Ocean Acidification in the Pacific Northwest Region

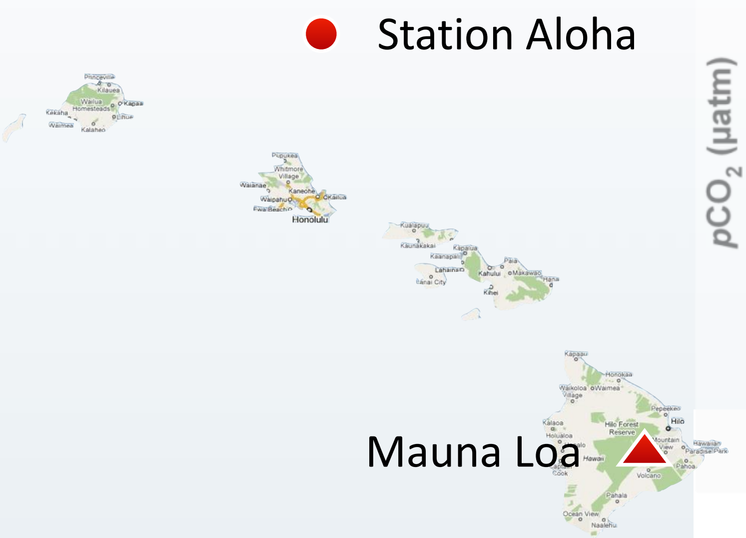
Outline

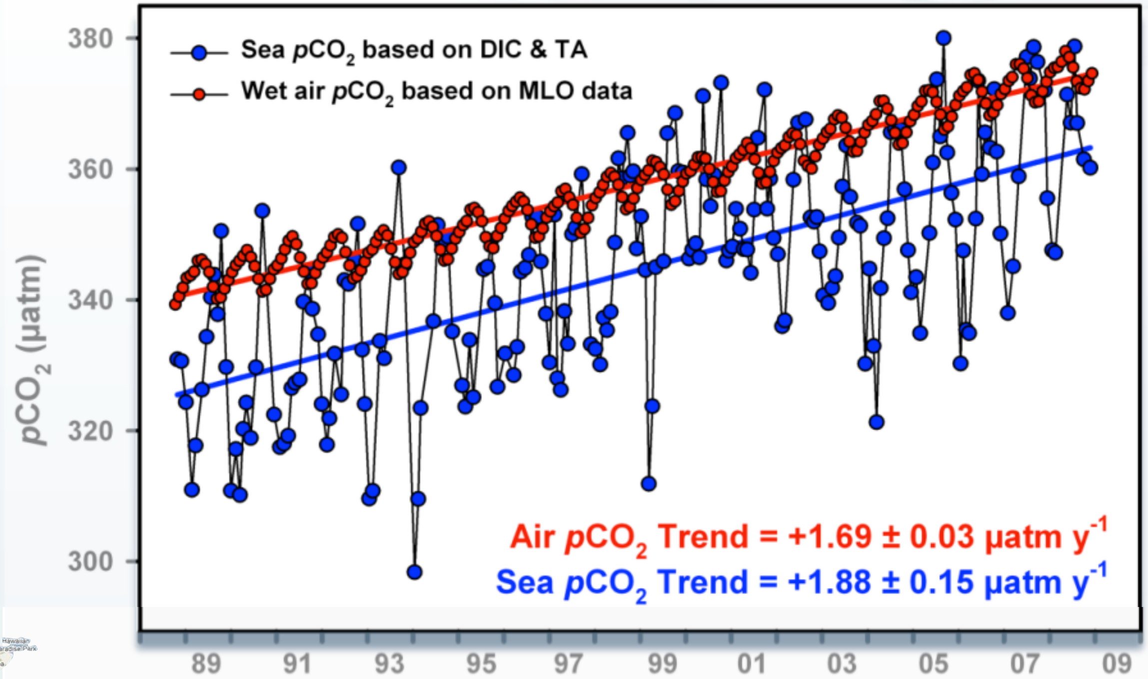
- Introduction to ocean acidification (OA)
- Why coastal oceans are especially vulnerable
- Present and future OA Impacts

Dr. Richard A. Feely
Pacific Marine Environmental Laboratory
Seattle, Washington USA
Sustainable Path Foundation Seminar Series
Seattle Town Hall, November 8, 2011

SUSTAINABLE PATH FOUNDATION
science for a healthy, sustainable future

Carbon Changes at the Hawaii Ocean Time-series (HOT) site





Surface water pCO_2 is increasing at about the same rate as atmosphere

We see a commensurate decrease in pH with the rise in surface water pCO_2

Doney, Science 2010
Dore et al., PNAS 2009

Fate of Anthropogenic CO_2 Emissions

1.1 ± 0.7 Pg C y^{-1}

7.5 ± 0.5 Pg C y^{-1}

4.1 ± 0.1 Pg C y^{-1}

Atmosphere

47%

2.6 Pg C y^{-1}

Land

27%

2.3 ± 0.4 Pg C y^{-1}

Oceans

26%

Canadell et al. PNAS 2007; LeQuere et al. Nature Geosciences 2009

Ocean CO_2 Chemistry

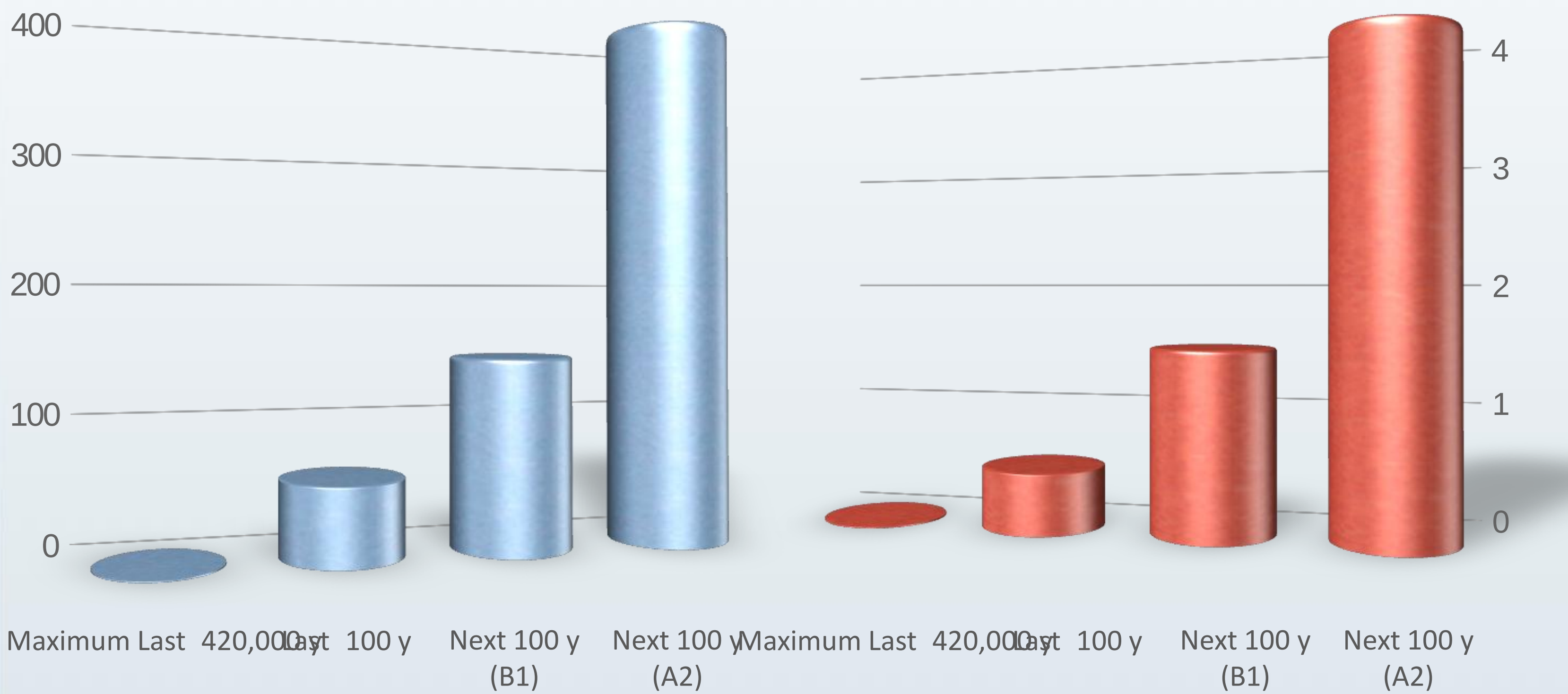
Rates of increase are important

Atmospheric CO_2

Rate of rise in CO_2 (ppm/100y)

Global Temperature

Rate of rise in global temperature (°C/100)



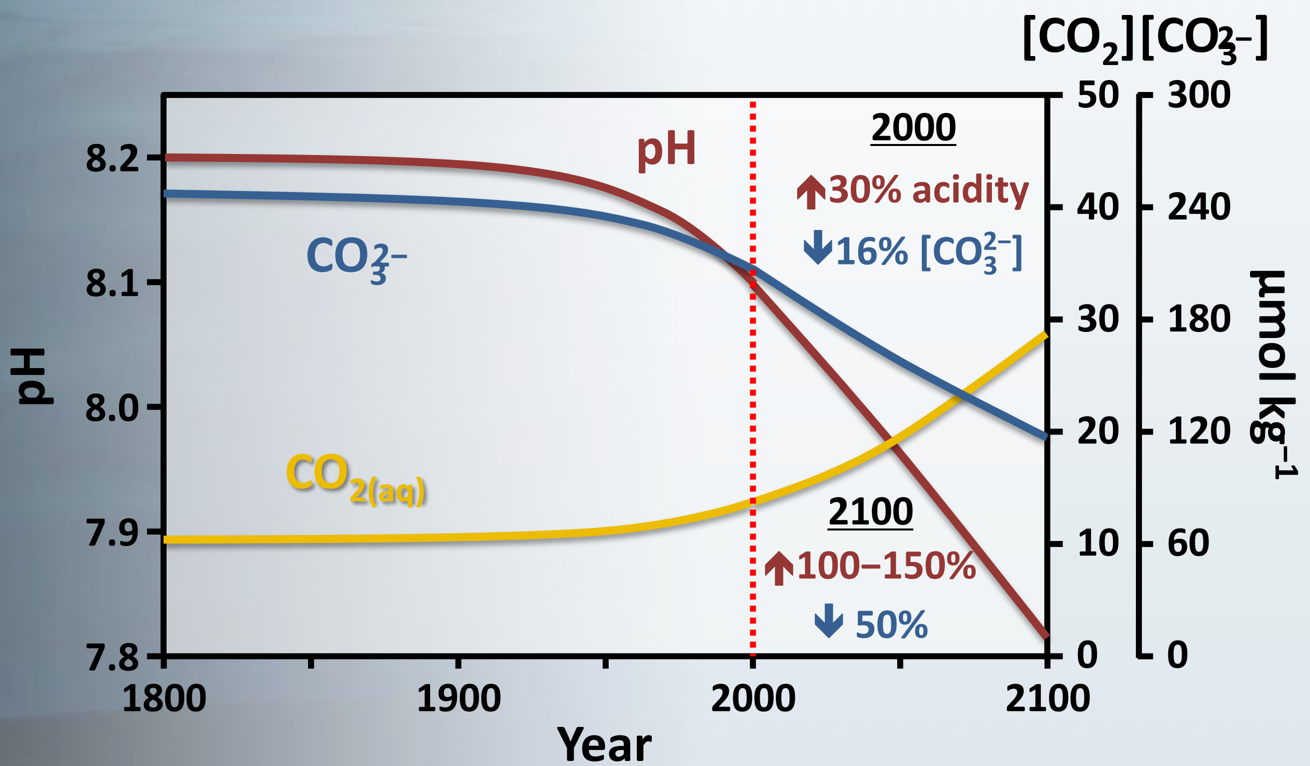
Hoegh-Guldberg et al. 2007, Science

Ocean Acidification

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$$

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

$$H^+ + CO_3^{2-} \rightarrow HCO_3^-$$



Wolf-Gladrow et al. (1999)

Saturation State

Ca^{2+} + CO_3^{2-} → $CaCO_3$

calcium carbonate calcium carbonate

Saturation State

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

$W > 1$ $CaCO_3$ precipitates

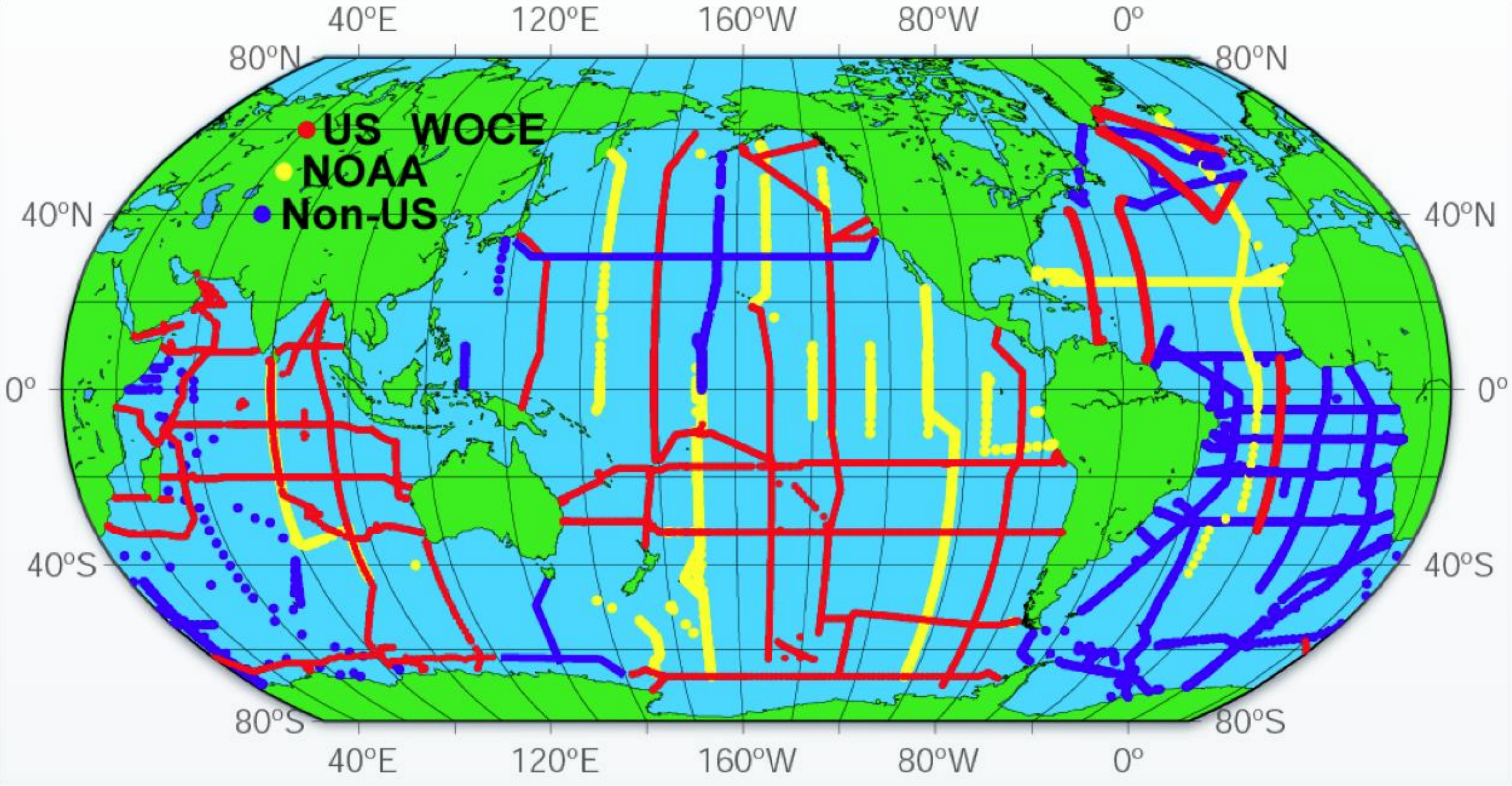
$W = 1$ equilibrium

$W < 1$ $CaCO_3$ dissolves

Common carbonate minerals:

aragonite (more soluble) and calcite (less soluble)

Field Observations

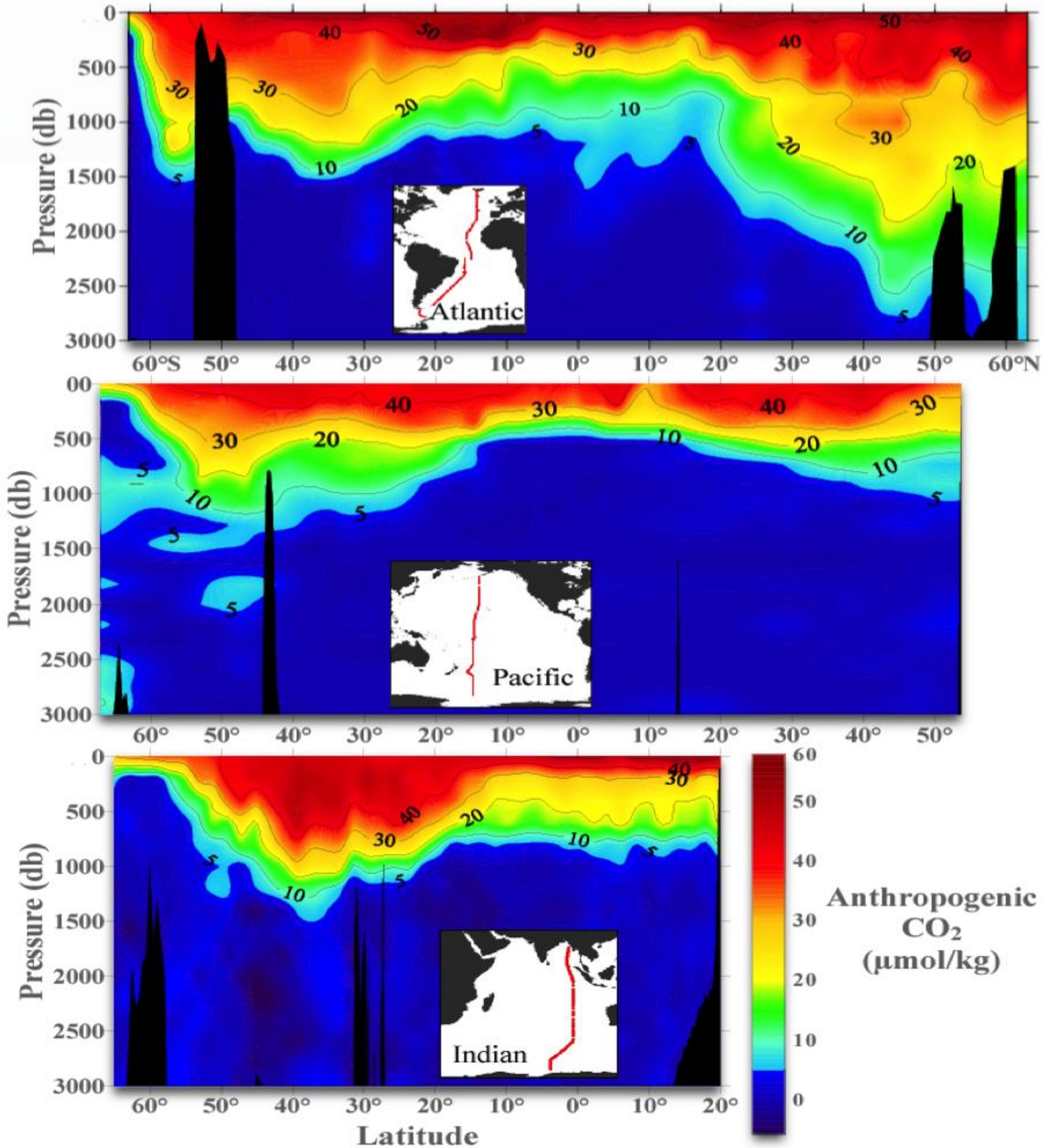


WOCE/JGOFS/OACES
Global CO_2 Survey

- ~72,000 sample locations
- collected in 1990s
- DIC ± 2 μmol kg^{-1}
- TA ± 4 μmol kg^{-1}

Monitoring Ocean Chemistry

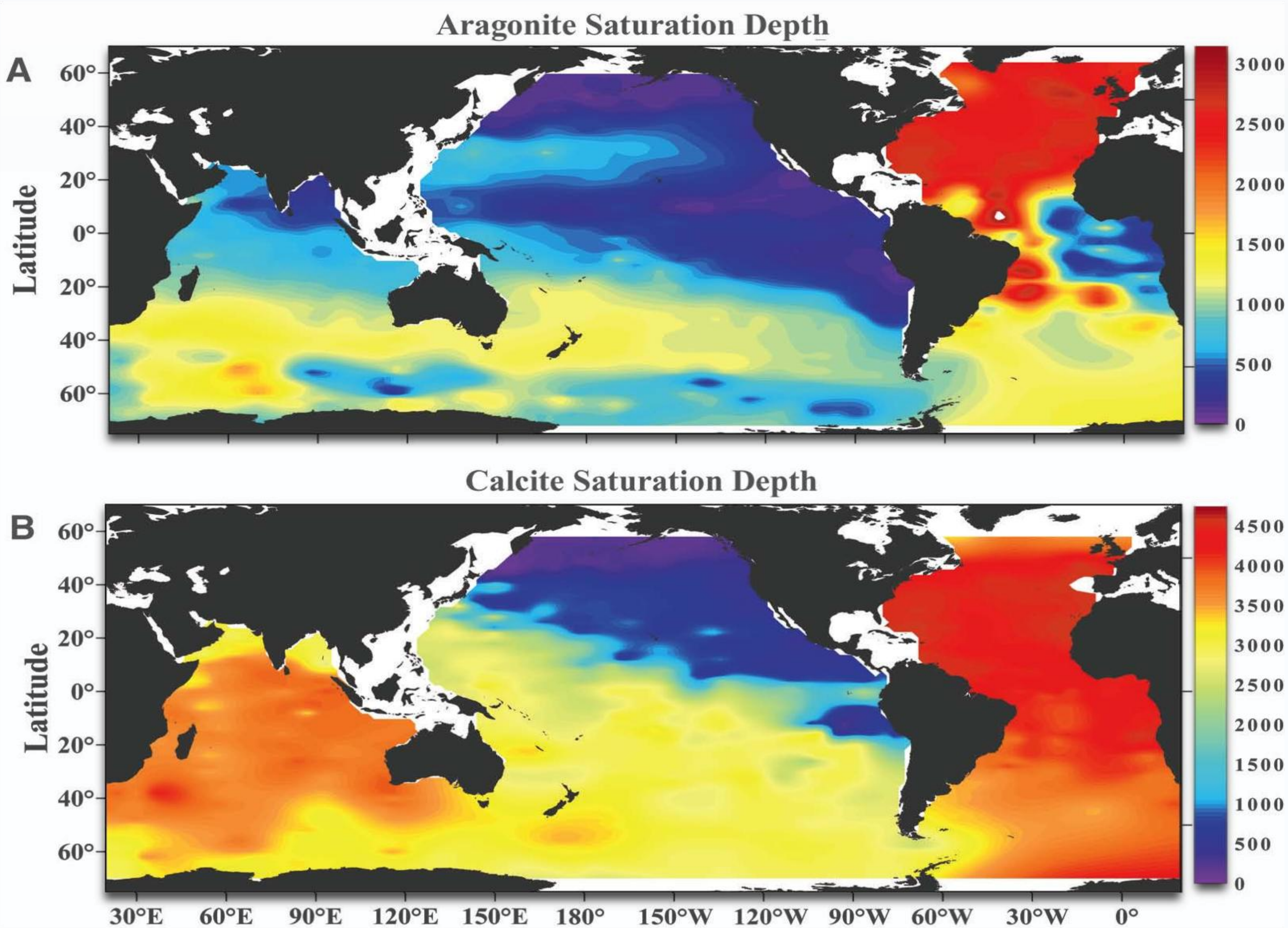
Penetration of Anthropogenic CO_2 into Ocean



- Difference of present-day levels minus pre-industrial (year 1800)
- Half trapped in upper 400 m
- Equivalent to about a third of all historical carbon emissions
- 148 Pg C since the beginning of the industrial era have accumulated in the oceans

Sabine et al. Science 2004

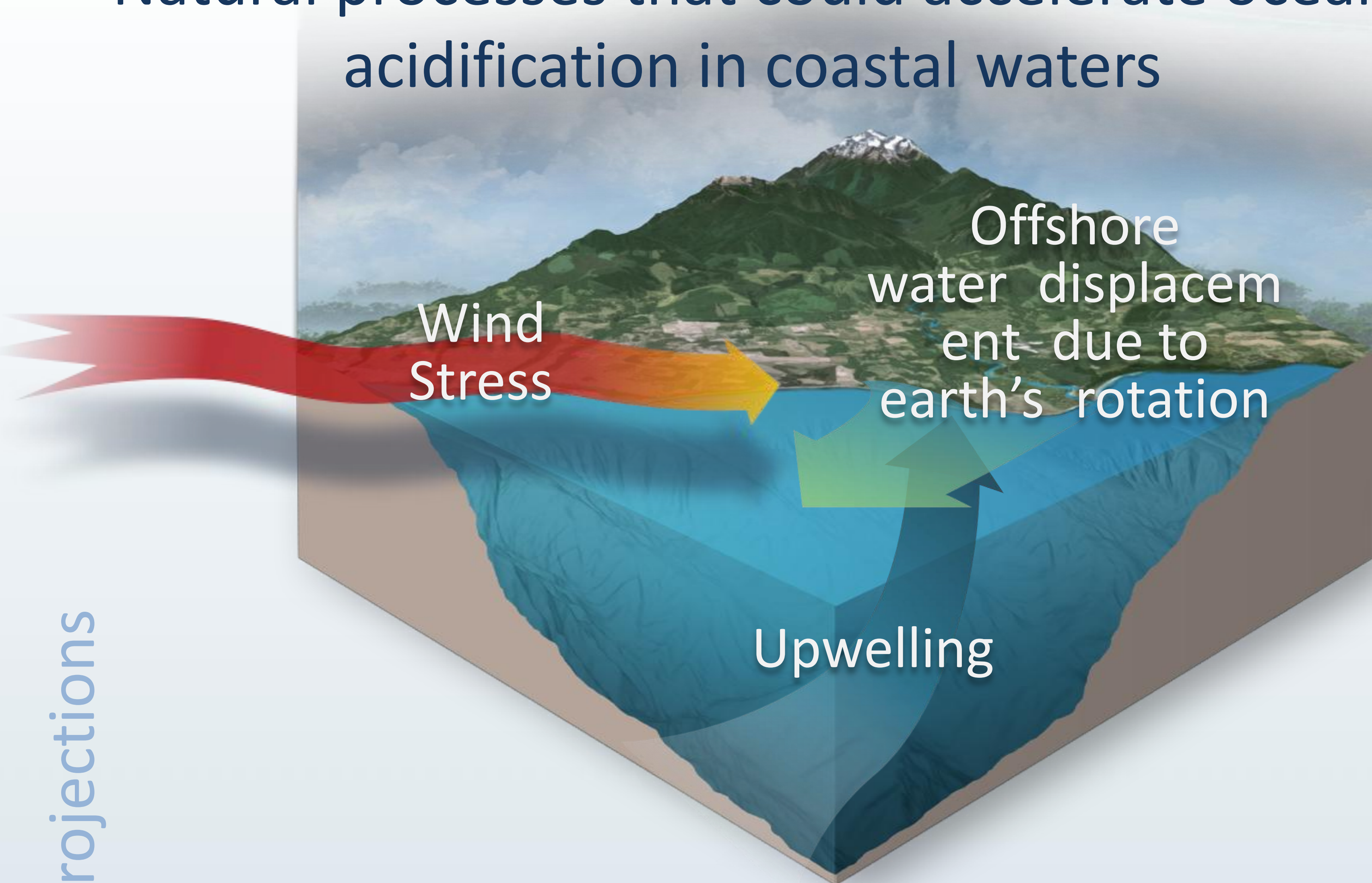
Observed aragonite & calcite saturation depths



Feely *et al.* (2004)

The **aragonite saturation state** migrates towards the surface at the rate of 1-2 m yr^{-1}, depending on location.

Natural processes that could accelerate ocean acidification in coastal waters

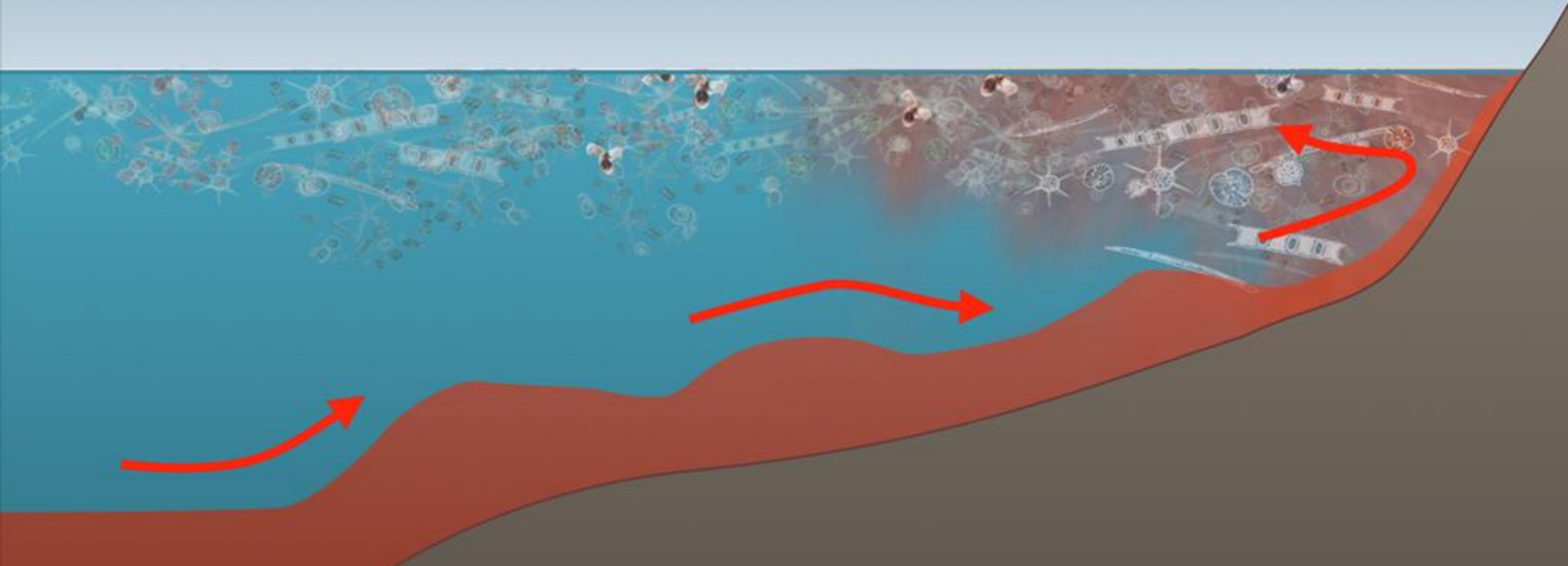


brings high CO_2, low pH, low Ω, low O_2 water to surface

Coastal Upwelling

Projections

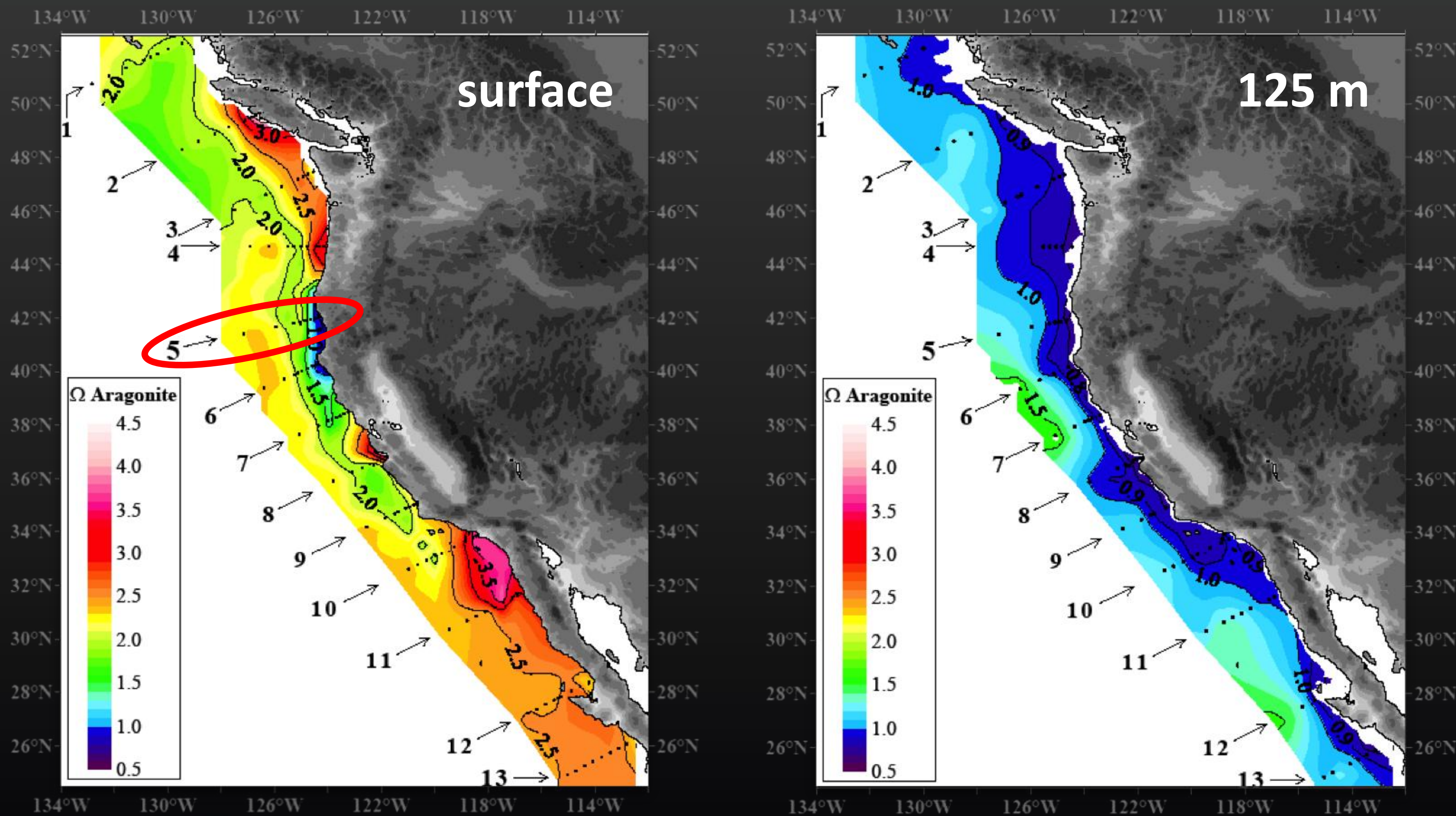
Seasonal invasion of corrosive upwelled water on the west coast of North America



- Upwelling of CO_2-rich intermediate waters, undersaturated with aragonite (Ω_{arag}), onto continental shelf from a depth of 150 – 200m
- Exposure of productive coastal ecosystems to corrosive upwelled water

West Coast Carbon Cruise

May–June 2007 – A first look at ocean acidification on our coast



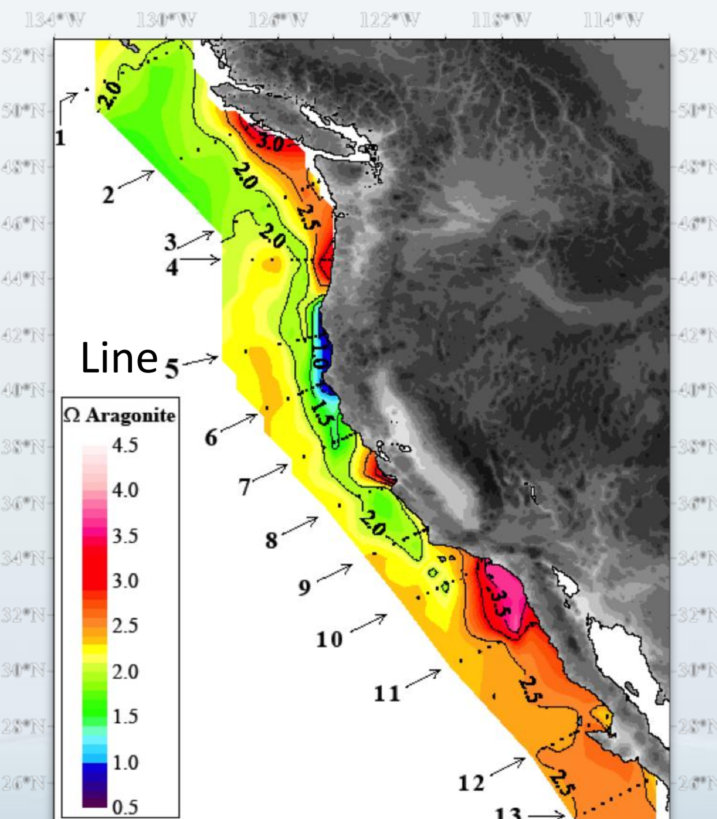
Aragonite saturation state in West Coast waters

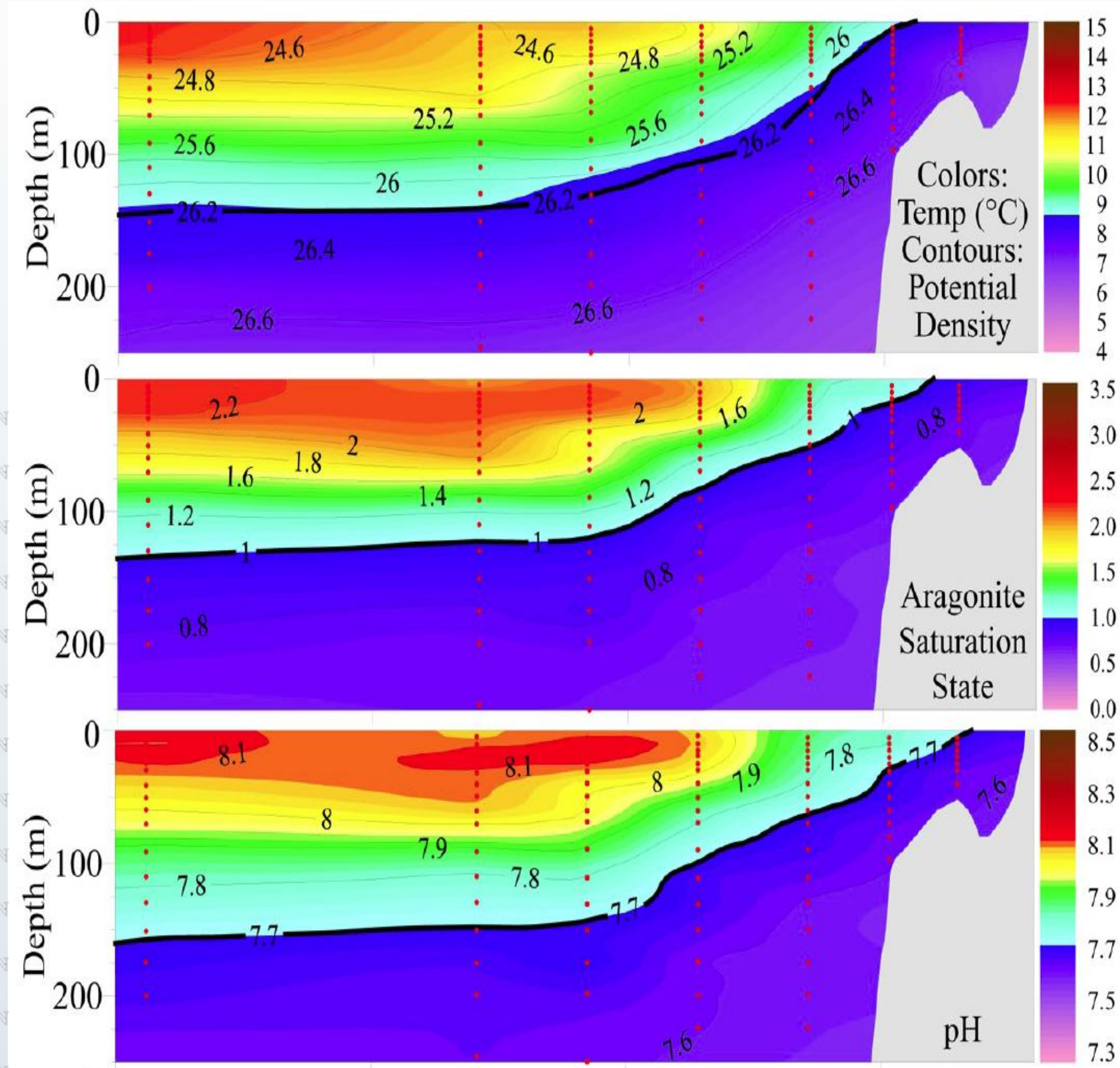
NACP West Coast Survey Cruise

11 May - 14 June 2007

Vertical sections from

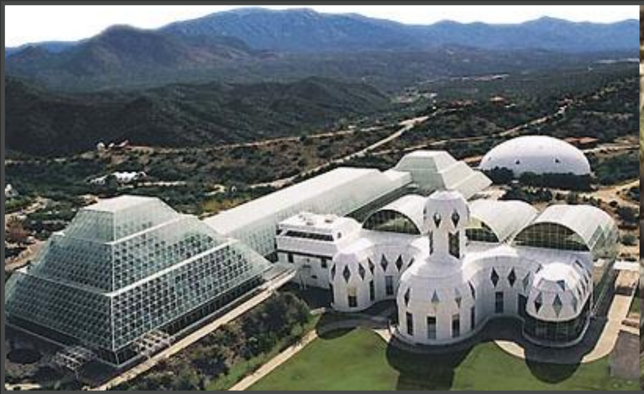
Line 5 - Pt. St. George, CA





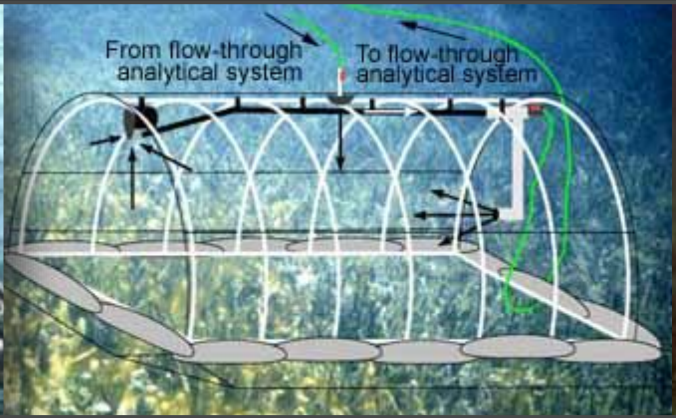
Feely et al., Science, 2008

Experiments on *many scales*




Biosphere 2
(provided by Mark Eakin)

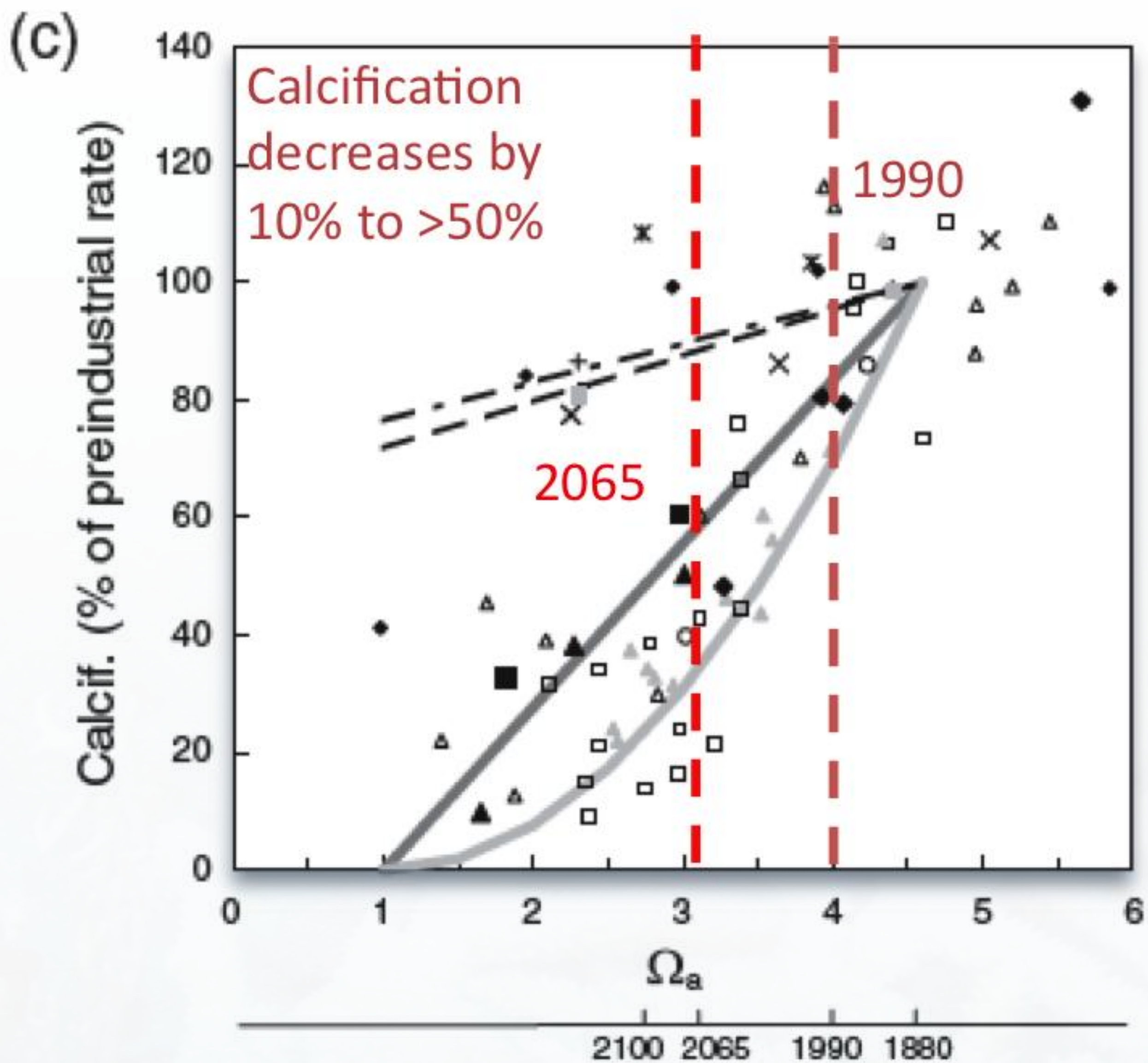
Aquaria
& Small Mesocosms

USGS science for a changing world

SHARQ
Submersible Habitat for Analyzing Reef Quality

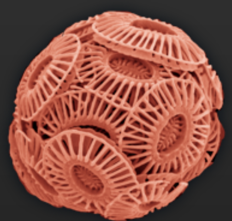
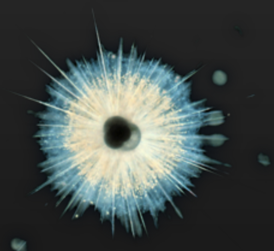
Tropical Corals

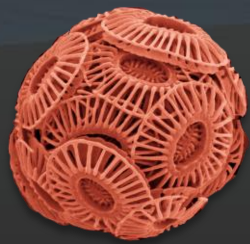


- Acidification reduces coral calcification & growth
- Corals threatened also by warming, over-fishing & pollution

Langdon and Atkinson 2005

Major planktonic calcifiers

		extant species	mineral form	generation time
	Coccolithophores algae	~ 200	calcite	days
	Foraminifera protists	~ 30	calcite	weeks
	Pteropods snails	~ 32	aragonite	months to year?



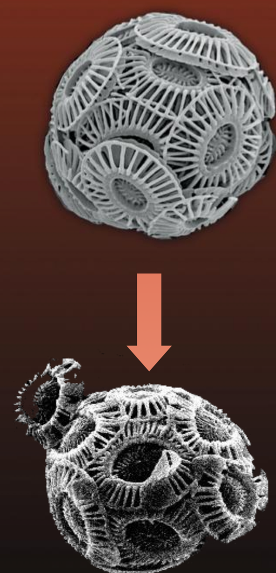
Coccolithopores

single-celled algae

manipulation of CO_2 system by addition of HCl or NaOH

pCO_2
280-380 ppmv

780-850 ppmv



Emiliana huxleyi

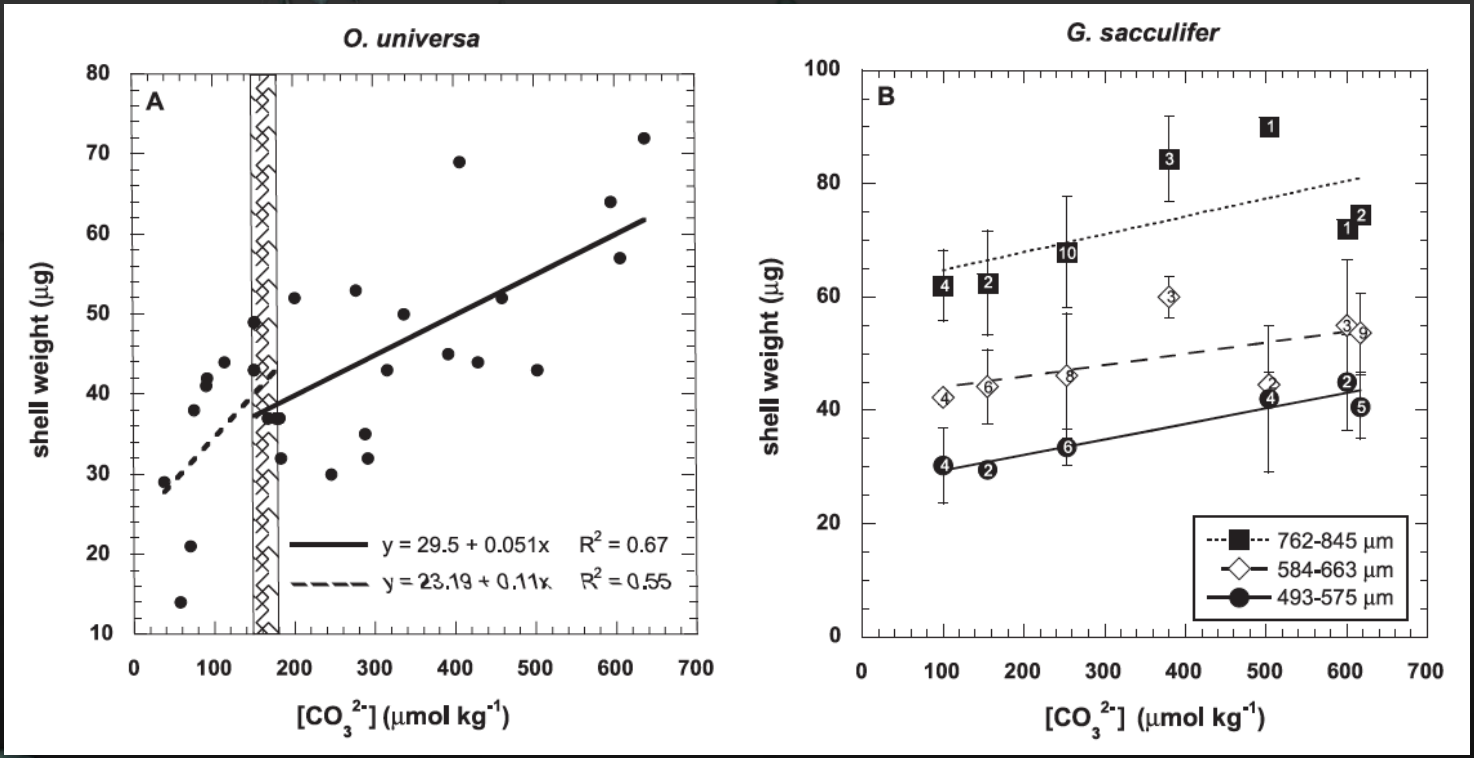
Gephyrocapsa oceanica

Calcification decreased	9-18%	45%

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

Foraminifera

single-celled protists



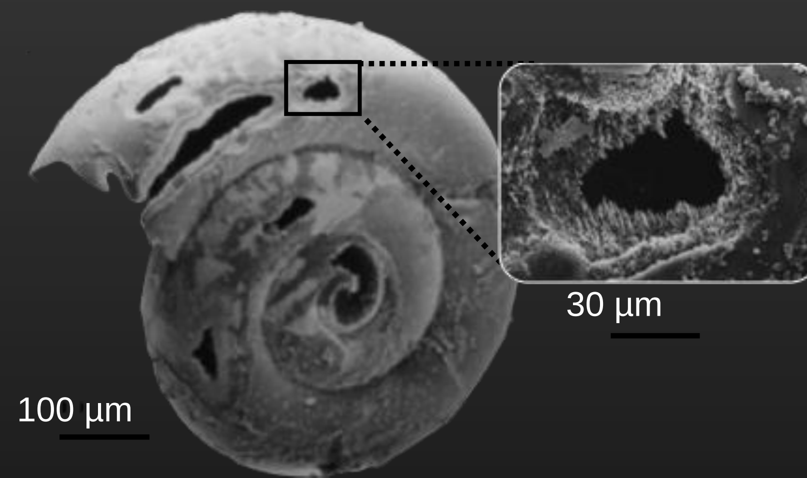
4-8% decline in calcification at pCO_2 = 560 ppm
6-14% decline in calcification at pCO_2 = 780 ppm

Shell mass is positively correlated with $[CO_3^{2-}]$

Bijma et al. (2002)

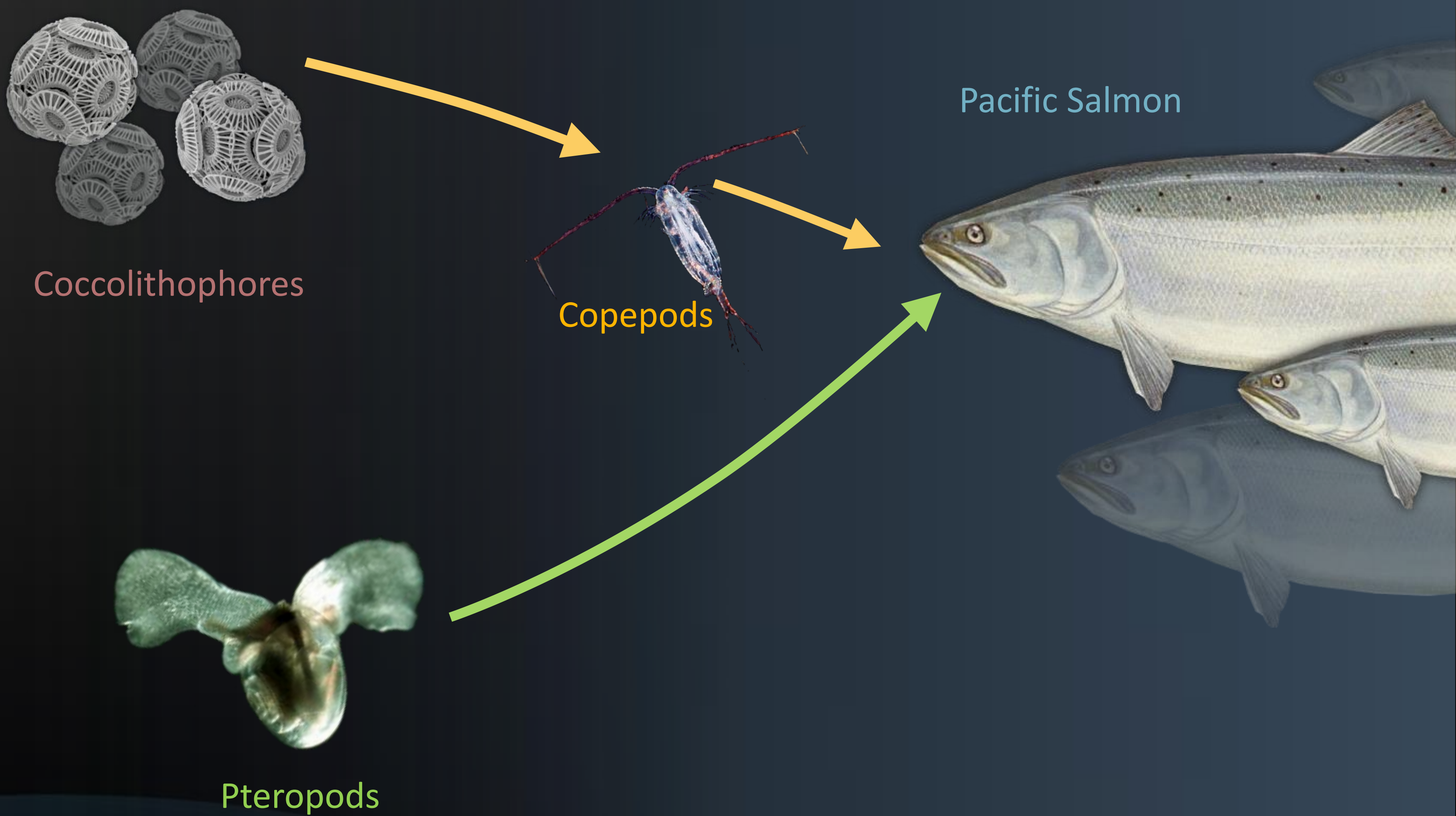
Shelled pteropods: planktonic snails

***Limacina helicina* fresh shell**

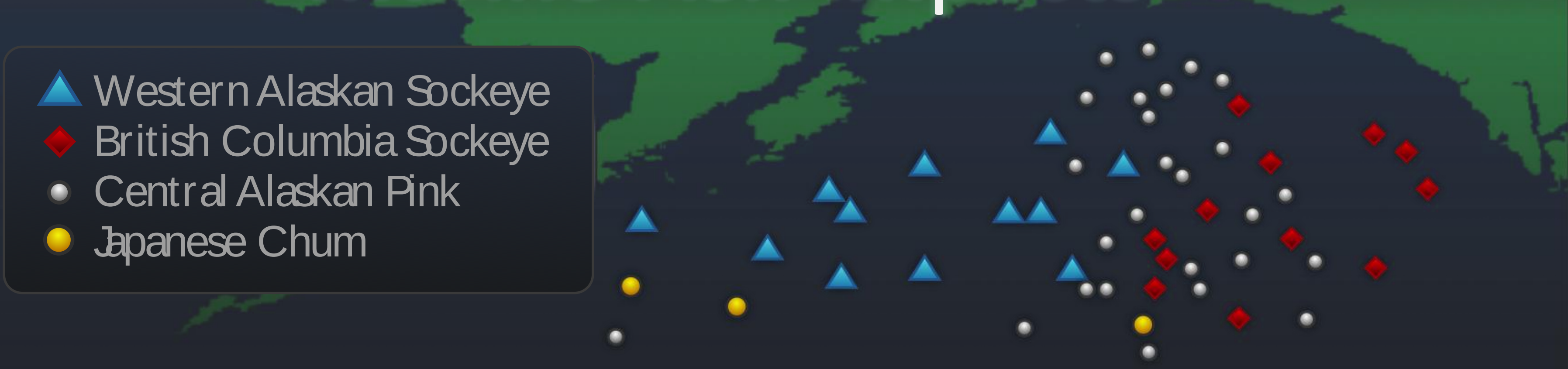


Shell dissolution in *Limacina helicina*; incubation at 1100 µatm pCO_2, 3˚C for 29 days.

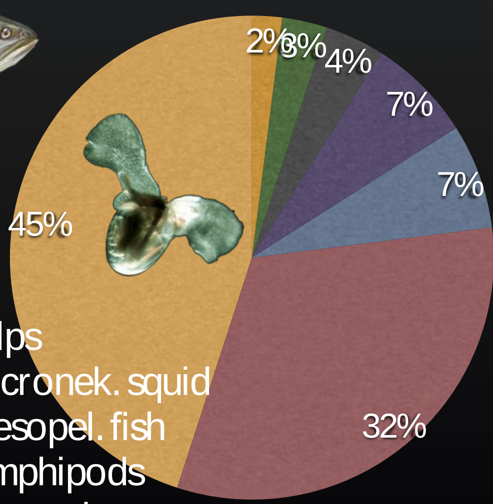
Potential *food web* impacts



Marine Fish impacts



Pink salmon diet



Predicted effect of climate change on pink salmon growth:

- 10% increase in water temperature leads to 3% drop in mature salmon body weight (physiological effect).
- 10% decrease in pteropod production leads to 20% drop in mature salmon body weight (prey limitation).

Aydin et al., 2005

Potential impacts:

marine organisms & ecosystems

- Reduced calcification rates
- Significant shift in key nutrient and trace element speciation
- Shift in phytoplankton diversity
- Reduced growth, production and life span of adults, juveniles & larvae
- Reduced tolerance to other environmental fluctuations

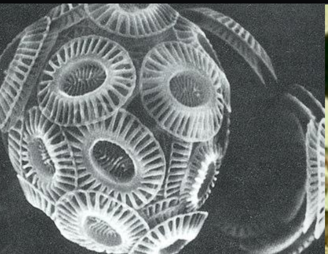
Changes to:

- Fitness and survival
- Species biogeography
- Key biogeochemical cycles
- Food webs

Reduced:

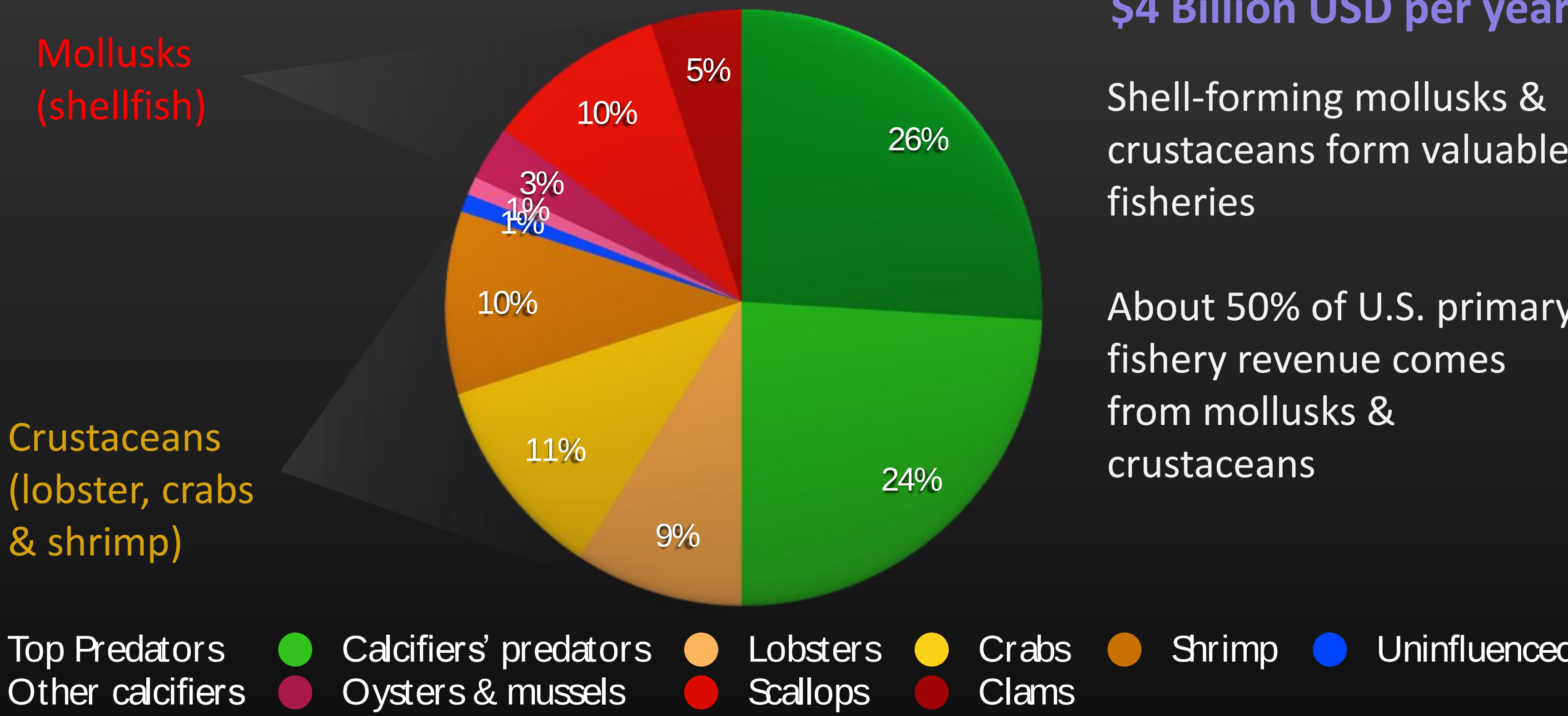
- Sound Absorption
- Homing Ability
- Recruitment and Settlement

Changes to ecosystems & their services






Valuable commercial fisheries depend on species sensitive to ocean acidification



$4 Billion USD per year

Shell-forming mollusks & crustaceans form valuable fisheries

About 50% of U.S. primary fishery revenue comes from mollusks & crustaceans

2007 U.S. domestic ex-vessel revenue

Cooley & Doney
Environment Research Letters, 2009

The Seattle Times

Monday, June 15, 2009 - Page updated at 11:38 AM

Corrected version

Oysters in deep trouble: Is Pacific Ocean's chemistry killing sea life?

By Craig Welch
Seattle Times environment reporter

WILLAPA BAY, Pacific County â€"

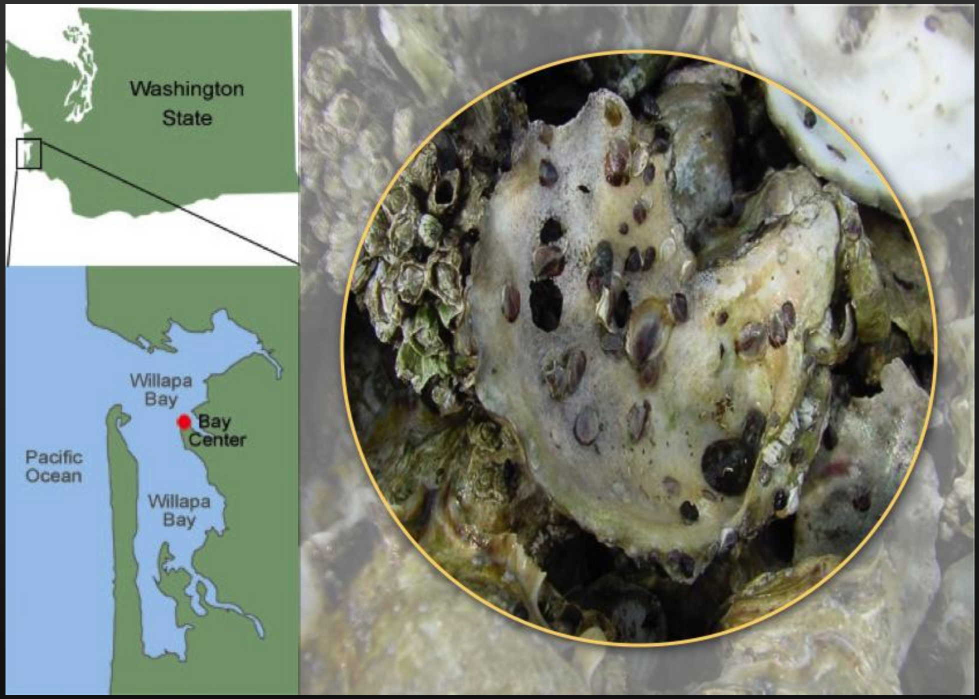
The collapse began rather unspectacularly.

In 2005, when most of the millions of Pacific oysters in this tree-lined estuary failed to reproduce, Washington's shellfish growers largely shrugged it off.

STEVE RINGMAN / THE SEATTLE TIMES
Oysters' failure to reproduce will lead workers like Northern Oyster Co.'s Gildardo Mendoza to collect far more of their product from a state "oyster preserve" in Willapa Bay. Pacific oysters haven't successfully reproduced in the wild since 2004.

Pacific Northwest *oyster emergency*

Are larval oysters the "canary in the coal mine" for near-shore acidification?



Willapa Bay seed crisis

- Failure of larval oyster recruitments in recent years
- Commercial oyster hatchery failures threatens $100M industry (3000 Jobs)
- Low pH "upwelled" waters a possible leading factor in failures

Coastal upwelling

-Linked to high mortality events

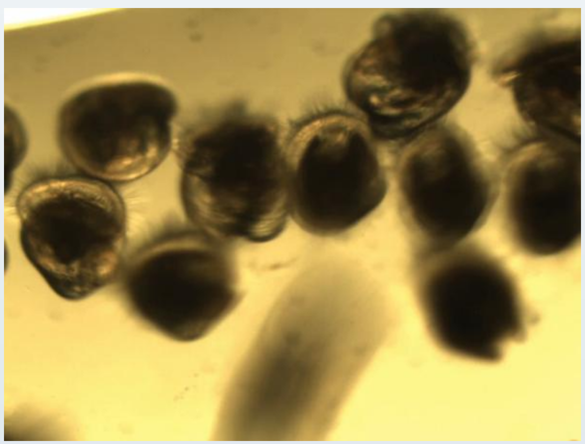
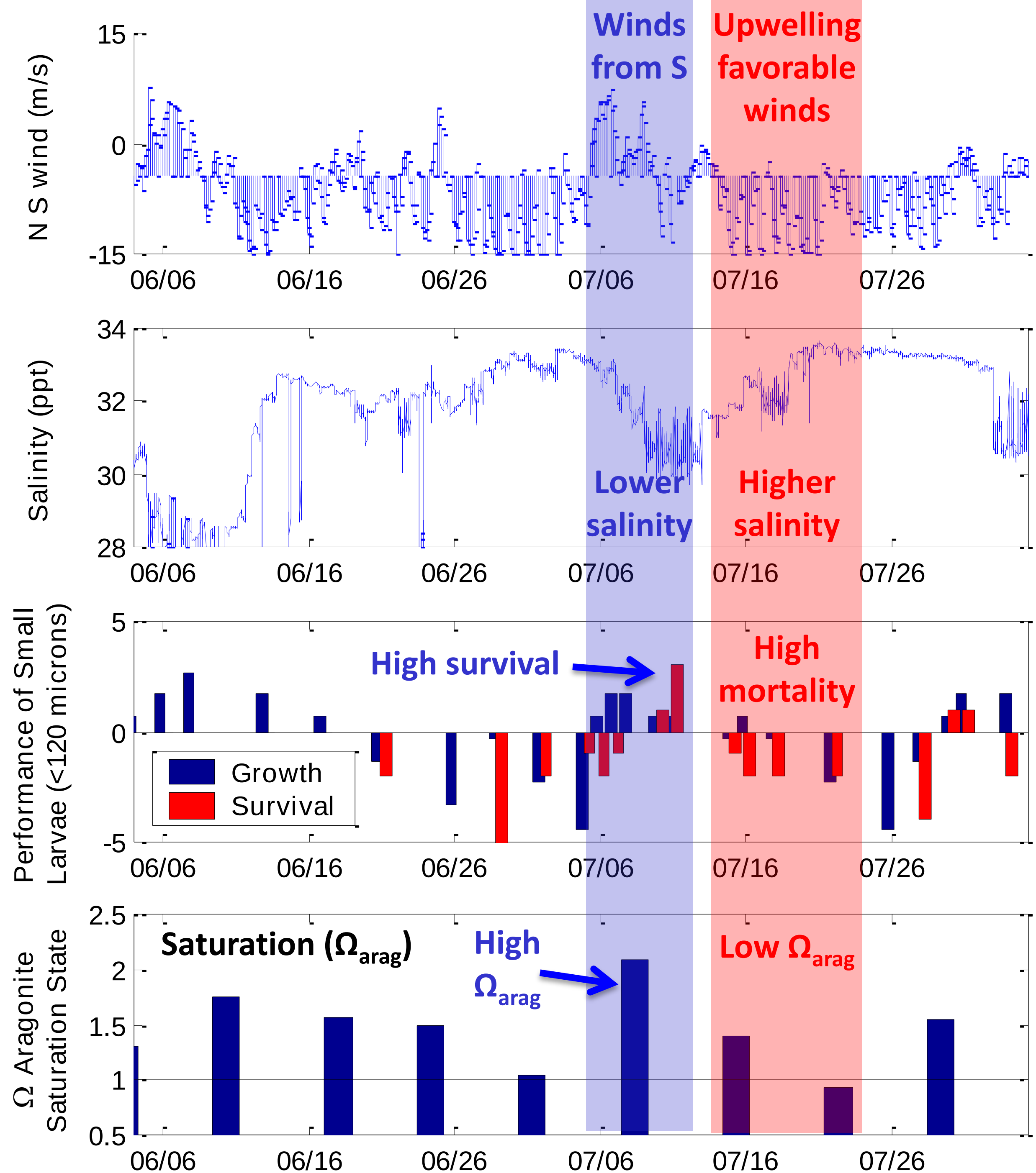


Figure courtesy of Alan Barton



Biological impacts & sensitivity to CO_2 perturbations

Much of our present knowledge stems from…

- abrupt CO_2/pH perturbation experiments
- with single species/strains
- under short-term incubations
- with often extreme pH changes

Provided by Ulf Riebesell, 2006

Hence, we know little about…

- responses of genetically diverse populations
- synergistic effects with other stress factors
- physiological and micro-evolutionary adaptations
- species replacements
- community to ecosystem responses
- impacts on global climate change

Conclusions

Since the beginning of the industrial age surface ocean pH (~0.1), carbonate ion concentrations (~16%), and aragonite and calcite saturation states (~16%) have been decreasing *because of the uptake of anthropogenic CO_2* by the oceans, i.e., ocean acidification. By the end of this century pH could have a further decrease by as much as 0.3-0.4 pH units.

Possible responses of ecosystems are speculative but could involve changes in species composition & abundances - could affect food webs, biogeochemical cycles.. *More research on impacts, vulnerabilities and economic impacts is needed.*

An *observational network* for ocean acidification is under development. Modeling studies need to be expanded into coastal regions. *Physiological response, mitigation and adaptation studies* need to be developed and integrated with the models.

OCB Ocean Carbon & Biogeochemistry

Special Thanks to:
Scott Doney, Chris Sabine, Simone Alin, Sarah Cooley, Alan Barton

Humankind's footprint in the oceans is now clearly detectable.

It is *warmer, more acidic,* and *less diverse*.

Thank you

www.tos.org/oceanography/issues/issue_archive/22_4.html
www.pmel.noaa.gov/co2/OA
www.epoca-project.eu
www.whoi.edu/OCB-OA