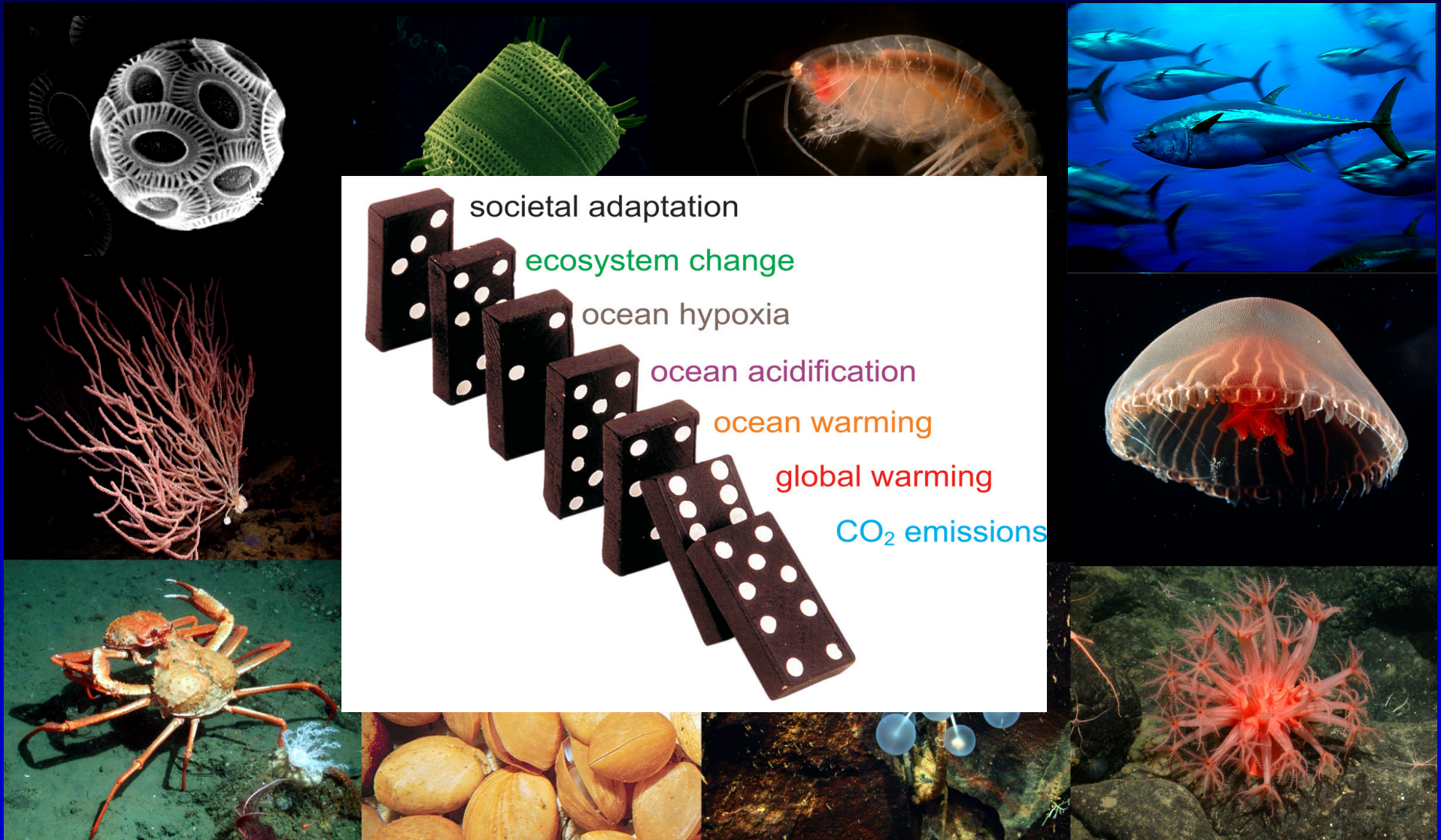


As dominoes fall... The consequences of rising atmospheric CO₂ for ocean conditions, ecosystems, and society

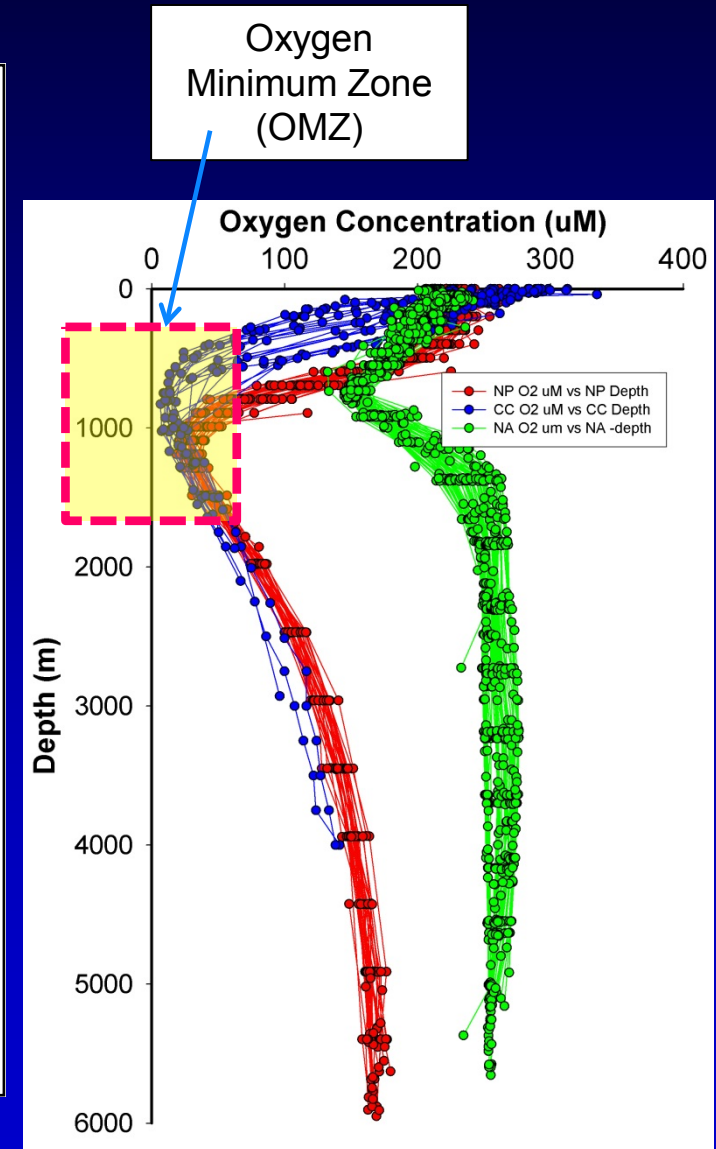


Jim Barry, Monterey Bay Aquarium Research Institute

Lockheed Martin ATC Colloquium, April, 2011

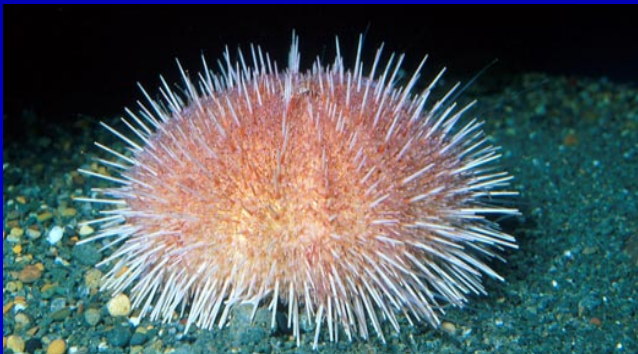
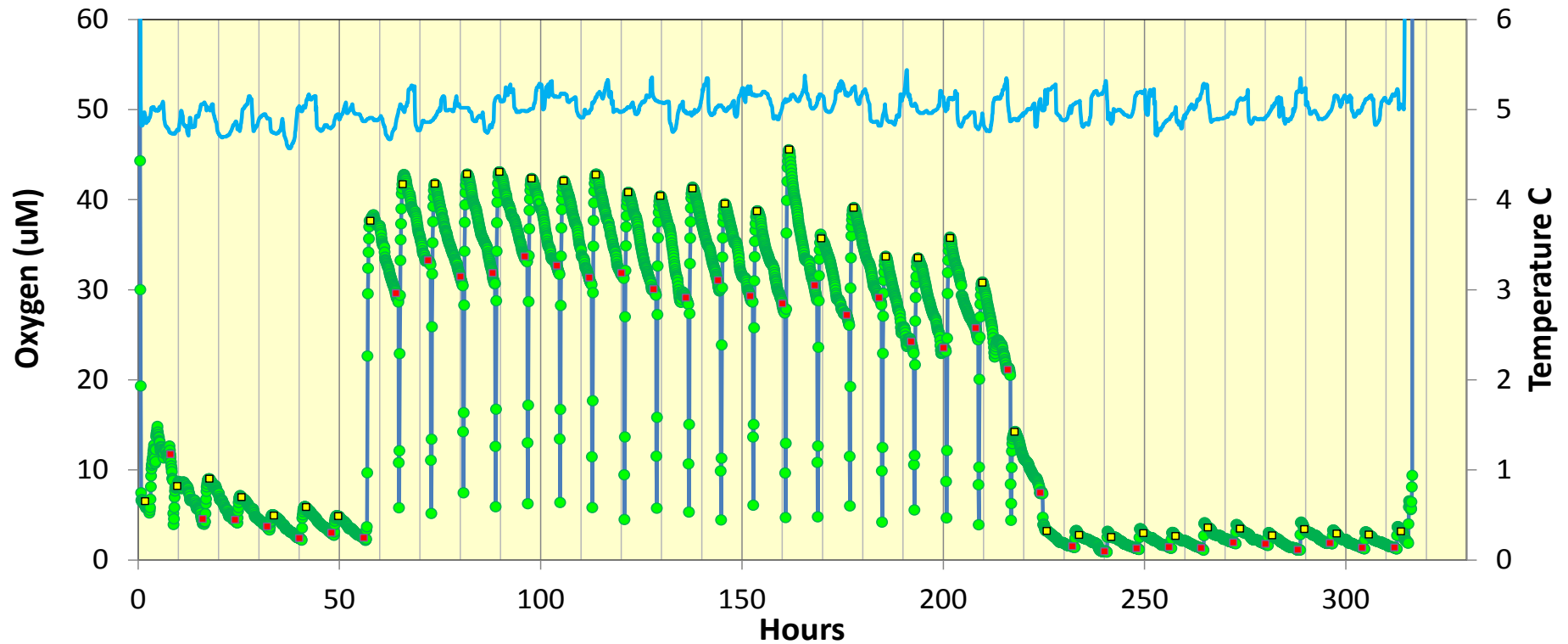


Measuring sea urchin respiration rates in the deep-sea



Urchins are stressed in the OMZ

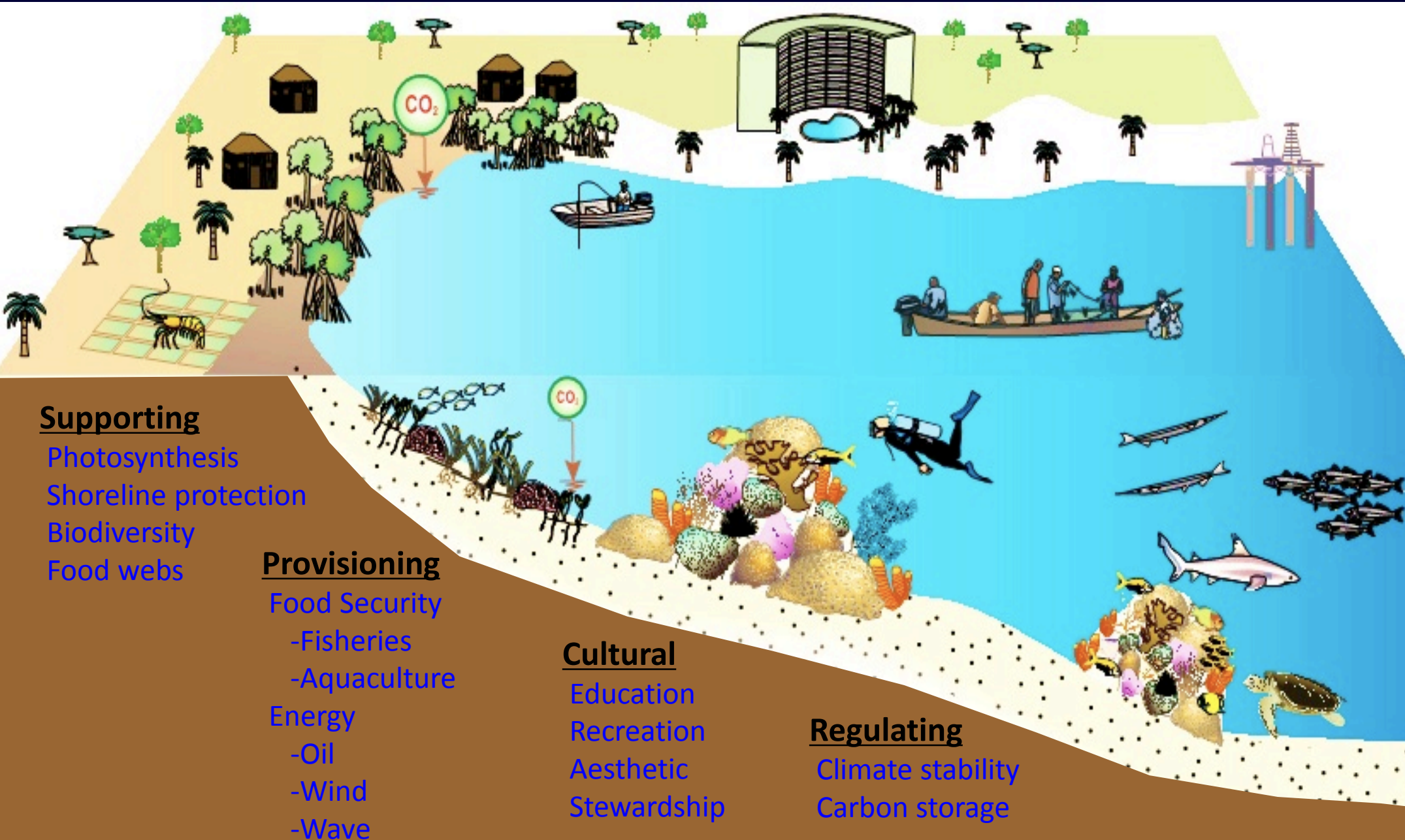
Given more oxygen, respiration increases



Fragile Urchin – *Allocentrotus californiensis*

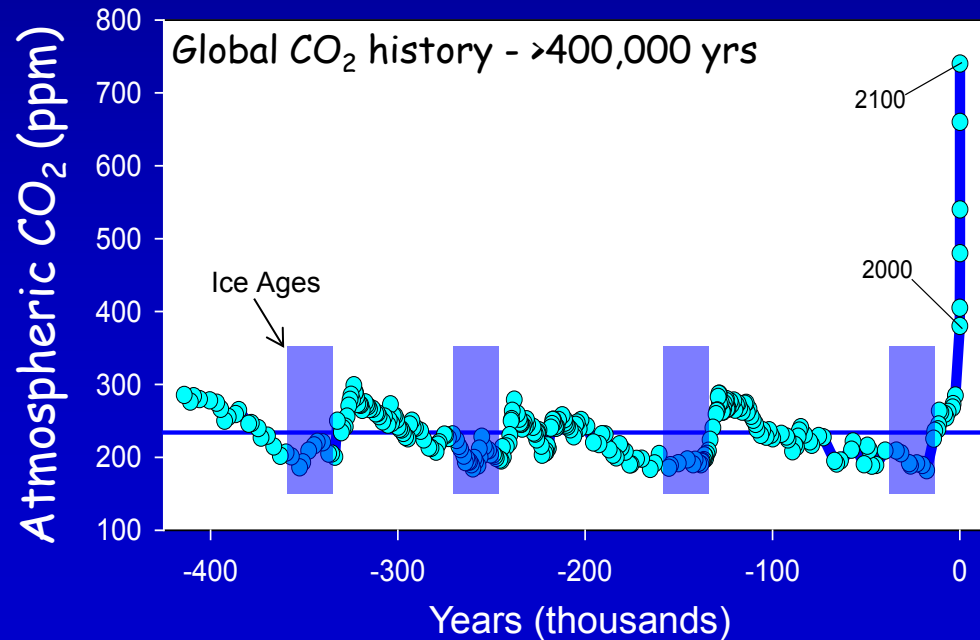
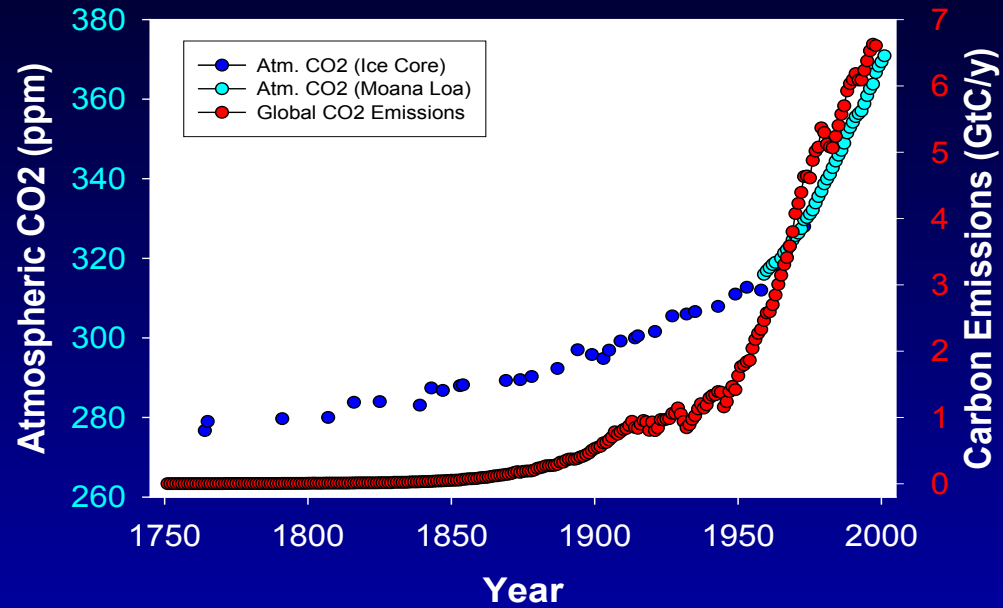
Marine Ecosystem Services

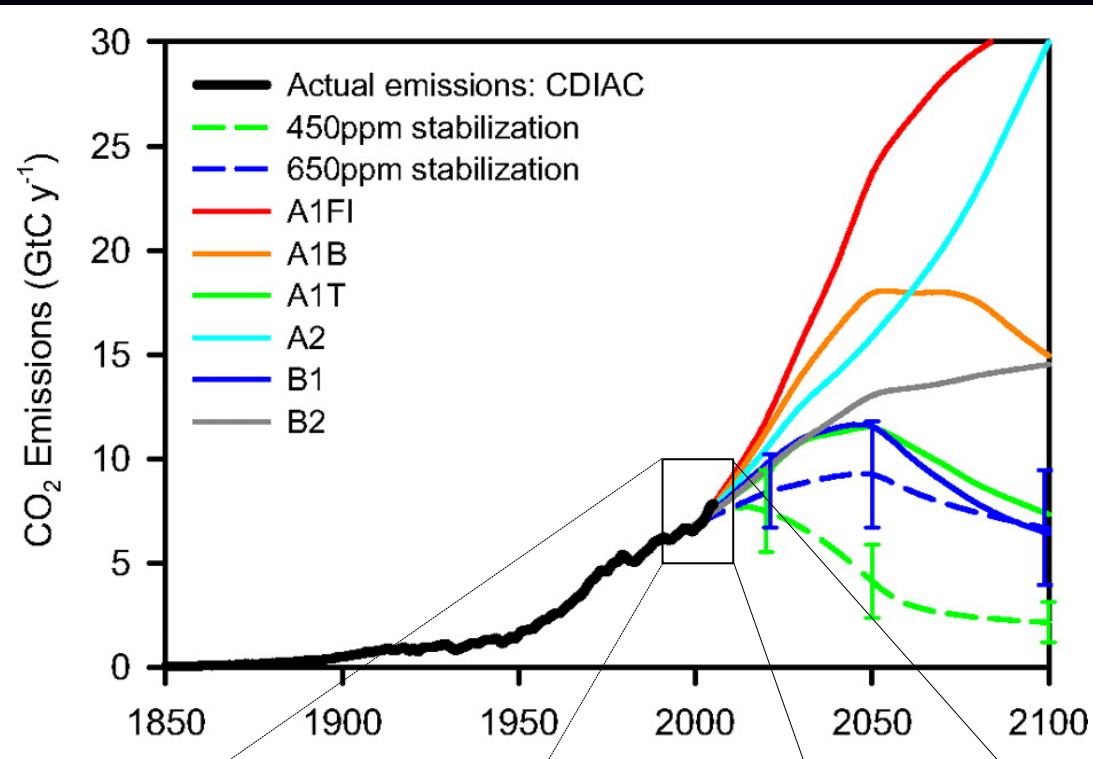
free stuff from nature



Fossil Fuel Carbon Dioxide has Changed the Atmosphere

Carbon Emissions over 250 years



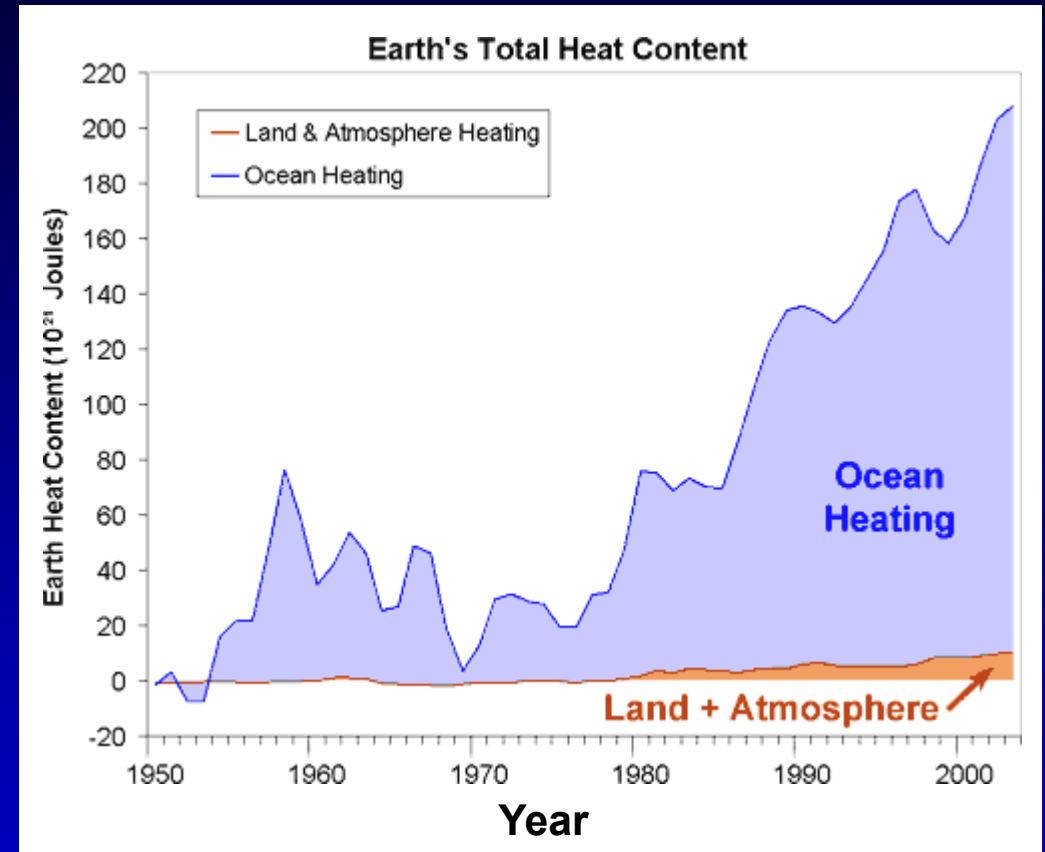
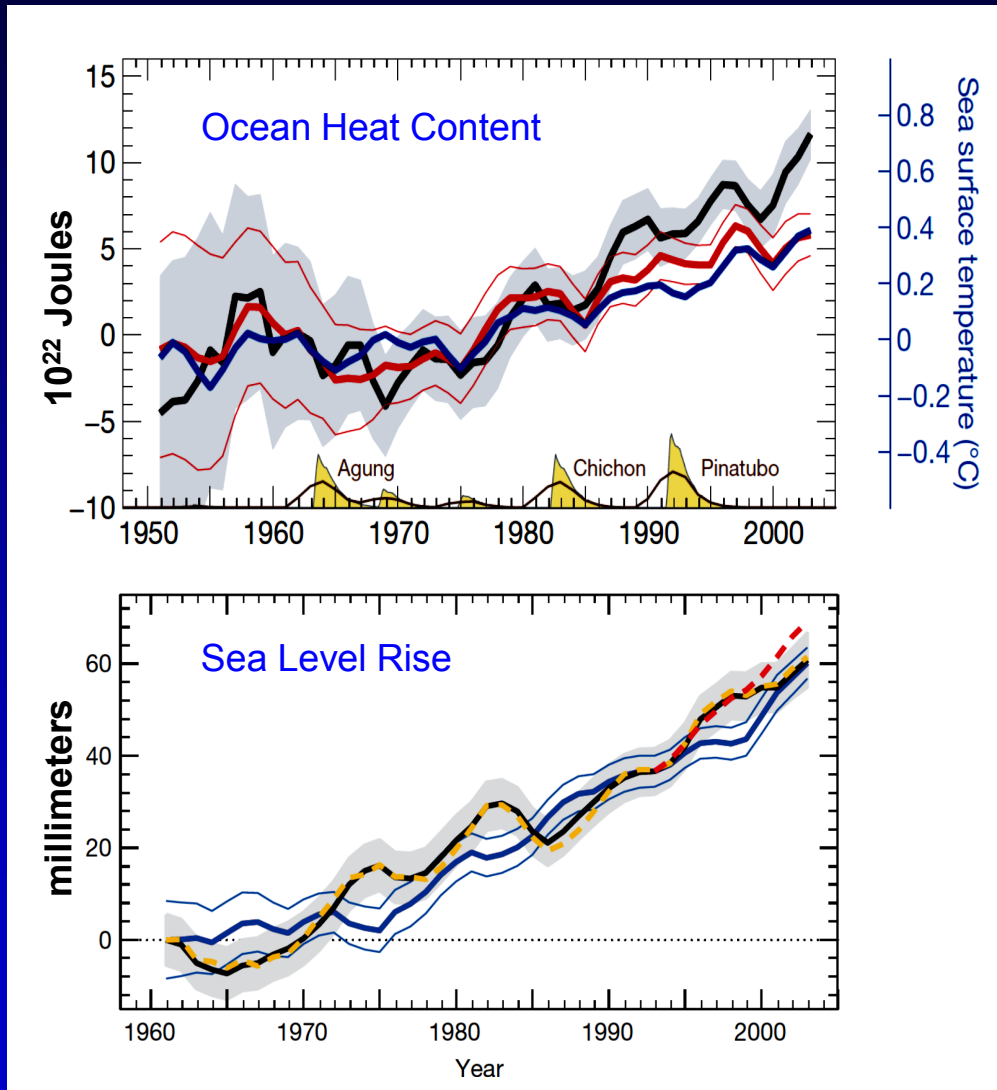


CO₂ emissions are rising rapidly

- Various scenarios
- Current emissions high, increasing
- Climate-agreements / legislation
- High emissions = larger climate / ocean changes

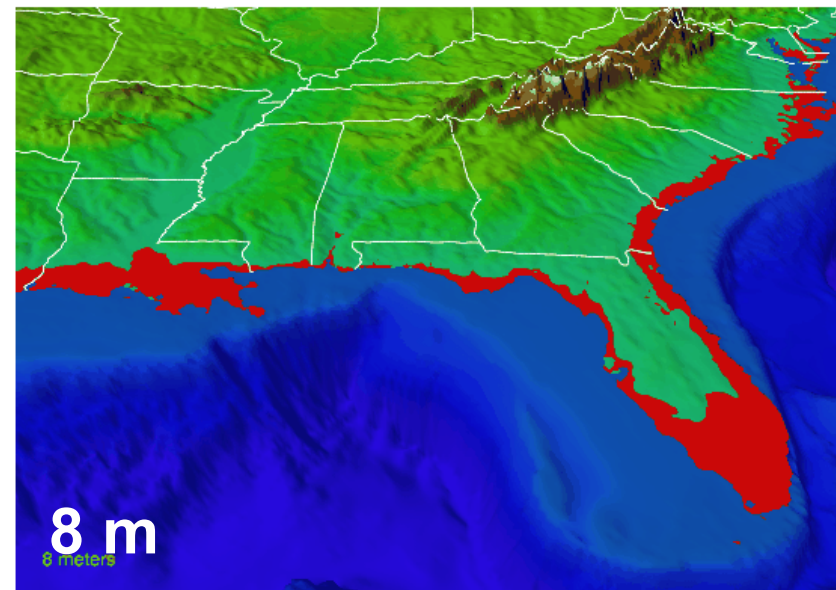
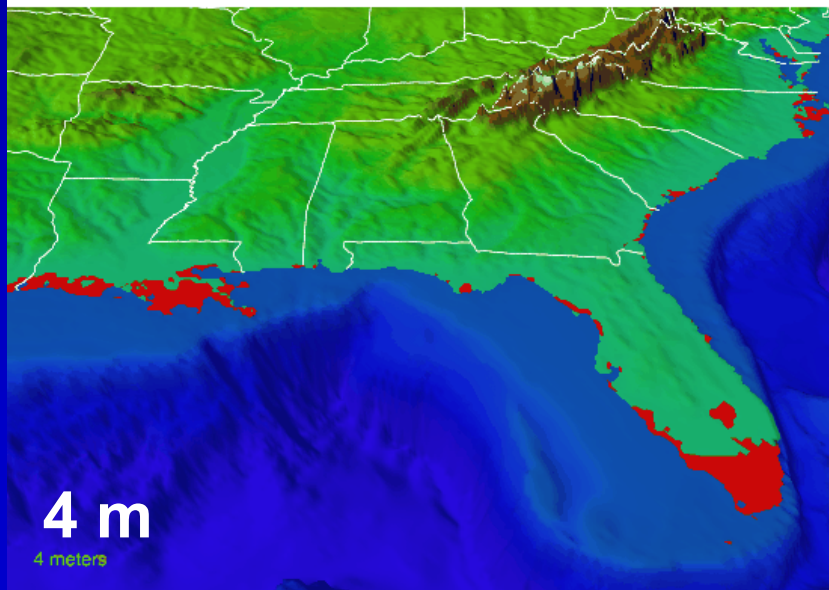
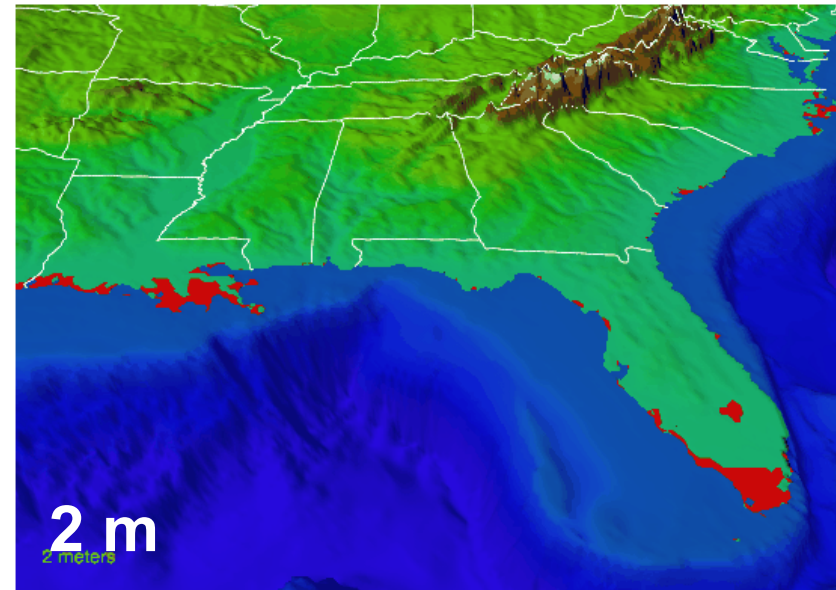
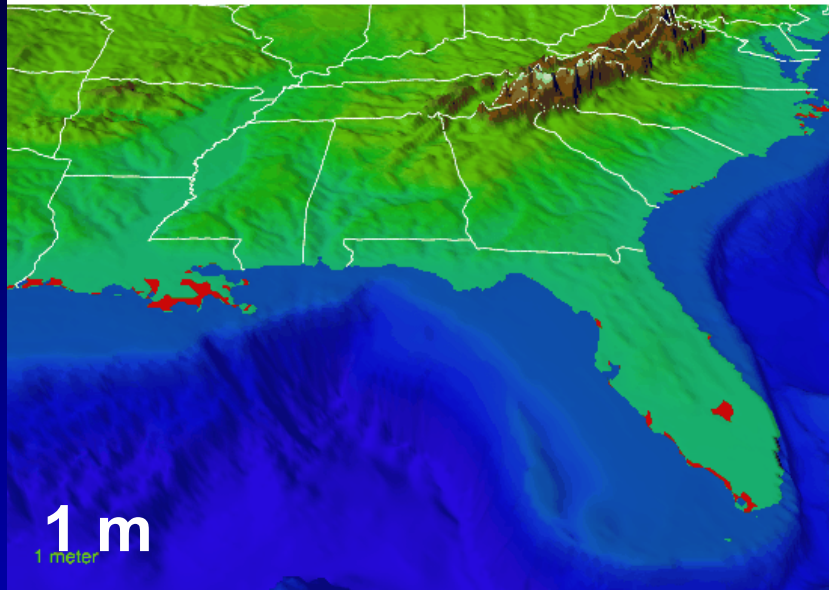


Global warming occurs mainly in the oceans

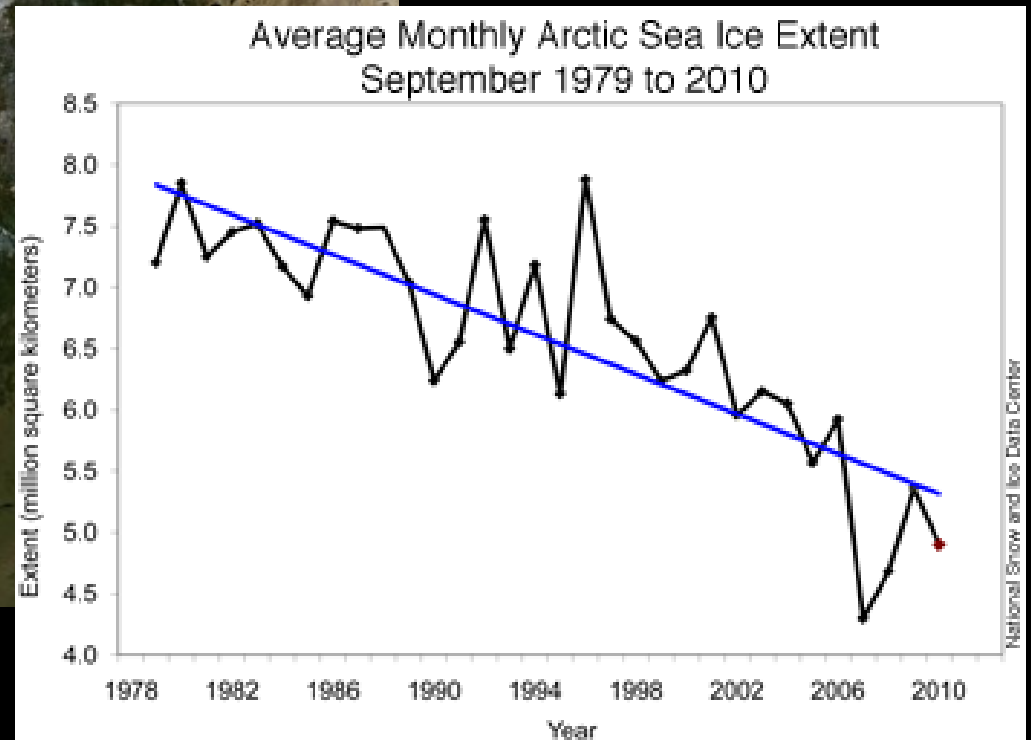
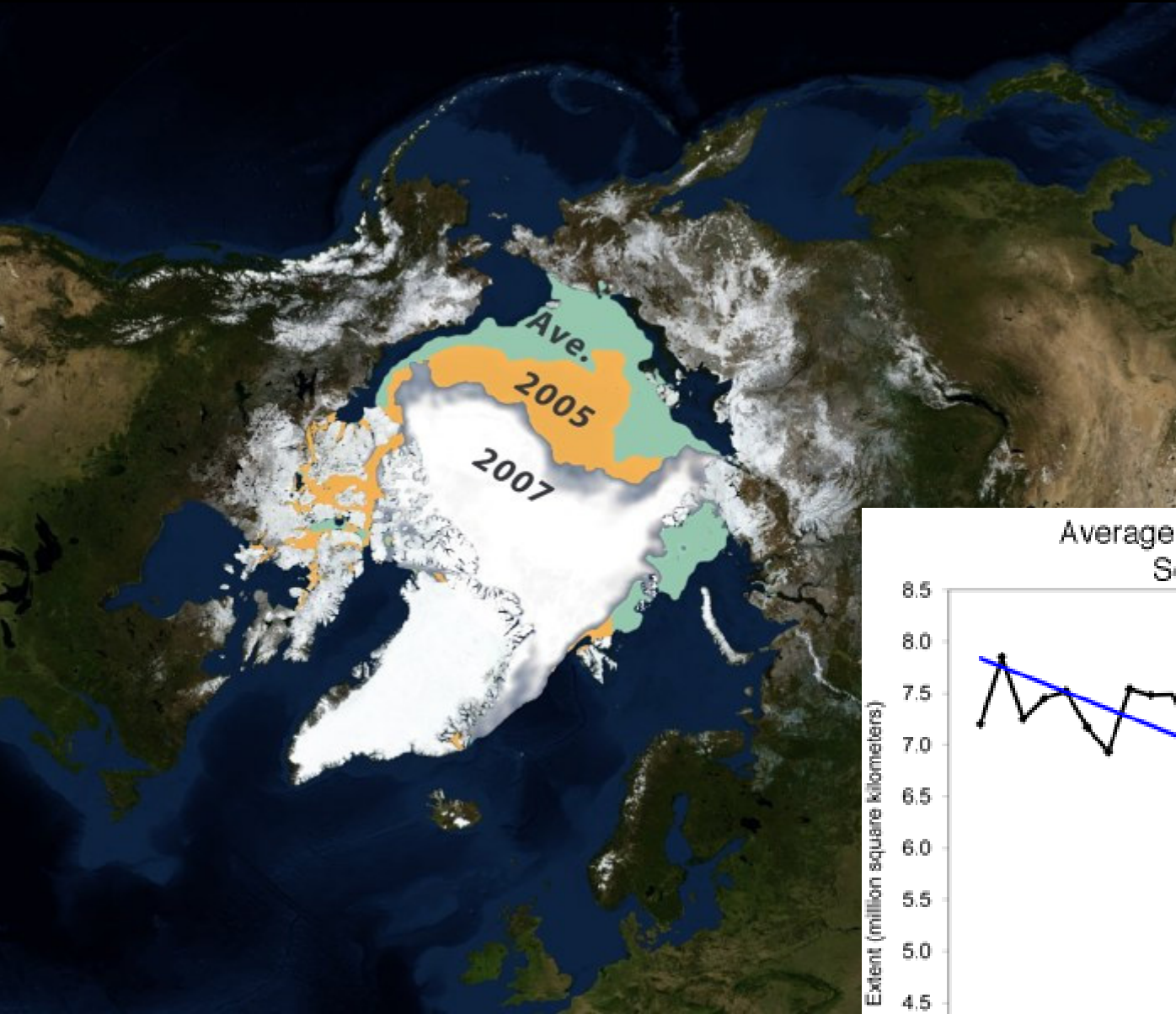


Sea Level Rise and Coastal Flooding

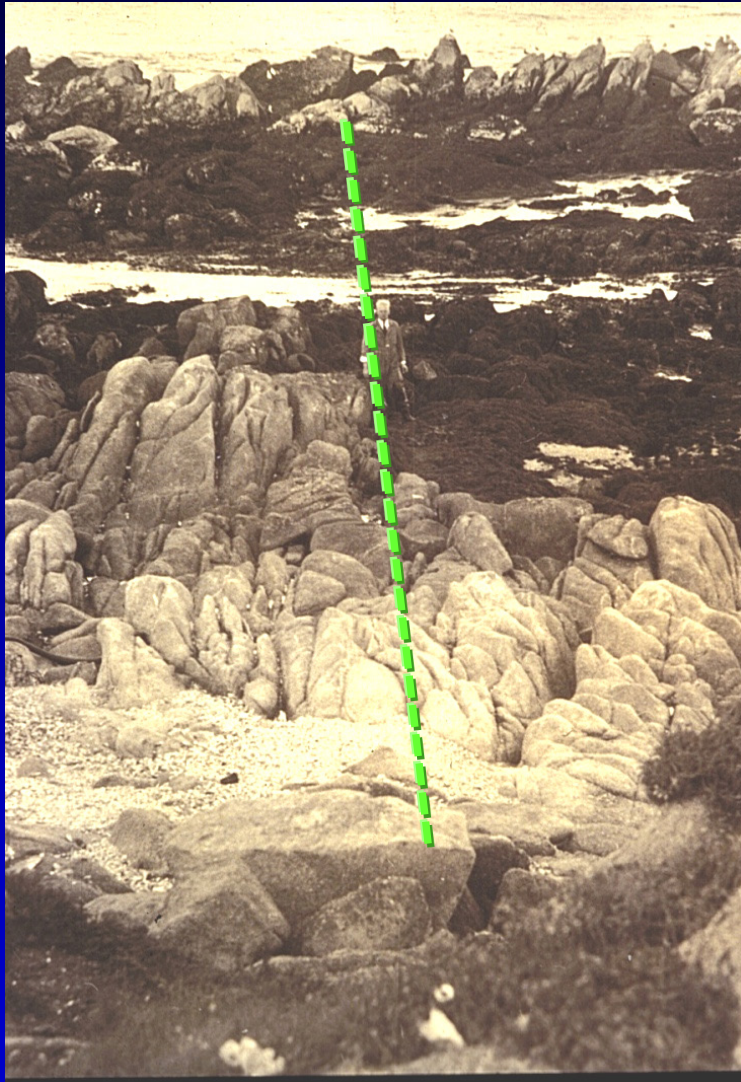
Sea Level Rise



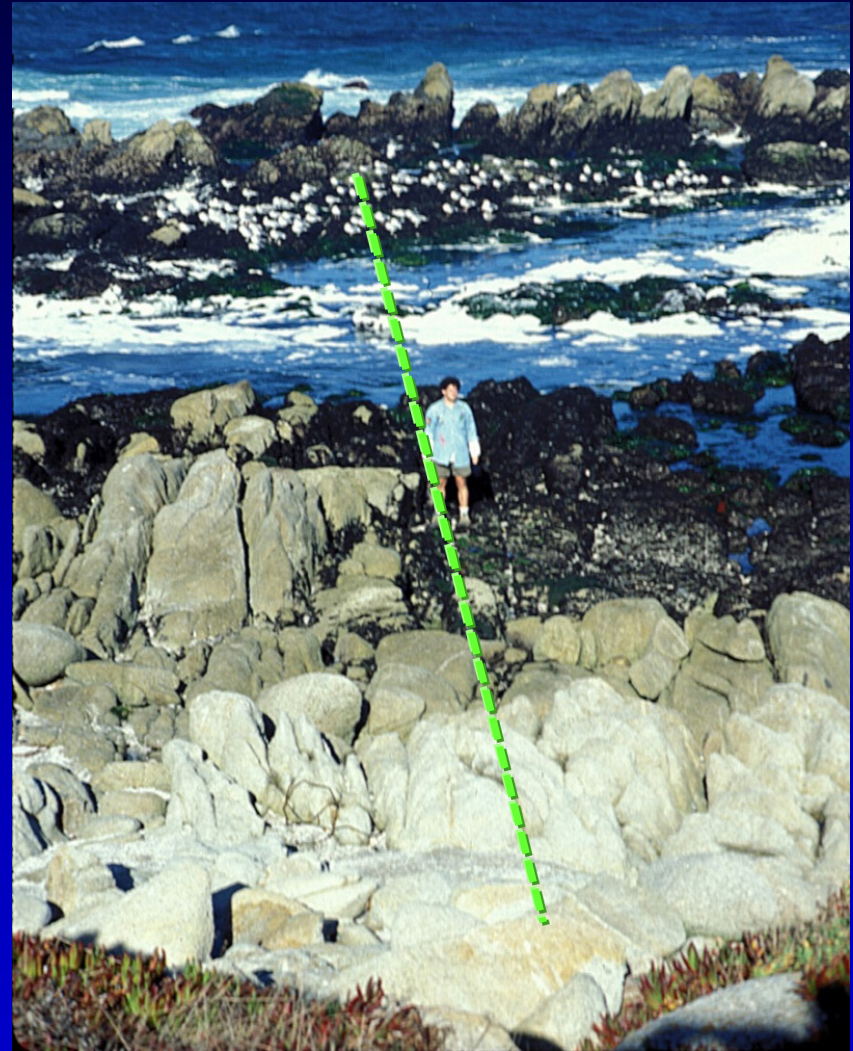
Summer Arctic sea-ice cover declining



Changes in intertidal animals over 75 years



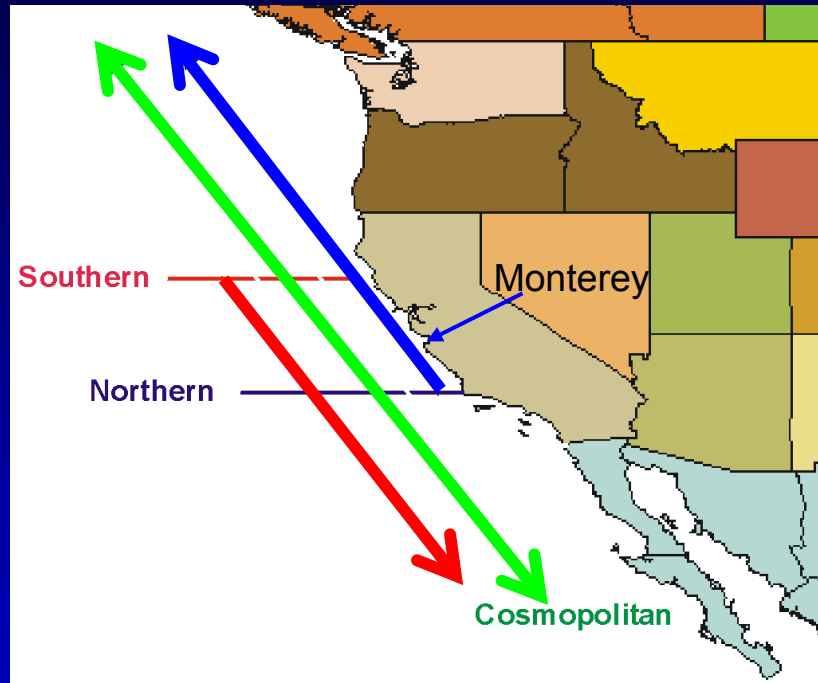
Hewatt: 1931



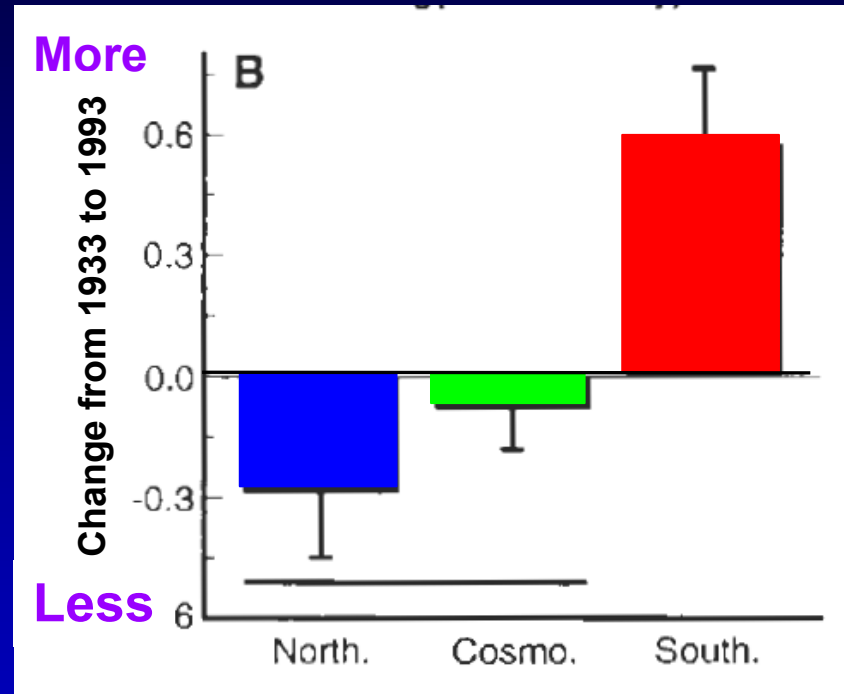
Barry, Baxter, Sagarin &
Gilman: 1990's & continuing

Animals distributions are changing with ocean warming

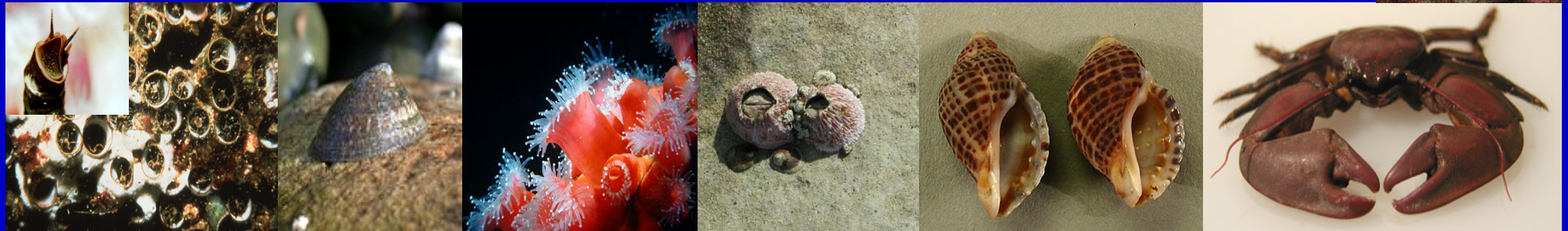
Monterey Bay rocky intertidal animals –
Warm water species increased, Cold water species declined



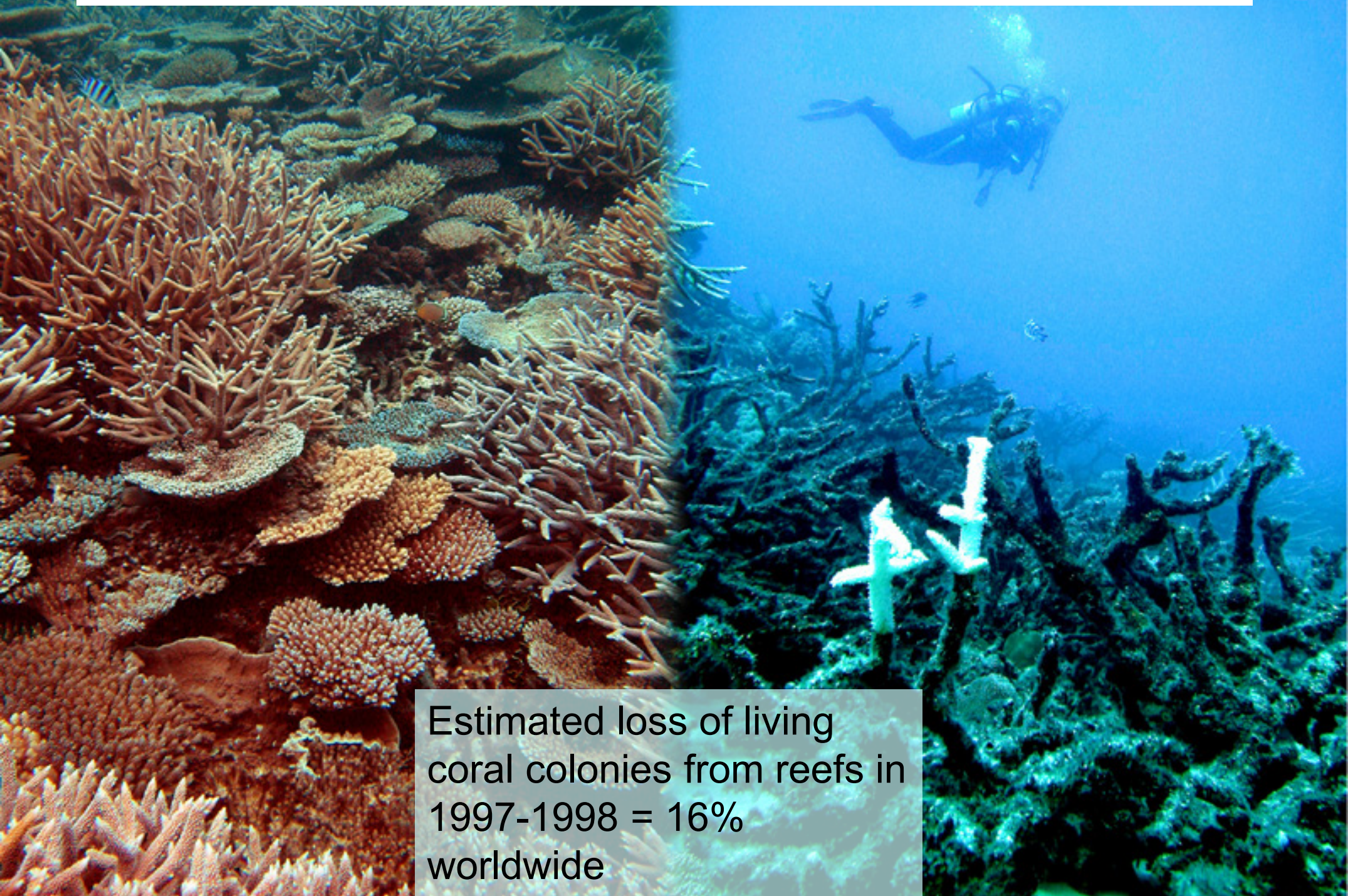
Southern Species Increased



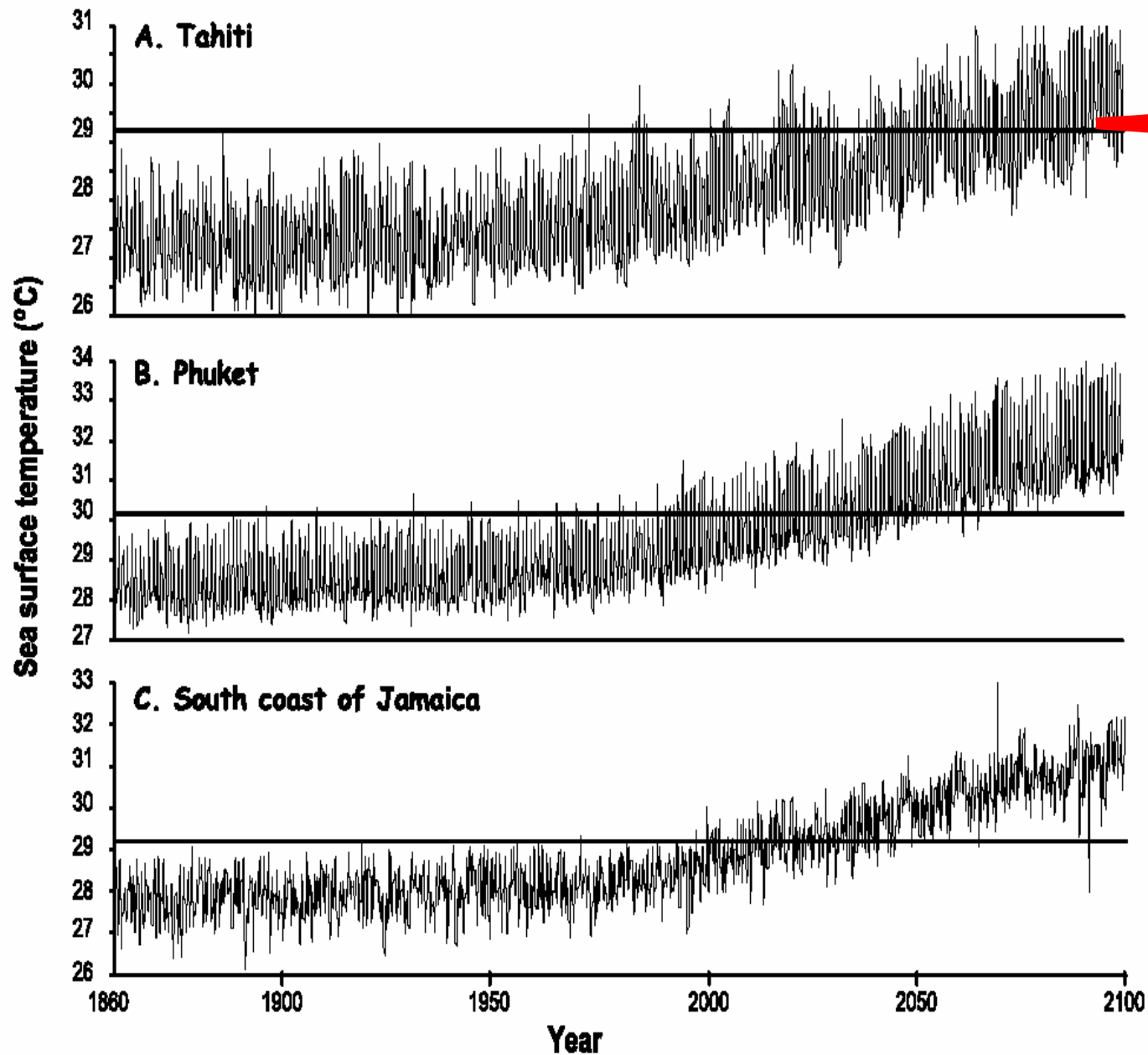
Northern Species Declined



Ocean Warming is Causing Coral Bleaching and Death



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

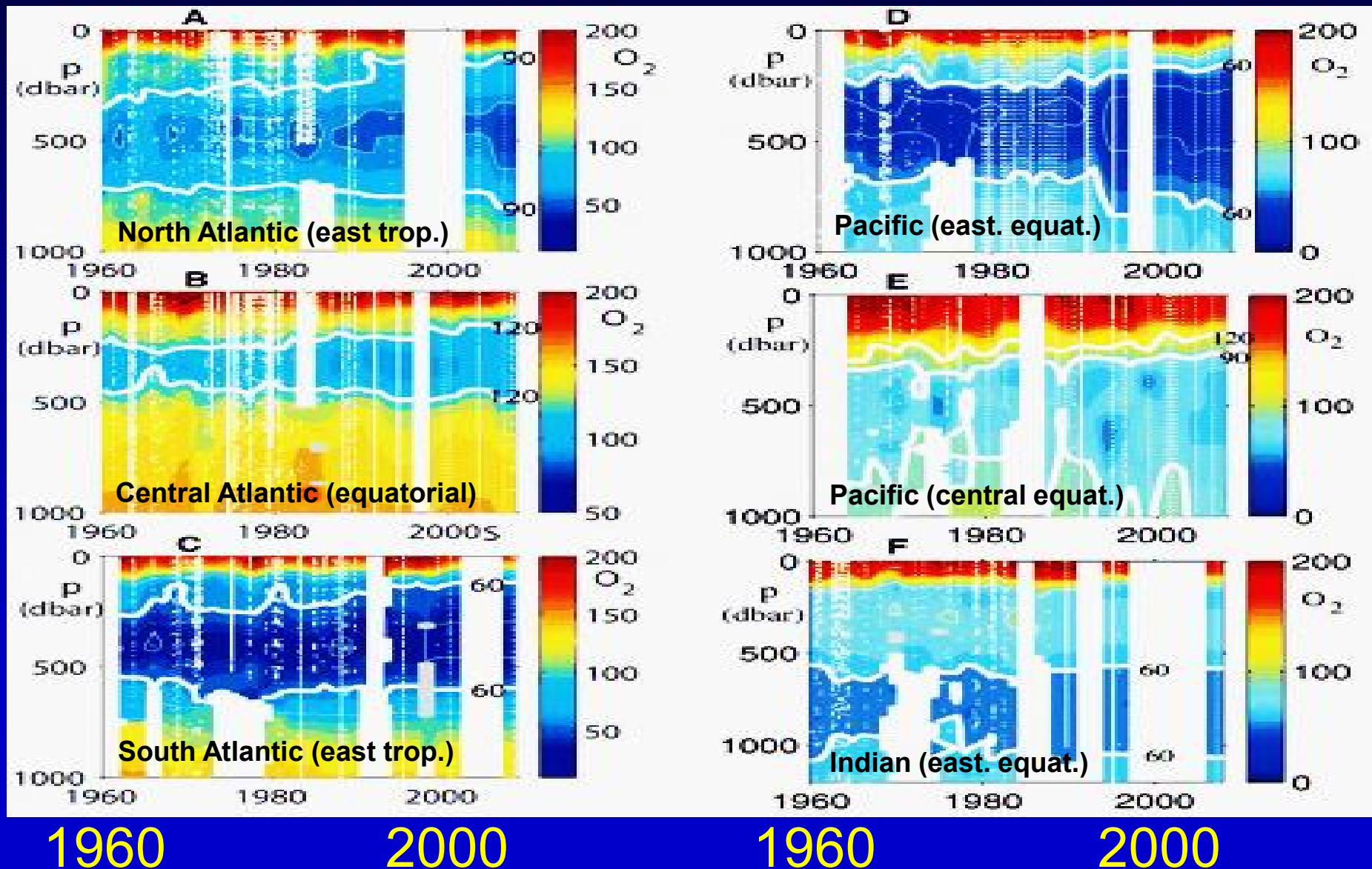


Threshold temperature - above which bleaching manifests itself (1-2°C above the long-term summer maximum temperatures)

WHAT DOES THE FUTURE HOLD?

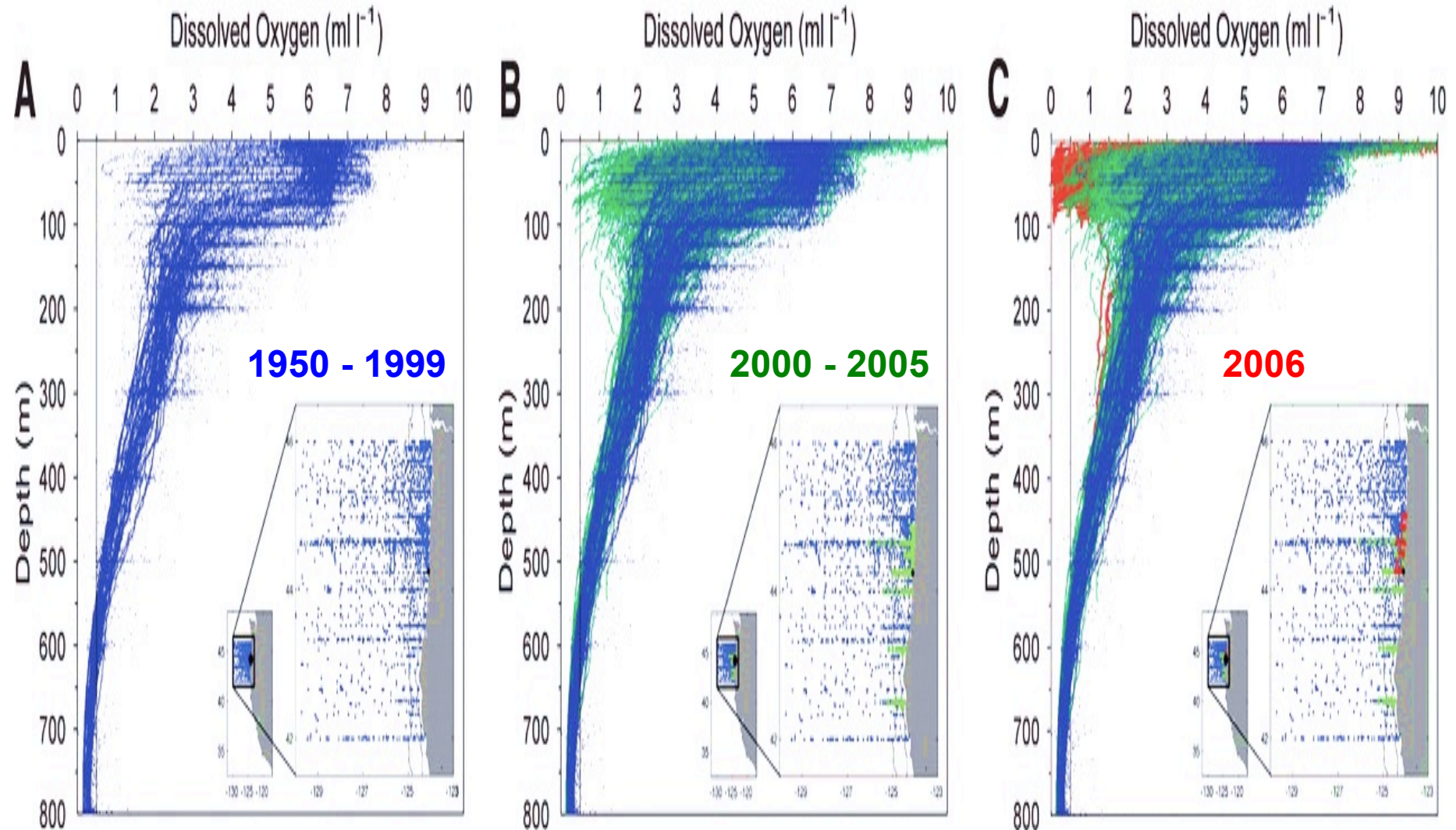
Oxygen levels in many ocean areas is declining (hypoxia)

Warmer surface waters inhibit mixing of oxygen to depth

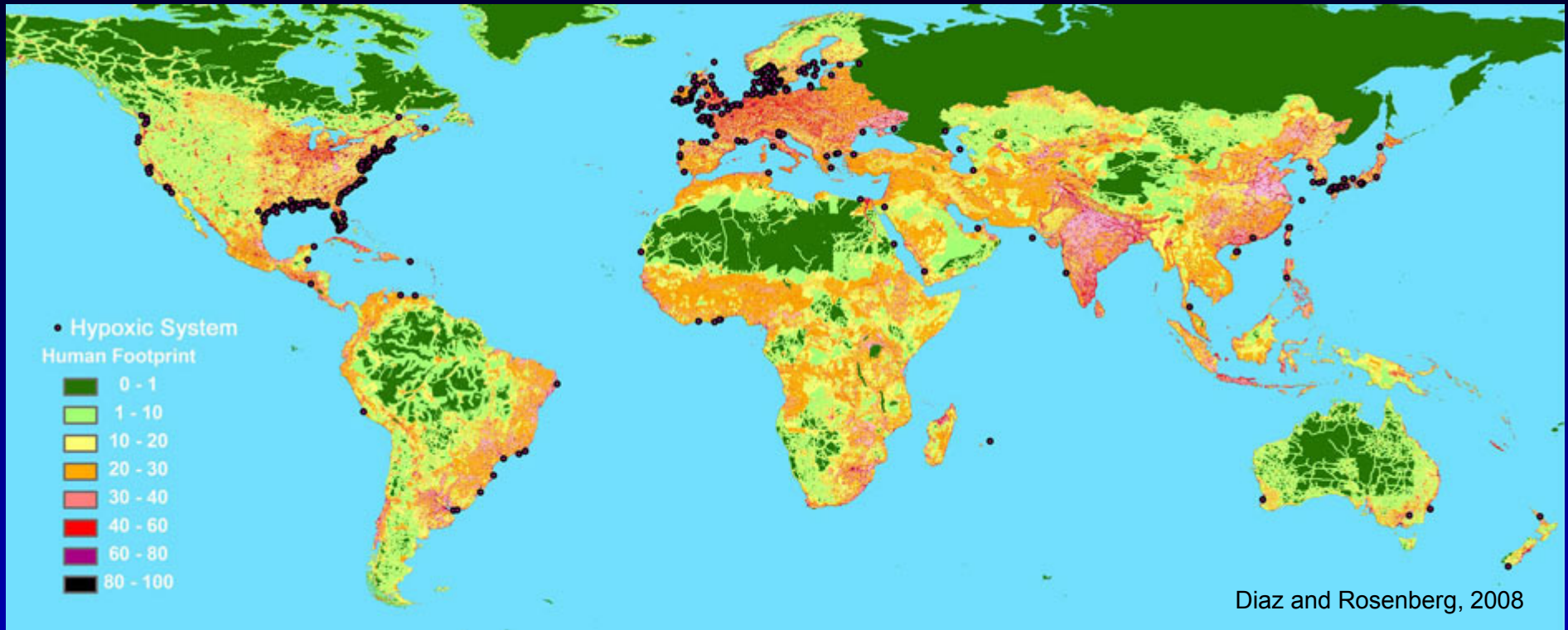


Hypoxic (low oxygen) waters are more common off Oregon

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.



Ocean hypoxia (dead zones) is increasing



Increased nutrient runoff

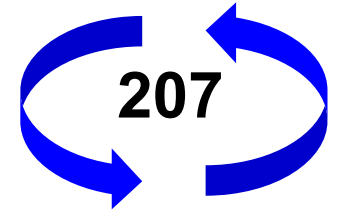


Humans play an import role in the global carbon cycle

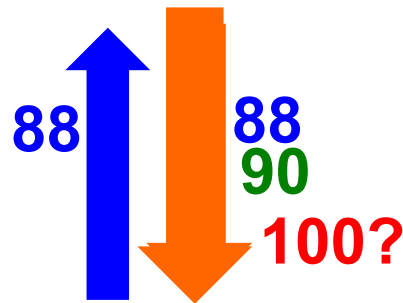
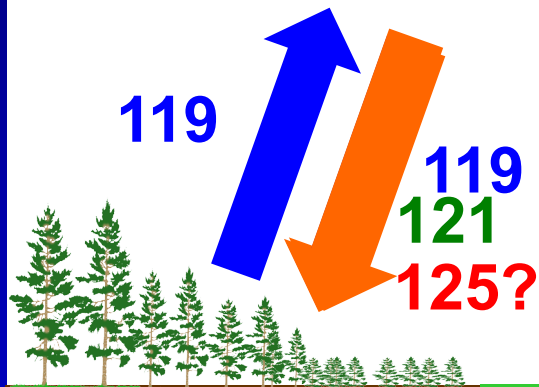
Arrows indicate CO₂ absorbed or released per year

Atmosphere

Natural
Cycle



Year	Human %C
<1800	<0.1
2007	4
2100	15

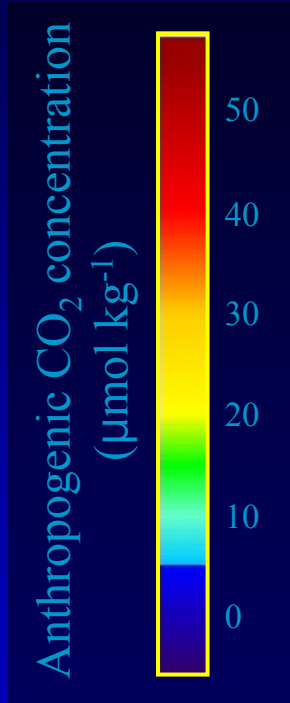


Land

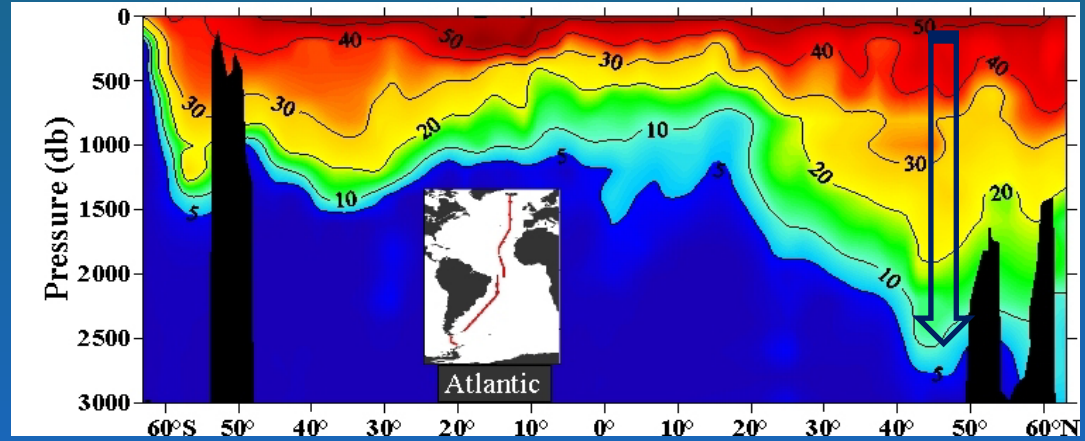
Ocean

Numbers are Billions of tons of Carbon (1 ton of Carbon = 3.7 tons of CO₂)

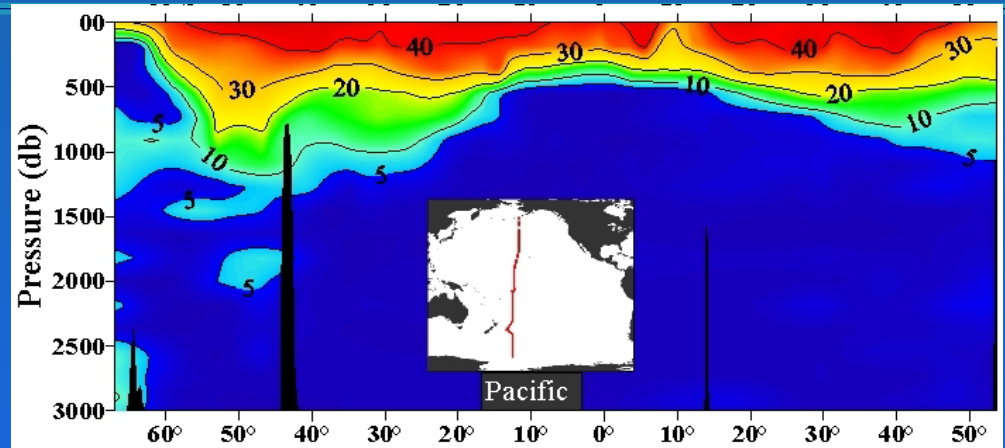
Fossil fuel CO₂ in the oceans (1994)



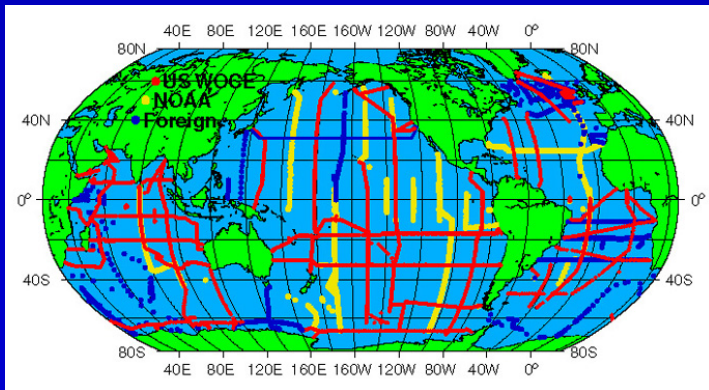
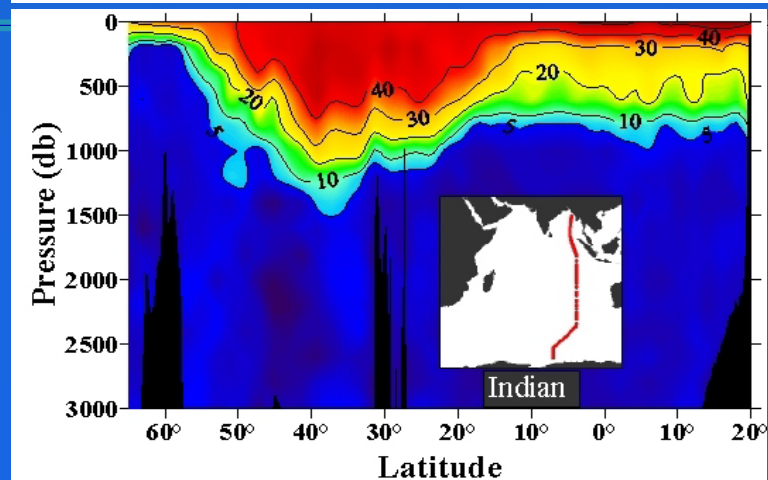
Atlantic



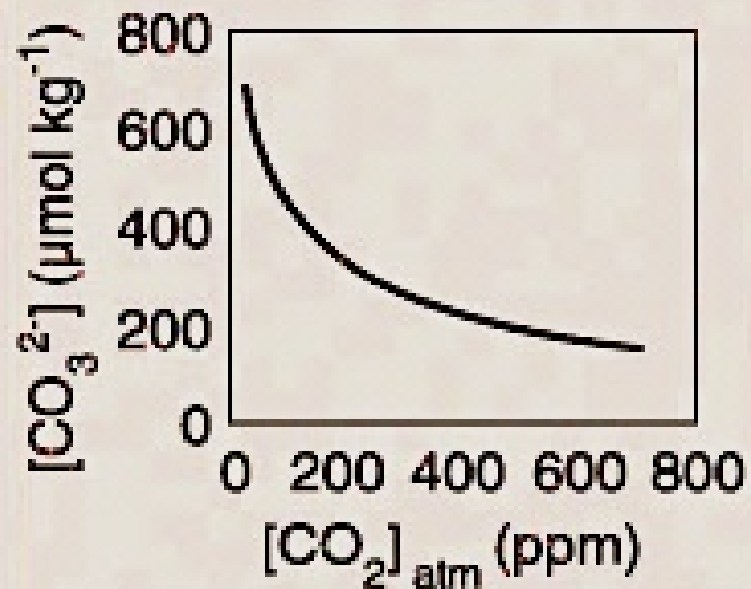
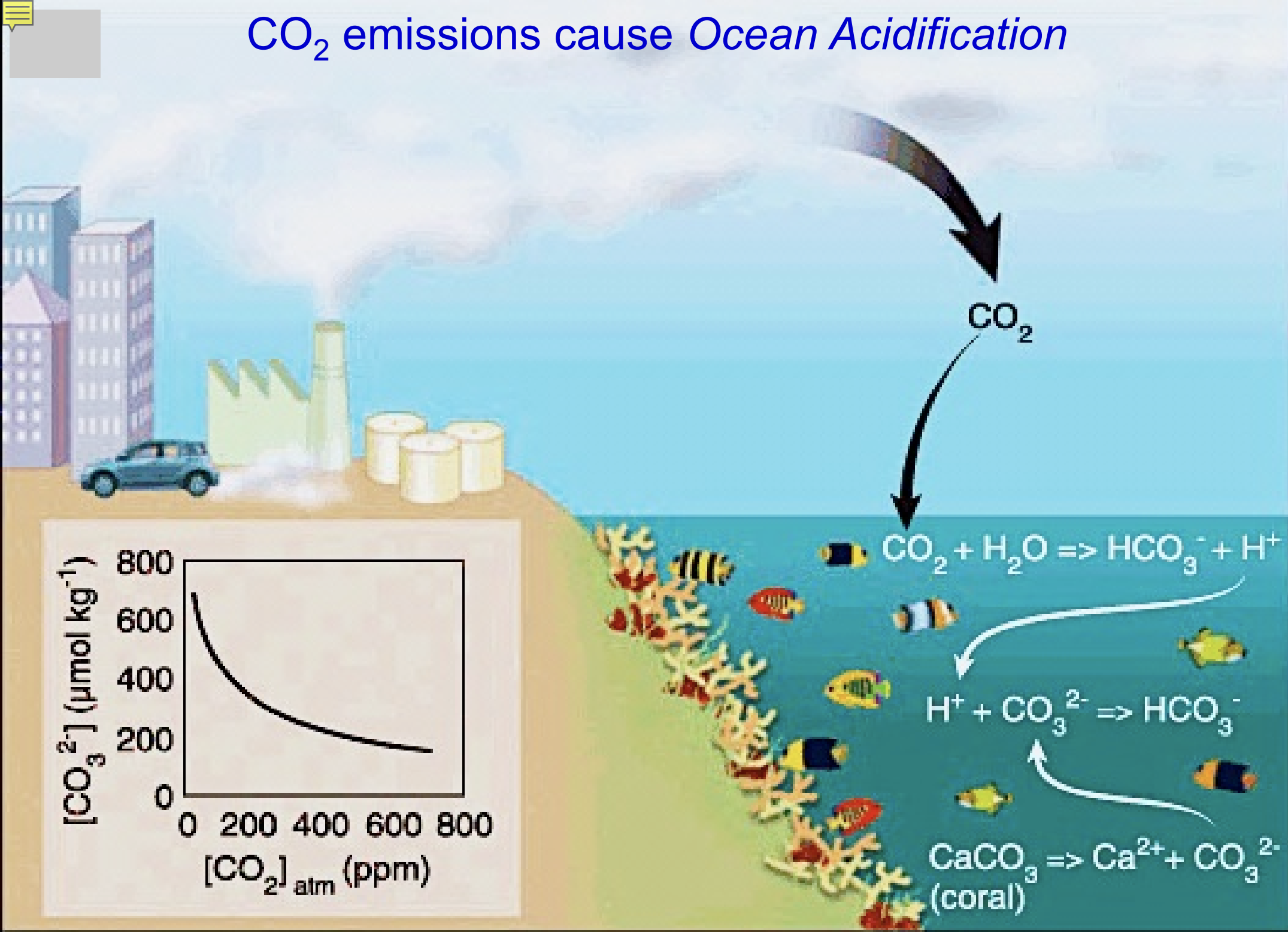
Pacific



Indian



CO₂ emissions cause *Ocean Acidification*

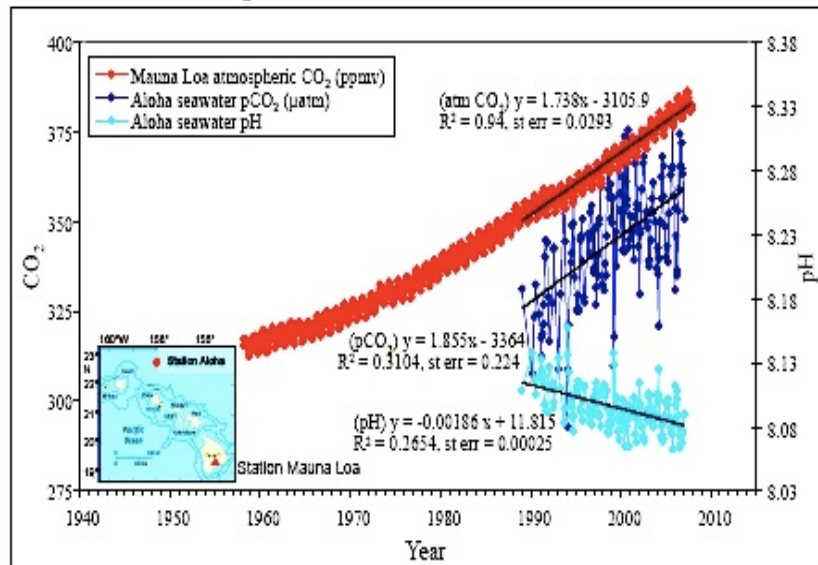


CO₂ Emissions are changing ocean chemistry

Ice Ages

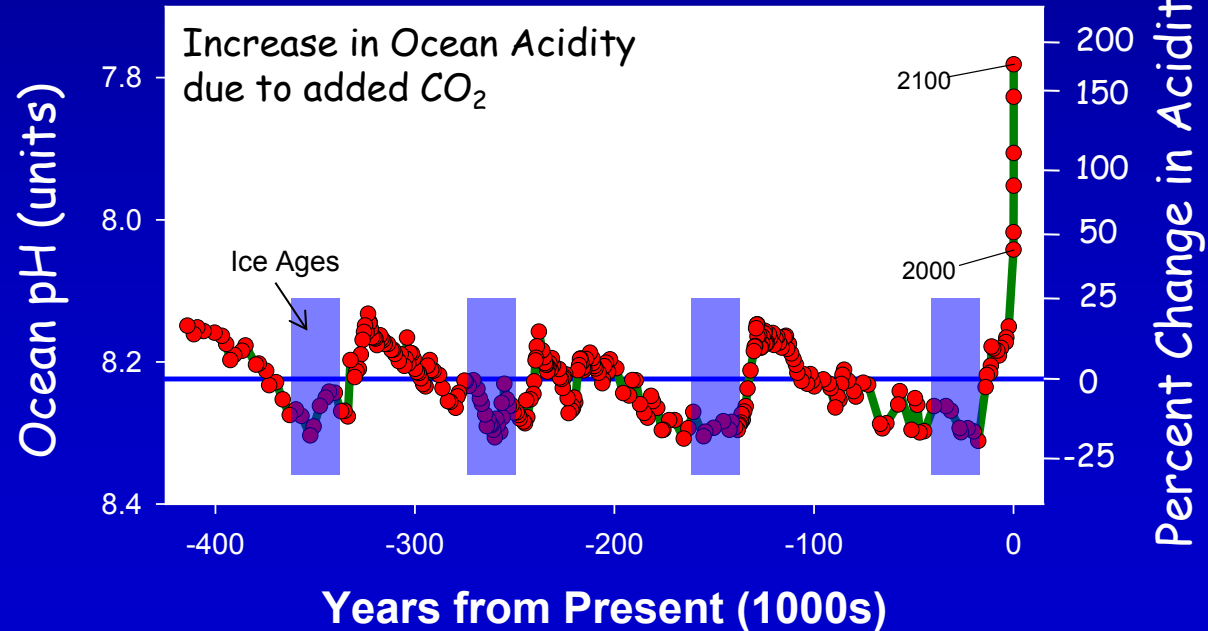
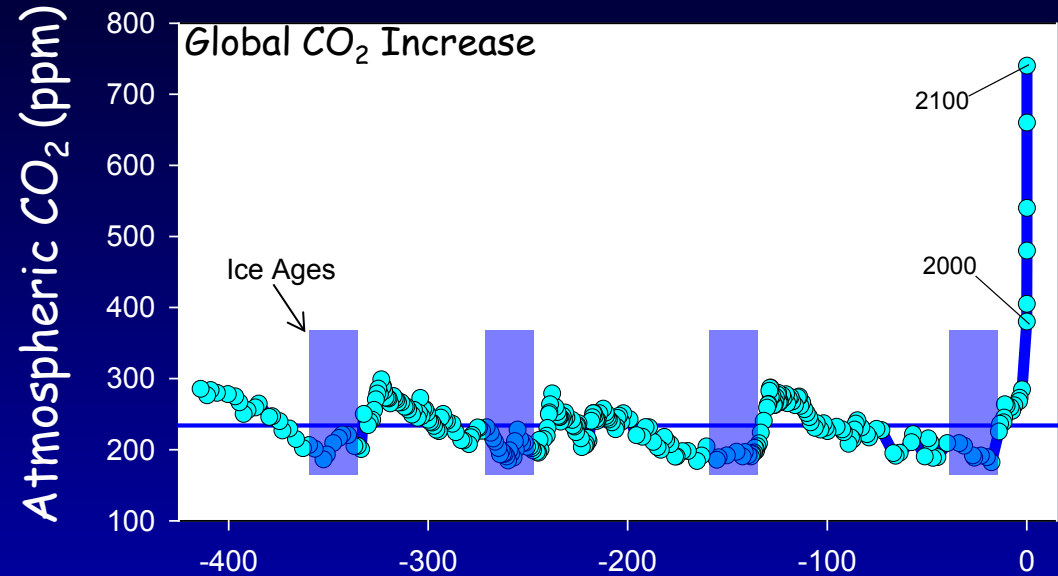
Ocean CO₂ tracks the atmosphere

CO₂ Time Series in the North Pacific Ocean

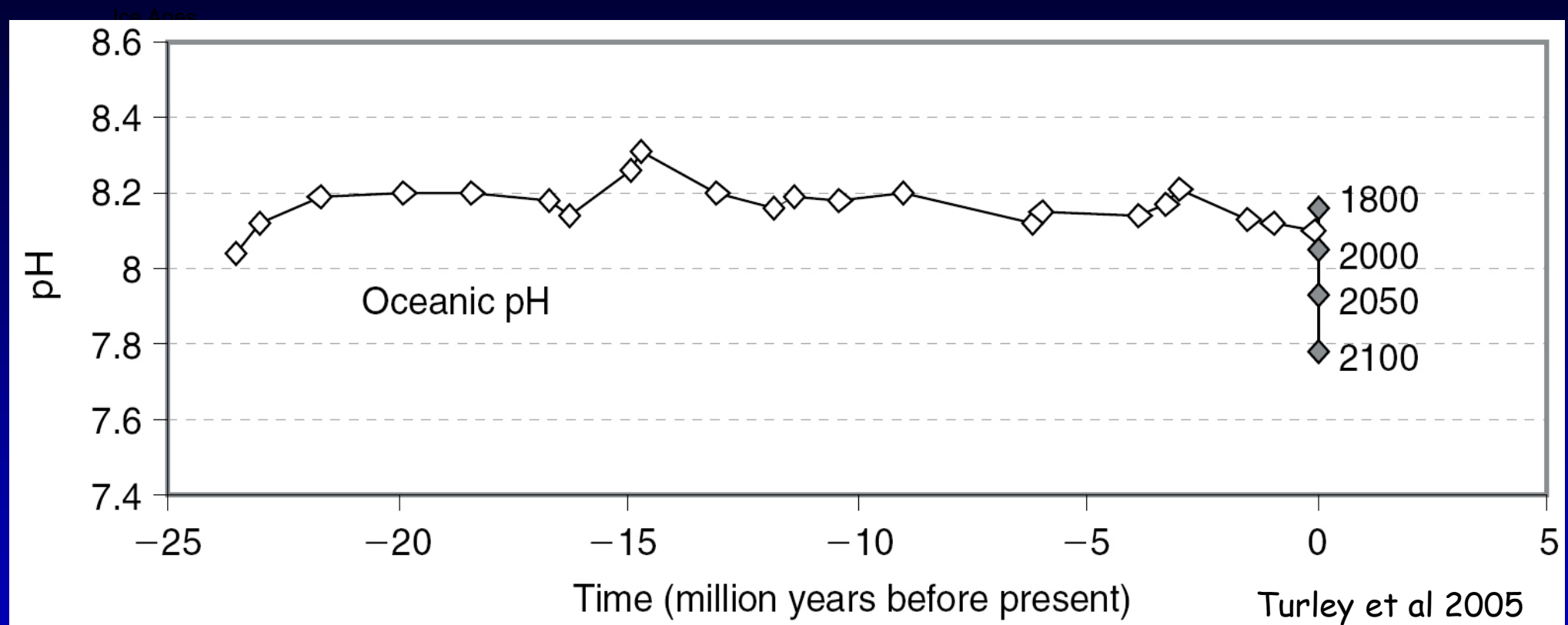


Doney et al. 2009

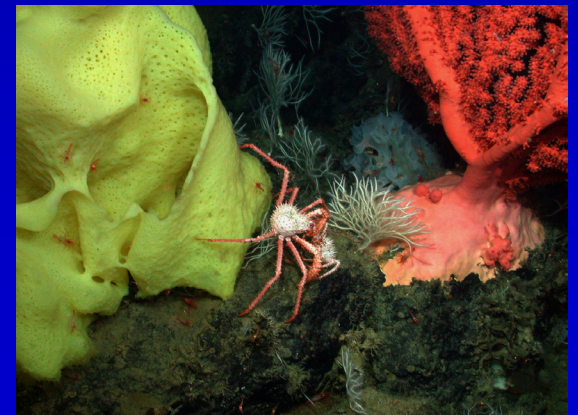
Higher CO₂ increases ocean acidity



Human-driven change in ocean pH is massive and rapid



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

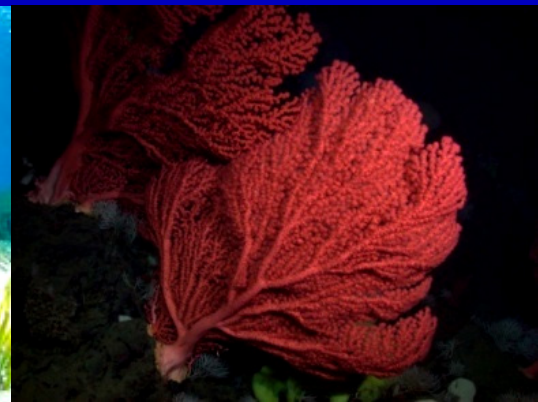
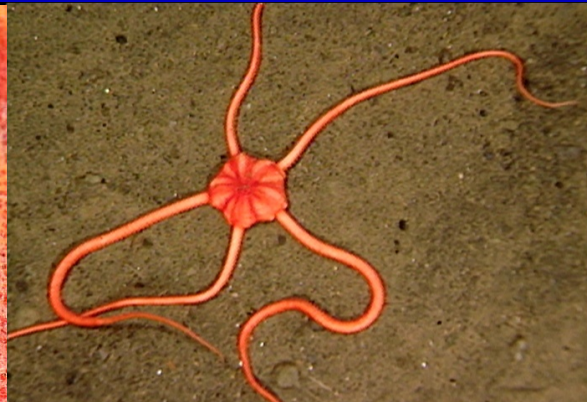


Ocean change affects physiological function

- *Photosynthesis*
- *Calcification **
- *Respiration*
- *Acid - Base Balance*
- *Cell Function*

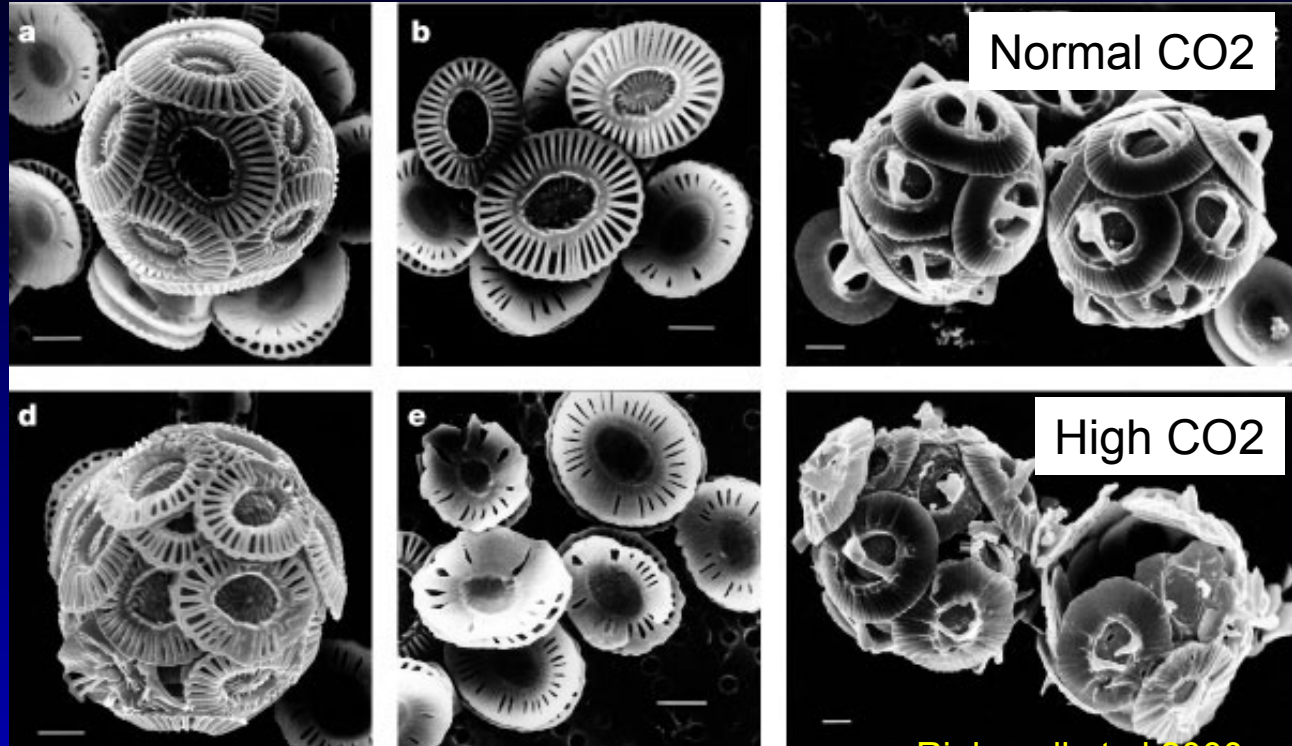


Vampire Squid



Reduced Calcification

Pteropod Mollusc



Normal CO2

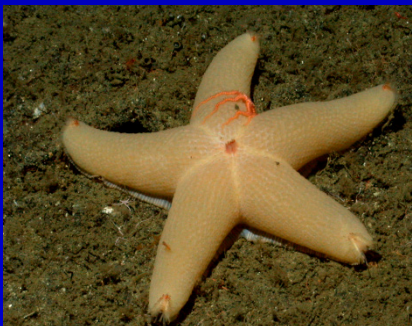
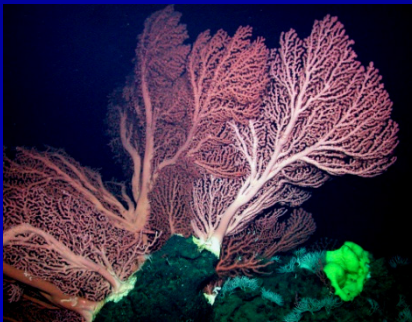
High CO2

Riebesell et al 2000

Environmental hypercapnia may affect calcification for many species

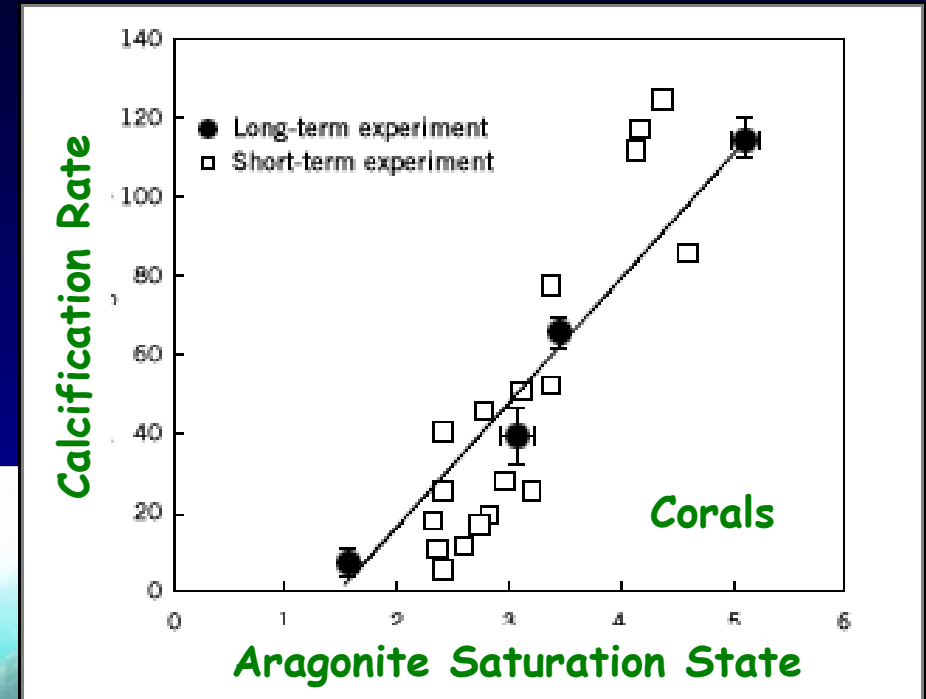
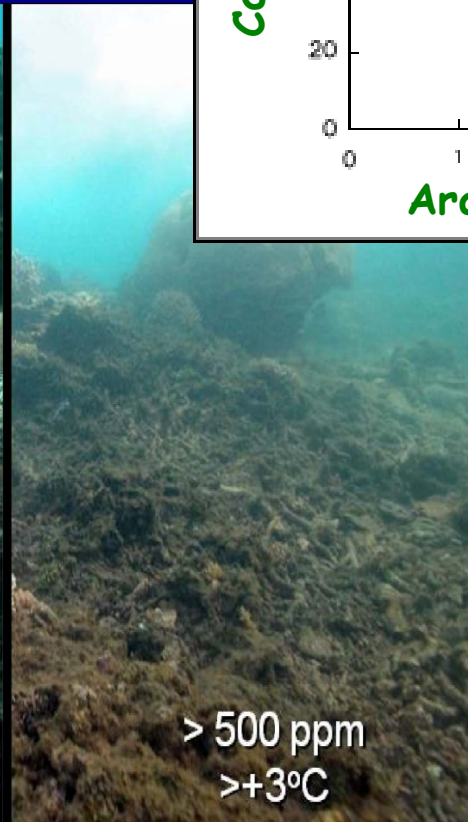
- Clams, snails, sea stars, urchins, crabs, shrimps, corals, ...
- Calcareous echinoderms largely absent from vent sites

Corals,
Echinoderms



Calcification and Coral Ecosystem Tipping Points

Low carbonate saturation
associated with low calcification
rate



Hoegh-Guldberg et al. 2007

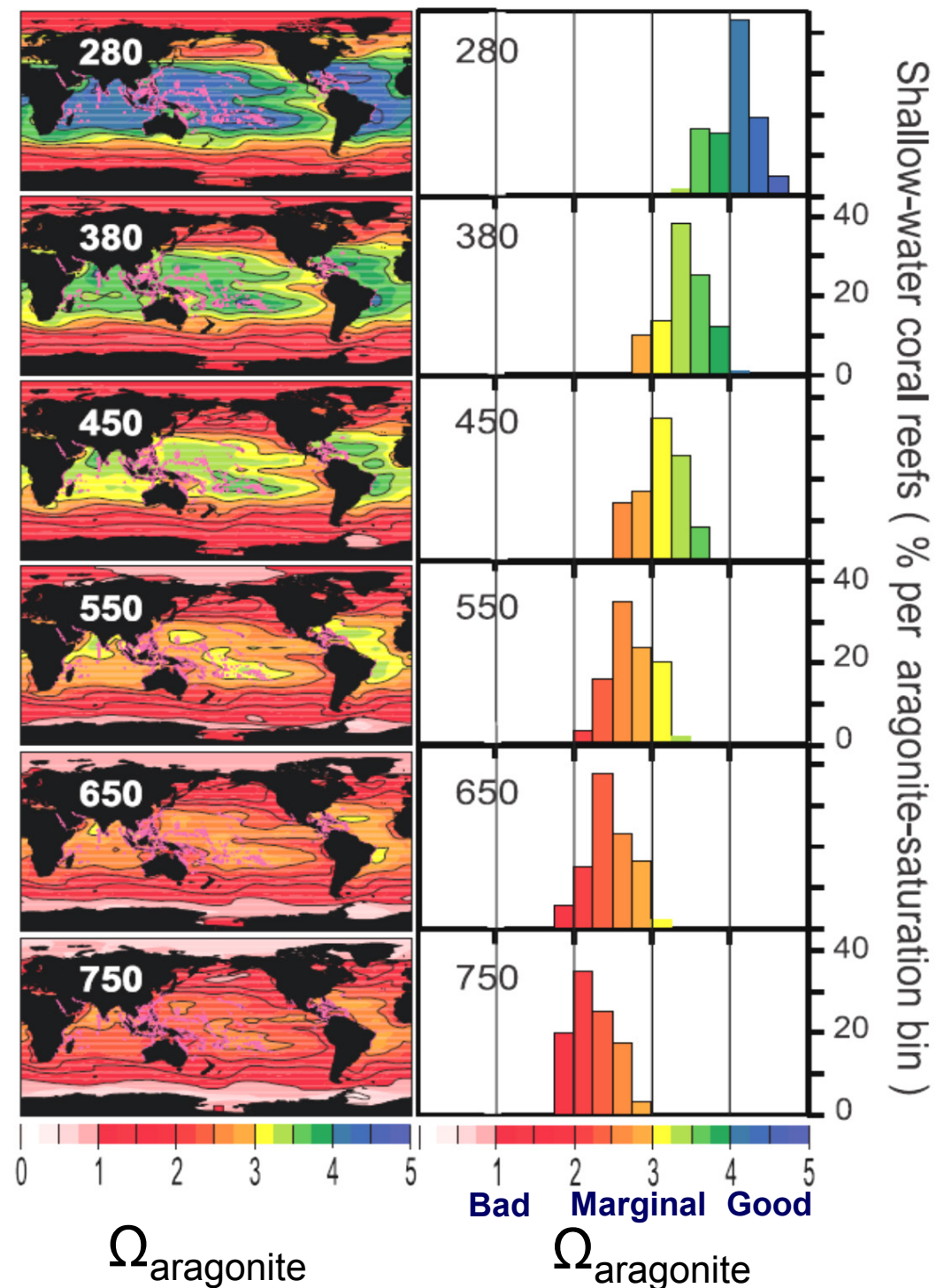
Ocean chemistry and the future of coral reefs?

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.

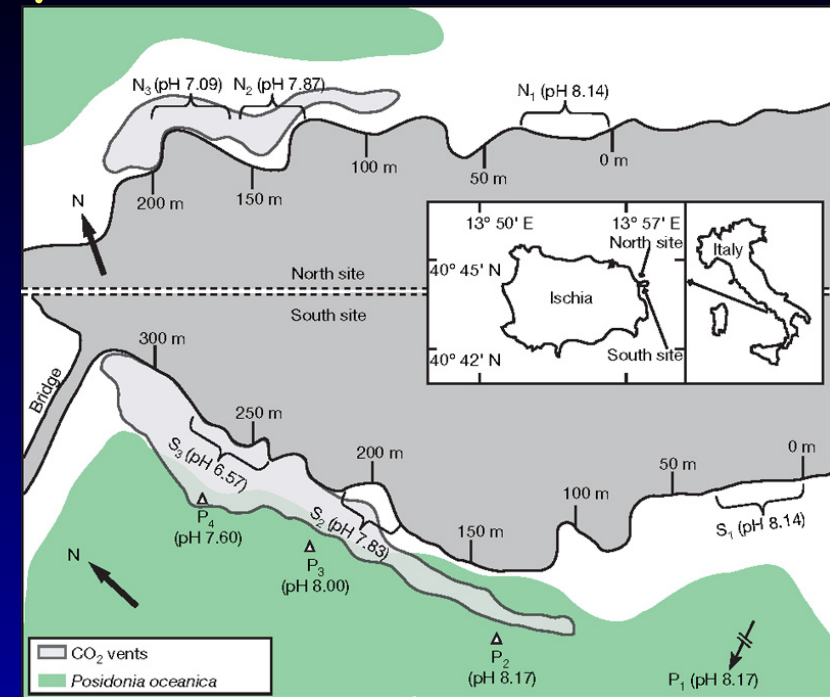
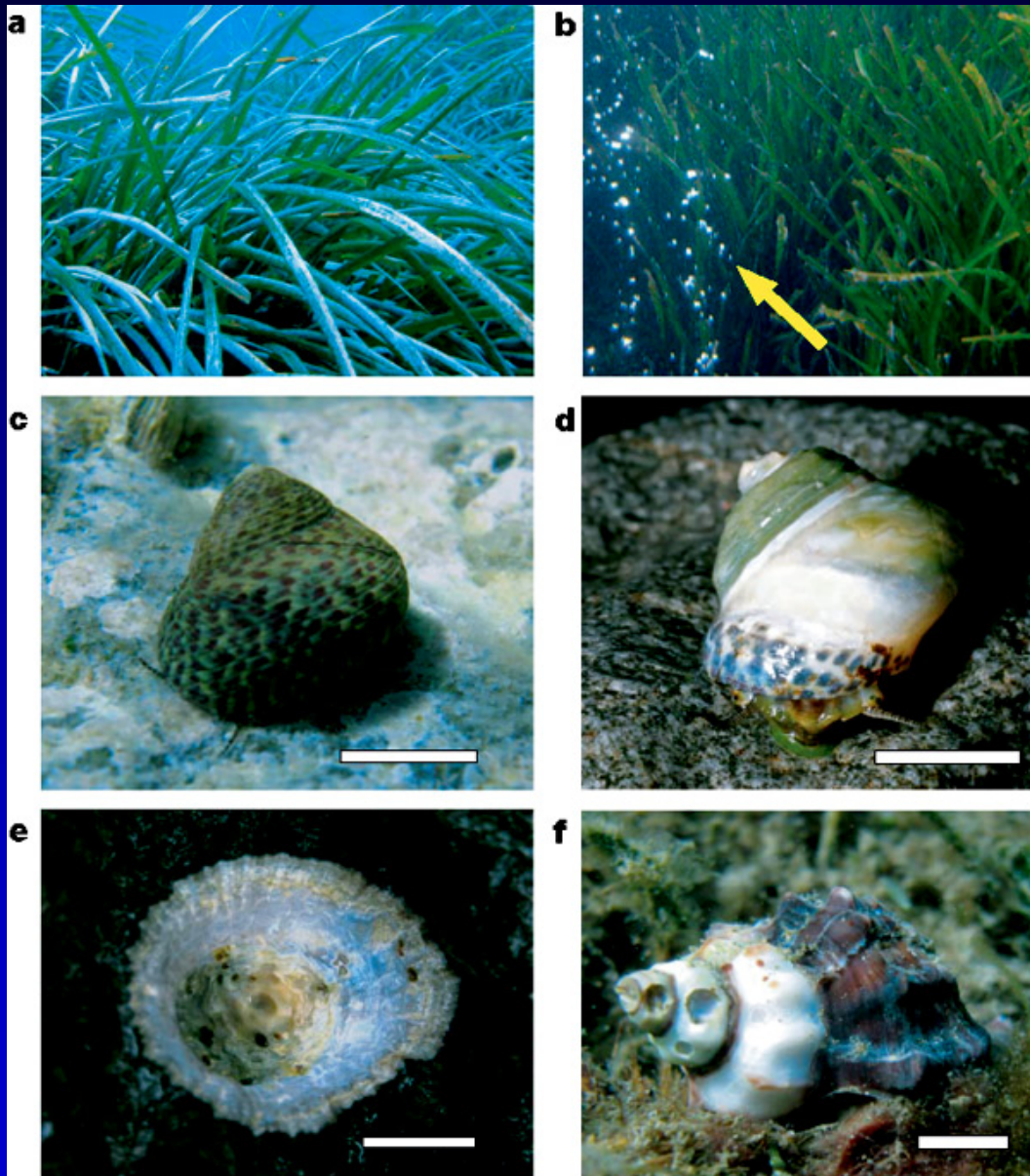
Corals grow best when carbonate minerals are abundant ($\Omega > 3$), and cease to grow at low mineral levels ($\Omega \sim 2$) and can dissolve at very low levels ($\Omega < 1$).

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.**

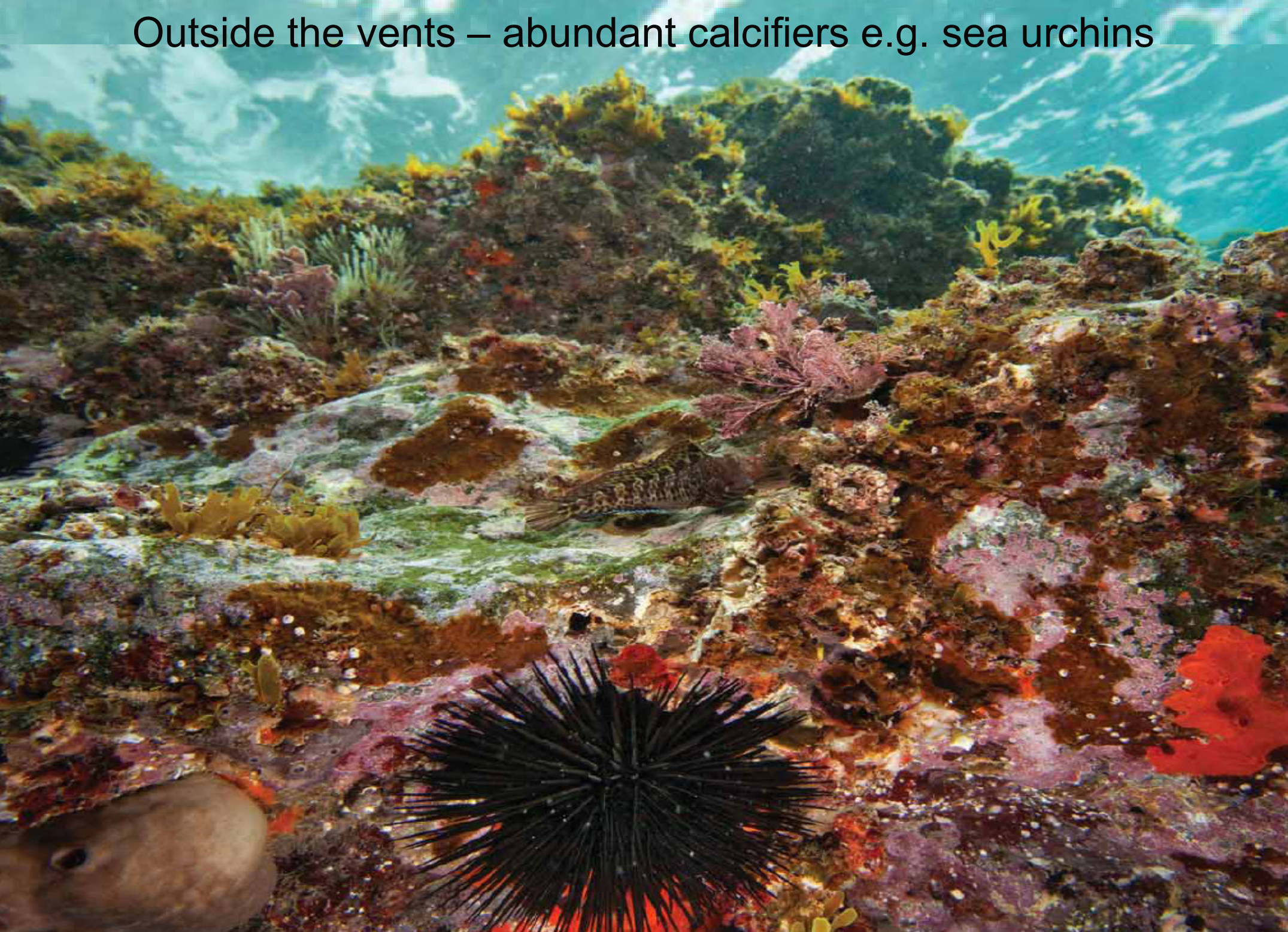


Field Survey of Natural CO₂ Venting Sites in Italy

- Echinoderms conspicuously absent, shell dissolution
- Seagrasses thrive



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



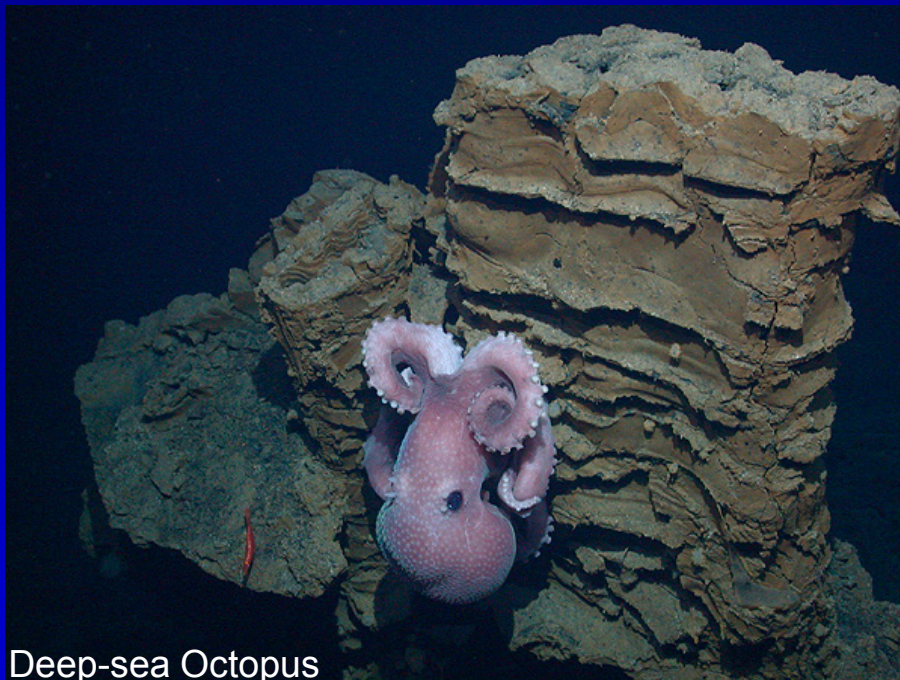
At high CO₂ there are almost no calcifiers, fleshy algae and invasive species dominate

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

Ocean change may be more difficult for deep-sea animals

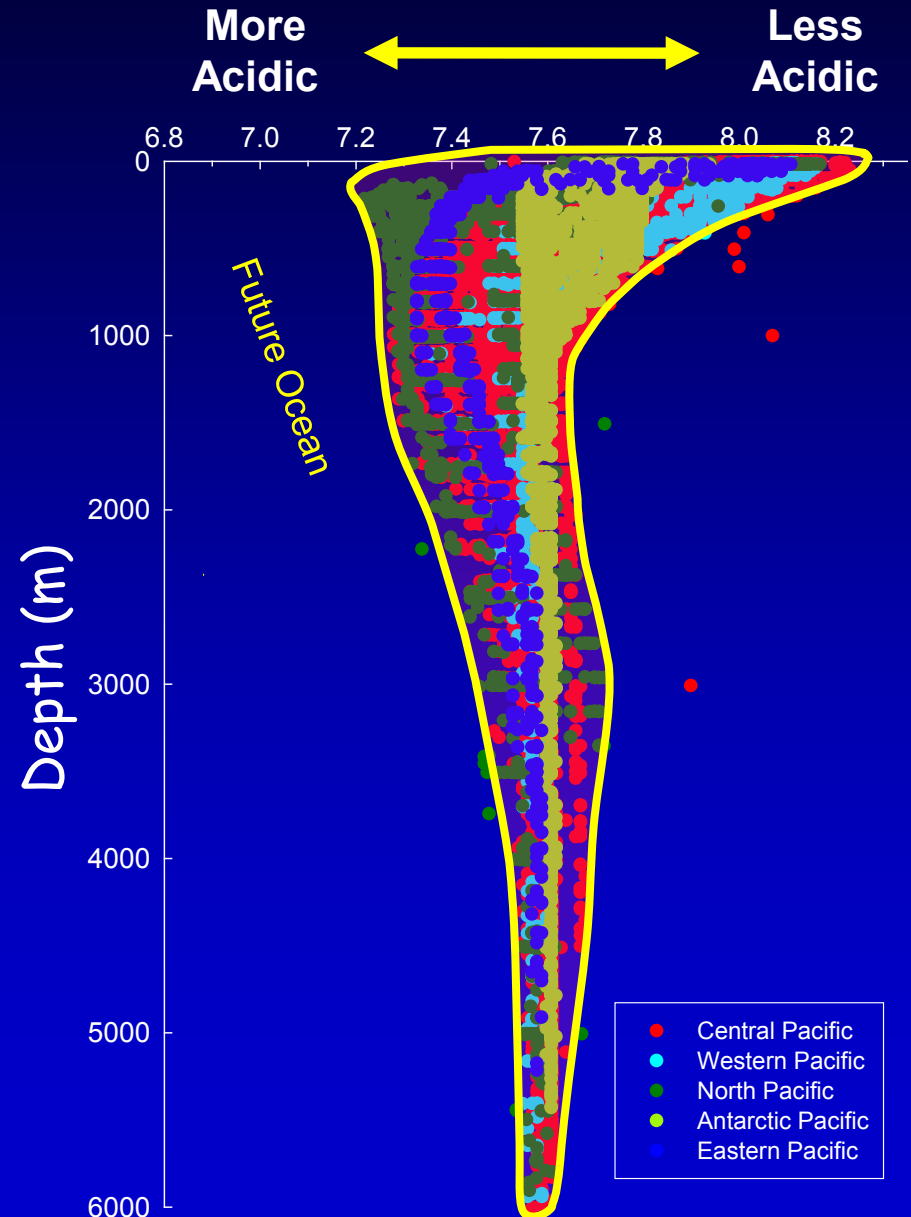
Deep-Sea Animals

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



Deep-sea Octopus

pH variation in the Pacific Ocean



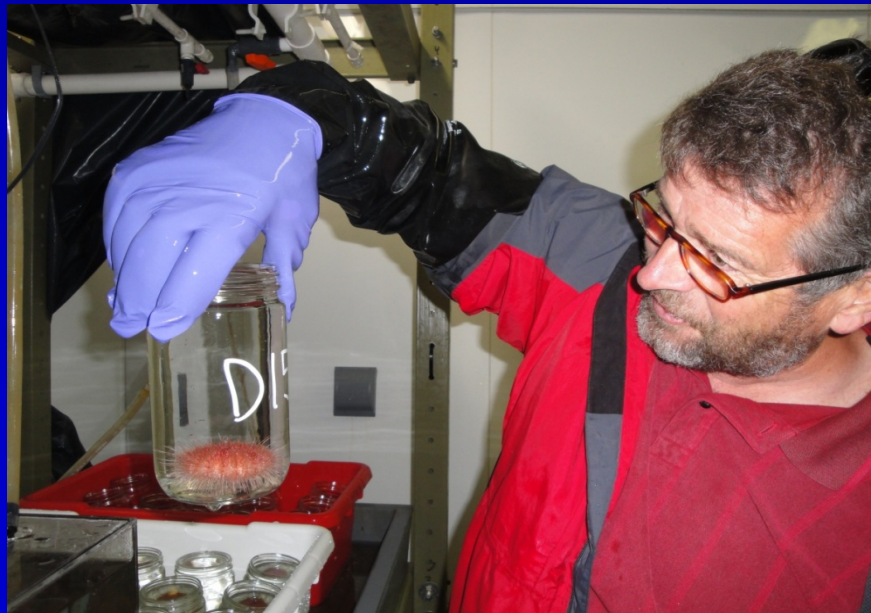
We are studying the effects of changing ocean conditions on deep-sea urchins, crabs, snails and fishes

What is their sensitivity to changing ocean pH, warming and hypoxia?

Ongoing studies

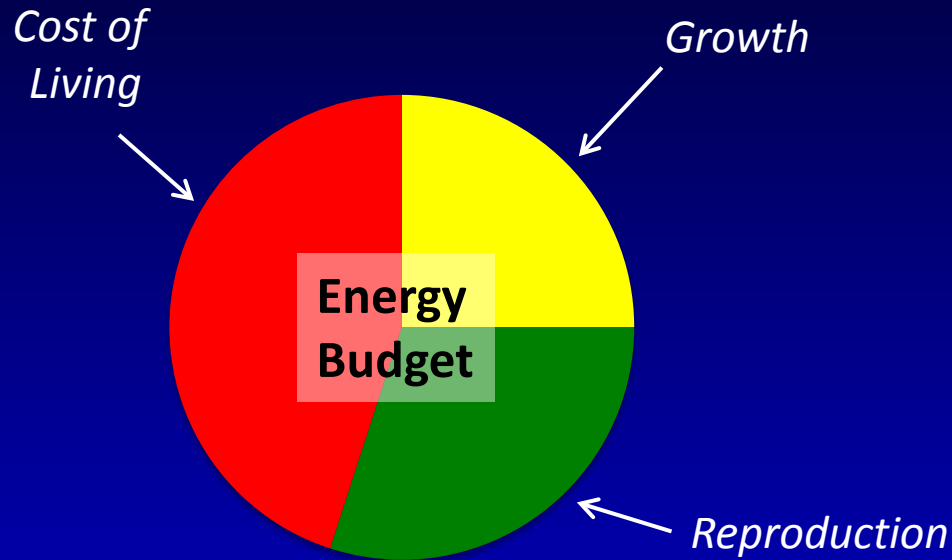
- Metabolic rate
- Acid-base chemistry
- calcification
- survival
- growth
- protein synthesis

Allocentrotus fragilis

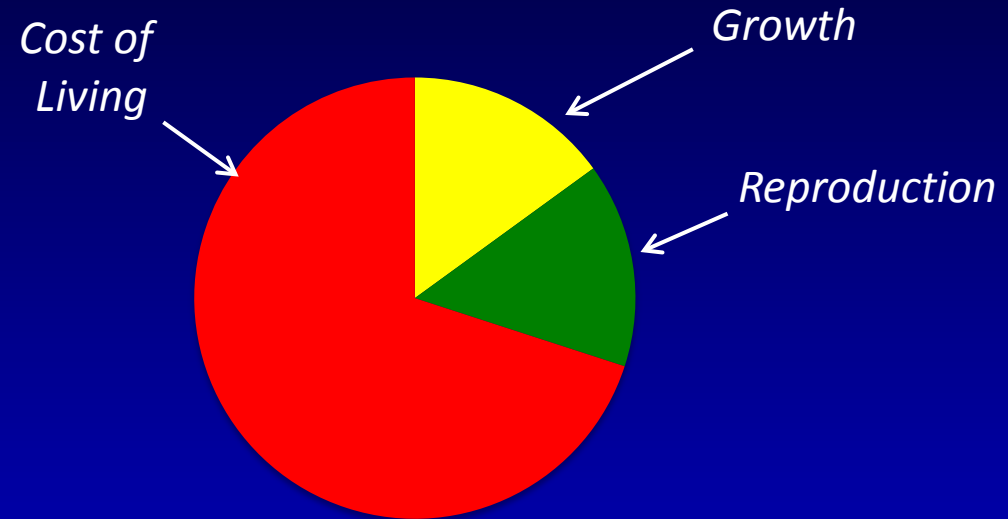


Stress increases the 'cost of living'

Normal



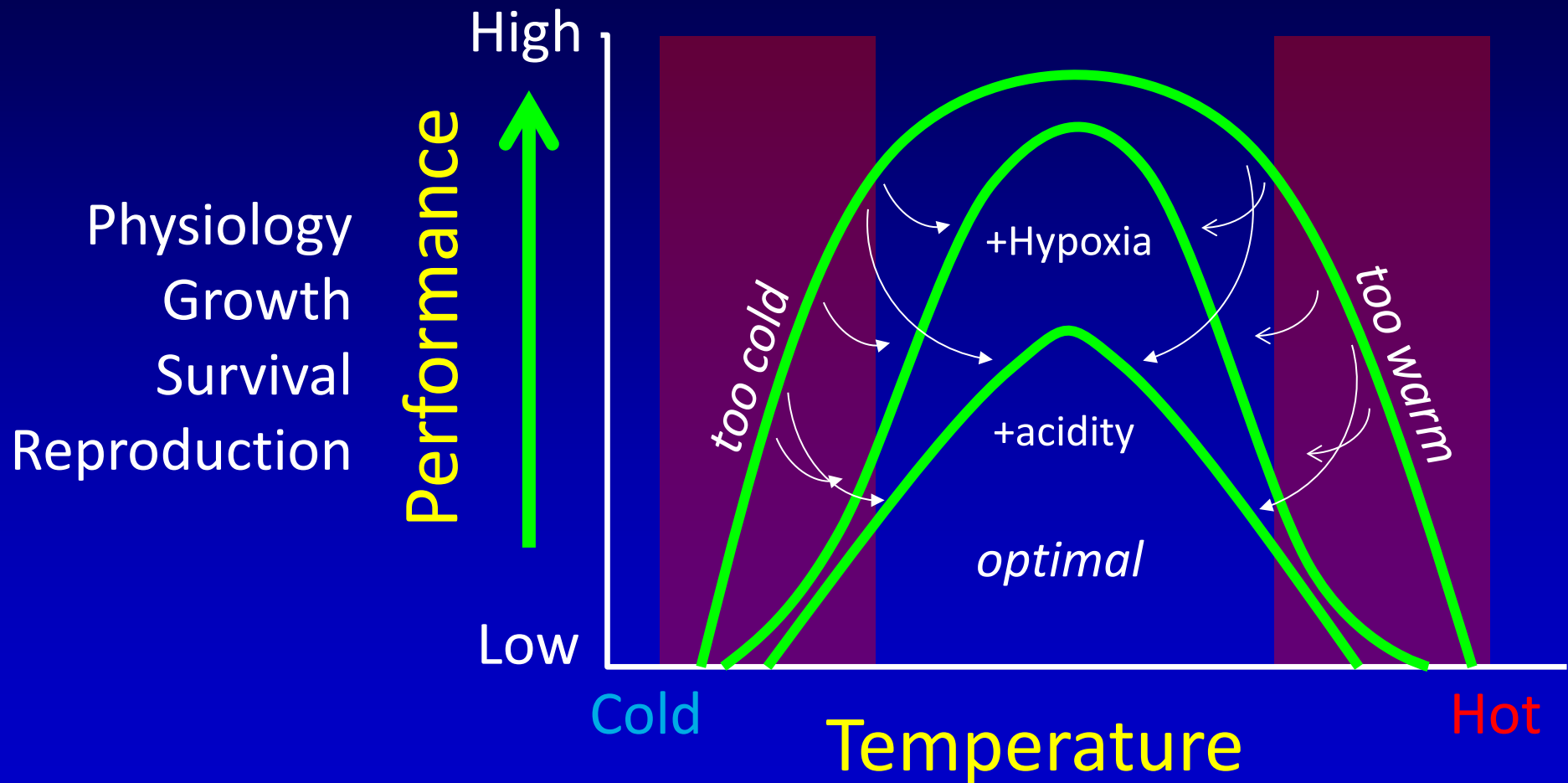
Stressed



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

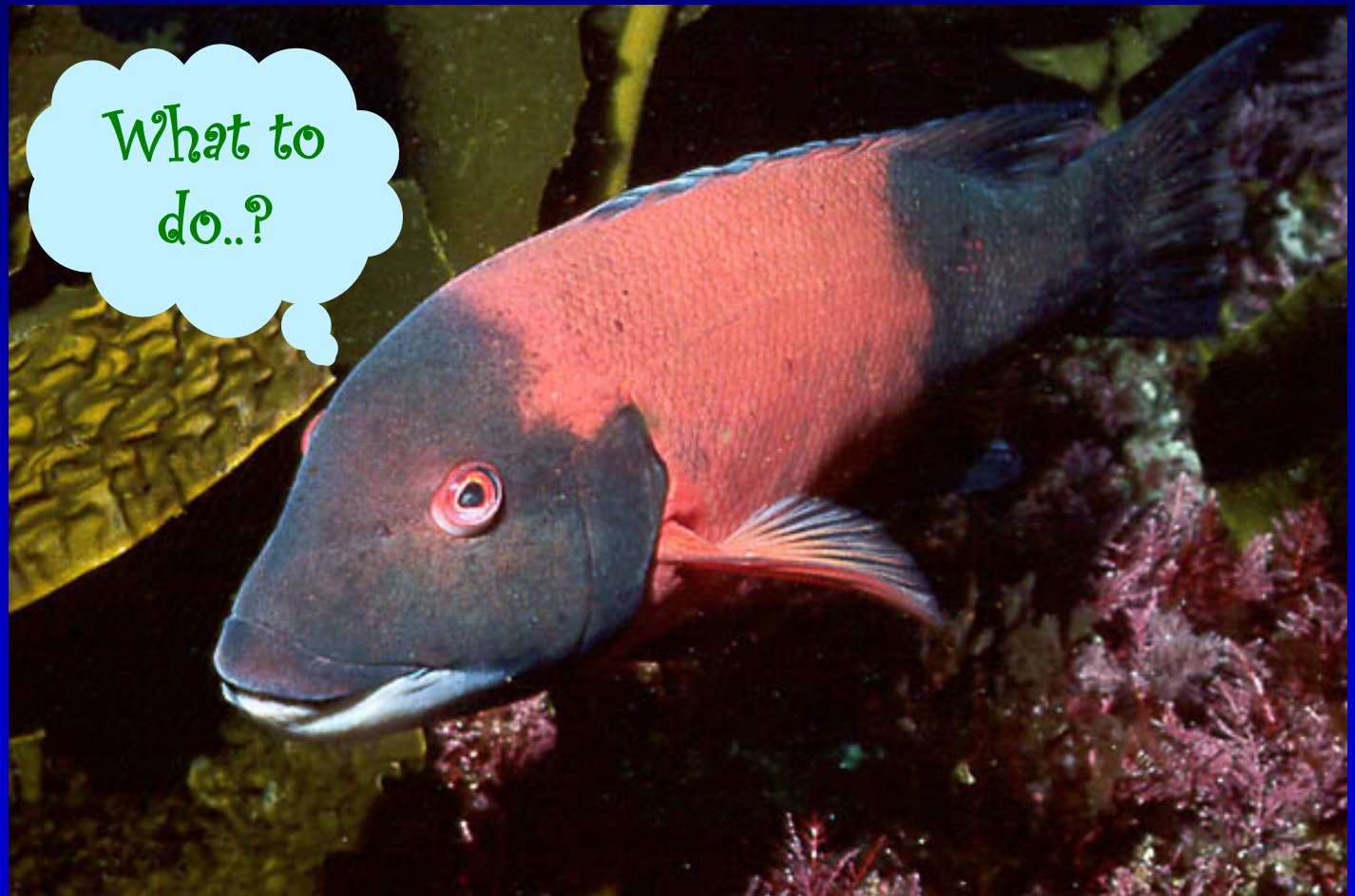
Stress affects animal performance

Multiple stressors can interact to affect animal performance



How do animals cope with changing ocean conditions?

- Migration
- Acclimation
- Adaptation
- Extinction

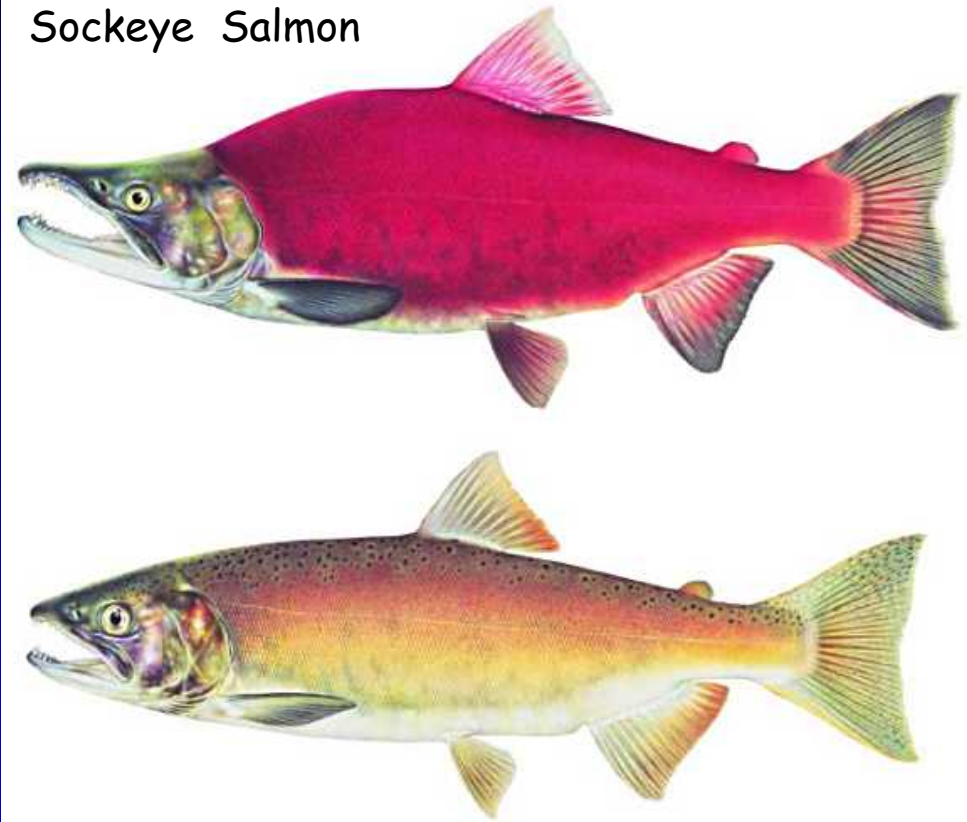


Will Ocean Acidification disrupt energy flow through marine food webs?

Pteropod = Salmon food

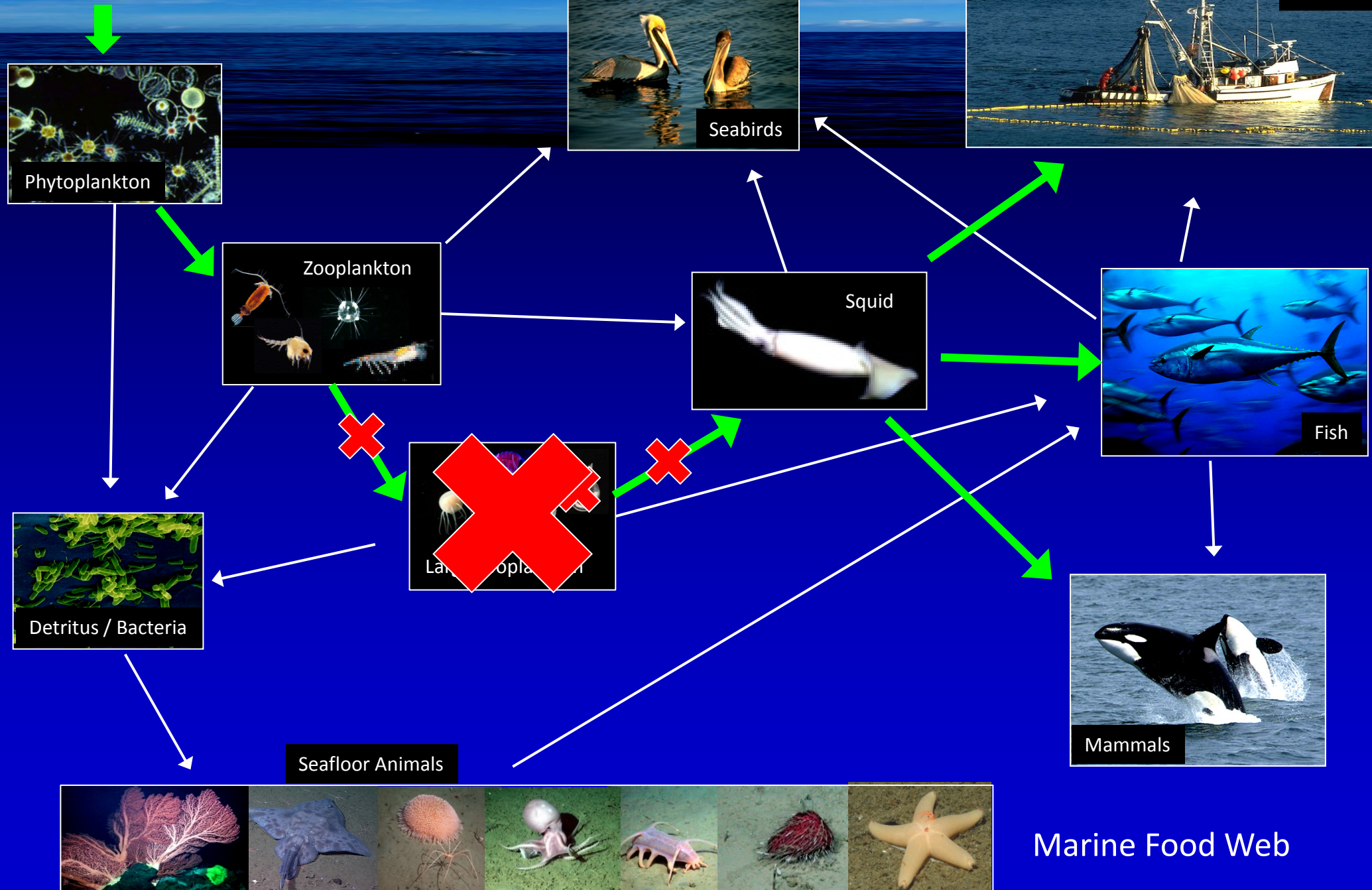


Sockeye Salmon



Marine Communities are Biological Networks

Primary Production



Society has choices for adaptation to a changing ocean

- Climate and ocean change is a problem for society
- Food and energy needs for society linked to ocean health
- Balancing ocean health and societal demands
- Can we avoid ocean tipping points?
- Early action reduces severity of impacts



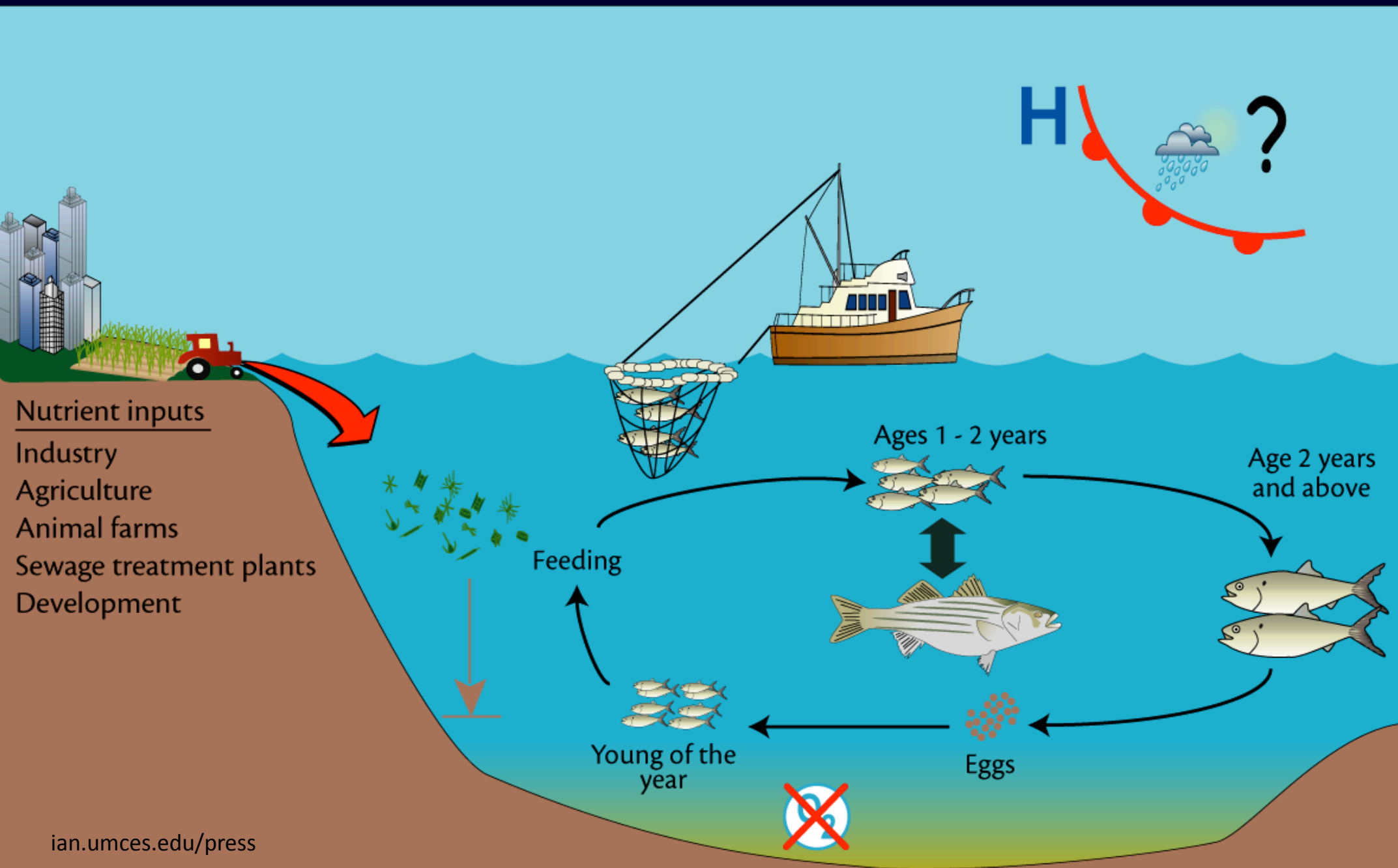
**Ecosystem
impacts**

**Ecosystem
Services**

Past

Future

Ecosystem-based management of marine resources

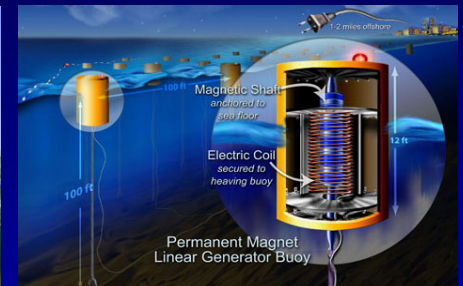
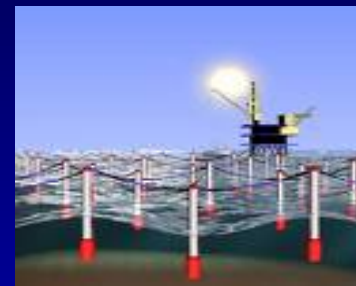


Reasons for Hope?

High-efficiency cars and trucks



Wave and Tidal Energy



Photovoltaic Energy (Solar)



Wind Power



Summary points

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?

Is it hopeless, too late, too big....?

Should we worry?

- YES! Climate change / OA affects the quality of our lives

What can we do?

- Education and outreach
- Energy efficiency, non-carbon energy, reduced emissions
- Reconnect with nature
- Value the oceans
- Vote!



Value the oceans

