The Briefest of Introductions to Ocean Acidification in the Southeast U.S. Coastal Zone

Key Points:

1) Ocean Acidification is a simple fact – you just can't argue with chemistry.
2) In the coastal zone, "OA" is a more complicated issue than in the open ocean.
3) Predictions of future pH levels in coastal waters must also account for possible changes to the other drivers of coastal CO_2 dynamics – especially eutrophication.

North Inlet – Winyah Bay
National Estuarine Research Reserve

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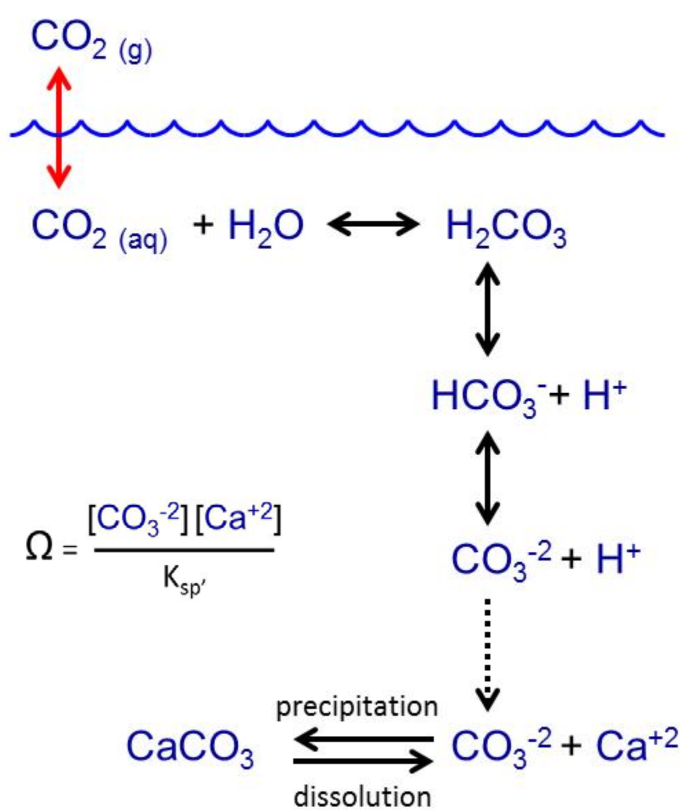
Ocean Acidification:

The physical dissolution of increasing atmospheric CO_2 in seawater

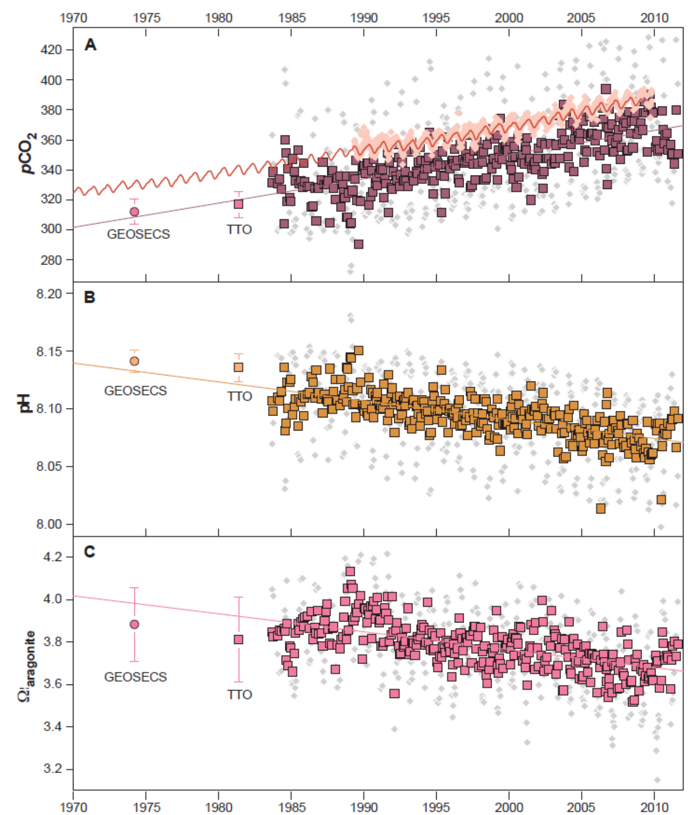
Increasing CO_2 = increasing H^+ (decreasing pH) and decreasing CO_3^{-2}

→ This is real and directly observable in the open ocean

The "Carbonate System" (Simplified)



OA observations off Bermuda



Source: Bates et al. 2012 Biogeosciences

Future acidification depends on future CO_2 emissions

Open-ocean pH decrease since pre-industrial = 0.1 pH units

Projections: additional 0.1 – 0.35 pH unit decrease by 2100

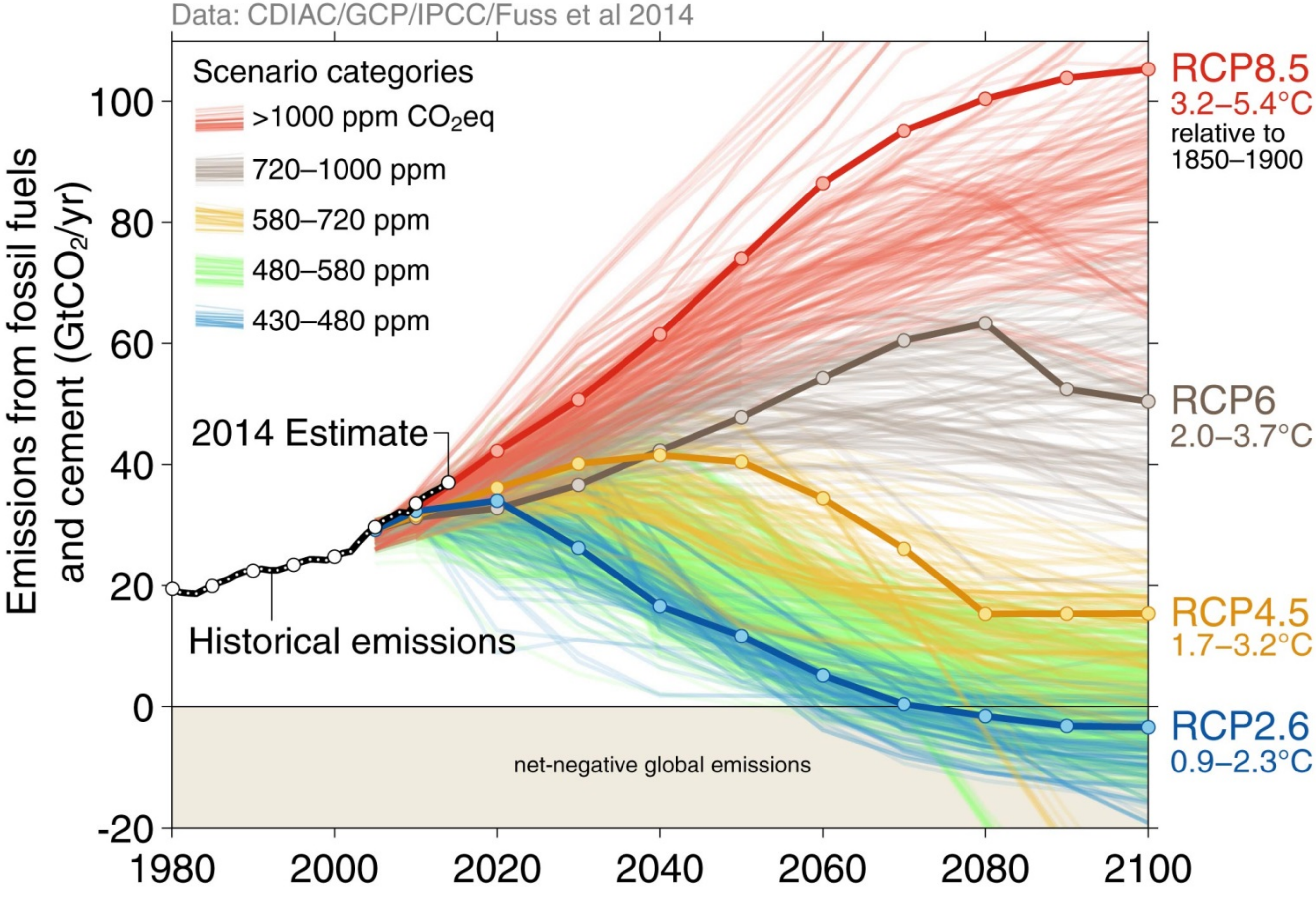


Figure: Globalcarbonproject.org

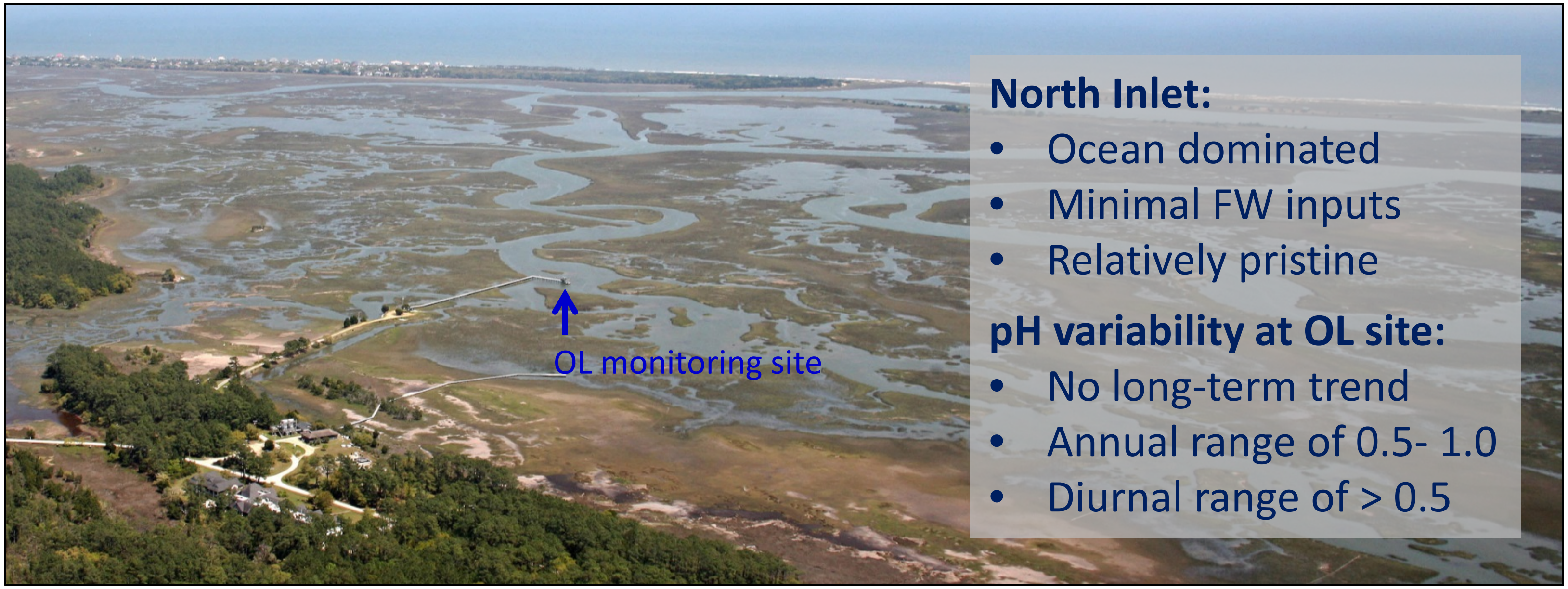
"Ocean" Acidification in estuaries and the near-shore:

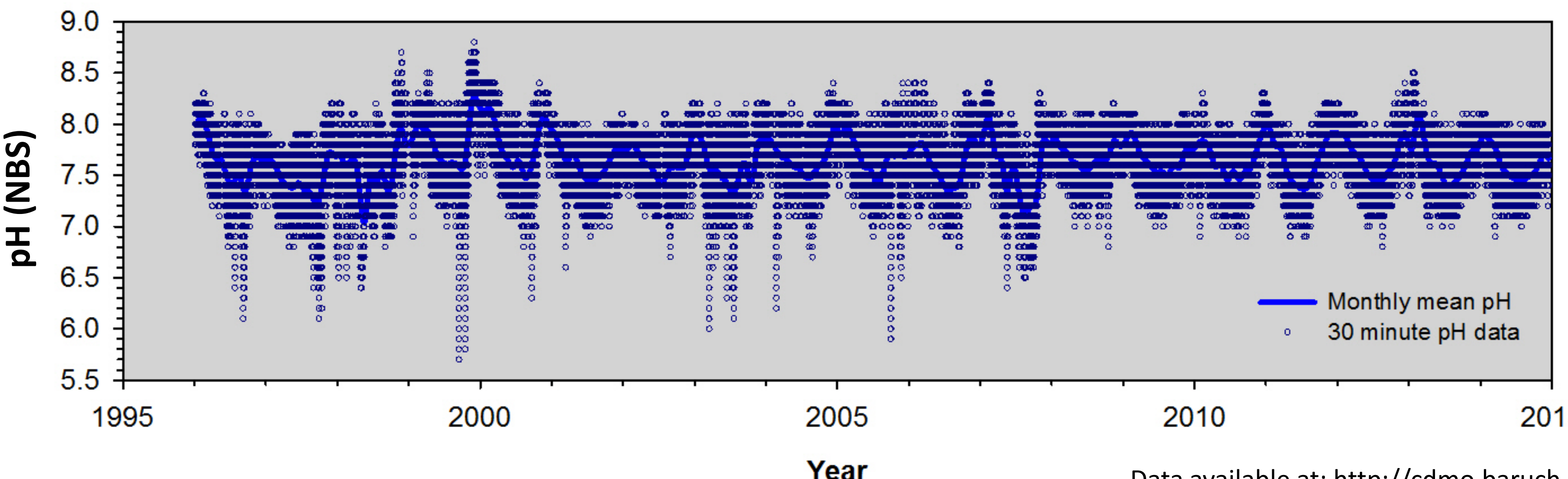
→ Much more complicated than in open ocean due to the increased number of factors that can affect carbon cycling

Driver	**Effect on pH**
Atmosphere – ocean interaction	
Dissolution of anthropogenic CO_2	Decrease
Watershed inputs	
$CO_{2(aq)}$	Decrease
Alkalinity	Increase
Humic & Tannic acids	Decrease
Nutrients	Indirectly Increase or Decrease
Ocean boundary conditions	
Upwelling of deep ocean water	Decrease
Changing coastal currents	Increase or Decrease ?
Ecosystem processes	
Photosynthesis (uptake of CO_2)	Increase
Respiration (remineralization of CO_2)	Decrease

pH variability in estuaries:

Example from North Inlet, SC (NERR long-term monitoring site)





Data available at: http://cdmo.baruch.sc.edu

pH variability in estuaries:

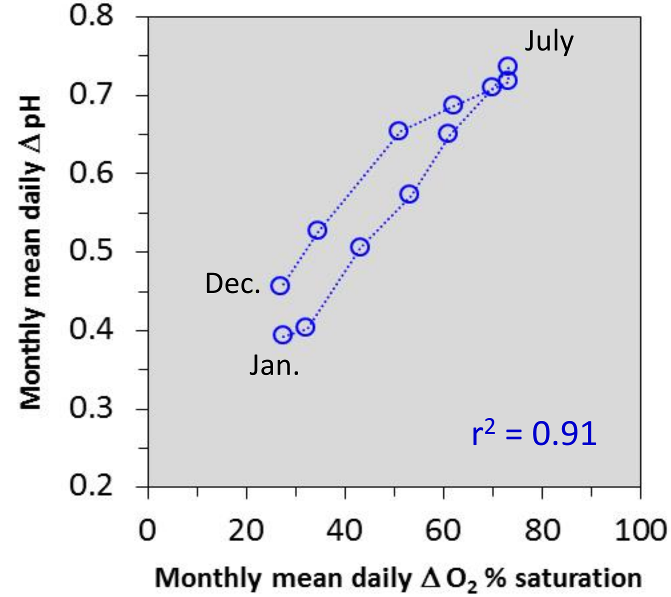
Example from North Inlet, SC (NERRS long-term monitoring site)

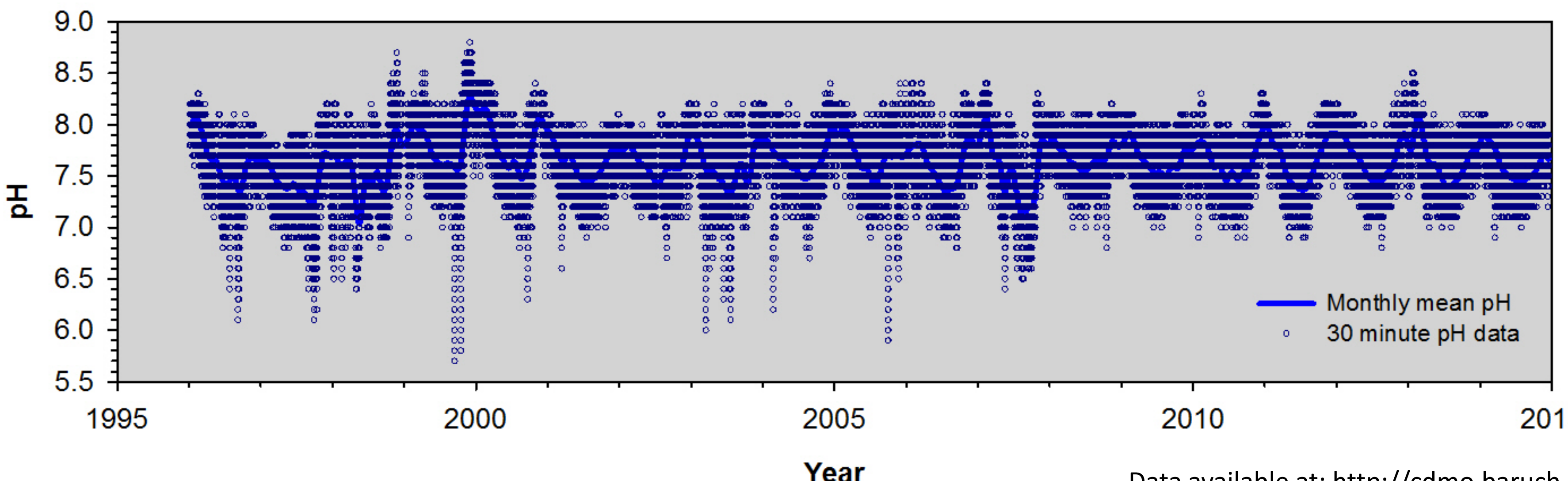
Biology (photosynthesis and respiration) is the **dominant** driver of this pH variability.

$$CO_2 + H_2O \underset{\text{Respiration}}{\overset{\text{Photosynthesis}}{\rightleftharpoons}} C_6H_{12}O_6 + O_2$$

$\updownarrow$

$$CO_2 + H_2O \rightleftarrows H_2CO_3 \rightleftarrows HCO_3^- + H^+ \rightleftarrows CO_3^{-2} + H^+$$





Data available at: http://cdmo.baruch.sc.edu

Eutrophication and coastal zone acidification

- The strong influence of ecosystem production and respiration on estuarine pH means that any future changes to P and R will have a substantial impact on future pH levels.

- Eutrophication (increased coastal production due to nutrient over-enrichment) has been a wide-spread problem for decades and is predicted to continue in the coming decades.*

- Eutrophication can act synergistically or antagonistically to OA, greatly complicating predictions of future coastal acidification.
  - Eutrophication in deep and/or stratified coastal systems promotes vertical decoupling of production (surface) and respiration (bottom waters).
    → bottom water hypoxia and low pH ("Estuarine OA")
  - SE has few stratified estuaries, limited opportunity to uncouple of P and R
    → enhanced diurnal variability in pH (but promote increase in mean pH?)

* NOAA National Estuarine Eutrophication Assessment Update (2007)

So what does the future hold for the SE coast?

- (Some level of) further coastal eutrophication is coming.
- (Some level of) further ocean acidification is coming.
- And both will also come in concert with rising temperatures, higher sea levels, and changing precipitation patterns, etc.

➢ There is still a great deal we do not yet know regarding how all these changes will interact to alter future coastal ecosystem conditions (to say nothing about what these changes may mean for the organisms that inhabit these coastal ecosystems).

➢ This lack of knowledge should not translate to a lack of concern.

While more work is desperately needed, the precautionary principle is highly applicable here and existing evidence suggests moving forward with strategies to mitigate climate change and OA is in our society's long-term interest.

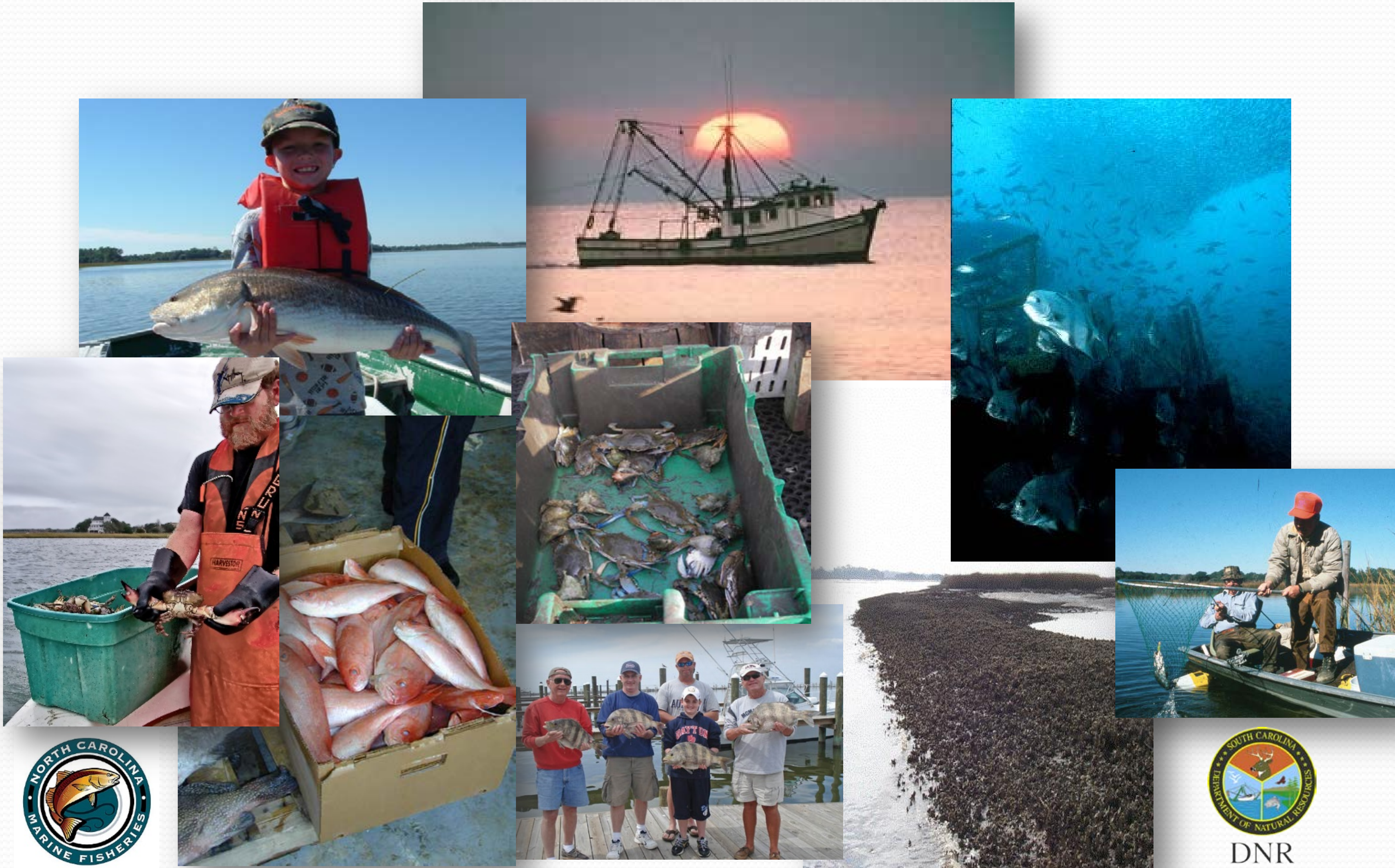
➢ This lack of knowledge also suggests predictions of negative consequences not over-reach the currently available facts.

Science, Industry, Management: Perception of Ocean Acidification and Fisheries in the Carolinas

SOCAN Webinar - August 25, 2015

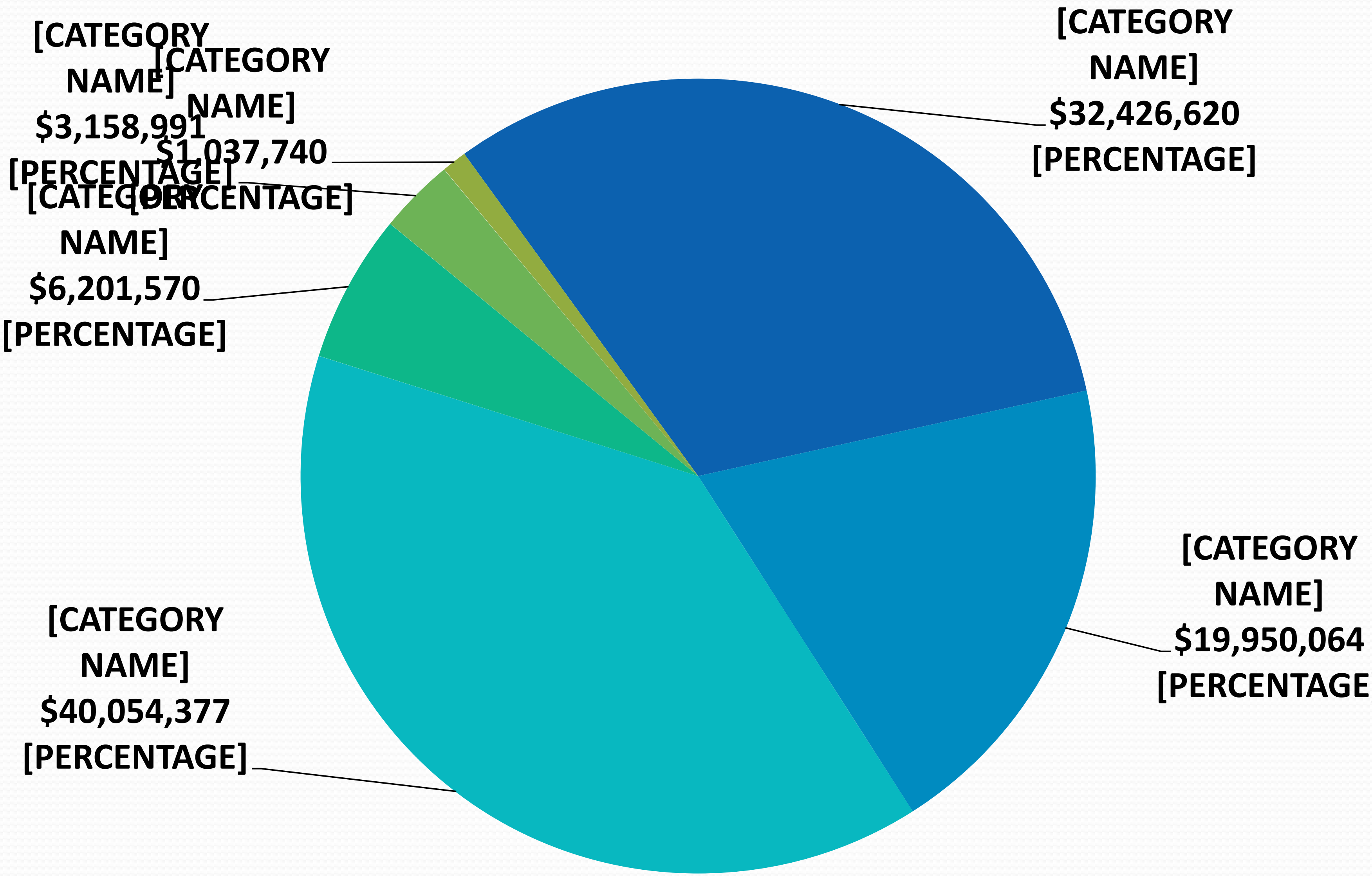
Mel Bell
Director, Office of Fisheries Management
South Carolina Department of Natural Resources

“Carolina” Marine Fisheries



Commercial Fisheries

Average Annual NC/SC Commercial Ex-Vessel Value (2010-2014)



Total Annual Average Value of Landings: $102,829,362

ACCSP

NC/SC COMMERCIAL FISHERIES

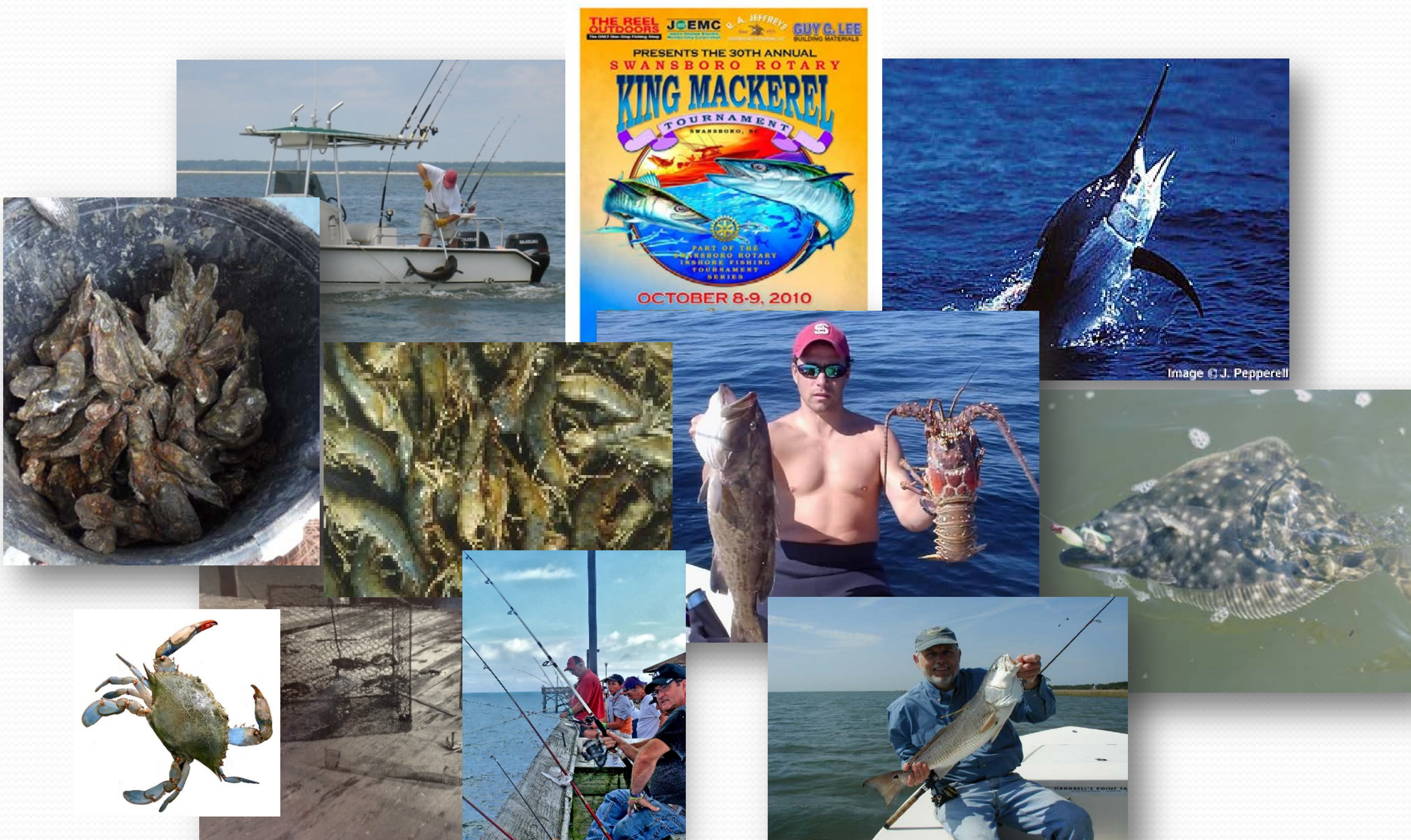
Economic Impacts - 2011:

- **Sales Impacts**
  - **North Carolina $ 796 million**
  - **South Carolina $ 88 million**

- **Jobs (Seafood Industry)**
  - **North Carolina 5,086**
  - **South Carolina 1,495**

NOAA TM NMFS-F/SPO-128; Dec 2012

RECREATIONAL FISHERIES



NC/SC RECREATIONAL FISHERIES

Trips (2011):

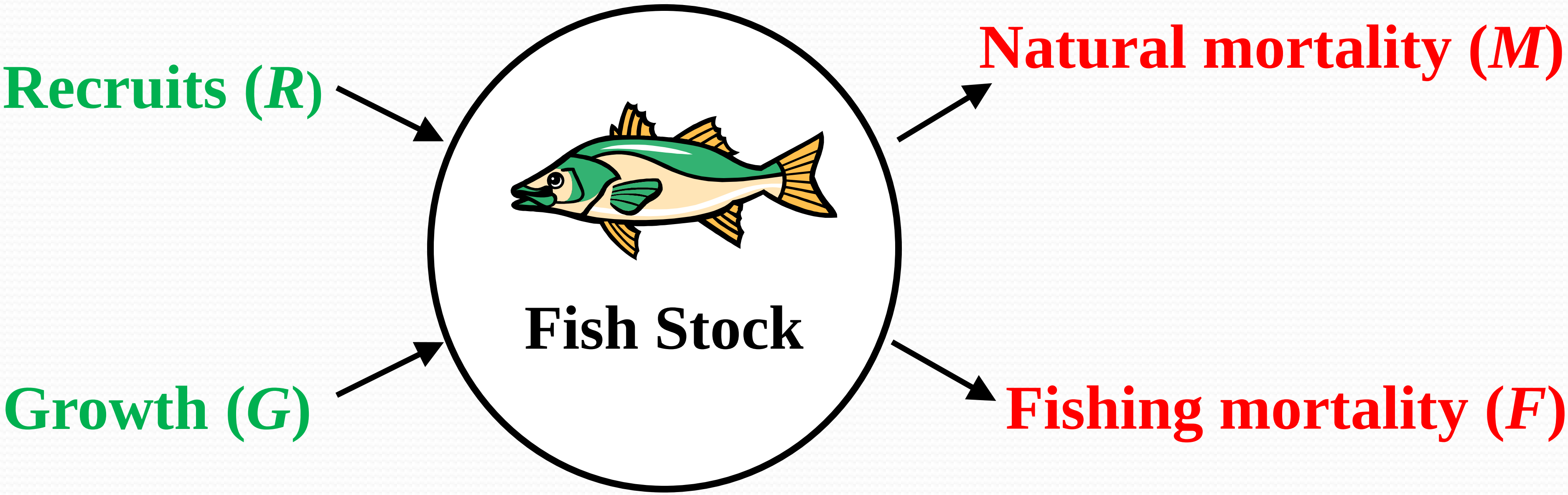
- North Carolina 4.74 million
- South Carolina 1.81 million

Economic Impacts - 2011:

- Sales Impacts
  - North Carolina $ 1.96 billion
  - South Carolina $ 282 million
- Jobs
  - North Carolina 17,737
  - South Carolina 3,254

NOAA TM NMFS-F/SPO-128; Dec 2012

Simplified Fishery Management



Stock Size(Biomass) = $R + G - (M + F)$

J. DeAlteris, URI Dept of Fisheries

Environmental Impacts on Fisheries

- **Changes in Water Temperature**
  - **Short term – Loss of overwintering white shrimp**
  - **Long term – Changes in ranges of finfish species**

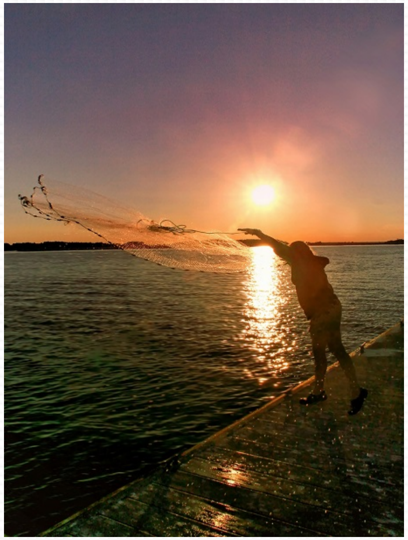
- **Changes in Salinity**
  - **Short term – Oyster die-off from heavy rainfall**
  - **Long term – Decrease in crab abundance in droughts**

- **Changes in pH from Ocean Acidification?**
  - **Short term – Diminished recruitment in crustaceans?**
  - **Long term – Decreased quality/viability of shellfish?**

Response to Possible Impacts of Ocean Acidification

- Continue/Increase field monitoring opportunities
- Continue laboratory studies on species of importance
- Model/predict impacts on natural mortality
- Better understand impacts on reproduction/growth
- Understand possible impacts on fisheries
- Inform/develop appropriate management responses
- Avoid competing with current pressing needs for research, monitoring and science-based fisheries management

QUESTIONS ?



DNR

Acidification Questions

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Official Disclaimer

- These thoughts, questions and comments are my own and are probably not shared by anyone else.
- I feel it is my duty to question the conventional thinking before I suggest the sky is falling.

To panic or not?

- I initially believed that shellfish were doomed.

- Several observations have made me question this conclusion.

I am not a climate change denier

- Acidification is coming. This is a proven fact. You add 750 gigatons of CO_2 to the atmosphere, 100+ gigatons dissolves into the oceans where it forms carbonic acid and the pH declines. Fact.

- We don’t yet know how it will impact shellfish growth or recruitment.

Three points

- It does not serve us well to conflate the separate issues of ocean acidification, upwelling of corrosive deepwater and eutrophication-induced acidification.
- To predict how OA will impact fisheries, we will need to know how it will impact the organisms.
- Bubbling CO2 into a beaker is a weak proxy for real world conditions.

Six years since Dr. Richard Feely raised the alarm

- ECSGA lobbied heavily for the FOARAM Act and acidification research funding.
- $6-8M per year spent largely on oceanographic cruises and monitoring. $30M in President's FY16 request.
- Frustratingly little research to predict how this will impact organisms like shellfish.

We want to avoid conflating three different issues:

1. Ocean Acidification (already here – avg. 30% increase in $[H^+]$, projected 0.2 pH decline in 50-100 yrs)

2. Upwelling of corrosive deepwater (Pacific Coast)

3. Eutrophication-induced acidification of both seawater and sediments (impacting estuaries worldwide right now)

Eutrophication

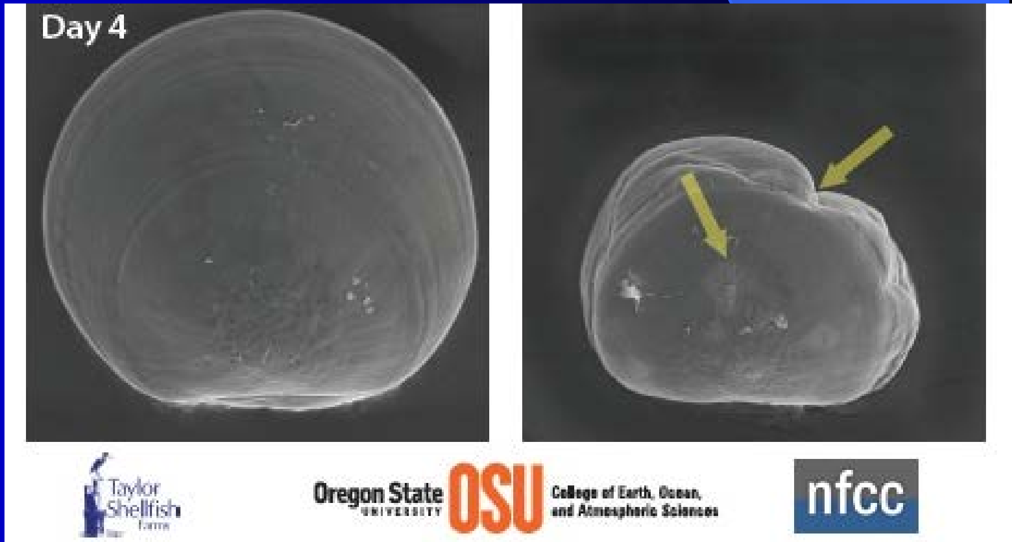
- Excess nitrogen causes blooms of microalgae and macrophytes.
- Decomposition of accumulating organic matter leads to hypoxia, high pCO_2, low pH and acidified muds = eutrophication
- Main sources of nitrogen include:

  fertilizer > WTPs > atmospheric deposition > road runoff > septic sys.

Pacific Coast Upwelling of Acidified Deepwater

- Deepwater has not been in contact with atmospheric oxygen for hundreds of years.
- Bacterial decay of sinking fecal pellets and dead plankton ↑ CO_2, ↓ O_2, ↑ NO_x, ↓ pH, ↓⮙
- Winds cause offshore currents and upwelling.
- Deepwater is corrosive

  and nutrient rich.
- Hatchery failures.



Eutrophication-induced estuarine pCO_2 levels are alarming

- In our eutrophic estuaries we commonly observe nighttime pCO_2 levels as high as 1000-3000ppm.
- Levels we are predicting for 50-100 years from now.
- There have been declines in shellfish biomass, but there are still successful sets.

Normal Estuarine Variation in pH

- Dense algal blooms suck up CO_2 when the sun is shining, they fix pCO_2 to form carbohydrates. The pH goes up.
- At night these same plants respire, giving off CO_2. By morning pH can drop below 7.
- On a daily basis we can see a 1.5+ pH unit swing.
- Projections are for OA to cause a pH decline of 0.1 - 0.2 units in 50-100 years.

Shellfish have survived a lot of climate change

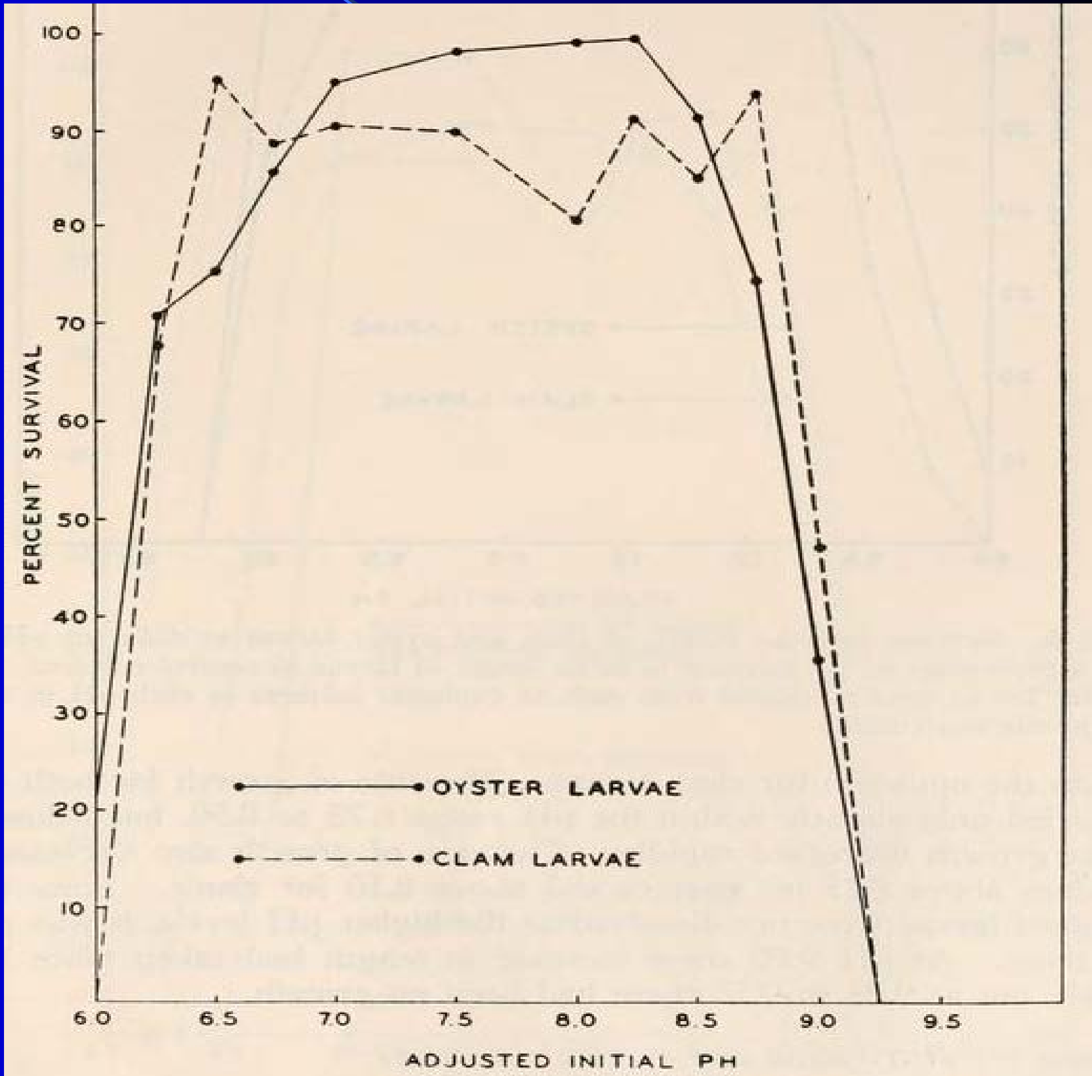
- Shellfish evolved 300 million years ago
- In geologic time, global CO_2 levels are now low.
- There may be enough inherited genetic variation that certain shellfish may tolerate low aragonite saturation states.
- Researchers in Australia have seen *Sydney Rock oysters* "adapt" to high CO_2 in two generations.
- West Coast research showing offspring of pH challenged *C. gigas* more "resistant."

Some studies appear to indicate shellfish larvae can tolerate a wide range of pH

The pH tolerance of embryos and larvae of *Mercenaria mercenaria* and *Crassostrea virginica*.

Anthony Calabrese & Harry Davis

(1966) Biol. Bull 131:427-436.



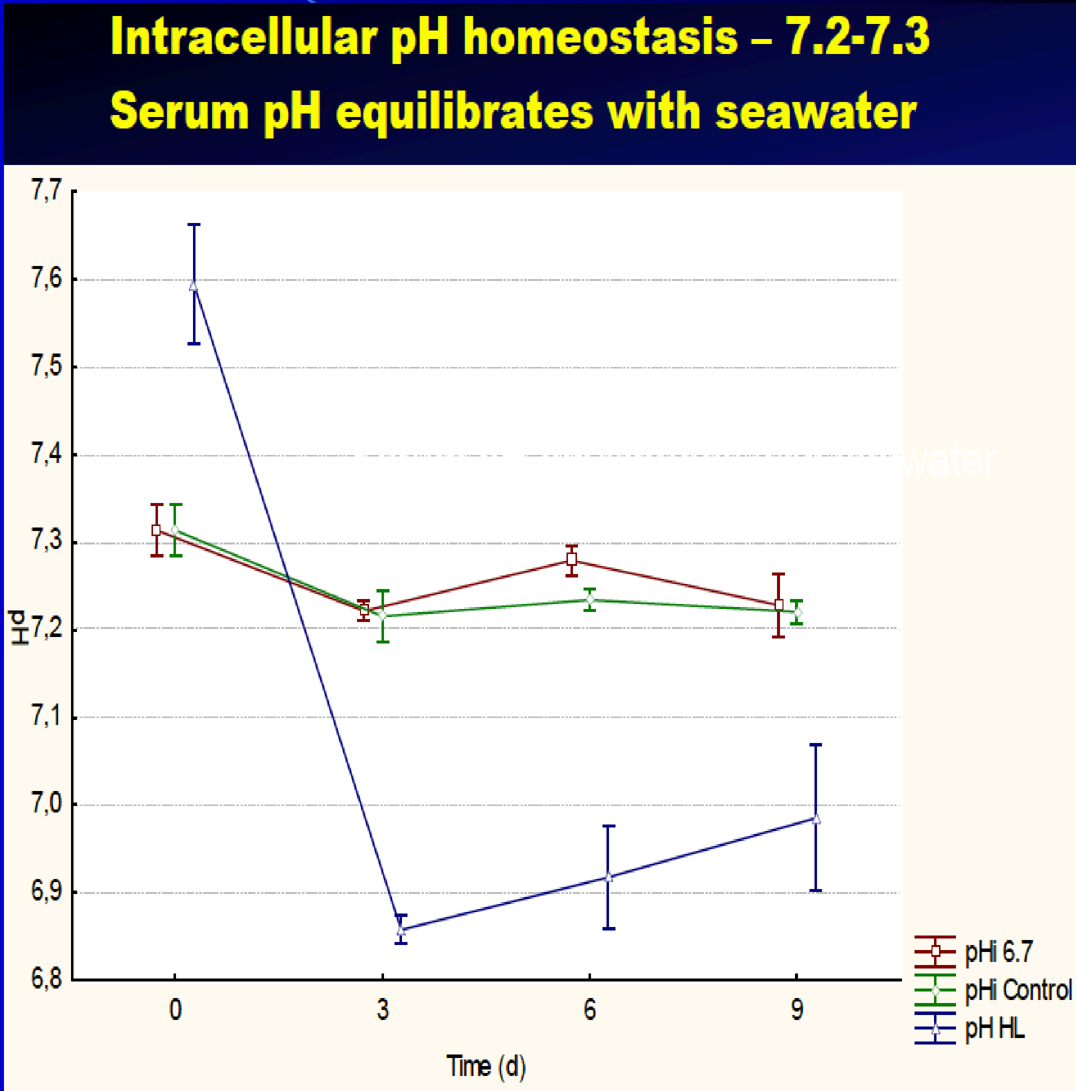
The internal pH of the hemocyte is maintained

Oyster hemocytes maintain internal pH and calcium under acidic conditions.

Gary Wikfors, Carsten Krome, & Shannon Mesec, In prep.

Even after 9 days in pH 6.7 the internal pH of the cells that deposit calcite is maintained at 7.2-7.3.

Hemolymph conforms.



Carbon in shell is dietary

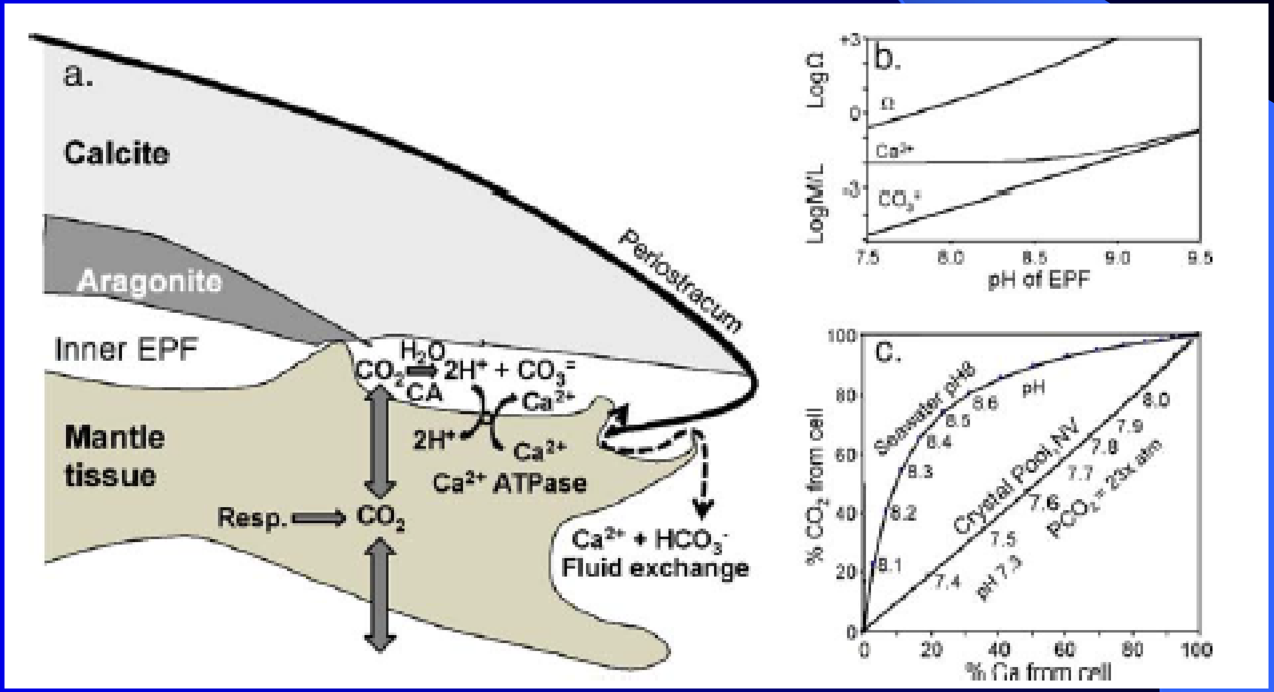
The carbon isotope ratio of shell is indicative of food rather than that of ambient water CO_2.

Is our fixation with aragonite saturation is misplaced?

Carbon isotopes in mollusk shell carbonates.

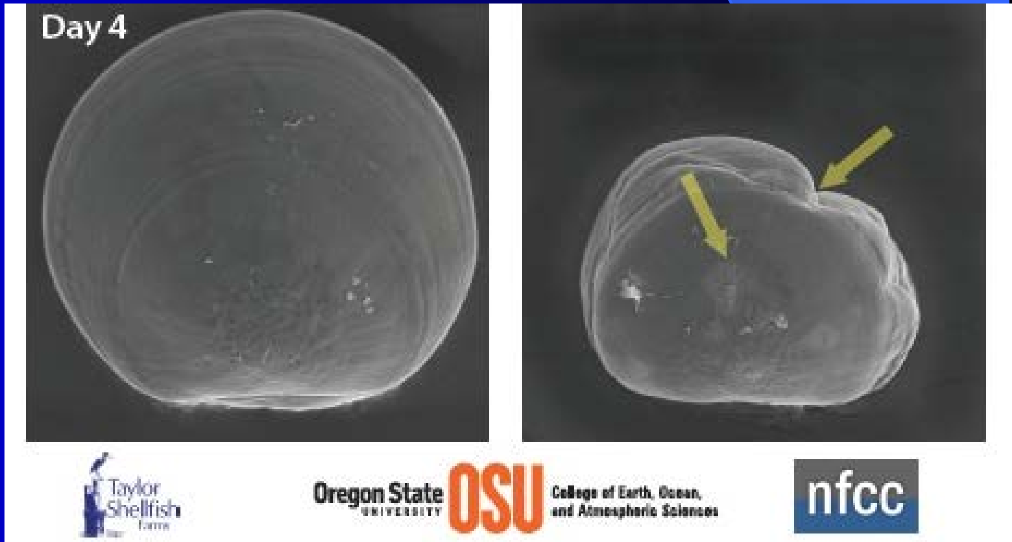
McConnaughy, T. & D.P. Gilligan (2008)

Geol-Mar Lett 28:287-299



Pacific Coast hatchery issues persist

- Even though hatcheries on the Pacific Coast are able to buffer their waters with carbonate and keep aragonite saturation levels high…
- Hatchery production is still not back to "normal"
- Perhaps there are other causative factors?



We know acidification is coming

(along with warming, sea level rise, eutrophication, hypoxia, new predator assemblages and parasites)

- We still don't know how OA will impact shellfish growth or recruitment.
- Many argonite-based corals are probably headed for extinction. (Palau exception?)
- We cannot rule out a collapse of the marine food chain (Salps and coccolithophores)
- Nitrate levels and eutrophication represent a clear and present danger. Acidified muds are impacting wild infaunal biomass now.

I am not suggesting that OA is nothing to worry about.

I am simply pointing out that we don't have enough information to predict who the winners and losers will be.

A plea for more research

- We need to know how this is going to impact the various species.
- What mitigation strategies may help? (hatcheries, breeding, ... what other options?)
- Will shellfish adapt or will there be mass extinctions? (probably both)
- Can they adapt on a time scale of 50-100 years instead of 50,000 – 100,000 years?