Climate Change Impacts on South Florida Coral Reefs

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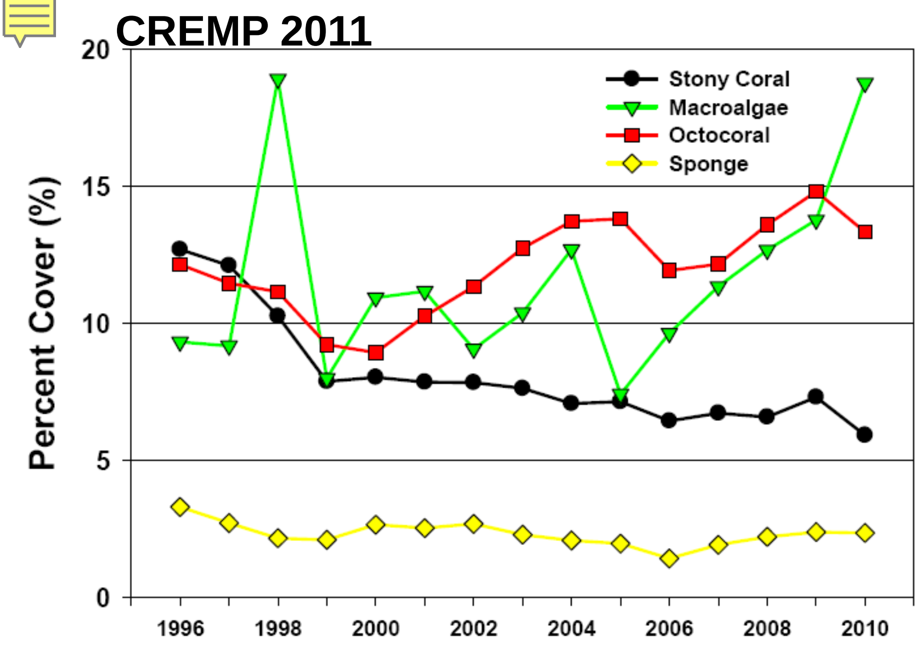
Mechanisms of Climate Change Impact on Corals

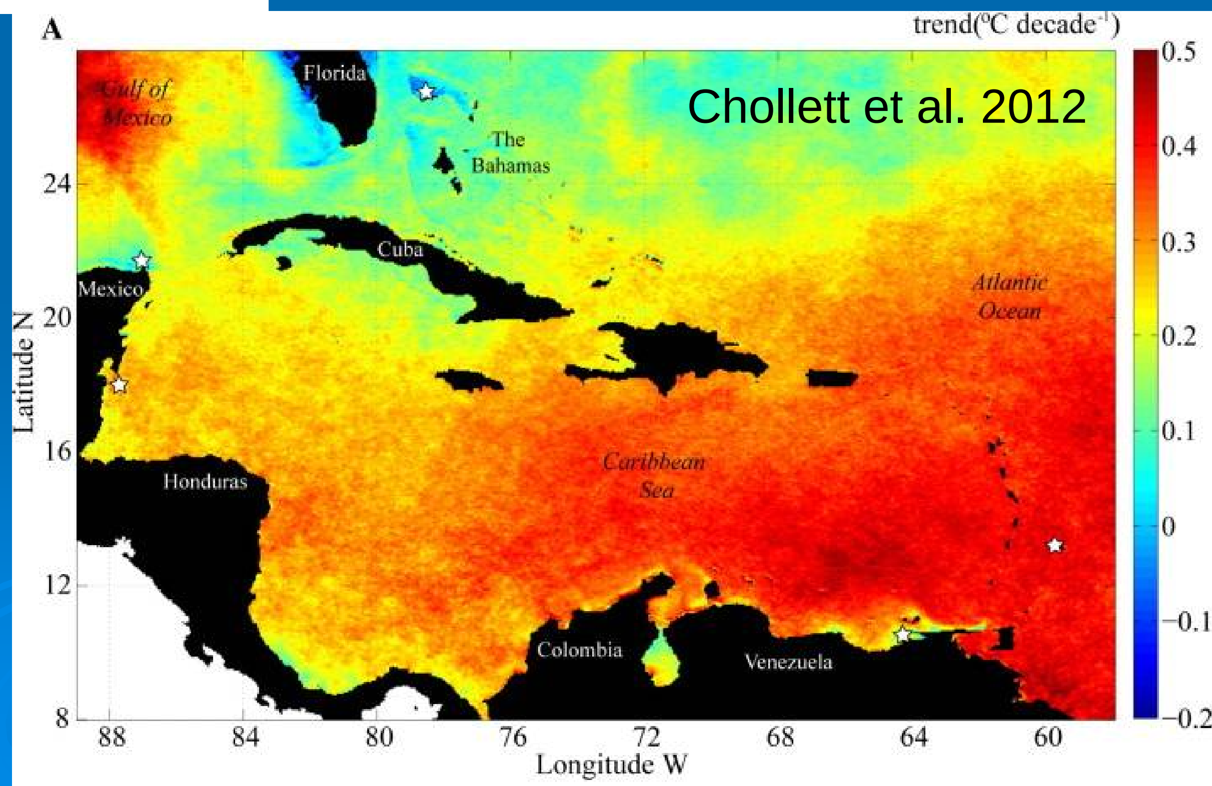
- Warming temperatures
- Ocean Acidification
  - i.e. carbonate chemistry changes
- Sea Level Rise

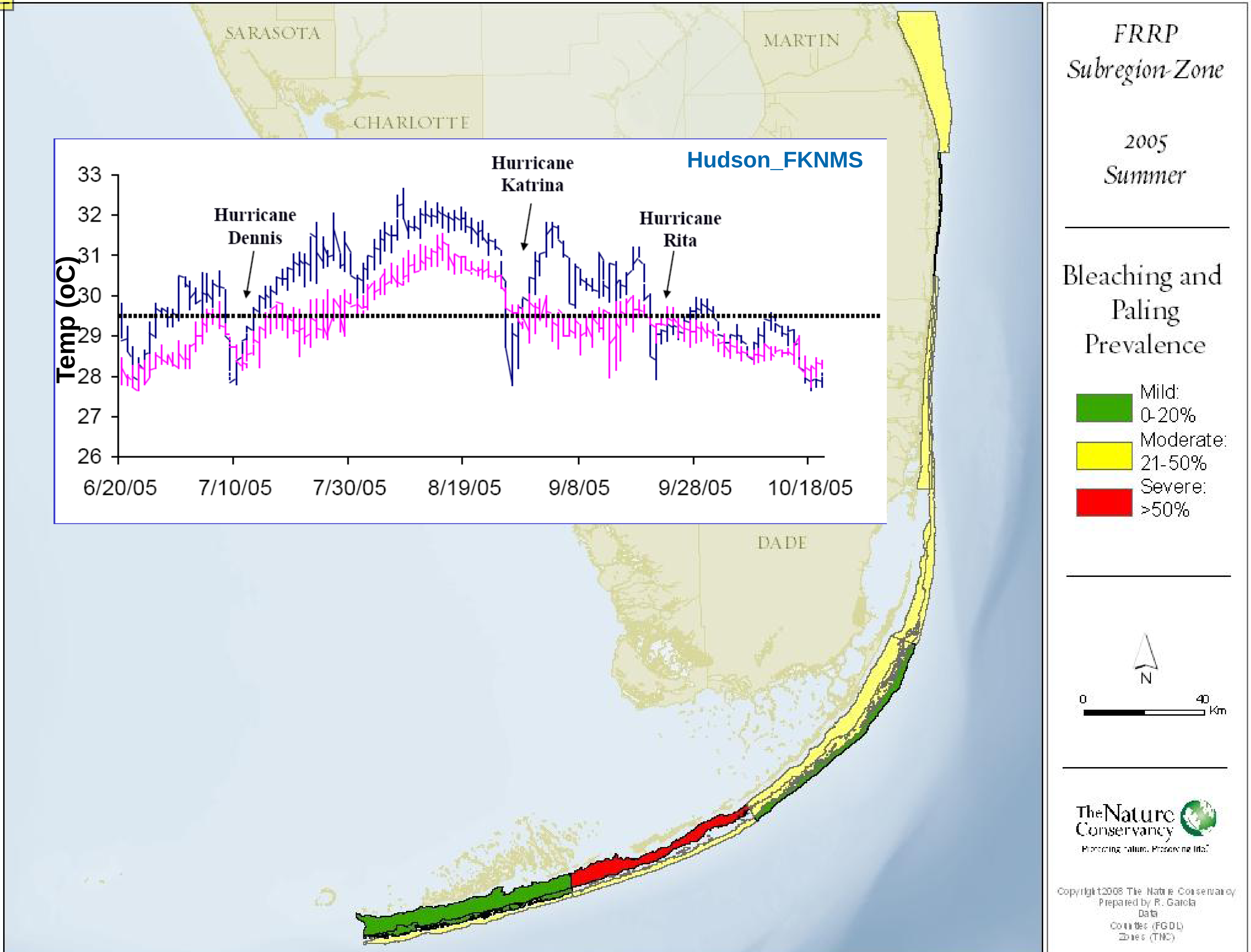
Mechanisms of Climate Change Impact on Corals - 2050

- Warming temperatures
- Already
  - (Bleaching, Disease, Reproduction)
- Ocean Acidification
  - i.e. carbonate chemistry changes
- Maybe/Maybe Not Yet
- Sea Level Rise
- Direct effects may be trivial . .
  - Indirect impacts unclear
    - Altered shoreline status
    - Altered runoff



- Coral Bleaching (physiological stress breaks down endosymbiosis)
  - Differential tolerance
- Major coral bleaching events in the Florida Keys:
  - 1983,1987, 1990, 1991, 1997-8 **(Causey 2001),** 2005




SARASOTA
MARTIN
CHARLOTTE
DADE
Hudson_FKNMS
Hurricane Dennis
Hurricane Katrina
Hurricane Rita
Temp (oC)
33
32
31
30
29
28
27
26
6/20/05
7/10/05
7/30/05
8/19/05
9/8/05
9/28/05
10/18/05
FRRP Subregion-Zone
2005 Summer
Bleaching and Paling Prevalence
Mild: 0-20%
Moderate: 21-50%
Severe: >50%
N
0
40 Km
The Nature Conservancy
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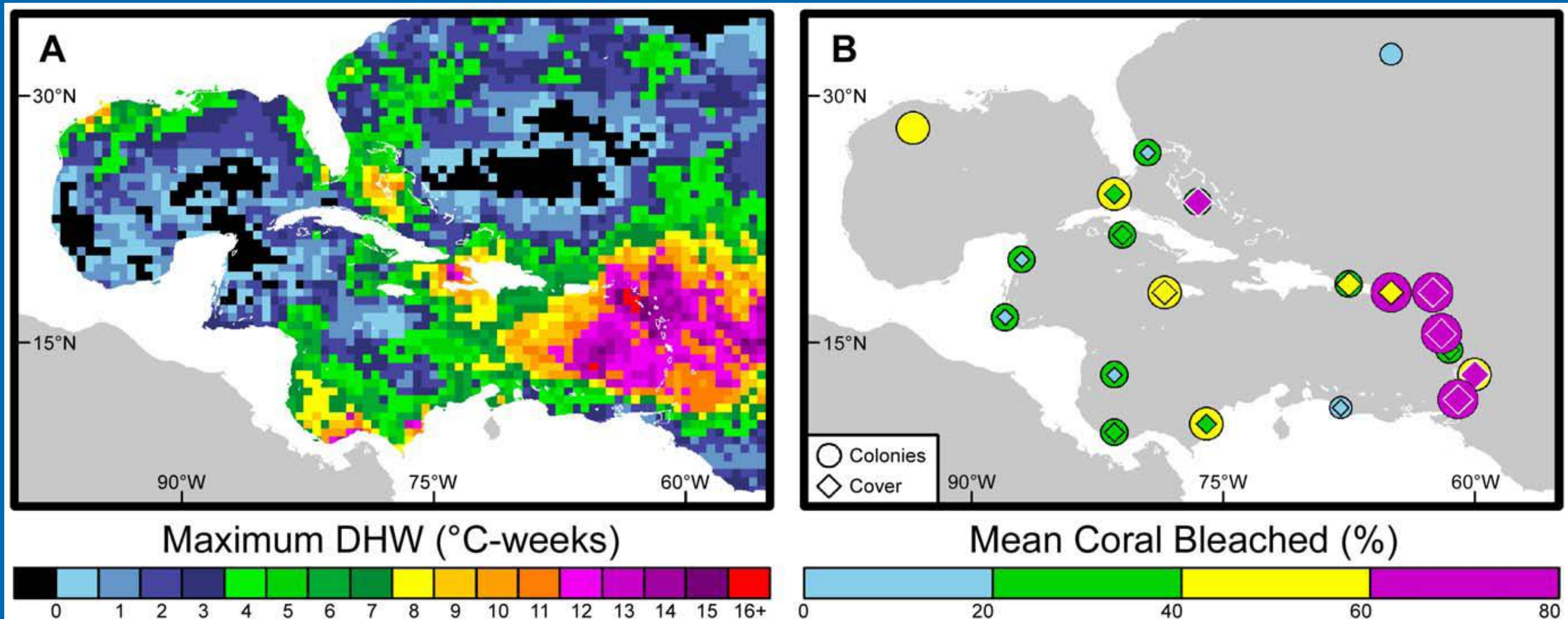
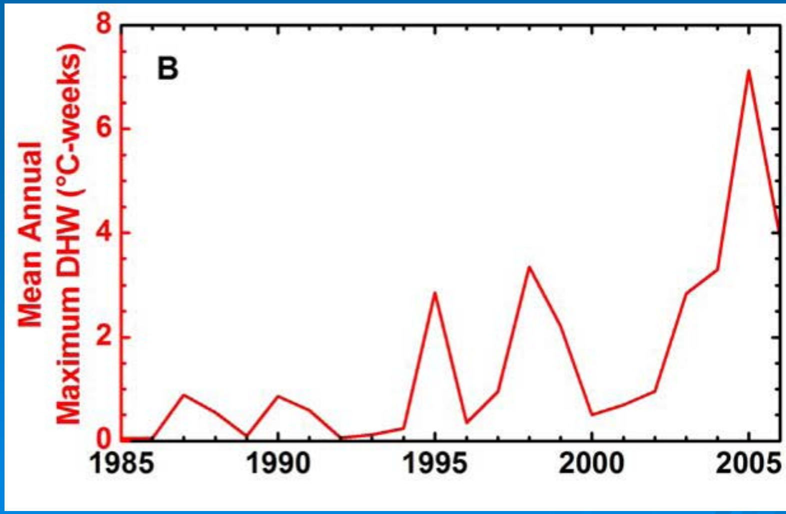
Prepared by R. Garcia
Data
Counties (FGDL)
Zones (TNC)

2005 Caribbean-wide

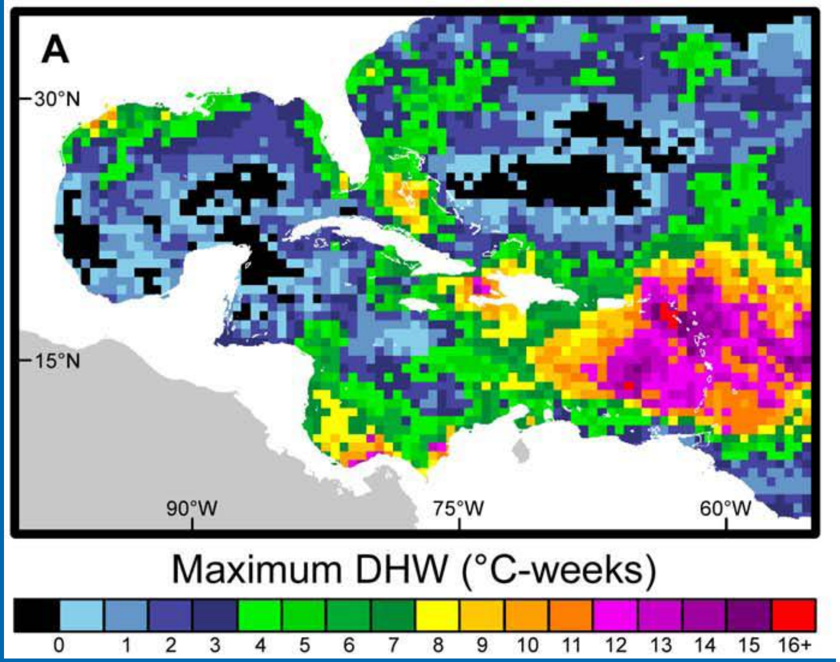


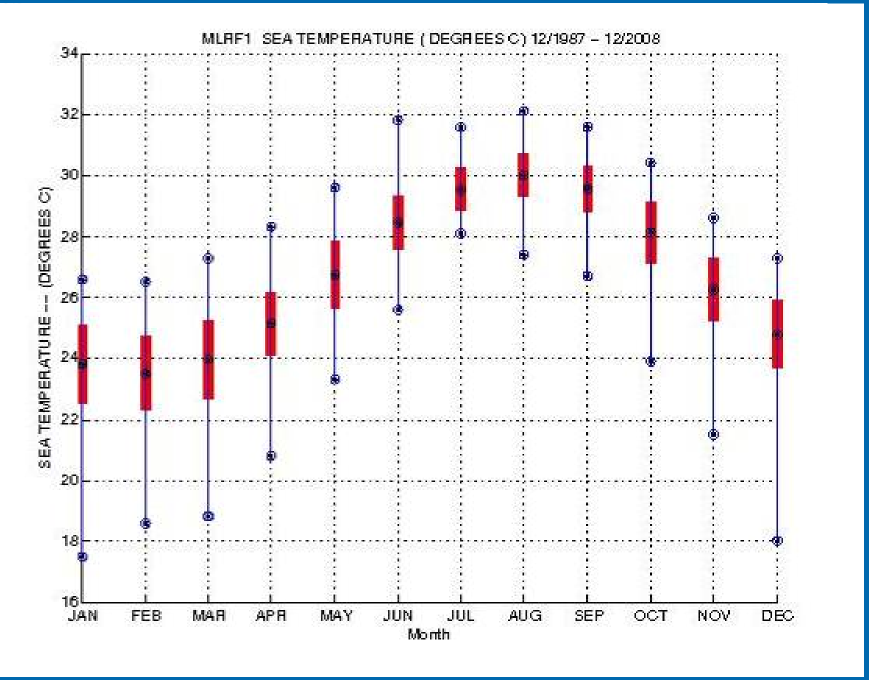


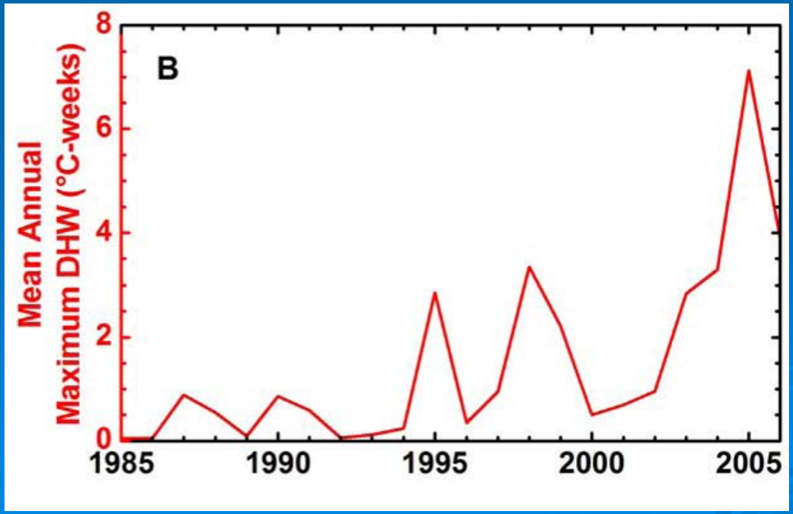
- Bleaching prediction currently based on cumulative ‘dose’ (DHW) over long term max temp.
- At +1.5-2oC, likely to be severe annual bleaching

Eakin et al. 2010

2005 Caribbean-wide







- Bleaching prediction currently based on cumulative 'dose' (DHW) over long term max temp.
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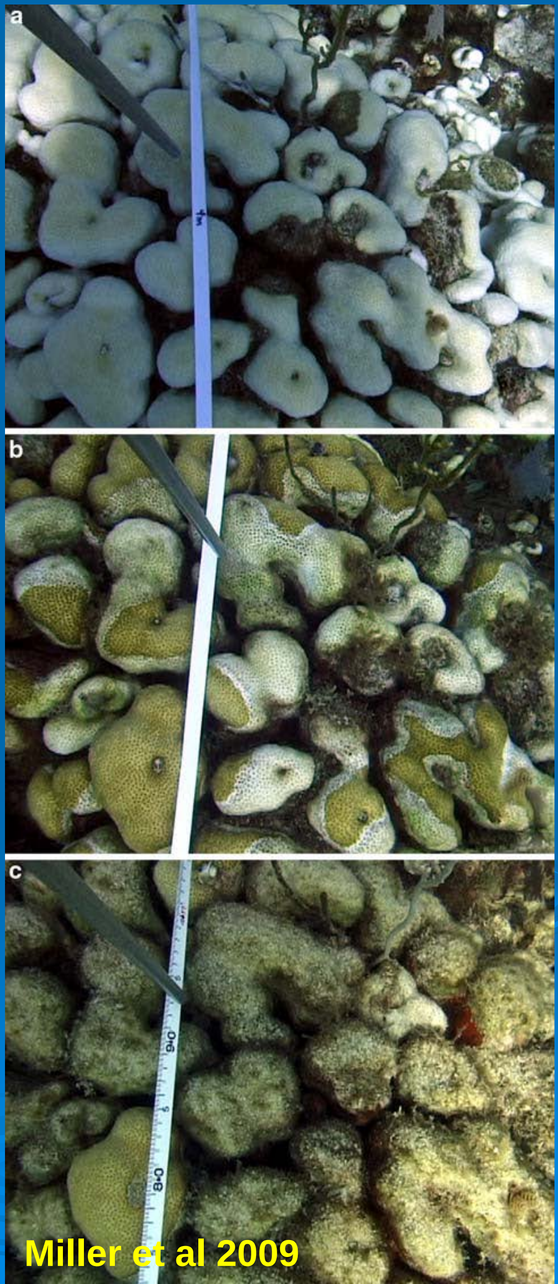
Eakin et al. 2010

Warming – So Far

- Disease
  - Etiologies poorly characterized
  - Linked with warm temp extremes, with and/or without bleaching
    - Host compromise
    - Increased pathogenicity?
  - Linked with warmer winters

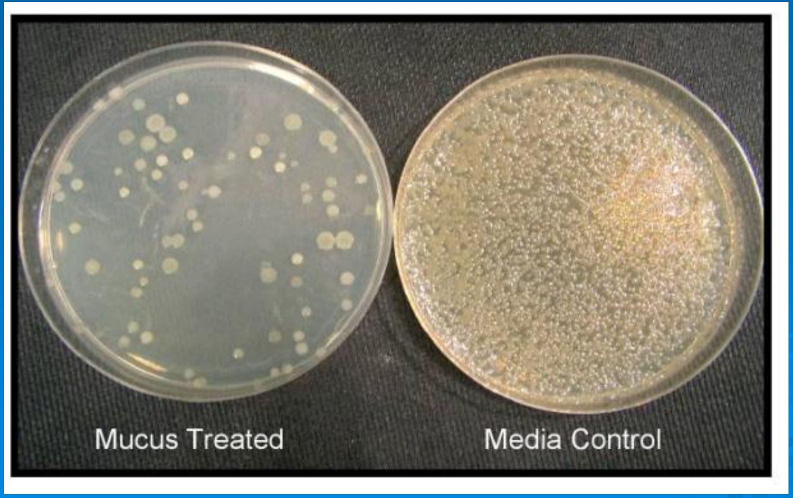
2005 USVI: 60% coral loss



Increased Disease Susceptibility

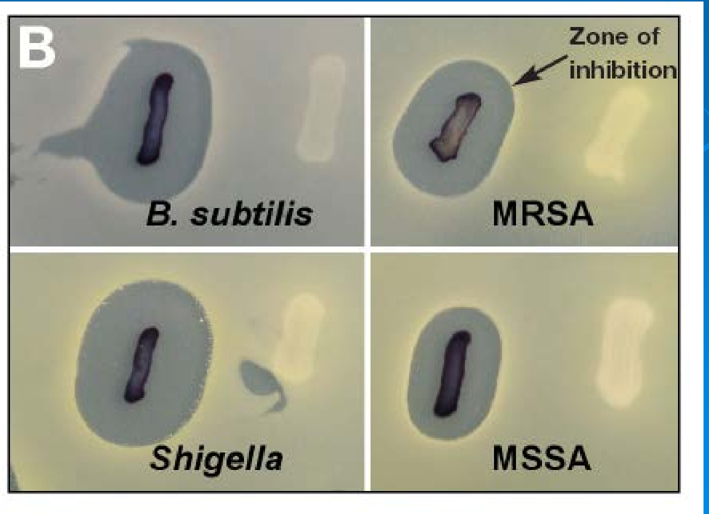
Inoculum	April 2005			September 2005		
	No. of colonies		Fold inhibition	No. of colonies		Fold inhibition
	G+UV (ctrl)	G+M+UV (expt)		G+UV (ctrl)	G+M+UV (expt)	
Bacillus subtilis	395 (±22)	51 (±11)	7.8	–	–	–
Staphylococcus aureus	245 (±40)	46 (±10)	5.4	–	–	–
Salmonella typhimurium	217 (±34)	55 (±12)	3.9	–	–	–
Serratia marcescens	193 (±33)	91 (±13)	2.1	233 (±26)	277 (±25)	–0.8
Water column	305 (±29)	76 (±7)	4.0	188 (±27)	231 (±14)	–0.8
Canal water	269 (±24)	27 (±9)	10.0	328 (±28)	274 (±20)	1.2
African dust	278 (±51)	65 (±9)	4.3	206 (±24)	191 (±22)	1.1

Ritchie 2006



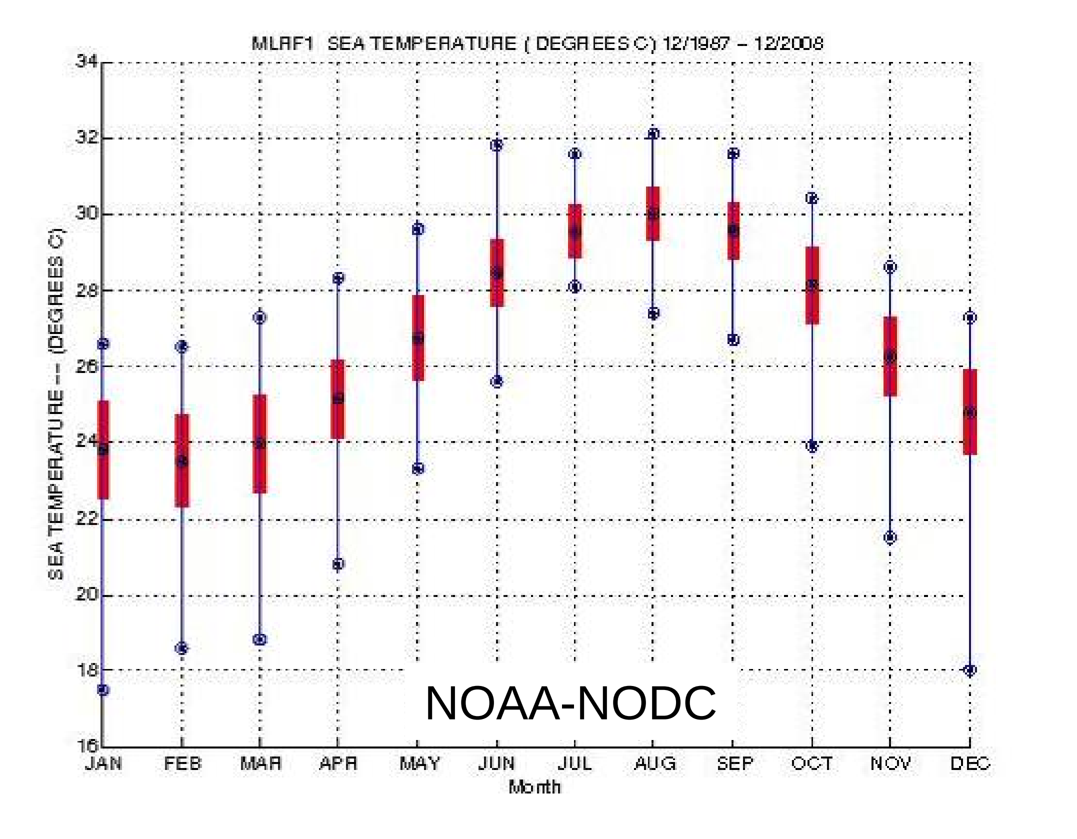
Before

Bleached

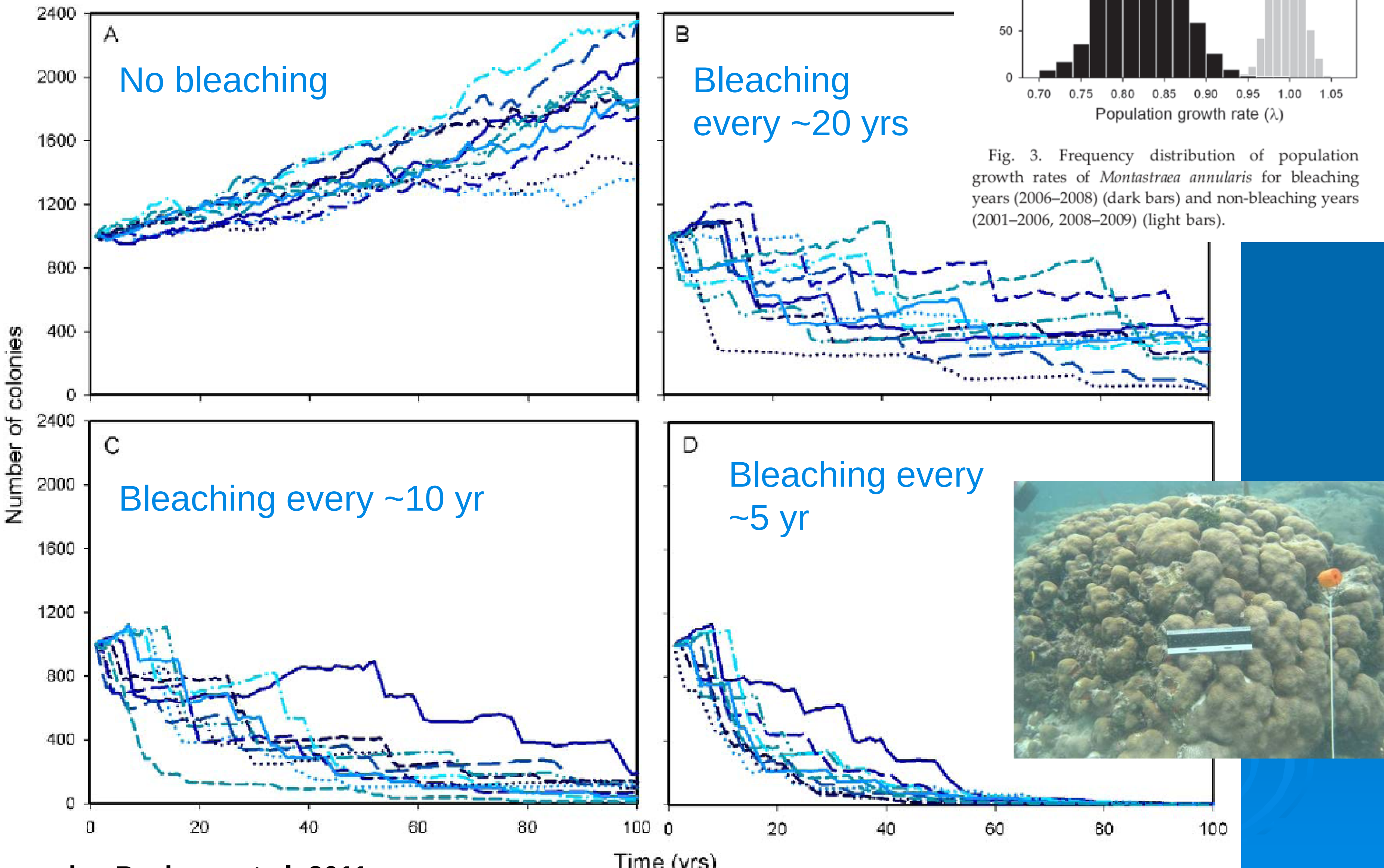


Warming on Coral Reproduction-Already?

- Experimental work suggests, in the range of 30-31.5oC
  - increased prevalence of abnormal embryonic development (Polato et al 2010, Randall and Szmant 2009)
  - Accelerated development
  - Reduced larval survivorship (up to 8-fold, Randall and Szmant 2009)
  - Reduced settlement (40%)
  - Reduced post-settlement survivorship (up to 90%, Ross et al. 2012)



Consequences



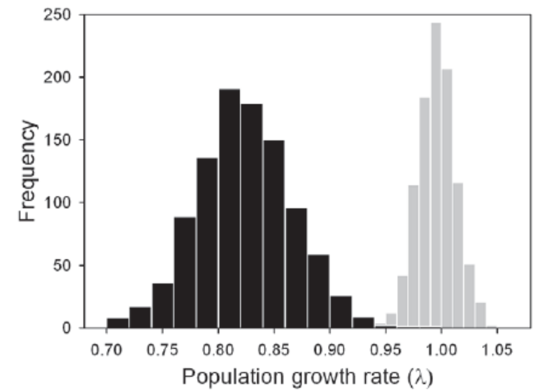
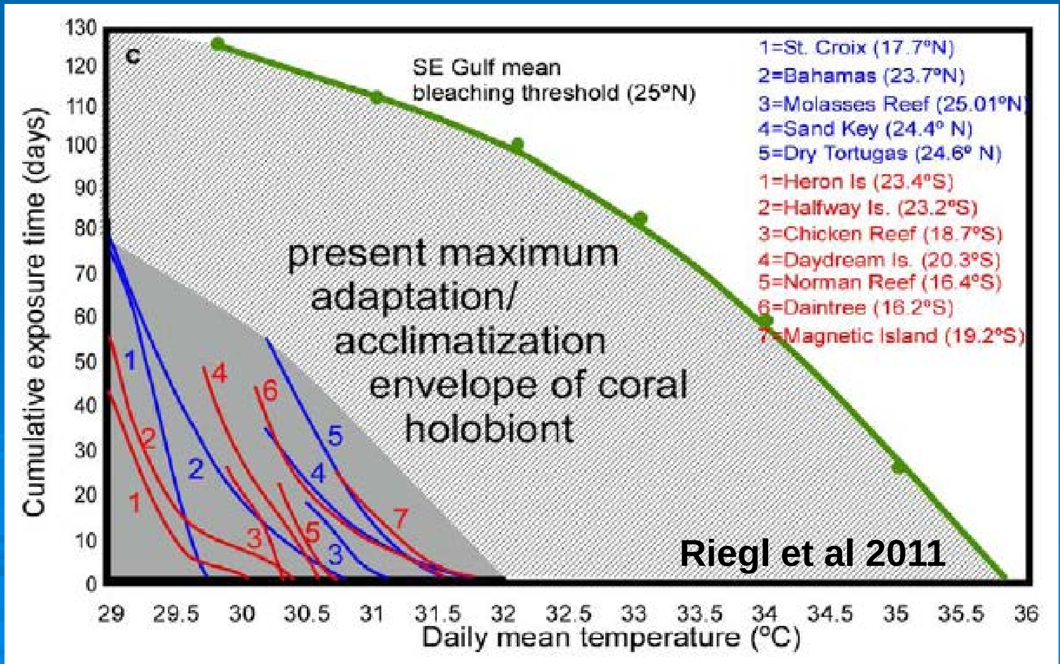


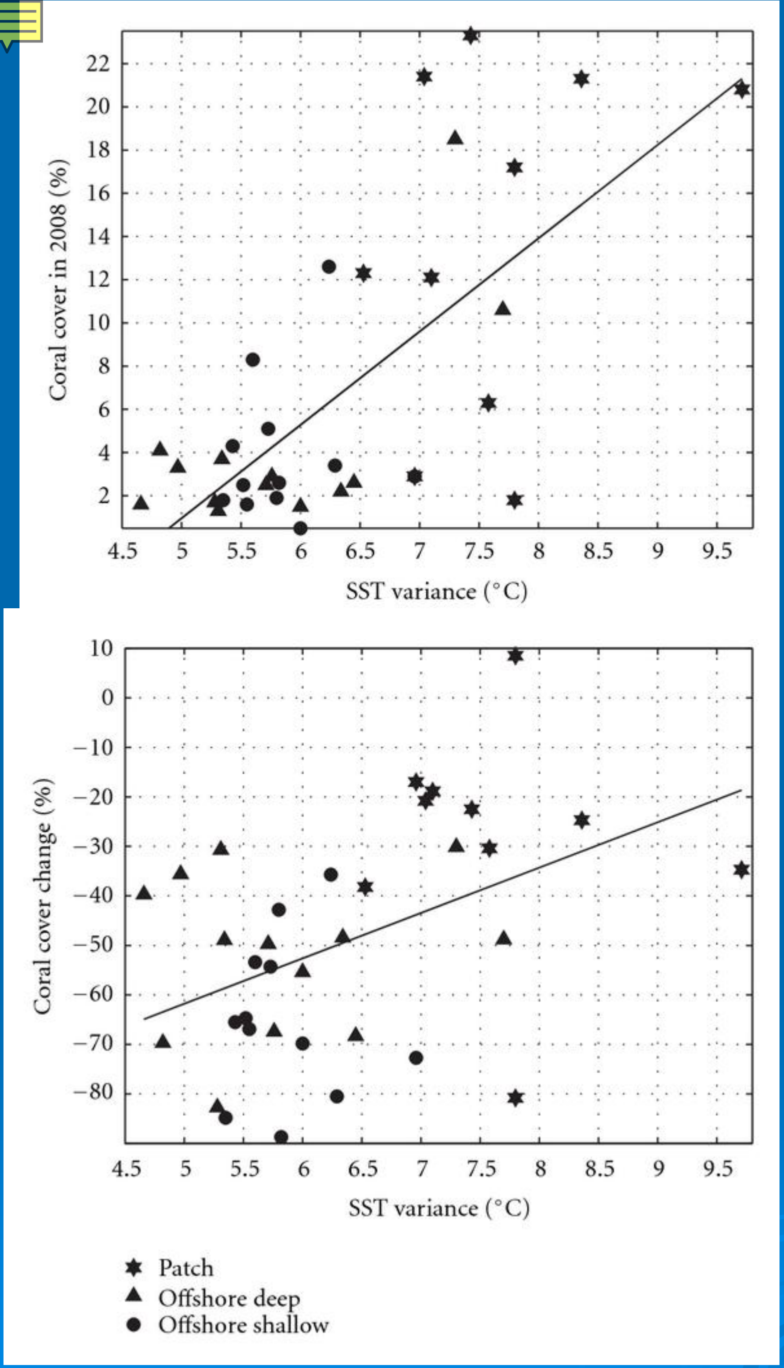
Fig. 3. Frequency distribution of population growth rates of *Montastraea annularis* for bleaching years (2006–2008) (dark bars) and non-bleaching years (2001–2006, 2008–2009) (light bars).

Hernandez-Pacheco et al. 2011

Adaptation/Acclimation?

- Acclimation via altered gene expression
  - Genomic studies indicate variation in gene expression with warm temp stress (Polato et al 2012)
  - Chronic warm exposure can lead to increased baseline expression (Barshis et al 2013)
- Adaptation via host or symbionts (e.g. mutation)
- Switching' to more resistant symbiont types
  - Temporary?
  - Slower growth
- We don't know how much warming this will buffer
  - Even Arabian Gulf corals showing susceptibility

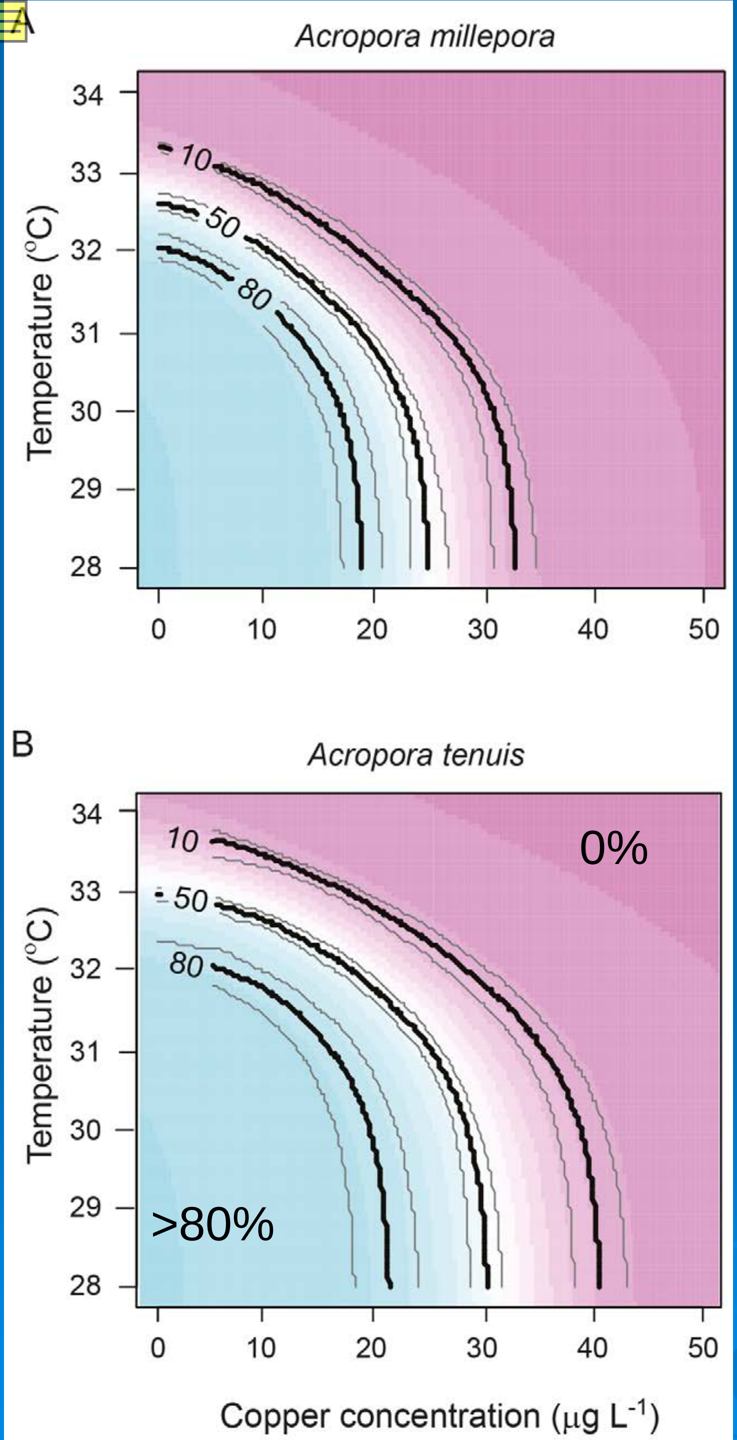




Soto et al 2011

Adaptation?

- Florida Keys: Site by site correlation of SST variance with less coral loss.

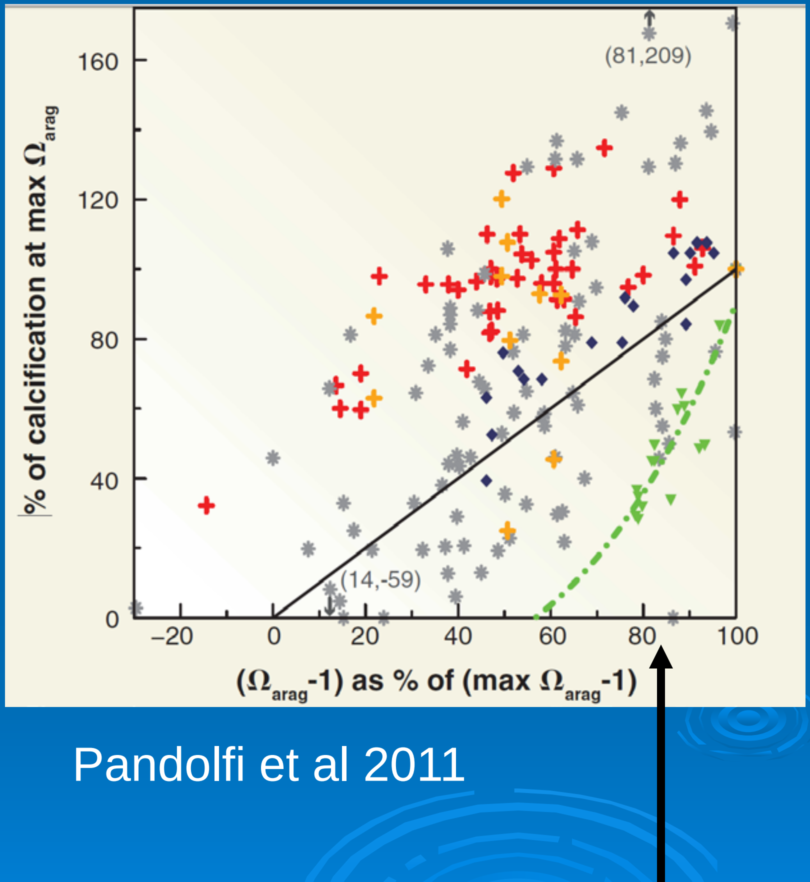


Potential mitigation via local WQ

- Copper concentration exacerbates temperature effects on larval metamorphosis
- ‘halving the concentration of Cu can protect corals from the negative effects of a 2–3oC increase in SST’ (Negri & Hoogenboom 2011)
- Similar conclusion regarding DIN exacerbating bleaching risk on GBR (Woolbridge&Done2009)

Ocean Acidification (OA) Calcification/Growth

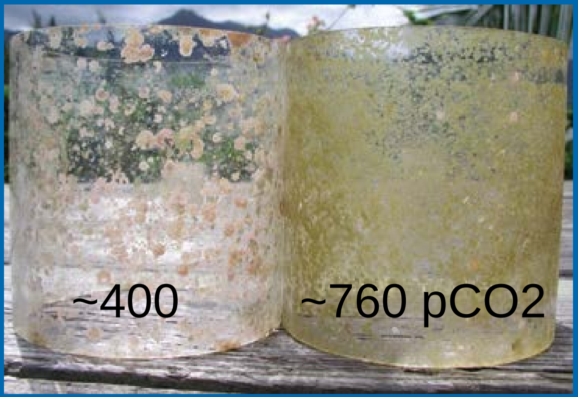
- Affects colony-scale calcification/growth rate
- Compensatory environmental factors
  - Nutrition (Cohen et al. 2012) No difference in conspecific growth rates across geographic gradient of 2.7-4.0 Ω attributed to variation in trophic status
  - Temperature
- At the target level (pCO2 ~ 500), possibly not significant



Pandolfi et al 2011

OA on Reproduction- 600-700 pCO2

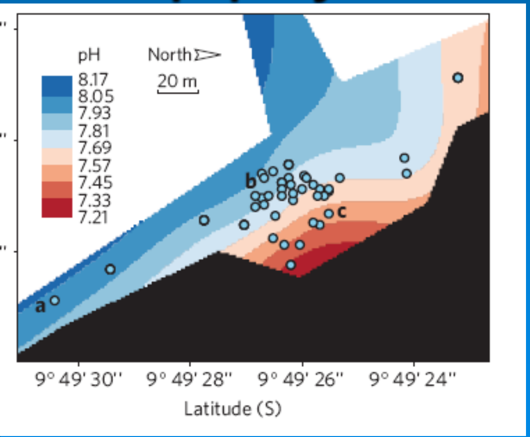
Kuffner et al 2007



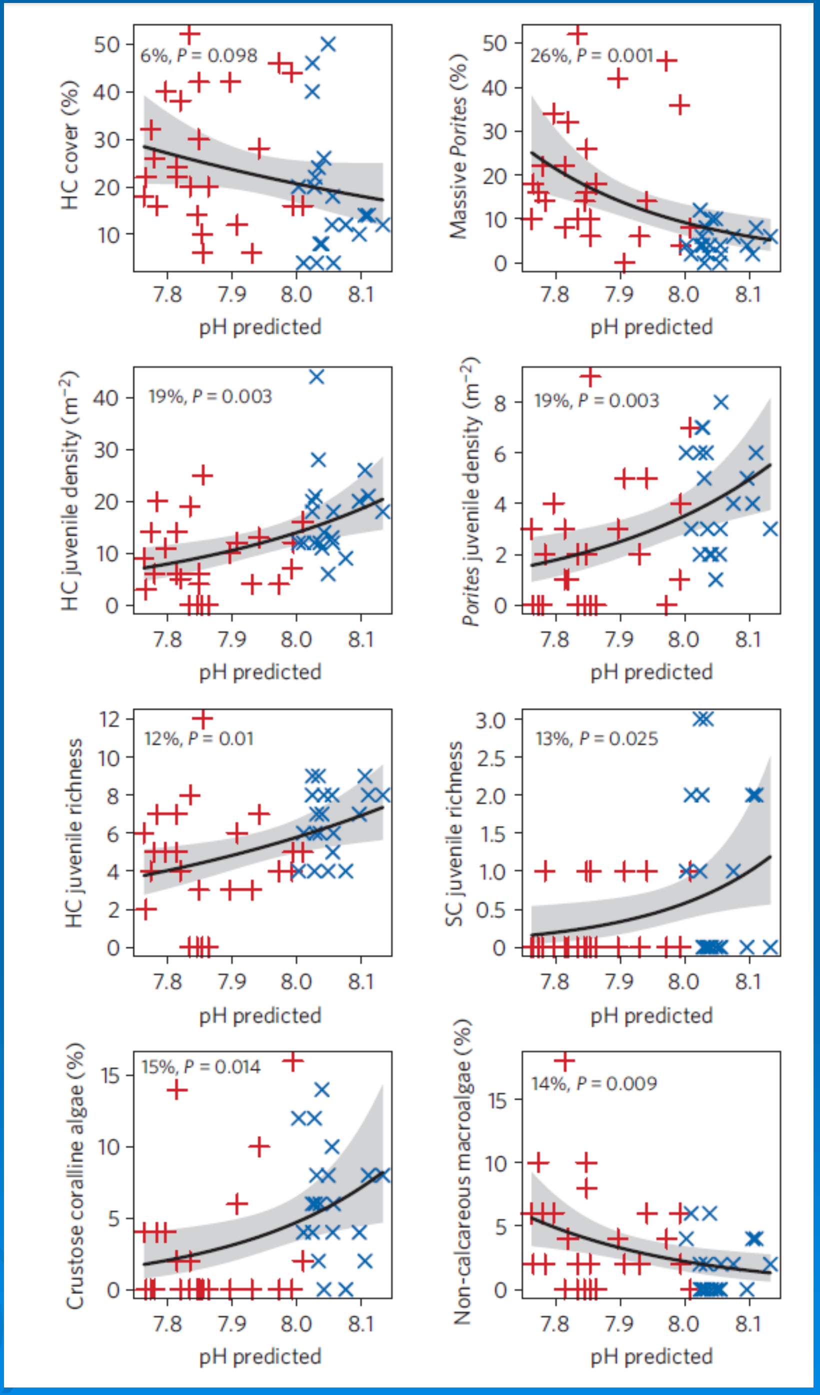
- Fertilization (600-700 pCO2; Albright et al 2010)
  - Observed at low sperm concentrations;
  - May affect other broadcast spawners exacerbating Allee effects (urchins, other sessile inverts)
- Settlement (Albright et al 2010, Webster et al 2012, Doropoulos et. al 2012)
  - Most apparent effect is indirect, on settlement cues/behavior more than direct physiology (Coralline algae)
  - Other chemical cues/behaviors may profoundly affect trophic interactions (e.g. fishes, Munday et al. (many))
- Post-settlement survivorship
  - Coral survivorship highly size-dependant
    - Growth impairment likely equates reduced survivorship (already approaching zero for reef-building species)
  - At least some reef fishes resistant up to ~800 in early stages (Munday et al 2011, Bignami et al 2012)

OA on Reef Community

- Cold CO2 Seep in PNG
- Reef at ~ 7.8 pH
  - 750 ppm CO2
  - Estimated ~ 2060-2080
- Reduced hard coral and soft coral juvenile density and richness (not cover); reduced CCA; increased macroalgae; decreased epiphytic forams

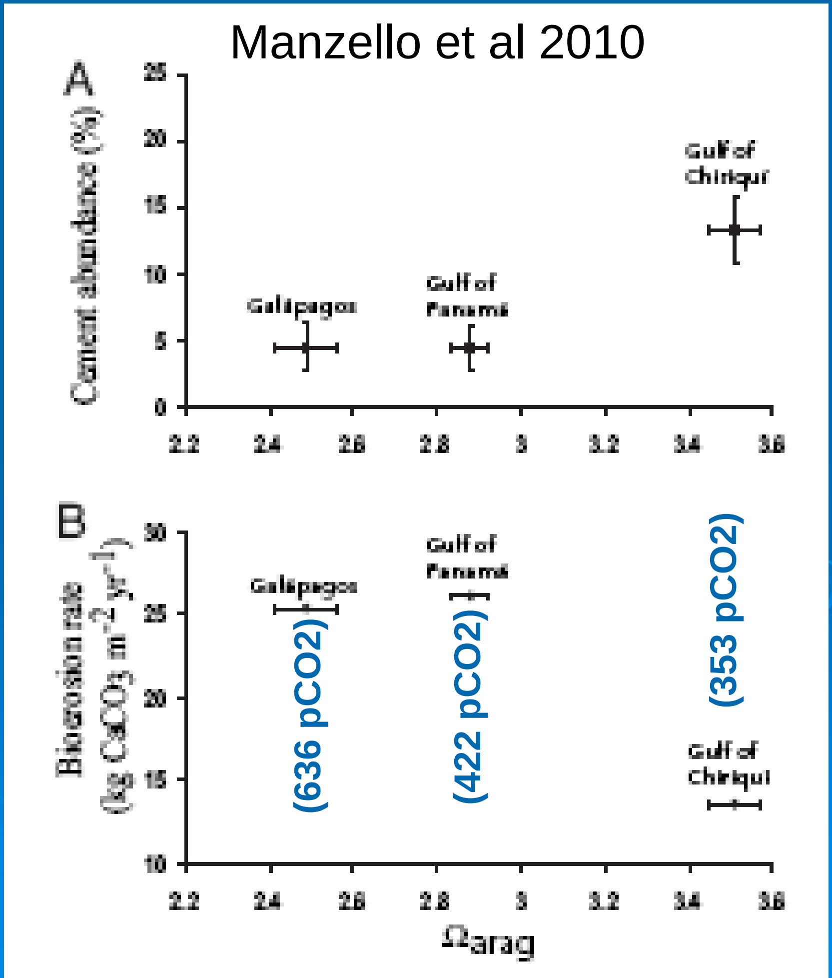


Fabricius et al. 2011

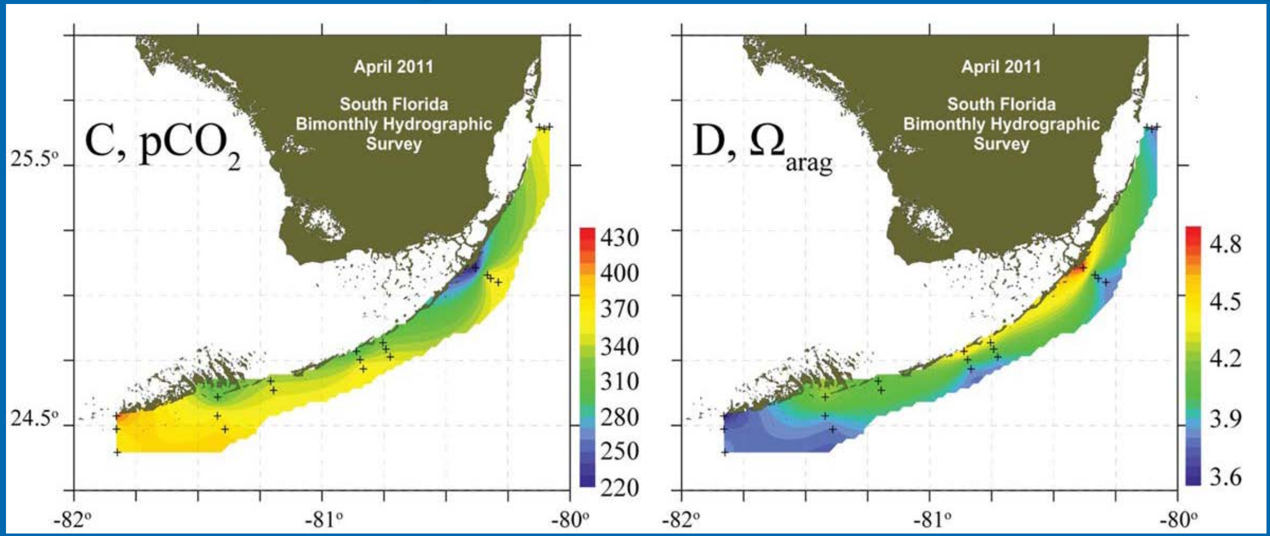


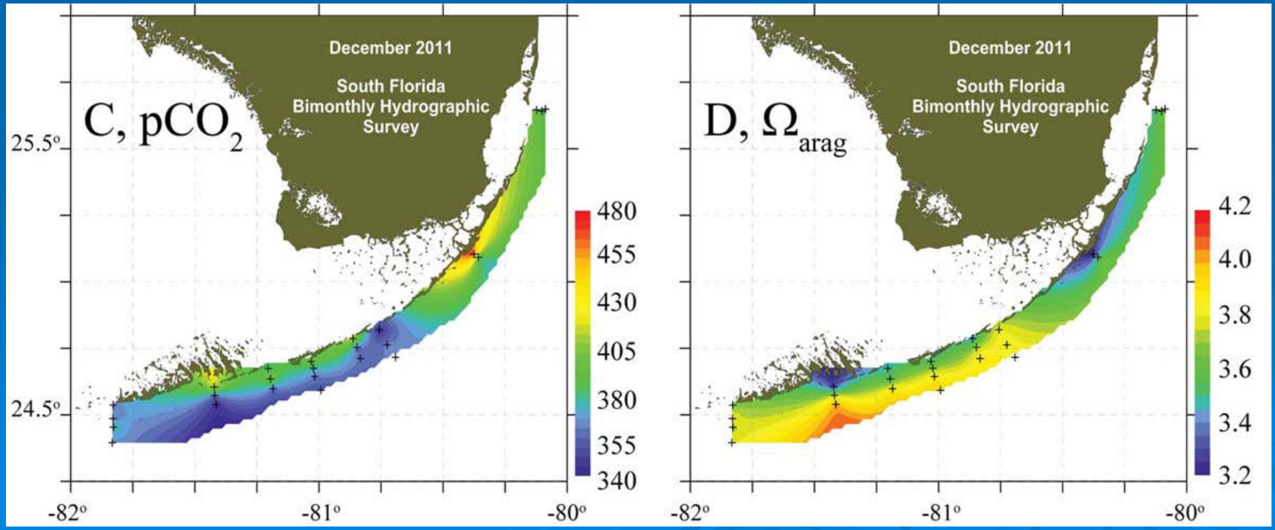
OA decreases reef geo-integrity

- Increasing sponge bioerosion of coral skeletons (5-10% by 2050; Wisshak et al 2012)
- Detrimental bioerosion and cementation rates observed in extant high CO2 environments



Potential nearshore OA refugia (at least seasonally)





- Seagrass productivity buffers CO2 excess nearshore
- Potential positive feedback
  - SG productivity Should increase with pCO2

Manzello et al 2012

Sea-Level Rise

- 18 inches probably does not represent an influential impact in terms of depth/light (i.e. 'drowning' the reef)
- On geological scales, corals can track SLR by relocating upslope
  - Previous sudden shifts 10-36 mm/yr (Barbados, **Blanchon et al 2009**) displaced shallow reef crest communities, but probably did not 'drown' all reefs.
  - Current recruitment failure does not suggest confidence in this over the longer term.

Inlets already source of WQ degradation to nearshore reefs

Port Everglades Inlet

- Turbidity
- Nutrients
- Contaminants?

- How much does this worsen with inundation, coastal erosion, and possibly increased runoff?

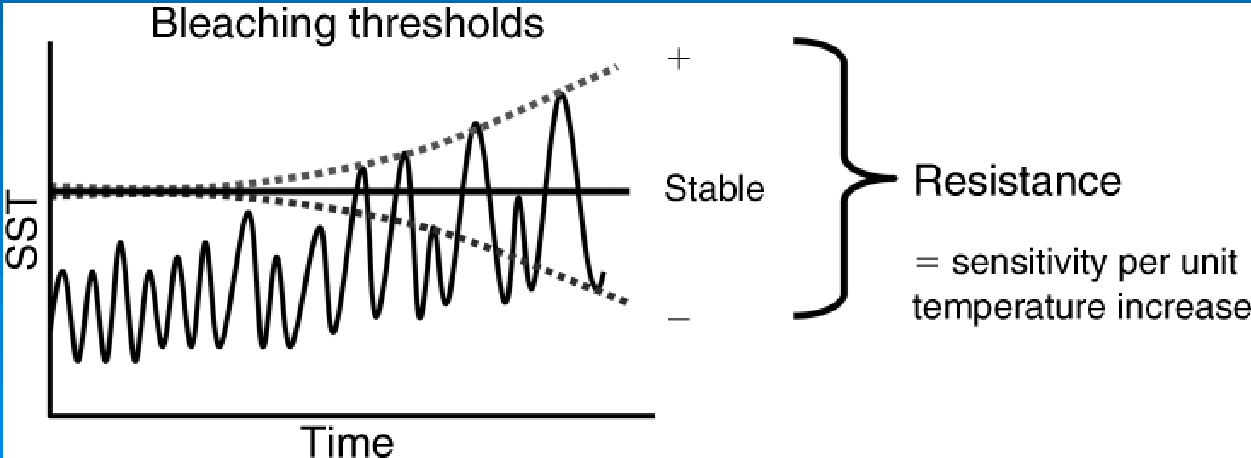
‘Big Picture’

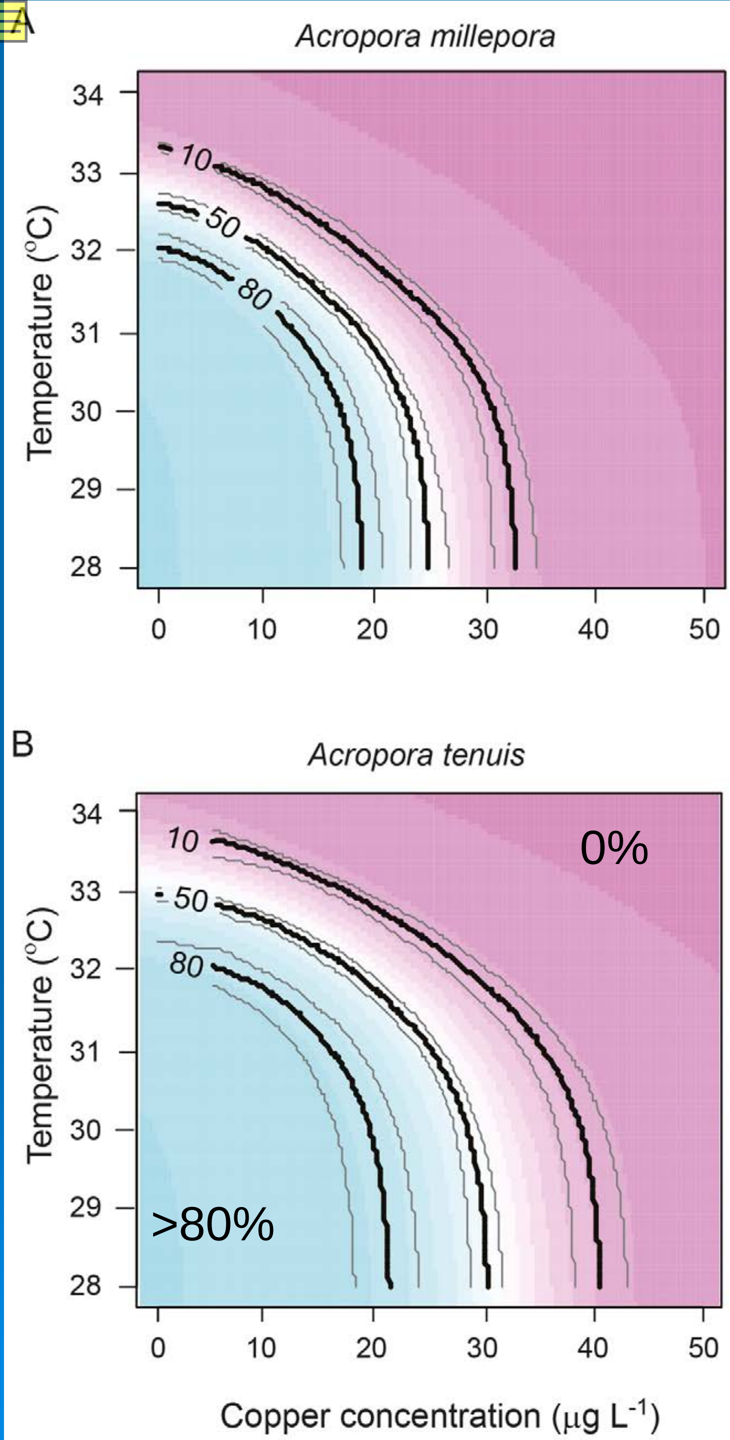
- We know a lot (and its pretty much all bad news) on
  - Direct effects of warming, possibly OA
  - Warming impacts already happening (bleaching, disease, possibly reproductive failure)
  - Local reef communities and coral species are already severely impaired
    - This realization (and ESA recovery mandates) prompting more proactive ‘interventionist’ strategies

‘Big Picture’

- There is much more uncertainty on
  - Adaptation potential of corals
  - Effectiveness of ‘Reef Resilience’ strategies
  - How much water quality change related to coastal inundation/runoff/water management plays into reef decline
    - Nutrients
    - Contaminants
    - Stratification?
    - Hydrography?

Wooldridge&Done 2009

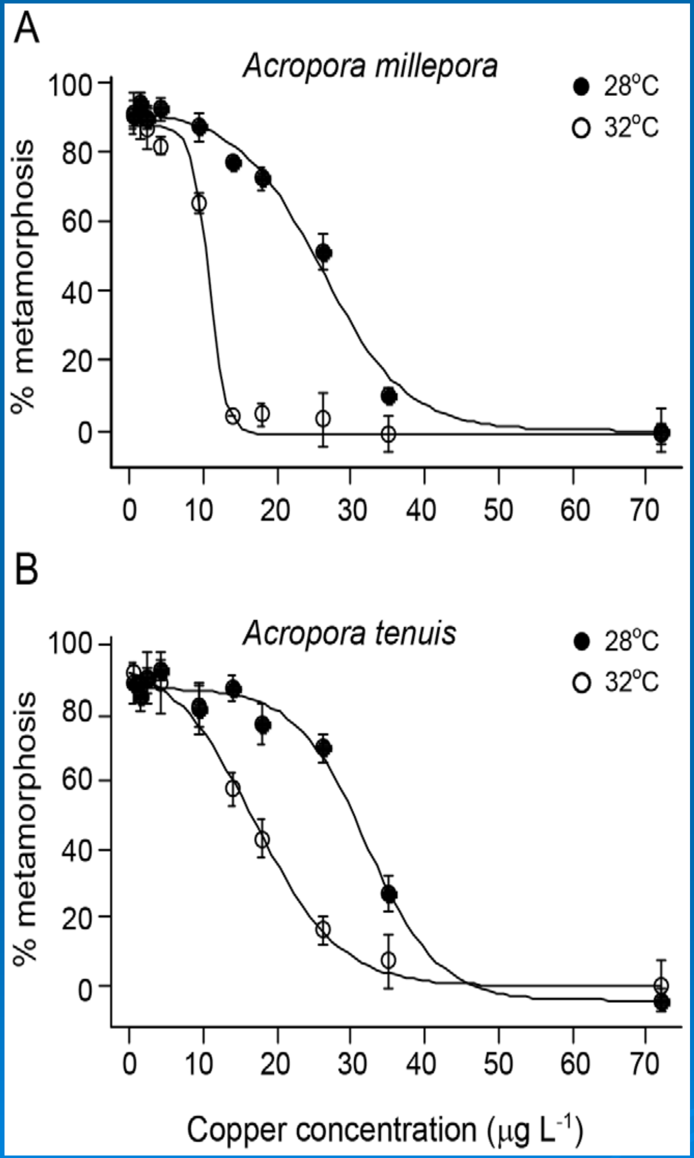




Potential mitigation via local WQ

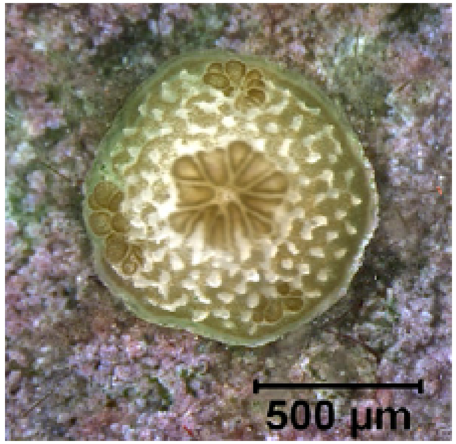
- Copper concentration exacerbates temperature effects on larval metamorphosis
- Effects additive to 29oC; synergistic above 31oC
- 'halving the concentration of Cu can protect corals from the negative effects of a 2–3oC increase in SST' (Negri & Hoogenboom 2011)
- Similar conclusion regarding DIN exacerbating bleaching risk on GBR (Woolbridge&Done2009)

Potential mitigation via local WQ



Negri & Hoogenboom 2011

A



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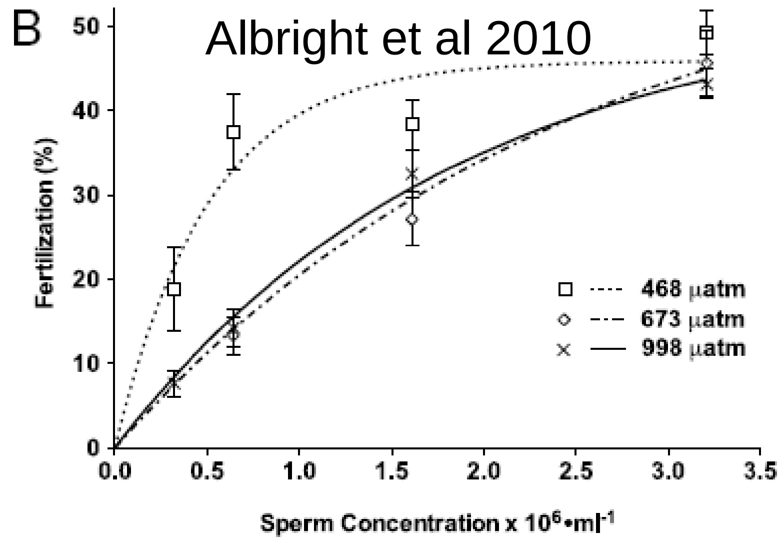
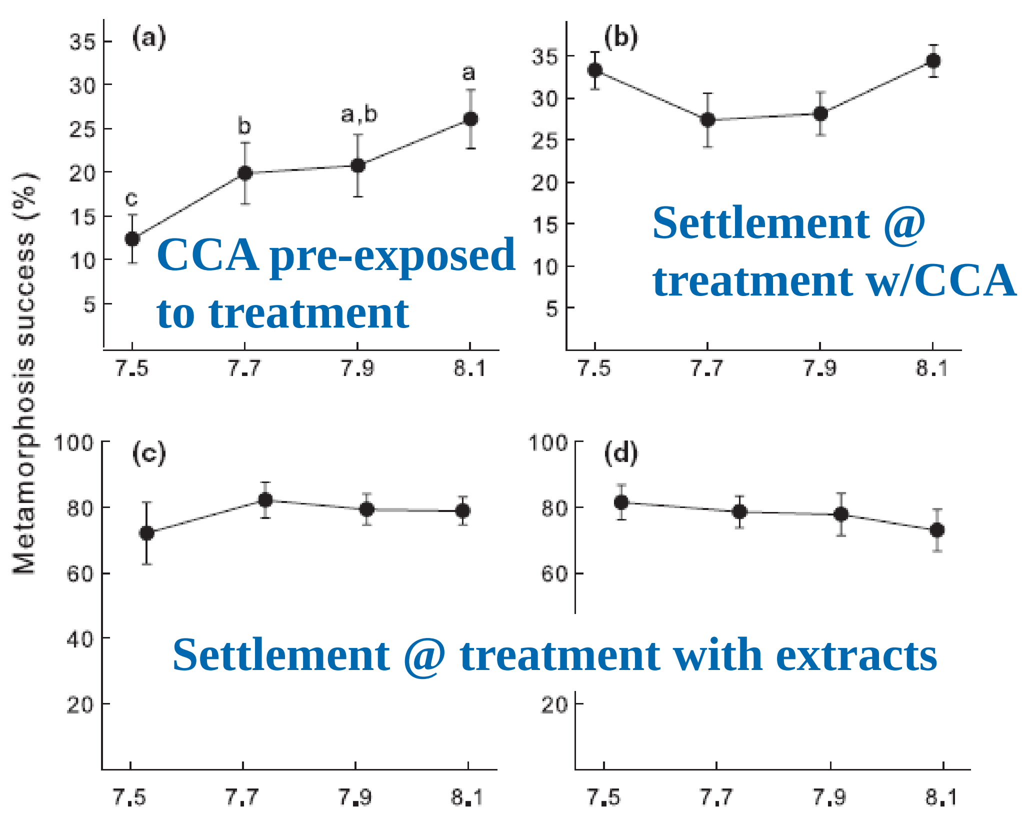
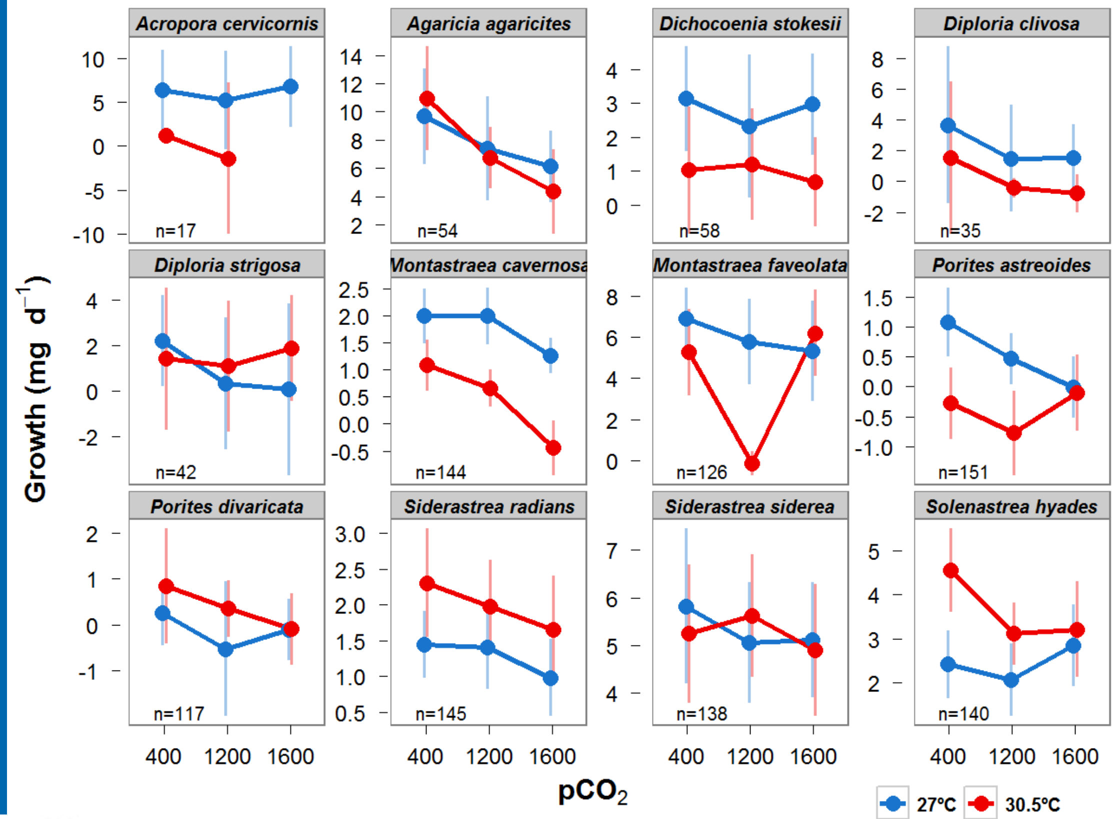


Acropora palmata

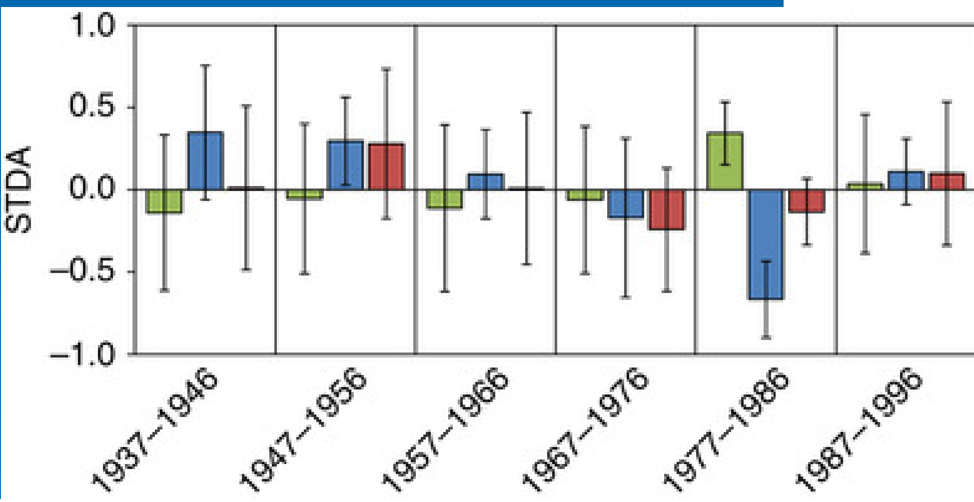


pH 8.1 ~ 464 pCO2
pH 7.9 ~ 822 pCO2
pH 7.7 ~ 1181 pCO2

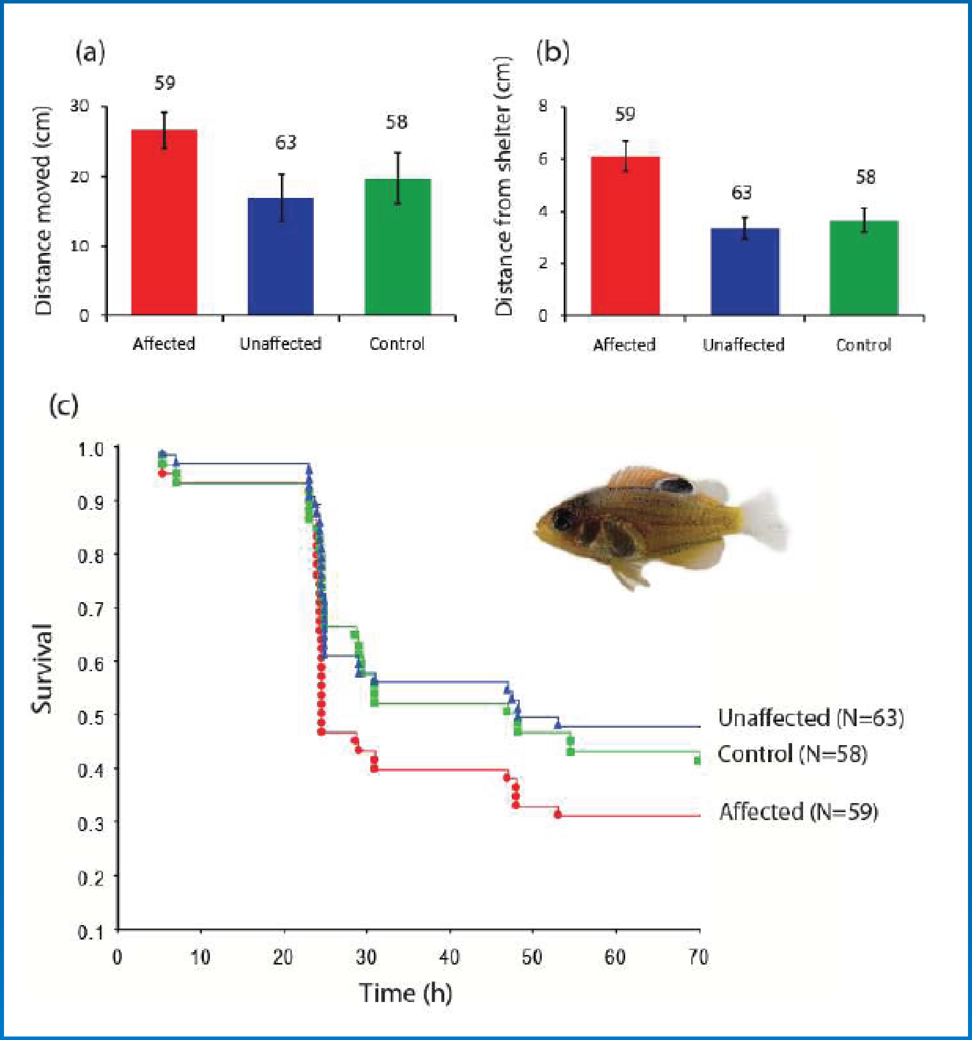
Webster et al 2012



Okazaki 2012

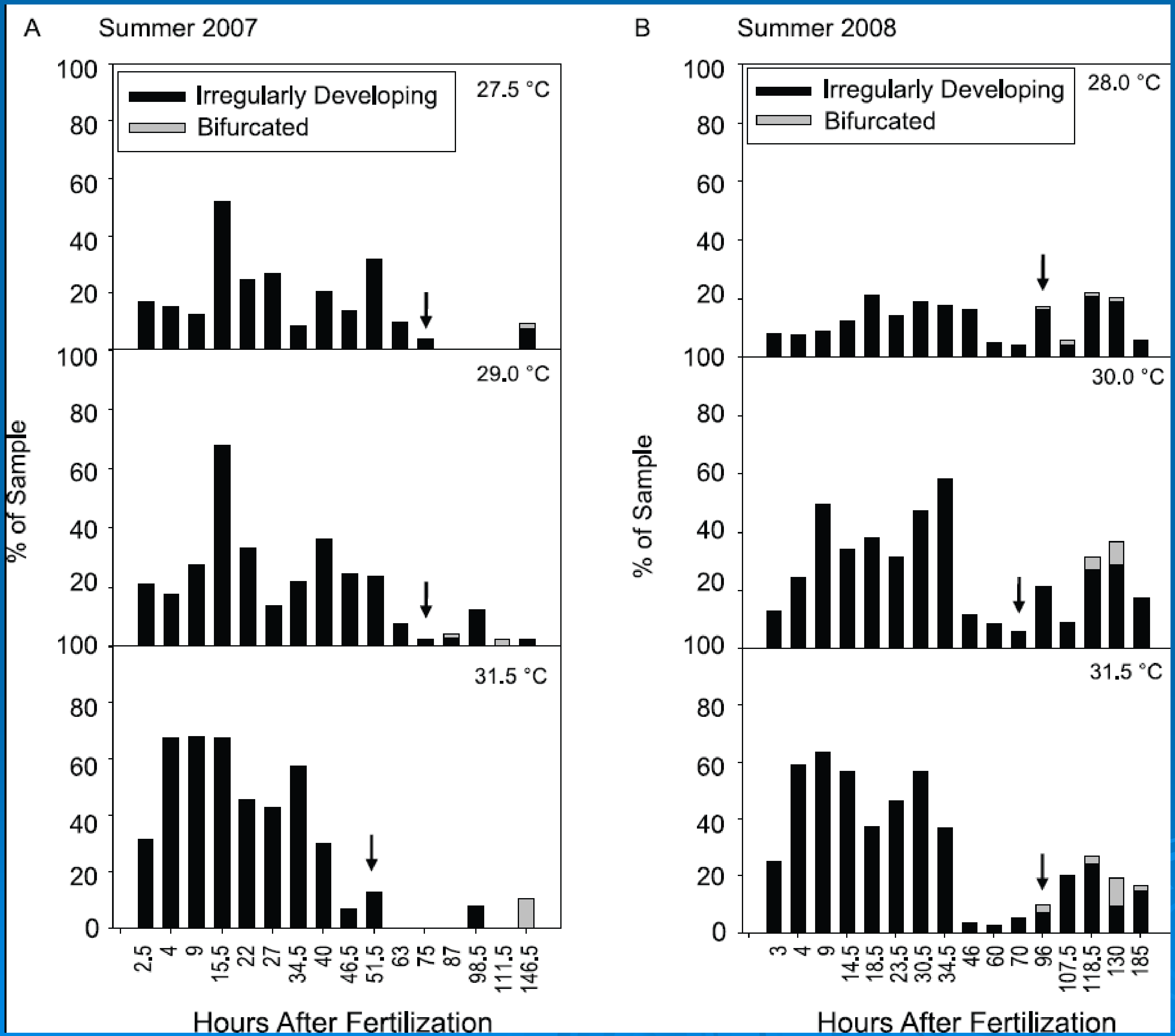


Decadal averages from master chronologies of annual extension in green, density in blue and calcification in red are presented in standardized anomaly (STDA) units with error bars representing the standard deviation for each decade (*n*=10) (Helmle et al 2011)

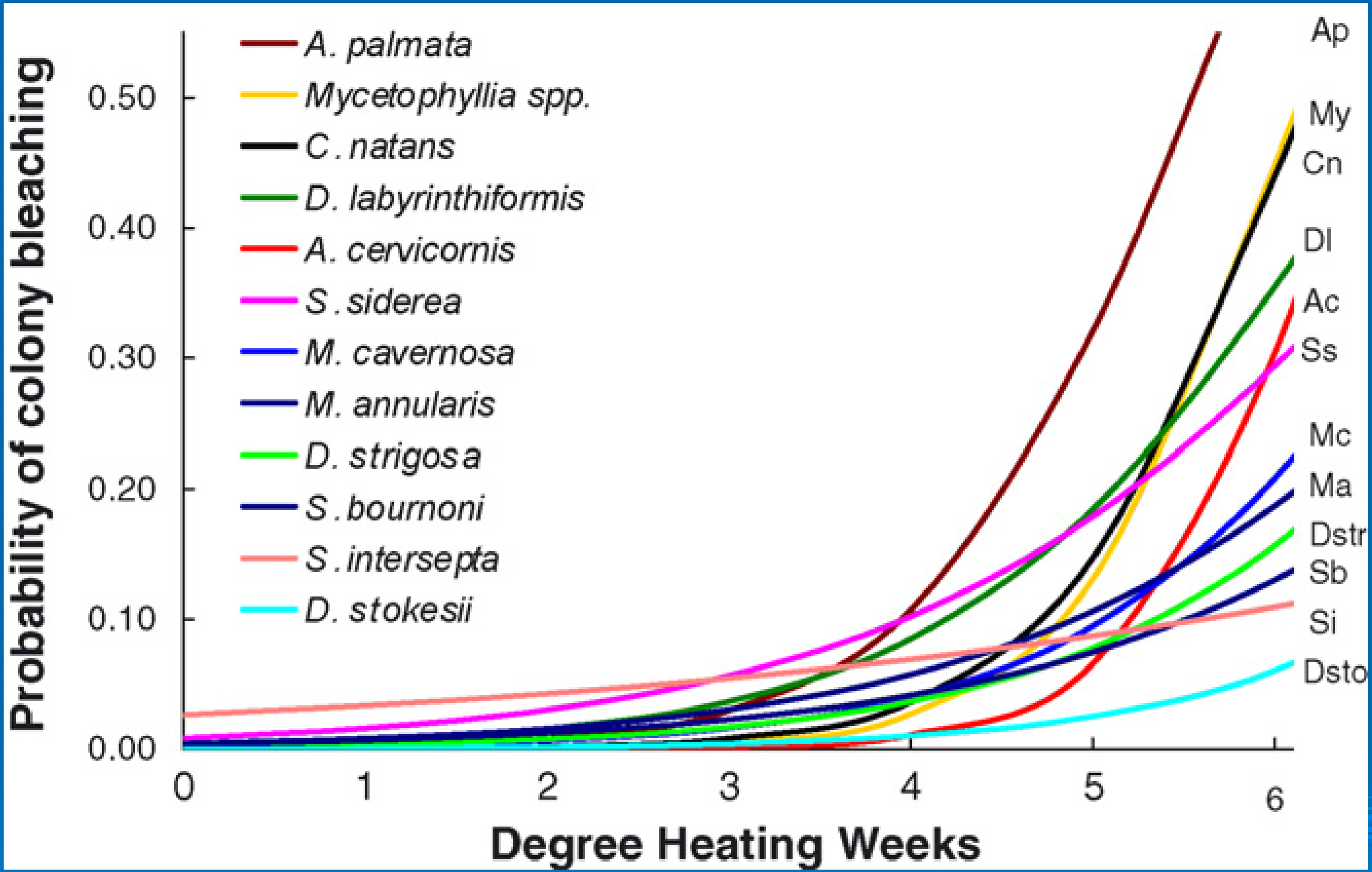


- 4 day exposure to 700 pCO2
  - Affected (sensory)
  - Unaffected
  - Control (425 pCO2)
- Differential behavior in the field led to differential mortality

Mundy et al. 2012



Randall and Szmant 2009)



Modeled probability of bleaching across different species based on data from 1998-2005 in the Florida Keys (Yee et al. 2008)