Science, Service, Stewardship

Ocean Acidification Briefing

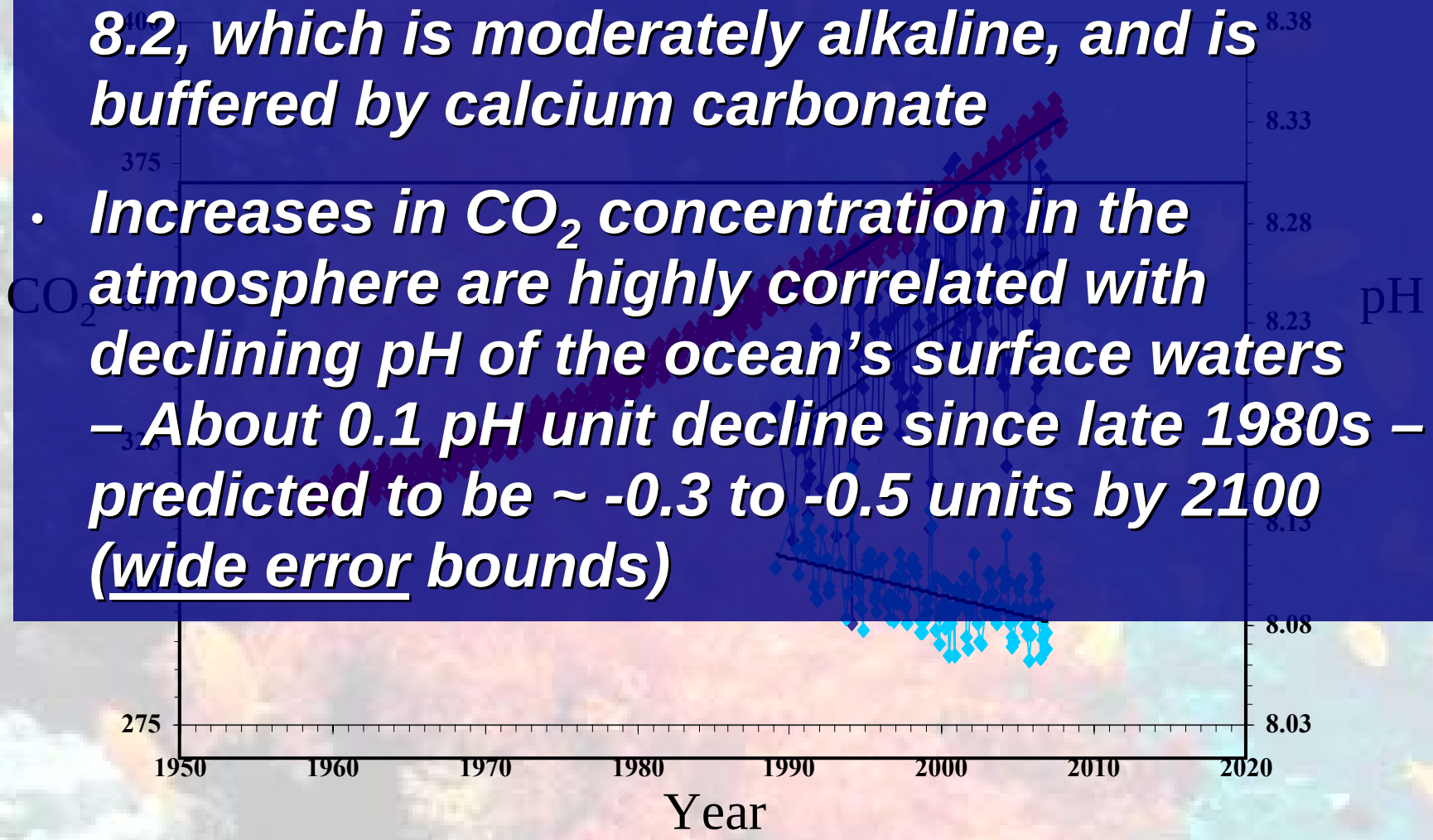
John Stein
Northwest Fisheries Science Center

Marine Fisheries Advisory Committee Meeting
Monterey, California
May 13, 2009

NOAA FISHERIES SERVICE

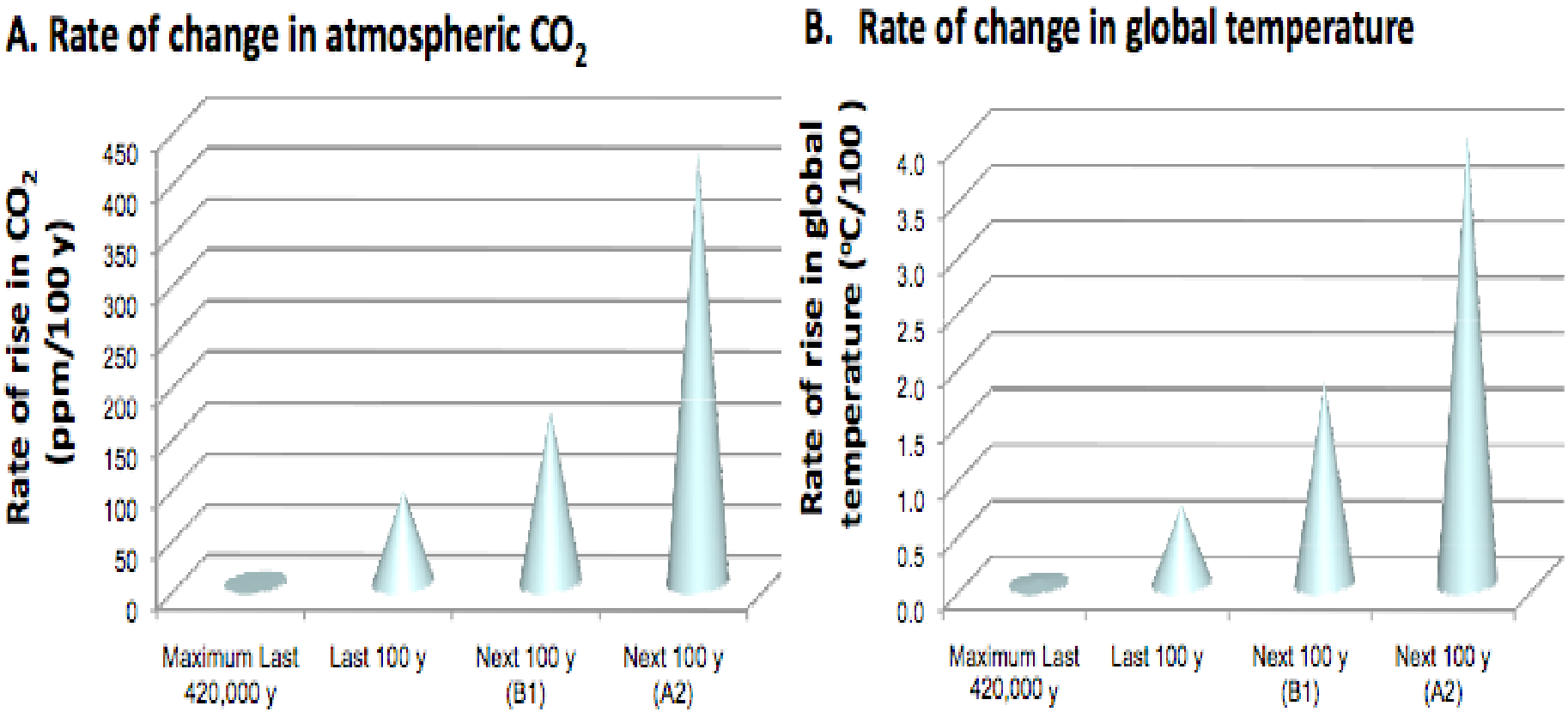
Ocean Acidification: Global Warming's *Evil Twin*

- ***Average pH of the world's oceans is about 8.2, which is moderately alkaline, and is buffered by calcium carbonate***
- ***Increases in CO_2 concentration in the atmosphere are highly correlated with declining pH of the ocean's surface waters – About 0.1 pH unit decline since late 1980s – predicted to be ~ -0.3 to -0.5 units by 2100 (wide error bounds)***



Adapted from Feely 2009

Rates of Increase are Important

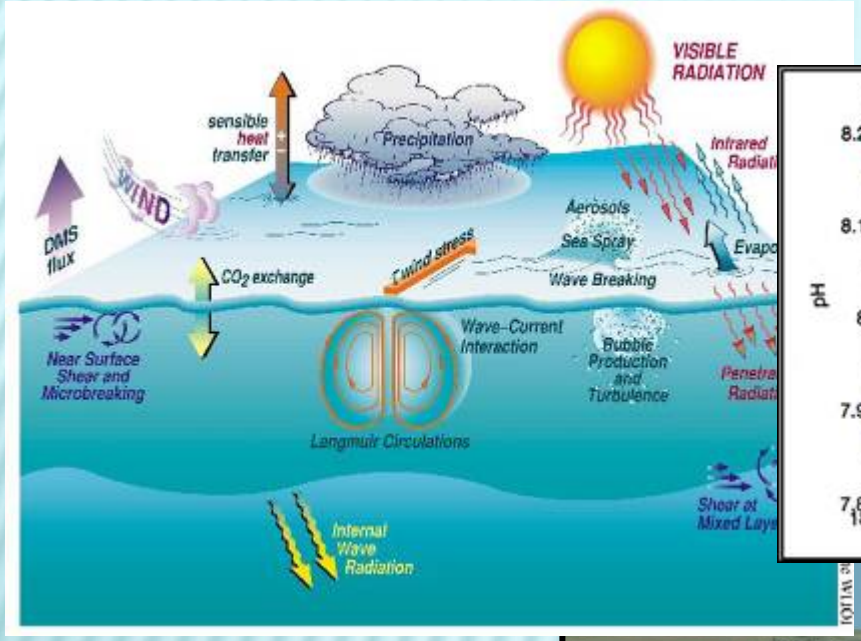


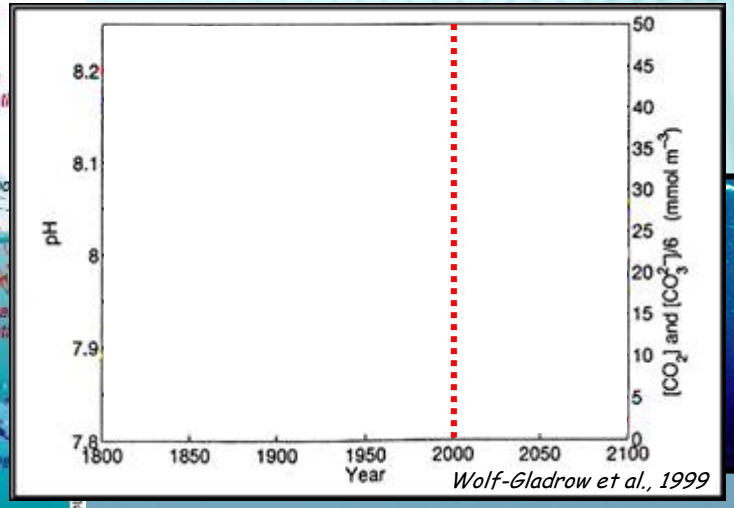
Hoegh-Guldberg et al. 2007, Science

Feely 2009

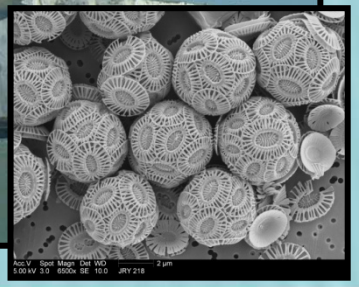
Ocean Acidification

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





Wolf-Gladrow et al., 1999



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OCEAN ACIDIFICATION: A CONSEQUENCE OF HUMAN PRODUCTION OF GREENHOUSE GASSES - OCEAN IMPACTS

Si
th
uptake of anthropogenic CO_2 by the oceans.

- Decrease in pH 0.1 over the last two centuries
- 30% increase in acidity; decrease in carbonate ion of about 16%

These changes in pH and carbonate chemistry may have serious impacts on open ocean and coastal marine ecosystems.

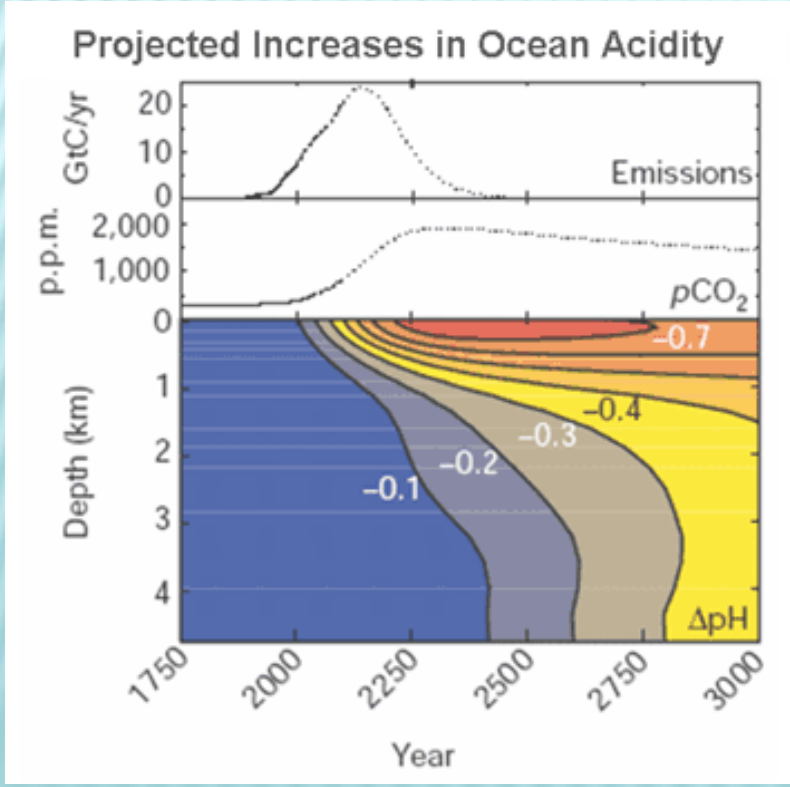
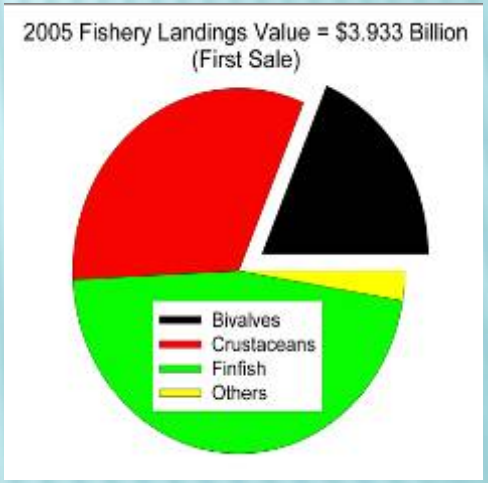


Photo: Missouri Botanical Gardens



Value:
Bivalves: $732M ex-vessel commercial value
Crustaceans: $1,265M ex-vessel commercial
Combined : $1,997M ex-vessel commercial value (51% of commercial catch by $)

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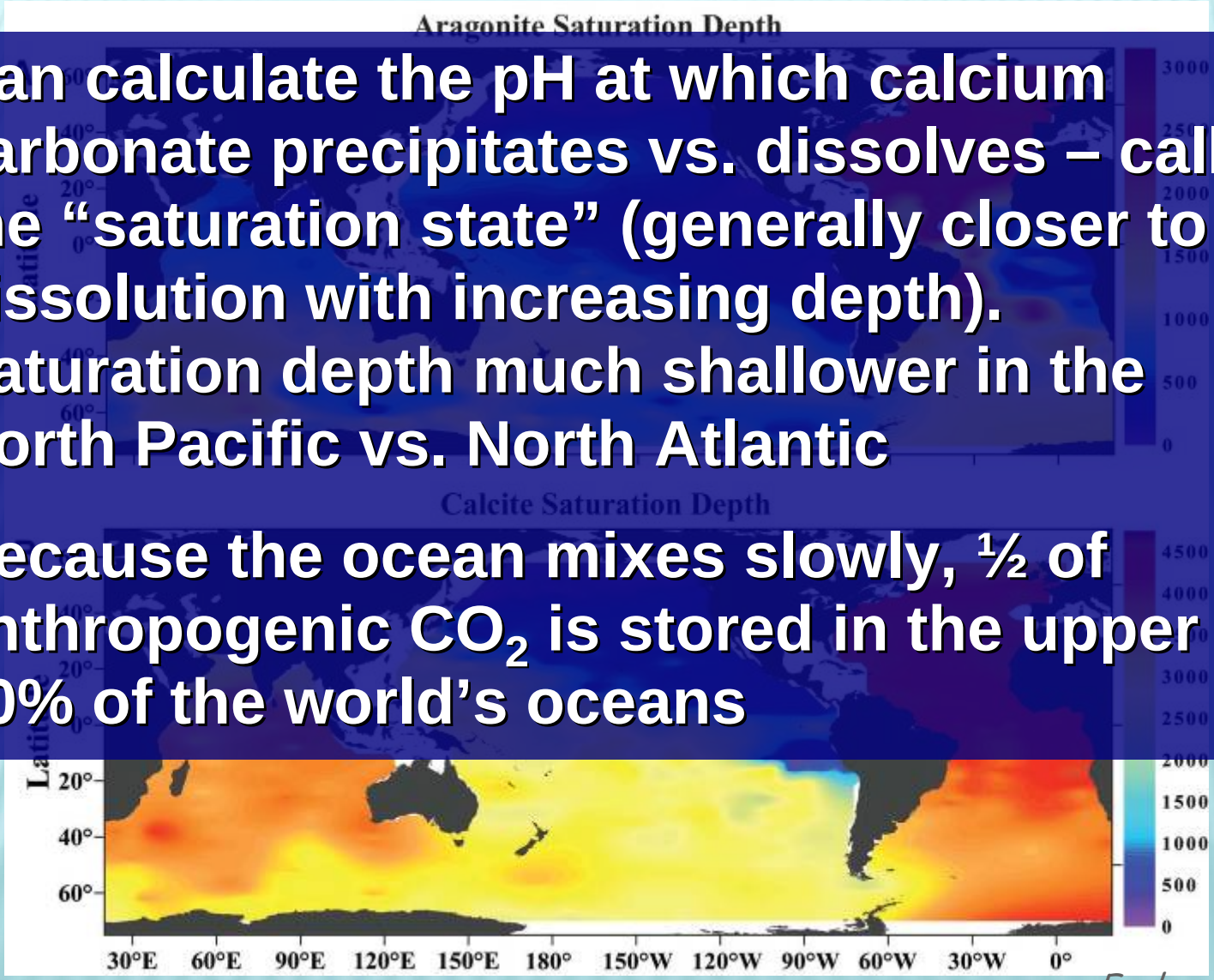
What we know about ocean CO_2 chemistry

…from observed aragonite and calcite saturation depths in the global oceans



- **Can calculate the pH at which calcium carbonate precipitates vs. dissolves – called the "saturation state" (generally closer to dissolution with increasing depth). Saturation depth much shallower in the North Pacific vs. North Atlantic**
- **Because the ocean mixes slowly, ½ of anthropogenic CO_2 is stored in the upper 10% of the world's oceans**

Feely et al. (2004)

What we know about the ocean chemistry of

...saturation state

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

Saturation State

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

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

calcium carbonate calcium carbonate

$\Omega > 1 = precipitation$

$\Omega = 1 = equilibrium$

$\Omega < 1 = dissolution$

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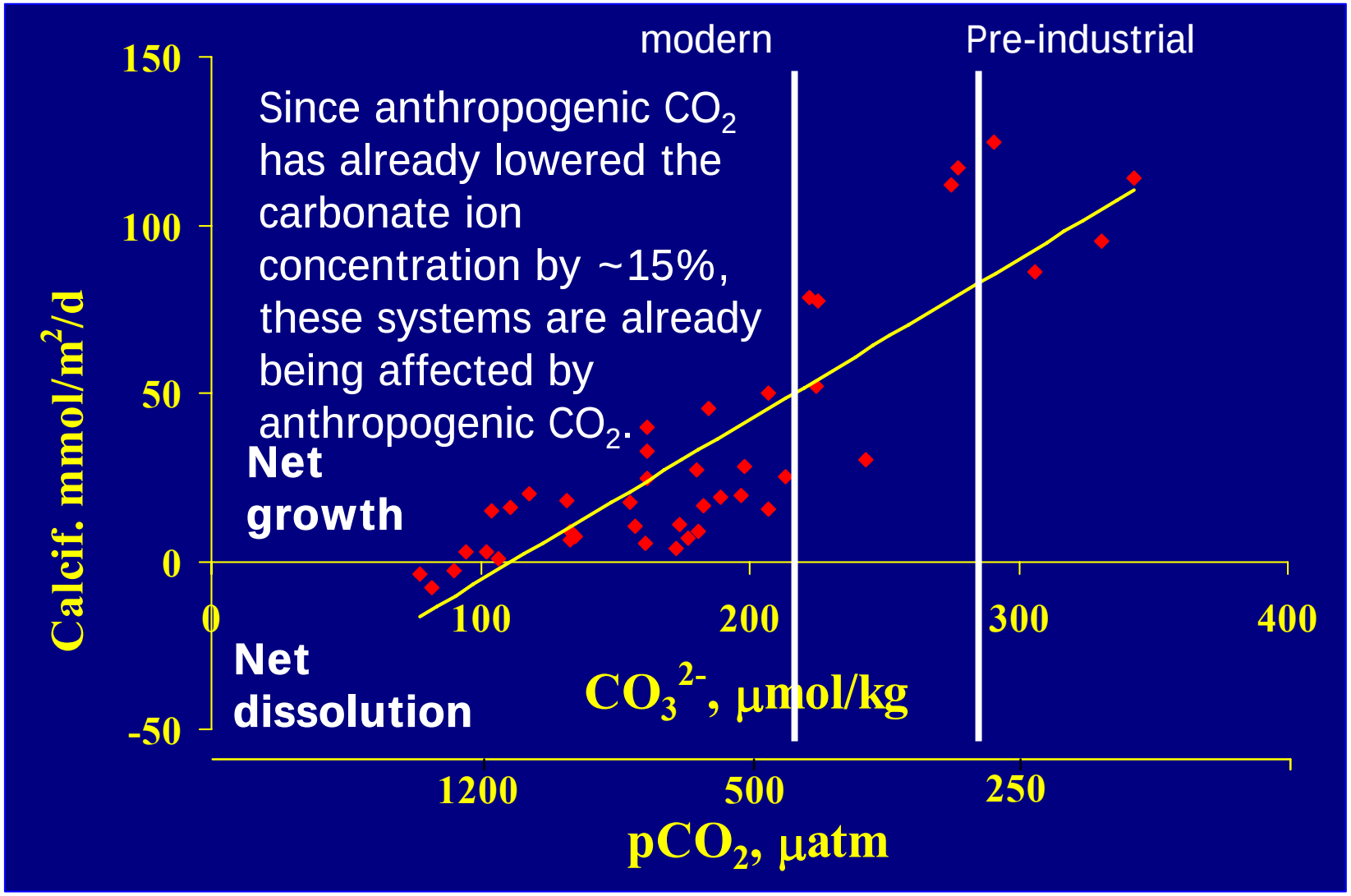
There appears to be a linear decrease in the calcification rate of coral reef systems with decreasing carbonate ion concentrations.



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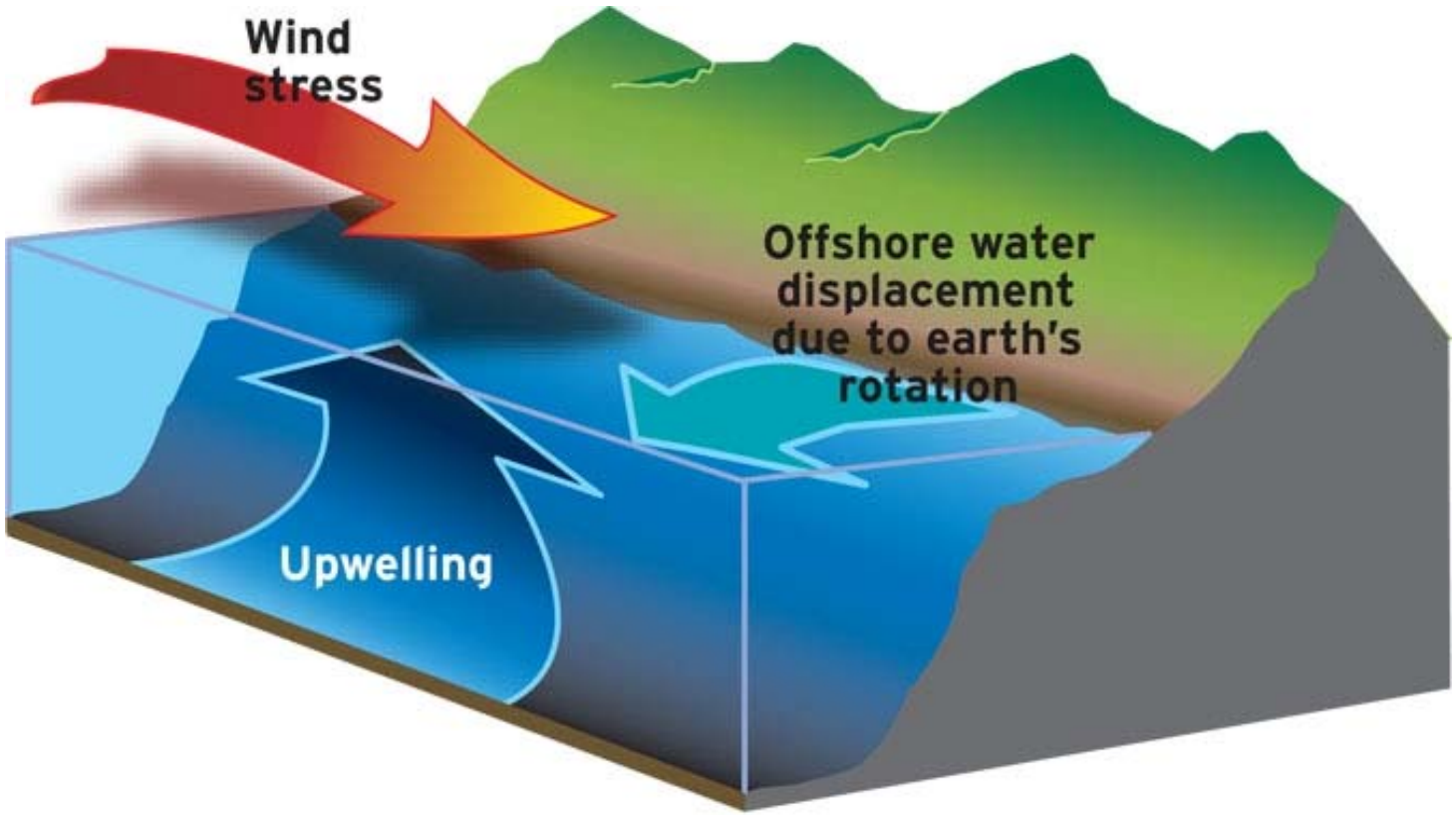
Natural processes that could accelerate the ocean acidification of coastal waters

- Coastal Upwelling



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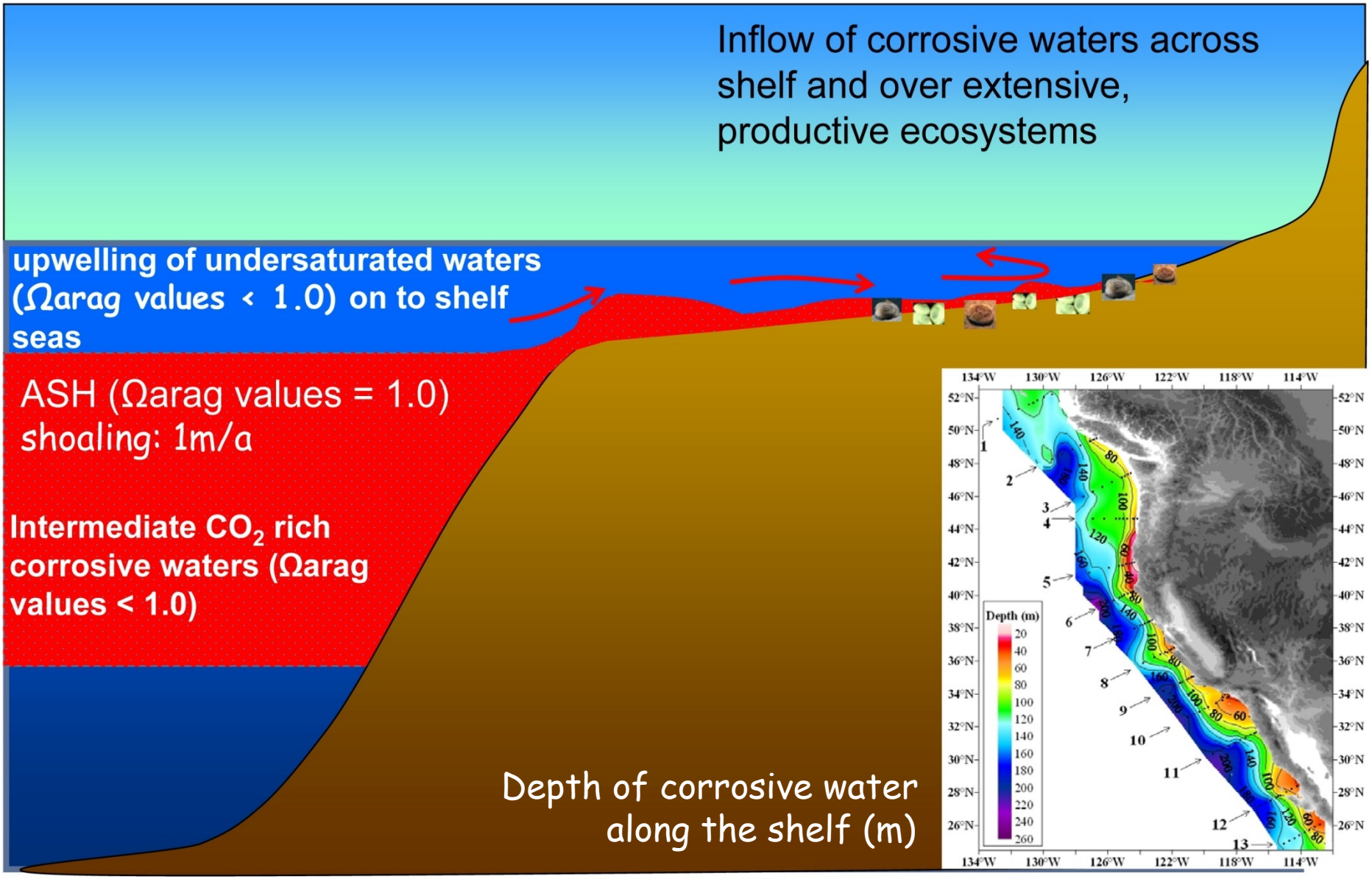
Seasonal Invasion of Corrosive Waters on West Coast North America



Schematic by C. Turley

Feely et al. Science (2008)

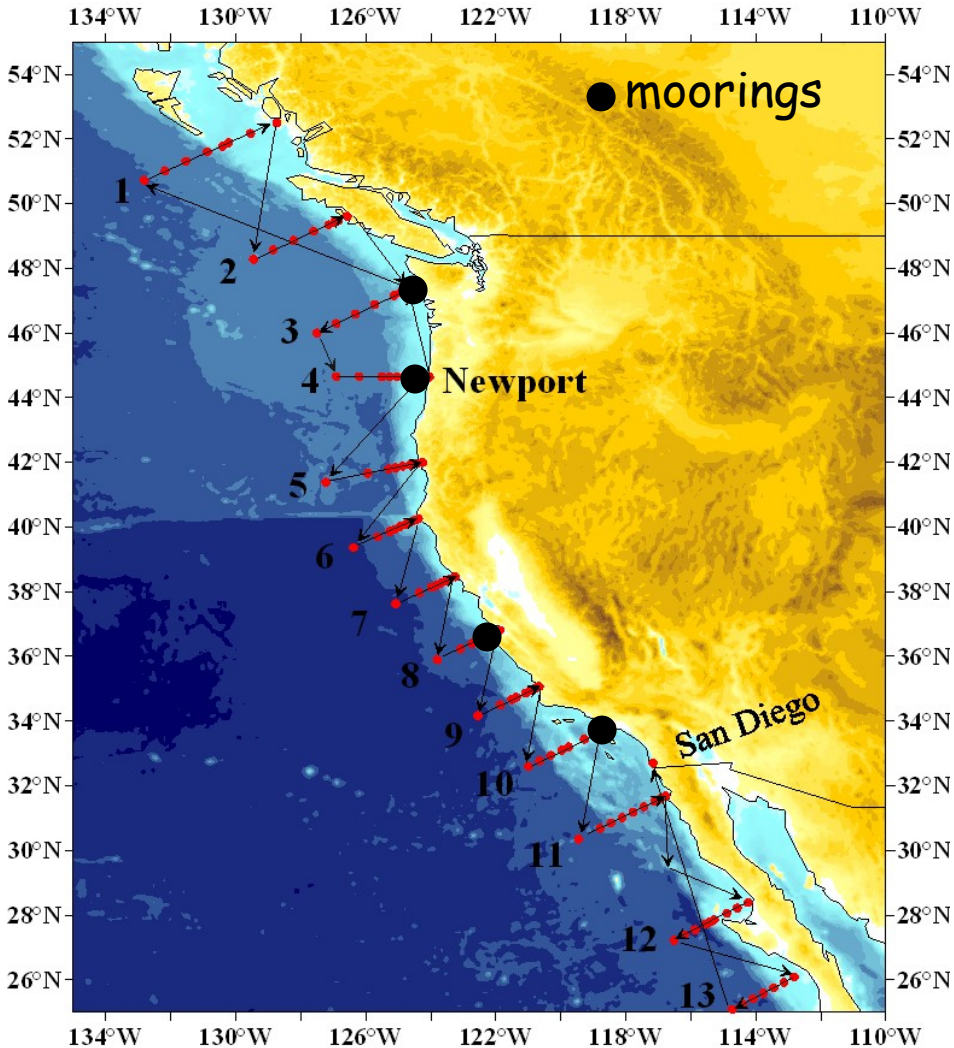
NACP West Coast Survey Cruise : 11 May - 14 June 2007 and mooring locations

Newport

Aberdeen

MBARI

UCLA



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Concern for Many Marine Organisms and 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
- Changes to species biogeography
- Changes to key biogeochemical cycles
- Changes to food webs
- Changes to ecosystem & their services
- Uncertainities great – research required

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Economic and Ecological Consequences

- Animals with calcium carbonate shells (two forms, calcite, aragonite), especially shallow water forms in the Atlantic and shallow and deep water forms in Pacific, Arctic, and Antarctic
- Bivalves, especially in shallow waters
- Carbonate shelled plankton (pteropods, some forms of phytoplankton, e.g., with shells)
- Crustaceans (crabs, lobsters, shrimps – perhaps)
- Shallow-water coral ecosystems (stony corals)
- Deep Corals especially in the North Pacific
- Finfishes dependent on calcium-containing food sources

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NMFS Research: Phytoplankton Response Studies

- Possible fertilization effect of increased CO_2 (carbon) as phytoplankton nutrient

- Studies with some phytoplankton indicate that reductions of 0.3-0.5 pH units have little impact on productivity, but may differentially impact species dominance

Unknown – interaction between Temp and CO2

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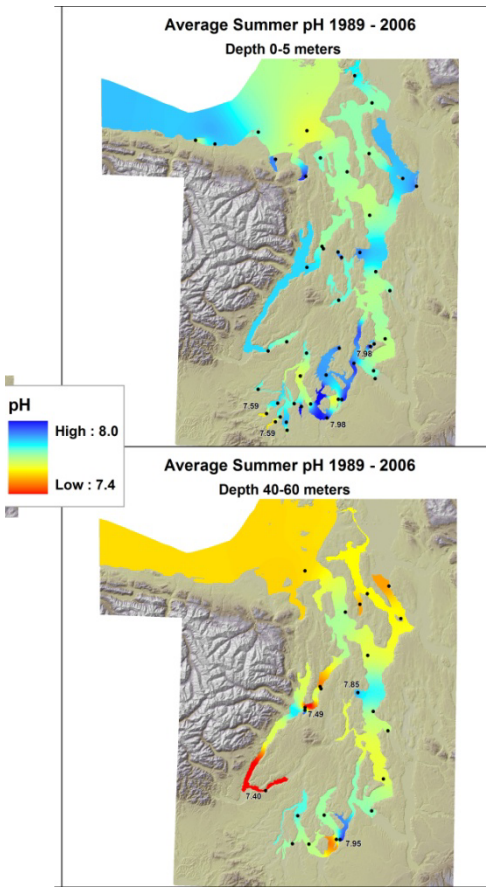
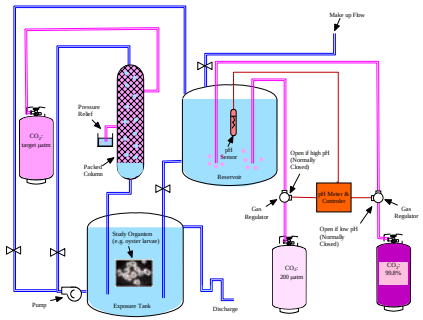
NMFS Research: Predicting ecological effects of OA

1 Patterns of acidification

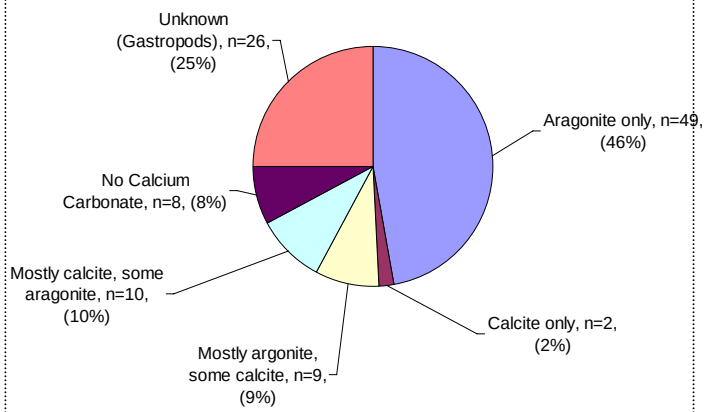


e.g. Puget Sound pH maps

2 Estimating species vulnerability

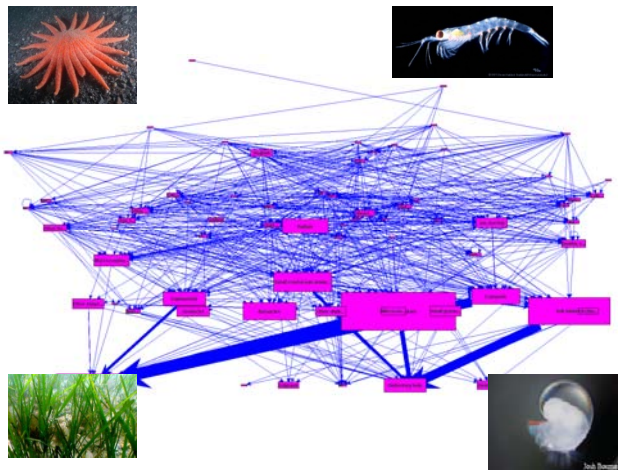


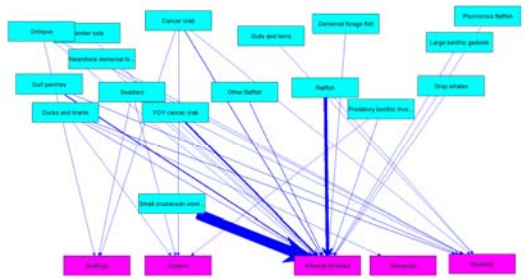
e.g. Treatment experiments



e.g. Survey of mineralogy of Puget Sound mollusks

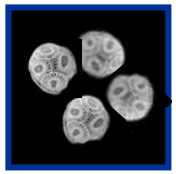
3 Impacts on food webs





e.g. Complete and bivalve-centric Puget Sound food webs

Potential Effects on Open Ocean Food Webs



Coccolithophores

ARCOD@ims.uaf.edu

Copepods

Pteropods

Pacific Salmon

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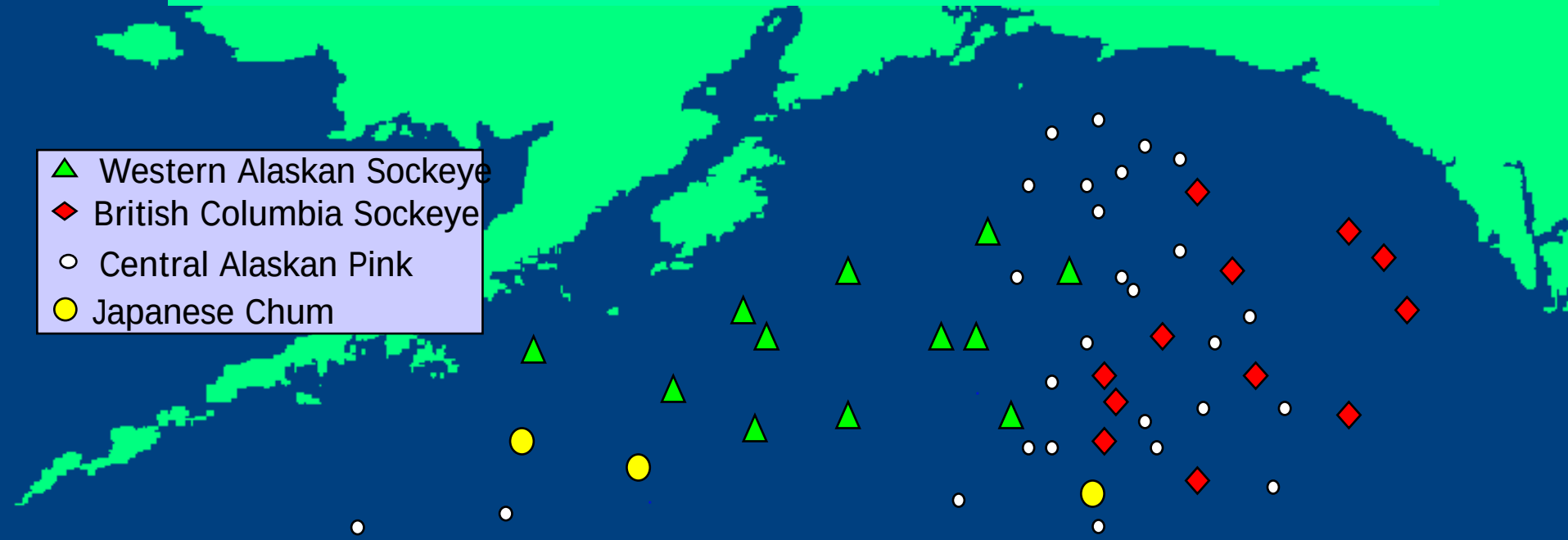
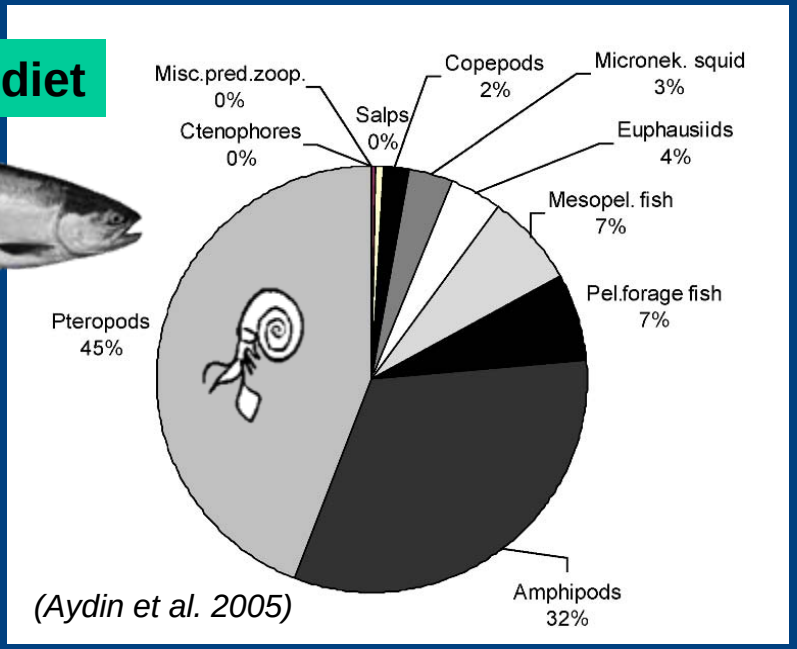
NMFS Research: Modeled Impacts of OA on Pacific Salmon



Pink salmon diet



(Aydin et al. 2005)

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).

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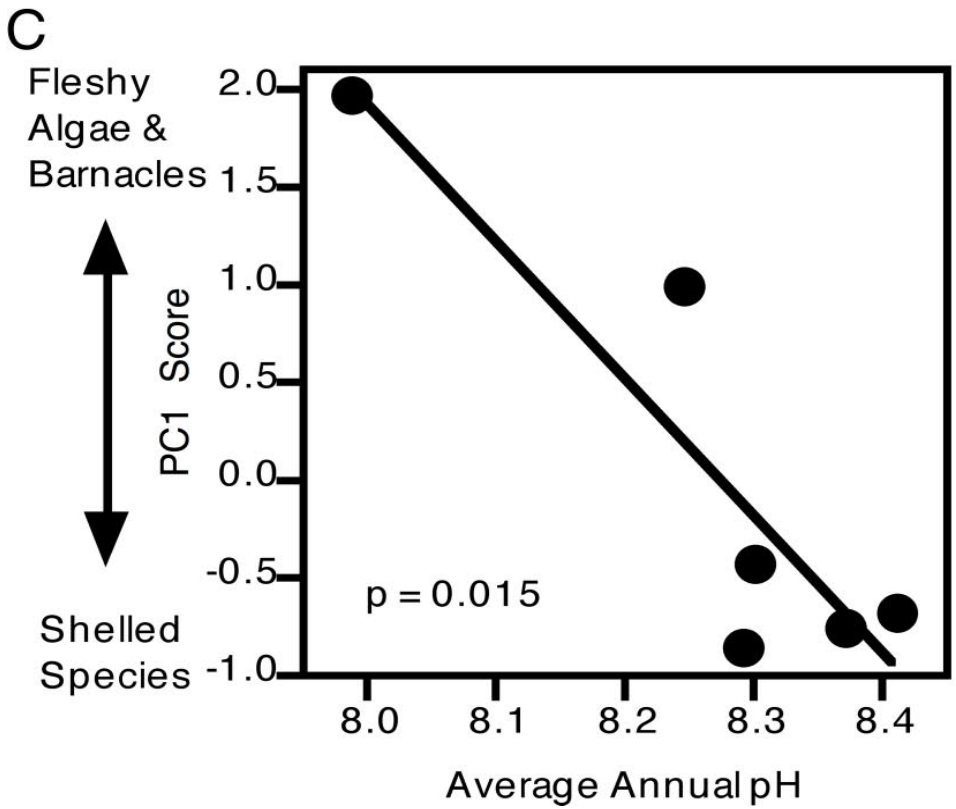
Other Examples – Ecosystem Change

Mussels on Tatoosh Island



Mussels generally performed more poorly than barnacles and fleshy algae in years with low pH

Wootton, et al. 2008. Dynamic patterns and ecological impacts of declining ocean pH in a high-resolution multi-year dataset. Proc. National Acad. Science.

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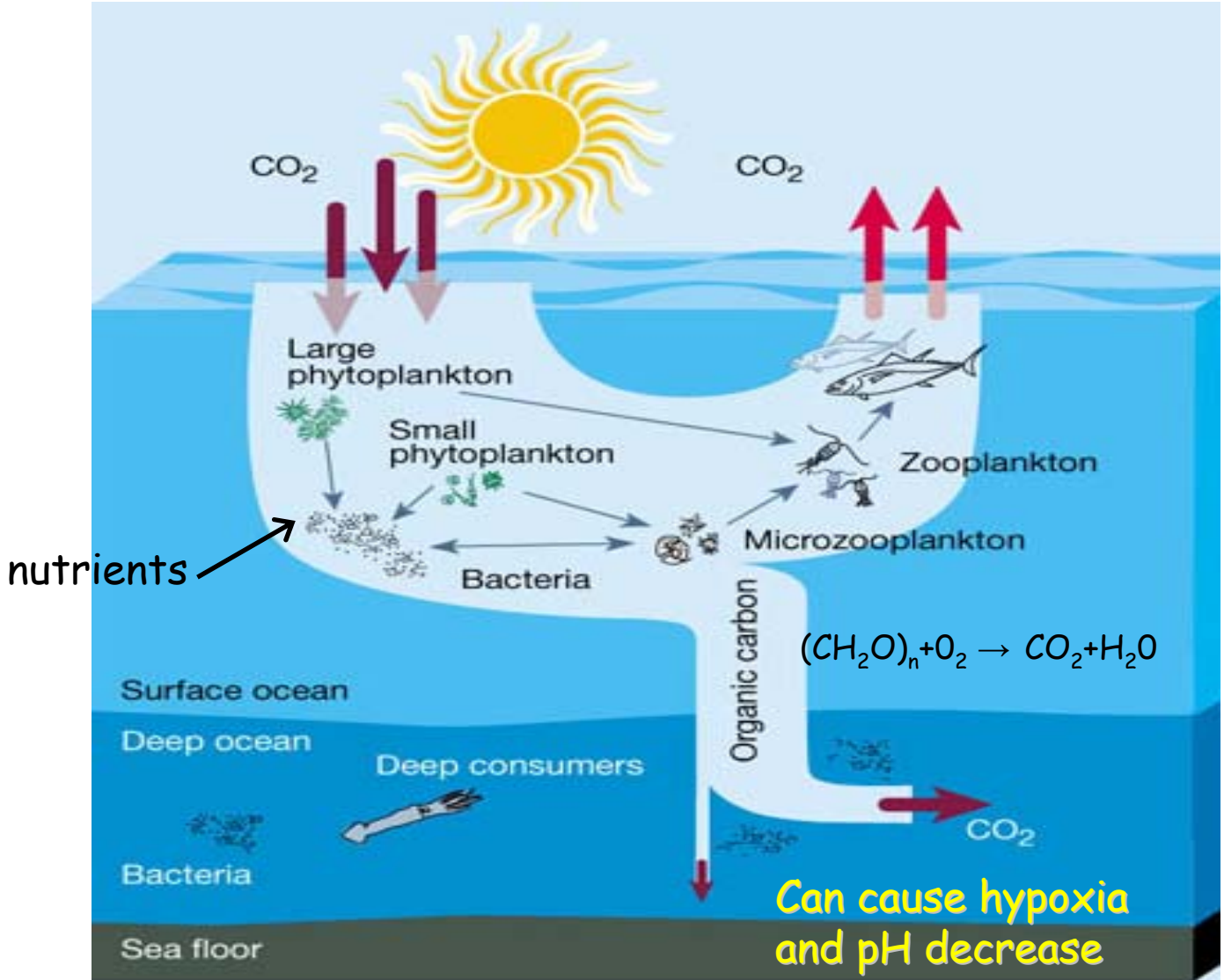
Natural Processes that can Accelerate the Ocean Acidification of Ocean Water Masses

Biological Remineralization of Organic Matter



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Pacific Northwest Oyster Emergency
Willapa Bay Seed Crisis

- Failure of larval oyster recruitments in recent years
- Commercial oyster hatchery failures threatens $100M industry (3000 Jobs)
- Low pH waters a possible leading factor in failures
- Larval oyster may be "canary in a coal mine" for near-shore acidification?

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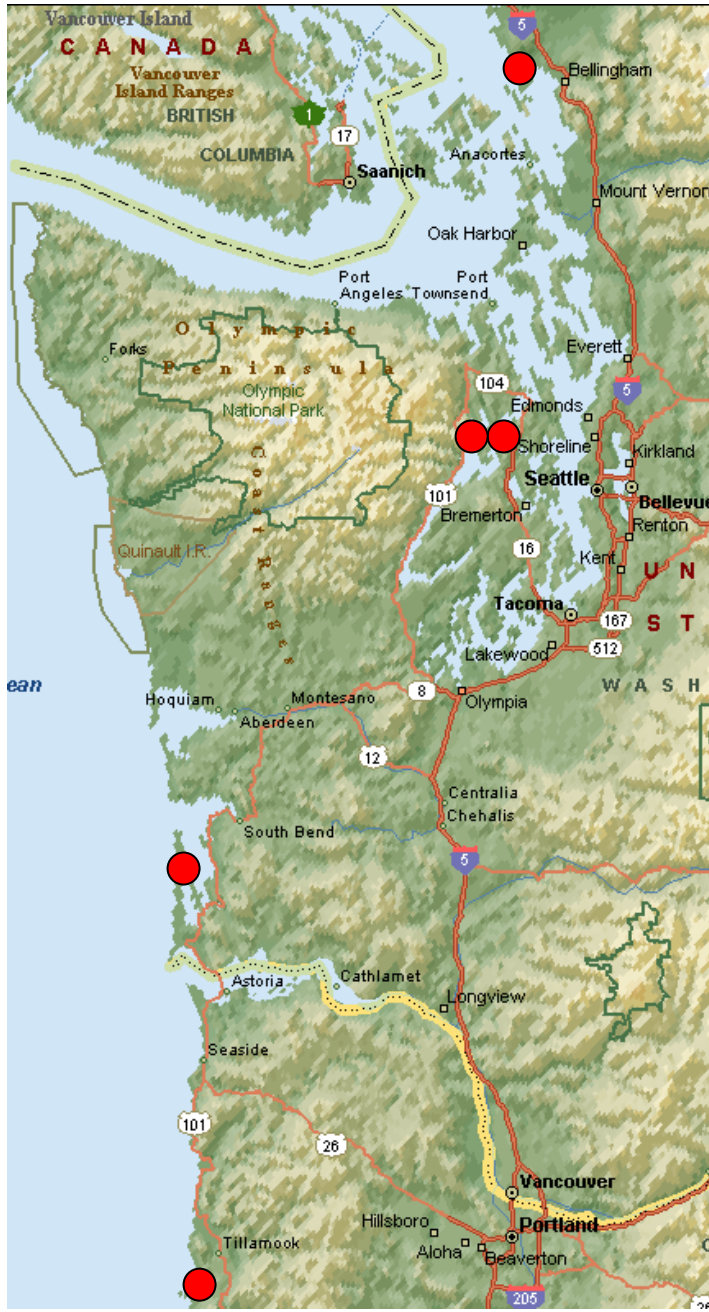
- Shellfish Hatcheries – Oregon, Washington, and beyond

Dan Cheney



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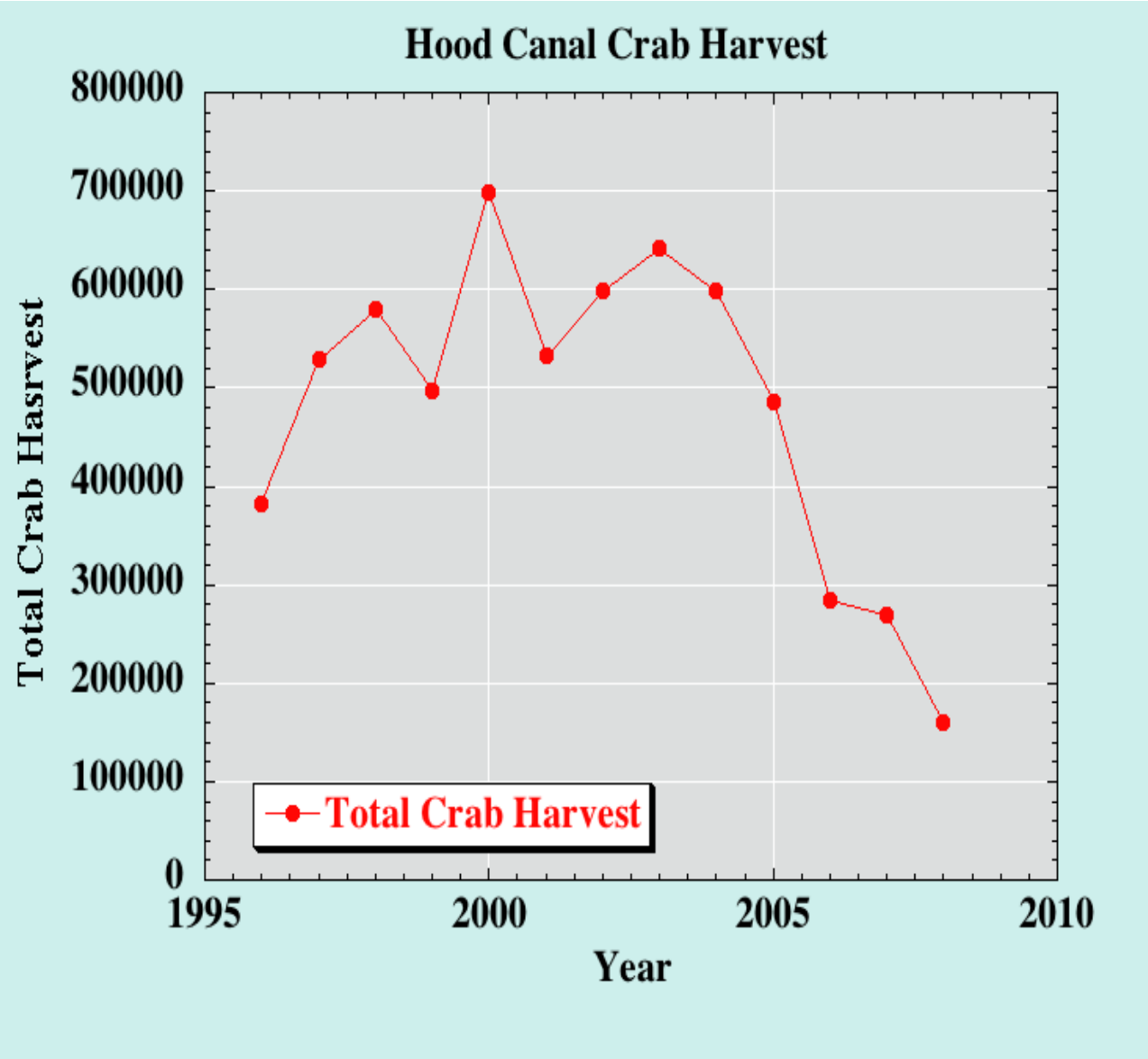
Surface water pH recorded at the Taylor Shellfish Hatchery in Dabob Bay, WA (September 08 to May 09)

Dan Cheney and Joth Davis

Feely 2009

Other Examples - OA contributing?



Total crab harvest in Hood Canal has been on the decline since 2003.

"The decline in overall crab abundance in Hood Canal since 2005 appears to be, in part, the result of detrimental environmental conditions that probably impacted juvenile survival" - Randy Hatch

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What we know about the biological impacts of ocean acidification *...and sensitivity to CO_2/pH perturbation*

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

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

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CONCLUSIONS--SCIENCE

- **Mankind's footprint** in the oceans is now clearly detectable – It is warmer, more acidic, and less diverse.
- 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 marine food webs, commercial shellfish, etc. *More research on impacts and vulnerabilities is needed.*
- An observational network for ocean acidification is under consideration. Modeling studies need to be expanded into coastal regions. Physiological response, mitigation and adaptation studies need to be developed and integrated with the models. *Estuaries should be included in this study.*

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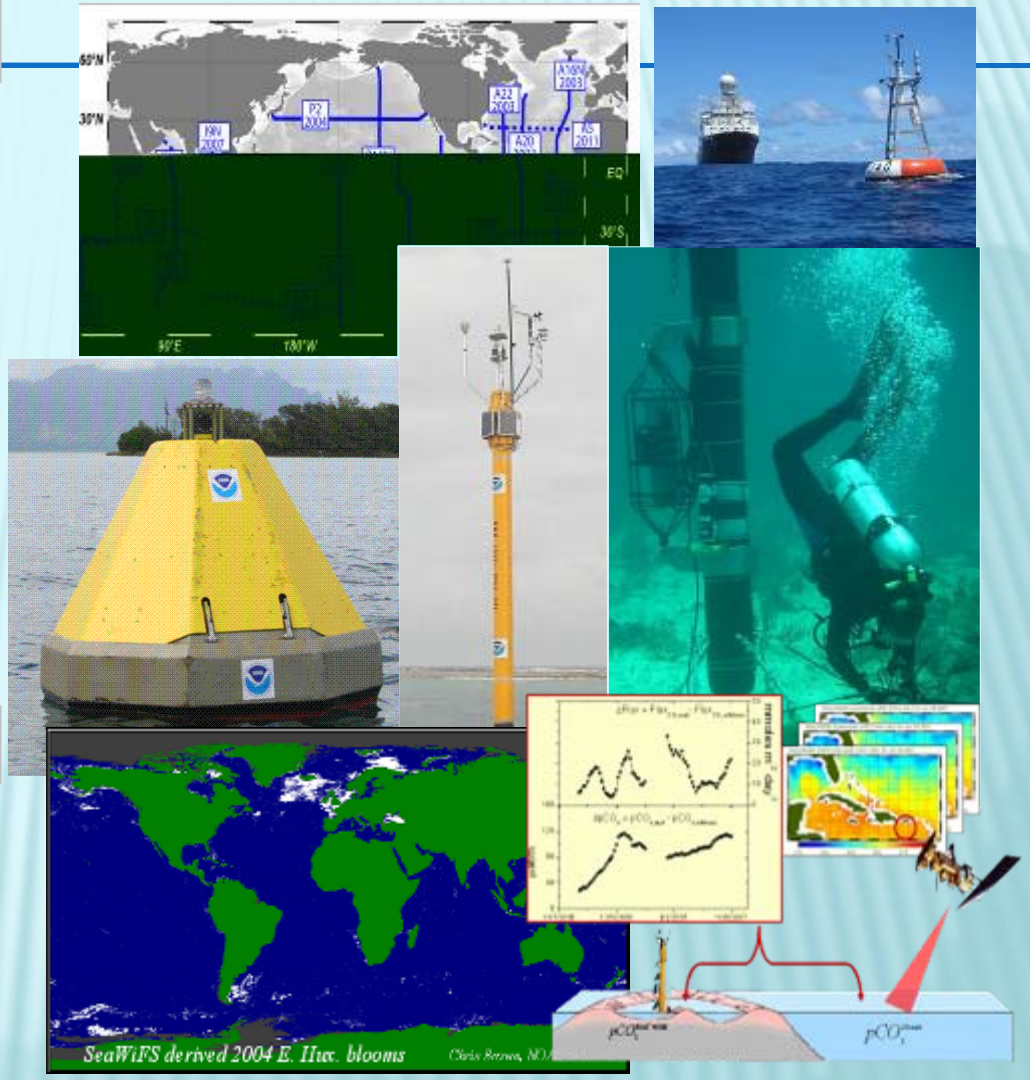
RECENT NOAA ACTIVITIES

NOAA Ocean Acidification Research and Planning Activities

A NOAA Ocean Acidification Strategic Planning meeting held in March, 2009

<u>NOAA OA Initiative Program Goals:</u>

- Characterize OA threats to marine ecosystems
- Develop monitoring capacity
- Develop improved forecasting capabilities
- Develop adaptive management tools and information on OA within EBM context



Existing and planned NOAA activities

- Ocean Carbon Inventory (Repeat Hydro)
- Global Ocean CO_2 Flux (VOS)
- Technology Development
- Remote Sensing Applications
- CO_2 Mooring Network
- Coral Reef Monitoring Networks
- Environmental Modeling
- Physiological Research
- Joint Workshop's & Interagency Collaboration

Adapted from Feely 2009

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STATUS OF LEGISLATION

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Omnibus Public Land Management Act of 2009

Federal Ocean Acidification Research and Monitoring Act of 2009 (H.R. 146)

- Introduced June and November 2007, respectively
- Senate Bill passed on 20 March 2009
- House Bill passed in 25 March 2009
- Signed by the President 30 March 2009

Goal: To establish an interagency committee to develop an ocean acidification research and monitoring plan and to establish an ocean acidification program within the National Oceanic and Atmospheric Administration.

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FORAM ACT OF 2009

The purposes of this subtitle are to provide for —

1. Development and coordination of a comprehensive interagency plan to:
   a) monitor and conduct research on the processes and consequences of ocean acidification on marine organisms and ecosystems; and
   b) establish an interagency research and monitoring program on ocean acidification;
2. Establishment of an ocean acidification program within NOAA;
3. Assessment and consideration of regional and national ecosystem and socioeconomic impacts of increased ocean acidification; and
4. Research adaptation strategies and techniques for effectively conserving marine ecosystems as they cope with increased ocean acidification.

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OCEAN ACIDIFICATION: POSSIBLE POLICY AND MANAGEMENT CONSIDERATIONS

Adaptation:

- Observation network
- Ecosystem model
- Spatial hazard assessment
- Infrastructure for authoritative decision support

Mitigation:

- For migratory resources – any feasibility to buffer a site (e.g., key spawning area)
- Hatchery/aquaculture facilities – informed siting
- Shellfish – buffer key enclosed bays
- *Reduced emissions*

EXTRAS

NWFSC Acidification Experimental Facility