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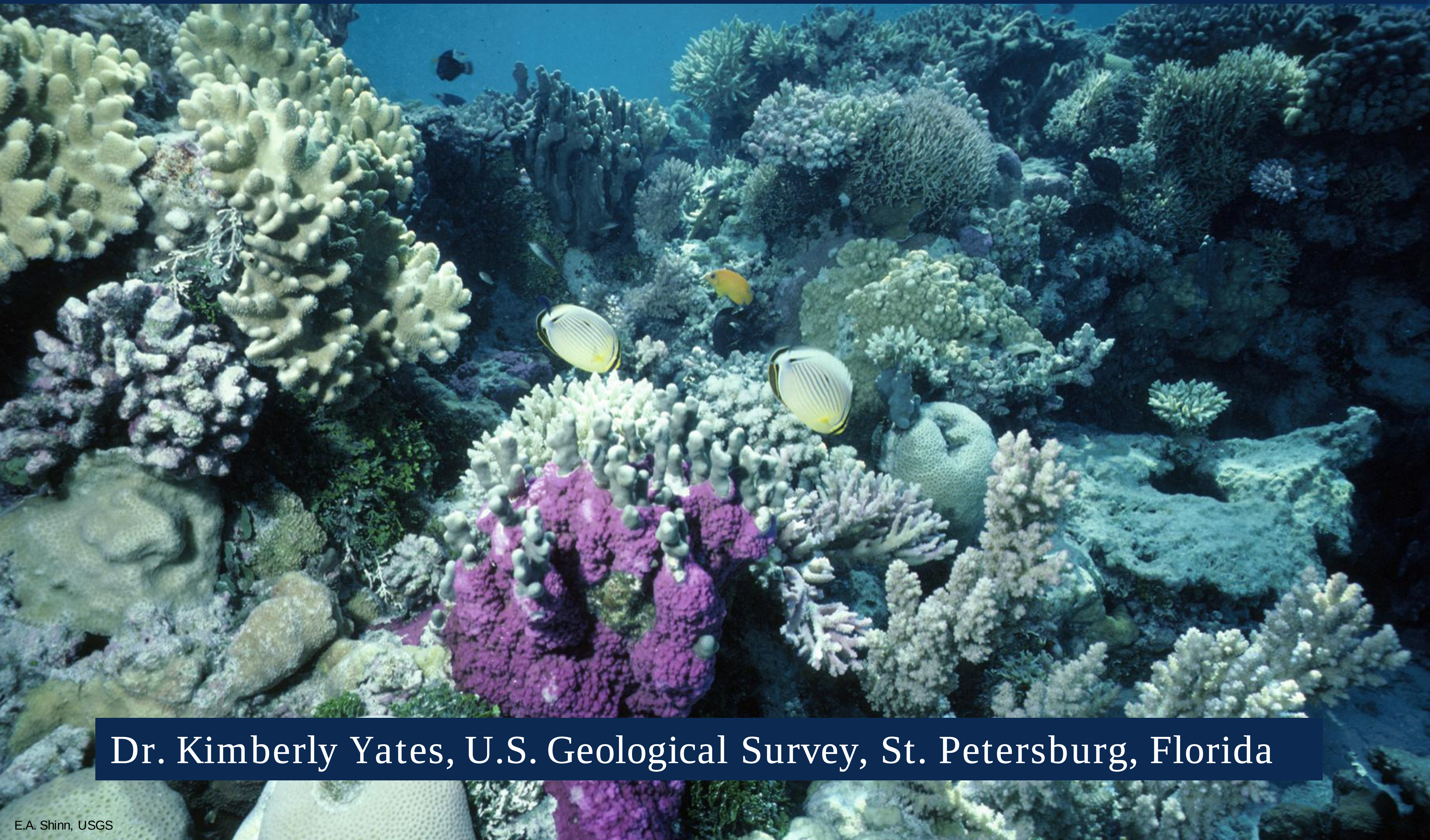
Effects of Ocean Acidification on Tropical Coral Reefs in Florida & the Caribbean



Dr. Kimberly Yates, U.S. Geological Survey, St. Petersburg, Florida

E.A. Shinn, USGS

Presentation outline

- Coral reefs 101

- Current threats to coral reefs and existing baseline of reef health

- The affects of ocean acidification on coral reef community metabolism & long-term implications for reef structure

- Results from recent studies on ecosystem-level responses of coral reefs to ocean acidification

Coral reefs provide…

- Fish habitat
- Major source of food
- Protection of coastlines from storm waves
- Sand for beaches
- Pharmaceuticals
- Recreational activities – fishing, diving, etc.
- Long term storage of carbon

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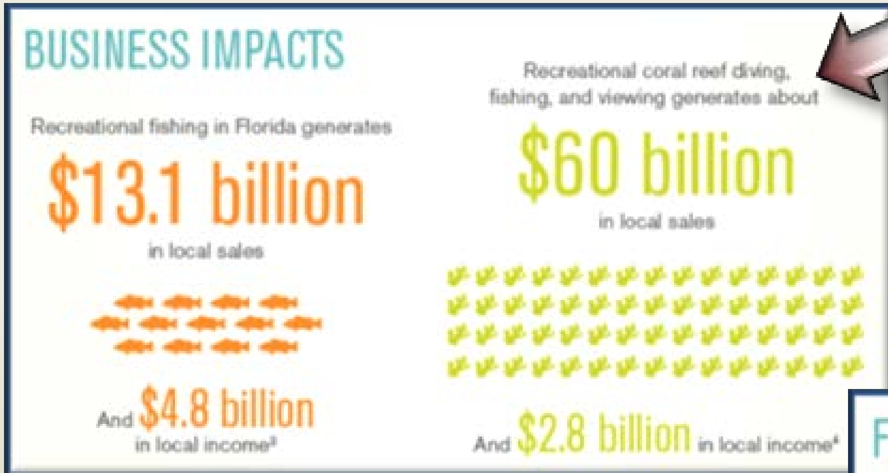
Florida jobs & businesses at risk from ocean acidification



Ocean Conservancy

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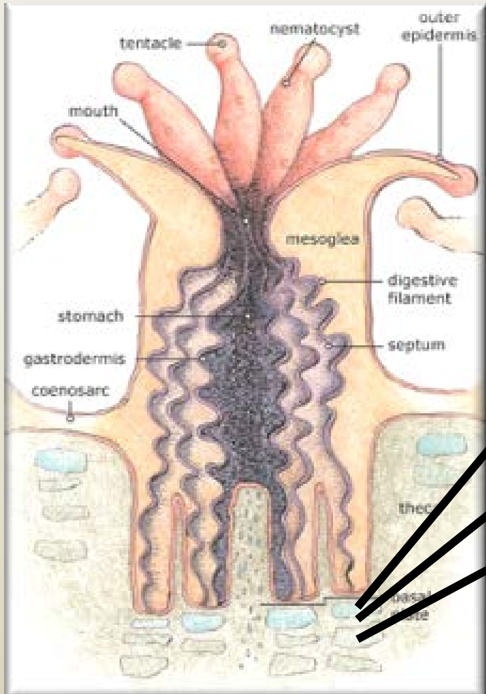
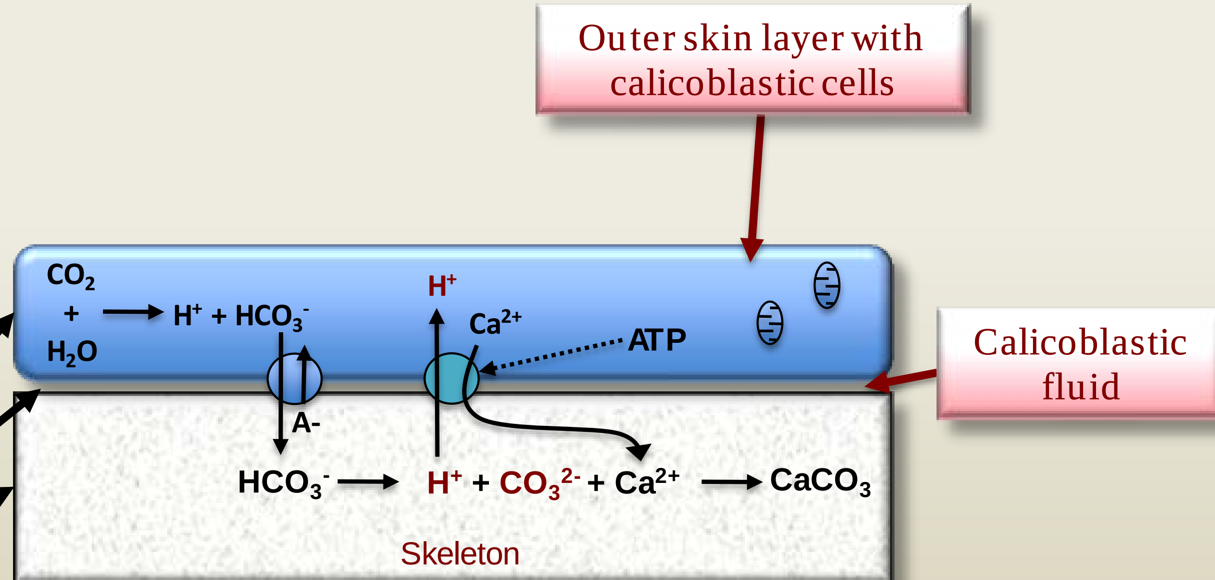
Ecosystem services depend on 3-D structure of coral reefs





Coral calcification creates the 3-D structure of coral reefs

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Calcification is a reversible process

Calcification →

$Ca^{2+} + 2HCO_3^{-} \leftrightarrow Ca^{2+} + 2CO_3^{2-} + 2H^{+} \leftrightarrow CaCO_3 + CO_2 + H_2O$

← **Carbonate Dissolution**

(Saturation State (Ω) = [Ca^{2+}] [CO_3^{2-}] / Ksp*)

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Coral reefs form slowly, over 1000's of years…

Biogenic Calcification

Skeletal Breakdown

Carbonate Sediment Production

Infilling of Reef Framework

Cementation of Reef

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Reef accretion and sea level rise

Buddemeier and Smith 1988

Up to 10s of mm yr^{-1}

~2.6 to 10 mm yr^{-1}

3.0 mm yr^{-1} reef flats
7.0 mm yr^{-1} coral thickets

IPCC Sea Level Rise 1961 – 2003 = 1.8 mm yr^{-1}

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Reefs – keeping up with rising sea level

Depends upon:

- The balance between calcification and chemical dissolution of carbonates
- Erosion (chemical, physical and biological) and sediment export
- Coral reef accumulation rates
- Calcification & accumulation must exceed erosion and transport

Healthy corals and other calcifying organisms!

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Coral reefs around the world are threatened!

Abundance of reef-building corals decreased over 80% since the 1970's on Caribbean reefs.

Loss of reef structure

Transition to algal-dominated communities

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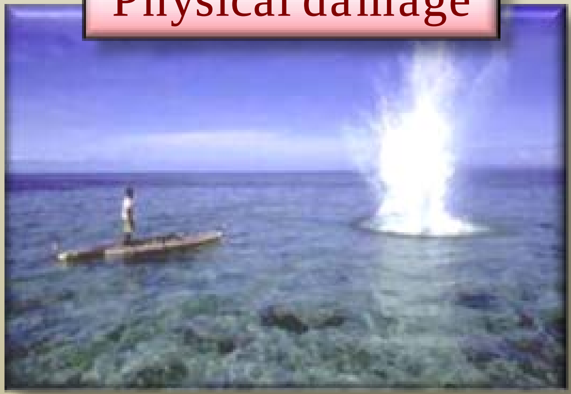
Reef degradation has been attributed to local stressors



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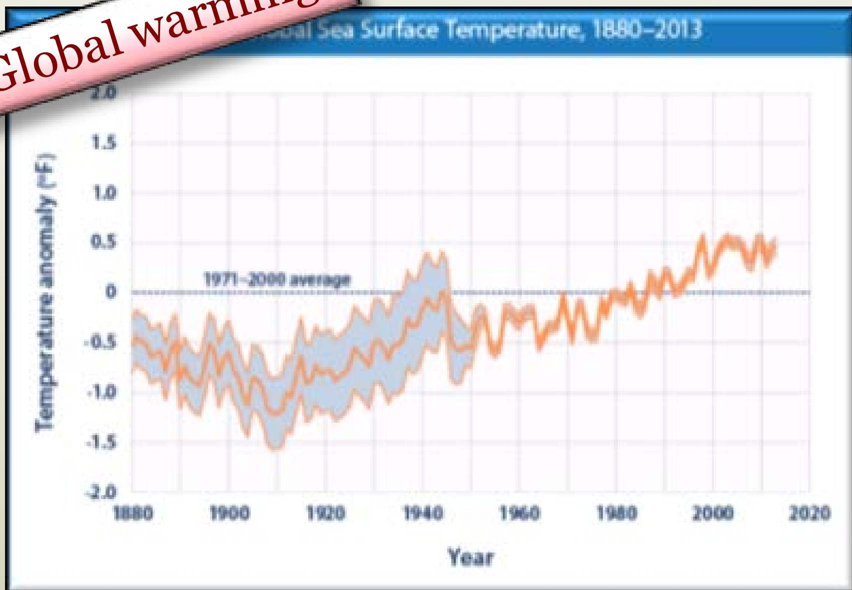
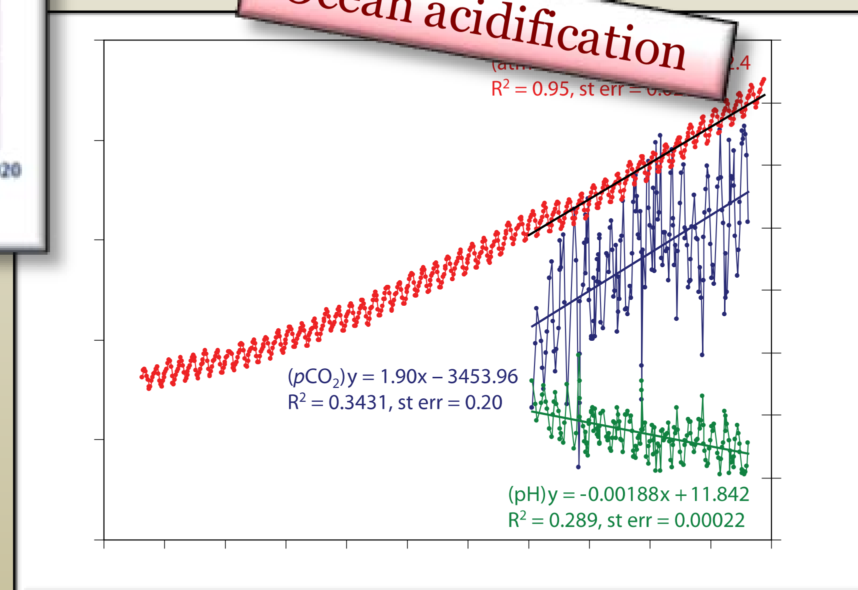
Global stressors as emerging threats

Elevated Atmospheric CO_2

Global warming



Ocean acidification



Emerging Threats

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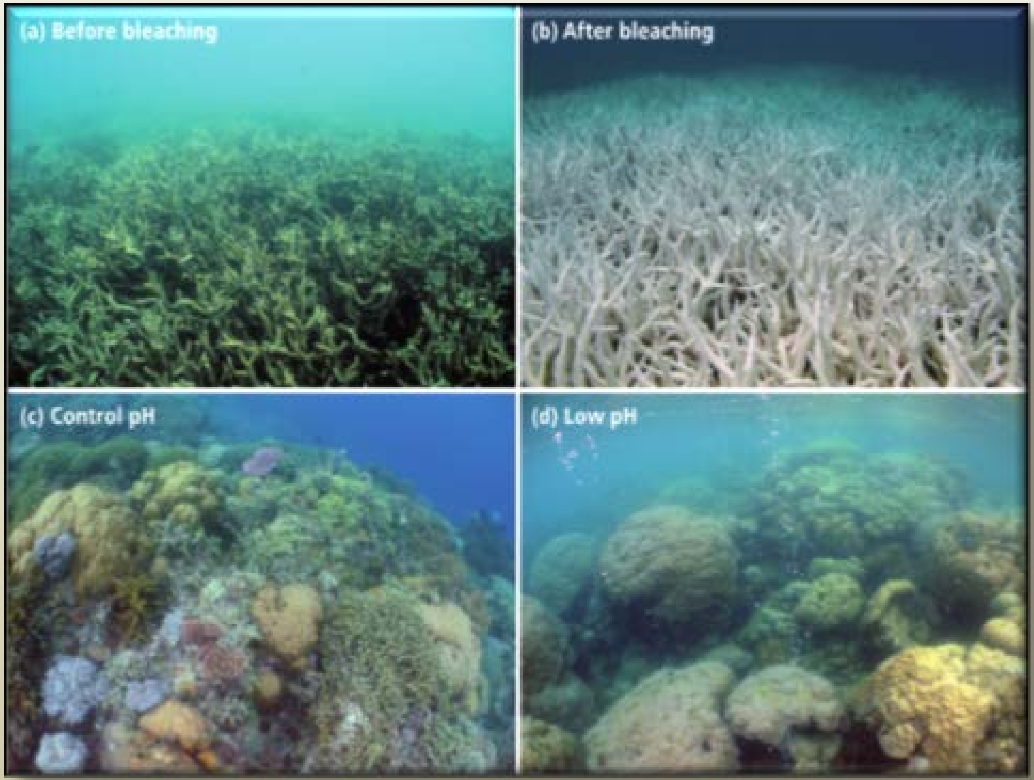
IPCC-AR5 projects 33% to 66% of world's coral reefs subject to long-term degradation in next few decades due to climate-driven impacts.

Solar (thermal) Stress

(elevated temp, light and UV radiation)

Ocean Acidification (OA)

(decreased pH & Ω_A)



From: Gattuso et al. 2014. Cross-chapter box on coral reefs. WGII, IPCC-AR5. Based on RCP3-PD and 4.5.

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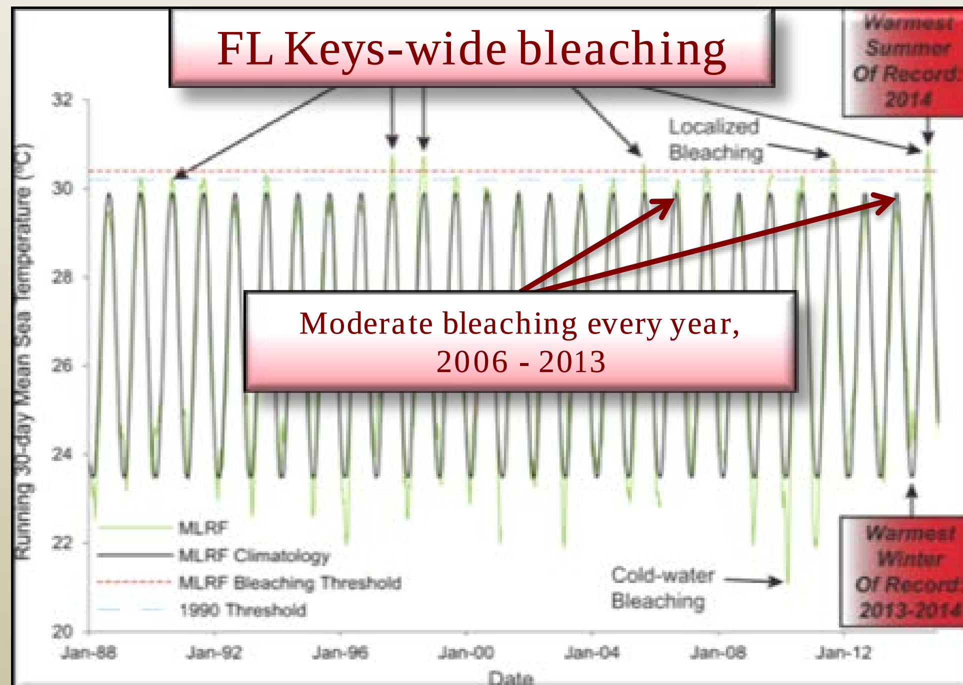
Global warming (thermal stress) basics

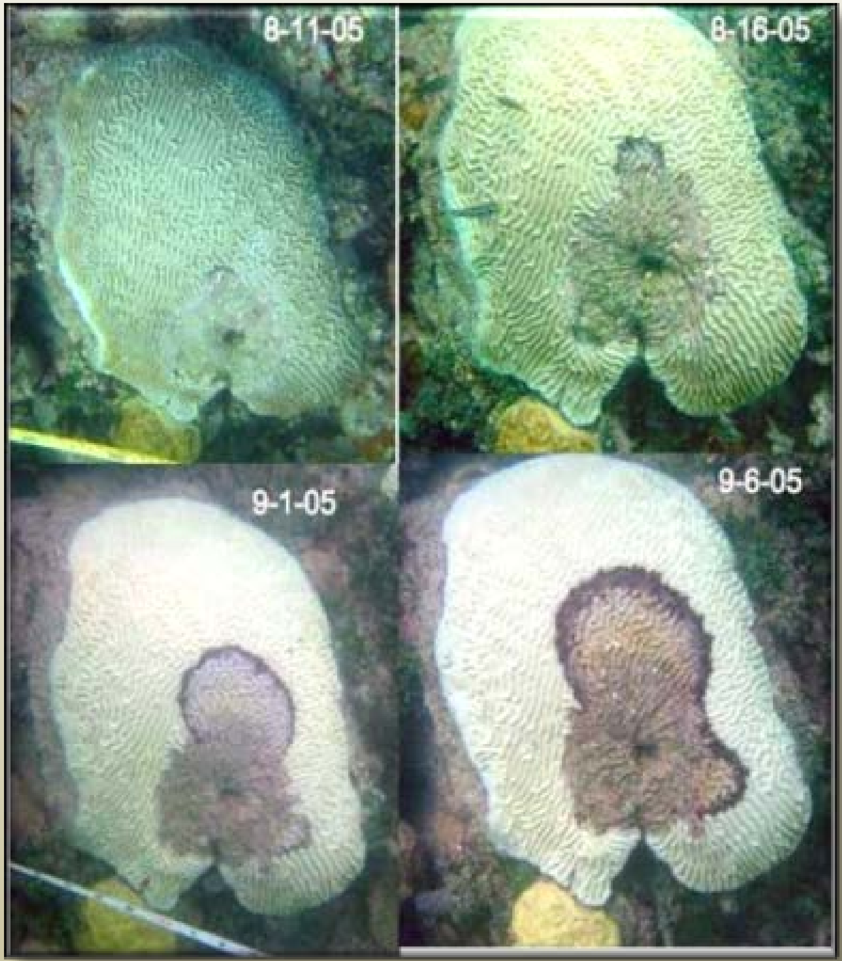
- If water gets 1 or 2°C higher than the summer average, corals get stressed & bleach. Some recover, many die.
- Elevated light/UV can increase thermal stress & bleaching.
- Annual bleaching expected as early as 2020 in FL Keys

Healthy coral with algae   Bleached coral without algae



From: Manzello 2015

Bleaching and coral disease



Marilyn E. Brandt, University of Miami

- High temperatures and bleaching can leave corals more vulnerable to disease
- Can quickly kill part or all of the coral colony
- By 1998, 82% of coral monitoring stations in the Keys were affect by disease

Porter et al. 2001

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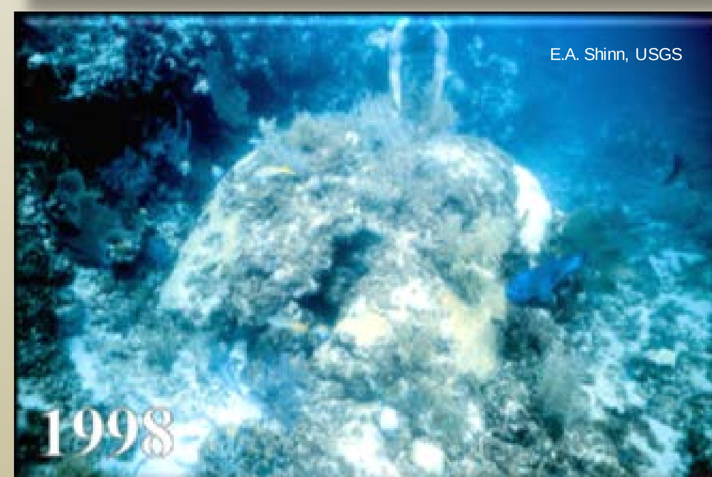
Bioerosion causes loss of reef structure

- Areas of dead coral are more vulnerable to bioerosion (when animals wear away the coral reef's limestone structure)
- Results in loss of reef structure
- The current baseline of reef health in the Atlantic & Caribbean



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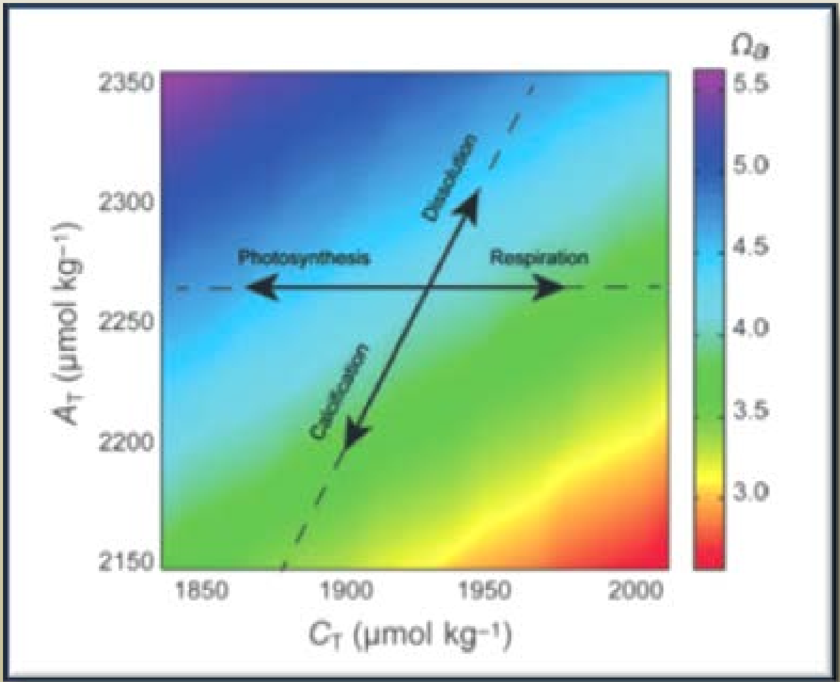
Coral reef community metabolism

Reef health as the balance between Net Ecosystem Production (NEP) and Net Ecosystem Calcification (NEC)

NEP= gross or total primary production (P) – gross respiration (R)

NEC= gross calcification – $CaCO_3$ dissolution



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How is ocean acidification anticipated to impact coral reef community metabolism?

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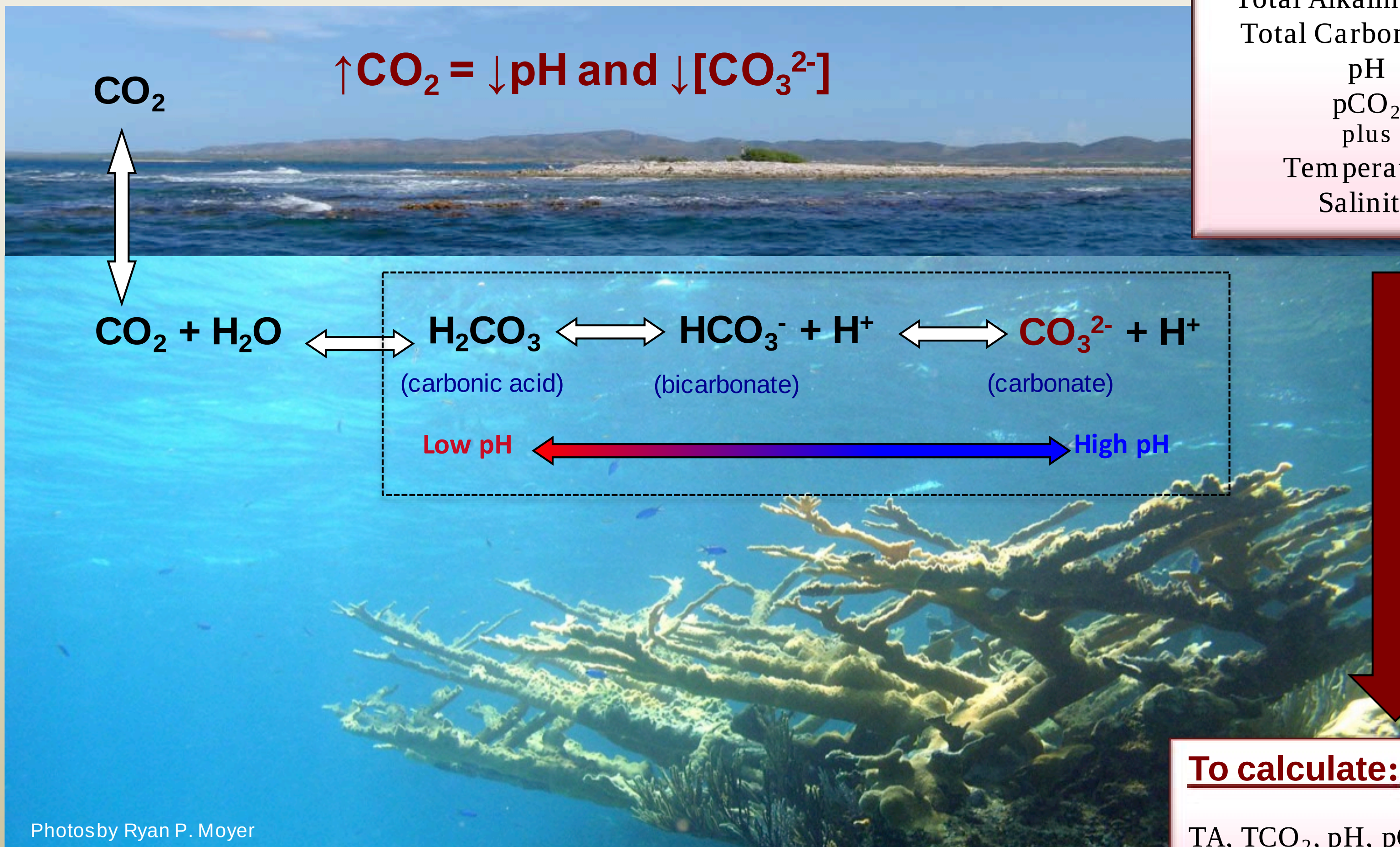
Ocean acidification (OA) basics



We measure:

Total Alkalinity (TA)
Total Carbon (DIC)
pH
pCO_2
plus
Temperature
Salinity

At least 2 of these

To calculate:

TA, TCO_2, pH, pCO_2, $[HCO_3^-]$, $[CO_3^{2-}]$, $[CO_2]$, Ω_C, Ω_A

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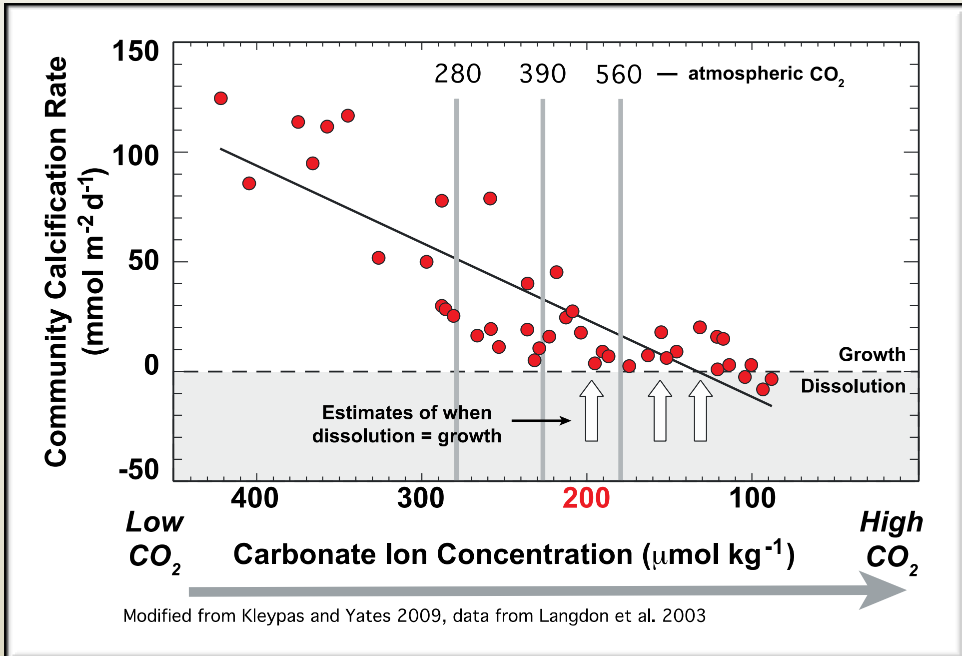
OA decreases rates of calcification



$CaCO_3$ production rates are estimated to decrease by as much as 60% by mid-century

(Guinotte & Fabry 2008, Jokiel et al. 2008, based on 11 coral species & 4 CCA species)

OA losers...

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…and increases carbonate dissolution

Calcification

Can produce CO_2, ↓$[CO_3^{2-}]$ & pH

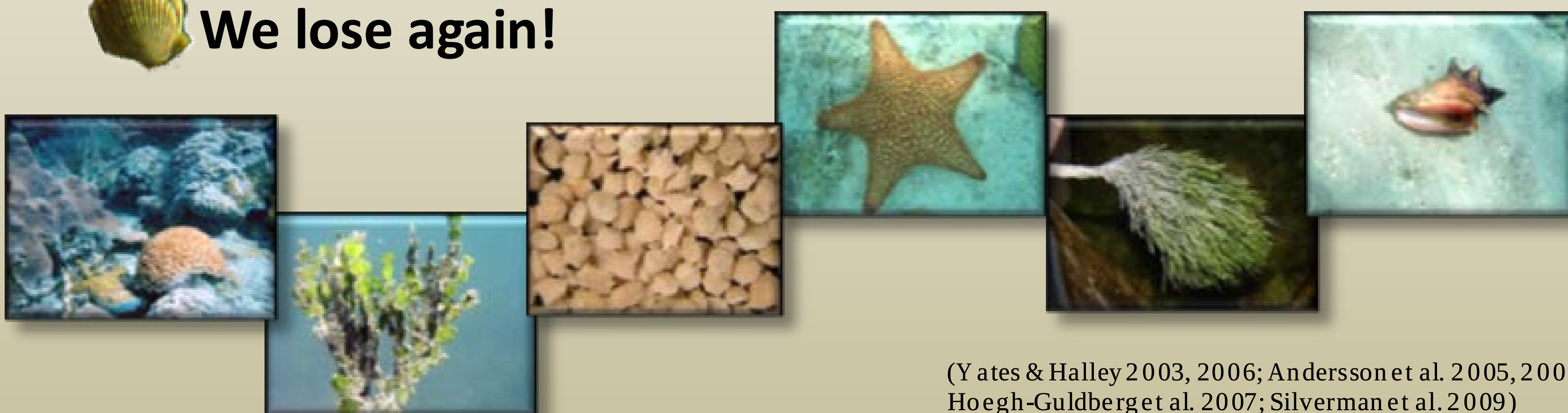
$Ca^{2+} + 2HCO_3^-$ ⟷ $Ca^{2+} + 2CO_3^{2-} + 2H^+$ ⟷ $CaCO_3 + CO_2 + H_2O$

Consumes CO_2, ↑$[HCO_3^-]$, can buffer pH

bonate Dissolution

(Saturation State (Ω) = $[Ca^{2+}]$ $[CO_3^{2-}]$ / Ksp*)

We lose again!



(Yates & Halley 2003, 2006; Andersson et al. 2005, 2009; Hoegh-Guldberg et al. 2007; Silverman et al. 2009)

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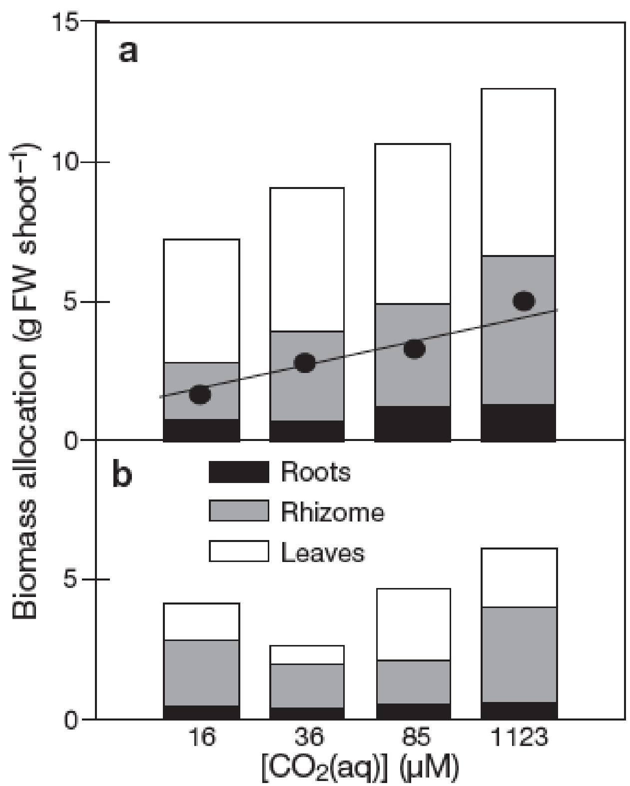
…and can increase photosynthesis

$$CO_2 + H_2O + \text{sunlight} \longleftrightarrow CH_2O + O_2$$



From: Palacios and Zimmerman 2007

Seagrasses: increased P & reduced light requirements
(Palacios & Zimmerman 2007, Jiang et al. 2010)

Macroalgae: 52% increase in growth (carbon uptake) at 2X CO_{2atm}
(Kübler et al. 1999, also check Hurd et al. 2009).

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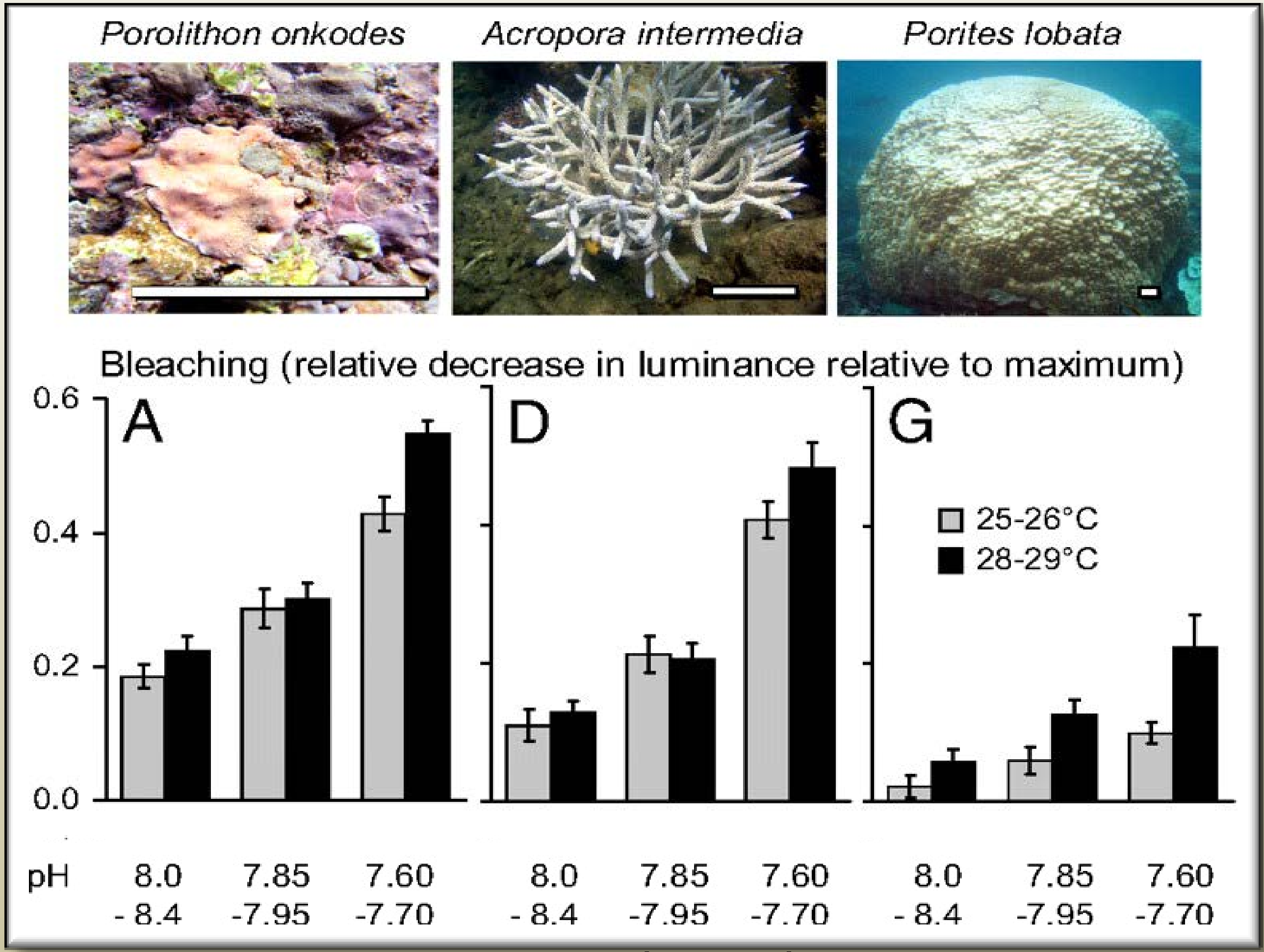
Ocean acidification increases susceptibi to coral bleaching



K. R. N. Anthony et al. PNAS 2008;105:17442-17446

Slide courtesy of Erin Muller, Mote Marine

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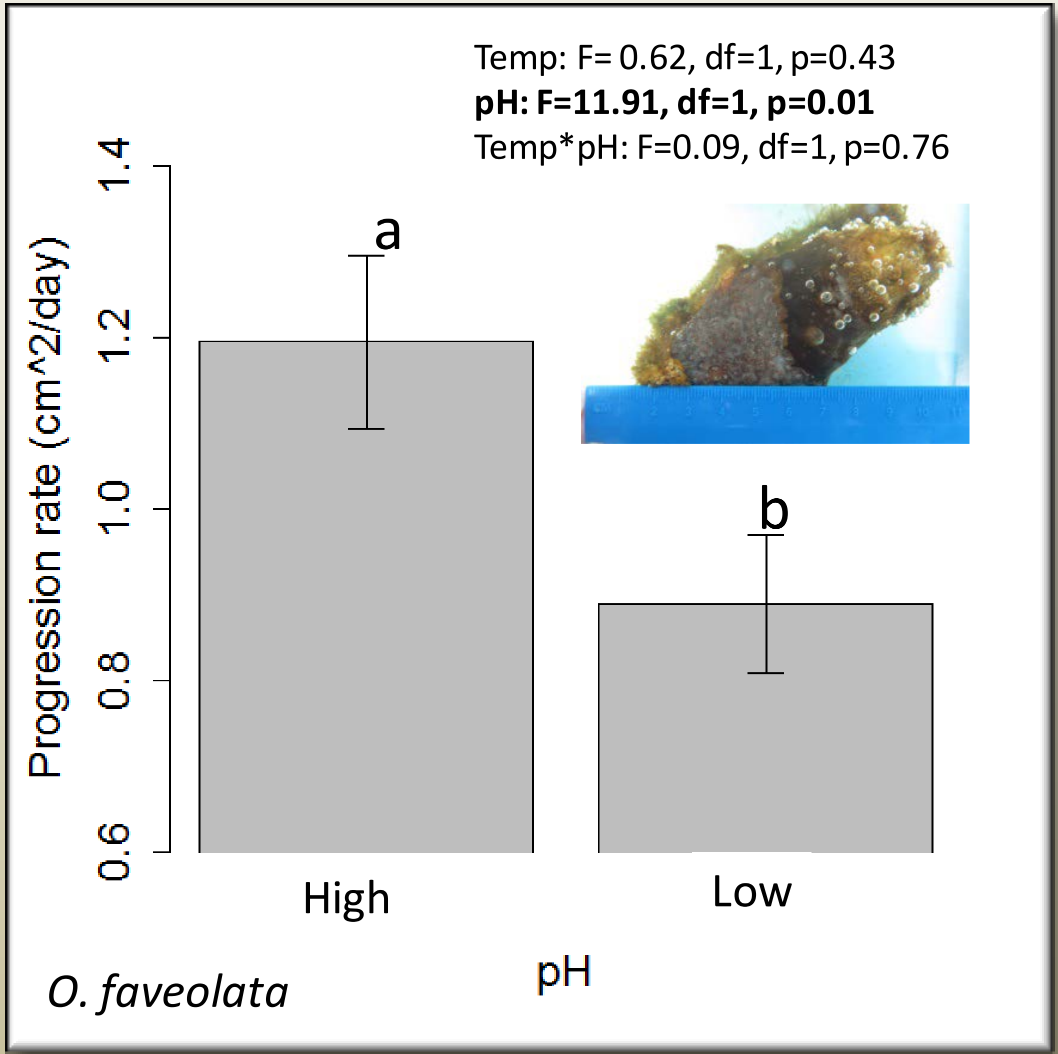
Low pH reduced progression of black band disease



Slide courtesy of Erin Muller, Mote Marine

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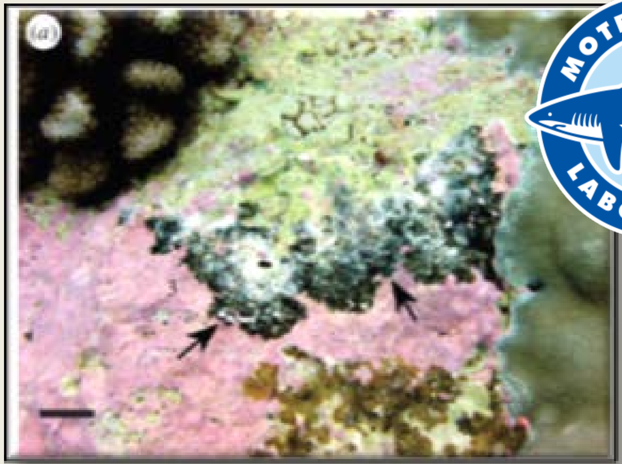
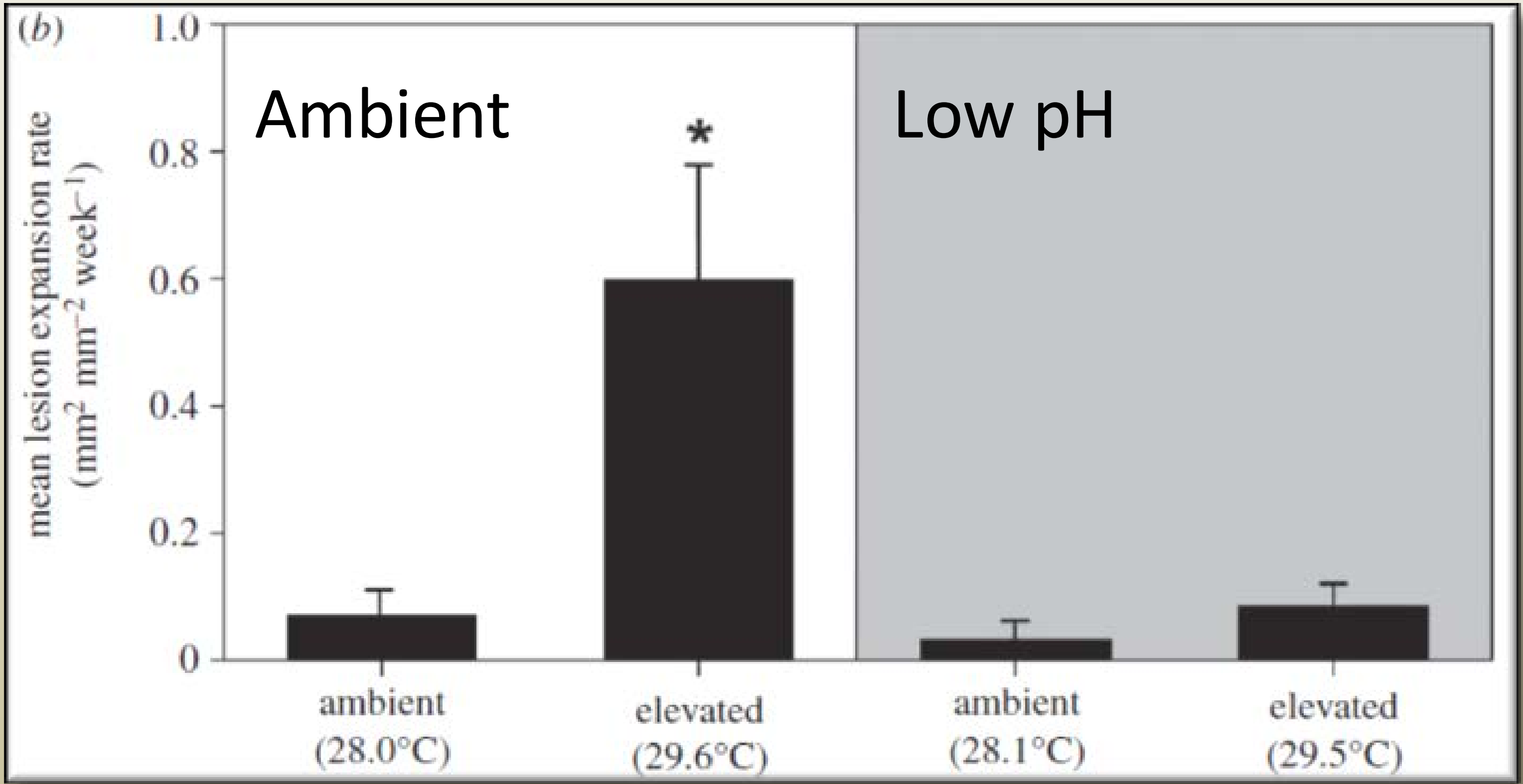
Low pH reduced virulence of coralline algae disease





Williams et al. 2014

Slide courtesy of Erin Muller, Mote Marine

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Ocean Acidification

-?

+?

Infectious disease

Coral Bleaching

?

Slide courtesy of Erin Muller, Mote Marine

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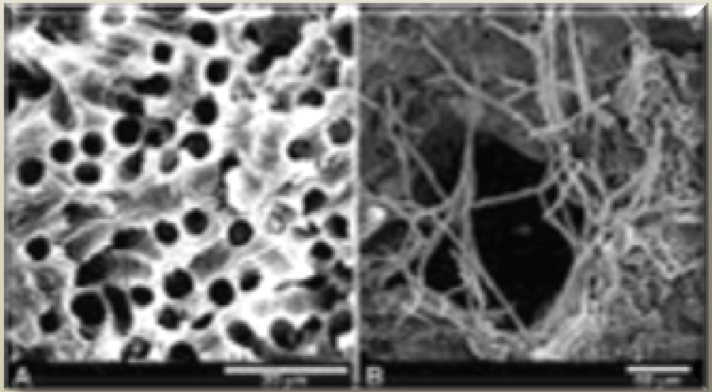
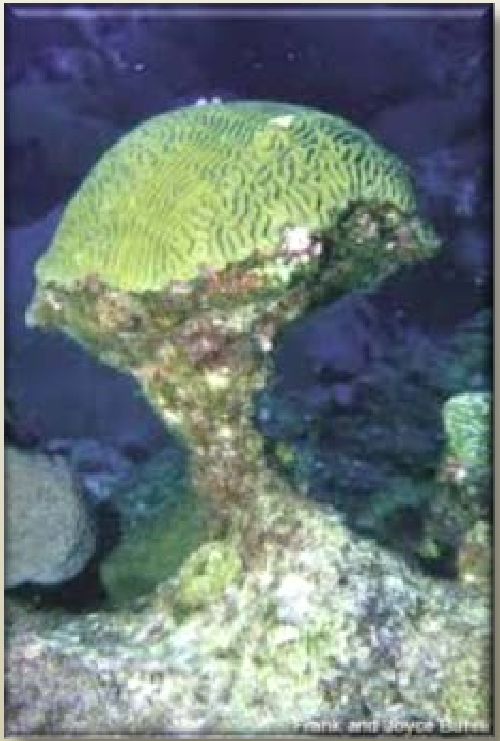
OA increases rates of bioerosion

At 2X pre-industrial CO_{2atm}…
…euendolithic algae dissolve
50% more carbonate
(Tribolet et al. 2009)





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Less of this

Long-term implications for reef function and structure

More of this

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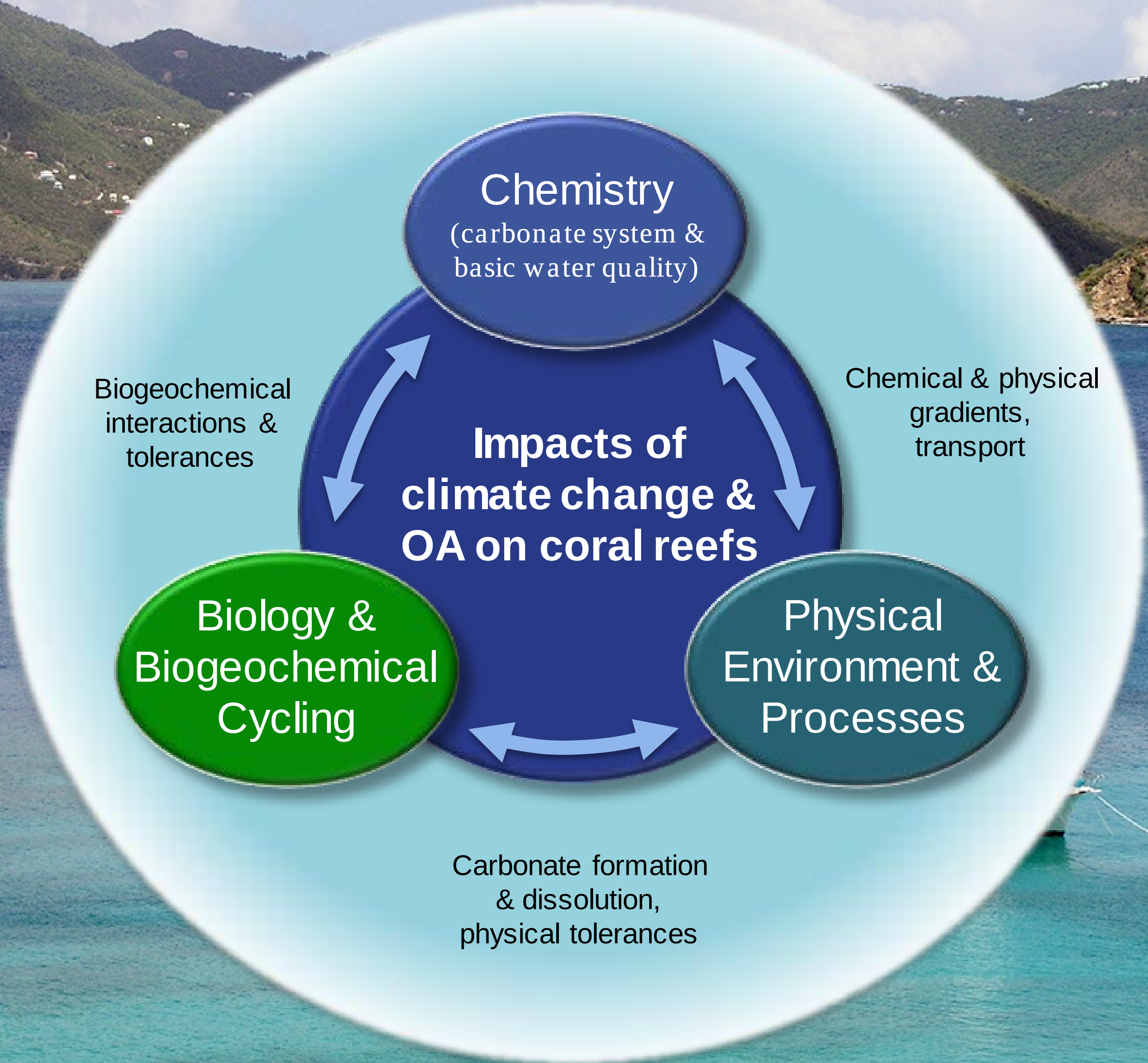
USGS Integrated Seascape Approach



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Measuring community calcification & dissolution

Biological processes

<u>Measured</u>

Total Alkalinity (TA)
Total Carbon (DIC)
Temperature
Salinity
pH
DO

Chemical environment

<u>Calculated</u>

Calc./Diss. ($g\ CaCO_3\ m^{-2}\ 4\ h^{-1}$)

$g = \frac{1}{2} \Delta TA \times {}^{SHARQ\ V}/_{SHARQ\ SA}$

CO_3^{2-}, pCO_2, Ω, exposure time

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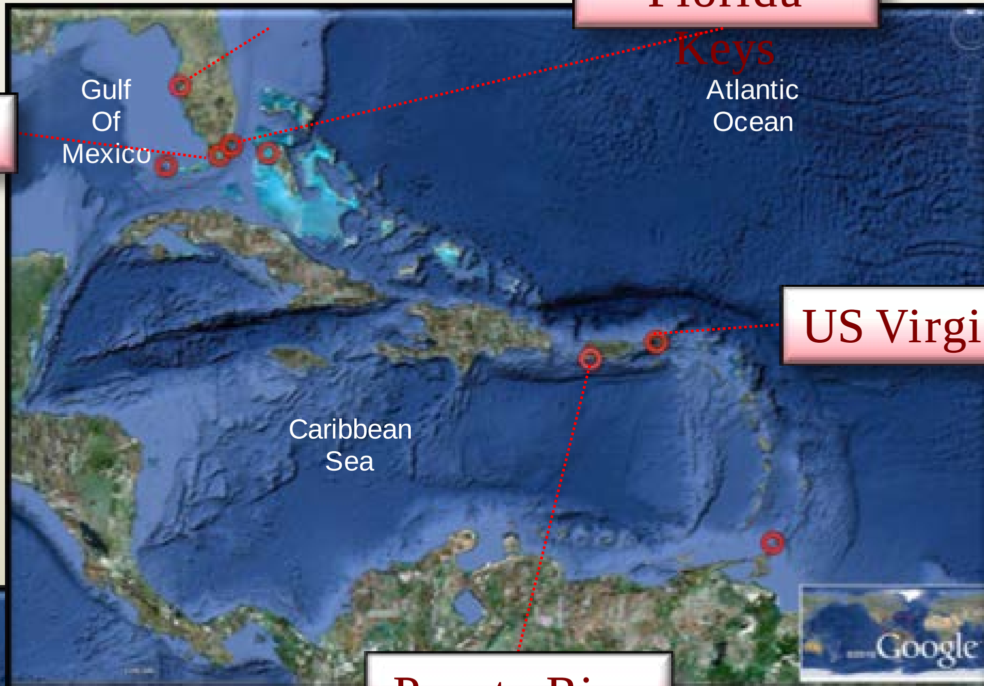
Atlantic, Pacific & Caribbean study sites…



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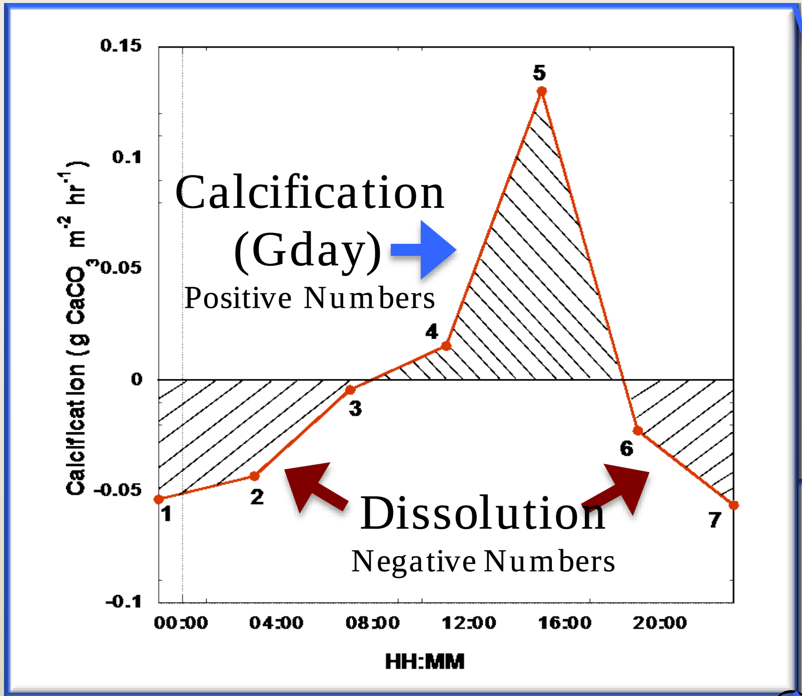
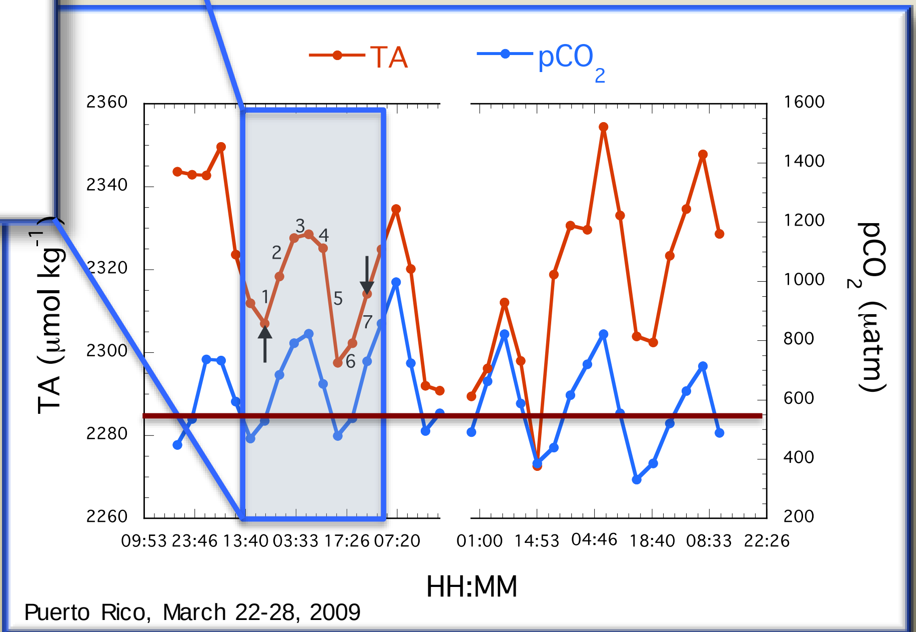
Calculating calcification & dissolution





Gnet = Gday + Dissolution

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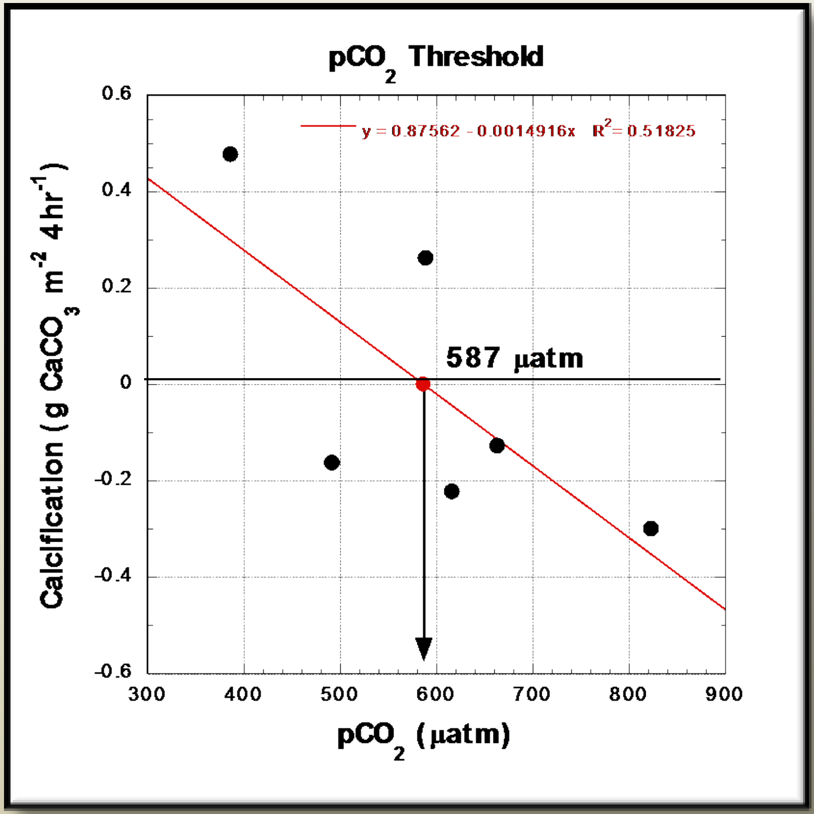
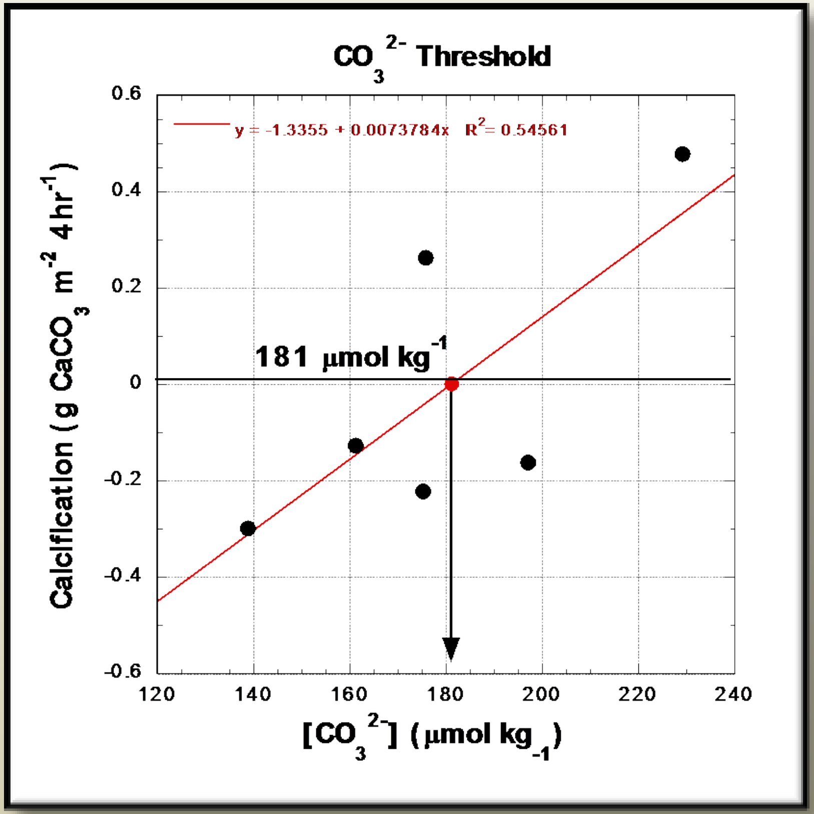
Calculating dissolution thresholds





Dissolution occurs when seawater pCO_2 > pCO_2 threshold and $[CO_3^{2-}]$ < CO_3^{2-} threshold.

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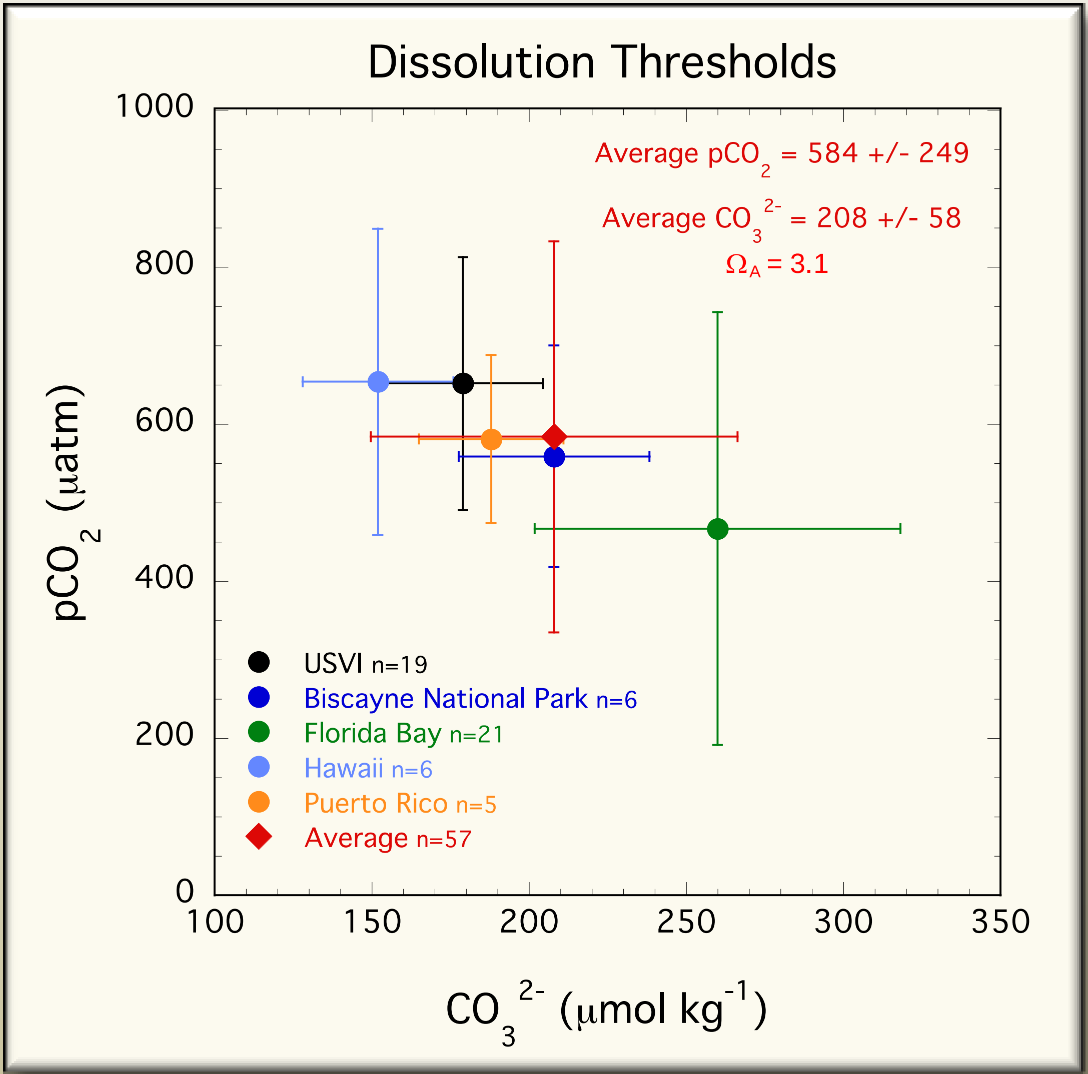
Dissolution thresholds are variable



Variation Due To:

- Community Composition
- Seasonal Variation in G
- Sediment composition
- Biological control on G
- Water mass residence time

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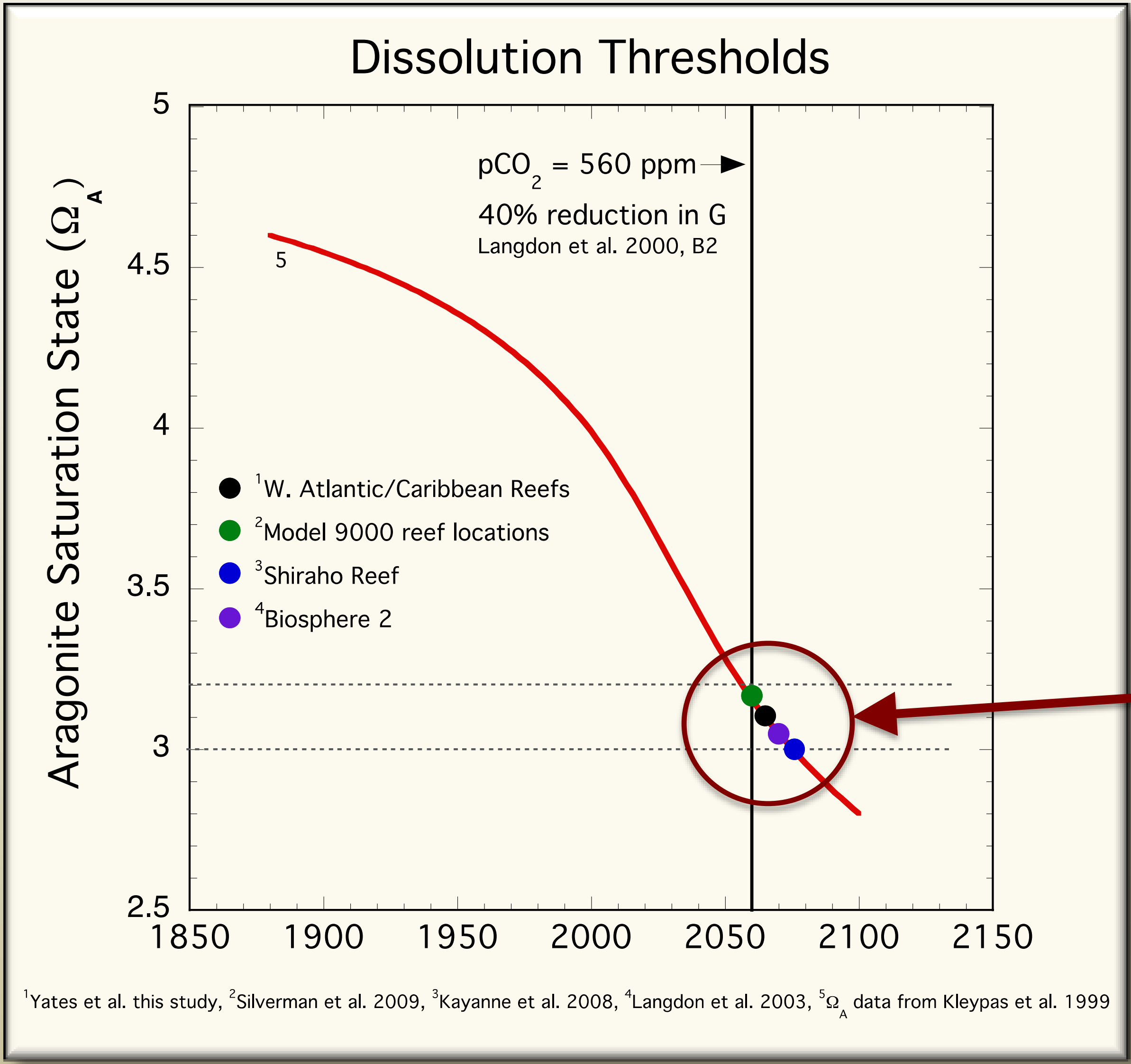
Merging Evidence for Dissolution Thresholds



Threshold Range

Ω_A 3.0 to 3.2

pCO_2 520 to 600 ppm

Year 2050-2060

Calcification/Dissolution Tipping Point

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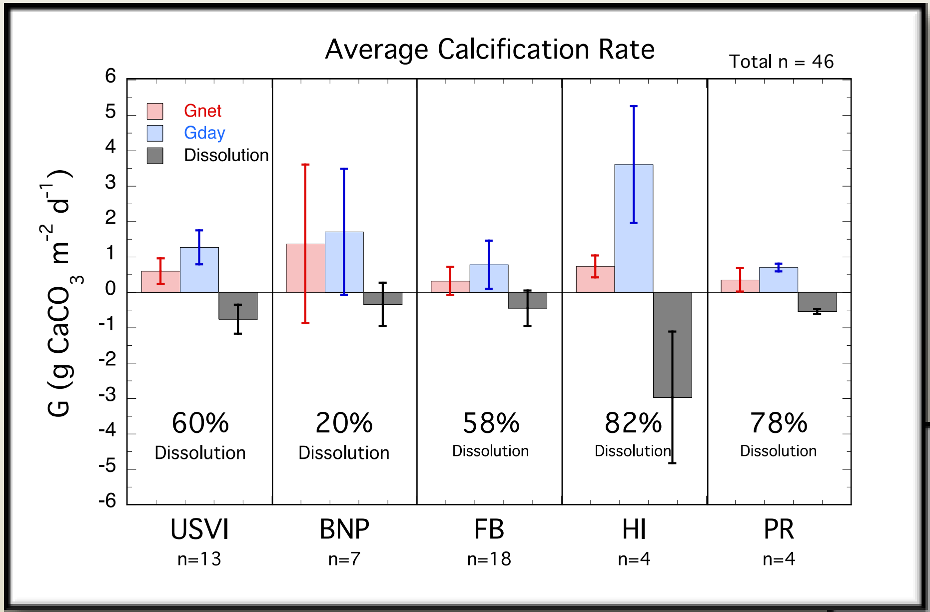
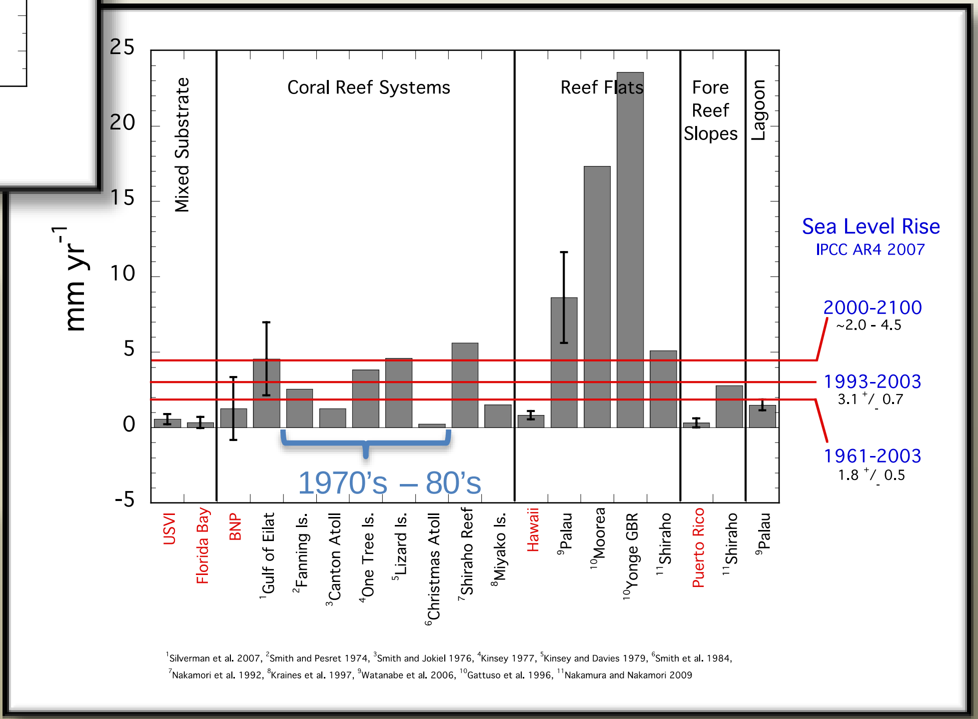
Reef accumulation & sea level rise



OA increases dissolution and decreases calcification

Much sediment dissolution is already occurring.

Many reefs are not keeping up with sea level rise…none of Caribbean sites



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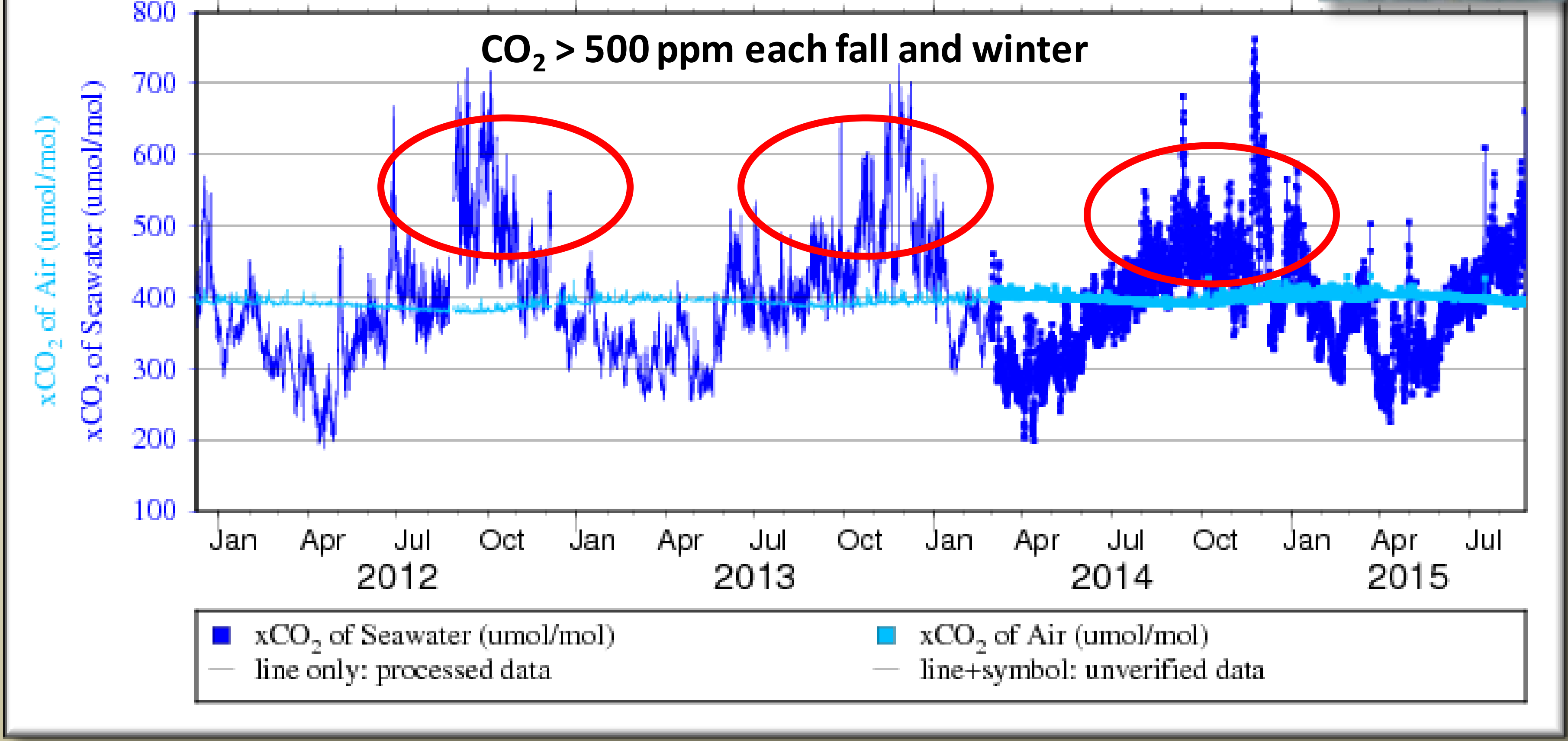
CO_2 thresholds are already exceeded during the winter



Slide courtesy of Chris Langdon, UM-RSMAS

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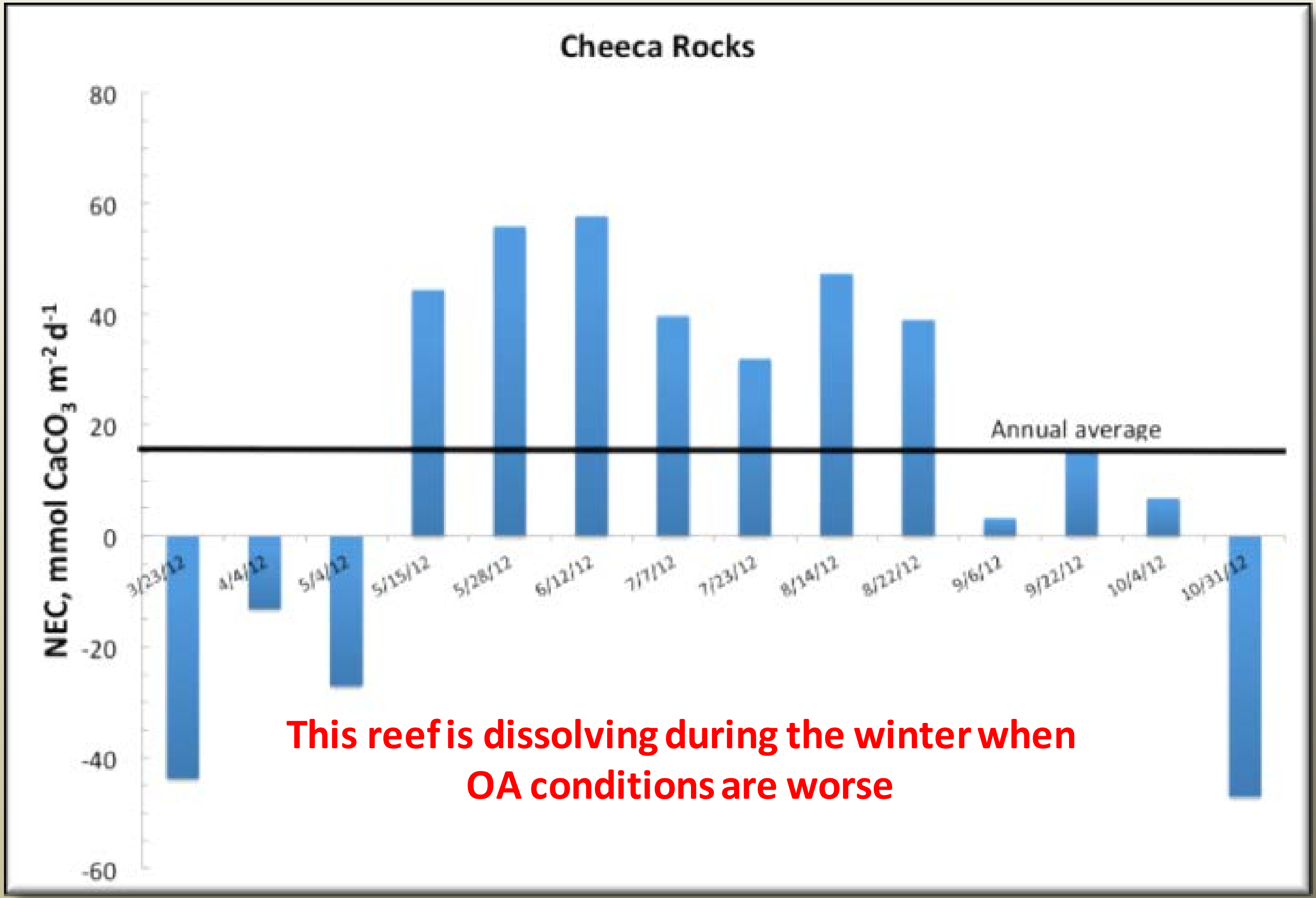
Reefs are already dissolving during the winter…

Annual cycle of reef-building and dissolution



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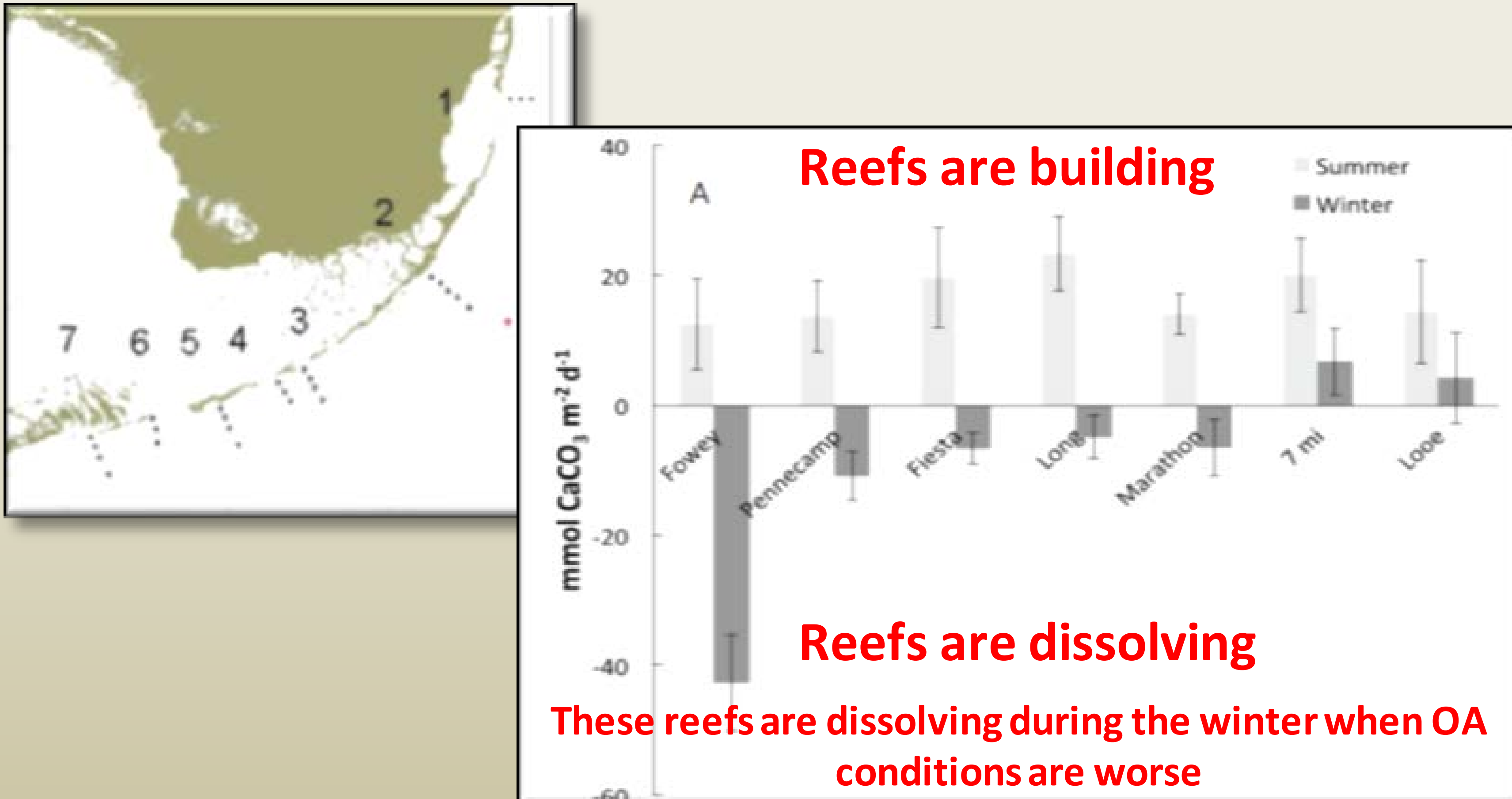
…throughout the Florida Keys

UNIVERSITY OF MIAMI

R/V Walton Smith surveyed the Florida Reef Tract in 2009 and 2010 to assess reef health



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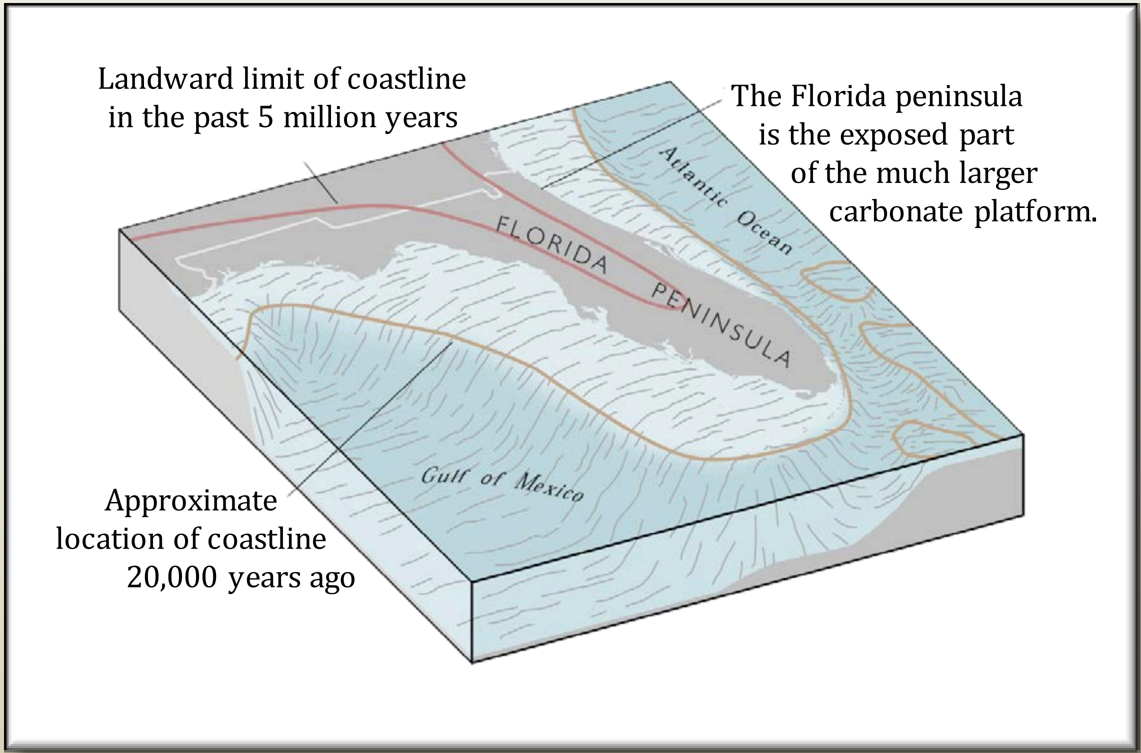
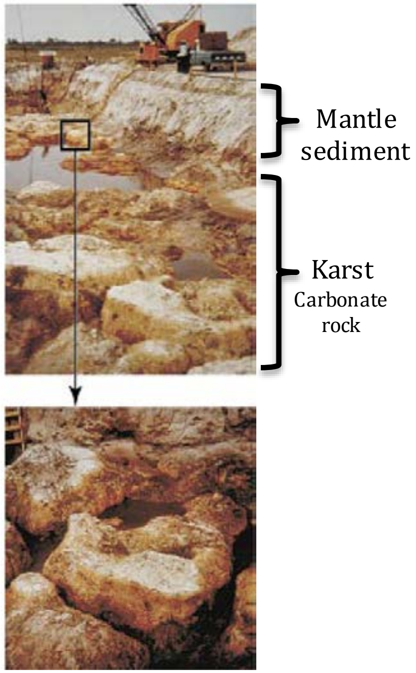
Florida is a carbonate platform that supports coastlines and coral reefs



Changes in sea level submerged & exposed the carbonate platform creating karst.

Karst topography



From: Tihansky 1999. US Geological Survey Circular 1182, p. 121-140.

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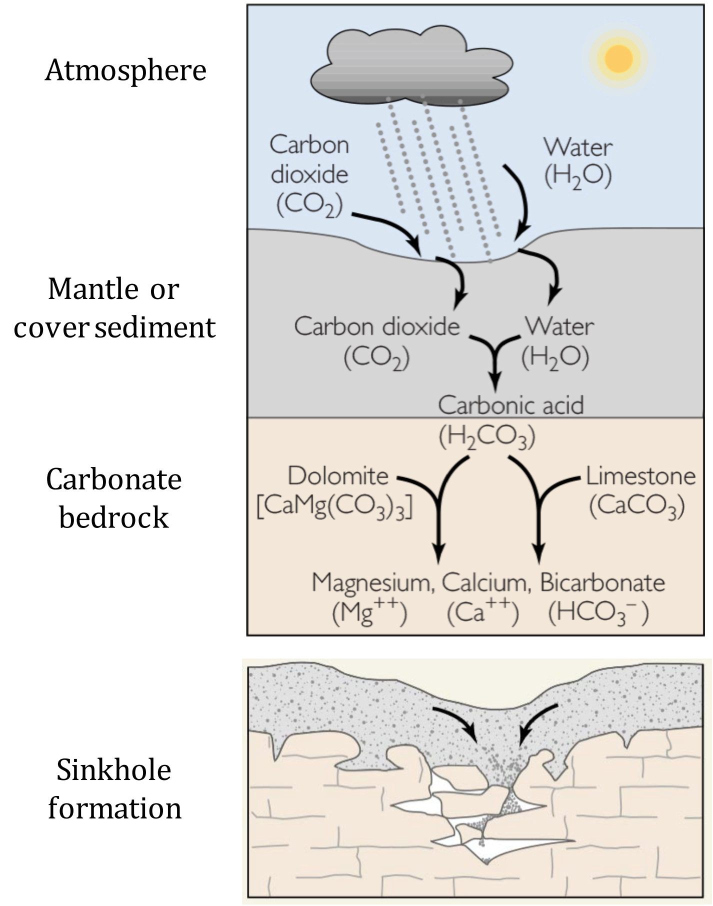
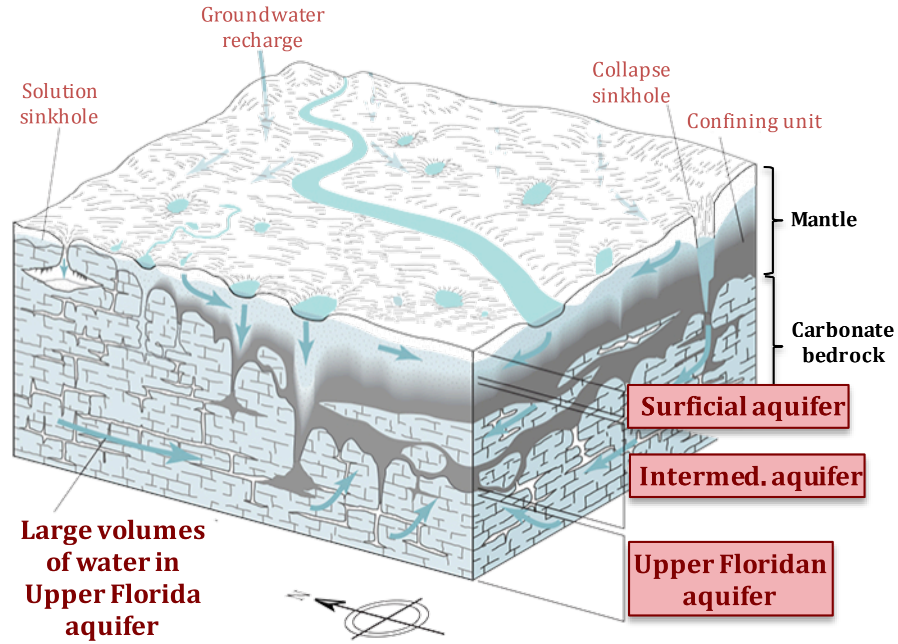
Karst forms Florida's sinkholes, aquifers & leaky coastal margins

Dissolution of carbonate rock forms sinkholes



How will coastal acidification affect carbonate coastlines, groundwater flow to aquifers & reefs?

Florida's aquifer system



From: Tihansky 1999. US Geological Survey Circular 1182, p. 121-140.

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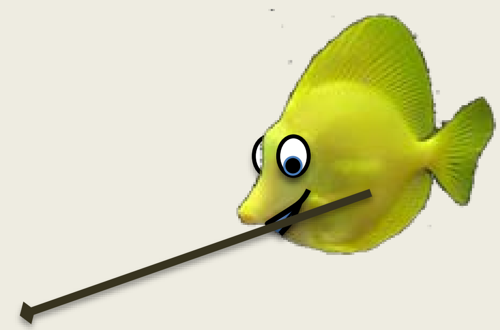
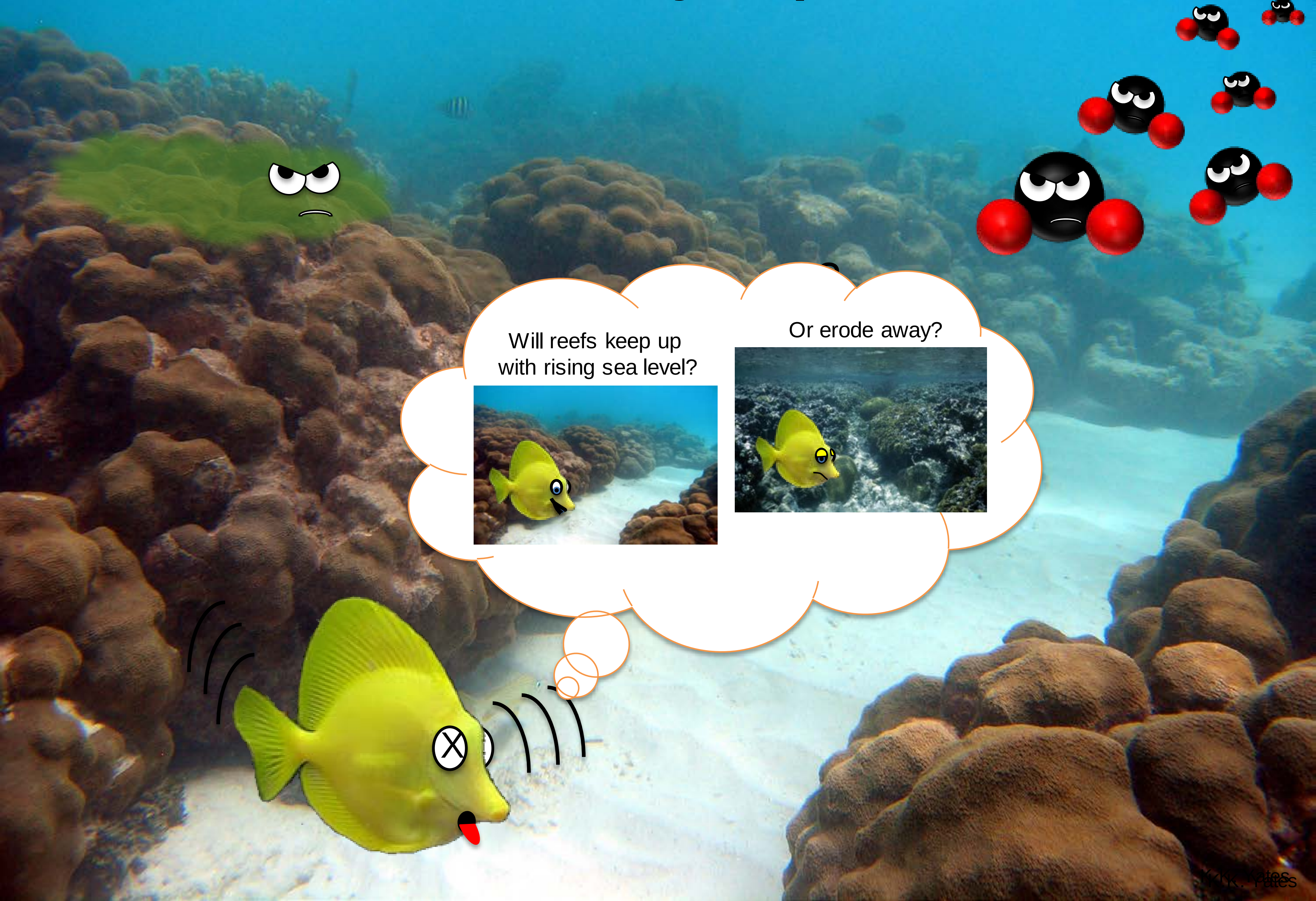
Key Points



- Reefs were not predicted to start dissolving until 2050-2060.
- The finding that reefs in Florida & the Caribbean are already starting to dissolve, even if for only part of the year, is surprising & alarming.
- The affects of coastal acidification on carbonate platforms are unknown but a concern.
- The threat of OA is a present threat…not a future threat.

Modified from C. Langdon, UM-RSMAS

Is there any hope?!?!



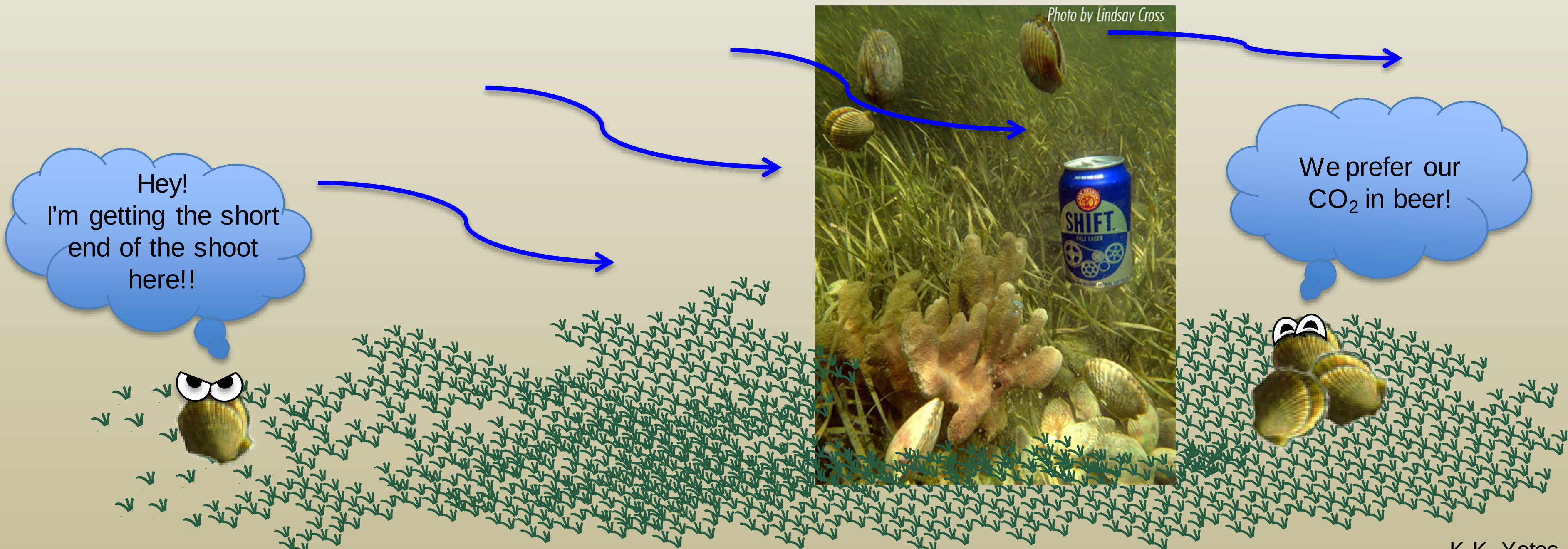
Seagrass photosynthesis buffers OA

Photosynthesis → Consumes CO_2, Produces O_2, Increases pH

$$CO_2 + H_2O + \text{sunlight} \longleftrightarrow CH_2O + O_2$$

Depends on:

- Proximity & water flow (short-term effects)
- Water mass residence time (short & long-term effects)



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Recent studies indicate that some reefs may function as either OA or solar stress refuges

2012

OPEN ACCESS Freely available online — PLoS one

Ocean Acidification Refugia of the Florida Reef Tract

Derek P. Manzello[1,2]*, Ian C. Enochs[1,2], Nelson Melo[1,2], Dwight K. Gledhill[3], Elizabeth M. Johns[2]

1 Cooperative Institute for Marine and Atmospheric Studies, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida, United States of America, 2 Atlantic Oceanographic and Meteorological Laboratories, National Oceanic and Atmospheric Administration, Miami, Florida, United States of America, 3 Ocean Acidification Program, National Oceanic and Atmospheric Administration, Silver Spring, Maryland, United States of America

OA Refuge

- photosynthesis increases pH, Ω_A
- water mass residence time
- habitat proximity & flow

Solar Stress Refuge

- shading in turbid water
- exposure to high temp
- more resistant species

2012

Ecology and Evolution — Open Access

Climate-change refugia in the sheltered bays of Palau: analogs of future reefs

Robert van Woesik[1], Peter Houk[2], Adelle L. Isechal[3], Jacques W. Idechong[3], Steven Victor[4] & Yimnang Golbuu[3]

[1]Department of Biological Sciences, Florida Institute of Technology, 150 West University Drive, Melbourne, Florida, 32901
[2]Pacific Marine Resources Institute, Saipan, MP, 96950
[3]Palau International Coral Reef Center, 1 M-Dock Road, P.O. Box 7086, Koror, 96940, Palau
[4]Nature Conservancy, Palau Field Office, P.O. Box 1738, Koror, 96940, Palau

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Natural, alternative (non-reef), shallow water refuges in mangrove-coral habitats of St. John, USVI protect from both solar stress and OA.

33 coral species!

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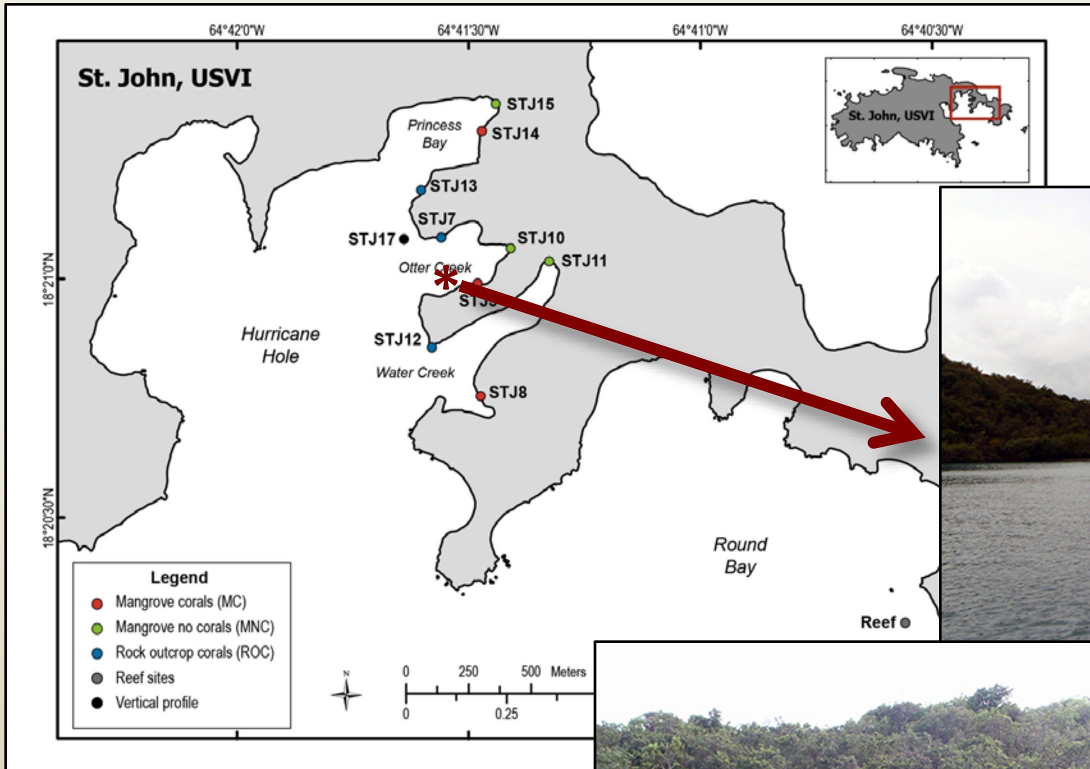
Hurricane Hole, St. John is characterized by…



Small watersheds and no permanent sources of freshwater inflow!

Most mangrove habitats will not be suitable as coral refuges!

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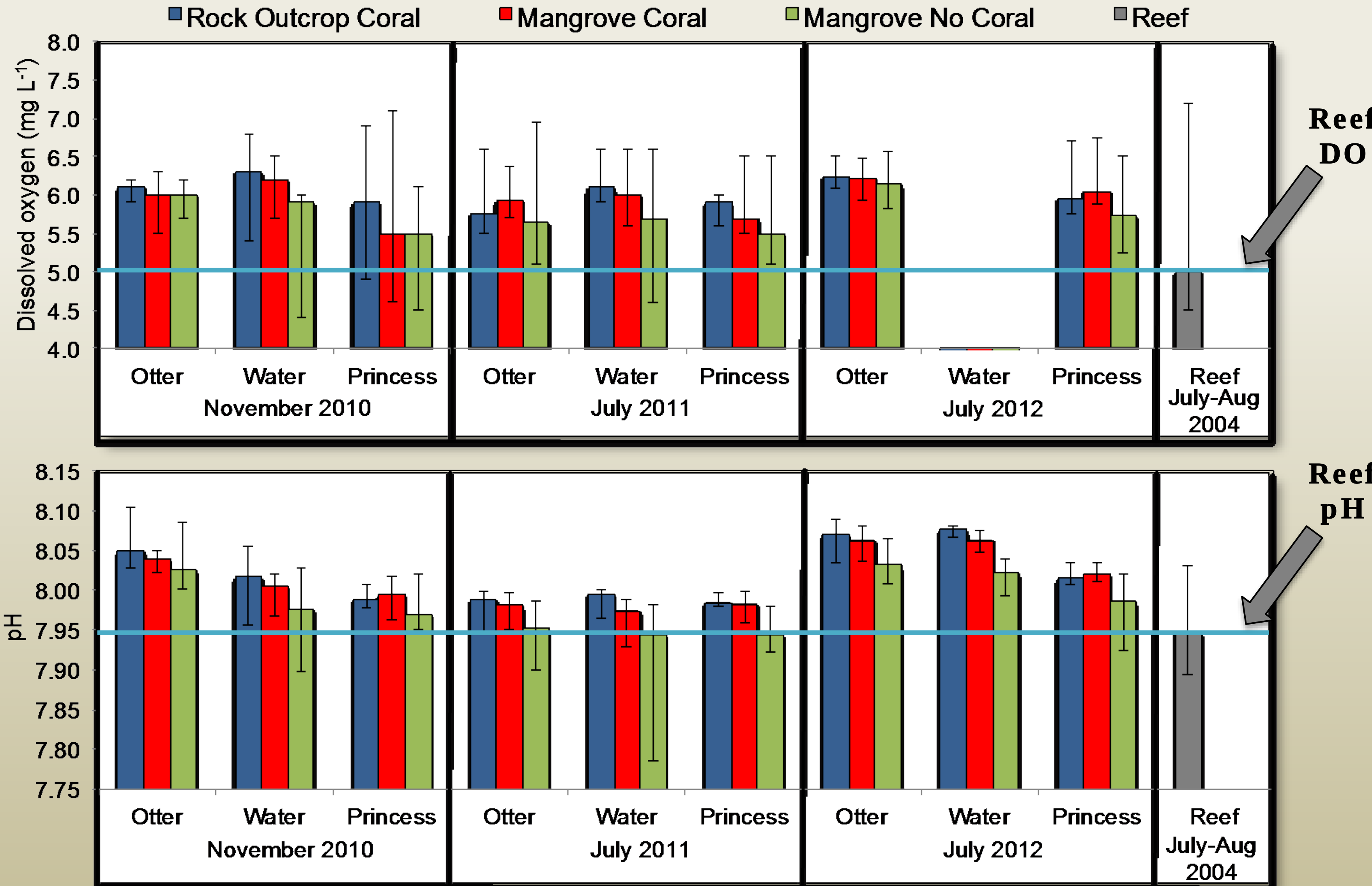
DO and pH is higher in mangrove habitats than on the reef



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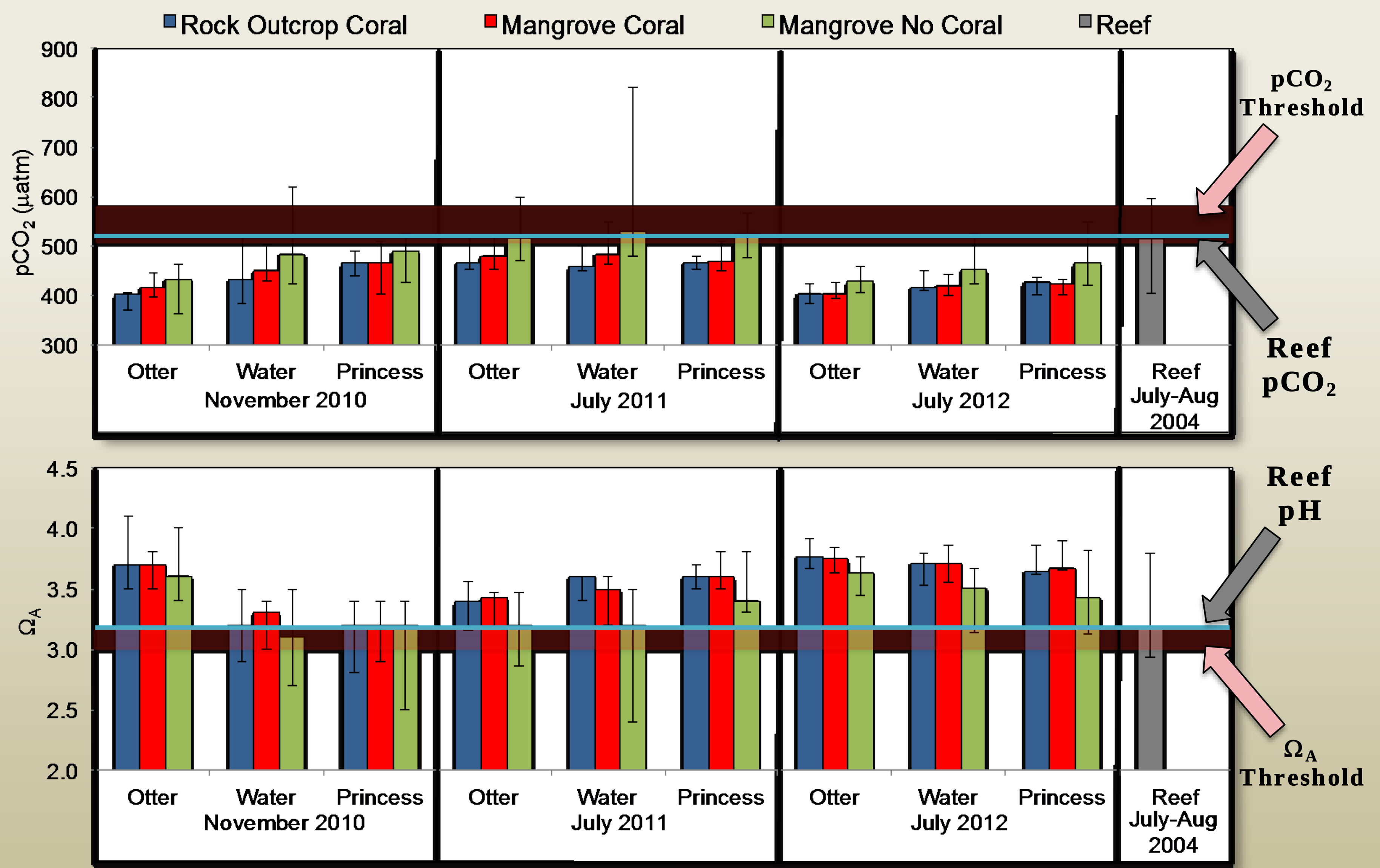
pCO_2 is lower and Ω_A is higher in mangrove habitats than on the reef



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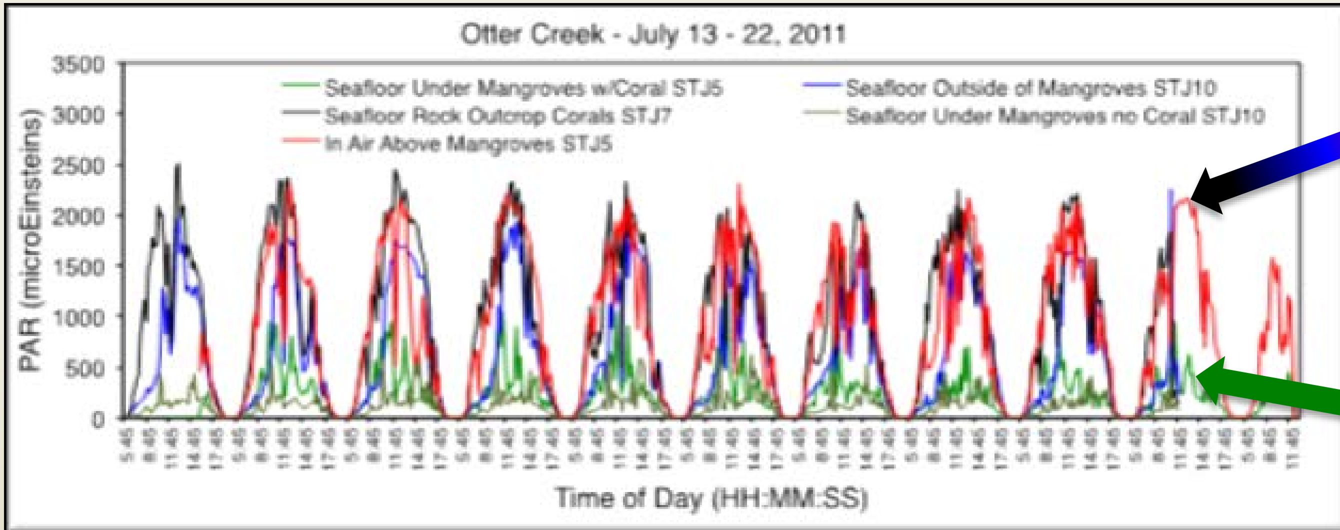
Mangrove corals live in the shade and at higher temperatures than reef corals

Physical Env.

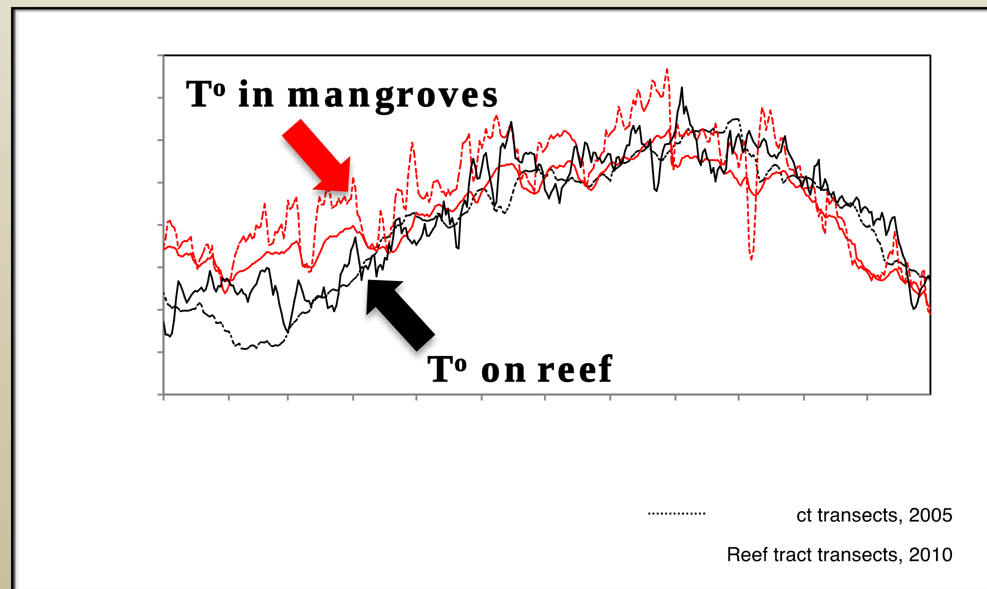


PAR outside mangroves

PAR under mangroves

Mangrove canopy shades corals and reduces PAR more than 70%

Temperature higher in mangrove-coral habitats than on reef



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Where in the world are other mangrove-coral refuges?

Indonesia, Raja Ampat

Panama Bocas del Toro

Belize, Pelican Cay

Florida, BNP?

- None in the geologic record.
- New ecosystem transition due to unprecedented rates of recent climate change?

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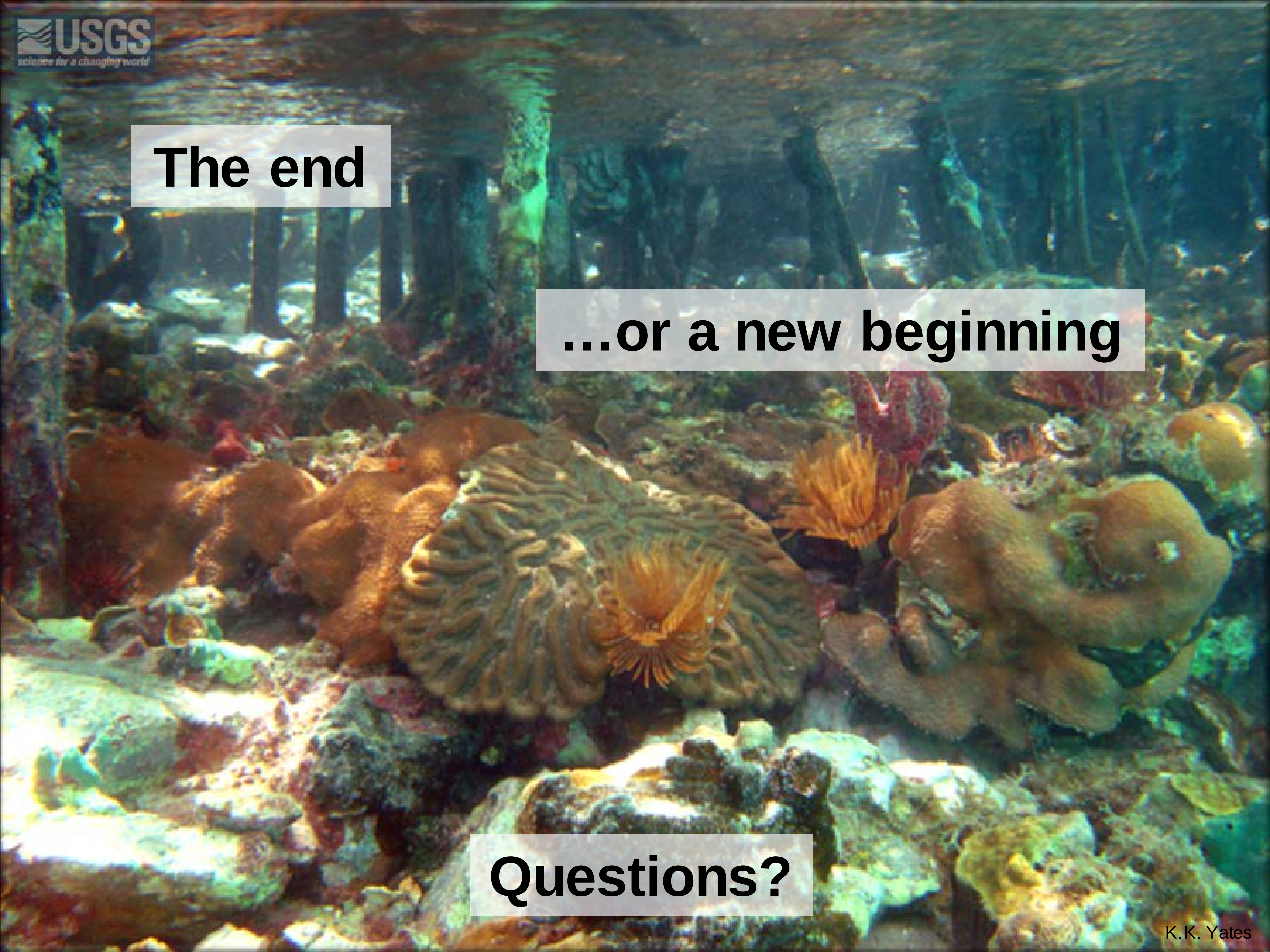
Presentation summary

- Coral reefs grow slowly & are degrading rapidly in the Florida Keys and Caribbean.
- Local threats have already set an ‘unhealthy baseline’.
- Ocean acidification causes loss of reef function & structure…reefs in the Keys and Caribbean are already dissolving…the threat is already here.
- Protection of natural, shallow-water refuges is a direct local action to help manage global climate change impacts, especially as sea level rises.

K.K. Yates


USGS
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The end
…or a new beginning
Questions?
K.K. Yates