Effects of Climate Change on the World's Oceans

Biodiversity consequences of climate change in the deep ocean

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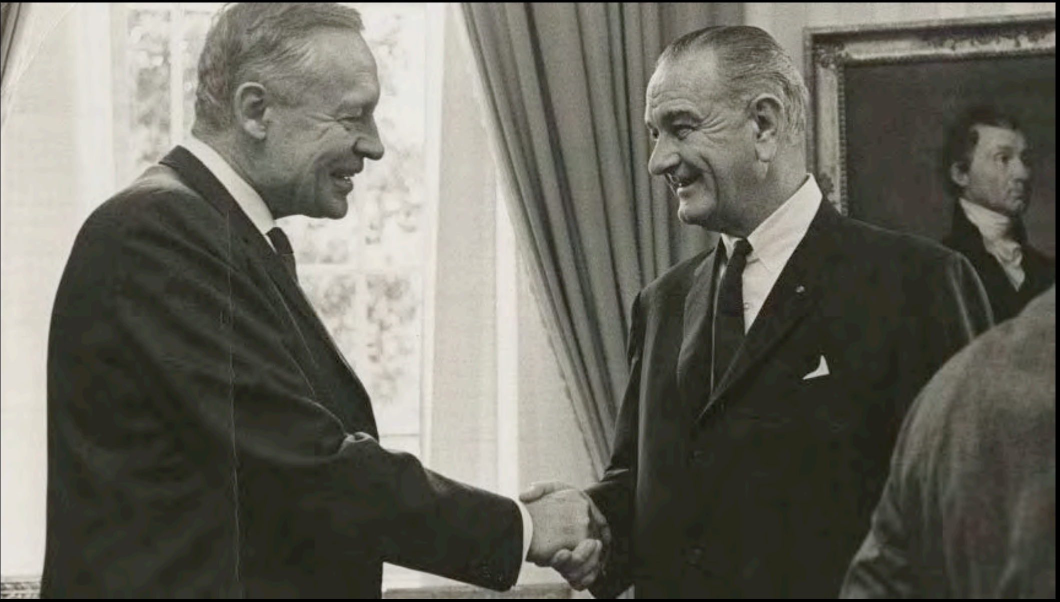
March 25, 2015
Santos City, Brazil



50 years ago …

This generation has altered the composition of the atmosphere on a global scale through radioactive materials and a steady increase in carbon dioxide from the burning of fossil fuels.
- President Lyndon B. Johnson, 1965

50 year later….

This generation has begun to alter the deep ocean….
Via CO_2-induced environmental change and resource exploitation

Delving Deeper

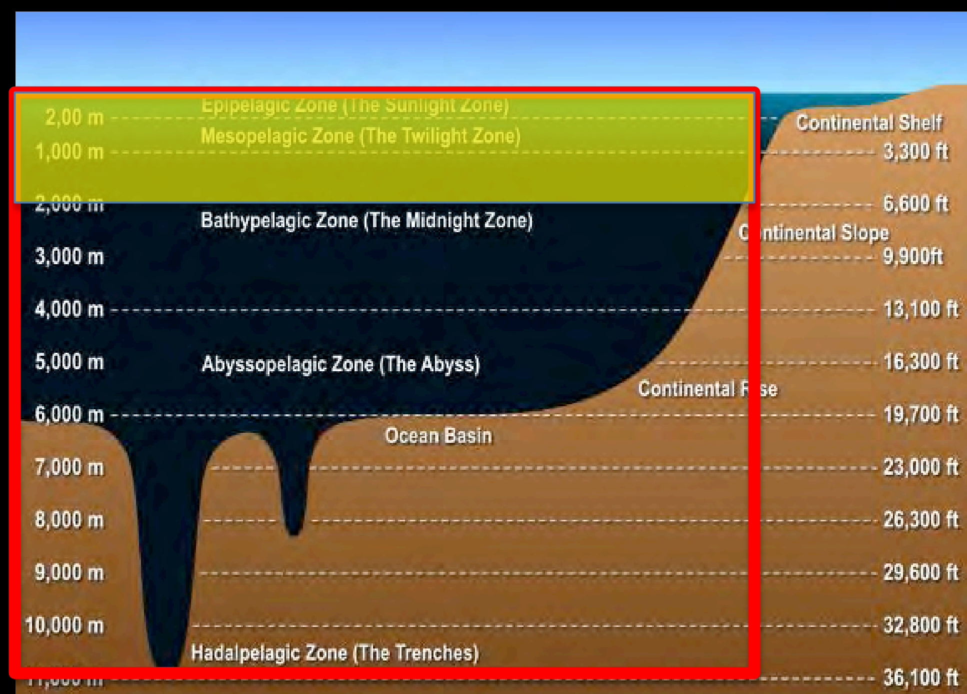
- Special Features of the Deep
- Climate Change (T, OA, O_2) in Deep water
- Biodiversity Consequences
  - Past: Paleoceanographic lessons
  - Present: Learning from natural gradients
  - Future: Projection and Adaptation

The largest habitat on earth

- The deep ocean (>200 m) comprises 2/3 of the planet's surface area and > 90% of its habitable volume

- We have seen < 5% of the deep sea floor thus most marine species are undescribed.

- Great depth limits access & measurement capability



Special Features of the Deep Sea

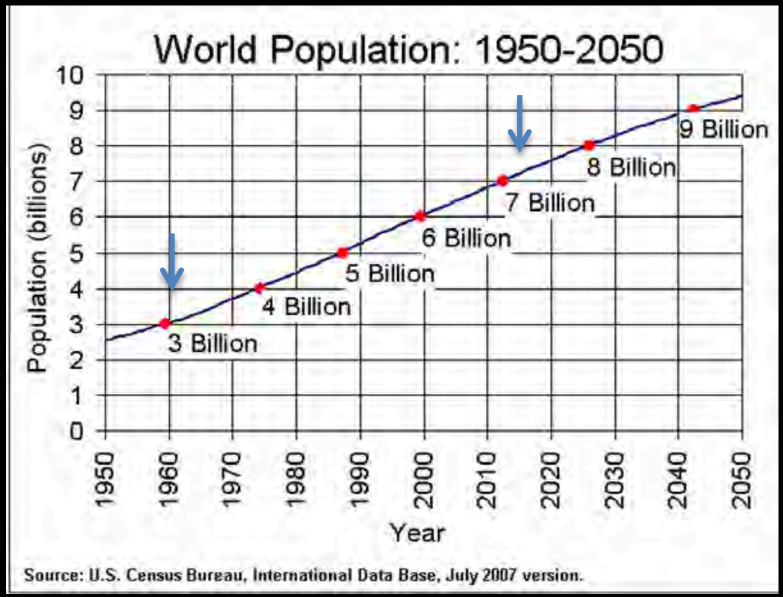
(that influence biodiversity and its response to changing environments)

- Vast areas – impossible to catalogue all biodiversity
- Remote and far from shore = high exploration & exploitation costs (=Protection!)
- Technology-limited advances in knowledge & exploitation (we lack full-ocean depth capability for a host of measurements)
- Heterogeneity of habitats and time/space scales (translates to variable response to climate change)

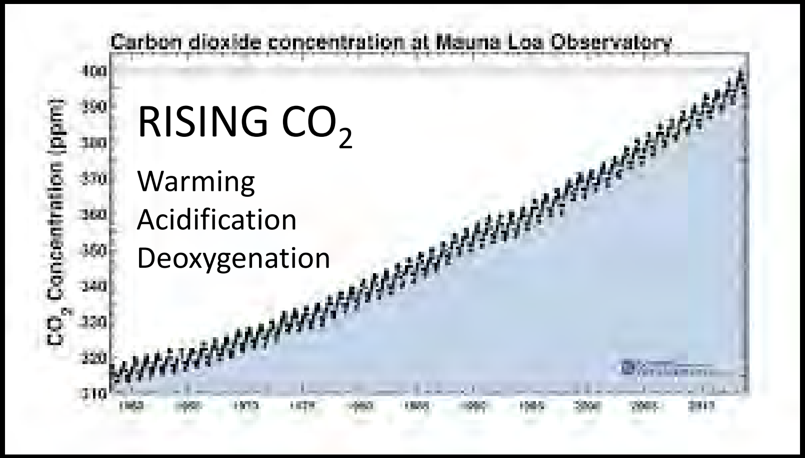
Special Features of the Deep Sea cont.

- Slow processes:
  - long- lived species, low replacement rates
  - long time lag between biodiversity response and receipt of services by humans
- Lack of scientific knowledge –many unknown unknowns adds to uncertainty
- Lack of public awareness
- Growing human influence

Industrialization of the Deep Ocean



A growing population



Demanding more:

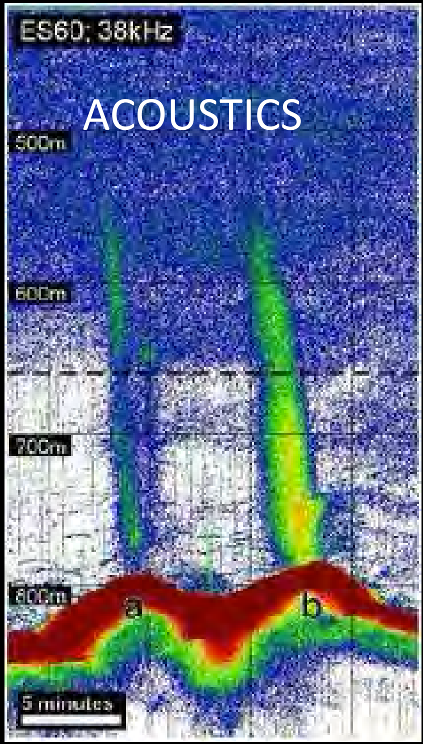
RAW MATERIALS

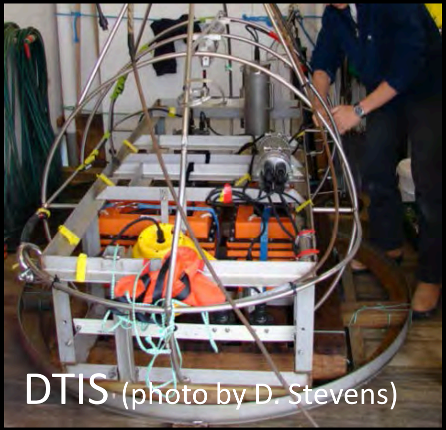
FOOD

ENERGY

RARE EARTHS

New exploration tools reveal a wealth of environmental heterogeneity

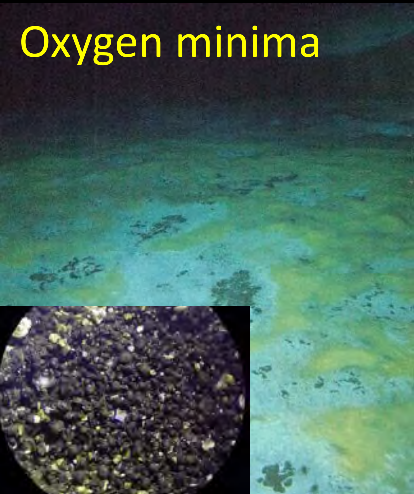




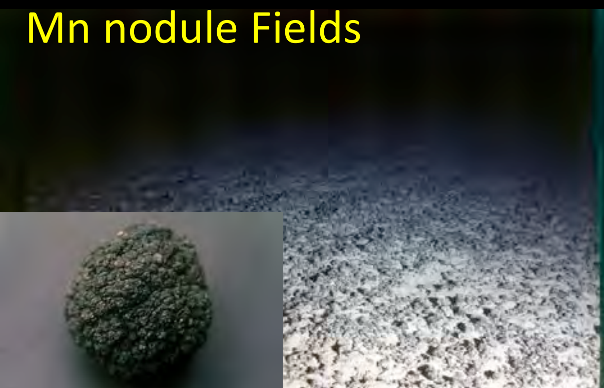
SOURCES OF HETEROGENEITY

- Large-Scale:
  - Hydrographic (O_2, pH, T, S)
  - Productivity
- Meso-Scale:
  - Geomorphic
  - Geochemical
- Small-Scale:
  - Biogenic Structures

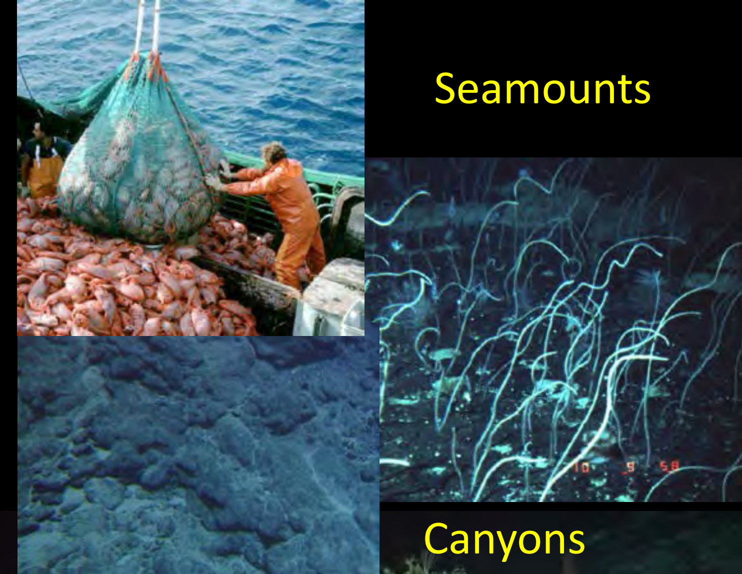
Oxygen minima



Mn nodule Fields



Seamounts



Canyons

Methane Seeps

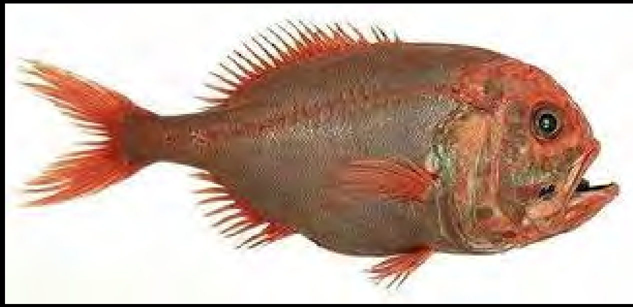
Hydrothermal Vents

Cold water coral & sponge reefs

Exceptional Longevity, Slow Growth

Smooth oreo dory – 100 y

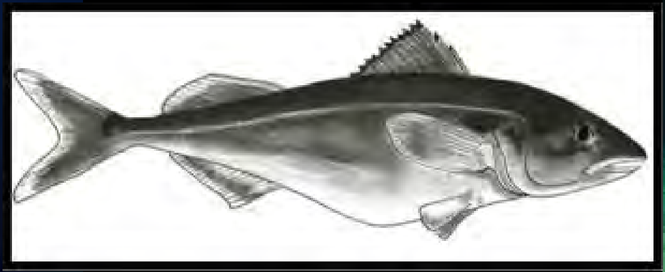
Black Oreo-153 y



Orange Roughy - 149 y

2,320 years old

Garrardia sp.



Sablefish – 114 y

4,265 years old

Leiopathes sp.

Technology - The enabler

New cables and gear to reach deep

deepseanews.com

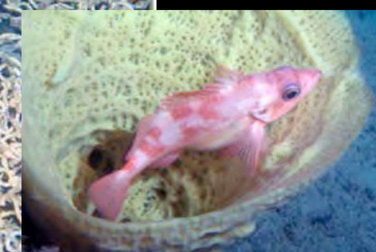
Oil and Gas Infrastructure

Offshoreenergytoday.com

Deep-Ocean Functions & Services

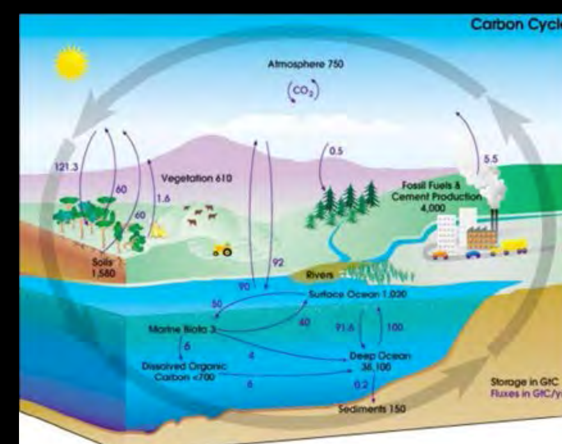
Provisioning Services: fish, shellfish, oil, gas, pharmaceuticals, industrial agents, minerals

Support Functions: habitat, trophic support, refugia, nursery grounds



Regulating Services: Carbon sequestration, nutrient cycling

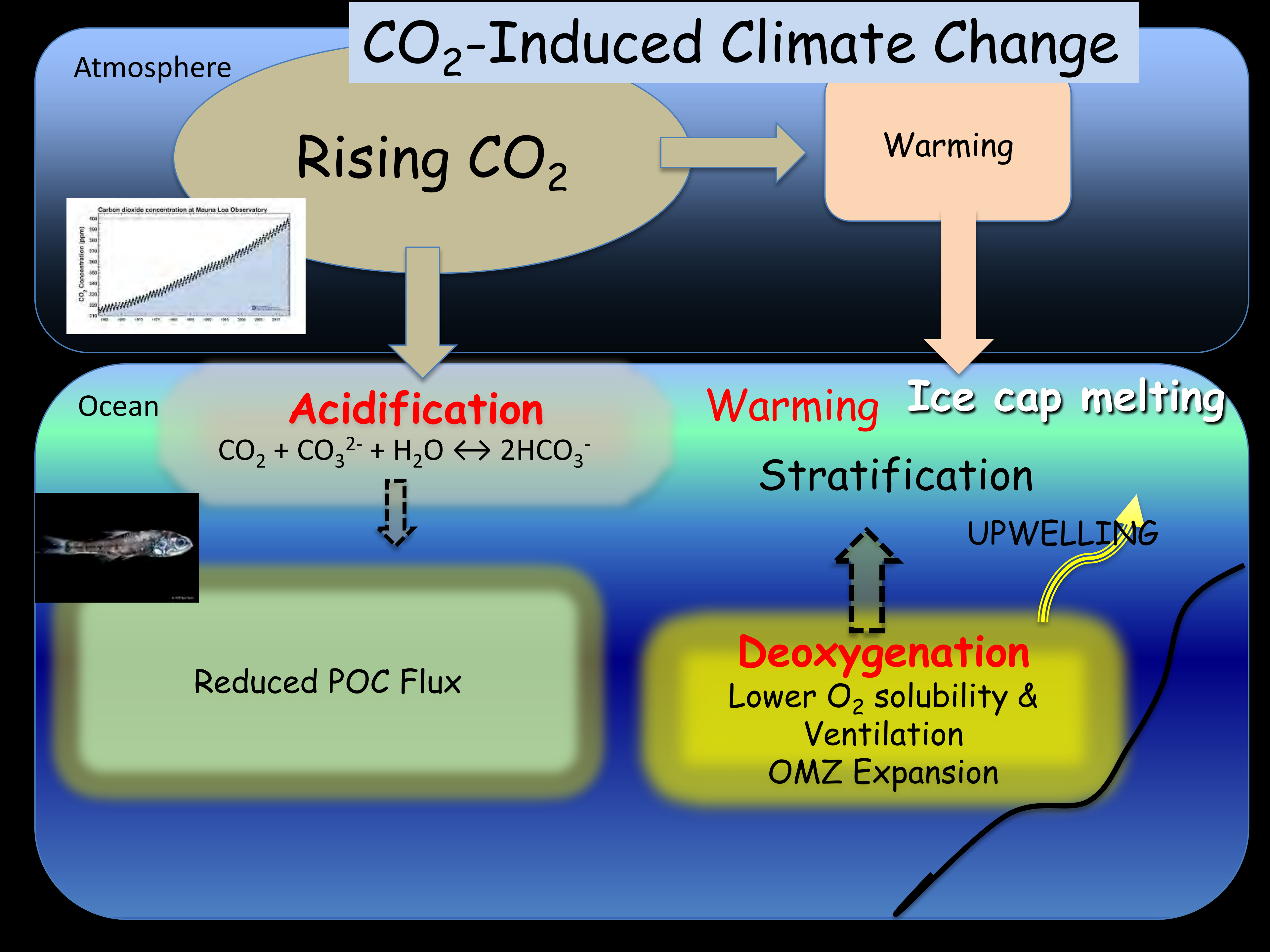
Biodiversity: genetic resources, biomaterials, adaptation to change



Scientific Research

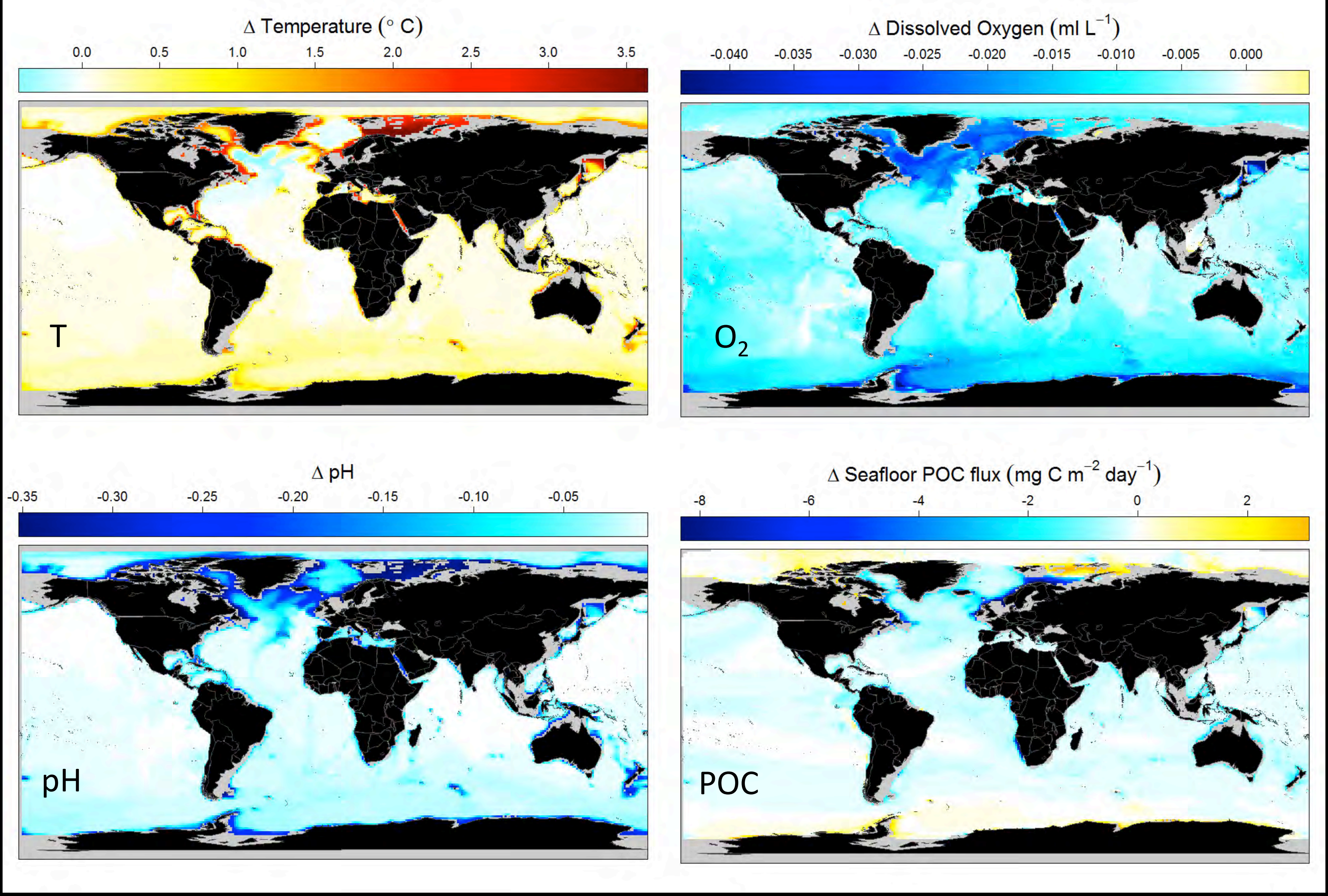
Communications

Artistic Inspiration

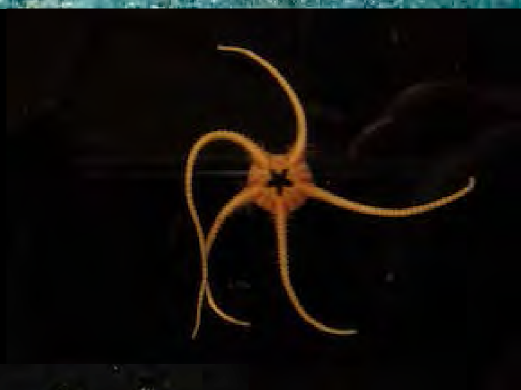


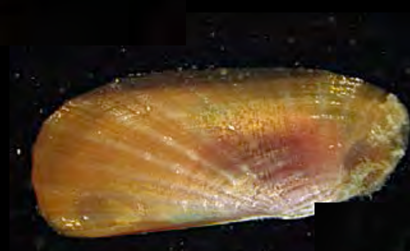
CO$_2$-Induced Climate Change
Atmosphere
Rising CO$_2$
Carbon dioxide concentration at Mauna Loa Observatory
CO$_2$ Concentration (ppm)
Warming
Ocean
Acidification
$CO_2 + CO_3^{2-} + H_2O \leftrightarrow 2HCO_3^-$
Warming
Ice cap melting
Stratification
UPWELLING
Reduced POC Flux
Deoxygenation
Lower O$_2$ solubility &
Ventilation
OMZ Expansion

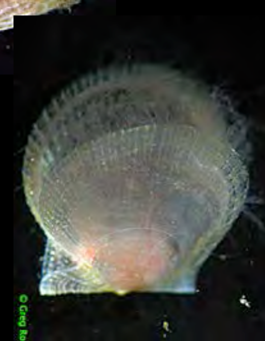
Projected Change on the Deep-Sea Floor - 2100
(Mora et al. 2013)



What are the biodiversity consequences?







Geologic record holds a long history of environmental change and biodiversity consequences

Episodic Anoxia (red) and Extinction Events

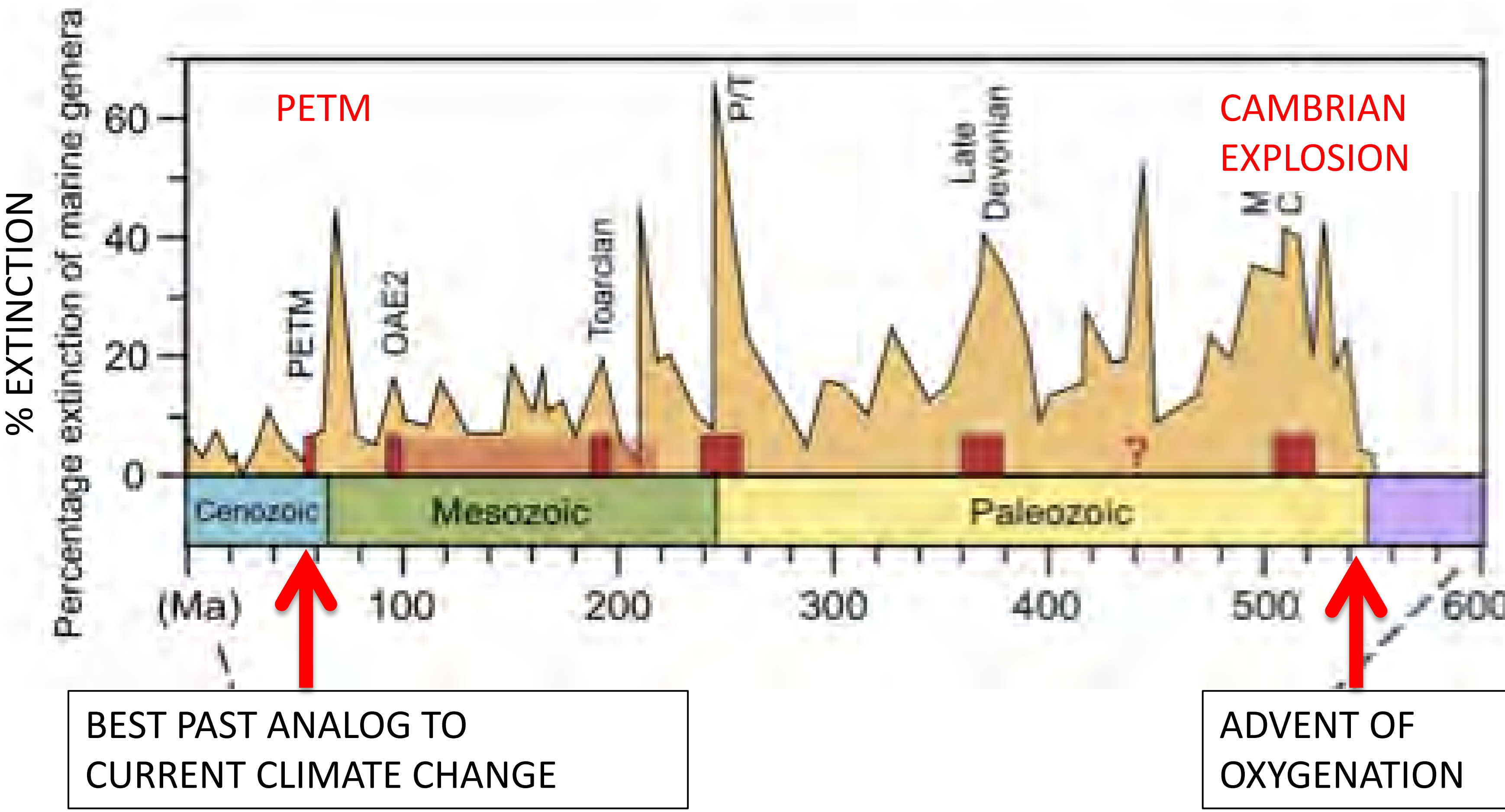
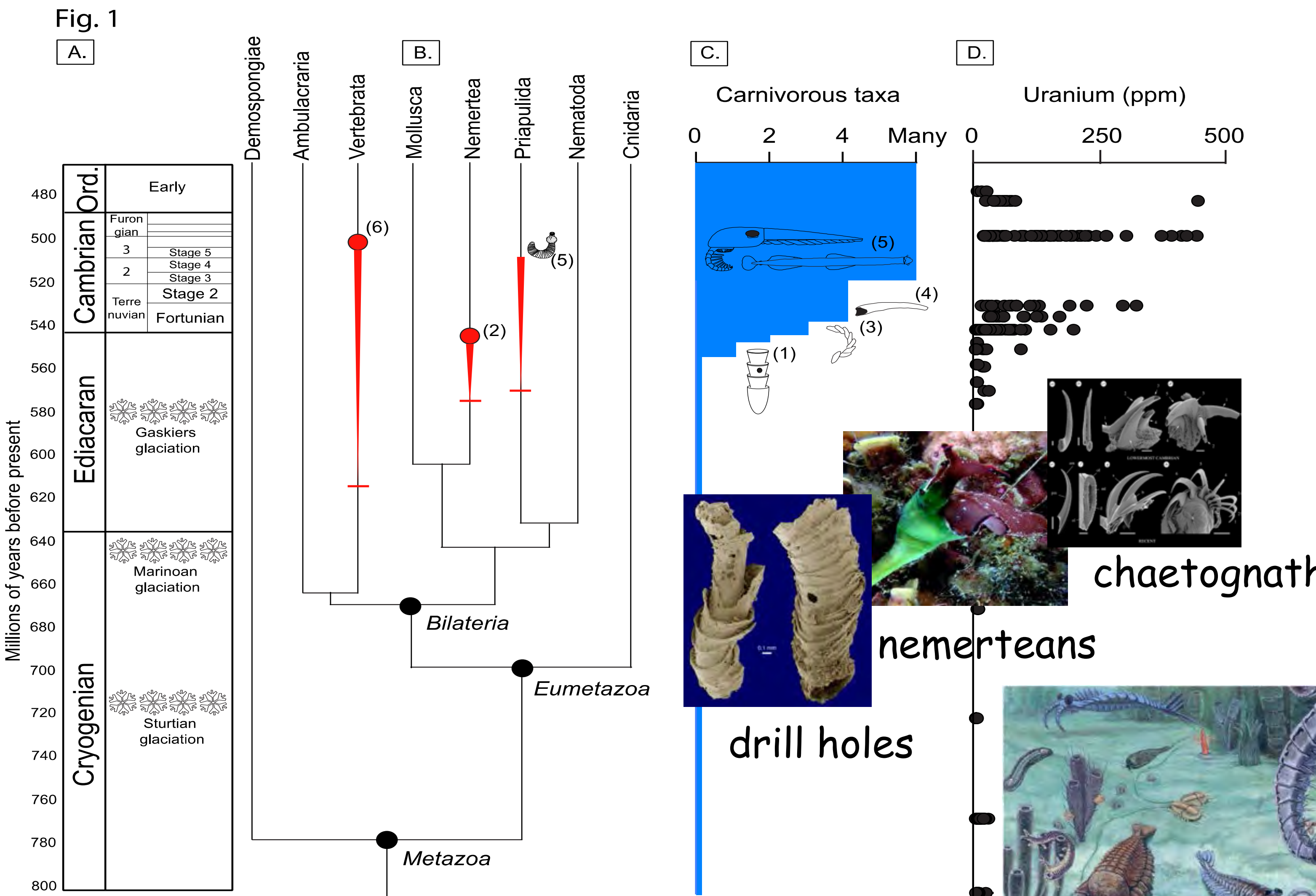


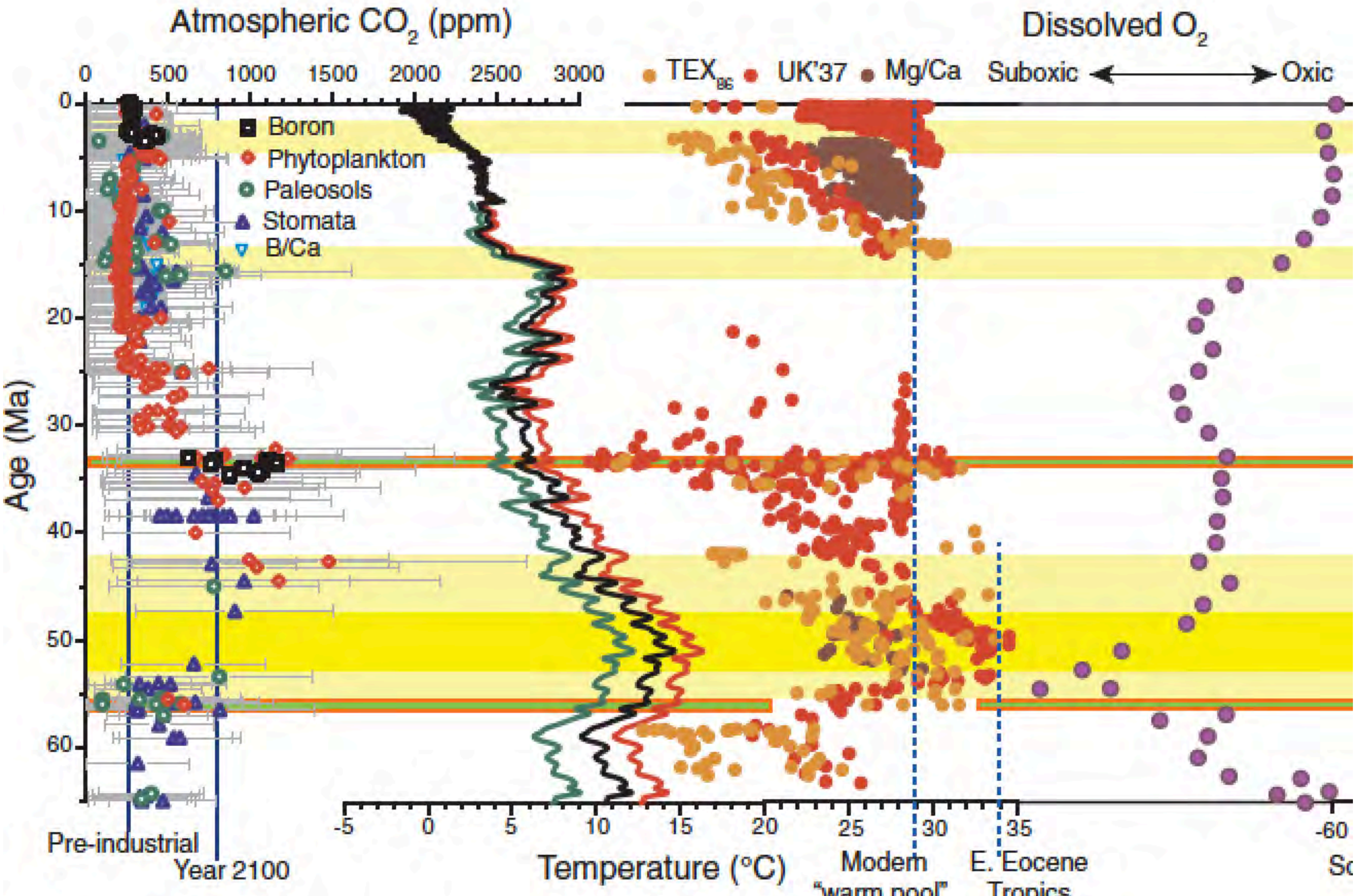
Figure courtesy Ariel Anbar and Timothy Lyons.

Oxygenation and advent of carnivory may help explain the timing and diversity increase of the Cambrian Explosion (540 MY)



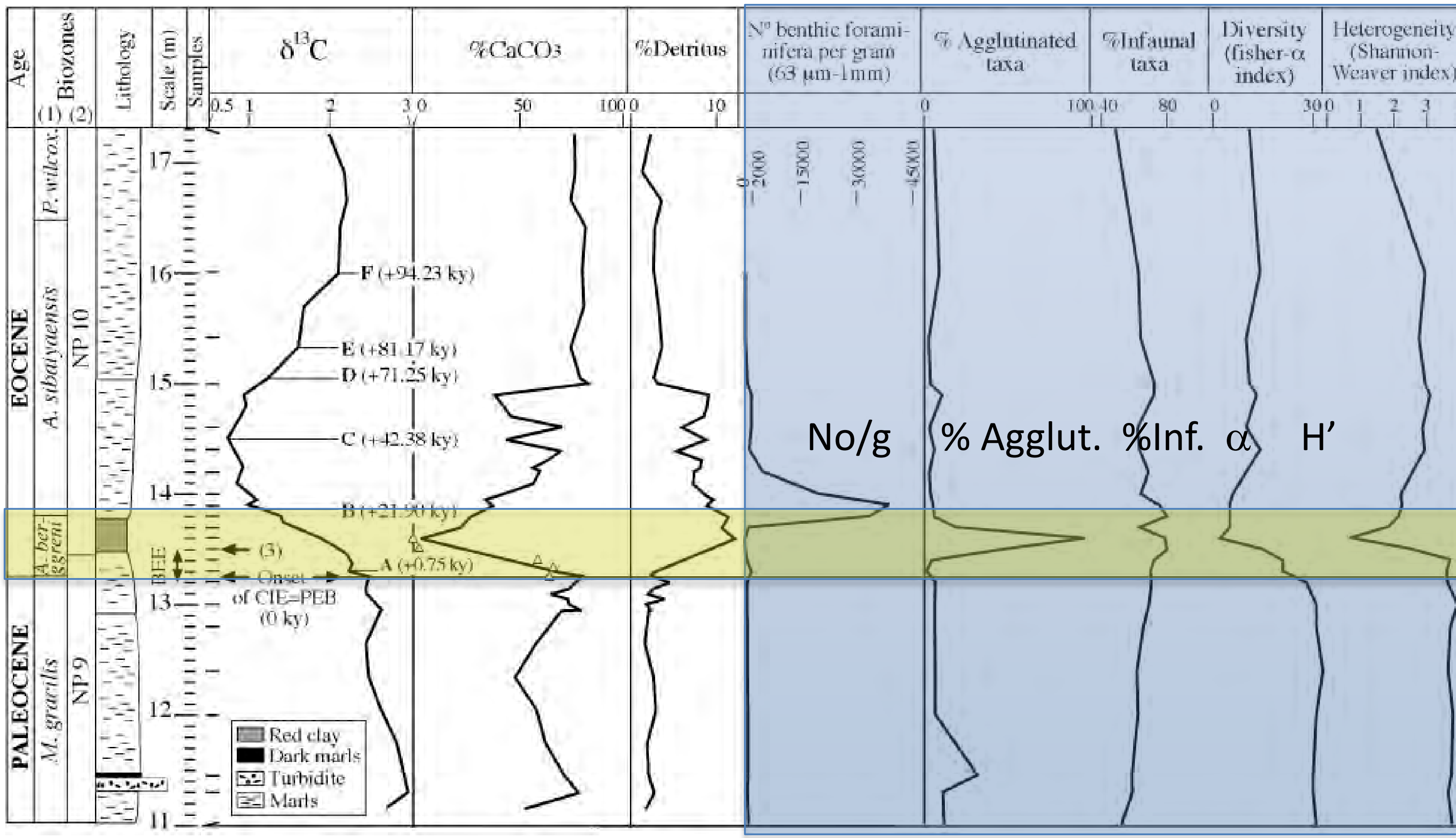
Sperling et al., 2013, PNAS 110: 13446

The PETM at 55 MY exhibits the deadly trifecta: Rising CO_2, and T, declining O_2



From Norris et al. 2013

55.8 MY: Rapid extinction and recovery of benthic foraminifera across the Paleocene–Eocene Thermal Maximum



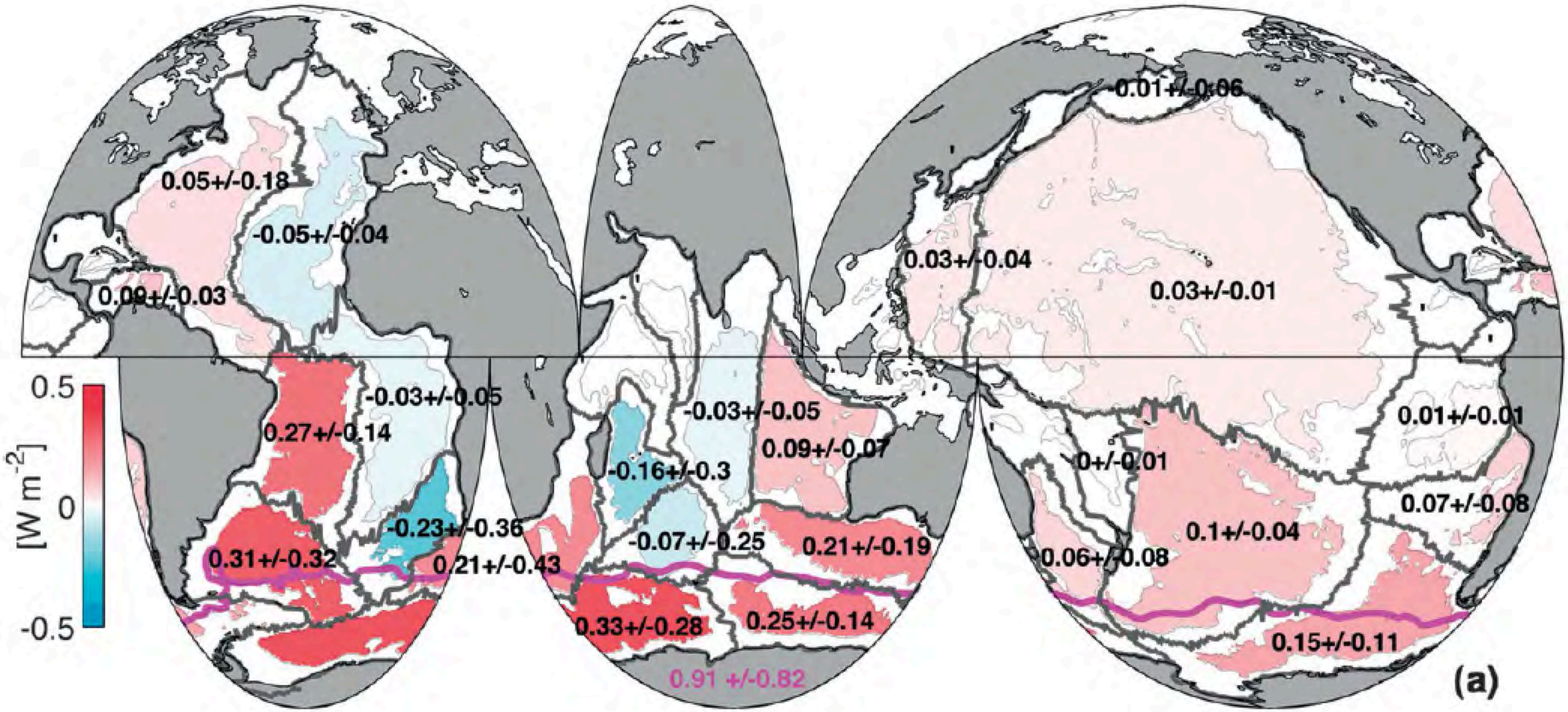
WARMING, ANOXIA, ACIDIFICATION

L. Alegret , S. Ortiz , E. Molina , 2009, Palaeo 3

(Alamedilla section -Southern Spain)

Recent Deep-Ocean Warming
based on repeat hydrography

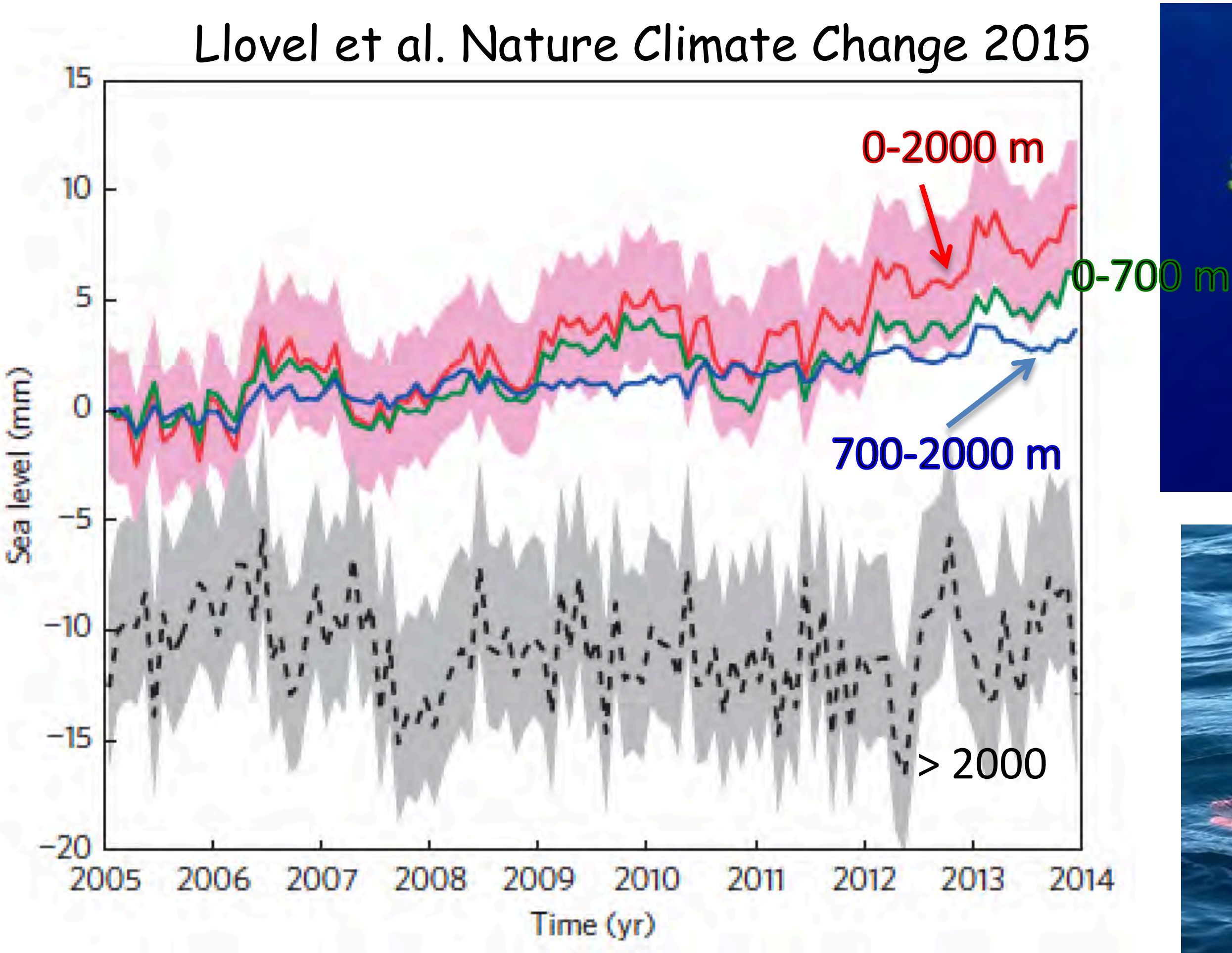
Rate of warming below 4000 m

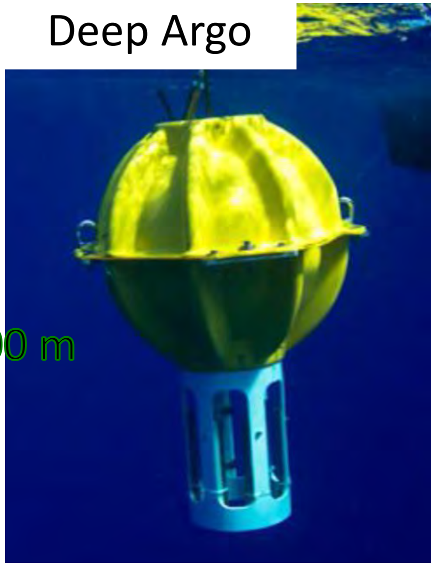


Purkey and Johnson (2010)

Deep-ocean contribution to sea level and energy budget not detectable over the past decade

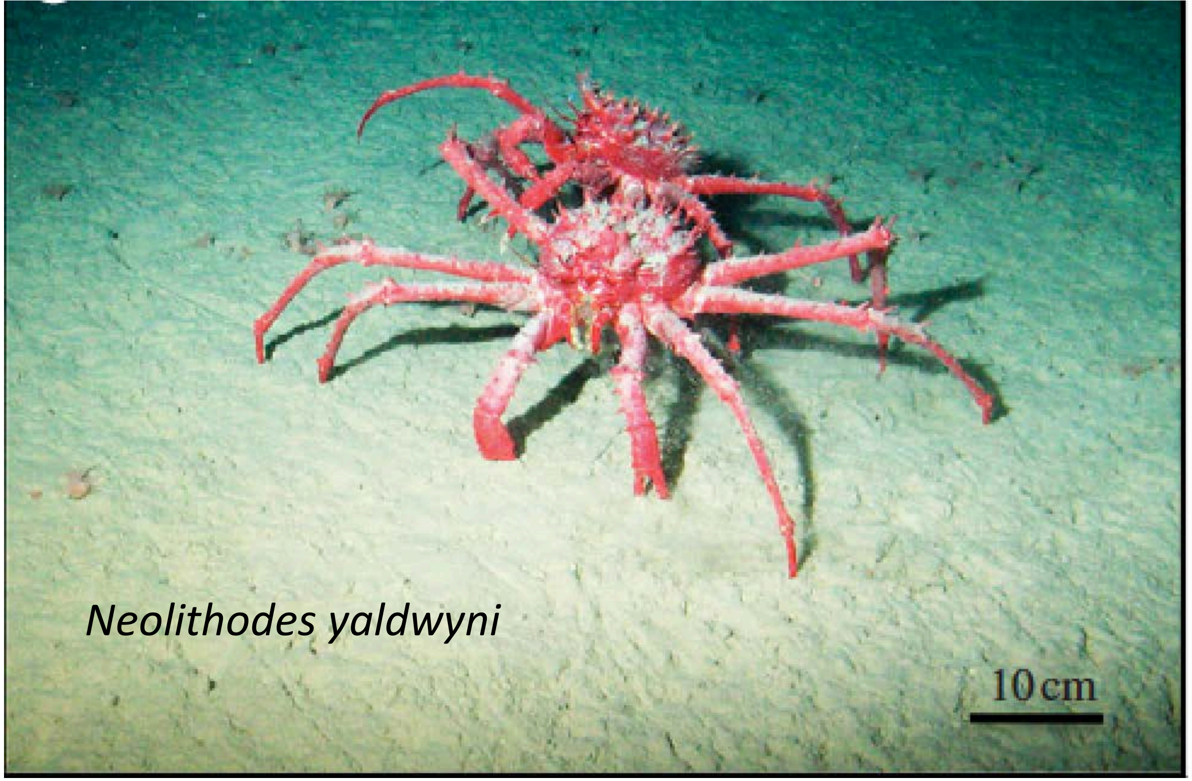
W. Llovel, J. K. Willis, F. W. Landerer & I. Fukumori

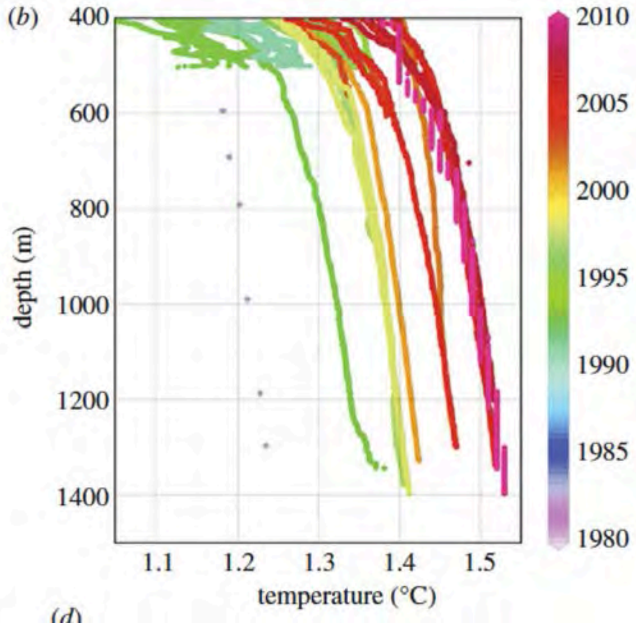




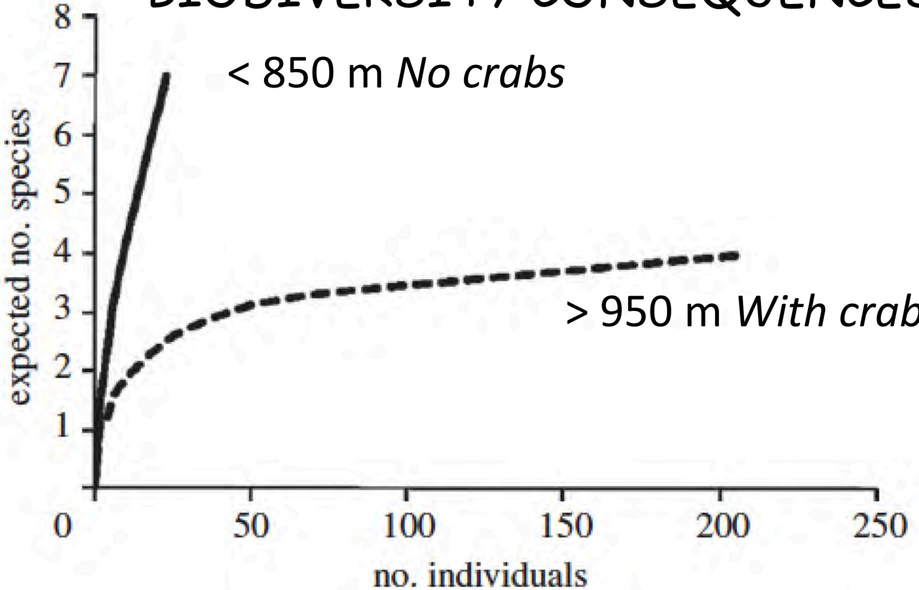
Nature Climate Change 2015

Warming to > 1.4°C has allowed a Lithodid Crab invasion In the Palmer Deep, Antarctica



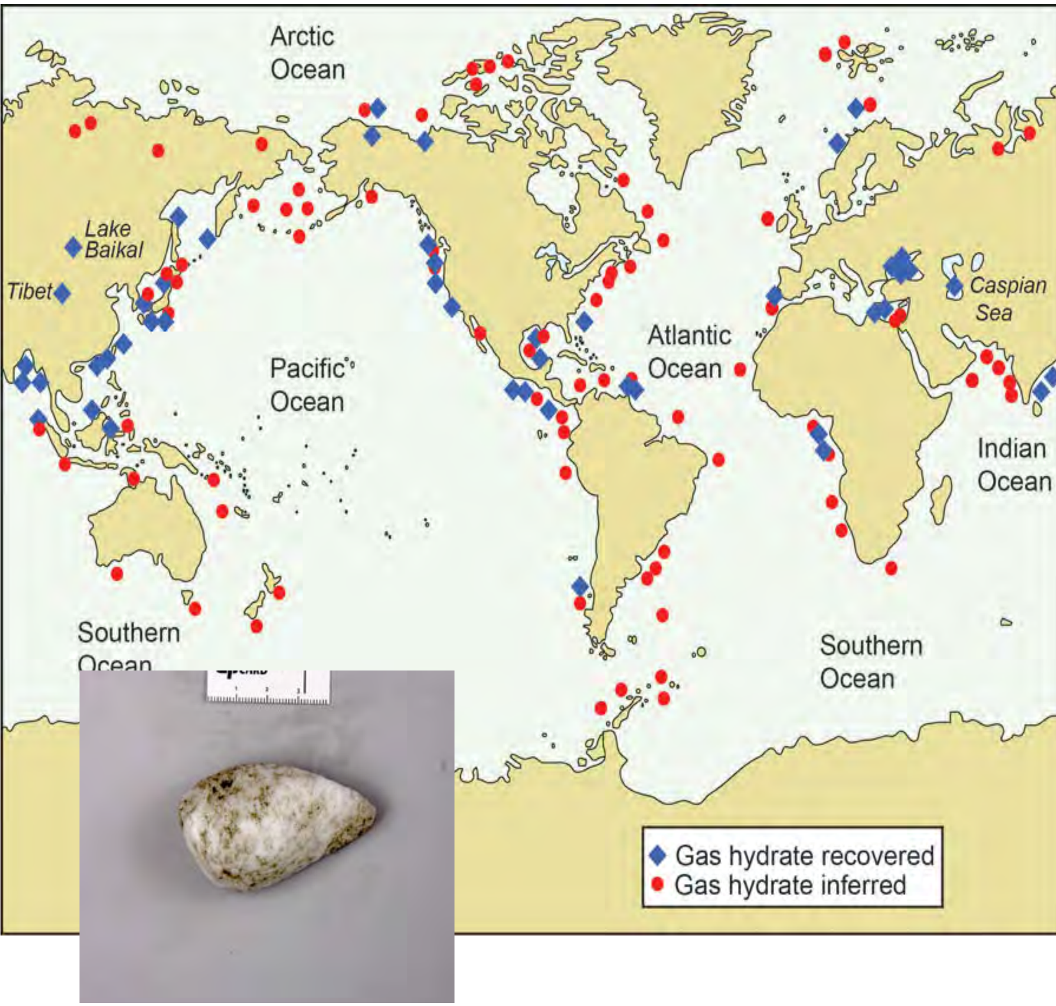


BIODIVERSITY CONSEQUENCES

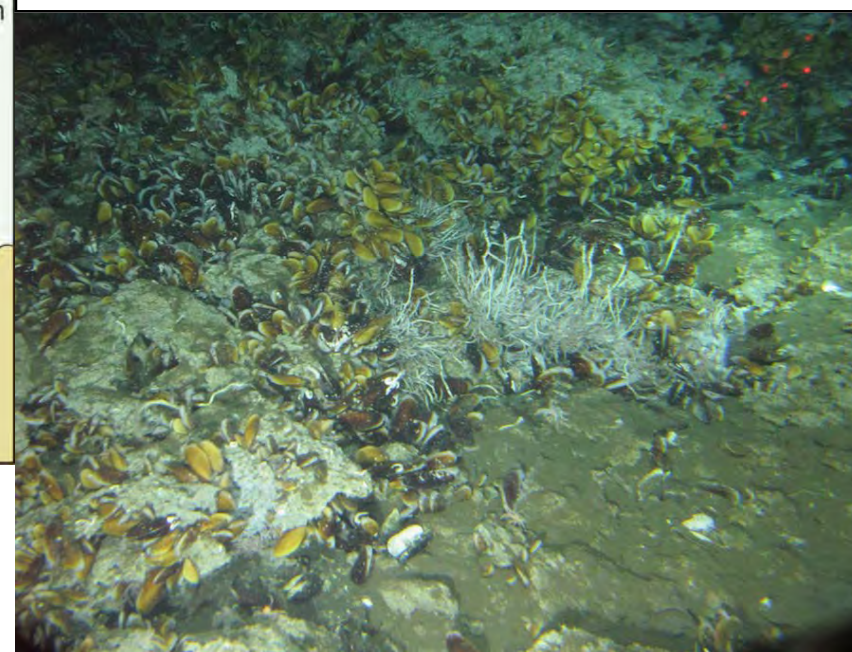


Smith et al. Proc. R. Soc. B 2011

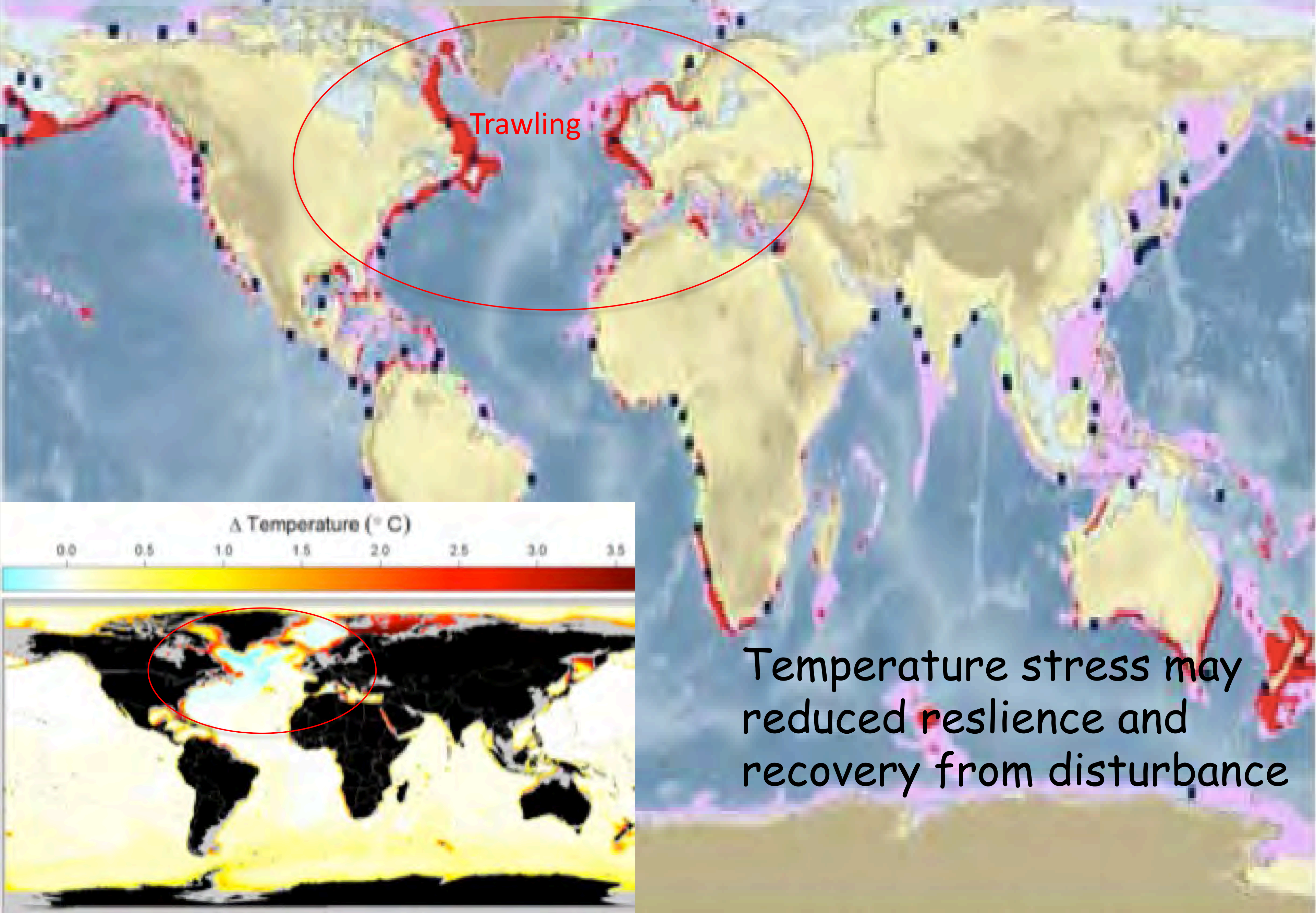
Warming may dissociate gas hydrates, pervasive throughout the margins and expand seep ecosystems



www.soundwaves.usgs.gov



The greatest warming is also subject to most intense bottom trawling



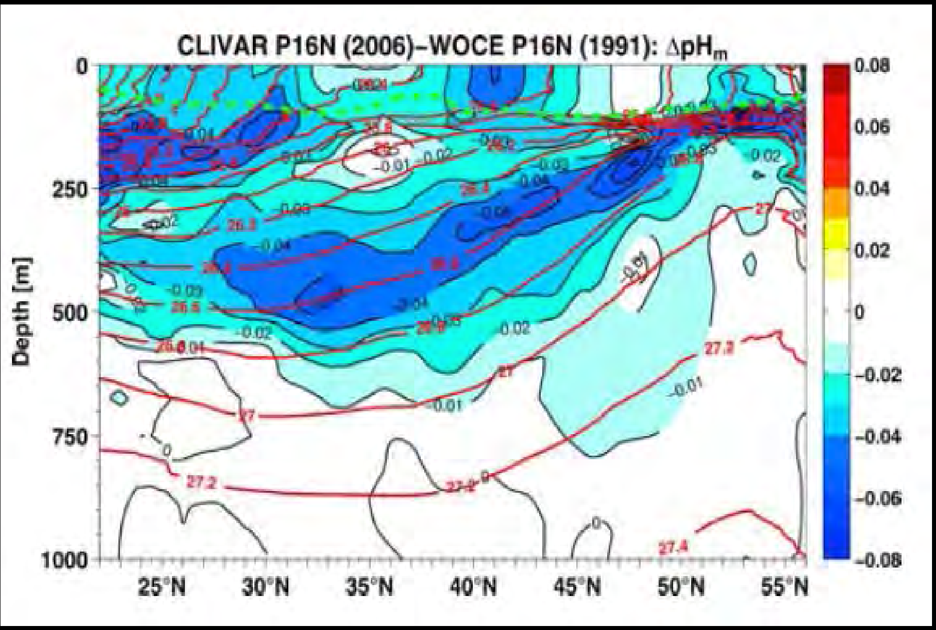
Temperature stress may reduced reslience and recovery from disturbance

pH Changes

North Pacific

Total pH Change (1991-2006)

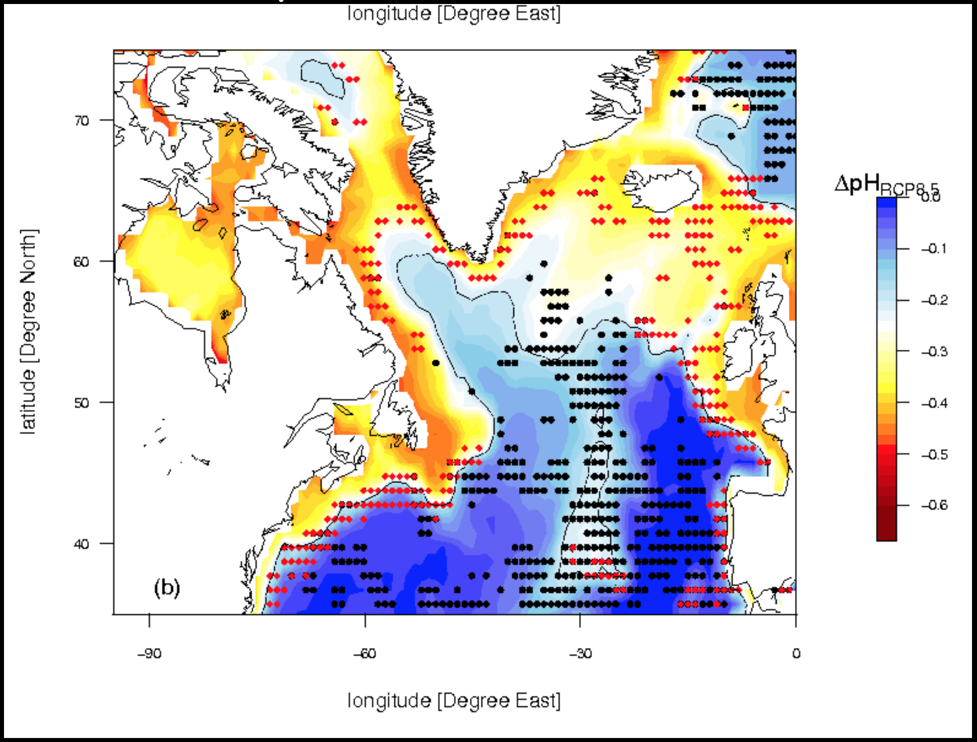
Atmospheric CO_2 + respiration



Byrne et al. 2010

North Atlantic

Deepwater formation draws down high- CO_2 water with transport by boundary currents.

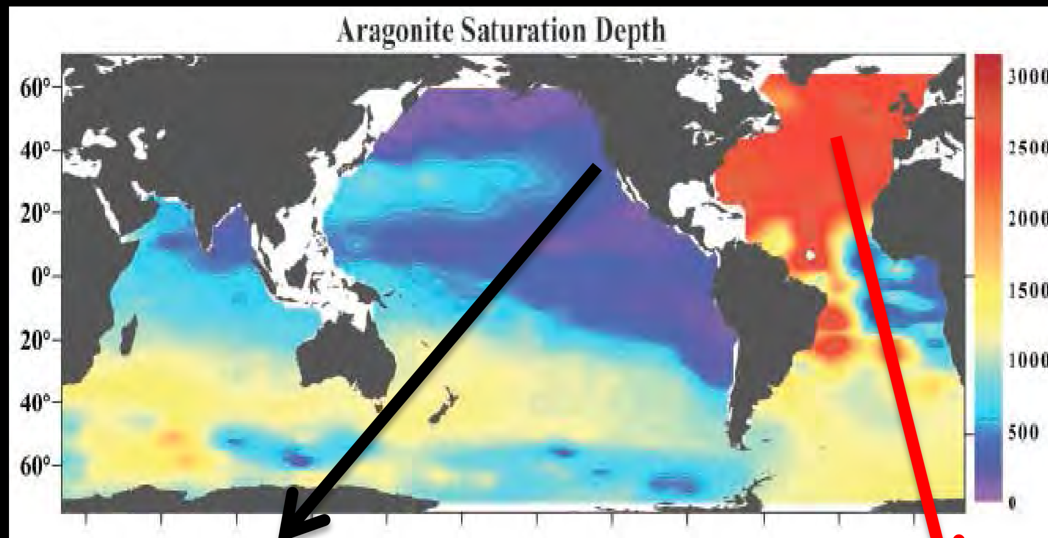


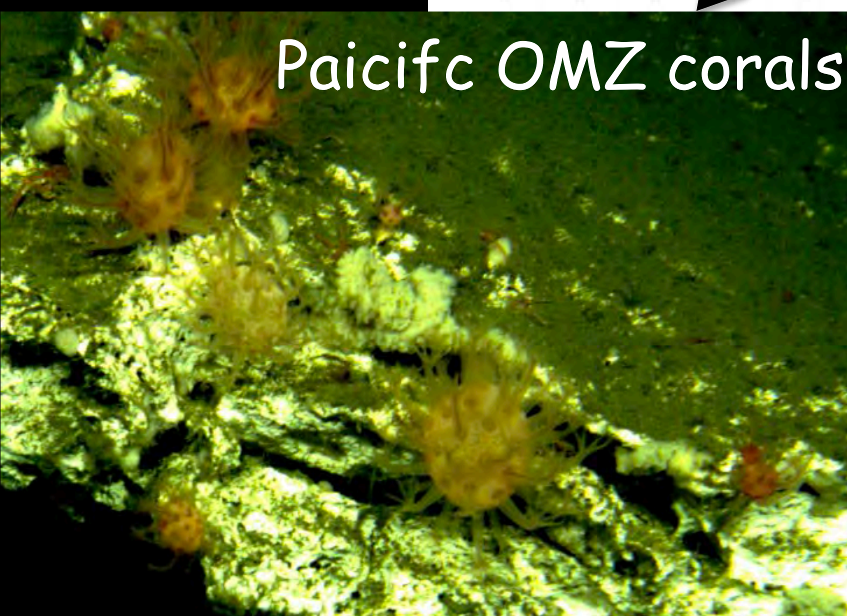
17-21% of N. Atlantic seafloor > 500 m will experience a 0.2 unit drop in pH by 2100.

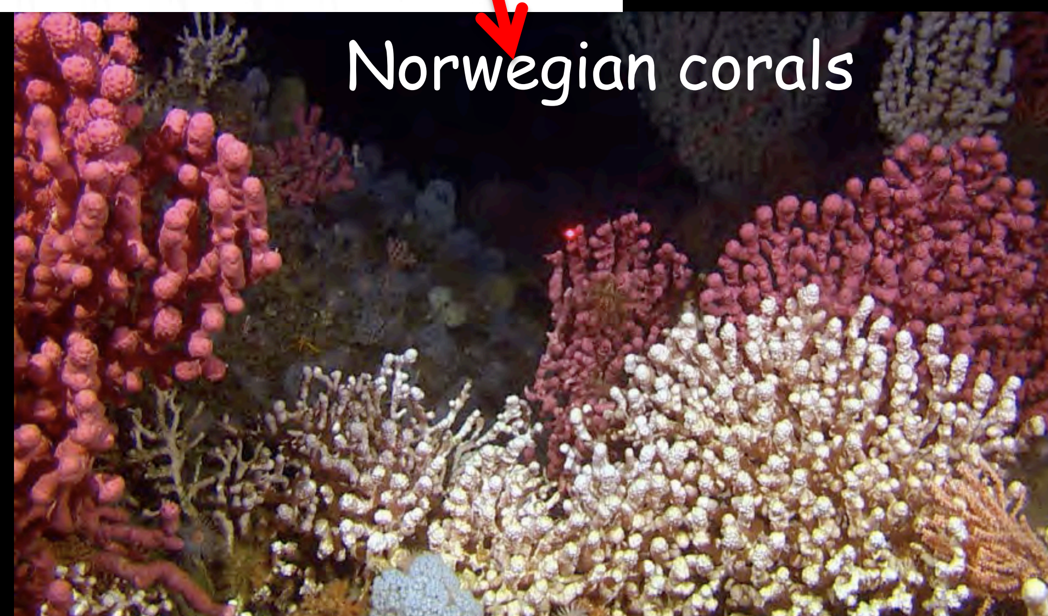
Gehlen et al. 2015

Differences in aragonite saturation between ocean basins affect deep-water calcifiers.

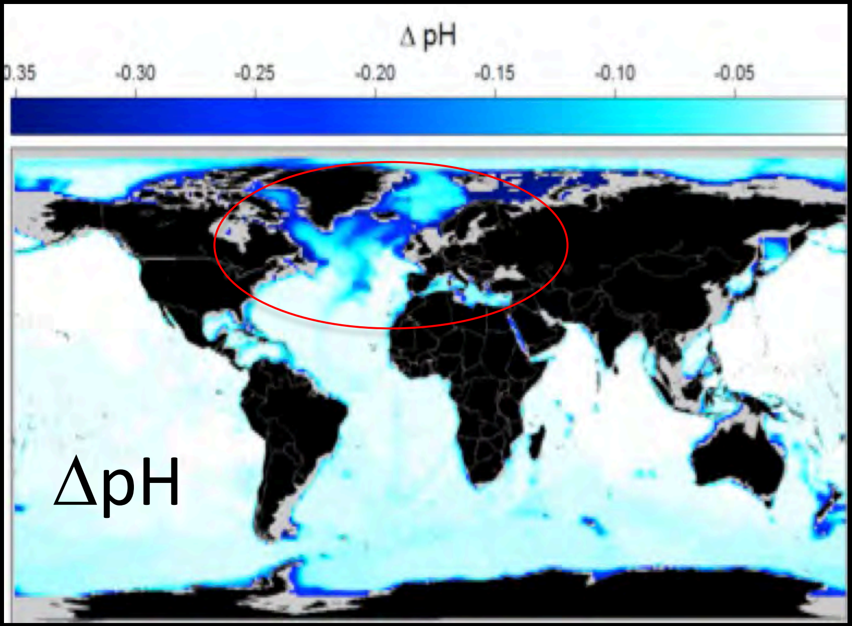
$\Omega_{arag} = [Ca^{2+}][CO_3^{2-}]/Ksp$

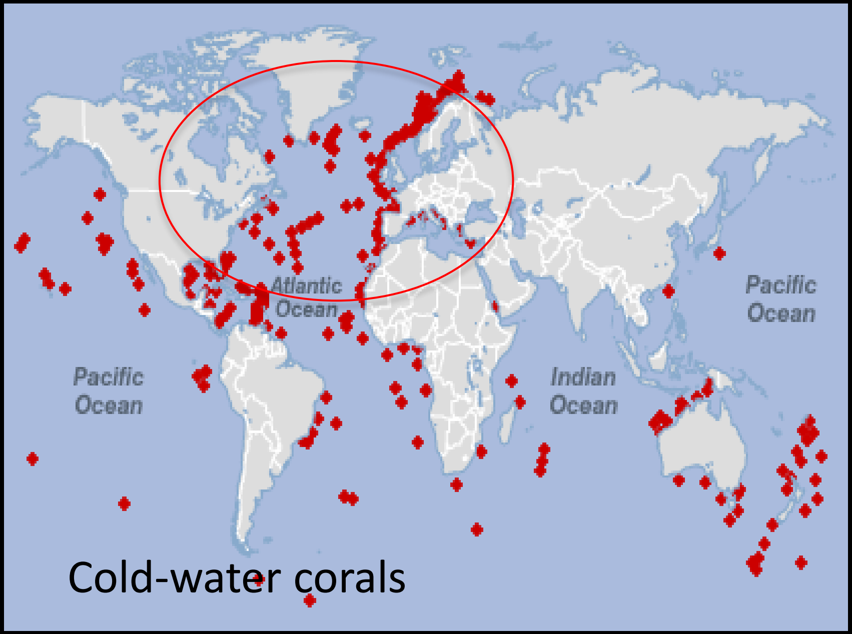


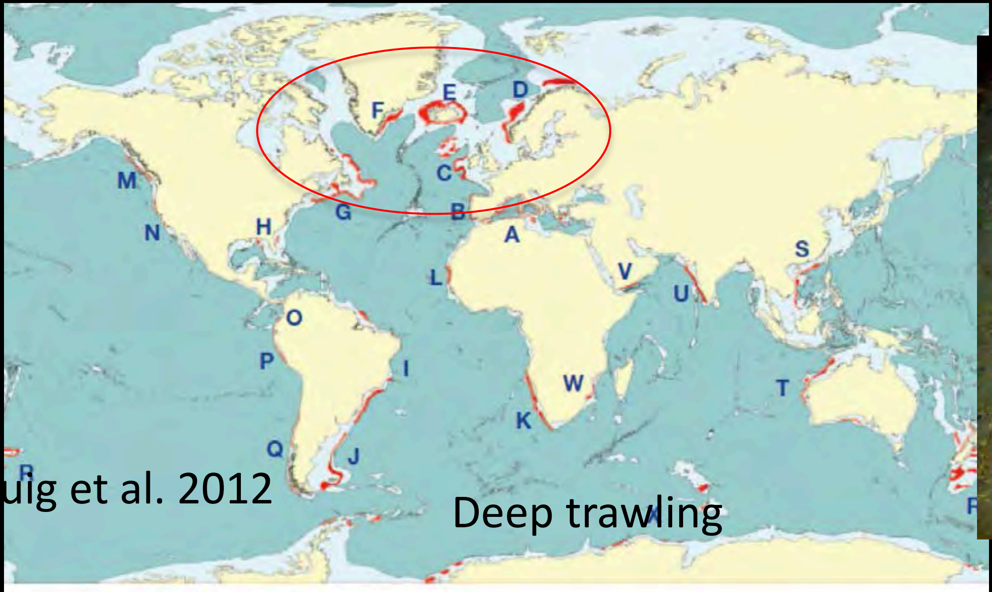




Ocean Acidification may weaken corals and slow recovery from trawl damage with cascading biodiversity consequences





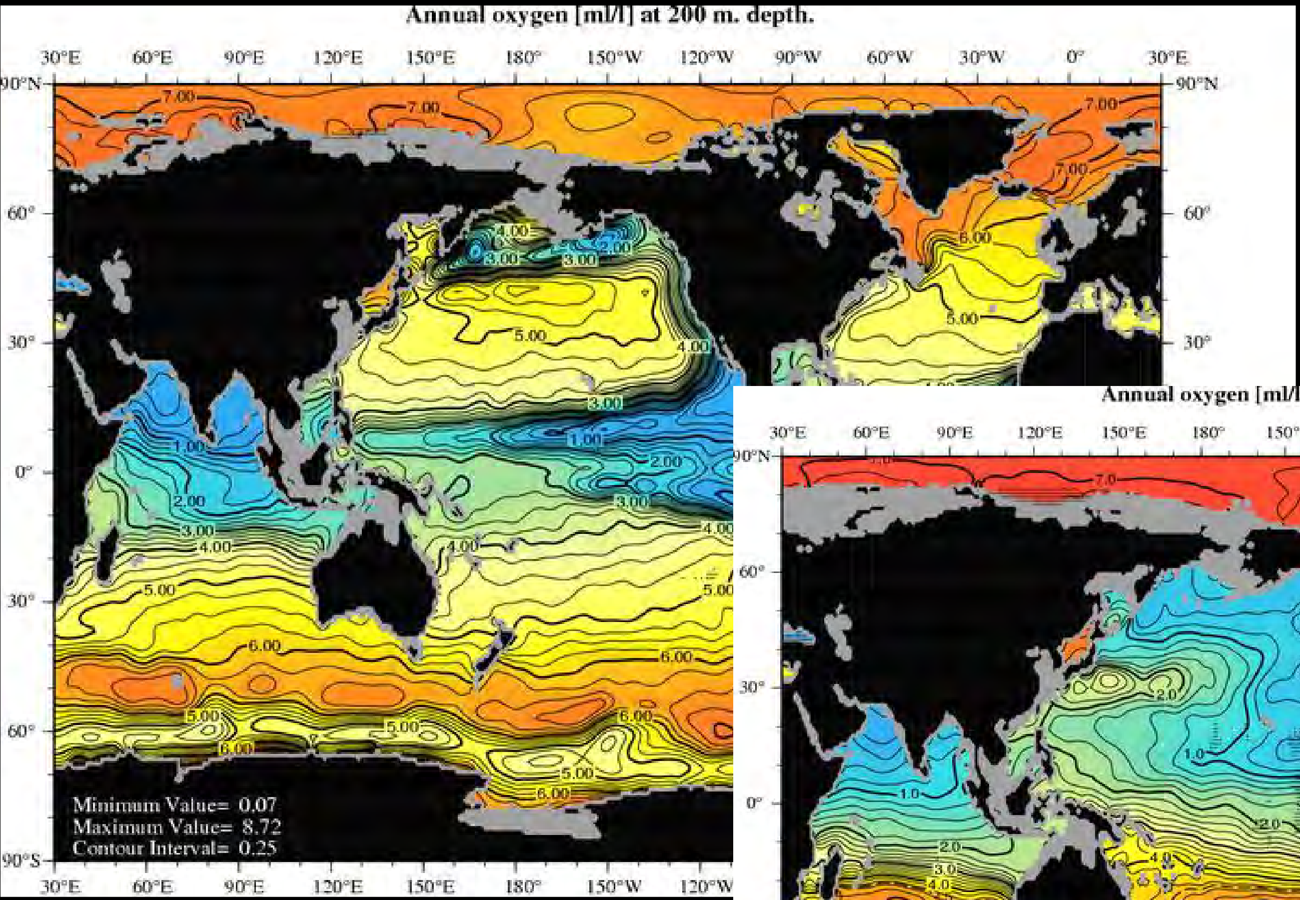


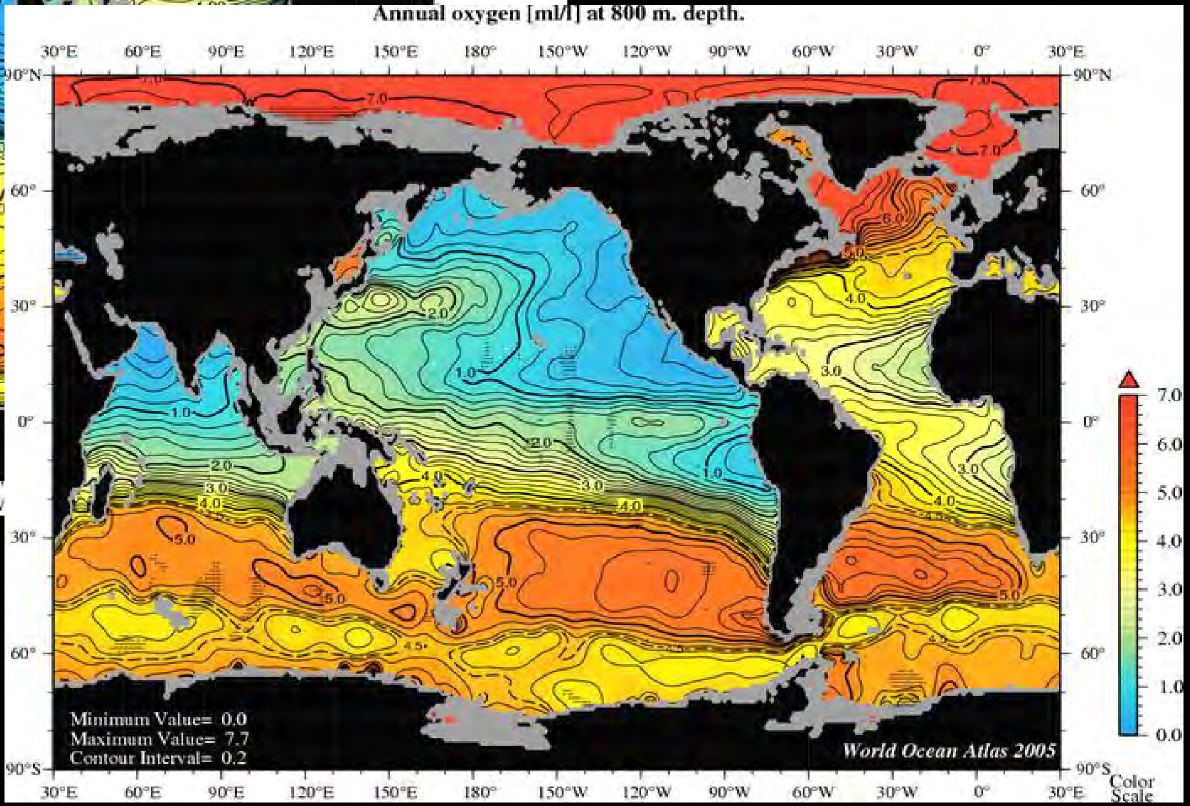
http://blogs.nature.com/news/2010/

Hypoxia is widespread in the oceans at upper bathyal depths

200 m

Oxygen minimum zones

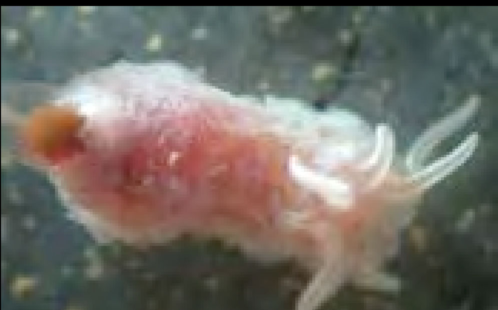


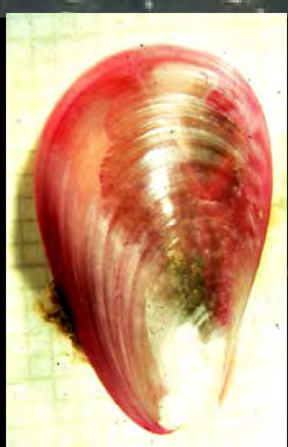


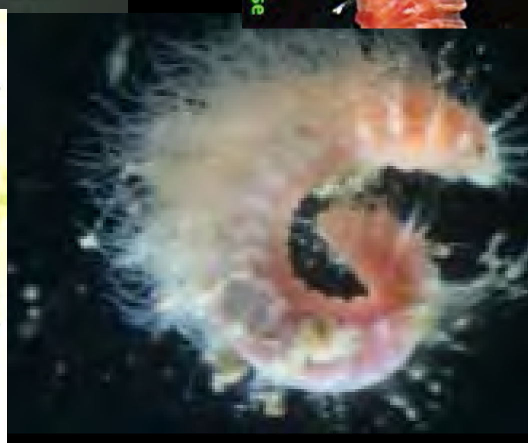
800 m

OMZ's are not Dead Zones!   Adaptations Abound

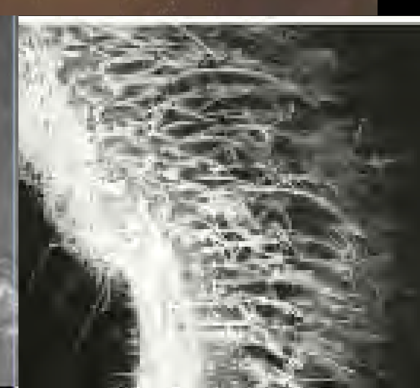
Blood Pigments
(Hemoglobin)



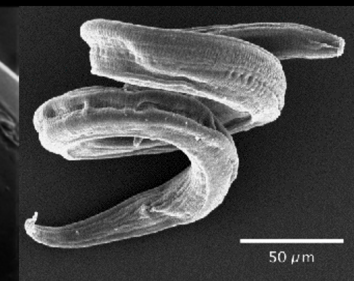




Enhanced Surface Area



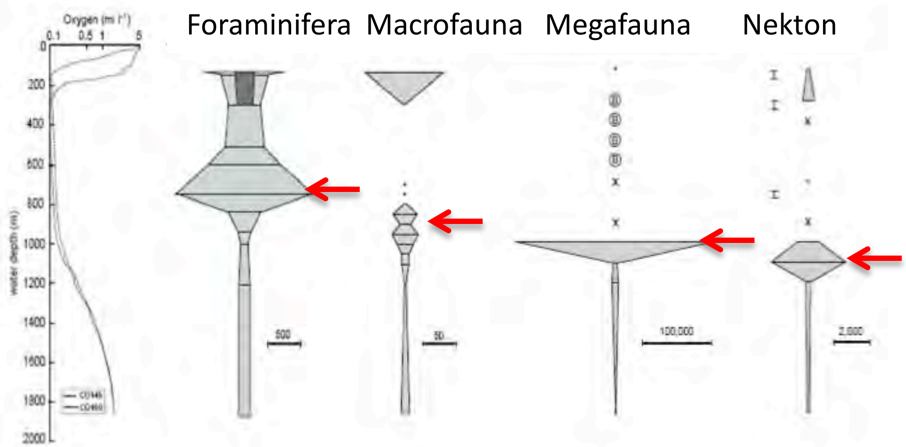
Small body size
long/thin shape



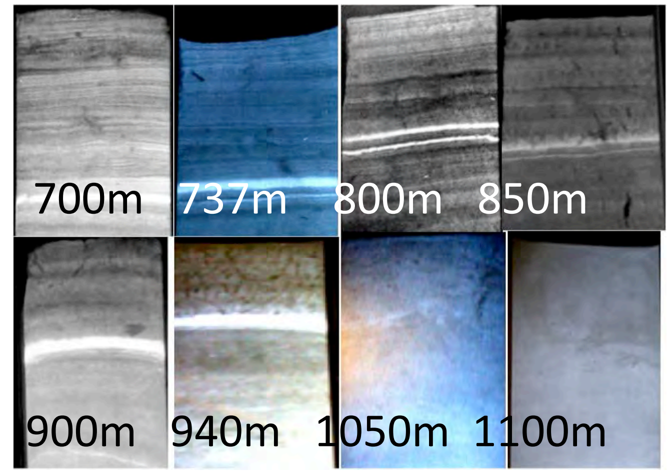
Multiple Consequences of Low O_2 in OMZs

Pakistan margin

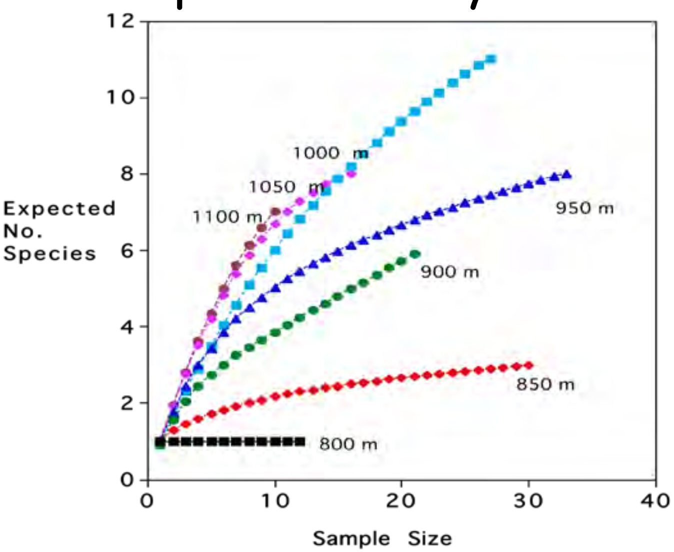
Altered Size Structure and Composition



Reduced Bioturbation

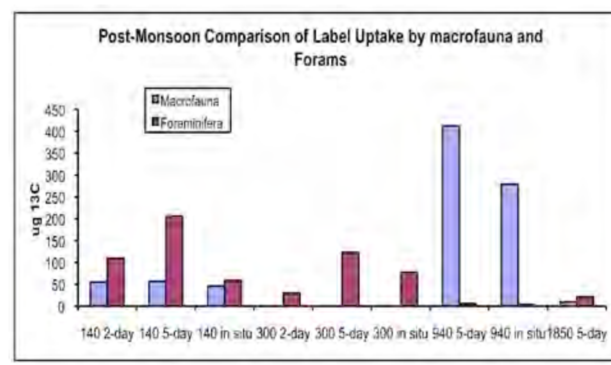


Rapid Diversity Shifts



Reduced Colonization

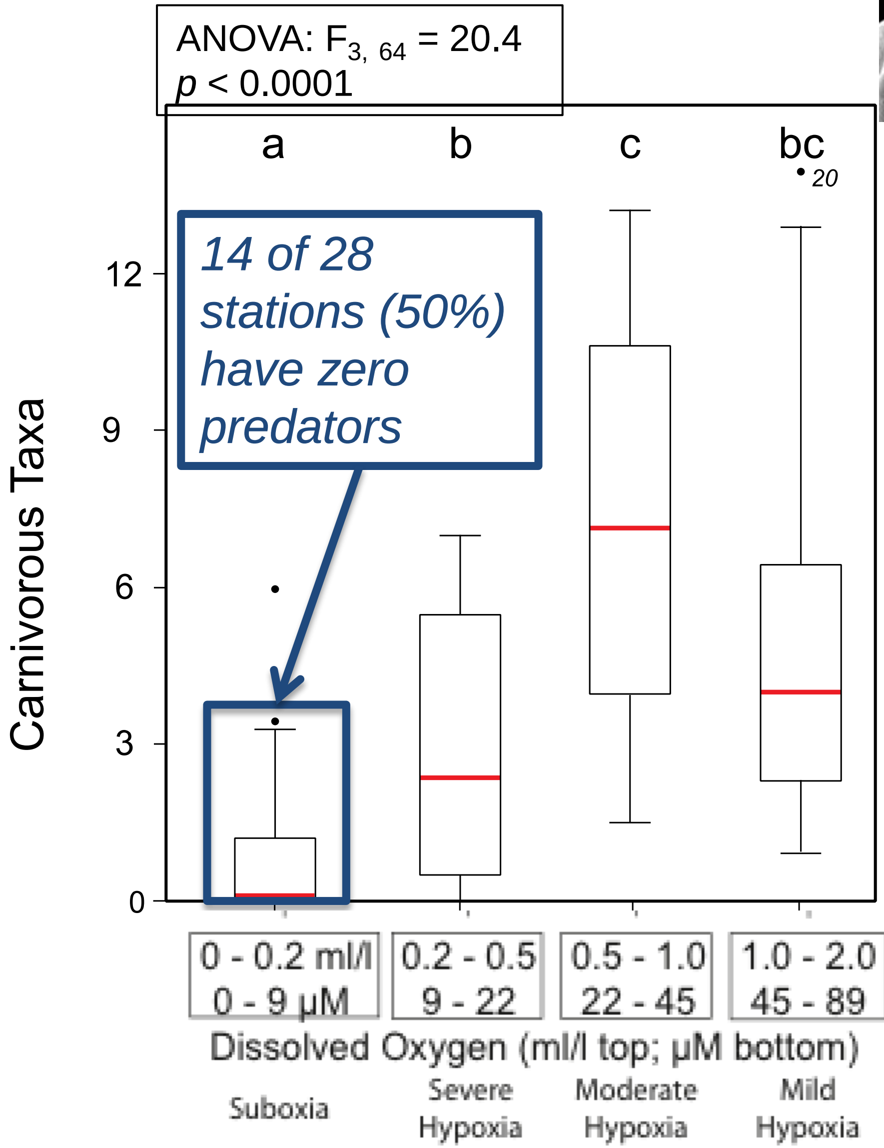
Altered Carbon Processing

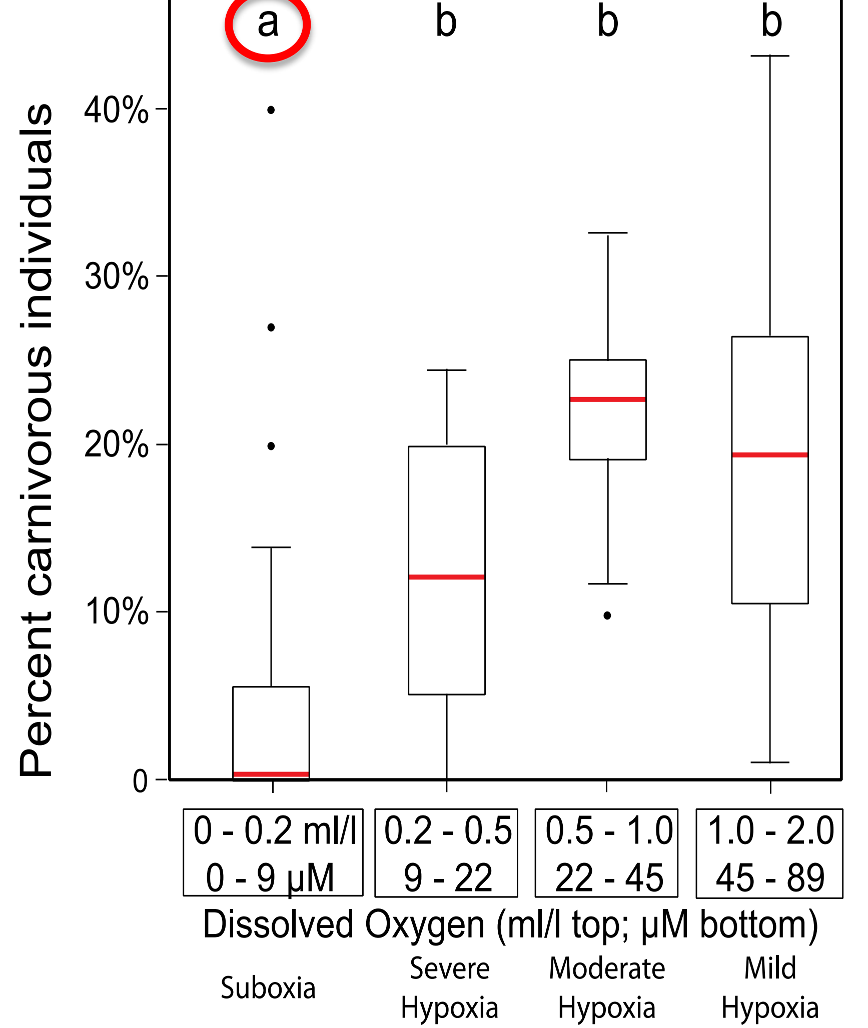


Woulds et al. 2007, Levin et al. 2009, Gooday et al. 2009, Levin et al. 2013

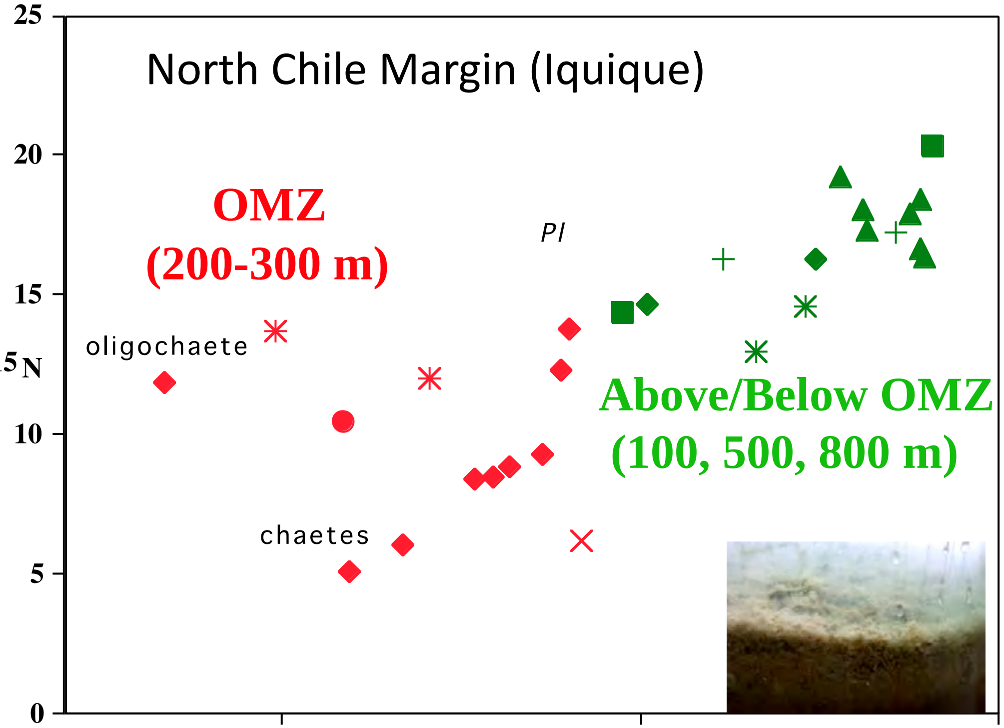
Very low oxygen is associated with loss of carnivores in OMZ sediments

(Polychaeta) Sperling et al., 2013, *PNAS* 110: 13446





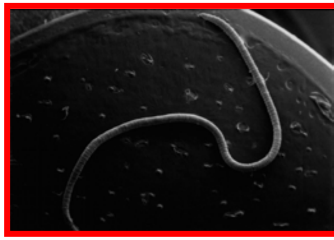
Chemosynthesis is among metazoans within the OMZ



Light C and N signatures reflect influence of chemosynthesis.

Lucinoma aequizonata

Olavius crassitunicatus



Thyasirids

Siboglinids

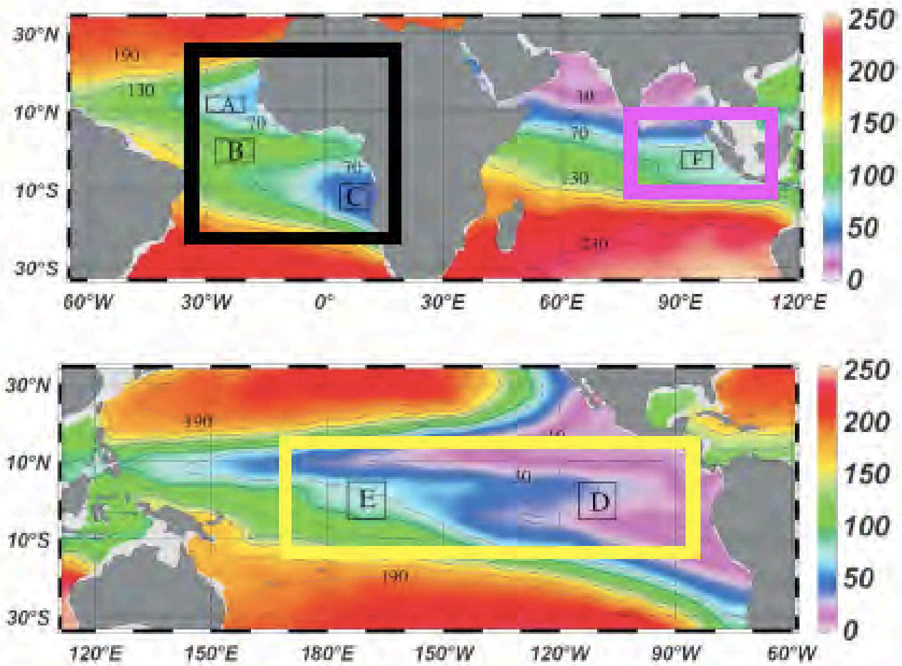
Acharax

Oxygen decline in the tropical O_2 minima

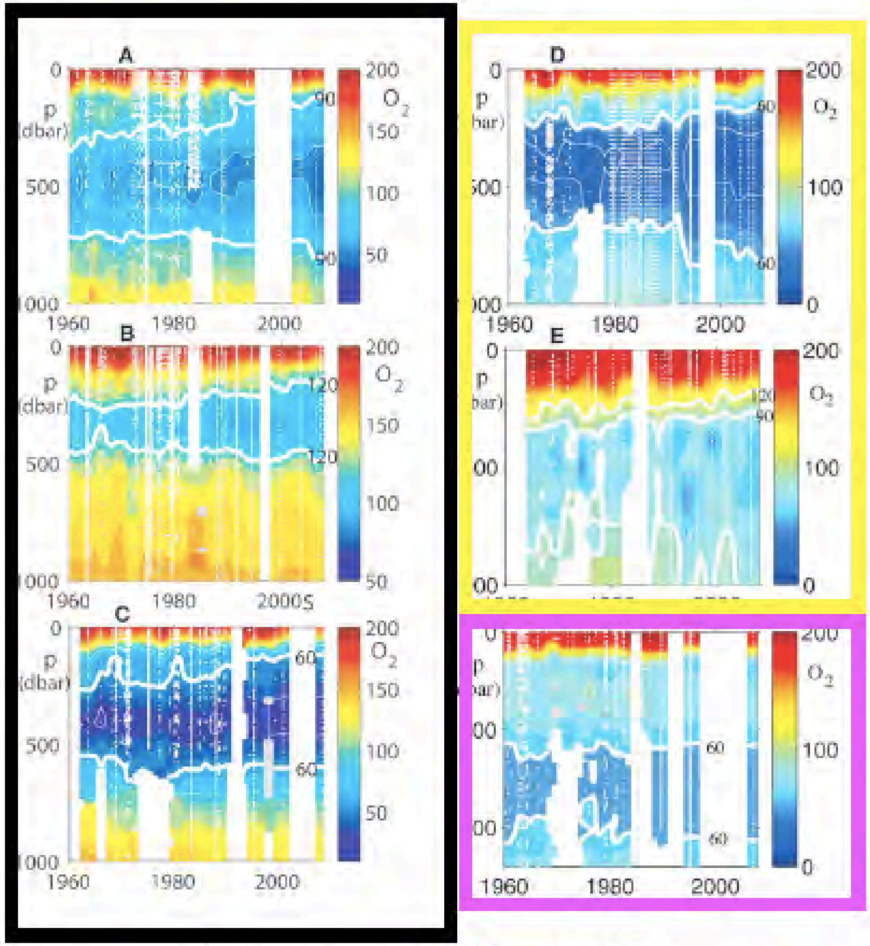
Oxygen minimum zones expanding, oxygen content decreasing

Consistent with climate change response (Bopp et al., 2002).

Stramma et al (2008)



Oxygen in the oxygen minima

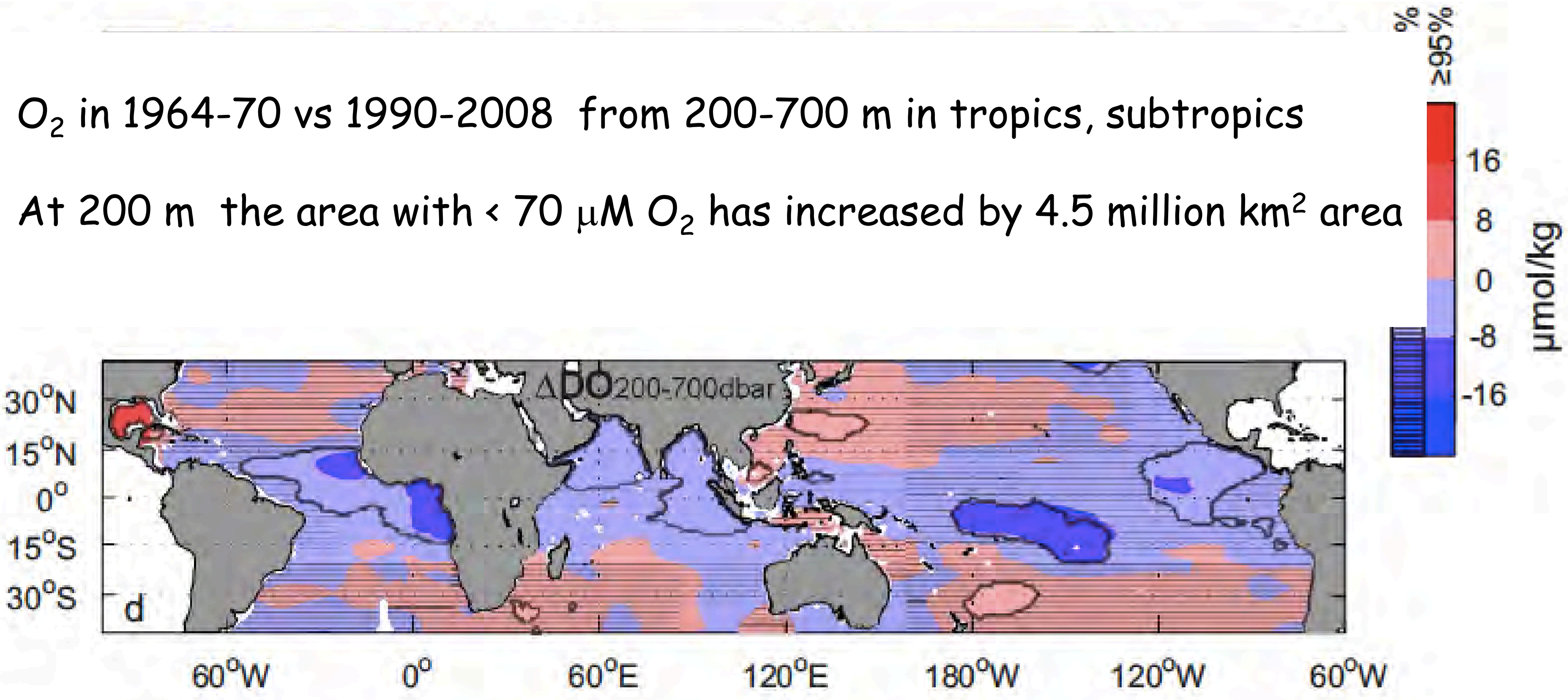


Time series 1960-present

Ocean Deoxygenation

O_2 in 1964-70 vs 1990-2008 from 200-700 m in tropics, subtropics

At 200 m the area with < 70 μM O_2 has increased by 4.5 million km^2 area

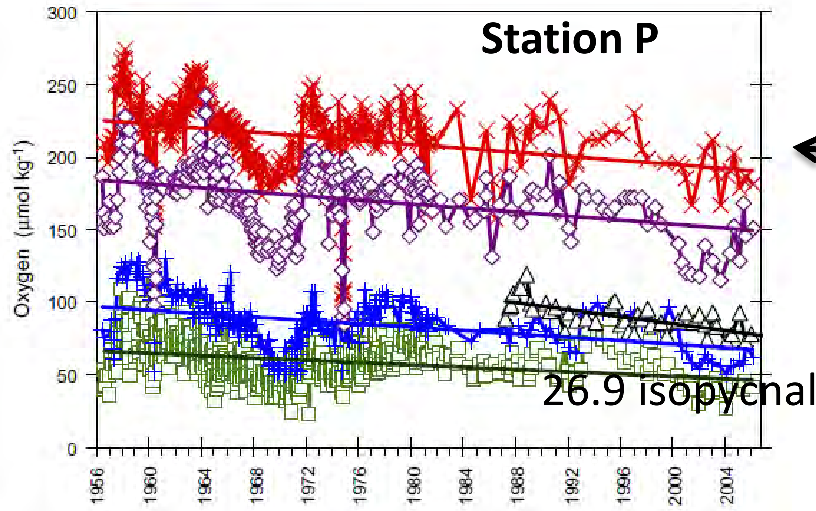


Stramma et al. 2010

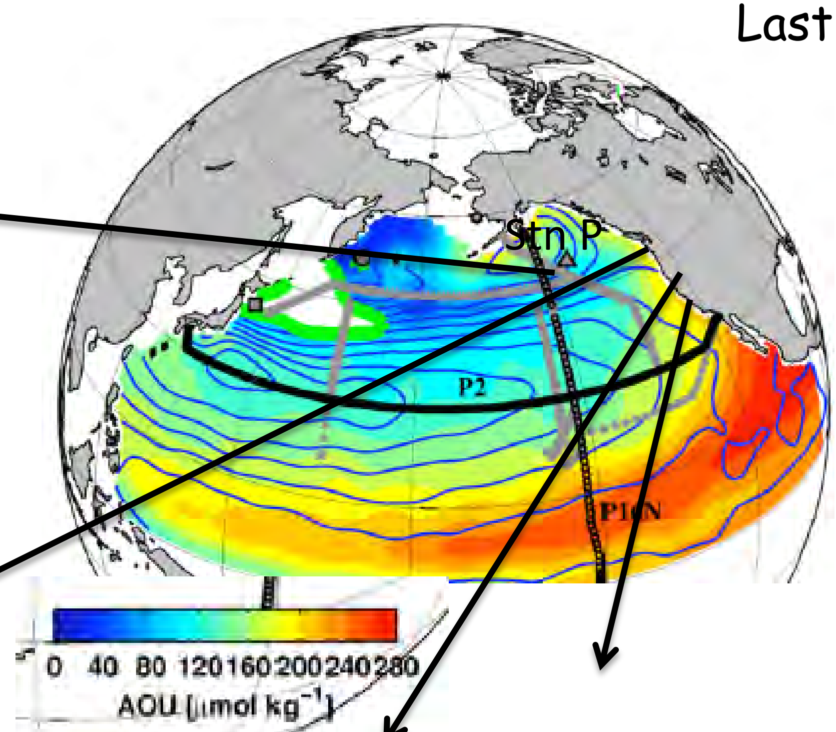
OXYGEN DECLINES in the NORTHEAST PACIFIC OCEAN

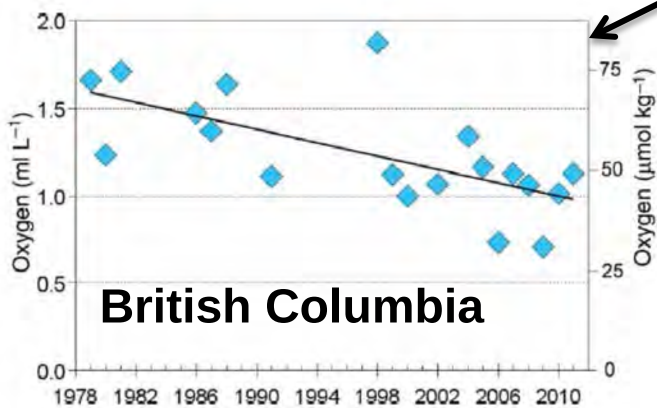
Oxygen loss of 0.67mM O_2/y

Last 50 y

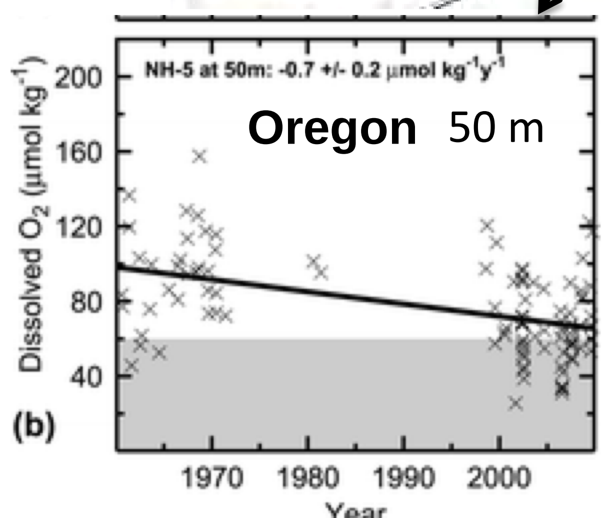


Whitney et al. 2007



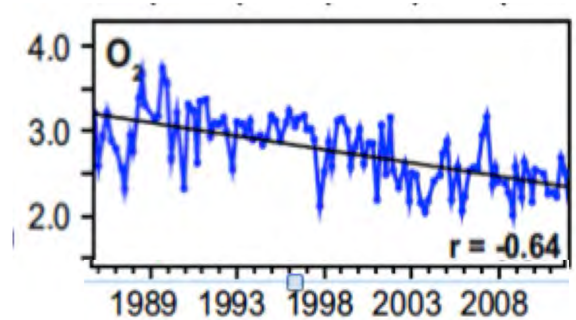


Crawford and Pena 2013



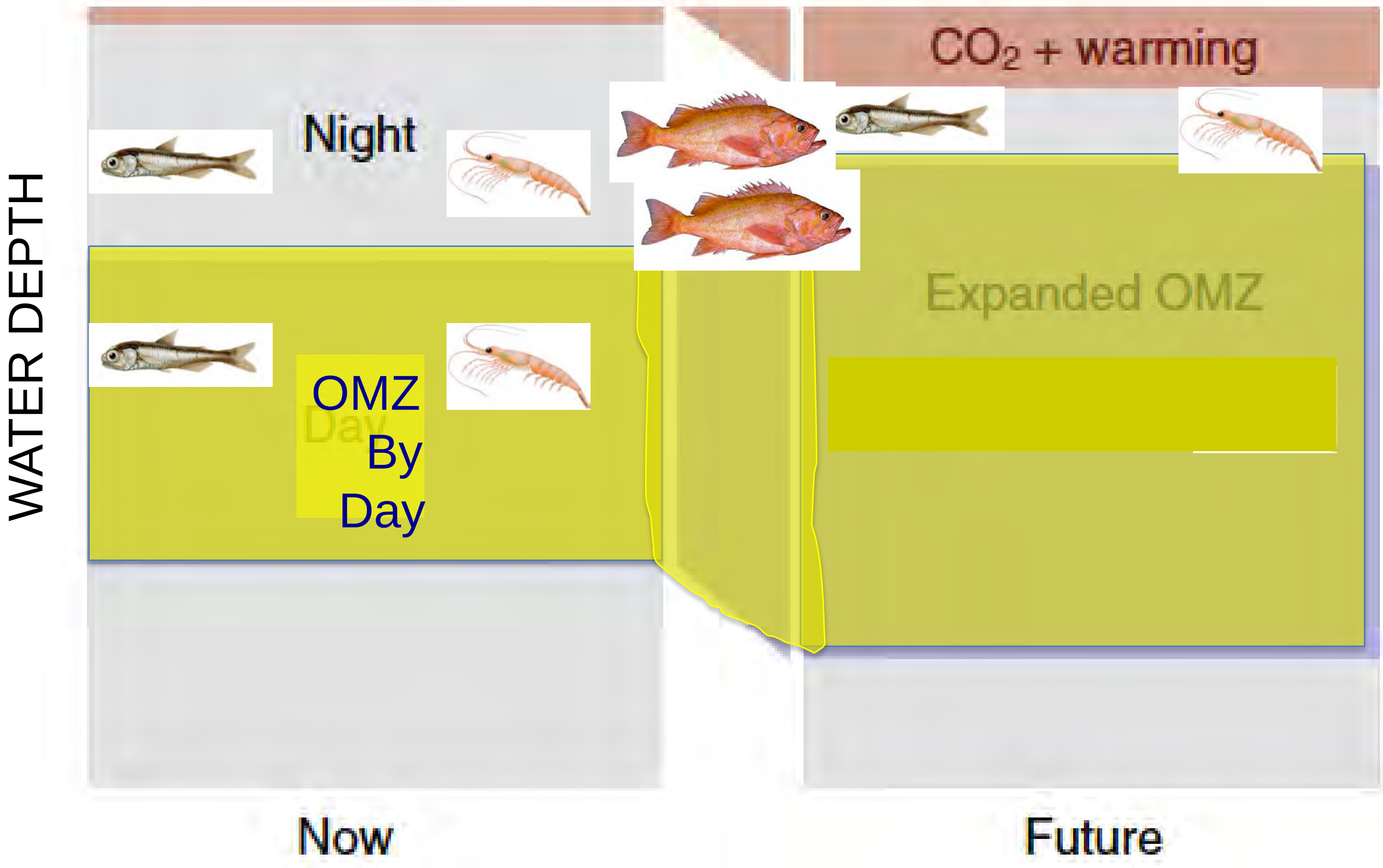
Pierce et al. 2012

So. Cal. Bight



Bograd et al. 2014

Vertical migrators – underpinning the food chain & nutrient cycling experience Habitat Compression



After Siebel 2011

Koslow et al. 2011

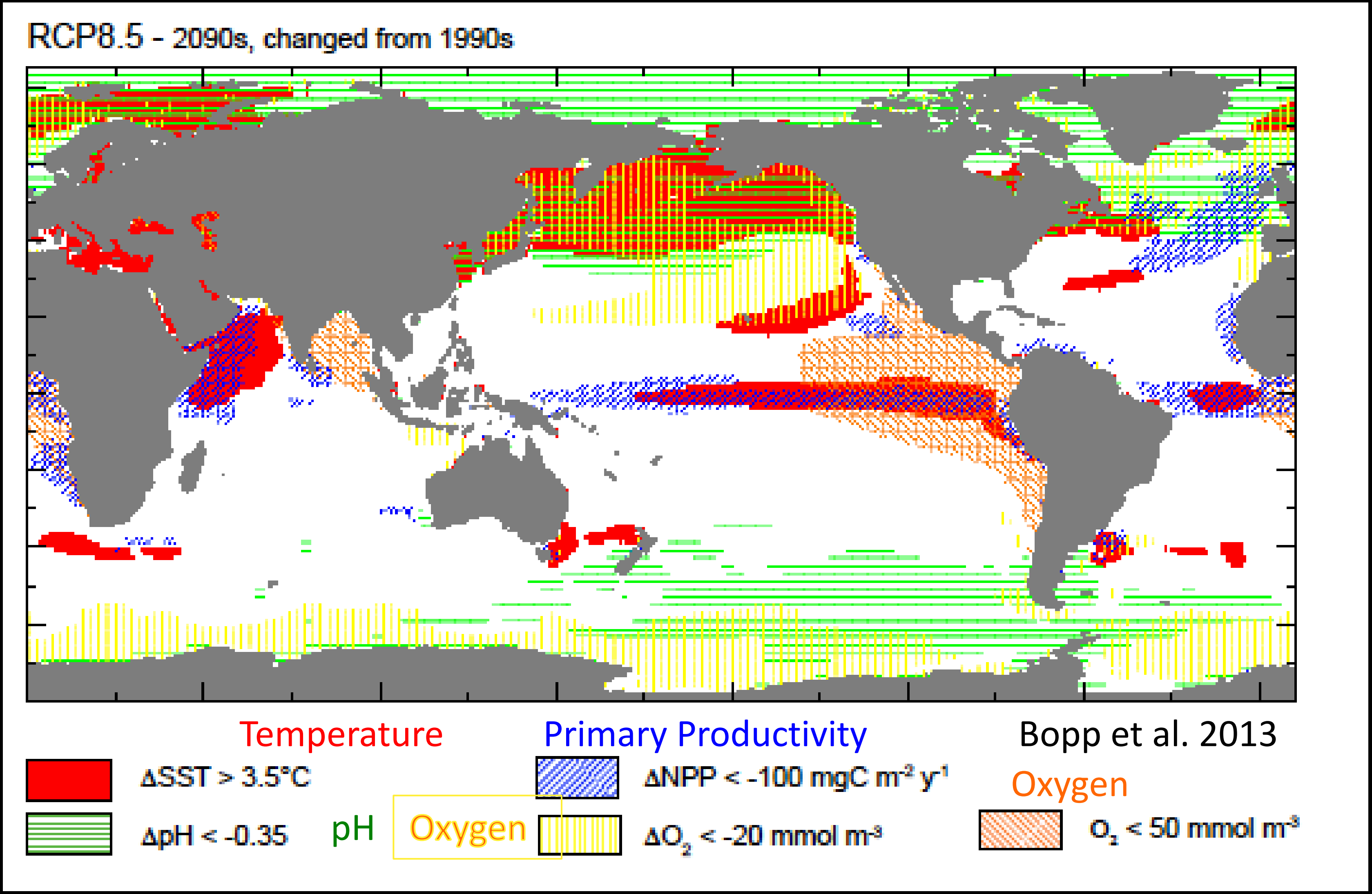
Loss of Groundfish Habitat

- SLIDE REMOVED – UNPUBLISHED DATA

Change in Urchin Distribution off Southern California

- SLIDE REMOVED – UNPUBLISHED DATA

Areas of convergent climate change projected from 1999-2099

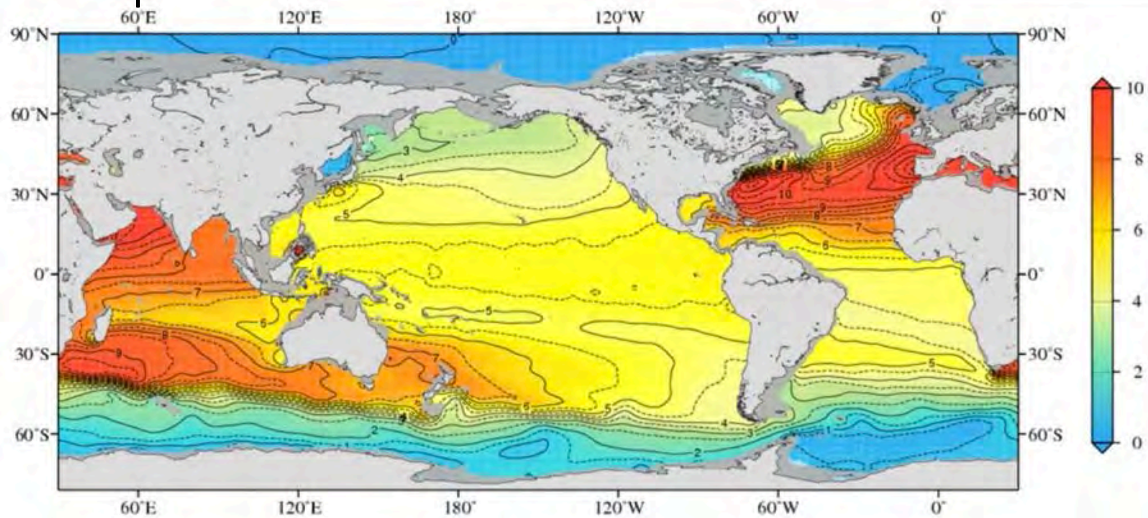


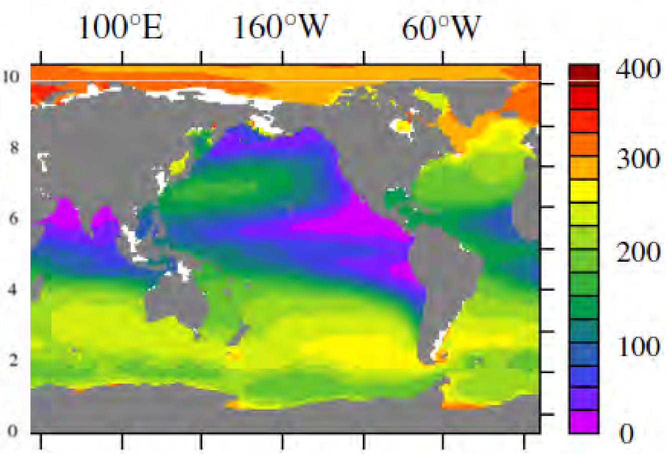
How can we untangle interacting climate variables?

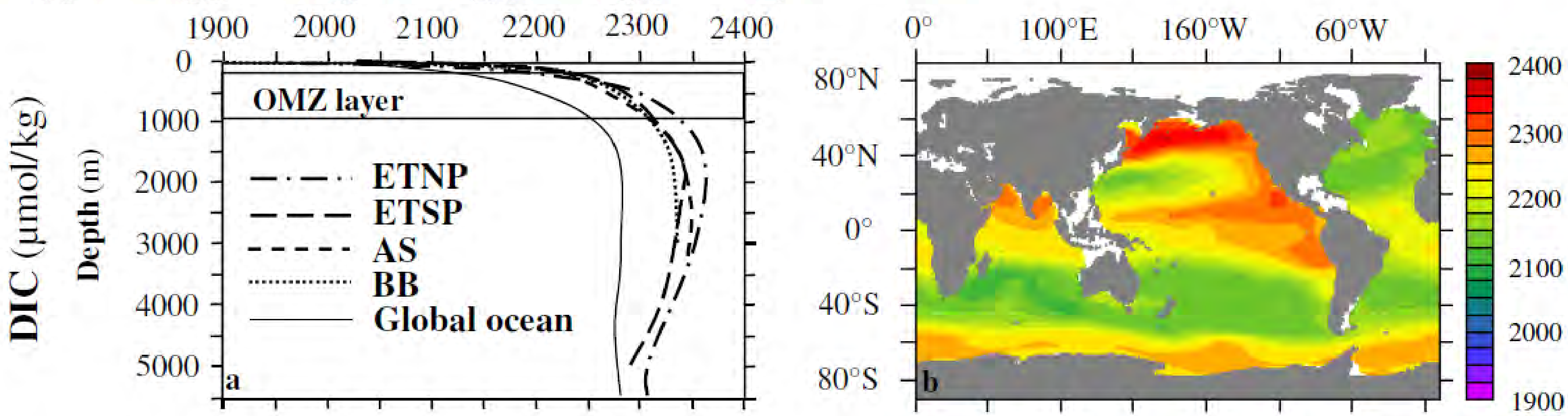
Oxygen Minimum Zones are Carbon Maximum Zones

Recent avg
Temp at 800 m

A model system for the study of multiple





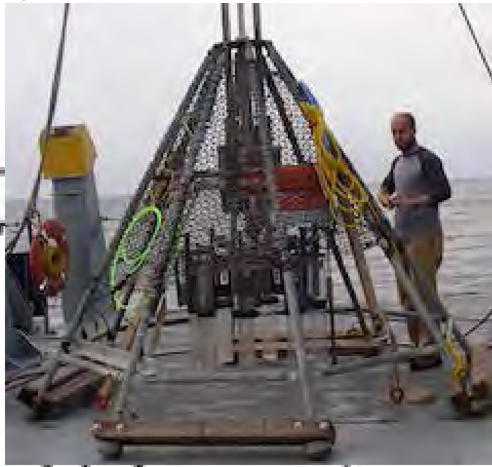


Paulmier et al. 2011

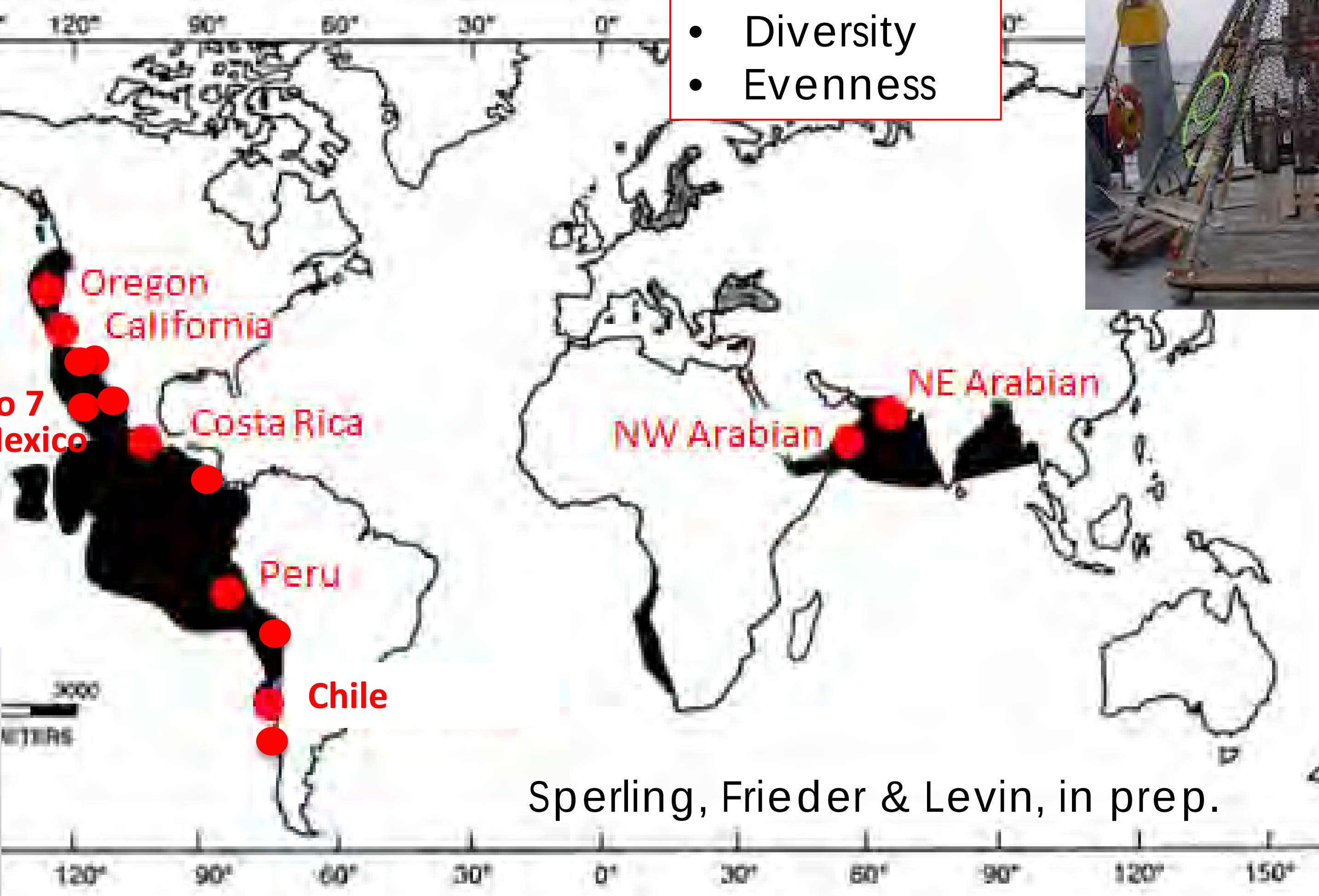
Use of natural gradients on OMZ/CMZ margins to unravel effects of multiple climate stressors (O_2, pCO_2, and T) on diversity

OMZ BENTHIC TRANSECTS - 95 stations – published literature and unpublished

VARIANCE PARTITIONING – Regression Trees and Random Forests



100-3400 m



Macrobenthos:

- Diversity
- Evenness

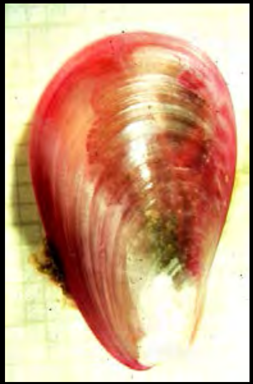
Sperling, Frieder & Levin, in prep.

The OMZ Biota

Molluscs

Echinoderms

Polychaetes



Crustacear

Oxygen is the overriding factor controlling macrobenthos diversity (H'_{log2}) in the Pacific

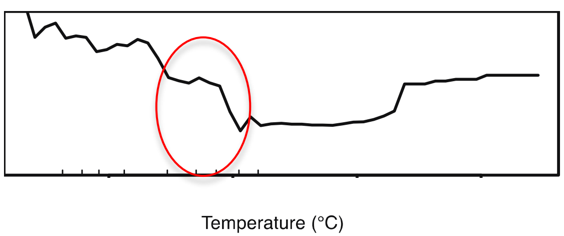
Diversity (H')

$R^2 = 0.40$
n = 57

$R^2 = 0.59$
n = 37

Threshold at 0.16 ml/l (7μM)

0.5 ml/l (22μM)



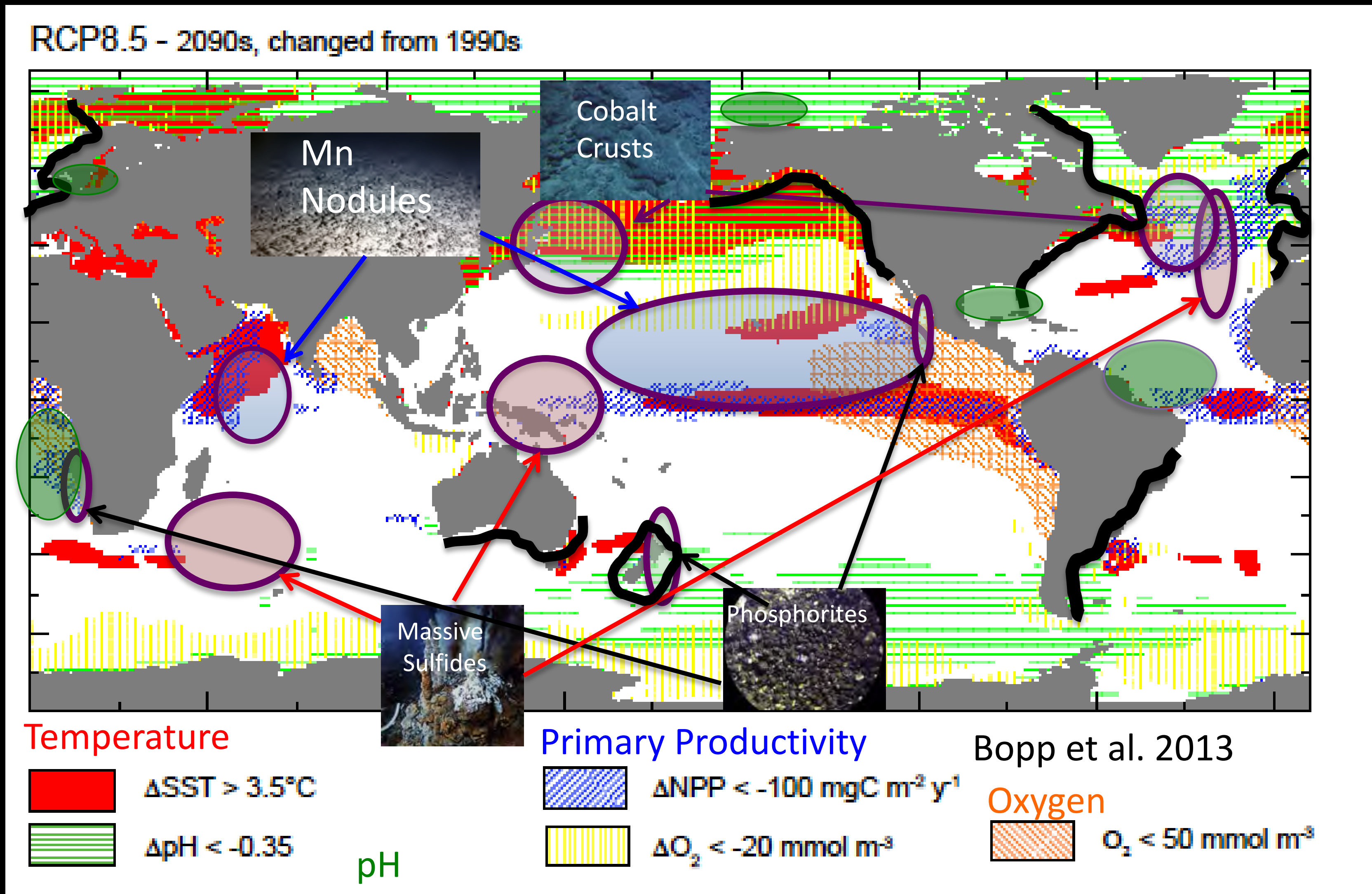
Threshold at 900 μatm

Sperling, Frieder, Levin, unpublished

RESULTS REMOVED

- UNPUBLISHED DATA

The greatest threats to deep-sea biodiversity will come from the intersection of climate change with direct human activities



Fishing, Energy, Mining Resource Extraction

Back to Biodiversity

- Deep-sea biodiversity is sensitive to warming, acidification and deoxygenation, but also holds key to future adaptation.

- Recognize climate change as a cumulative impact - with interactions among stressors and with direct human activities in the deep ocean.

- Initiate a global 'deep' observing network targeting ecosystems and regions at the nexus of climate change and deep-sea industrialization.
  - Argo, moorings, observatories, exploration, biodiversity
  - (Deep-Ocean Observing System)

- Incorporate climate change into environmental planning in the deep sea.

Shukran

Spasibo

Thank you for listening !

Ayo

Obrigada

Danke

On jaaraama

Special Thanks to E. Sperling, C. Frieder, K. Sato
Funding from NSF, CA Sea Grant

Merci

Ke a leboha

Iyaloo

Jai-rruh-jef

Nee-kay

Na pandura

Abhivandanam

Gracias

Okuhepa

Ngiyabonga

Dankie