Possible Consequences of Global Warming and Ocean Acidification on Marine Ecosystems

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The Changing Ocean: Warmer and More Acidic

Climate Forcing: Rising ocean temperature and *p*CO_2

- More stratified
- Lower nutrient availability
- Decreased oxygen
- Lower pH
- Lower $[CO_3^{2-}]$
- Lower carbonate saturation state

Physiological Effects

- Photosynthesis
- Calcification
- N-fixation
- Metabolism
- Growth
- Reproduction
- Tolerance to other environmental fluctuations
- Fitness and survival

Ecosystem Effects

- Productivity
- Species succession
- Food webs
- Fisheries
- Species abundances and biogeography
- Biodiversity
- Air-sea gas exchange
- Biogeochemical cycles (C, N, S, P)
- Feedbacks to climate

Uncertainties great – research required

50 YEARS Recording the Past
Informing the Future

Examples:

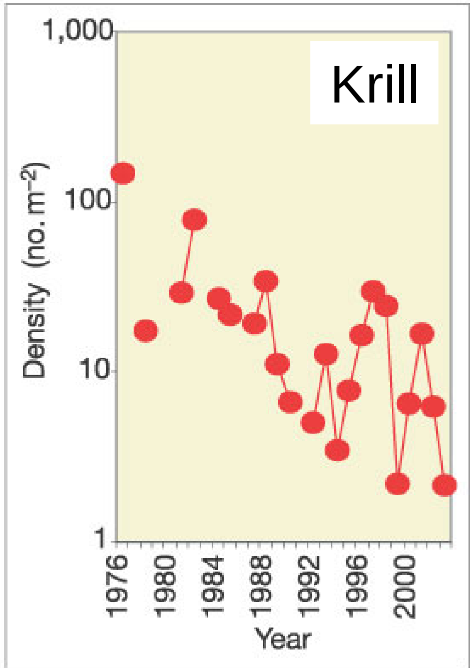
1. Decline in Antarctic Krill
2. Coral Bleaching
3. Ocean Acidification
4. Mitigation and Adaptation

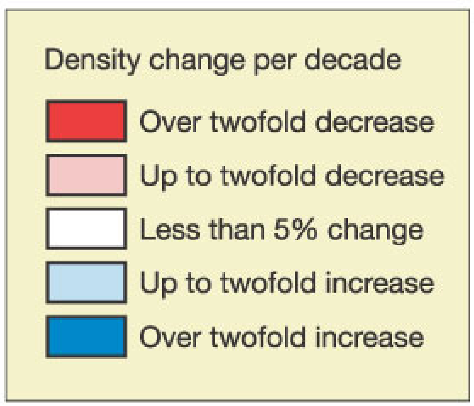
OCB Ocean Carbon & Biogeochemistry

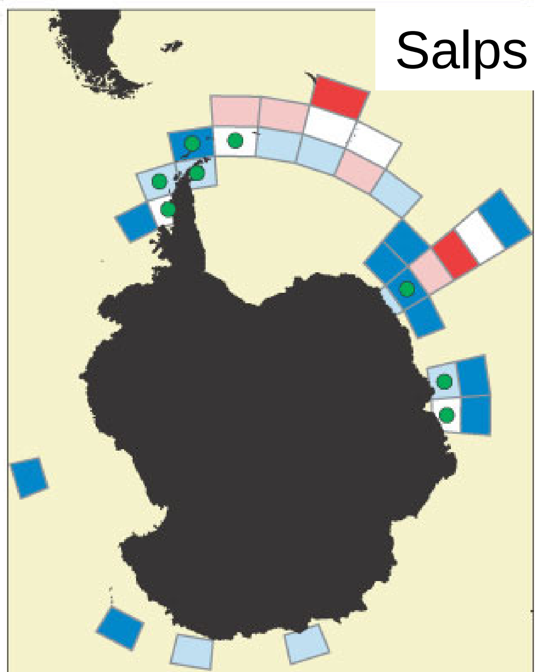
NSF

NOAA

Victoria Fabry, Richard A. Feely, Mark Eakin, and Chris Langdon







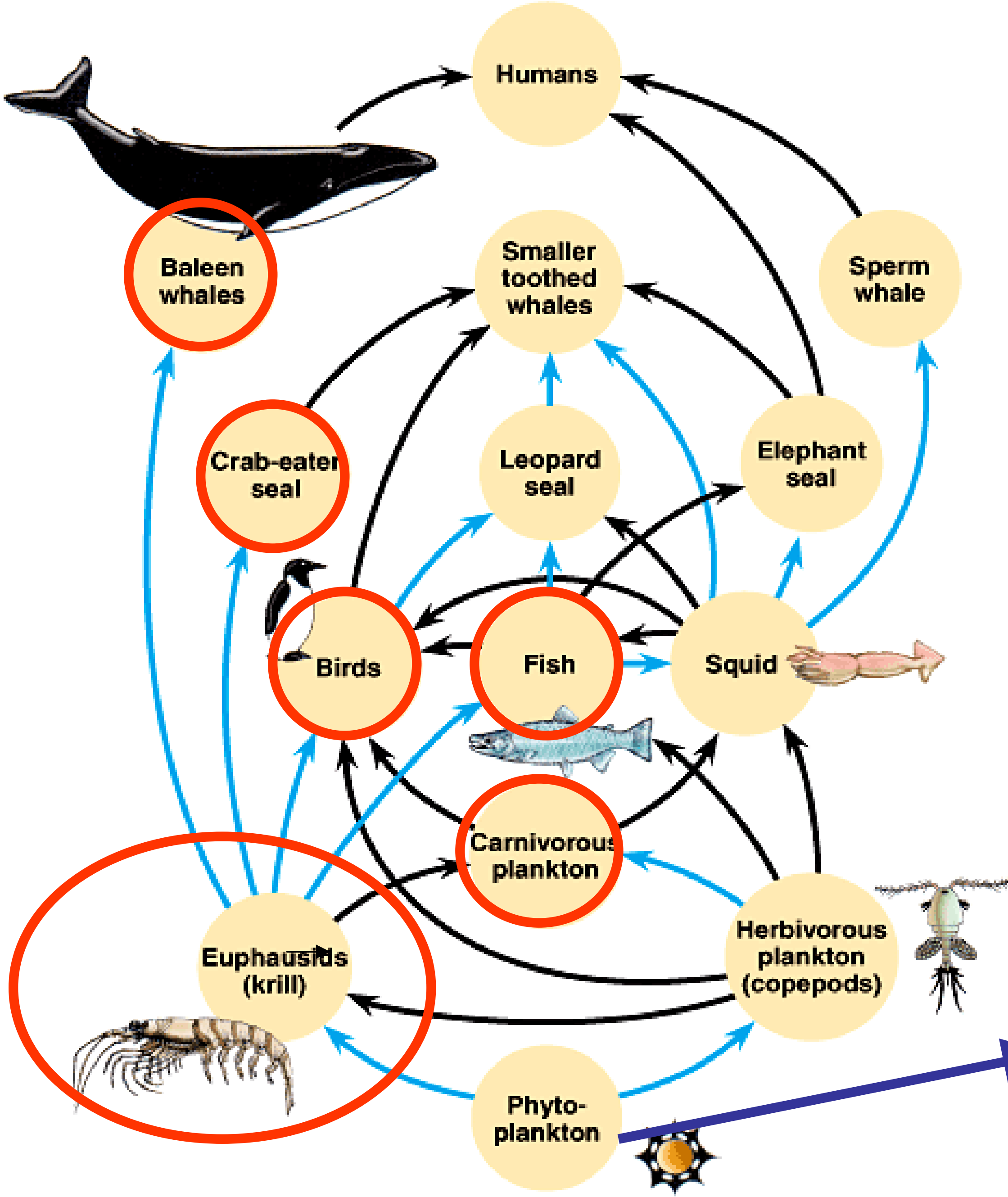
Atkinson et al., 2000
Ducklow et al., 2007

Decline in Krill Stocks in Southern Ocean

Krill distributions:

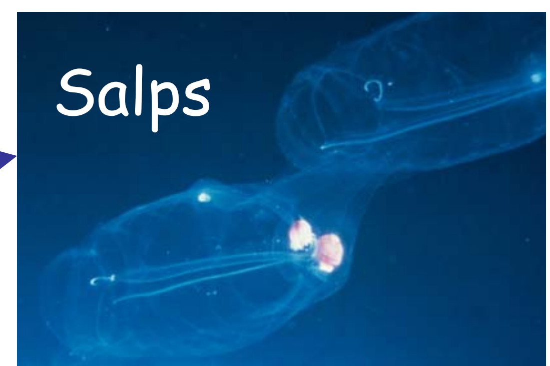
- need both summer phytoplankton and winter ice algae
- spatial correlation with chlorophyll;
- temporal correlation with winter sea-ice extent
- Western Peninsula – winter sea ice duration is decreasing
- May see future regime shift from krill dominated to salp dominated system

Implications for Antarctic Food Web



Salps:

- Carbon-poor food source; not preferred prey of higher trophic levels
- Fast generation times
- Associated with lower latitudes



L. Madin

50 YEARS
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Coral Bleaching

Under certain environmental stresses, colorful symbiotic algae (zooxanthallae) which live in coral body are expelled by the transparent host coral

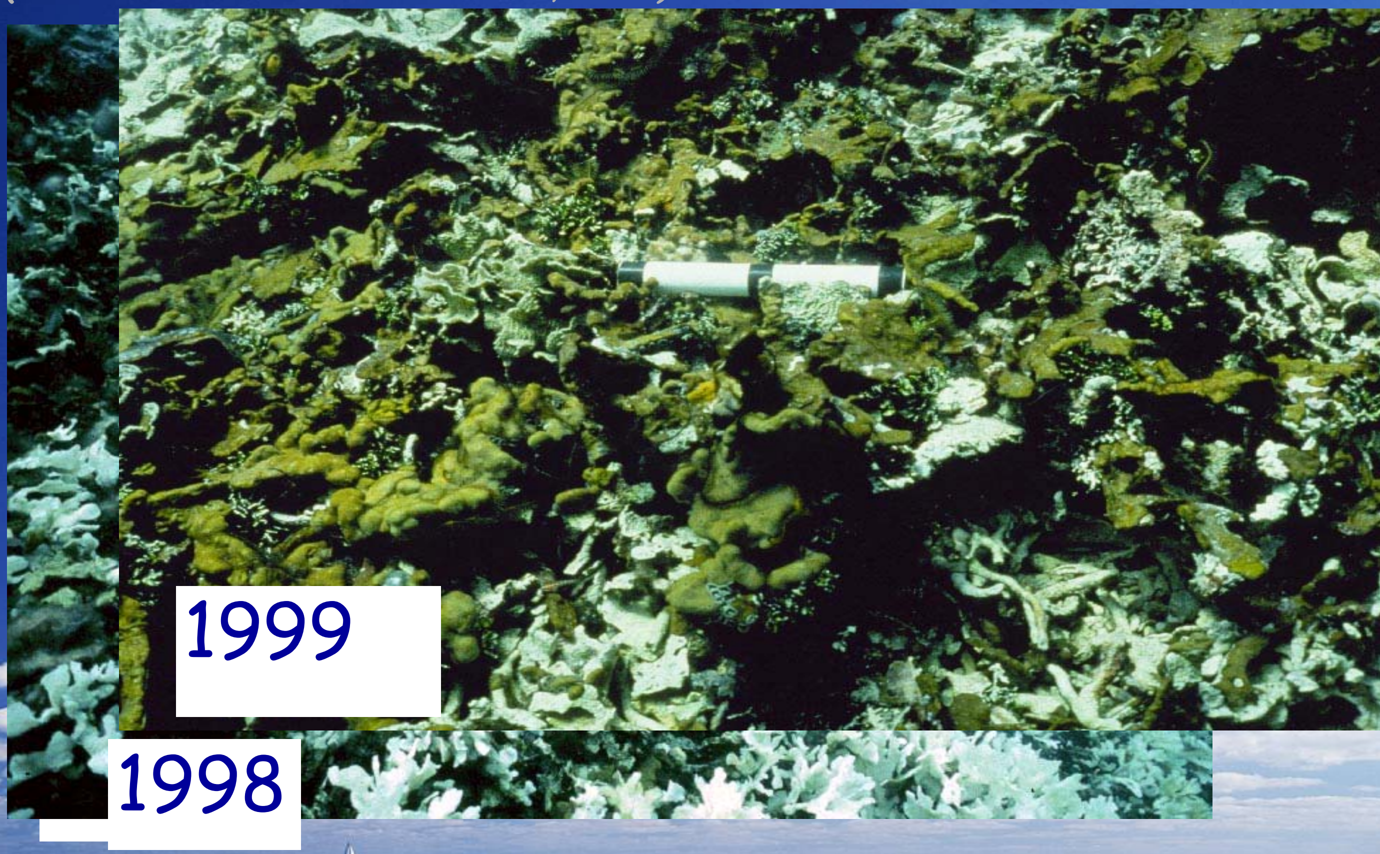
→ the white coral calcium carbonate skeleton is exposed

Abnormally warm water temperatures are one of the major causes of massive coral reef bleaching in recent years

Catastrophic, Unprecedented Coral Bleaching

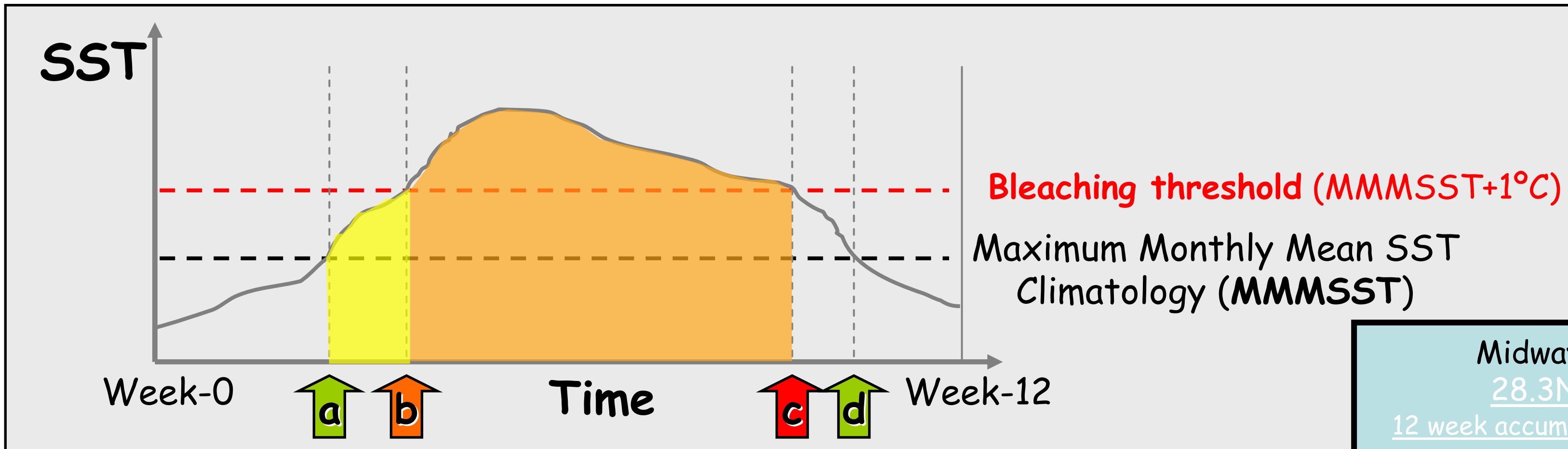
Widespread bleaching in Belize

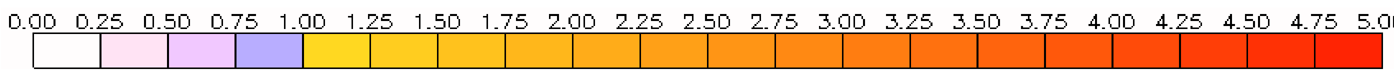
(from Aronson and Precht 1997, 2001)



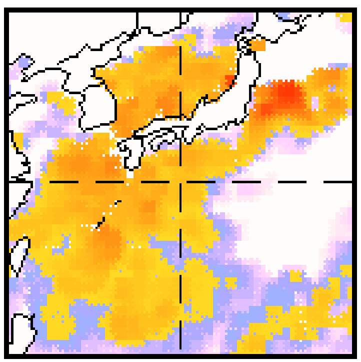
Provided by Mark Eakin

Operational Bleaching HotSpots and Degree Heating Weeks (DHW)





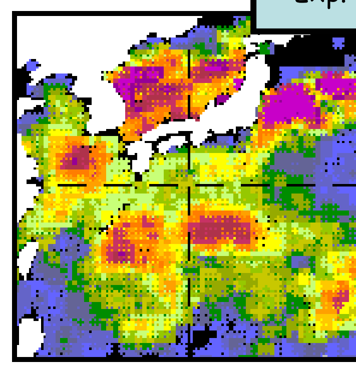
Midway Atoll, US	
28.3N, 177.4W	
12 week accumulation today	0.0
Max 12WK	2(99)
Current Temp (°C)	27.2
Exp. Max Temp	26.9



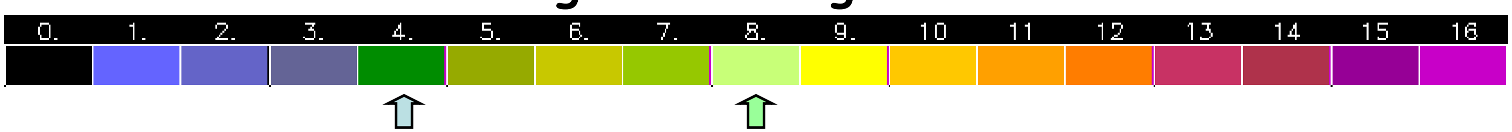
HotSpots

12 weeks

(HotSpot value × duration) ≥ 1°C

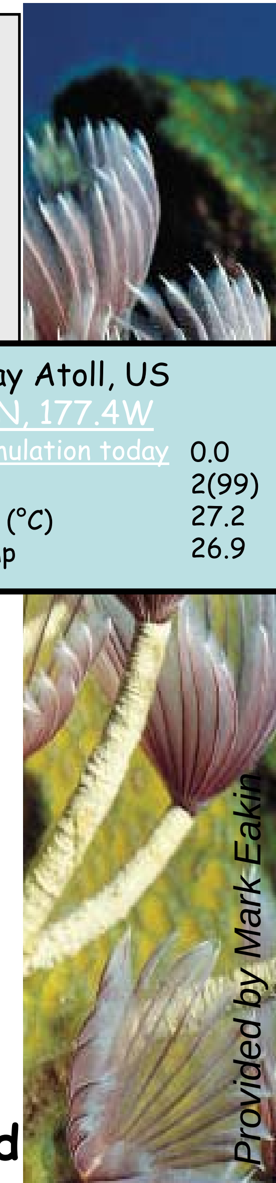


Degree Heating Weeks

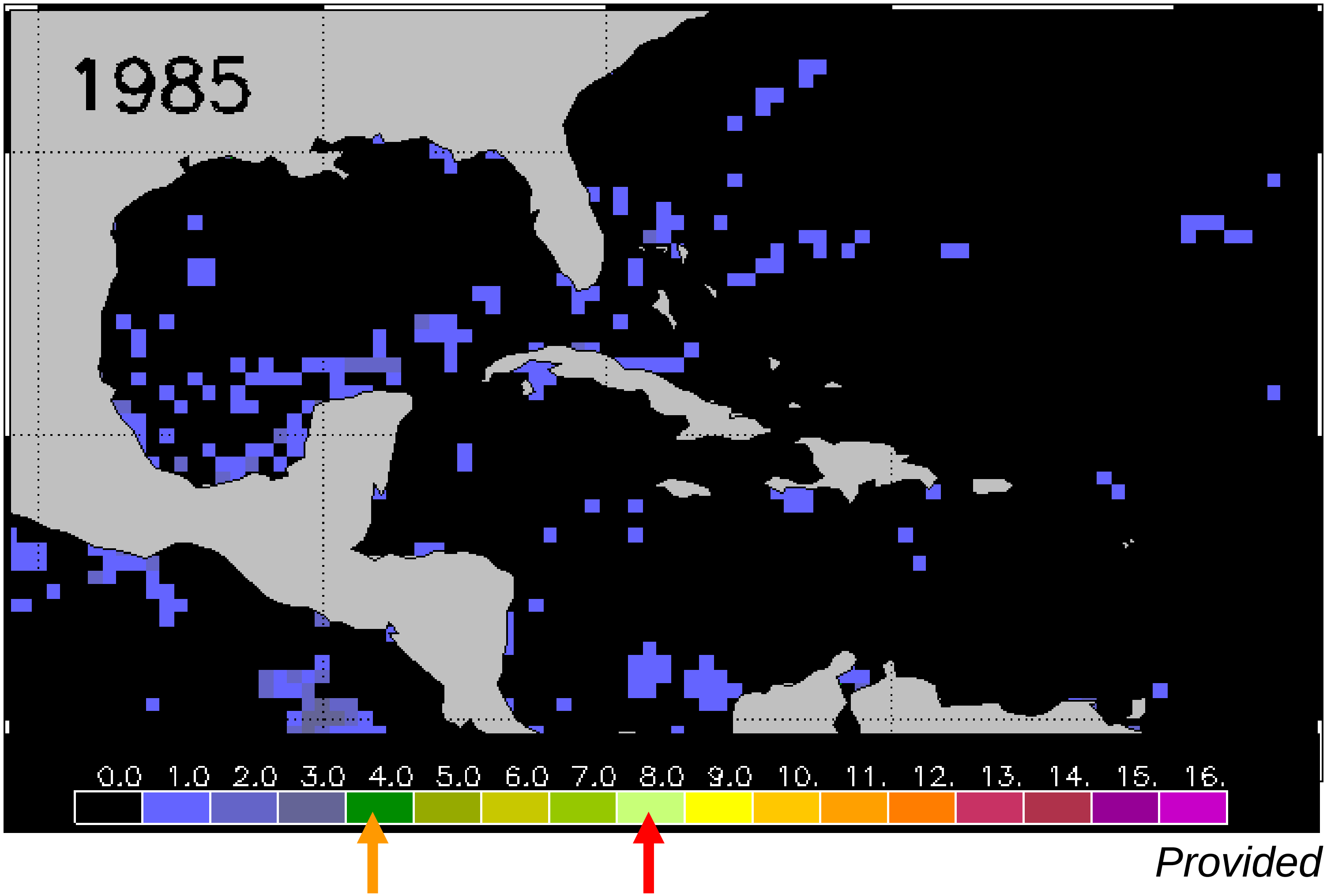


≥ 4 DHWs → coral bleaching is expected

≥ 8 DHWs → mass bleaching and mortality are expected



NOAA Degree Heating Weeks
Highest Caribbean Stress in 21 Years

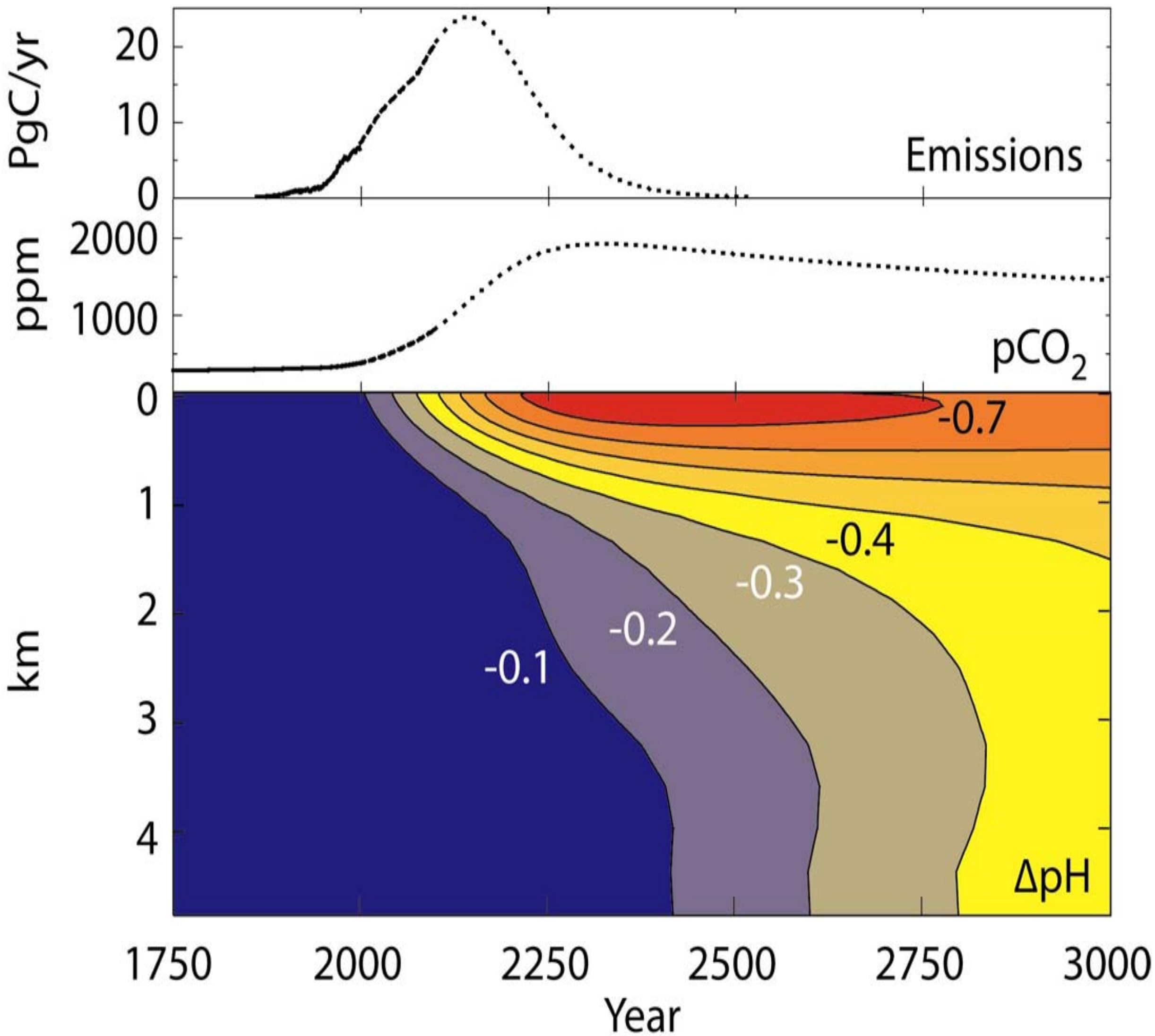


1 Degree Heating Week (DHW) = 1°C above maximum monthly mean for 1 week

Provided by Mark Eakin

≥ 4 DHWs → coral bleaching is expected
≥ 8 DHWs → mass bleaching and mortality are expected

By 2100, the pH of surface water could drop by 0.3 to 0.5 units relative to the pre-industrial value



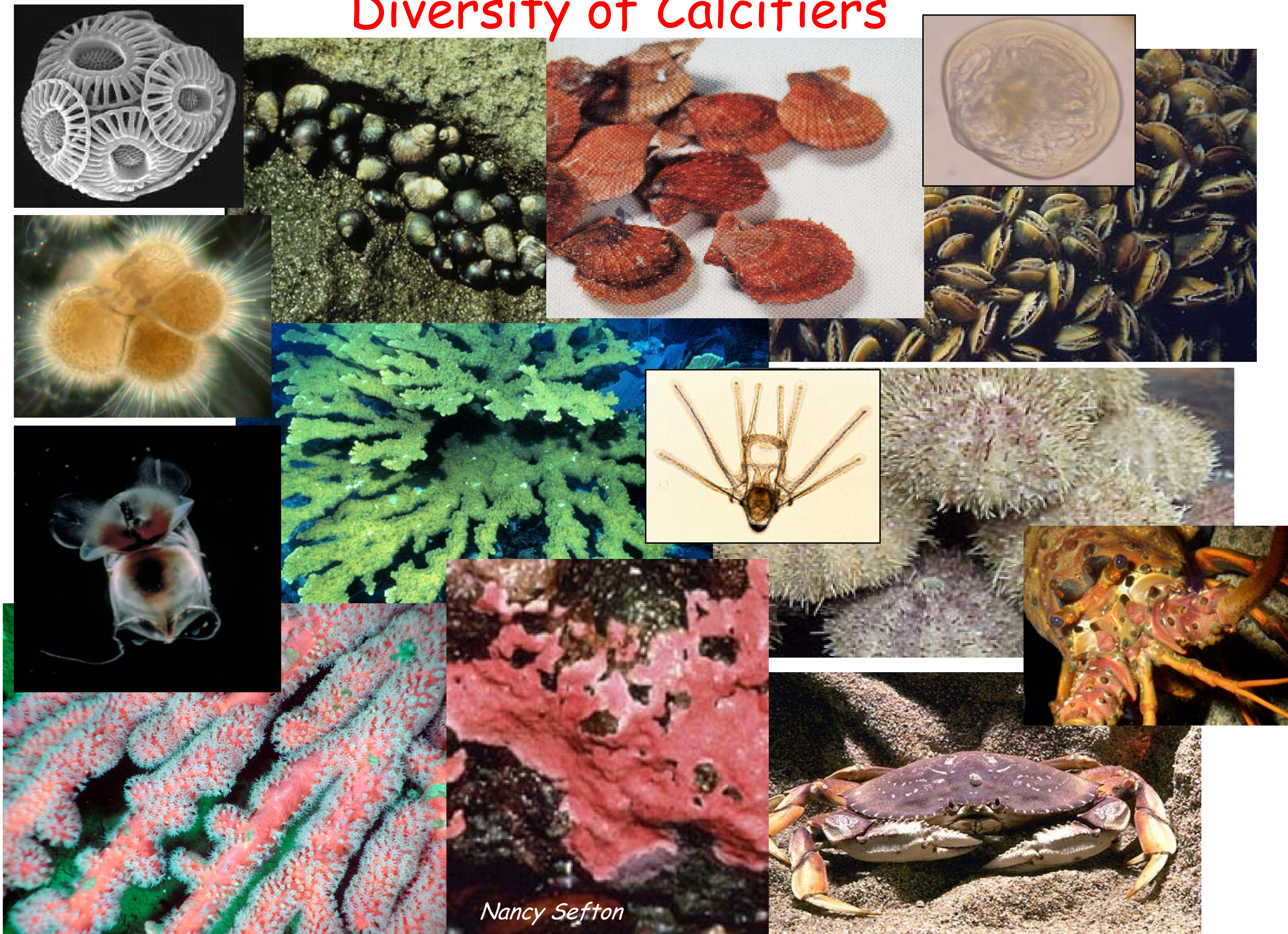
Caldeira & Wickett (2003)

Ocean uptake of anthropogenic CO_2 is lowering the pH in the surface ocean

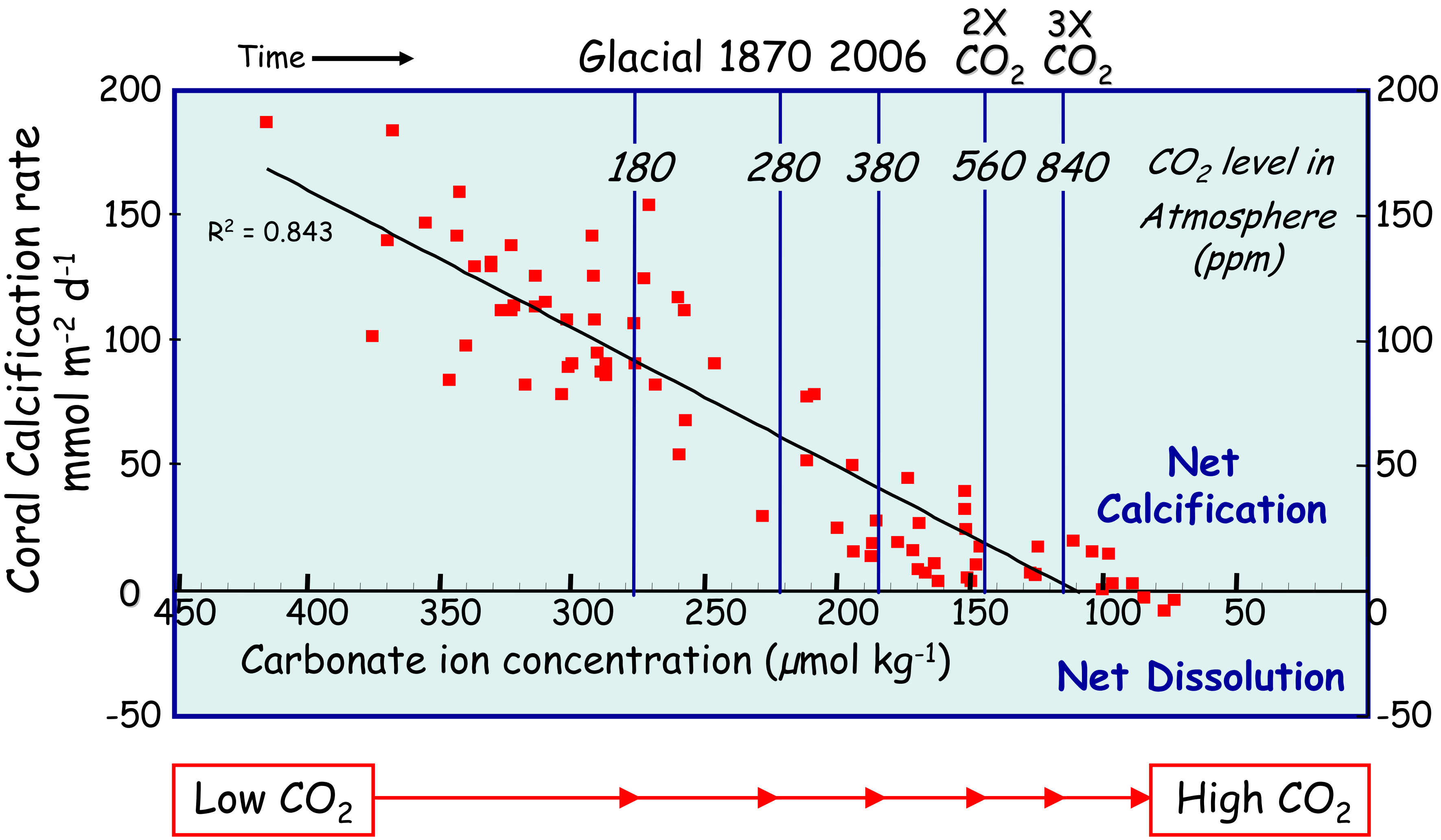
Today's surface waters are slightly alkaline

Future surface waters will be less alkaline

Diversity of Calcifiers

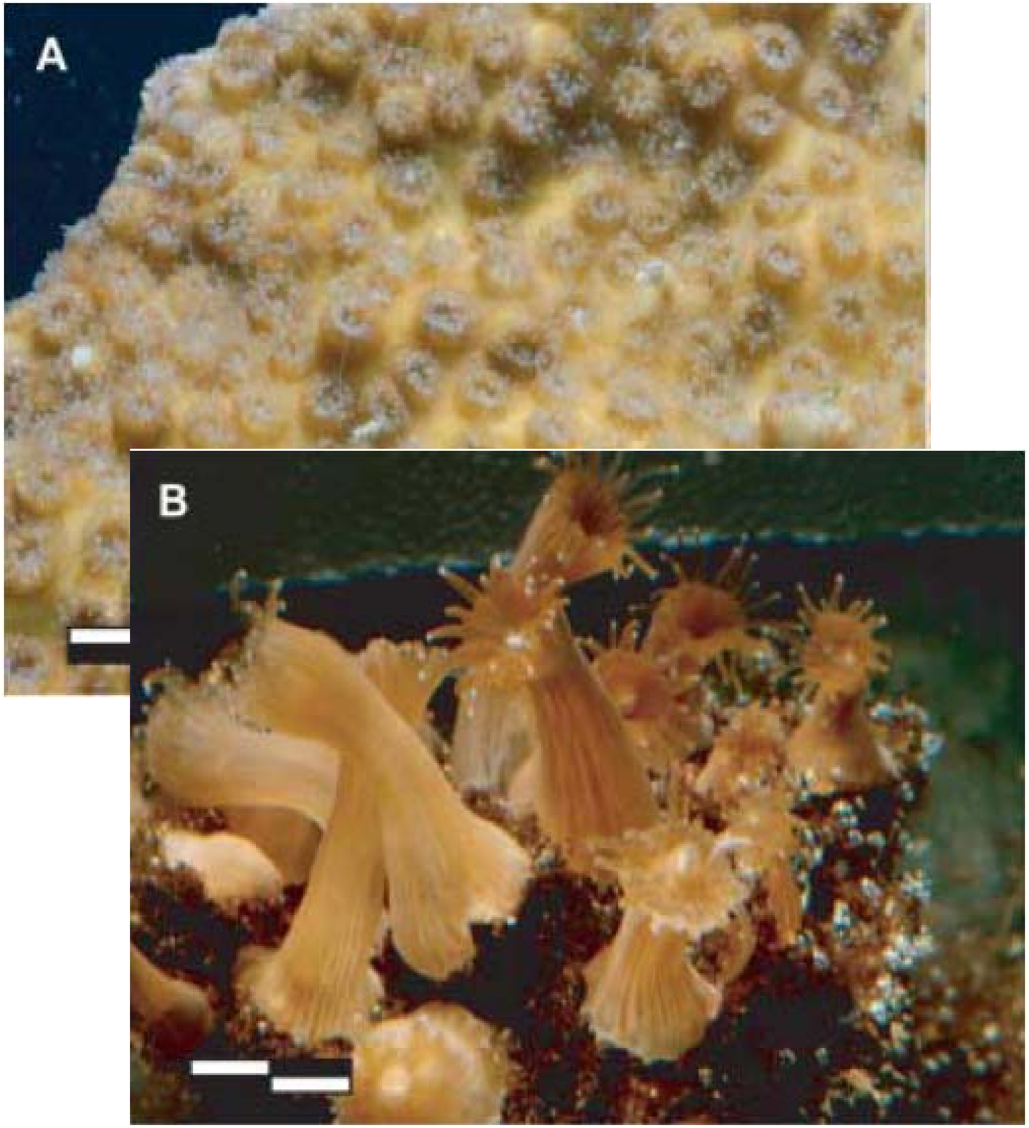


Evidence suggests a linear decrease in the calcification rate of coral reef systems with decreasing carbonate ion concentrations



Langdon & Atkinson, (2005)

Some Corals Can Survive and Recover from Decalcification



Fine & Tchernov, 2007

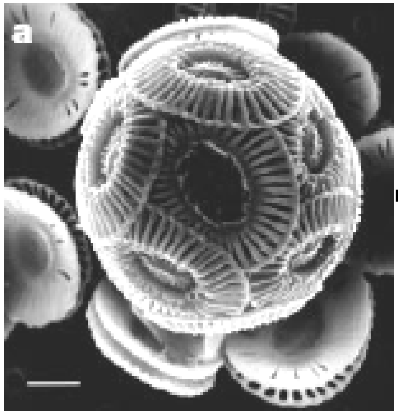
- Grown in corrosive water (pH 7.3 to 7.6) conditions for 12 months
- Skeleton dissolved & colony dissociated into anemone-like polyps
- When returned to normal pH, calcified & reformed colonies

- Predation on exposed polyps?
- Loss of reef structure would cause major changes in ecosystem services

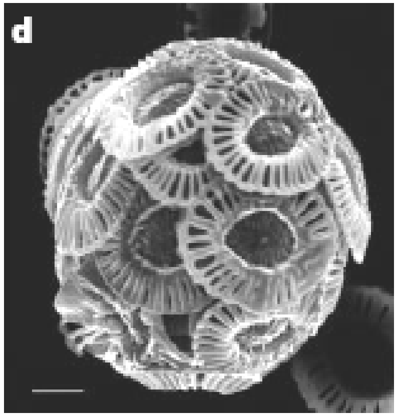
Coccolithophores

pCO_2 280-380 ppmv

pCO_2 780-850 ppmv

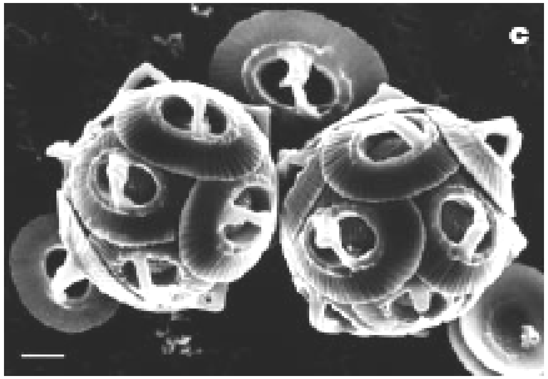


Emiliania huxleyi

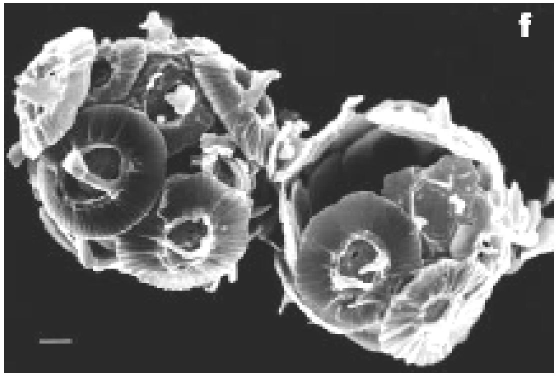


Calcification decreased

- 9 to 18%



Gephyrocapsa oceanica



- 45%

Some coccolithophore species not sensitive to increased CO_2

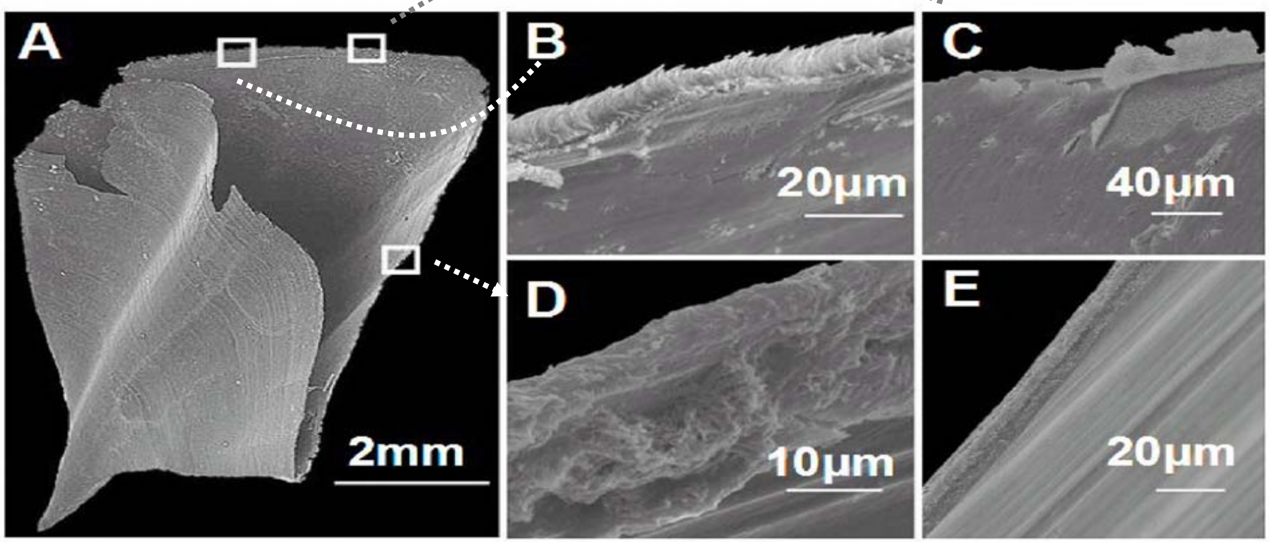
Riebesell et al.(2000); Zondervan et al.(2001)

Shells of living pteropods begin to dissolve at elevated CO_2 levels

Whole shell: *Clio pyramidata*

Arag. rods exposed

Prismatic layer (1 µm) peels back



(Orr et al., 2005)

Aperture (~7 µm): advanced dissolution

Normal shell: unexposed to undersaturated water

R. Hopcroft

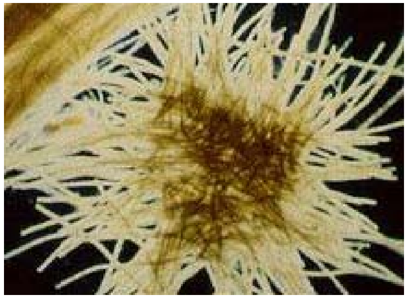
In polar & subpolar regions:

- Pteropod populations high (reaching >1000/m^3)
- Abundant food source for marine predators (including salmon, pollock & other fish)
- Integral component of food webs
- Can be important in biogeochemical cycles (C, S)

Evidence for Other Ocean Acidification Impacts

- Adverse effects on reproductive success
  - -Decreased fertilization rates (sea urchins, bivalves)
  - -Increased juvenile mortality (bivalves, sea urchins, copepods, fish larvae)
- Reduced growth in adults (sea urchins, bivalves)
- Impaired oxygen transport and scope for activity (squid)
- Increased rates of N-fixation (potential for major changes in algal abundances and nutrient limitation)



Mitigation and Adaptation

Mitigation

- Decrease CO_2 emissions
- Iron fertilization
- Direct injection of CO_2 into deep water
- Seawater electrolysis
- Urgency
  10-20 year window
  (Stern Report, 2006; Hansen *et al.*, 2006)

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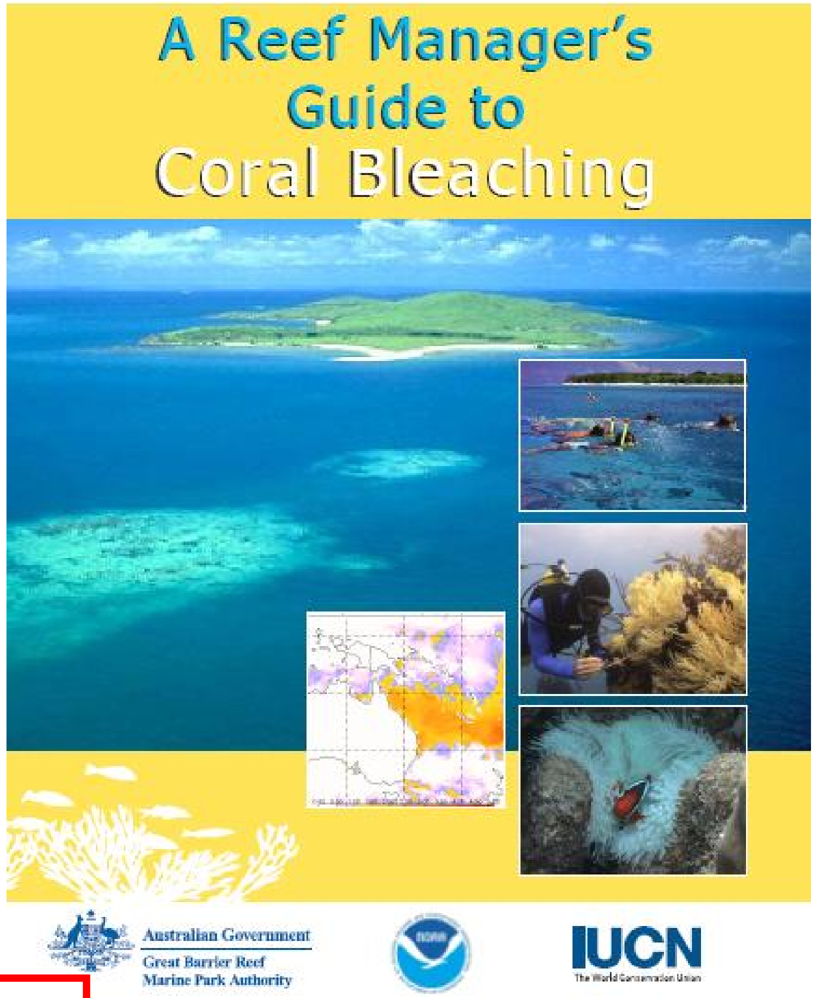
Mitigation and Adaptation

Adaptation (Coping)

- Reef Manager's Guide to Coral Bleaching (NOAA, EPA, Australia Great Barrier Reef Park Authority)
- Rear potentially vulnerable juvenile stages under controlled conditions
- Re-populate impacted areas with resistant species



Research required

Thank you