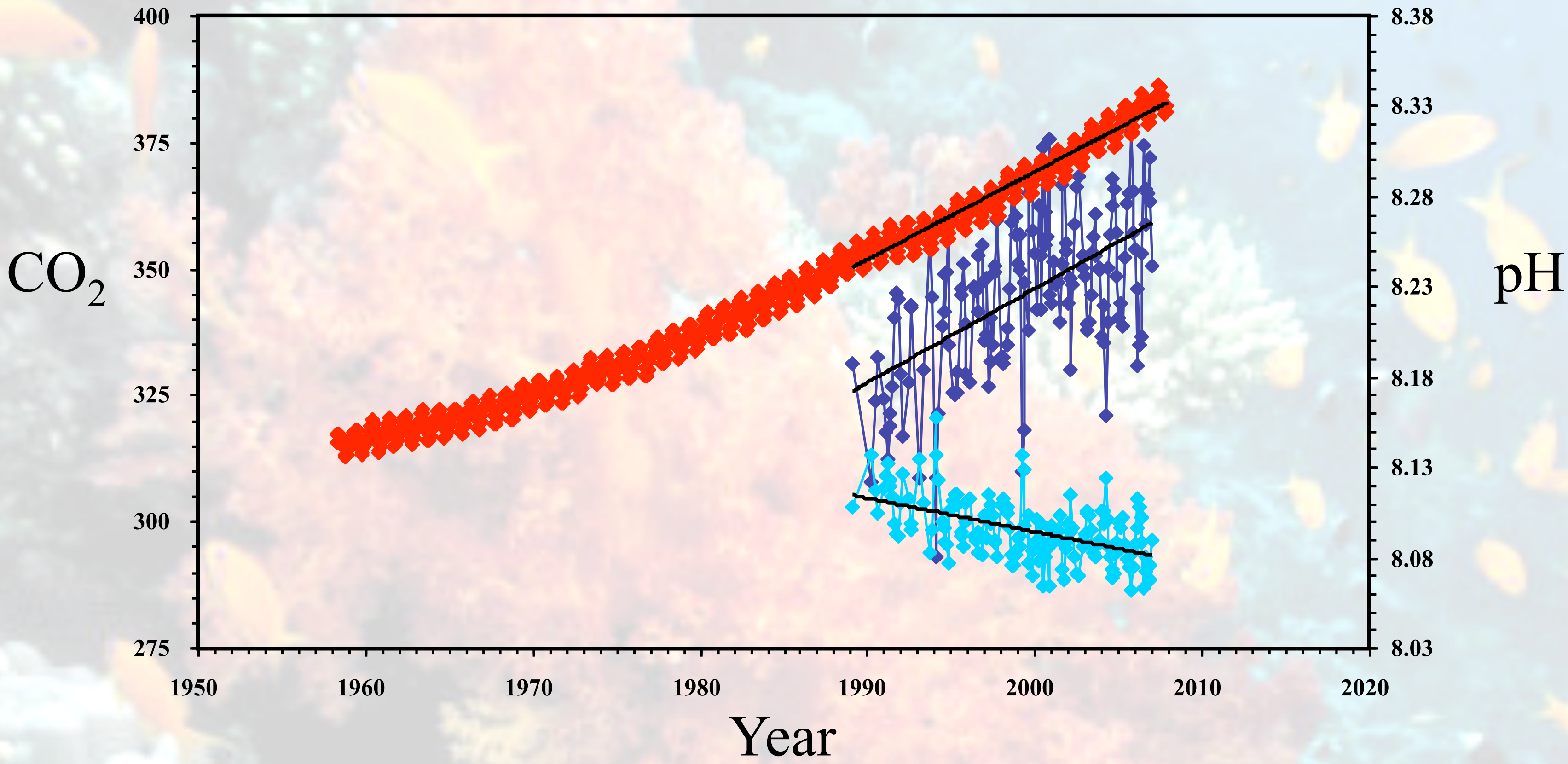
Ocean Acidification: The Other CO_2 Problem

Richard A. Feely
NOAA/Pacific Marine Environmental Laboratory

January 30, 2009

With special thanks to: James Orr, Victoria Fabry, Carol Turley, Chris Sabine, Joanie Kleypas, Kitack Lee, and Simone Alin



What we know about the ocean chemistry of *...saturation state*

$$CO_2 + CO_3^{2-} + H_2O \Leftrightarrow 2HCO_3^-$$

Saturation State

$$\Omega_{phase} = \frac{[Ca^{2+}][CO_3^{2-}]}{K^*_{sp,phase}}$$

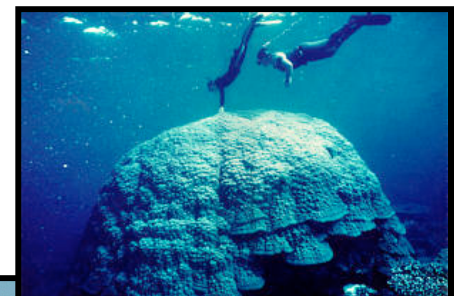
$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$$

calcium + carbonate → calcium carbonate

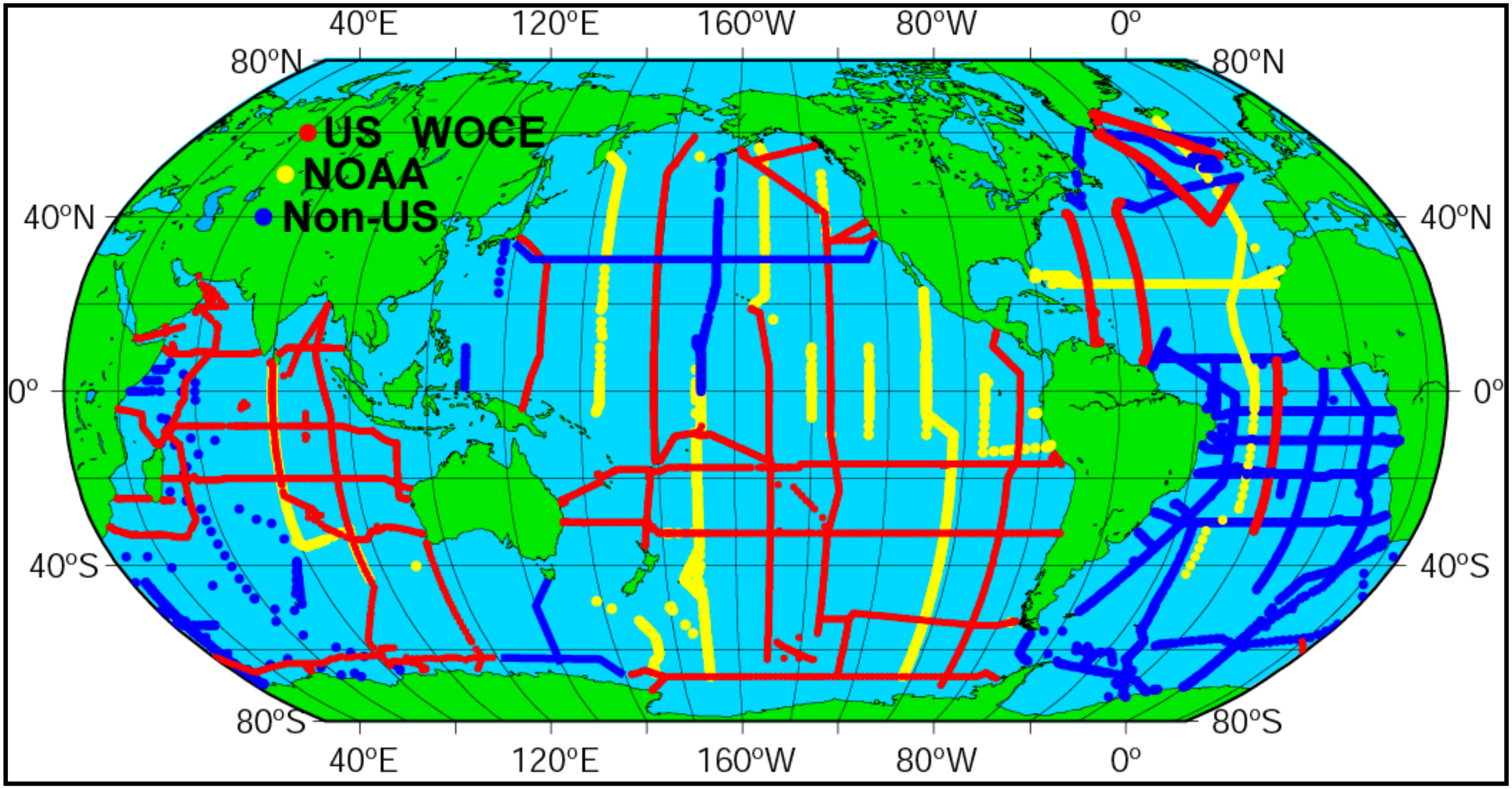
$\Omega > 1 = precipitation$

$\Omega = 1 = equilibrium$

$\Omega < 1 = dissolution$



What we know about ocean CO_2 chemistry *...from field observations*



WOCE/JGOFS/OACES Global CO_2 Survey

~72,000 sample locations collected in the 1990s

DIC ± 2 μmol kg^{-1}

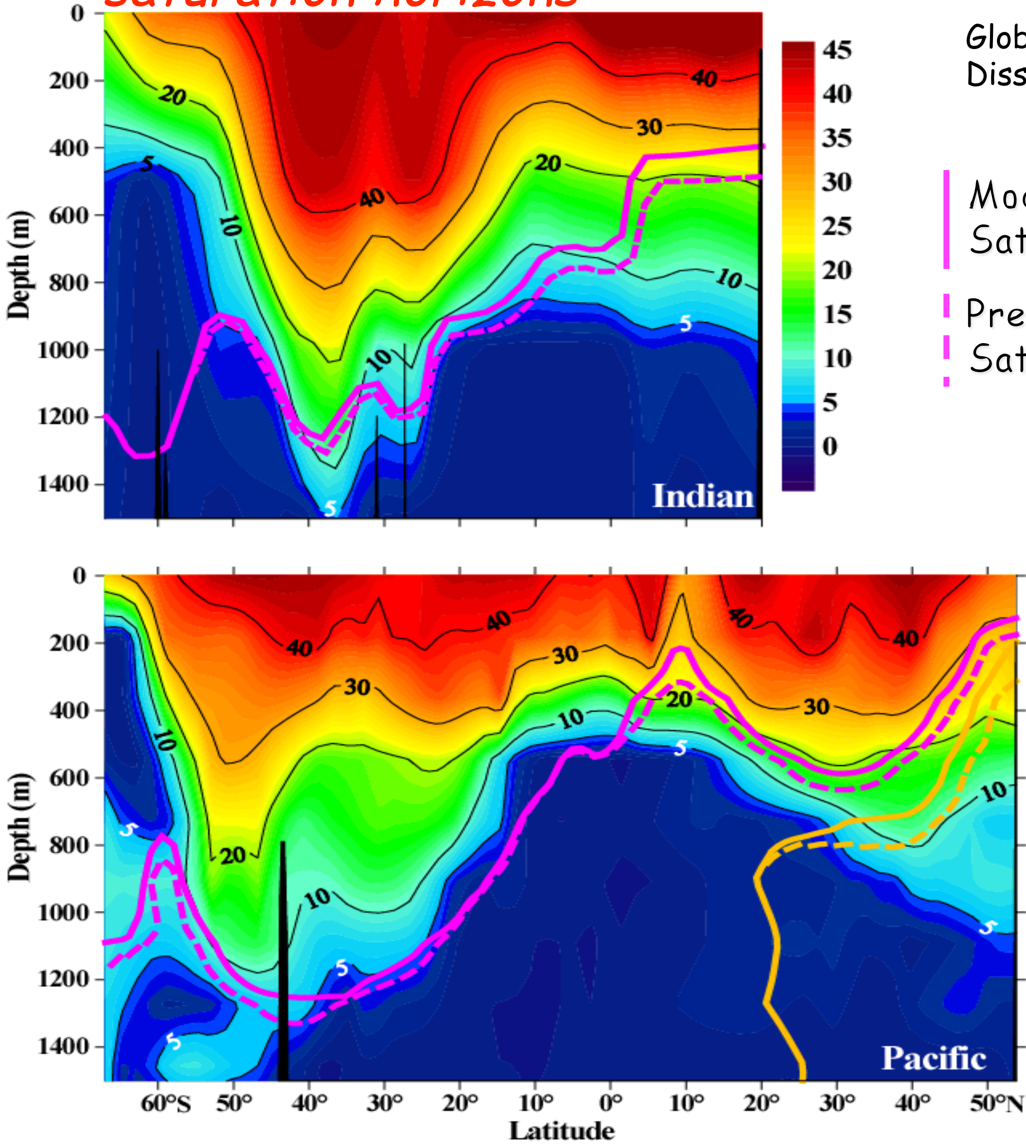
TA ± 4 μmol kg^{-1}

Sabine et al (2004)

CLIMATE CHANGE, NATURAL RESOURCES AND COASTAL MANAGEMENT

A WORKSHOP ON THE COASTAL ECOSYSTEMS OF CALIFORNIA, OREGON AND WASHINGTON

What we know about ocean CO_2 chemistry…*from observed shoaling saturation horizons*



Global Water-column Dissolution = 0.5 Pg C yr^{-1}

Modern Aragonite Saturation Horizon

Preindustrial Aragonite Saturation Horizon

Modern Calcite Saturation Horizon

Preindustrial Calcite Saturation Horizon

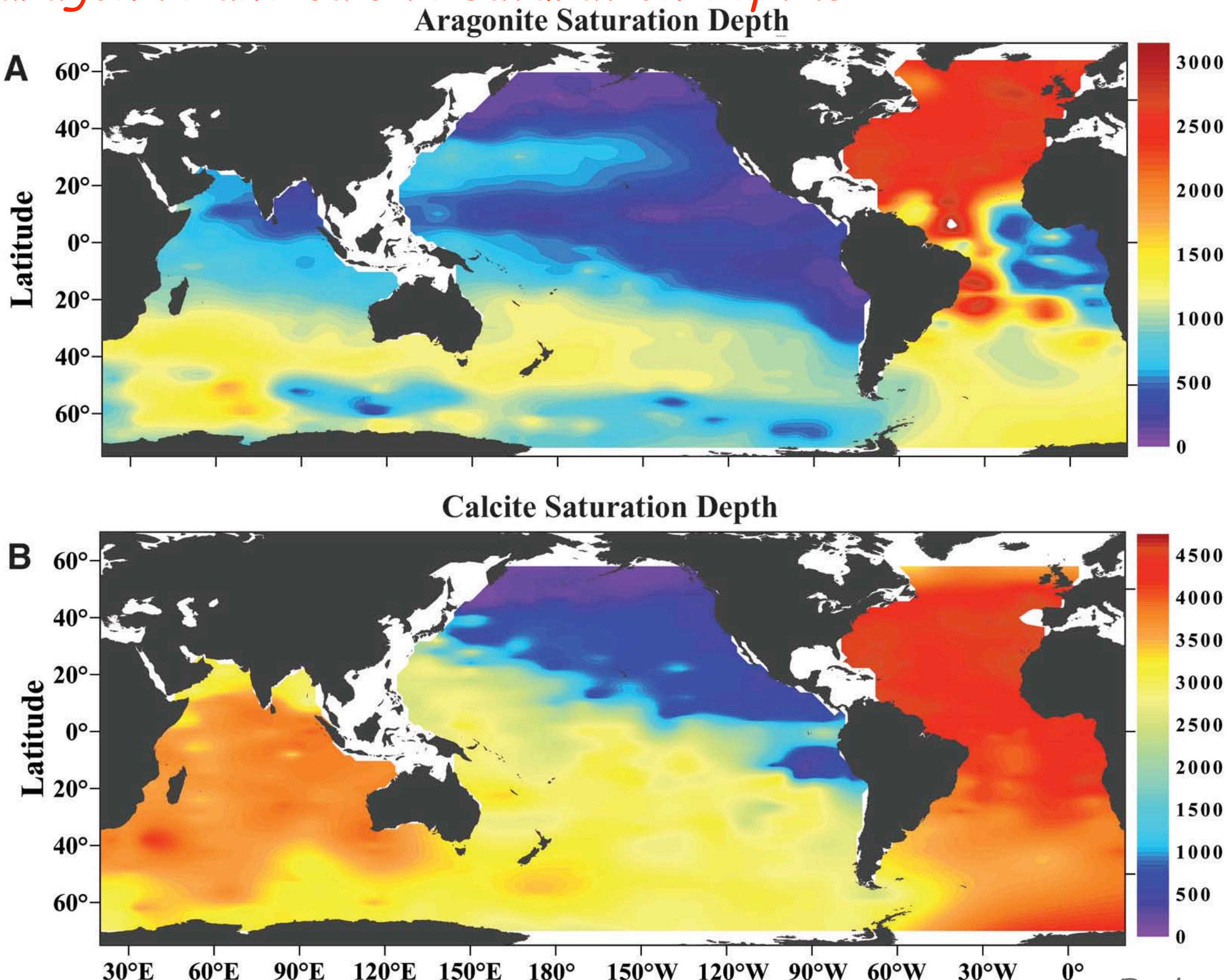
The aragonite and calcite saturation horizons have shoaled towards the surface of the oceans due to the penetration of anthropogenic CO_2 into the oceans.

Feely et al. (2004)

Climate Change, Natural Resources and Coastal Management

A workshop on the coastal ecosystems of California, Oregon and Washington

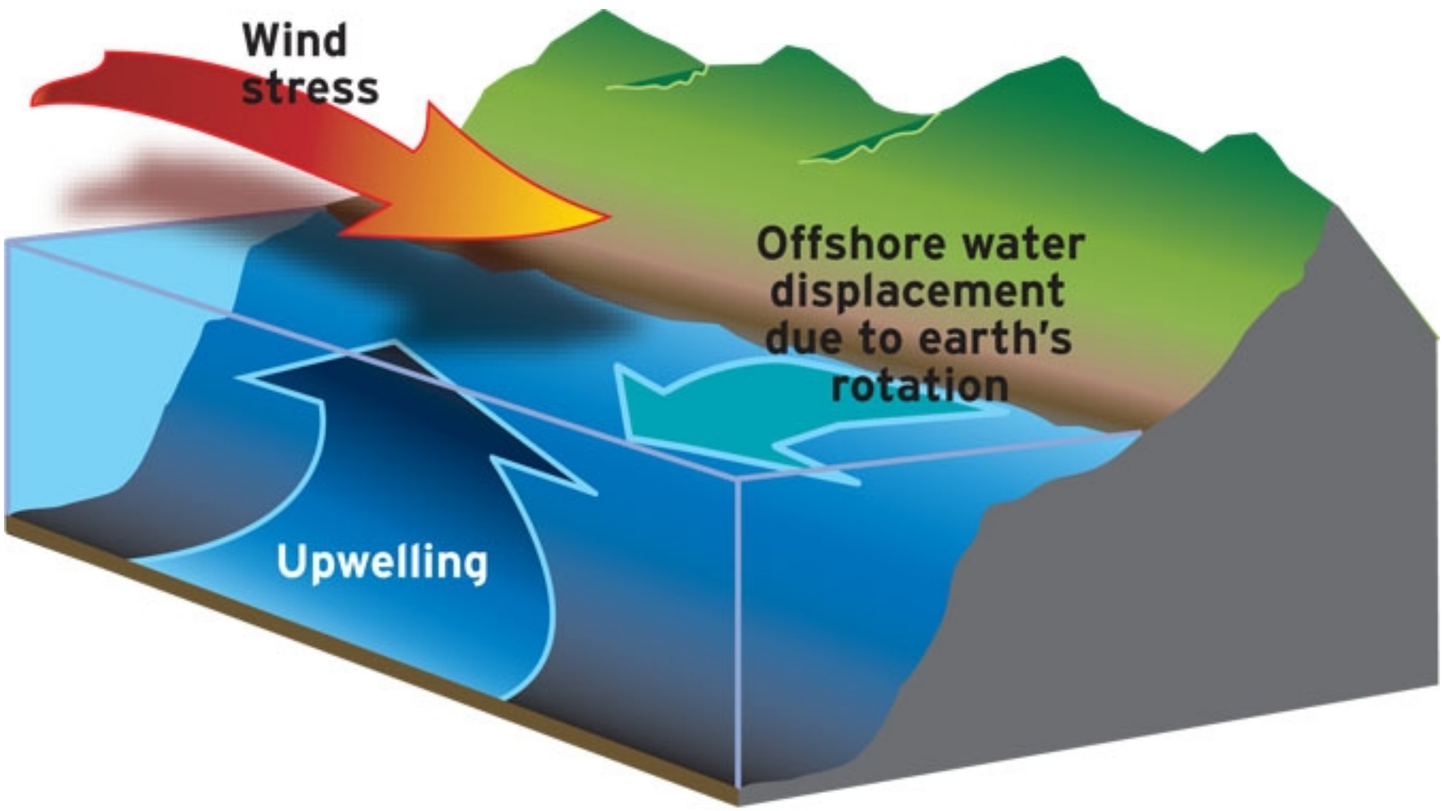
What we know about ocean CO_2 chemistry*…from observed aragonite and calcite saturation depths*



Feely et al. (2004)

Natural processes that could accelerate the ocean acidification of coastal waters

- Coastal Upwelling



North American Carbon Program

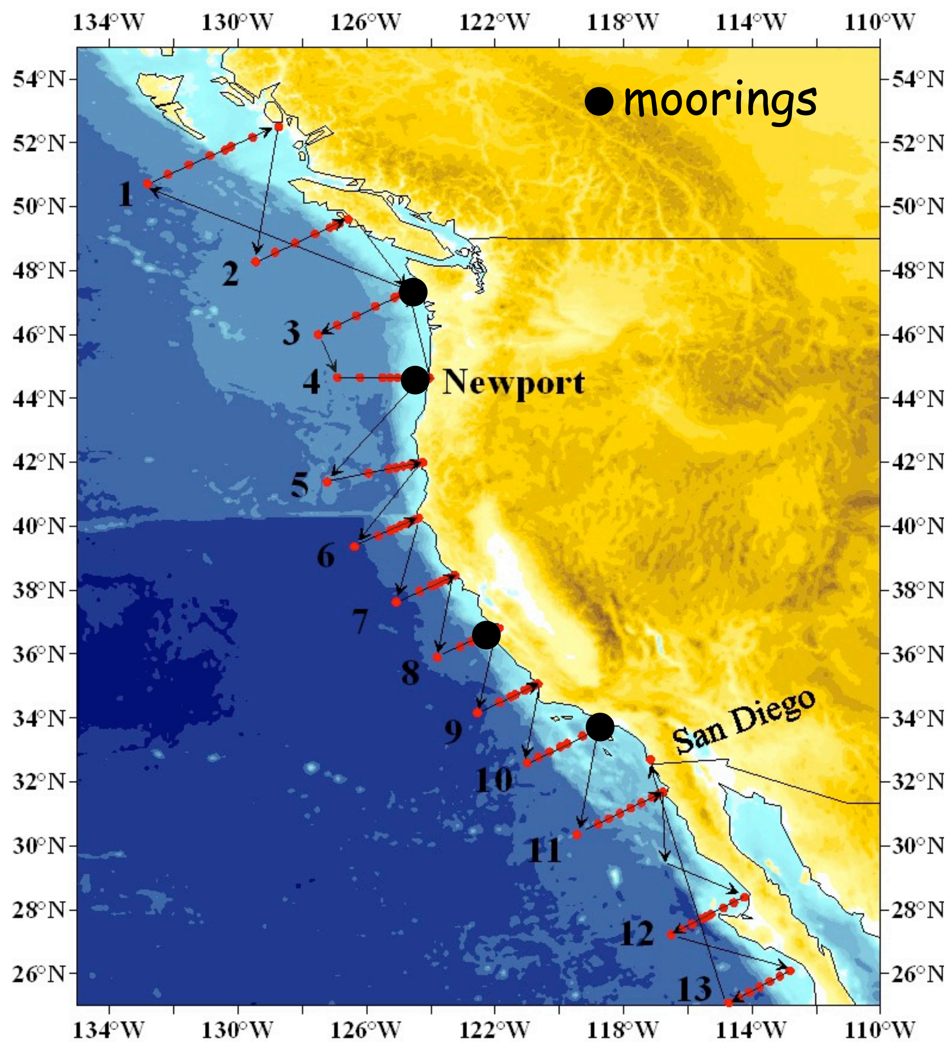
Continental Carbon Budgets, Dynamics, Processes, and Management

Newport

Aberdeen

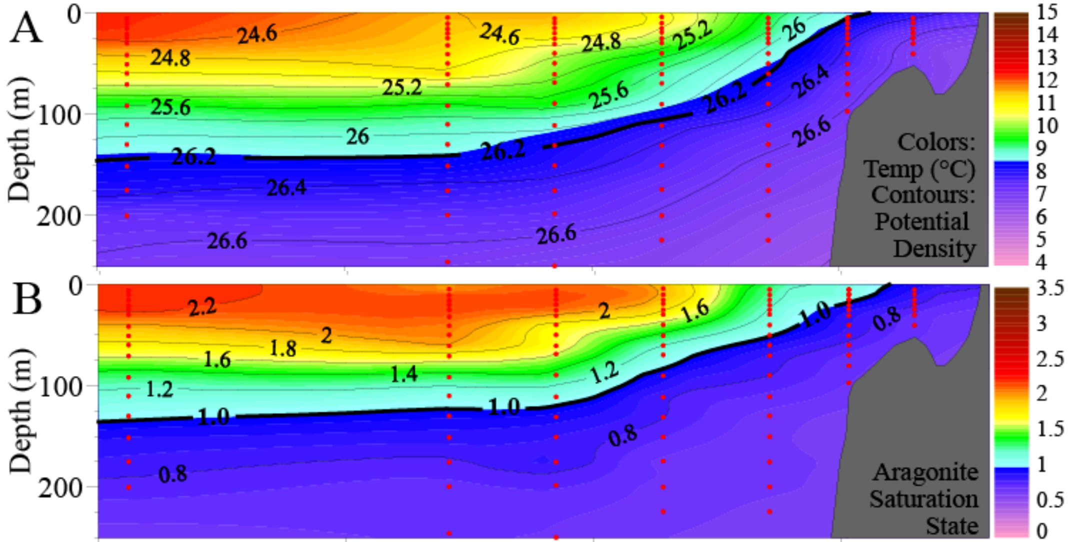
MBARI

UCLA

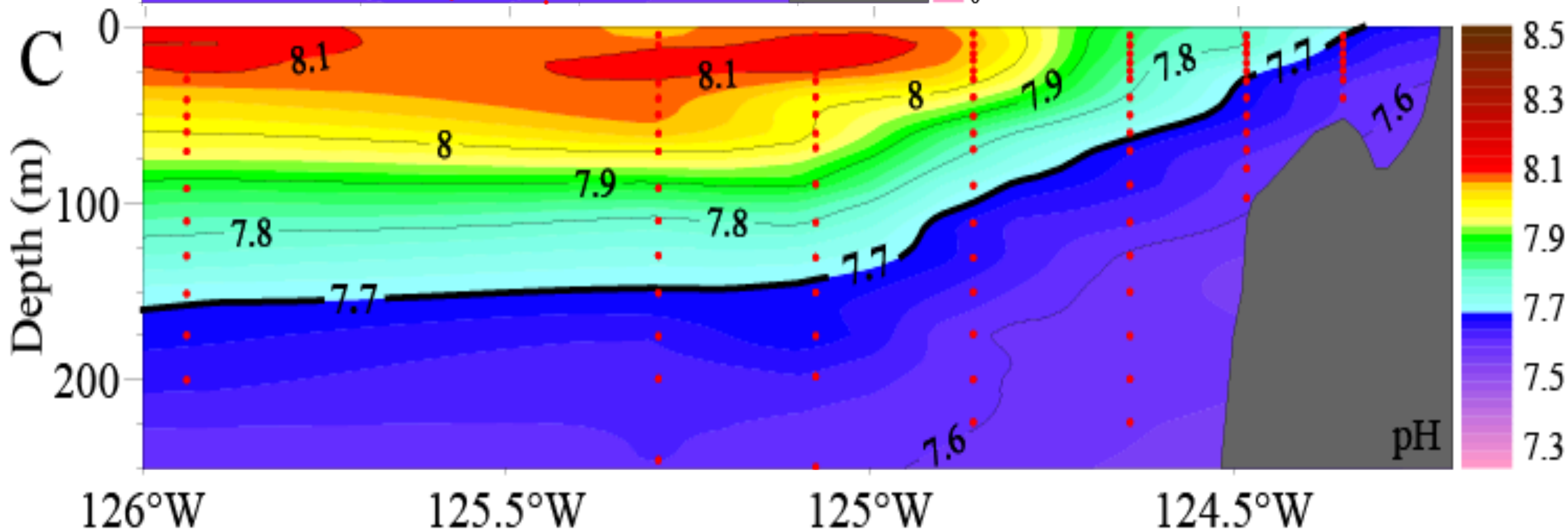


NACP West Coast Survey Cruise : 11 May - 14 June 2007
and mooring locations

NACP Coastal Survey Cruise: 11 May - 14 June 2007



The 'ocean acidified' corrosive water was upwelled from depths of 150-200 m onto the shelf and outcropped at the surface near the coast.



Red dots represent sample locations.

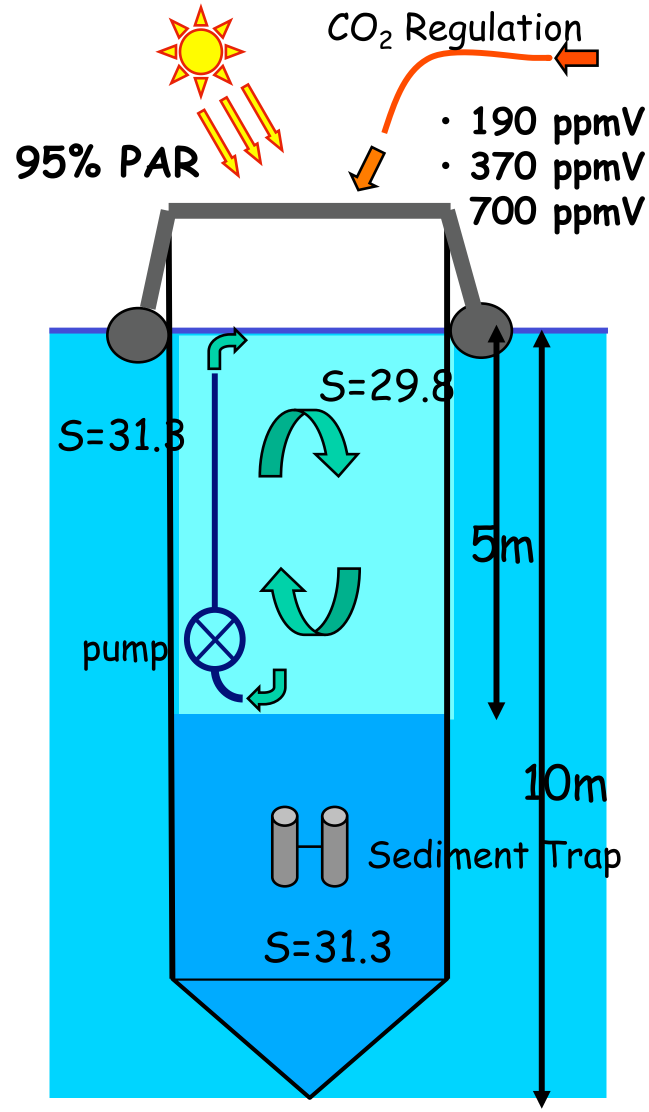
Vertical sections from Line 5 (Pt. St. George, California)

Feely et al. (2008)

Mesocosm experiment, Bergen Pelagic Ecosystem CO_2 Enrichment Study

Three pCO_2 treatments representing: Glacial, Present, and Year 2100

Large Scale Mesocosm Facility, University of Bergen, Norway

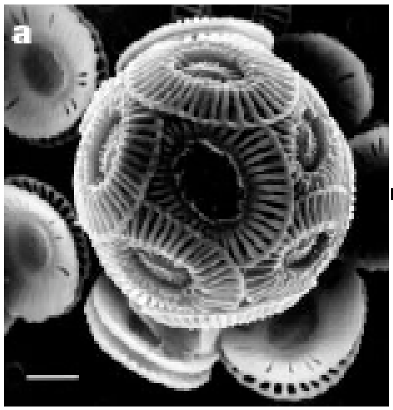


from U. Riebesell & B. Rost

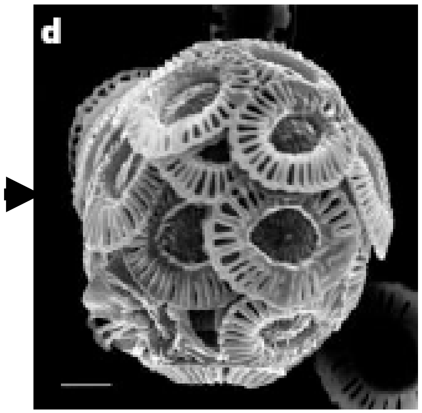
Coccolithophore
(single-celled algae)

pCO_2 280-380 ppmv

pCO_2 780-850 ppmv

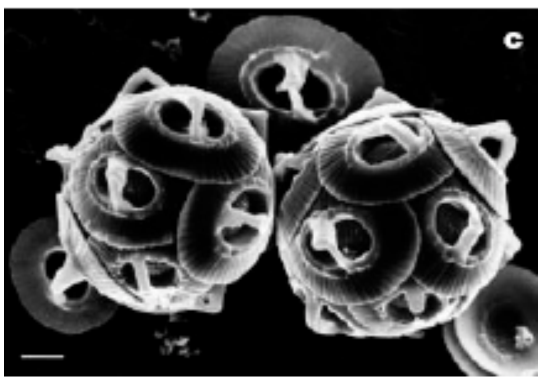


Emiliania huxleyi

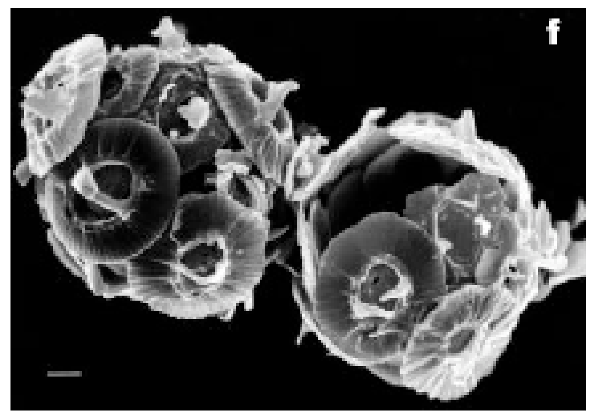


Calcification decreased

- 9 to 18%



Gephyrocapsa oceanica



- 45%

Malformed liths at high CO_2

Manipulation of CO_2 system by addition of HCl or NaOH

Riebesell et al.(2000); Zondervan et al.(2001)

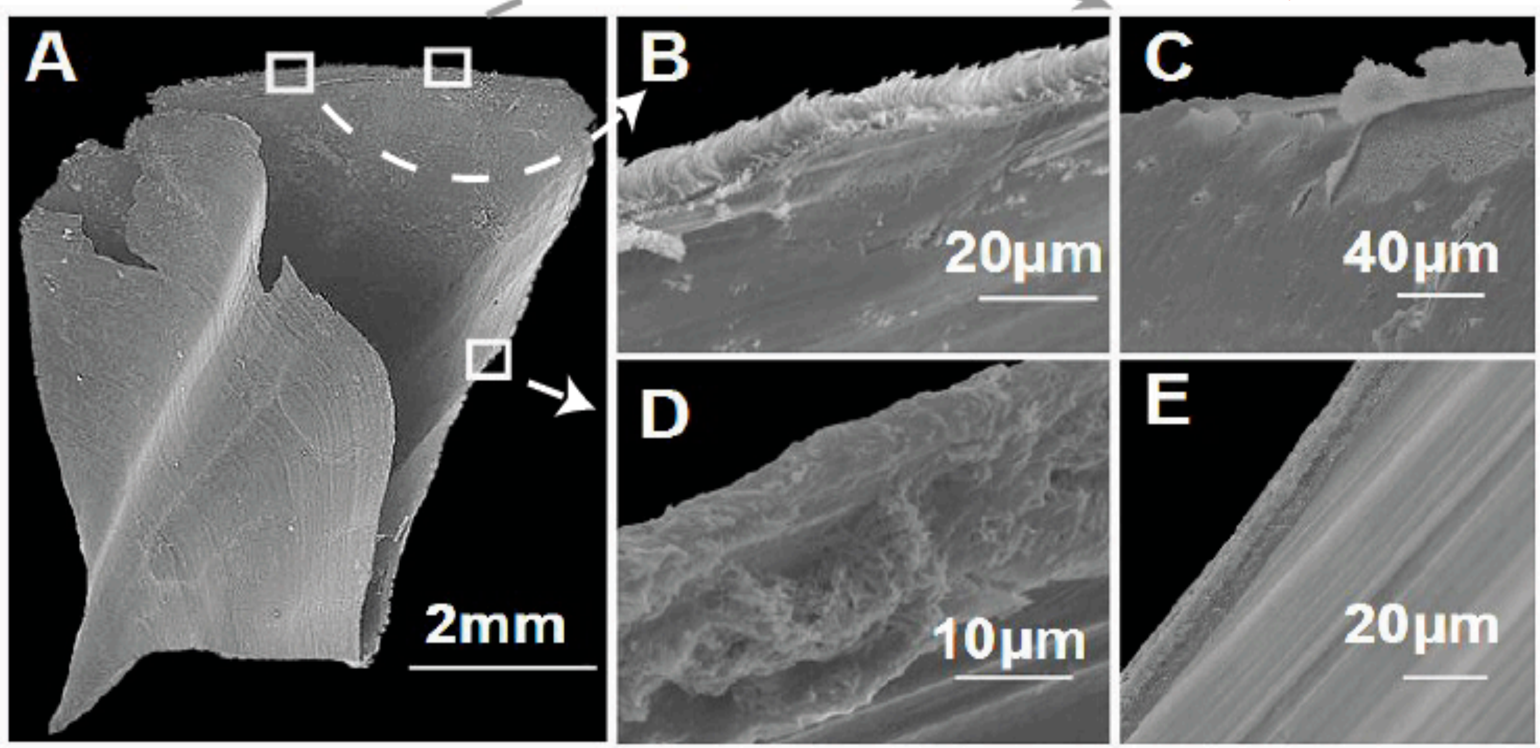
Shelled Pteropods
(planktonic snails)

Respiratory CO_2 forced Ω_A <1
Shells of live animals start to dissolve within 48 hours

Whole shell: *Clio pyramidata*

Arag. rods exposed

Prismatic layer (1 μm) peels back



Aperture (~7 μm): advanced dissolution

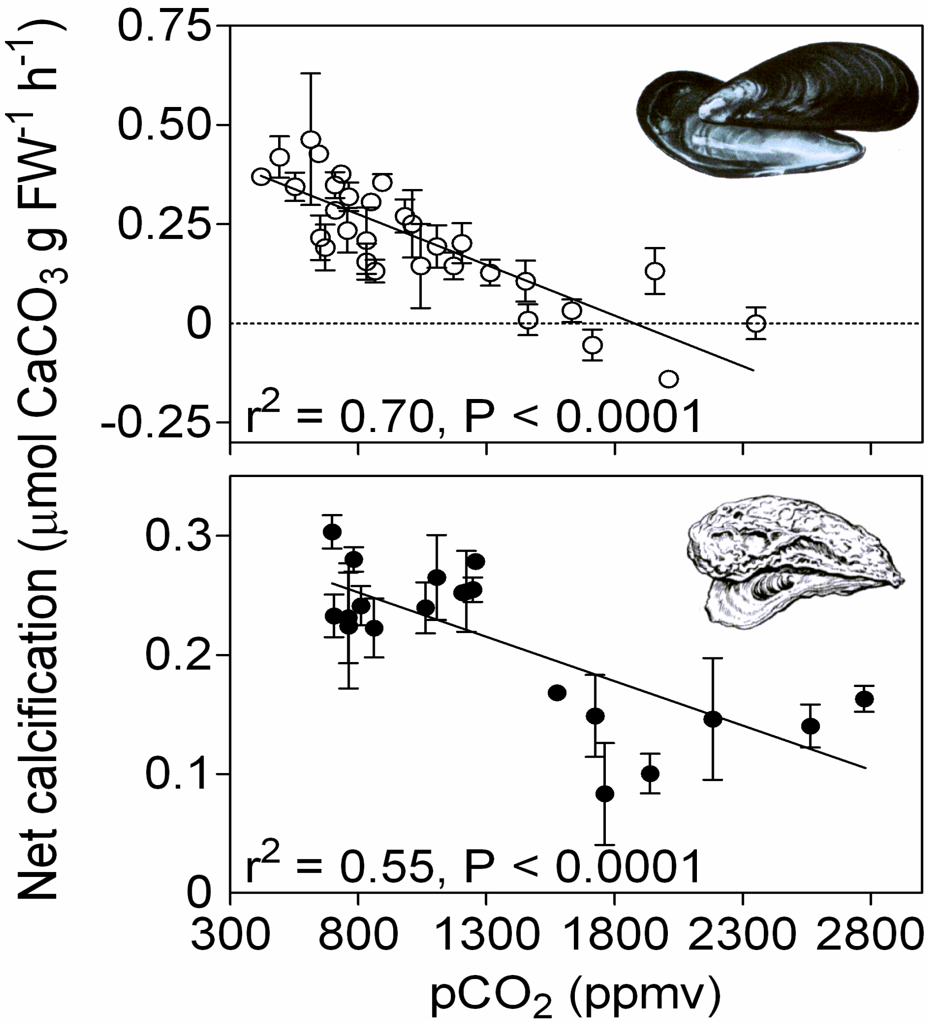
Normal shell: no dissolution

Orr et al. (2005)

CLIMATE CHANGE, NATURAL RESOURCES AND COASTAL MANAGEMENT

A WORKSHOP ON THE COASTAL ECOSYSTEMS OF CALIFORNIA, OREGON AND WASHINGTON

Response of mussels & oysters to elevated CO_2



Decrease in calcification rates for the 2 species:

Mytilus edulis

Crassostrea gigas

- Significant with pCO_2 increase and $[CO_3^{2-}]$ decrease

At pCO_2 740 ppmv:

- 25% decrease in calcification for mussels
- 10% decrease in calcification for oysters

Gazeau et al., 2007

Ecologically and economically important organisms with planktonic larval stages

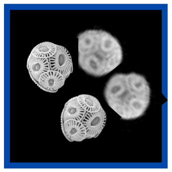
- **Bivalves**: clams, scallops, mussels, oysters
  - Valuable commercial fisheries
  - Mussels & oysters: ecosystem engineers
- **Echinoderms**: sea urchins, sea stars, sea cucumbers
  - Commercial fisheries: sea urchins & sea cukes
  - Sea stars: keystone species
- **Crustaceans**: shrimp, crabs, lobsters, copepods
  - Valuable commercial fisheries
  - Copepods: central role in marine food webs

Annual $2 Billion Dollar Industry

CLIMATE CHANGE,
NATURAL RESOURCES
AND COASTAL MANAGEMENT

A WORKSHOP ON THE COASTAL ECOSYSTEMS OF CALIFORNIA, OREGON AND WASHINGTON

Potential Effects on Open Ocean Food Webs



Coccolithophores

ARCOD@ims.uaf.edu

Copepods

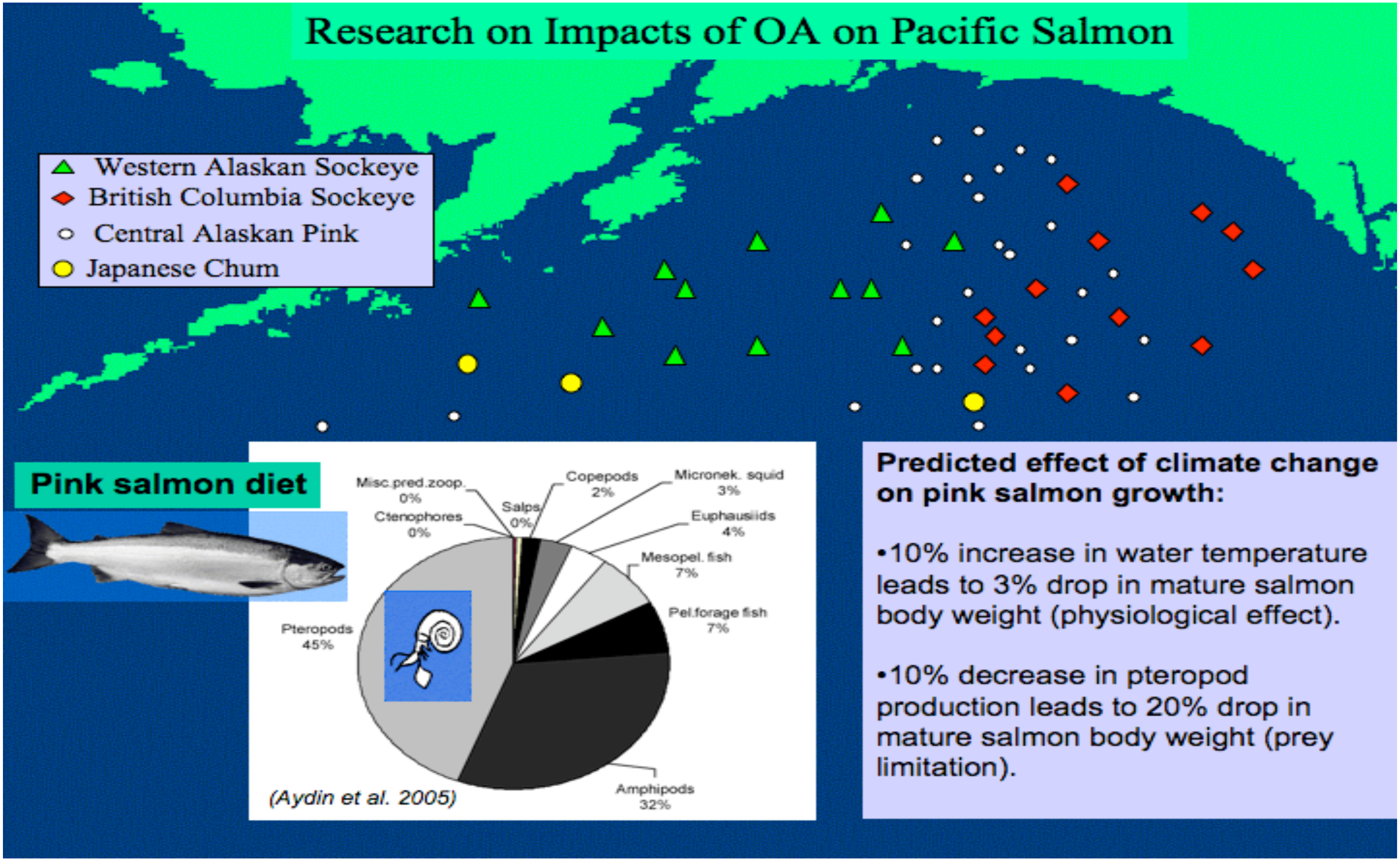
Pteropods

Pacific Salmon

CLIMATE CHANGE,
NATURAL RESOURCES
AND COASTAL MANAGEMENT

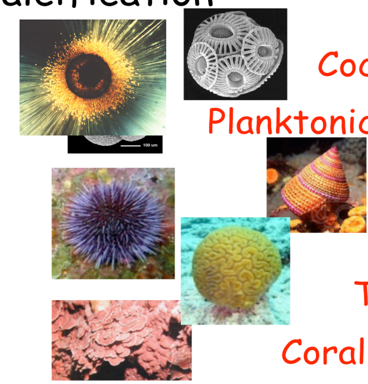
A WORKSHOP ON THE COASTAL ECOSYSTEMS OF CALIFORNIA, OREGON AND WASHINGTON

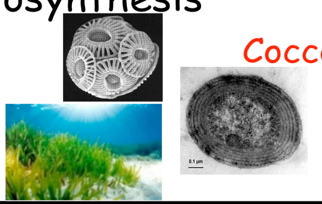
What we know about the biological impacts of ocean acidification *…on marine fish*

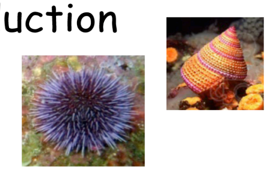


Scorecard of Biological Impacts

Response to increasing CO_2







Physiological process	Major group	# species studied	\	/	—	∩
Calcification	Coccolithophores	4	2	1	1	1
	Planktonic Foraminifera	2	2	-	-	-
	Molluscs	4	4	-	-	-
	Echinoderms	2	2	-	-	-
	Tropical Corals	11	11	-	-	-
	Coralline Red Algae	1	1	-	-	-
Photosynthesis[1]	Coccolithophores[2]	2	-	2	2	-
	Prokaryotes	2	-	1	1	-
	Seagrasses	5	-	5	-	-
Nitrogen Fixation	Cyanobacteria	1	-	1	-	-
Reproduction	Molluscs	4	4	-	-	-
	Echinoderms	1	1	-	-	-

1) Strong interactive effects with nutrient and trace metals availability, light, and temperature
2) Under nutrient replete conditions

Figure from Doney et al. (2009)

Conclusions

- Impacts of ocean acidification on ecosystems are largely unknown.
- Calcification in many planktonic organisms is reduced at elevated CO_2, but the response is not uniform.
- Possible responses of ecosystems are speculative but could involve changes in species composition & abundances - could affect food webs, biogeochemical cycles.
- Baseline data with sufficient resolution are lacking in regions where $CaCO_3$ saturation states are expected to decrease <1 over in next 50-100 years.