National Marine Sanctuaries

Ocean Acidification: The Other CO_2 Problem

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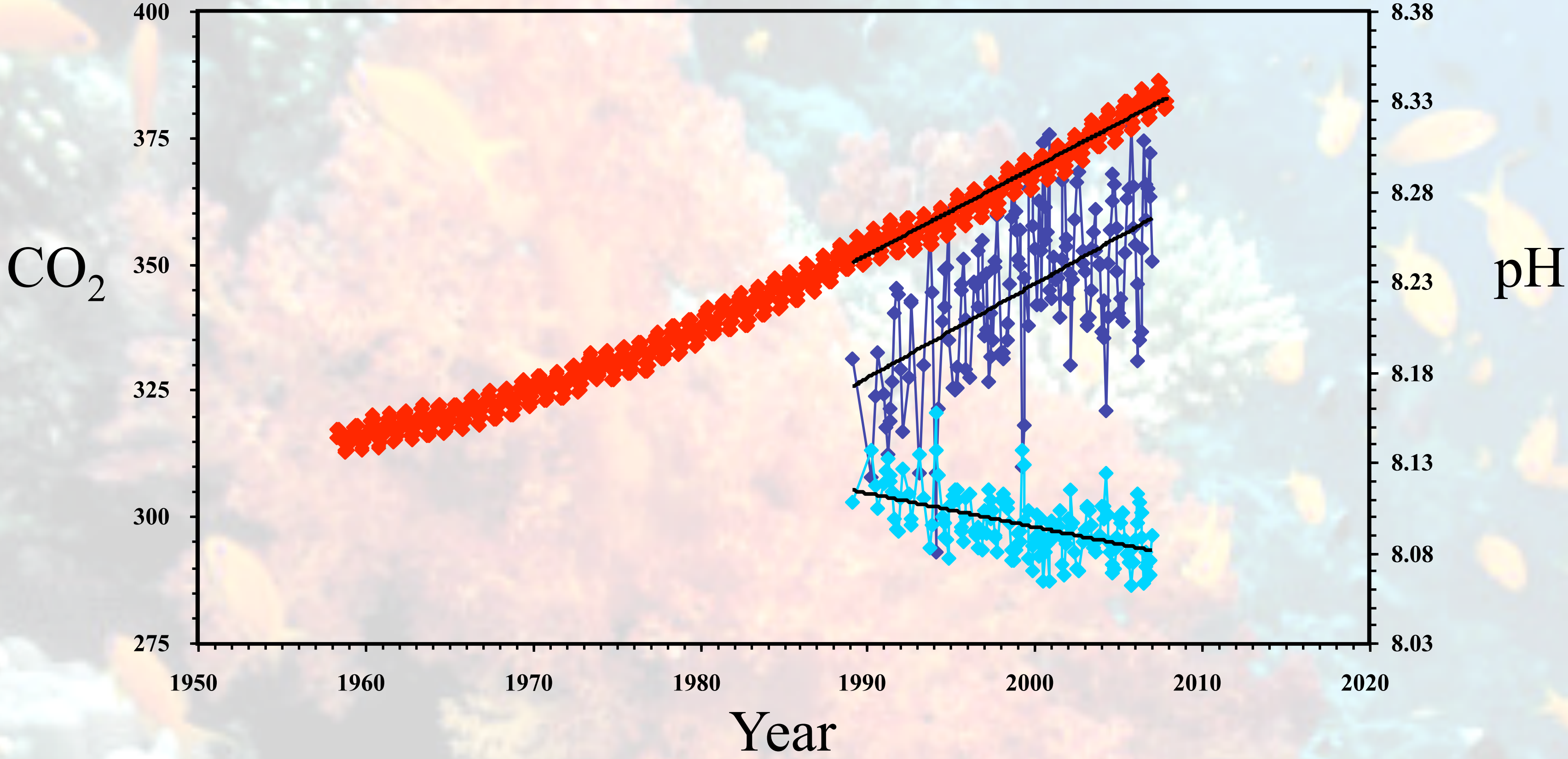


What we know about the ocean chemistry of *...saturation state*

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

Saturation State

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

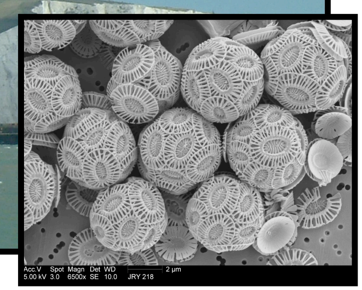
$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$$

calcium + carbonate → calcium carbonate

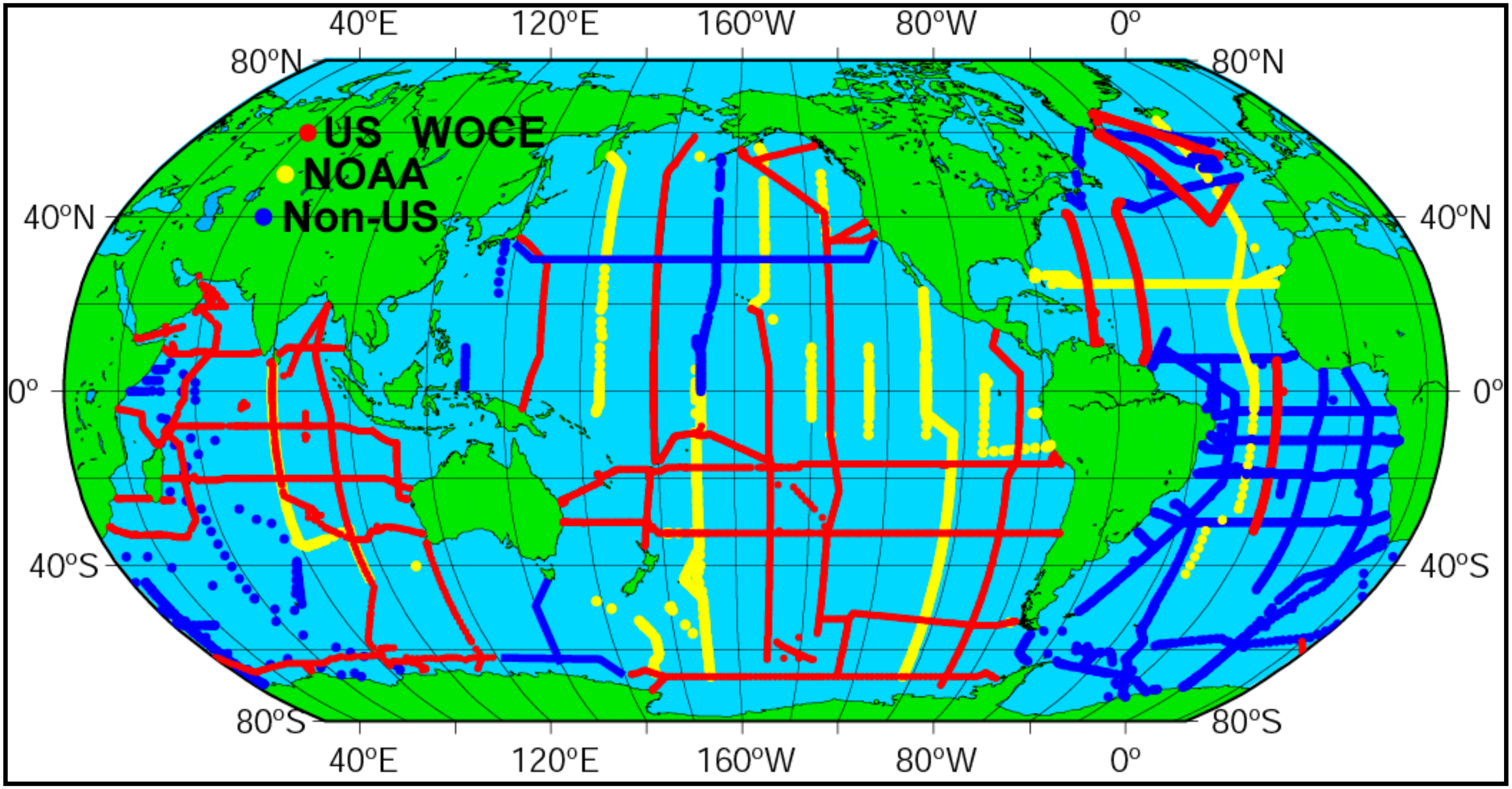
$\Omega > 1 = precipitation$

$\Omega = 1 = equilibrium$

$\Omega < 1 = dissolution$



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



WOCE/JGOFS/OACES Global CO_2 Survey

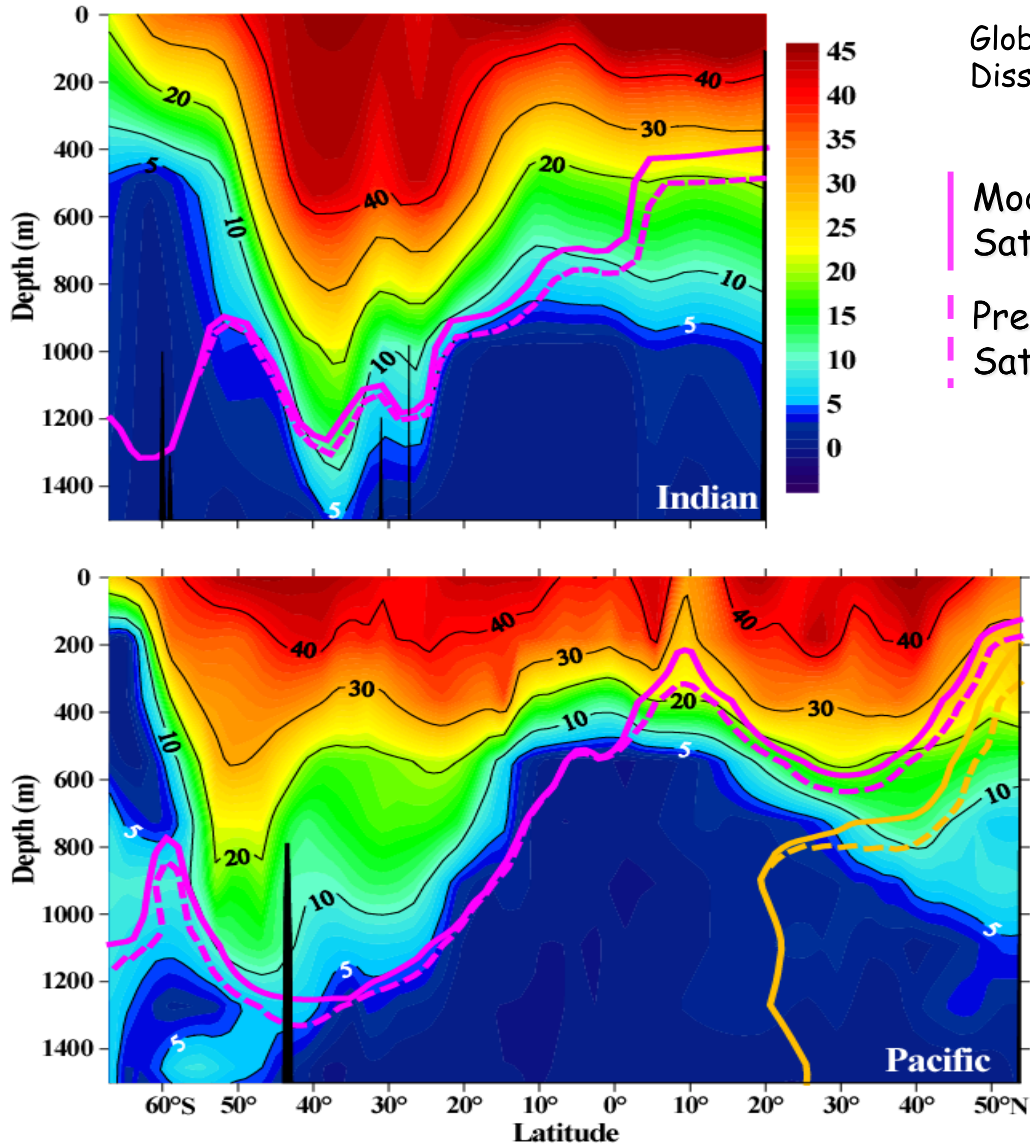
~72,000 sample locations collected in the 1990s

DIC ± 2 μmol kg^{-1}

TA ± 4 μmol kg^{-1}

Sabine et al (2004)

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

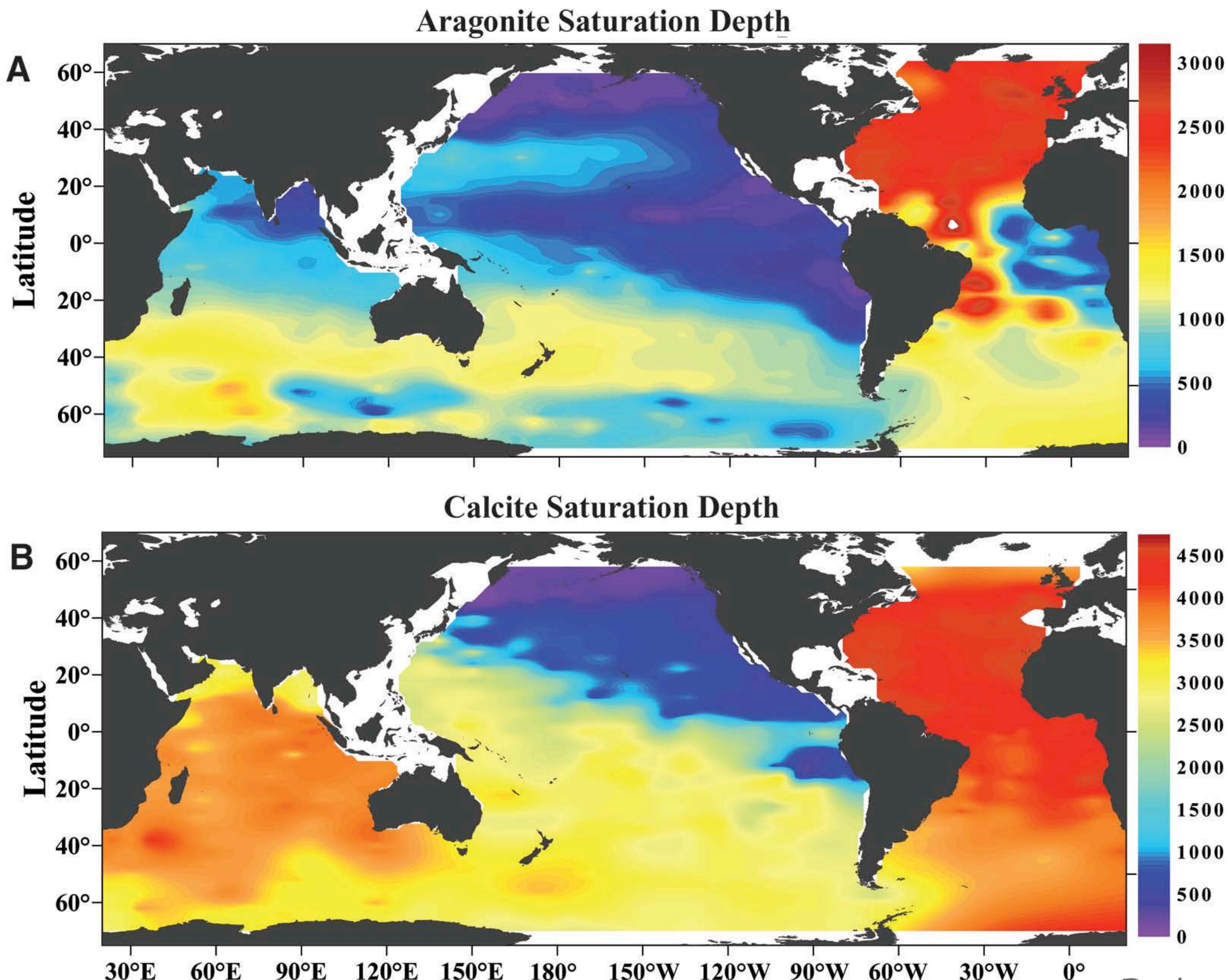
Modern Calcite Saturation Horizon

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)

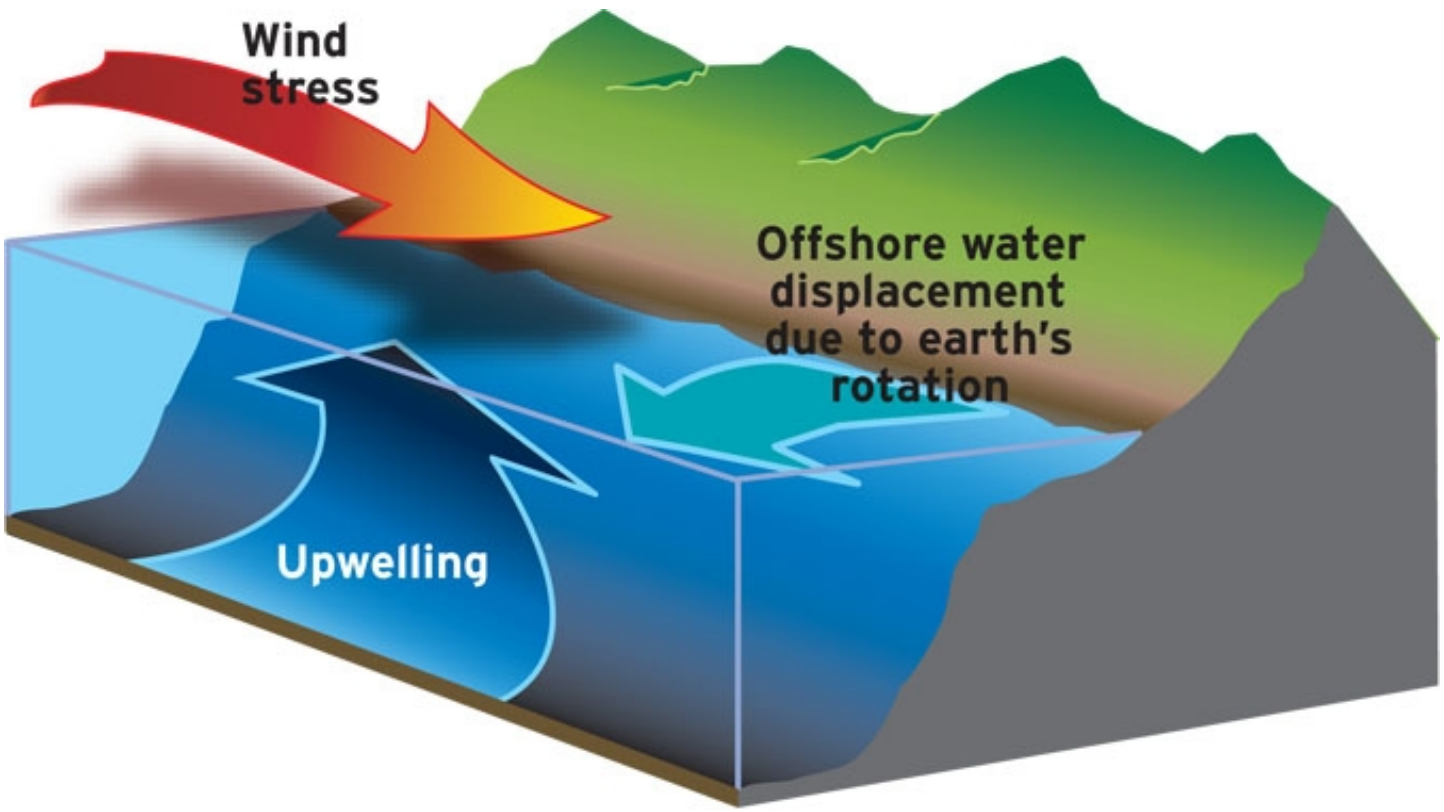
What we know about ocean CO_2 chemistry*…from observed aragonite and calcite saturation depths*



Feely et al. (2004)

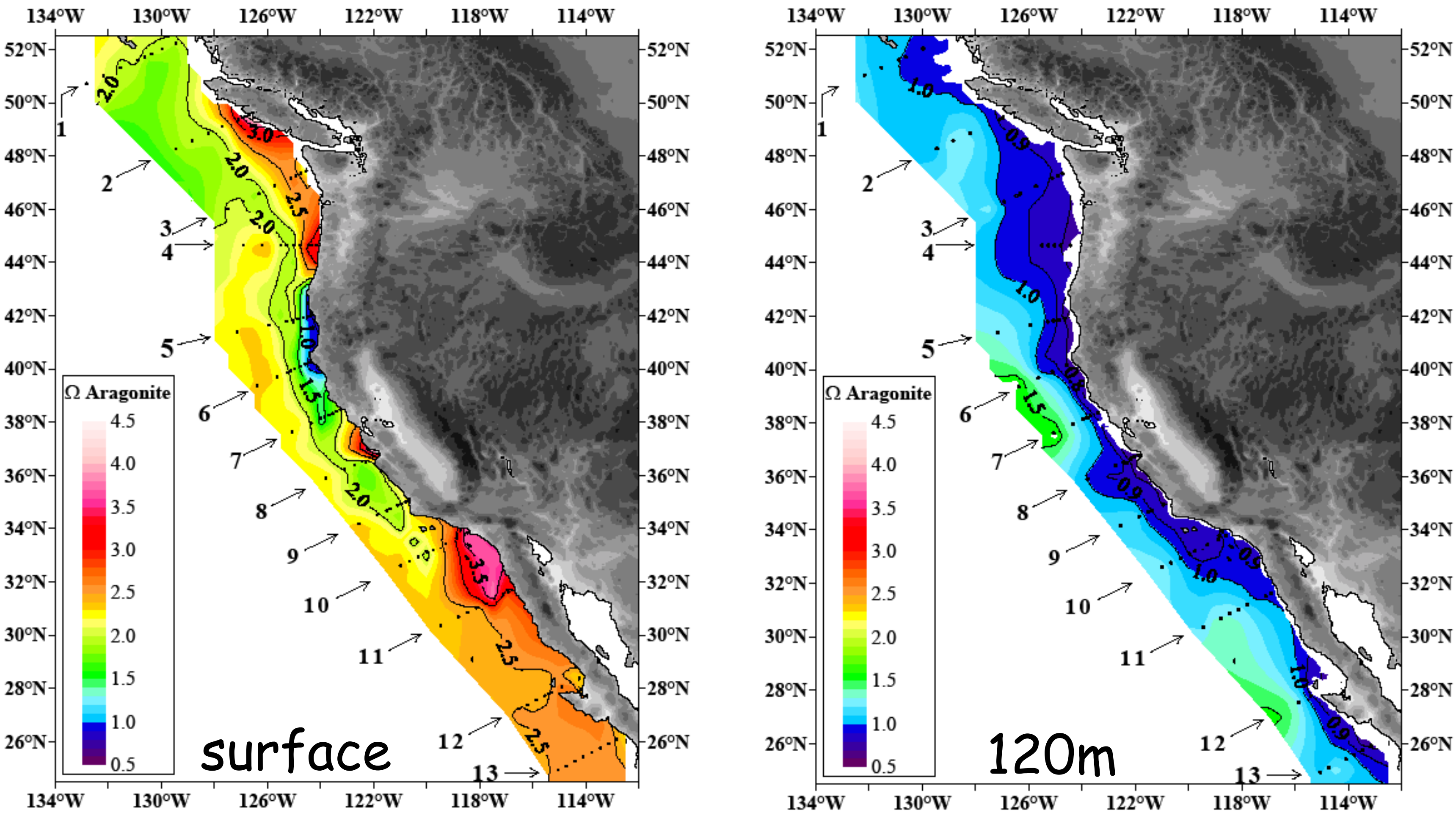
Natural processes that could accelerate the ocean acidification of coastal waters

- Coastal Upwelling



North American Carbon Program

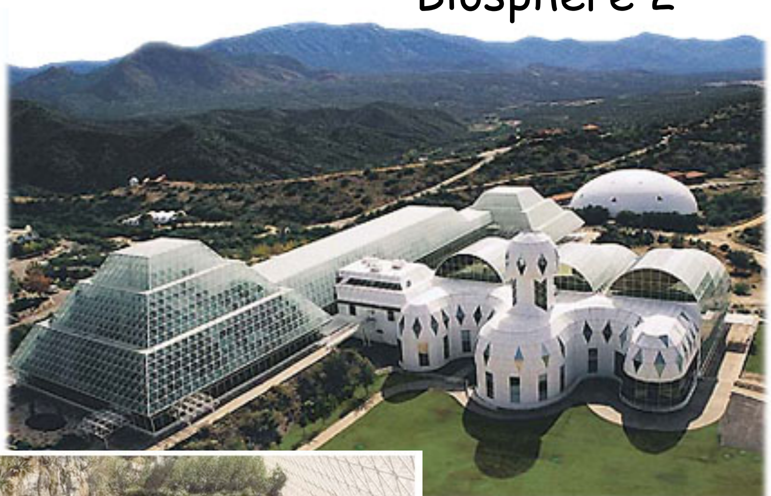
Continental Carbon Budgets, Dynamics, Processes, and Management

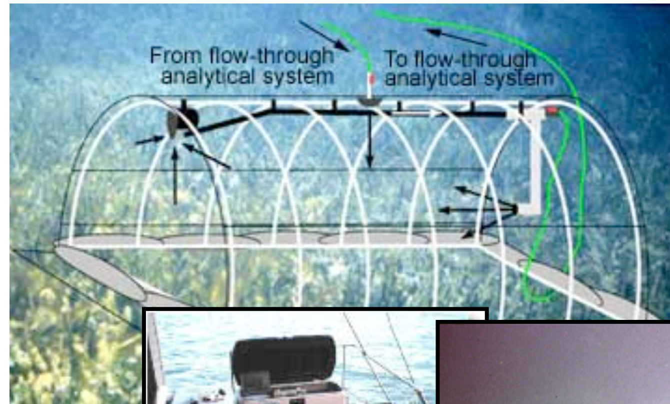


Aragonite Saturation State in west coast waters

Experiments on Many Scales

Biosphere 2





SHARQ
Submersible Habitat for Analyzing Reef Quality

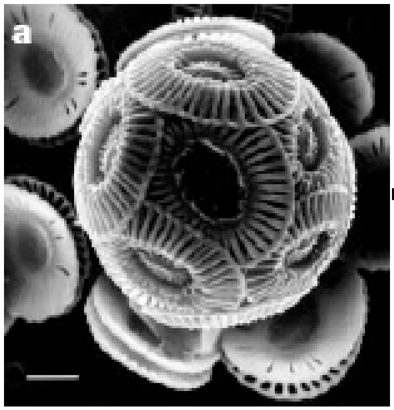
Provided by Mark Eakin

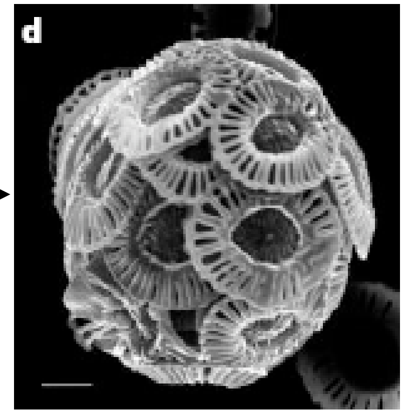
Aquaria and Small Mesocosms

Coccolithophore (single-celled algae)

pCO_2 280-380 ppmv

pCO_2 780-850 ppmv

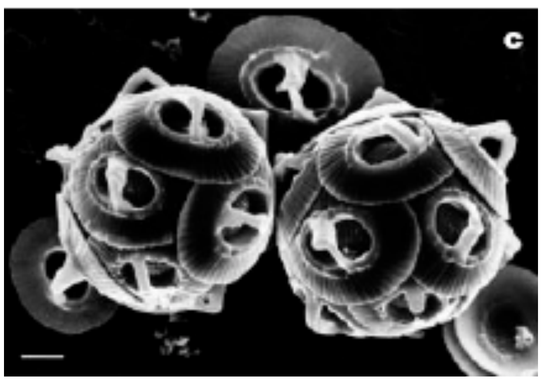


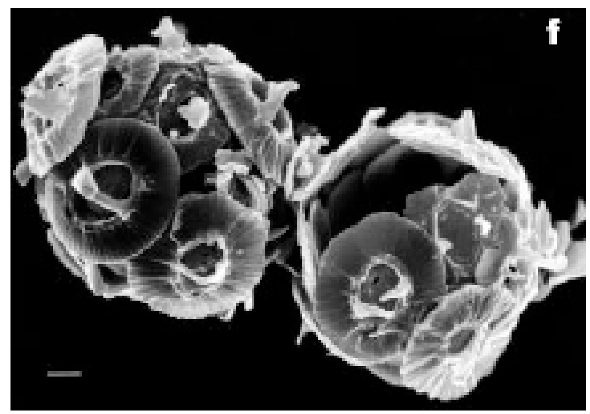


Calcification decreased

- 9 to 18%

Emiliania huxleyi





- 45%

Gephyrocapsa oceanica

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)

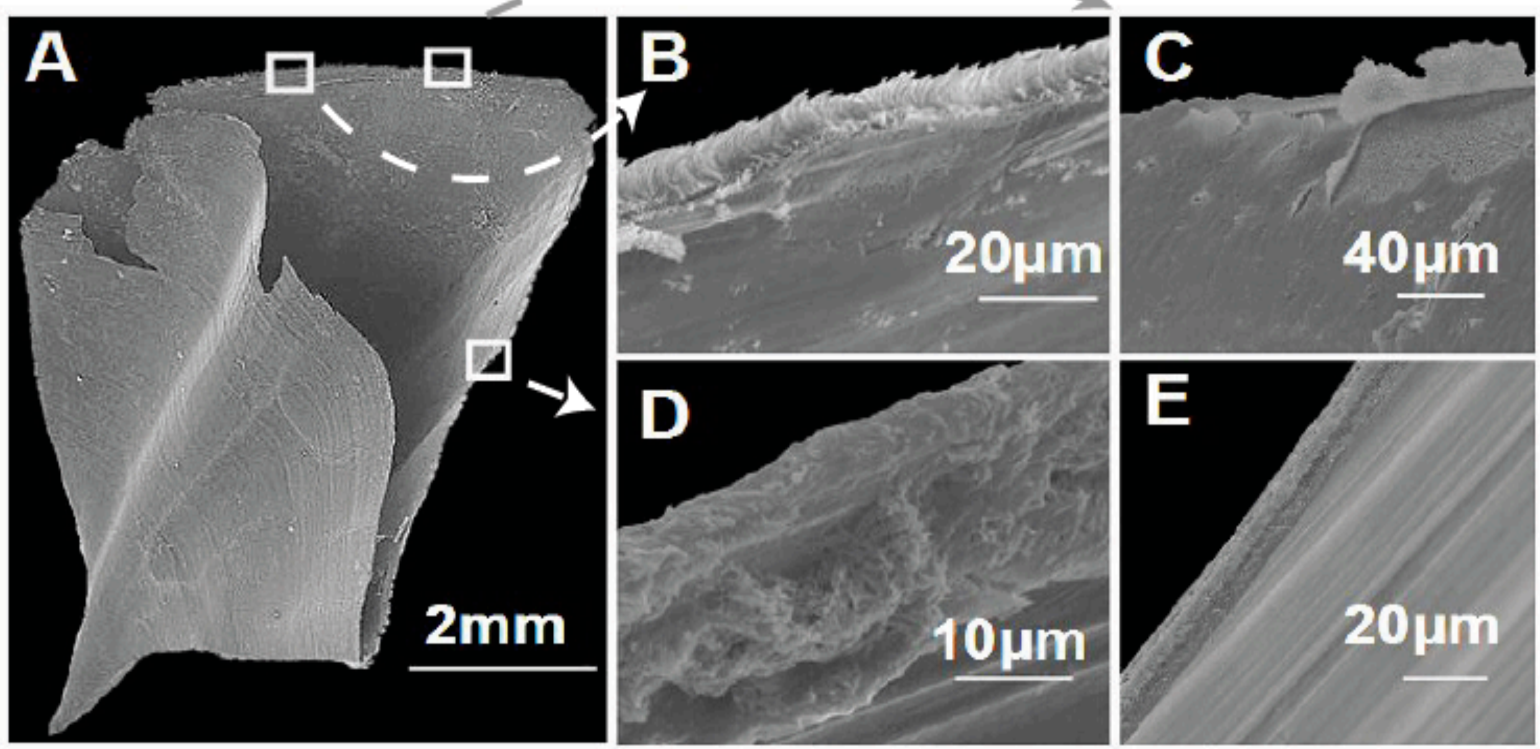
Respiratory CO_2 forced $\Omega_A < 1$

Shells of live animals start to dissolve within 48 hours

Whole shell: *Clio pyramidata*

Arag. rods exposed

Prismatic layer (1 μm) peels back

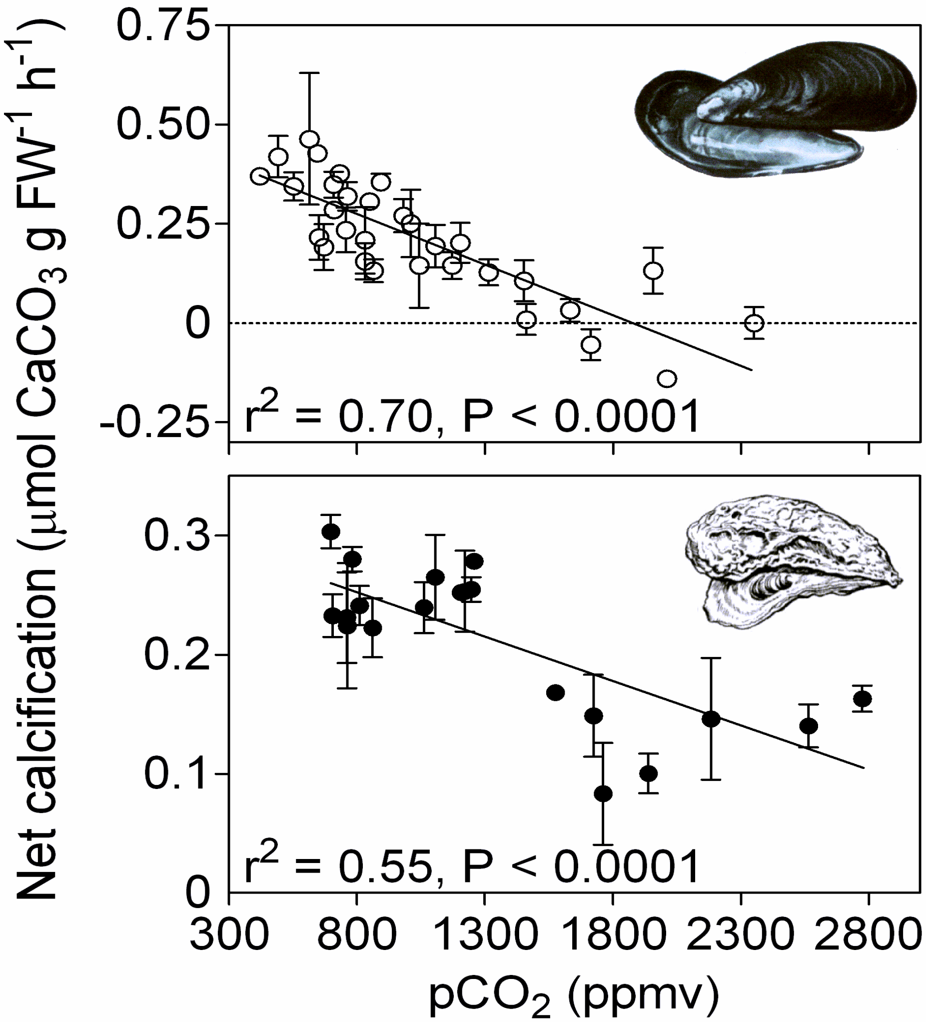


Aperture (~7 μm): advanced dissolution

Normal shell: no dissolution

Orr et al. (2005)

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

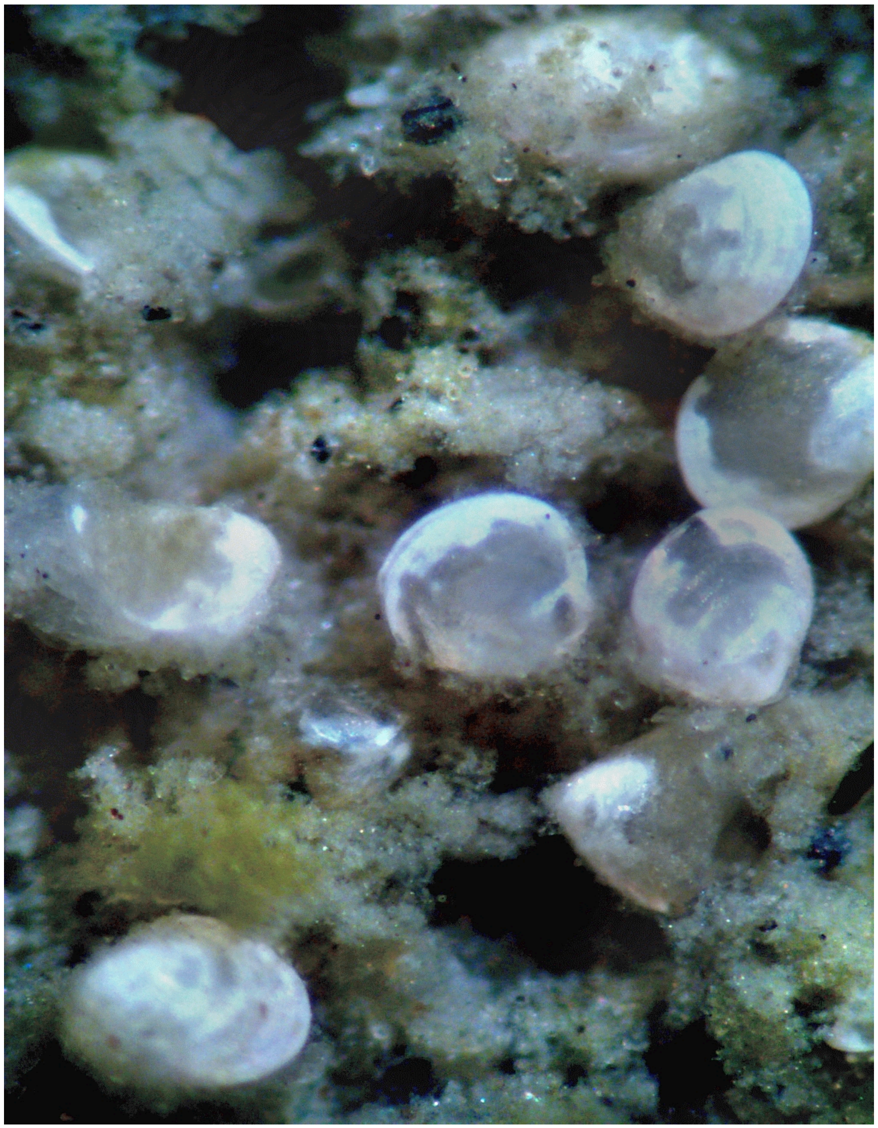
At pCO_2 740 ppmv:

•25% decrease in calcification for mussels

•10% decrease in calcification for oysters

Gazeau et al., 2007

Bivalve juvenile stages can also be sensitive to carbonate chemistry



Hard shell clam *Mercenaria*

- Common in soft bottom habitats

Used newly settled clams

- Size 0.3 mm
- Massive dissolution within 24 hours in undersaturated water; shell gone within 2 weeks
- Dissolution is source of mortality in estuaries & coastal habitats

Green et al., 2004

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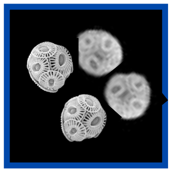
Potential Effects on Open Ocean Food Webs



Coccolithophores

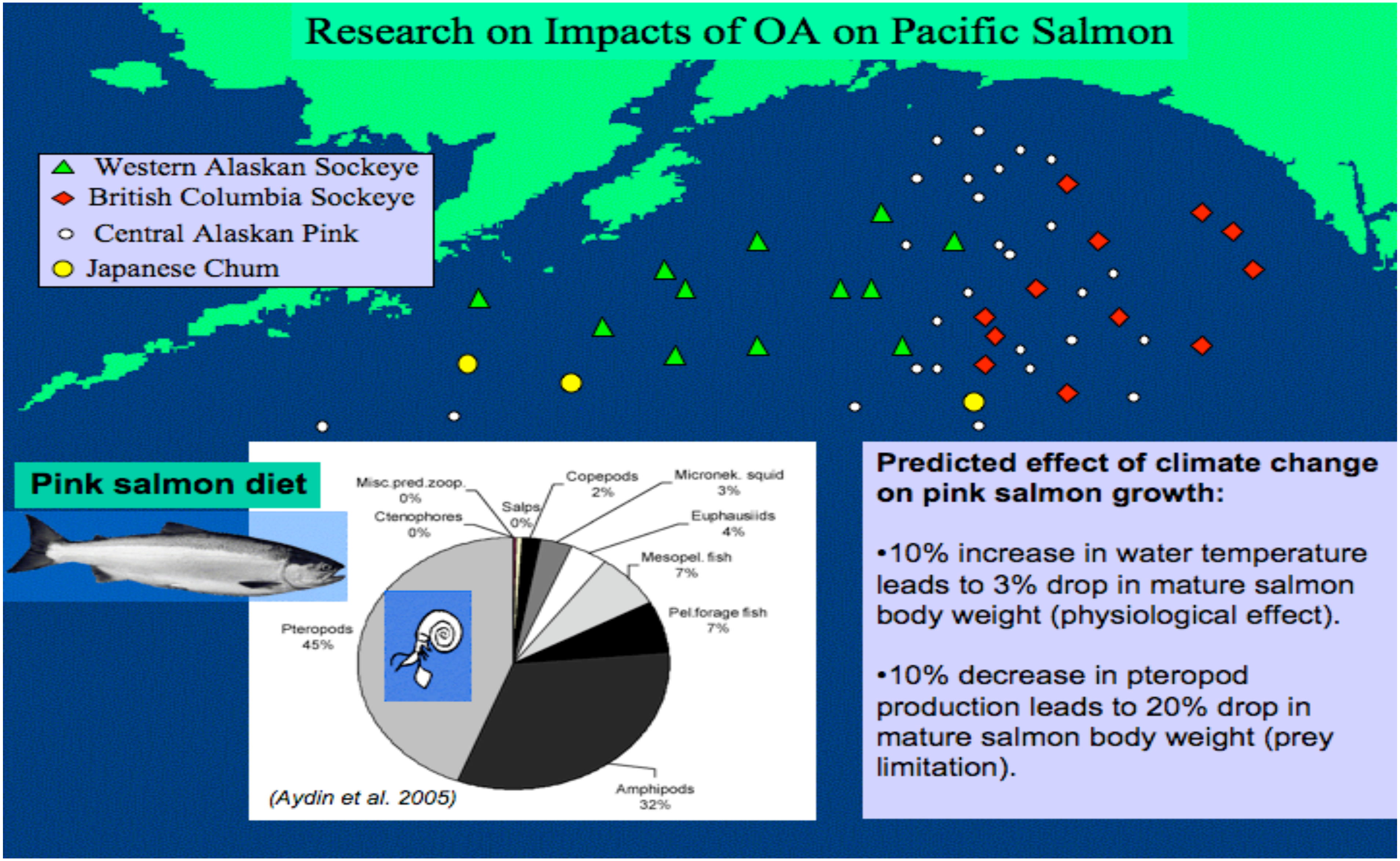
ARCOD@ims.uaf.edu

Copepods

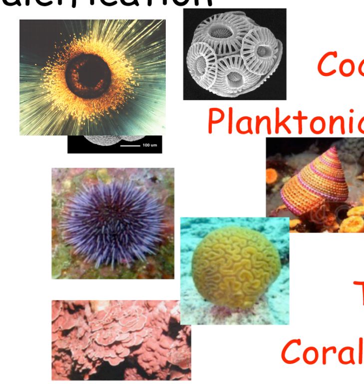
Pteropods

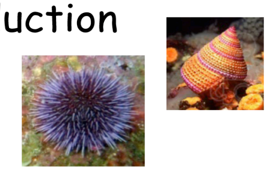
Pacific Salmon

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



Scorecard of Biological Impacts



Physiological process	Major group	# species studied	Response to increasing CO_2: \	/	—	∩
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 coastal regions where $CaCO_3$ saturation states are expected to decrease dramatically over in next 50-100 years.