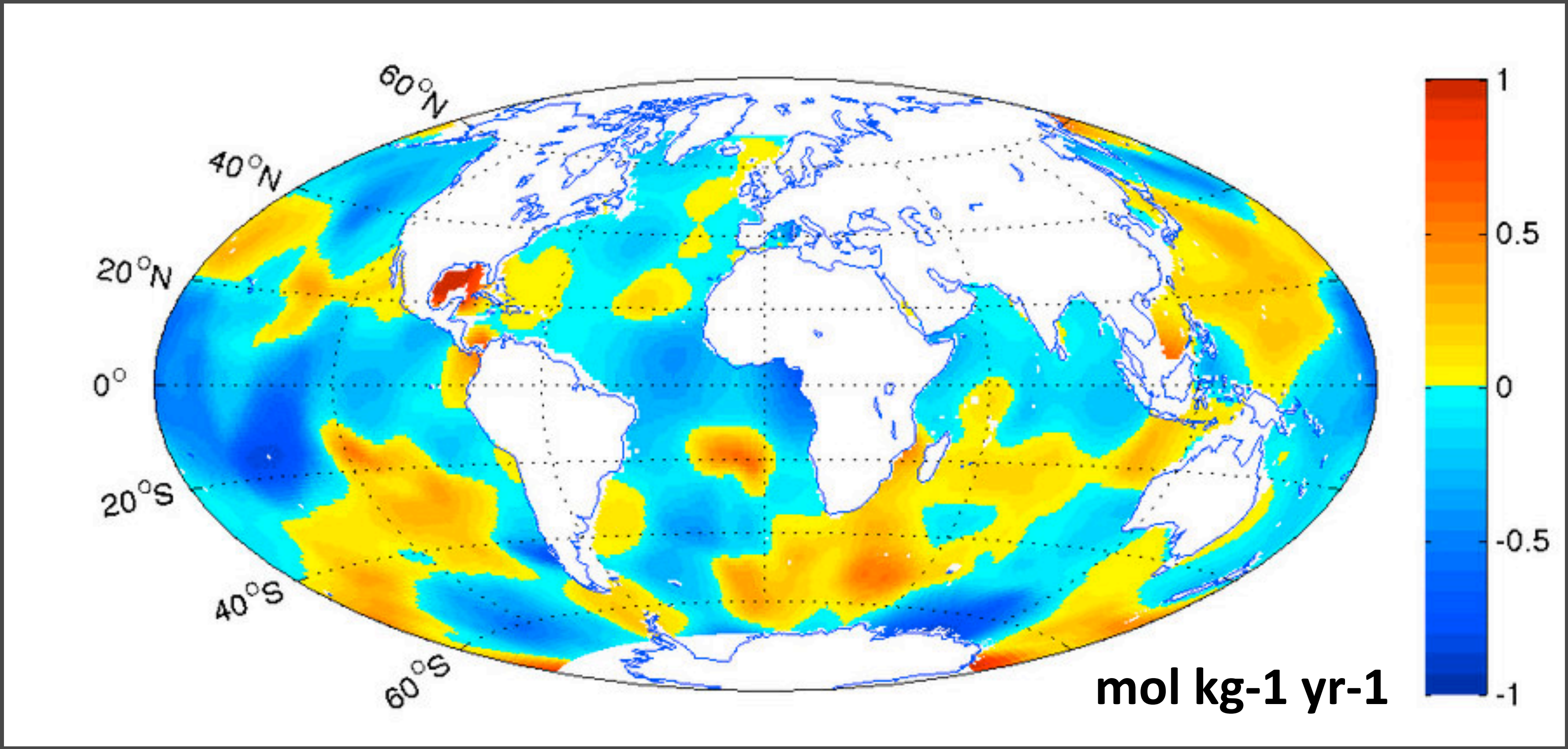


Data source: Bindoff, N.L., J. Willebrand, V. Artale, A. Cazenave, J. Gregory, S. Gulev, K. Hanawa, C. Le Quéré, S. Levitus, Y. Nojiri, C.K. Shum, L.D. Talley, and A. Unnikrishnan. 2007. Observations: Oceanic climate change and sea level. In: Climate change 2007: The physical science basis (Fourth Assessment Report). Cambridge, United Kingdom: Cambridge University Press.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climatechange/science/indicators.

Climate Changes impacts on Oxygen

Is the Ocean loosing oxygen?



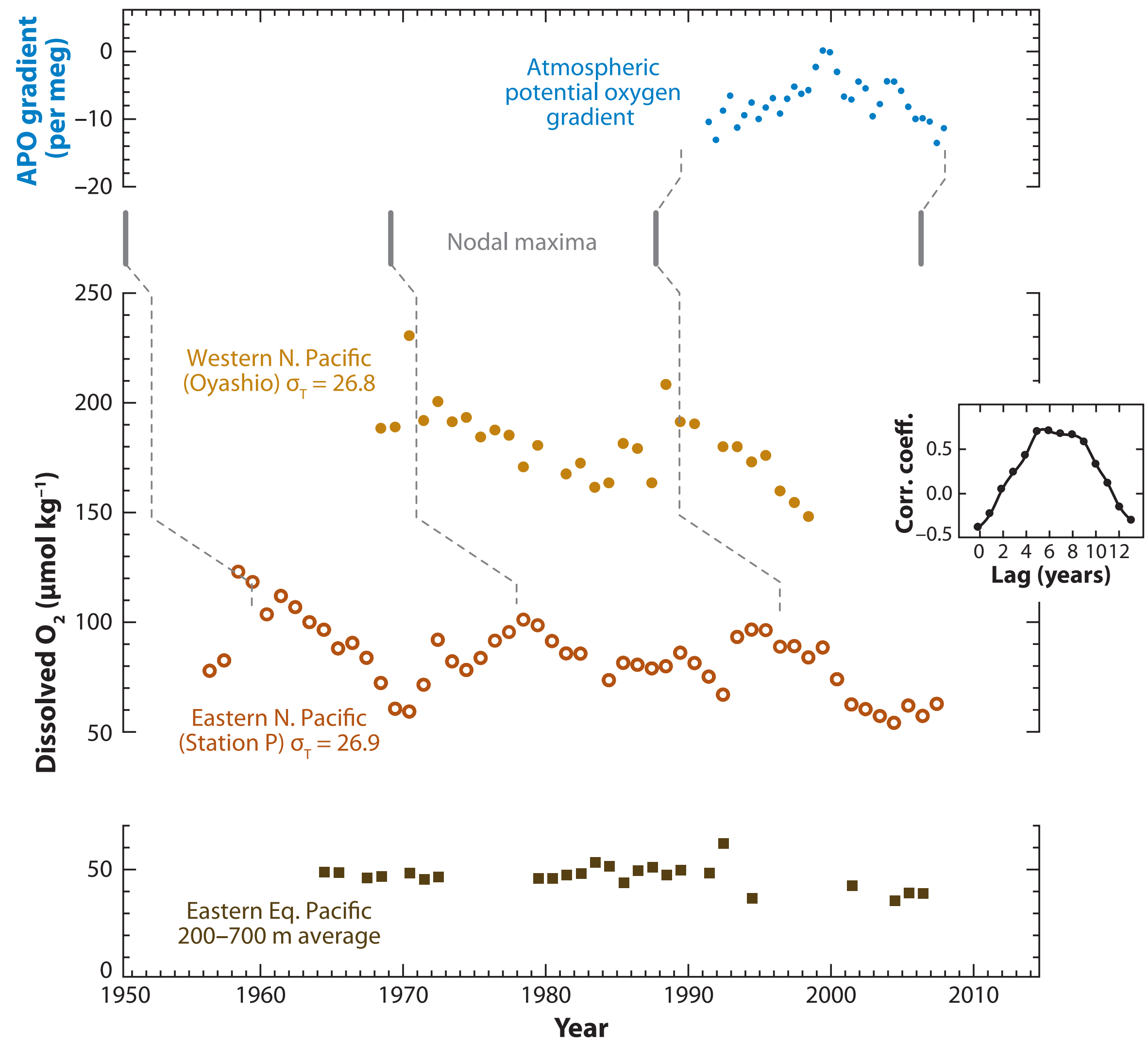
Oxygen Trends @300m 1960-2010

source: Stramma et al. GEOMAR

Climate Changes impacts on Oxygen

Is the Ocean loosing oxygen?

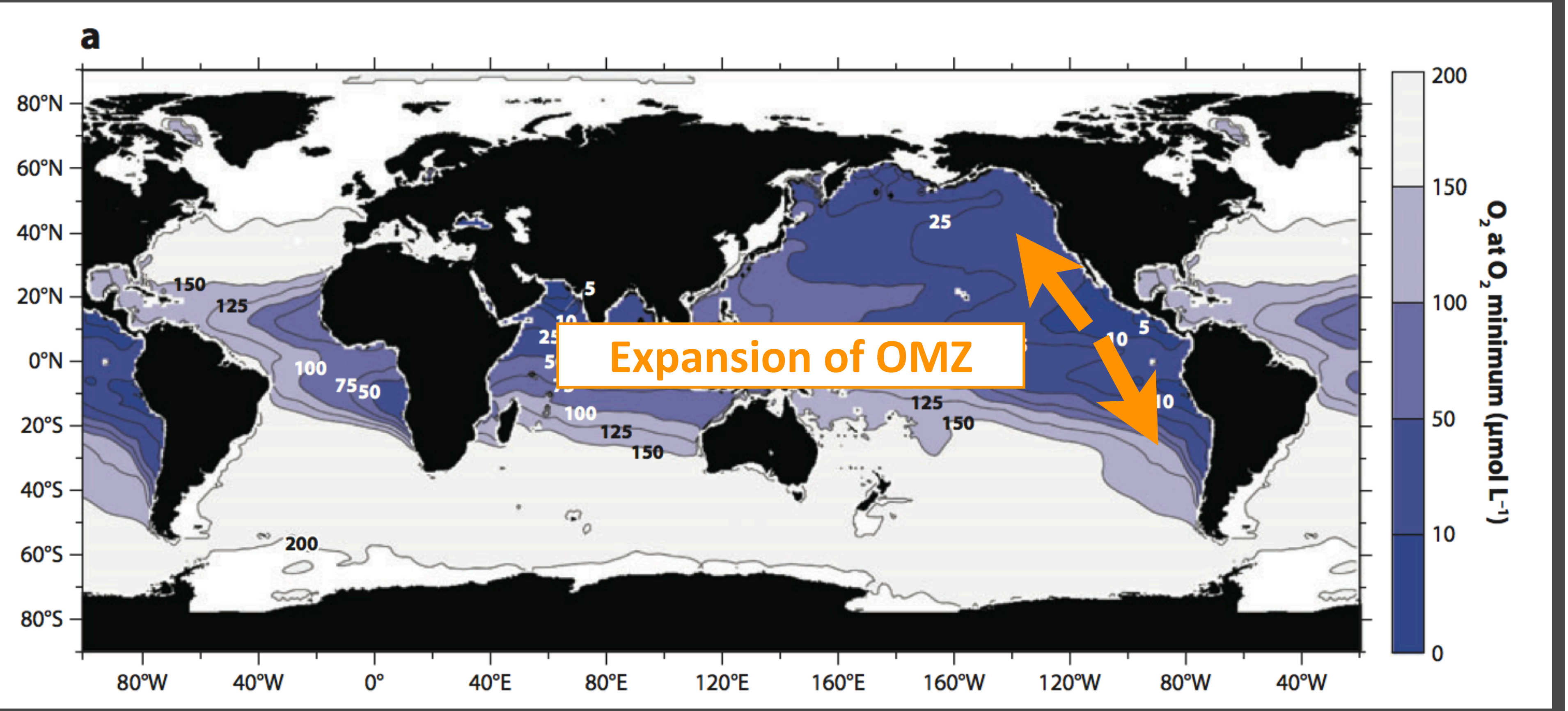
Long-term Observations in the Pacific



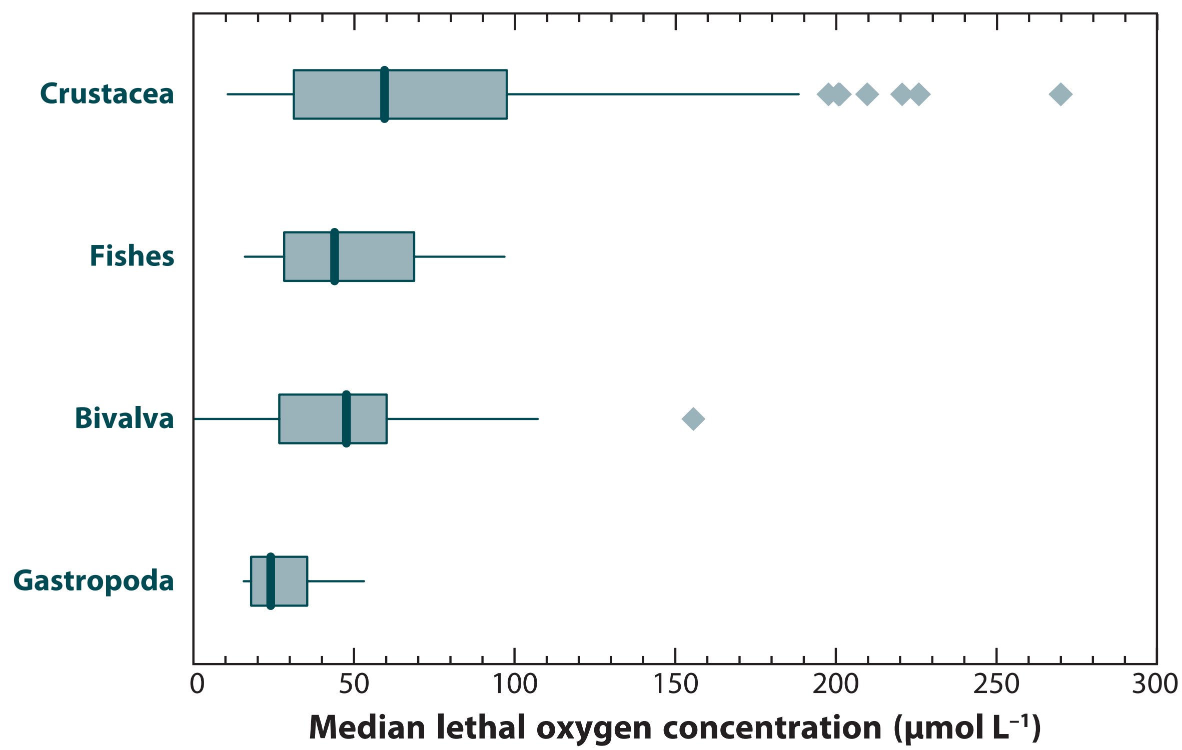
Keeling et al., 2010

Expanding Oxygen Minimum Zones (OMZ)

Warming, reduced ventilation from stratification and circulation changes may contribute to an expansion of the OMZs

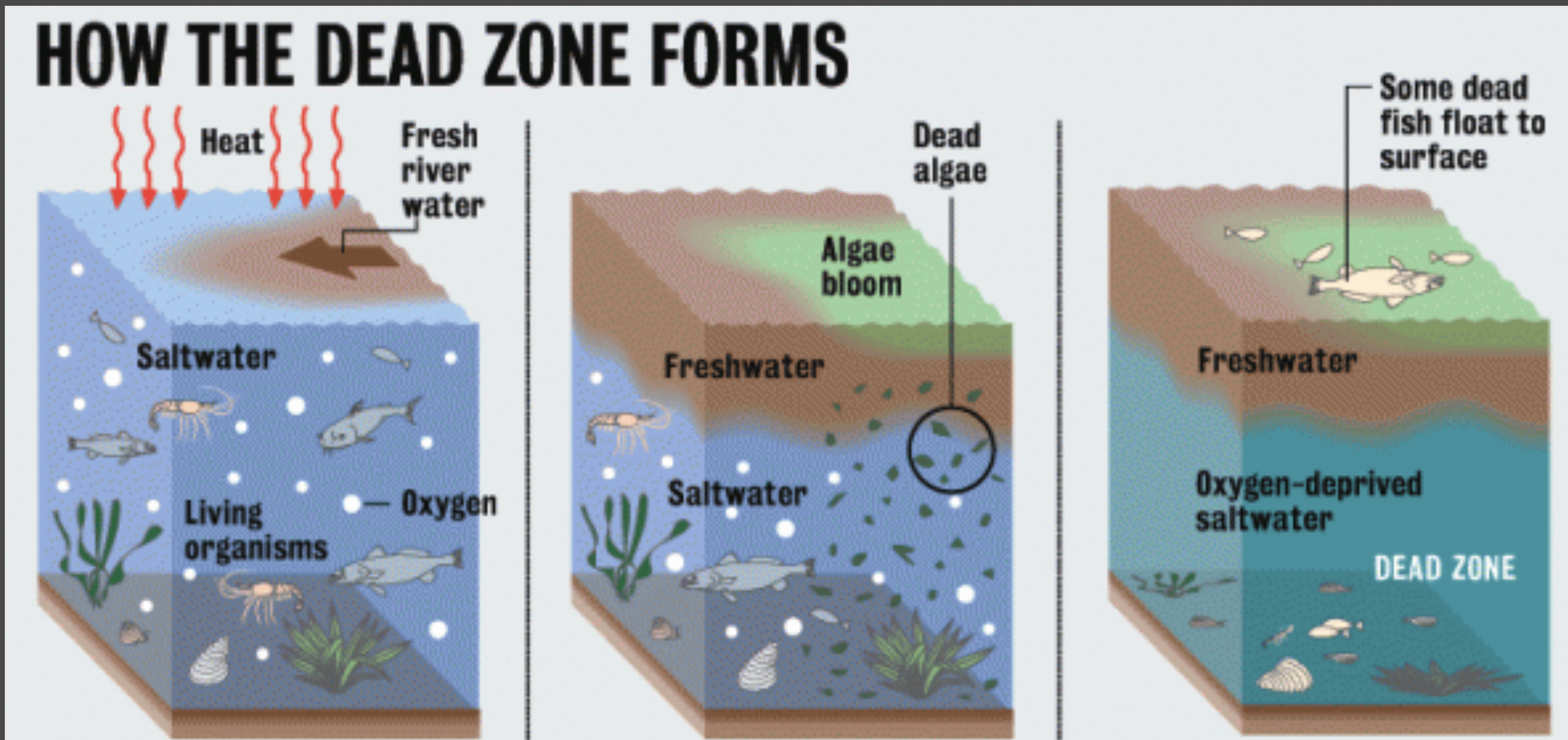


Sensitivity of Ocean Taxa to Oxygen



Keeling et al., 2010

Coastal Hypoxia: The Dead Zones



1. Spring Stratification

from heating and freshwater

2. Nitrogen Inputs & Blooms

to the surface (e.g. river runoff or upwelling) trigger blooms

Flux of organic matter to the deep

3. Respiration

of organic induces oxygen depletion in the deep

Climate Changes impacts on Oxygen

Costal Hypoxia is increasing leading to Dead Zones

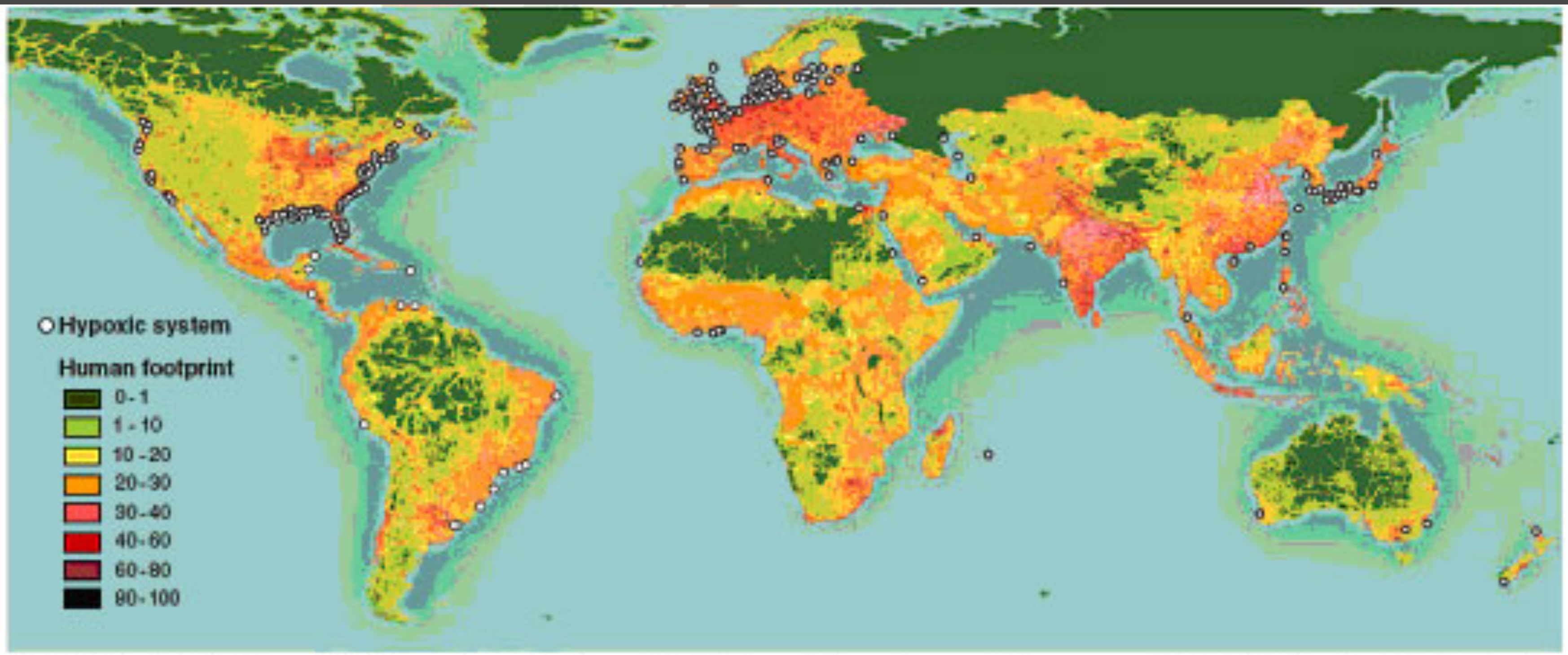


Fig. 1. Global distribution of 400-plus systems that have scientifically reported accounts of being eutrophication-associated dead zones. Their distribution matches the global human footprint [the normalized human influence is expressed as a percent (*41*)] in the Northern Hemisphere. For the Southern Hemisphere, the occurrence of dead zones is only recently being reported. Details on each system are in tables S1 and S2.

<u>Causes</u>

- Increase the amount of bioavailable nitrogen runoff
- Expansion of OMZs

Ecosystem Response to Climate

Physical and chemical changes have strong direct and indirect effects on the physiology and behavior of marine organisms.

Types of Response:

- Physiological responses
- Population and Community Responses
- Ecosystem Structure and Function

Physiological Responses

Environmental Change / Types of Response:

✦ **Temperature & Oxygen** --> **Metabolic Rates Constraint**

adaptation, migration or extinction

✦ **Ocean Acidification** --> **Calcification**

lost of biogenic habitats (e.g. corals reefs and oyster beds)

alteration of food webs (e.g. pteropods and mollusks)

changes in global bio-geochemical cycles (e.g. coccolithophore algae)

Physiological Responses

Environmental Change / Types of Response:

✦ **Temperature & Oxygen** --> **Metabolic Rates Constraint**

adaptation, migration or extinction

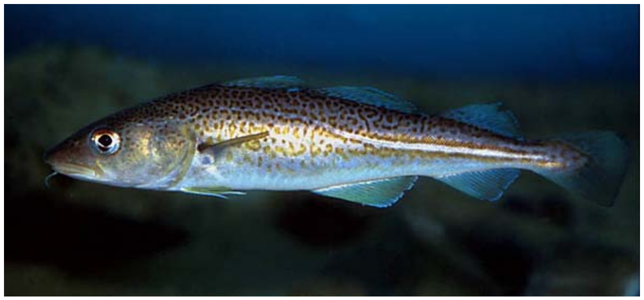
Define:

$$\text{Metabolic Index} = \frac{\text{Oxygen Supply}}{\text{Oxygen Demand}}$$

(depends also on Temperature)

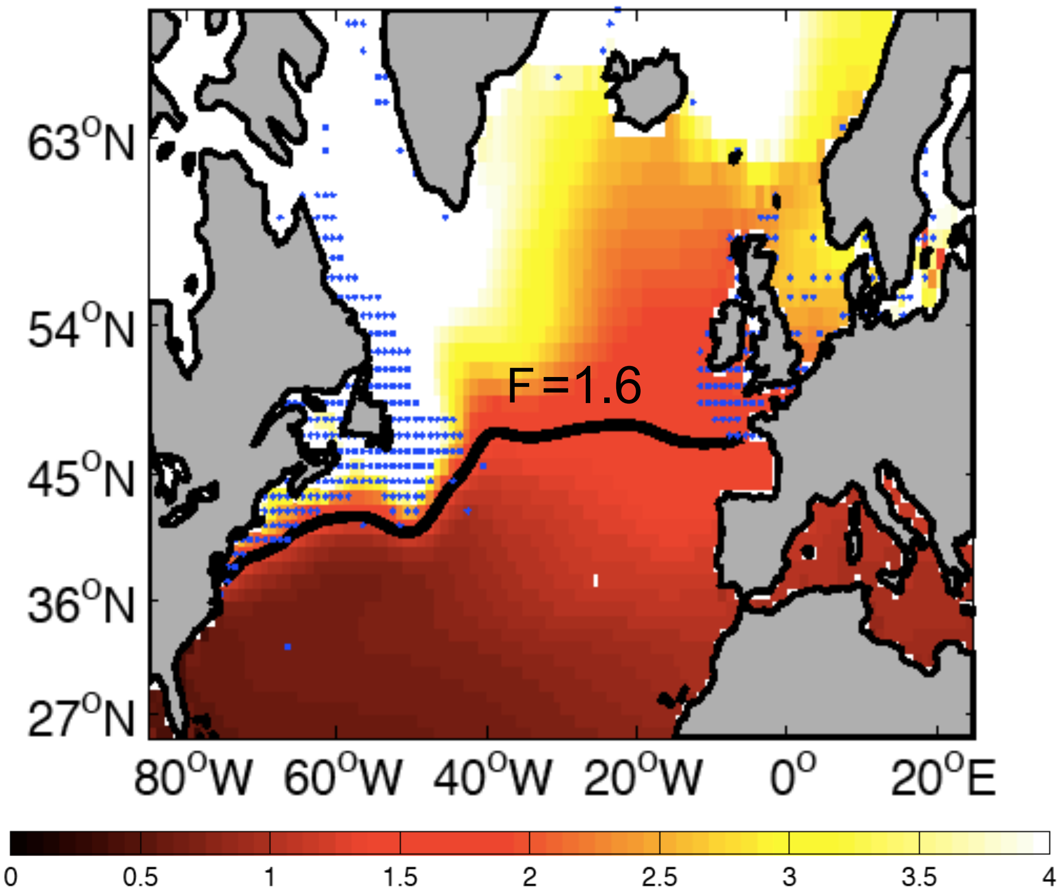
F = Metabolic Index (contour maps)

Distribution data: Cod



Cod Characteristics:

Depth of habitat
0-400m
Mass at maturity
500-1500g
Range of F_{crit}
1.3-2.6



courtesy of C. Deutsch (UCLA)

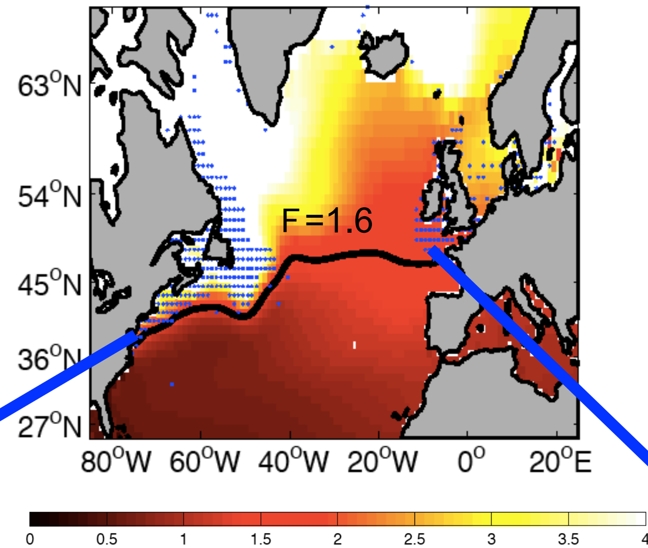
Distribution data from Fishbase.org

Metabolic Index (contour maps)

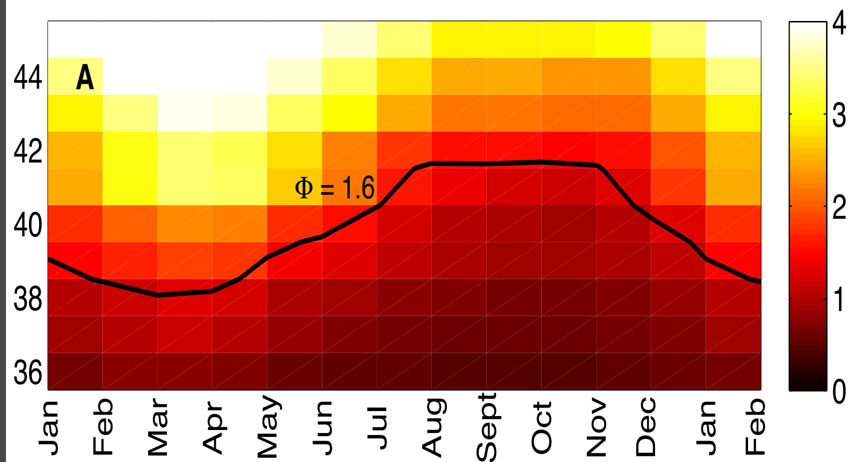
Seasonal Migration

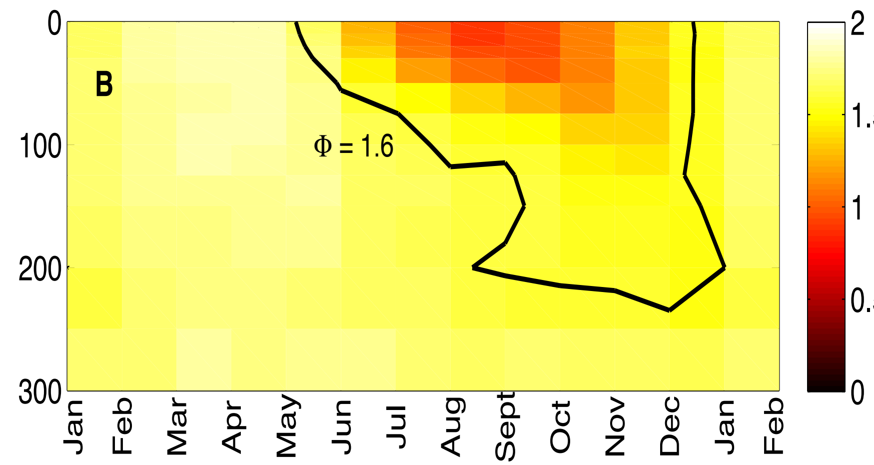
courtesy of C. Deutsch (UCLA)

Western Population
Migrates
From ~37°N in winter
To ~41°N in summer



Eastern Population
Migrates
Surface in spring/winter
To ~250 m in summer/fall



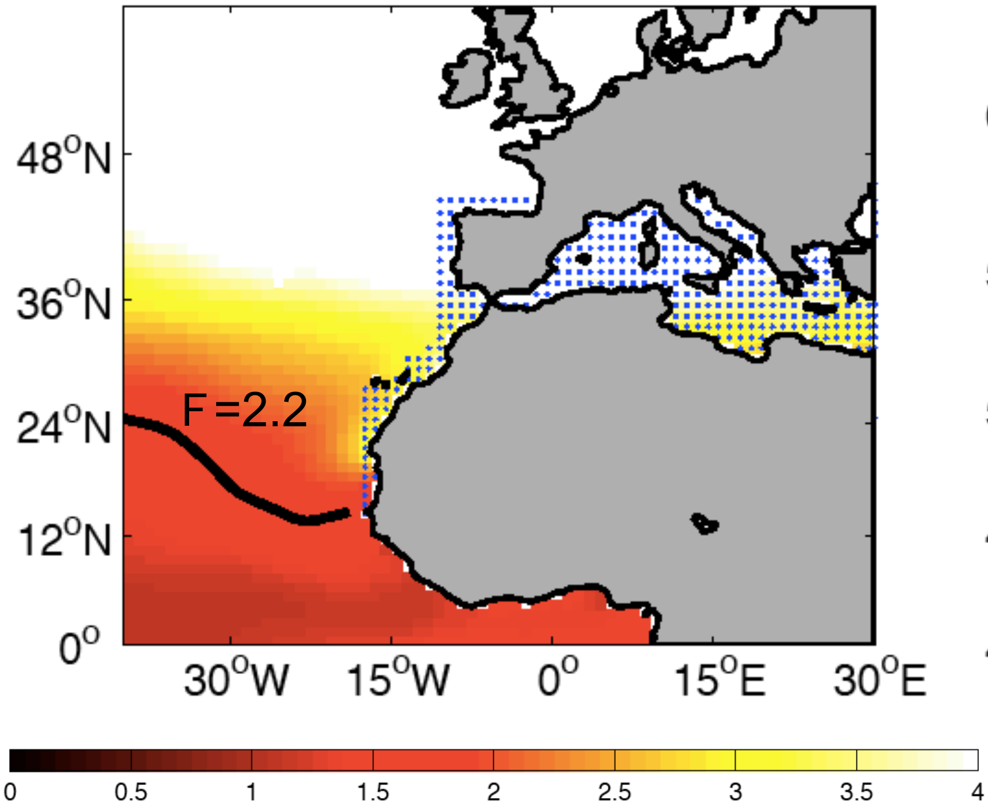


Metabolic Index (contour maps)

Species Distribution: Seabream

Seabream Characteristics:

Depth of habitat
0-60m
Mass at maturity
300-900g
Range of F_{crit}
1.6-4.0



Distribution data digitized from Andriashev 1986 and Van Neer 1997

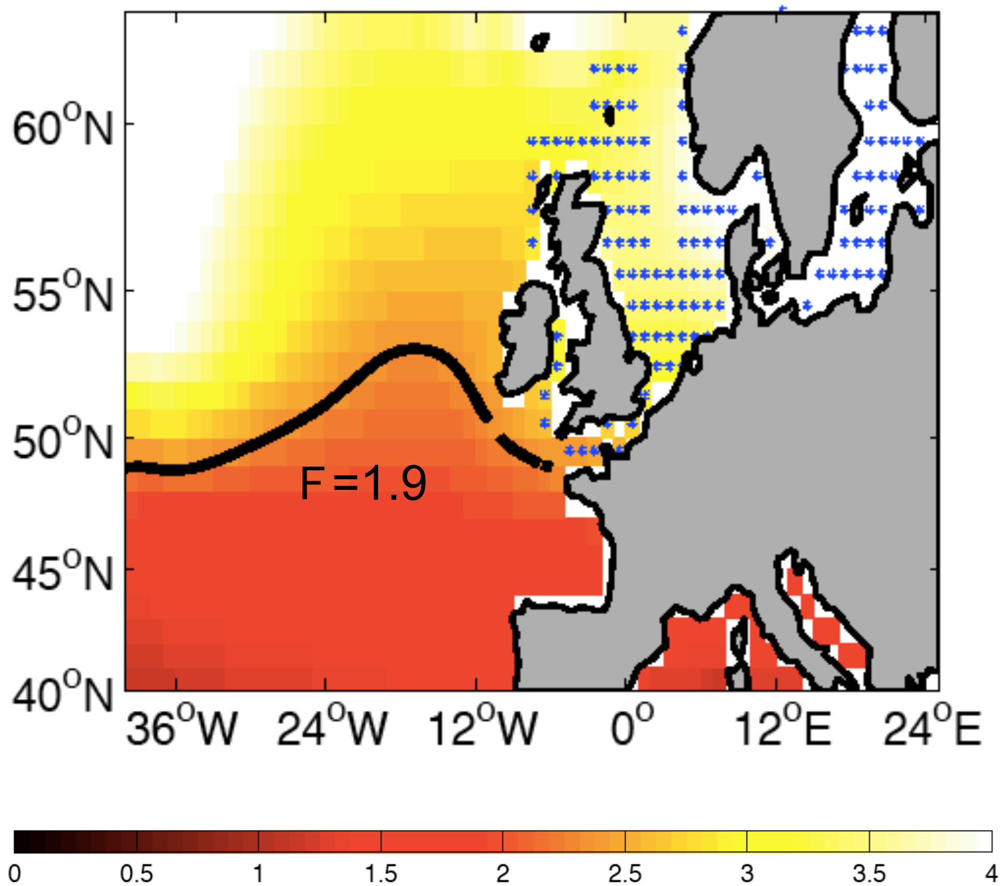
courtesy of C. Deutsch (UCLA)

Metabolic Index (contour maps)

Species Distribution: Eelpout

Eelpout Characteristics:

Depth of habitat
0-40m
Mass at maturity
100-300g
Range of F_{crit}
1.4-3.3



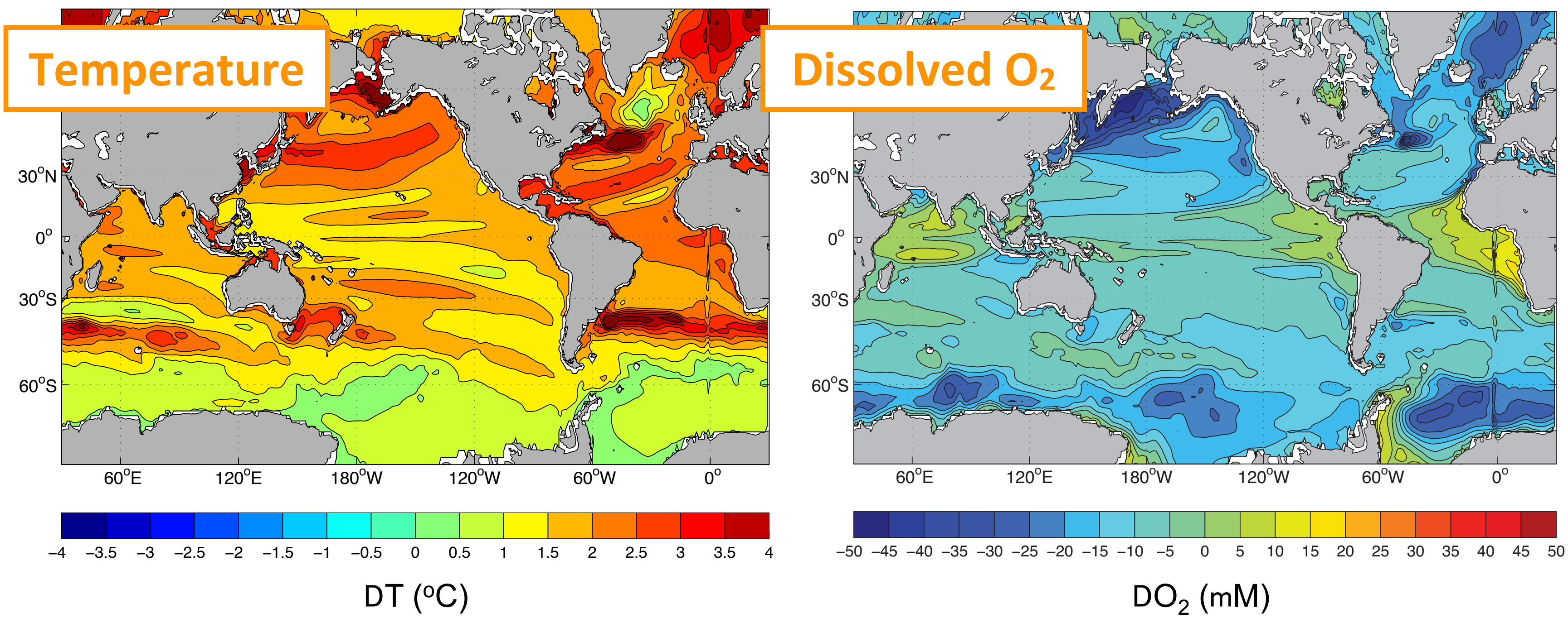
Distribution data digitized from Svetodvidov 1986

courtesy of C. Deutsch (UCLA)

Climate Change impacts on Metabolic Index

Climate Projections

Projected T, O_2 changes in 2071-2100, 0-400m
IPCC Earth System Model mean, RCP8.5 scenario

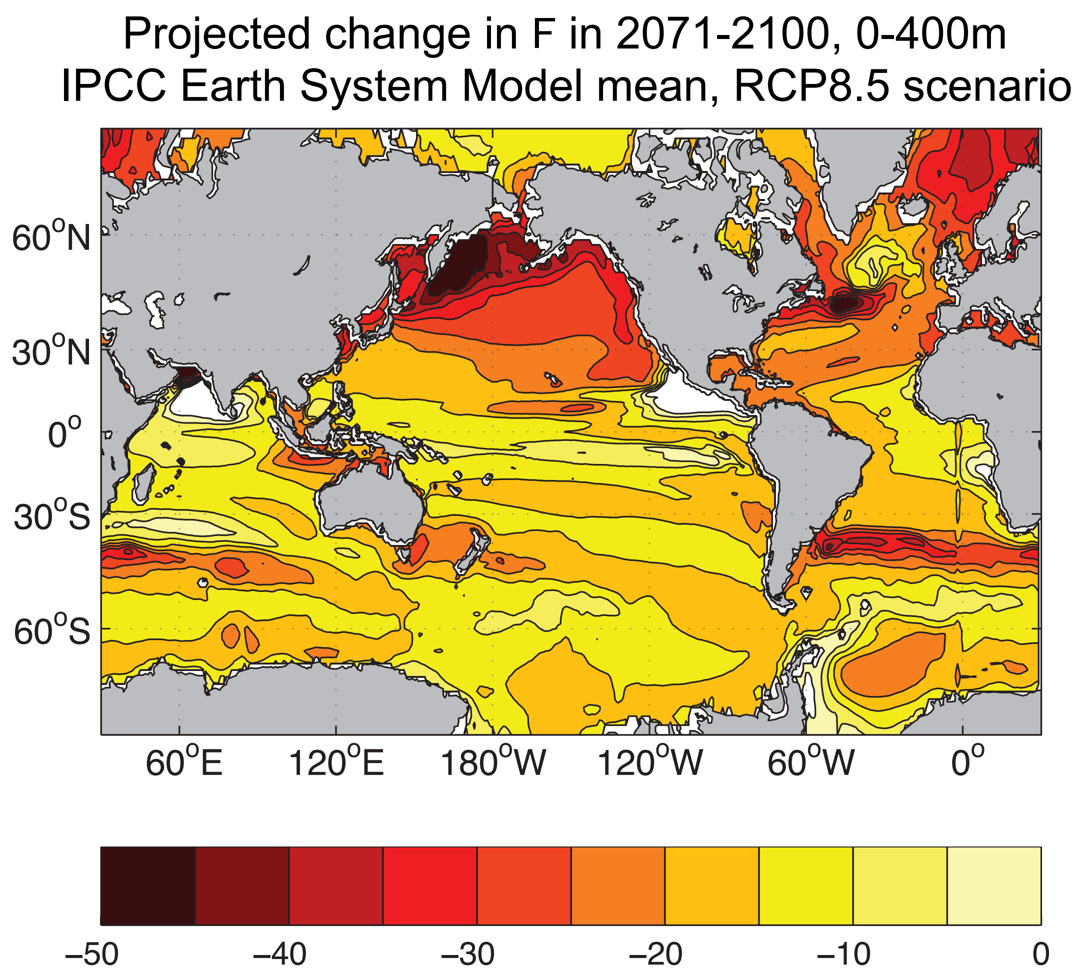


Warming is global, deoxygenation is extra-tropical.

courtesy of C. Deutsch (UCLA)

Climate Change impacts on Metabolic Index

Declining Metabolic Index



Global mean Decrease ~20%

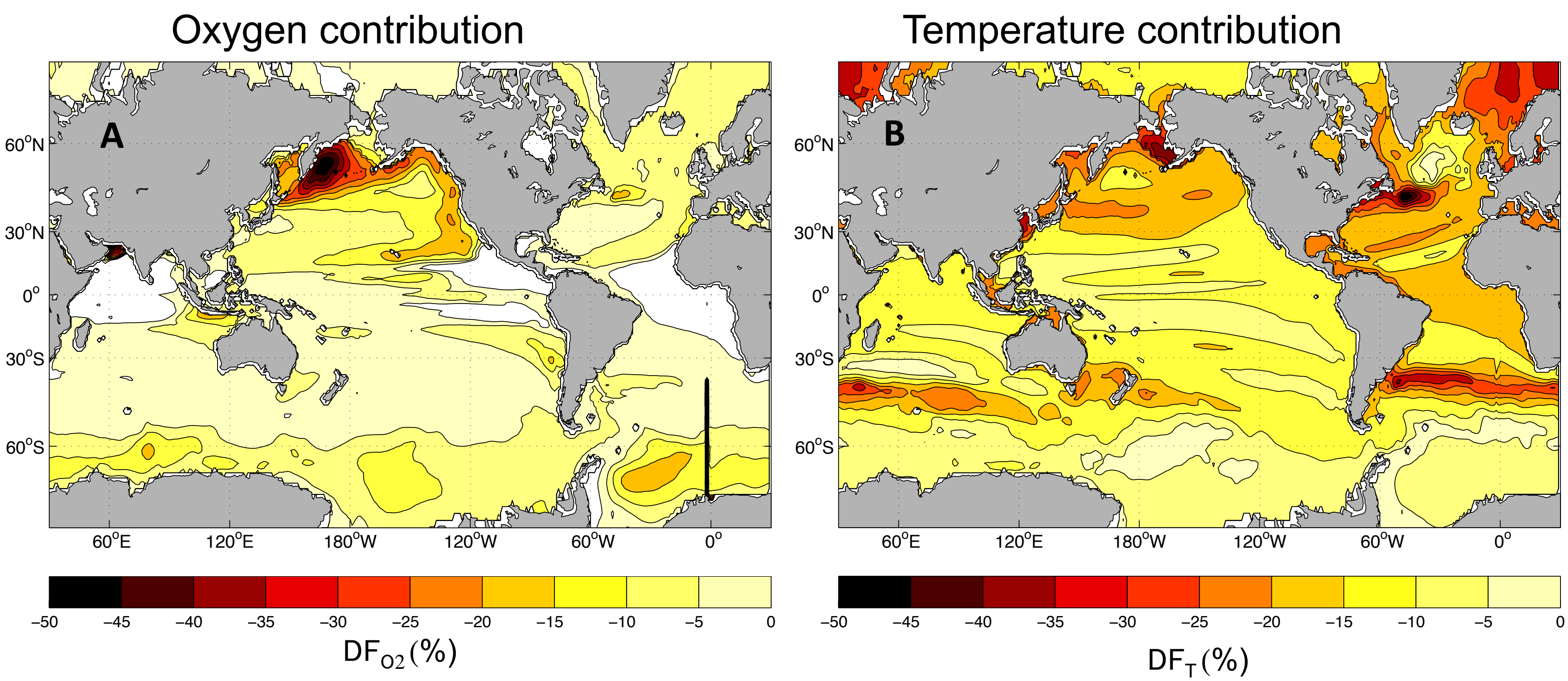
Northern High Latitudes ~40%

courtesy of C. Deutsch (UCLA)

Climate Change impacts on Metabolic Index

courtesy of C. Deutsch (UCLA)

Temperature vs Oxygen



Globally, warming and deoxygenation contribute ~15% and 5% reduction of metabolic index, respectively. The role of O_2 is greater in the Pacific, where O2 is already lower.

Climate Change impacts on Metabolic Index

Metabolic Habitat Loss

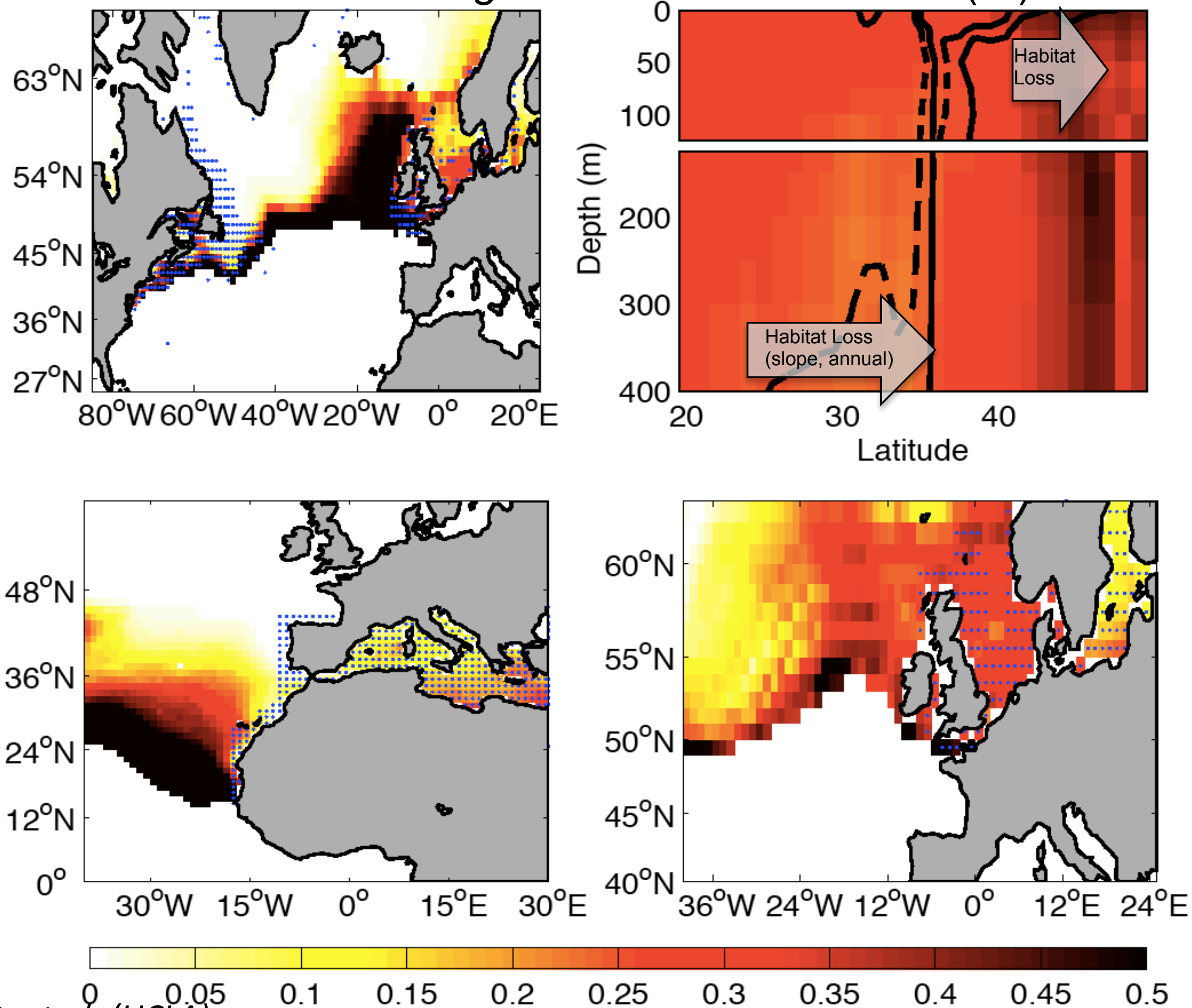
Relative change in habitable thickness (%)

Cod
-24%

Rock Crab
-22%

Seabream
-14%

Eelpout
-26%



courtesy of C. Deutsch (UCLA)

Physiological Responses

Environmental Change / Types of Response:

✦ **Temperature & Oxygen** --> **Metabolic Rates Constraint**

adaptation, migration or extinction

✦ **Ocean Acidification** --> **Calcification**

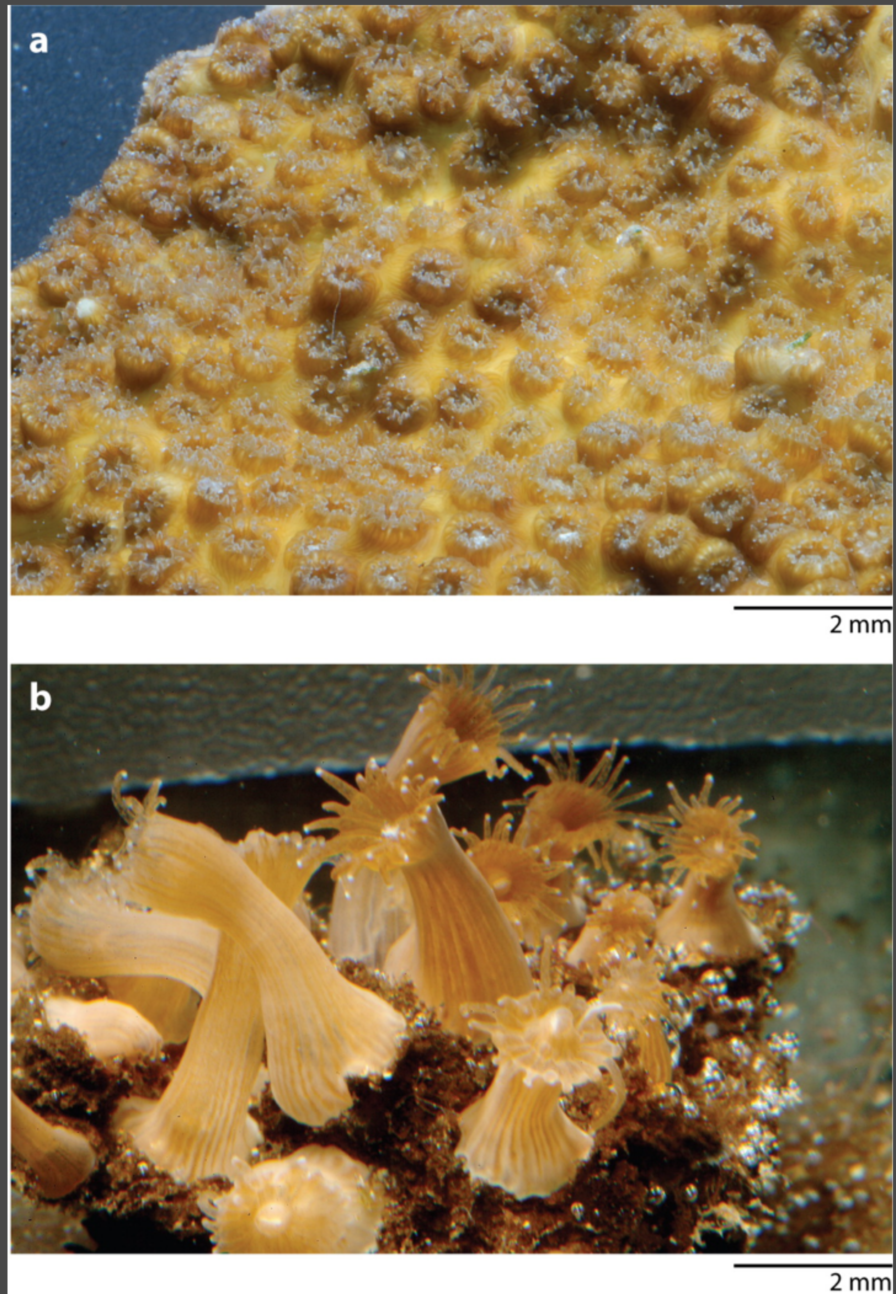
lost of biogenic habitats (e.g. corals reefs and oyster beds)

alteration of food webs (e.g. pteropods and mollusks)

changes in global bio-geochemical cycles (e.g. coccolithophore algae)

Ocean Acidification Forecasts

Acidification may impact calcification in ***Corals***

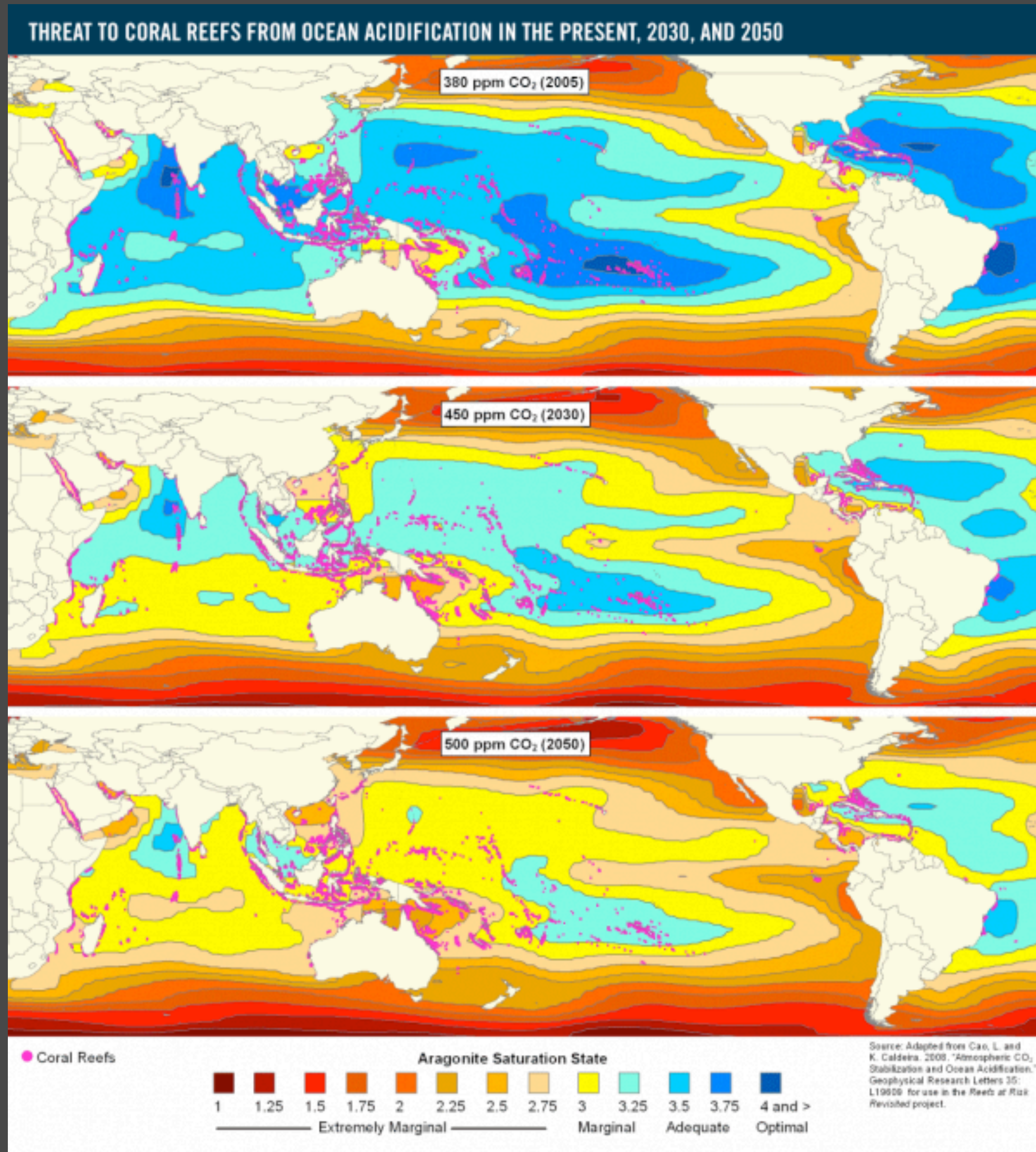


normal seawater

Photos of scleractinian coral Oculina patagonica after being maintained for **12 months** in (a) normal seawater (pH = 8.2) and (b) acidified seawater (pH = 7.4). From Fine & Tchernov (2007). Reprinted with permission from AAAS

acidified seawater

Ocean Acidification Forecasts



Acidification may impact calcification in ***Corals***

Population and Community Responses

Environmental Change / Types of Response:

- **Phenology** --> **Growing Season**

  changes in primary productivity

  and predator/prey interaction, changes in net biomass

- **Ocean Warming** --> **Species Range**

  shifts in species distributions

  and niche boundaries (e.g. invasions)

  changes in competition and local extinctions

Population and Community Responses

Environmental Change / Types of Response:

✦ **Phenology** --> **Growing Season**

changes in primary productivity

and predator/prey interaction, changes in net biomass

Phenology: Timing of seasonal cycle

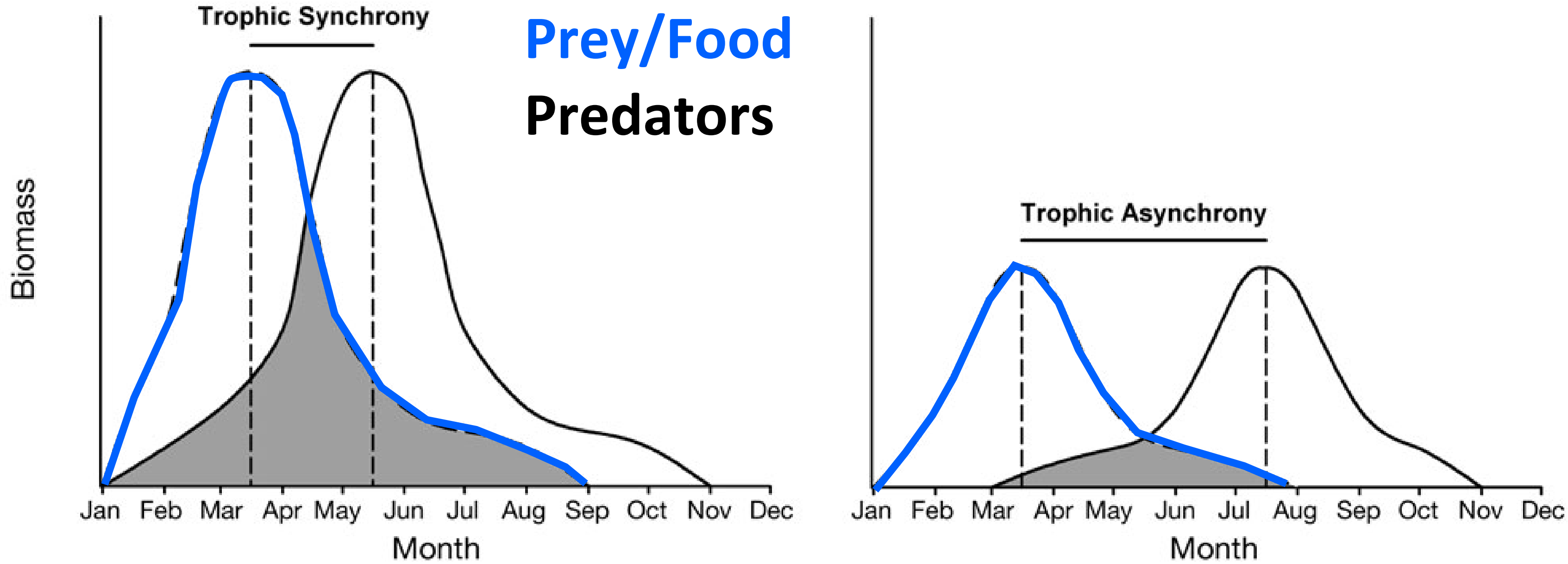


Fig. 1. Schematic of how phenology (timing) and relative abundance (biomass) affect the degree of trophic match-mismatch (after Durant et al. 2005). The key variable is the degree of trophic overlap of predator needs (continuous line) and prey availability (dashed line) in time and space. Dashed curves reflect biomass of prey (height) and seasonality of prey abundance (position of maximum). Reproductive success and other demographic traits will be high when there is great trophic overlap (grey area under curves)

Population and Community Responses

Environmental Change / Types of Response:

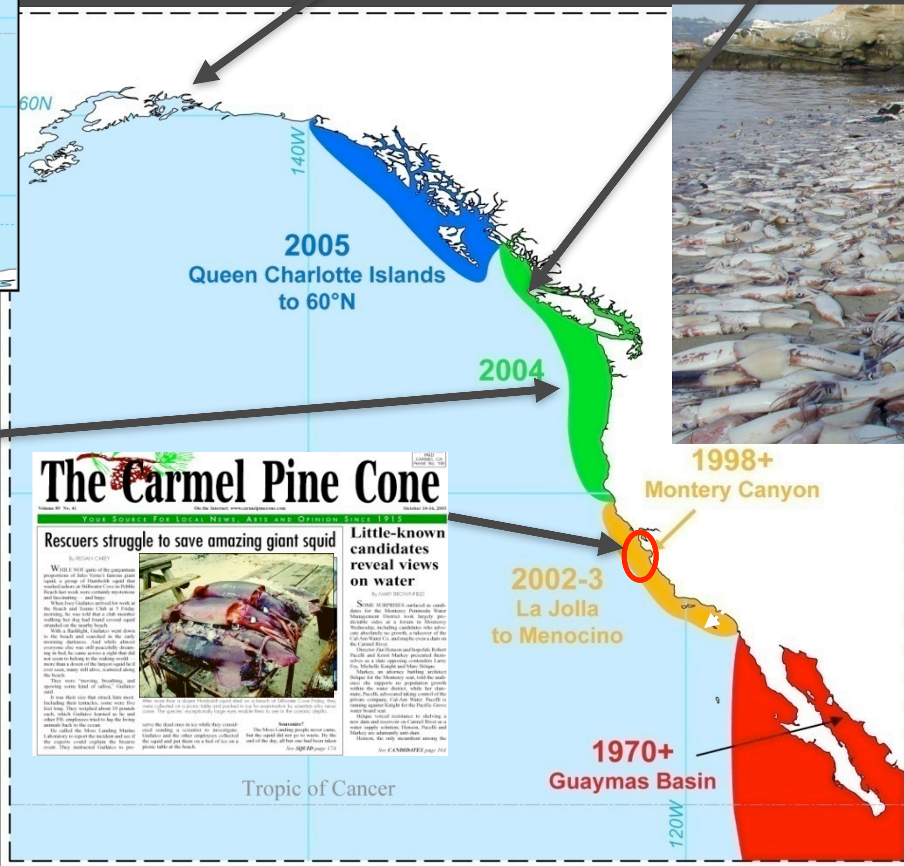
✦ **Ocean Warming** --> **Species Range**

shifts in species distributions

and niche boundaries (e.g. invasions)

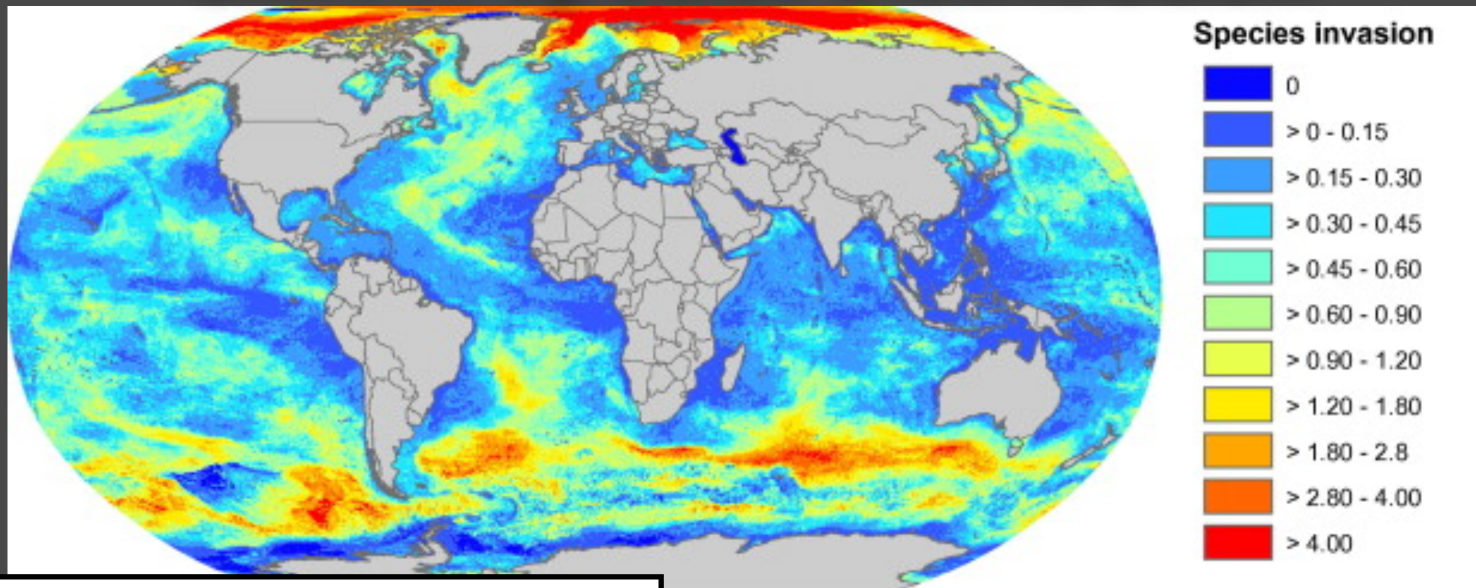
changes in competition and local extinctions

Expansion of Habitats

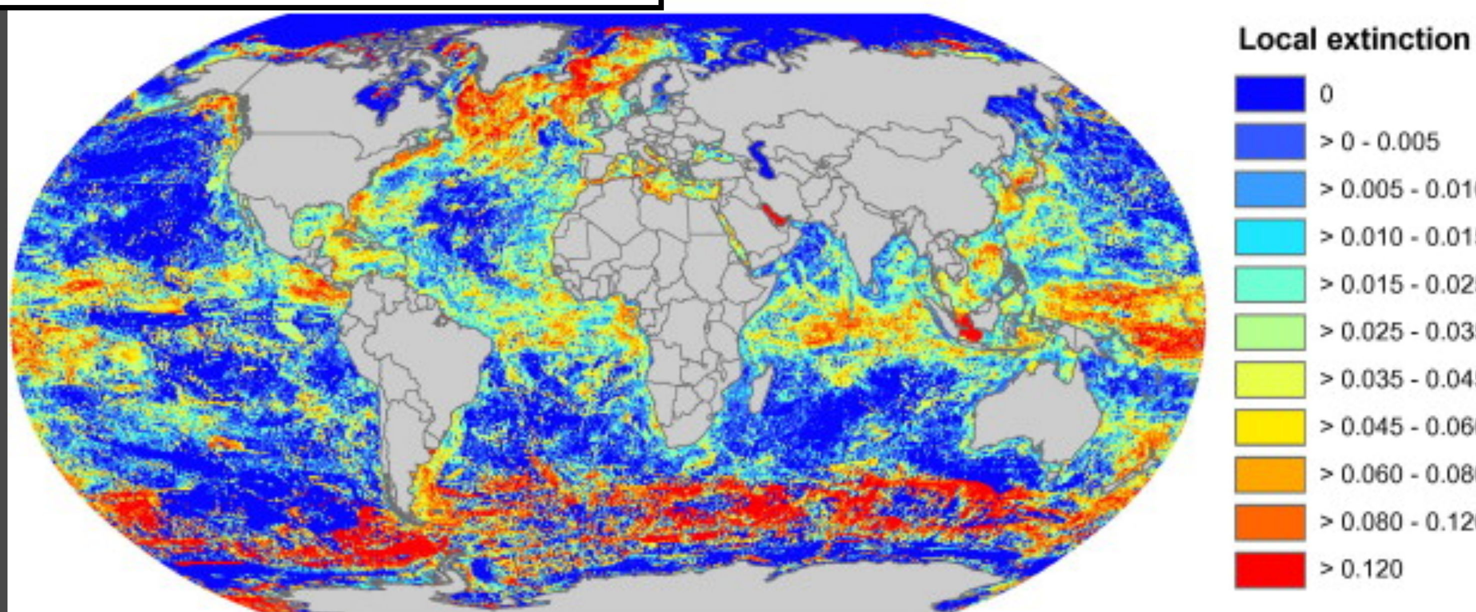


An example: Expansion of *Dosidicus gigas* habitat in 2000s

Shift in Species Distribution

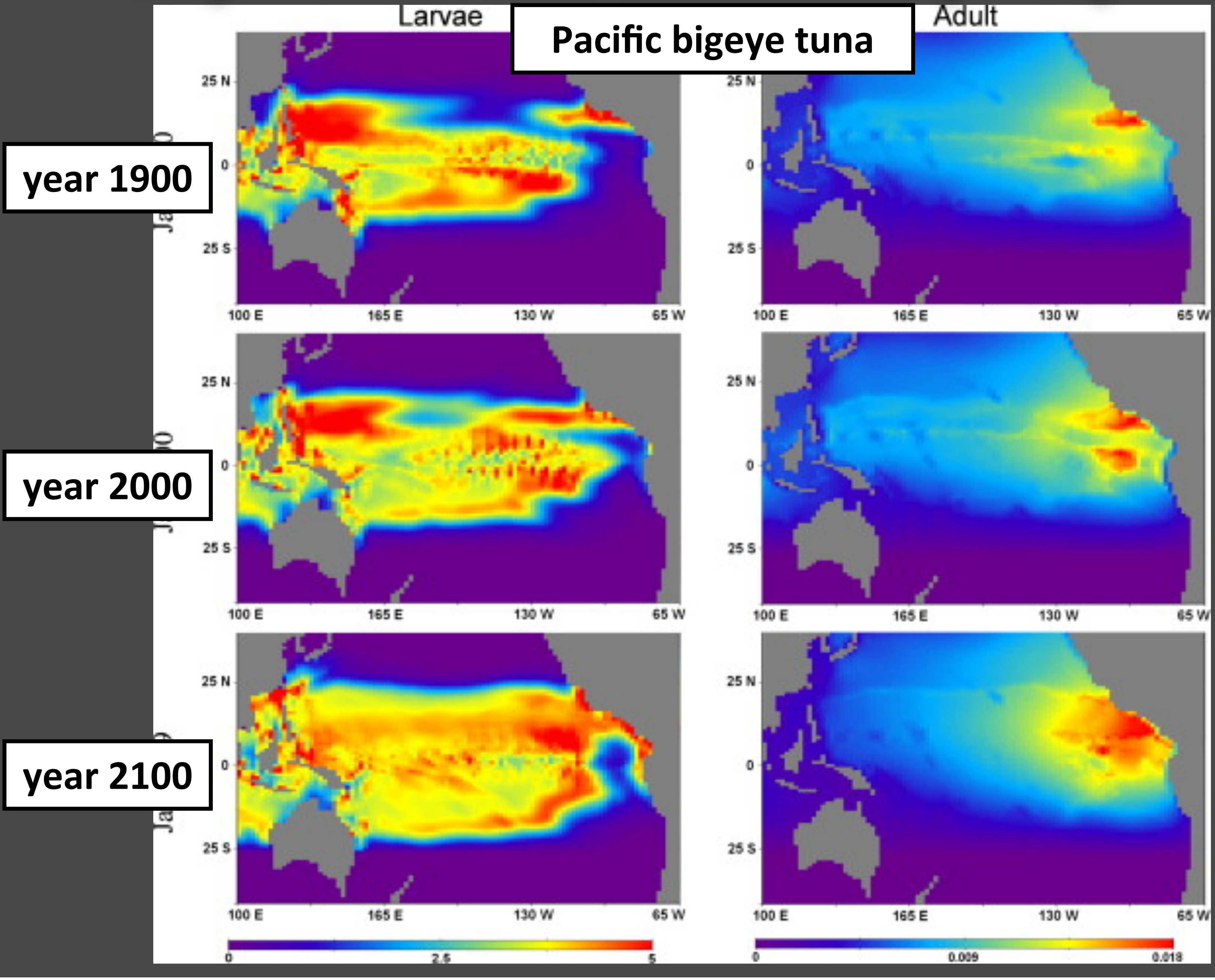


year 2050 *(relative to 2000)*



Cheung et al. 2009

Population and Community Responses



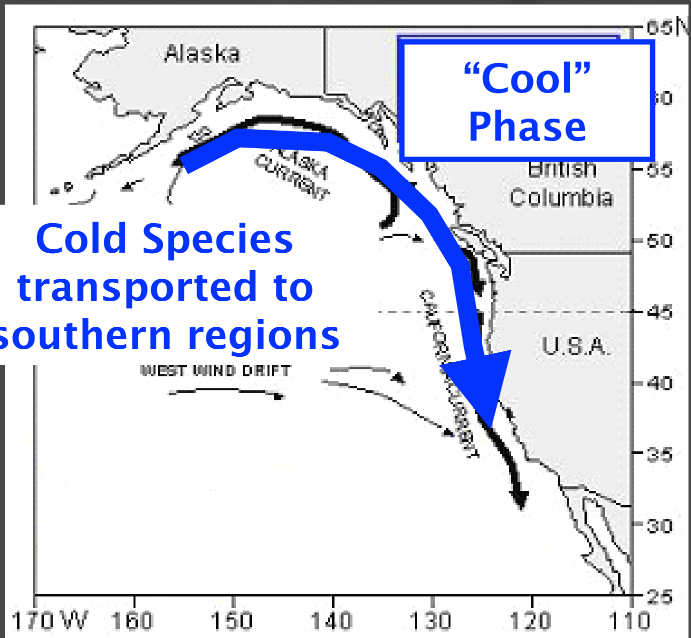
Lehodey et al. 2010

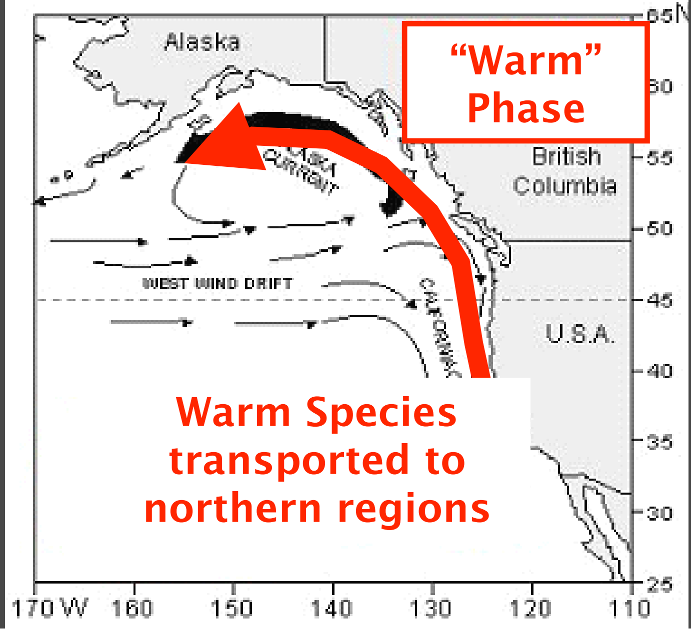
Ecosystem Structure and Function

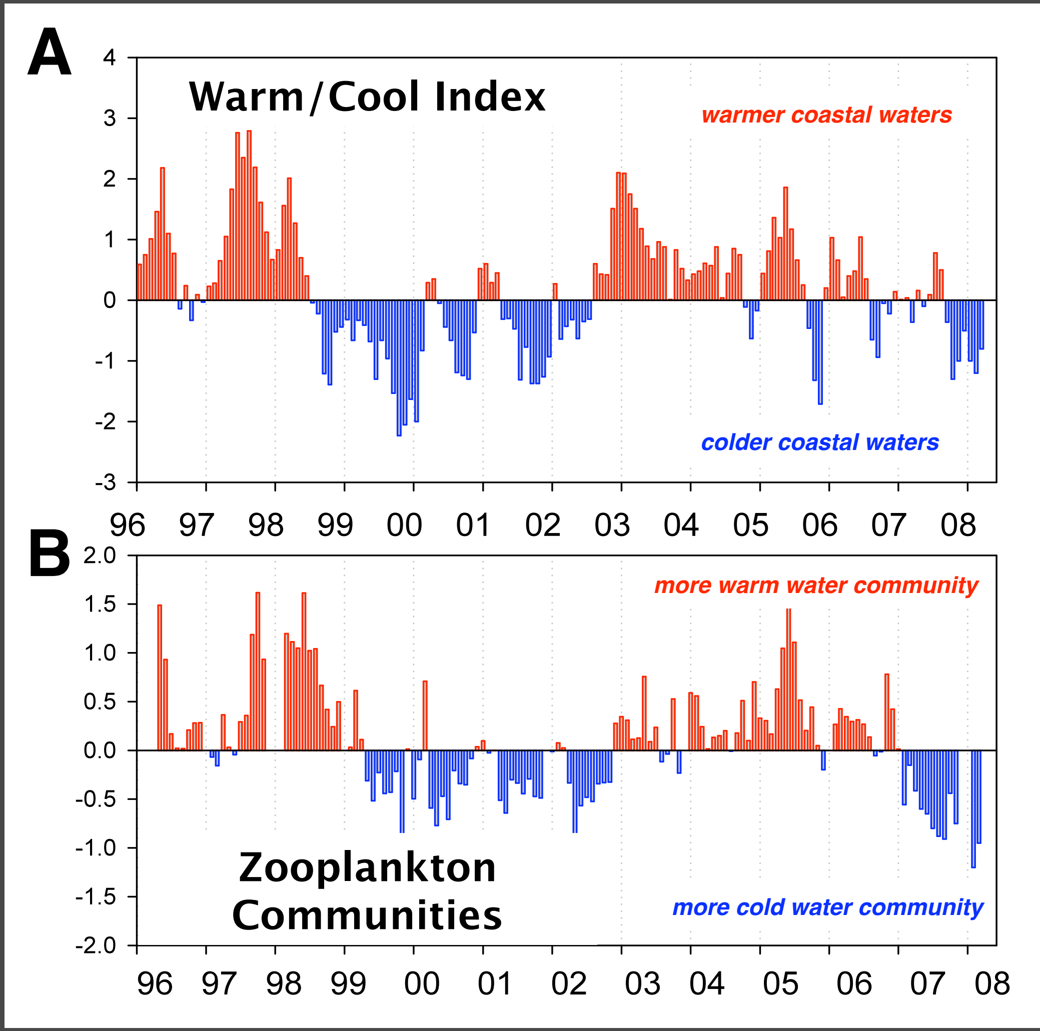
Environmental Change / Types of Response:

- **Ocean Circulation** --> **Species Compositions**
  --> **Nutrient Supply**
  --> **Connectivity**

Ocean Transport and Species Composition







Ecosystem Structure and Function

Environmental Change / Types of Response:

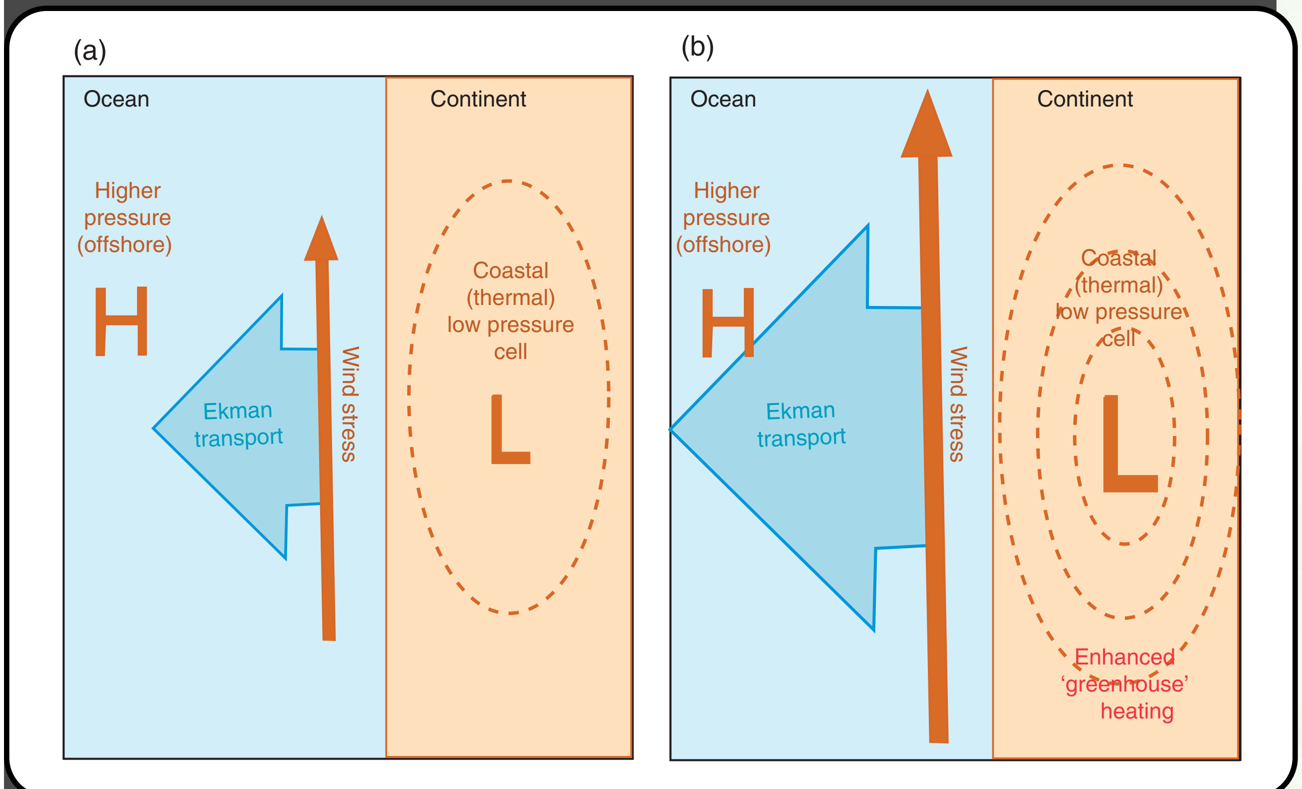
✦ **Ocean Circulation** --> **Species Compositions**

--> **Nutrient Supply**

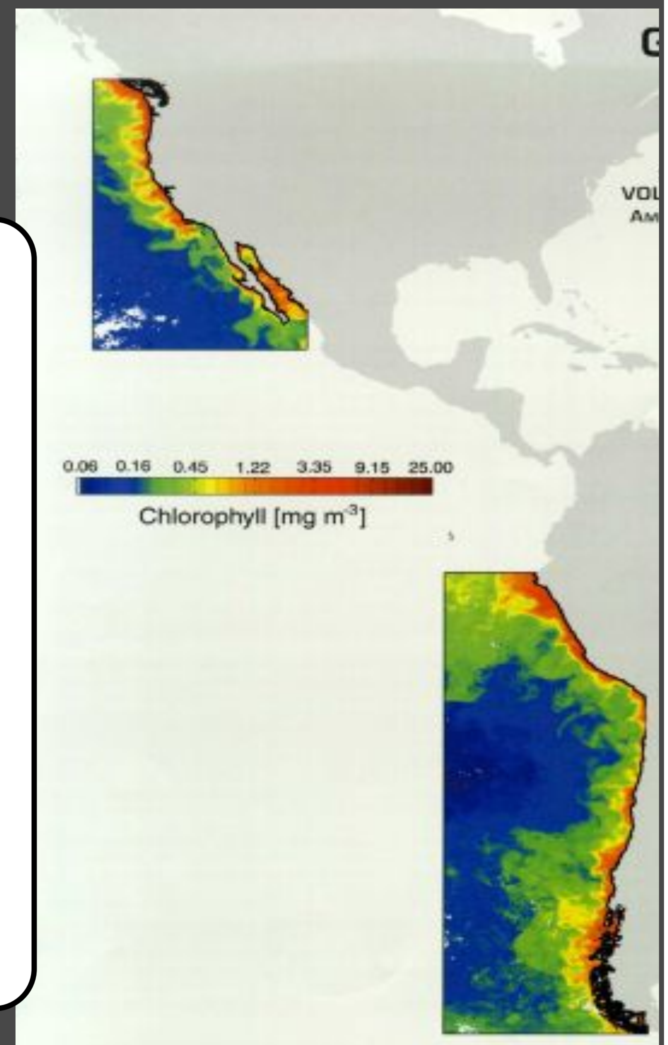
--> **Connectivity**

Changes in Nutrient Supplies in Eastern Boundary Upwelling Systems

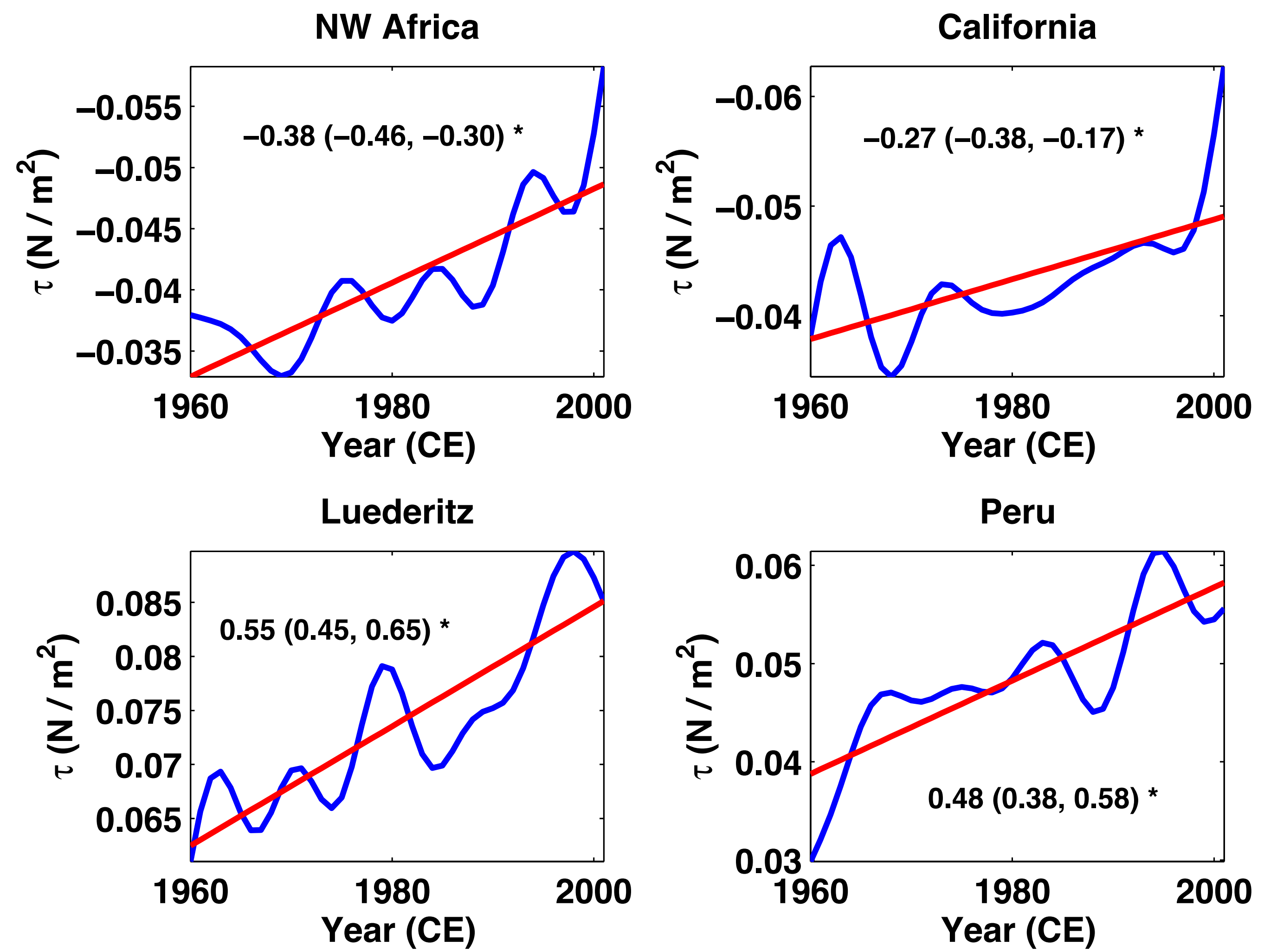
Upwelling winds may intensify in response to climate change



Bakun et al. 2010



Intensification of Upwelling winds?



OSD

7, 335–360, 2010

Trends in coastal upwelling intensity

N. Narayan et al.

Ecosystem Response to Climate

Physical and chemical changes have strong direct and indirect effects on the physiology and behavior of marine organisms.

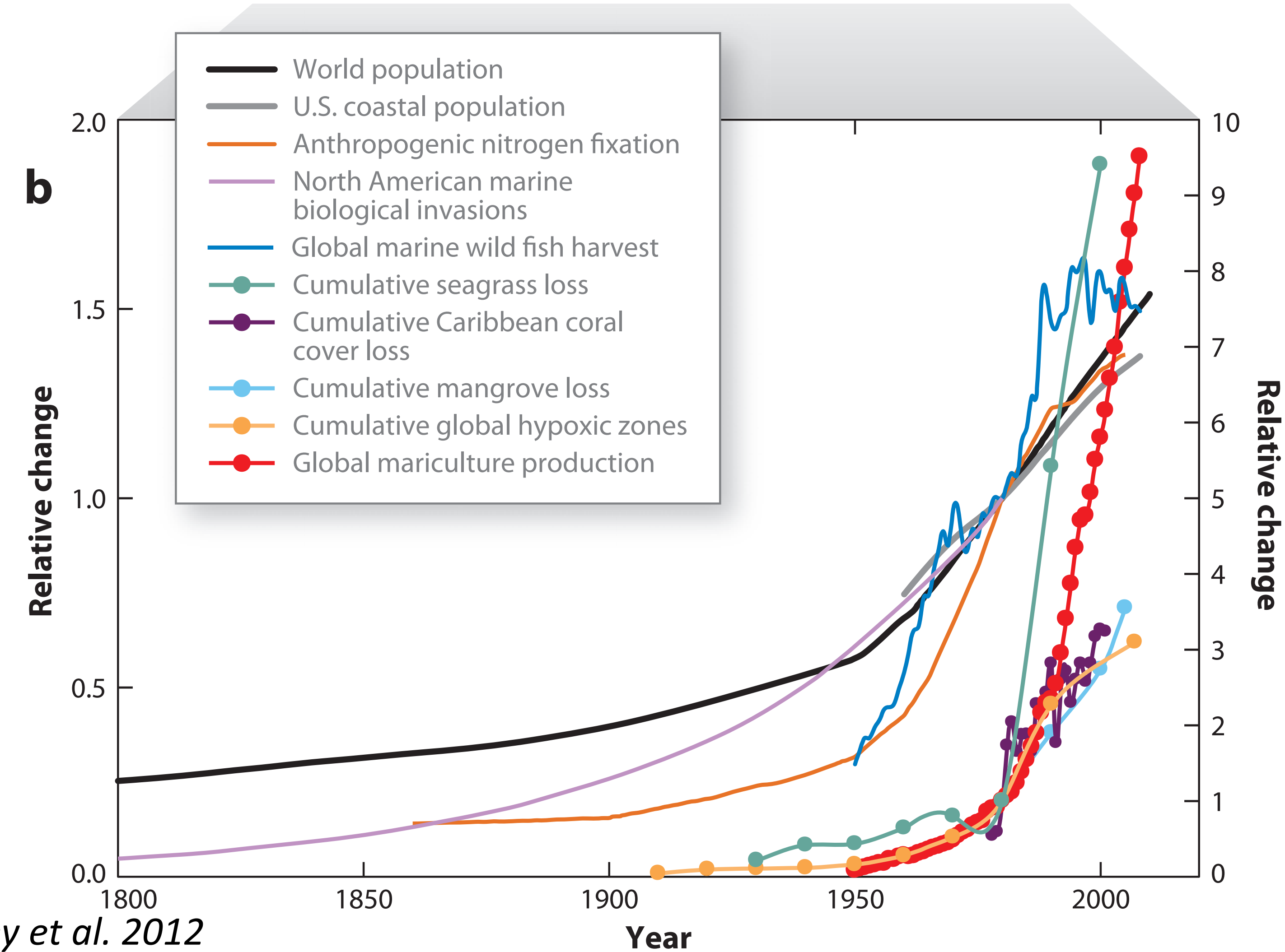
Types of Response:

- Physiological responses
- Population and Community Responses
- Ecosystem Structure and Function

We have reviewed some examples of responses, however the ecosystem response is more complex and integrated.

Additional Ecosystem Pressures

the need for an integrated approach to Ecosystem Structure and Function



Doney et al. 2012