Bentho-Pelagic Coupling Under Climate Change & Other Human Disturbances

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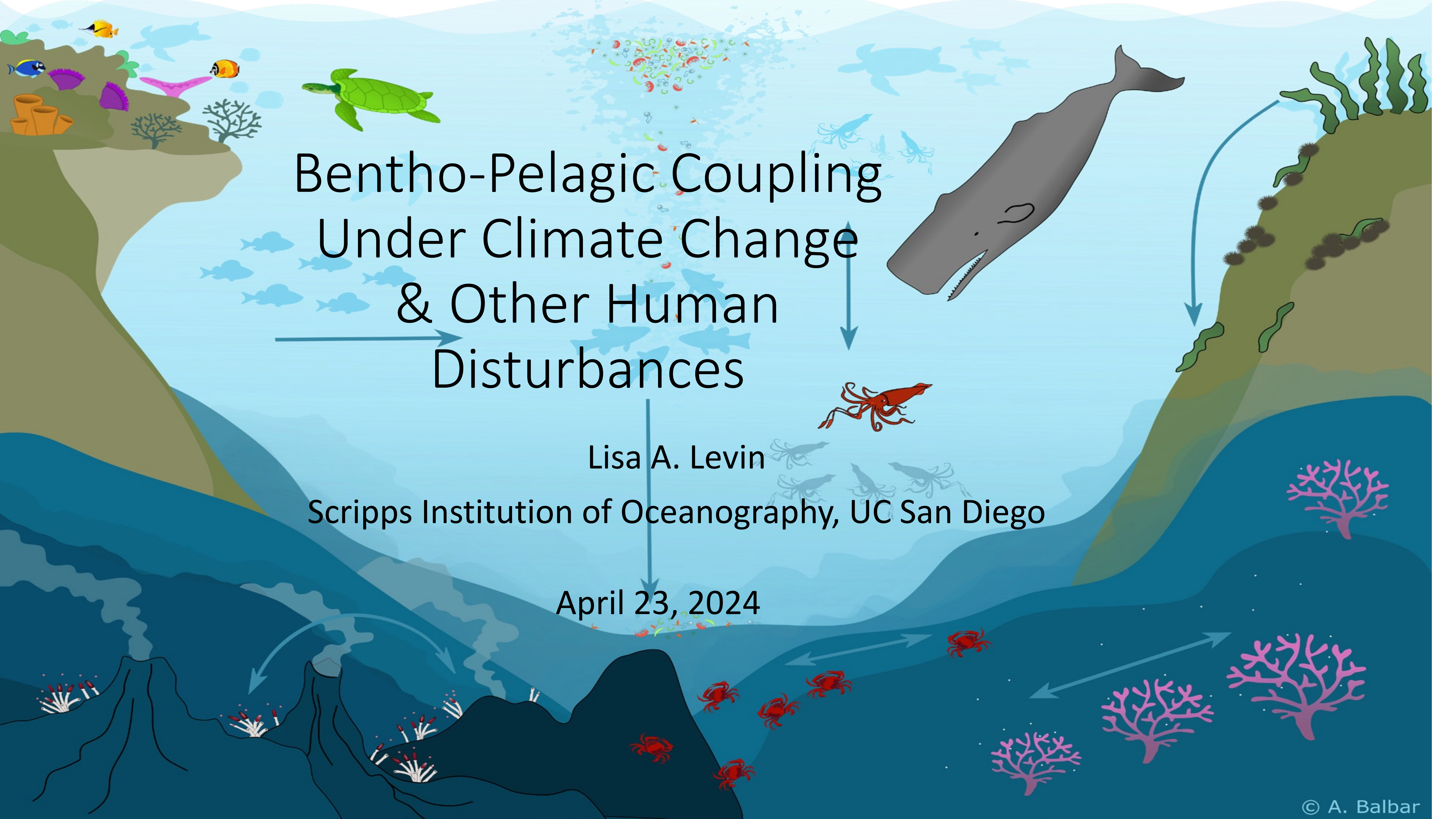
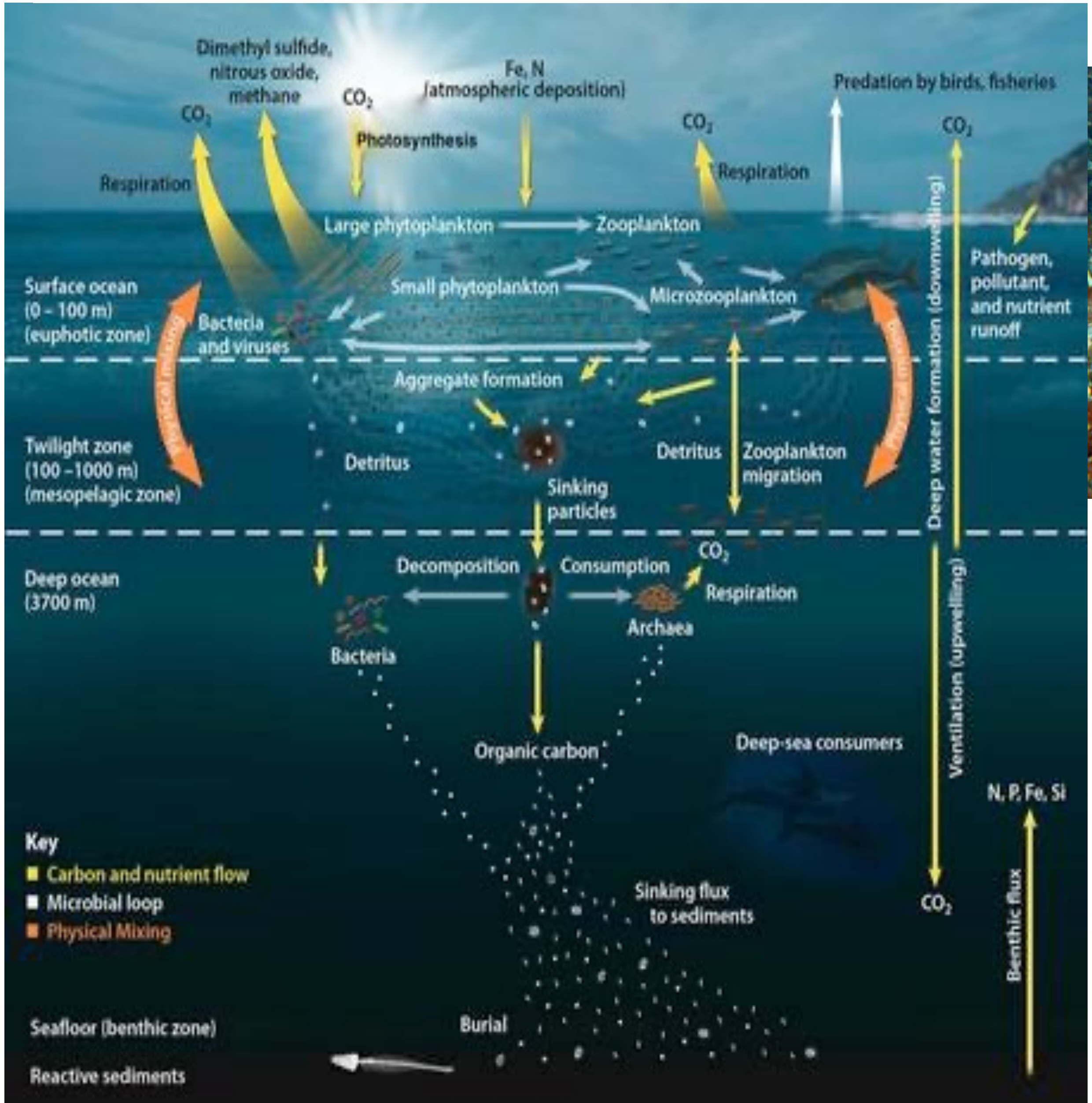


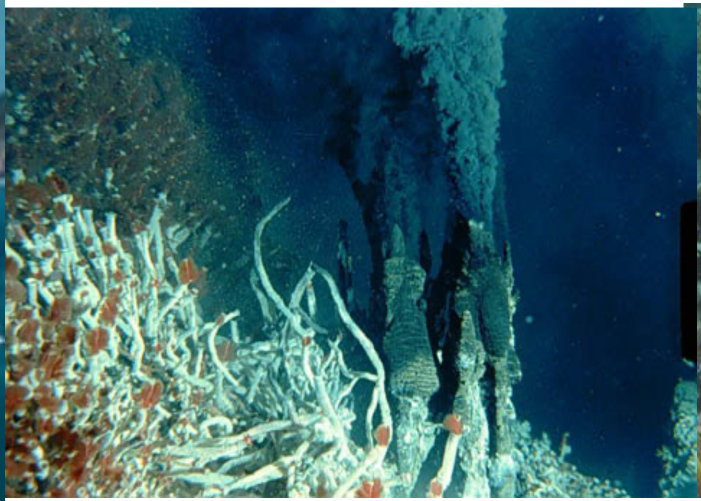
Main Themes

- **Biodiversity underpins the carbon cycle**
- **Seafloor as carbon recipient**
- **Many forms of benthopelagic coupling**
- **Critical Role of continental margins and Deoxygenation**
- **Human Disruption of the Benthic Boundary Layer**
  - Trawling, Oil and Gas, Mining, mCDR
- **Governance and jurisdiction challenges at the seafloor-water interface**

Carbon services provided by the biological pump

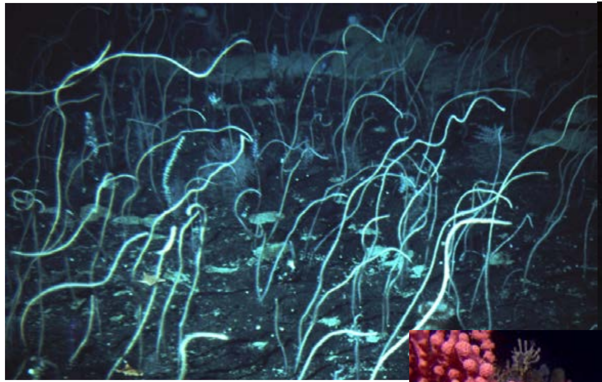


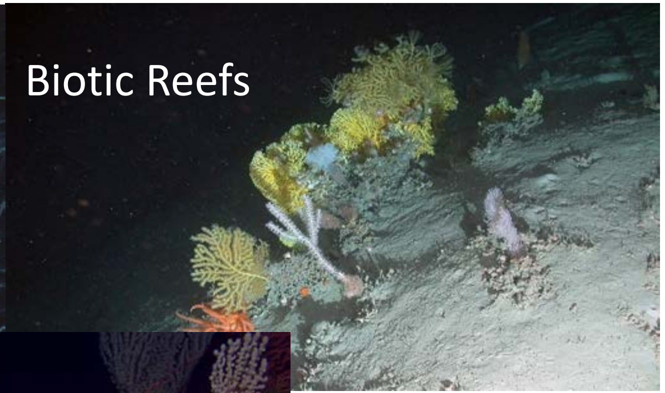
Fertilization by iron



Nutrient flux from bubbles

Mixing and Turbulence from Topography

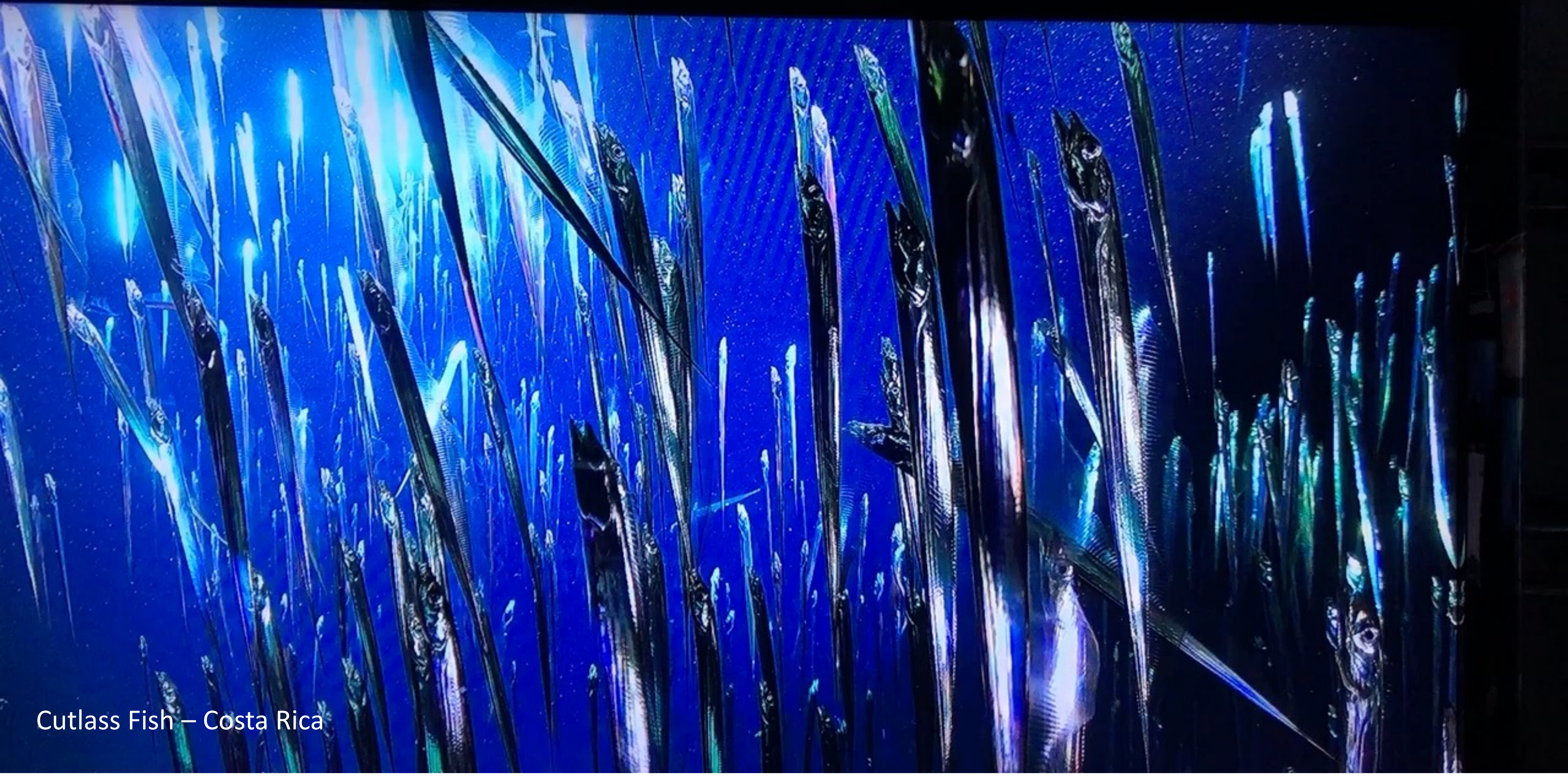




Seamounts

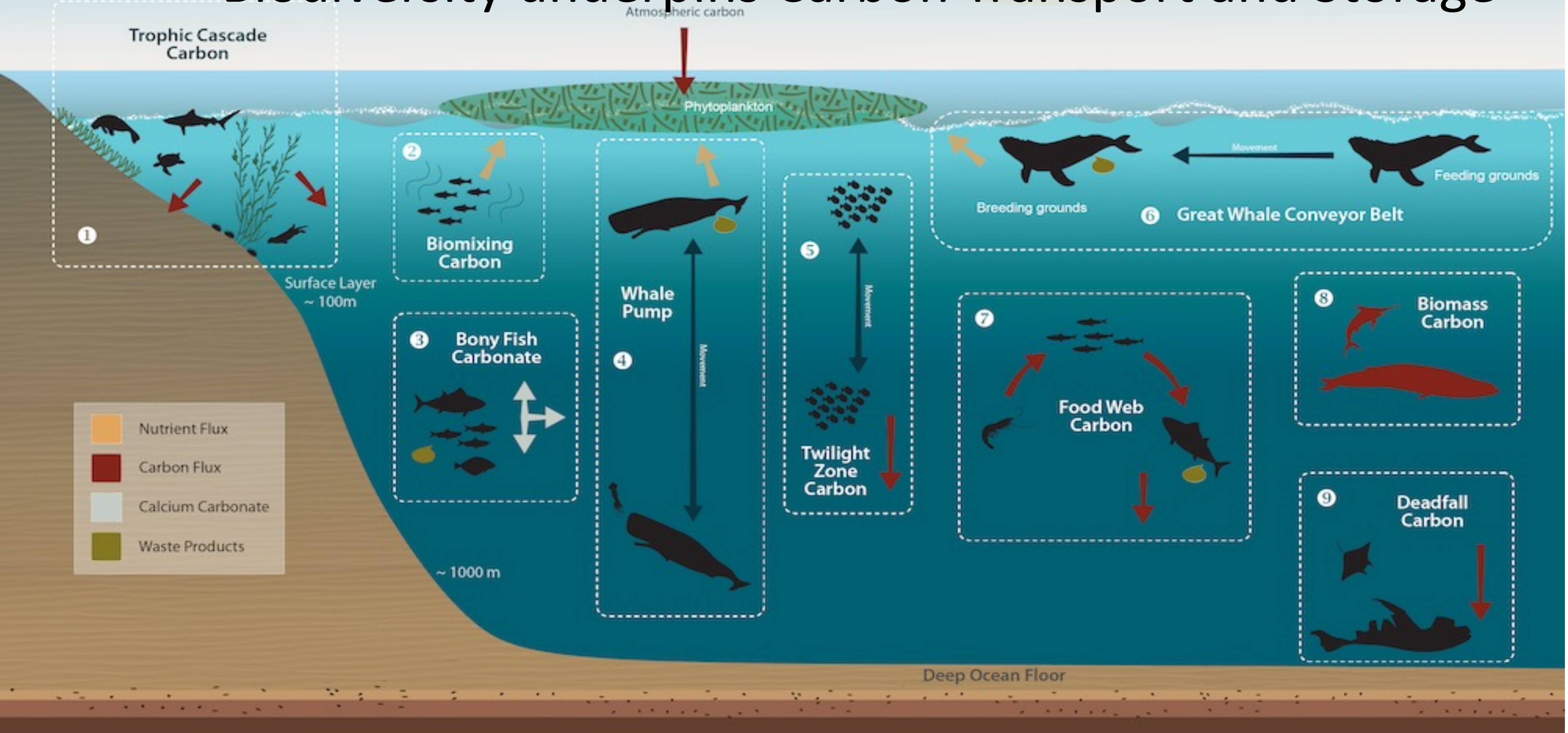
Canyons

Beyond small particles and fecal pellets: Blue carbon in action



Cutlass Fish – Costa Rica

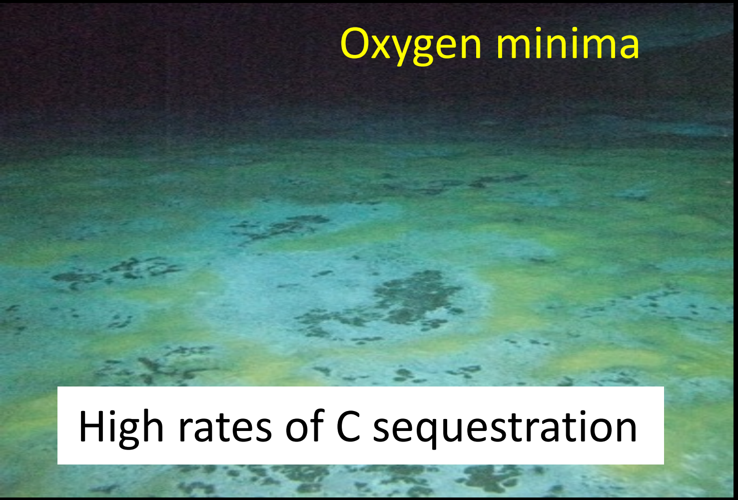
Biodiversity underpins Carbon Transport and Storage

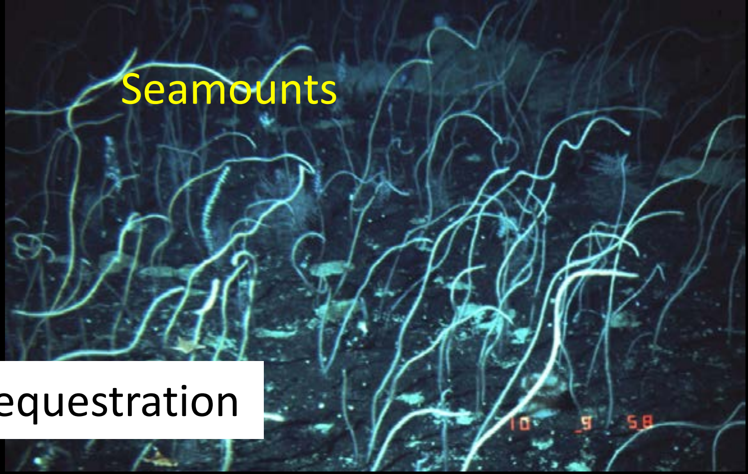


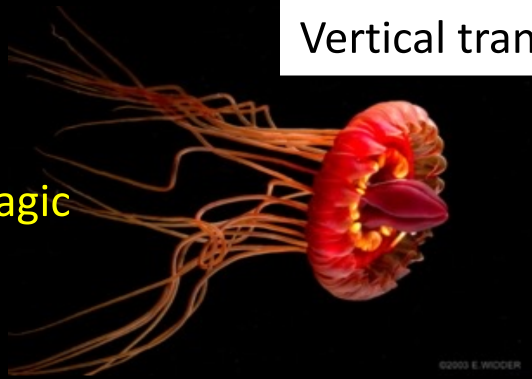
Reference: Lutz, S.J., Pearson, H., Vatter J., Bhakta D. (2018): Oceanic Blue Carbon. Arendal: GRID-Arendal

The **Deep Sea** is NOT a single ecosystem!

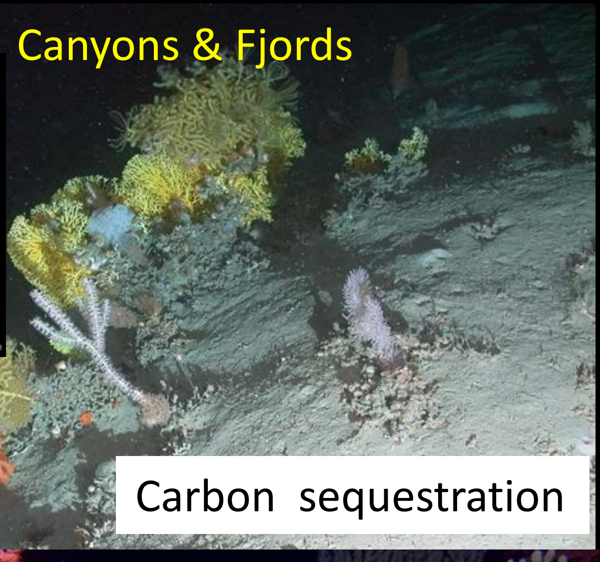
Heterogeneity generates biodiversity and Carbon services

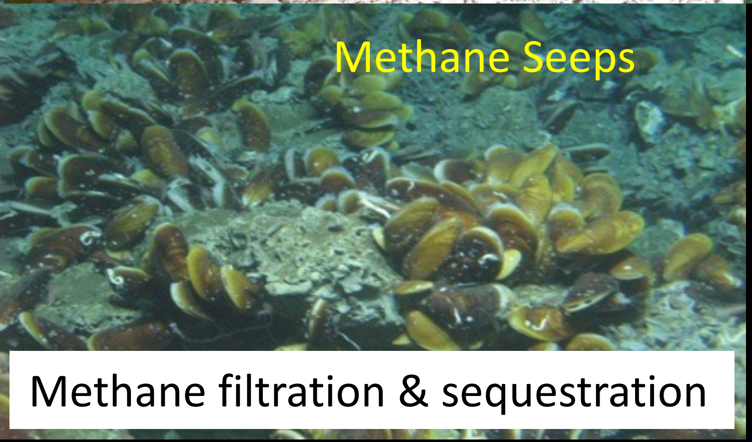




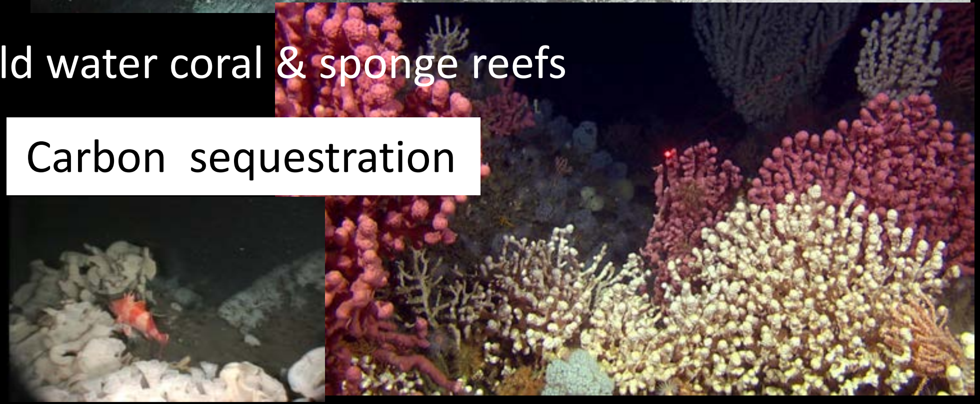


Vertical transport of Carbon





Cold water coral & sponge reefs



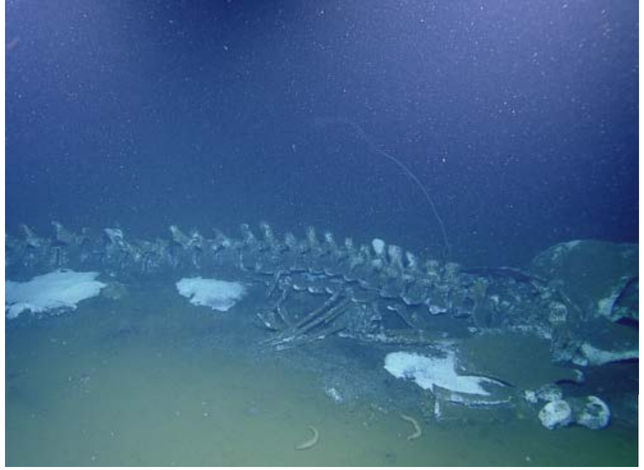
Decade for Ocean Science Barcelona Statement

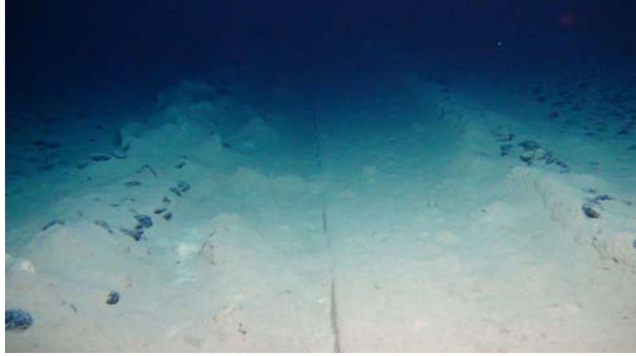
The Conference discussed and identified the following **future priorities for ocean knowledge and science generation and uptake** that could be fulfilled via the Ocean Decade framework. These include the co-design and co-delivery of science and knowledge to:

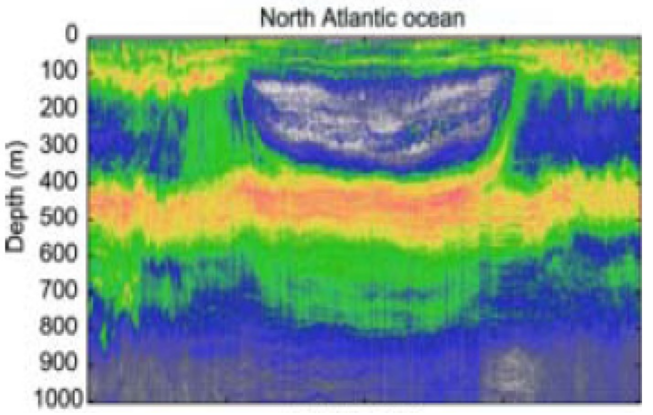
- Understand global distribution and human health and ecosystem impacts of marine pollution across the land-sea continuum, including the identification of priority pollutants and consideration of emerging and unregulated pollutants.
- Enhance and scale-up marine and coastal ecosystem-based management approaches, including a focus on better understanding of and solutions for multiple stressors.
- Better understand deep-sea ecosystems, including vulnerability to climate change and new or emerging economic activities.

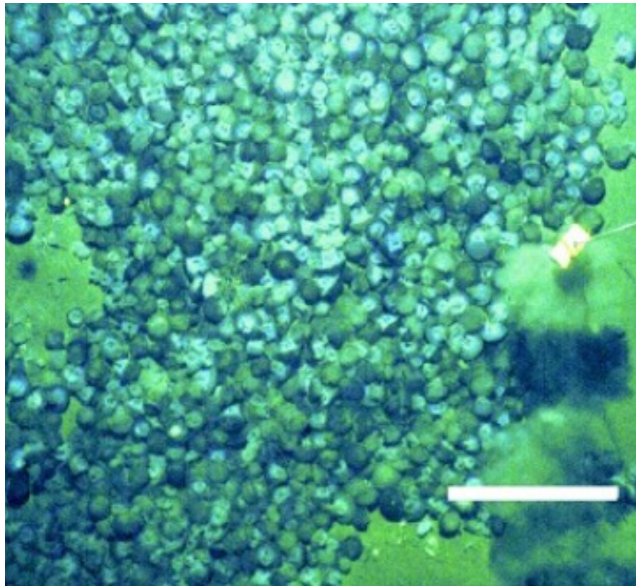
Forms of bentho-pelagic coupling

- Migrations – ontogenetic, diurnal, seasonal
- Food webs and feeding behavior
- Sinking particles
- Sinking algae and carcasses
- Resuspension
- Bottom disturbance



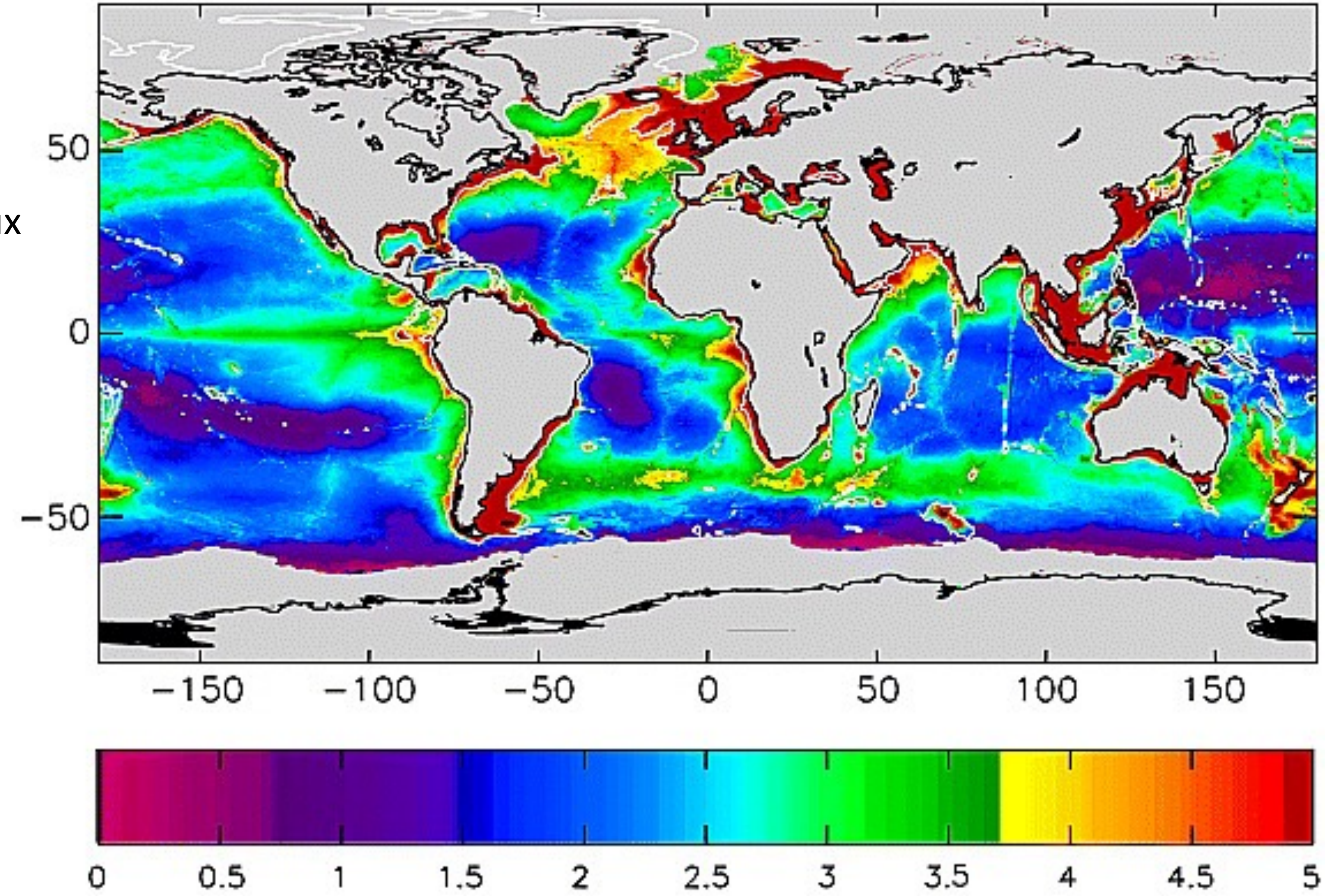






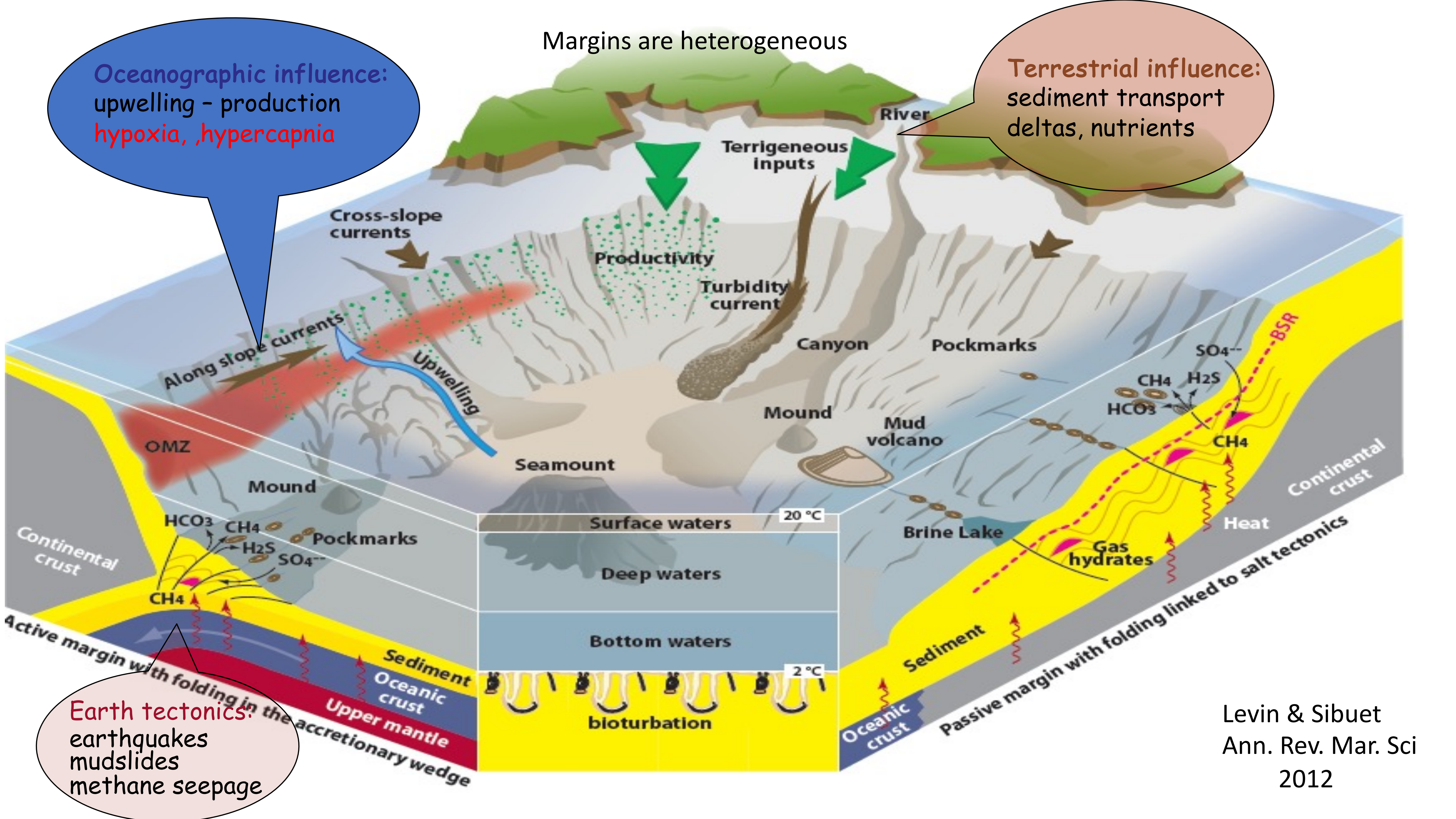
Continental margins extend 150,633 km around the ocean. They (<2000 m) account for a disproportionately large fraction of carbon burial (> 40%) (Muller-Karger et al. 2005)

1998-2001 POC Flux



0.62 Pg C y-1
reaches seafloor

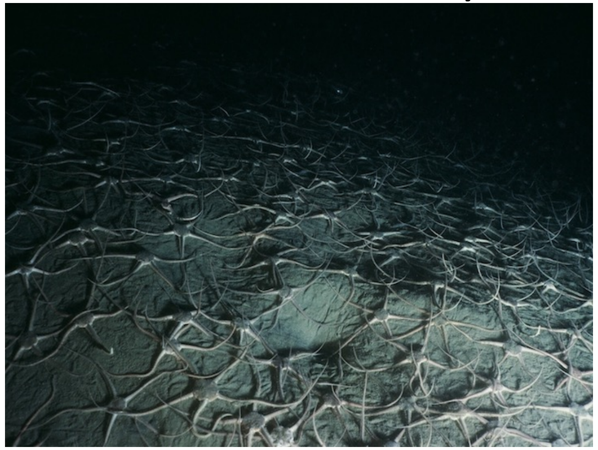
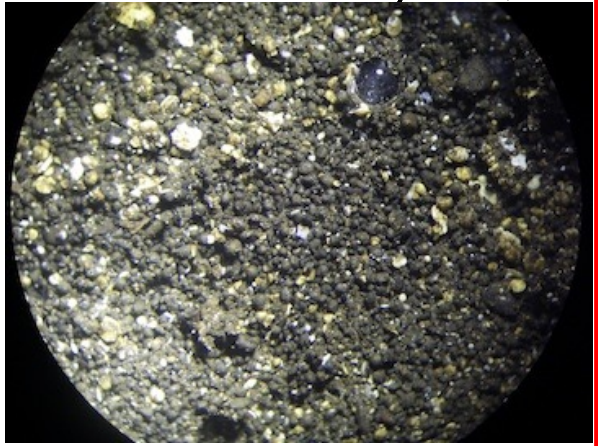
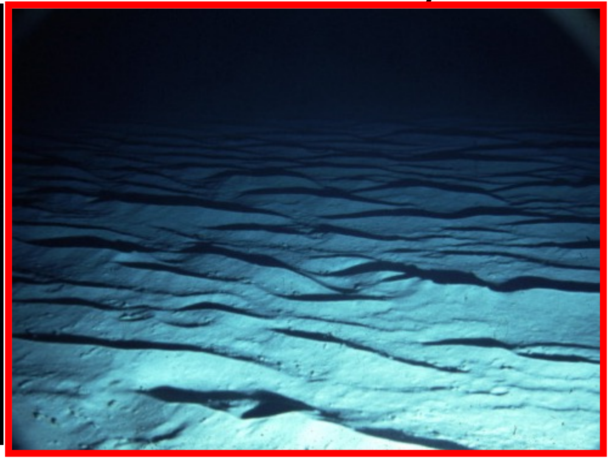
Margins are heterogeneous



Levin & Sibuet
Ann. Rev. Mar. Sci
2012

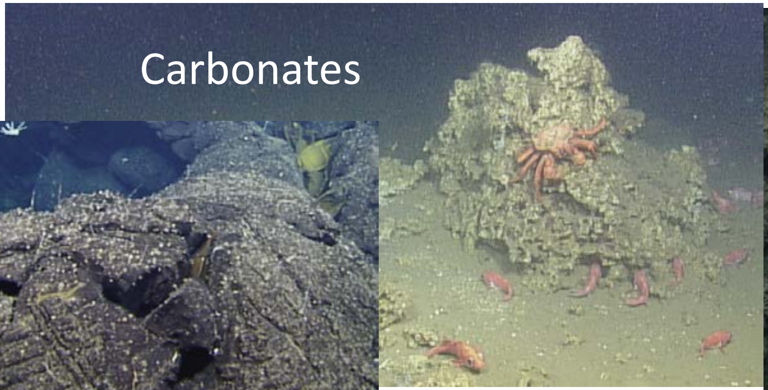
Many Substrates in the Deep Sea –
Each with own biodiversity, role in carbon cycle, and vulnerability to climate change

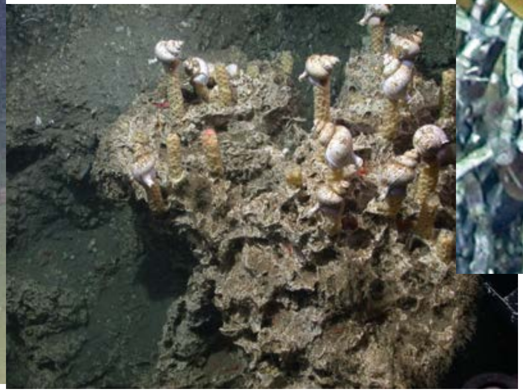
Soft Sediment


Biotic

Sulfides



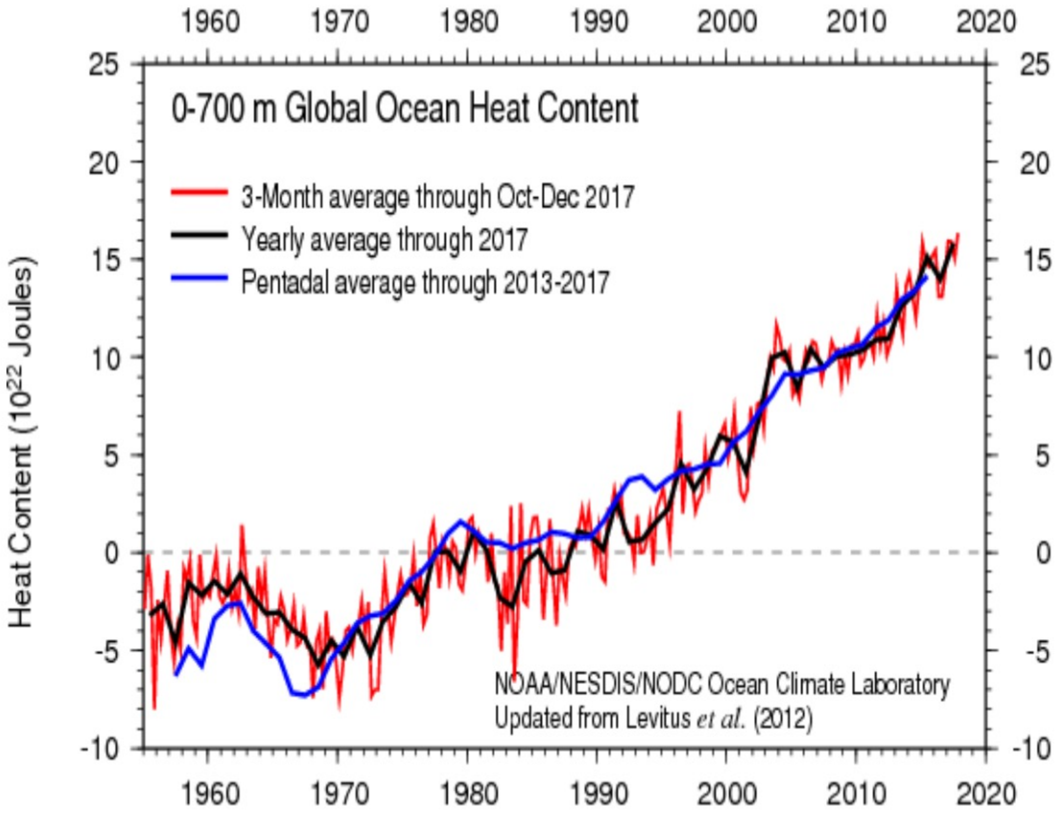
Basalts –

Canyon walls

FeMn Nodules, Crusts

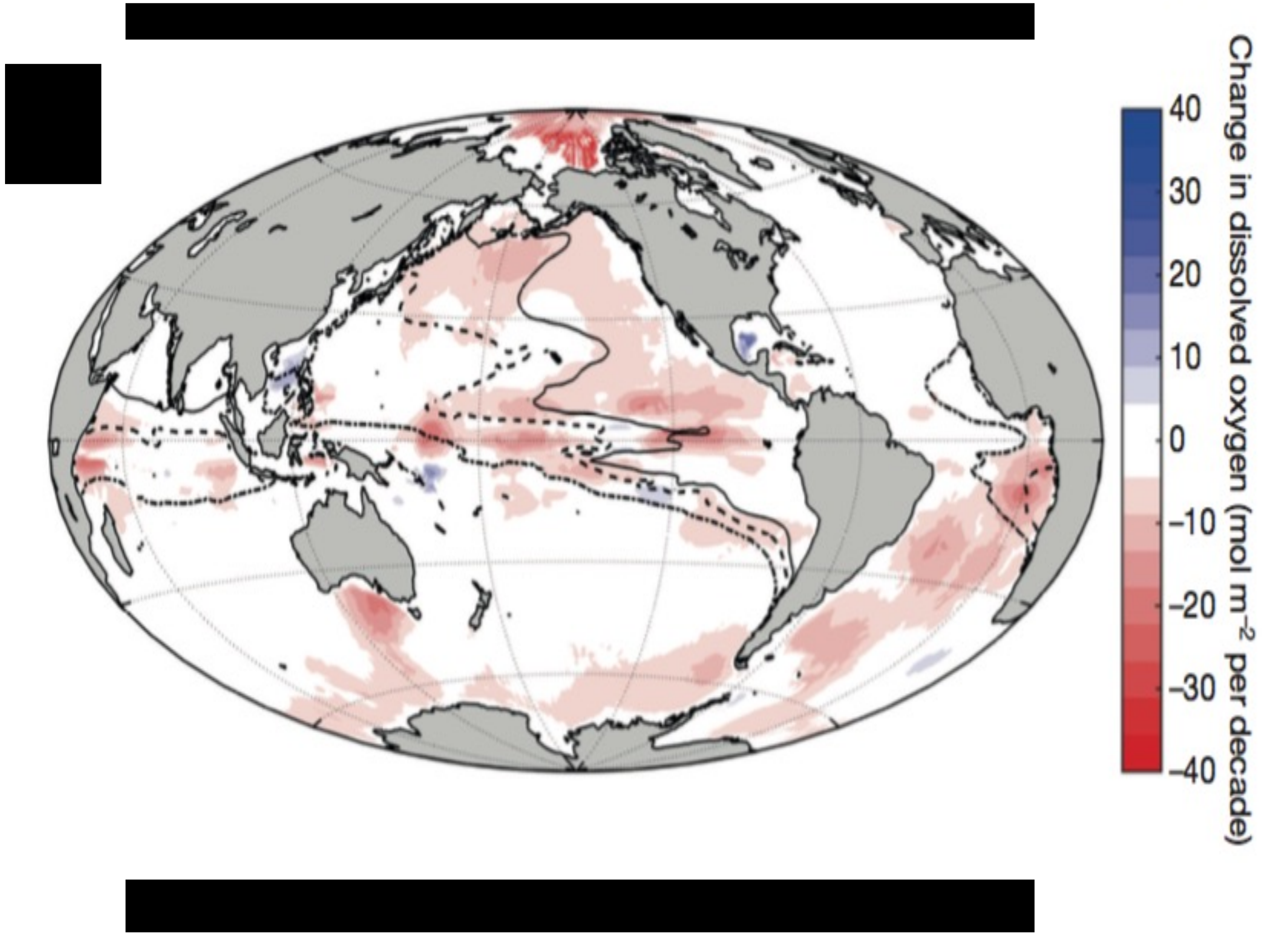


Warming and deoxygenation in the deep sea



Observed changes in global ocean heat content
(NOAA, updated from Levitus et al. 2012)

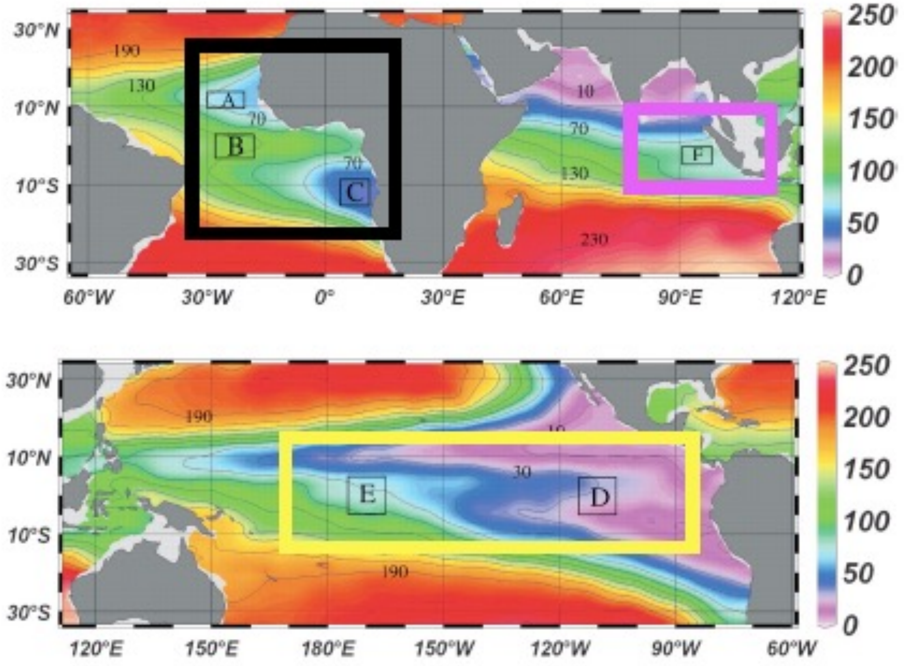
Observed changes in dissolved oxygen
(Schmidtko et al. 2017)



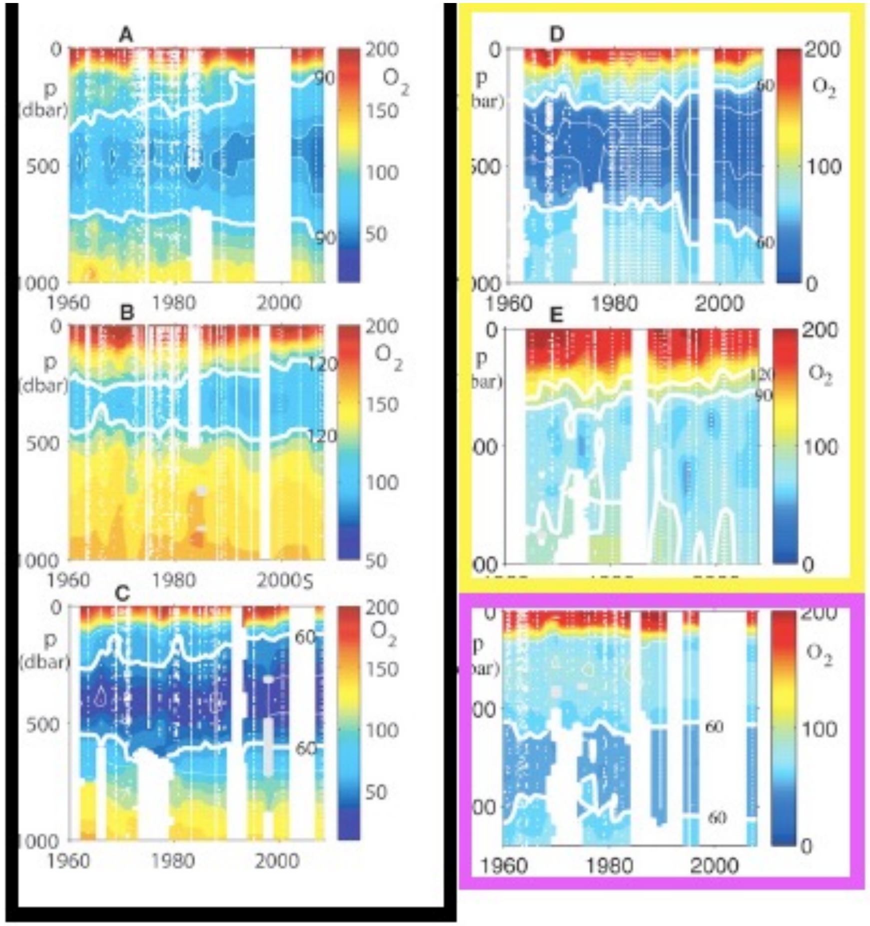
Warming causes OMZ expansion in tropical waters

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

Stramma et al. 2008



Oxygen in the oxygen minima



Time series 1960-present

Gong et al. in prep. (pers. comm. From Y. Zhou)
In N. Pacific OMZ increase by 15 m/y;
Lower boundary of NP and EP OMZ drops 5 m/y

Iron fertilization causes deoxygenation

In the past.....

RESEARCH ARTICLE | FEBRUARY 05, 2024

Iron fertilization–induced deoxygenation of eastern equatorial Pacific Ocean intermediate waters during the Paleocene–Eocene thermal maximum

Xiaodong Jiang; Xiangyu Zhao; Xiaoming Sun; Andrew P. Roberts; Appy Sluijs; Yu-Min Chou; Weiqi Yao; Jieqi Xing; Weijie Zhang; Qingsong Liu

+ Author and Article Information

Geology (2024) 52 (4): 276–281. | https://doi.org/10.1130/G51770.1 | Article history

Eolian dust and volcanic eruptions
Induce deoxygenation

And for marine Carbon Dioxide Removal (mCDR)

If OIF is successful then increased export production will eventually fuel increased aerobic microbial decomposition and oxygen consumption at depth (Cullen and Boyd 2008), which could lead to the development of hypoxia or anoxia below the euphotic zone (Yoon et al. 2016).

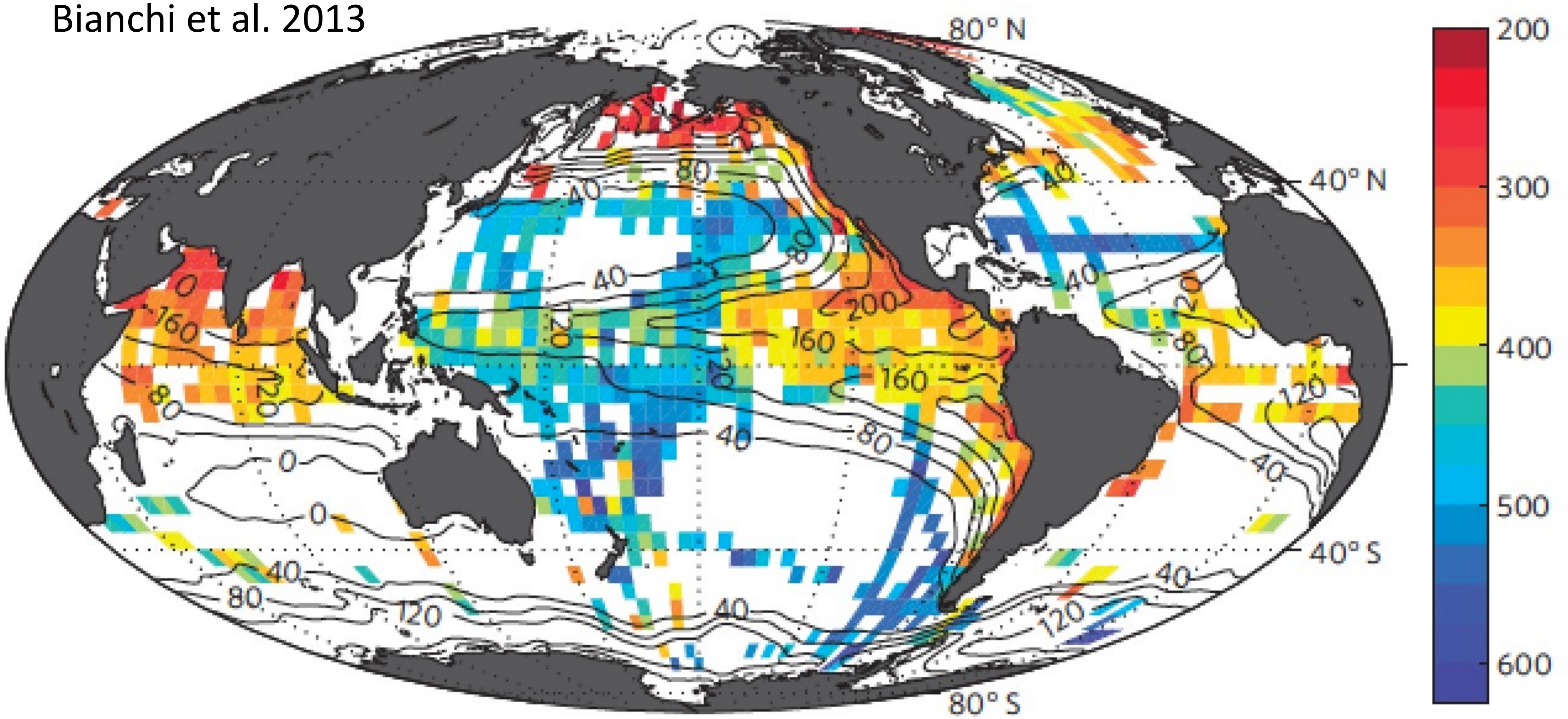
Net improvement in global export is tied to a net deterioration of subsurface oxygen. (Rohr 2019)

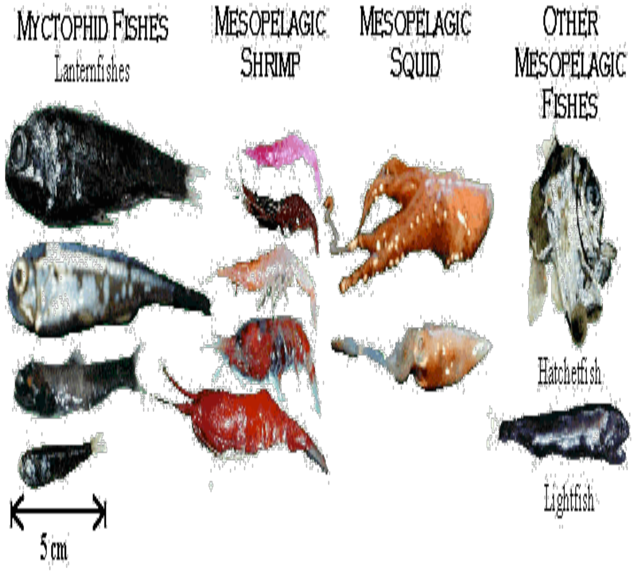
How does this influence biodiversity and the carbon cycle?

Mesopelagic migrant pump has the greatest potential to contribute to carbon sequestration (Boyd et al. 2019)

Diel Vertical Migration (DVM) depth set by oxygenation Shoaling oxycline predicted to cause reduced depth of daily migrations, less vertical carbon transfer to depth.

Bianchi et al. 2013

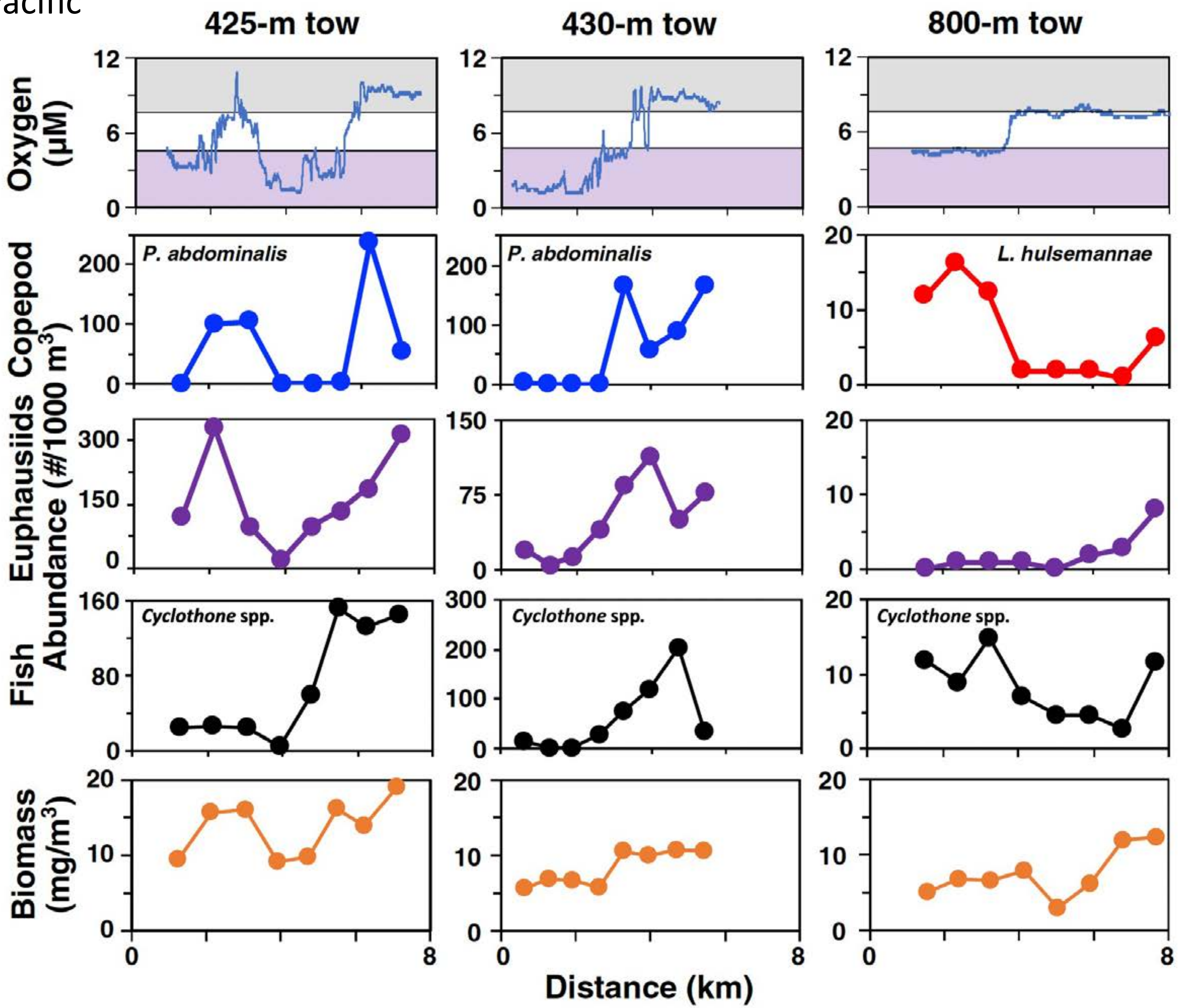




Eastern Pacific

Copepods, euphausids and fish respond to fine-scale variation in Oygen at low (threshold) levels

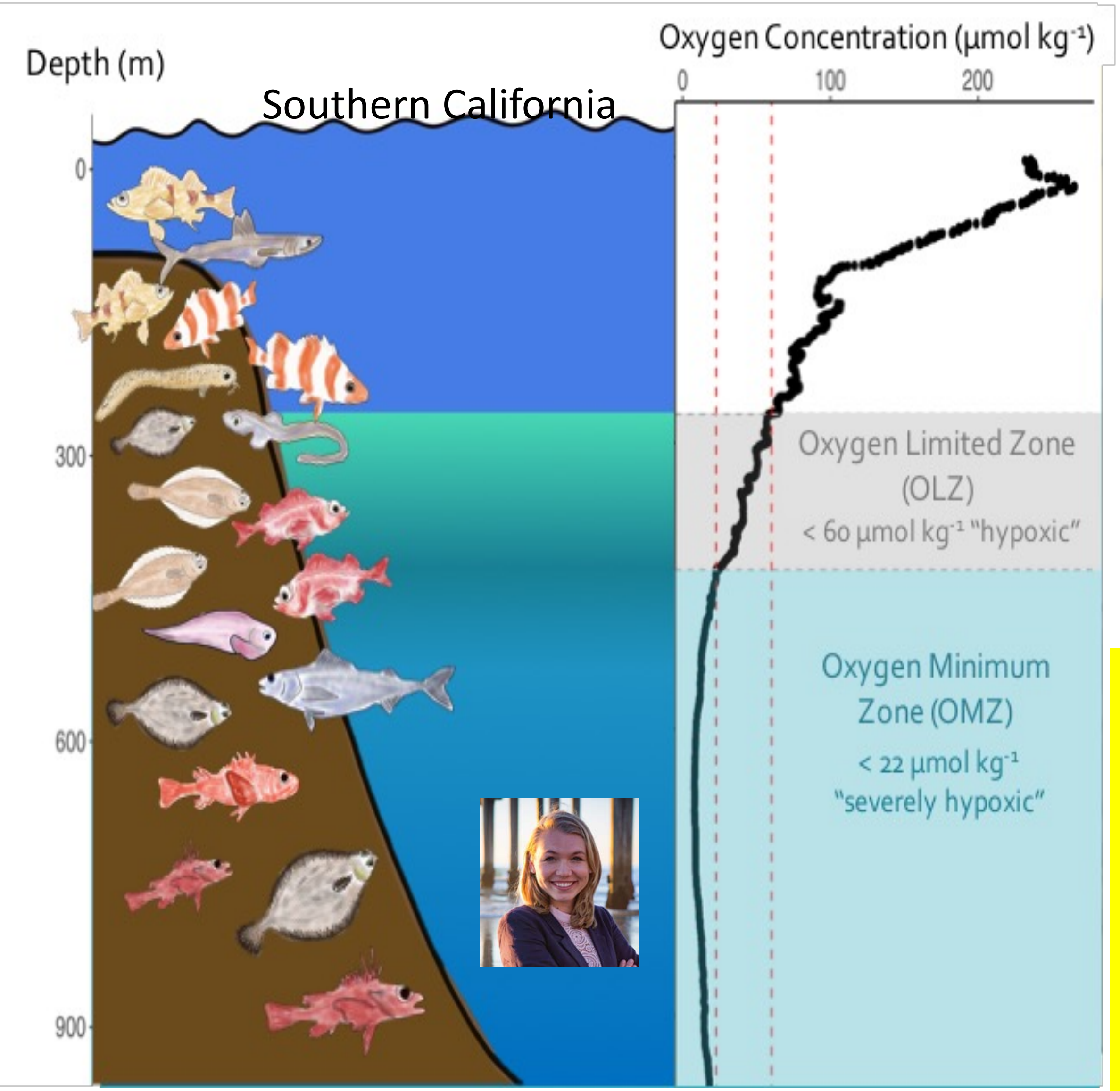
Wishner et al. 2020
Science Advances



DVM can reach the seafloor

FOOD CHAIN: Off CA, demersal fish shift from pelagic to benthic diets in the OMZ

= Longer, less efficient food chains, Low productivity, Less demersal fish!



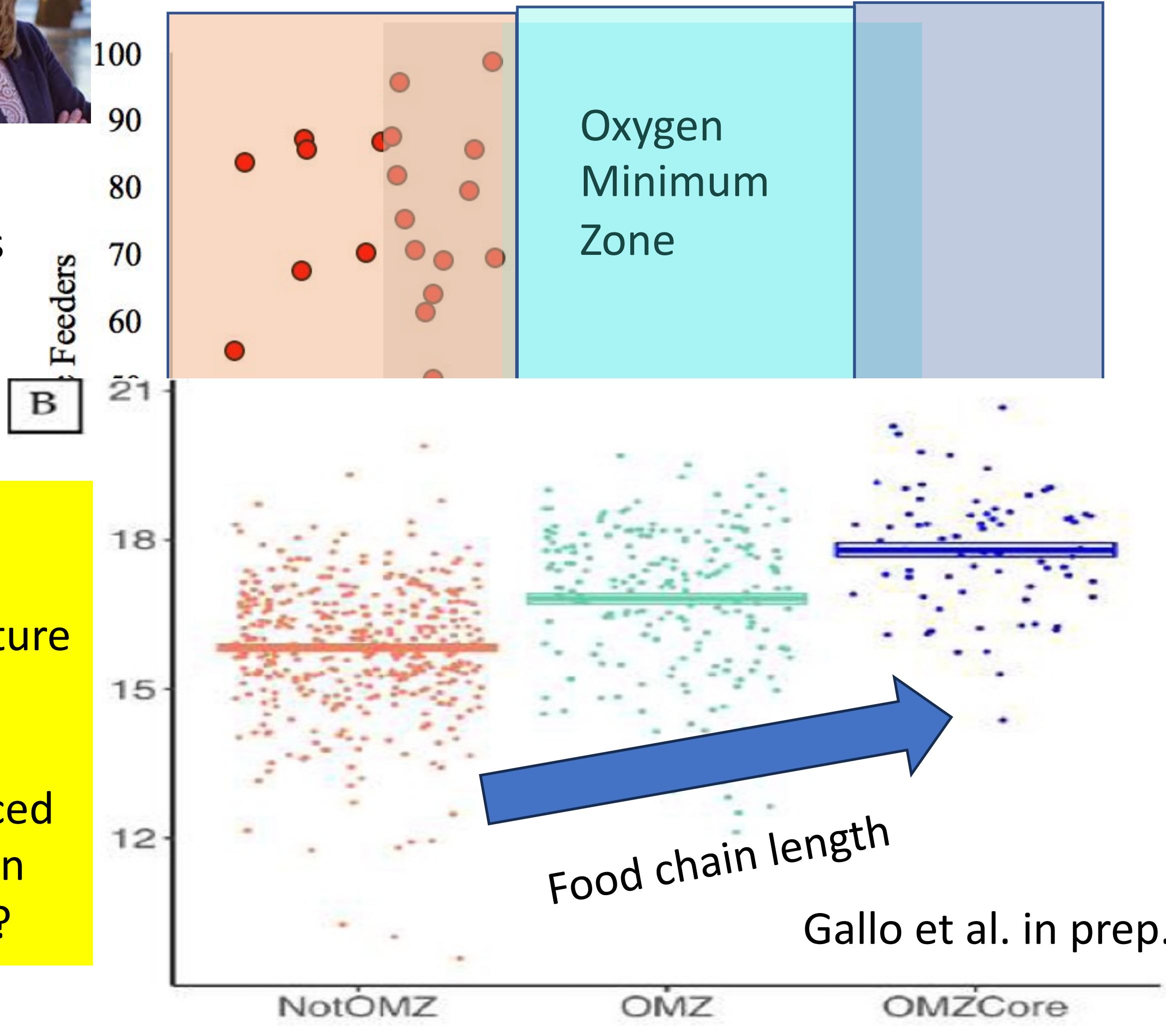
Gallo & Levin 2019, IUCN report

Gut contents

Altered Energy expenditure of fish?

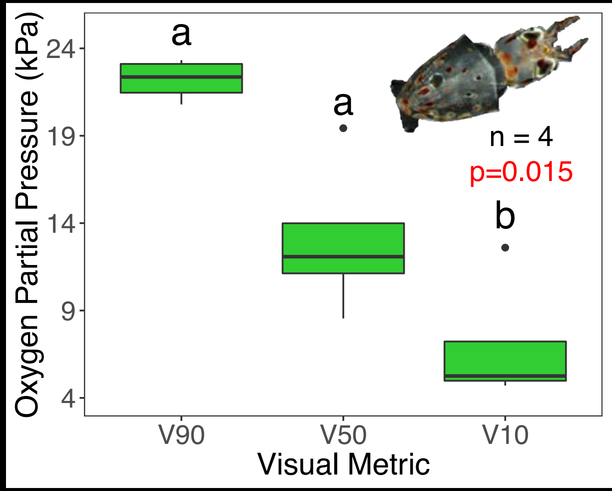
Or reduced Migration Of DVM?

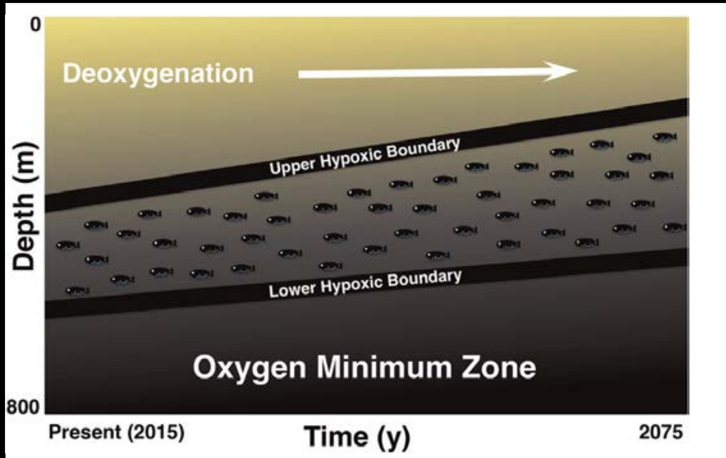
% Pelagic feeders in demersal fish community Southern California



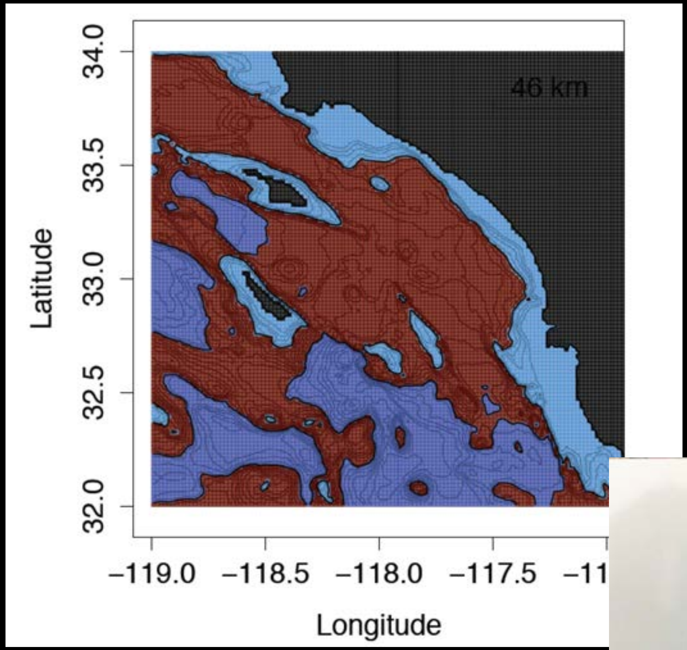
Gallo et al. in prep.

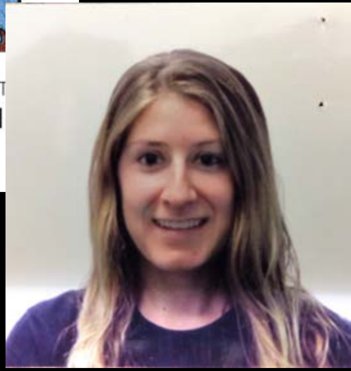
Deoxygenation affects Vision
Larvae need more light to see at low O_2 concentrations





Netburn & Koslow 2015





McCormick et al. 2017, 2022

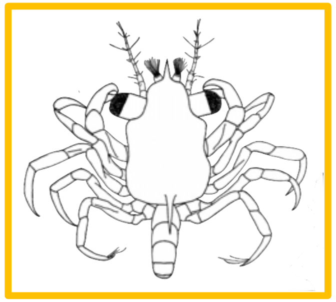
Critical Luminoxyscape:

Combinations of light and oxygen in the environment that enable visual function

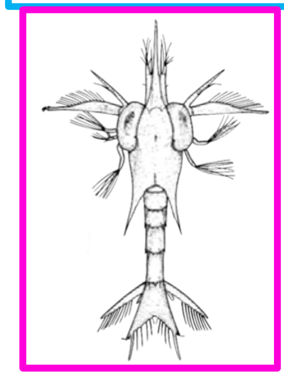
VISION IN LARVAE: Cephalopods and brachyuran crab show visual sensitivity at pO_2 > hypoxia (~5 kPa/60 μmol/kg)

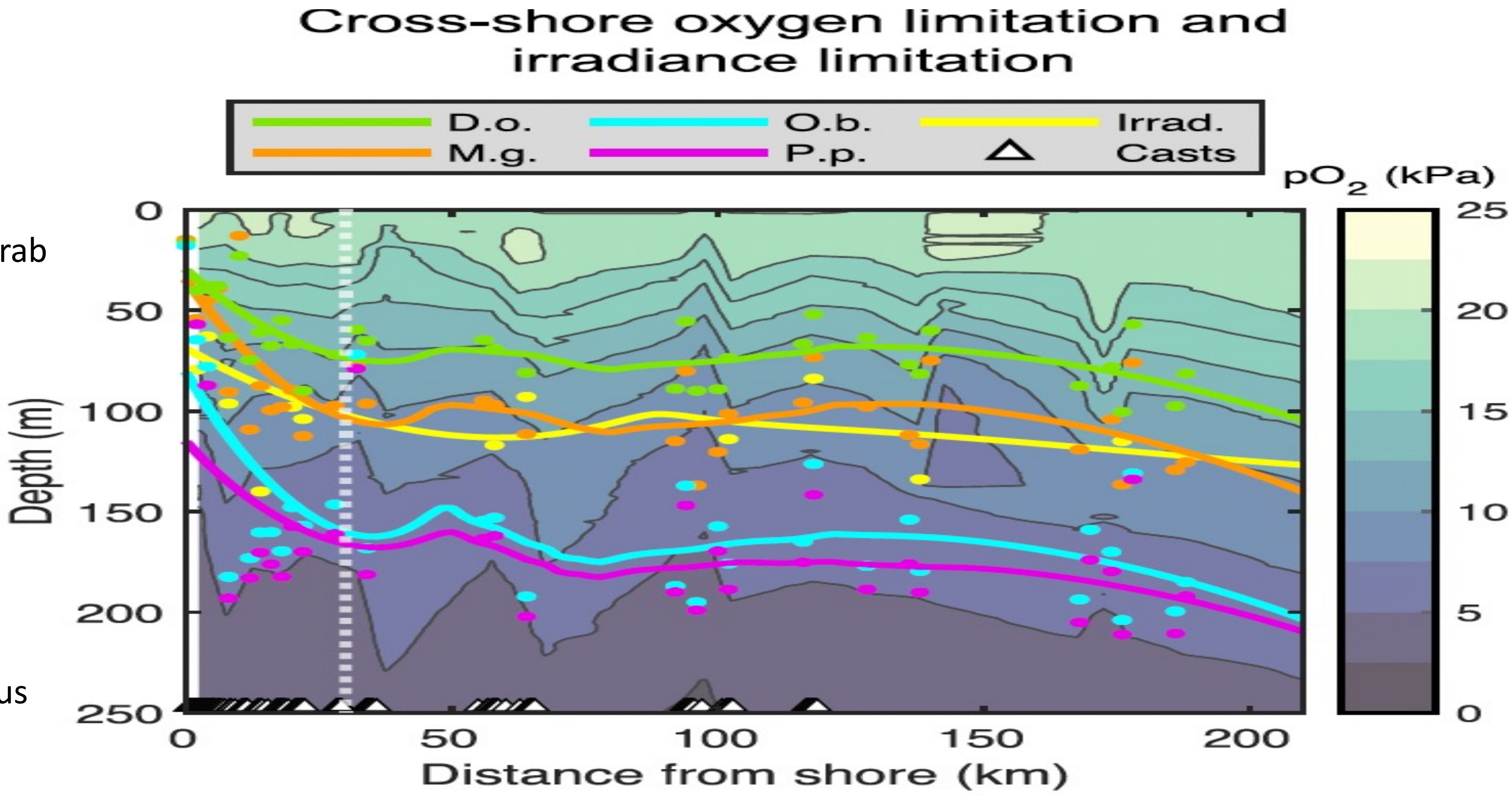
Luminoxyscape defines visually suitable habitat


Squid


Rock crab

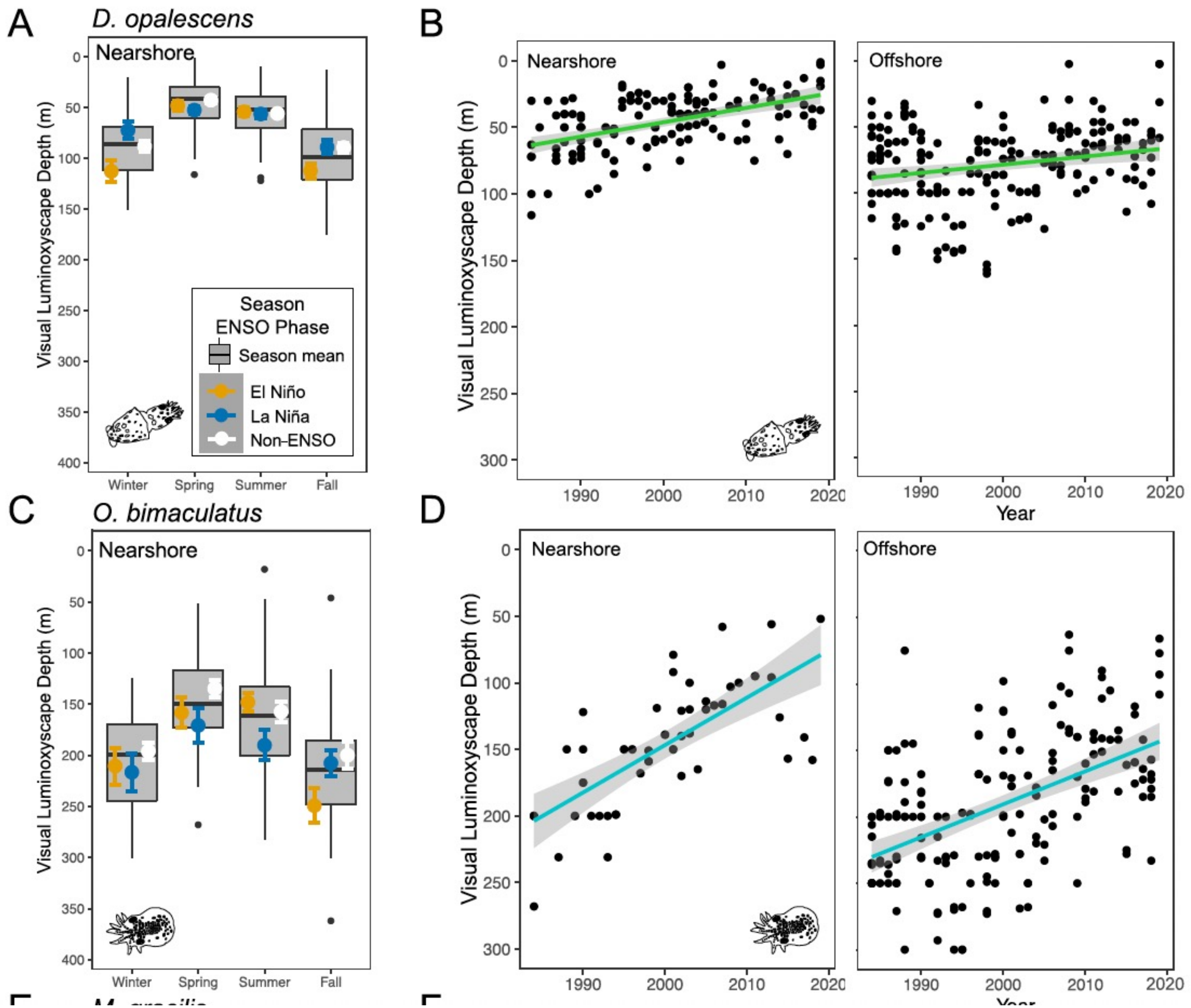

Tuna crab


Octopus



McCormick et al. 2022

Shoaling larval distributions are expected as deoxygenation occurs seasonally, during La Nina, and over longer time (CC) due to visual limitations.



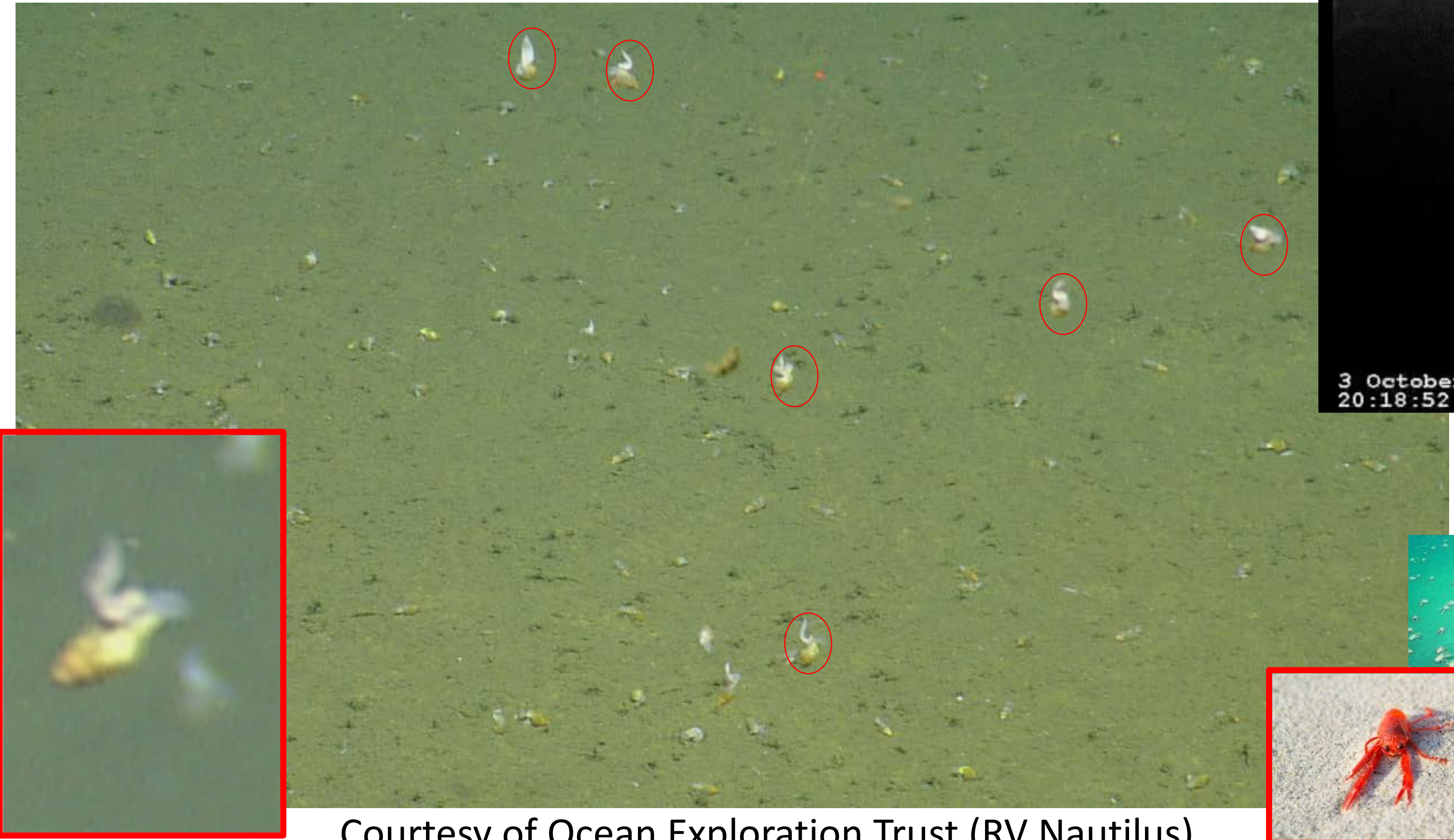
Larvae are released into the water from benthic adults. Larvae contribute to food chains, and transfer of energy to the sea floor when they settle.

McCormick et al. 2022
L&O Letters

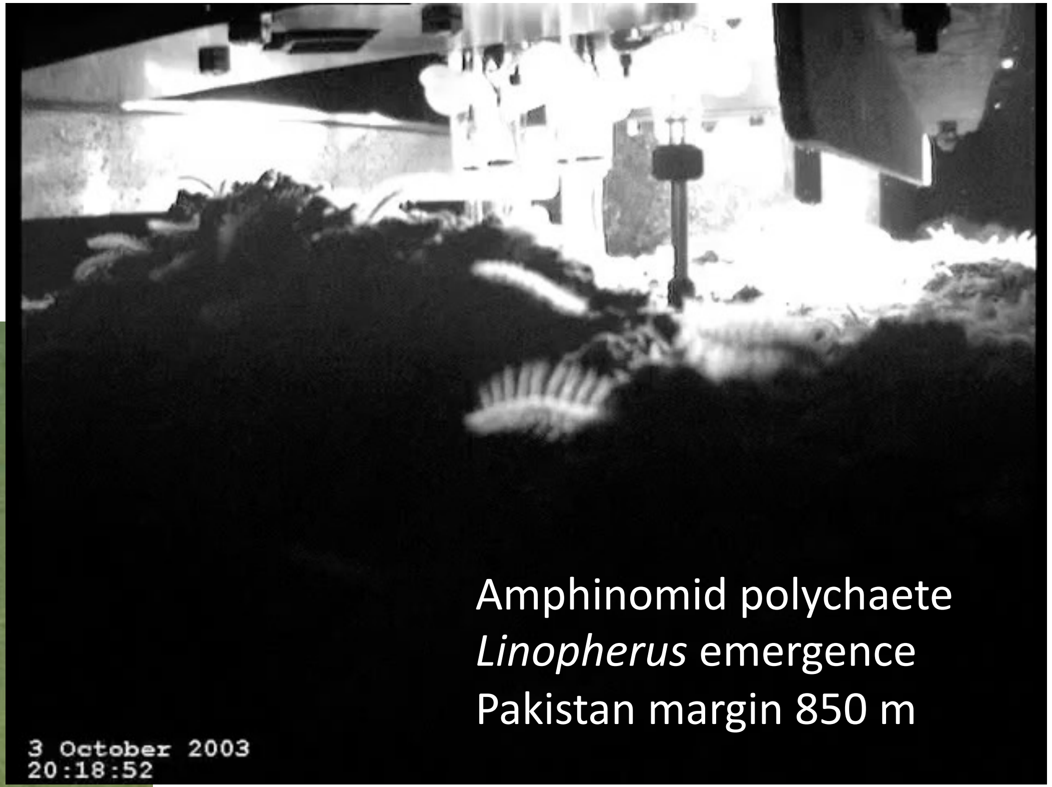
Low oxygen brings benthos into the water. Promotes dispersal.

Para-sailing snails
Allia (Astyris) permodesta
in the Santa Monica Basin (830 m)

< 1 μM O_2



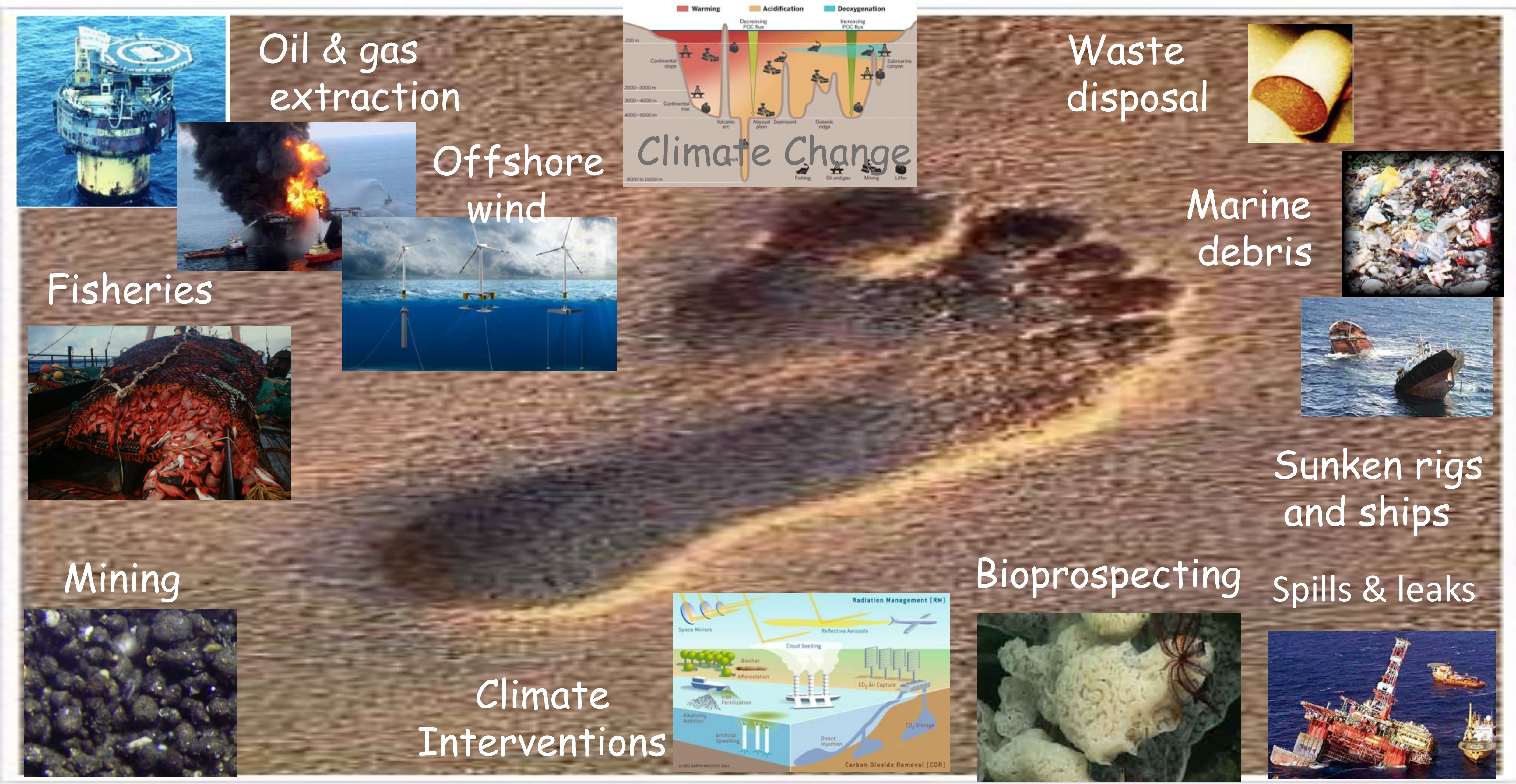
Courtesy of Ocean Exploration Trust (RV Nautilus)



Amphinomid polychaete
Linopherus emergence
Pakistan margin 850 m

Tuna crab *Pleuroncodes planipes* shifts from benthic to pelagic mode – Costa Rica 400 m

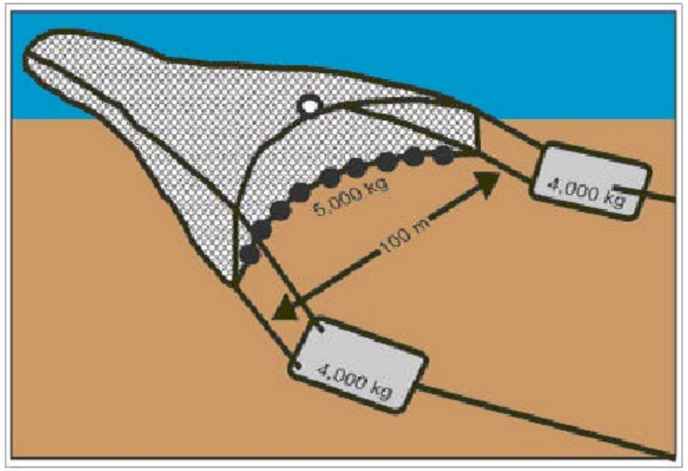
A Deeper Human Footprint alters the Carbon Cycle



Bottom Trawling impacts on Carbon: It’s complicated

Reduction of OC stores in seabed due to:

- lower production of flora and fauna
- the loss of fine flocculent material
- increased sediment resuspension
- mixing and transport
- Increased oxygen exposure.



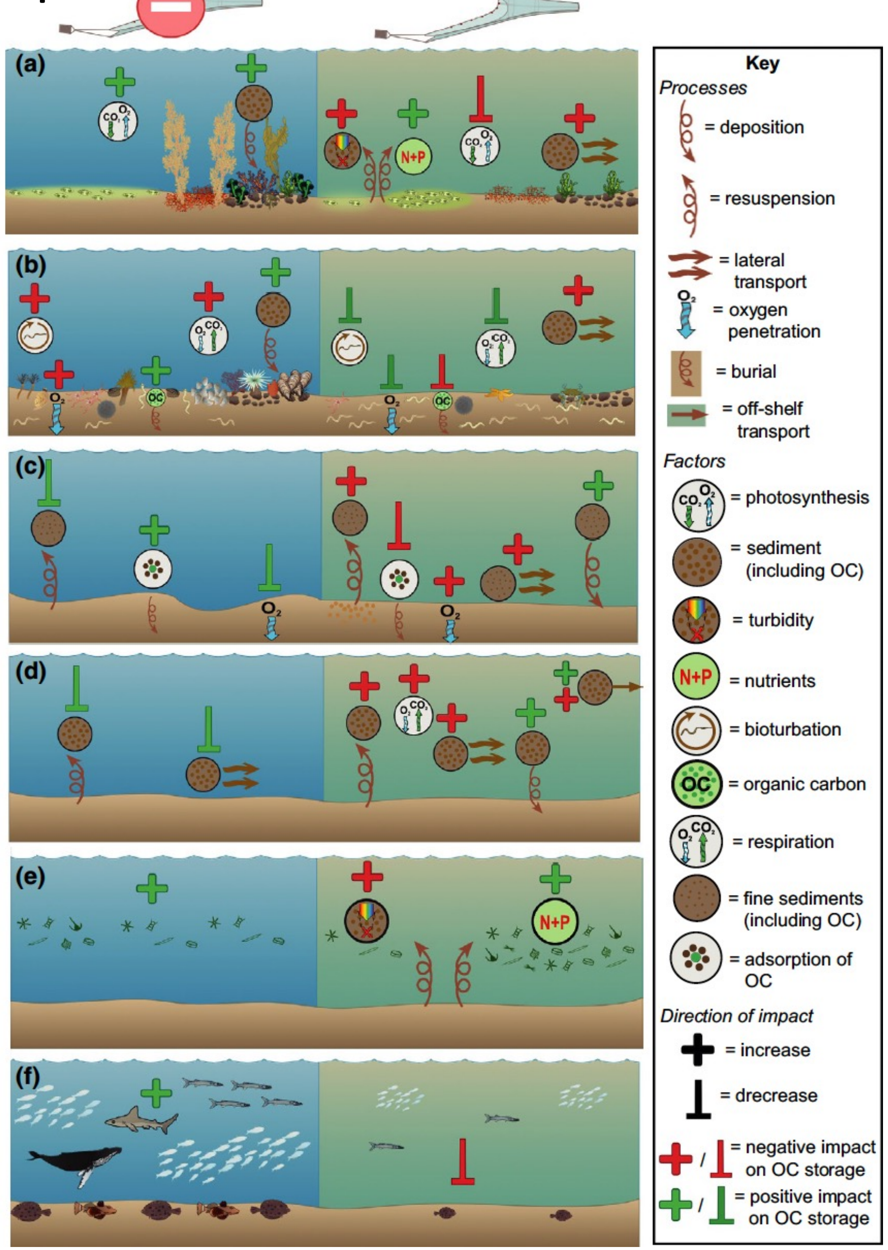
These offset by:

- reduced faunal bioturbation
- reduced community respiration
- increased off-shelf transport
- Increases n primary production from the resuspension of nutrients

55-60% of trawling-induced aqueous CO_2 (0.34-0.37 Pg CO_2) is released to the atmosphere over 7-9 years (Atwood et al. 2024)

Carbon Protection Zones:

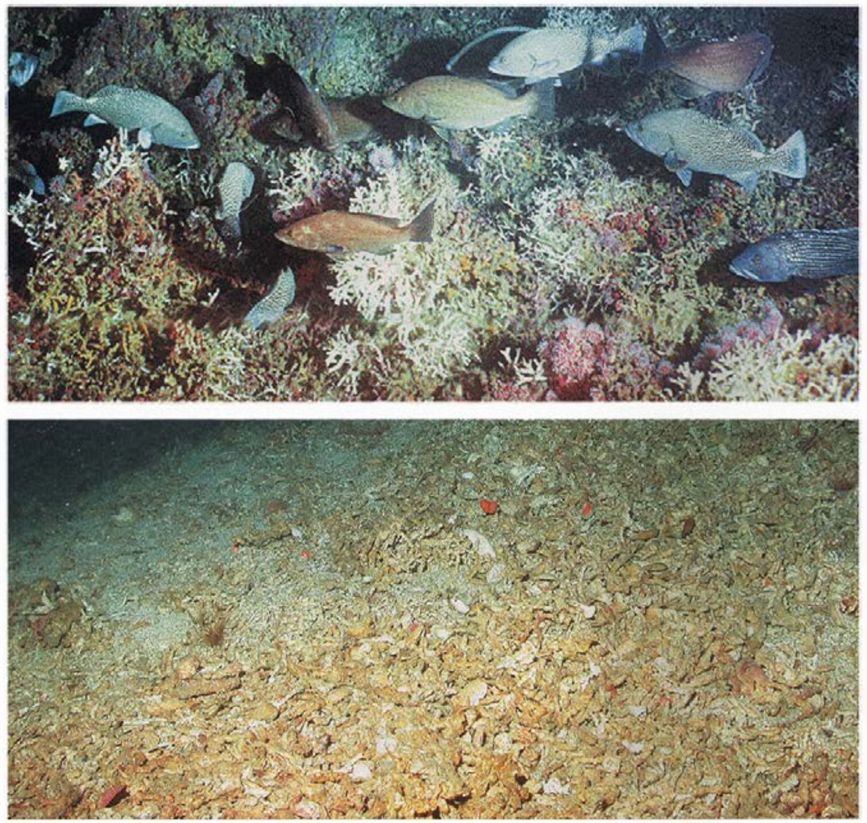
Only 2-3 % of seabed currently closed to trawling
Trawling ban proposed for carbon conservation (Porz et al. 2024)



Epstein et al. 2021

Bottom Trawling:

Loss of Calcifying Ecosystems and associated fish



Overfishing and Ghost Fishing:
Loss of Biomass storing C

Deep-sea corals can be 4000 + years old!

Increasingly deeper oil and gas exploitation

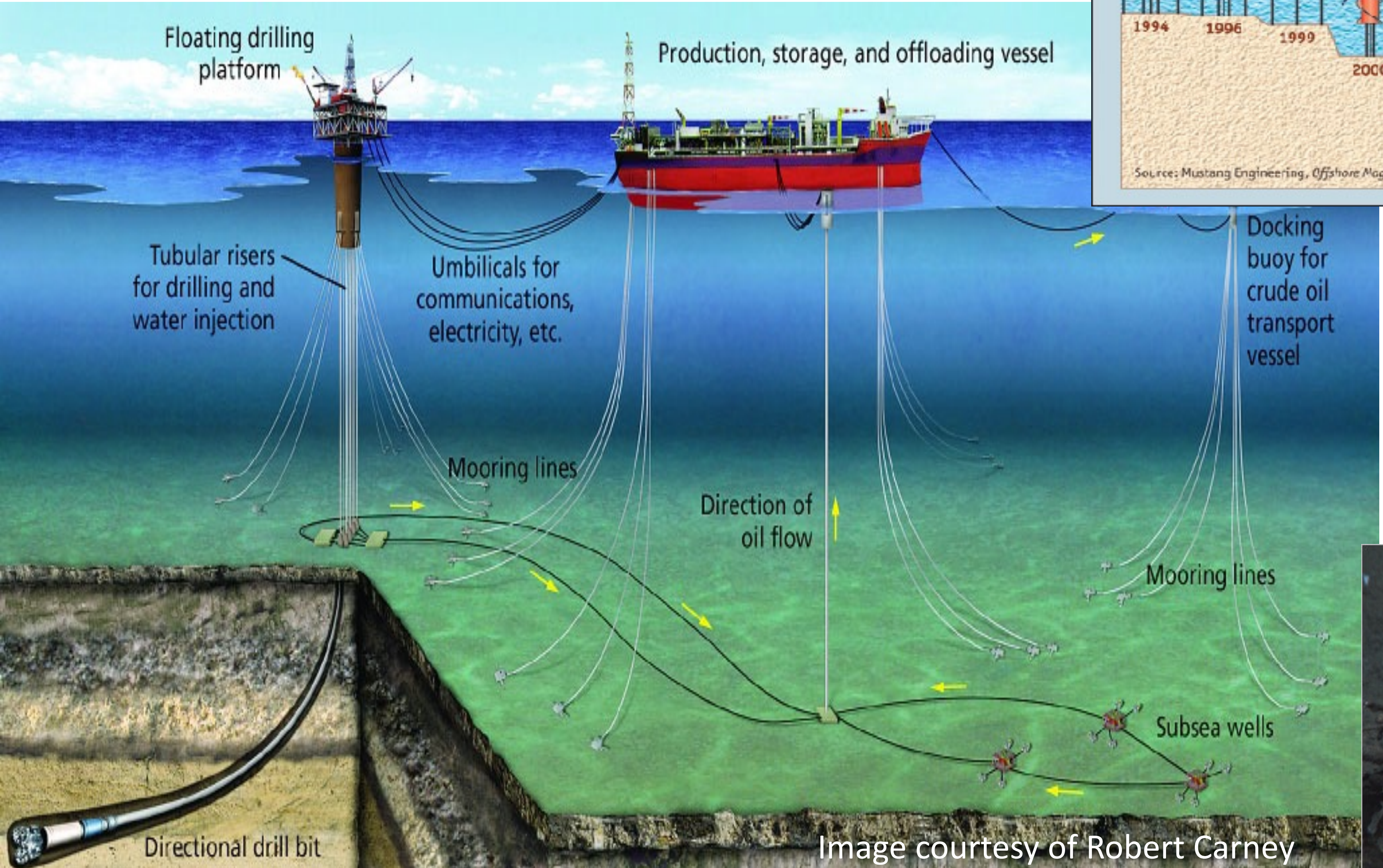
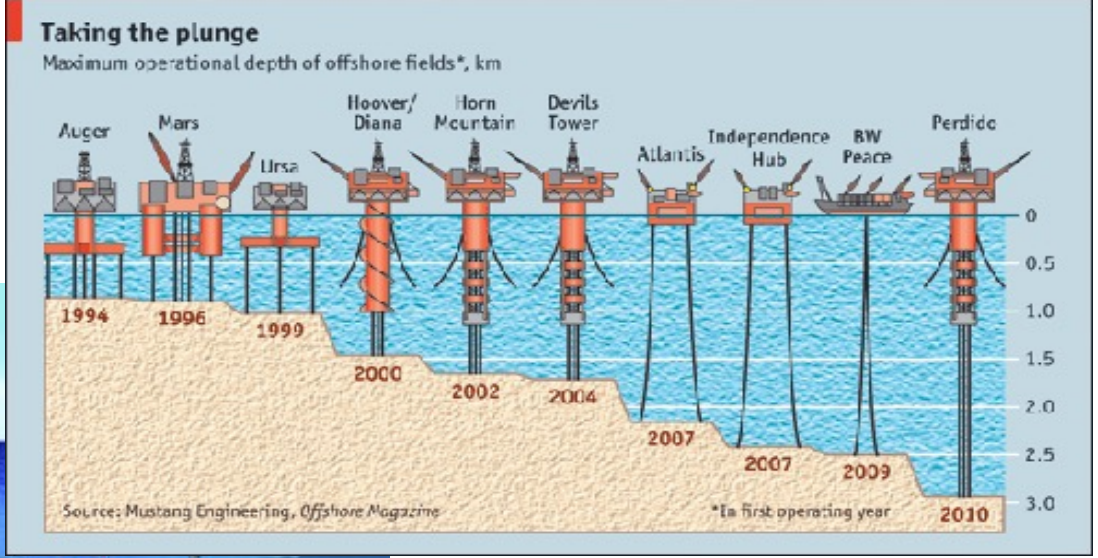
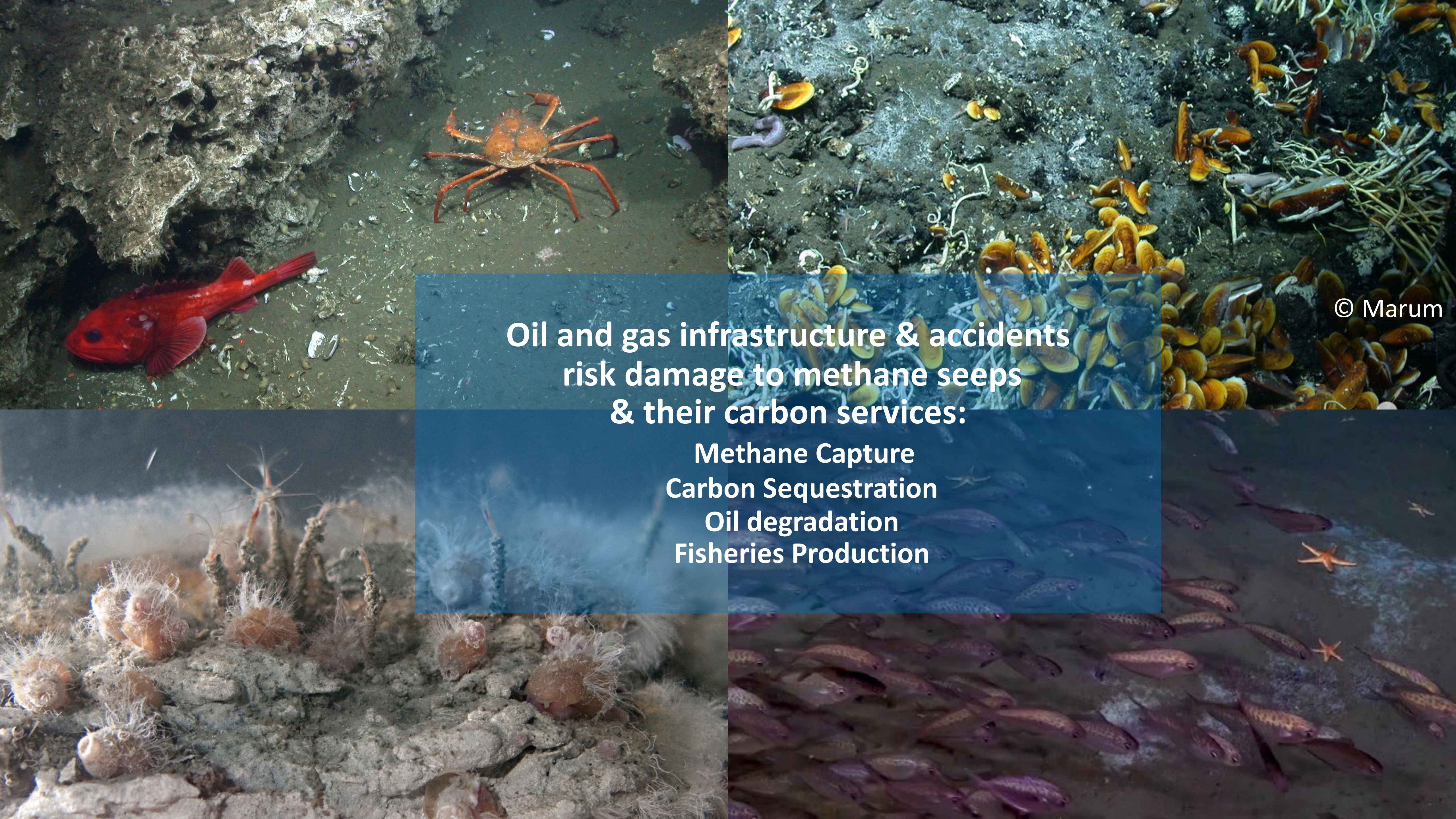


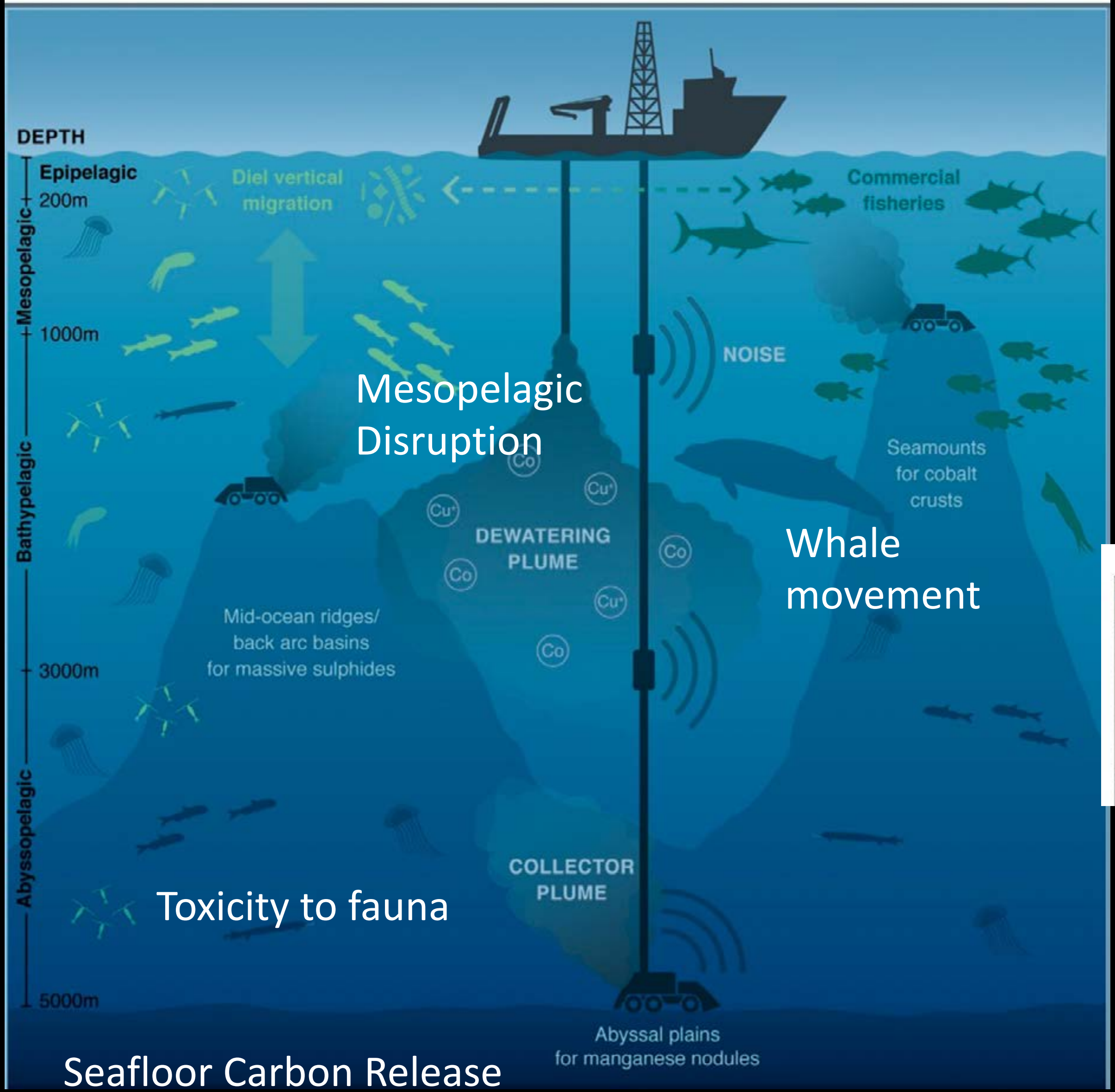
Image courtesy of Robert Carney



Oil spills damage biodiversity:
Mesopelagic fishes & crustaceans
Benthic invertebrates, calcifiers
Fishes and mammals

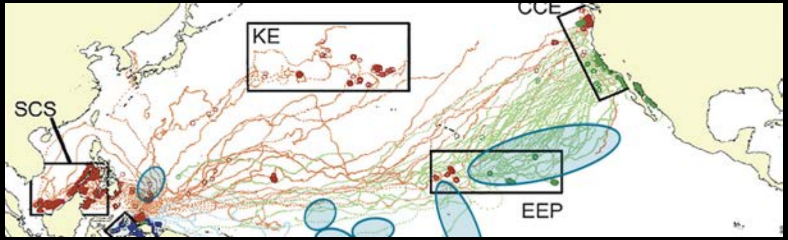

Oil and gas infrastructure & accidents
risk damage to methane seeps
& their carbon services:
Methane Capture
Carbon Sequestration
Oil degradation
Fisheries Production
© Marum

Seabed Mining: Bentho-pelagic coupling and pelagic impacts

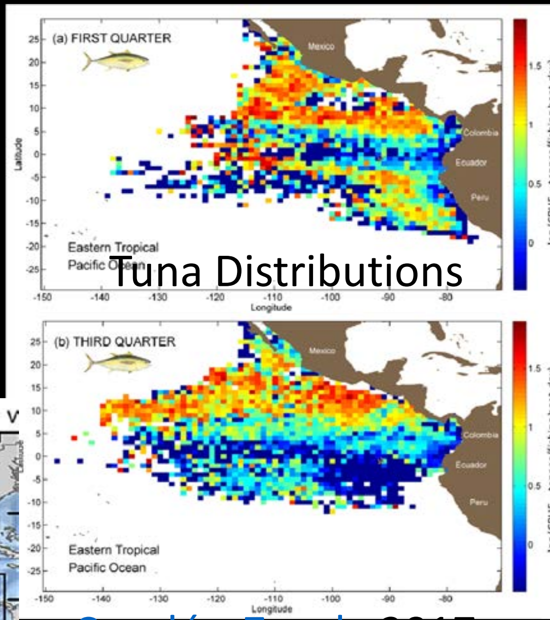


Mesopelagic migrations

Leatherback Turtle Migrations

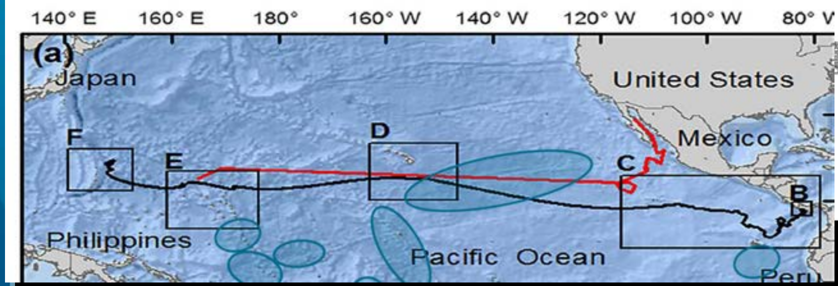


Chin and Hari, 2020



Tuna Distributions

Whale Shark Migrations



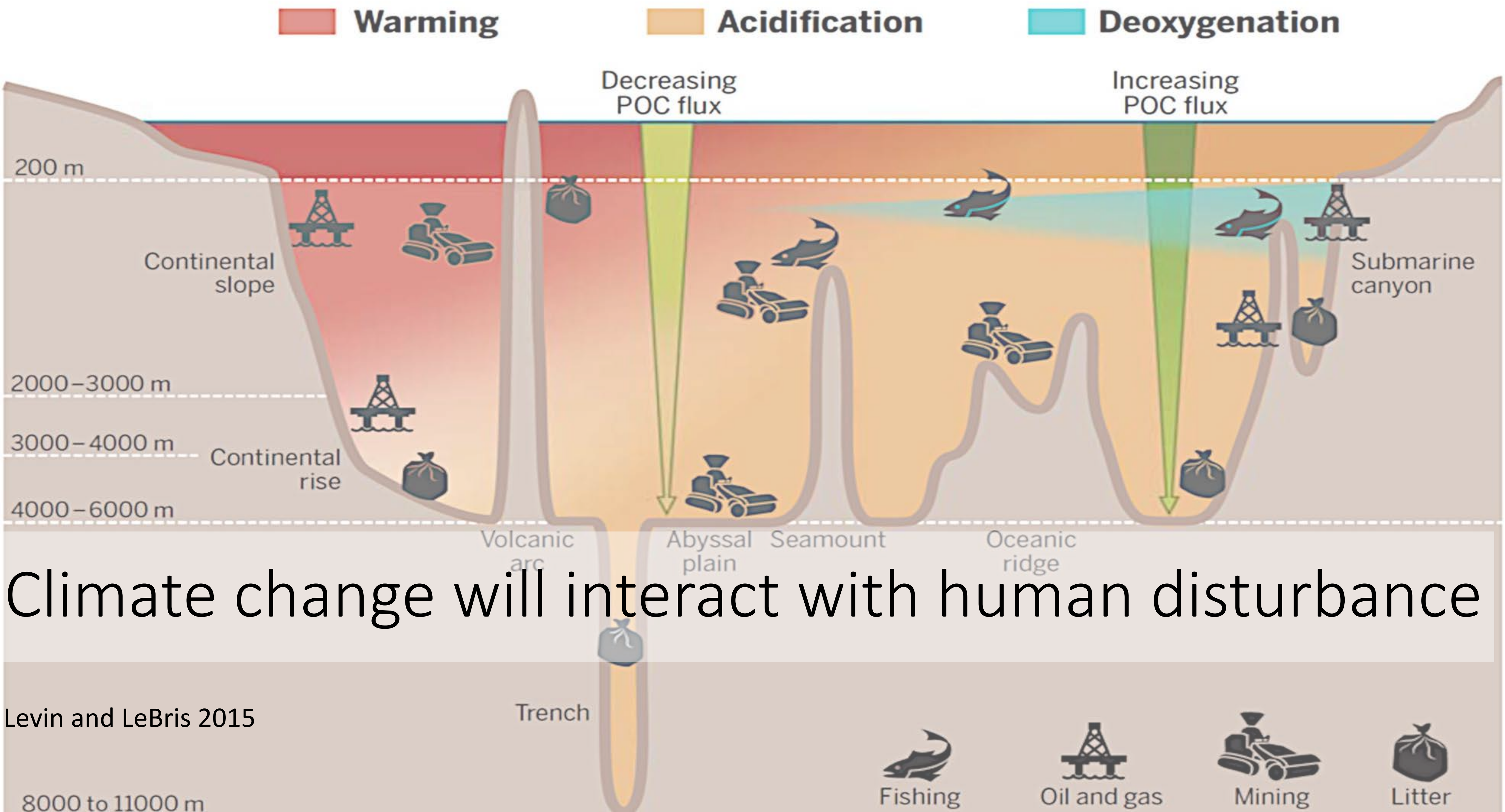
Cucalón-Zenck

Individuals
- Respiratory distress
- Auditory distress
- Reduced feeding
- Reduced visual communication
- Buoyancy issues
- Toxicity

Populations
- Changes in community composition
- Emigration
- Mortality
- Decreased fitness/reproduction

Ecosystem Services
- Fisheries
- Seafood contamination
- Carbon transport
- Biodiversity

Climate change will interact with human disturbance

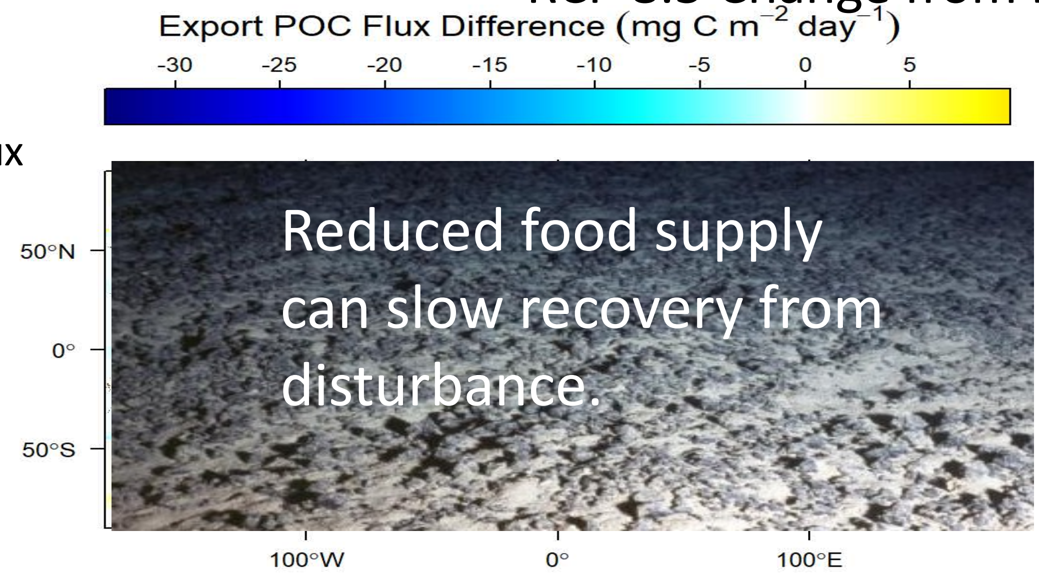


Levin and LeBris 2015

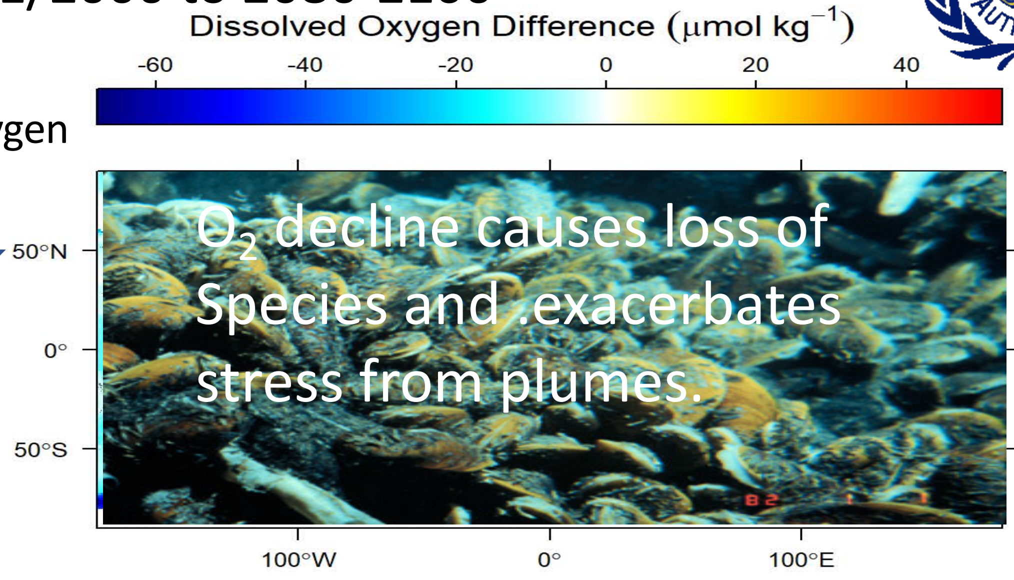
Climate Change, resilience and Carbon

RCP 8.5 Change from 1951/2000 to 2080-2100

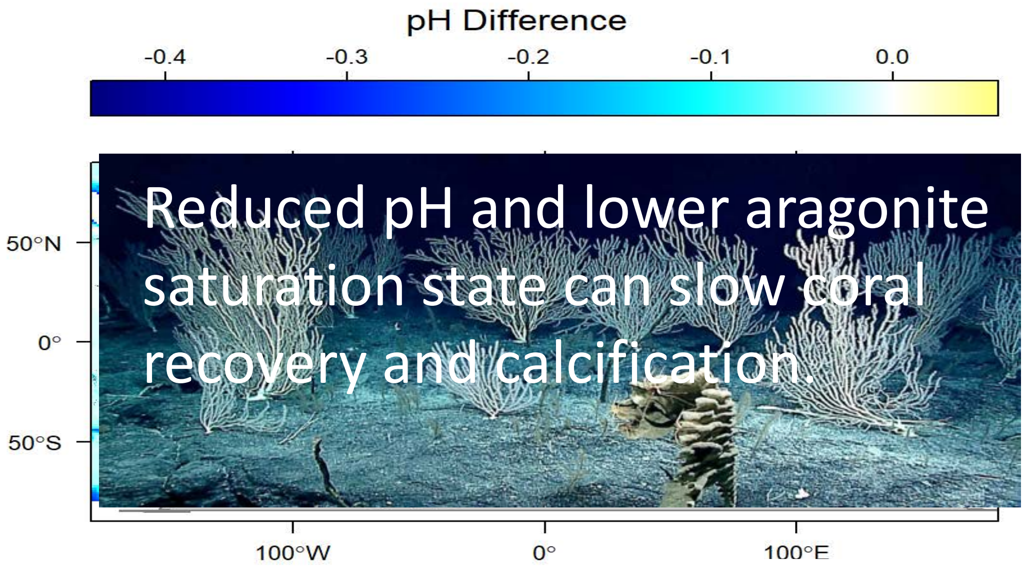
POC flux



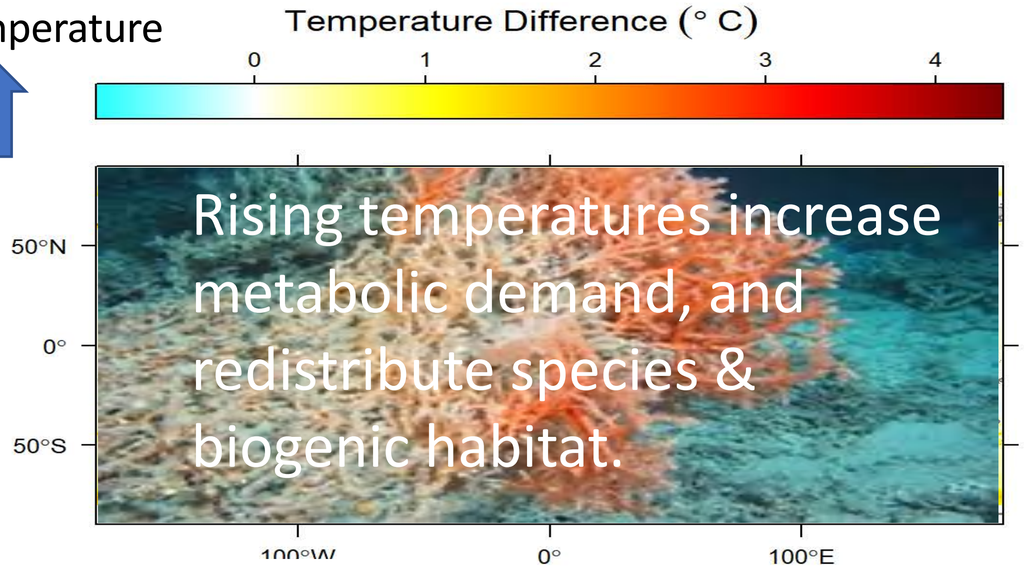
Oxygen



pH

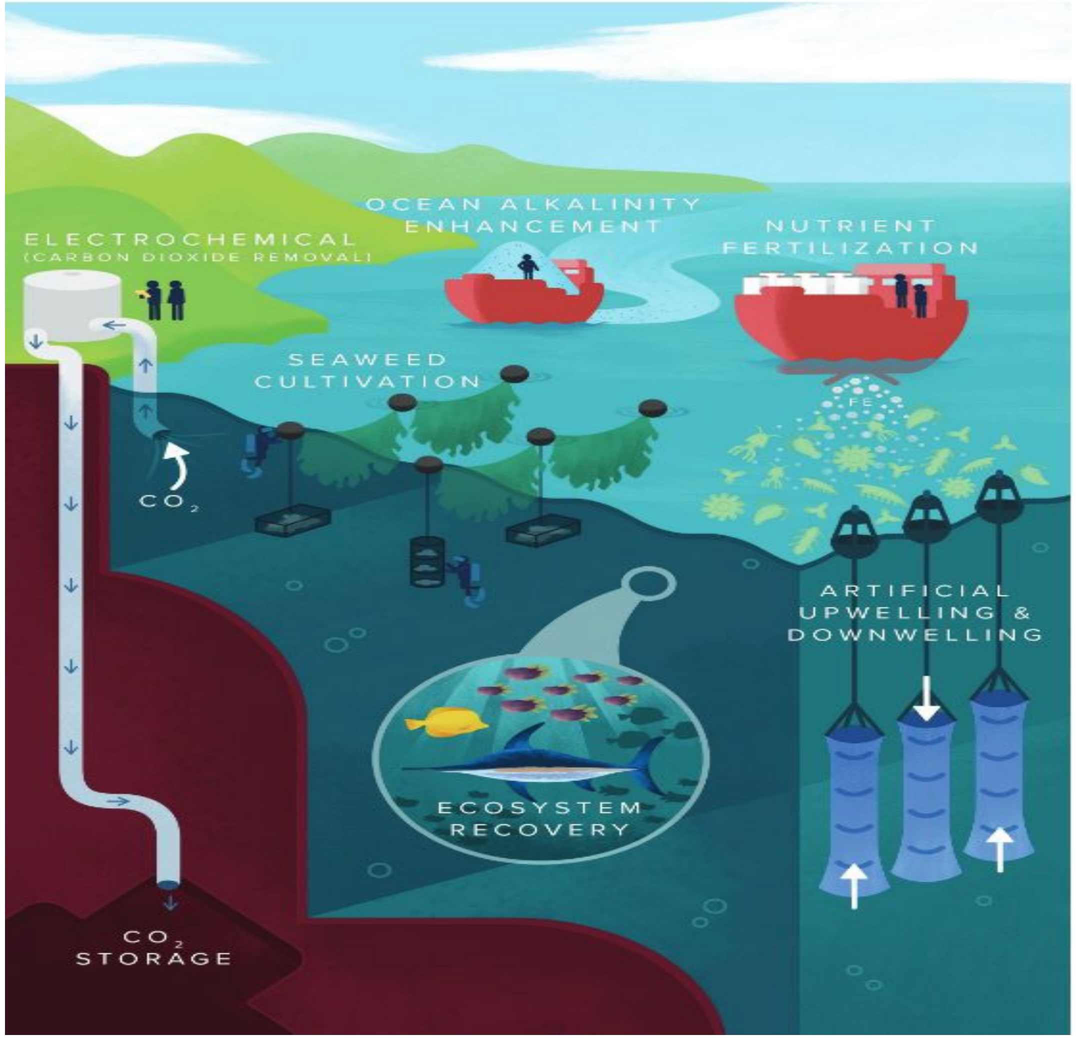


Temperature



Sweetman et al. 2017; FAO 2019

Marine Carbon Dioxide Removal



APRIL 11, 2024 | 4 MIN READ

The U.S. Will Need to Spend $100 Billon a Year on Carbon Removal

The U.S. needs to vastly increase taxpayer spending on direct carbon removal technology to meet President Biden's climate goals, the Rhodium Group says

BY CORBIN HIAR & E&E NEWS

Ocean Visions & Esri Unveil New Tool For Ocean Iron Fertilization (OIF) Planning

by Violet George · April 11, 2024 · 3 minute read

NEWS | CLIMATE

Startups aim to curb climate change by pulling carbon dioxide from the ocean—not the air

Schemes to use renewable energy to process seawater may be cheaper and easier than air capture

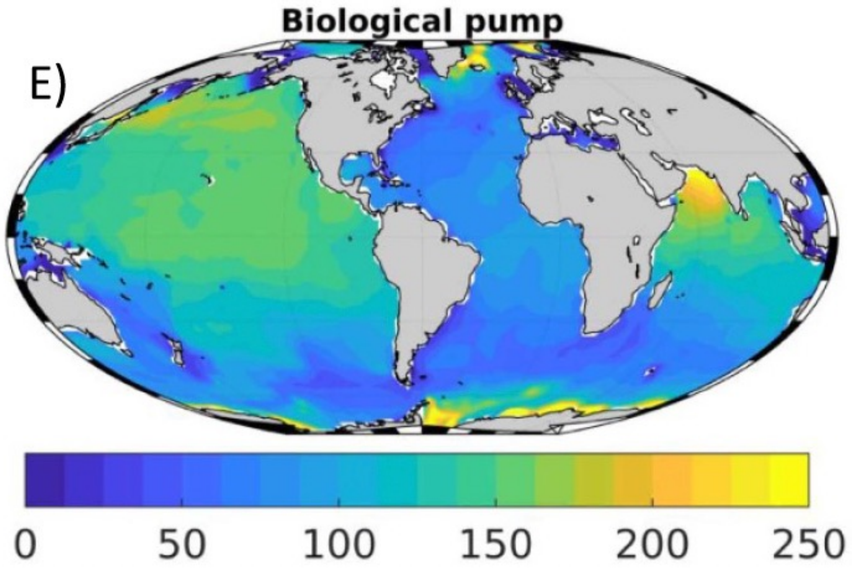
26 MAR 2024 · 5:35 PM ET · BY ROBERT F. SERVICE

Enhancing natural carbon fluxes? Or disrupting the carbon cycle?

The Deep Ocean is the disposal target…. But how deep?

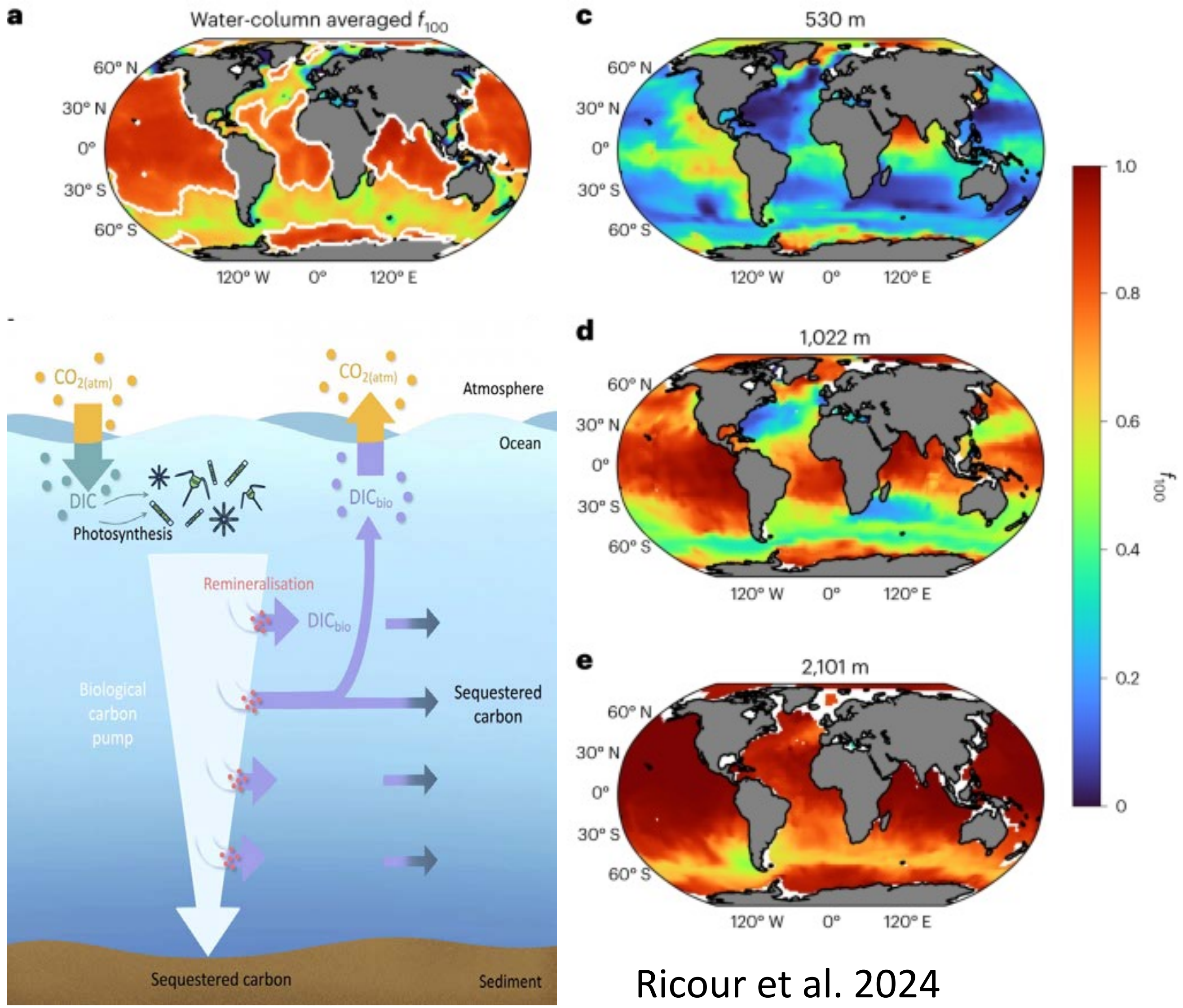
Waters below 1000 m are targeted because carbon can stay out of the atmosphere for > 100 years

Siegel et al. 2021
Env. Res. Letters



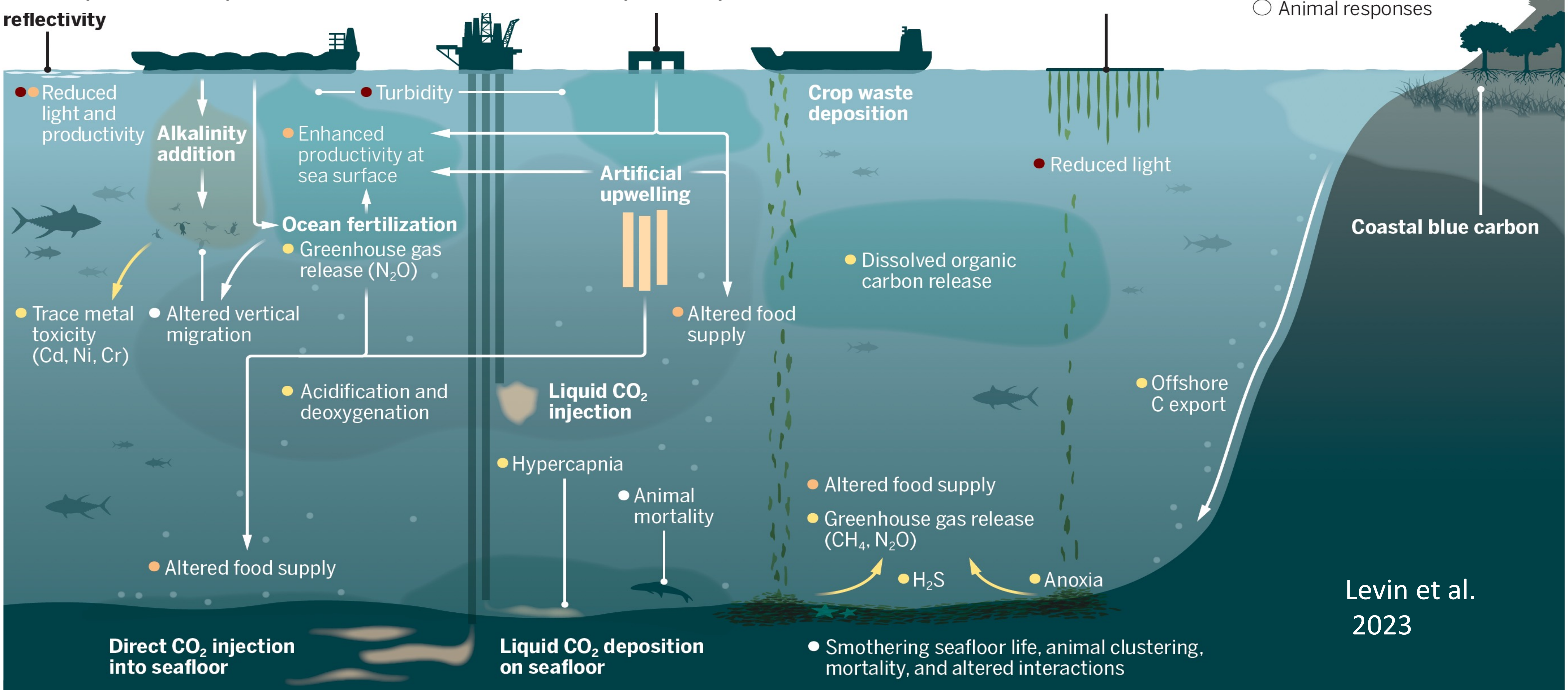
Carbon Residence Time (yr)
varies with Ocean Basin & Water Depth

100-year sequestration..



Ricour et al. 2024

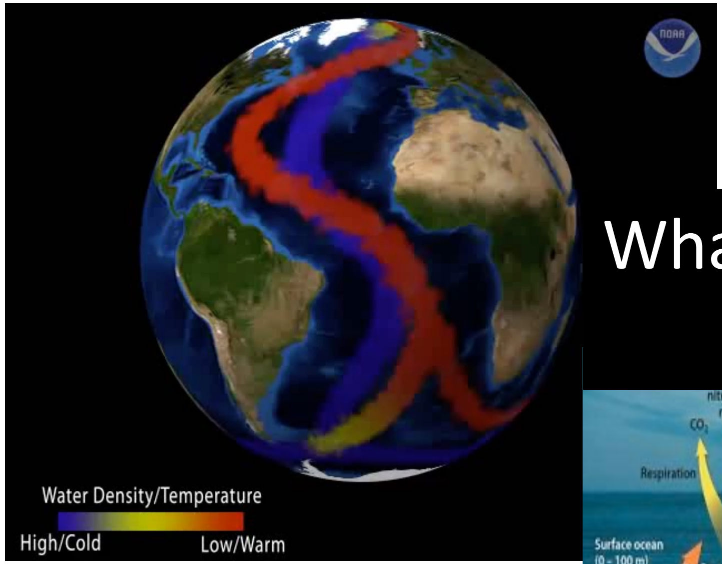
Marine climate interventions (mCDR) will alter deep ecosystems & carbon cycle processes



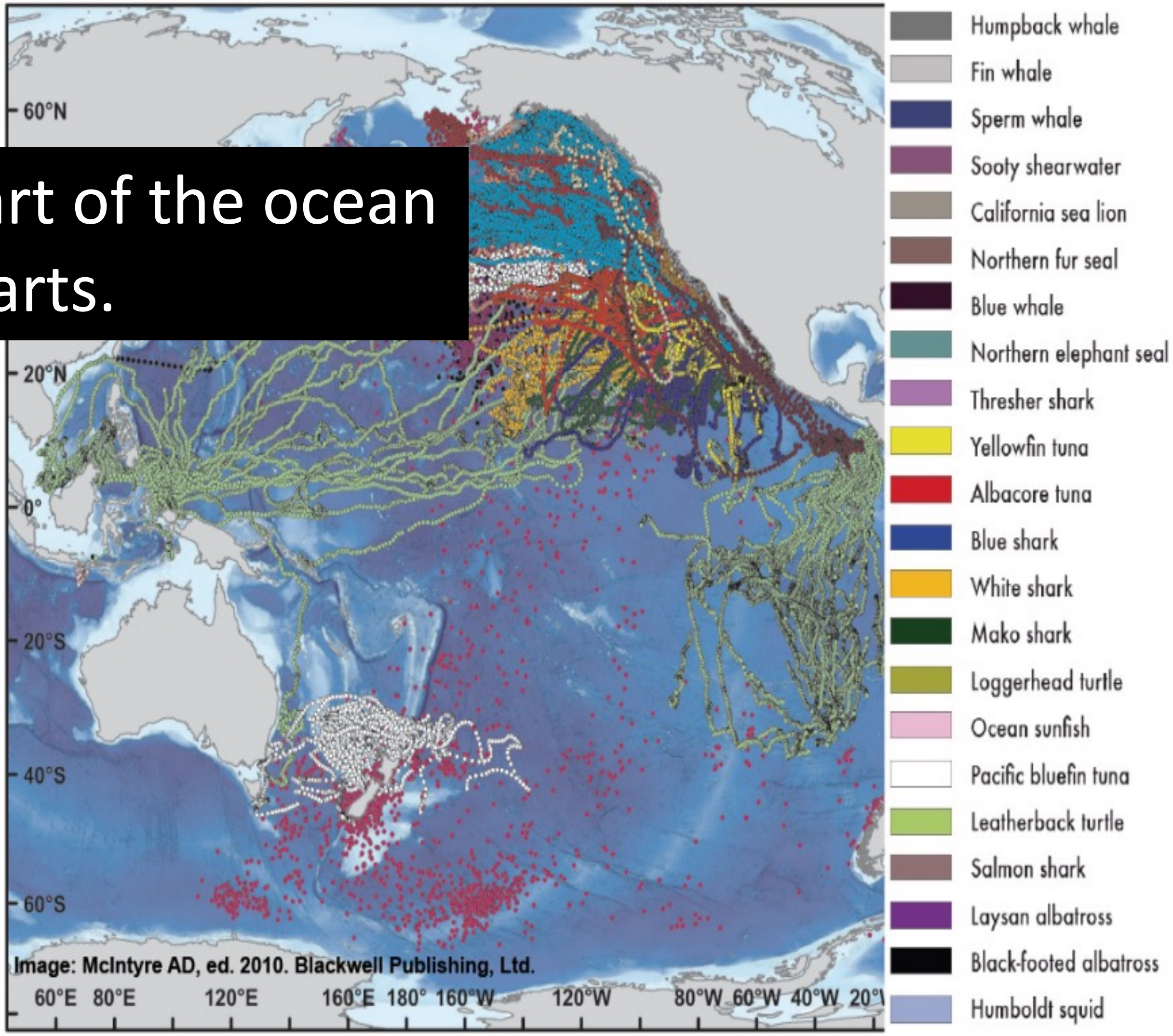
Science can help evaluate effectiveness, location, depth & associated impacts of ocean carbon dioxide removal interventions

Science has revealed that the ocean is highly connected!

Thermohaline Circulation

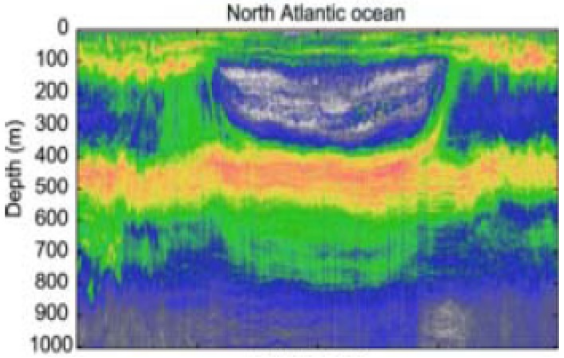


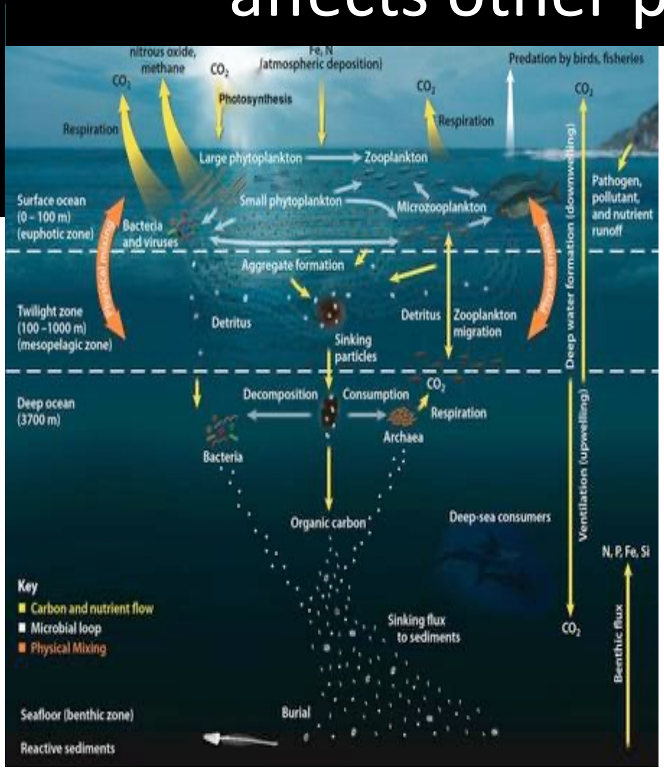
Animal migrations:
whales, sea lions, tuna, turtles, sharks, albatross, squid



What we do in one part of the ocean affects other parts.

Vertical Migration





DOI: 10.1111/gcb.16854

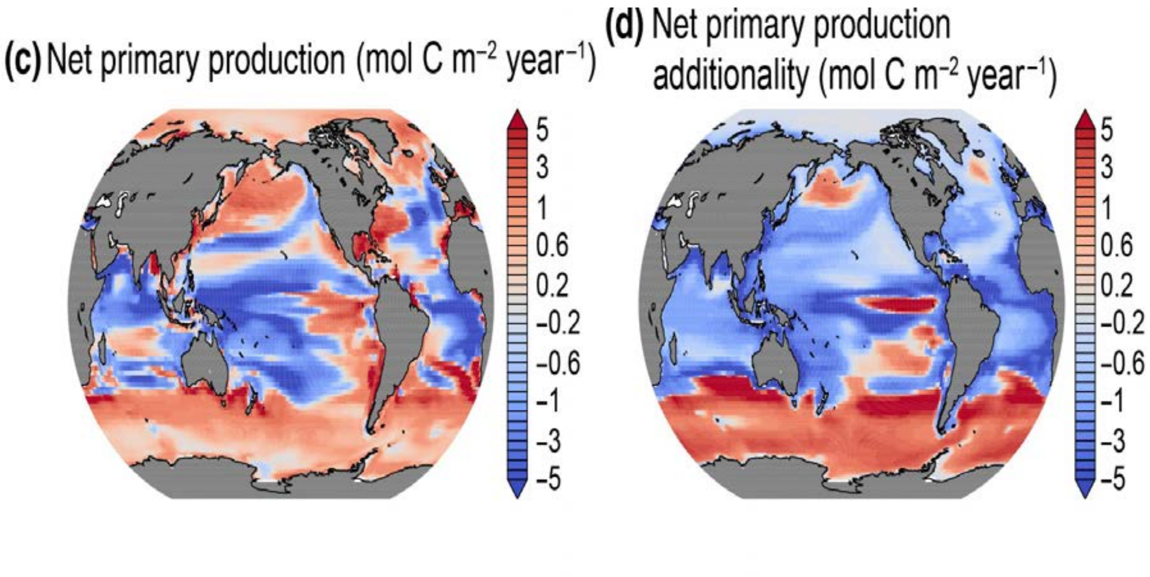
RESEARCH ARTICLE

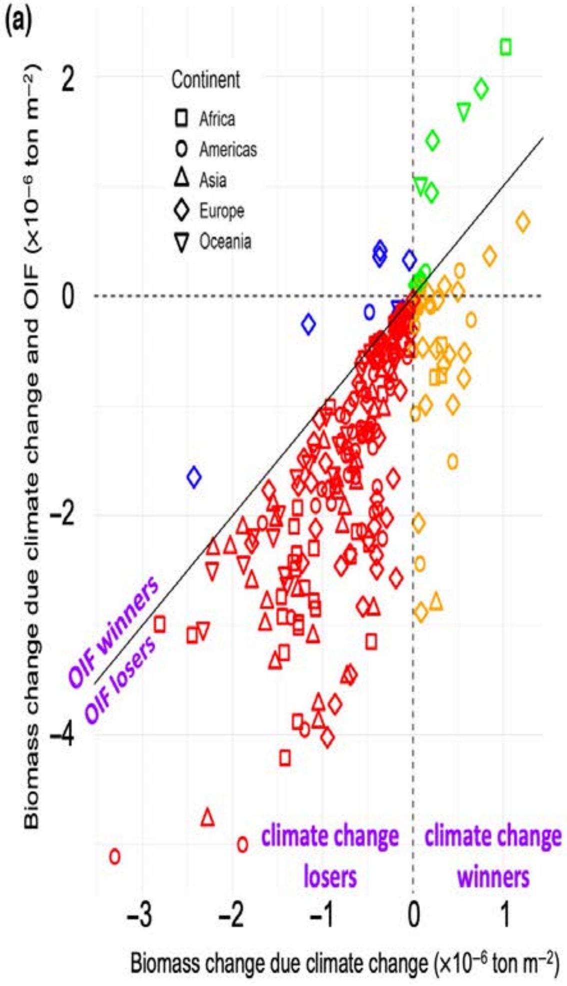
Global Change Biology WILEY

Ocean iron fertilization may amplify climate change pressures on marine animal biomass for limited climate benefit

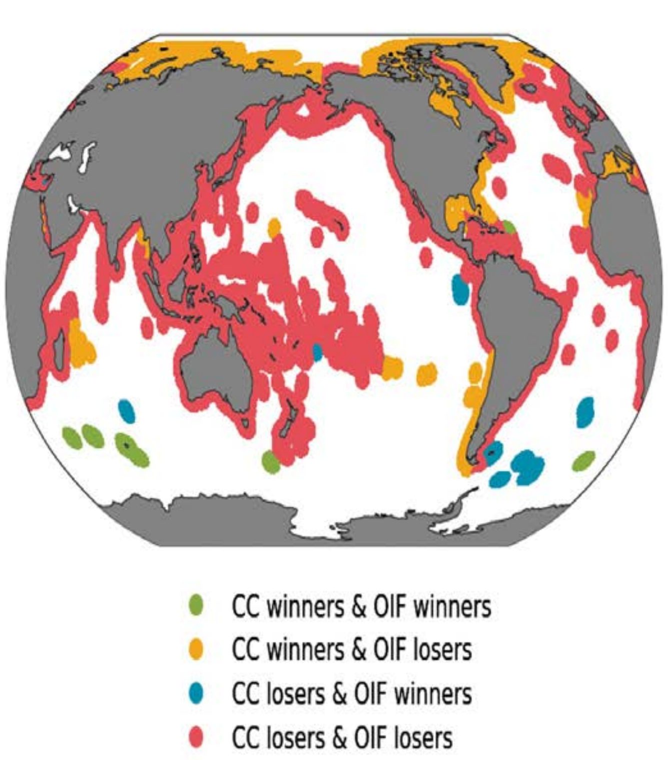
Alessandro Tagliabue[1] | Benjamin S. Twining[2] | Nicolas Barrier[3] | Olivier Maury[3] | Manon Berger[4] | Laurent Bopp[4]

Iron fertilization may amplify negative effects of climate Change on productivity and fisheries in the tropics.
Only a few countries will benefit and many will loose



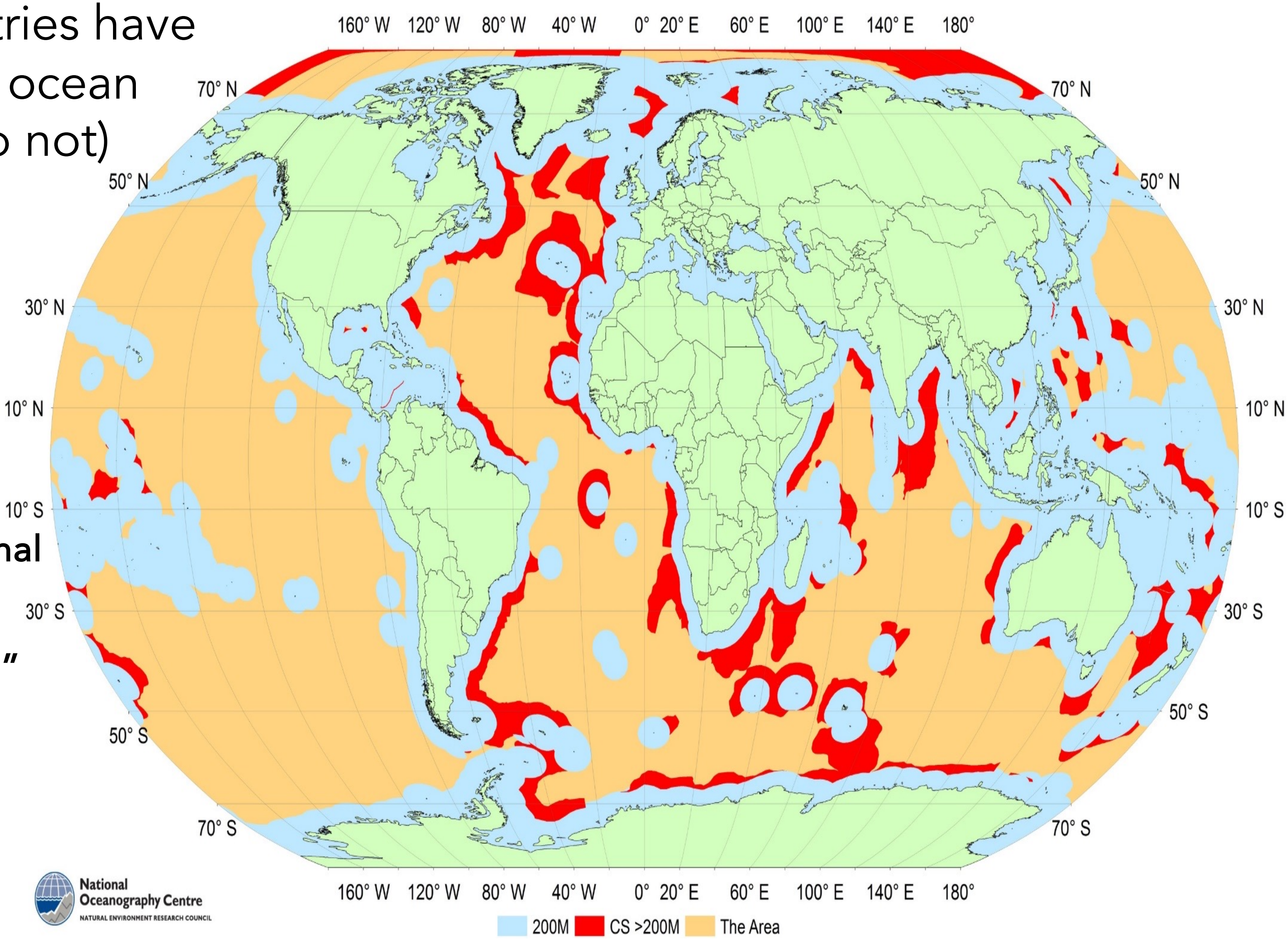


(b) Change in animal biomass in EEZs



Governance - Who owns the ocean?
Most is deep sea!

154 countries have coastal ocean (48 do not)

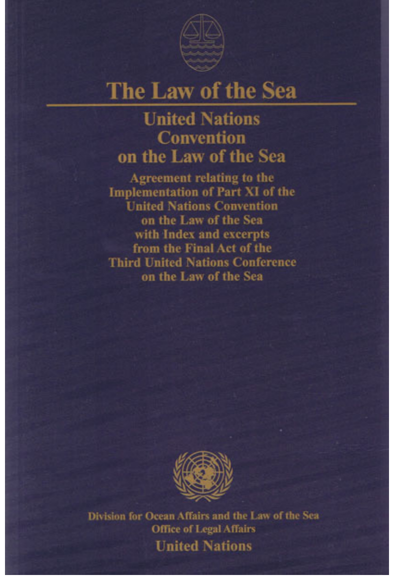


National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

International

Seabed = "The Area" (ISA)

Water = High Seas (FAO)



UN Convention on Law of the Sea

36% **Exclusive Economic Zones (EEZ)**
75% >200 m

4% **Extended Continental shelf**

60% **Area Beyond National Jurisdiction (ABNJ)**
96%>200 m
85%>2000 m

Complex management of the International Ocean
The Alphabet Soup of High Seas & Deep Sea Governance

Sea floor and Water column are separate jurisdictions!

BIODIVERSITY

FISHERIES

MINING

POLLUTION

CLIMATE

SCIENCE

CONSERVATION

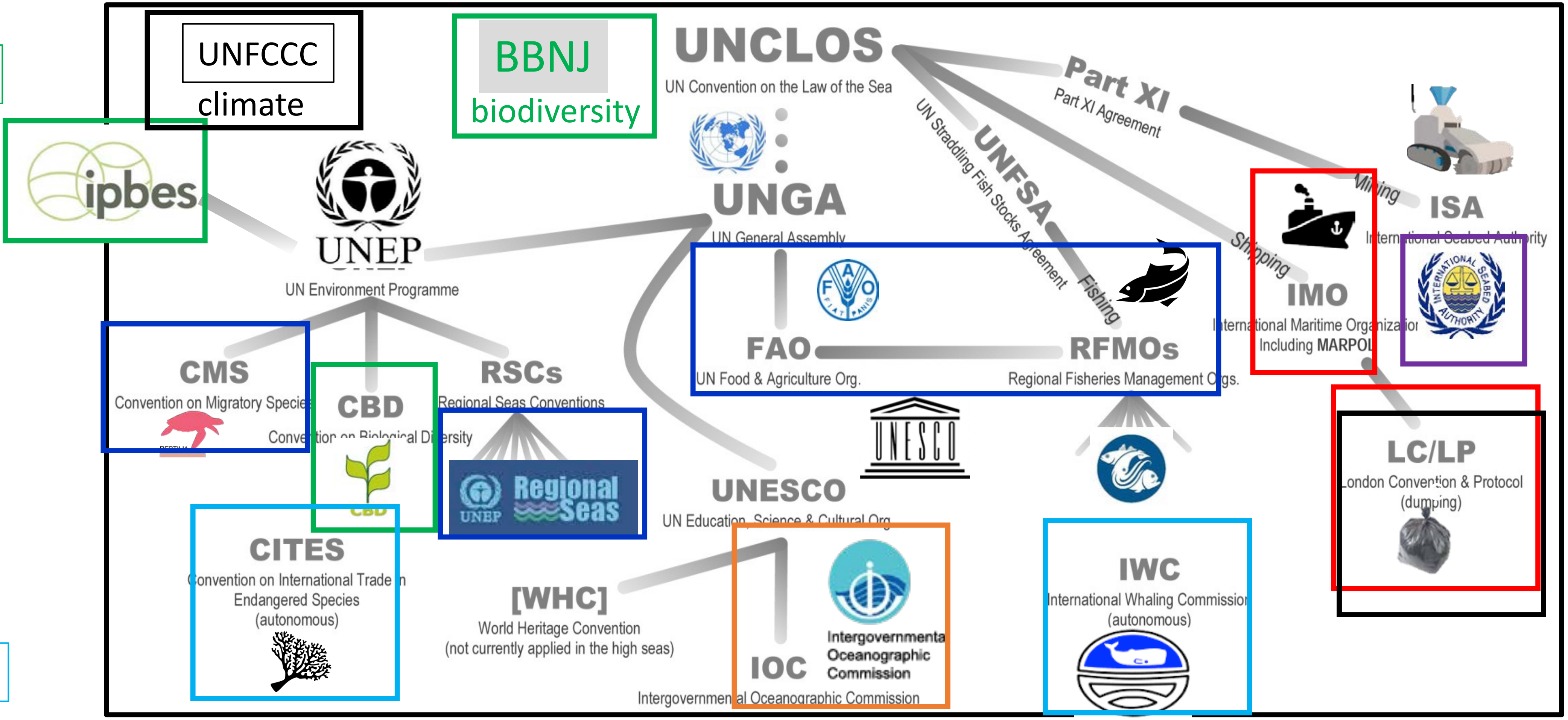
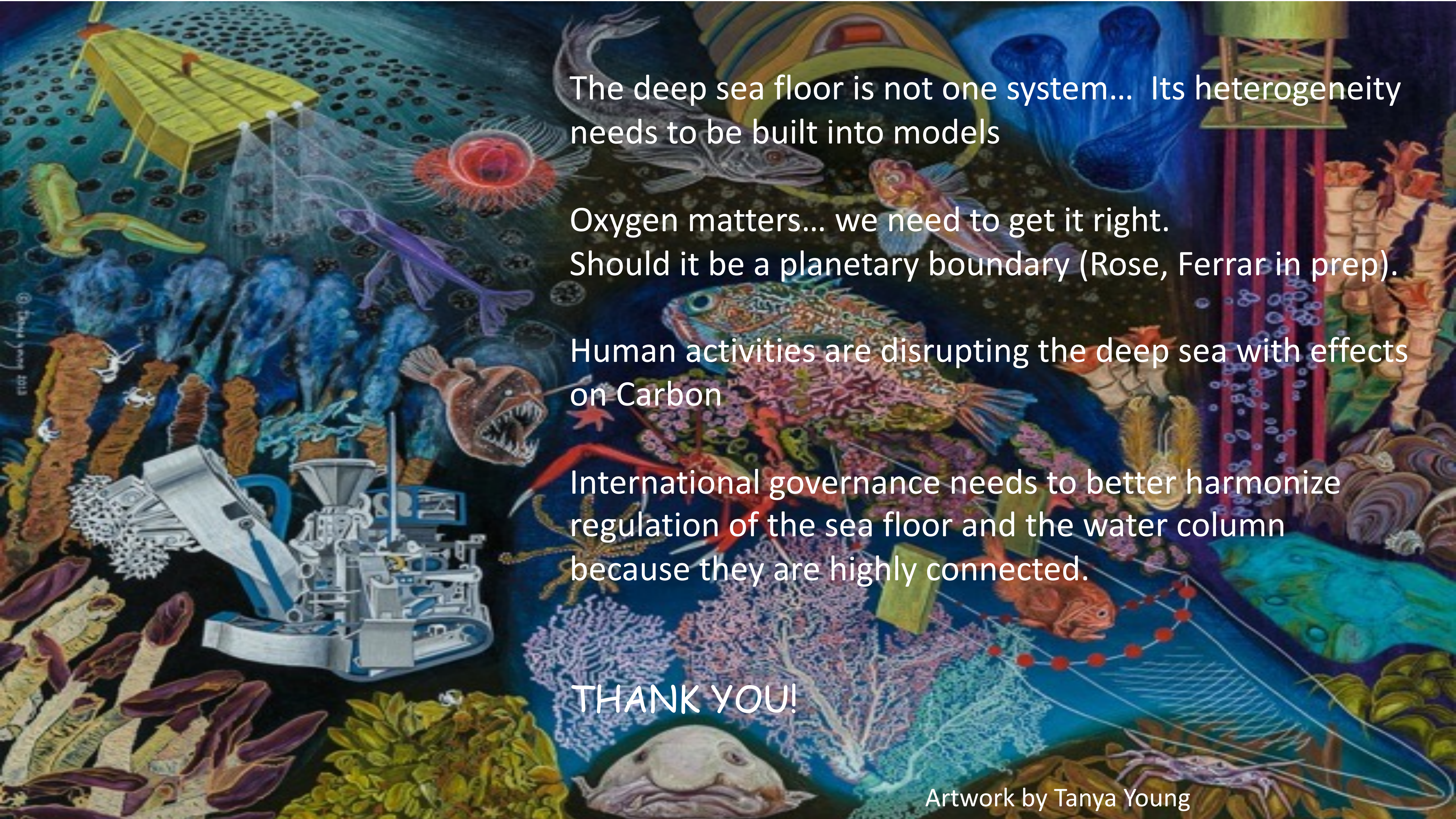


Figure from chapter by Ardron & Warner, in Handbook of Ocean Resources, Earthscan Books



The deep sea floor is not one system… Its heterogeneity needs to be built into models

Oxygen matters… we need to get it right.
Should it be a planetary boundary (Rose, Ferrar in prep).

Human activities are disrupting the deep sea with effects on Carbon

International governance needs to better harmonize regulation of the sea floor and the water column because they are highly connected.

THANK YOU!

Artwork by Tanya Young

Bentho-Pelagic Coupling Under Climate Change and Other Human Disturbances

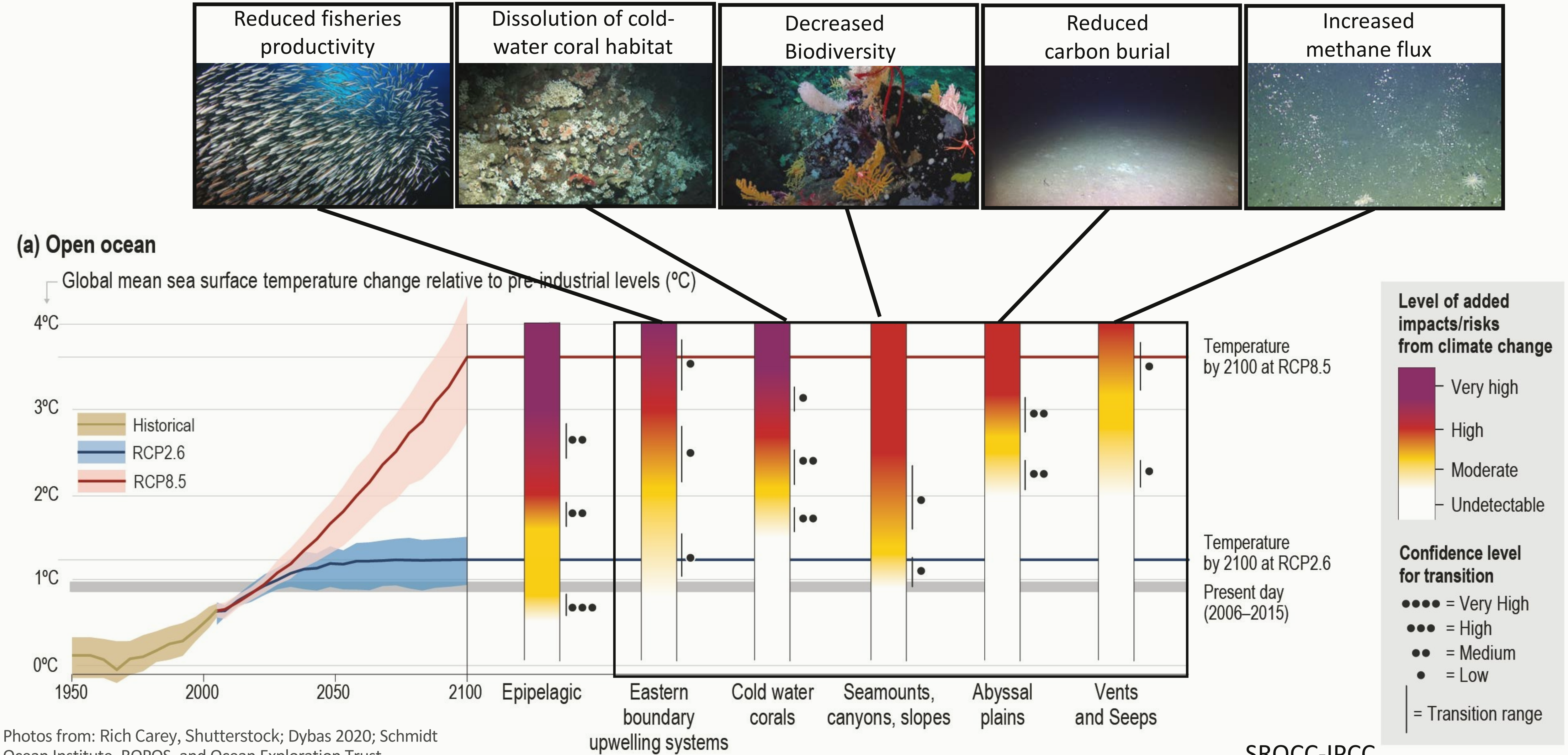
ABSTRACT:

This presentation will discuss how deep-sea biodiversity underpins the carbon cycle, and the importance of seafloor heterogeneity and forms of pelagic-benthic interactions that are involved. Continental margins play an outsized role in carbon sequestration, and climate change has major consequences for deep ecosystems on margins. Deoxygenation in particular can alter carbon flux to the sea floor. Additionally, human activities on the seabed, such as bottom trawling, energy extraction, seabed mining and ocean—based climate interventions, can act to disrupt the carbon cycle and carbon services provided by biodiversity. Finally, I will discuss how disjunct governance of the water column and seabed creates challenges in management and conservation from a carbon conservation perspective.

Risk Scenarios for the Deep Sea from Cumulative Climate Stressors (Warming, Deoxygenation, Acidification)

(not including potential compounded impacts from direct human impacts from extraction, mCDR, etc.)

Courtesy
S. Seabrook



Photos from: Rich Carey, Shutterstock; Dybas 2020; Schmidt Ocean Institute, ROPOS, and Ocean Exploration Trust

SROCC-IPCC