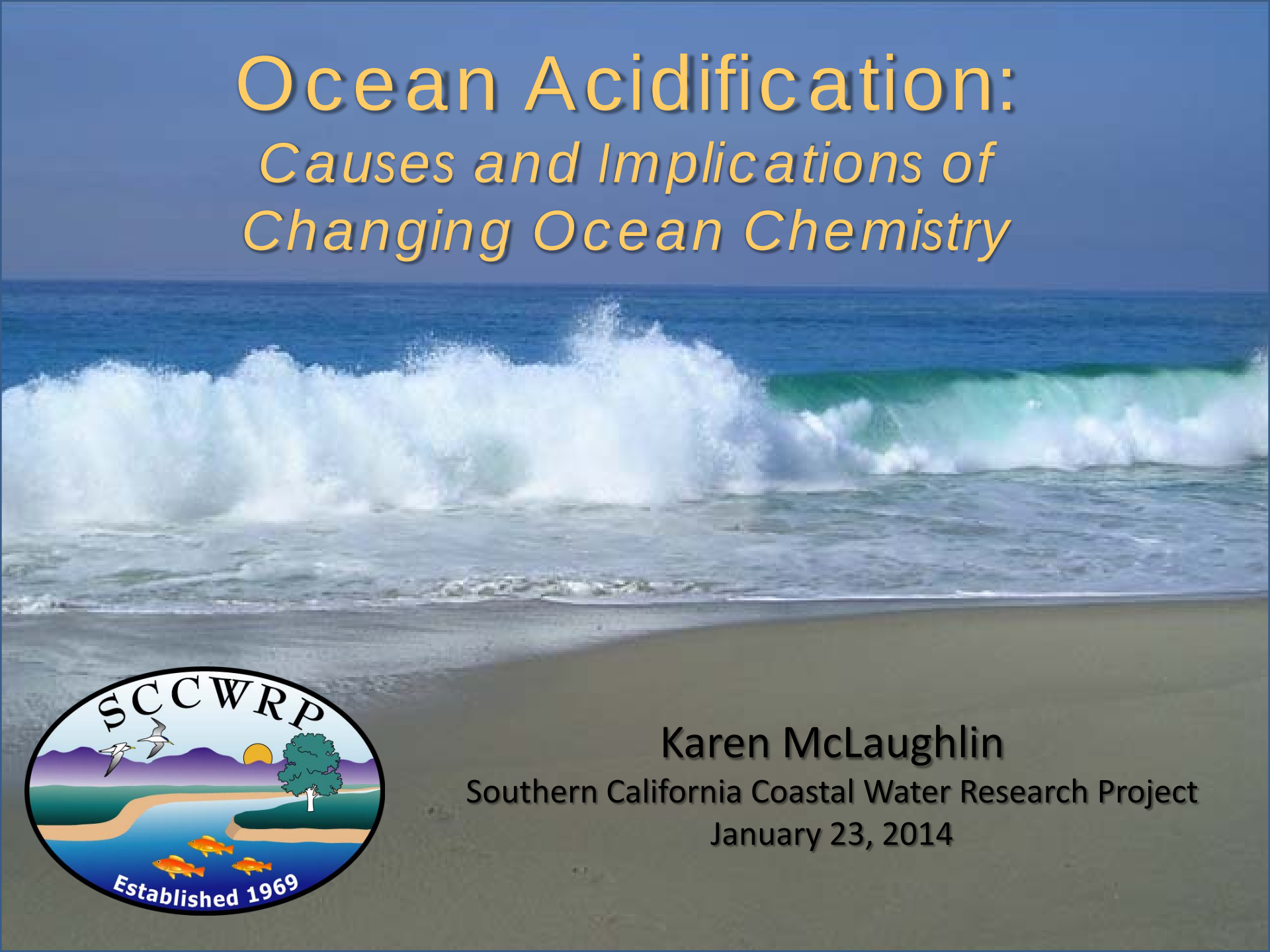
Ocean Acidification:

Causes and Implications of Changing Ocean Chemistry



Karen McLaughlin

Southern California Coastal Water Research Project

January 23, 2014

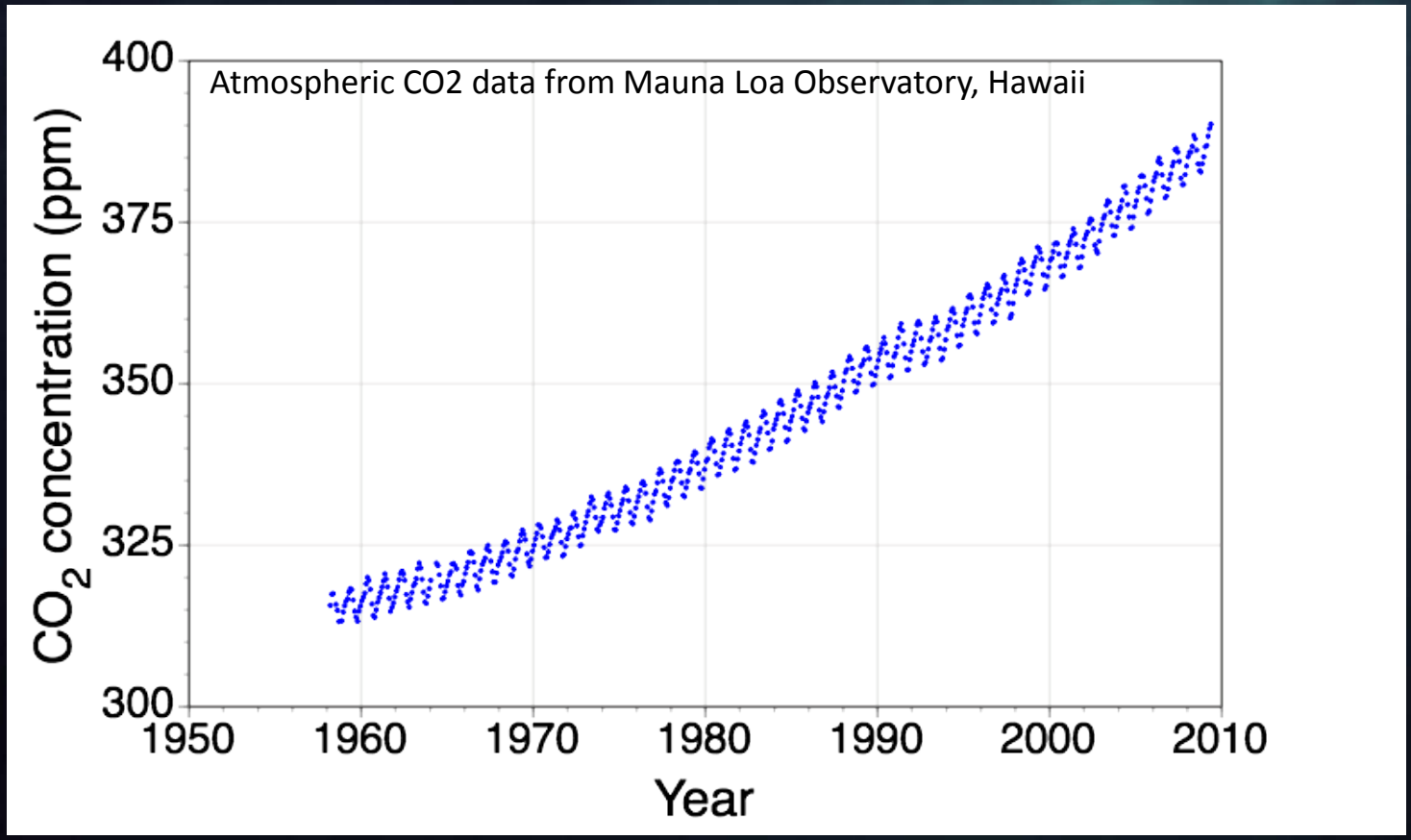
Today's Talk (In Two Acts...)

- What is ocean acidification and why should we care?
- What efforts are underway to address the issue?

What is Ocean Acidification and Why Should We Care About it?

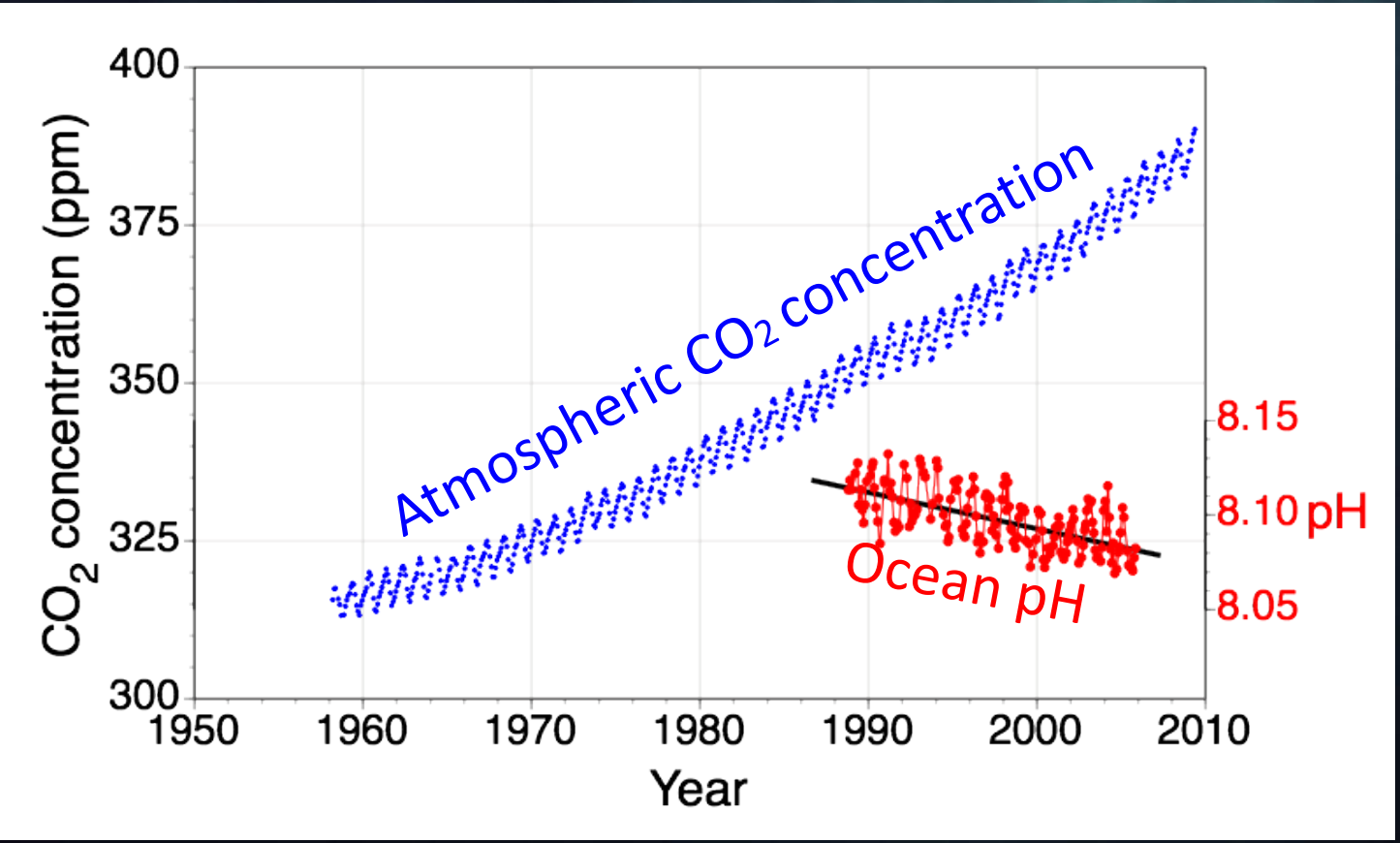
The CO_2 Story You've Already Heard…

Atmospheric CO_2 concentrations are rising



Ocean Acidification: The Other CO_2 Story

Ocean pH decreases when CO_2 dissolves in seawater



Feely et al. (2009)

Effect of Adding CO_2 to Seawater

CO_2

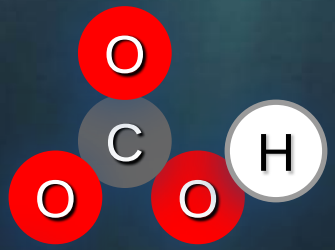
1. Dissolves in the ocean

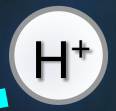
H_2O

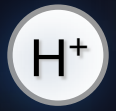
2. Reacts with water to form bicarbonate ion

and hydrogen ion

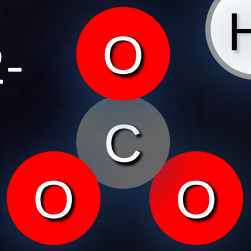
HCO_3^-





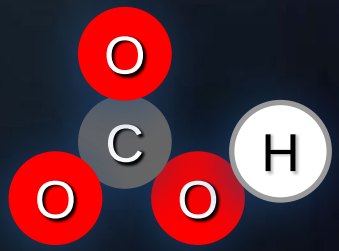


CO_3^{2-}



3. Most of the hydrogen ions react with carbonate ions to form bicarbonate ion

HCO_3^-



Problem for Shell-Formation

- pH is the measure people know….
- But changes in carbonate chemistry are the real concern
  - Affects shell-forming organisms
- Scientists use aragonite saturation state to quantify this:
  - $\Omega > 1$: Shells form
  - $\Omega < 1$: Difficult to form shells

Healthy Organisms

Organisms under acidified conditions

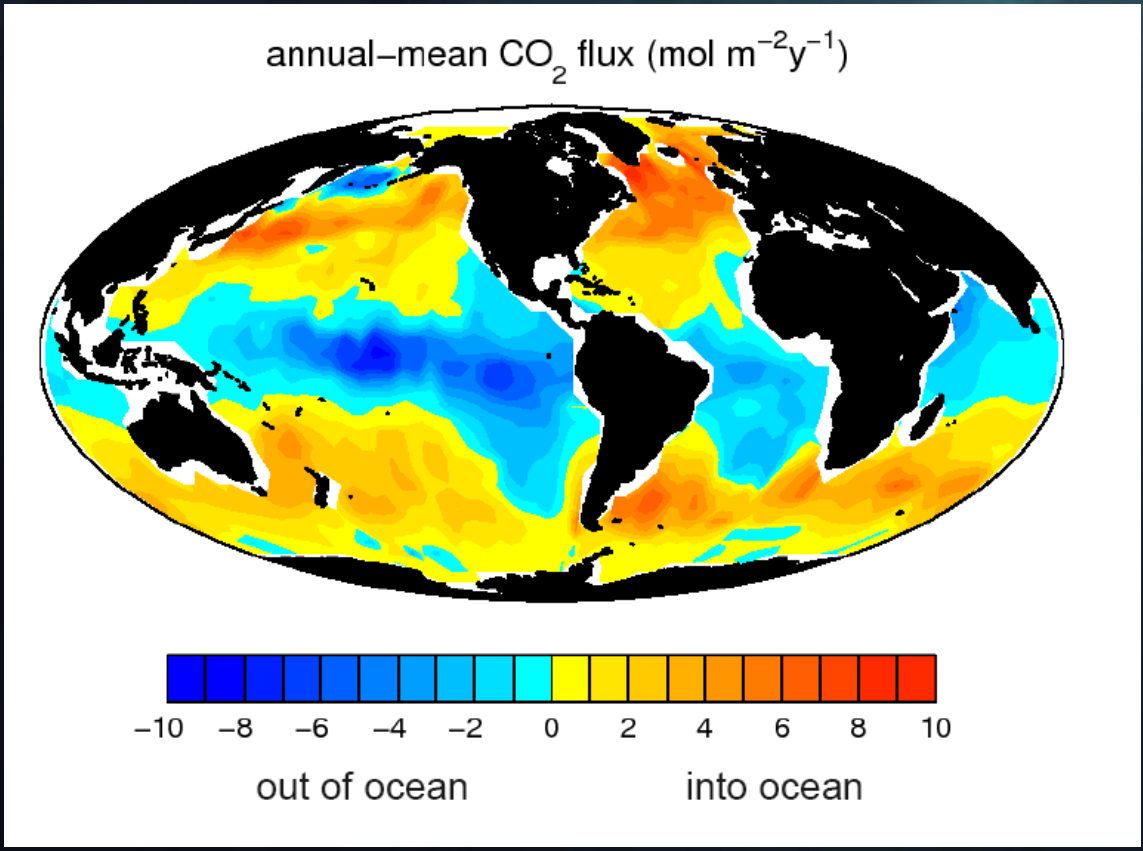
photos: David Littschwager/National Geographic Society

Ocean Acidification is Occurring Rapidly

- Approximately 25% of the CO_2 generated by human activities since the mid-1700s has been absorbed by the oceans
- Ocean acidity has increased 30% since the start of the industrial age.
  - Ocean acidity is projected to increase 100-150% percent by 2100.
- Current rate of acidification is nearly 10x faster than any period over the past 50 million years.
  - Organisms may not be able to adapt to rapidly changing conditions

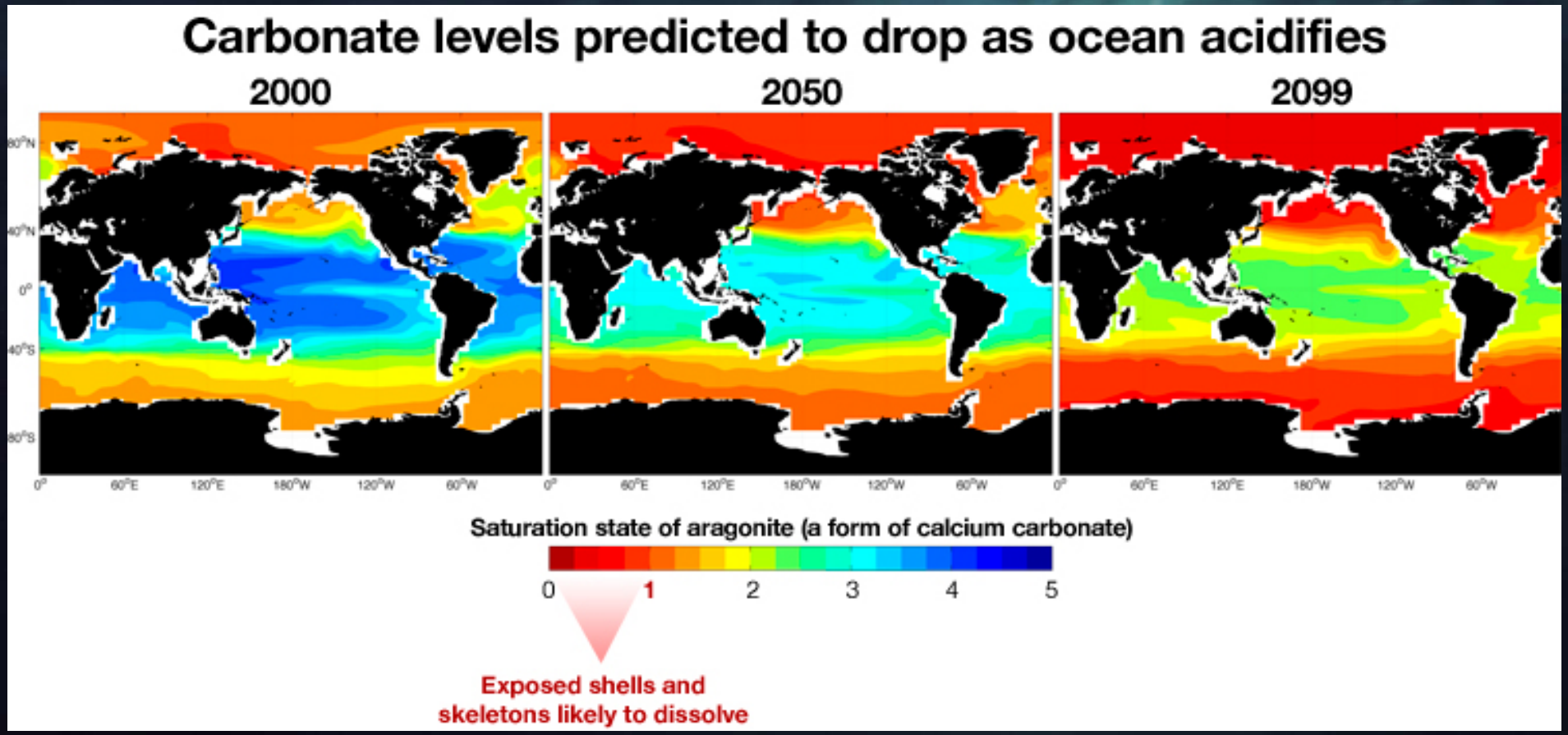
This is Mostly A Deep Ocean Problem

- CO_2 dissolves most readily in cold waters (high latitudes)
- Cold water sinks, moving CO_2 to depth



Takahashi et al (2002)

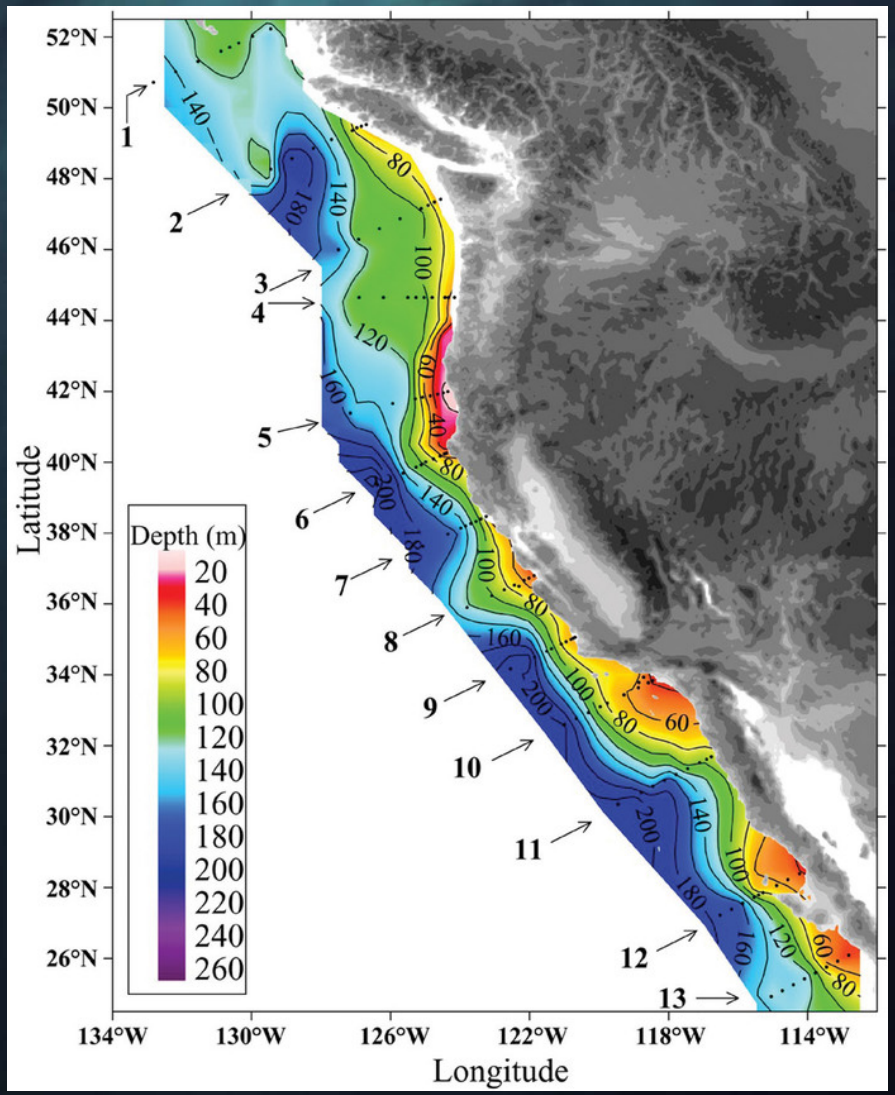
And It's Going to Get Worse



Feely et al. (2009)

The West Coast Is Particularly Vulnerable

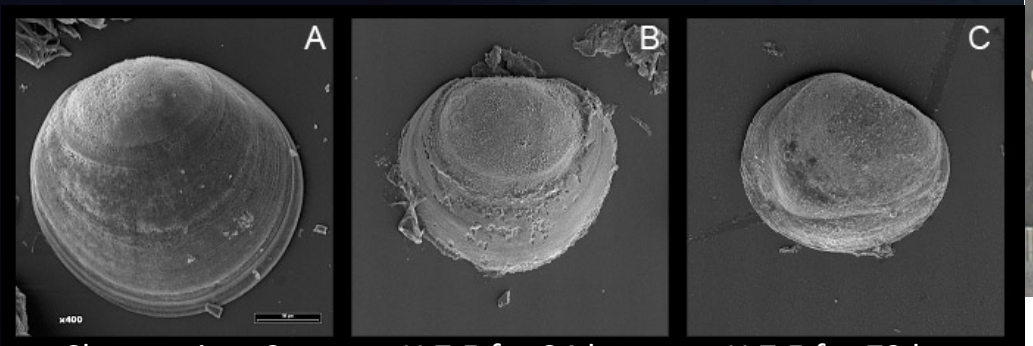
- Our winds stimulate upwelling
  - Brings deep ocean CO_2 waters to the surface
- We have a narrow continental shelf
  - Upwelling occurs close to shore
- Corrosive water already being seen in shallow water close to shore



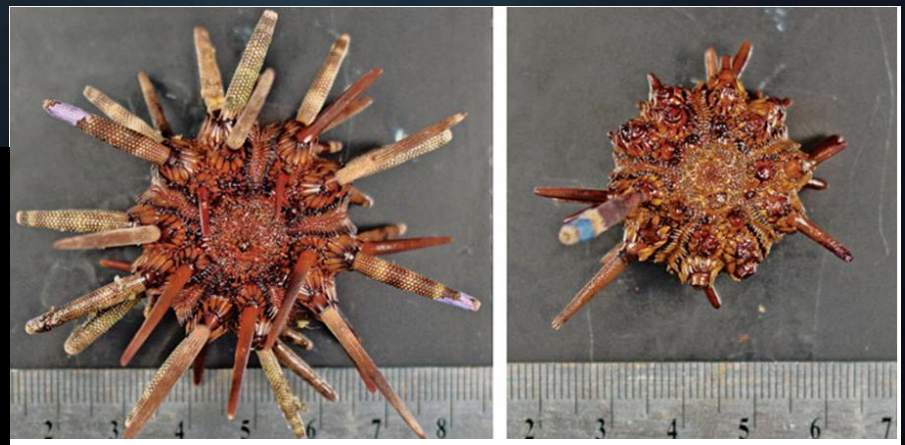
Feely et al. (2008)

Shellfish Industry is Threatened

- Decrease in aragonite saturation affects shell formation
  - Larval forms are most vulnerable
- Four hatcheries provide >90% of farmed seed and three have suffered acidification-related failures
  - Ability to produce oyster seed is presently throttling the industry



Clam at time 0 | pH 7.5 for 24 hrs | pH 7.5 for 72 hrs



Urchin at normal CO_2 | Urchin at elevated CO_2

Media Attention

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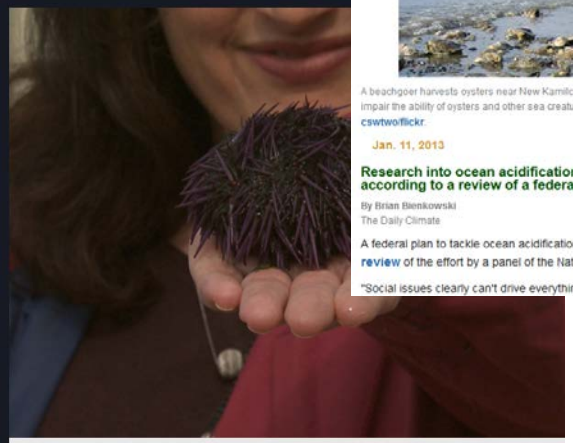

Rising Acidity in the Oceans Causing Problems for the Oyster Population

Rising acidity in the oceans, due to an increased presence of CO_2, is bad news for the oyster population. Madeleine Brand does her field report for "SoCal Connected" on how industrial

Federal effort on acidification should focus on human impacts - report

A beachgoer harvests oysters near New Kamilche, Wash. Scientists fear increasing ocean acidification as a result of greenhouse gas emissions could impair the ability of oysters and other sea creatures to grow a shell, impacting the lives and livelihoods of many dependent on the sea. Photo by cswtwo/flickr.

Jan. 11, 2013

Research into ocean acidification should focus first on issues with the most human and economic harm, according to a review of a federal program tackling the problem.

By Brian Bienkowski
The Daily Climate

A federal plan to tackle ocean acidification must focus more on how the changes will affect people and the economy, according to a review of the effort by a panel of the National Research Council.

"Social issues clearly can't drive everything but when it's possible they should."

Social issues clearly can't drive everything

Washington is first state to tackle ocean acidification

Comments 10 | Email | Share 128 | Tweet 37 | Like 91 | +1 0

ters harvest oysters in the Puget Sound, an estuary with increasingly acidic water that threatens Washington state's fish industry. (Liz O. Baylen/Los Angeles Times)

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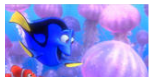
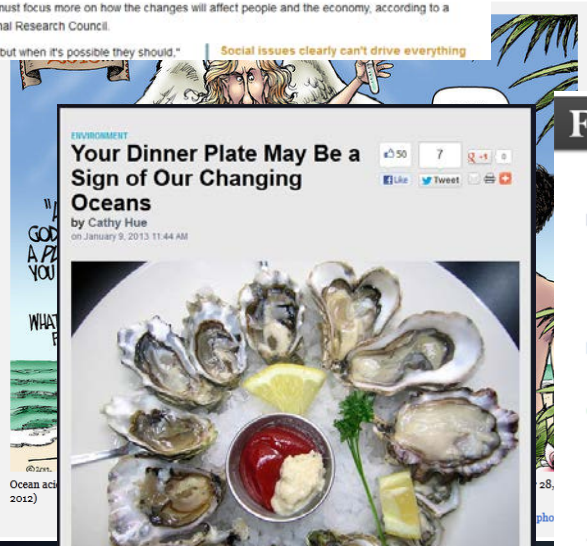


By Kenneth R. Weiss
Los Angeles Times
November 27, 2012 | 5:24 p.m.

Washington Gov. Chris Gregoire on Tuesday ordered state agencies to take initial steps to combat ocean acidification, making it the first state to address problematic changes in ocean chemistry that threaten shellfish farms, wild-caught fish and other marine life.

Gregoire signed the executive order based on the



ENVIRONMENT

Your Dinner Plate May Be a Sign of Our Changing Oceans

by Cathy Hue
on January 9, 2013 11:44 AM

50 | 7 | +1 | Like | Tweet

A plate of oysters at Dan & Louis Oyster Bar in Portland, Ore. | Credit: pingpongdeath/Flickr/Creative Commons License

Our ocean is absorbing carbon dioxide at a rapid rate, and the window of opportunity to do something about it is getting smaller and smaller. Madeleine Brand follows how our changing ocean is affecting not only the marine organisms that live in it, but also the west coast shellfish industry and, ultimately, the seafood we eat. (Watch that segment here.)

At L&E Oyster Bar in Silver Lake, we spoke with chef Spencer about the luxurious, sensual, and appetizing appeal of the oyster. But local restaurants are becoming increasingly affected by the lack of local Pacific oyster supplies -- the

RESOURCES

RESEARCH HIGHLIGHT: SCRIPPS SCIENTISTS THINK OUTSIDE THE TANK

Ocean aci
2012)

Changes in ocean put shellfish business in jeopardy

By **Bill Sheets**, Herald Writer

Next >>

EVERETT -- Between 2005 and 2009, billions of oyster larvae began dying at hatcheries around the state before anyone knew what was going on or could do anything about it.

The state's $270 million shellfish industry, which employs about 3,200 people, is in danger.

One oyster farm, Goose Point Oysters in Willapa Bay, has begun raising oyster larvae in Hawaii because it can no longer grow them here.

Dan Bates / The Herald

Penn Cove Shellfish workers on Wednesday harvest mussels, clams and oysters.

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TECH | 1/24/2013 @ 9:01AM | 315 views

Unleashing Innovation to Save Our Oceans

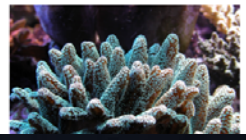
Singularity University Affiliate, Contributor

+ Comment Now + Follow Comments

By Robert K. Weiss , Vice Chairman and President of the X PRIZE Foundation.

Rapid acidification of our oceans presents a challenge well suited for utilizing the incentivized competition methodology to crowdsource the genius required to create the solutions sorely needed before it's too late.

Our beautiful Blue Planet has another problem with acid in its waters. In the 1980s, "acid rain" was contaminating lakes and rivers across the Northeast. Eventually, a joint effort across state lines helped develop new air-quality standards,



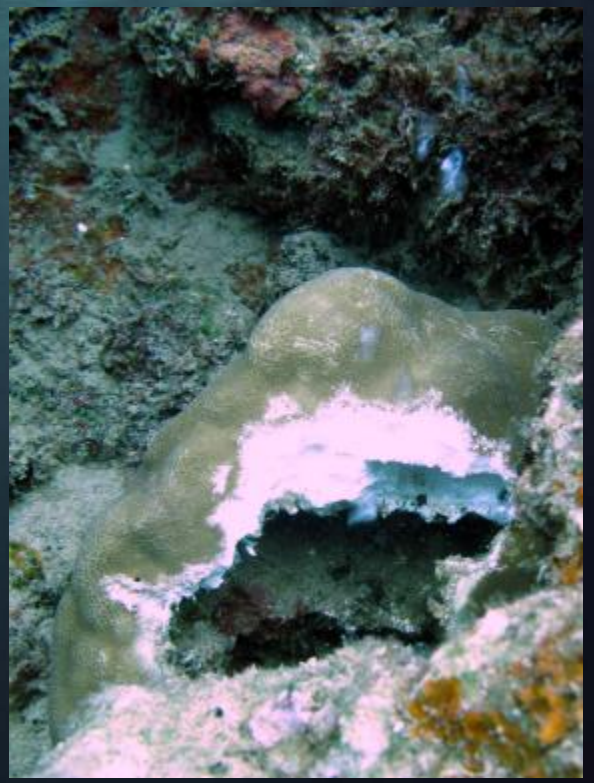
Potential Effects Are Ecosystem Wide

- Changes ocean food webs
- Changes how organisms take in nutrients and metals
- Higher Cost of Living
  - High CO_2 causes physical stress in fish and invertebrates
  - Affects behavior and response
- Loss of habitat
- Some evidence of increased toxin production in HAB species

Clownfish predatory avoidance is diminished under elevated CO_2

Coral Reefs

- Coral reefs are sensitive to both warming and acidification
  - High water temperatures cause coral "bleaching"
  - Acidification makes it harder to build their skeletons
  - Warming and acidification are a one-two punch
- At current CO_2 levels, 60% of coral reefs are in waters with suboptimal aragonite saturation state
  - Could increase to >90% in the next 50 years



Coral dissolves in high CO_2 water near a volcanic carbon seep

Photo: Laetitia Plaisance

What's Being Done About Ocean Acidification?

How Can We Change the Course of Ocean Acidification?

- The ONLY way to change the course ocean acidification is to eliminate excess atmospheric CO_2
  - Global regulation of atmospheric carbon emissions
  - Geologic sequestration of atmospheric CO_2

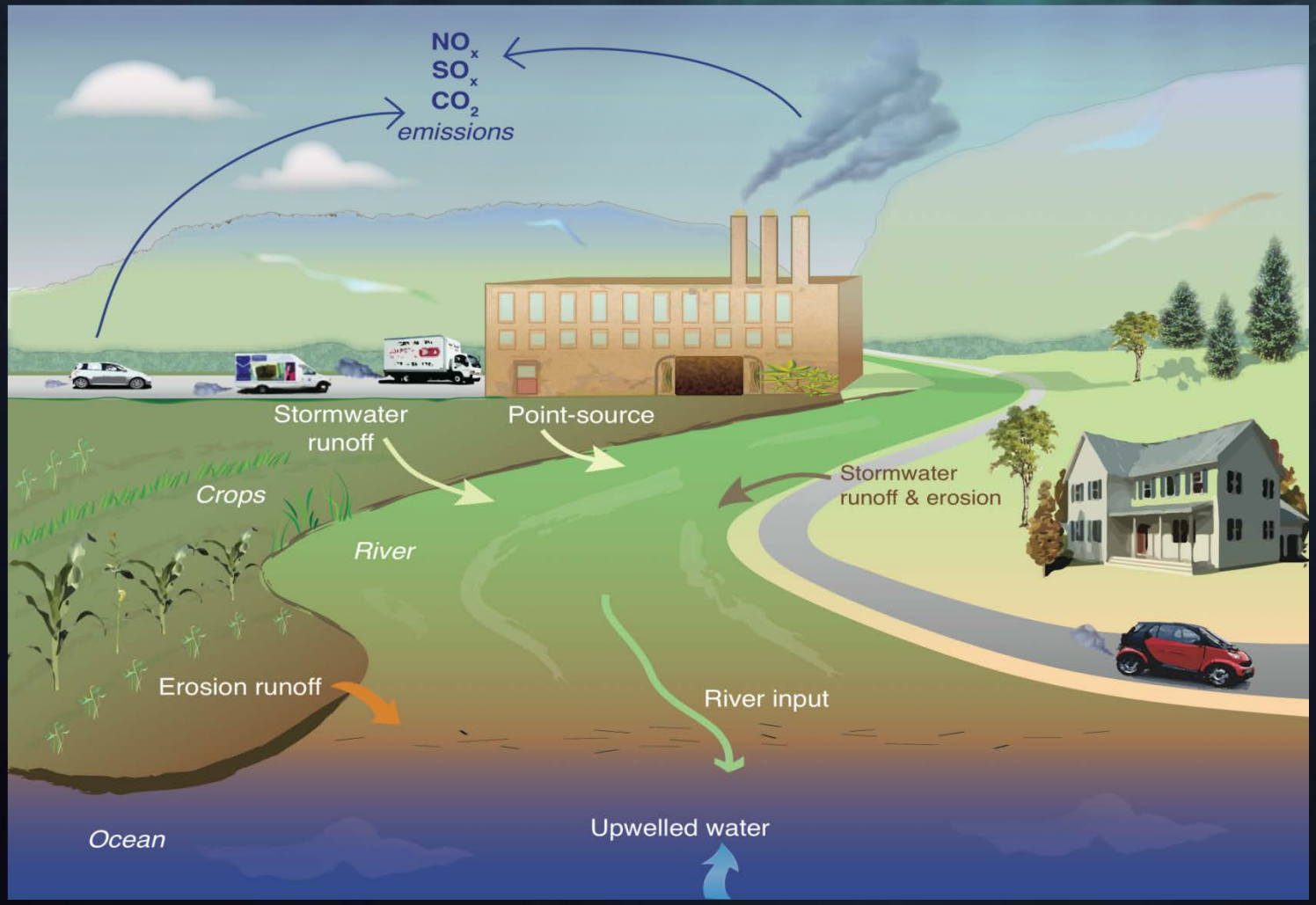
- Federal, Regional, State, and Local actions to understand the problem and manage response

- Local actions could potentially delay the problem in some regions
  - Potentially allowing time for ecosystems to adapt

Federal Actions

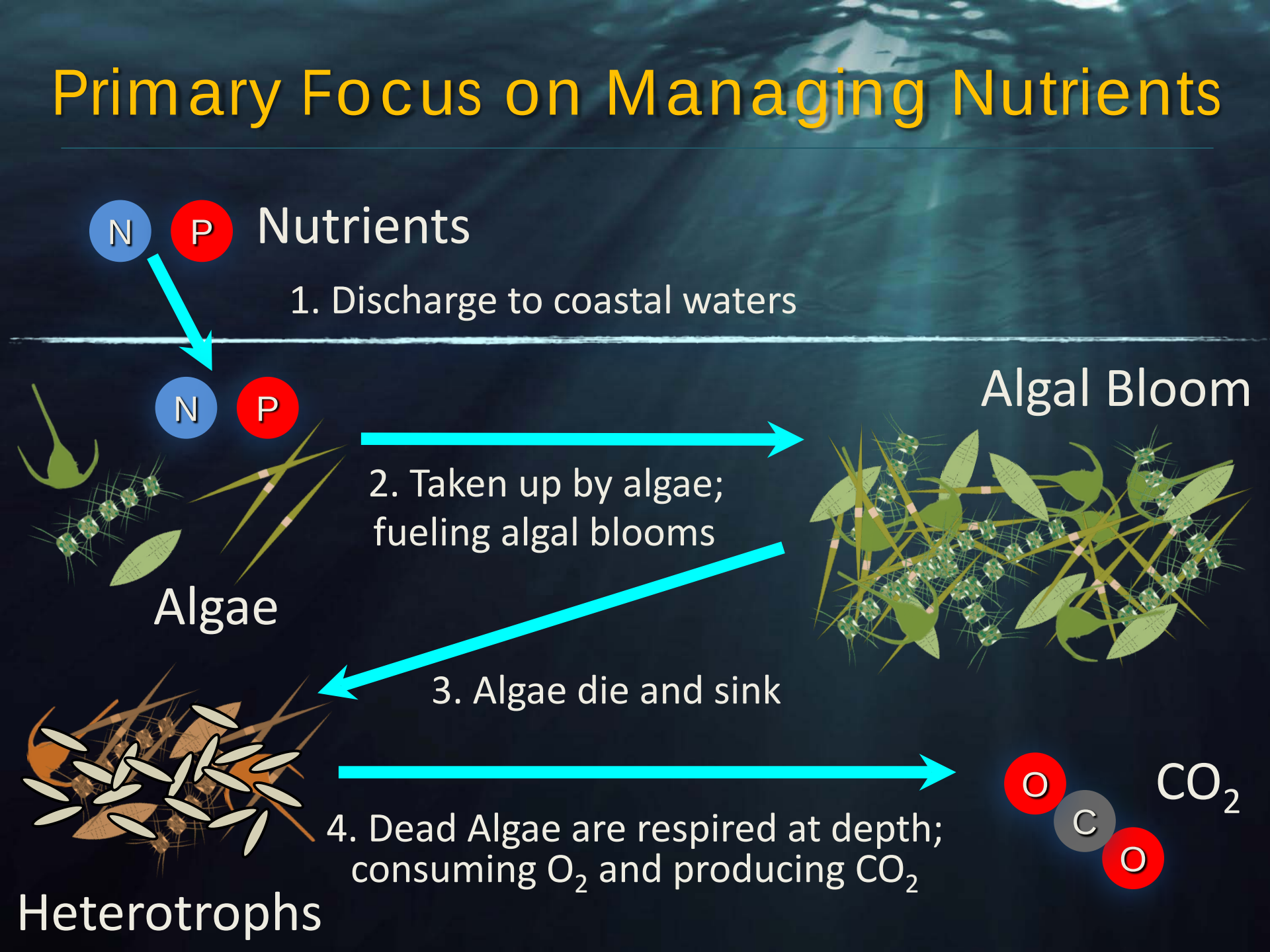
- May 2007: Supreme Court Ruled the EPA can regulate green house gasses as pollutants under the Clean Air Act (CAA)
- January 2011: EPA began regulating greenhouse gases under the CAA from mobile and stationary sources of air pollution.
- May 2009: EPA was sued for failing to address ocean acidification under the Clean Water Act (CWA)
- Nov 2010: EPA issued a memorandum on how states should address OA under the CWA
  - States should list waters not meeting pH water quality standards on their 2012 303(d) lists
  - BUT… Hard to consider listings because we don't have the data to define reference condition

What Can Be Managed At the Local Level?



Modified after Kelly et al. (2011) *Science*

Primary Focus on Managing Nutrients



Understanding the Issue…

- California Current Acidification Network (2010)
  - Develop a coordinated OA measurement system for the West Coast
- Washington State's Blue Ribbon Panel (2012)
  - Issued a series of recommendations for local measures to protect marine resources
- Ocean Acidification and Hypoxia Modeling Group (2013)
  - Develop models to understand drivers of OA and forecast ocean changes
- The West Coast Ocean Acidification and Hypoxia Science Panel (2013)
  - Framing the issue for West Coast decision-makers

California Ocean Plan

- Ocean Plan sets water quality criteria for ocean waters:
  - "pH shall not be changed at any time more than 0.2 units from that which occurs naturally"
  - "Nutrient materials shall not cause objectionable aquatic growths or degrade indigenous biota"
- The State of California is currently reviewing this criteria to make better assessments of changing ocean acidity
- Scientists are working with coastal dischargers and management to determine if runoff and wastewater is contributing to acidification

Summary

- Ocean Acidification is a well documented effect of increasing atmospheric CO_2 concentrations
- Ocean acidification is occurring at a rate that is unprecedented in Earth's history
- Ocean acidification is likely to change the structure and function of ocean ecosystems
- Ocean acidification is one more stress on marine environments that may endanger economies of coastal communities
- Efforts are being undertaken at local scales to address the issue; but acidification will continue until global CO_2 emissions are limited

Questions?

Resources:

NOAA Pacific Marine Environmental Laboratory
http://www.pmel.noaa.gov/co2/story/Ocean+Acidification

National Geographic Society
http://ocean.nationalgeographic.com/ocean/critical-issues-ocean-acidification/

National Resources Defense Council- Acid Test Movie:
http://www.nrdc.org/oceans/acidification/

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