Ocean Acidification – Souring the Waters in Maine?

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Partners on this work include: Maine Sea Grant, Maine Coastal Program, Sustainable Fisheries Partnership, The Ocean Conservancy, Representative Mick Devin and other members of the Maine OA Working Group

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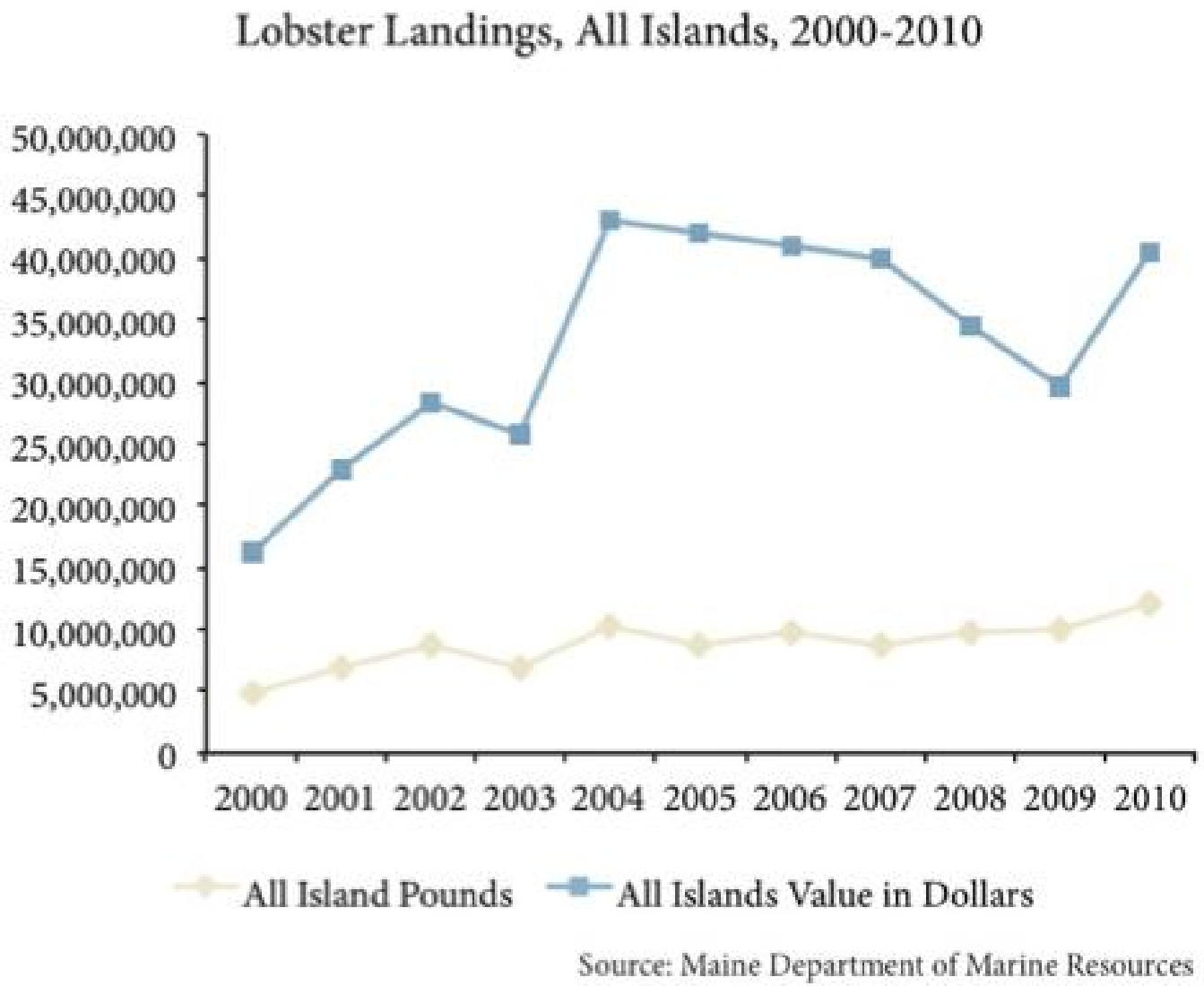
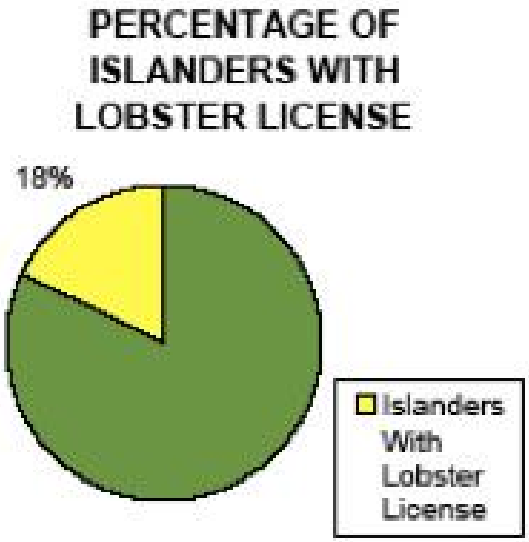
ISLAND INSTITUTE 30th 1983 - 2013

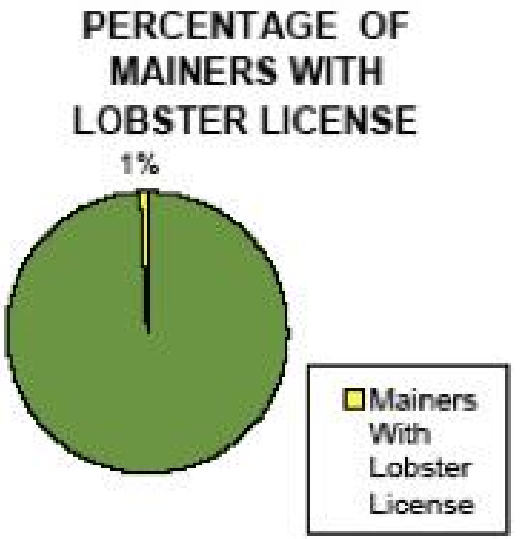
The Island Institute works to sustain Maine's island and remote coastal communities, and exchanges ideas and experiences to further the sustainability of communities here and elsewhere.

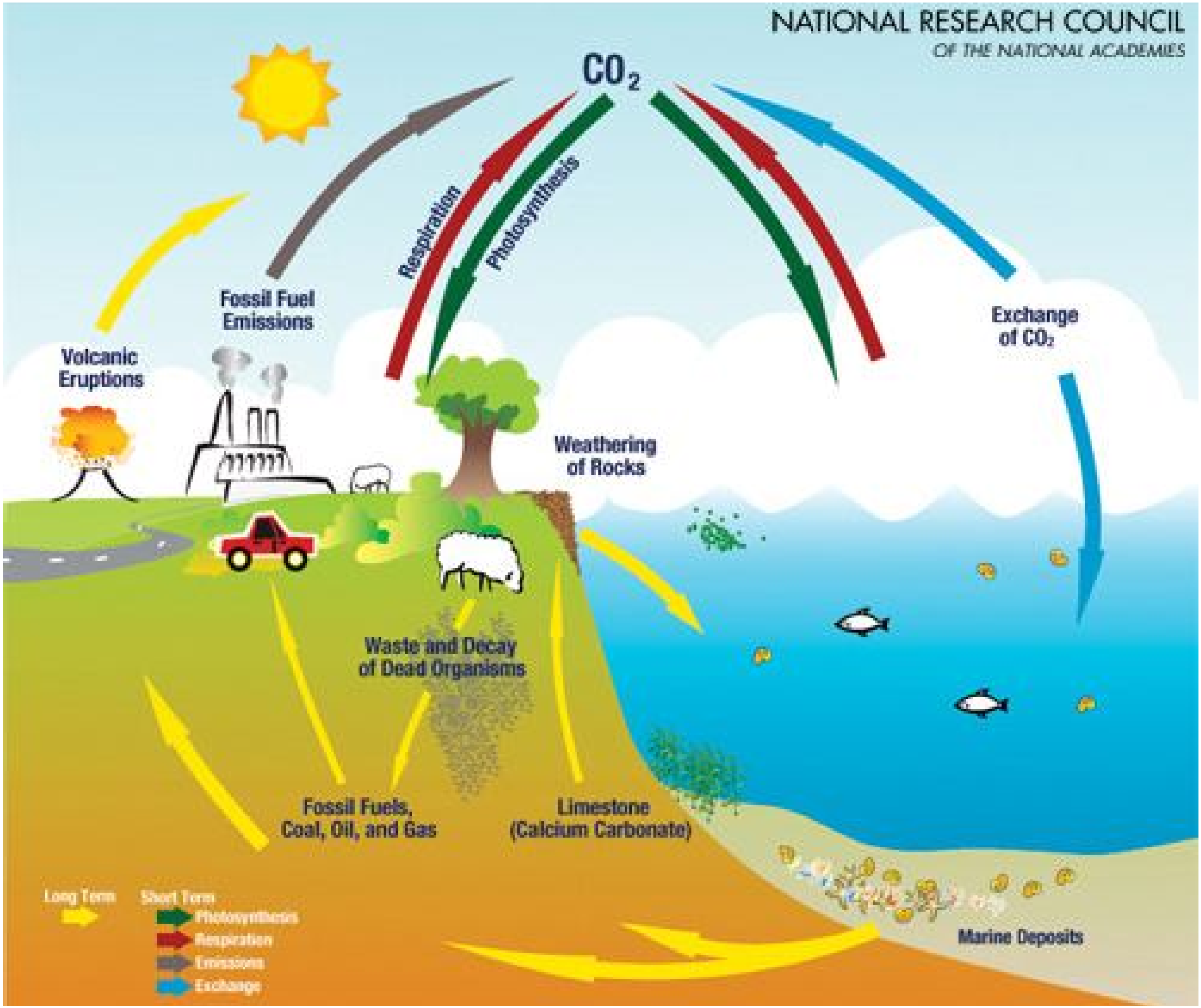
Lobstering is critical for island communities



Source: Maine Department of Marine Resources

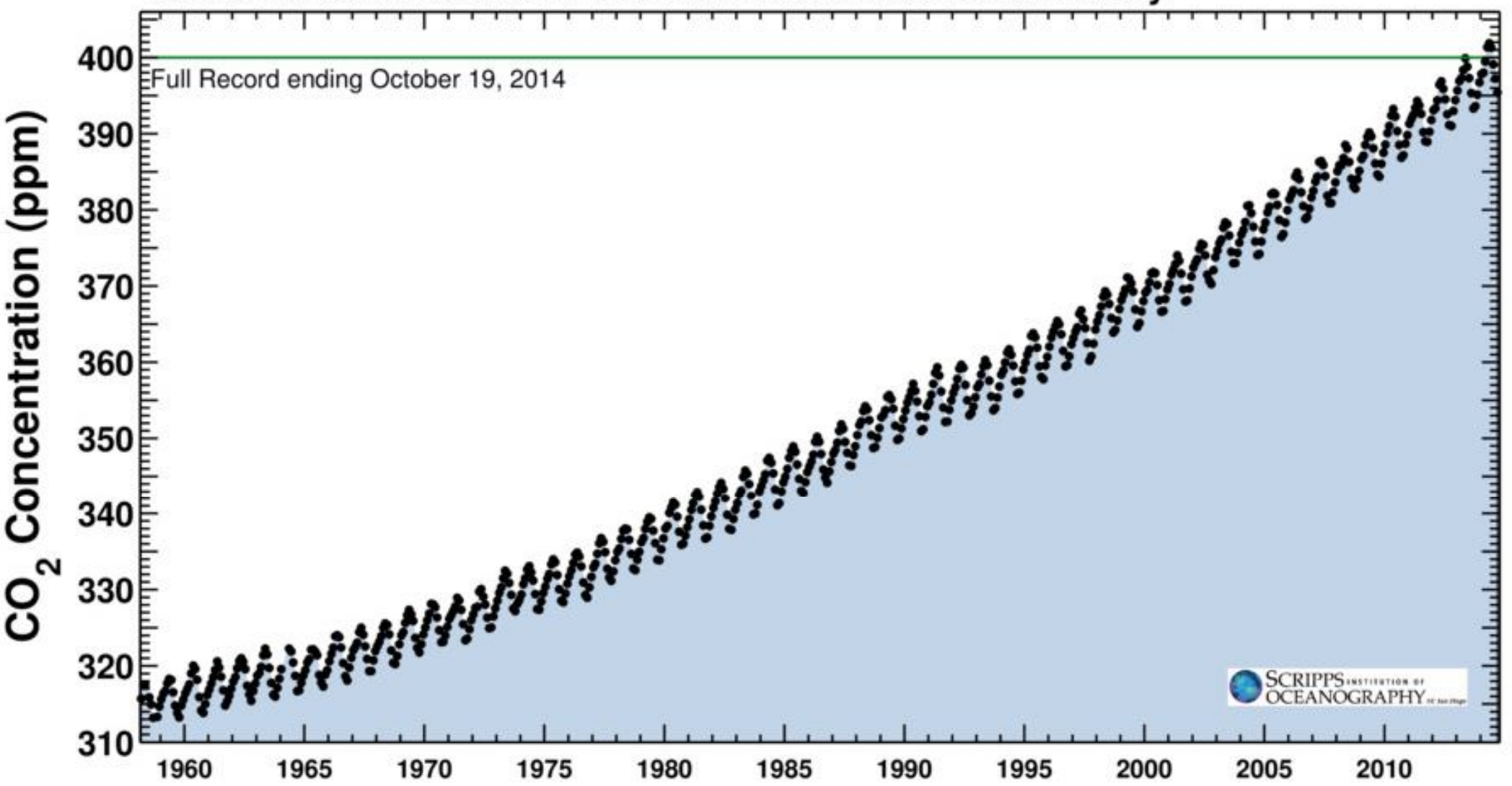





NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES
CO_2
Respiration
Photosynthesis
Fossil Fuel Emissions
Volcanic Eruptions
Exchange of CO_2
Weathering of Rocks
Waste and Decay of Dead Organisms
Fossil Fuels, Coal, Oil, and Gas
Limestone (Calcium Carbonate)
Marine Deposits
Long Term
Short Term
Photosynthesis
Respiration
Emissions
Exchange

Latest CO_2 reading
October 16, 2014

395.75 ppm



http://keelingcurve.ucsd.edu

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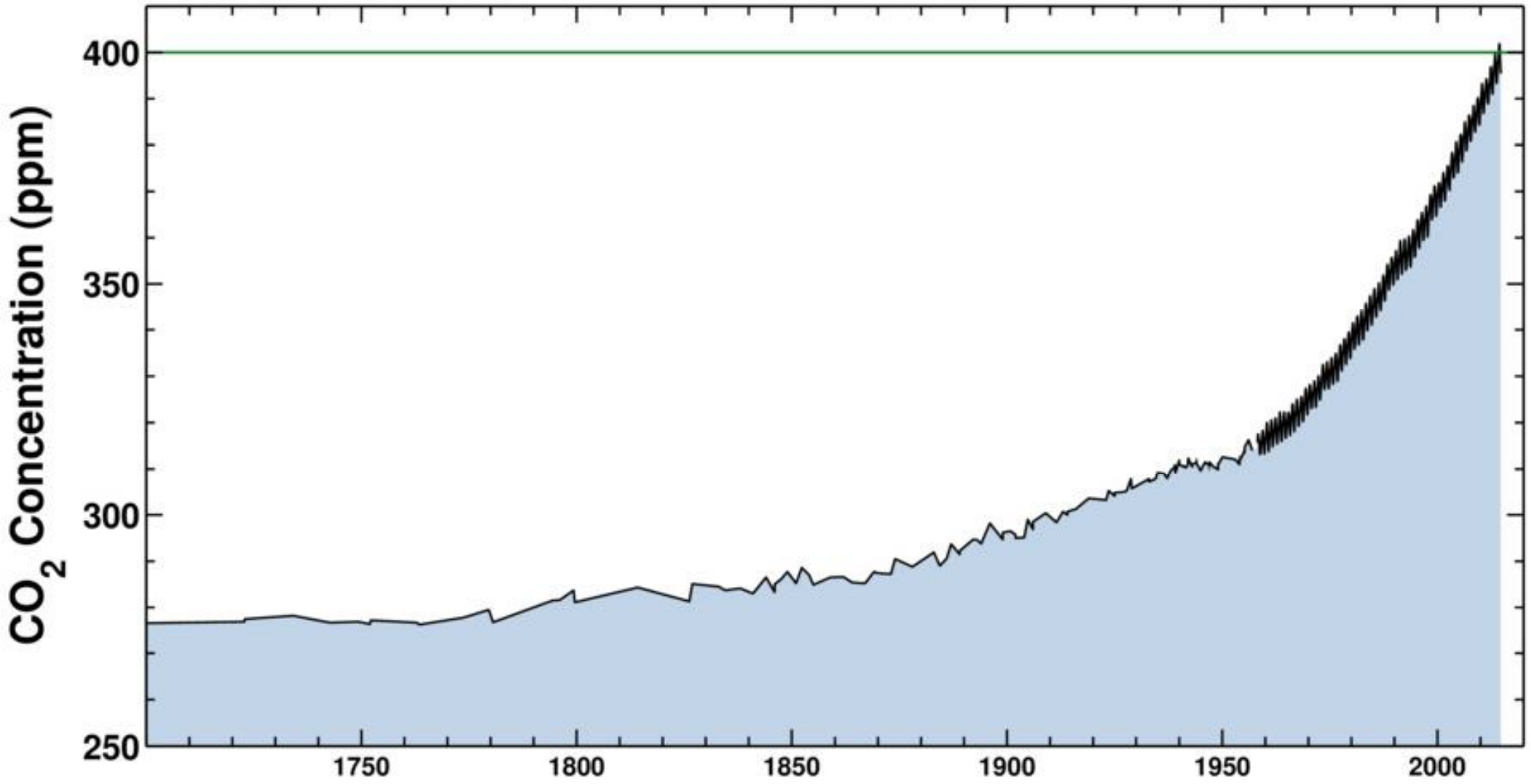

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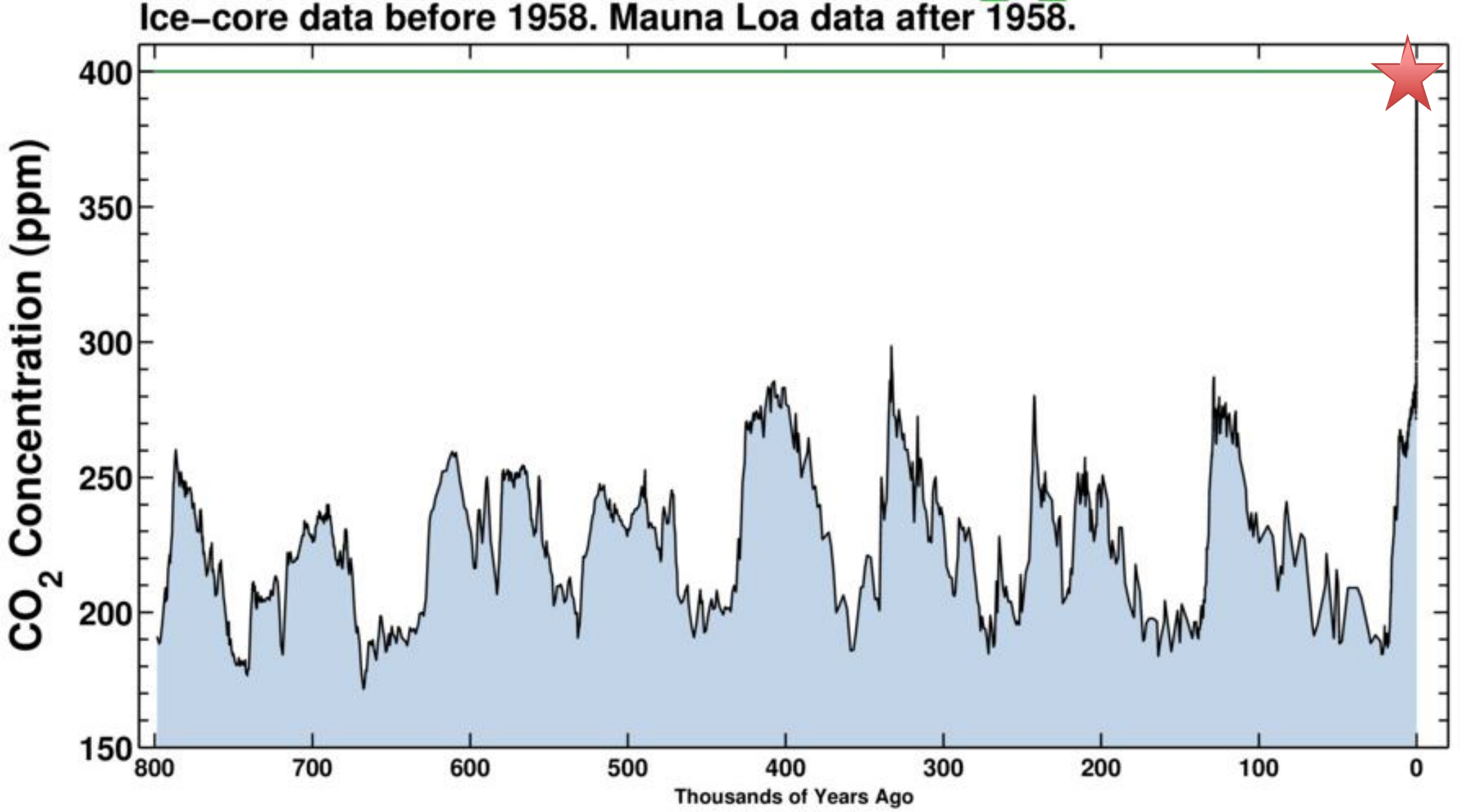


http://keelingcurve.ucsd.edu

Fate of human-driven CO_2 emissions (2003-2012)

\+ ~9.5 billion tons carbon per year

Atmosphere 45%

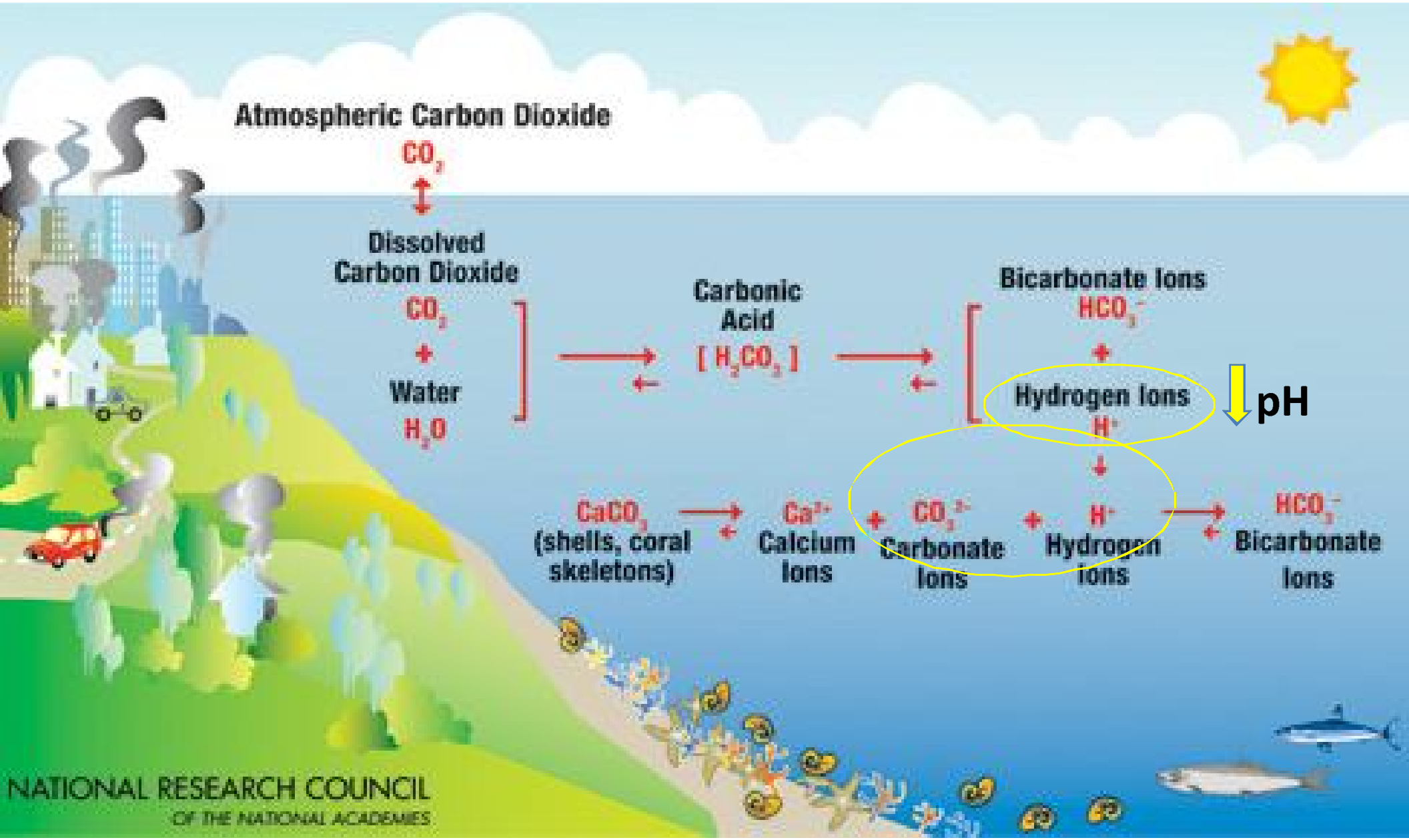
Land 29%

Oceans 26%

(LeQuere et al. Earth System Sci. Data 2014 ; Global Carbon Project 2014)

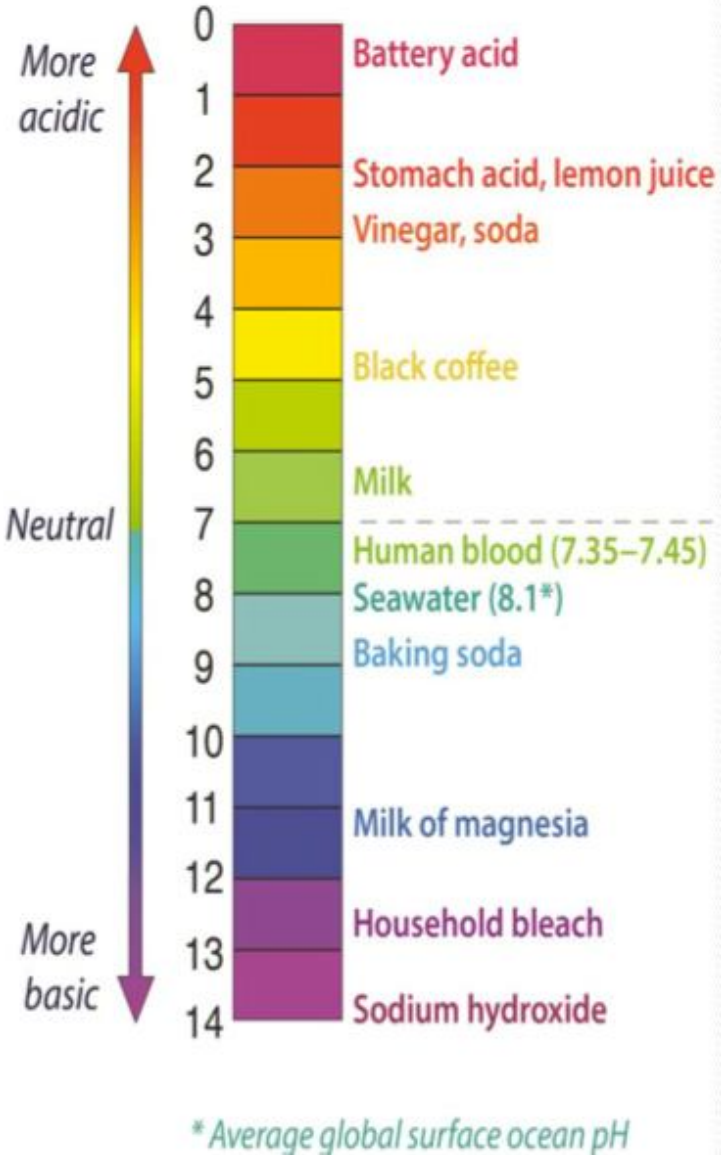
Credit: Scott Doney (WHOI)

Ocean Acidification

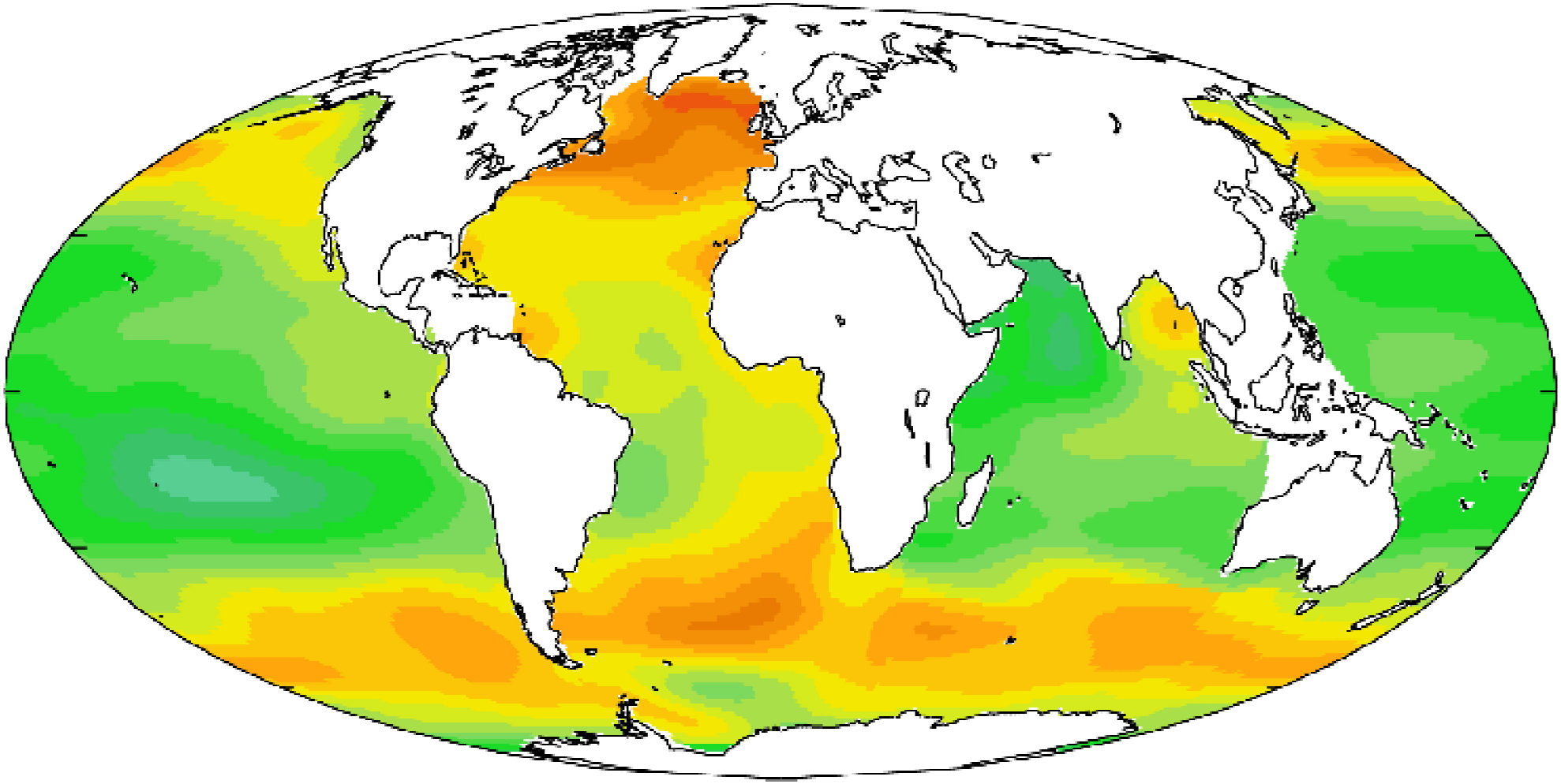


Acidity and the pH scale

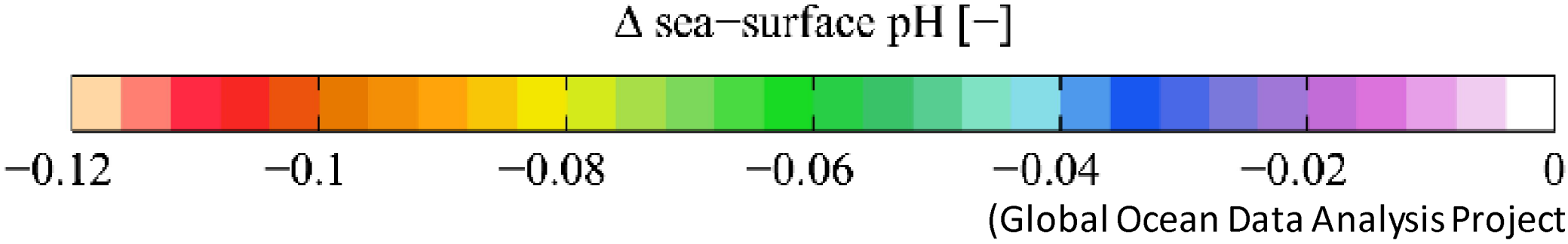
- Acidity is a measure of H+
- pH is the scale used to measure how acidic or basic something is
- pH is measured on the log scale
- a change of 0.1 pH units is a 30% change in the concentration of H+



Acidification- Not just a future problem. It has already occurred.



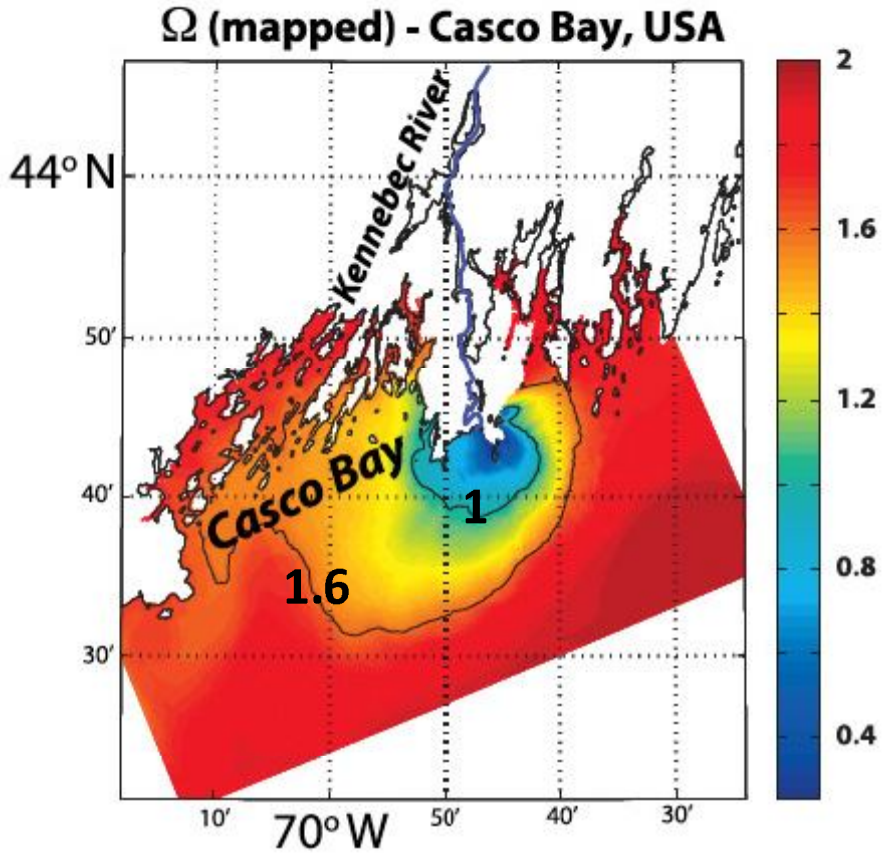
Change in pH between the 1700s and the 1990s



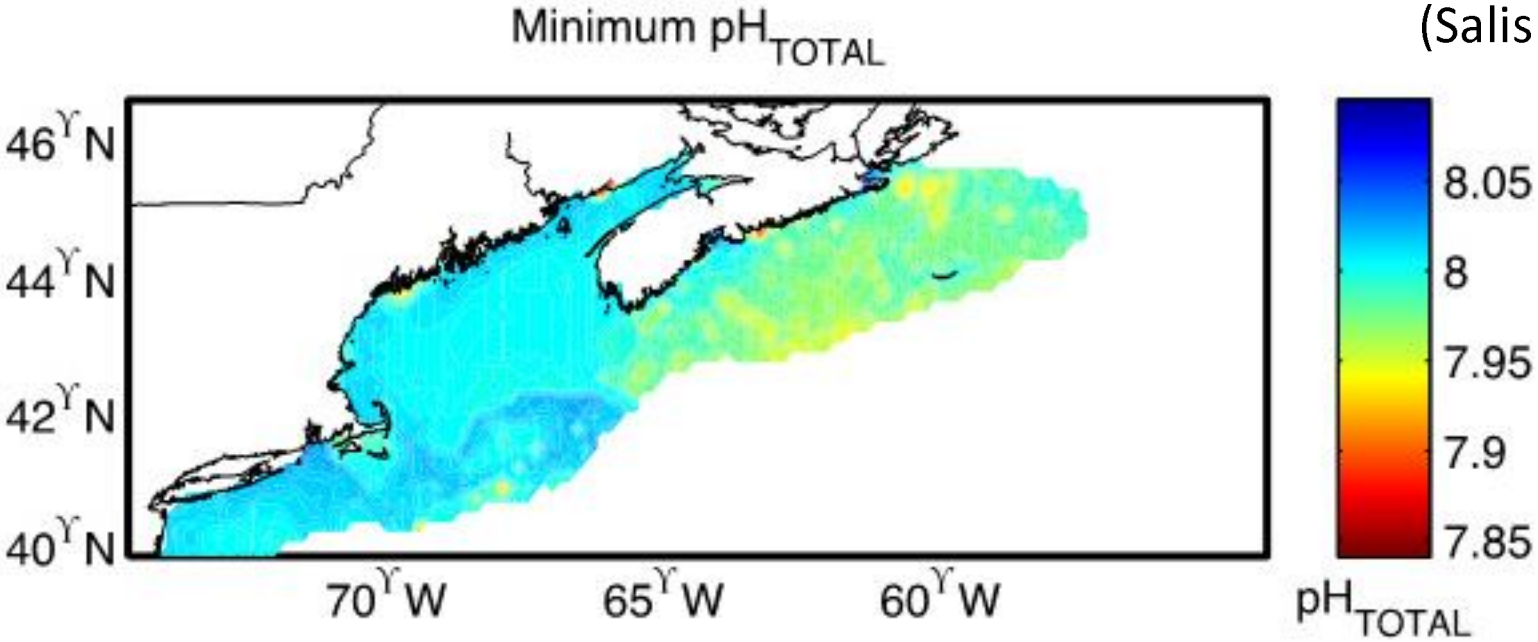
(Global Ocean Data Analysis Project)

The Gulf of Maine is uniquely susceptible

- Cold water absorbs CO_2 more readily
- Colder, fresher water entering GoM from Scotian Shelf has lower pH
- Fresh water coming in from many rivers is more acidic
- Semi-enclosed shape may increase residence time

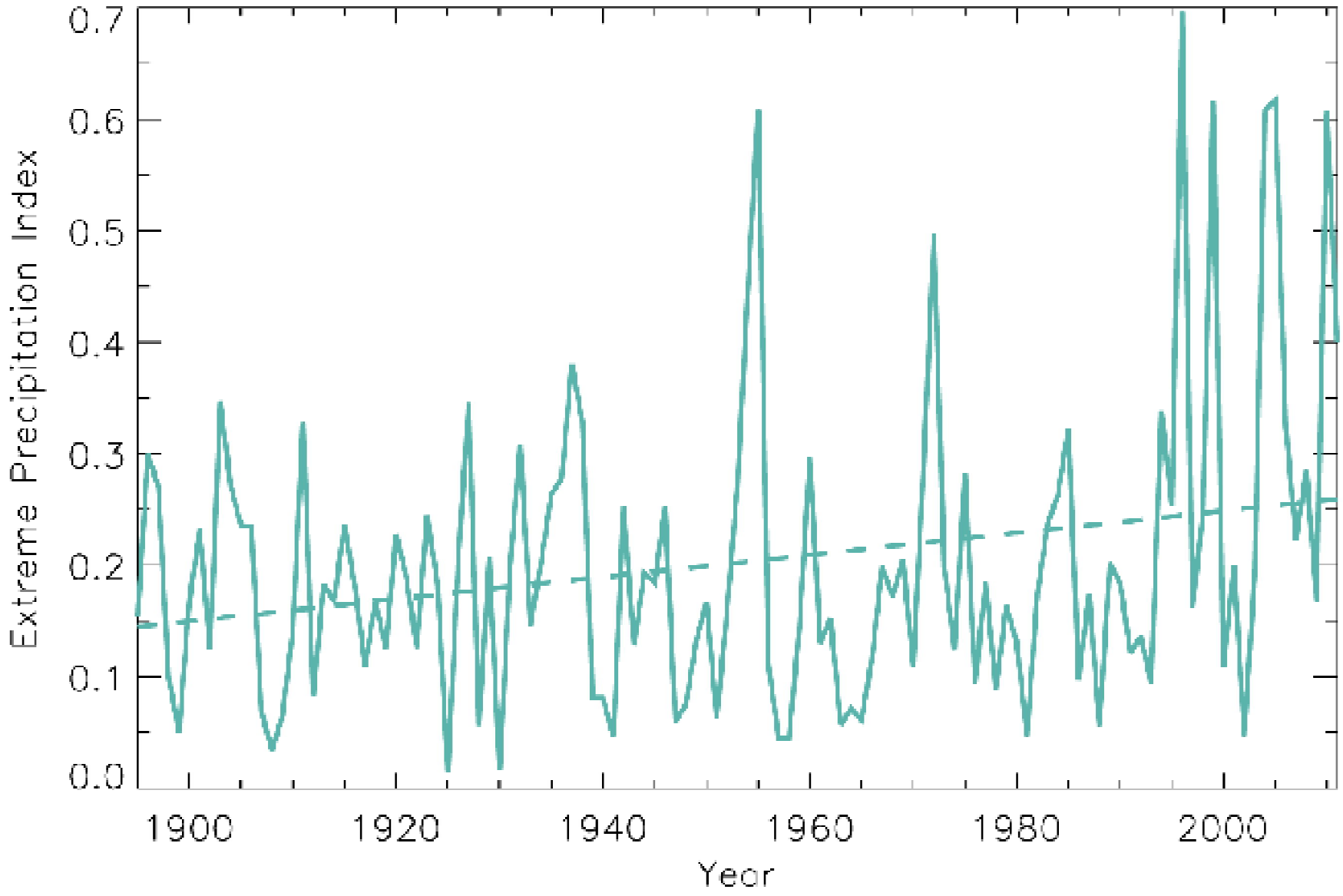


(Salisbury et al. EOS 2008)



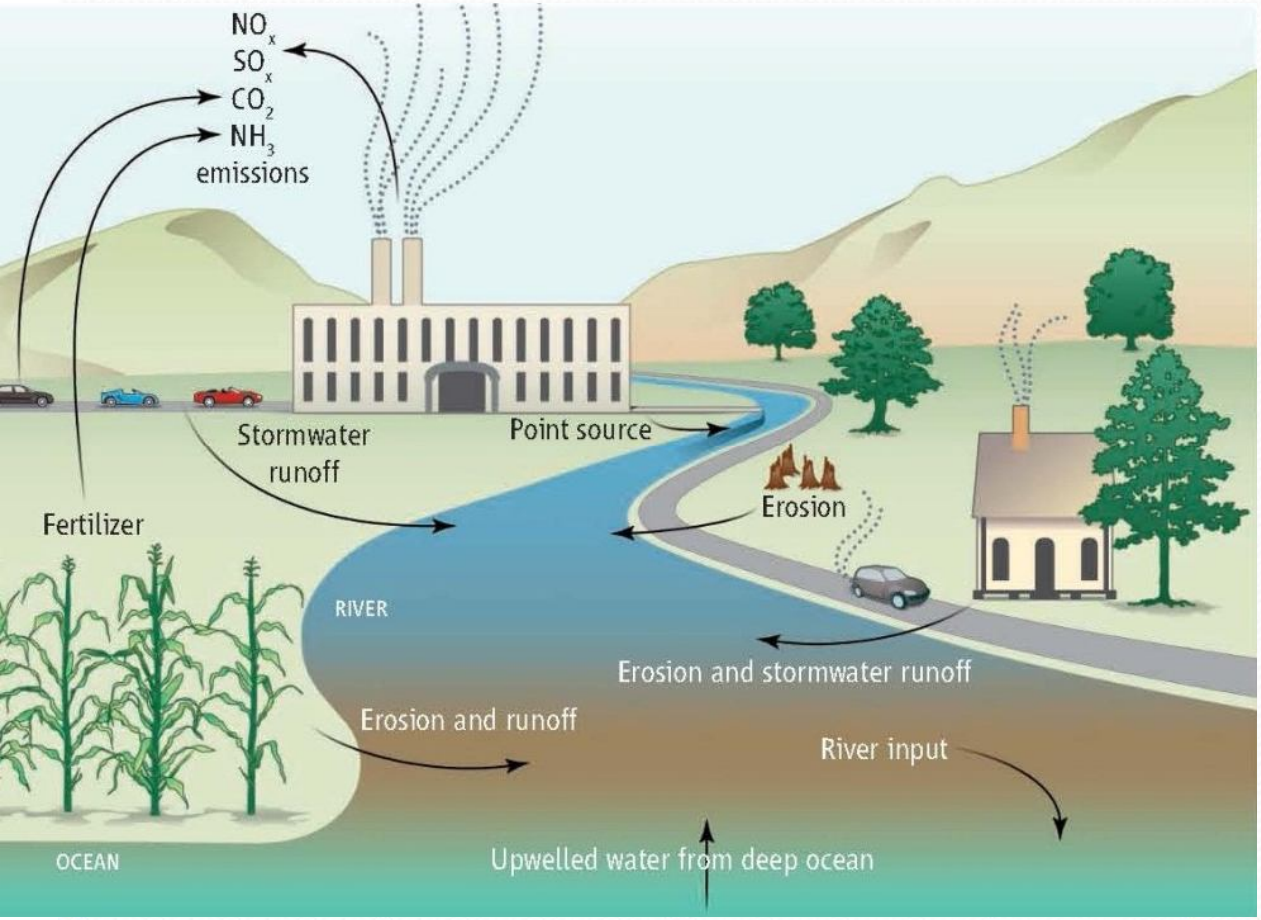
(Salisbury and Hunt, unpublished)

Precipitation is increasing in the Northeast

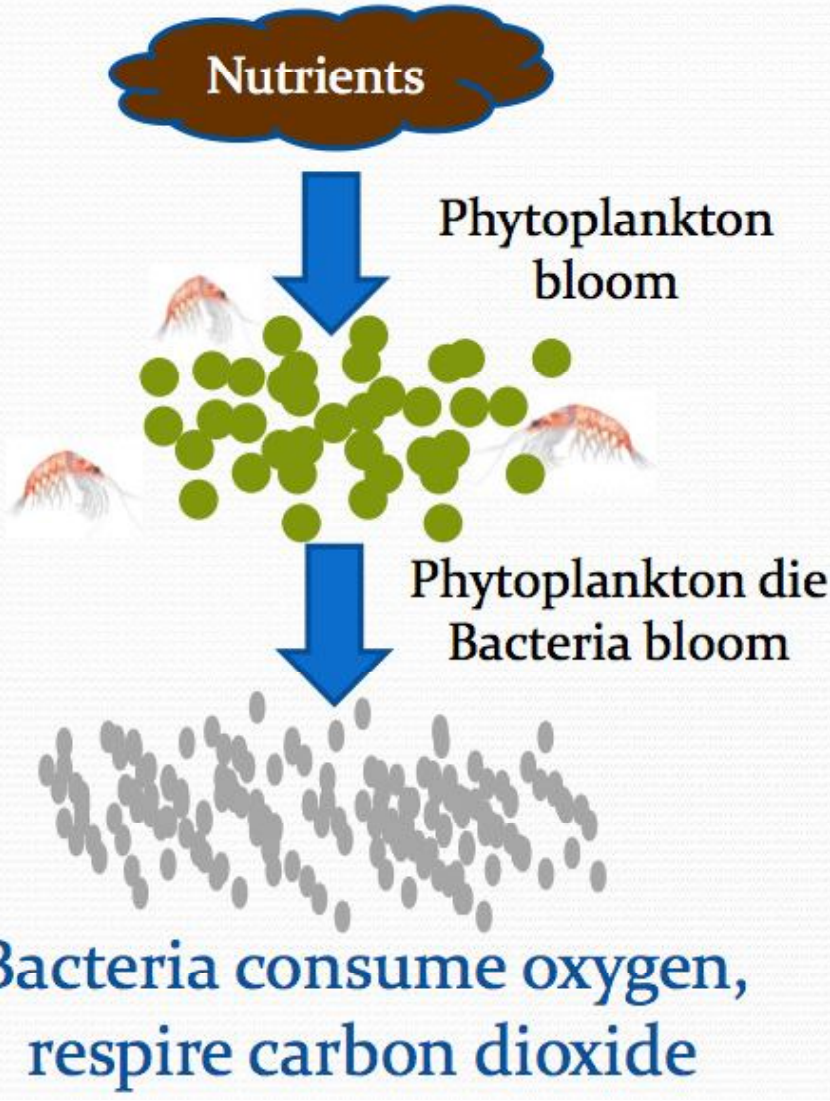


(based on daily COOP data from long-term stations in the National Climatic Data Centers Global Historical Climate Network data set)

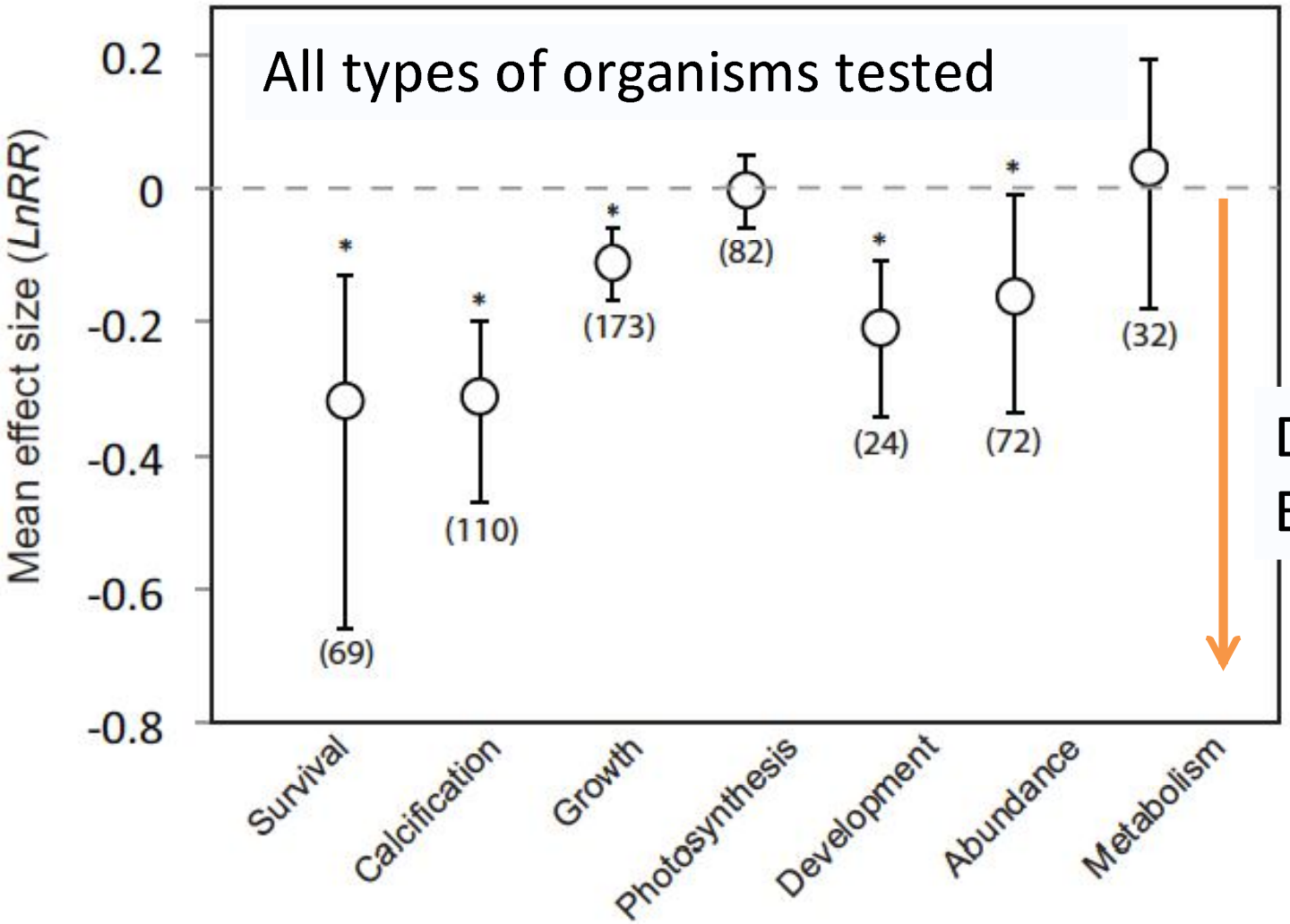
Input of nutrients can cause acidification of coastal waters- “coastal acidification”

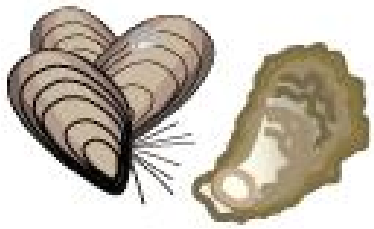


From Kelly et al. 2011. Science.



How will it impact marine organisms?





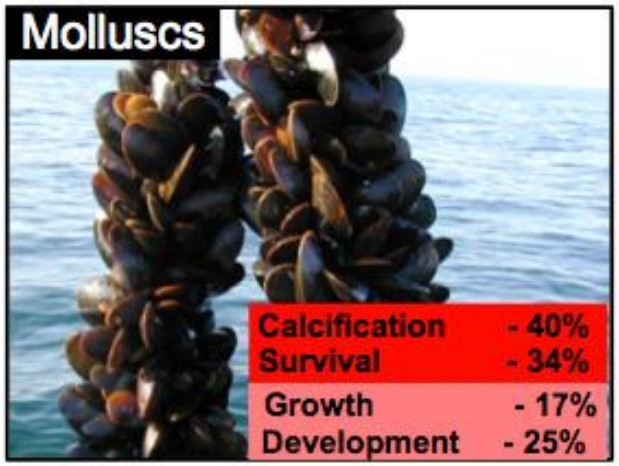
Molluscs

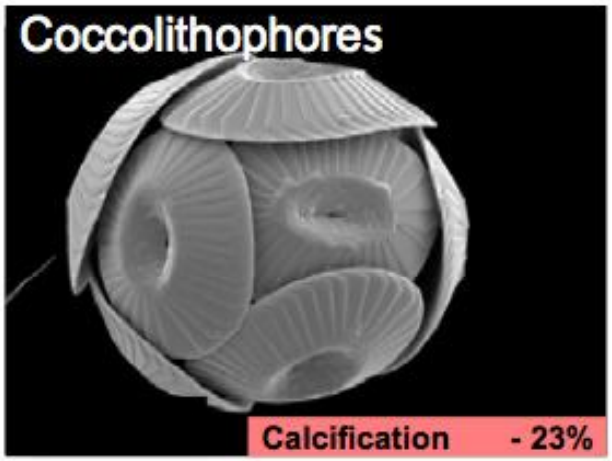
Survival	-34%
Calcification	-40%
Growth	-17%
Development	-25%
Abundance	

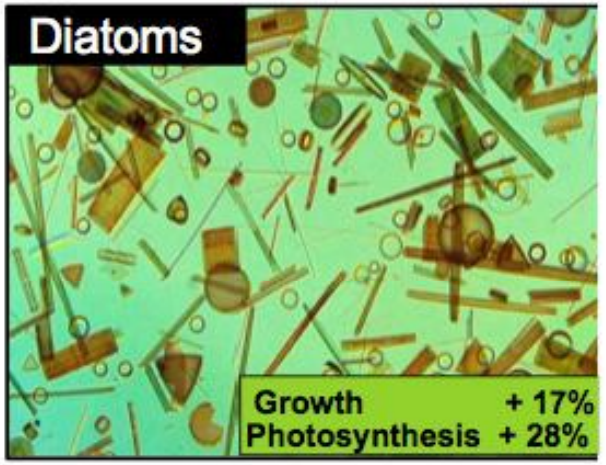
Not tested or too few studies
Enhanced <25%
95% CI overlaps 0
Reduced <25%
Reduced >25%

(Kroeker et al. 2009, 2013)

Responses by Group:







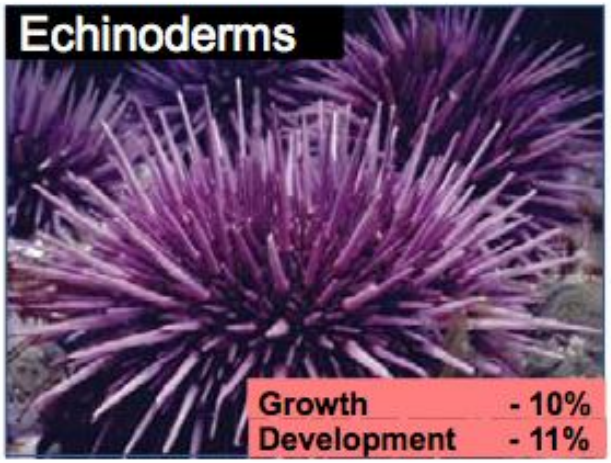
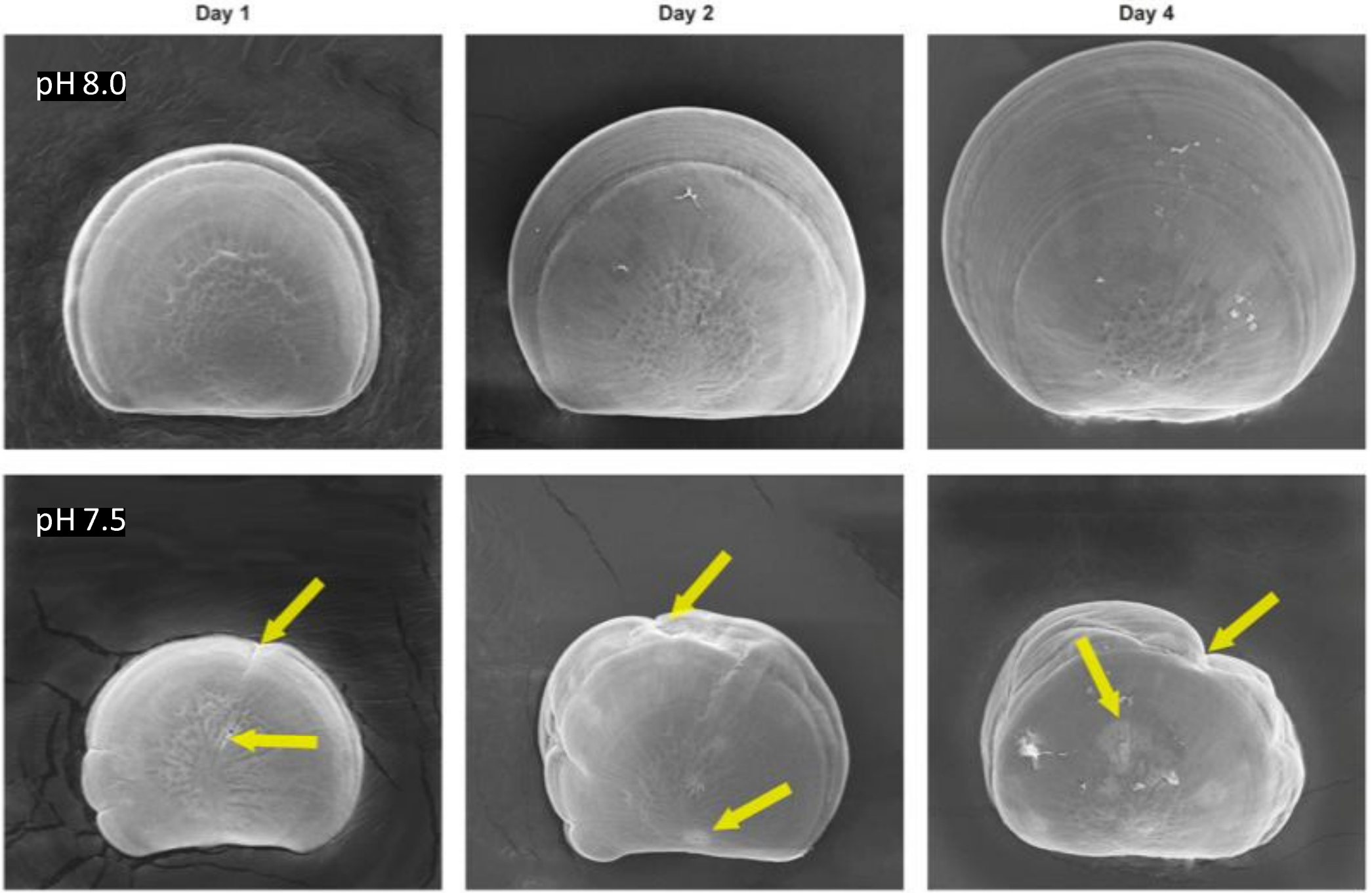


Figure 1.4. Summary of the main effects of a decrease of 0.5 pH units on taxa showing greatest sensitivity, based on metadata analysis from 228 experimental studies. From[6] (Kroeker et al. 2013)

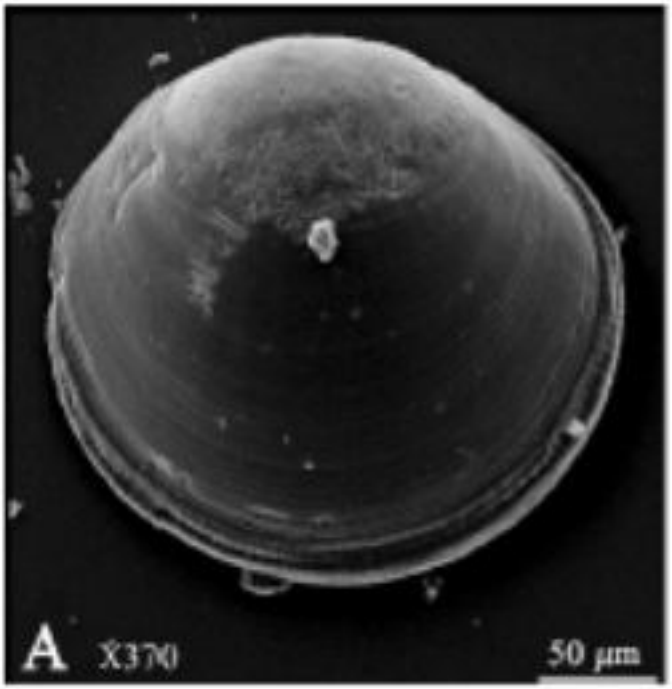
Pacific Oysters:



(Waldbusser et al. 2013)

Hard clams:

Reared in sediments maintained at $\Omega_{aragonite} = 0.6$



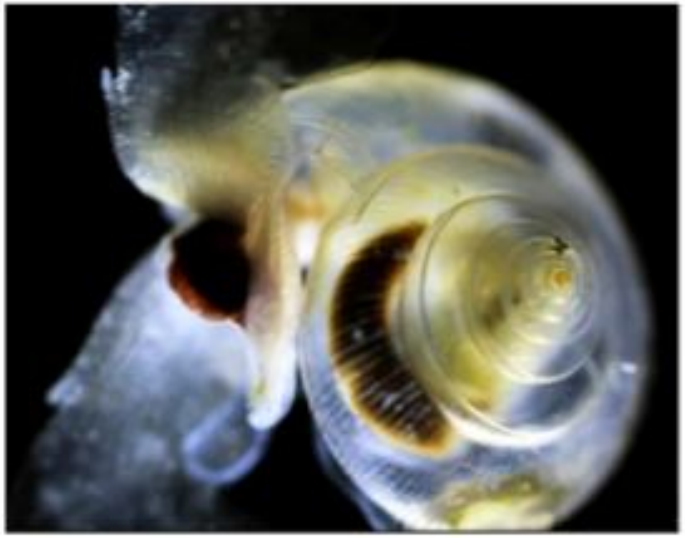
0 days

4 days

7 days

(Green et al. 2009)

Pteropods:



collected in pH 8.0

collected in pH 7.8

in lab at pH 7.5 for 2 wks (NOAA)

Ocean Acidification Research on Lobsters and Crabs

	Embryos	Larvae	Juveniles	Adults
American Lobster (*Homarus americanus*)				
 Reis et al. 2009			↑ Growth, Calcification	
Keppel et al. 2012		↓ Growth, Development		
European Lobster (*Homarus gammarus*)				
 Arnold et al. 2009		↓ Growth, Calcification		
Agnalt et al. 2013		↔ Growth ↑ Deformities	↔ Growth ↑ Deformities	
Norwegian Lobster (*Nephrops norvegicus*)				
 Styf et al. 2014	↔ Development			
King crab (*Paralithodes camtschaticus*) **Alaska**				
 Long et al. 2009			↓Survival & Growth ↔ Calcification, ↓ Condition index	
Tanner crab (*Chionoecetes bairdi*) **Alaska**				
 Long et al. 2009			↓Survival & Growth ↑ Calcification, ↔ Condition index	

Credit: Rick Wahle, UMaine

Value of US Fisheries (calcifiers and others) by Region

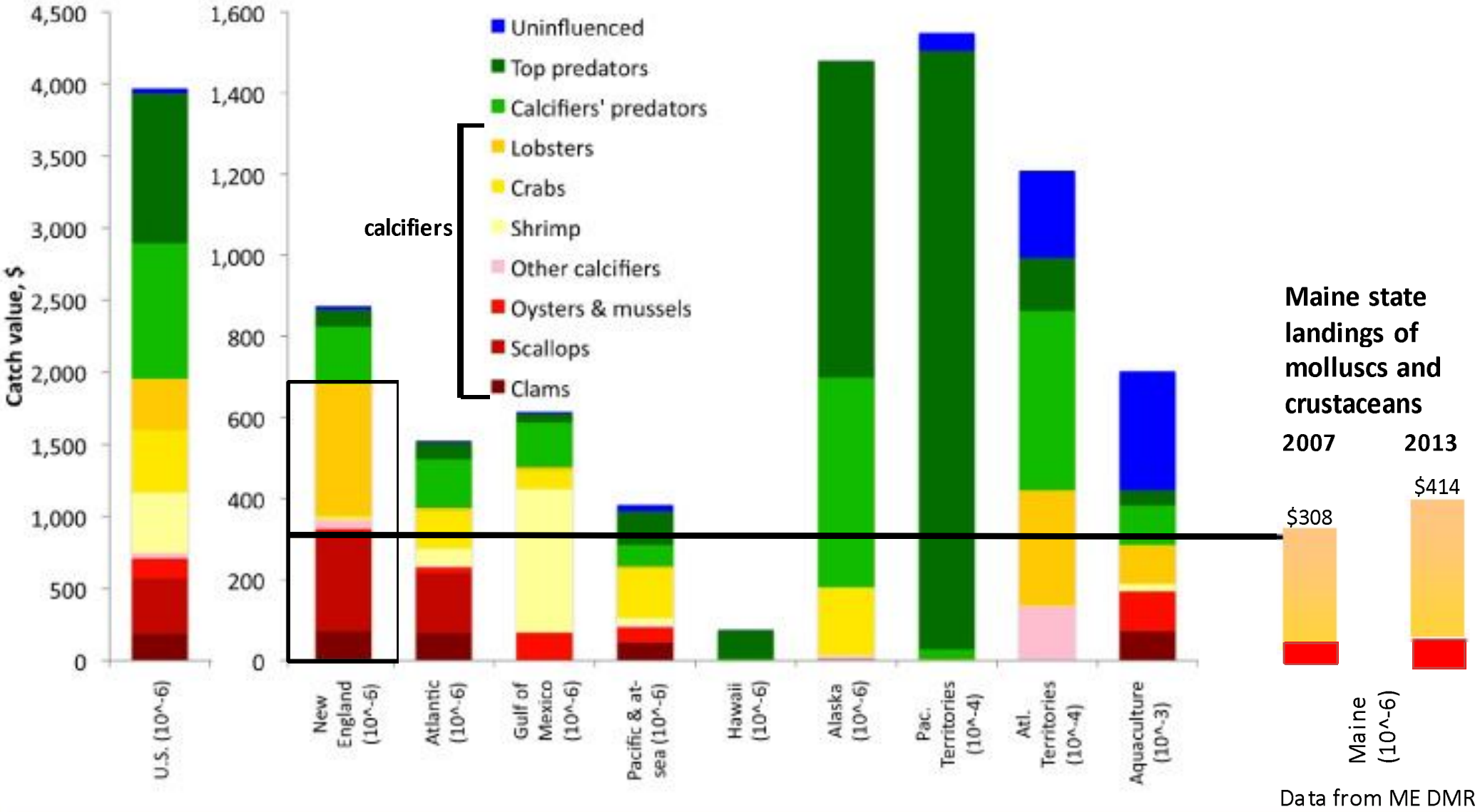
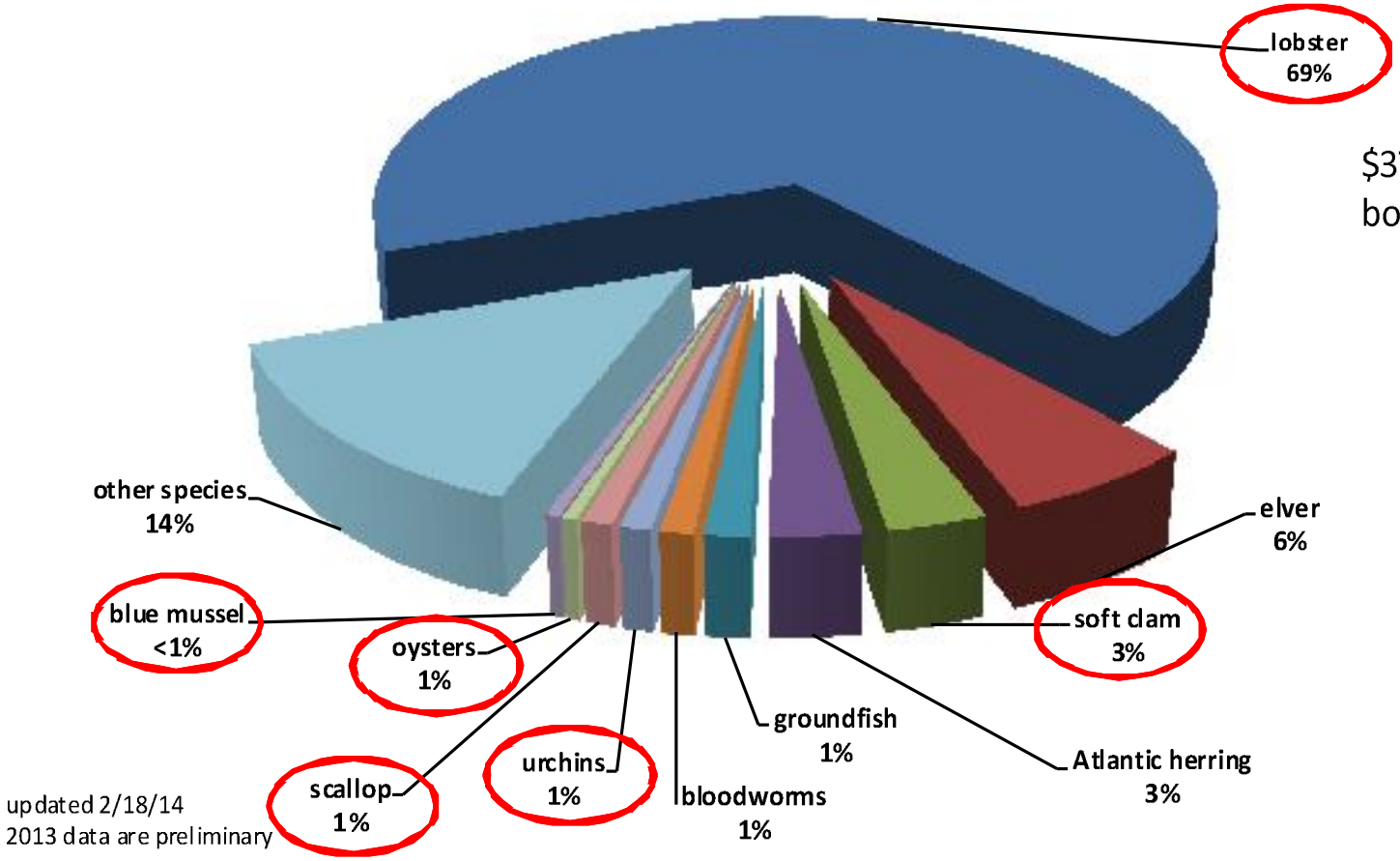


Figure 2. US commercial fishing ex-vessel revenue for 2007 (NMFS statistics, accessed October 2008). Reds indicate organisms containing primarily aragonite, yellows indicate those using primarily calcite, greens indicate predators, and blue indicates species not directly influenced by ocean acidification. (NMFS statistics and **Andrews *et al* 2008**.)

Figure adapted from Cooley and Doney 2009

Preliminary 2013 Commercial Maine Landings by Ex-vessel Value

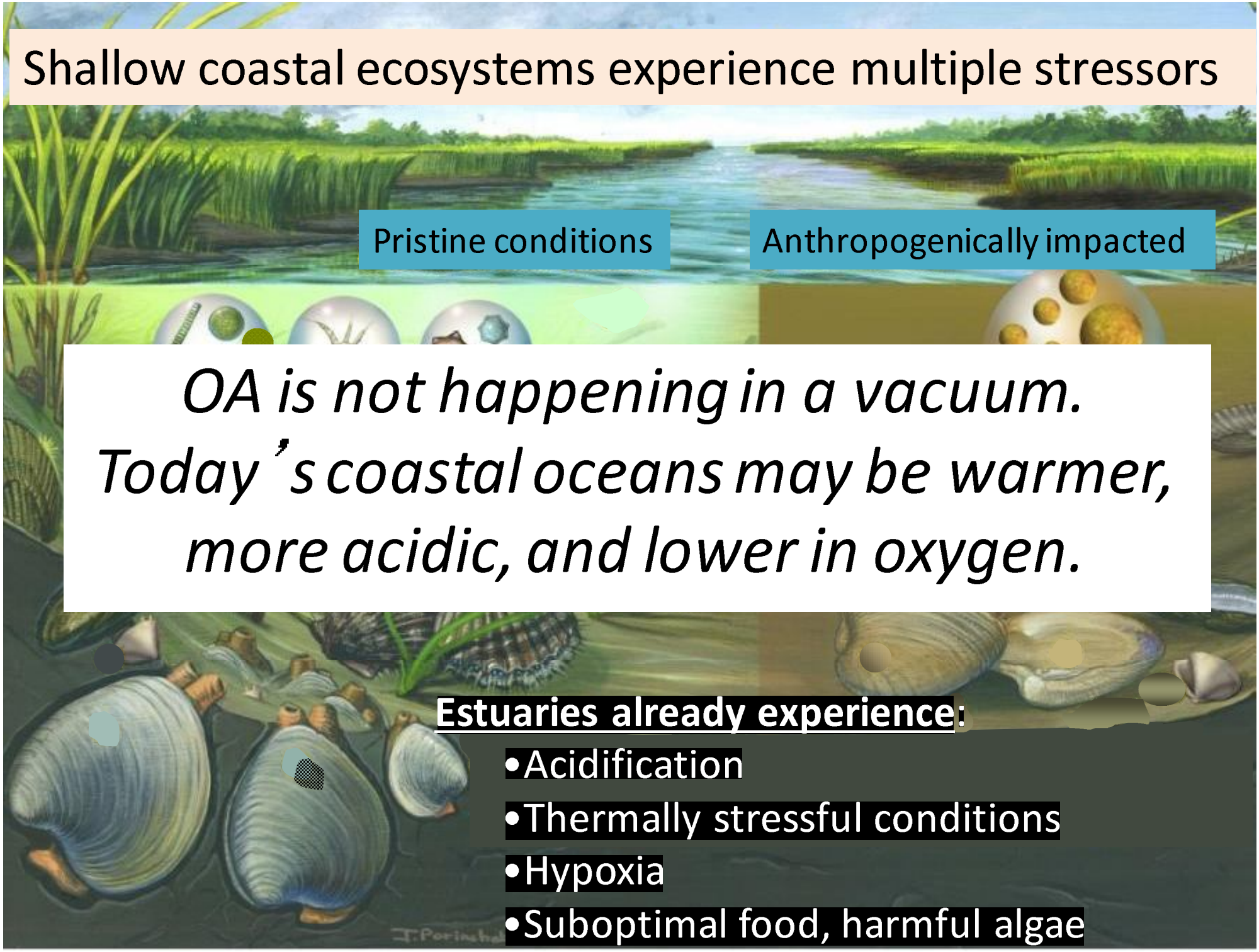
Total $531,224,216 as of 2/18/14



$375 million (including coop bonuses of 11 million)

- over 75% of Maine's fisheries (by landings value) are shell producing species, including lobster, clams, urchins, scallops, oysters, and mussels
- lobster alone accounts for approximately 69% of the value of all fisheries landings in the state with a value of $375 million in 2013 and an overall contribution of around $1 billion to the state economy
- ~7,500 active harvesters targeted shell-building species in 2012

Shallow coastal ecosystems experience multiple stressors



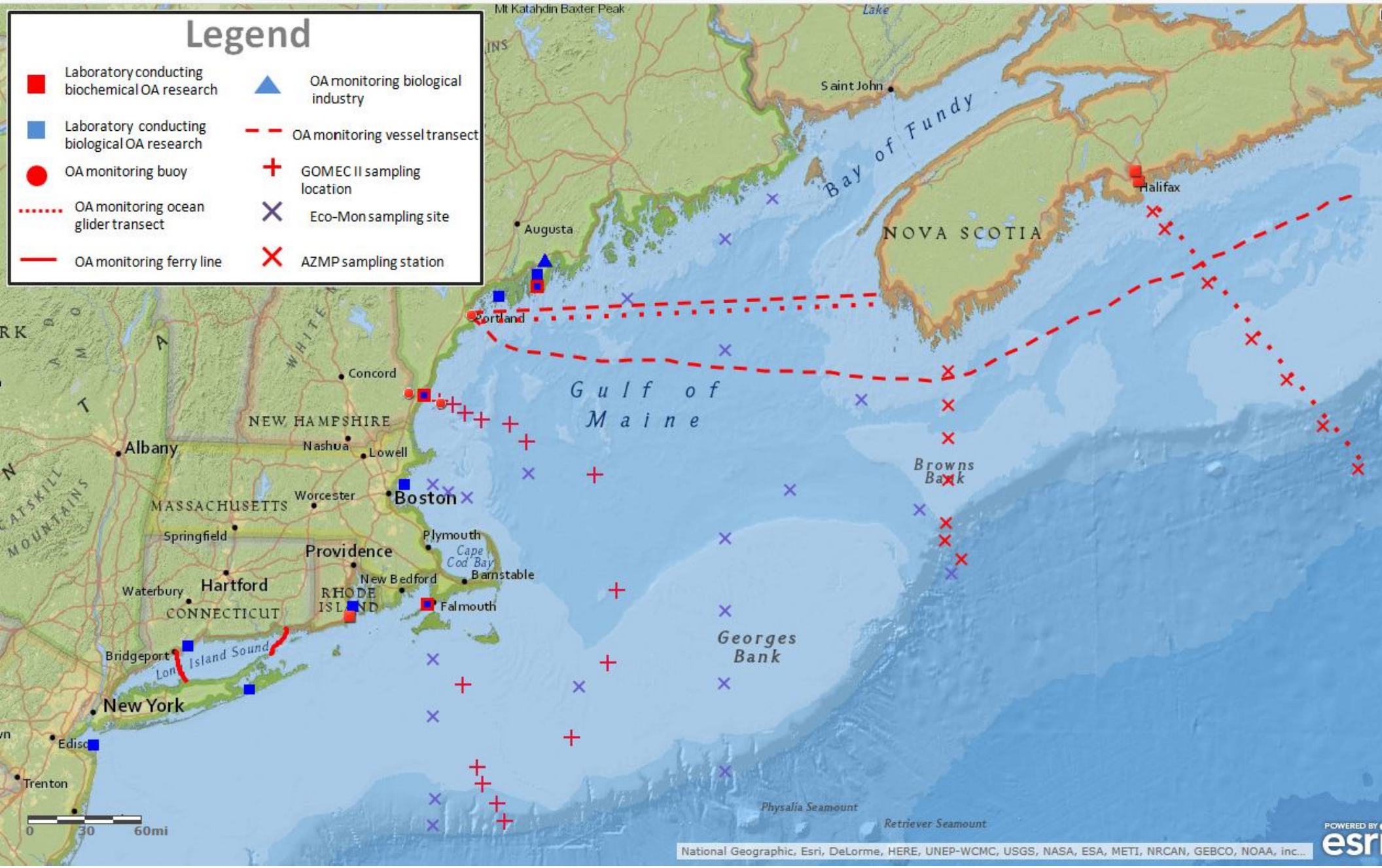
OA is not happening in a vacuum. Today's coastal oceans may be warmer, more acidic, and lower in oxygen.

Estuaries already experience:

- Acidification
- Thermally stressful conditions
- Hypoxia
- Suboptimal food, harmful algae


No need to wait…
we can act now
788 ppm CO_2
400 ppm CO_2
310 ppm CO_2
Credit: Lisa Suatoni, Natural Resources Defense Council

Expand monitoring and research efforts



(Gledhill et al. in prep.)

Table 1. Number of studies investigating organismal responses of Maine commercially important species to increased pCO_2 conditions. The number of studies are broken down into the distinct life stages of the organisms. The total number of studies may not equal the sum of studies for all life stages or the sum of the references listed because some studies consider multiple life stages and some references include multiple studies.

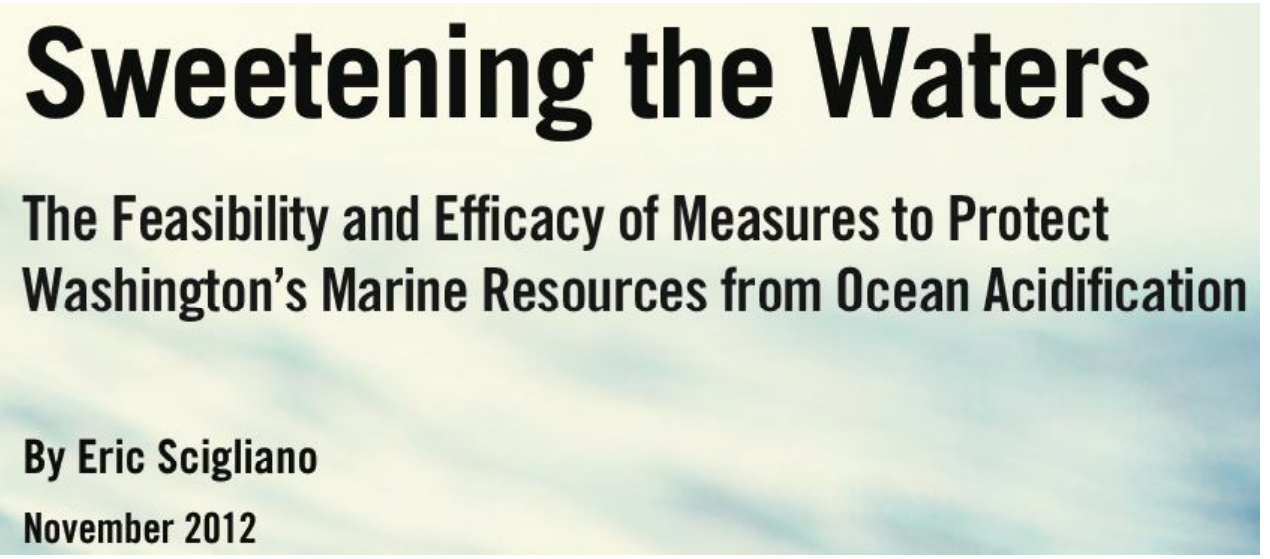
Common Name *Scientific Name*	2013 Landings Value ($)	Life Stage				Total Studies	References
		Reproduction/ Fertilization/ Eggs	Larvae	Juveniles	Adults		
American lobster *Homarus americanus*	378,736,030	0	1	1	0	2	Keppel et al. 2012, Ries et al. 2009, Ries 2011
Elvers (American eel) *Anguilla rostrata*	32,926,991	0	0	0	0	0	
Soft shell clam *Mya arenaria*	16,915,005	0	0	3	1	4	Green et al. 2009, Green et al. 2013, Clements & Hunt 2014, Ries et al. 2009
Atlantic Herring *Clupea harengus*	15,391,192	2	2	0	0	2	Frommel et al. 2014, Franke & Clemmesen 2011
Total Groundfish	**7,626,795**						
Pollock *Pollachius virens*	2,560,807	0	0	0	0	0	
White hake *Urophycis tenuis*	1,477,447	0	0	0	0	0	
Atlantic cod *Gadus morhua*	736,154	2	4	3	0	8	Frommel et al. 2010, Frommel et al. 2012, Frommel et al. 2013, Maneja et al. 2013a, Maneja et al. 2013b, Melzner et al. 2009, Moran & Støttrup 2011
Monkfish *Lophius americanus*	726,130	0	0	0	0	0	
Plaice *Hippoglossoides platessoides*	779,015	0	0	0	0	0	
Witch flounder *Glyptocephalus cynoglossus*	576,799	0	0	0	0	0	
Atlantic halibut *Hippoglossus hippoglossus*	328,587	0	0	2	0	2	Bresolin de Souza et al. 2014, Gräns et al. 2014
Haddock *Melanogrammus aeglefinus*	211,279	0	0	0	0	0	
Acadian redfish *Sebastes fasciatus*	170,134	0	0	0	0	0	
Cusk *Brosme brosme*	17,618	0	0	0	0	0	
Winter flounder *Pseudopleuronectes*	Not enough data to report	0	0	0	0	0	

(OA Commission Report, in prep)

Mitigation and Adaptation Strategies:

Lessons from Washington State-

http://www.ecy.wa.gov/water/marine/oceanacidification.html



Regulatory Actions-

POLICYFORUM

OCEANS

Mitigating Local Causes of Ocean Acidification with Existing Laws

R. P. Kelly,[1*†] M. M. Foley,[1*] W. S. Fisher,[2] R. A. Feely,[3] B. S. Halpern,[4] G. G. Waldbusser,[5] M. R. Caldwell[1]

Even as global and national efforts struggle to mitigate CO_2 emissions, local and state governments have policy tools to address "hot spots" of ocean acidification.

Clean Water Act: Point Sources

stringent technology-based standards upgrade standard POTWs

Regulatory Actions-
Clean Water Act: Water Quality Criteria

revise pH criteria

revise criteria

more acidic

Δ 0.2

7.0

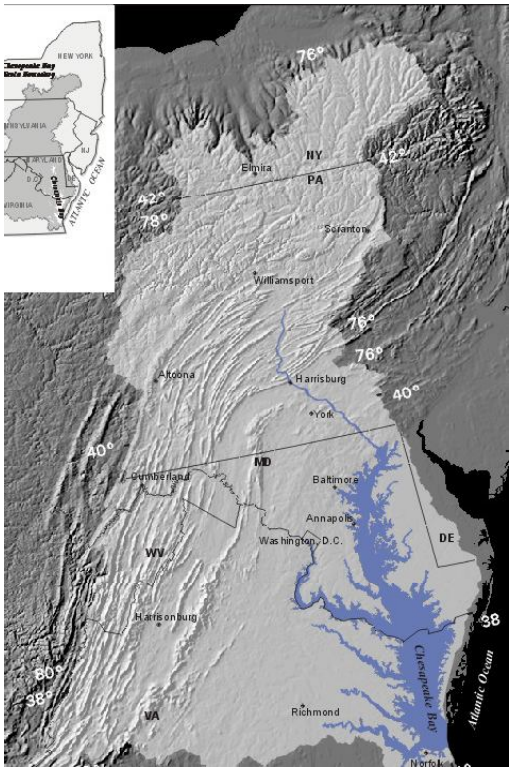
less acidic

pH scale

new water quality criteria specific to OA

Total Alkalinity
Dissolved Inorganic Carbon

TMDL requirements



used for classifying waters as impaired

new "ecologically-based" designated uses

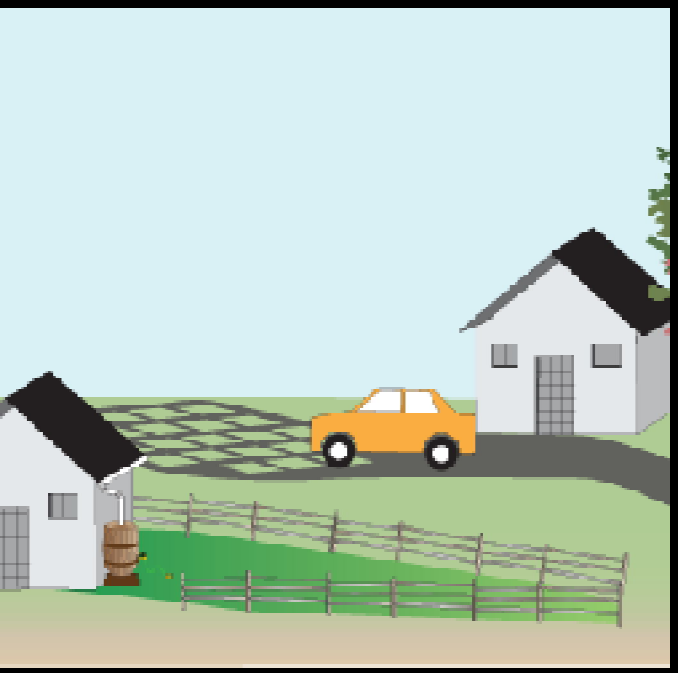
Water body must… be able to sustain bivalves

Regulatory Actions-
Clean Water Act: Non-Point Sources

Establish Best Management Practices §319(h) CWA and §306 CZMA

Smart Growth

National Estuary Program/NERRS



NATIONAL ESTUARINE RESEARCH RESERVE SYSTEM

Federal support for state run plans

Impervious surfaces, buffers

Comprehensive plans/ sites designated for long-term research, monitoring, education, coastal stewardship

Local Efforts- Biogas Digesters

- Reduce nutrients and emissions
- Nationwide, dairy manure digesters reduce CO_2 emissions by > 860,000 t, generating 52.8 mw of power
- Six dairy digesters in Washington reduced CO_2 emissions by 44,870 t
- Tulalip WA's project has enfranchised farmers in habitat, water quality efforts

Credit: Brad Warren (SFP)

Local Efforts-
Buffering Clam Flats with Shells

Photo credit: Brad Warren

Oyster shell stockpiled at a shucking plant in Willapa Bay, Washington.

Many species of seaweed respond positively to CO_2 enrichment and may be more productive under OA

		
Species	*Ascophyllum nodosum* (Rockweed)	*Fucus vesiculosis* (Bladderwack)
Aquaculture practice	harvested	harvested
Habitat	intertidal	intertidal
Response to high CO_2	↑ a[1-3], ↑ b[4-6]	↔ a[2,3,7], ↑ b[8], ↓ c[9]

a – CO_2 assimilation, b – photosynthesis, O_2 evolution, c – production, growth, d – gametophyte size

↑ = increase in physiological process, ↔ no effect, ↓ decrease



Credit: Nichole Price (Bigelow Labs)

What are we doing about OA in Maine?

BDN MAINE

How shifting ocean chemistry threatens Maine

By Mick Devin, Special to the BDN
Posted Oct. 27, 2013, at 1:16 p.m.

An environmental crisis is looming on the marine horizon. Ocean acidification threatens Maine's inshore fisheries, growing aquaculture industry and the jobs that rely on them.

The culprit in this story is carbon dioxide. It's changing the chemistry of the ocean and endangering shellfish like lobster, oysters, clams and sea urchins.

The oceans are naturally slightly basic, or alkaline. But as the oceans absorb more carbon dioxide resulting from fossil fuels use, they move toward the other end of the pH scale, becoming acidic. The acidity level of the oceans has increased 30 percent since the Industrial Revolution.

Courtesy photo

October 2013- Representative Mick Devin submits bill: LR 2511: *Resolve, Establishing a Commission To Study the Effects of Ocean Acidification and Its Potential Impacts on Commercial Shellfish Harvested and Grown along the Maine Coast*

- Oct. 30, 2013- Legislative Council (made up of legislative leaders from both parties — 6 D, 4 R) rejects bill 3-7
- Nov. 21, 2013- after a massive outreach effort, Rep. Devin successfully appeals the decision (passes 7-3) and the bill was considered during the 2nd session of the Legislature

126th MAINE LEGISLATURE

LD 1602 **LR 2511(02)**

COMMITTEE AMENDMENT " " to H.P. 1174, L.D. 1602, "Resolve, Establishing the Commission To Study the Effects of Ocean Acidification and Its Potential Effects on Commercial Shellfish Harvested and Grown along the Maine Coast"

Amend the resolve by striking out the title and substituting the following:

'Resolve, Establishing the Commission To Study the Effects of Coastal and Ocean Acidification and Its Existing and Potential Effects on Species That Are Commercially Harvested and Grown along the Maine Coast'

Whereas, the Commission To Study the Effects of Coastal and Ocean Acidification and Its Existing and Potential Effects on Species That Are Commercially Harvested and Grown along the Maine Coast is established to identify the actual and potential effects of coastal and ocean acidification on commercially valuable marine species, to identify the scientific data and knowledge gaps that hinder Maine's ability to craft policy and other responses to coastal and ocean acidification and prioritize the strategies for filling those gaps and to provide policies and tools to respond to the adverse effects of coastal and ocean acidification on commercially important fisheries and Maine's shellfish aquaculture industry; and

Boothbay Register.

Ocean acidification bill wins broad public support

Changes in ocean chemistry can threaten coastal environment, jobs

By Stefanie Veneziano | Posted: Monday, January 13, 2014 - 4:00pm

Evolution of LD1602:

- Enacted in House in March by a vote of 135-0
- Senate moved it to 'Study Table' where at the conclusion of the session the Legislative Council determined funds they would appropriate to each of the 'study bills'
- Returned to the Senate for enactment
- Goes to the Governor- he does not sign OR veto
- The bill has an emergency rider, so it took effect immediately

Sec. 2. Commission membership. Resolved: That the commission consists of the following members:

1. Two members of the Senate appointed by the President of the Senate, including one member from each of the 2 parties holding the largest number of seats in the Legislature;

2. Three members of the House of Representatives appointed by the Speaker of the House, including at least one member from each of the 2 parties holding the largest number of seats in the Legislature;

3. Eight members appointed by the Commissioner of Marine Resources, including:

A. Two representatives of an environmental or community group;

B. Three persons who fish commercially, including at least one aquaculturist; and

C. Three scientists who have studied coastal or ocean acidification; and

4. Three members as follows:

A. The Commissioner of Marine Resources or the commissioner's designee;

B. The Commissioner of Environmental Protection or the commissioner's designee; and

C. The Commissioner of Agriculture, Conservation and Forestry or the commissioner's designee; and be it further

Sec. 5. Duties. Resolved: That the commission shall meet a minimum of 4 times to review, study and analyze existing scientific literature and data on coastal and ocean acidification and how it has affected or potentially will affect commercially harvested and grown species along the coast of the State and shall address:

1. The factors contributing to coastal and ocean acidification;

2. How to mitigate coastal and ocean acidification;

3. Critical scientific data and knowledge gaps pertaining to coastal and ocean acidification as well as critical scientific data and knowledge gaps pertaining to the effects of coastal and ocean acidification on species that are commercially harvested and grown along Maine's coast. The commission shall include in its review of the relevant scientific literature and data the results of studies presented at conferences or workshops held in the New England or Northeast region that relate to coastal and ocean acidification, and the commission shall coordinate with the Northeast Coastal Acidification Network to prevent duplication of effort;

4. Steps to strengthen existing scientific monitoring, research and analysis regarding the causes of and trends in coastal and ocean acidification; and

5. Steps to take to provide recommendations to the Legislature and increase public awareness of coastal and ocean acidification; and be it further

Sec. 8. Report. Resolved: That, no later than December 5, 2014, the commission shall submit a report of its findings and recommendations to date, including suggested legislation, to the joint standing committee of the Legislature having jurisdiction over marine resources matters. The joint standing committee is authorized to submit a bill to the First Regular Session of the 127th Legislature related to the subject matter of the report.

Preliminary Recommendations:

- Expand monitoring and research
  - Prioritize commercially important species and phytoremediation
- **Reduce CO_2 emissions**
- **Improve wastewater treatment**
  - **Prioritize upgrades**
  - **Revise standards (pH and nitrogen)**
- **Improve land-use practices**
  - **reduce impervious surfaces**
  - **agricultural land BMPs**
- **Improve communication and education about OA with public and key stakeholders**
- Propose legislation for ongoing state OA body to continue to address OA
- Streamline regulations hampering mitigation and remediation
  - Buffering clam flats
  - Seaweed aquaculture licensing

Education and Outreach:

Series of documentaries on the impacts of climate change and ocean acidification on fishing communities- view them at www.islandinstitute.org/climateofchange

1. Maine lobster fishery and warming waters- debut in DC at National Council for Science and the Environment in January 2014

2. Ocean acidification in Alaska- piloted at Maine OA meeting and debut at 2014 Maine Fishermen's Forum

2013 - 38th Annual Maine Fishermen's Forum Presents:

Facing Ocean Acidification in Maine:
Identifying our stakes, questions, and tools to adapt and protect fisheries

Voices from the Working Waterfront:

Clams

- Mark Green, St. Joseph's College of Maine
- Chad Coffin, Maine Clammers Association

Oysters

- Bill Mook, Mook Sea Farms, Walpole, ME
- Jeff 'Smokey' McKeen, Pemaquid Oyster Company, Walpole, ME

Lobsters

- Tim Bowden, University of Maine
- Dave Cousens, Maine Lobstermen's Association

Presentations:

- Brad Warren & Todd Capson, Global Ocean Health Program
- Benoit Eudeline, Taylor Shellfish, WA
- Joe Salisbury, UNH
- Dwight Gledhill, NOAA

Ocean Acidification
in the Gulf of Maine

CO^2 is being released into the atmosphere by human activities at historic rates.

More CO^2 in the atmosphere means more CO^2 is absorbed by the ocean, offsetting the balance of carbon molecules. This leads to an increase in the concentration of hydrogen ions (H^+) and a decrease in the concentration of carbonate (CO_3^{-2}) (an important component of shell building).

↑H^+ ↓pH ↑Acidity

Ocean Acidification (OA) is a term used to describe this changing chemistry. The pH scale is a measure of H^+ in water. More H^+ causes a drop in pH and an increases the acidity.

↓ Shell Growth ↓ CO_3^{-2}

The shells of marine organisms like clams and oysters are made out of calcium carbonate ($CaCO_3$). These organisms take up carbonate (CO_3^{-2}) and dissolved calcium (Ca^{+2}) to build their shells. A decrease in the concentration of carbonate decreases the amount of available shell-building material, making it more difficult for many organisms to build their shells.

Coastal Acidification

Pollution runoff from human activities causes coastal waters to acidify more rapidly.

Shell Damage

Increased acidity can even cause some calcium carbonate shells to dissolve like a drop of vinegar (mild acid) dissolves a piece of chalk (calcium carbonate).

Vulnerable Organisms

Clams: OA has been found to increase mortality, delay the onset of metamorphosis, slow growth, and depress calcium uptake (the shell building process) in hard clams .

Plankton: Some plankton, which make up the base of the food chain, contain calcium carbonate and are impacted by OA. This could cause problems for organisms higher up the food chain like fish and lobsters.

Finfish: Early work on the response of finfish indicates that some species undergo behavioral changes when exposed to OA conditions predicted for next century.

Lobsters: The impacts of OA on lobsters are not yet understood.

Resources for more information

Island Institutes's Ocean Acidification page: www.islandinstitute.org/OceanAcidification

NOAA's PMEL Carbon Program: http://www.pmel.noaa.gov/co2/story/Ocean+Acidification

NOAA's Ocean Acidification Program: http://oceanacidification.noaa.gov

Woods Hole Oceanographic Institution: http://www.whoi.edu/main/topic/ocean-acidification

Created for the Island Institute by Julia Maine ™ August 2014

BDN MAINE

POLL QUESTION

As ocean becomes more acidic, will 'dead mud' consume Maine's bountiful shellfish flats?

By Christopher Cousins, BDN Staff

Follow on Twitter Find on Facebook

Posted Jan. 13, 2014, at 5:04 p.m.

Do you think higher acidity levels in seawater will damage Maine's shellfish industry?

Yes 83.44% (131 votes)

No 16.56% (26 votes)

Total Votes: 157

Maine OA Meeting on January 16 in Augusta hosted by the Island Institute with support from the Maine Outdoor Heritage Fund, Maine Sea Grant, Maine Coastal Program, and Sustainable Fisheries Partnership

Steering committee: *Susie Arnold (Island Institute), Angie Brewer (DEP), Curtis Bohlen (CBEP), Todd Capson (SFP), Linda Mercer (DMR), Bill Mook (Mook Sea Farm), Emily Norton (MCP), Joe Payne (FOCB), Joe Salisbury (UNH), Esperanza Stancioff (SeaGrant), Beth Turner (NOAA)*

Goals of the Meeting-

- Building a constituency. Participants feel informed about OA in Maine and empowered to take action with the help of others in the group, whether being more proactive about potential implications for their businesses or making OA a priority for their organizations.
- Improving and coordinating the messaging from Mainers about OA and our concerns about impacts on our state (ecologic and economic), why the Gulf of Maine is particularly susceptible to OA, and how multiple stressors can compound coastal and ocean acidification.
- Identifying knowledge gaps and prioritizing next steps. Improving coordination among researchers, resource managers, and other groups in the state.

Some key concerns, questions, and knowledge gaps identified at the meeting-

- lack of knowledge about OA impacts on commercially important species, particularly lobster, and the potential socioeconomic consequences
- impacts on the base of the food chain
- the role of polluted runoff in exacerbating coastal acidification
- how OA will interact with other changes like rising sea water temperatures
- how do we raise visibility to an invisible problem?

Meeting summary, agenda, participant list, and notes from presentations are all downloadable at www.islandinstitute.org/OceanAcidification

ISLAND INSTITUTE

Increasing Community Resilience to Ocean Acidification in Maine: Analyzing and Responding to the Economic, Cultural, and Social Impacts

A Workshop in the Island Institute's Climate of Change Series

Cohosted by the Natural Resources Defense Council

Date: October 7, 2014

Time: 9:00 - 4:30 (lunch will be included)

Venue: Long Reach Hall at the Maine Maritime Museum in Bath

- **Address: 243 Washington Street, Bath, Maine**
- **Parking at the museum is free, ample, and convenient - see http://www.mainemaritimemuseum.org/visit/parking/**

REGISTER HERE BY SEPTEMBER 29th

Some spots will be held for fishermen who face unpredictable weather and changing schedules. Please inquire via email if interested.

Primary goals of the workshop:

1) Raise awareness in Maine about tools and data that can be used to assess social and economic vulnerability to OA

2) Explore mitigation and adaptation options and demonstrate how the results of a vulnerability analysis can be used to focus these efforts

3) Solicit feedback on the methods of existing vulnerability assessments and identify local data and information needs for mitigation and adaptation to inform future priorities for Maine

Summary Points:

- The ocean is acidifying rapidly, due primarily to CO_2 emissions but also local inputs, such as nutrient runoff
- Some local species will be sensitive to OA
- Impacts of OA will ripple through food webs
- Other stressors can exacerbate species response
- There are regulatory and local actions we can take now to mitigate this threat