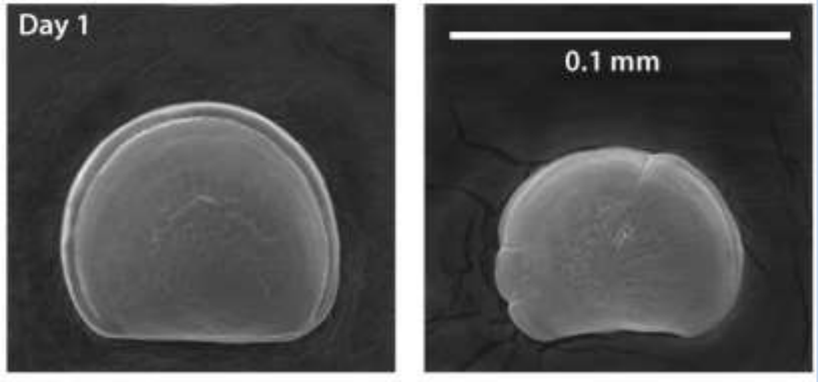
Acidification in Estuaries and Coastal Zones: Timing is Everything

George G. Waldbusser and many others



Key Points About Coastal Zone Acidification

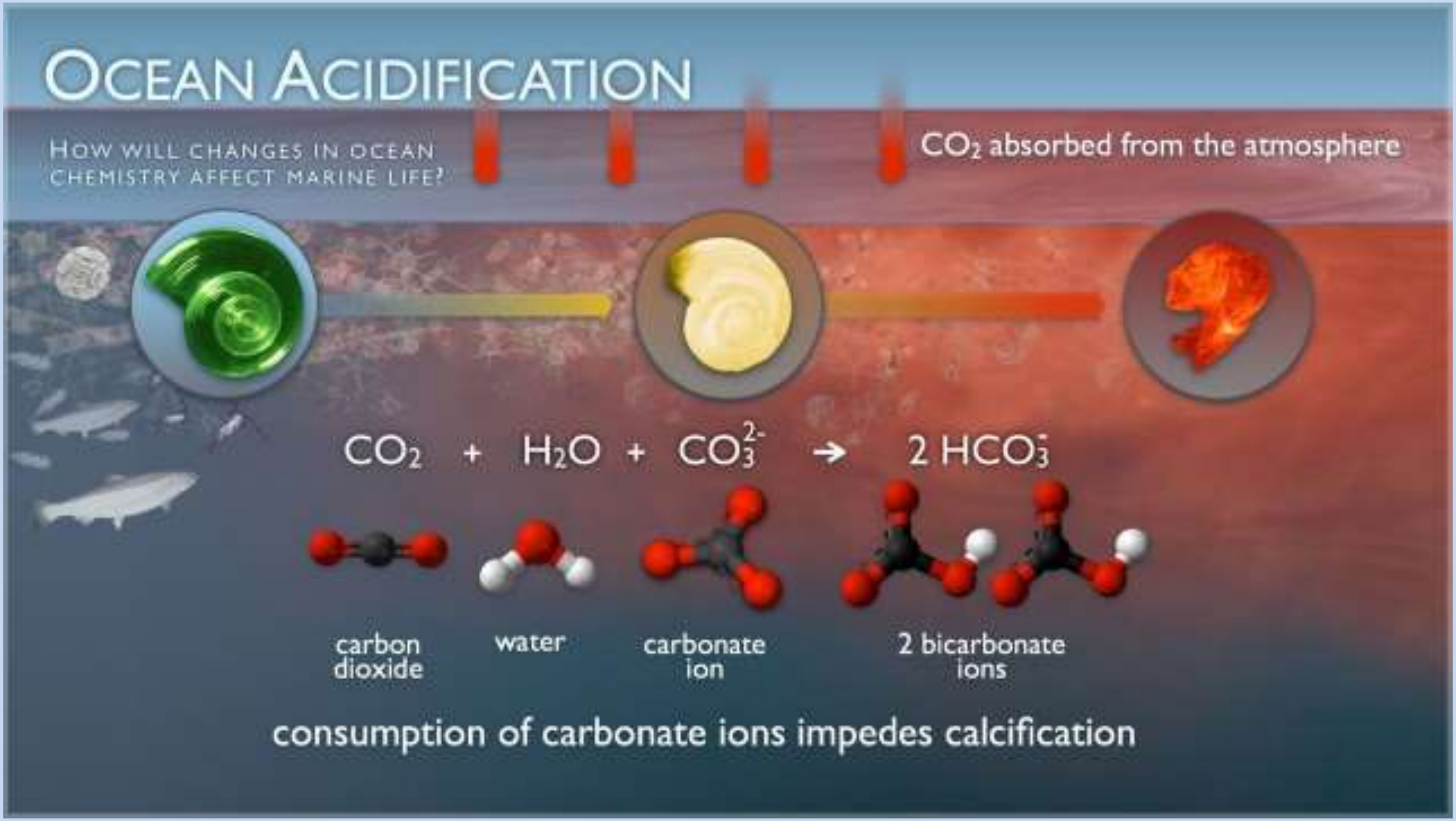
I. **Just because an environment is variable doesn't make an organism pre-adapted nor does it mean baseline shifts may not be important.**

II. **Changes in average conditions are informative, but provide cursory information for relevance to organisms.**

III. **In coastal zones understanding the chemistry well is necessary to determine organismal impacts.**

IV. **Almost all organisms do not like too much CO_2 but we are still in our infancy in understanding responses. (this doesn't preclude us from responsibility to act!)**

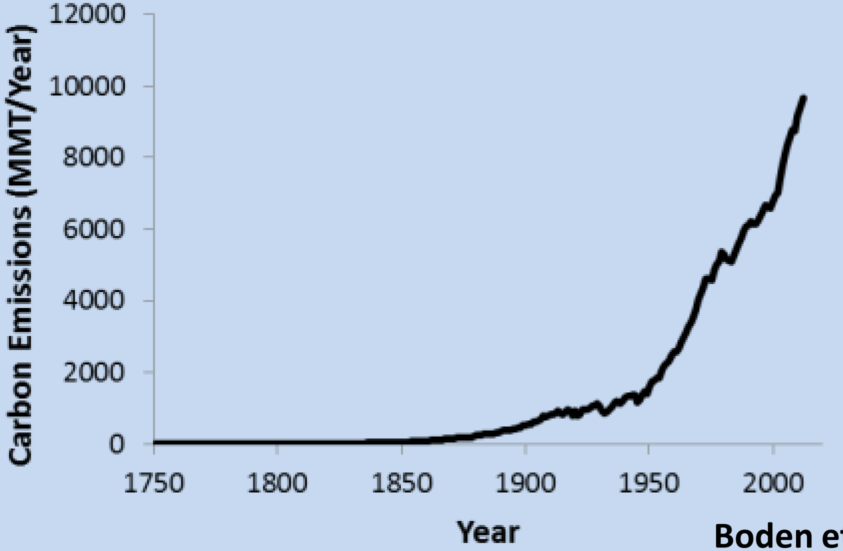
Definitions and Carbonate Chemistry Primer



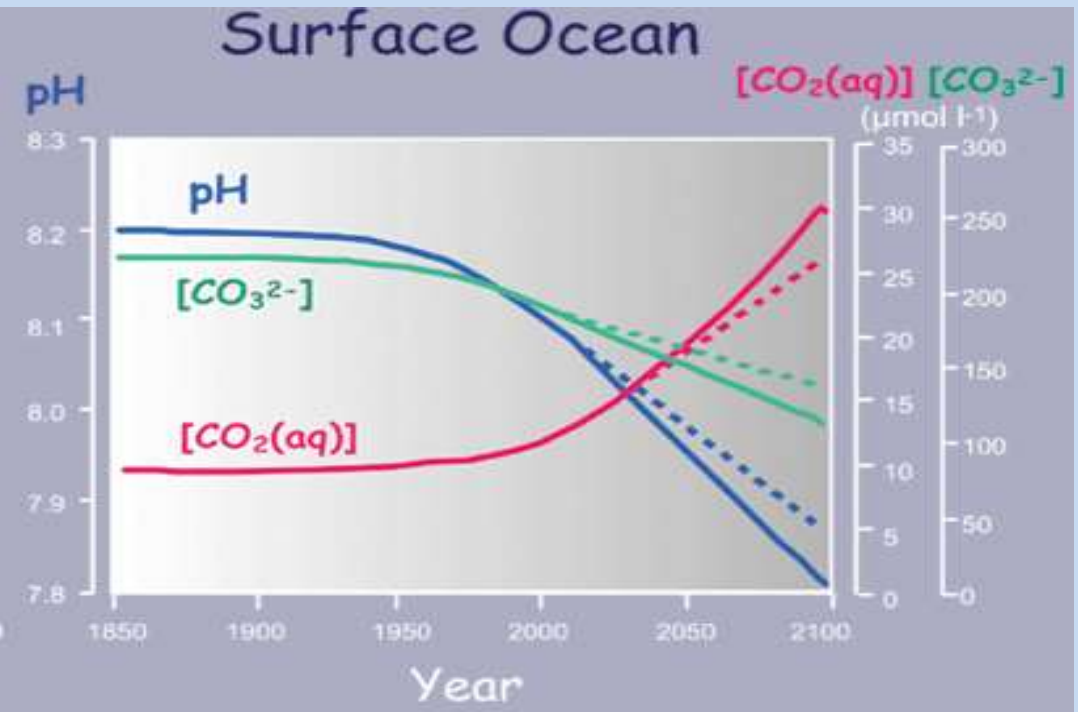
$$pH = -Log_{10}\left(\sqrt{K_1 * K_2 * \frac{[CO_2^*]}{[CO_3^{2-}]}}\right)$$

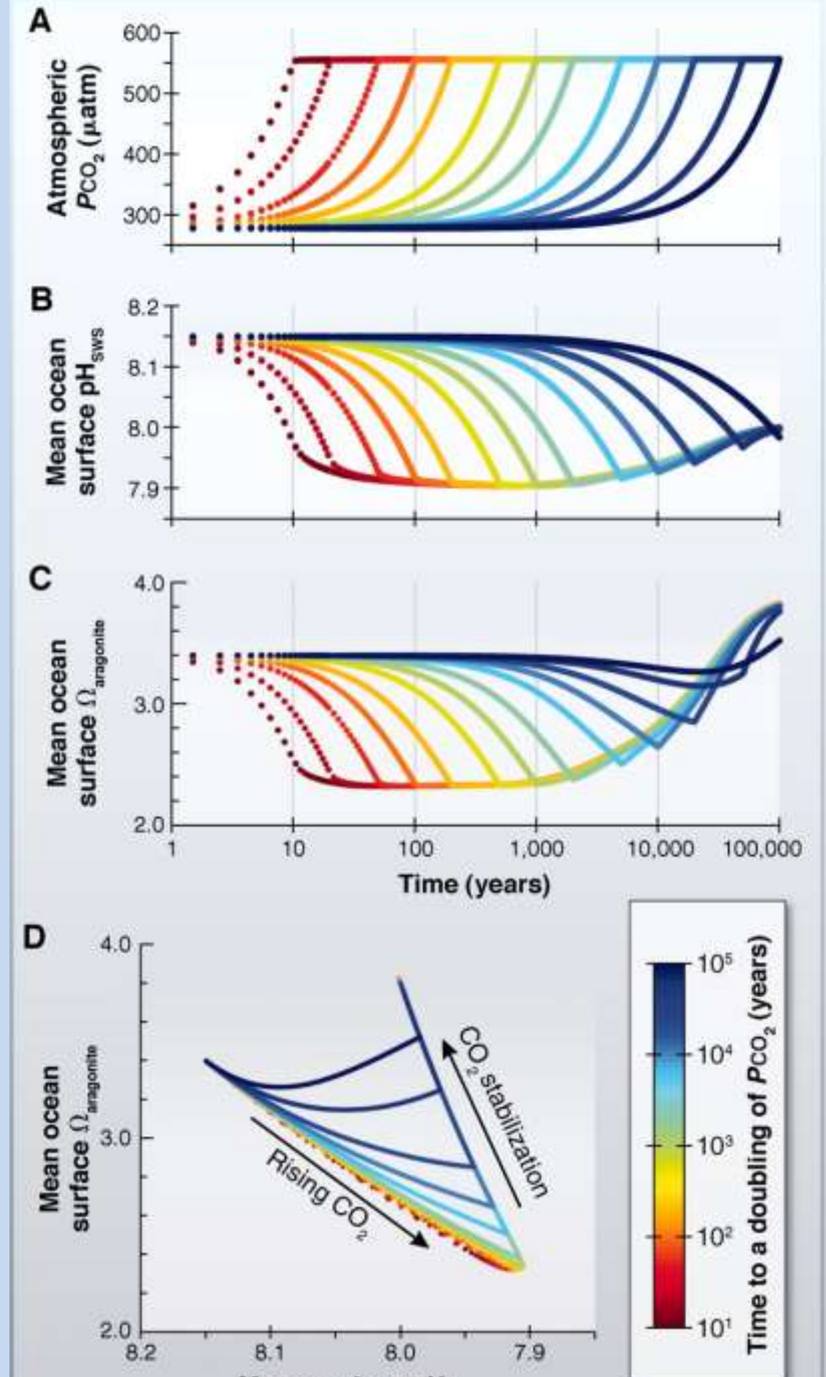
$$\Omega CaCO_3 = \frac{[Ca^{2+}][CO_3^{2-}]}{K^*_{sp-CaCO_3}}$$

What is Ocean Acidification



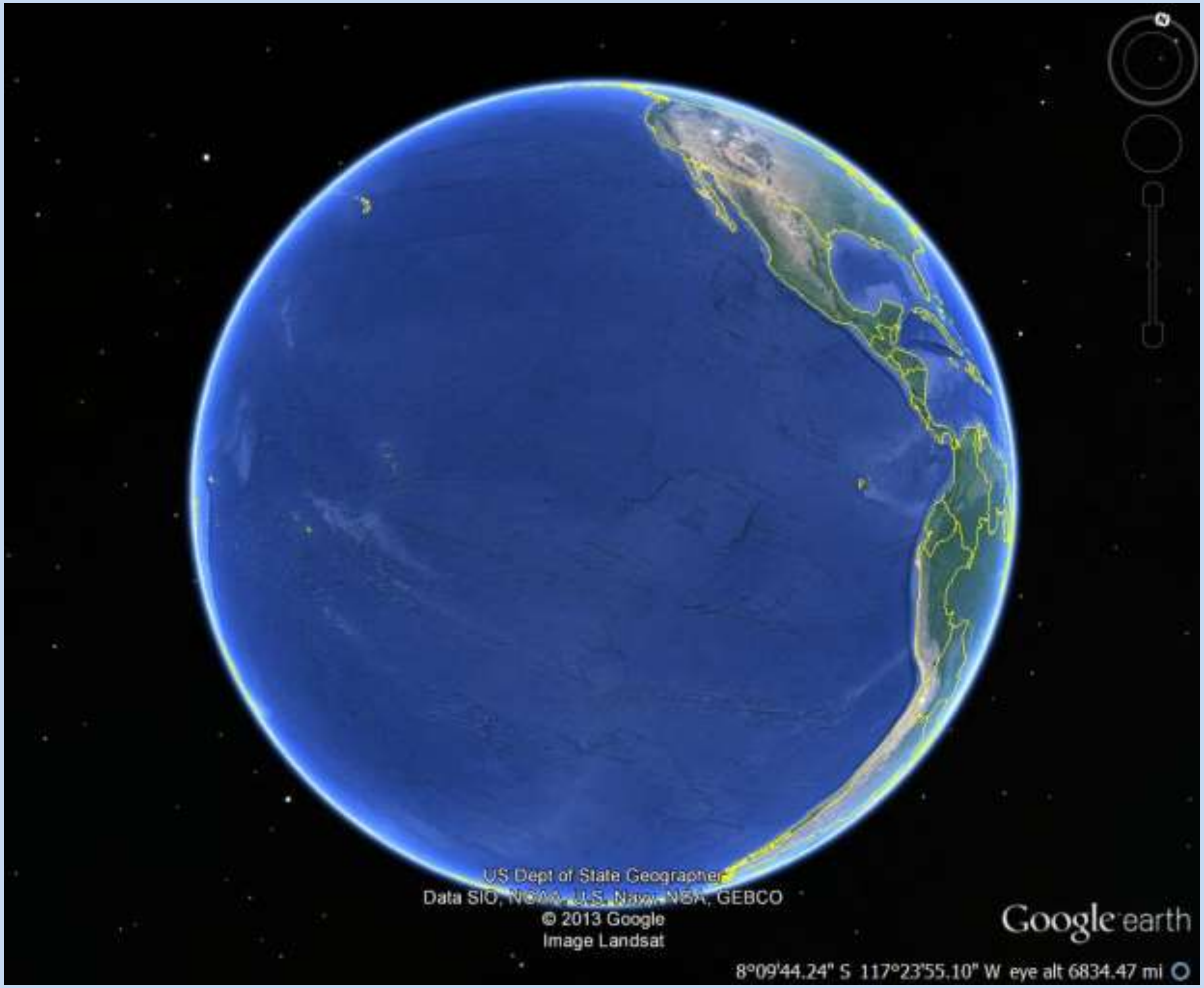
Boden et al. 2013





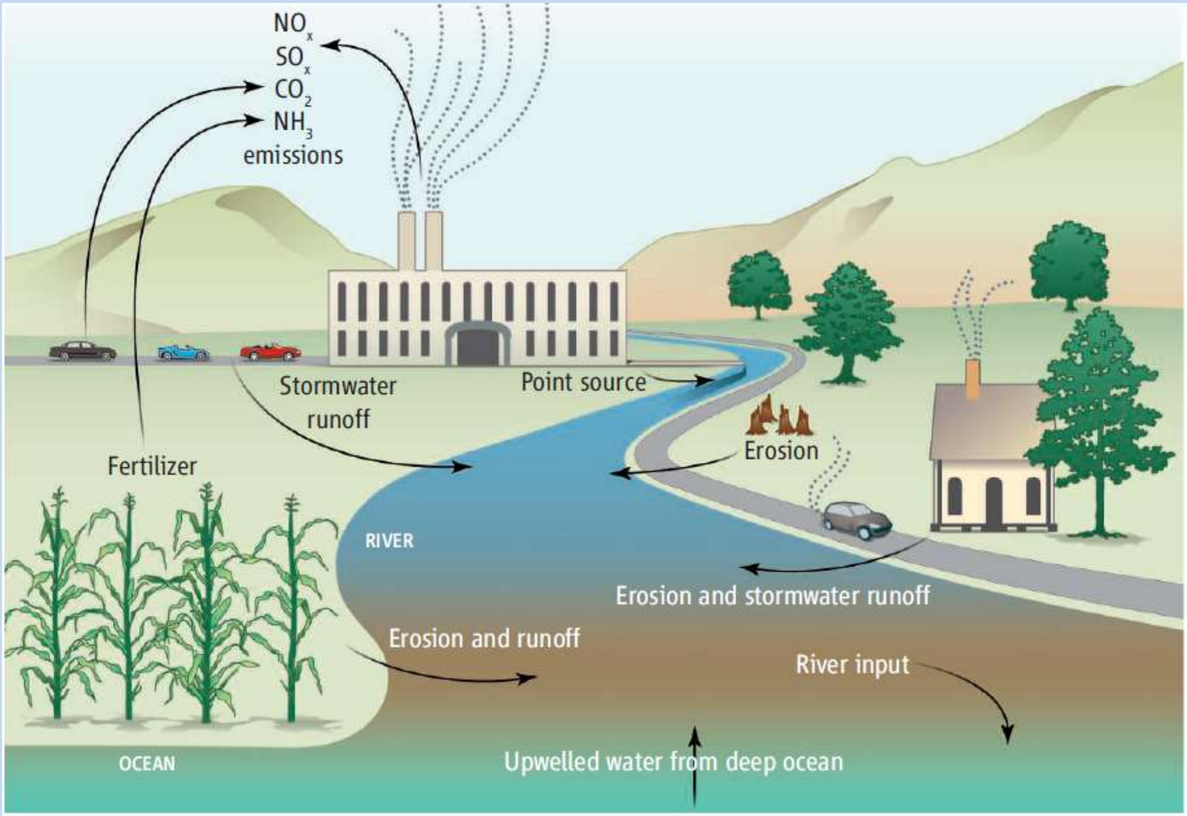
Hönisch et al. 2012

What is Ocean Acidification: The Global Scale



Organisms don't experience the decadal temperature change, nor will the 0.1 pH unit change direct matter to most critters!

Acidification in the Coastal Zone: Carbonate Weather



Contributors to ocean acidification. In addition to global atmospheric CO_2, this figure depicts the major local (within 100 km) sources contributing to coastal ocean acidification. **Kelly et al. 2011**

The local drivers can (and often will) be additive to the gradual baseline shift.

Effects can result in greater variability (e.g. eutrophication)…

This doesn't mean that the global baseline doesn't matter…

Heat Island Analogy…

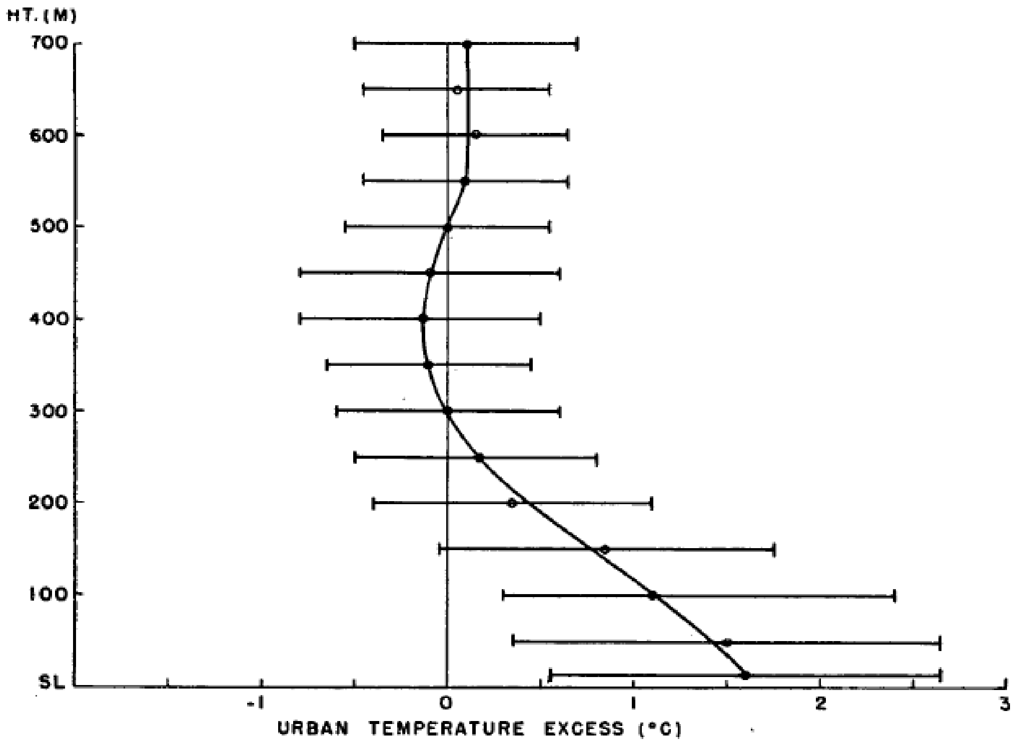
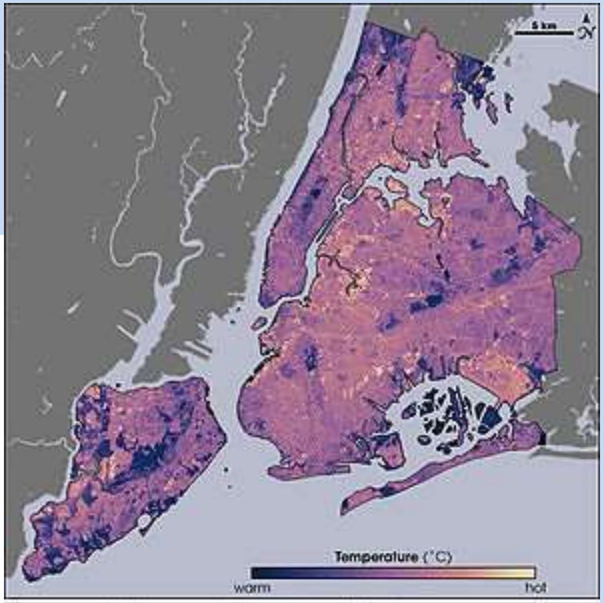
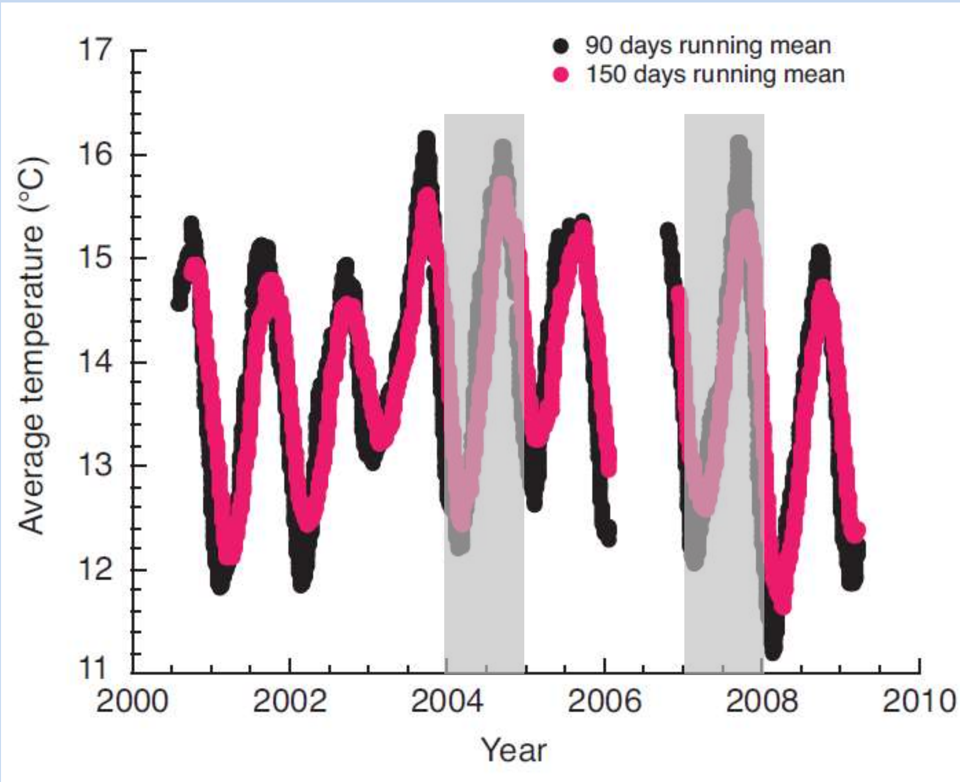


FIG. 7. Height variation of the magnitude of the urban heat island of New York City during the hours near sunrise. Range of plus and minus one standard deviation is also shown.

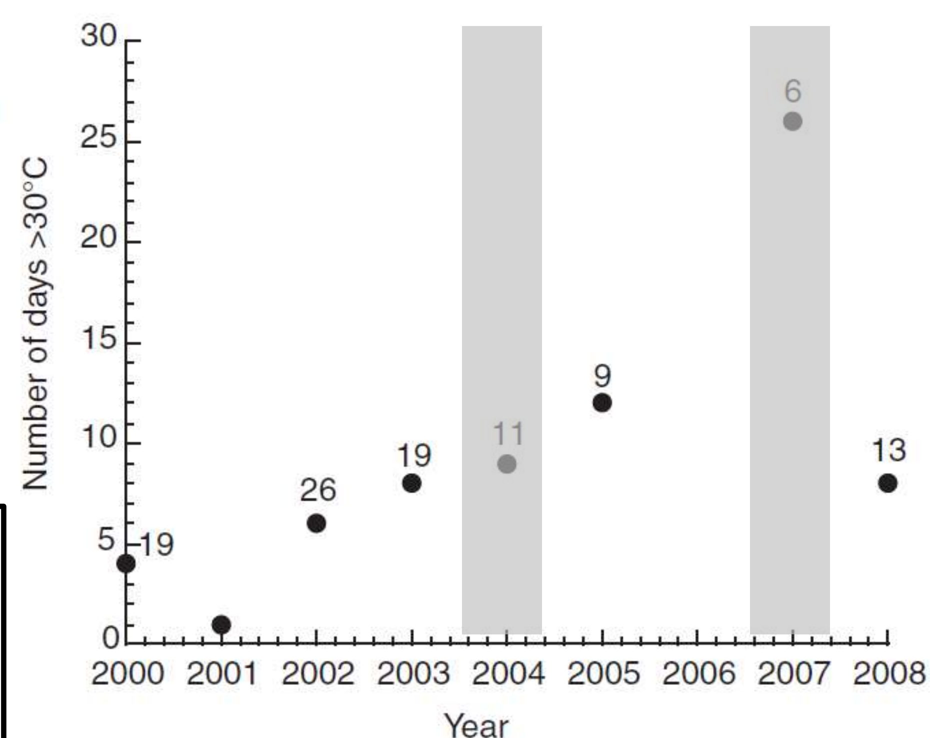


Mussel Body Temperature in the Intertidal Helmuth et al. (2010)



Average Temperatures

Extreme Events



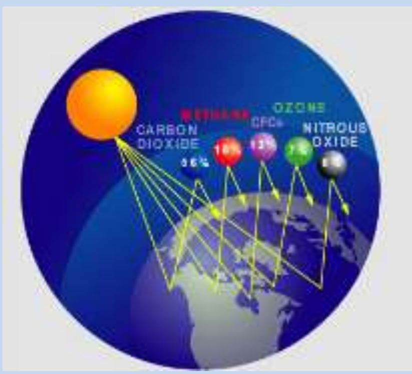
While climate change is a global phenomenon, to an organism, all relevant environmental changes are very local as the organism moves through space and time. (Helmuth et al. 2010)

Back to Carbonate Chemistry and Weather Scales

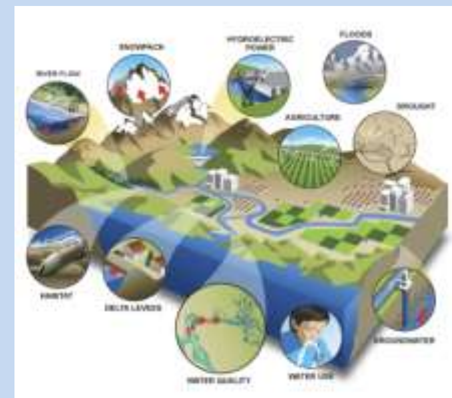
Daily temperature change does not precludes a change in the global heat budget…

The milieu of processes that alter carbonate chemistry do not preclude the current baseline shift in acidification, and impacts on carbonate weather.

Global Warming ~~versus~~ Climate Change



Causes



Ocean Acidification ~~versus~~ Carbonate Weather (?)

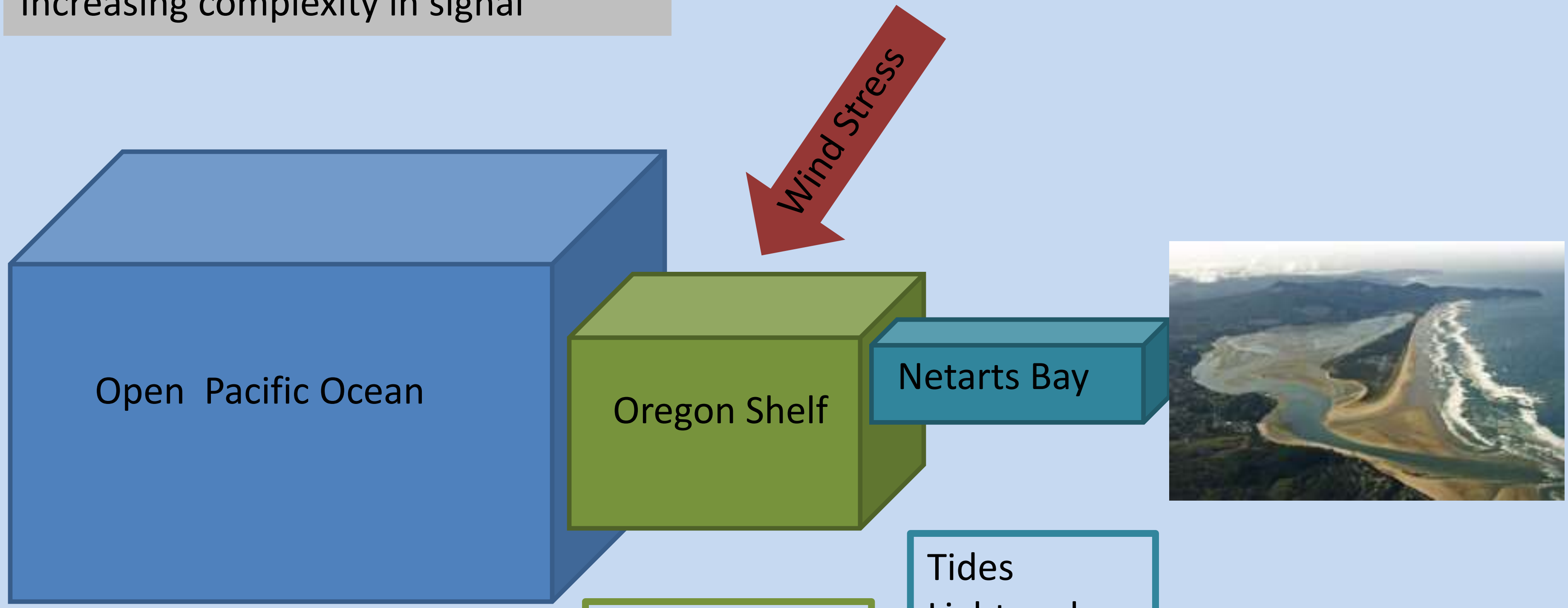
Causes

Changes to carbonate chemistry regimes in ways that affect organisms' ability to make shells or otherwise adds to environmental stress…

So what about the Carbonate Weather off Oregon?

Multiple "Boxes" Set the Stage for Oregon Estuarine Conditions

Increasing temporal variability
Increasing complexity in signal



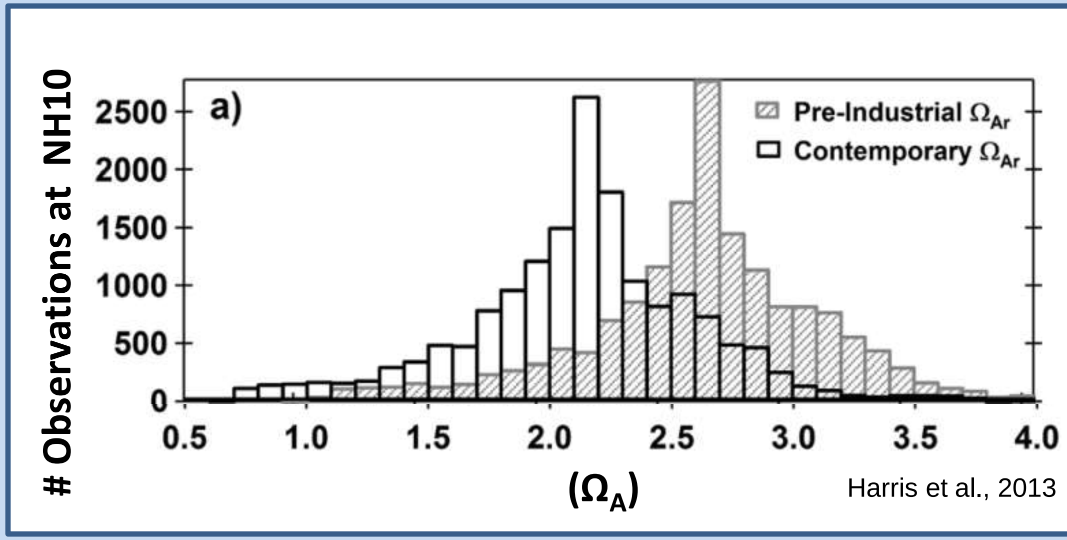
Baseline CO_2
Uptake from atmosphere Plus respired deep water carbon signal

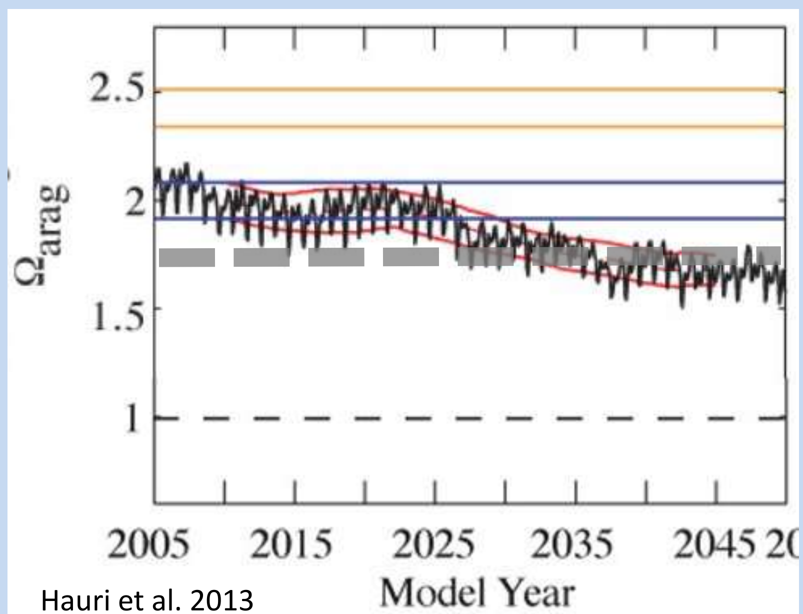
Upwelling,
Production-respiration
Water-benthos

Tides
Light cycle
Seagrass
Respiration

The Carbonate Weather, or what organisms experience, is the integration of all these processes.

California Current: Acidification Hot Spot





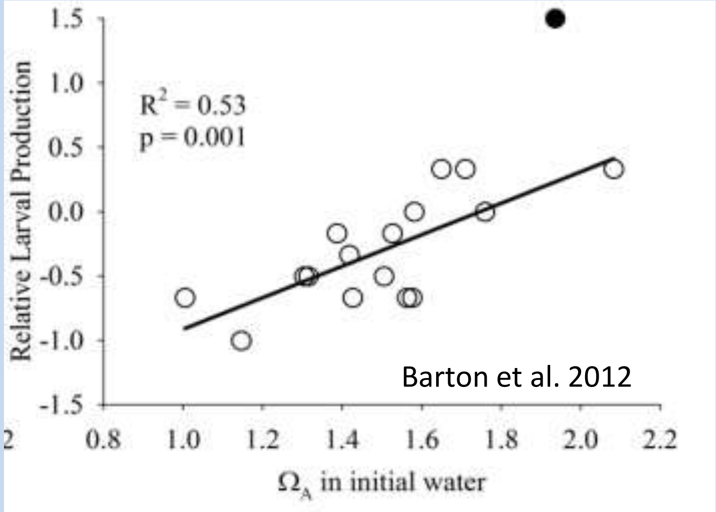
280 ppm CO_2

400 ppm CO_2

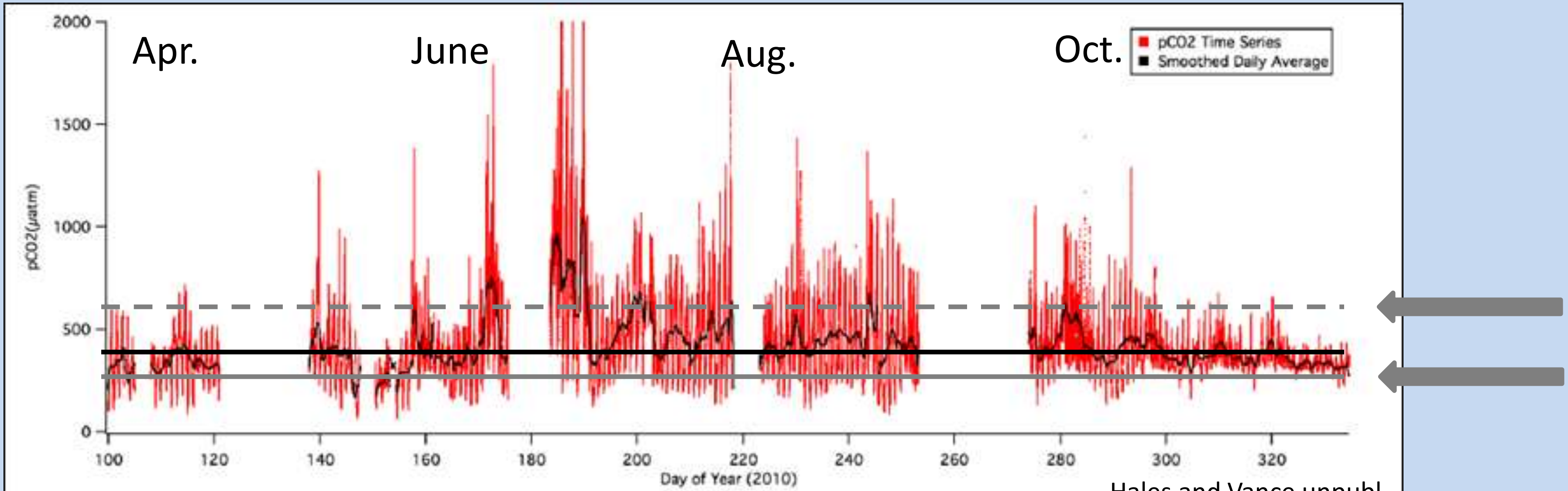
550 ppm CO_2

550 ppm is the low emissions scenario for 2100

Netart's Bay, OR and Whiskey Creek



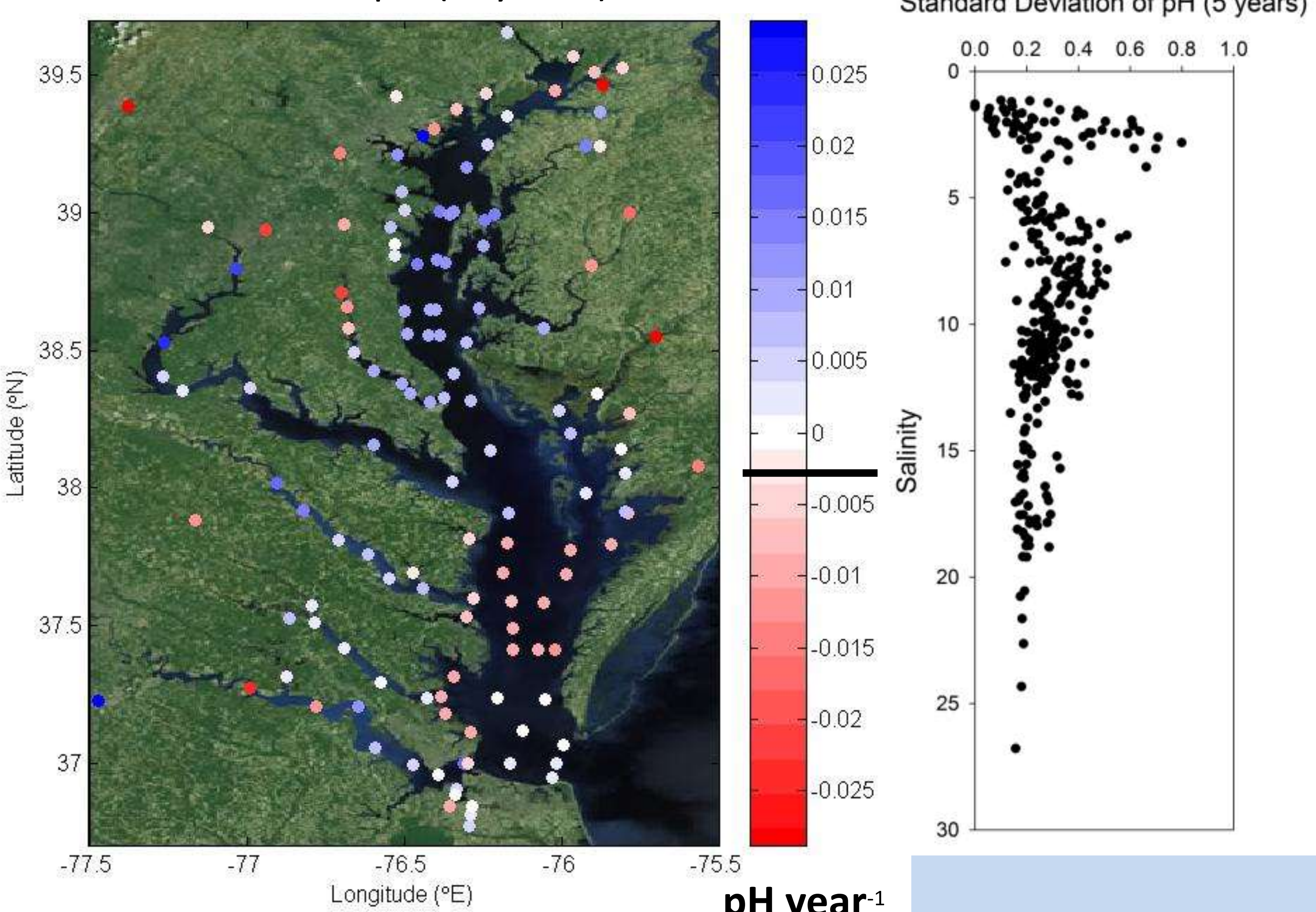
Chemistry during first 48 hours…



Hales and Vance unpubl

Chesapeake Bay pH Trends: More Carbonate Weather Trends

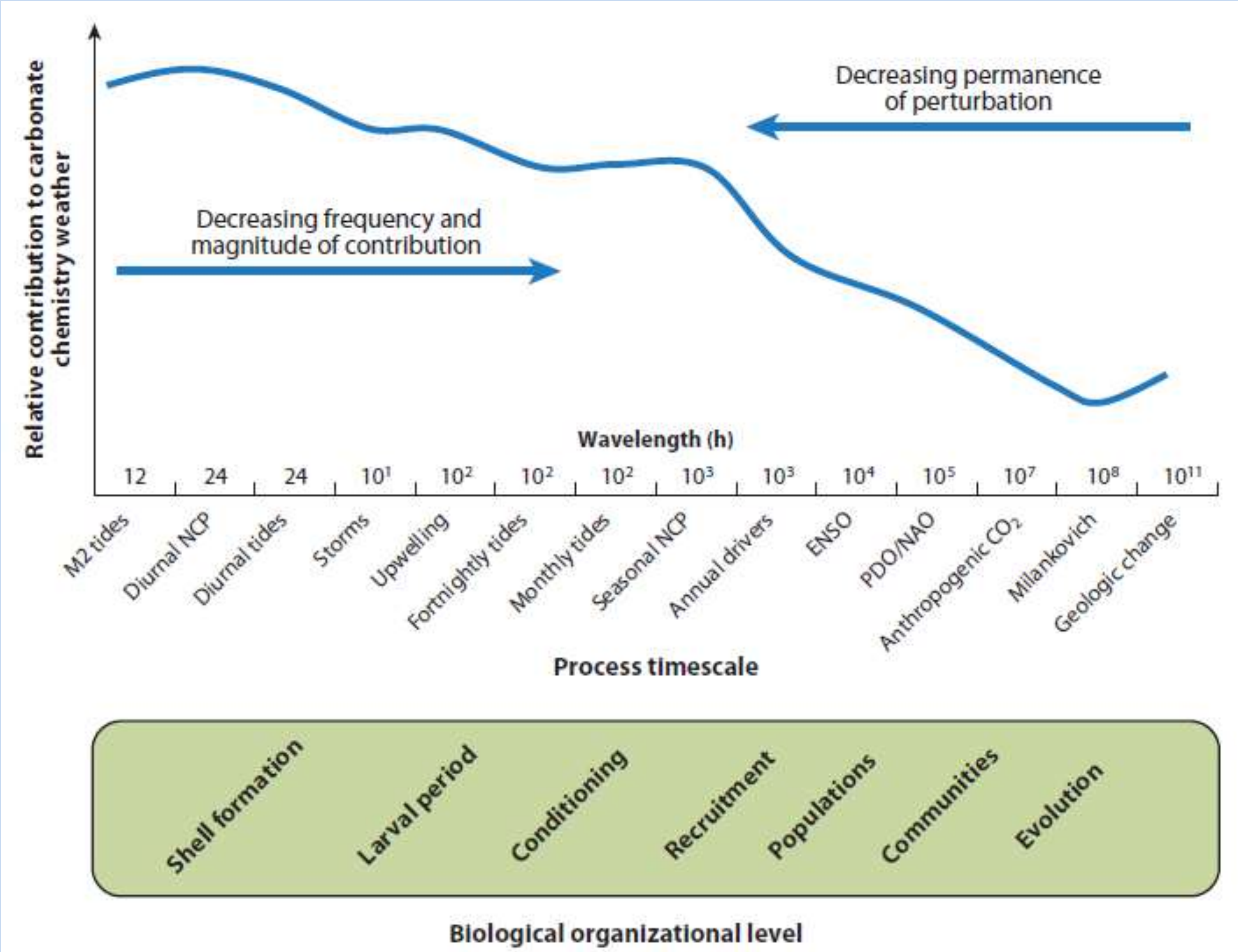
Annual trends in pH (daytime) 1984-2008



Waldbusser unpublished

Meshing the Carbonate Climatology and Biological Responses

Carbonate Chemistry, Frequency, and Biology



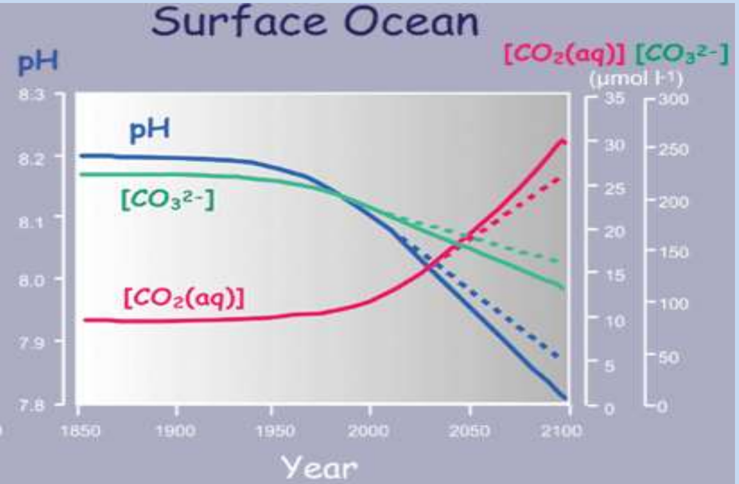
Waldbusser and Salisbury 2014

Coastal “acidification” mechanisms

- Changes in Freshwater Delivery and Loadings of (N, P, POM, DOM, etc)…
- Stack and tailpipe emissions of Nox and Sox
- Carbon pumping by C3 plants in marshes
- Tidal pumping of sand and mud flats

In all these cases, the carbonate system parameters can decouple

$$pH = -Log_{10}\left(\sqrt{K_1 * K_2 * \frac{[CO_2^*]}{[CO_3^{2-}]}}\right) \qquad \Omega CaCO_3 = \frac{[Ca^{2+}][CO_3^{2-}]}{K^*_{sp-CaCO_3}}$$



Organisms don’t care what the acidification source, but understanding what they are responding to is important for understanding this issue in the coastal zone.

Experiments to Understand Biological Responses to Carbonate Weather:

What Carbonate System Parameter is Most Important to Bivalve Larvae?

Experiments to determine important variable

Oyster Experiment 1

P_{CO2} (uatm)	369	433	476	589
Ωarag	3.25	1.47	0.81	0.39
pH(sws)	8.07	7.86	7.71	7.51
DIC (umol/kg)	1957	1374	1049	806
Talk (umol/kg)	2247	1519	1133	845
	653	685	809	815
	3.32	1.58	0.75	0.40
	7.95	7.78	7.58	7.44
	2568	1771	1234	903
	2836	1904	1365	980
	1352	1256	1360	1240
	3.02	1.61	0.78	0.45
	7.77	7.65	7.47	7.37
	3438	2399	1723	1253
	3644	2506	1761	1269
	3334	3191	2767	2599
	3.35	1.77	1.04	0.57
	7.60	7.47	7.38	7.27
	5619	3977	2695	1935
	5772	4025	2851	2026

We manipulated the chemistry to let the bivalve larvae tell us what is important.

Working with multiple species, native and non-native.

Orthogonal with P_{CO2} and Ω, pH on diagonals

Measure:

- Normal Shell Development
- Shell Length (normal)
- Respiration
- Feeding

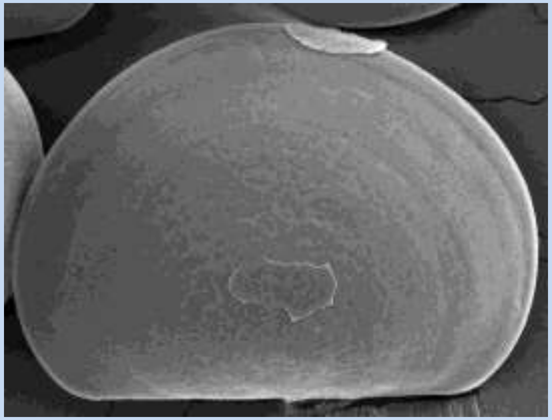
Only acute impacts, 48 hours.

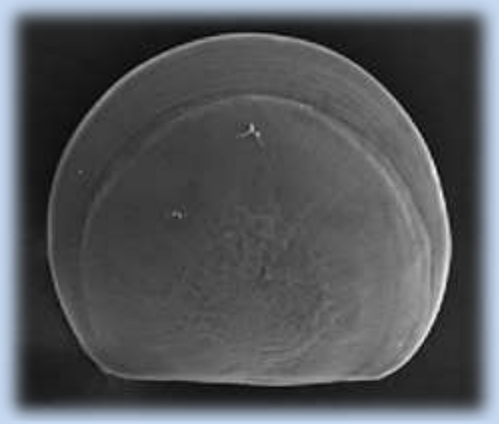
Results

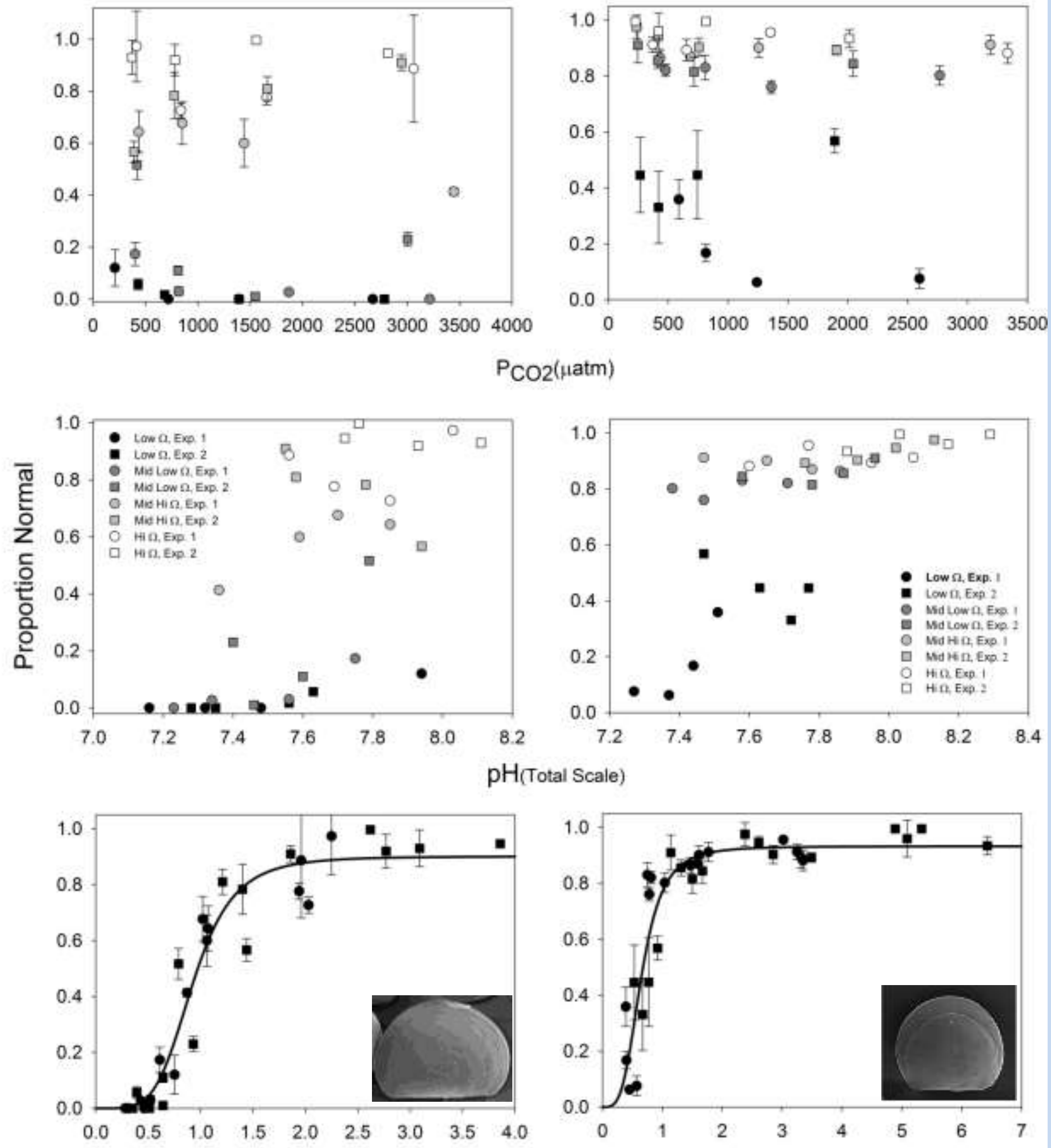
Pacific Oyster

Mediterranean Mussel

Only Shell Parameters







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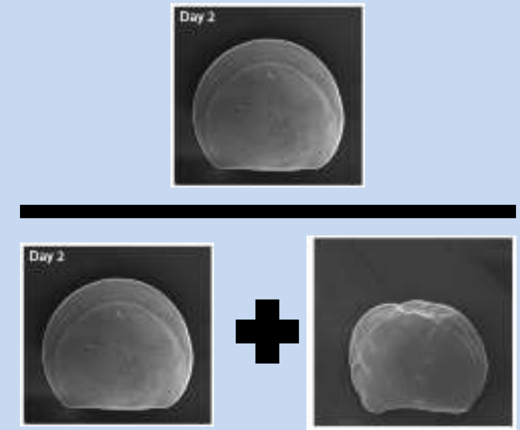
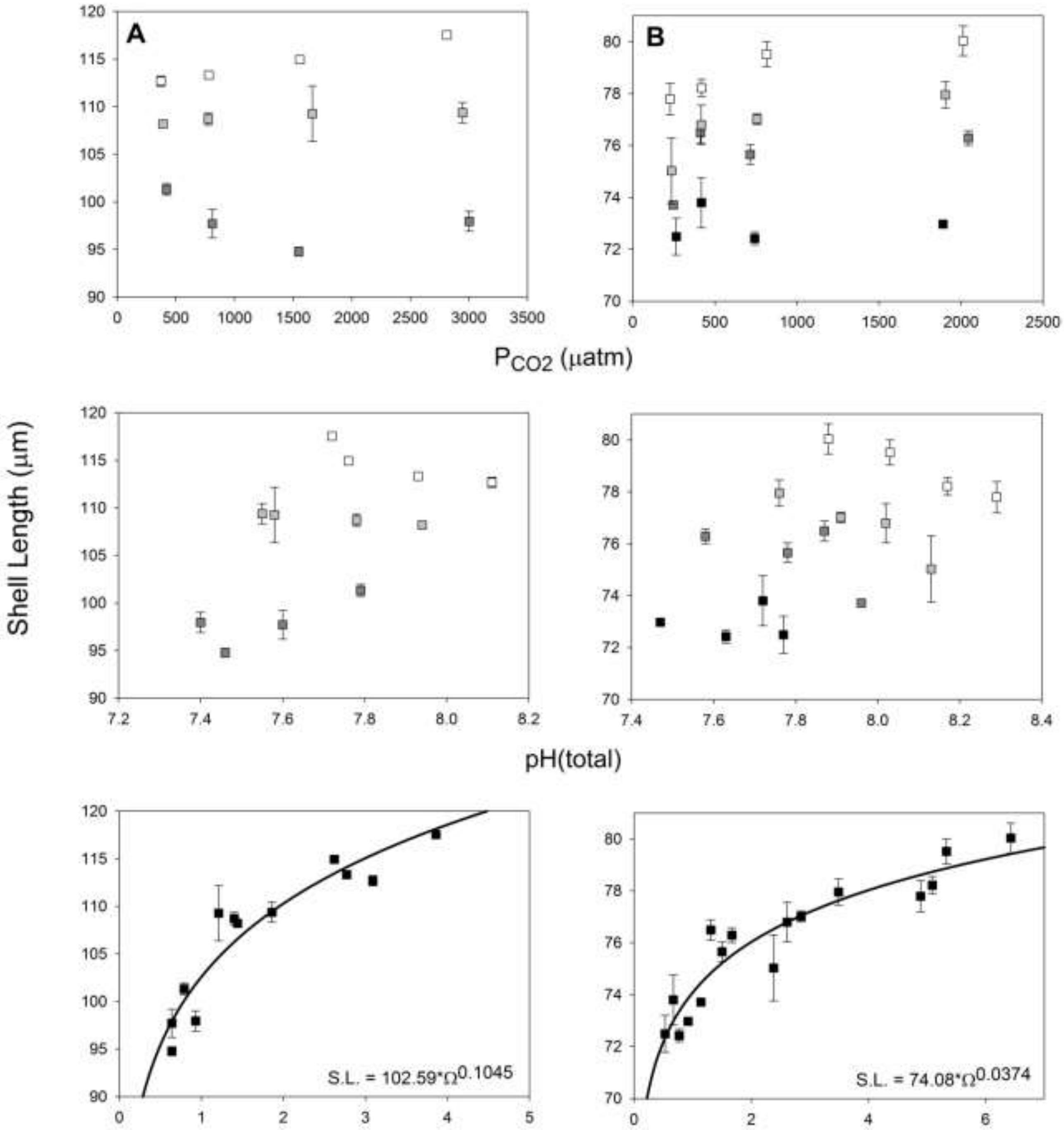
Proportion Normal

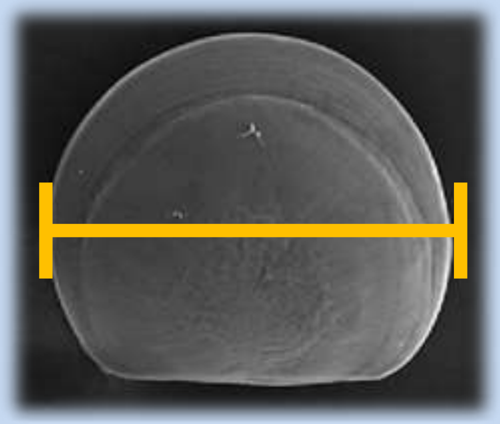


Saturation state is the primary variable of importance for these larvae.

Little to no pH impact until very low values, and only in undersaturated condtions.

Shell Length





For the normally developed larvae, decreases in saturation state make smaller larvae.

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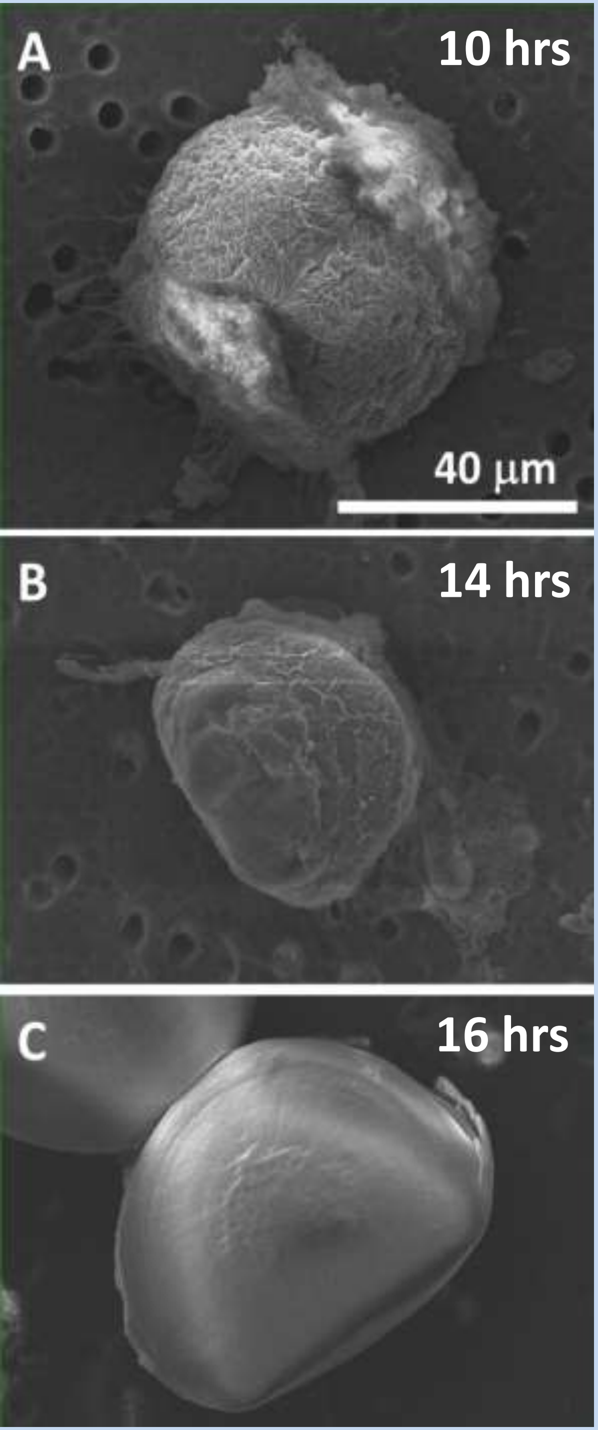
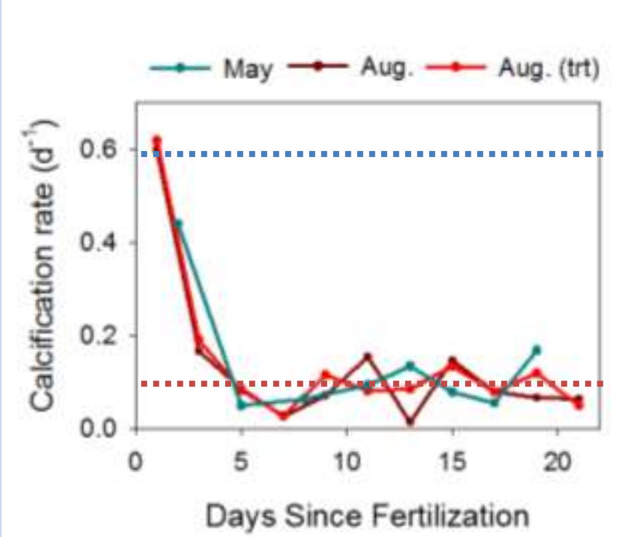
Why Saturation State Matters…





Brunner et al. in prep

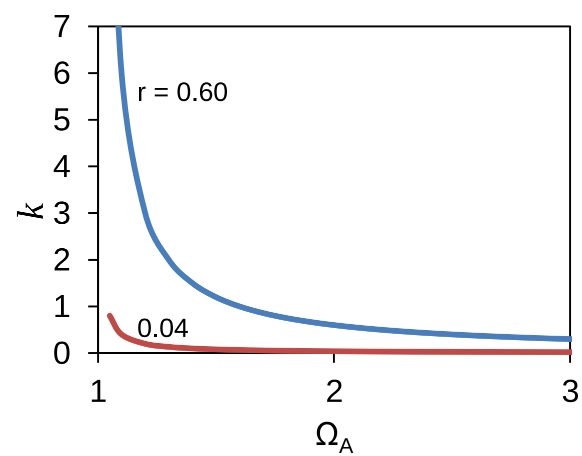
Within 48 hours, 80-90% of body weight is added as $CaCO_3$

Until this, feeding not possible, and energy is limited.

Also more "exposed".

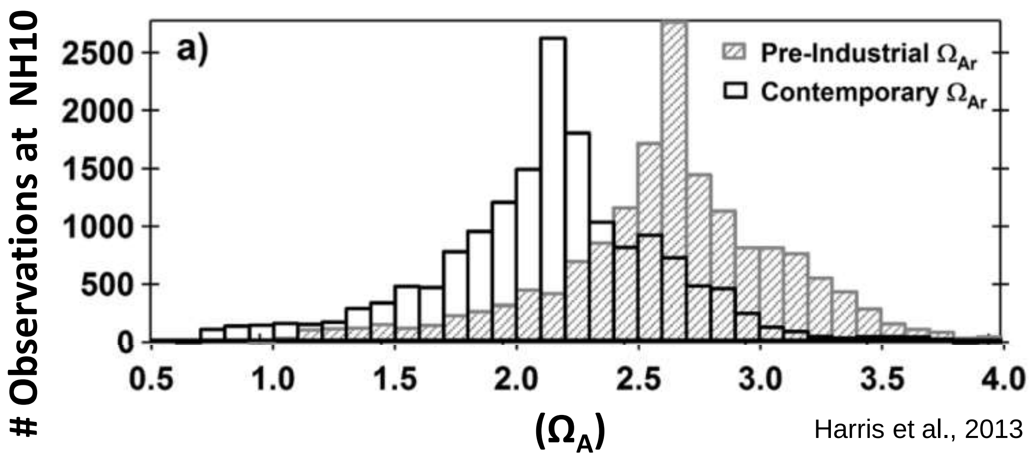
$$r = k(\Omega - 1)^n$$

r = calcification rate
k = rate constant
Ω = saturation state
n = rate order (1)

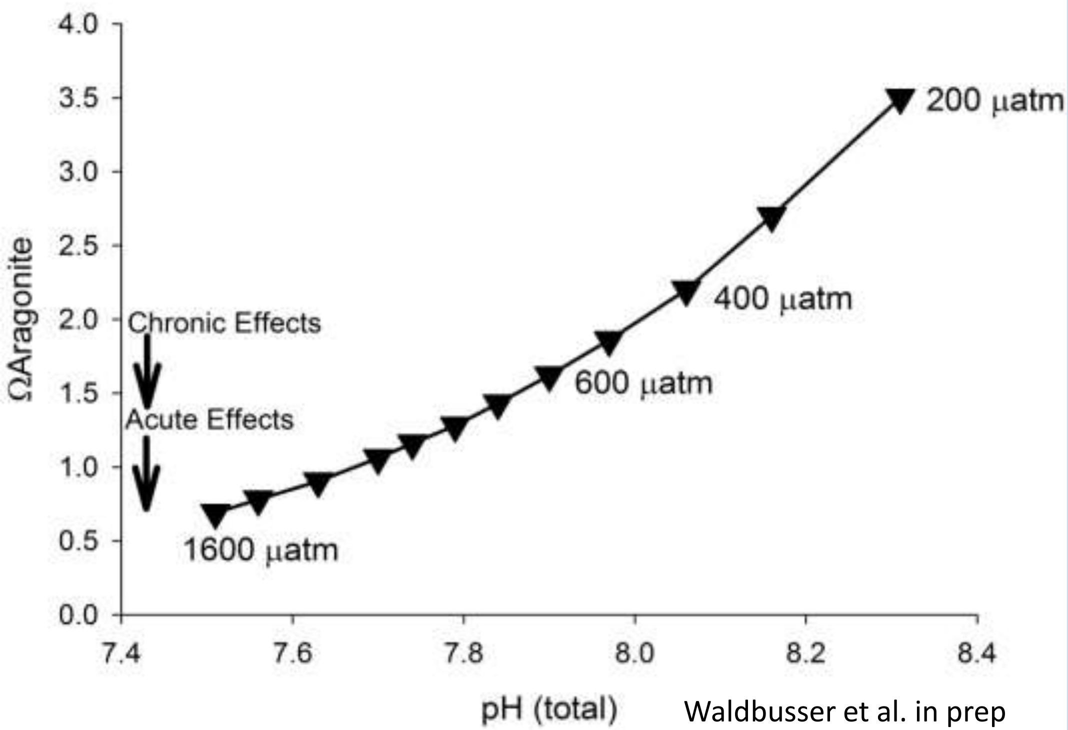


Waldbusser et al., 2013

Environmental Relevance



Harris et al., 2013



Waldbusser et al. in prep

For early larvae, we will cross saturation state thresholds well before pH thresholds.

It is still very likely that pH is having an effect, but trivial for the larvae at this stage.

Adult organisms more robust, so two perspectives…

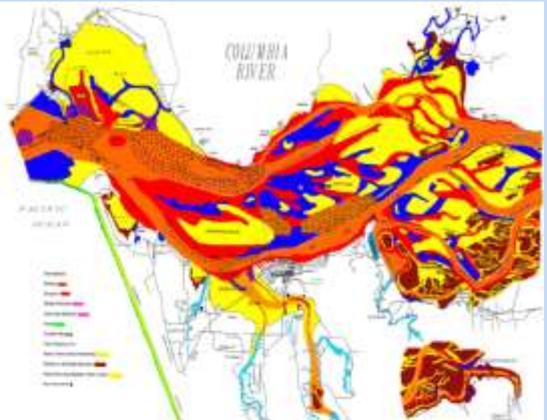
> **Only need a brief period of good chemistry**

> **Only need a brief period of bad chemistry**

Predictions are greater intensity, duration, and magnitude of bad times…

Relevance to Columbia River Estuary…

- We are estuarine scientists, embrace the variability…
- Changes in water regimes will alter salinity and alkalinity
- Acidification does not happen in a vacuum.
  - Multiple stressors are important, but let’s be sure to understand the single stressor also
- Early life history stages are important (*duh… ecology*), and understanding how systems change at the those times seems key to me.



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Questions… Just not about the Columbia!