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Potential Impacts of Ocean Acidification on Shellfish: Laboratory Culturing Studies and Research in Waquoit Bay

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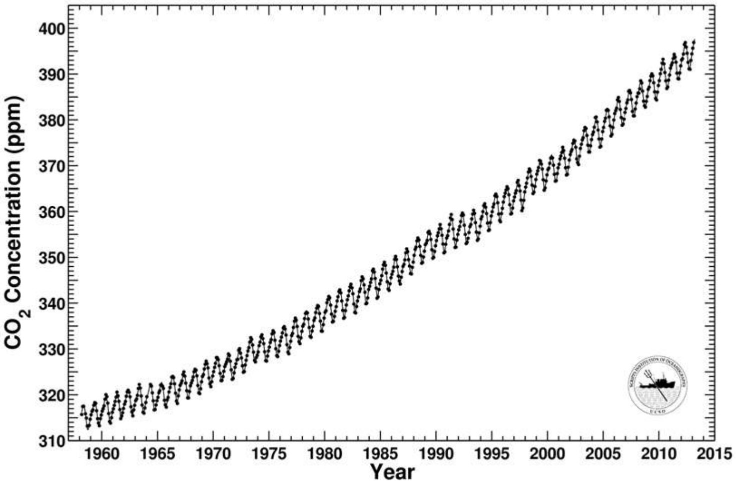
Liz Bonk
Katherine Hoering

WBNERR:
Chris Weidman
Marykay Fox

What are the impacts of rising carbon dioxide on the oceans and marine life?



How does rising CO_2 change ocean chemistry?

Ocean acidification (OA)

Can we see acidification in estuaries and coastal waters? (Waquoit Bay & WBNERR)

How does OA affect marine organisms?

(larval bay scallops)

What I won't say!

Estuaries Already Too Damaged To Be Impacted By Climate Change

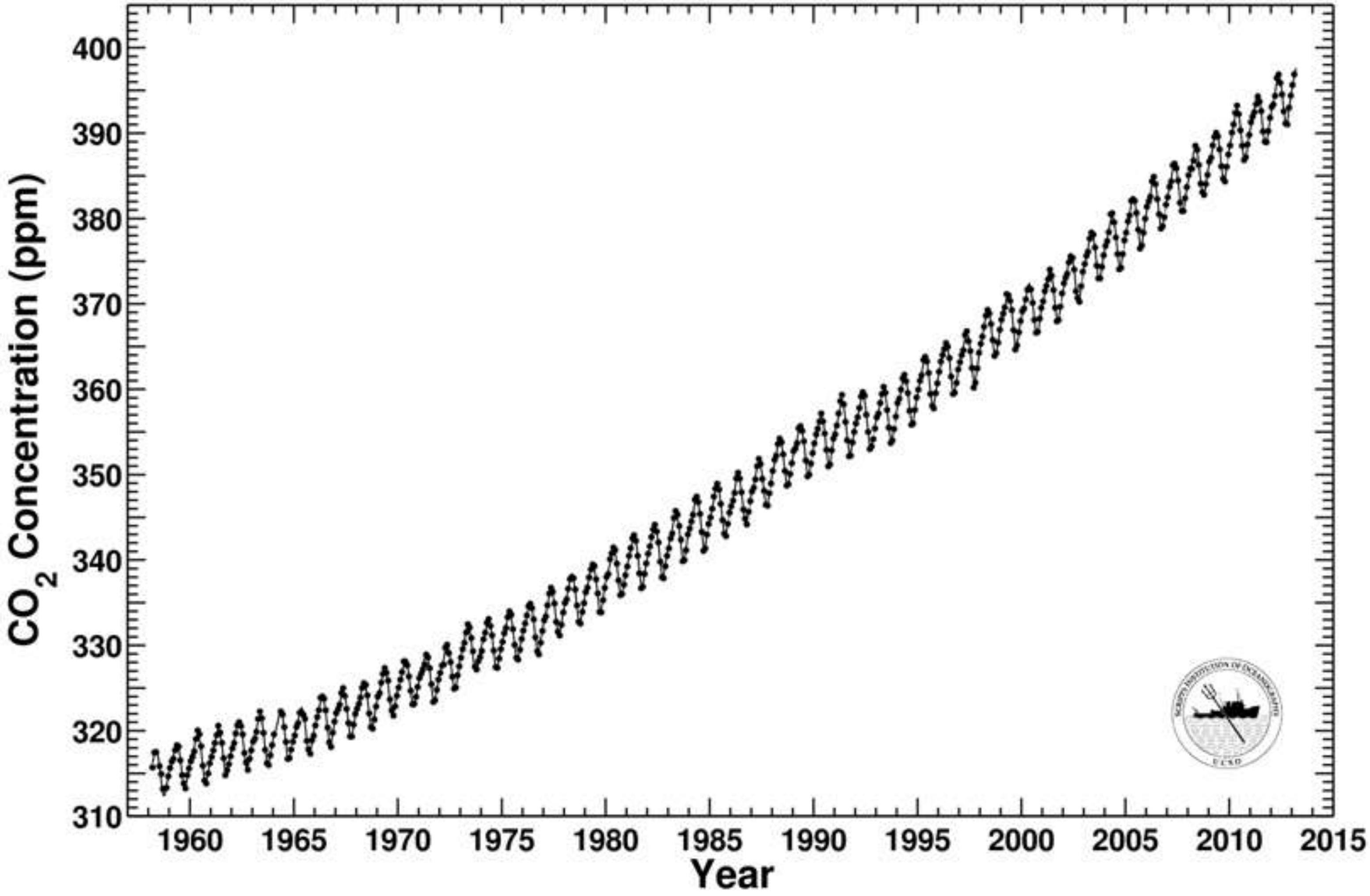
What will the effect of climate change and an ocean with increasing acidity levels be on the shellfish populations of Falmouth's coastal estuaries? Daniel C. McCorkle of Woods Hole Oceanographic Institution believes not much.

(The article itself was accurate.)

"For Cape estuaries, future changes (e.g., climate, acidification) will be superimposed on already-stressed systems…"

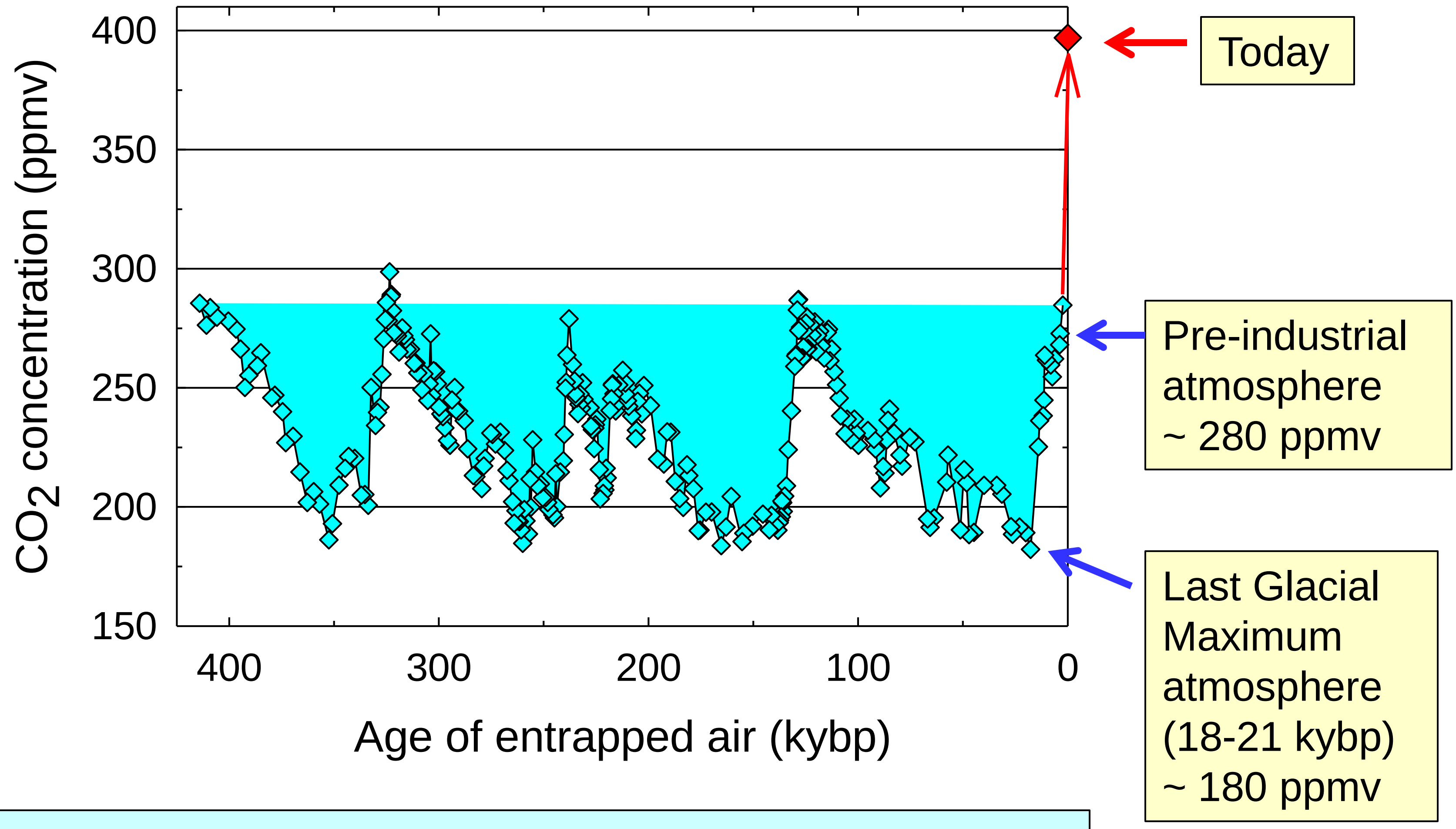
An introduction to ocean acidification

Carbon dioxide in the atmosphere (Mauna Loa, HI)



http://scrippsco2.ucsd.edu mauna_loa_record

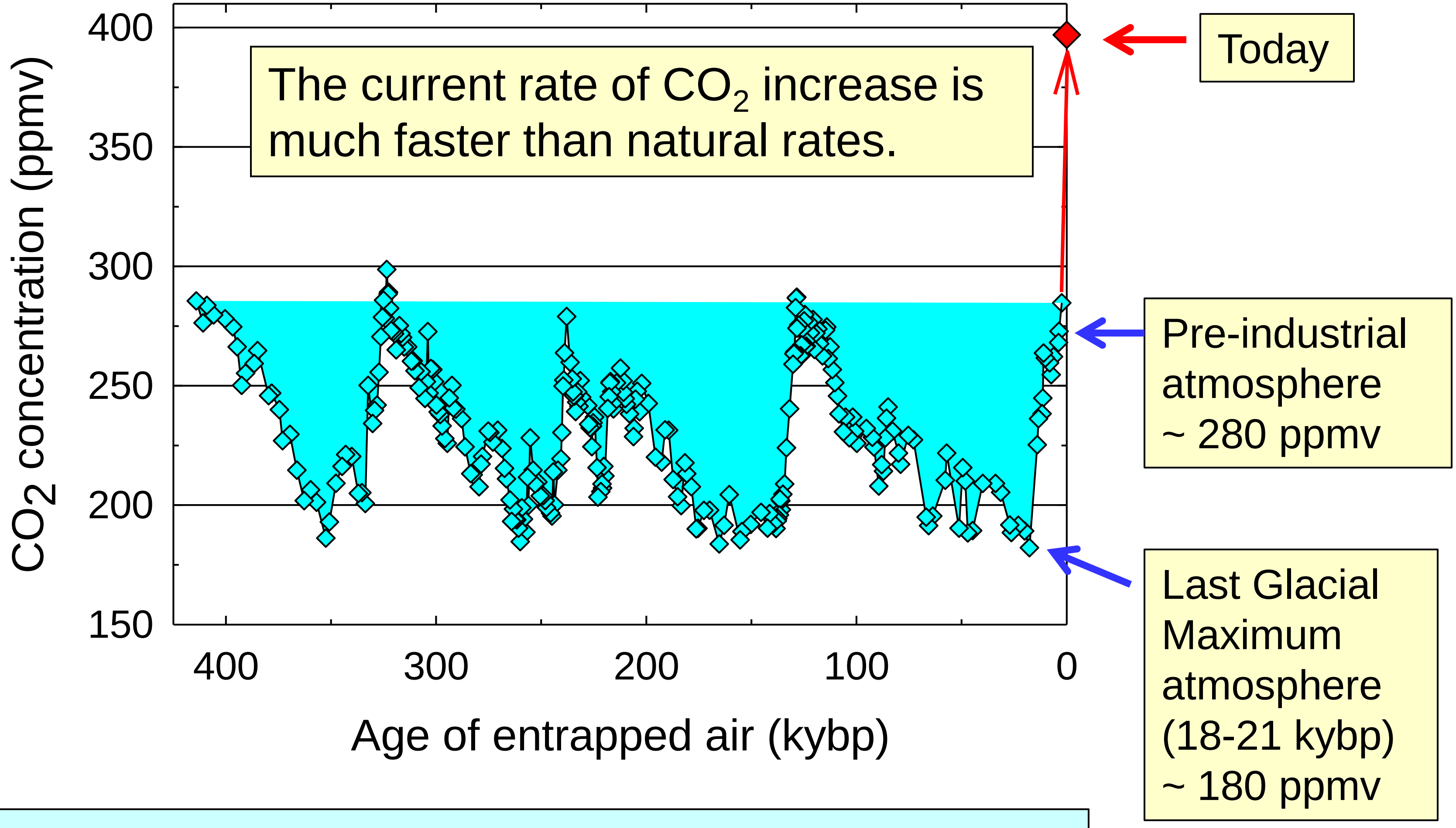
400,000-year Antarctic ice core record of atmospheric CO_2



Natural cycles in atmospheric carbon dioxide
+ fossil fuel combustion, deforestation,…

Barnola et al., 1999

400,000-year Antarctic ice core record of atmospheric CO_2



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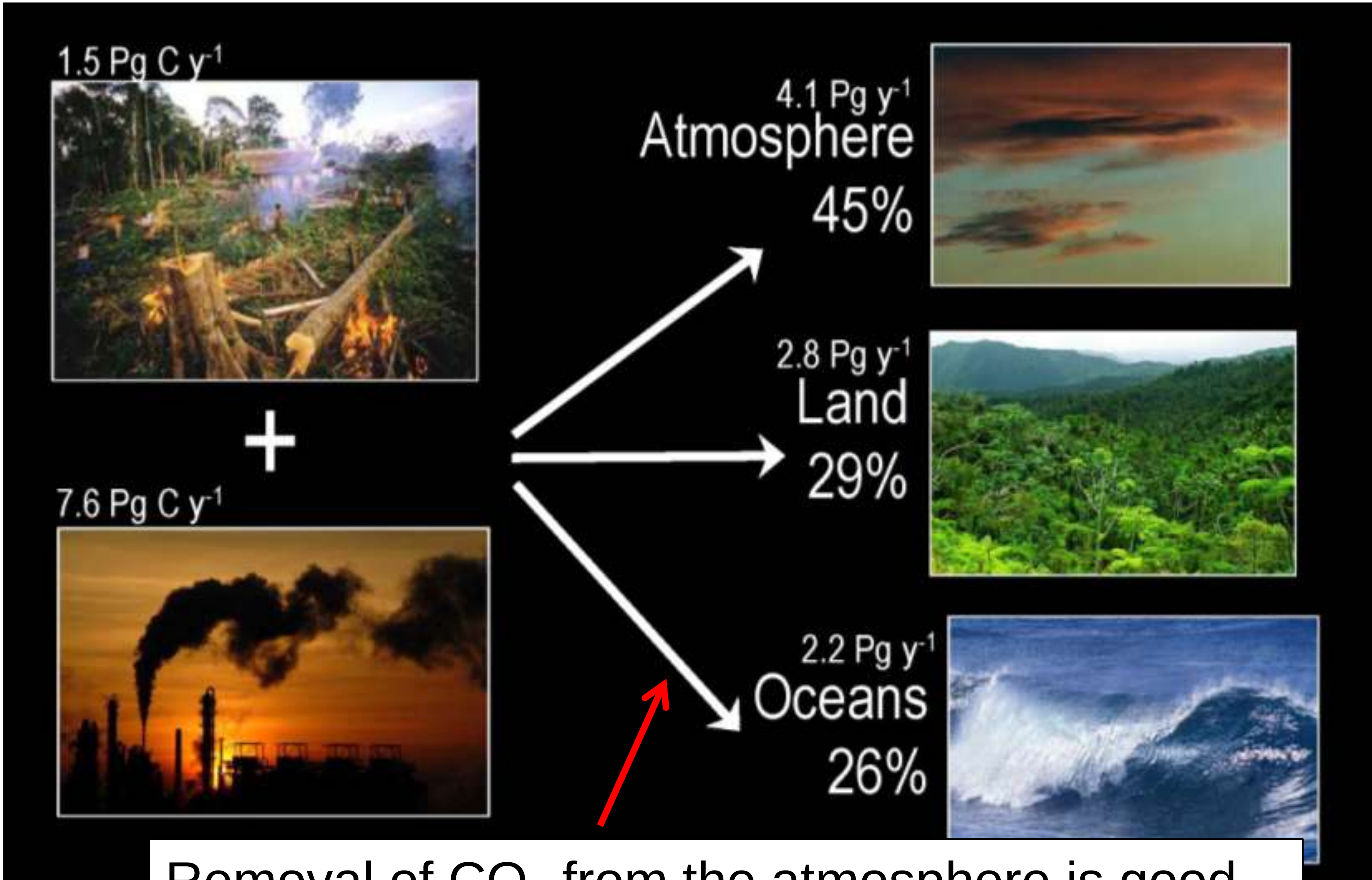
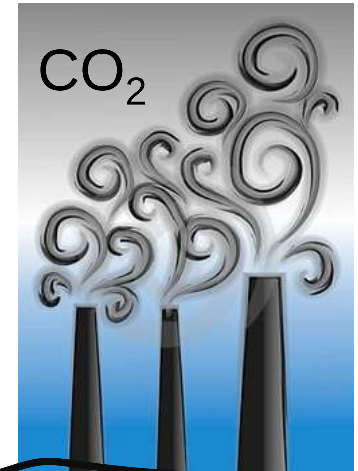
Current budget for CO_2 from human activities



Removal of CO_2 from the atmosphere is good, but addition to the ocean is not…



Ocean acidification – the chemistry of carbon dioxide in seawater

Atmosphere

$CO_{2(g)}$

$\uparrow\downarrow$

Ocean

$$CO_{2(aq)} + H_2O \rightleftharpoons H_2CO_3$$

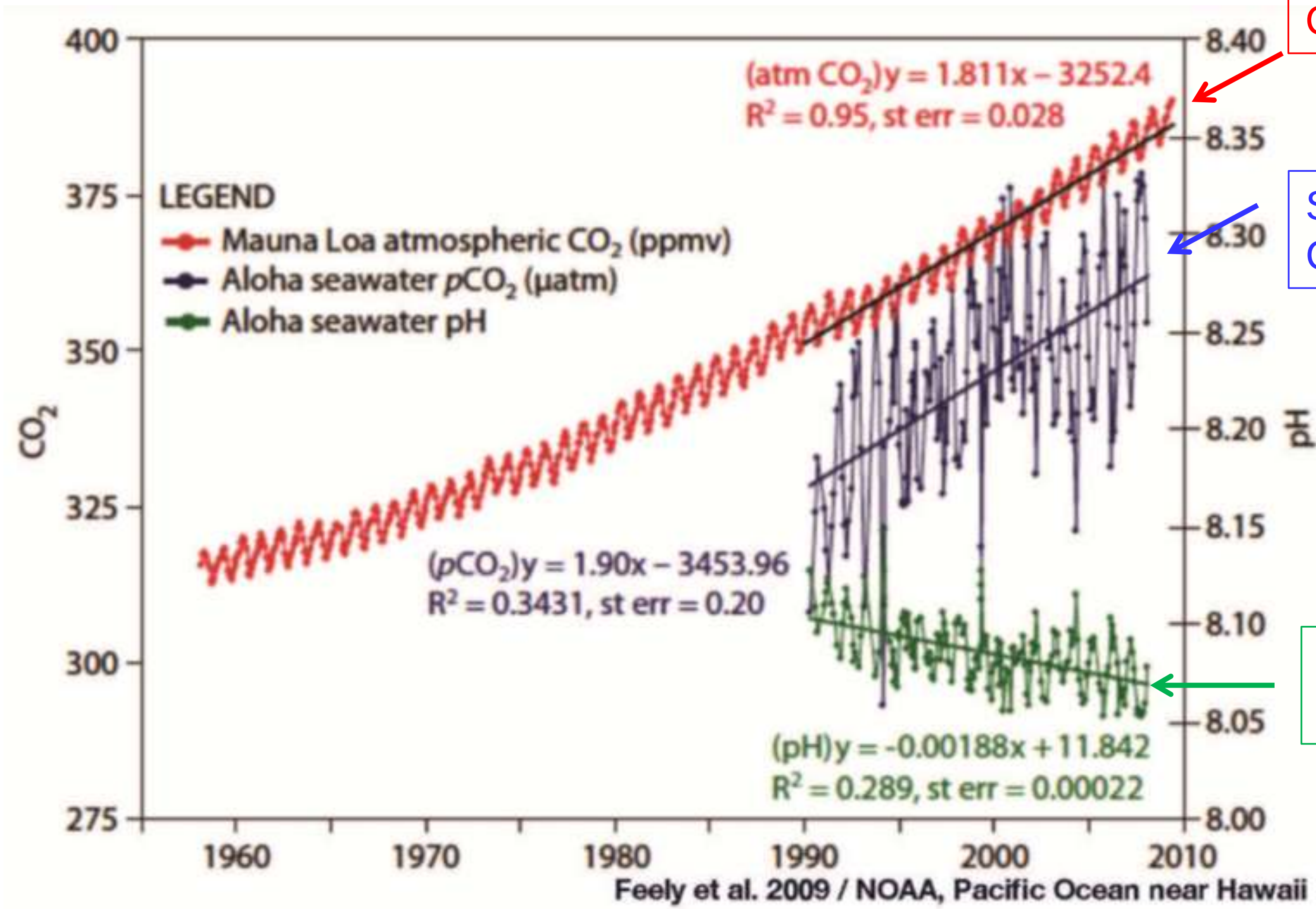
$$H_2CO_3 \rightleftharpoons HCO_3^- + H^+ \uparrow$$

$$HCO_3^- \rightleftharpoons CO_3^{2-} + H^+$$

As CO_2 is added to water, H^+ is produced: pH decreases (= acidification), and CO_3^{-2} (carbonate ion) decreases

Ocean Acidification is observable -
the pH of the surface ocean is dropping.

Atmospheric CO_2



Seawater CO_2

Seawater pH

Open Pacific: 20-year decrease, and annual cycle in pH, less than 0.05 units

2. Estuarine acidification in Waquoit Bay, MA

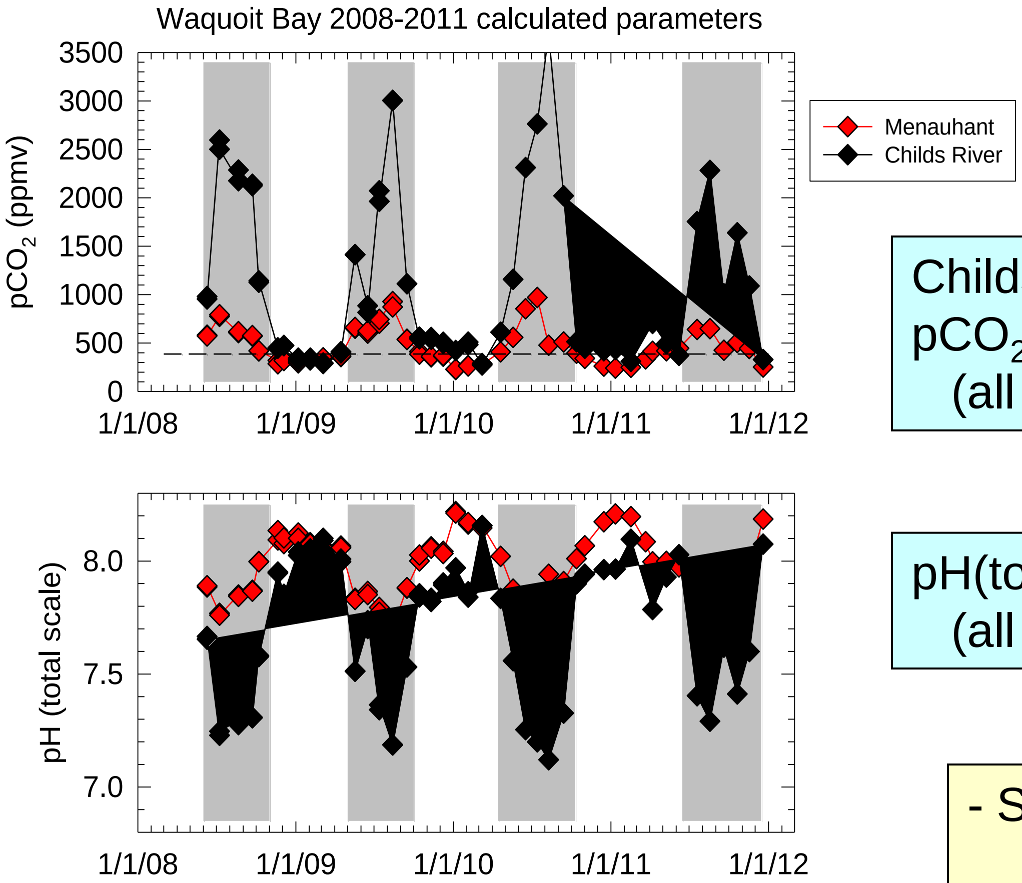
Thanks to:
Chris Weidman & Marykay Fox
(WBNERR)
Rebecca Belastock, Liz Bonk, and Katherine Hoering
(WHOI)

Funding: Sea Grant

Monthly discrete samples just before low tide from 4 stations
(NERR system-wide monitoring program (SWMP))

O_2 data from continuous monitoring stations
(NERR CDMO – Centralized Data Management Office)

Focus on:
Menauhant (most like inflow water)
Childs River (most strongly modified).



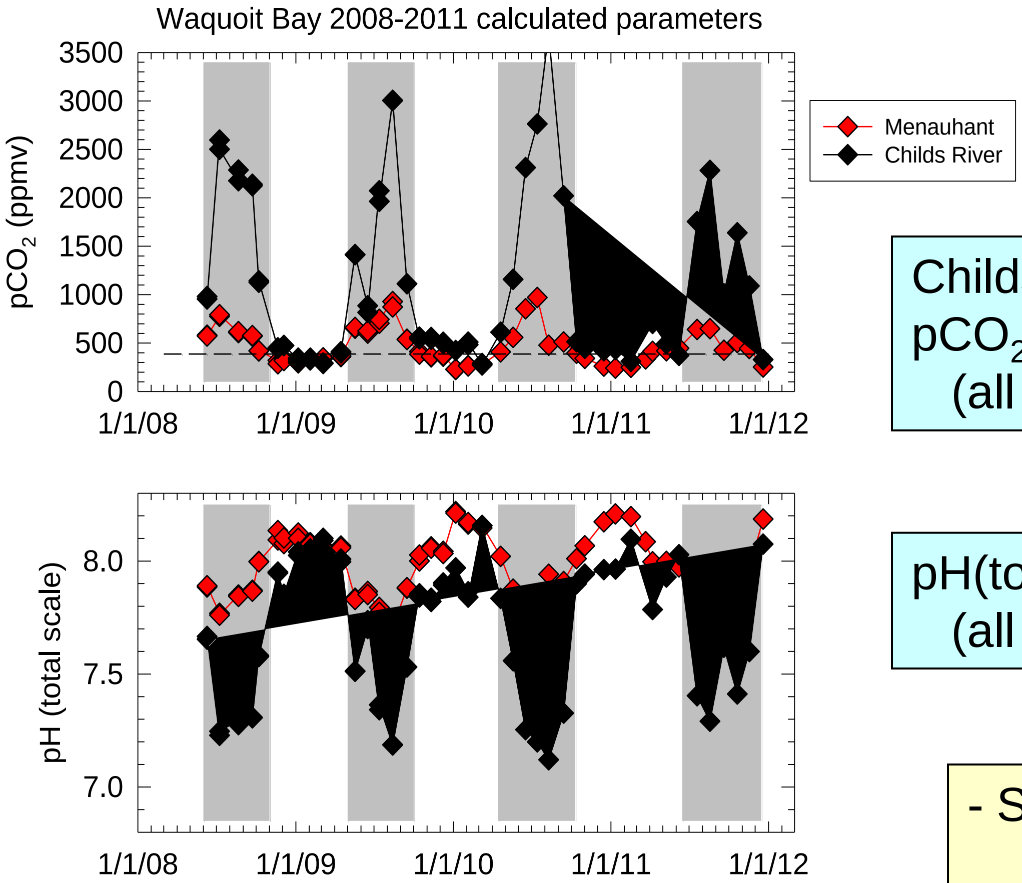
Childs River summer:
pCO_2 above 2000 ppmv
(all sites 100s of ppm above atm)

pH(total) values well below 7.5
(all sites below 7.8)

- Strong seasonality of pH, pCO_2.

- Most extreme in Childs River:
  Low (volume)/(bottom area)
  Low flushing rate

Calculated pH and pCO_2, from measured Alkalinity and DIC and temperature



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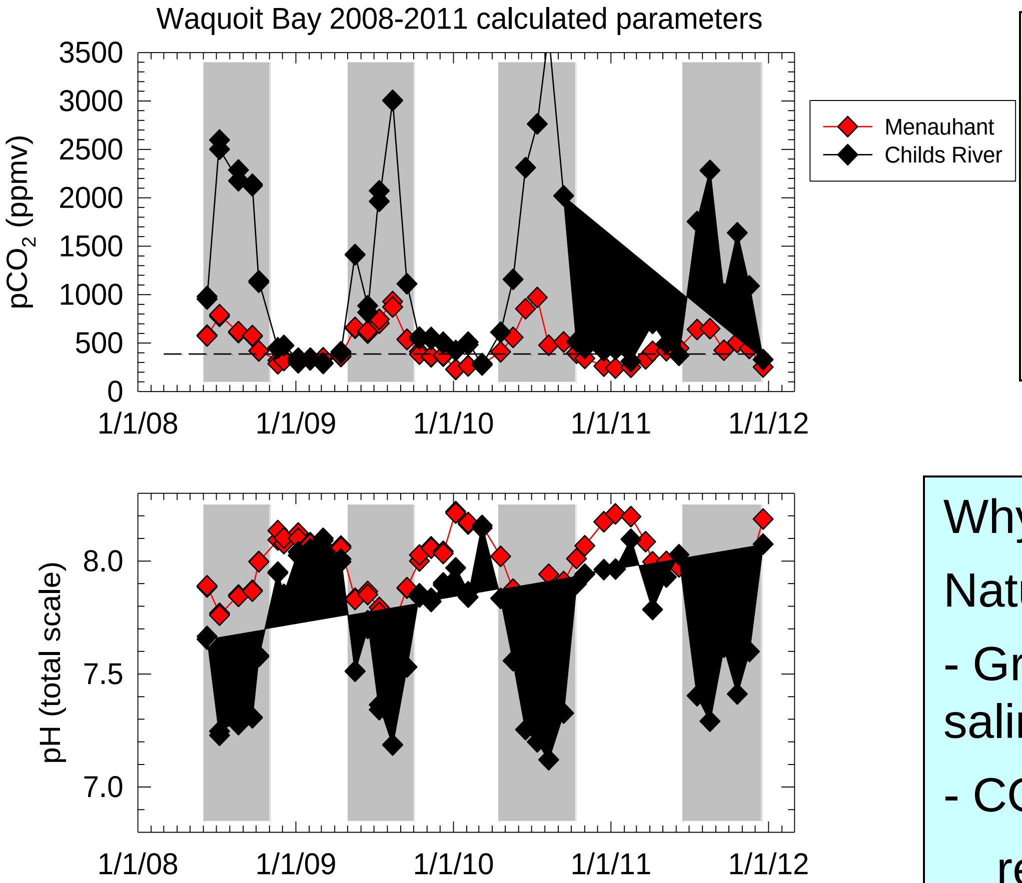


In Waquoit Bay, modern conditions dramatically exceed open ocean OA predictions for 2100 AD.

The ocean acidification future is already here.

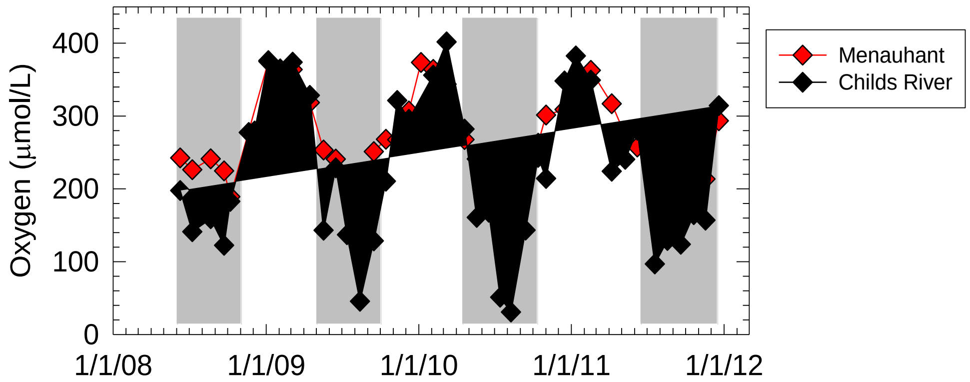
Why?

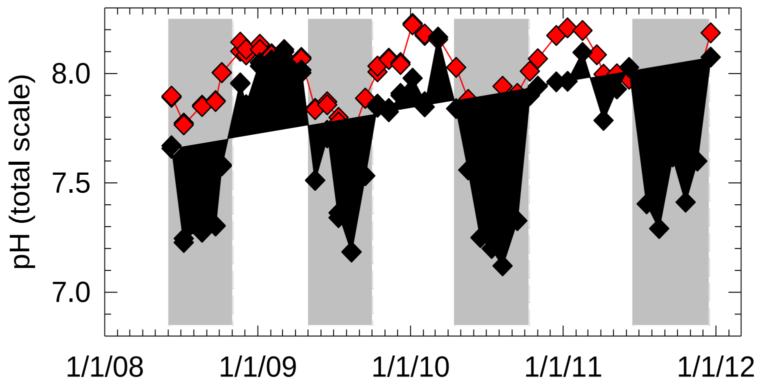
Natural & perturbed cycles of

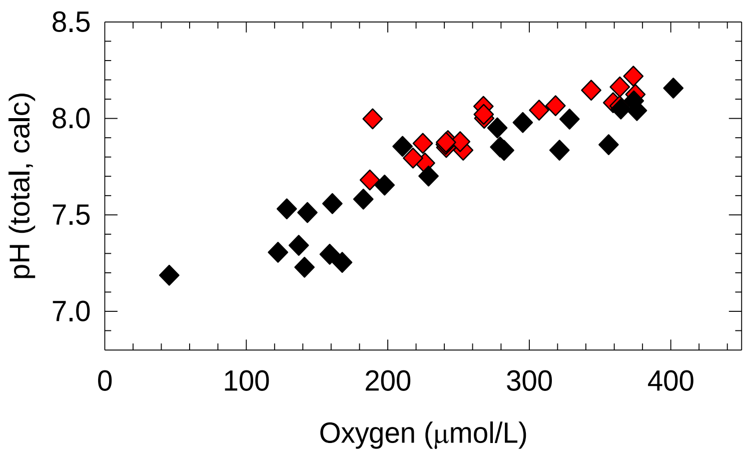
- Groundwater discharge (fresh and saline) and g.w. chemistry
- CO_2 uptake (e.g., photosynthesis) or release (respiration/decomposition)
- H^+ production / consumption

Implications for shellfish?
Most extreme conditions (low pH) occur in summer, when shellfish spawn and first form their shells.

Larvae affected by multiple stressors.







Low pH and high pCO_2 linked to low dissolved oxygen.

Driven by organic matter decomposition in sediments (which produces CO_2, and groundwater discharge.

Natural and anthropogenic contributions to both processes (e.g., eutrophication).

As atmospheric pCO_2 increases, the pH and Ω(ar) at a given oxygen concentration will drop.

Is acidification the biggest threat to shellfish health (recruitment and growth)?
Or low oxygen?
Or combined impacts…?

O_2 data from WBNERR continuous monitoring stations (NERR CDMO – Centralized Data Management Office)

3. Laboratory culture studies of ocean acidification to understand OA impacts on calcifying organisms

Critical high-pCO_2 exposure windows during early development of larval bay scallops

Larva (3 days old, ~82 μm)

Adult (2 years old, ~7 cm)

Larva (7 days old, ~123 μm)

Meredith M. White (recent WHOI PhD)
(Lauren Mullineaux, Daniel McCorkle, Anne Cohen)

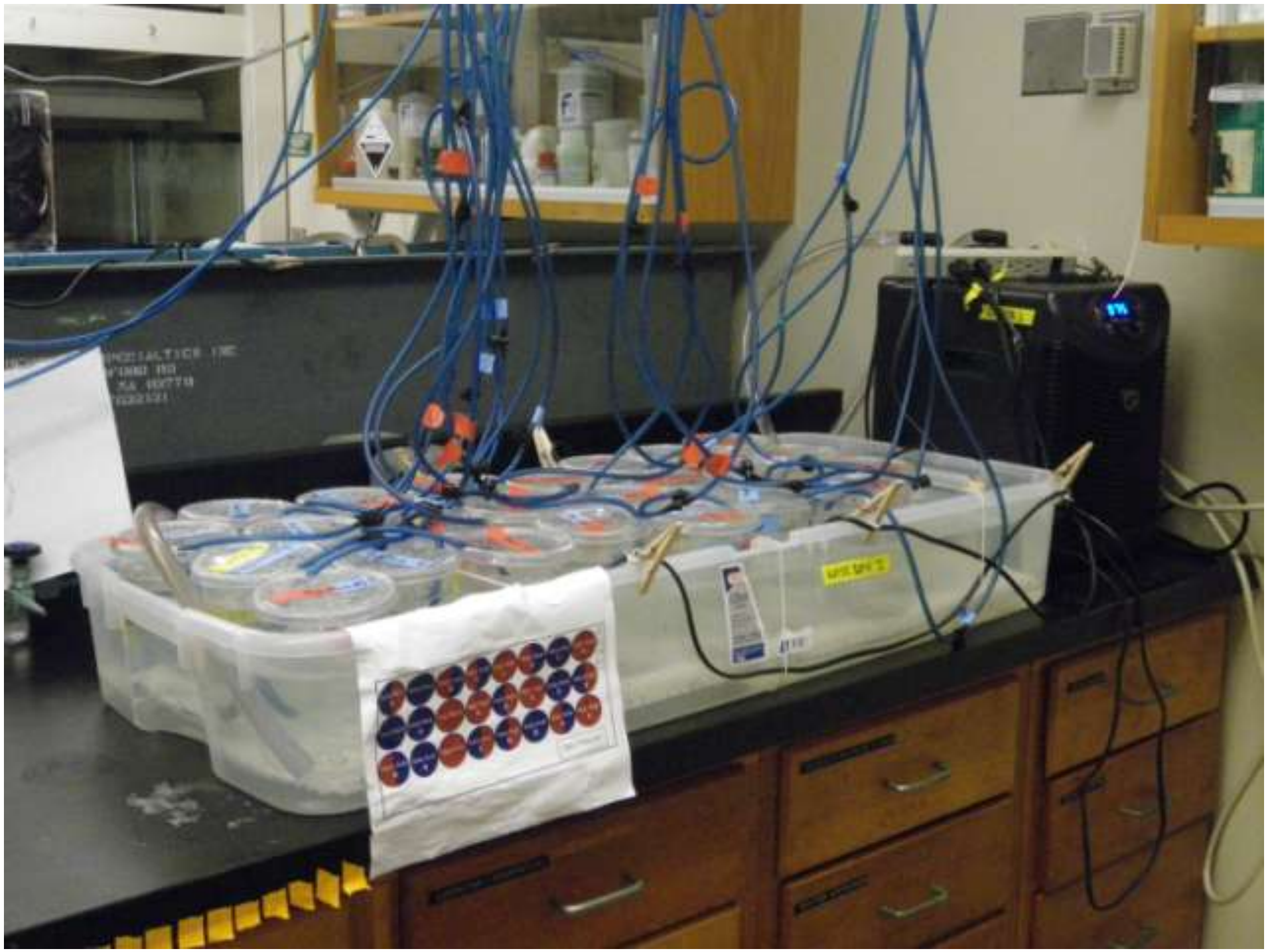
The results of our culture experiments:

- Exposure to high CO_2 has a negative affect on survival and growth of larval bay scallops.

- There is variability in these impacts (suggesting potential for adaptation, or breeding (for hatchery species)?)

- Work with other species suggests that nutrition can help organisms cope with OA

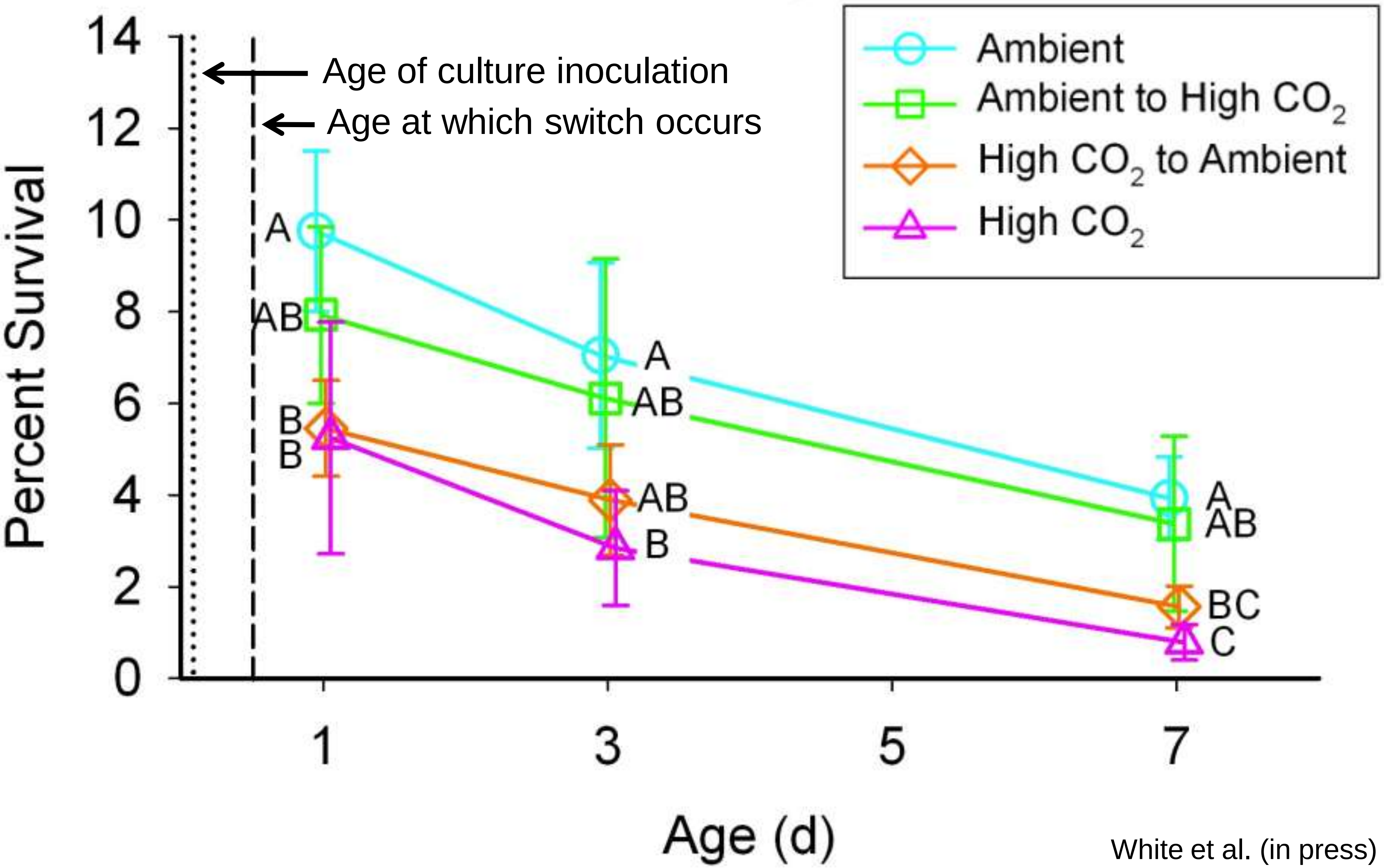
Experimental Set-Up



- 800 mL culture containers in temperature-controlled water bath (T = 23.5 °C)
- Two CO_2 levels 390 ppmv and 2200 ppmv
- Water changed every 2-3 days
- Larvae fed microalgae every day

Exposure to high CO_2 reduces survival

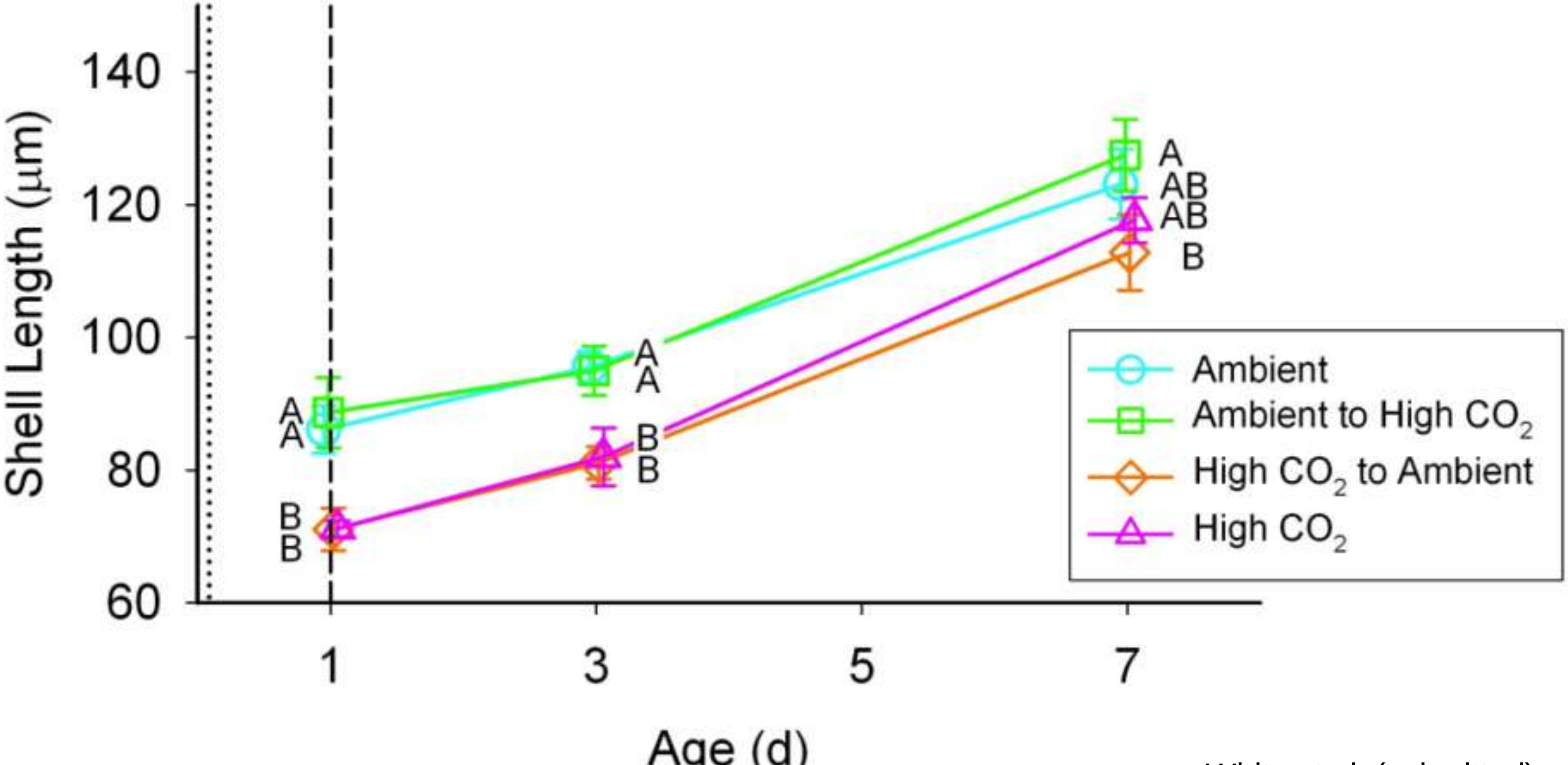
12 hour switch



White et al. (in press)

Shell size impacted by CO_2 level during the initial calcification (12-24 hr).
They don't catch up.

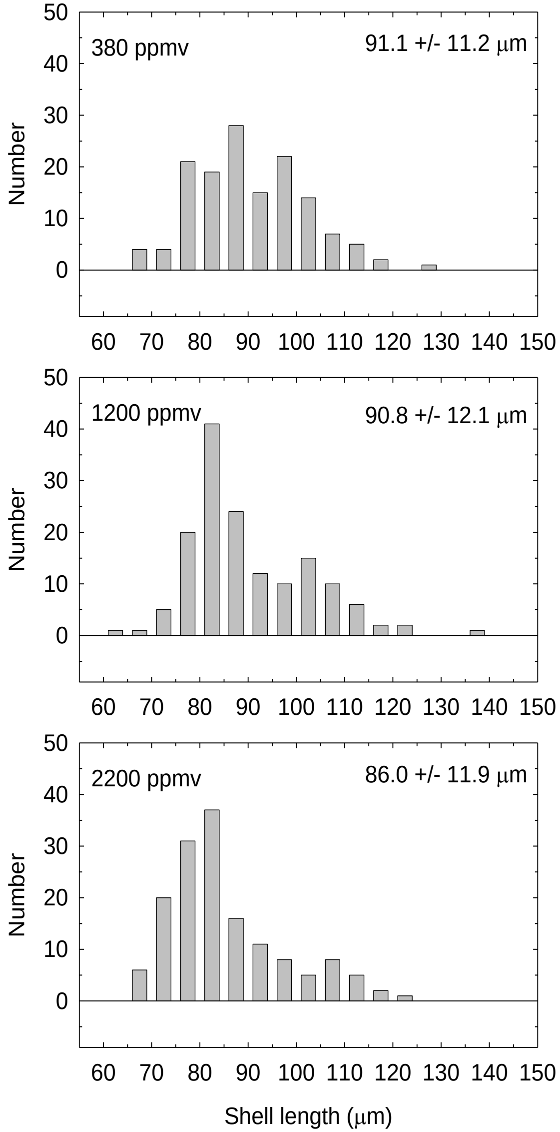
24 Hour Switch



White et al. (submitted)

2011 surf clam experiment, day 6

Shell length histograms reveal a range of responses for each treatment (each CO_2 level)



Average size decreases as CO_2 increases, but even the high-CO_2 treatments include some large individuals.

Suggests possibility of selection for CO_2 tolerance:

Natural selection (in the field) likely to be too slow.
(rate of CO_2 increase)

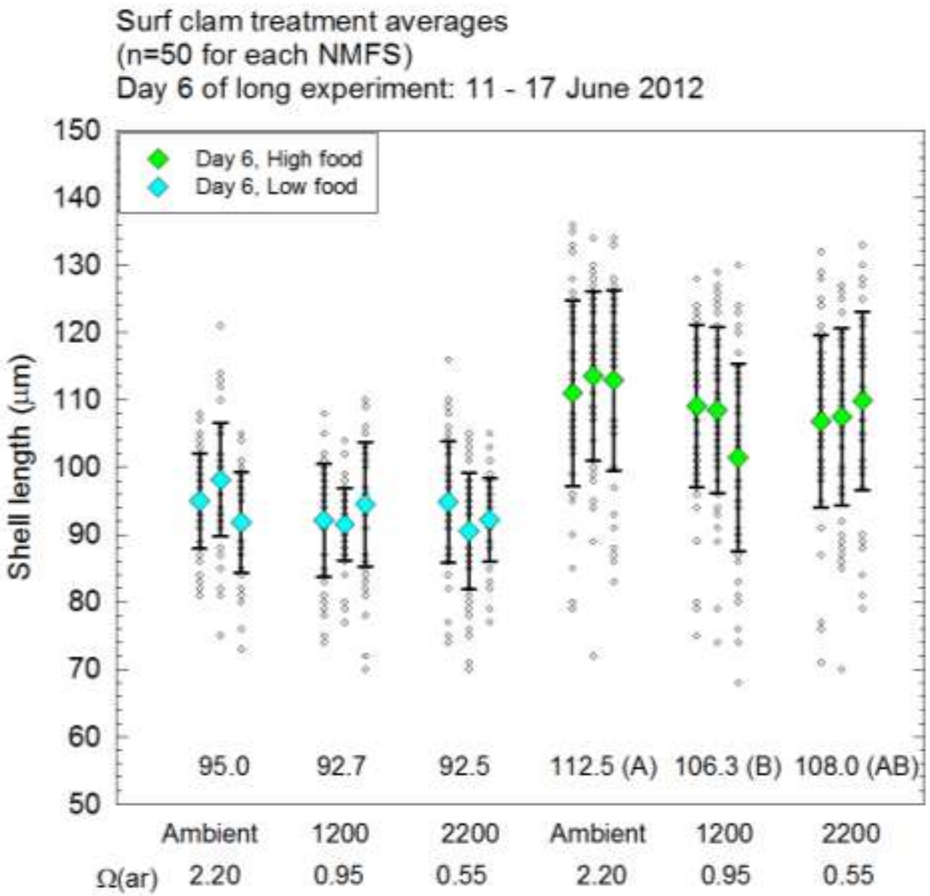
Active selection (in hatcheries) may help commercial species.
(but not whole ecosystems)

Most fundamental solutions are to cut CO_2 emissions, and reduce nutrient pollution!

McCorkle and Cohen (WHOI), Milke and Widman (NOAA/NMFS)

2012 surf clam experiment, day 6

Feeding rate has a strong influence on shell length.



Low food

High food

Shell length at day six

Feeding may offset some OA impacts – the high-food high-CO_2 shells are larger than shells from all of the low-food treatments.

But nutrition does not eliminate impacts of OA - at high feeding rates, shells from the high-CO_2 treatments are still smaller than those from ambient-CO_2 treatments.

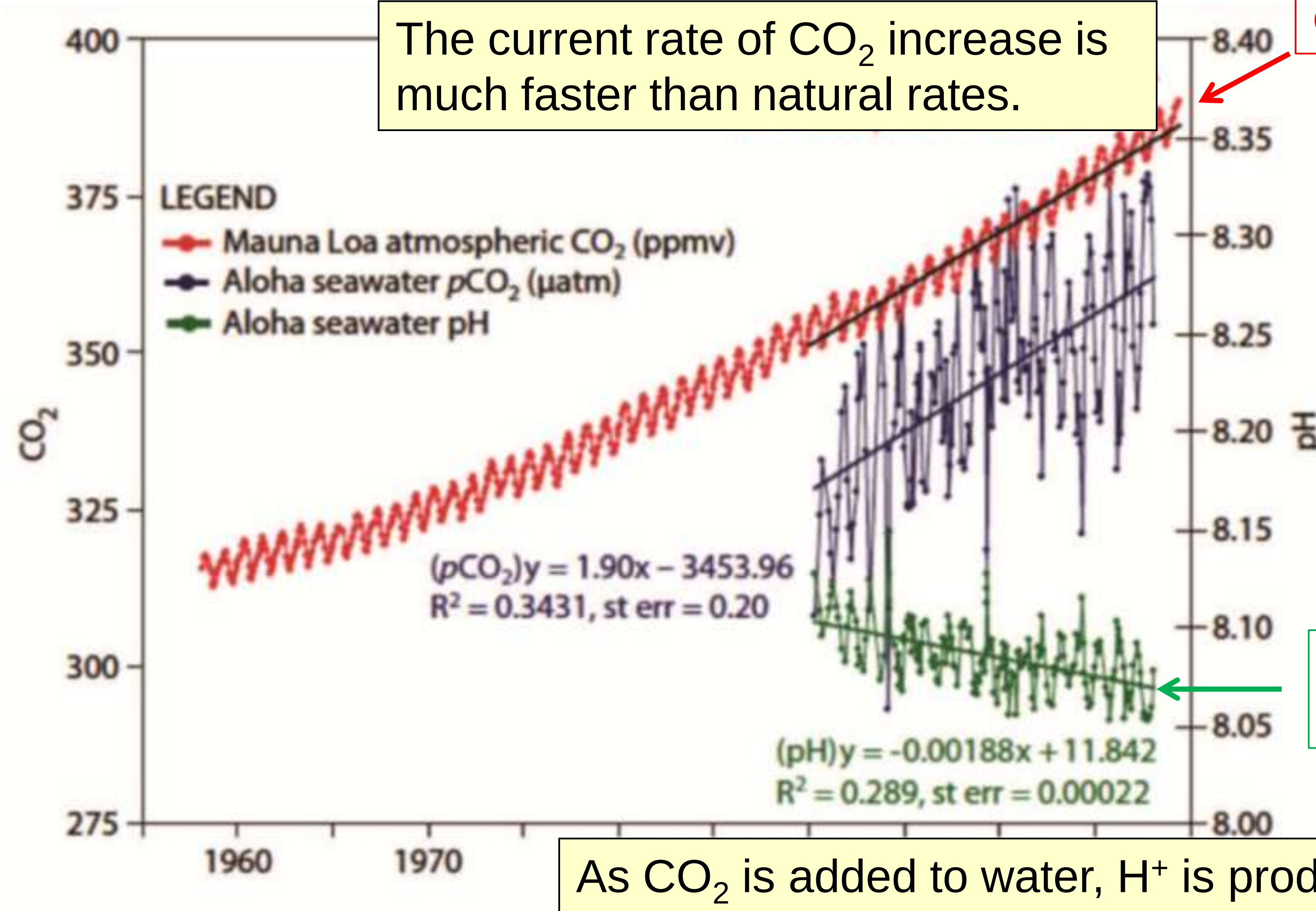
If warming reduces ocean productivity, the beneficial impact of nutrition on field populations may decrease.

McCorkle and Cohen (WHOI), Milke and Widman (NOAA/NMFS)

1. The physics and chemistry of ocean acidification are well-understood

The current rate of CO_2 increase is much faster than natural rates.

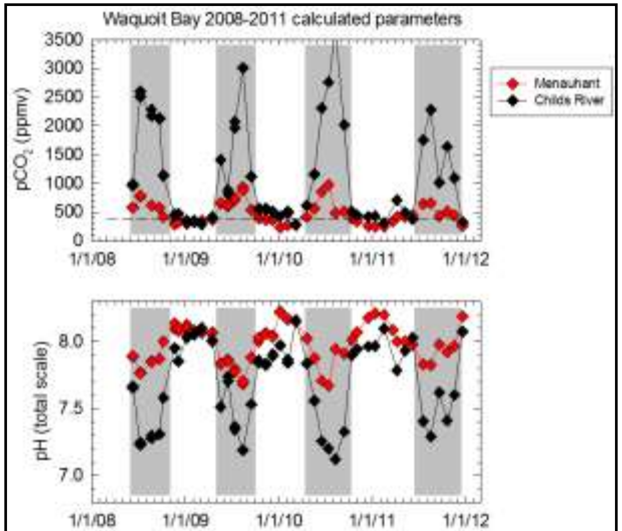
Atmospheric CO_2



Seawater pH

As CO_2 is added to water, H^+ is produced; pH decreases, and CO_3^{-2} decreases

2. Many nearshore environments already experience strong acidification, both naturally and due to human activities.

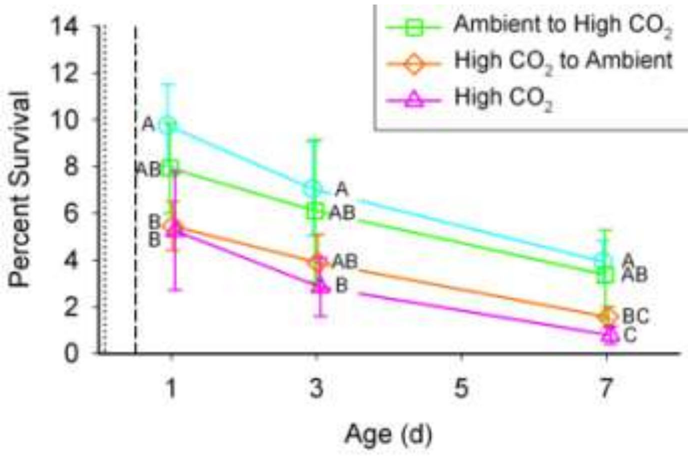


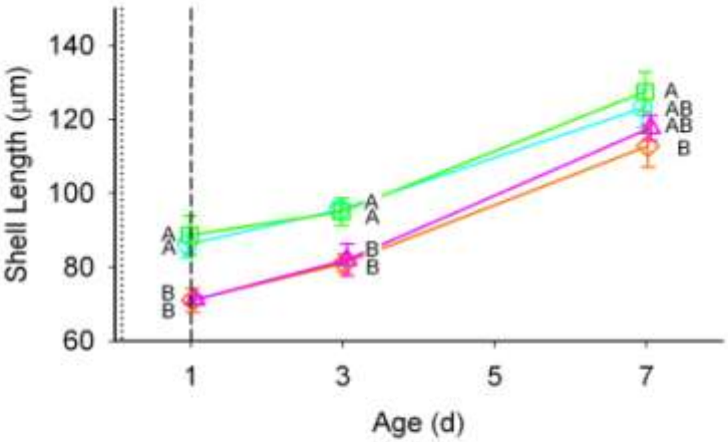
The strong background cycles in water chemistry (natural and human-driven, on a range of timescales) will make direct detection of OA in coastal waters difficult.

Organisms in these environments are likely to feel multiple stressors: acidification; nutrient loading and low oxygen; temperature increase.

Are these organisms and their ecosystems pre-adapted
(& thus resilient),
or pre-stressed
(& thus vulnerable)?

3. Laboratory culturing studies show multiple impacts of ocean acidification on marine life



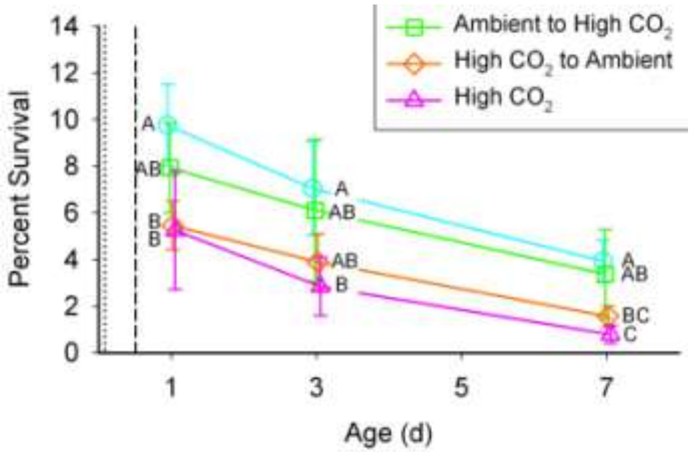


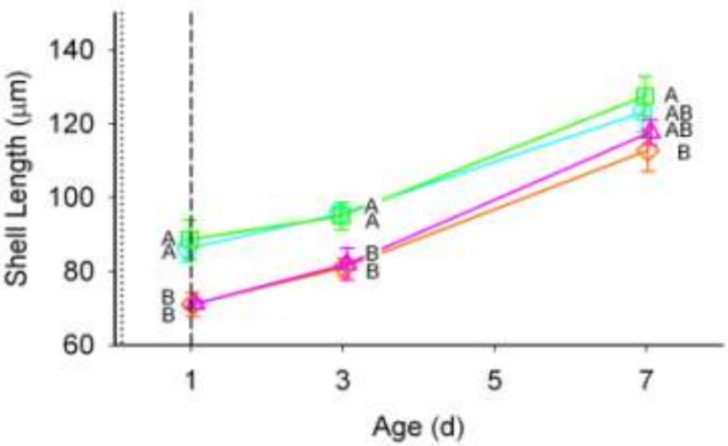
Negative impacts of OA on calcifying organisms (e.g.,shellfish) are clear, though not always simple.

Growing evidence of impacts of OA on non-calcifying organisms as well. (larval development; stress physiology; behavior)

Nutrition can improve resilience (and thus reduced food may decrease it), and there is a range of resilience within any population.

3. Laboratory culturing studies show multiple impacts of ocean acidification on marine life





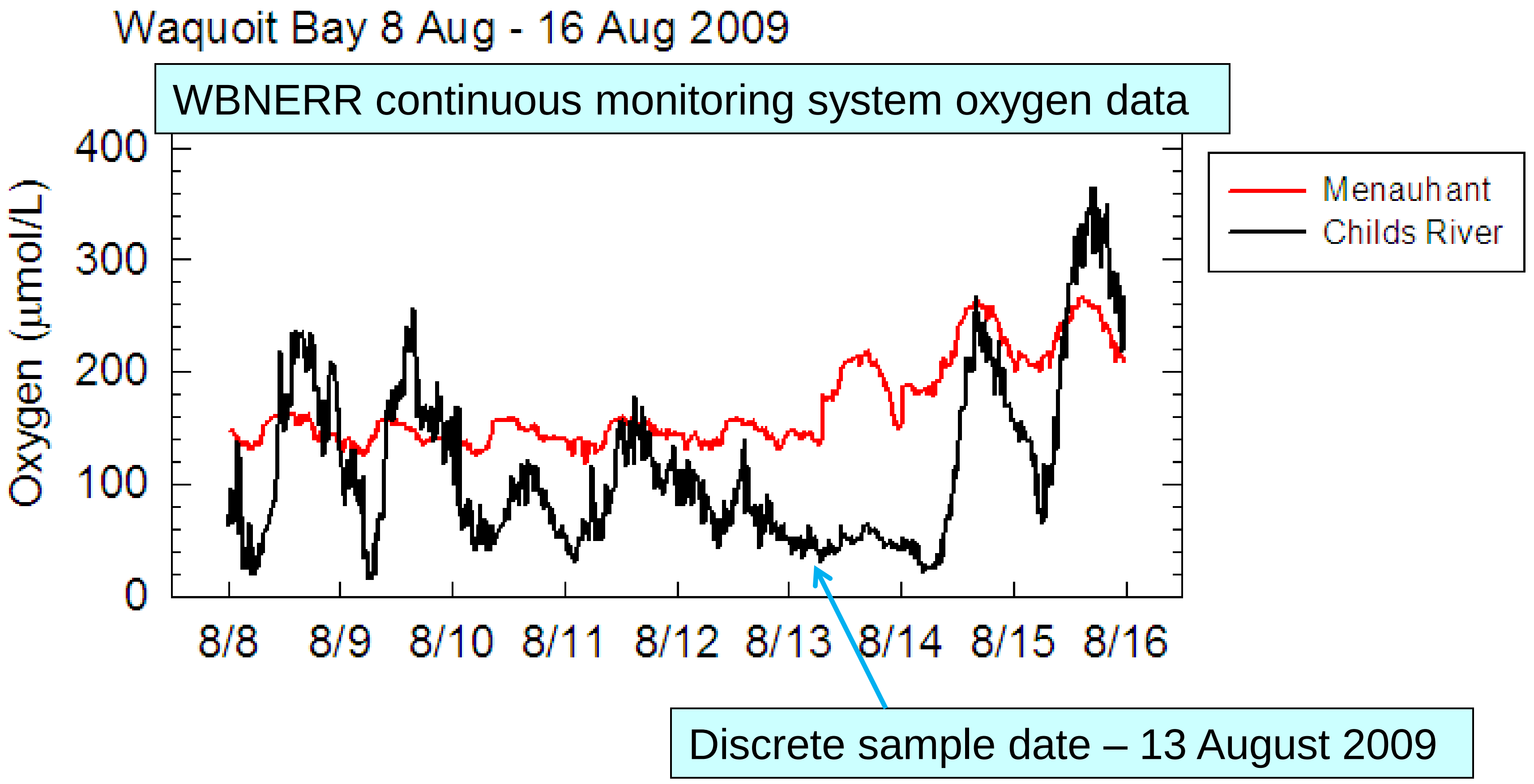
Negative impacts of OA on calcifying organisms (e.g.,shellfish) are clear, though not always simple.

The impact of rising CO_2 on marine ecosystems is not yet predictable, but "wait and see" is not wise, or responsible.

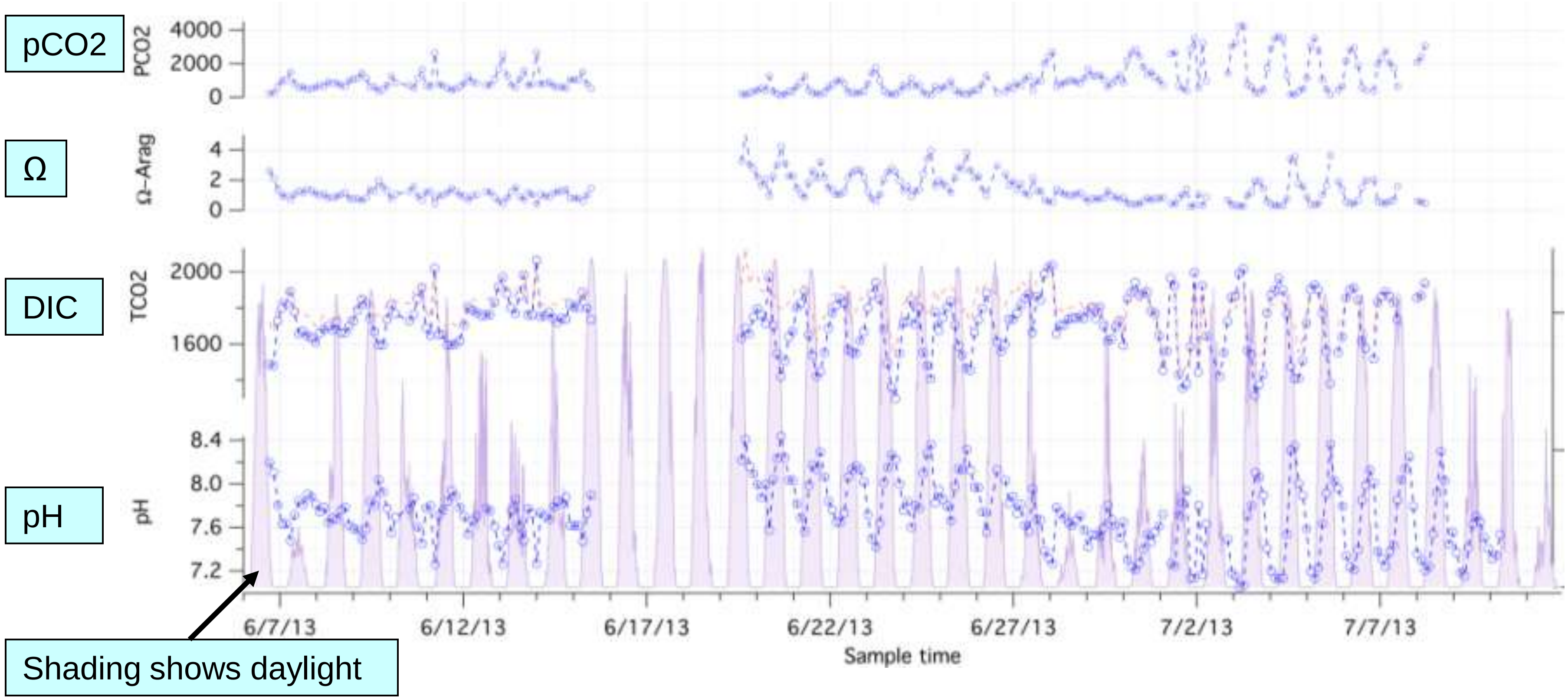
Nutrition can improve resilience (and thus reduced food may decrease it), and there is a range of resilience within any population.

White, Cohen, and McCorkle

The variability is not just seasonal.
WBNERR dissolved oxygen data show strong daily cycles.
Since [O_2] and pH are linked, this suggests that we're missing a lot with only monthly sample resolution for carbonate chemistry.



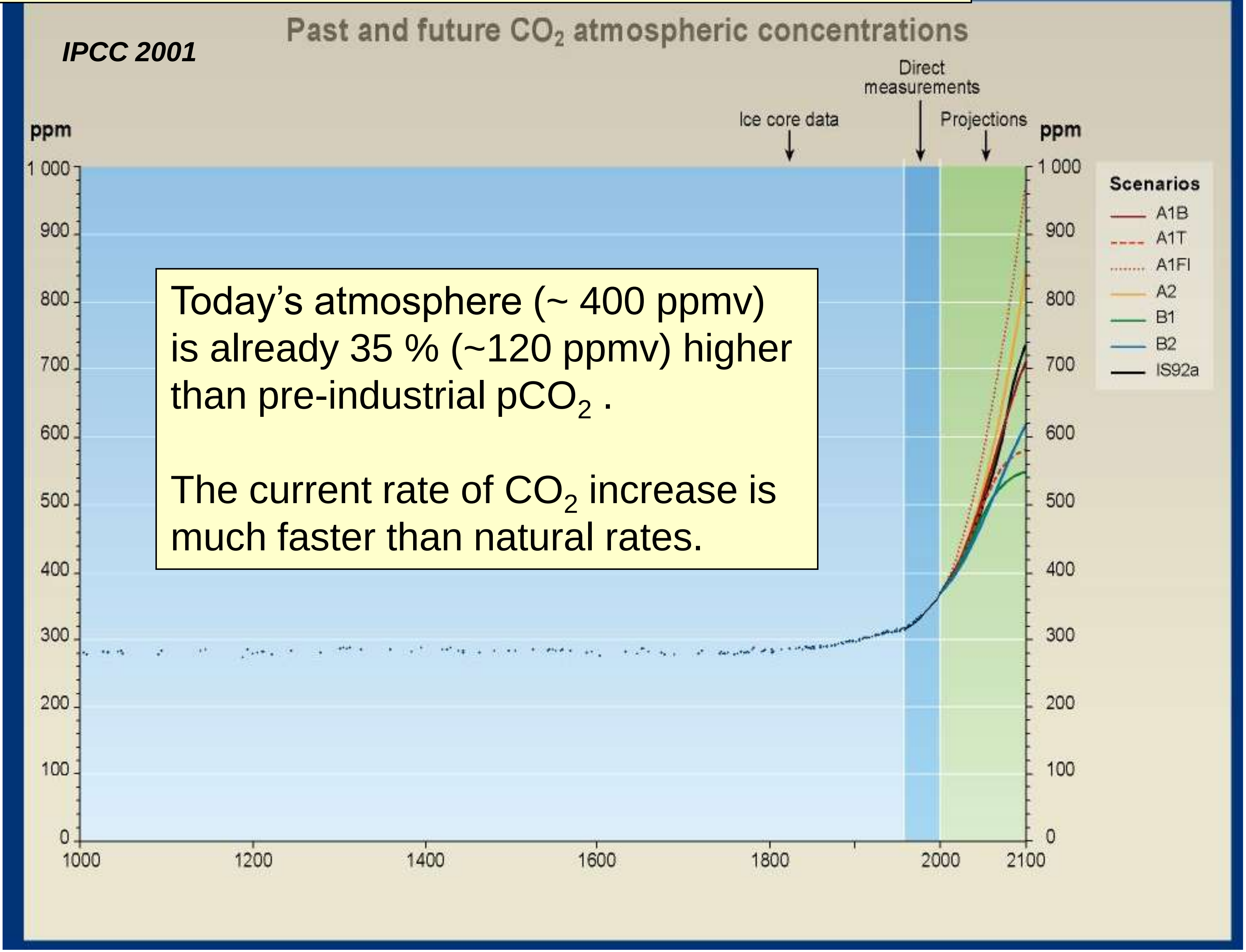
Automated in situ pH and DIC analyses show daily cycles as large as the season cycles. (Martin, Sayles, McCorkle, & Weidman)



We’ve missed a lot with monthly sample resolution for carbonate chemistry!

What factors are most important to the health of the bay, or its shellfish?
Minimum values (pH, O_2); sustained values; variability…

Rising atmospheric CO_2 due to human activities



Today's atmosphere (~ 400 ppmv) is already 35 % (~120 ppmv) higher than pre-industrial pCO_2 .

The current rate of CO_2 increase is much faster than natural rates.