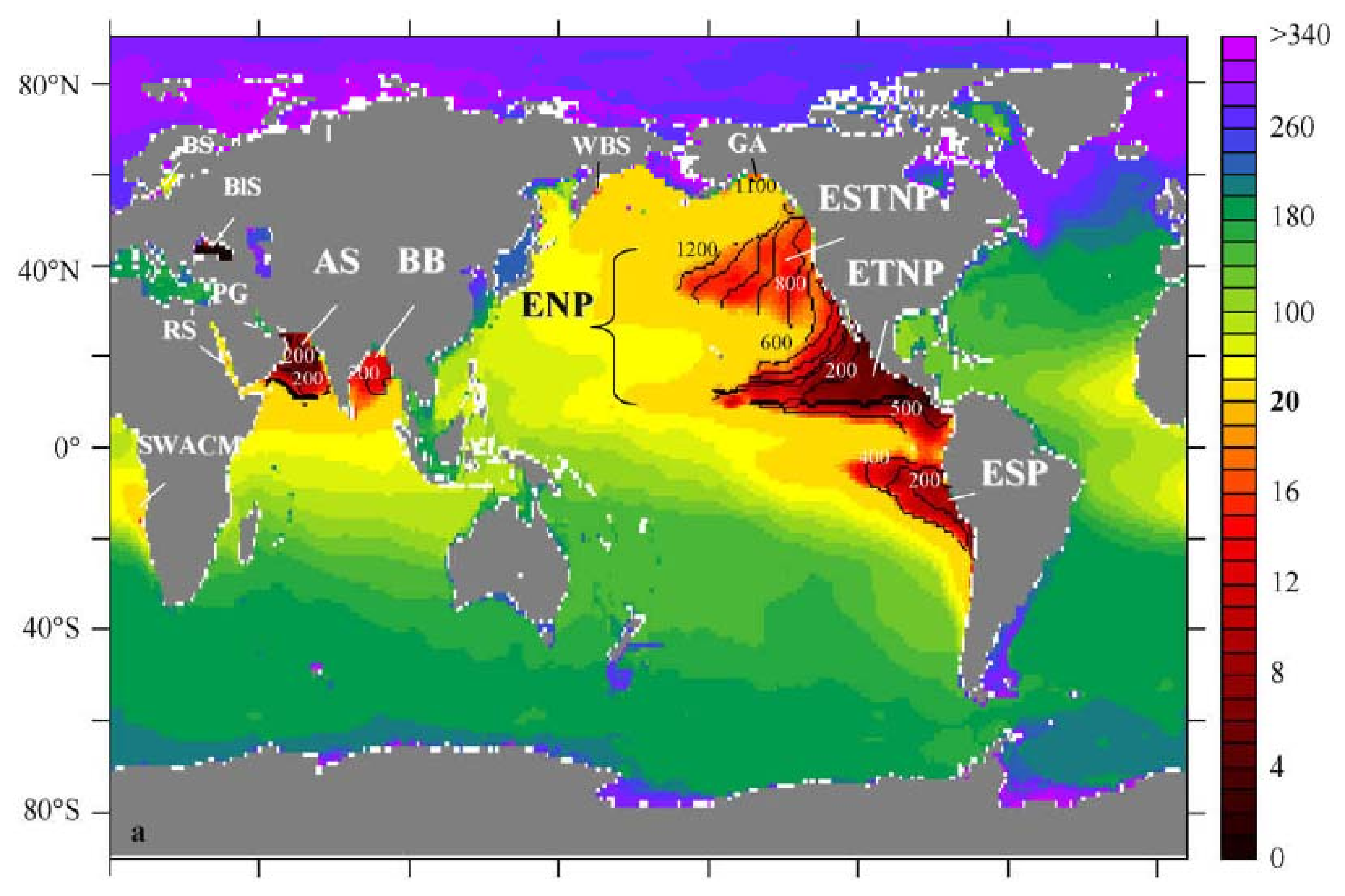
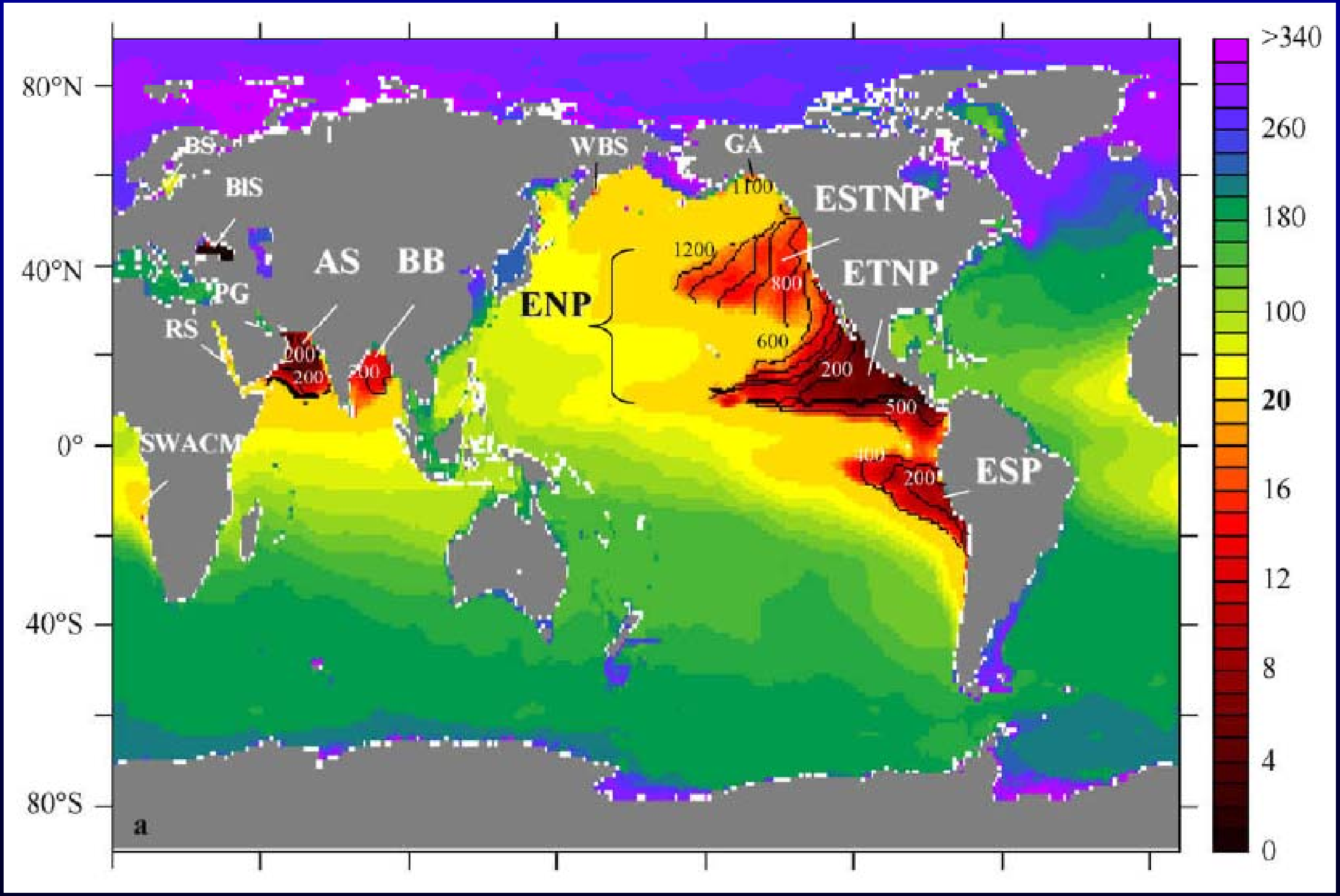
Low Oxygen Regions of the World's O



OCB Summer Workshop 2010

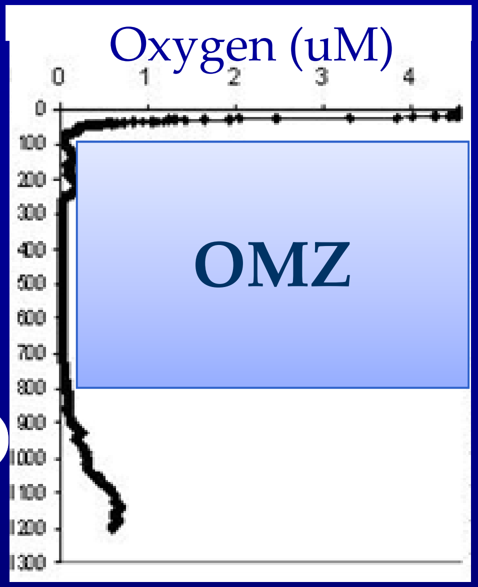
Paulmier & Ruiz-Pino (2009)

Permanent OMZs (O_2 < 20 μmol kg^{-1}) are ~ 8% of the World's Ocean by Surface Area



Paulmier & Ruiz-Pino (2009)

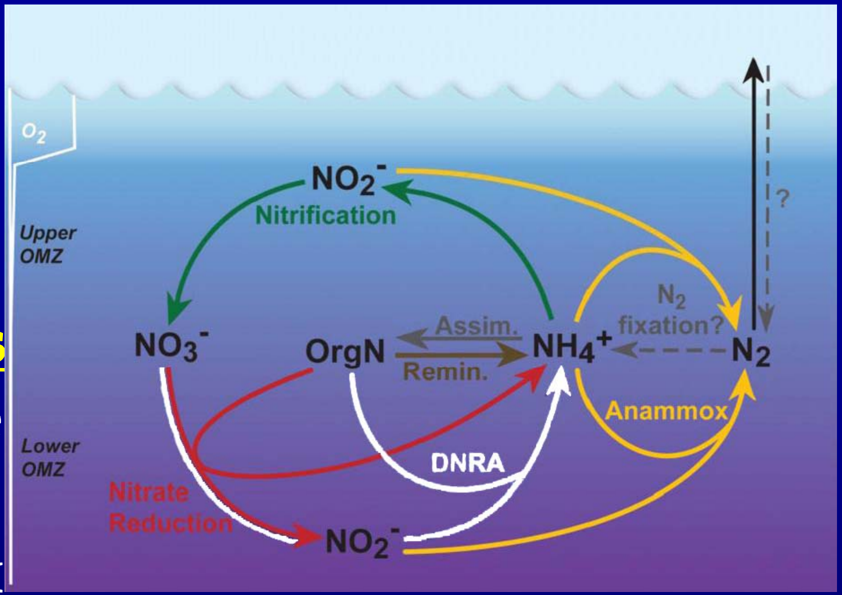
Characteristics of OMZs



- Oceanic regions with low midwater O_2
- Strong vertical oxygen gradients (oxyclines) structure biological assemblages and biogeochemical processes
- Chemolithoautotrophy is a source of new C in OMZs
- OMZs alter the oceanic biological sequestration of CO_2

Characteristics of OMZs

Nitrogen Cycle



Lam et al.

- Interplay of microbial processes and the N cycle. In suboxic zone denitrification (NO_3 as primary electron acceptor) and anammox (anaerobic ammonia oxidation) are the major remineralization pathways (instead of aerobic remineralization)

- OMZs are primary areas of nitrogen loss (as N_2, N_2O) flux to the atmosphere through denitrification and anammox.

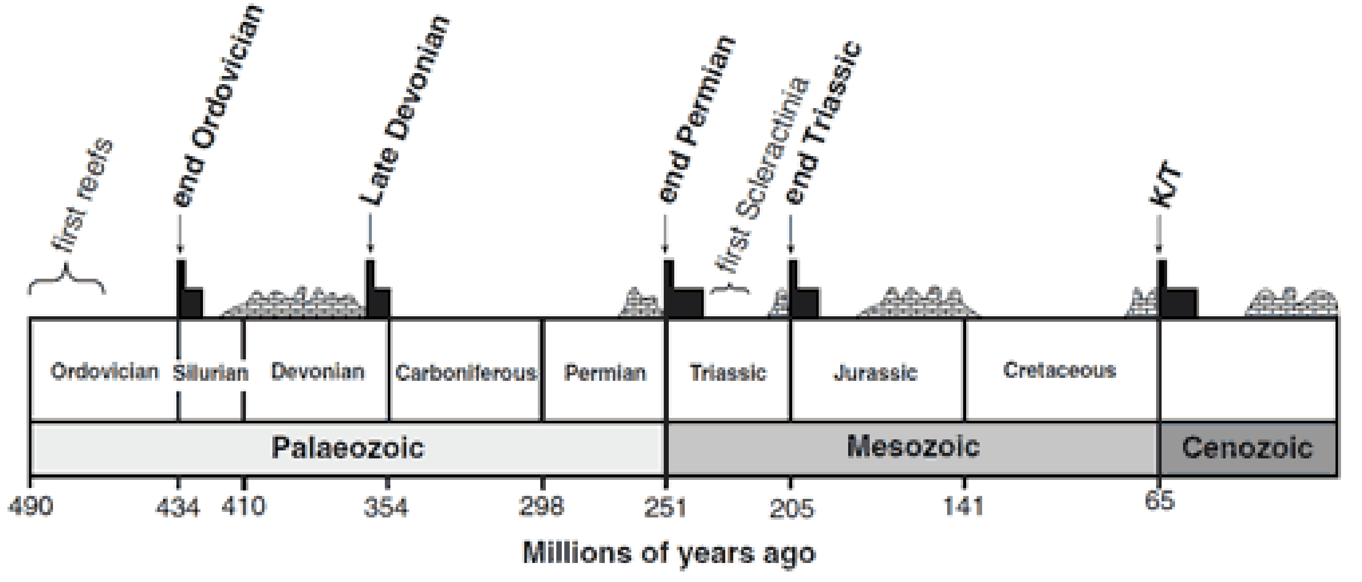
- The role of N_2 fixation is being debated.

The Deep Past

- OMZs have contracted and expanded during cold and warm periods and widespread anoxia has occurred over the Earth's geological history.
- The anoxic and low pH ocean at the end of the Permian was associated with elevated atmospheric CO_2 and massive extinctions on land and sea.

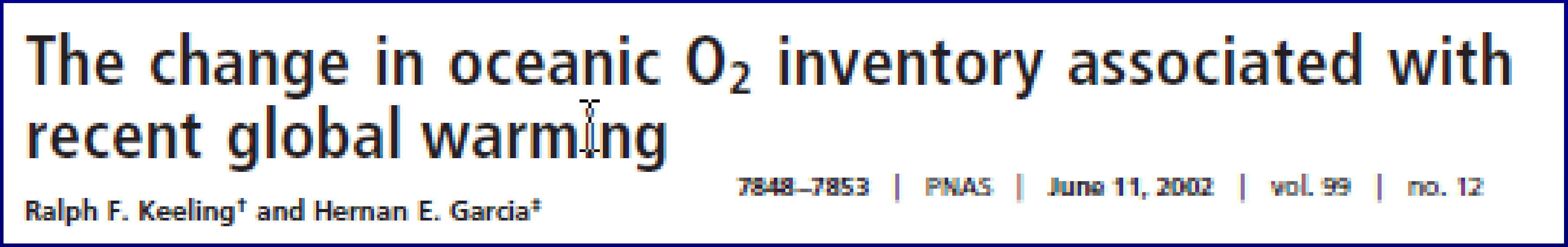
Mass Extinction Events

(Vernon 2008)



Today

In situ observations document decreased O_2 levels in many regions of the ocean.



The change in oceanic O_2 inventory associated with recent global warming

7848–7853 | PNAS | June 11, 2002 | vol. 99 | no. 12

Ralph F. Keeling[†] and Hernan E. Garcia[‡]

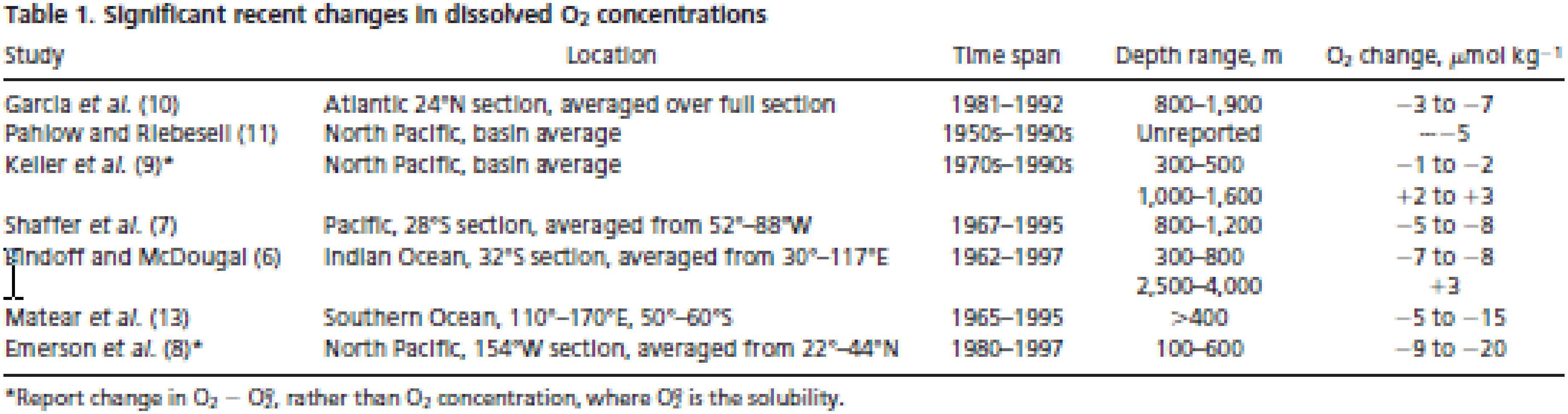


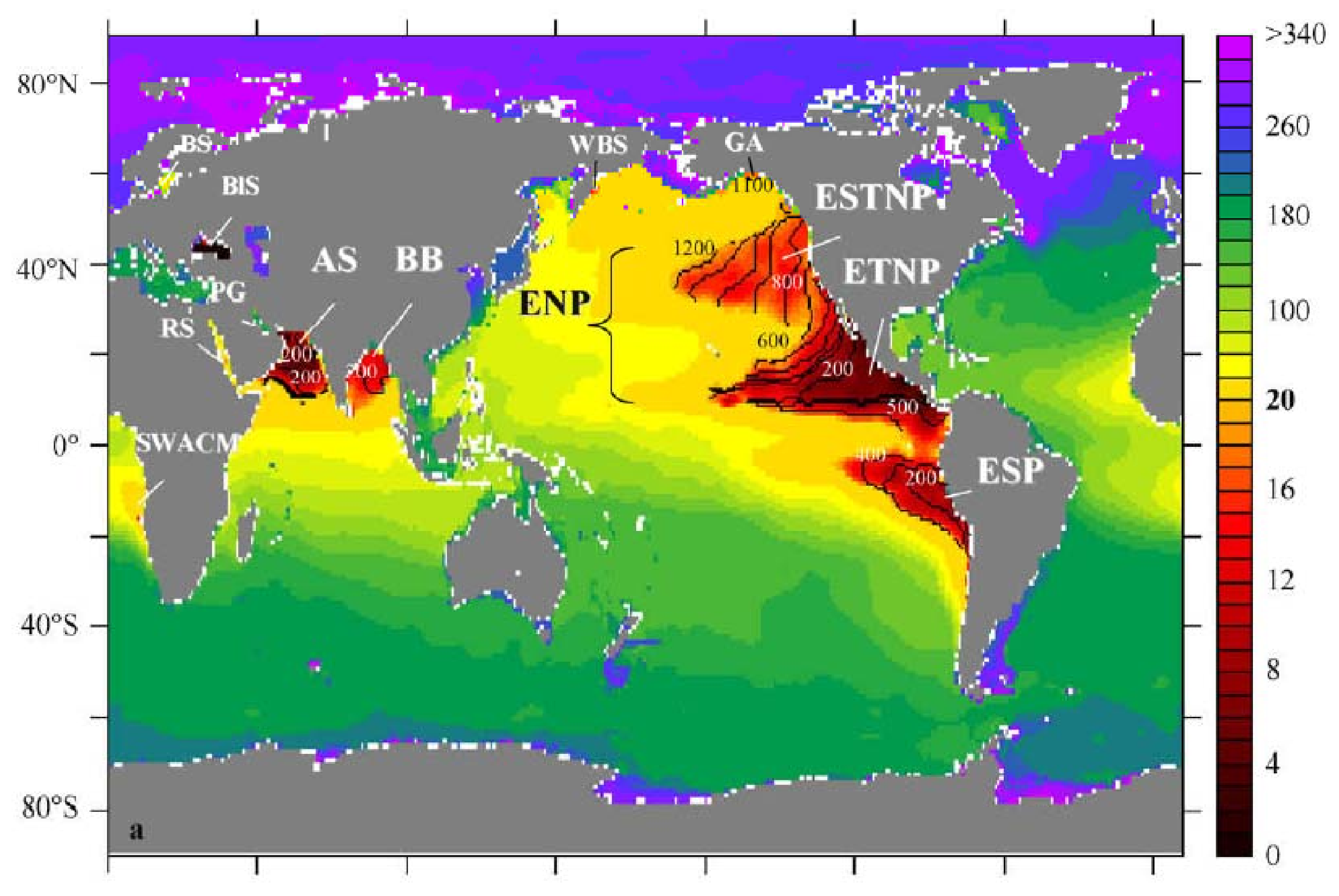
Table 1. Significant recent changes in dissolved O_2 concentrations

Study	Location	Time span	Depth range, m	O_2 change, μmol kg^{-1}
Garcia *et al.* (10)	Atlantic 24°N section, averaged over full section	1981–1992	800–1,900	−3 to −7
Pahlow and Riebesell (11)	North Pacific, basin average	1950s–1990s	Unreported	∼−5
Keller *et al.* (9)*	North Pacific, basin average	1970s–1990s	300–500	−1 to −2
			1,000–1,600	+2 to +3
Shaffer *et al.* (7)	Pacific, 28°S section, averaged from 52°–88°W	1967–1995	800–1,200	−5 to −8
Bindoff and McDougal (6)	Indian Ocean, 32°S section, averaged from 30°–117°E	1962–1997	300–800	−7 to −8
			2,500–4,000	+3
Matear *et al.* (13)	Southern Ocean, 110°–170°E, 50°–60°S	1965–1995	>400	−5 to −15
Emerson *et al.* (8)*	North Pacific, 154°W section, averaged from 22°–44°N	1980–1997	100–600	−9 to −20

*Report change in $O_2 - O_2^s$, rather than O_2 concentration, where O_2^s is the solubility.

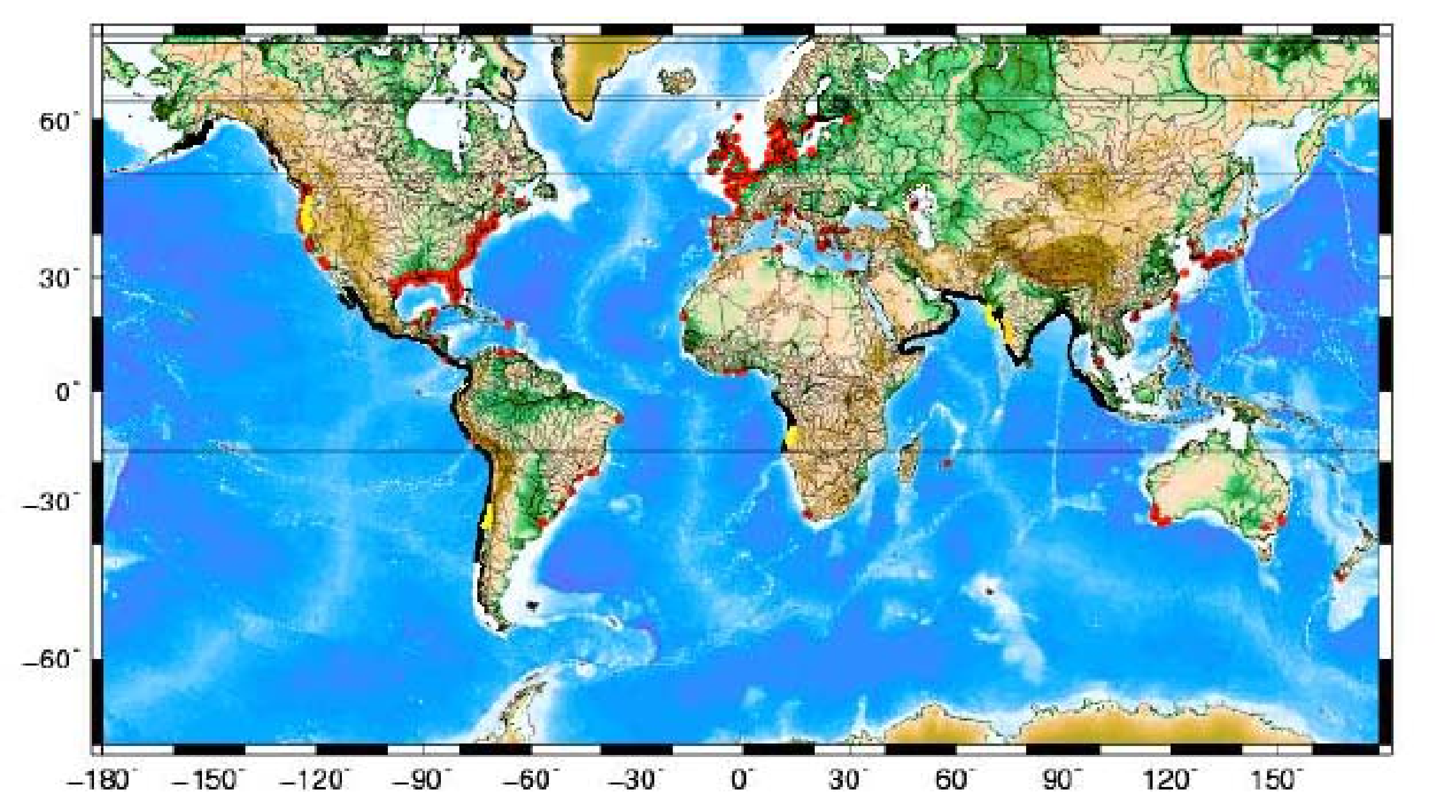
The Specter of Expanding OMZs: Habitat Compression and the Biological Pump

Kendra Daly (USF)



Paulmier & Ruiz-Pino (2009)

The Spector of Expanding OMZs: Benthic and Breathless - Lisa Levin (Scripps)

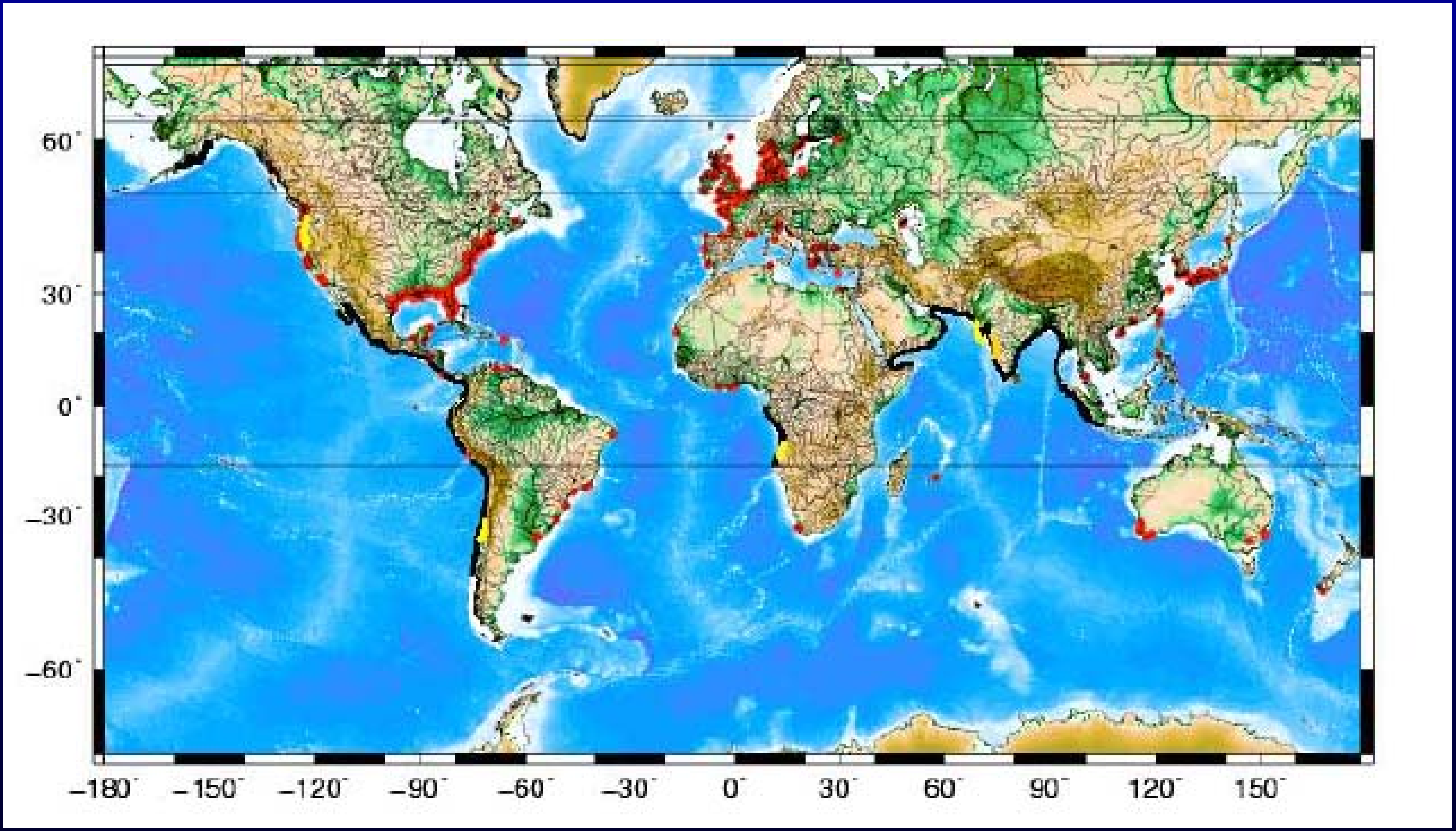


OMZs are important features on the eastern margins of ocean basins and in the northern Indian Ocean

World distribution of coastal hypoxia. Eutrophication-induced coastal hypoxia (red), <u>outer shelf (200 m) hypoxia (black),</u> and inner shelf hypoxia (yellow).

Levin et al. 2009. Biogeosciences 6

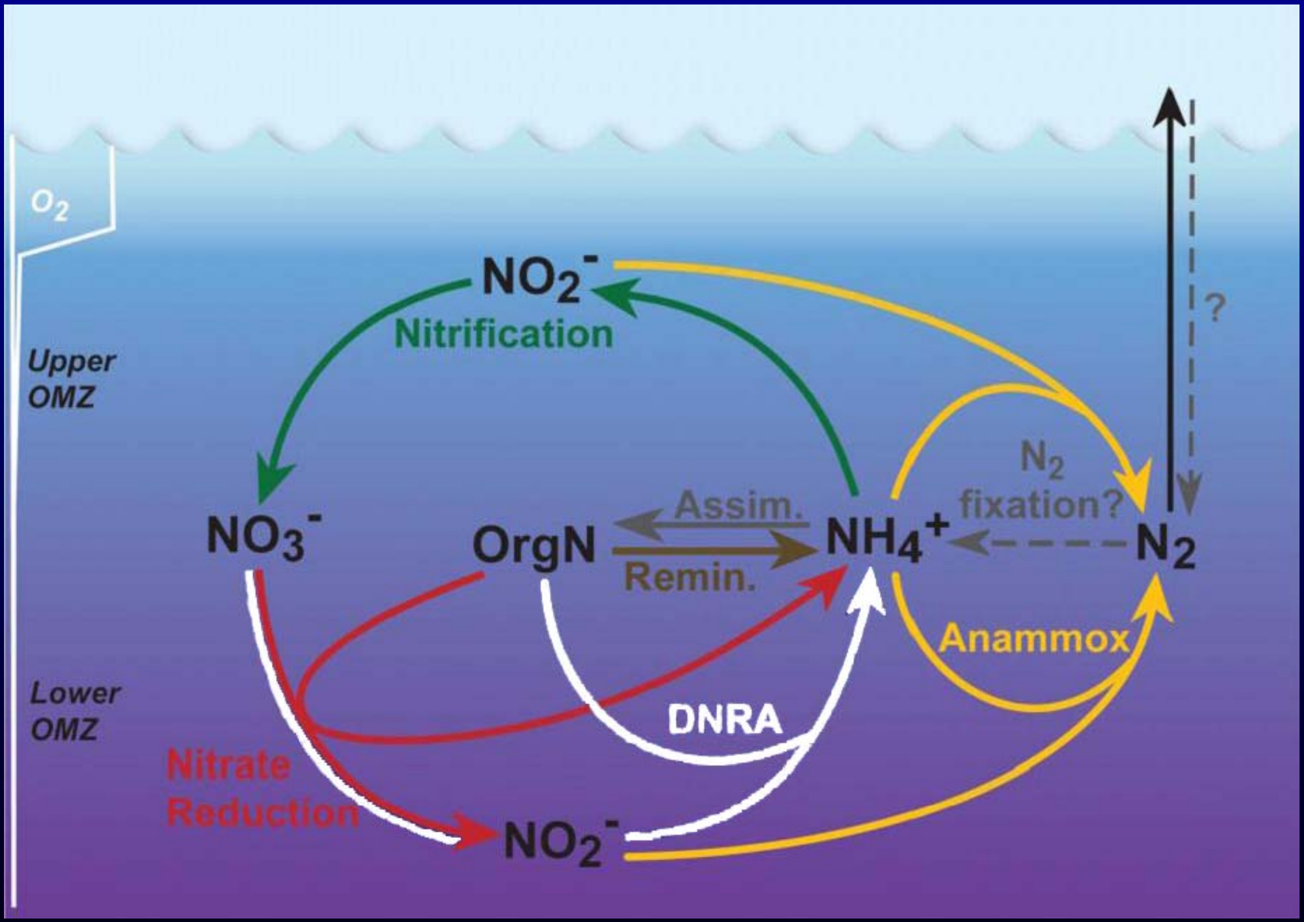
Eutrophication, Coastal Hypoxia, Carbon, and Climate
Nancy Rabalais (LUMCON)



Eutrophication-induced coastal hypoxia (red), outer shelf (200 m) hypoxia (black), and inner shelf hypoxia (yellow).

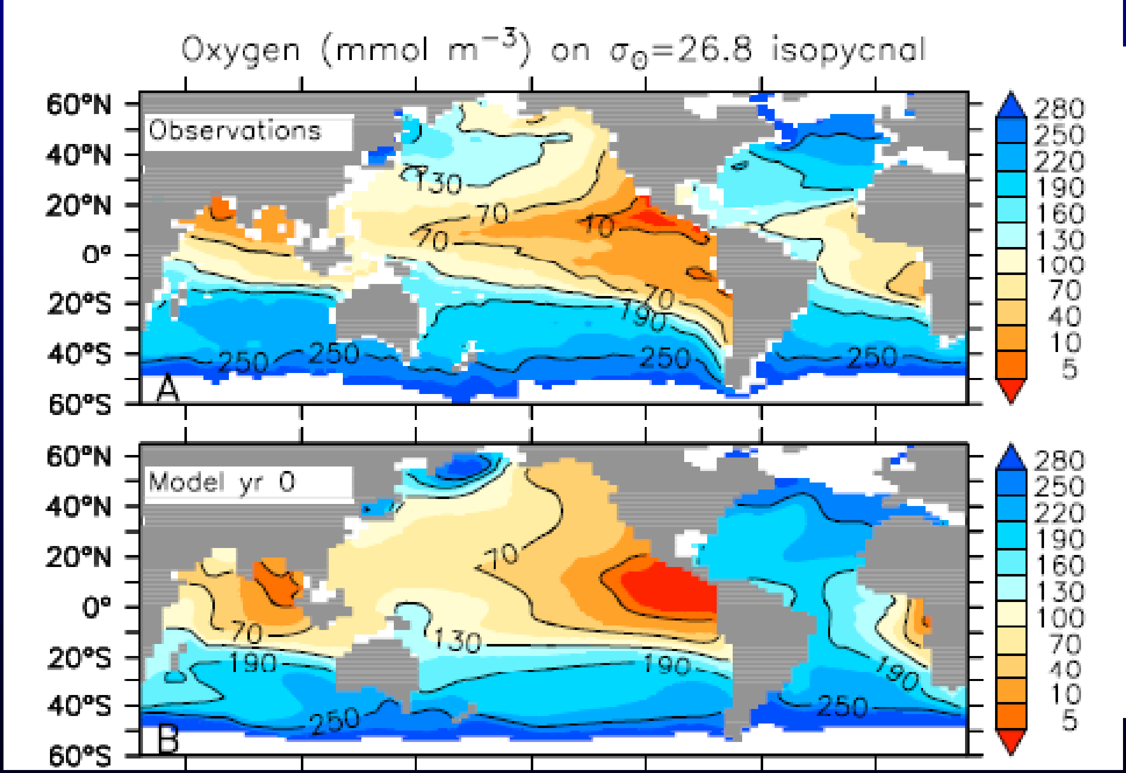
The Evolving Story of Microbial Nitrogen Cycling Processes in Low Oxygen Zones

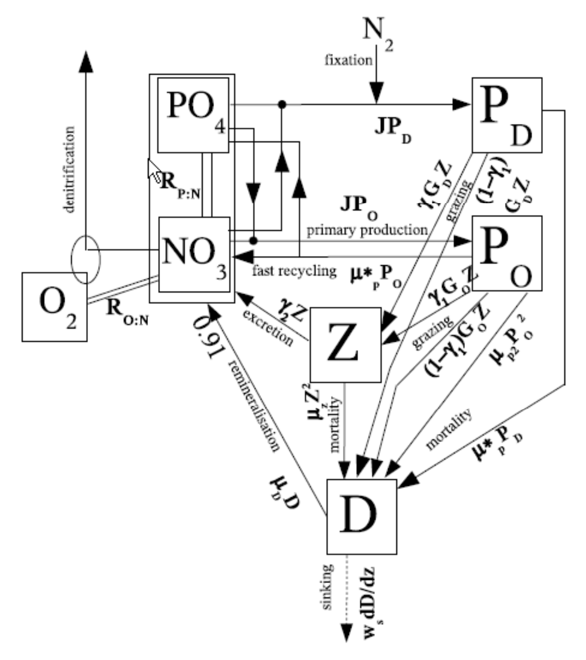
Jonathan Zehr (UCSC)



Modeling Low-Oxygen Regions: Past and Future

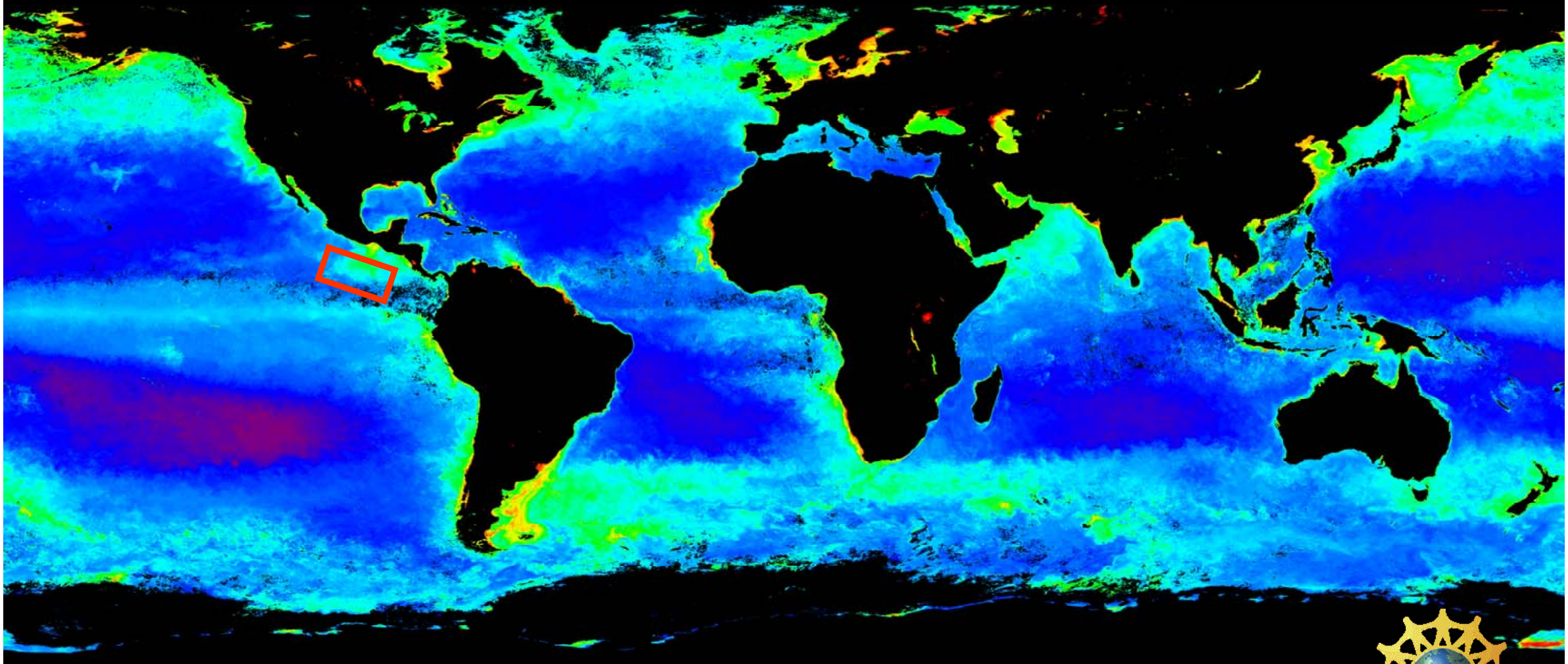
Andreas Schmittner (OSU)





The Specter of Expanding OMZs: Habitat Compression and the Biological Pump

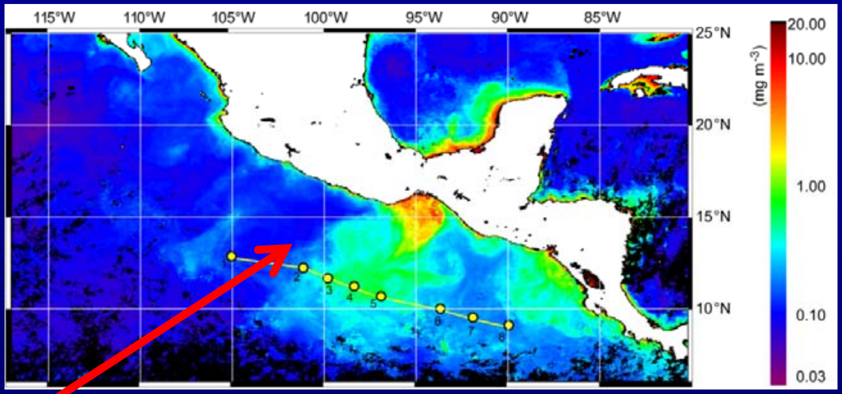
Kendra Daly (USF) & Collaborators

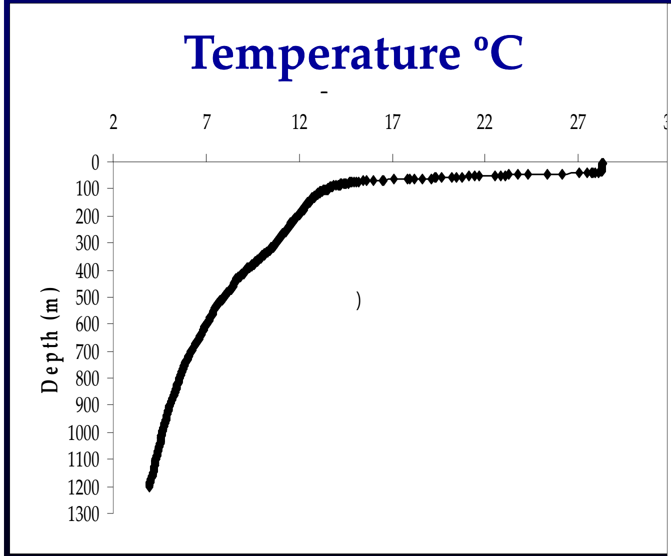


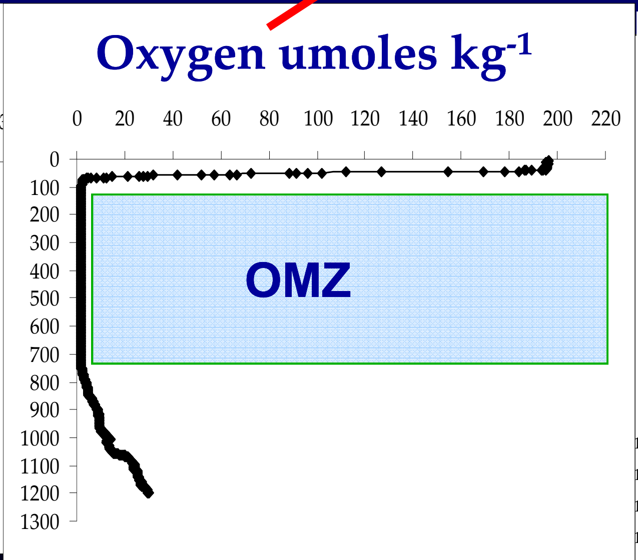
Some results from Eastern Tropical Pacific Project

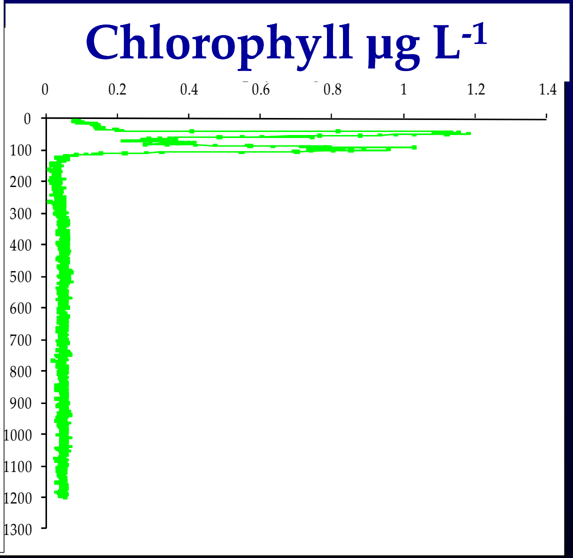
Organism vertical distribution, metabolism and physiology, and particle flux influenced by large gradients in

Temperature
Oxygen
pH
Food availability
Predation influences

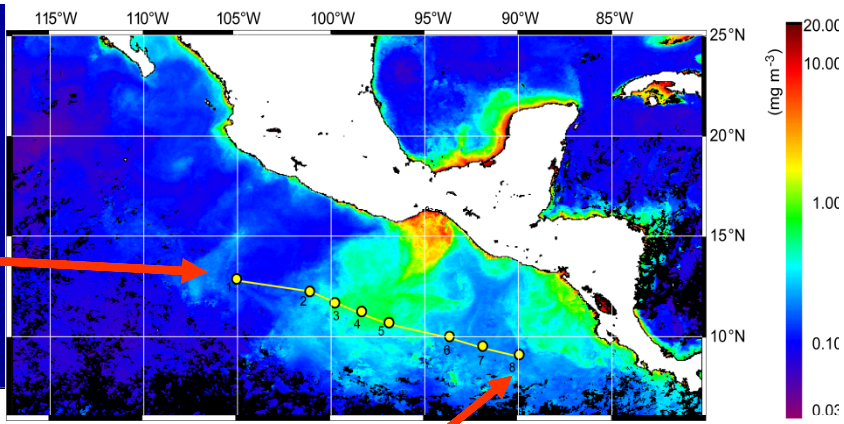



Temperature °C

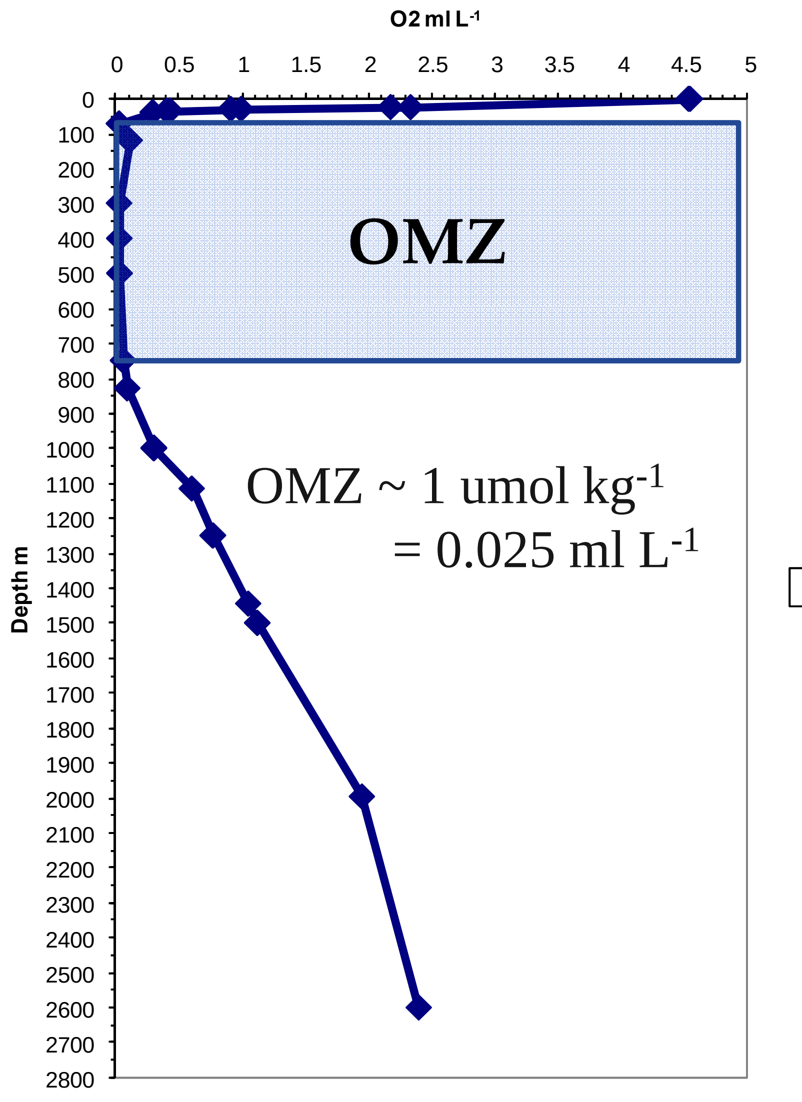

Oxygen umoles kg^{-1}


Chlorophyll μg L^{-1}

Variability in Depth Range of Oxygen Minimu



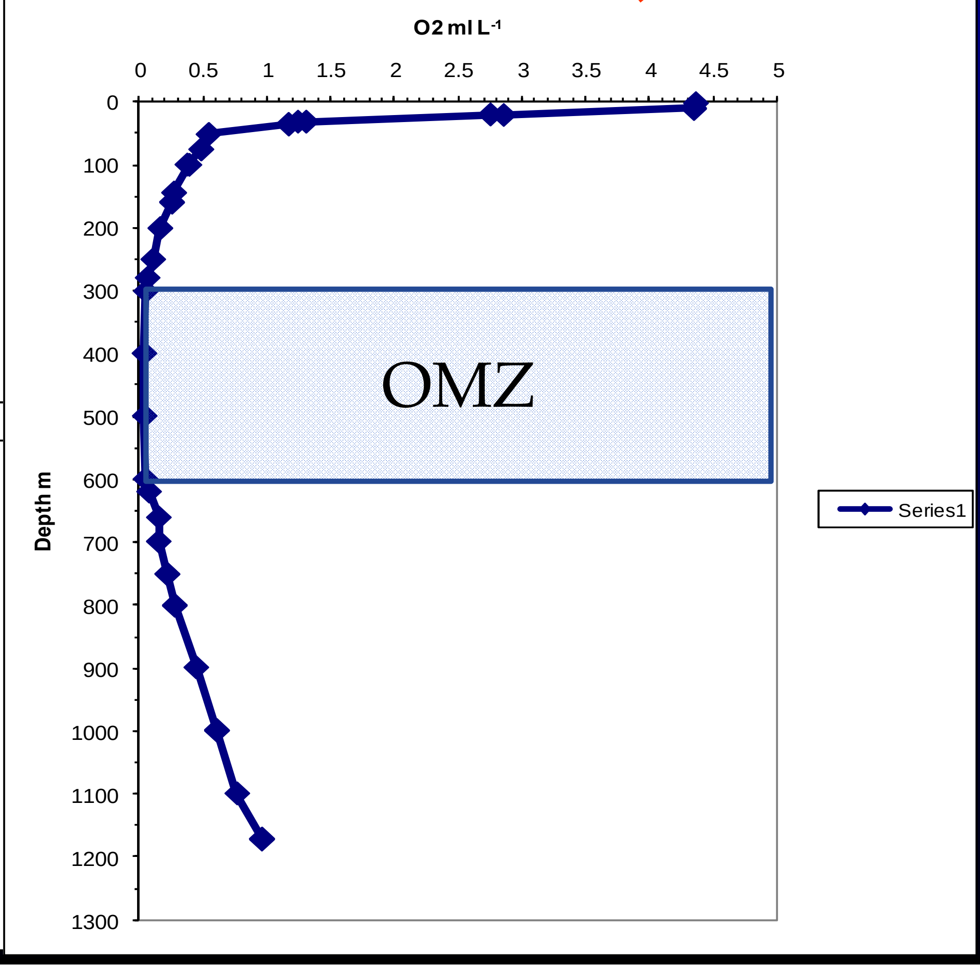
Station 1



OMZ ~ 1 umol kg^{-1}

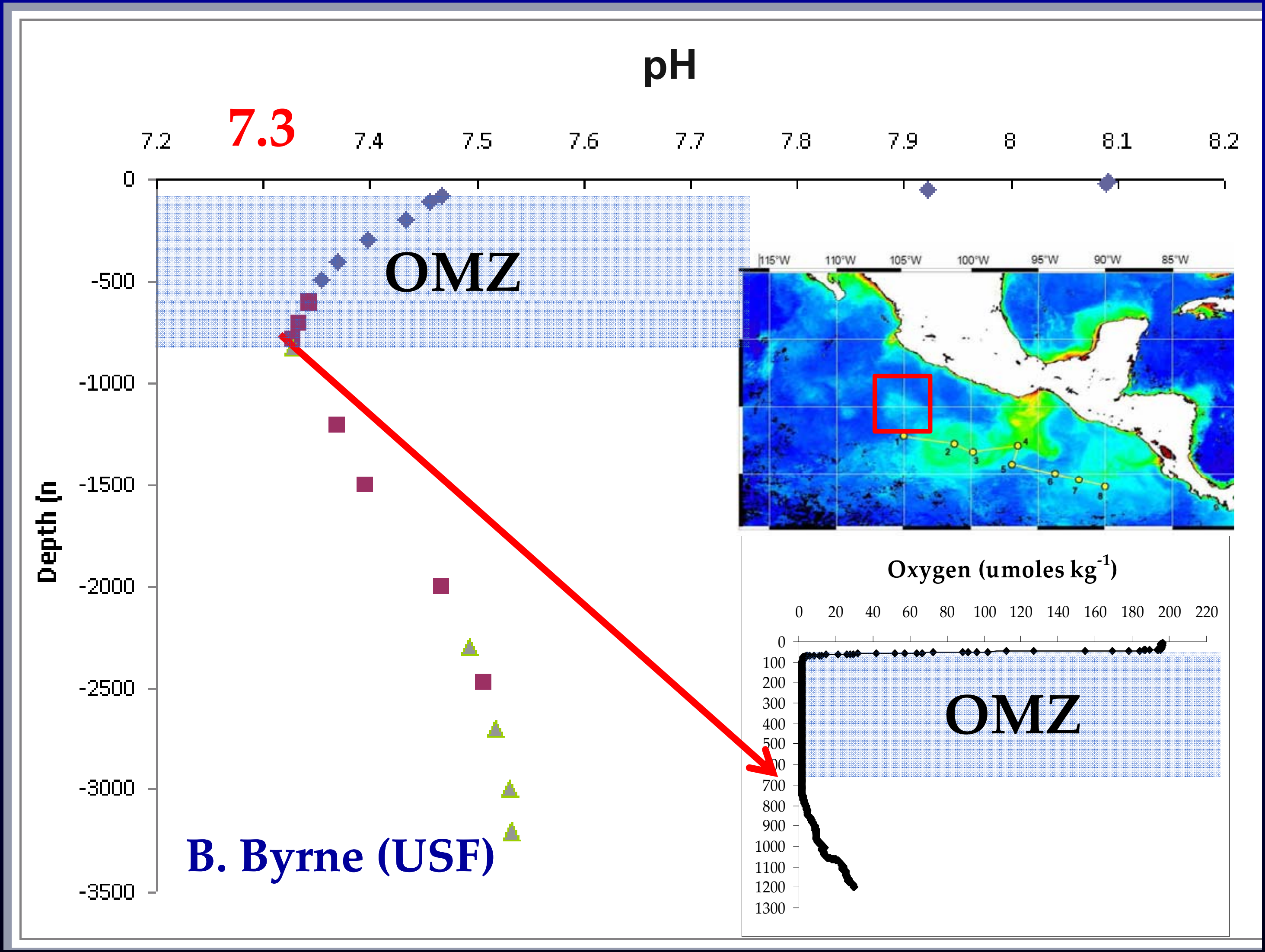
= 0.025 ml L^{-1}

Station 8



Interplay of Ocean Acidification and OMZs

Lowest pH Values in Lower Oxycline



B. Byrne (USF)

Features of the OMZ Biological Pump

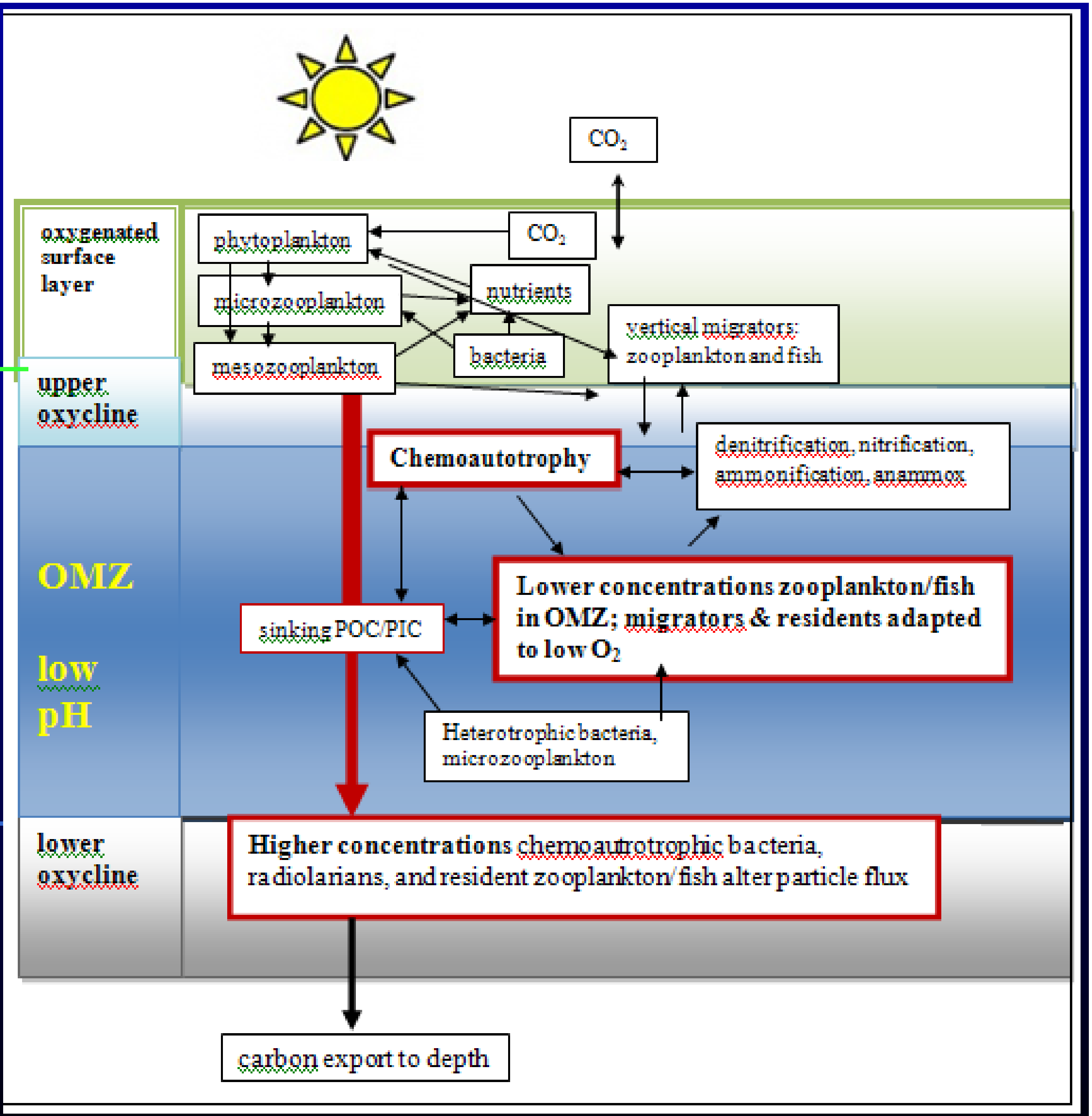
Most Carbon Remineralized in Surface Layer

Chemoautotrophy source of new C

Microbial-N Cycle

Reduced mesopelagic community

Resident lower oxycline community



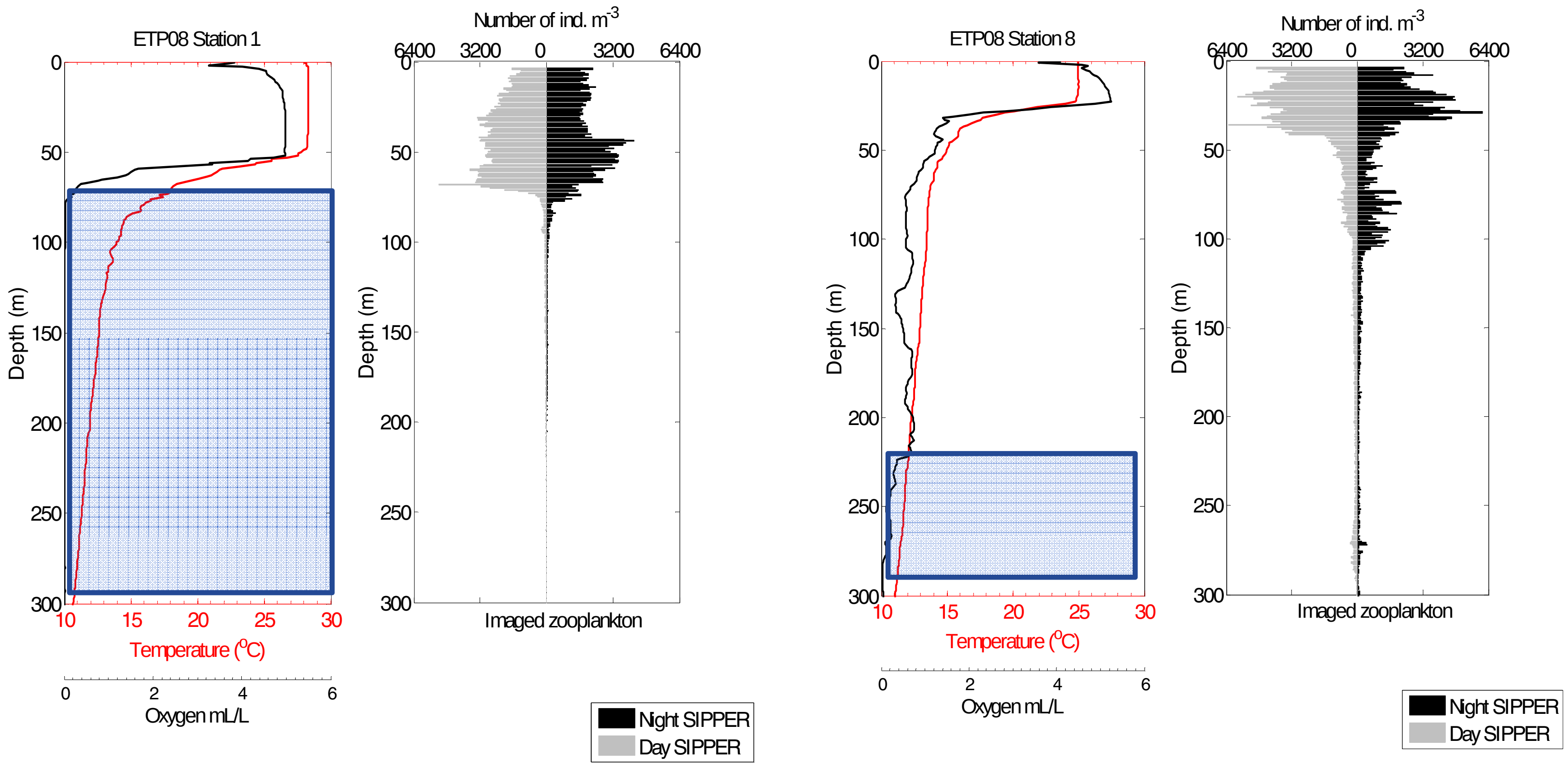
New technologies provide detailed, fine-scale vertical resolution of components of the Biological Pump.

SIPPER – Line Scan Camera continuously images particles and zooplankton. Sensors: CTD, fluorescence, optical backscatter, transmissometer

A. Remsen & K. Daly (USF)

Gelatinous Zooplankton, poorly characterized by nets, comprised ~ 10% of imaged zooplankton

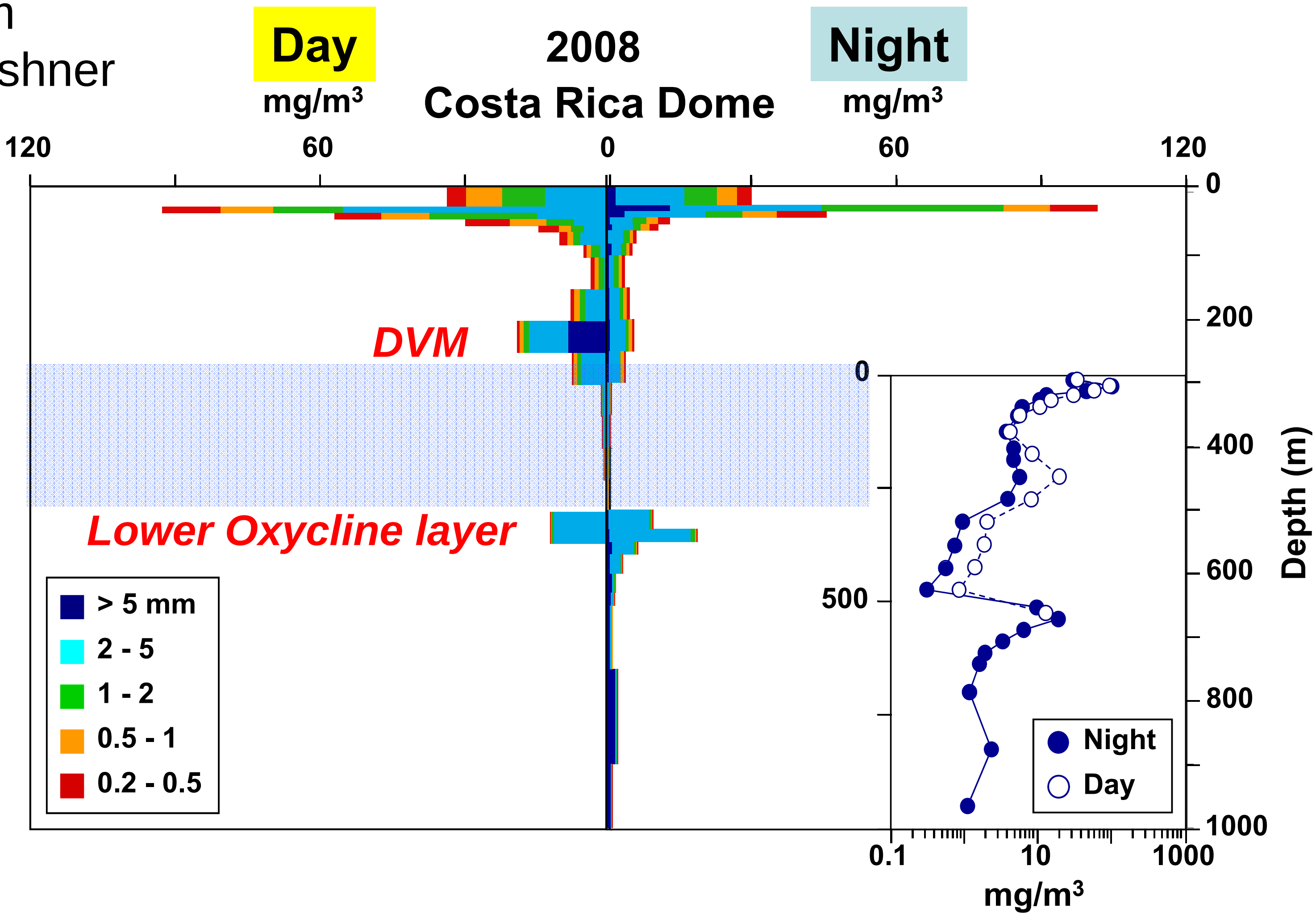
Habitat Compression
Zooplankton were concentrated in near-surface waters >13 µmole kg^{-1} (0.3 ml L^{-1}) and reduced in OMZ



	Sta. 1 Day	Sta. 1 Night	Sta. 8 Day	Sta. 8 Night
Mixed layer zooplankton	45%	43%	31%	23%
Thermocline zooplankton	95%	96%	77%	64%

Biomass Profiles with Size Classes

Slide from
Karen Wishner



- *Narrow biomass peaks at Upper and Lower Oxyclines*
- *Diel vertical migration into OMZ and Upper Oxycline*

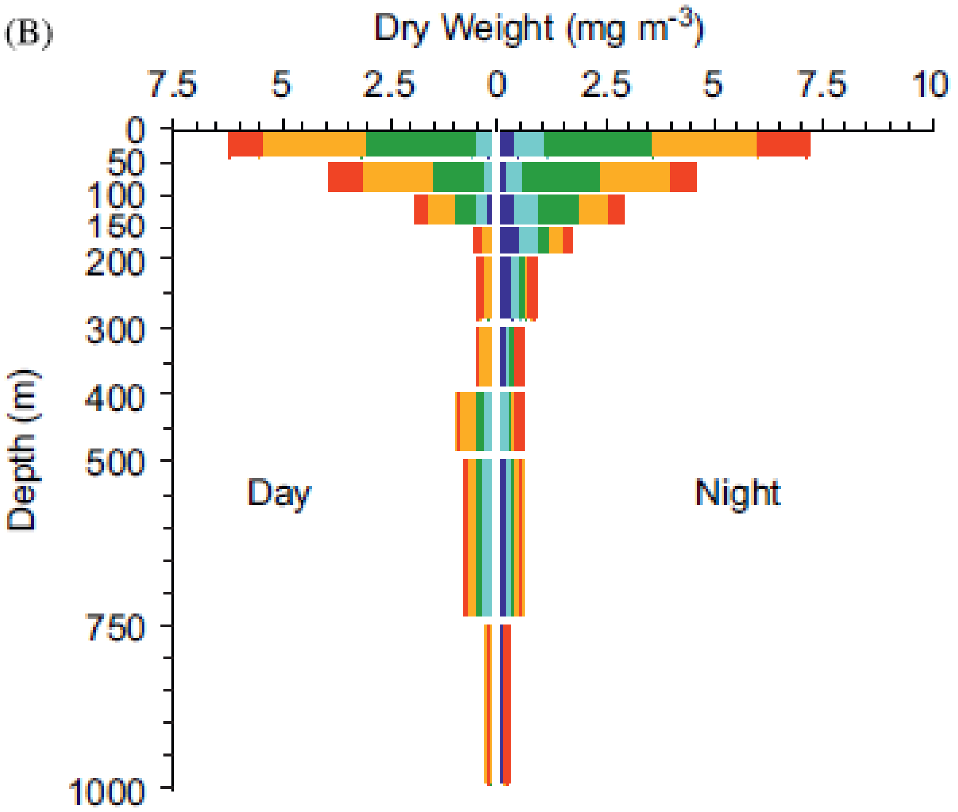
OMZ Twilight Zone Community Biomass Reduced Compared to Biomass in Oxygenated Subtropical Pacific Waters

ETNP OMZ Zooplankton

- **Maximum surface biomass ~ 90 mg m^{-3}**

- **OMZ biomass ~ 0.2 - 1 mg m^{-3}**

Station ALOHA

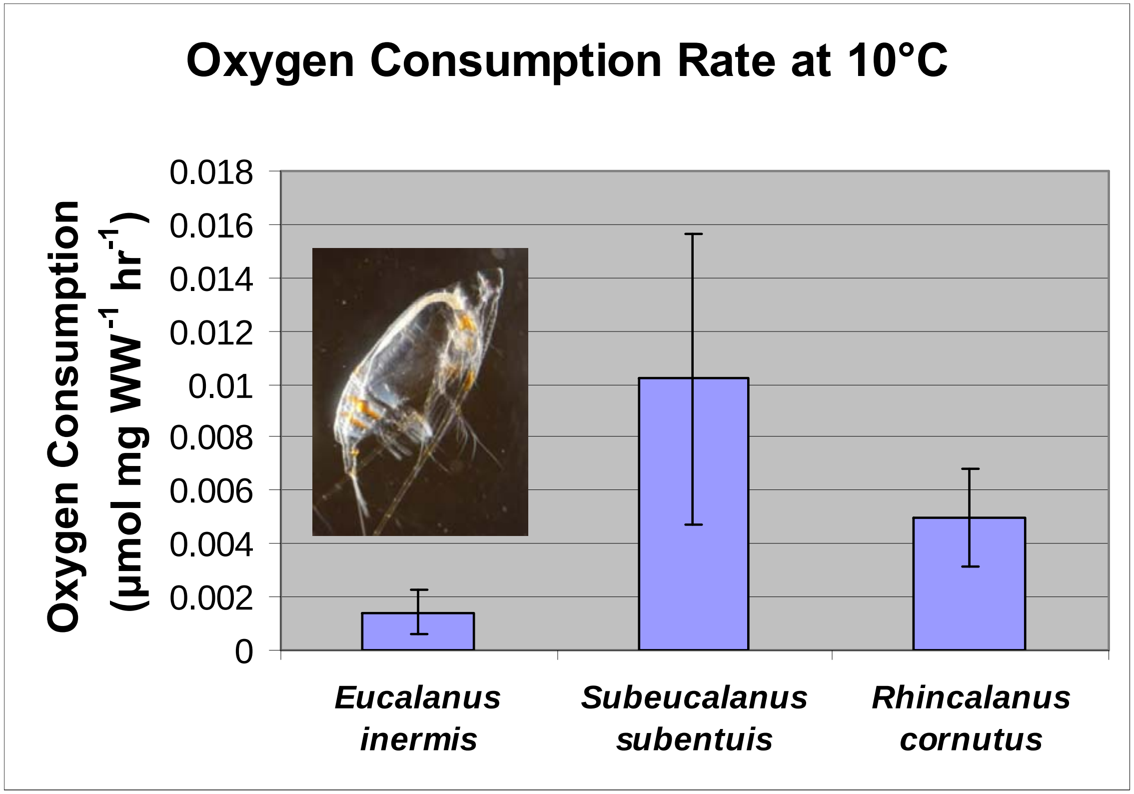


Steinberg et al. (2008)

Closely Related Species Have Varying Tolerances to Low Oxygen

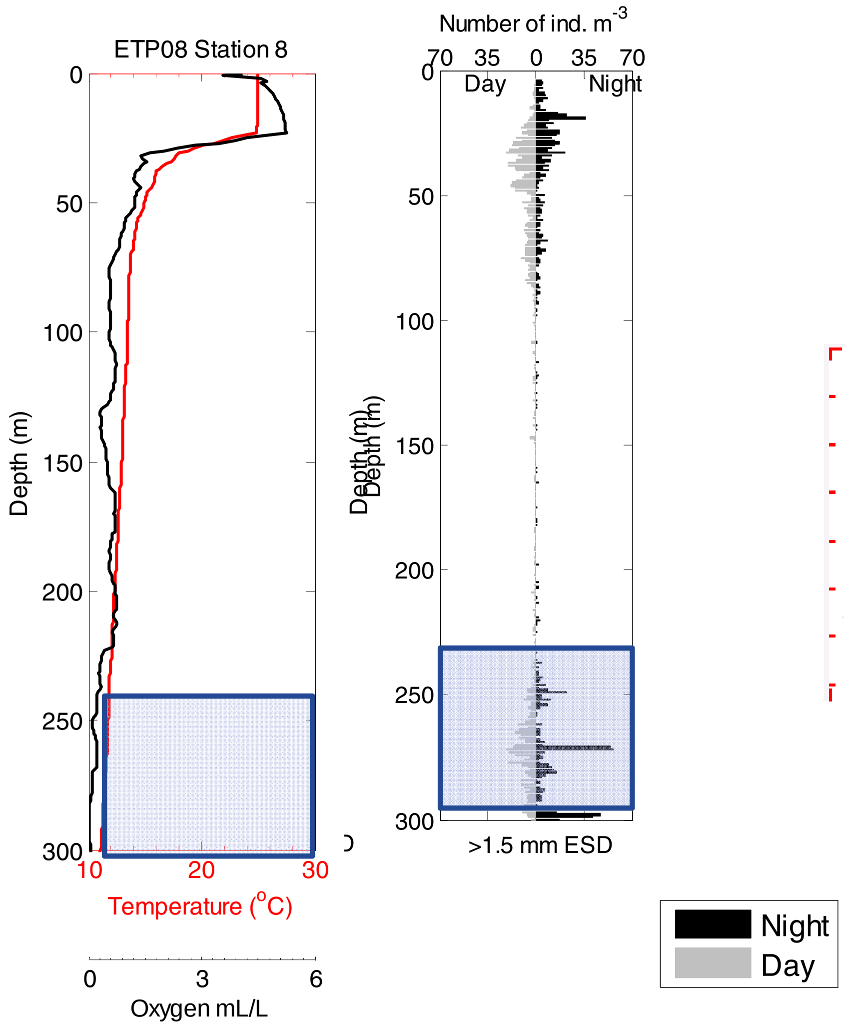
Subeucalanus subtenuis has higher oxygen demand and is restricted to surface waters.

Eucalanus inermis has a very low oxygen demand; a portion of the adult females reside in the OMZ.

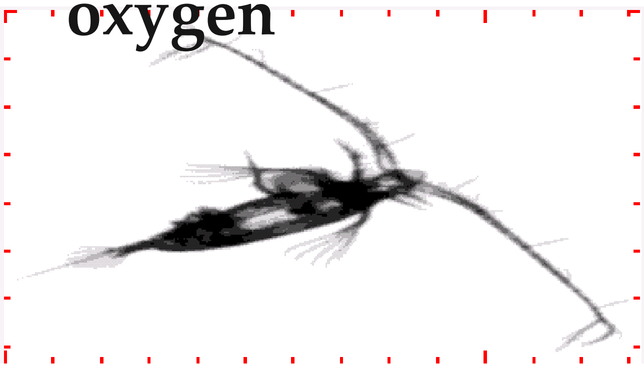


Adaptations of pelagic crustaceans to the OMZ include:

(1) enhanced ventilatory volume, (2) large gill surface area, (3) short diffusion distance from the water to the blood and (4) haemocyanin respiratory proteins with very high affinity for oxygen

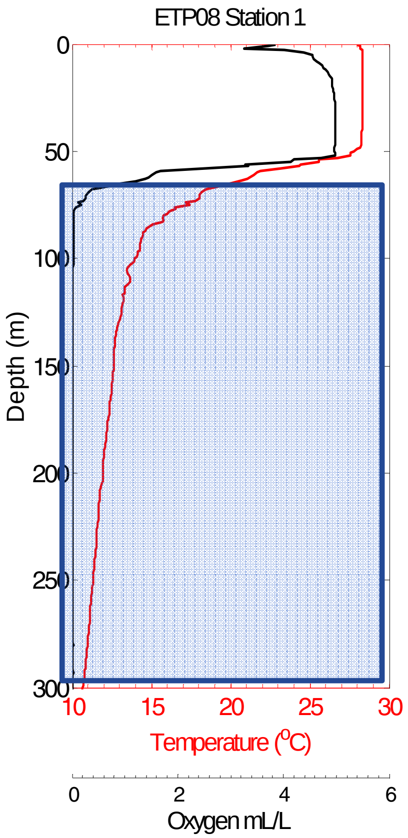


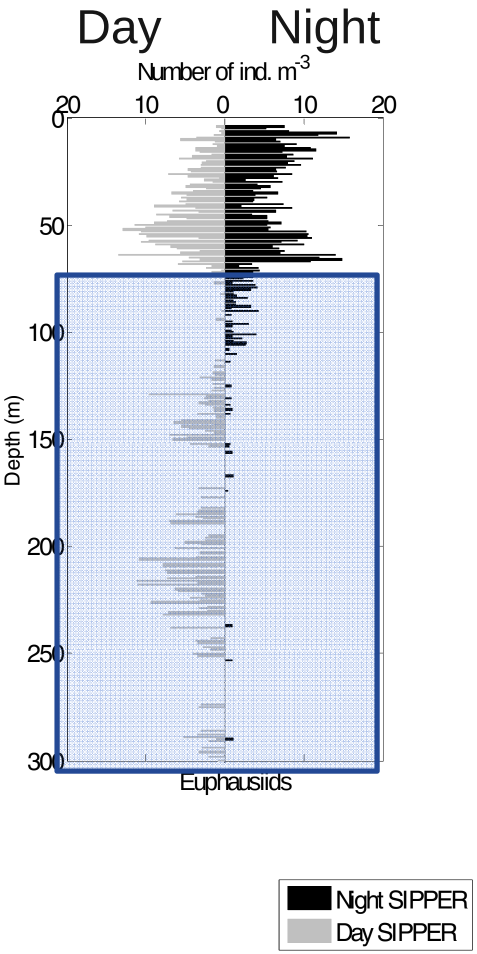
Species and stage-specific tolerances to low oxygen

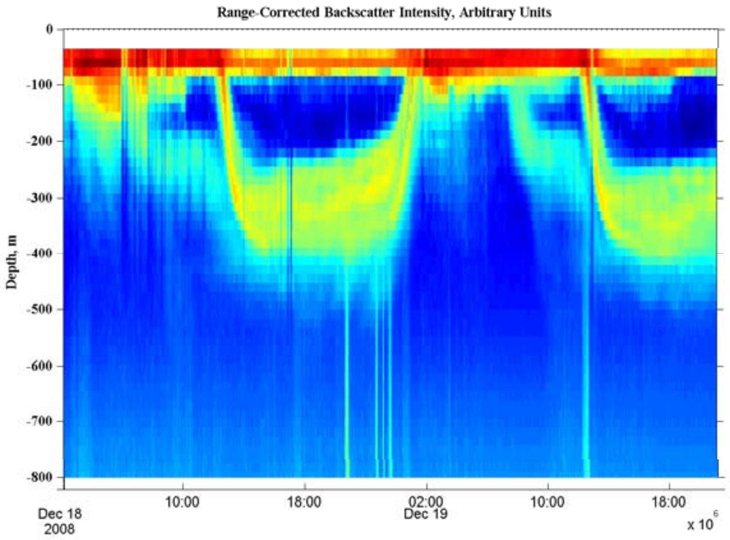


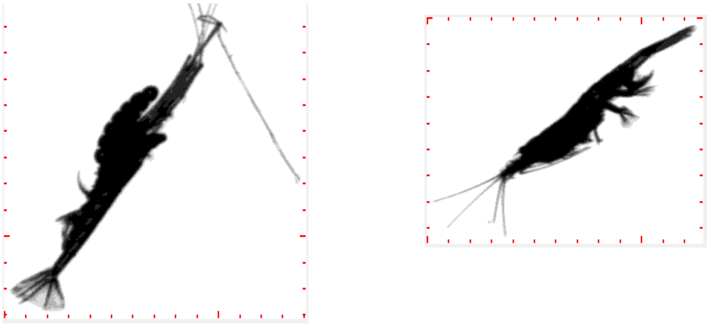
Eucalanus inermis adult females in OMZ

Diel Vertical Migration into OMZ









Euphausiids

Other zooplankton in OMZ: amphipods, polychaetes, calanoid copepods, and the pteropod Creseis

“Jumbo Squid Invasions”

Inhabits OMZs; OMZ expansion allows range extension

Influence on Biological Pump:

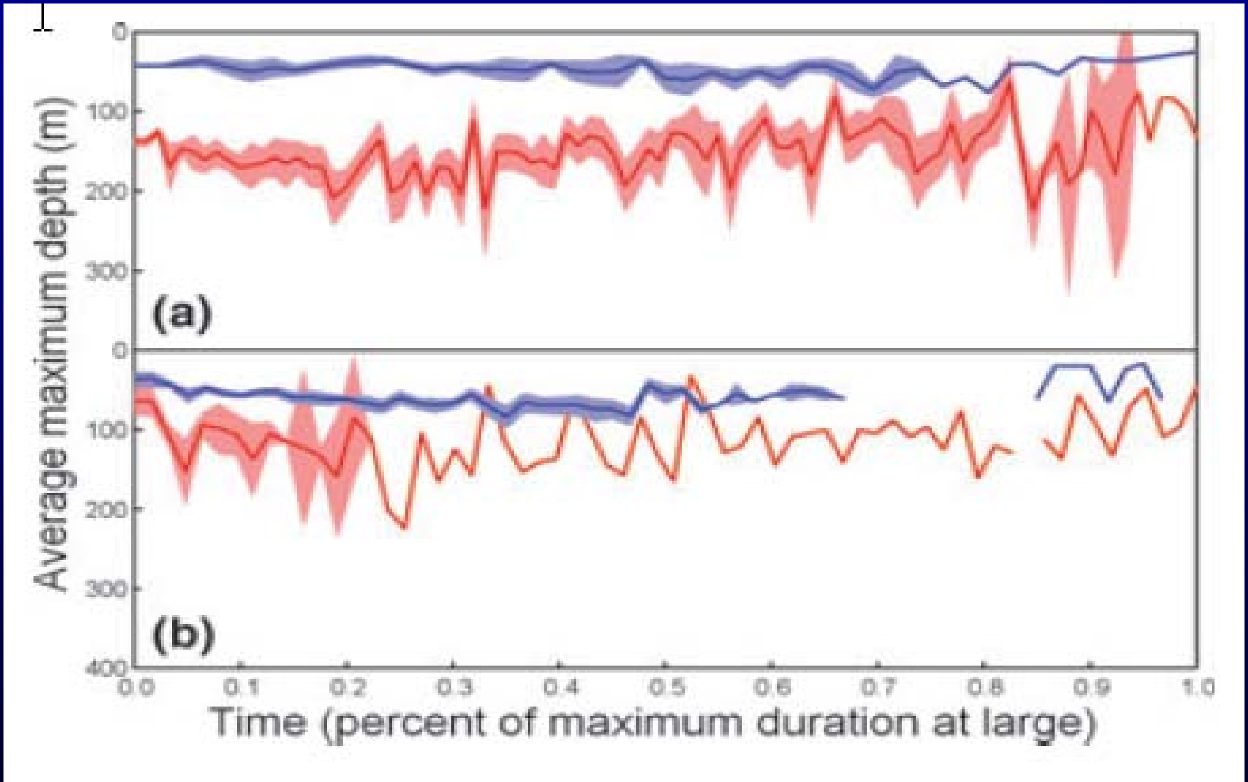
- Key predator of mesopelagic organisms such as myctophid fish

- Primary prey for sperm whales, other toothed whales, plus tunas, billfish, and sharks

- Potential trophic cascade effect

Marlin, tuna, and sailfish: High-performance physiology results in a higher oxygen threshold (158 umole kg^{-1}; 3.5 ml L^{-1})

- These fish are restricted to surface waters in Pacific OMZ
- Fish harvest is elevated in OMZs



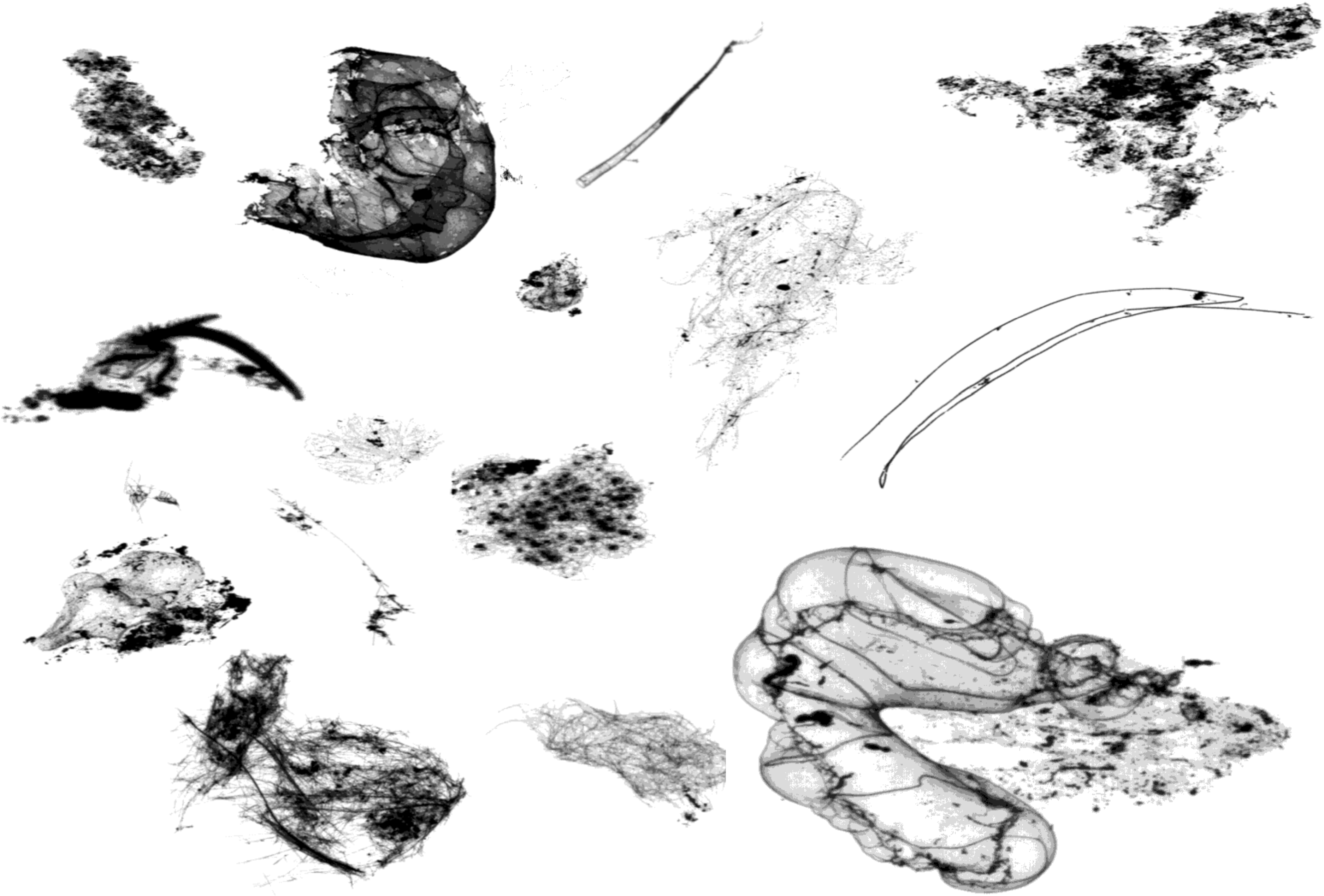
Marlin

Sailfish

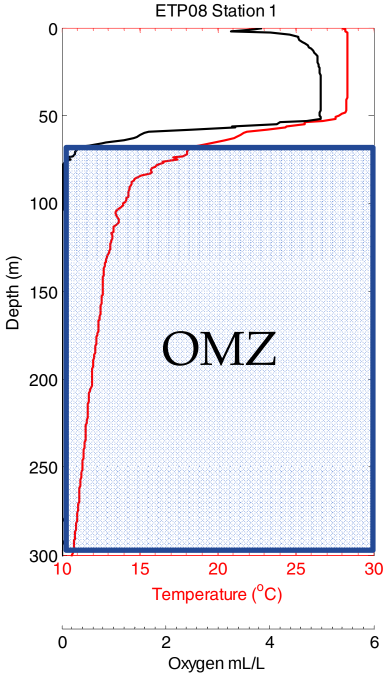
Average maximum depth (m) in the OMZ Pacific (blue solid line) and Atlantic oxygenated waters (red solid line)

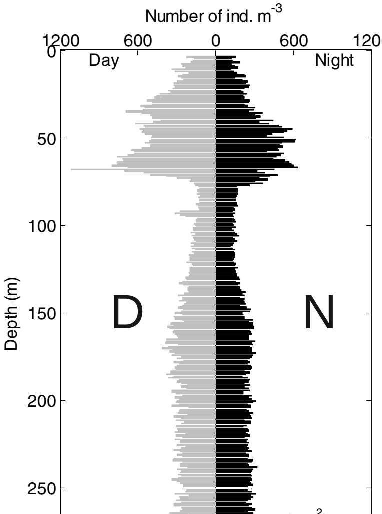
Prince & Goodyer 2006 Fish. Oceanogr. 15

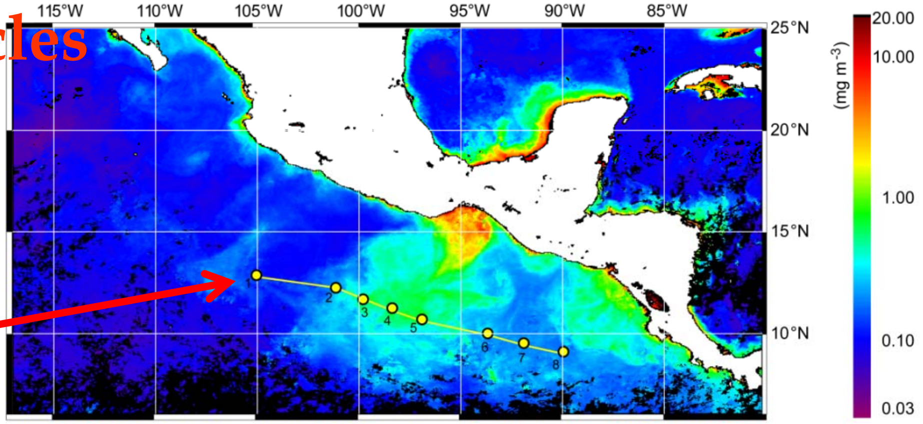
Type and Size of OMZ Detrital Particles



Day/Night Total Detrital Particles



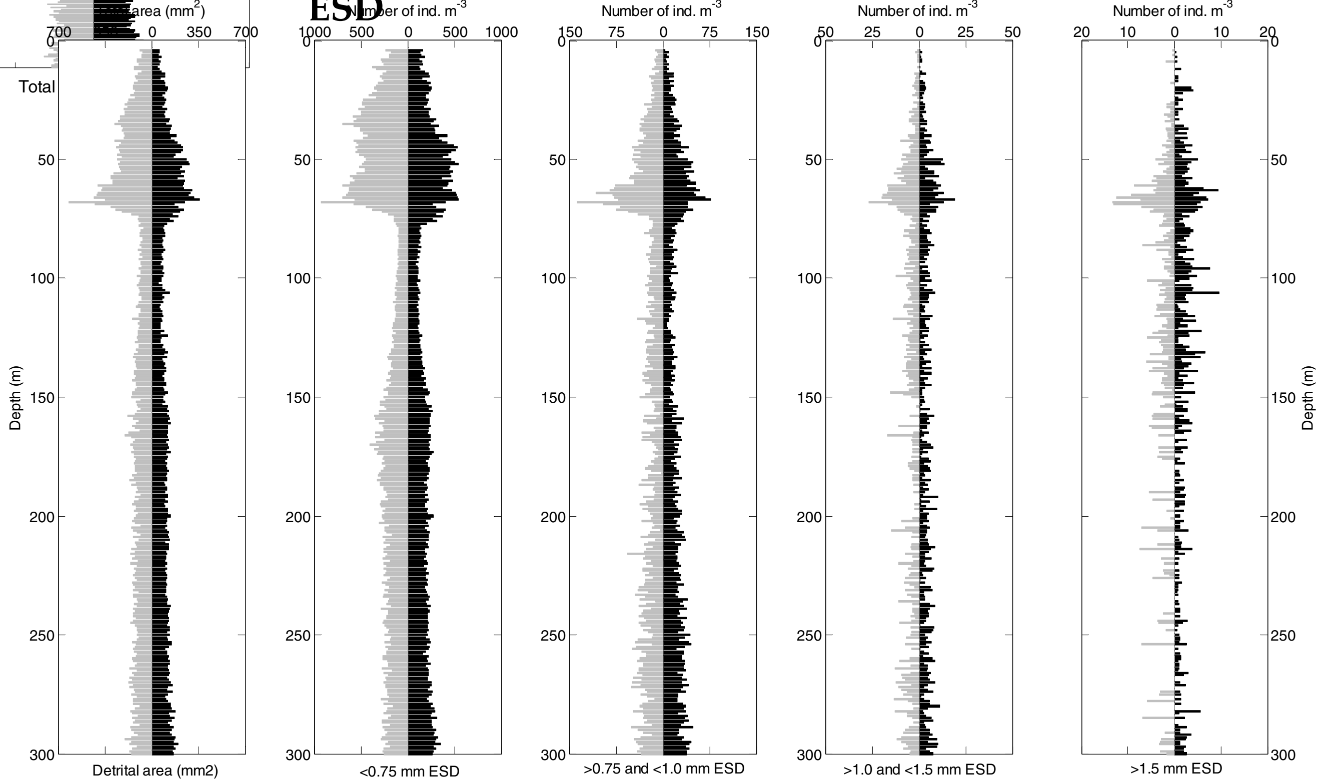




Particle Size →

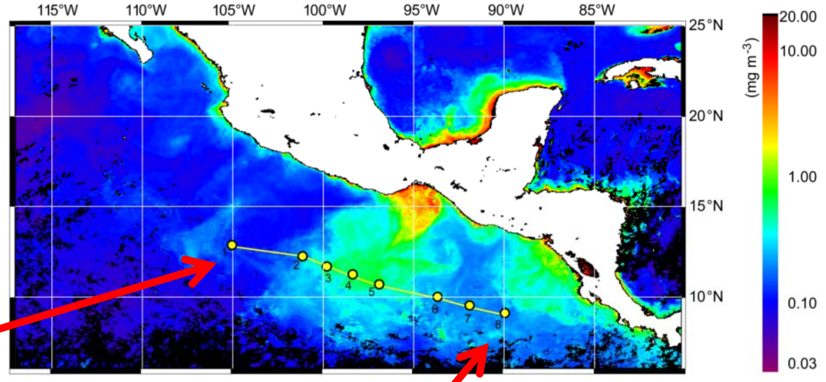
<0.7 mm ESD

>1.5 mm ESD

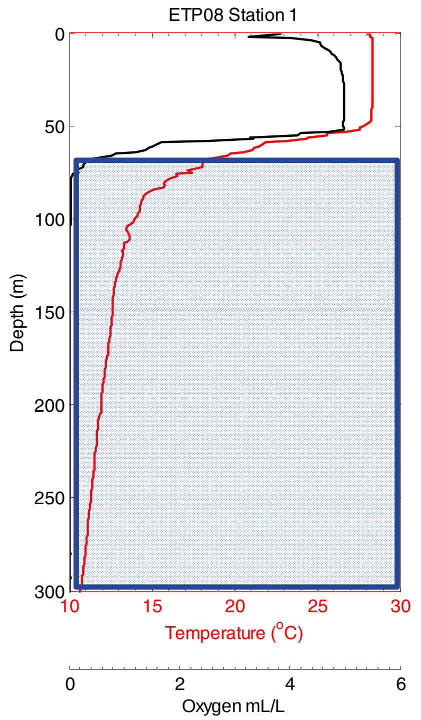


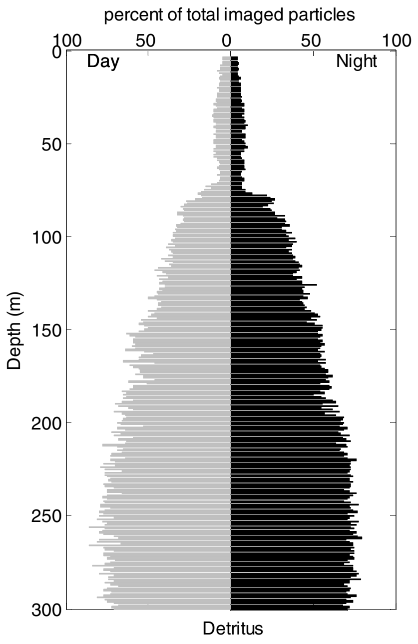
Smaller-sized suspended?particles most common in OMZ

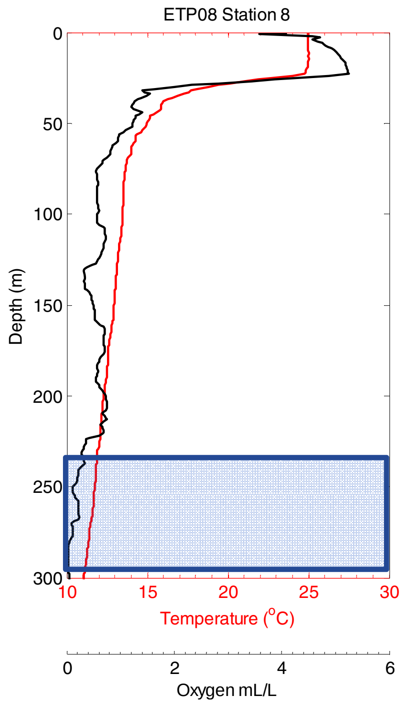
Percent of detritus increased with depth in the OMZ relative to the total number of particles imaged.

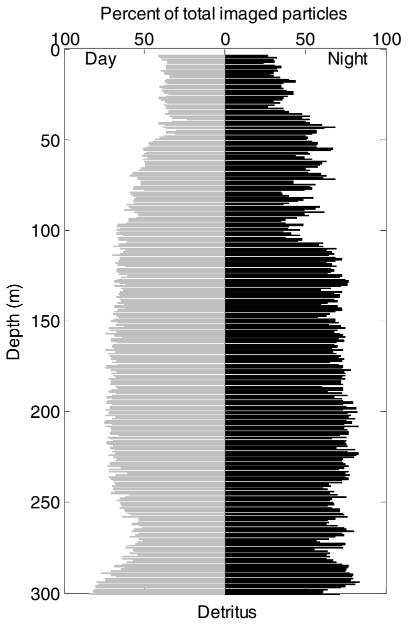


Costa Rica Dome





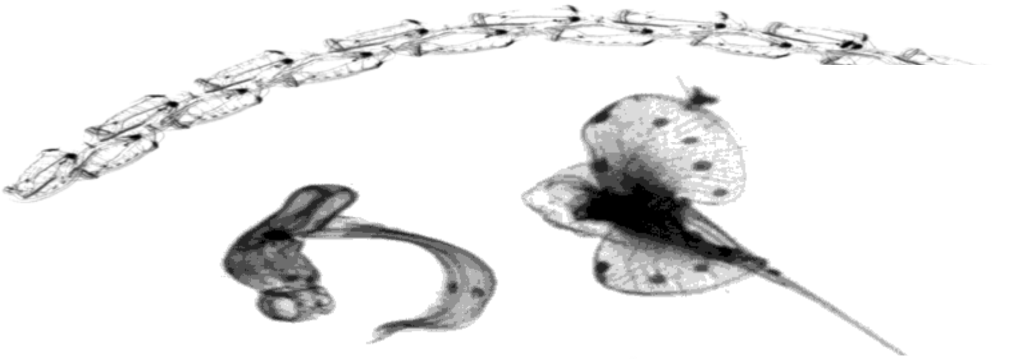


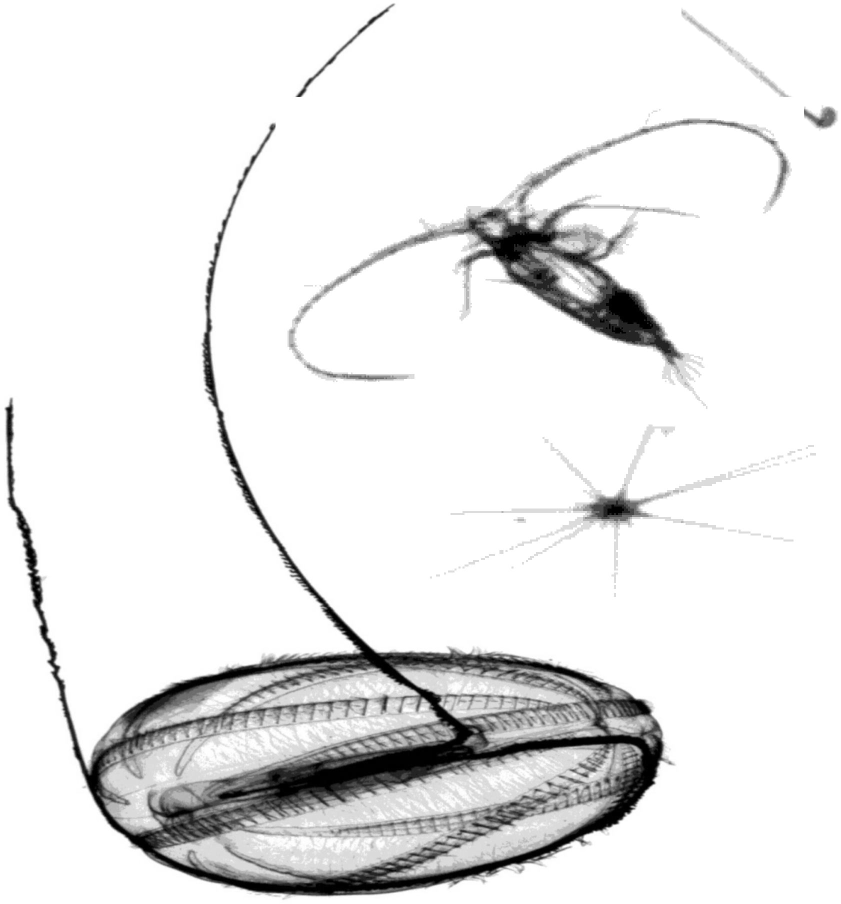


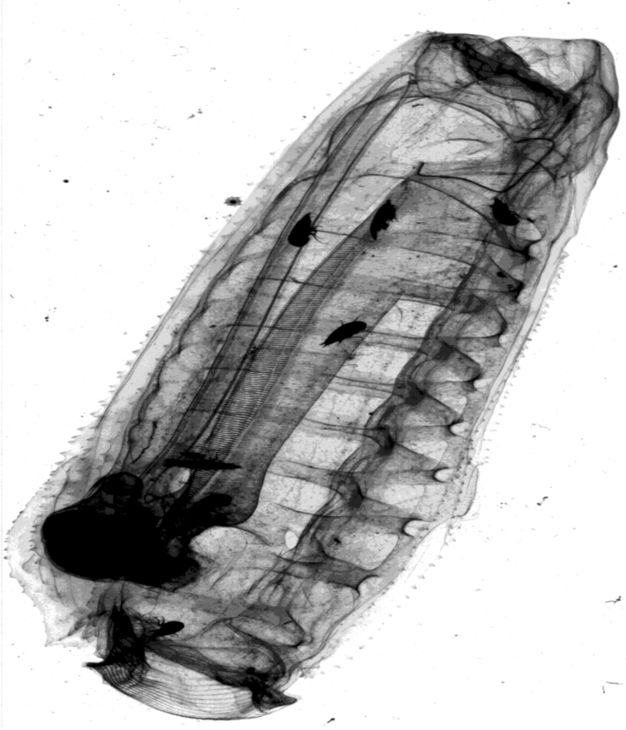
Acknowledgements

NSF/OCE

Officers & Crew of R/V
Seward Johnson & R/V Knorr







Questions

What is the variability in vertical and spatial extent of OMZs?
Are OMZs expanding?

What is the role of OMZs in global C flux? Is C flux higher in OMZs? Role of Biological Pump; particle characterization.

What is the variability of N cycle processes in OMZs (denitrifcation, anammox, N-fixation, N2O flux)? Microbial rate measurements.

How do low pH and low oxygen levels affect marine food webs? Tolerance thresholds, adaptations, recruitment, ecosystem stability

What new tools and approaches are needed to address OMZ questions? (improved oxygen measurements, molecular techniques)

Low-Oxygen Regions

Terminology

Suboxia - threshold at which heterotrophic remineralization of organic matter transitions to using oxygen from nitrate (removes NO_3) releasing nitrite: 0.7 to 20 μmol kg^{-1}

Hypoxia - O_2 threshold below which mobile macro-organisms are stressed or die; threshold varies depending on the species ~ 8 to 120 μmol kg^{-1}

Anoxia - is defined by transition from NO_3 respiration to sulfate-reduction: $O_2 <0.1$ μmol kg^{-1}

Reviewed in: Karstensen et al. (2008) Paulmier & Ruiz-Pino (2009)