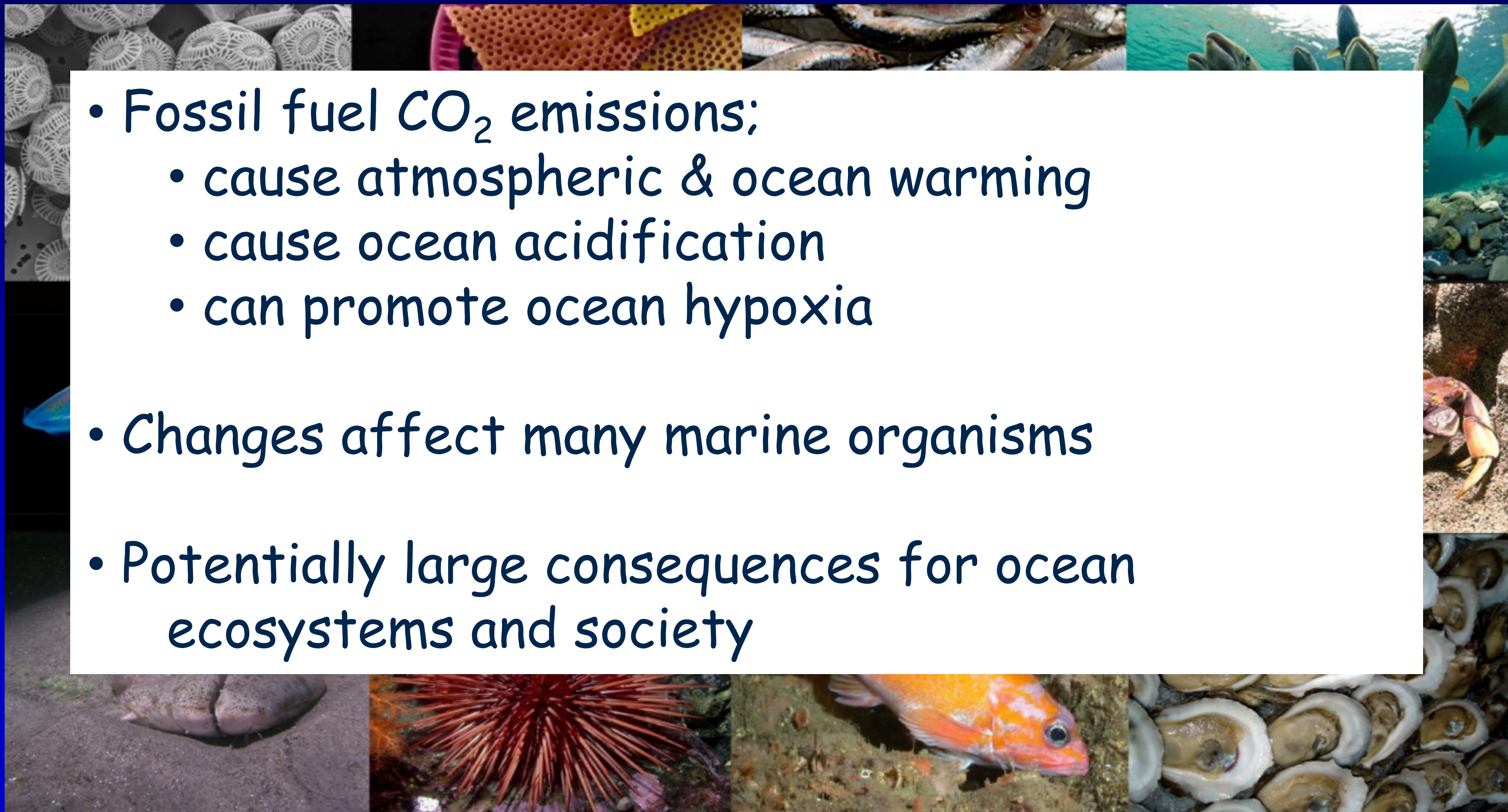
Ocean warming, acidification, and hypoxia -
The dominoes of climate change...

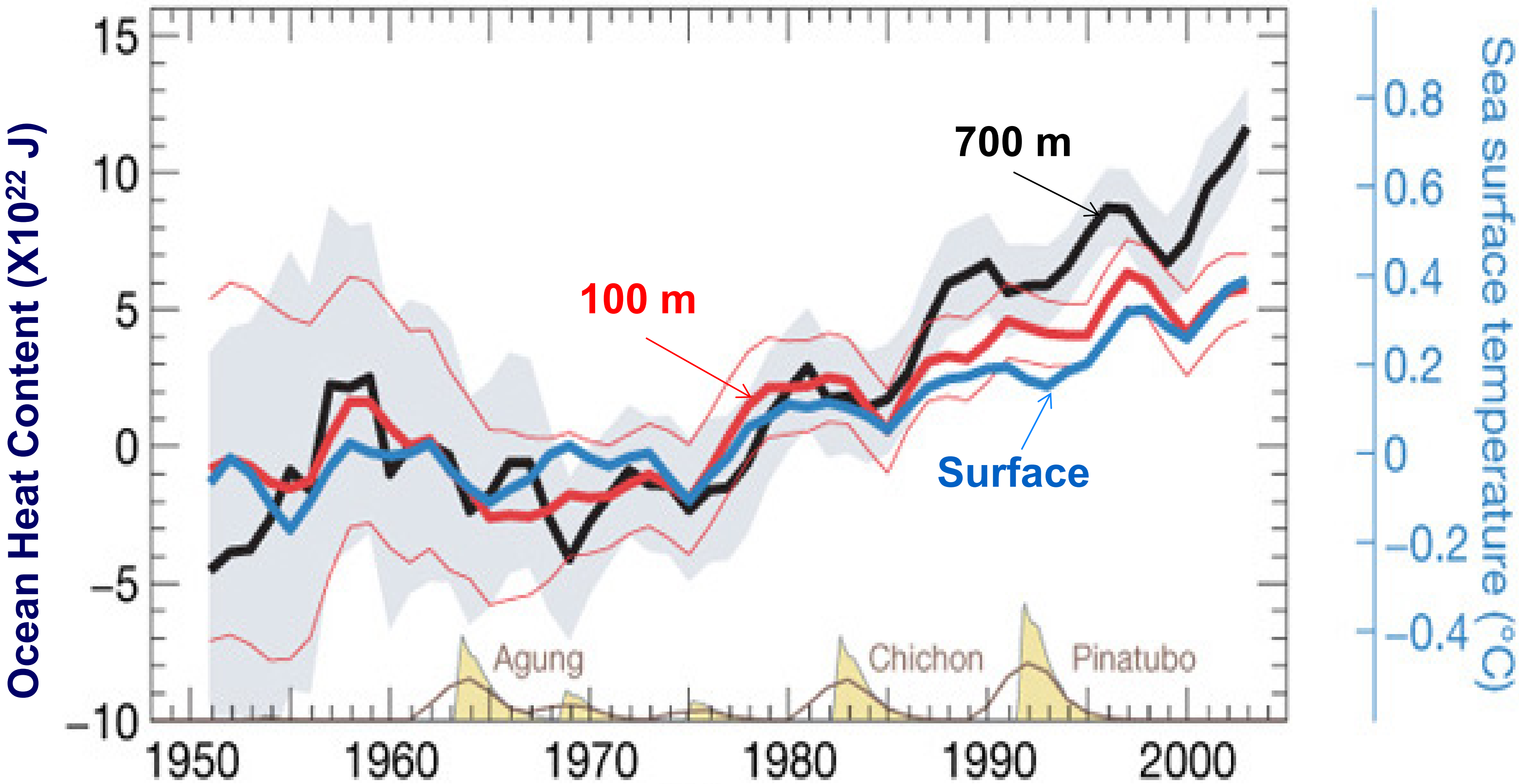
Jim Barry, Monterey Bay Aquarium Research Institute

Naval Postgraduate School, 2011



- Fossil fuel CO_2 emissions;
    - cause atmospheric & ocean warming
    - cause ocean acidification
    - can promote ocean hypoxia
- Changes affect many marine organisms
- Potentially large consequences for ocean ecosystems and society

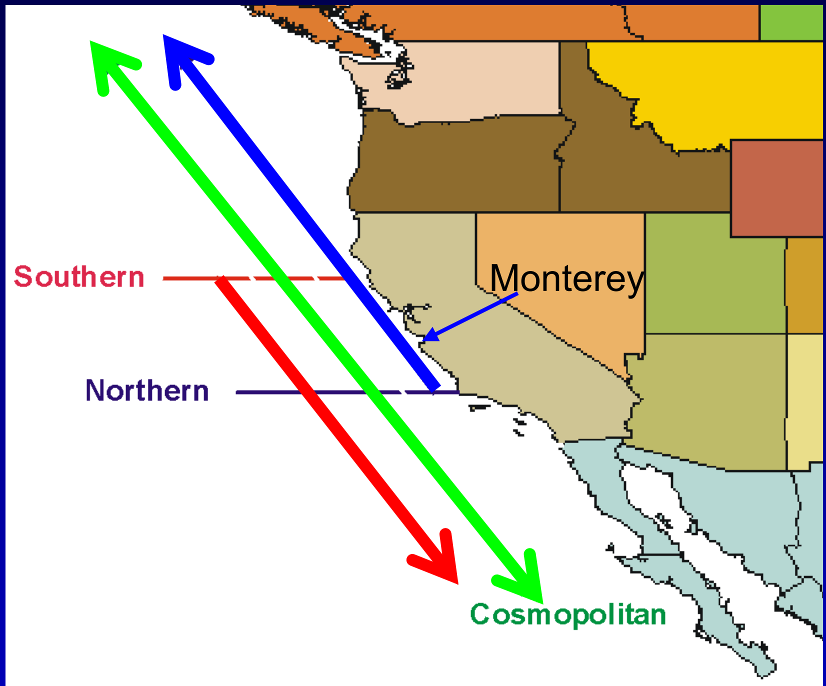
Ocean heat content increasing with global temperature

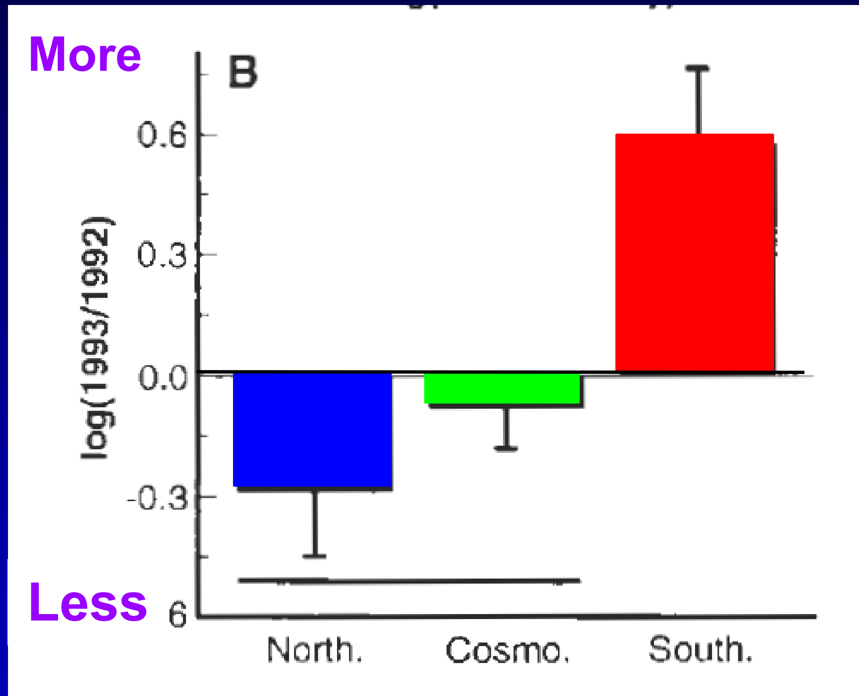


Domingues et al. 2008 (Nature)

Animals distributions are changing with ocean warming

Monterey Bay rocky intertidal animals –
Warm water species increased, Cold water species declined





Southern Species Increased

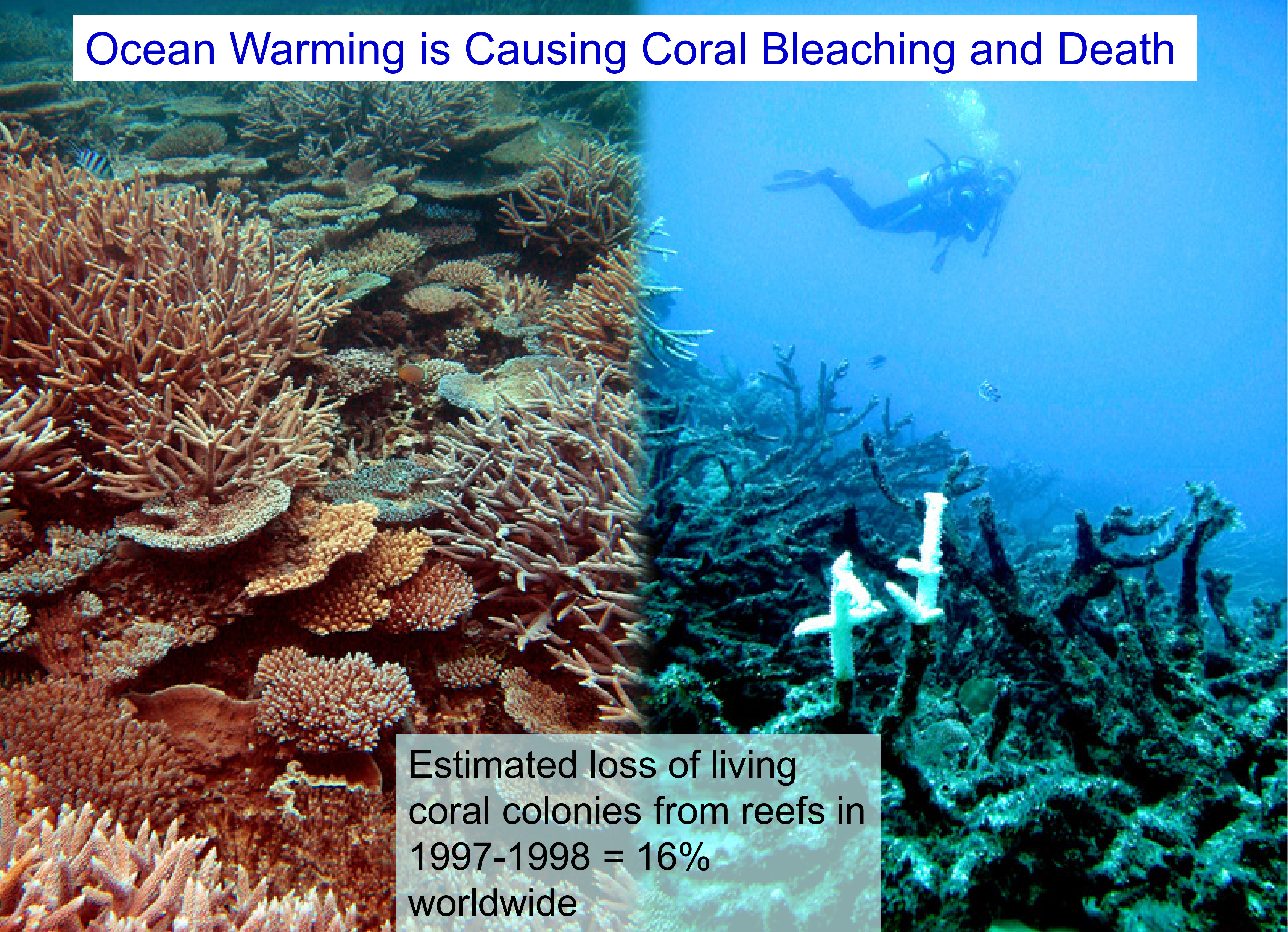
Northern Species Declined



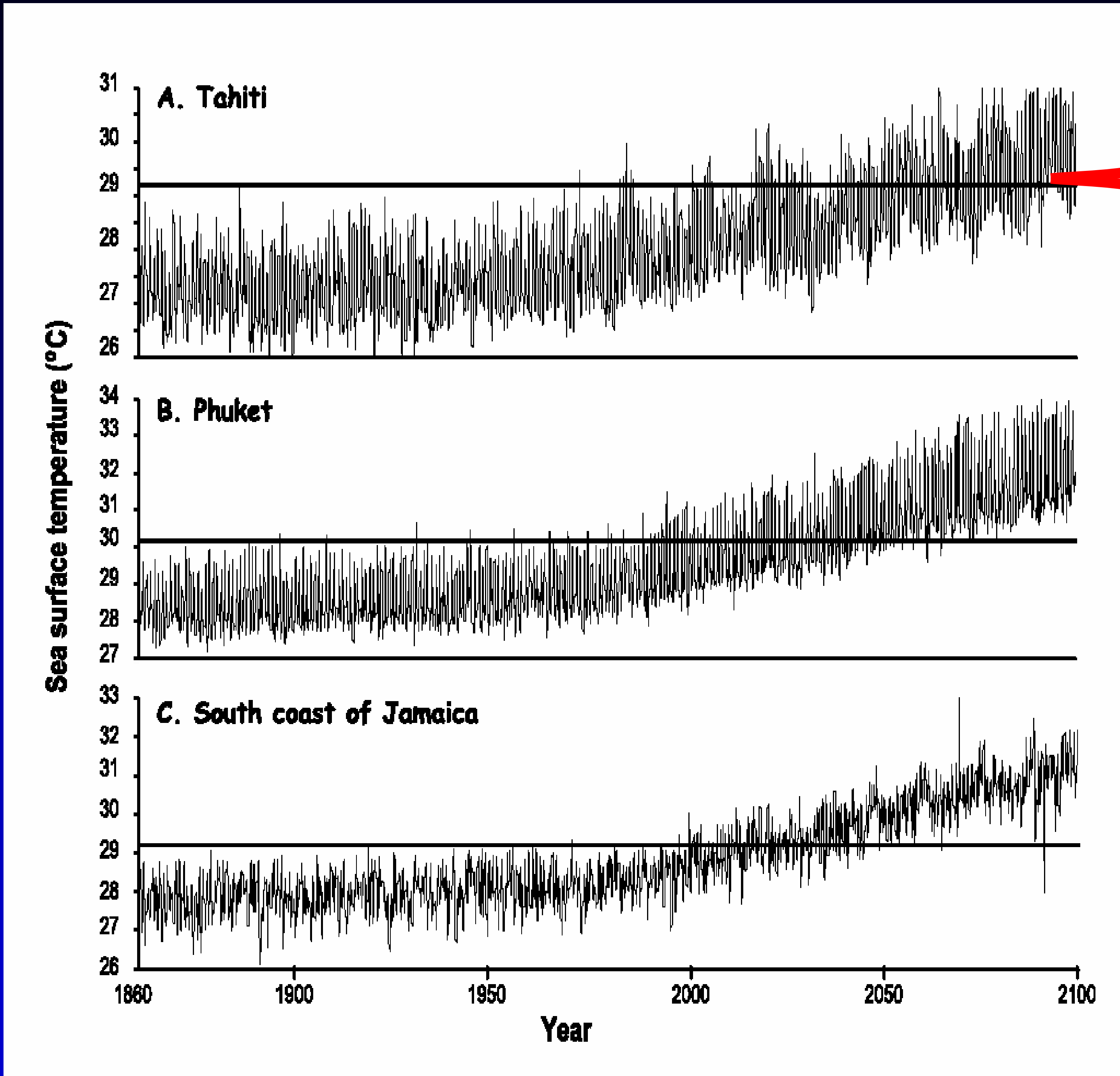



Barry et al. 1995, Sagarin et al. 1999

Ocean Warming is Causing Coral Bleaching and Death



Estimated loss of living coral colonies from reefs in 1997-1998 = 16% worldwide



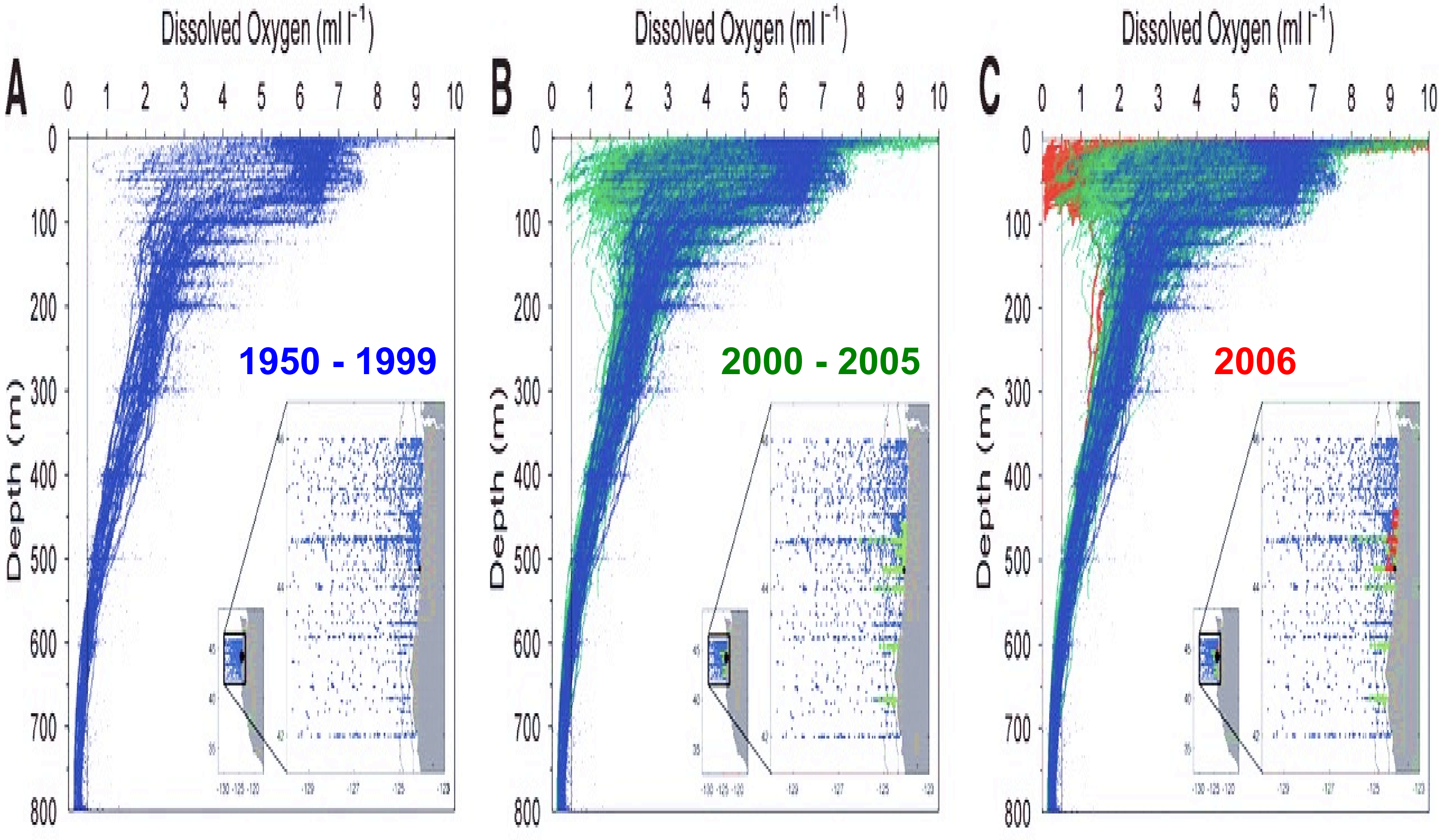
Threshold temperature – above which bleaching manifests itself (1-2oC above the long-term summer maximum temperatures

WHAT DOES THE FUTURE HOLD?

Hoegh-Guldberg (1999)

Hypoxic (low oxygen) waters are more common off Oregon

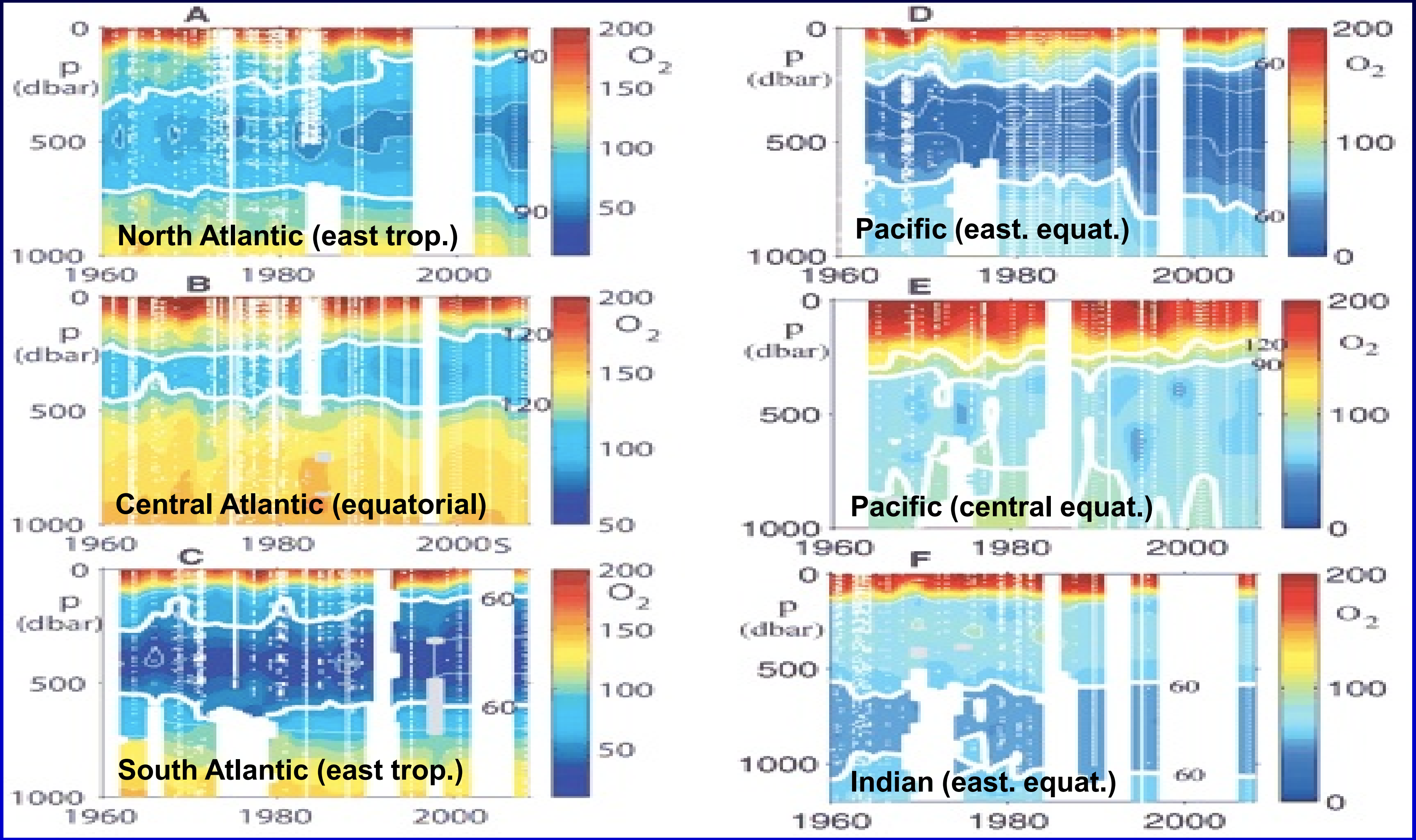
Dissolved oxygen profiles during the upwelling season (mid-April to mid-October) in the upper 800 m of the continental shelf and slope of Oregon.



F Chan et al. Science 2008;319:920-920

Oxygen levels in many ocean areas is declining (hypoxia)

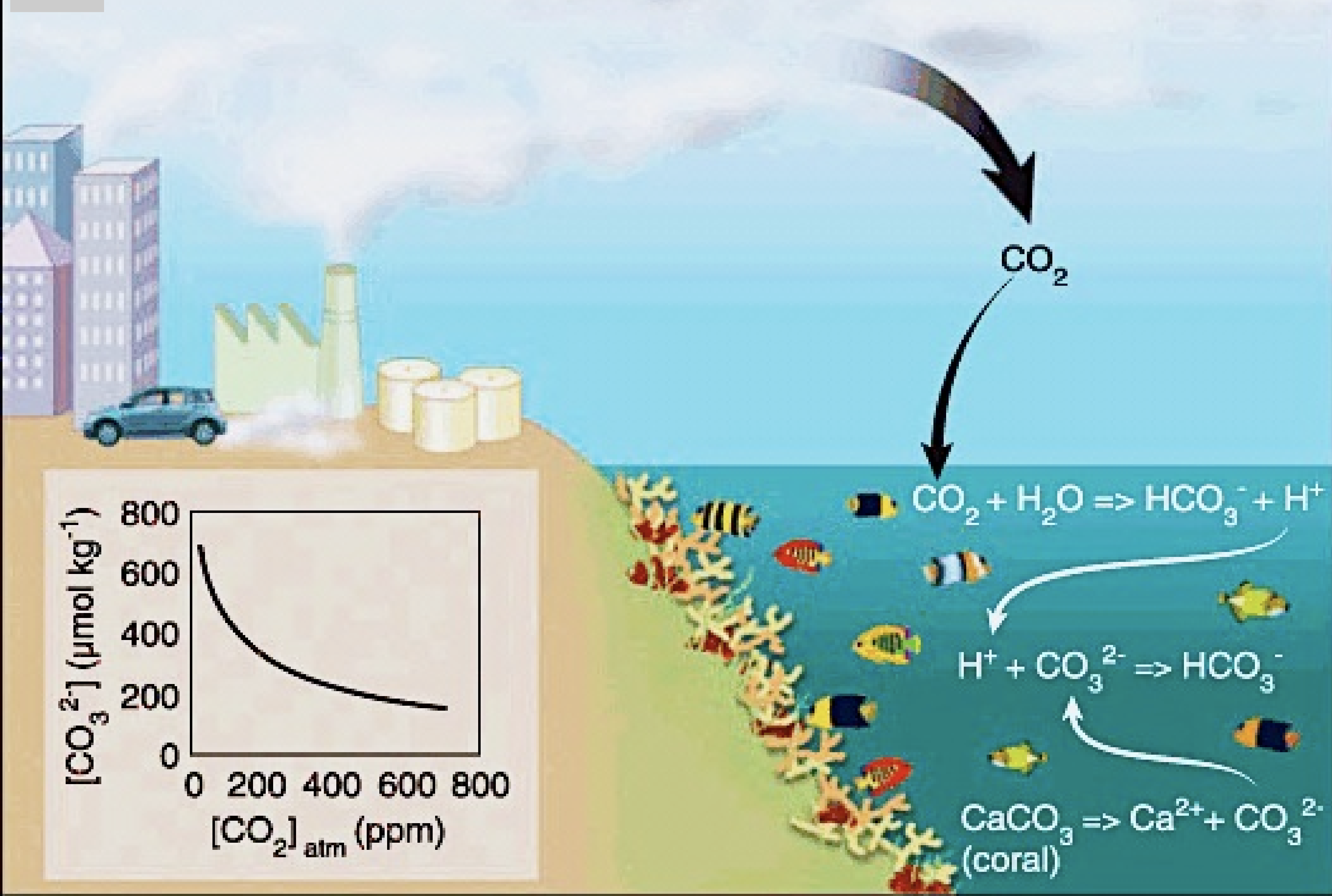
Warmer surface waters inhibit mixing of oxygen to depth



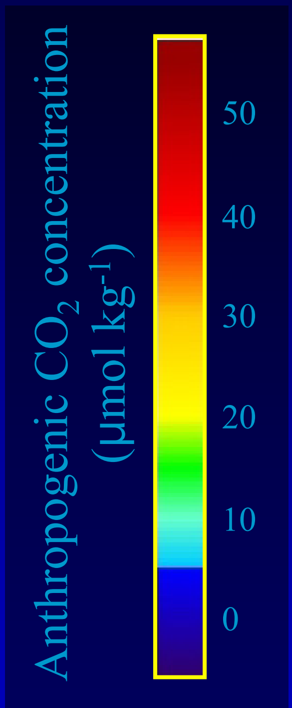
1960 2000 1960 2000

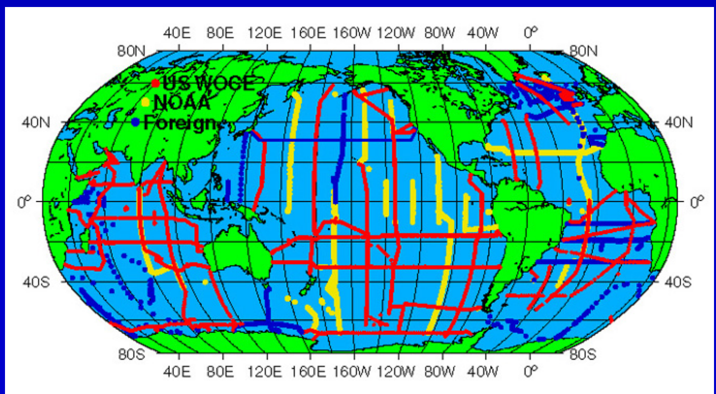
Stramma et al. 2010

CO_2 emissions cause *Ocean Acidification*

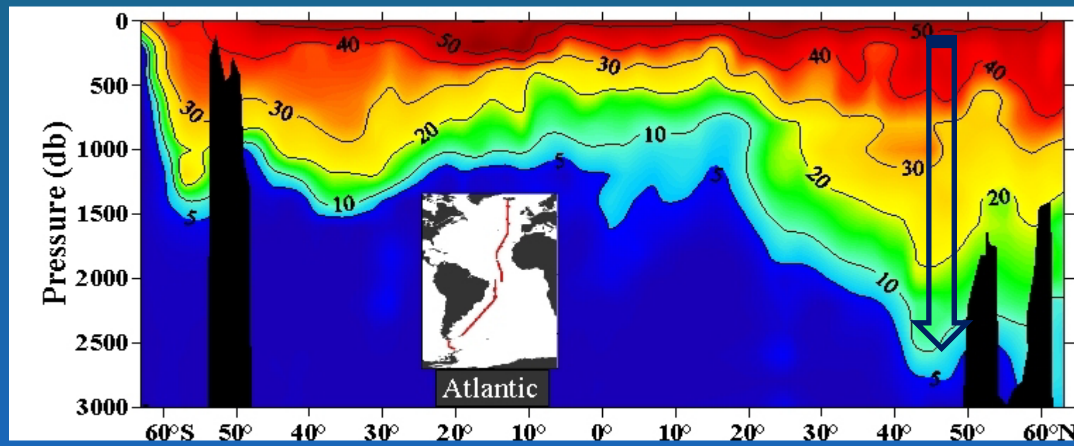


Fossil fuel CO_2 in the oceans (1994)

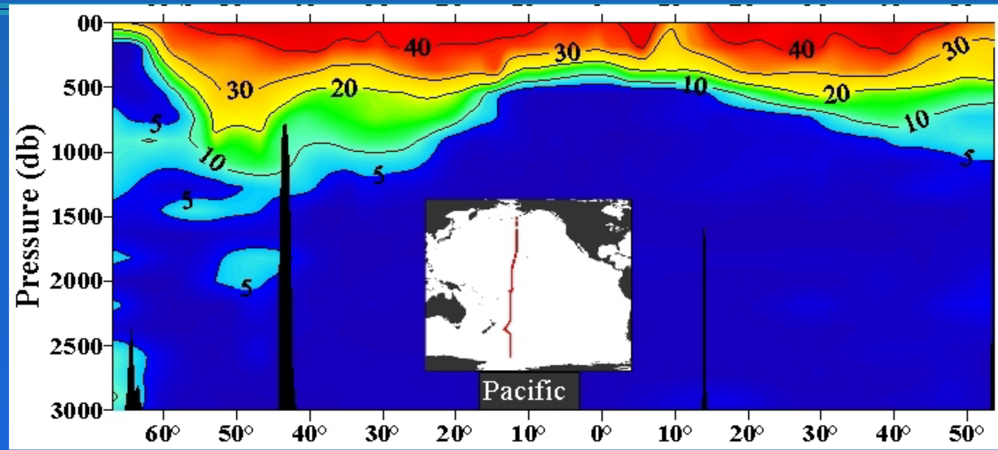




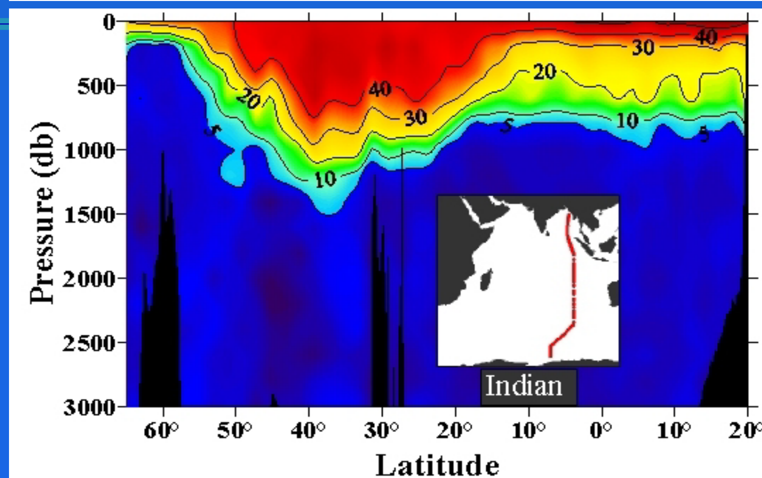
Atlantic



Pacific



Indian



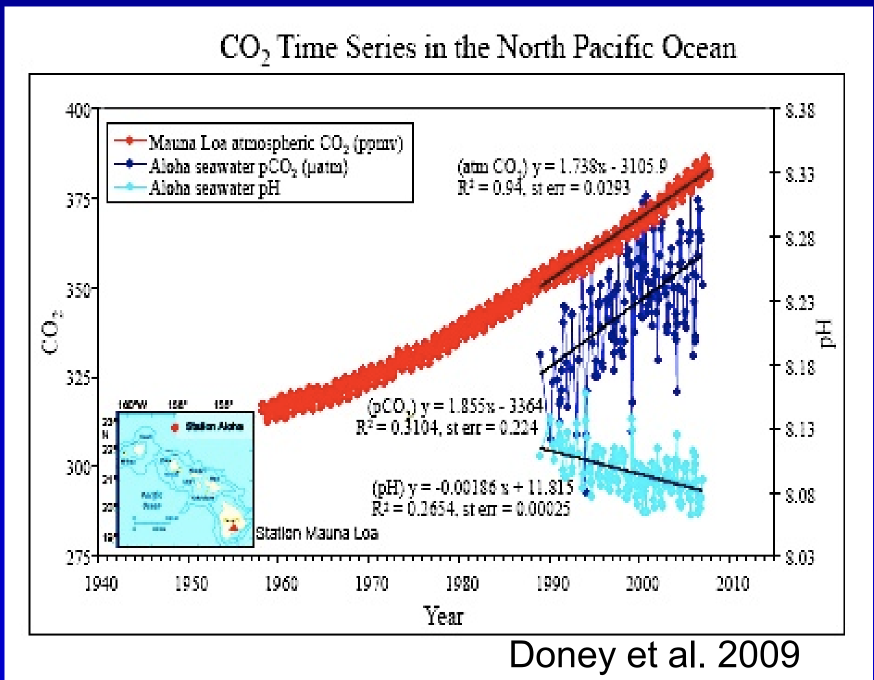
[Sabine et al. *Science*, 2004]

Variation in CO_2 and ocean acidity (pH)

CO_2 on Earth

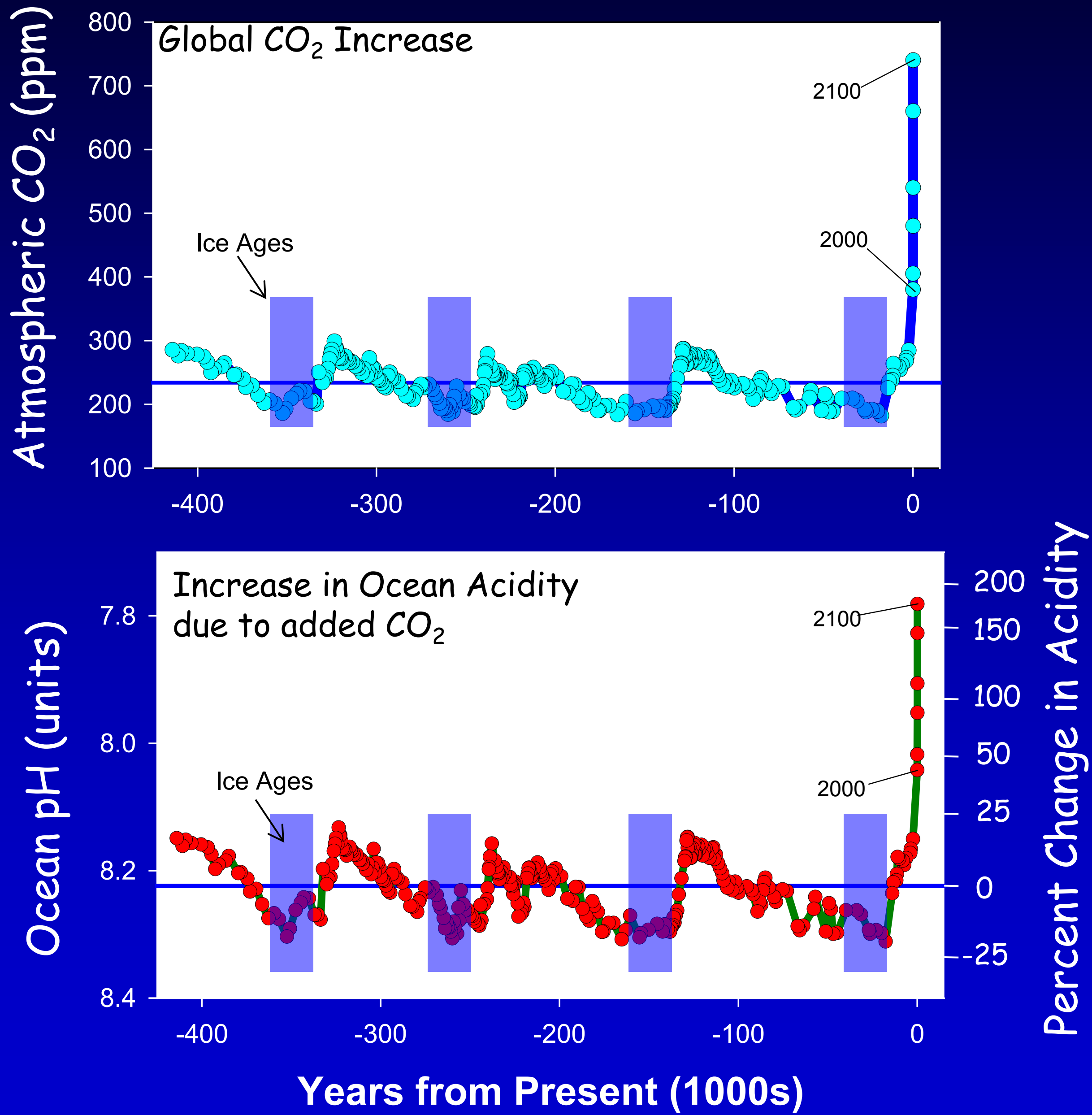
- CO_2 emissions rising
- Ocean becoming more acidic

Atmospheric, Ocean CO_2, & Ocean pH

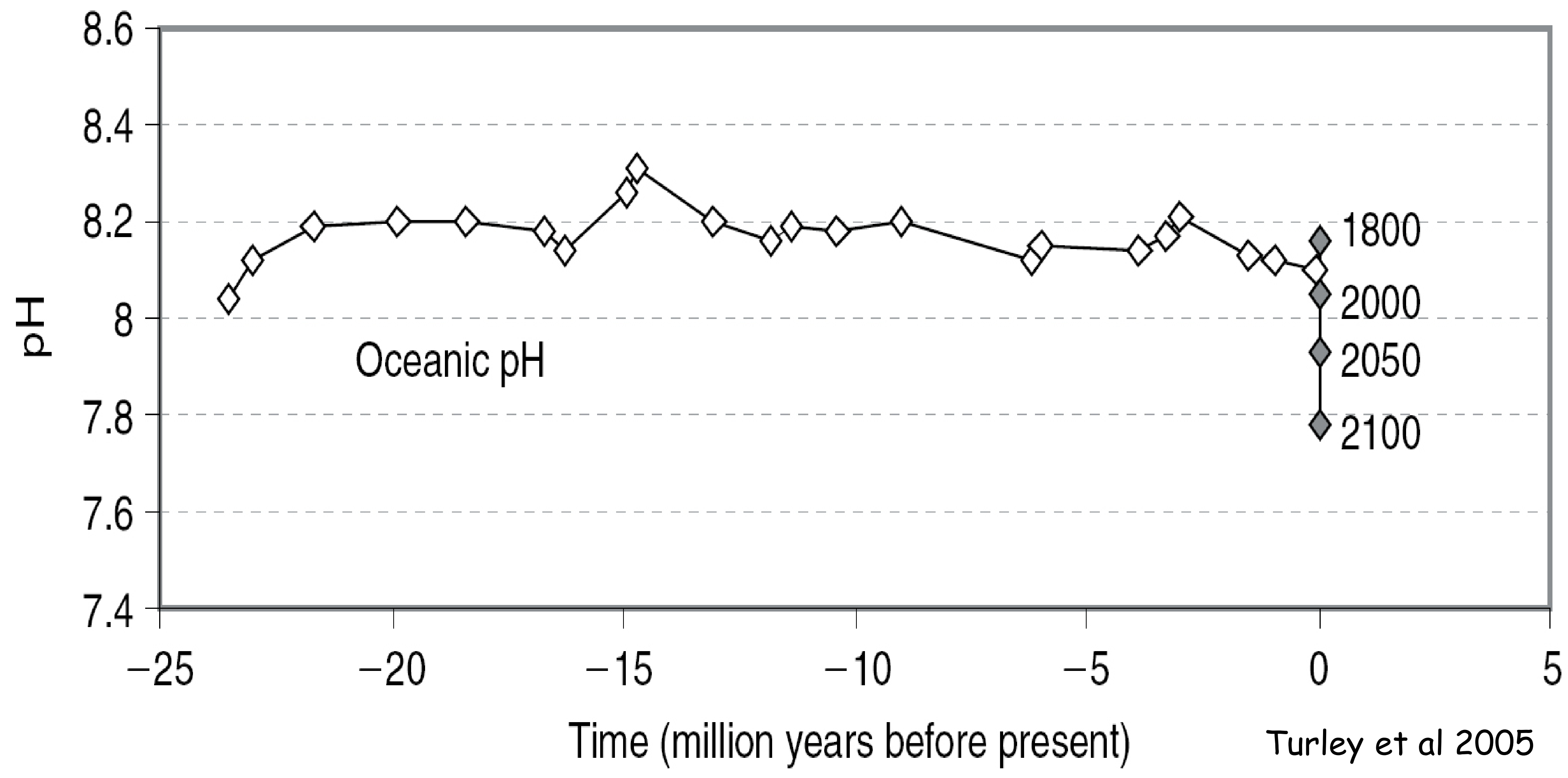


Doney et al. 2009

425,000 year history



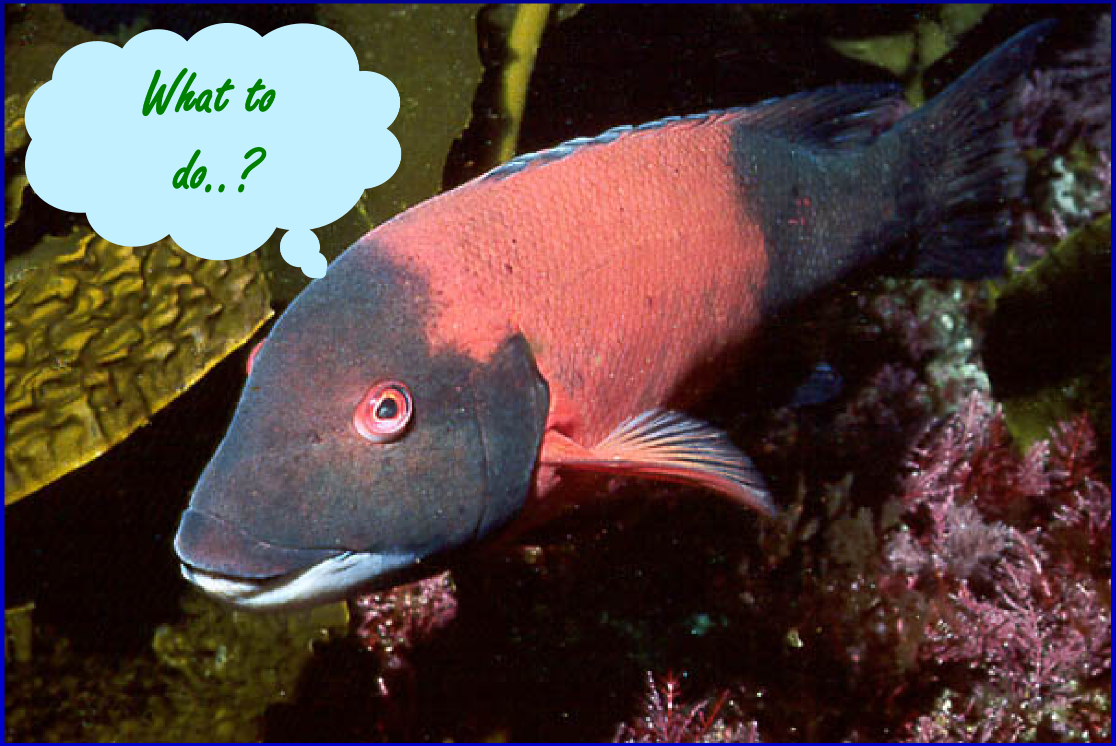
Change in ocean pH over 25 million years



- Estimated from boron isotopes in seabed foraminifera
- Note speed and size of current pH change

Options for organisms faced with warming, hypoxia, and ocean acidification?

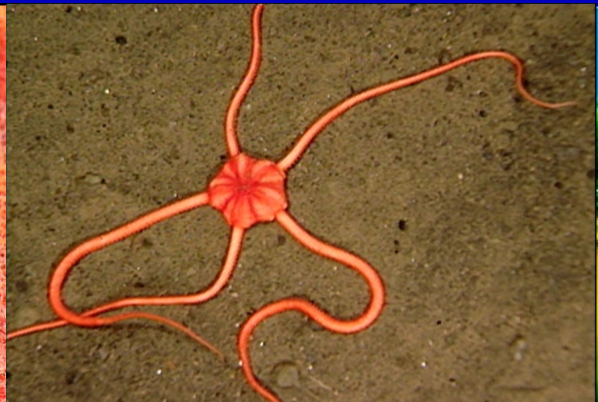
- Migration
- Tolerance & Acclimation
- Adaptation (linked to evolutionary history, generation time)
- Extinction

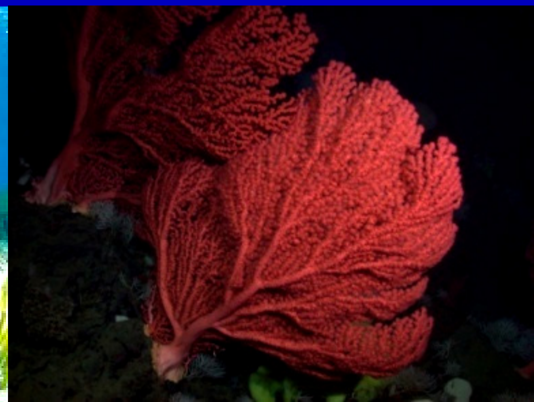


Ocean change affects physiological function

- *Photosynthesis*
- *Calcification **
- *Respiration*
- *Acid – Base Balance*
- *Metabolism*

Vampire Squid

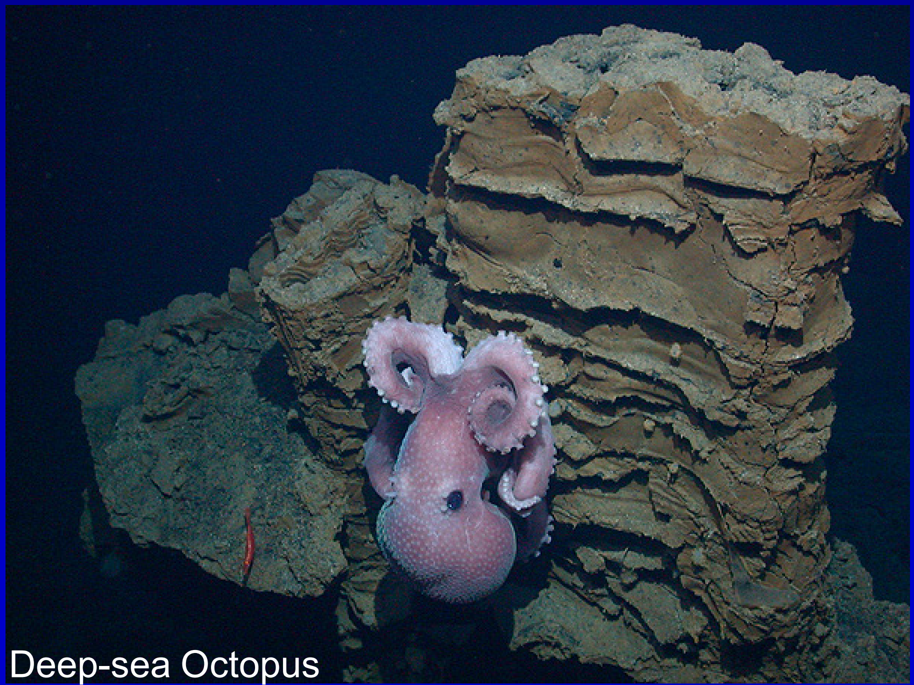




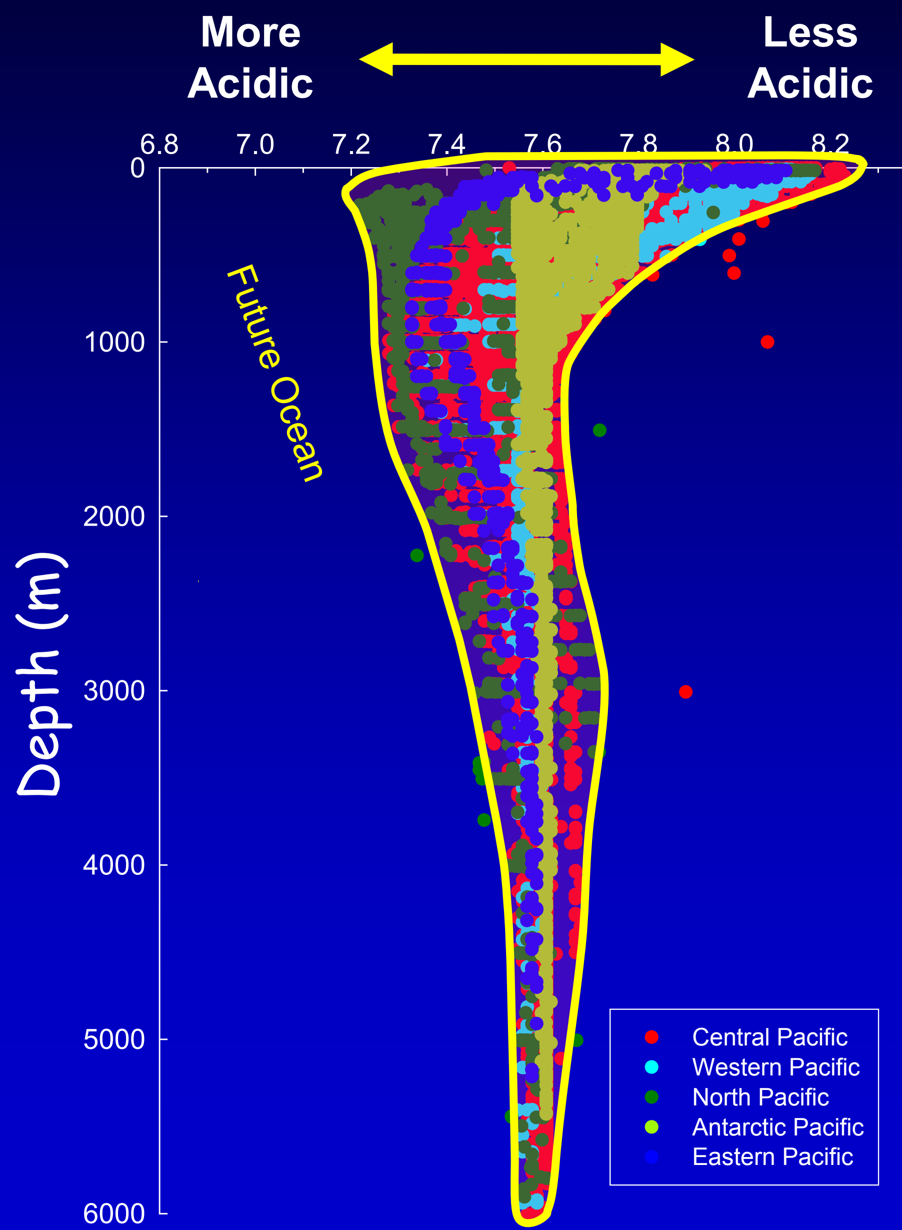
Ocean change may be more difficult for deep-sea animals

Deep-Sea Animals

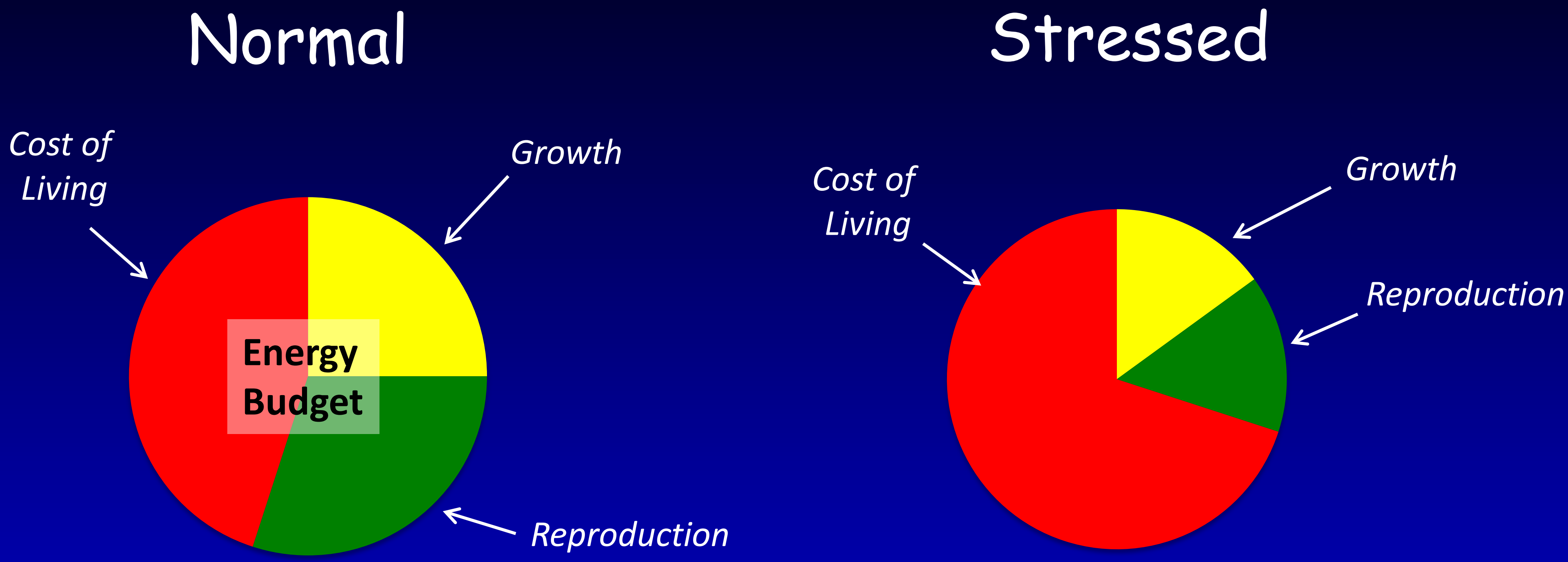
- Low metabolic rates
- Low enzyme function
- Evolved in highly stable deep-sea environment
- Food-limited – "Living on the edge"



pH variation in the Pacific Ocean



Stress increases the 'cost of living'



Energy budgets – If the cost of living (e.g. shells) increases, less is available for growth and reproduction.

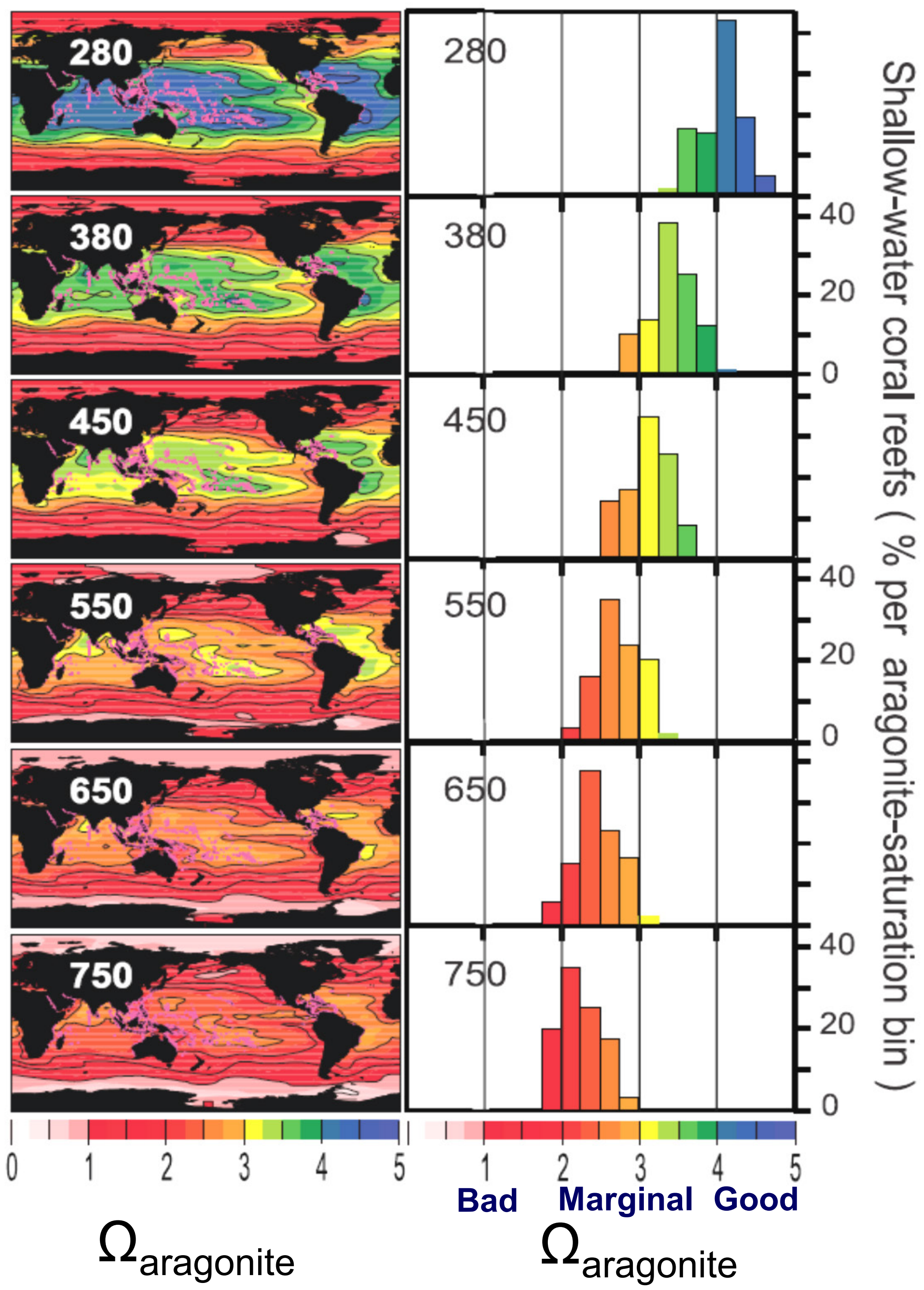
Ocean chemistry and the future of coral reefs?

Predicted aragonite saturation (Ω) [a measure of the amount of minerals available to make coral skeletons] is shown over a global map of existing coral reef locations (pink dots) for various atmospheric CO2 levels. Note that Ω decreases drastically with higher CO2 levels.

280 ppm is the preindustrial level of CO2 in the atmosphere. During 2011 CO2 is ~390 ppm. Most climate models indicate that we will reach ~800 ppm CO2 by 2100.

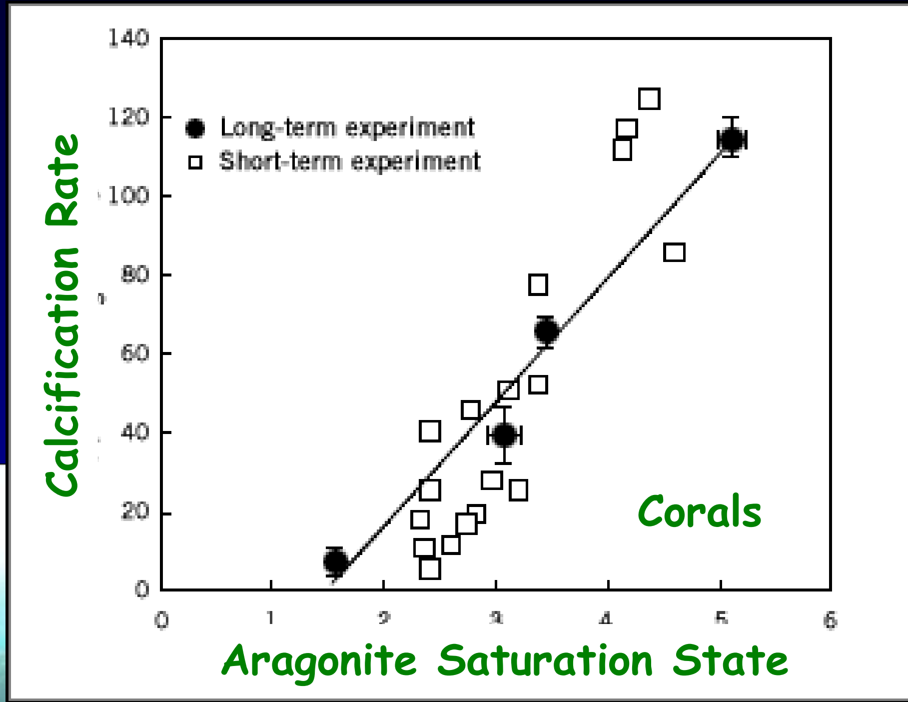
Corals grow best when carbonate minerals are abundant (Ω >3), and cease to grow at low mineral levels (Ω ~2) and can dissolve at very low levels (Ω < 1).

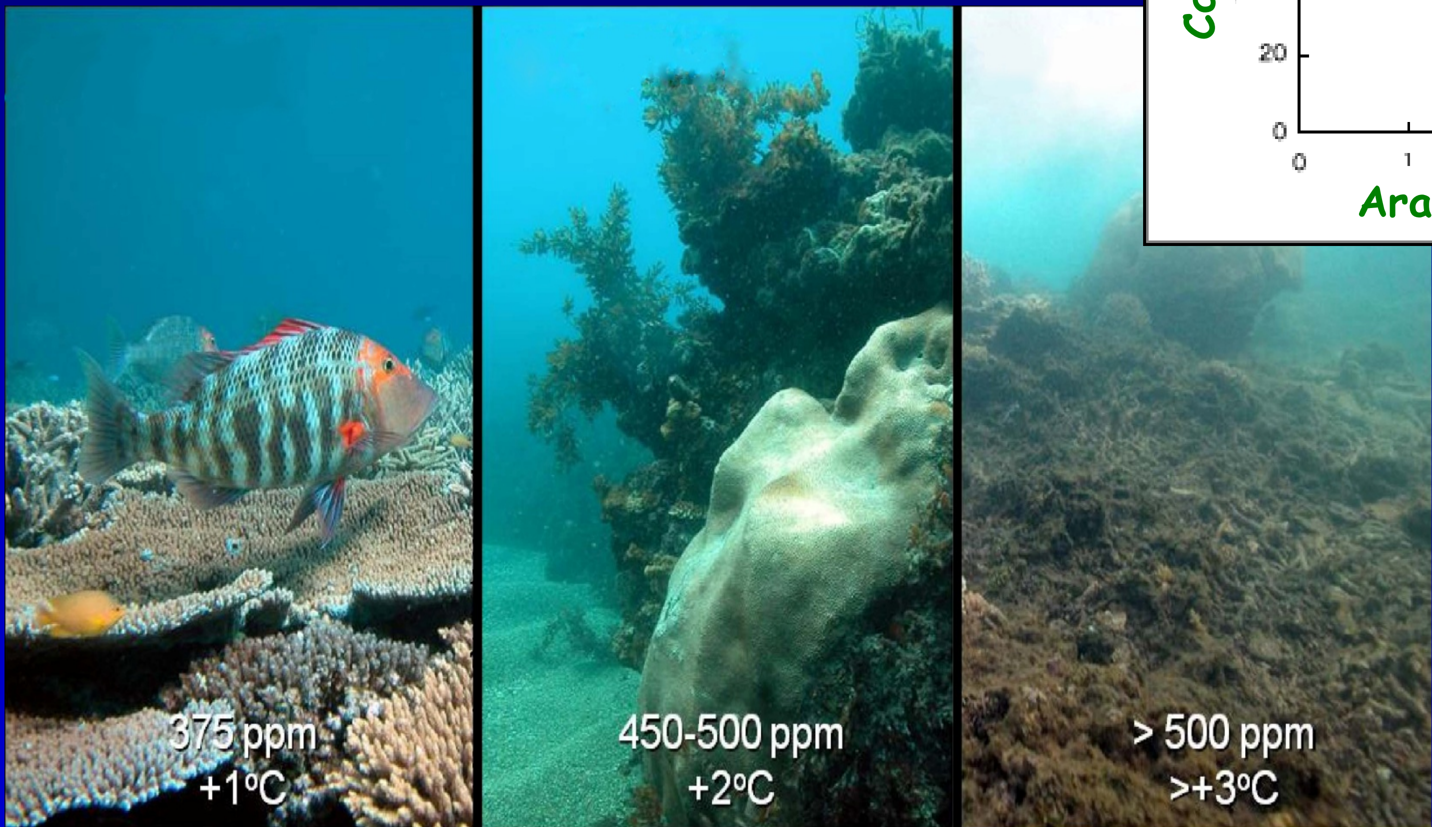
On the right, there is a count of the mineral conditions for the locations of all global coral reefs. Note that the preindustrial climate (280 ppm CO2) all reef locations had mineral conditions favorable to growth (high Ω). As CO2 levels rise through this century, ALL existing reef are expected to have marginal or poor conditions for coral growth.



Calcification and Coral Ecosystem Tipping Points

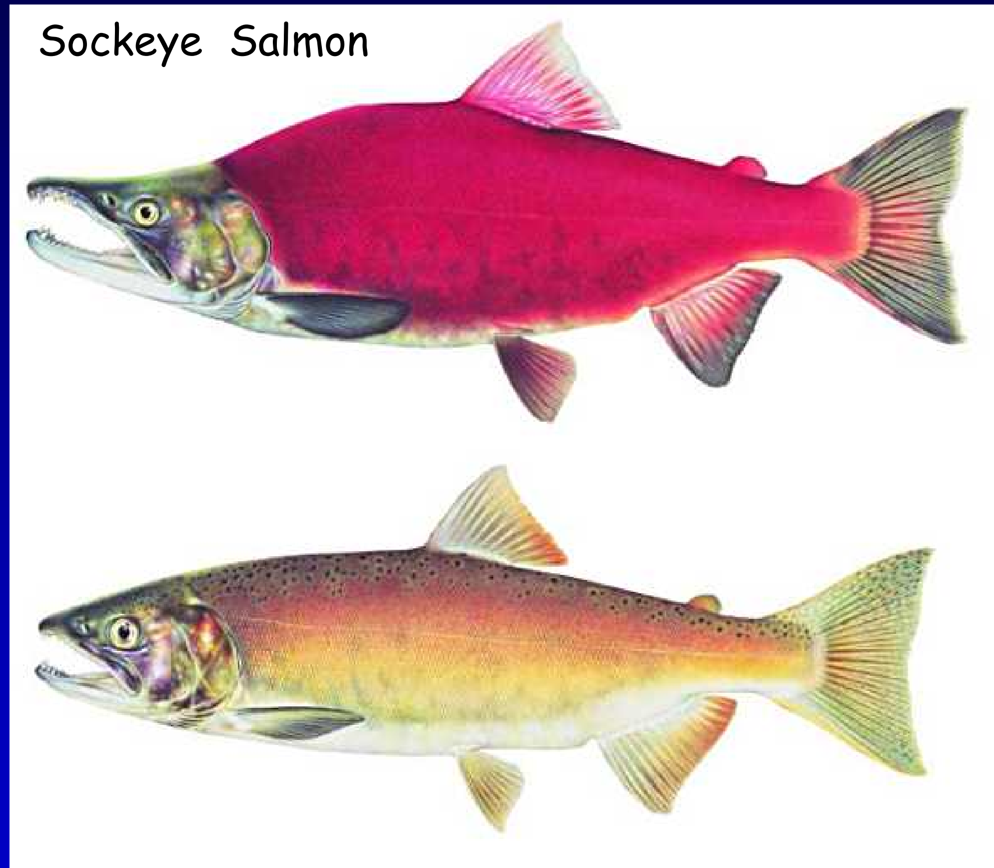
Low carbonate saturation associated with low calcification rate



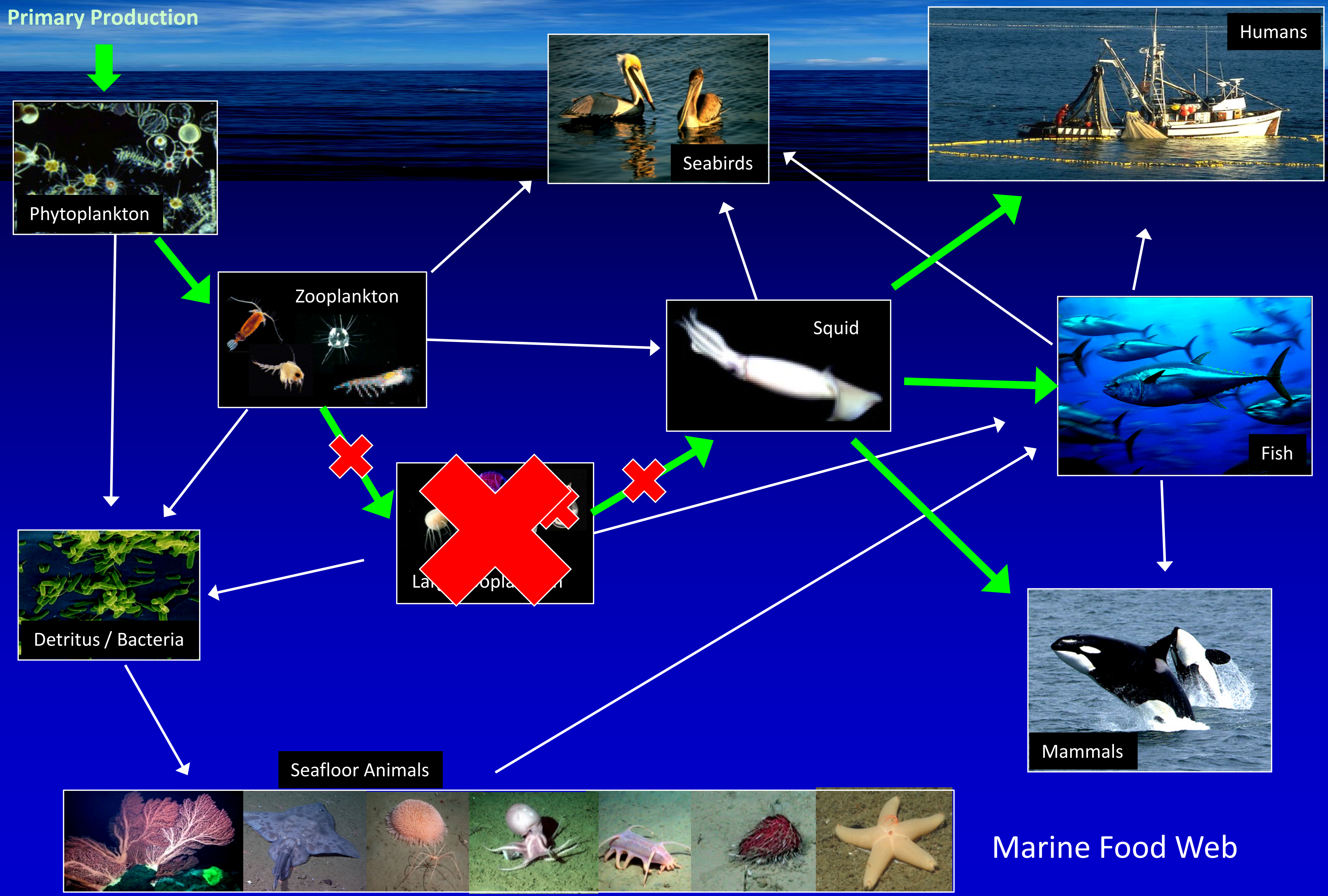


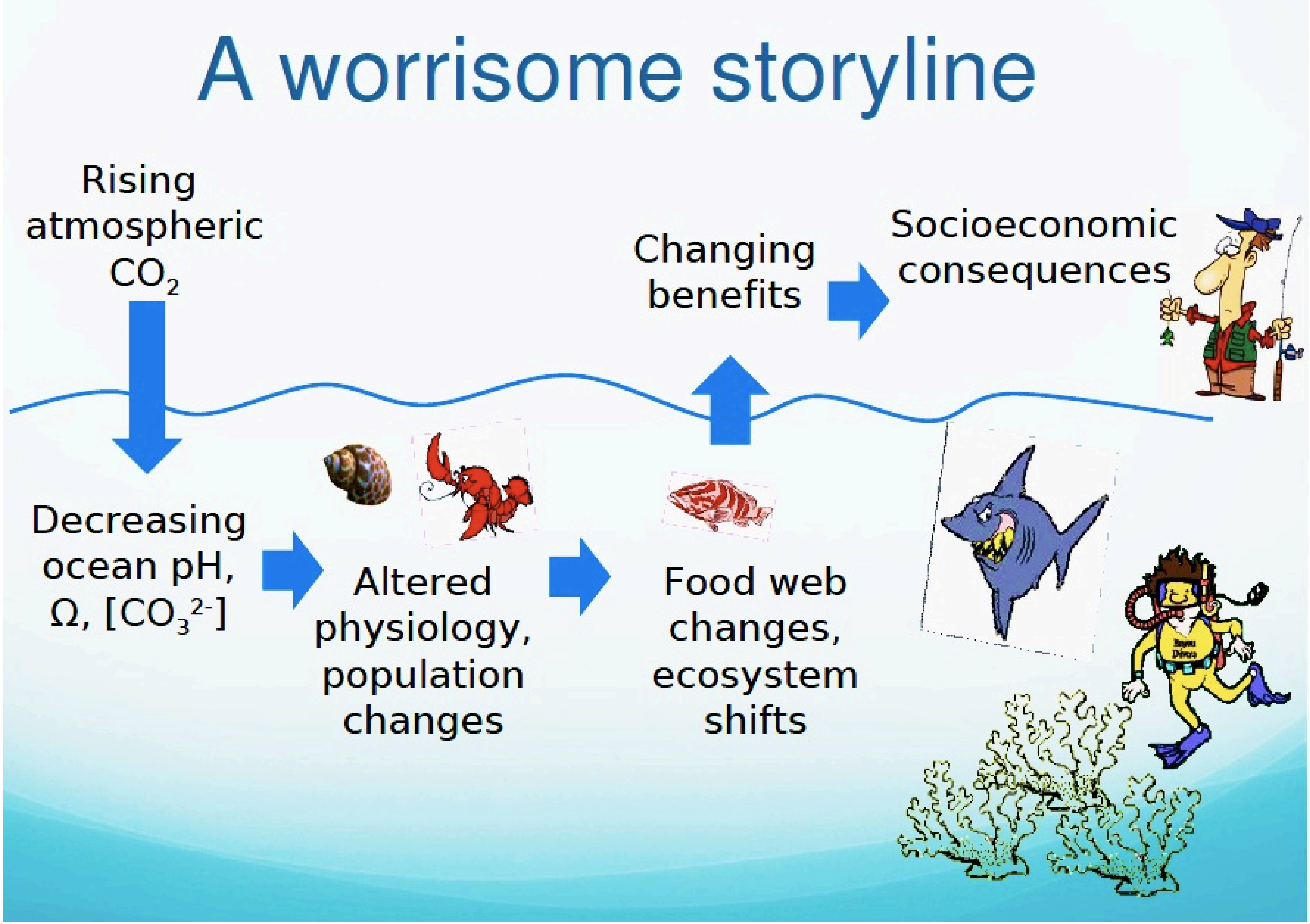
Hoegh-Guldberg et al. 2007

Will Ocean Acidification disrupt energy flow through marine food webs?



Marine Communities are Biological Networks




A worrisome storyline
Rising atmospheric CO_2
Decreasing ocean pH, Ω, $[CO_3^{2-}]$
Altered physiology, population changes
Food web changes, ecosystem shifts
Changing benefits
Socioeconomic consequences

Conclusions

What we know:

- Carbon dioxide emissions causing ocean change
- Warming, hypoxia, acidification
- Stressful for many organisms

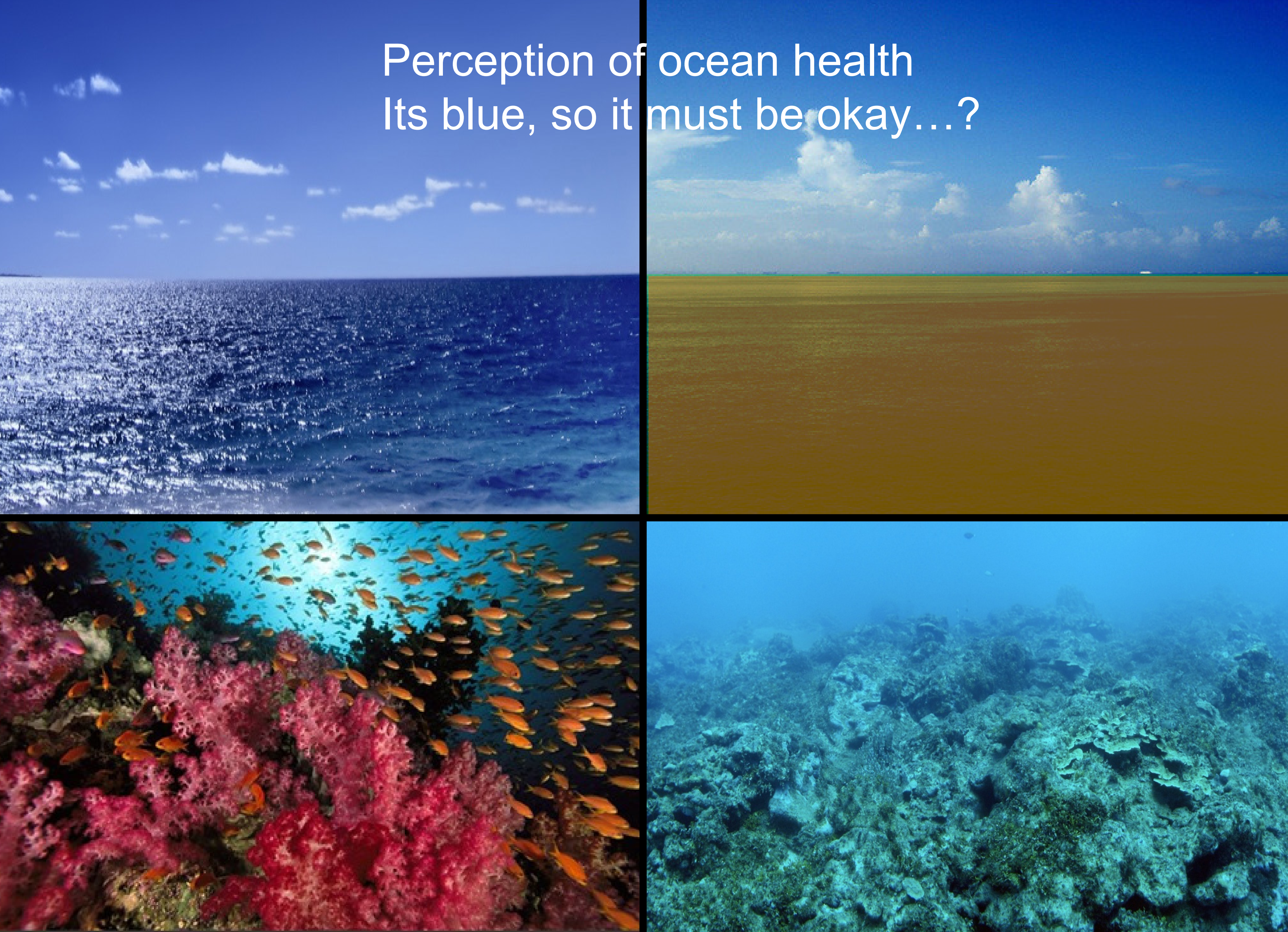
What we expect:

- Food webs will be affected
- Ecosystem services (e.g. fisheries) will change

What we don't know:

- Long term effects
- Sensitive life stages
- Acclimation and adaptation
- Multiple Stressors
- Ecosystem tipping points?

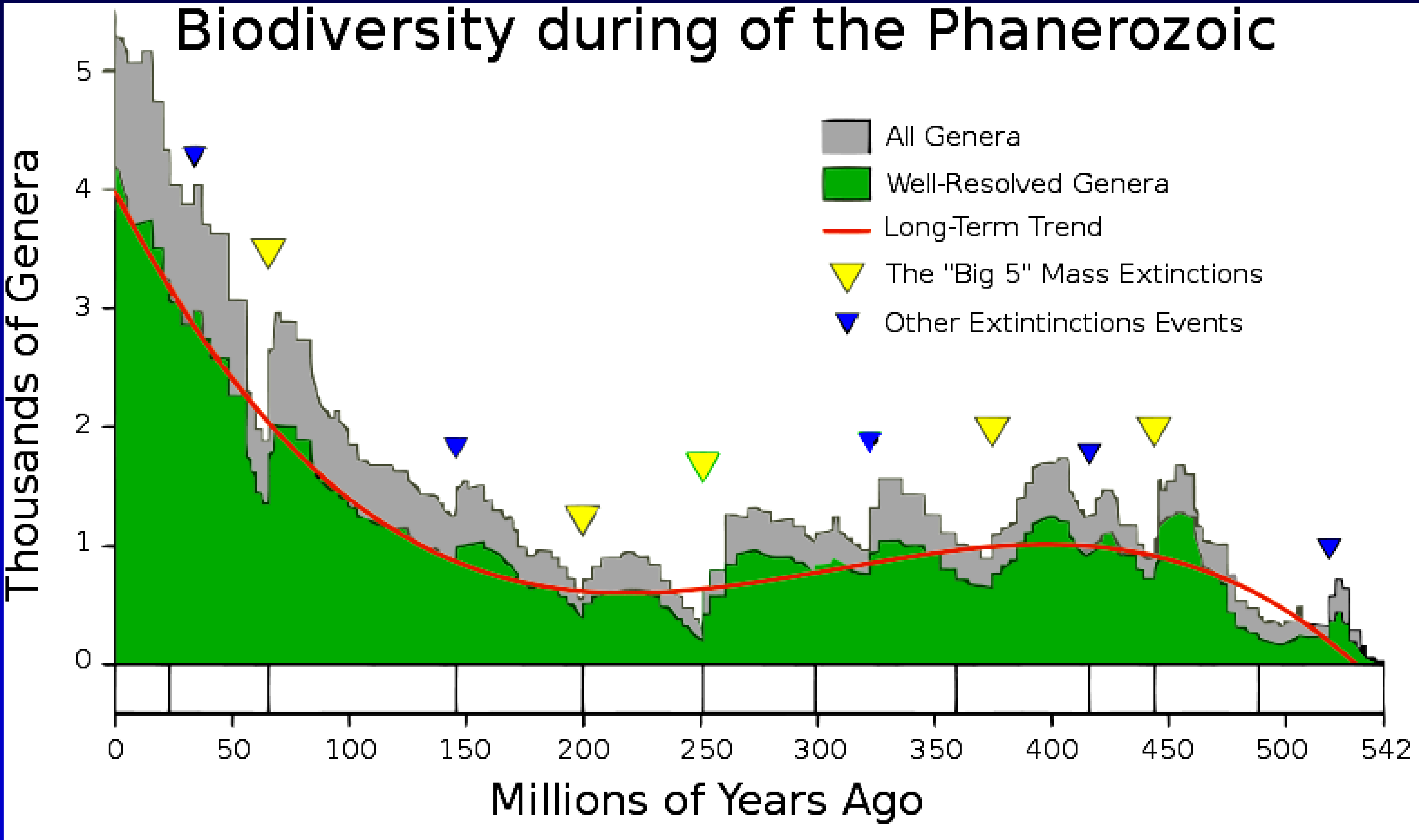
Perception of ocean health
Its blue, so it must be okay…?



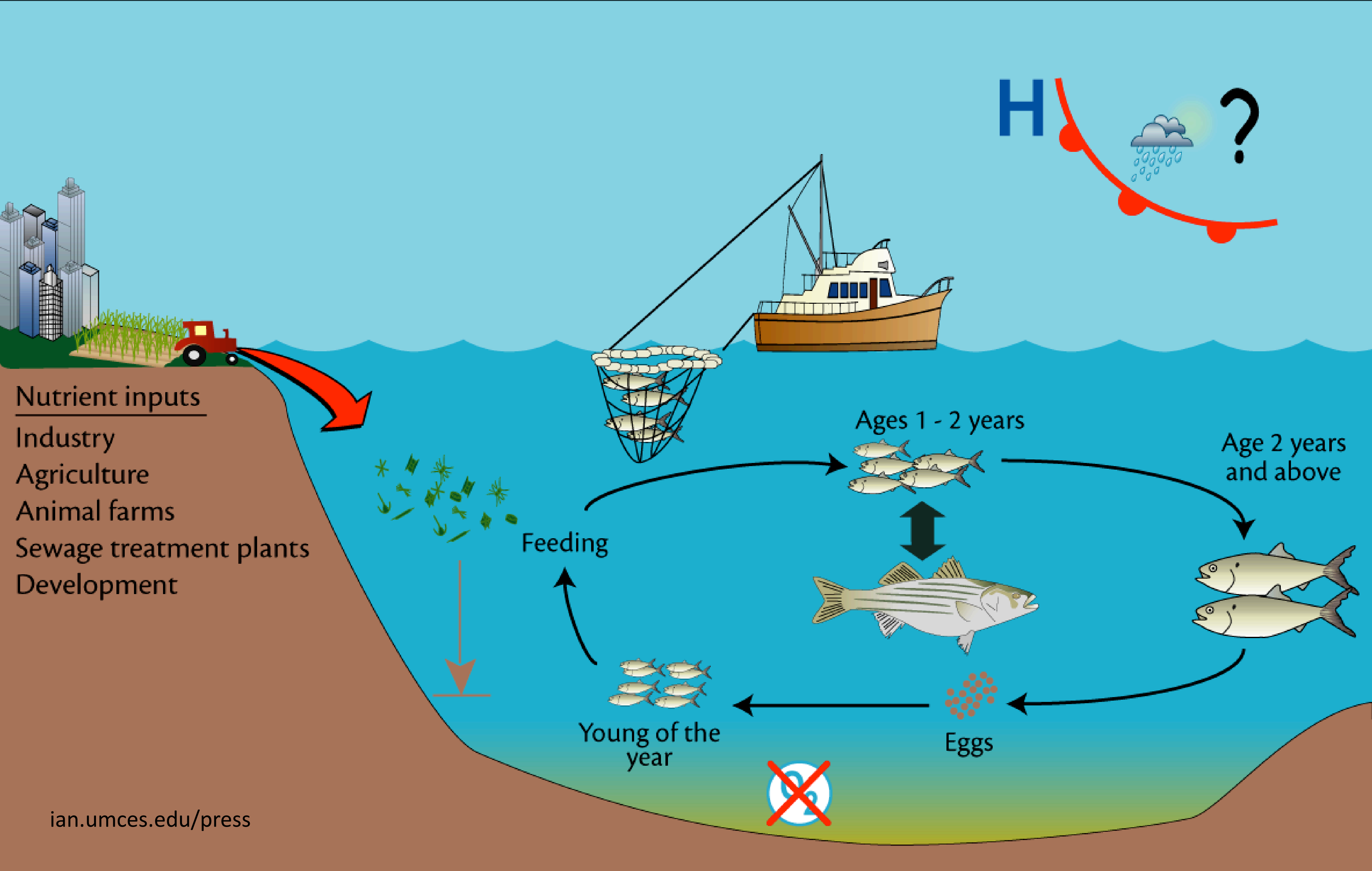
Value the oceans

Mass extinctions during Earth history

- 5 major mass extinctions with >70% extinction of all species
- 10+ million years to recover (rediversify)

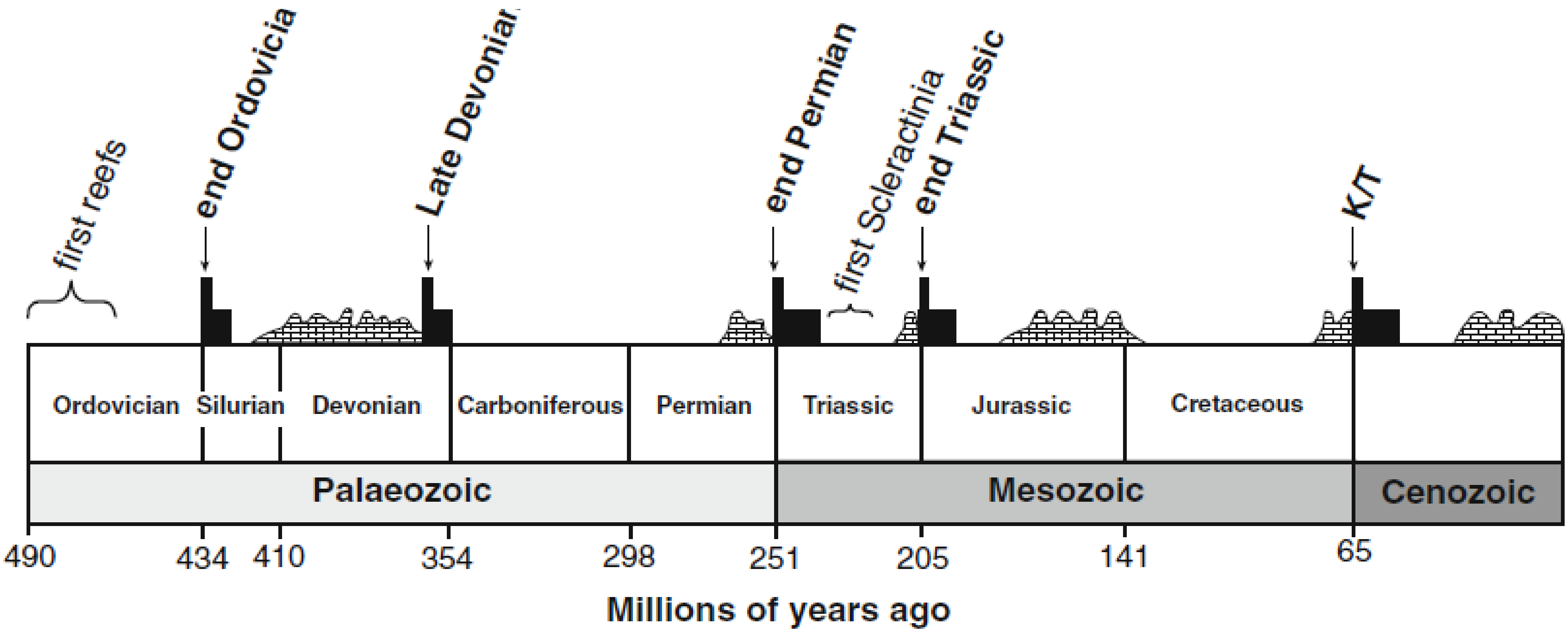


Ecosystem-based management of marine resources



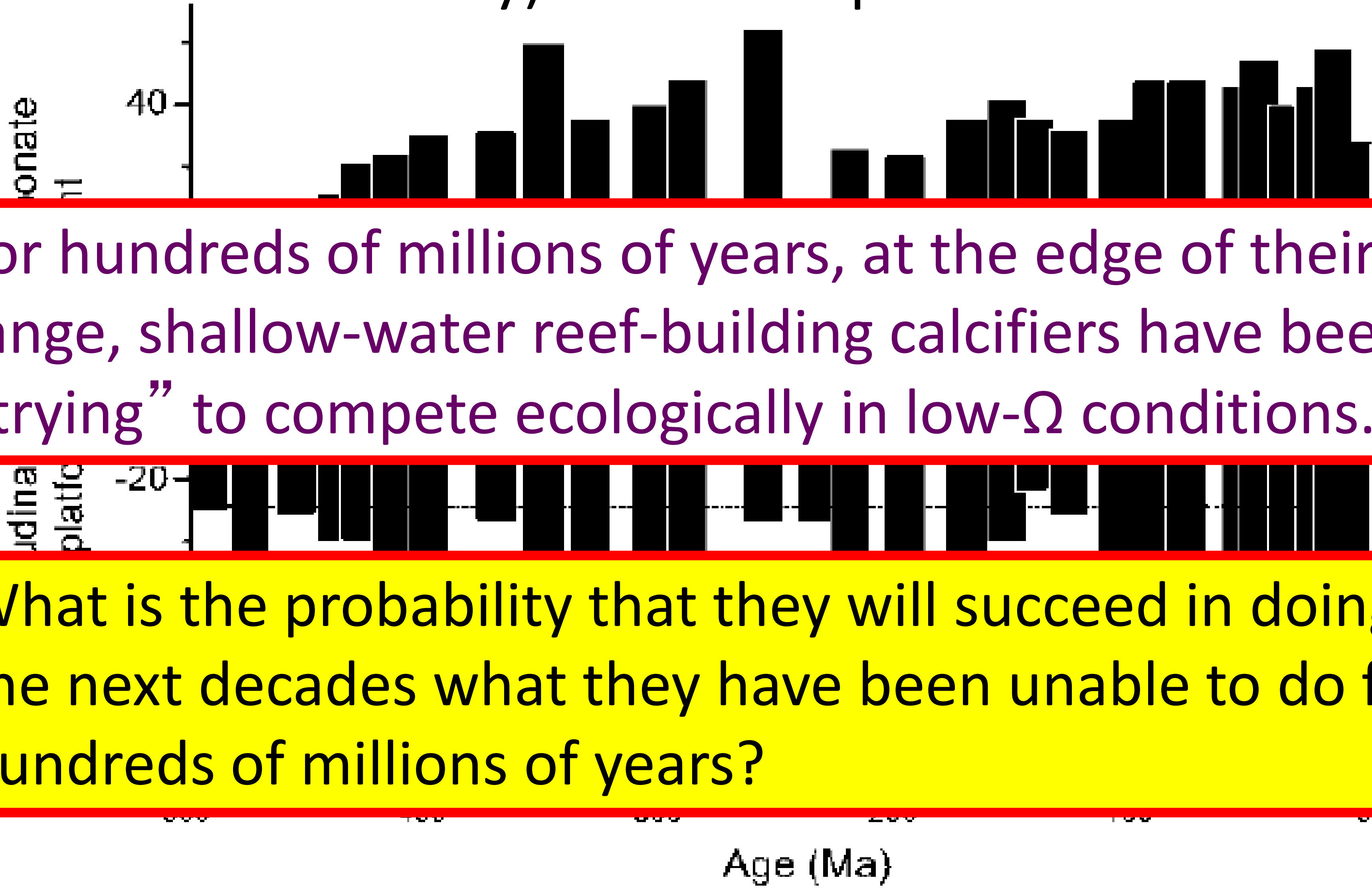
Mass extinctions and ocean acidification: biological constraints on geological dilemmas

J. E. N. Veron Coral Reefs (2008) 27:459–472



Latitudinal range of carbonate (coral) reefs

No correlation with temperature, so Ω (ocean chemistry) is more important



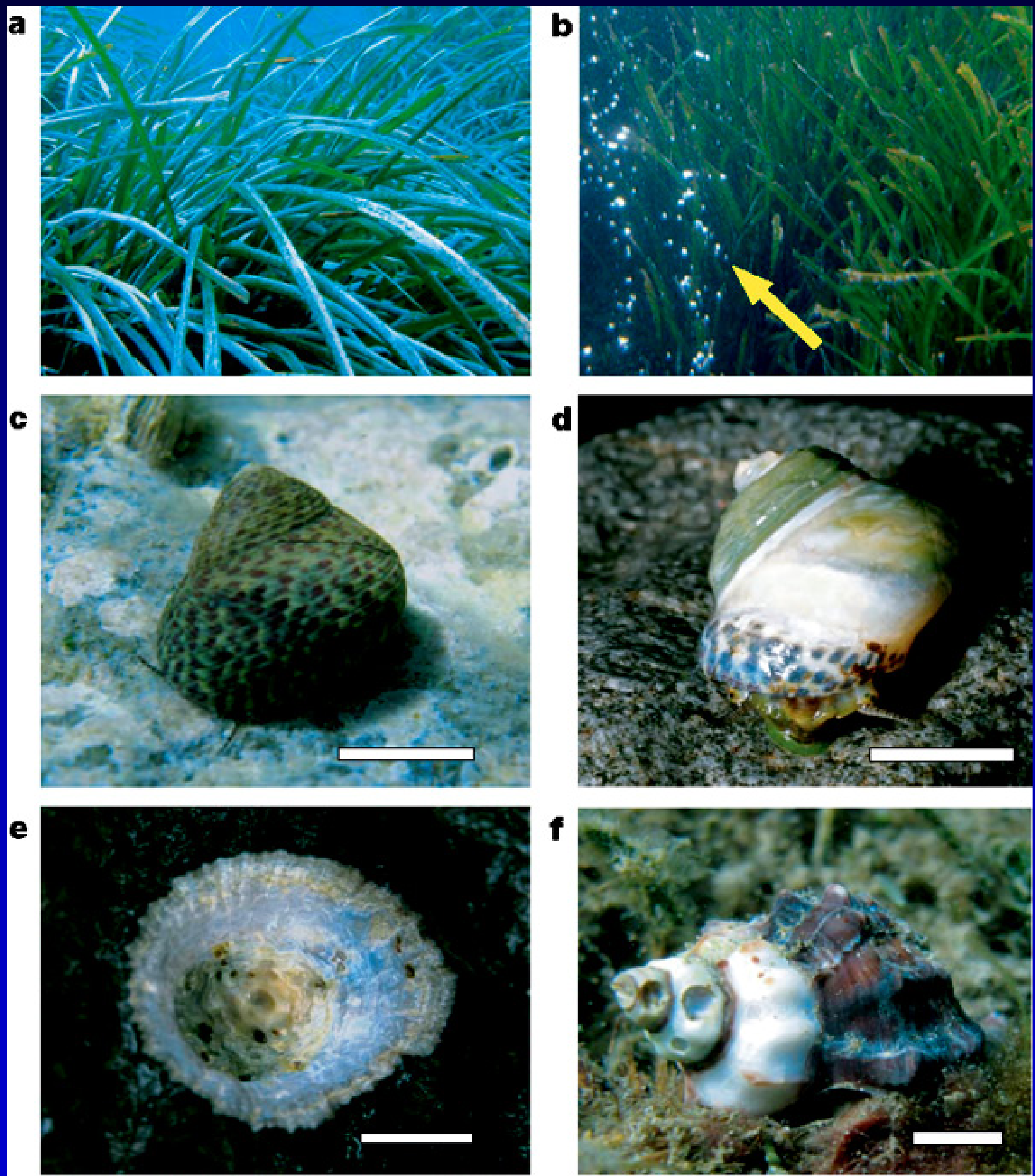
For hundreds of millions of years, at the edge of their range, shallow-water reef-building calcifiers have been "trying" to compete ecologically in low-Ω conditions.

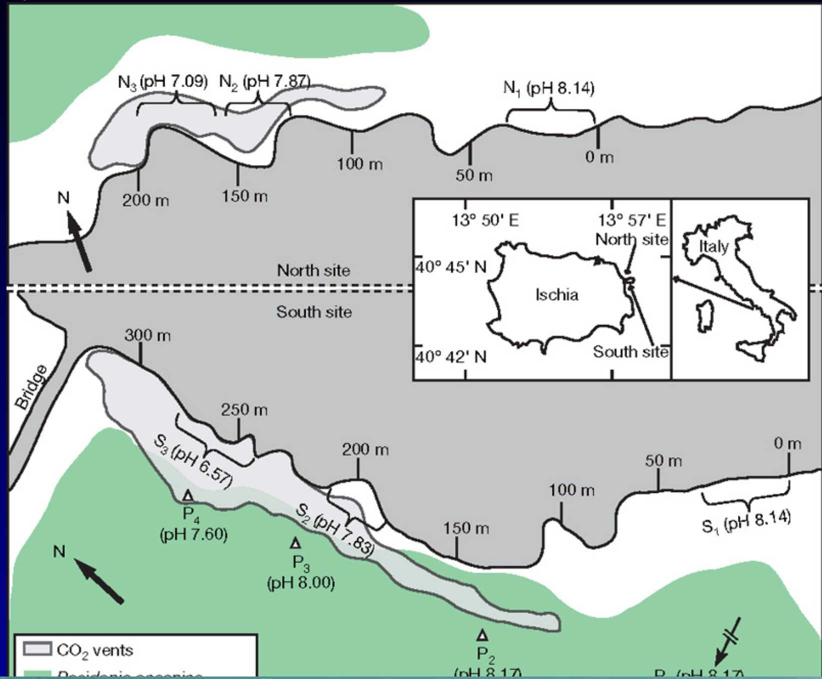
What is the probability that they will succeed in doing in the next decades what they have been unable to do for hundreds of millions of years?

Kiessling, W., Flügel, E. & Golonka, J. 2003 09 12: Patterns of Phanerozoic carbonate platform sedimentation. *Lethaia*, Vol. 36, pp. 195–226. Oslo. ISSN 0024-1164.

Field Survey of Natural CO_2 Venting Sites in Italy

- Echinoderms conspicuously absent, shell dissolution
- Seagrasses thrive

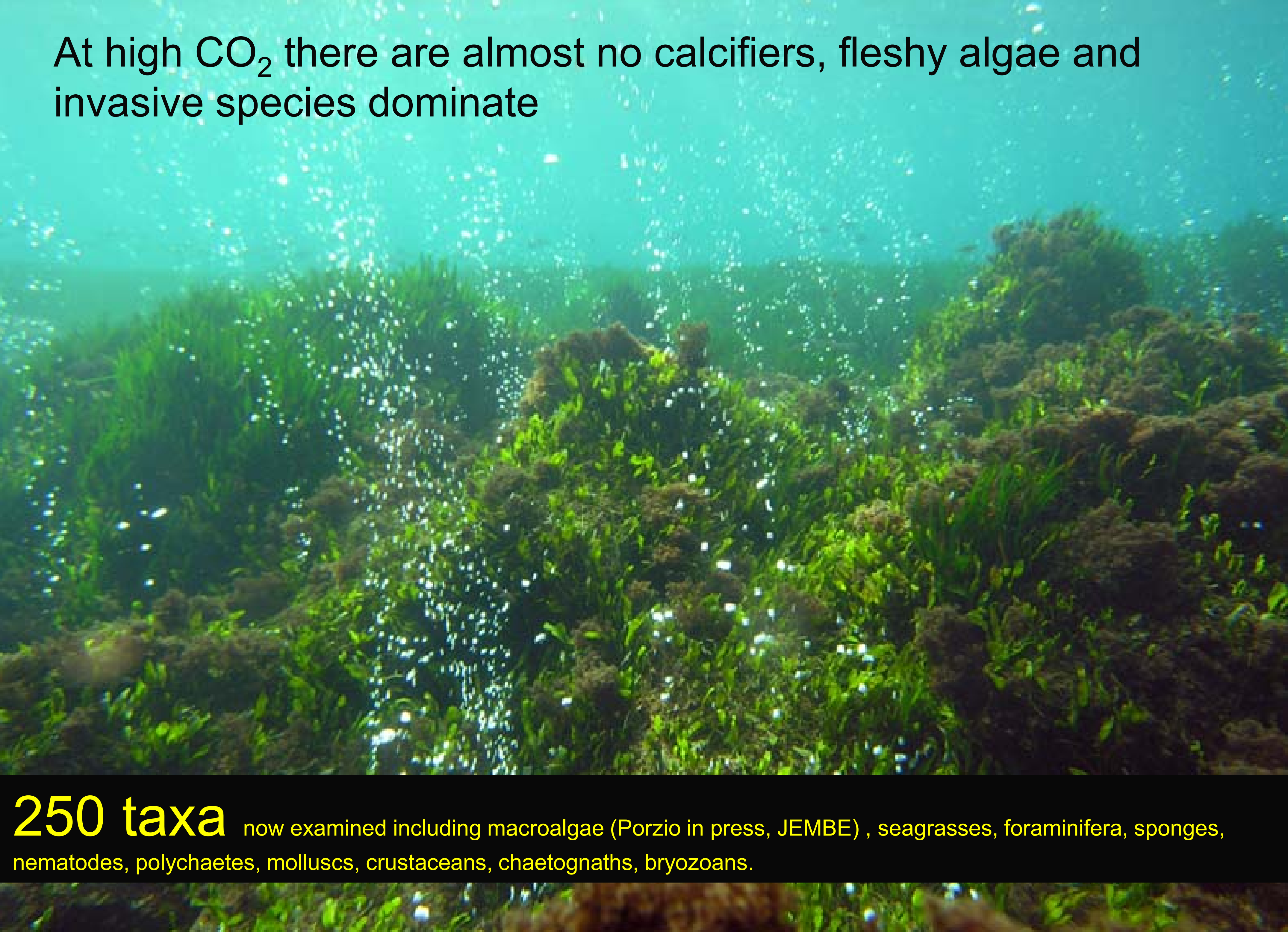




Jason Hall-Spencer et al. 2008

Outside the vents – abundant calcifiers e.g. sea urchins

At high CO_2 there are almost no calcifiers, fleshy algae and invasive species dominate



250 taxa now examined including macroalgae (Porzio in press, JEMBE) , seagrasses, foraminifera, sponges, nematodes, polychaetes, molluscs, crustaceans, chaetognaths, bryozoans.