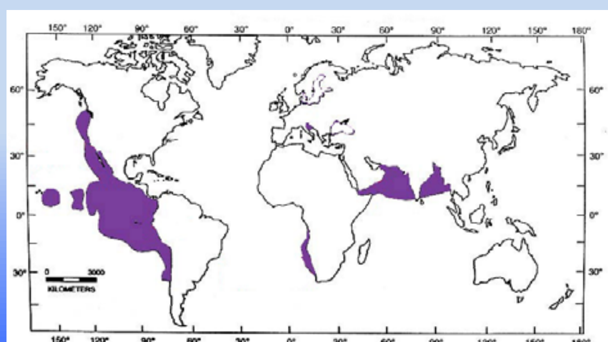
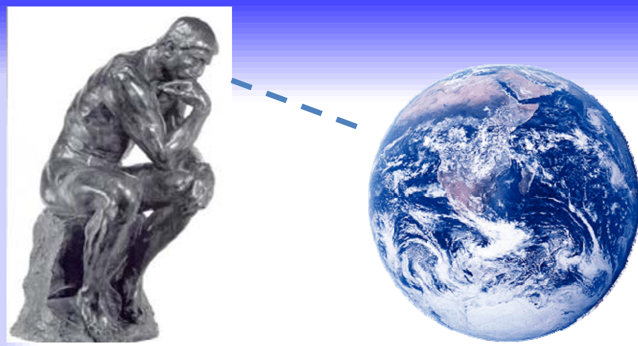
Benthic and Breathless in the OMZ



Lisa A. Levin
SCRIPPS INSTITUTION OF OCEANOGRAPHY

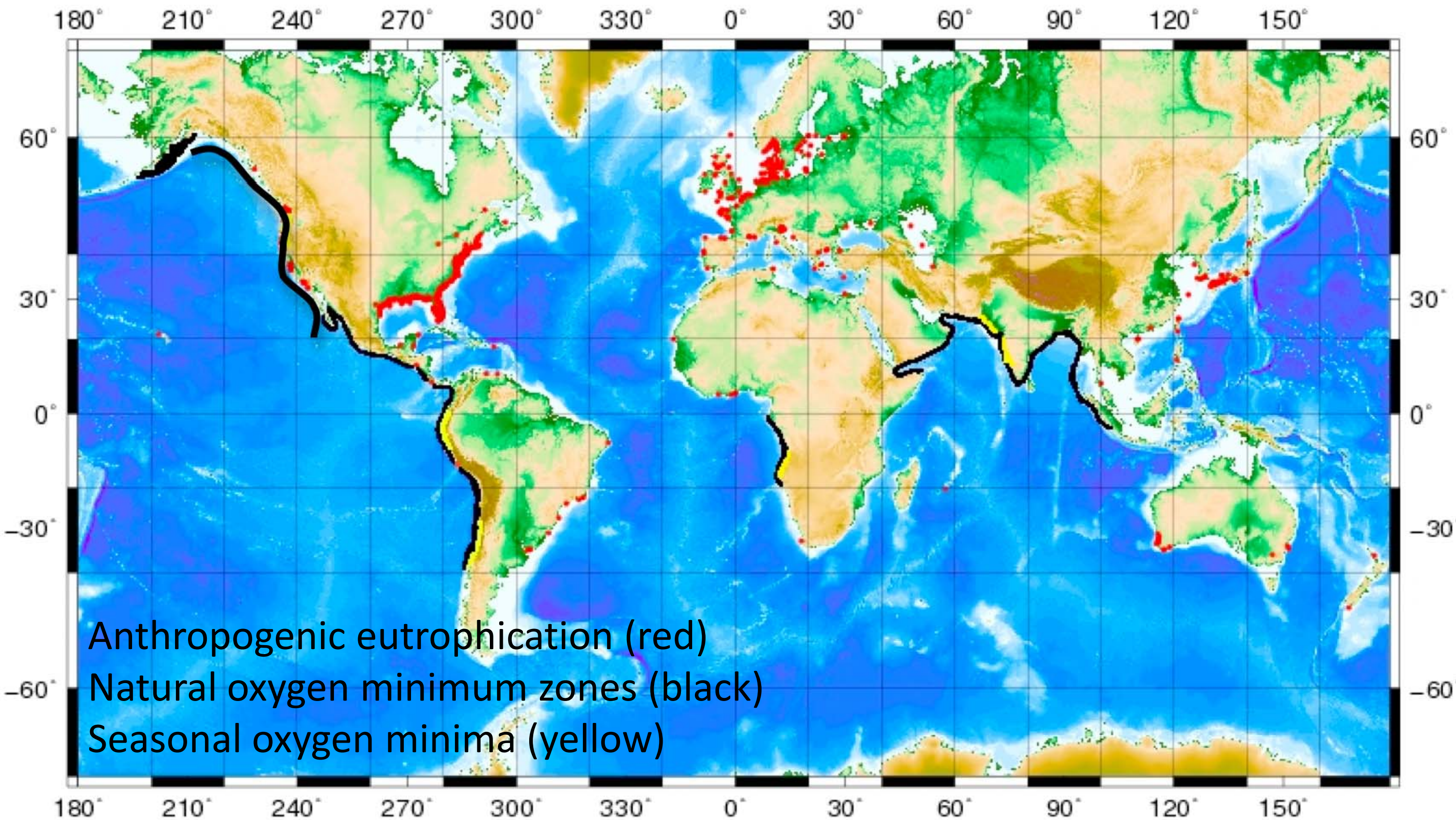


What do we know about *natural* hypoxia and its effects on benthos along upwelling margins?

What is changing and where?

Ecosystems of the future?

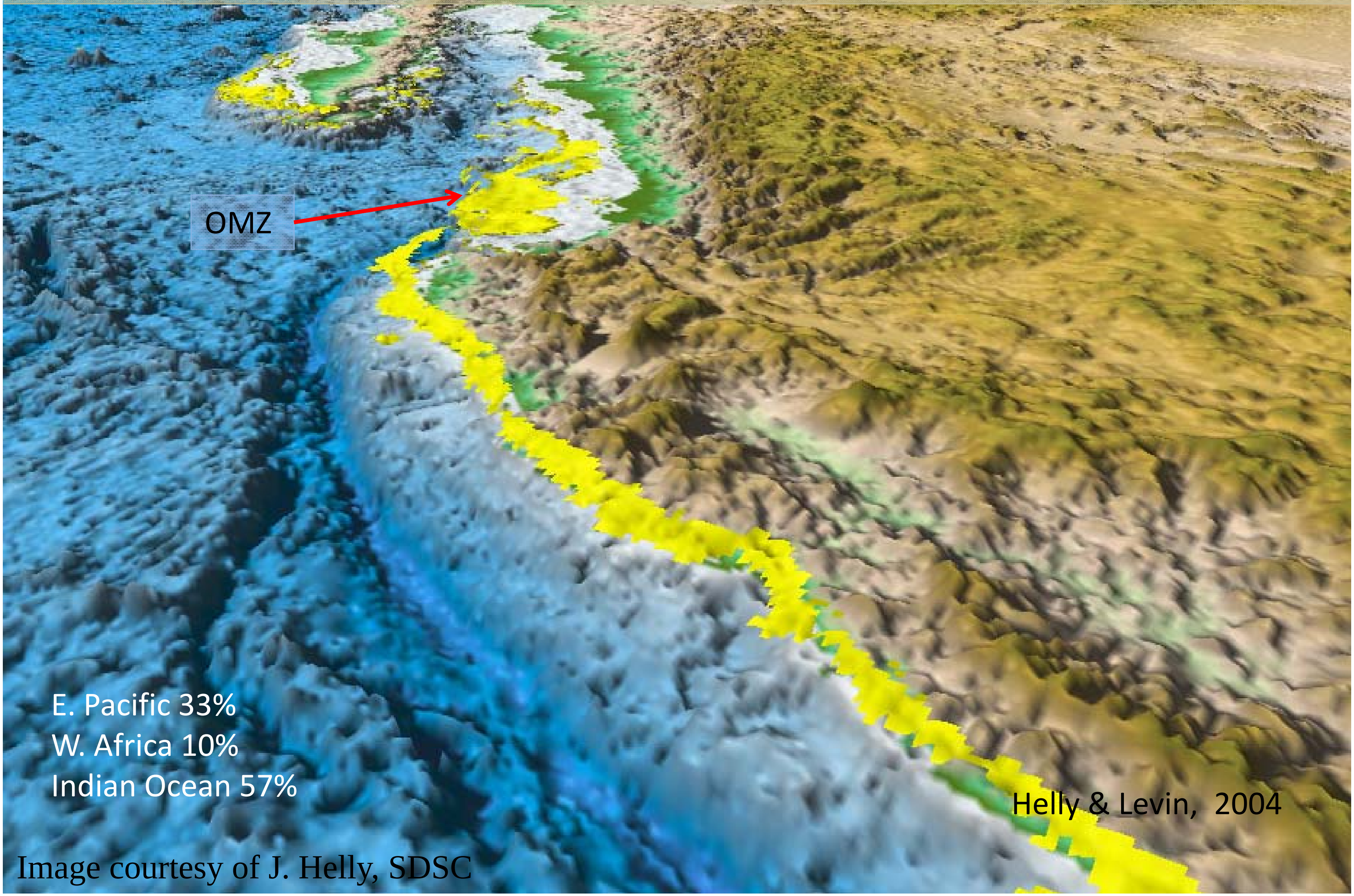
Along the continental margins natural and anthropogenic hypoxia have distinct distributions



Levin et al. Biogeosciences, 2009

(Anthropogenic data from R. Diaz)

Over 1,100,000 km² of continental margin are naturally hypoxic (<0.5 ml/L)



Helly & Levin, 2004

Image courtesy of J. Helly, SDSC

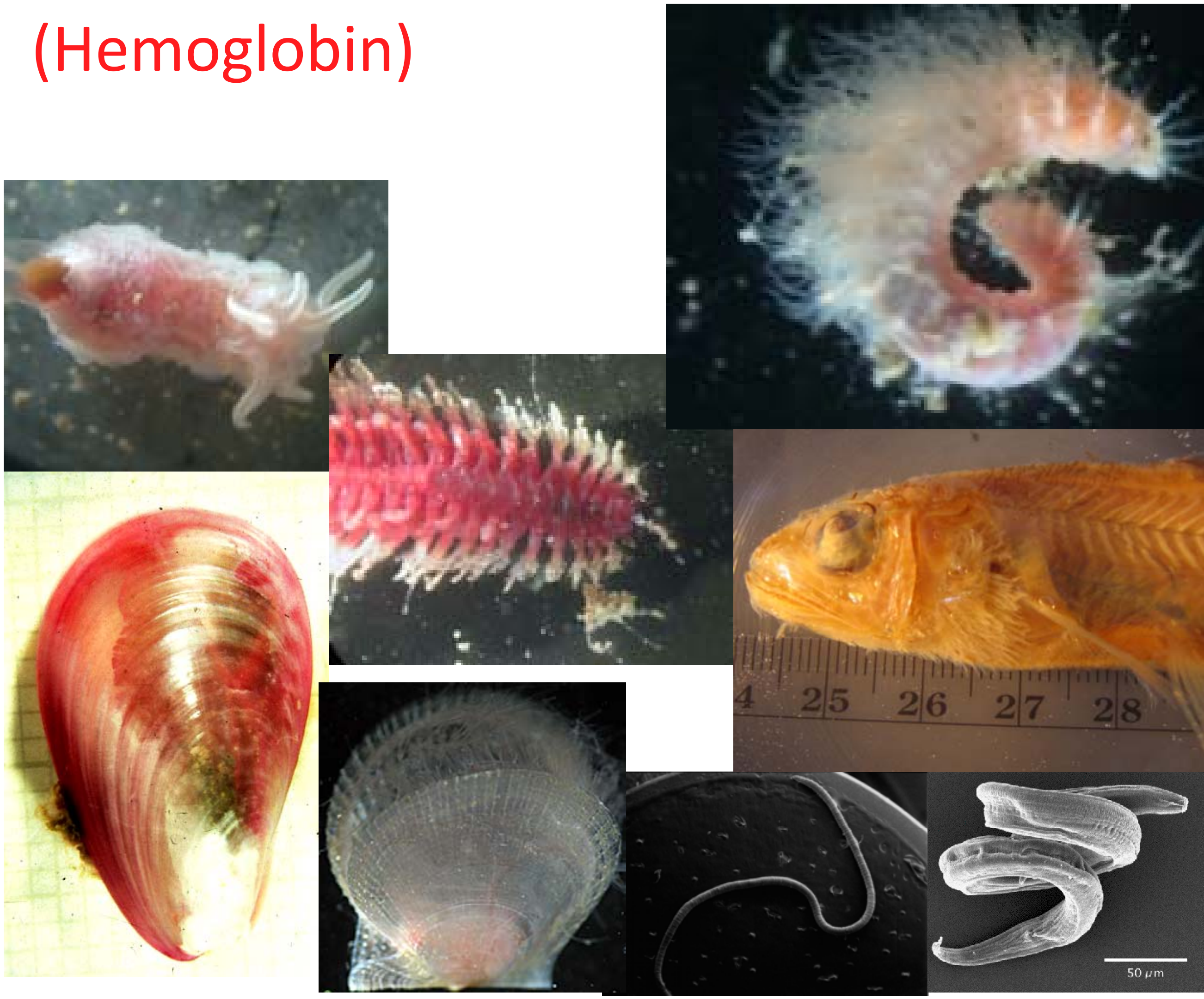
EVOLUTIONARY RESPONSES

Enhanced oxygen access/ ventilation abilities:

Blood Pigments

(Hemoglobin)

Enhanced Surface Area

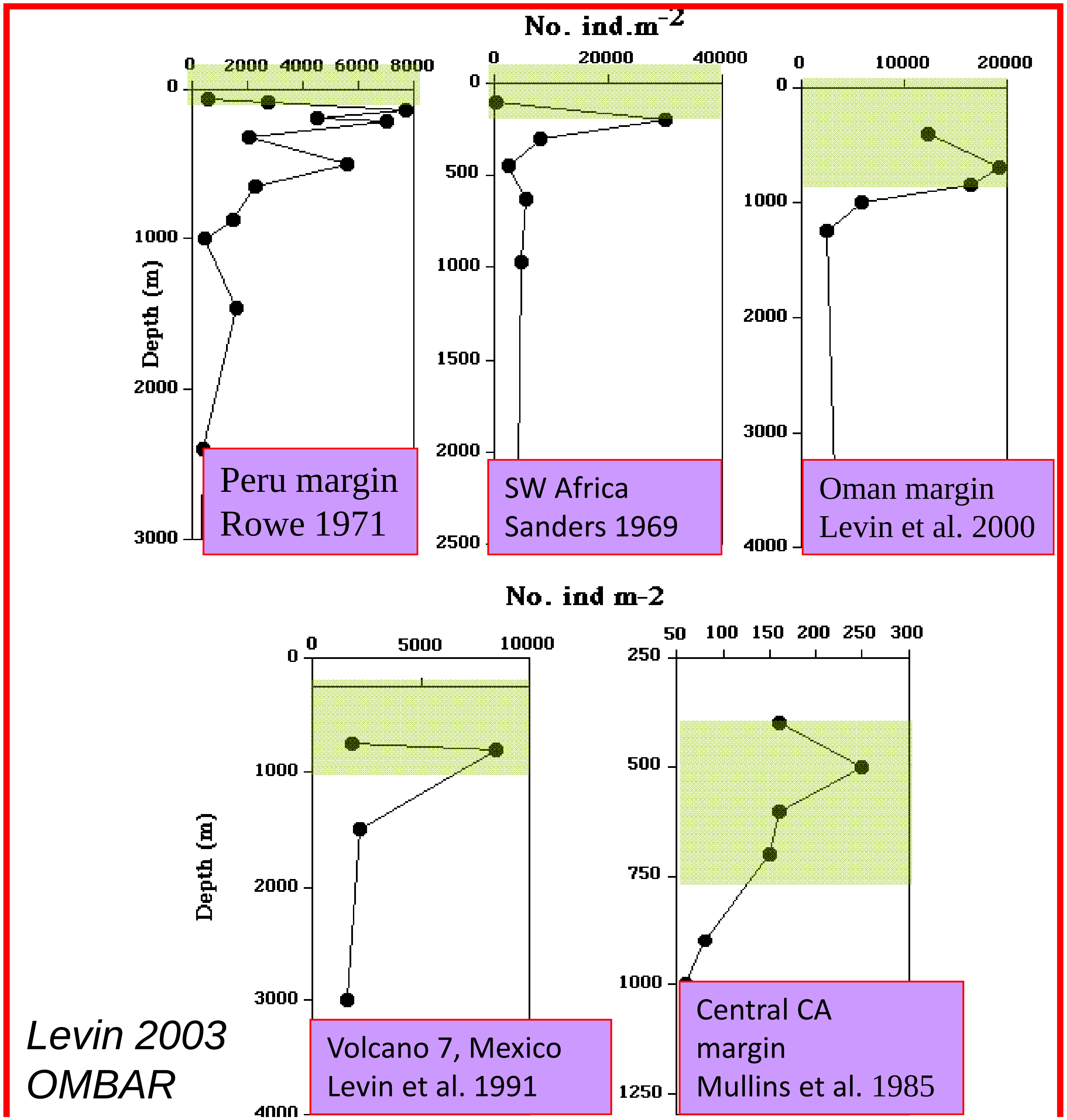


Small body size

Macrofaunal **DENSITY:** **DEPRESSION within the OMZ,**
MAXIMUM just above physiological thresholds

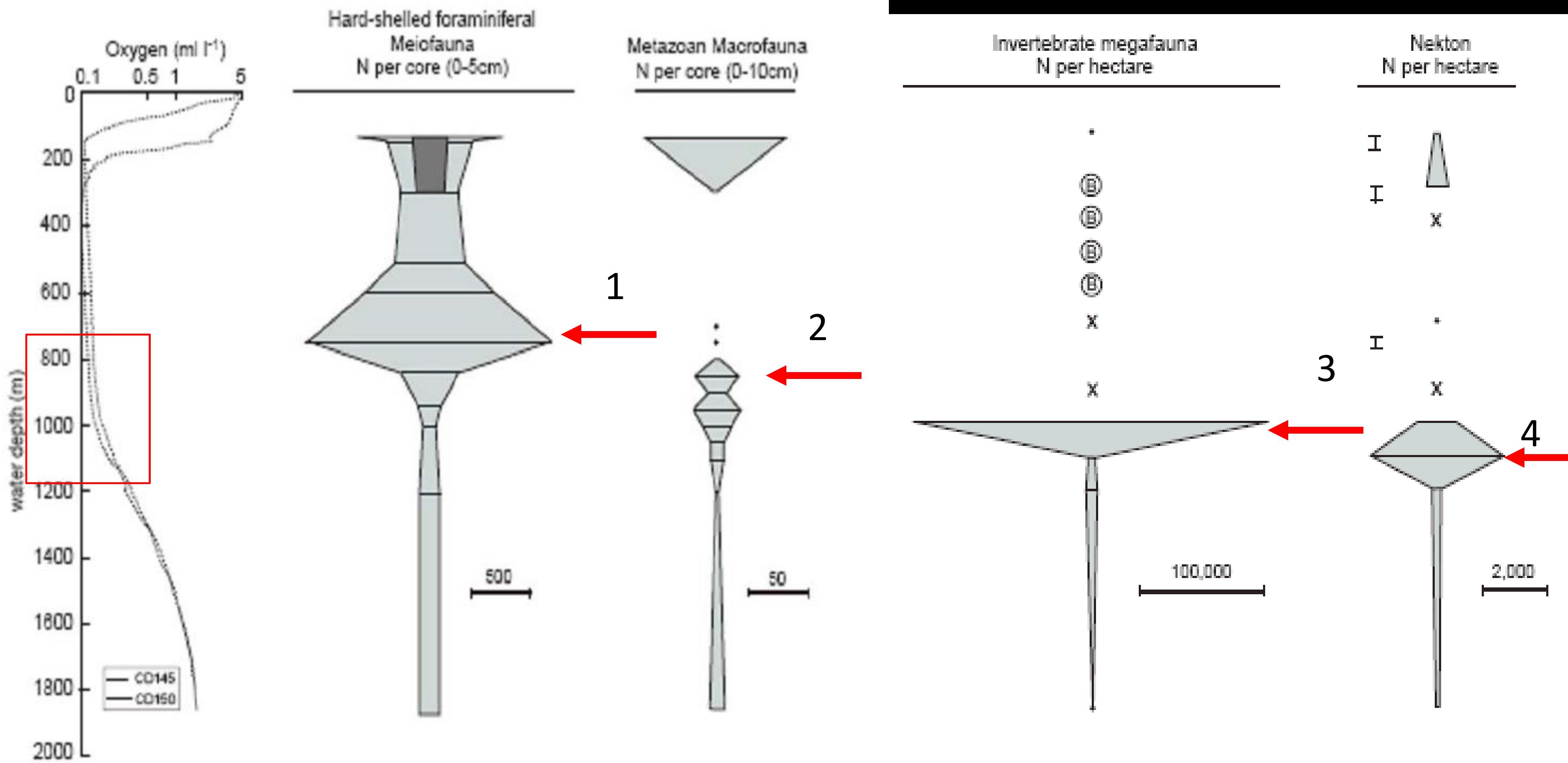
MACROFAUNA
(>0.3 mm)

- Oxygen Threshold (4-9 μM; 0.1-0.2 ml/l)
- Elevated Food
- Reduced Predation

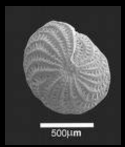


Levin 2003
OMBAR

SIZE MATTERS:
Size-specific oxygen thresholds are reflected in increasingly deeper maxima on the Pakistan Margin



Foraminifera



Macrofauna

Megafauna

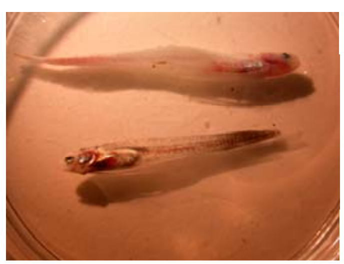
Nekton

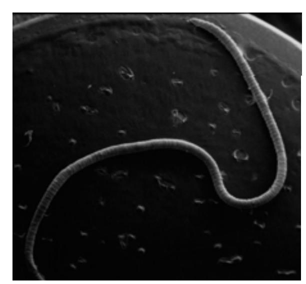
Gooday et al. 2009, DSR II

DOMINANCE: (Near) Single-Species Macrofaunal Communities Develop in the OMZ core

LOCATION	O_2 ml/l	DEPTH	DOMINANT TAXON	Proportion
Peru margin	0.02	300 m	*Olavius crassitunicatus*	83%
Pakistan margin	0.11	800 m	*Linopherus* sp.	84%
Oman margin	0.13	400 m	*Prionospio* sp.	63%
India margin	0.02	650 m	*Prionospio* sp.	100%
Chile margin	<0.20	200 m	*Diaphorosoma* sp.	73%
Volcano 7 (MX)	0.08	750 m	*Lepidomeniidae* sp.	49%
St. Barbara Basin	0.10	585 m	Nerillidae sp.	87%

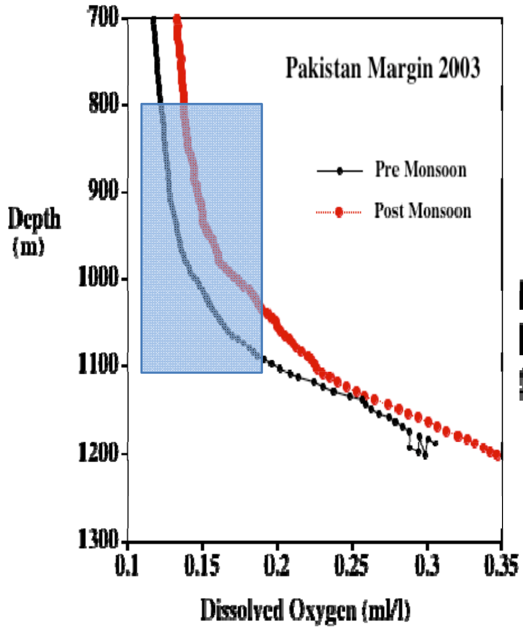
Low oxygen selects for high dominance

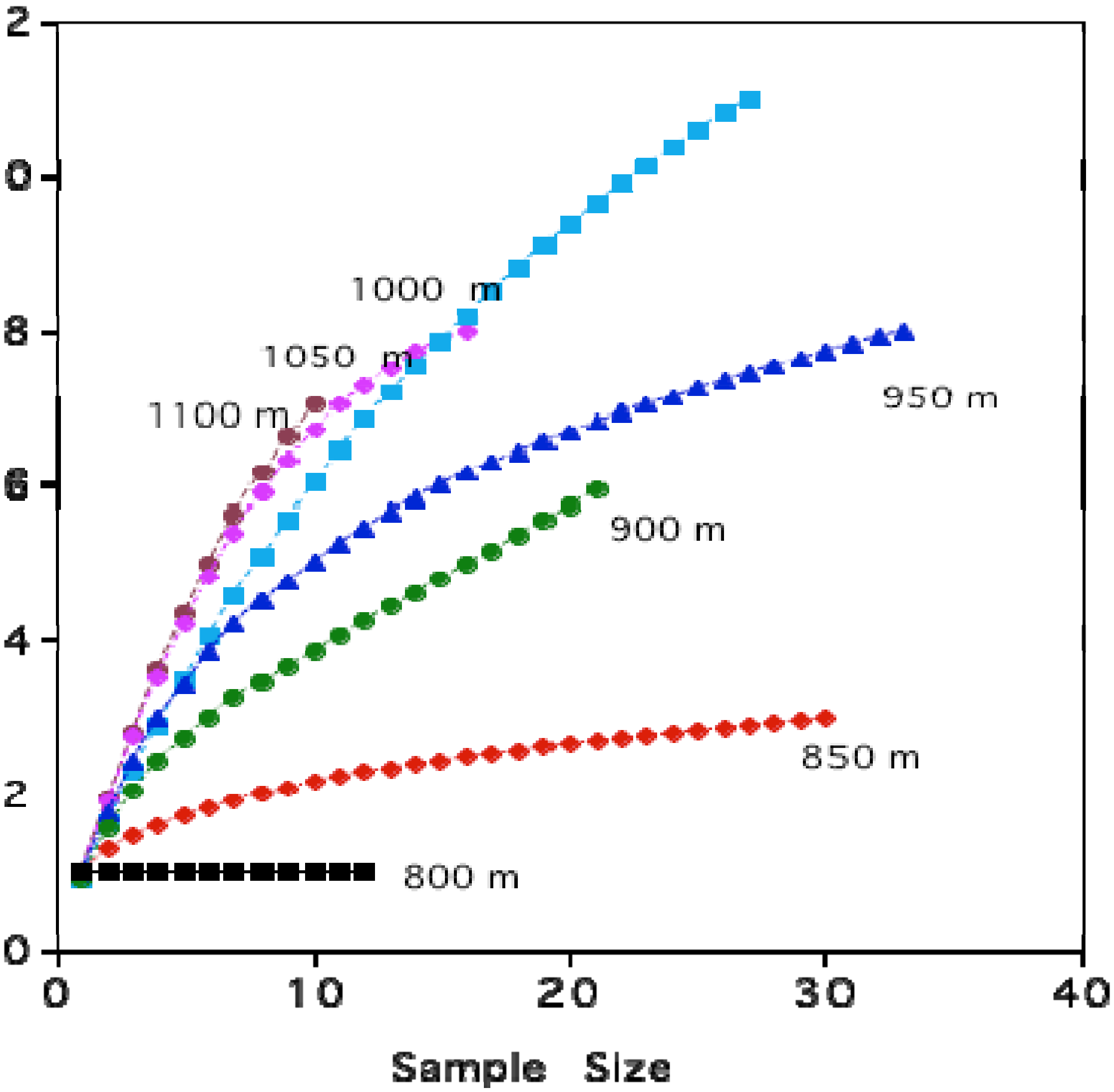






DIVERSITY: rapid shifts across oxygen gradients

Pakistan margin macrofauna in the Lower OMZ





HIGH DOMINANCE

Linopherus sp. (Amphinomidae)

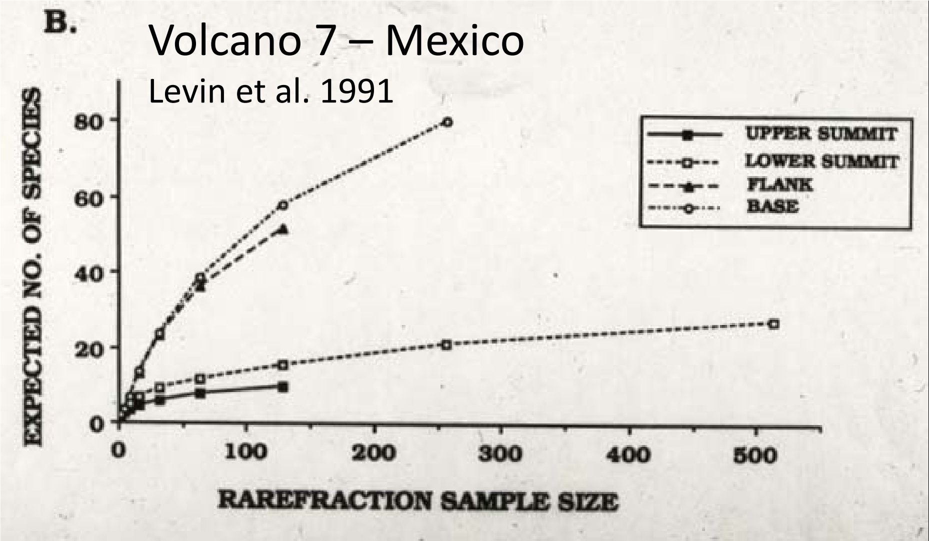
800 m 100% of macrofauna

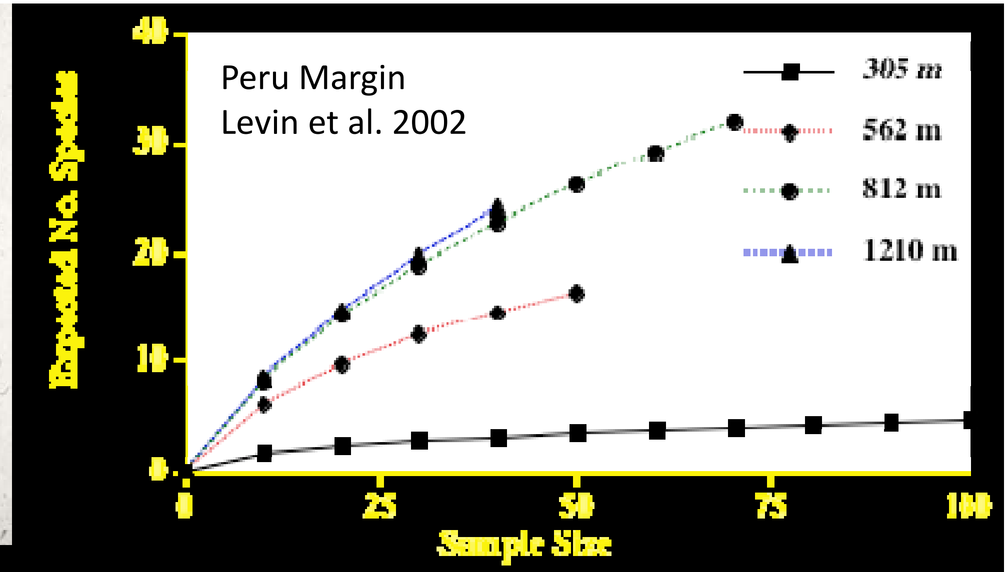
850m 80-84%

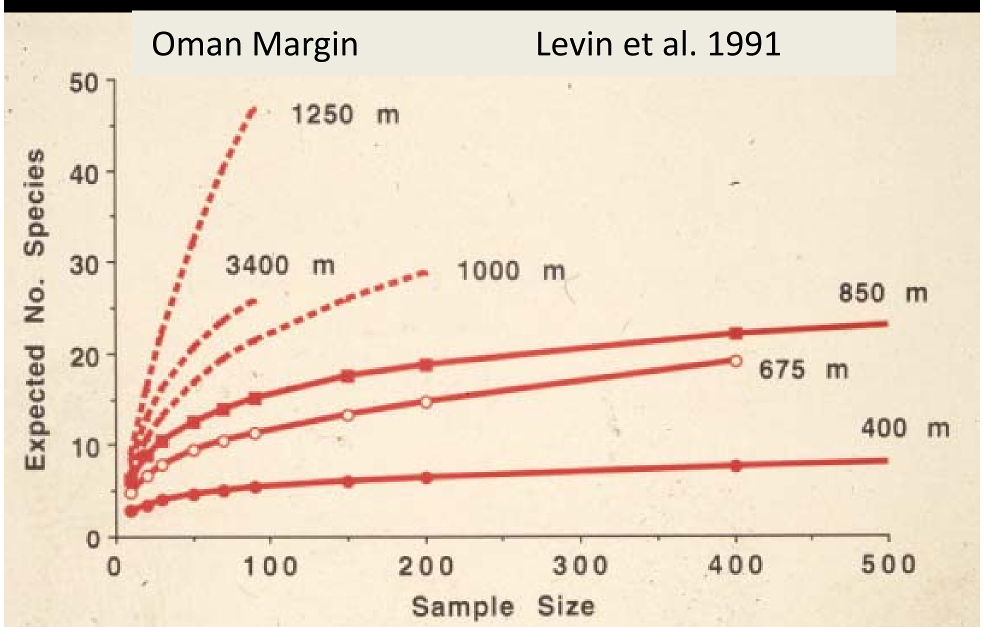
900m 44% of fauna

950m 24% of fauna

Levin et al. 2009 DSR II







74 BENTHIC MARINE DIVERSITY AND THE STABILITY-TIME HYPOTHESIS

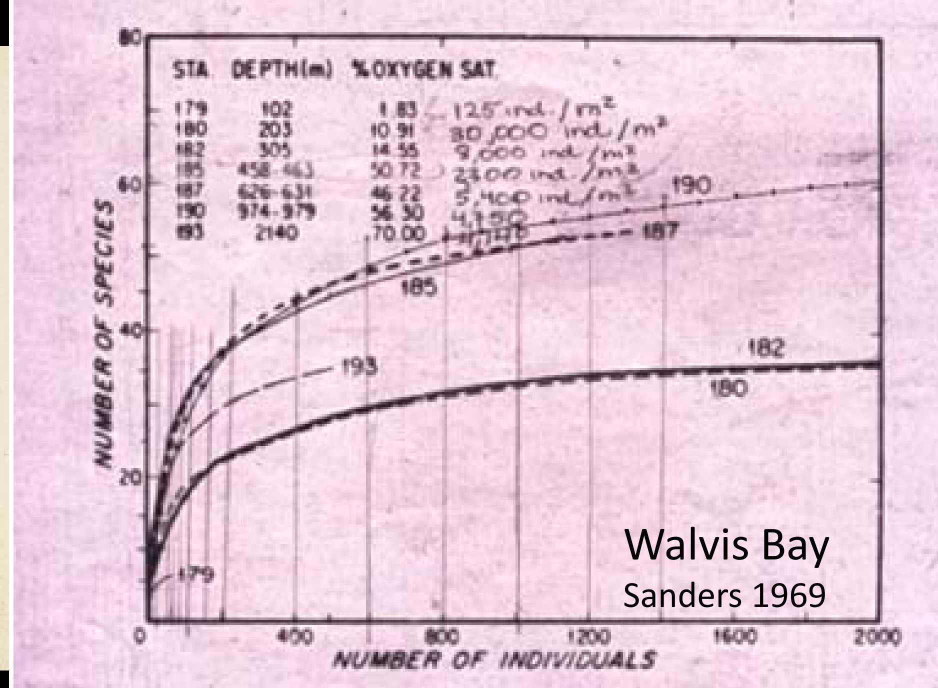
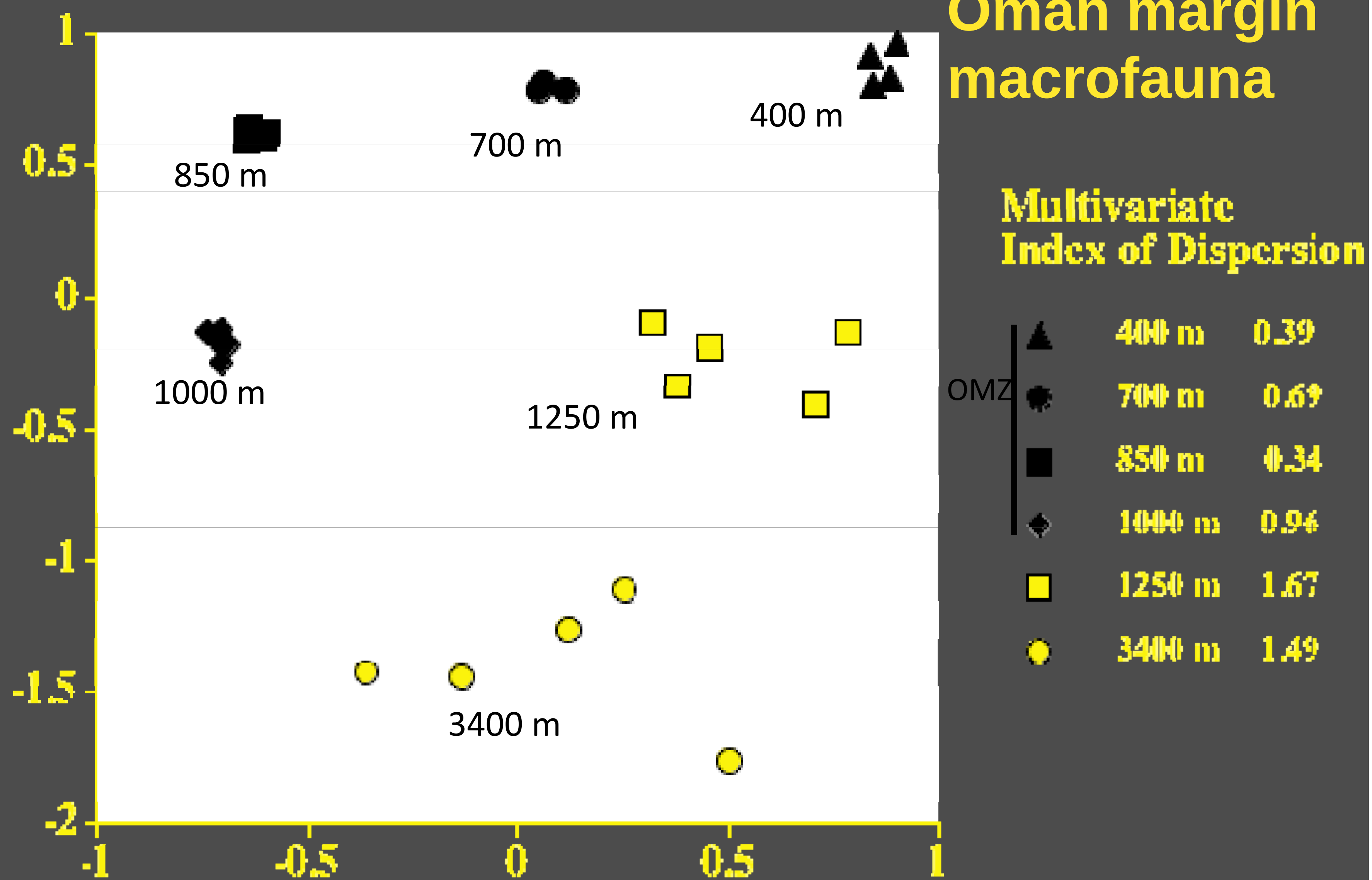


Figure 3. Diversity curves derived by the rarefaction method for the benthic stations of the Walvis Bay transect.

STRONG ZONATION and Reduced Spatial Heterogeneity

Oman margin macrofauna



MDS PLOT

Levin et al. 2000

What are the functional consequences of community responses to hypoxia?

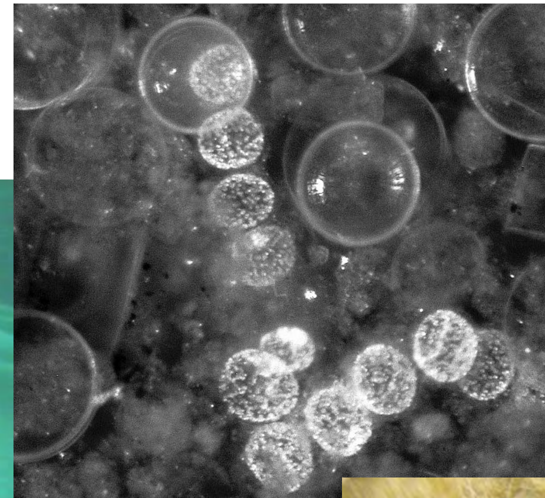
- Altered Trophic Pathways
- Changes in Carbon Processing
- Reduced Bioturbation and Carbon Burial

BACTERIAL MAT FORMATION

Sulfide-oxidizing/ bacteria form dense mats

Methane oxidation also occurs

Beggiatoa mats, Walvis Bay, Namibia



Thiomargarita
Namibia,
Costa Rica

Thioploca mats
Concepcion Bay,
Chile

HYPOTHESES:

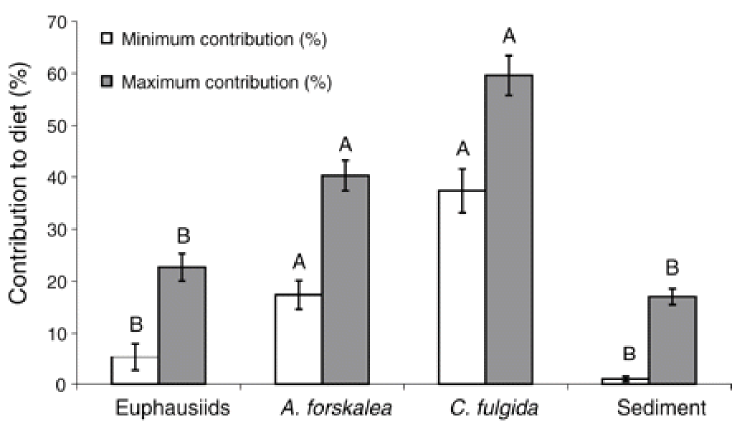
Metazoans associate with mats for

- -Detoxification of sulfide
- -As a food source
- -Physical refuge

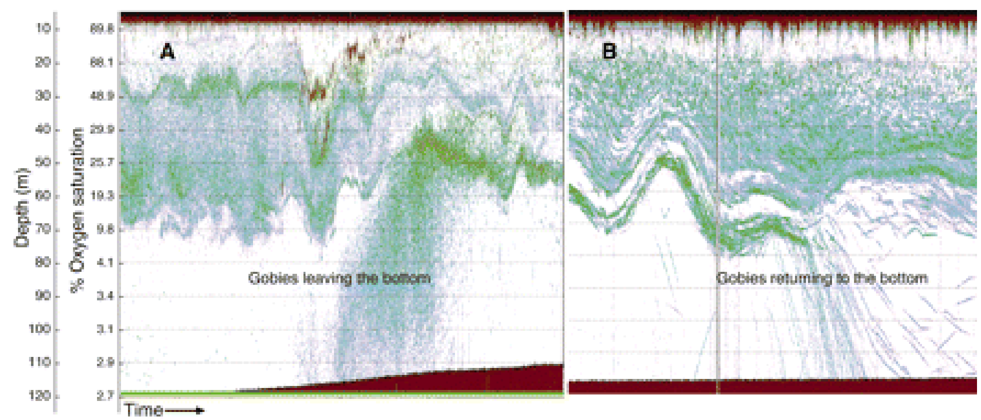
ARE THERE BACTERIAL CONSUMERS?

Dorvilleid & Onuphid Polychaetes

Utne-Palm et al. (Science 2010)

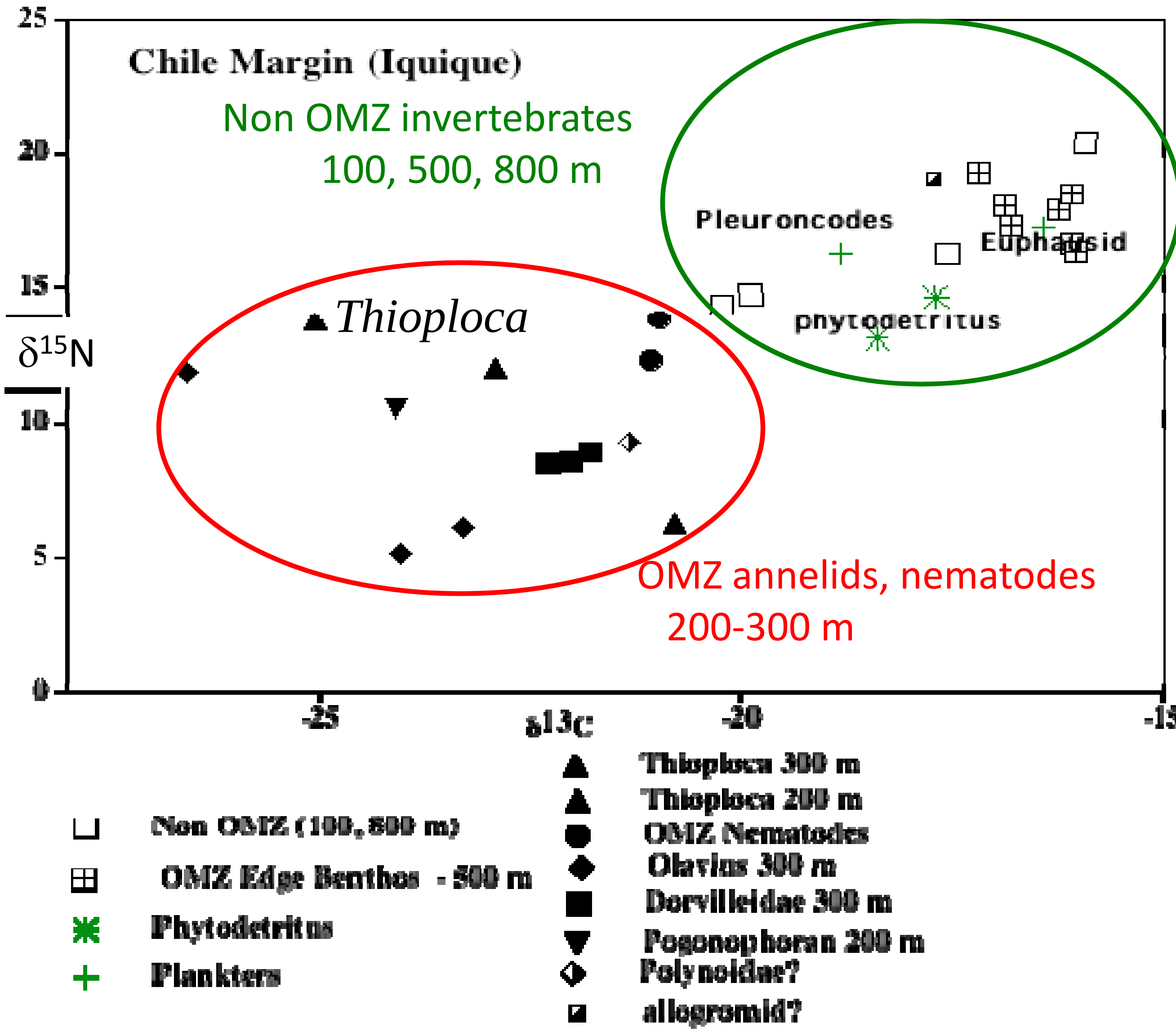


euphausids jellyfish bacteria



Increased importance of **chemosynthetic pathways**

Indicated by stable isotope signatures

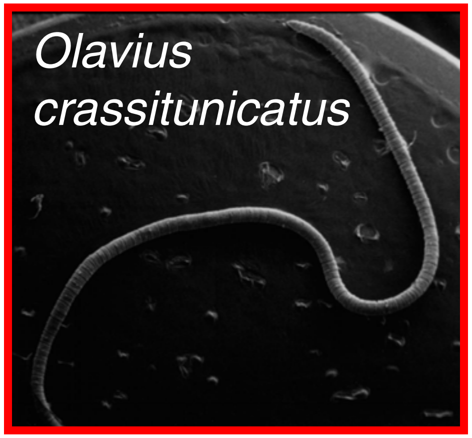


Shortened food webs with bacteria, phytodetritus at the base

Bacteria

Increased role for chemosynthetic symbioses

Peru margin - Oligochaetes



Santa Barbara Basin

Lucinoma aequizonata

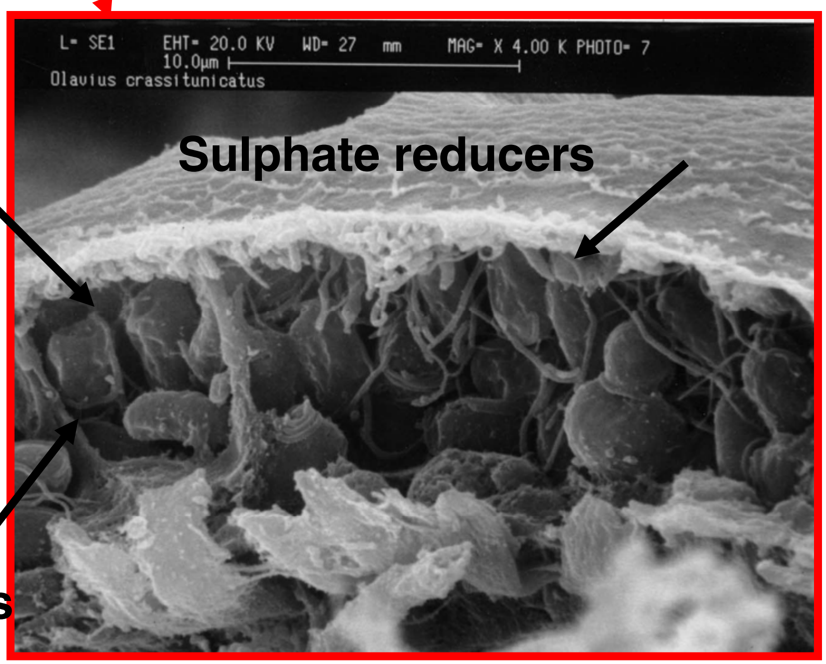
Oman margin

Lucina

Pakistan margin

Thyasira

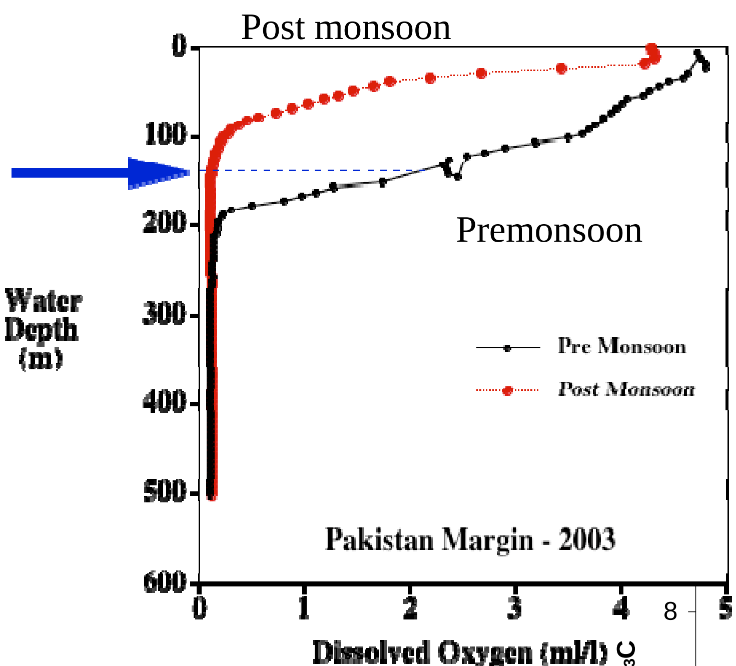
Sulphide oxidizers



Spirochaetes

OXYGEN CAN CONTROL KEY CARBON PROCESSORS

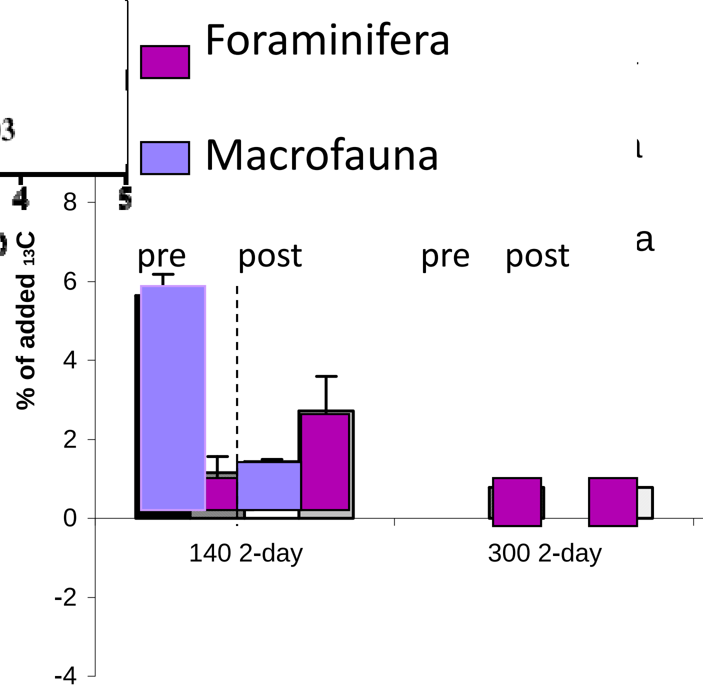
Pakistan Margin 140 m.

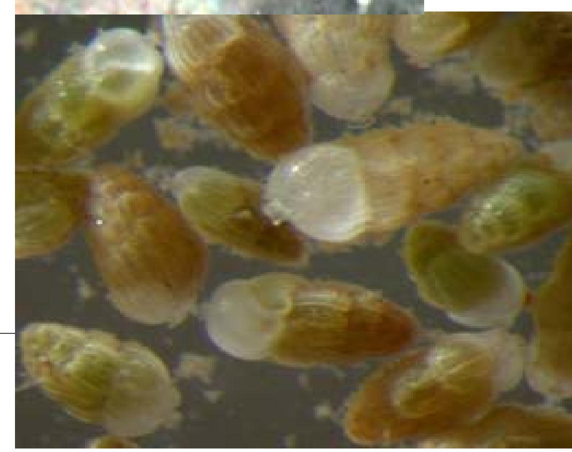


Organic Carbon processing is shifted from metazoan to protozoans (foraminifera) under hypoxic conditions

^{13}C phytodetritus labeling experiments

reveal C pathways.



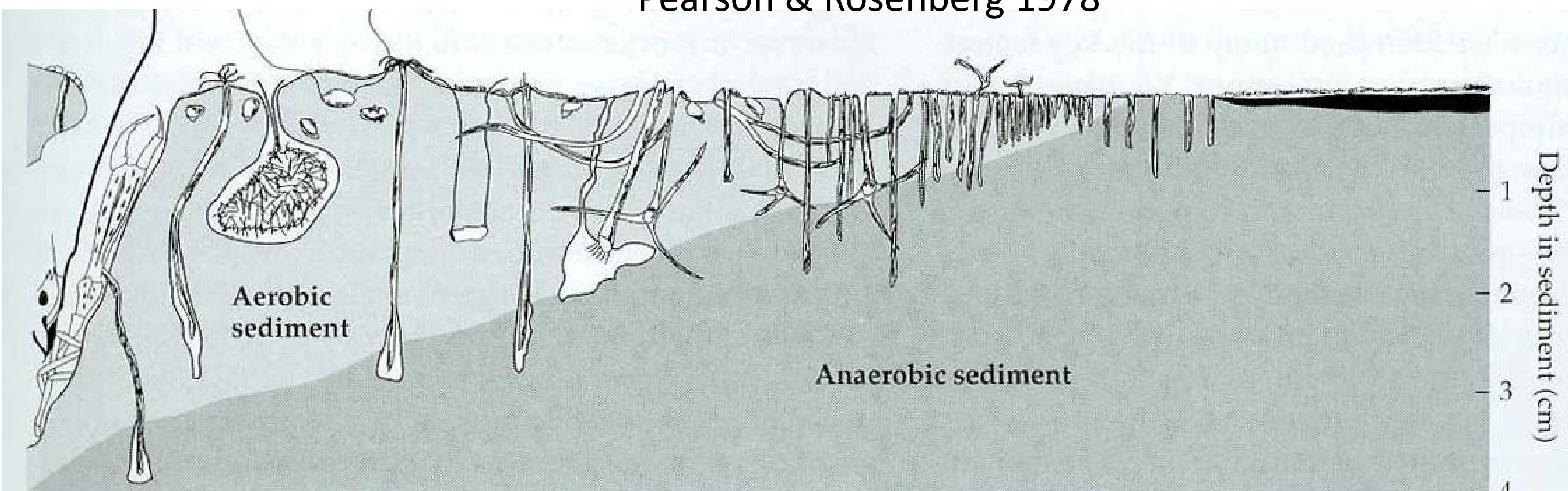


On the Pakistan margin the summer monsoon raises the OMZ upper boundary, making the shelf hypoxic

Woulds et al. 2007 L & O

FUNCTIONAL CONSEQUENCES:
Oxygen and organic matter control animal lifestyles and thus bioturbation within sediments

Shallow-Water Pollution Gradients
Pearson & Rosenberg 1978

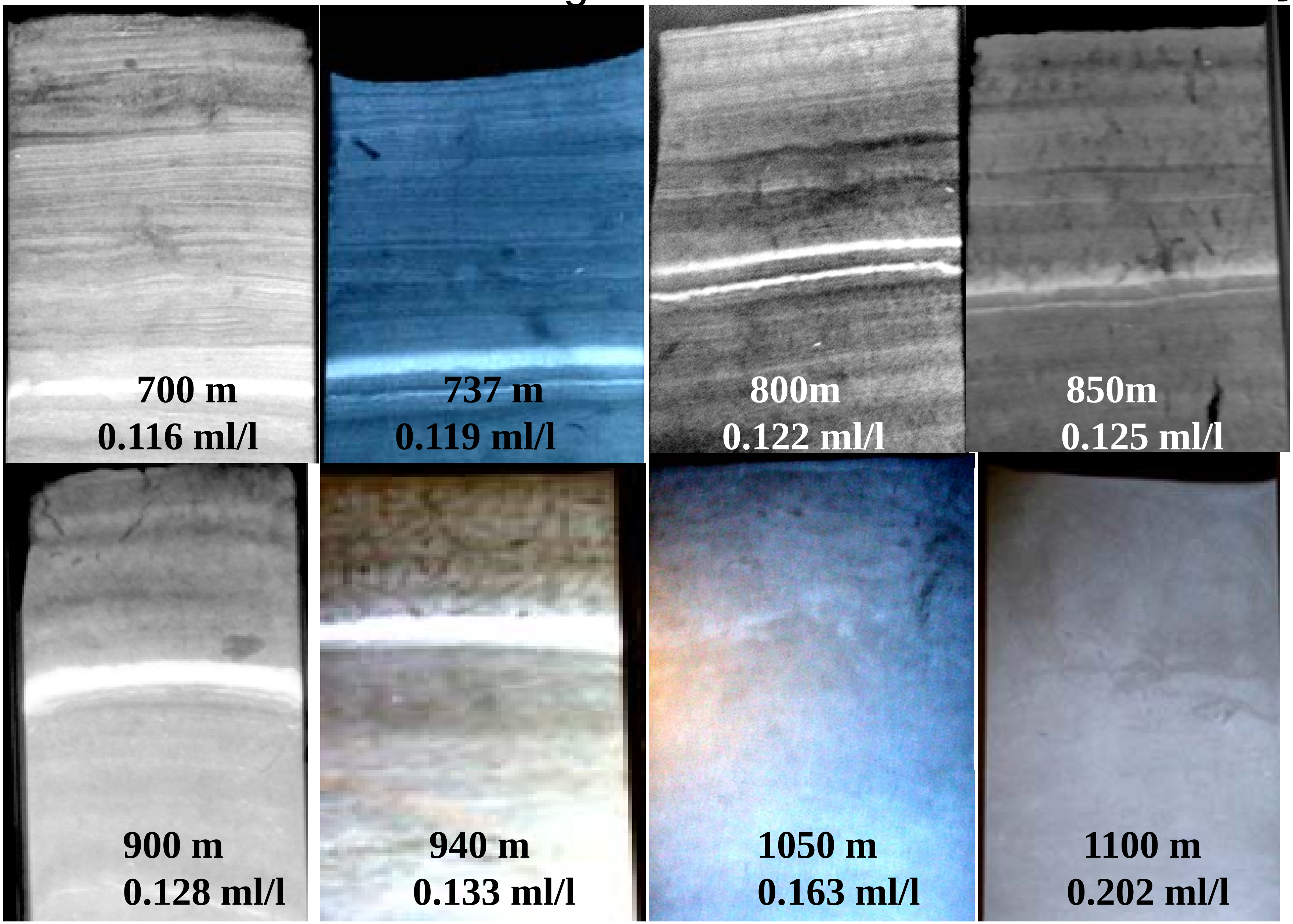


Zone	Normal	Transitory		Polluted	Grossly polluted
Typical macro-fauna domi-nants	*Nucula* *Amphiura* *Terebellides* *Rhodine* *Echinocardium* *Nephrops*	*Lobidoplax* *Corbula* *Goniada* *Thyasira* *Pholoe*	*Chaetozpne* *Anaitides* *Pectinaria* *Myriochele* *Ophiodromus*	*Capitella* *Scolelepis*	No macrofauna Surface covered by fiber "blanket"

high
low

Changes in bioturbation across oxygen gradients
Pakistan Margin – Lower OMZ

Levin et al. 2009
DSR II



HOW IS OXYGEN CHANGING?

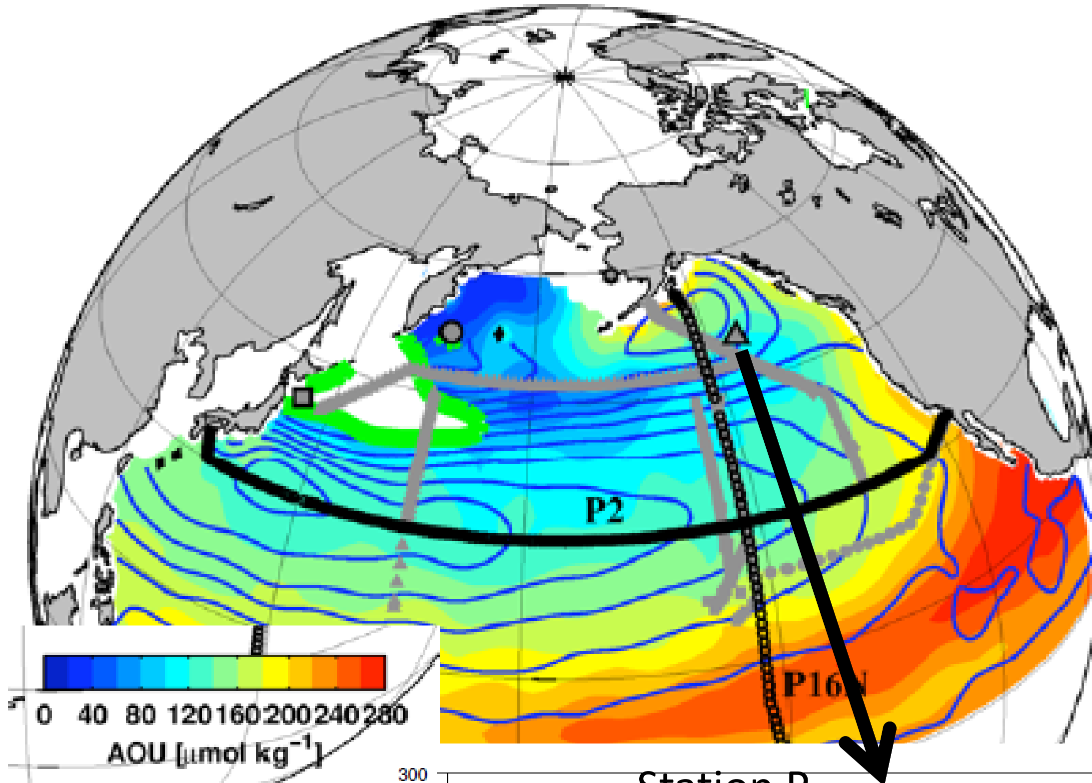
- Declining oxygen concentrations
(N. Pacific, Subtropical, Tropical Oceans)

- Expanding OMZs

- Interactions with Eutrophication, Warming,
Ocean Acidification

DECADAL-SCALE OXYGEN CHANGES in the NORTH PACIFIC OCEAN

Mecking et al. (2008)
Whitney, Freeland, Robert (2007)
Mecking, Warner and Bullister (2006)
Deutsch, Emerson & Thompson (2006)
Deutsch, Emerson & Thompson (2005)
Emerson et al., (2004)
Emerson, Mecking and Abell (2001)
Watanabe et al., (2001)
Ono et al. (2001)
Andreev & Kusakabe (2001)

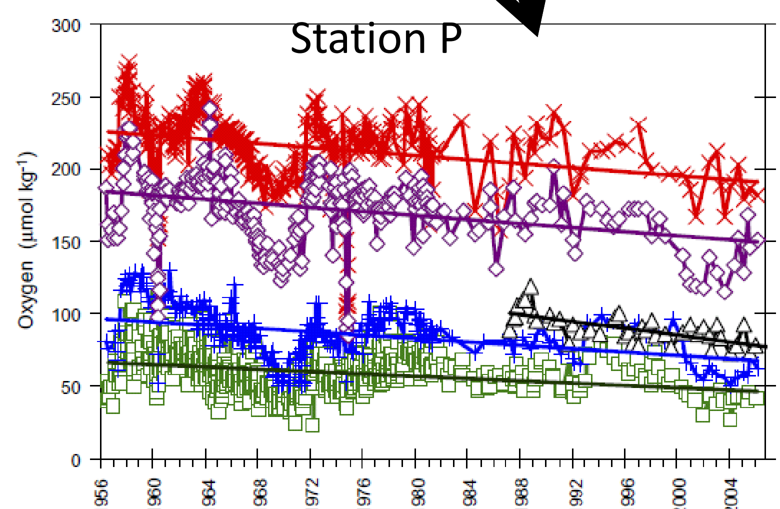


Locations of O_2 change studies in the North Pacific superimposed on AOU on σ_θ= 26.6

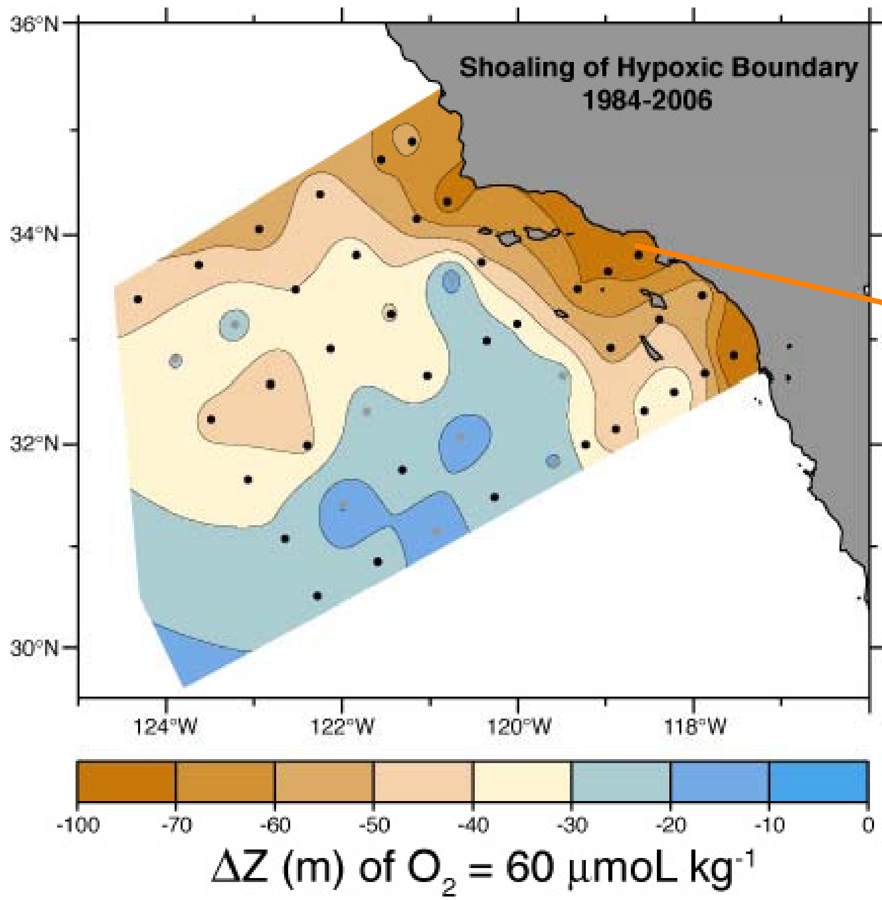
$$AOU = \{ [O_2] - [O_2]^{sat} \}$$

figure from Mecking et al., 2008

Whitney et al. 2007



Expansion of Low-Oxygen Habitat in southern California over the last 22 y



ΔZ_{mean} = -41 m

ΔZ_{max} = -92 m

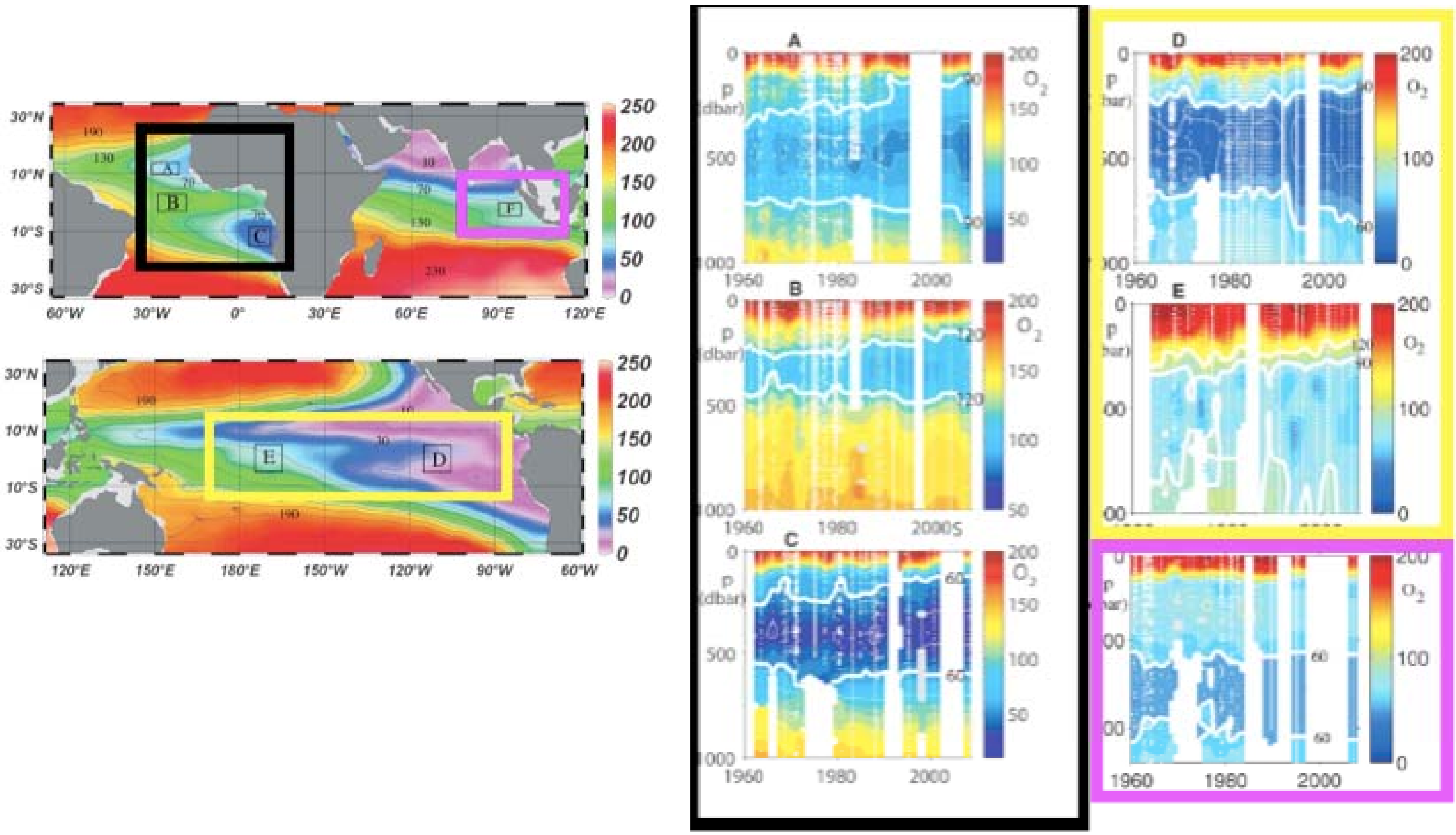
20-30% decline in oxygen at 200-300 m off southern CA

Shoaling of the hypoxic upper boundary

Bograd et al. 2008

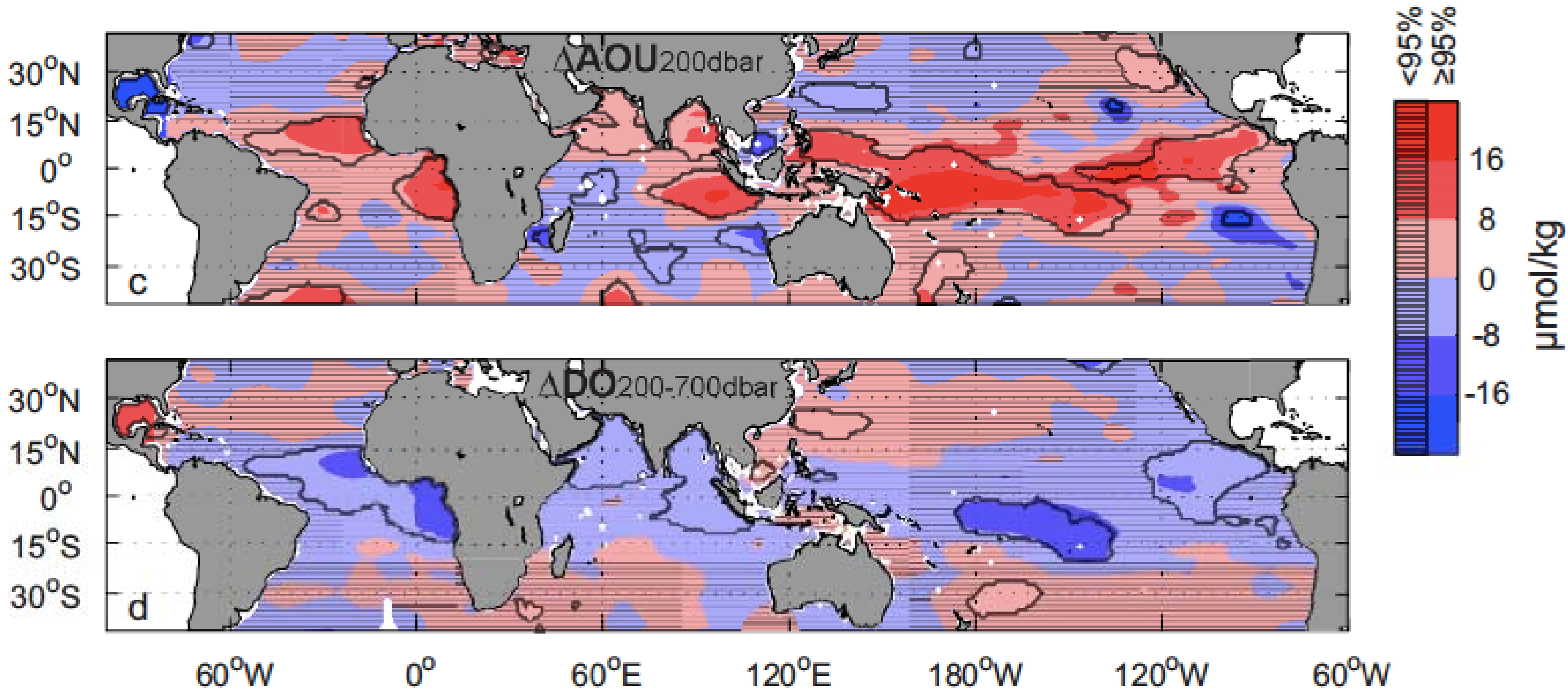
Expanding OMZs

Stramma et al. 2008



Time series 1960-present

Global changes in O_2 in 1964-70 vs 1990-2008 (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

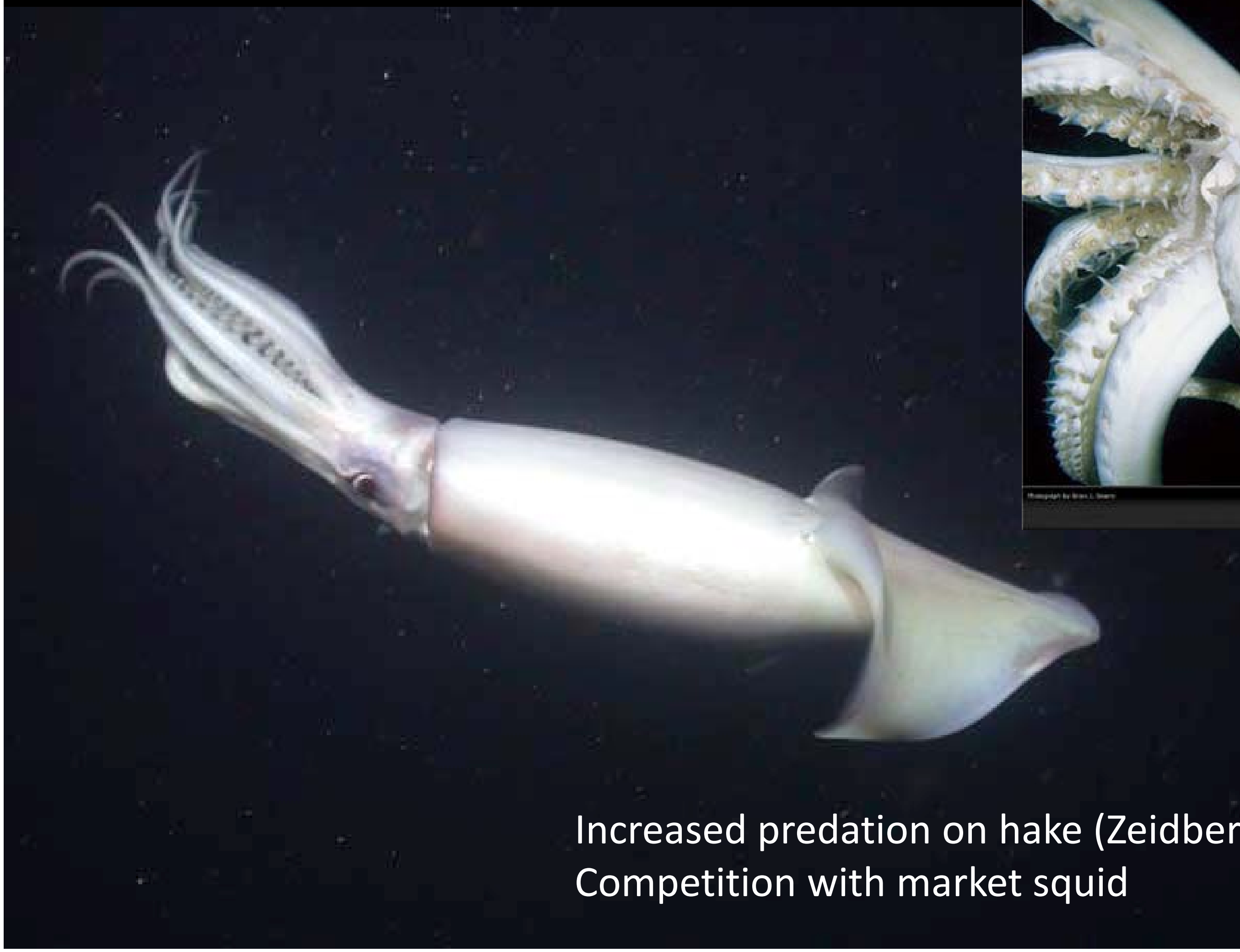
Stramma et al. 2010

What are the benthic consequences of expanding OMZs ?

Expansion of Humboldt Squid

(*Dosidicus gigas*)

to the North (Canada, Alaska) and to the South (central Chile)



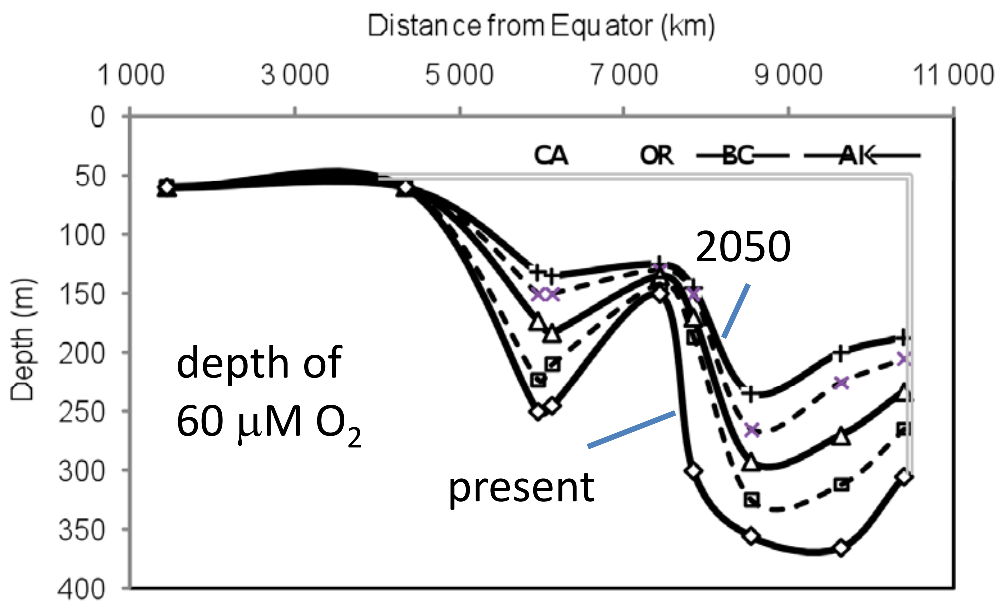
Increased predation on hake (Zeidberg & Robison 2007)

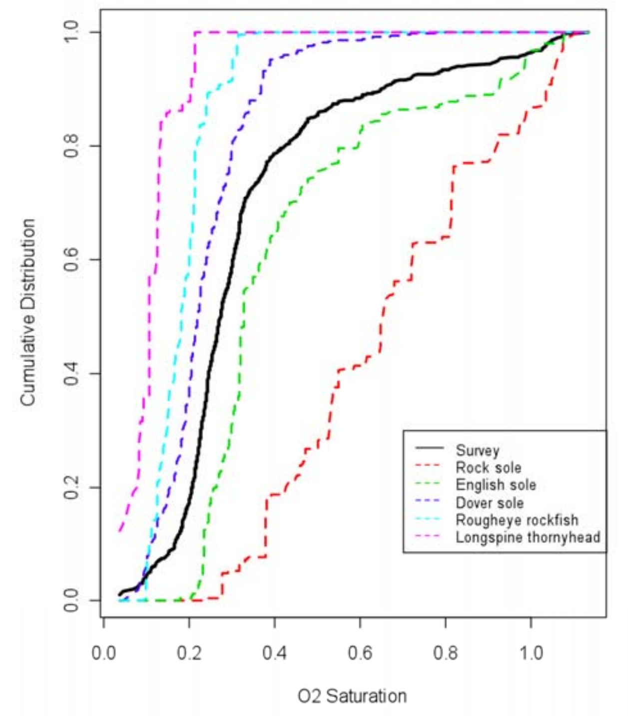
Competition with market squid

Vertical and Horizontal Habitat Compression

Crustaceans and Fish most susceptible

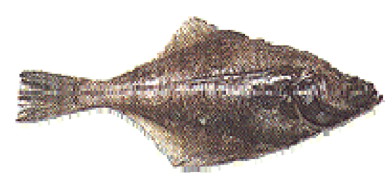
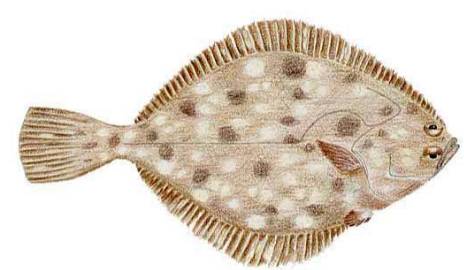
Whitney and Sinclair (Unpublished)
Loss of groundfish habitat from British Columbia & CA due to shoaling of hypoxic boundary



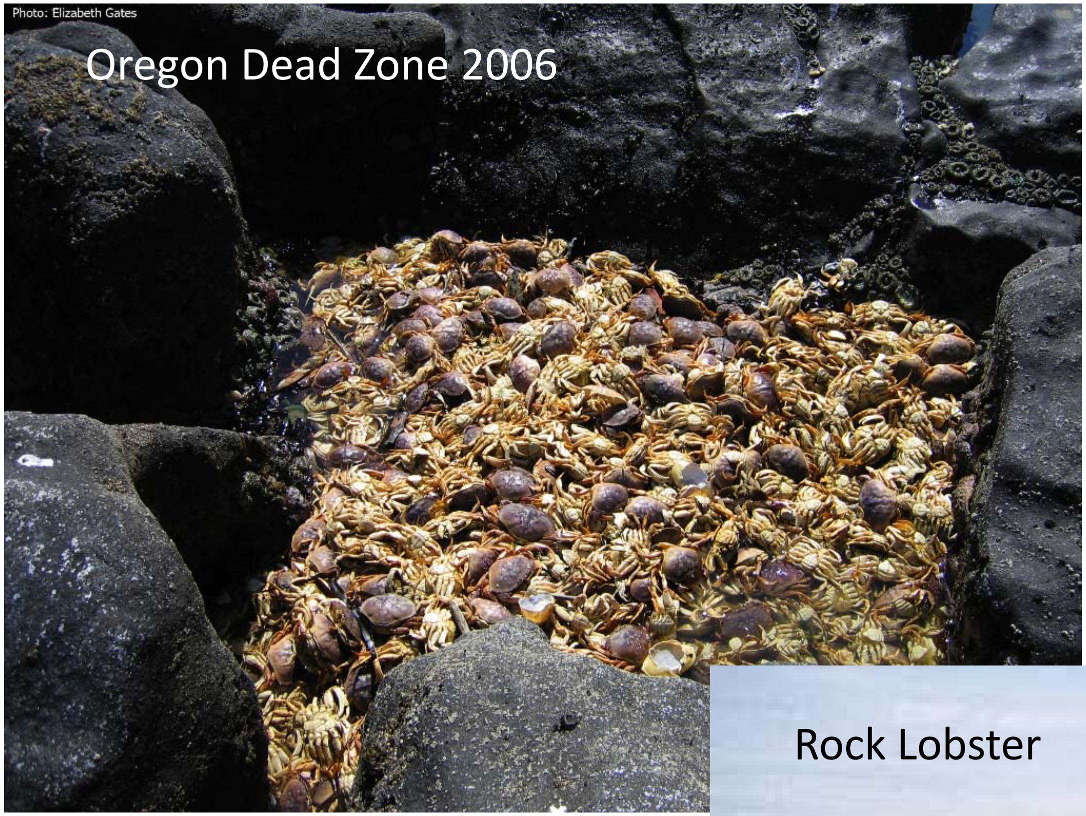


Groundfish distributions move shallower, northward
For species unable to tolerate $O_2 < 60\ \mu M$
By 2050 they will have lost 50% of their depth range



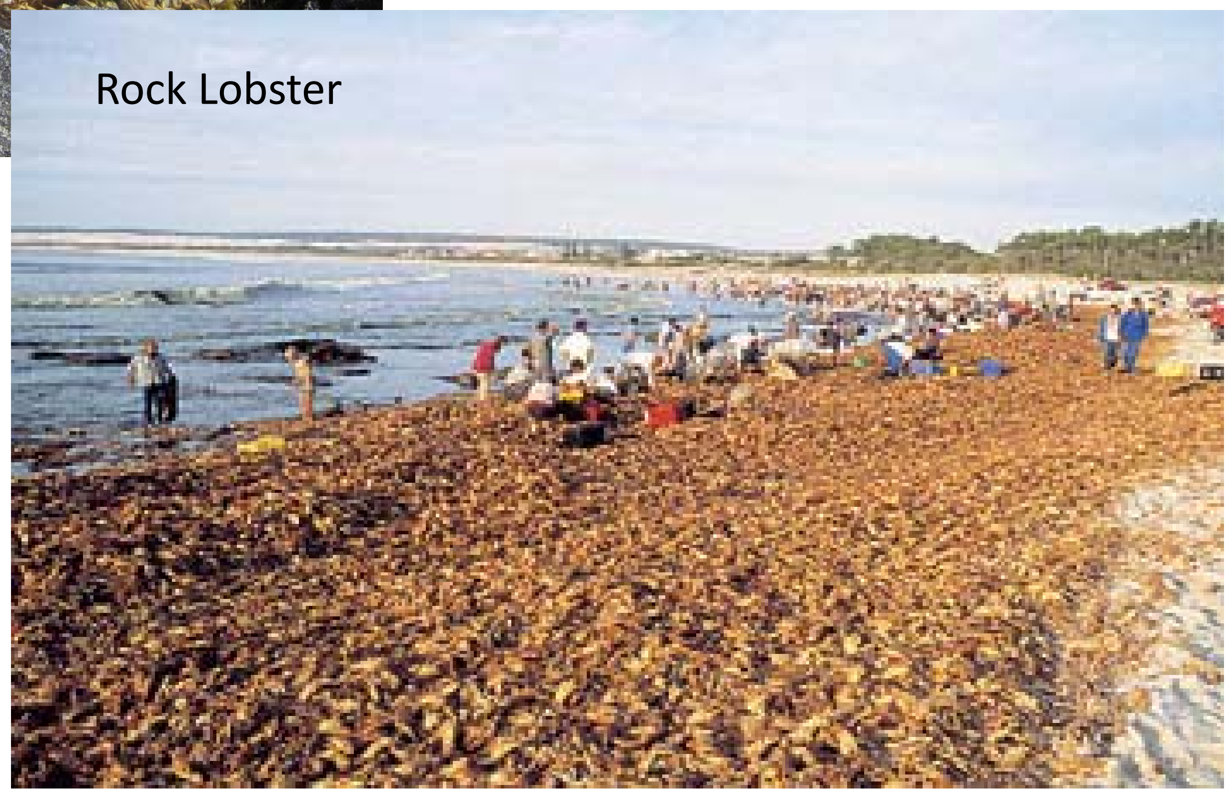



Crustacean die-offs



media.oregonlive.com/environment_impac
t/photo/crabjpg -de0ec1297074da2c.jpg

Benguela Walkout



OMZ Expansion will yield loss of faunal:

- Biomass (size)
- Diversity, Calcifiers
- Vertical range & habitat area
- Roles in carbon processing & burial, shorter food chains

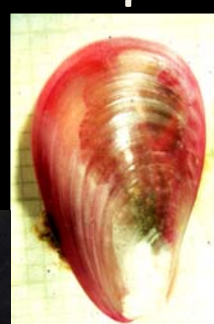
Losers: Echinoderms, Crustaceans, Groundfish

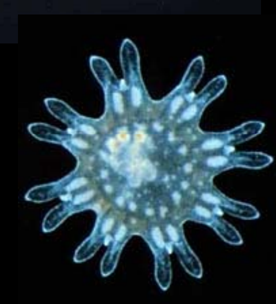




Winners: Annelids, Molluscs, Bacteria
(Cephalopods, Jellyfish)

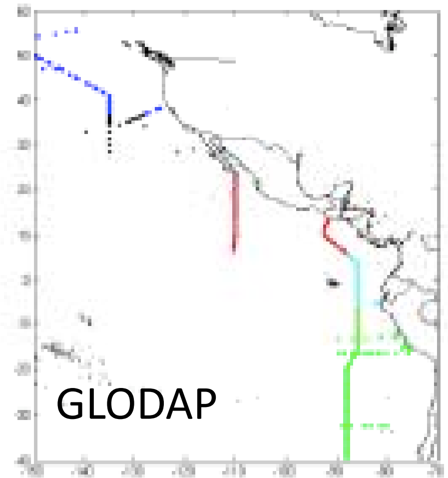




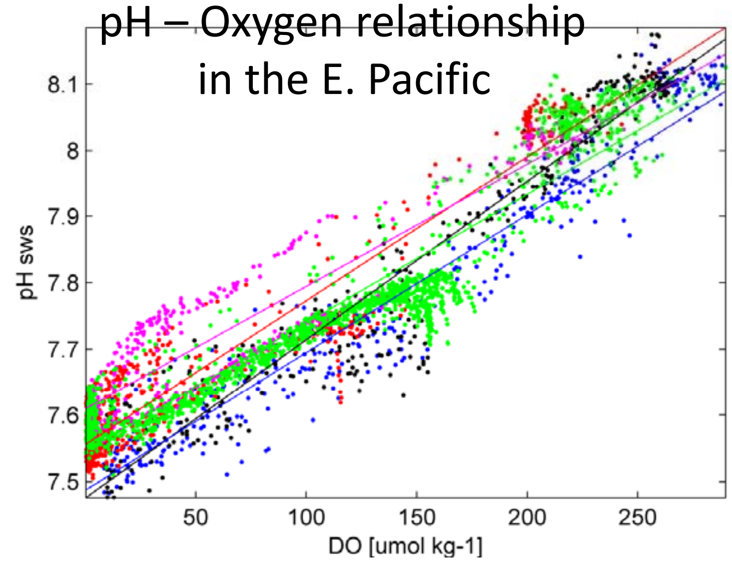



How will deoxygenation interact with other climate change features?

- **Warming**
  - *Reduced oxygen solubility*
  - *Hypoxia will reduce ability to cope with thermal shifts (Portner and Knust 2007)*



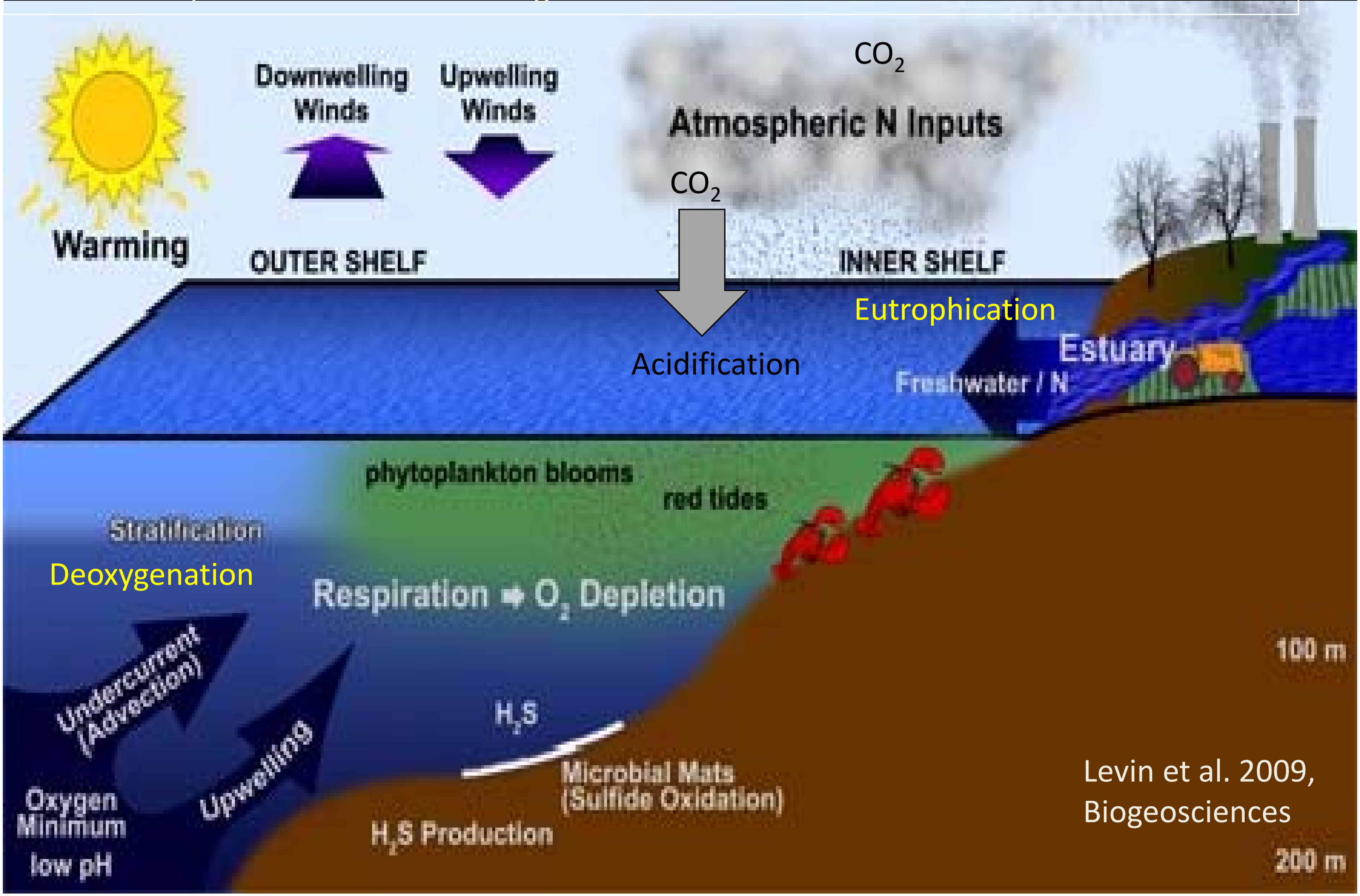
- **Ocean acidification**
  - *Hypoxic waters are corrosive*
  - *Anthropogenic CO_2 will exacerbate already low pH*
  - *Calcifiers may be hardest hit.*



AND WITH OTHER HUMAN INSULTS

- **Coastal eutrophication**
- **Harmful algal blooms**
- **Overfishing**

Upwelling margins might experience the *perfect 'climate' storm*:
-Rising Temperature –Eutrophication - Acidification, -Upwelling of low O2/low pH water - Stratification/reduced ventilation - Algal bloom



QUESTIONS AND NEEDS

- Are oxygen trends secular or cyclical?
- How do we distinguish pH from hypoxia effects on benthos?
- Can animals adapt to oxygen declines? At what rate?
- How will oxygen-induced changes in diversity translate to changes in function and services?
- What management activities address deoxygenation?

DATA & TECHNOLOGY

- Can we monitor oxygen remotely (with satellites)?
- How can we address the poor quality of archived oxygen data?
- How to increase synoptic O_2 coverage – floats and gliders?
- Can we develop proxies for oxygen (and pH) exposure?

Deoxygenation:

The Br[other] CO_2 Problem

(as in Oh Brother!)