PML | Plymouth Marine Laboratory

Marine Matters

The Ocean in a High CO_2 World Symposium Monaco, 6-9 October 2008

Science Summary of the Symposium for Policy Makers

Dr Carol Turley

ct@pml.ac.uk

Monaco, 9 October 2008

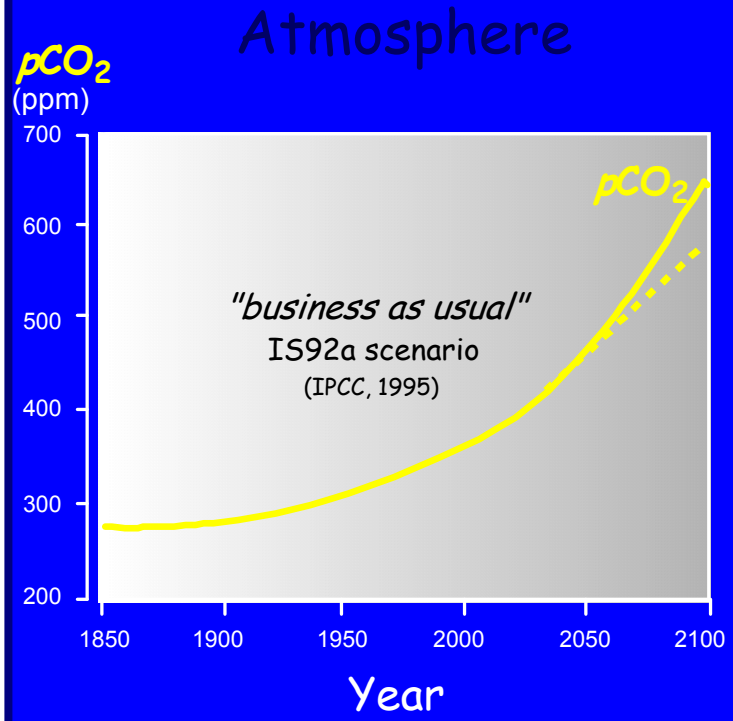
What is Oceanic Acidification?

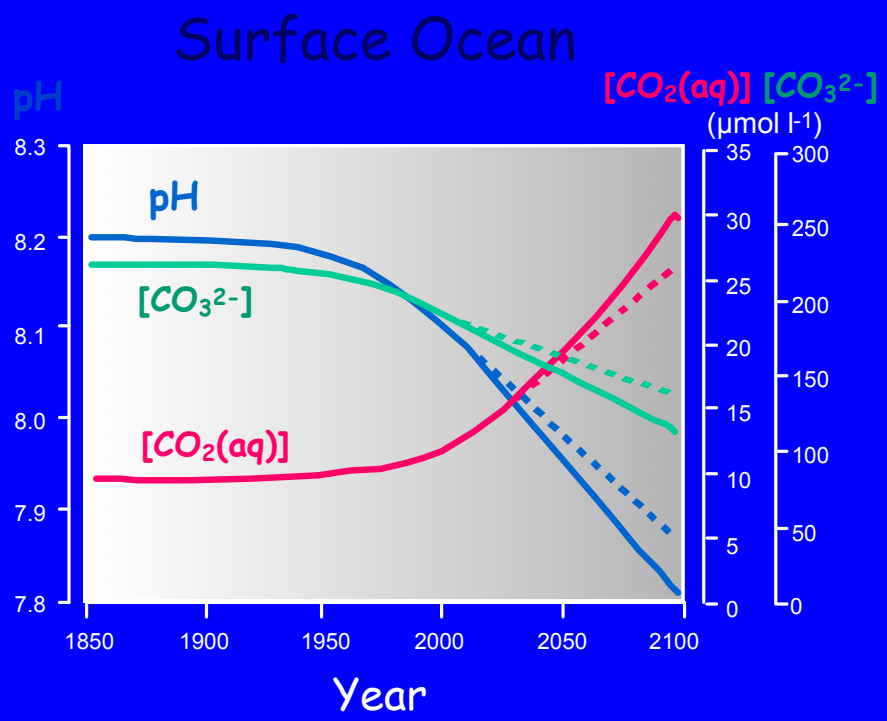
Atmosphere

CO_2 (g)

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

Surface Ocean



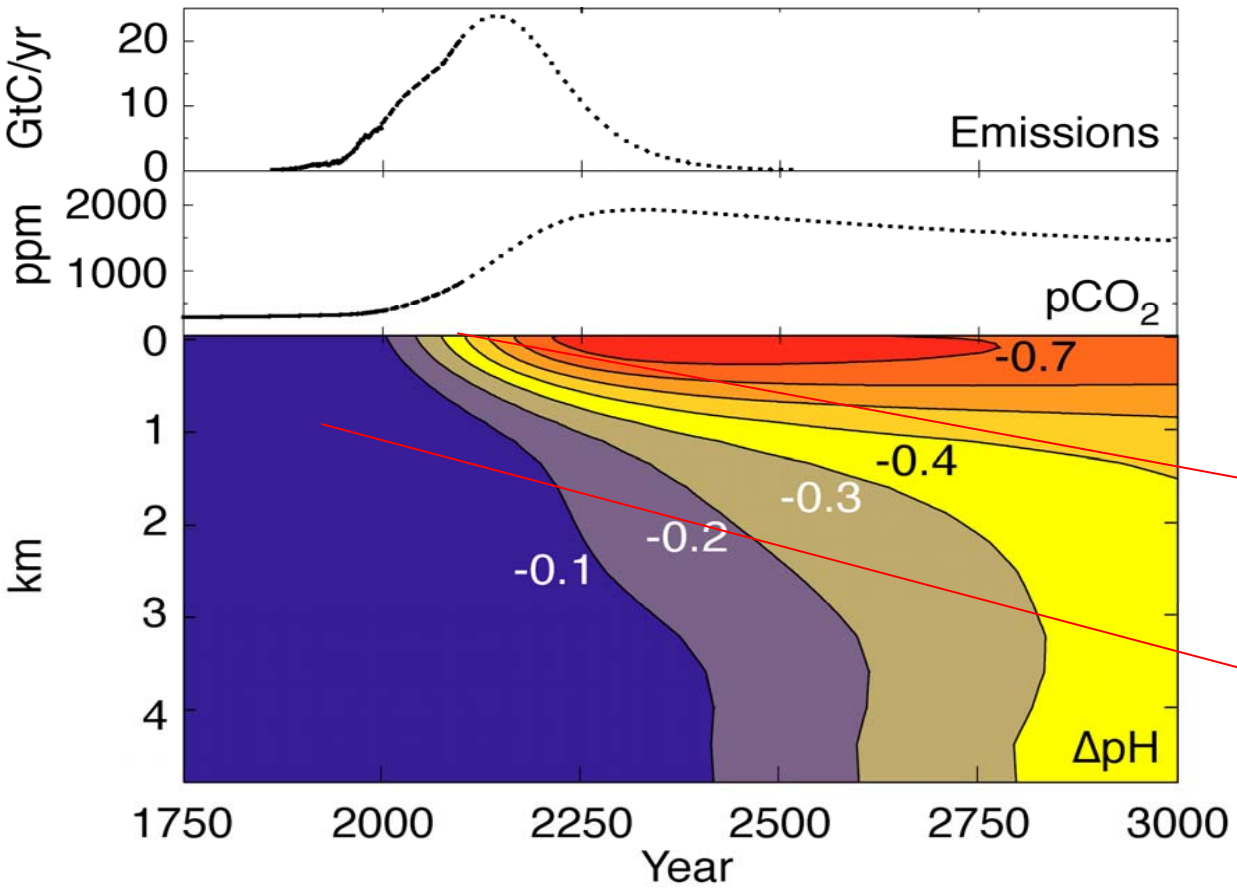


The Oceans are becoming more acid as they take up more CO_2

Wolf-Gladrow, Riebesell, Burkhardt, Bijma (1999) Tellus 51B, 461

The Ocean Acidification Timeline …….

While climate change has uncertainty, these geochemical changes are highly predictable.



Caldeira & Wickett 2003, Nature: A simulation of changes in ocean pH assuming continued usage of known fossil fuel reserves

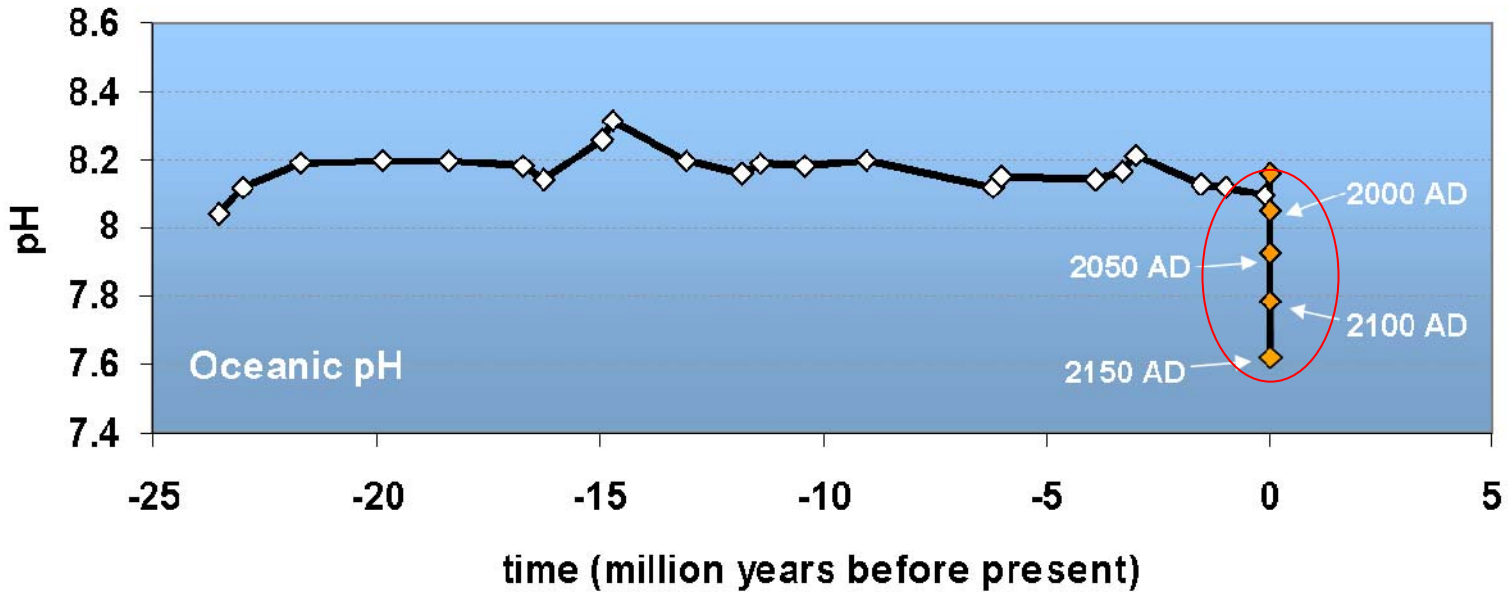
Oceans are an important reservoir for CO_2 with c. 30% of CO_2 produced from fossil fuel burning & land-use change taken up by oceans (Sabine et al. 2004 *Science*) – effectively buffering climate change

CO_2 produced by humans is predicted to decrease surface ocean pH by 0.4 +/- 0.1 depending on scenario by 2100

pH has already changed by 0.1 in surface waters due to absorption of anthropogenic CO_2 - equivalent to 30% increase in acidity

……the Oceans are Acidifying Fast

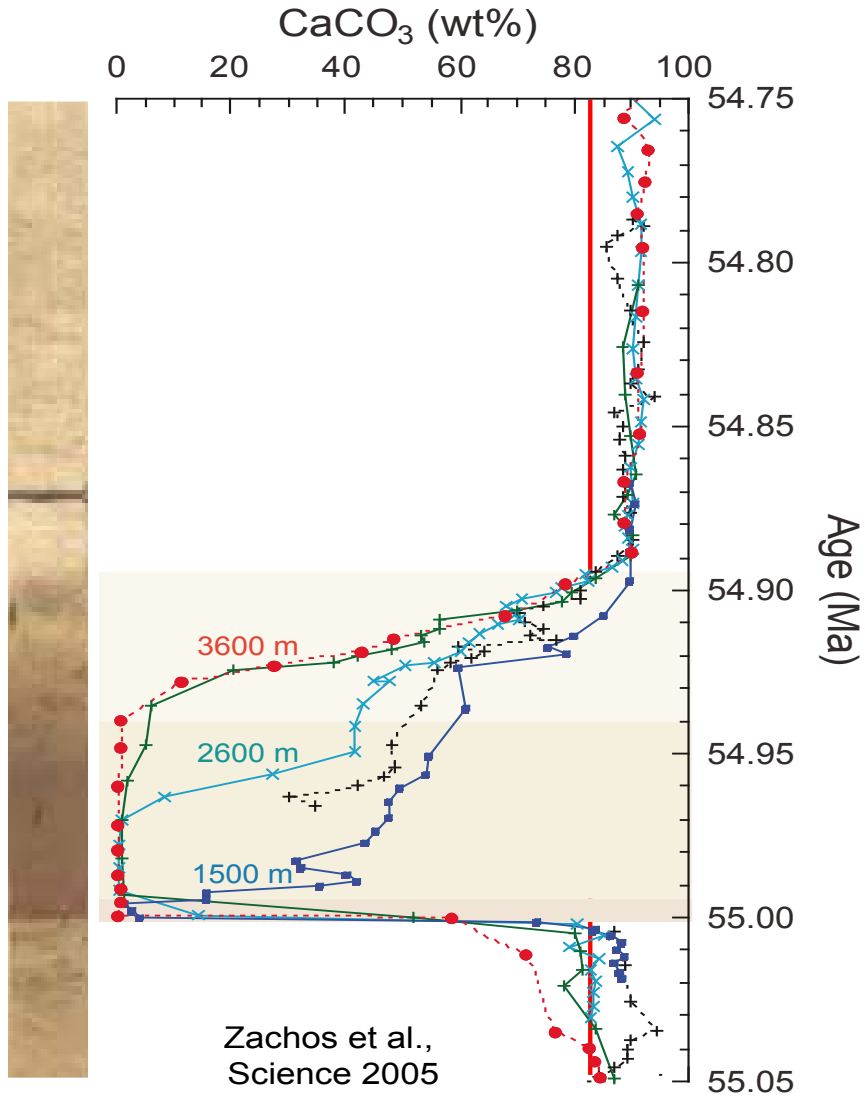
Changes in pH over the last 25 million years



It is happening now, at a rate and to a level not experienced by marine organisms for ~ 20MY perhaps even 100's MY

Turley et al. (2006) Avoiding Dangerous Climate Change

Learning From the Past – Are There Clues to Future Impacts?



Zachos et al.,
ODP IR, 2003

Change in the
baseline

- **Mass extinctions linked to previous ocean acidification events**
- **Takes millions of years to recover**

end of acidification

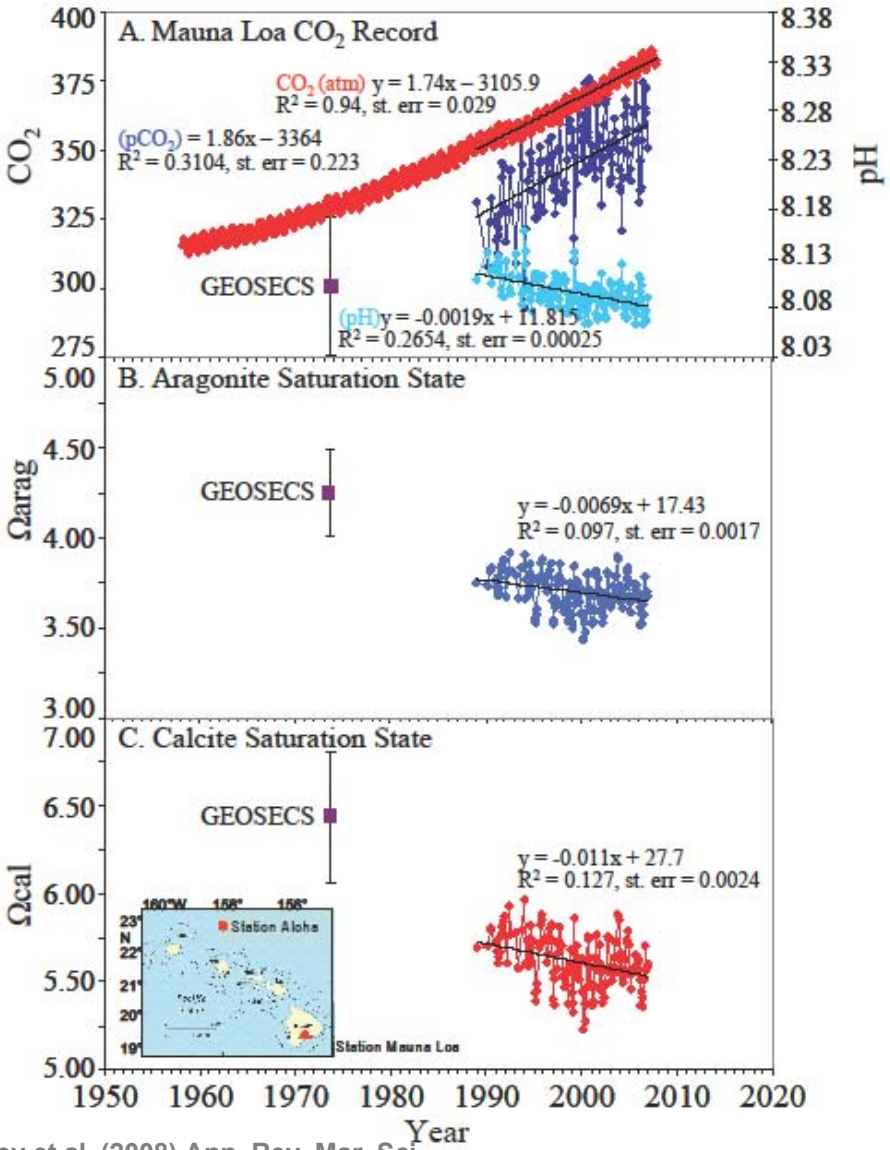
Benthic foraminiferal mass extinction

onset of acidification

"Today is a rare event in the history of the World"

Ocean Acidification is Happening Now and is Measurable ……

Pacific - HOTS



Doney et al. (2008) Ann. Rev. Mar. Sci.

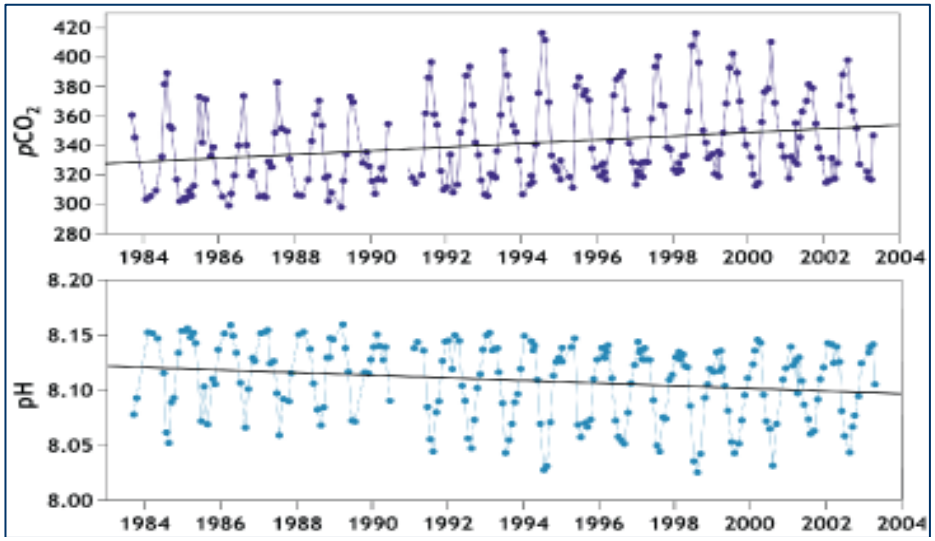
- **CO_2 in oceans increases with increasing atmospheric CO_2: this is certain!**

Observed trends indicate possible impacts already emerging in:

- Shell weight decrease with time in Pteropods, Foraminifera and Brachiopods

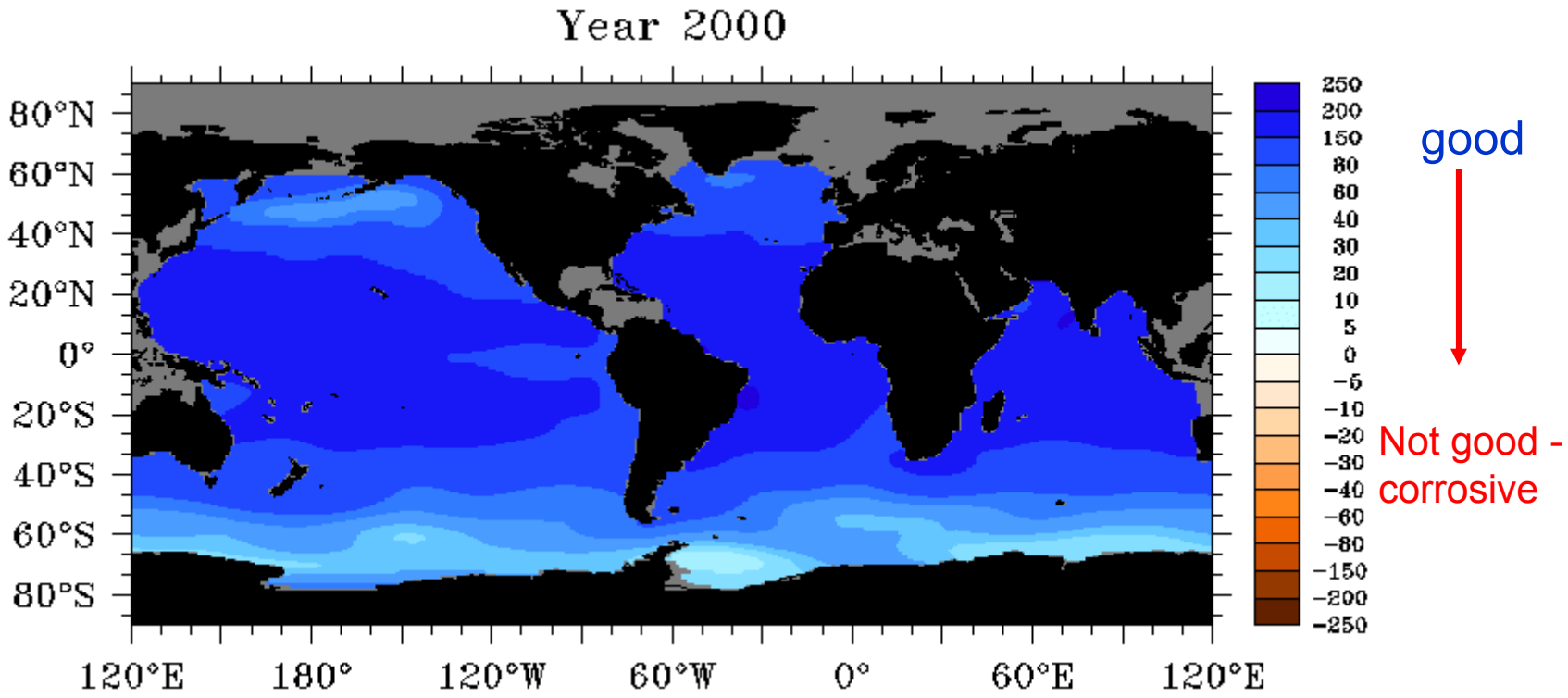
- Reduced calcification in coral reefs from GBR over last 2 decades

Atlantic - BATS



Present and Future Global Aragonite Saturation States …….

The extent of aragonite saturation controls the rate an organism such as a reef forming coral can build its skeletons or shells



Aragonite Saturation State of Surface Waters
(Orr et al 2005, Nature)

Note:

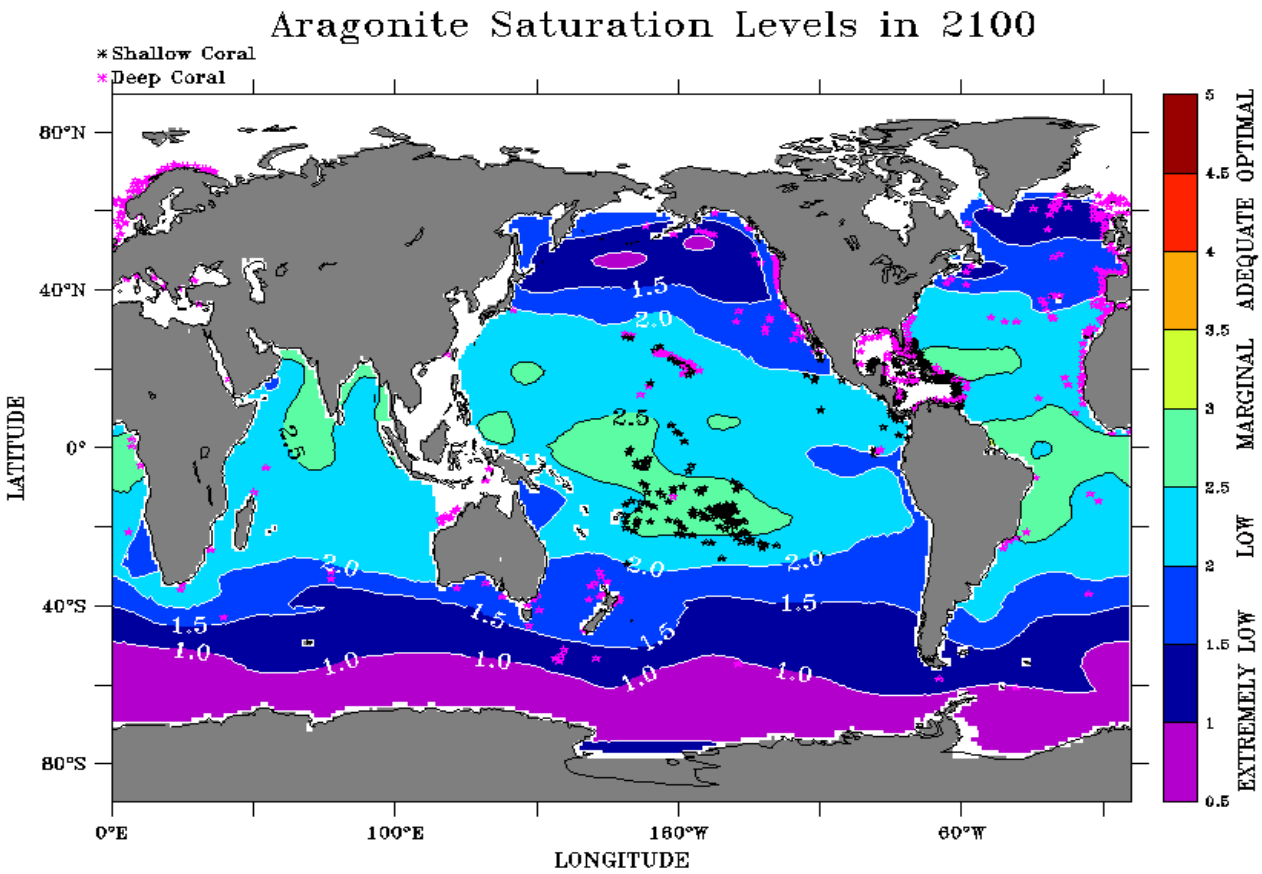
- Overall decline in aragonite saturation in the global ocean
- Polar and subpolar waters become undersaturated (corrosive)

Projections of Aragonite Saturation Levels With Locations of Corals

Corals like warm, sunlit waters saturated in aragonite

Coral Reef calcification
- 1765 Adequate
- 2000 Marginal
- 2100 Low

Calcification rates in the tropics may decrease by 30% over the next century.



After Feely et al (2004) with Modeled Saturation Levels from Orr et al (2005)

In a future ocean Calcification < Erosion
- very serious for reef ecosystems as we know them

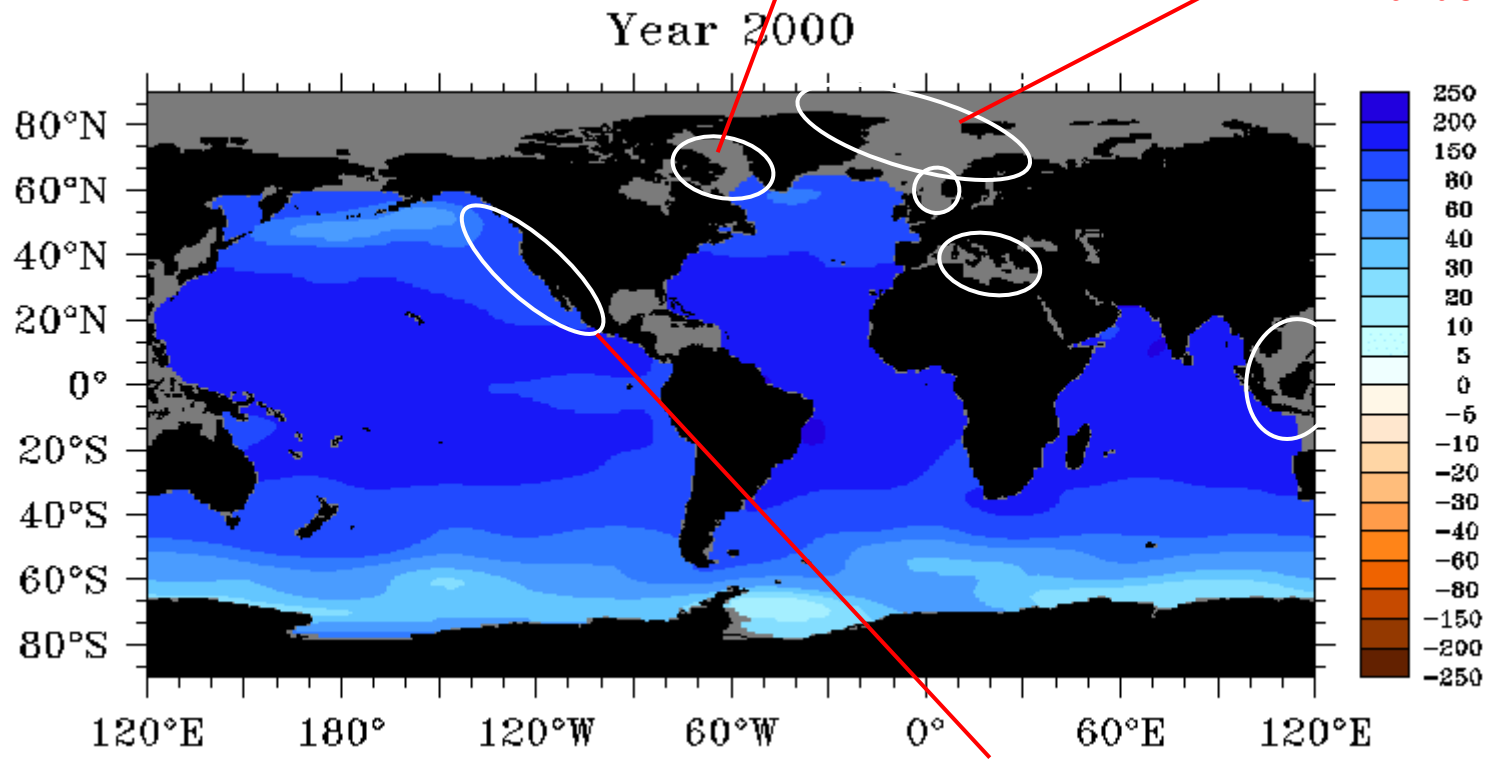
But Global Ocean Models Have Limitations Around:

- Continental margins
- Arctic Sea
- Shelf Seas and coastal waters
- Enclosed or semi-enclosed seas
- Upwellings

New research indicating that:

Labrador Sea – low saturated waters from above and below

Arctic Ocean also vulnerable to undersaturation



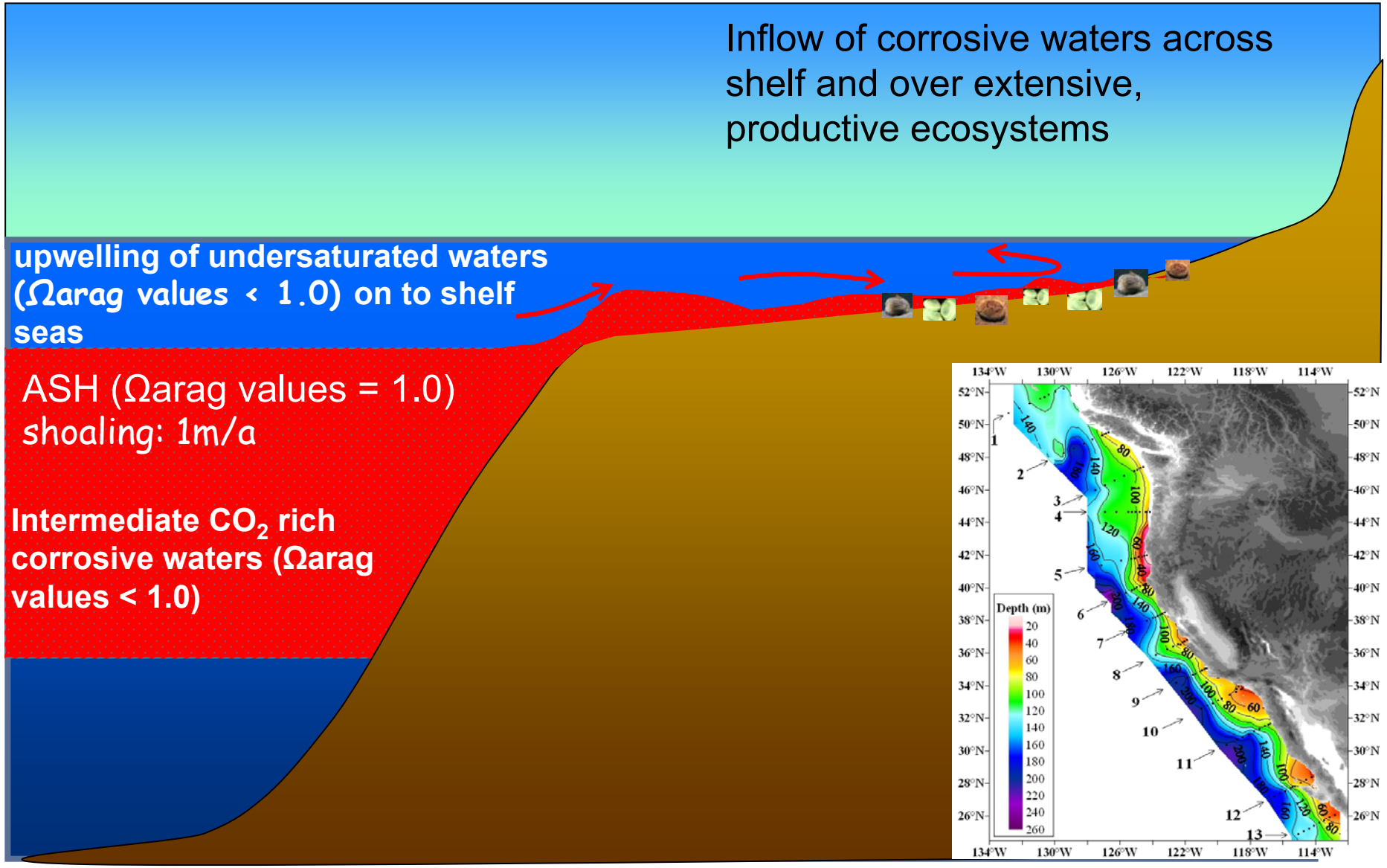
good

Not good - corrosive

West Coast of N America already experiencing seasonal undersaturation

Aragonite Saturation State of Surface Waters
(Orr et al 2005, Nature)

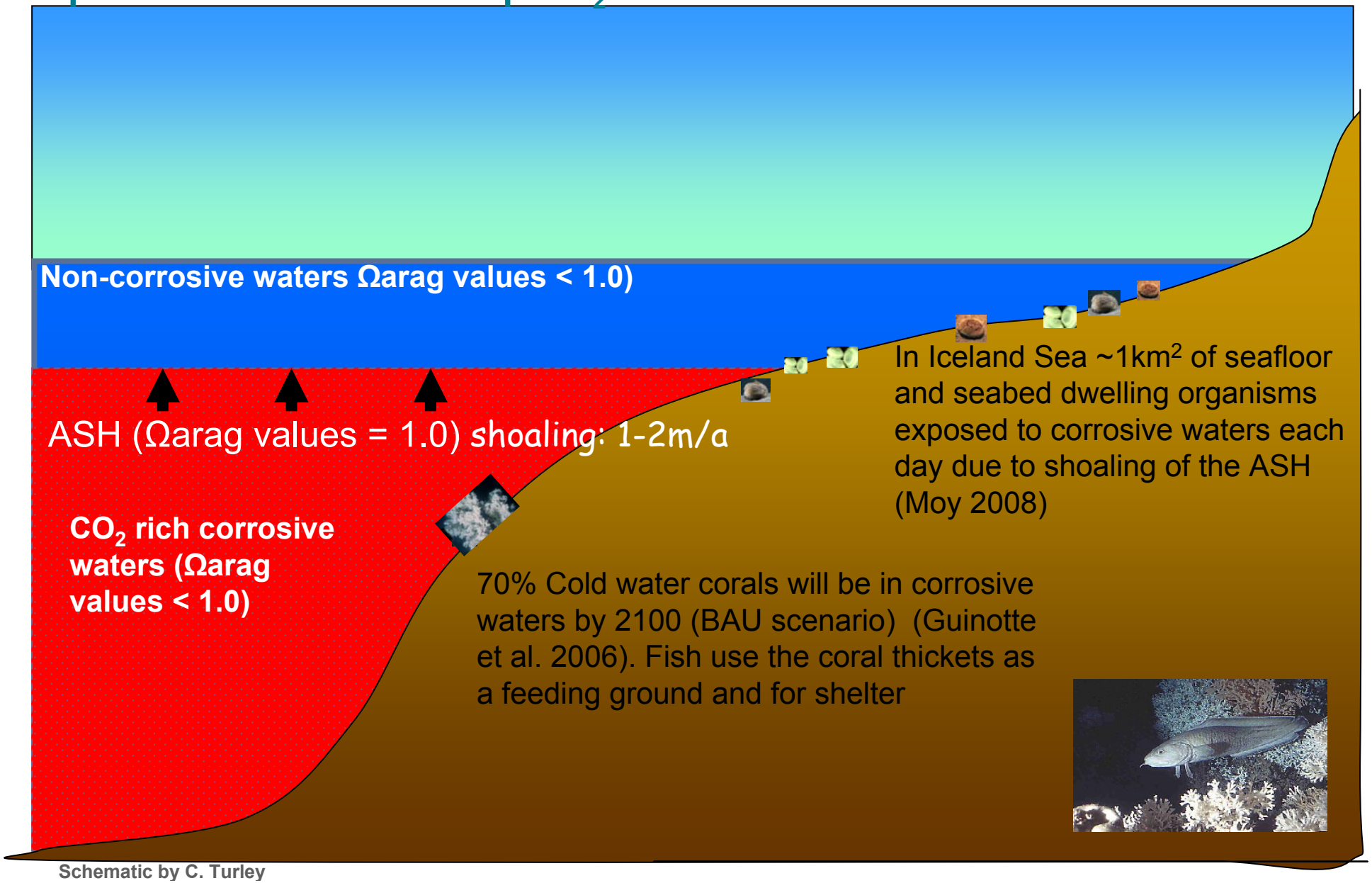
Seasonal Invasion of Corrosive Waters on West Coast North America



Schematic by C. Turley

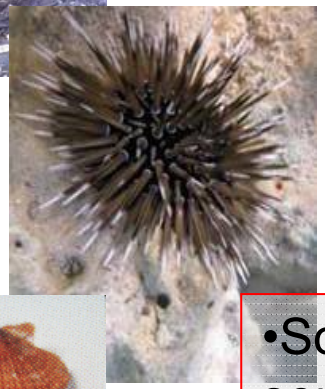
Feely et al. Science (2008)

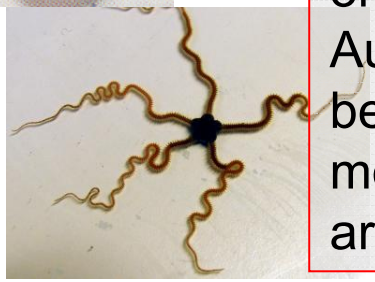
Upward Movement of Deep CO_2 Rich Corrosive Water



Schematic by C. Turley

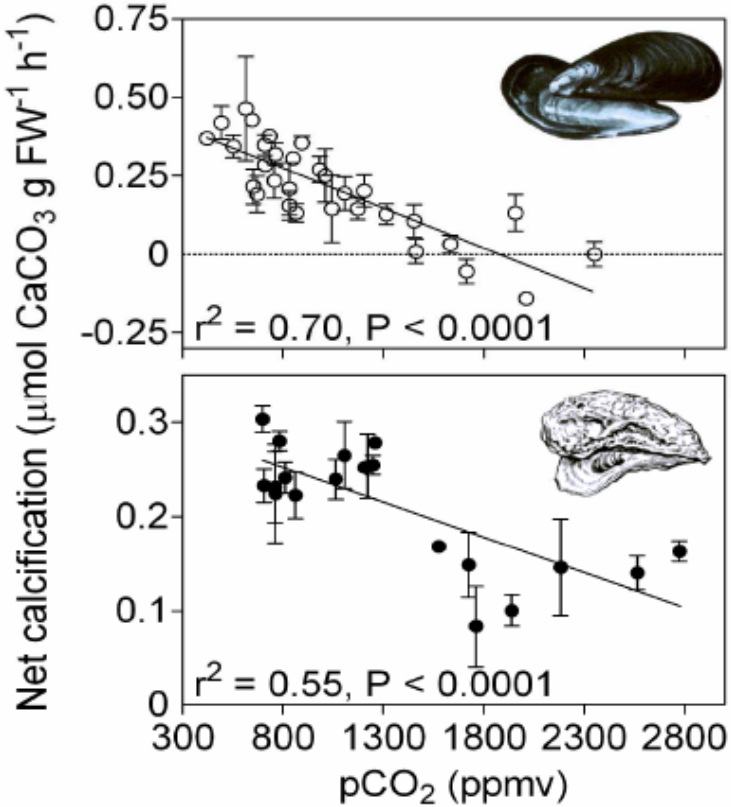
Effects on Other Calcareous Seabed Dwelling Invertebrates





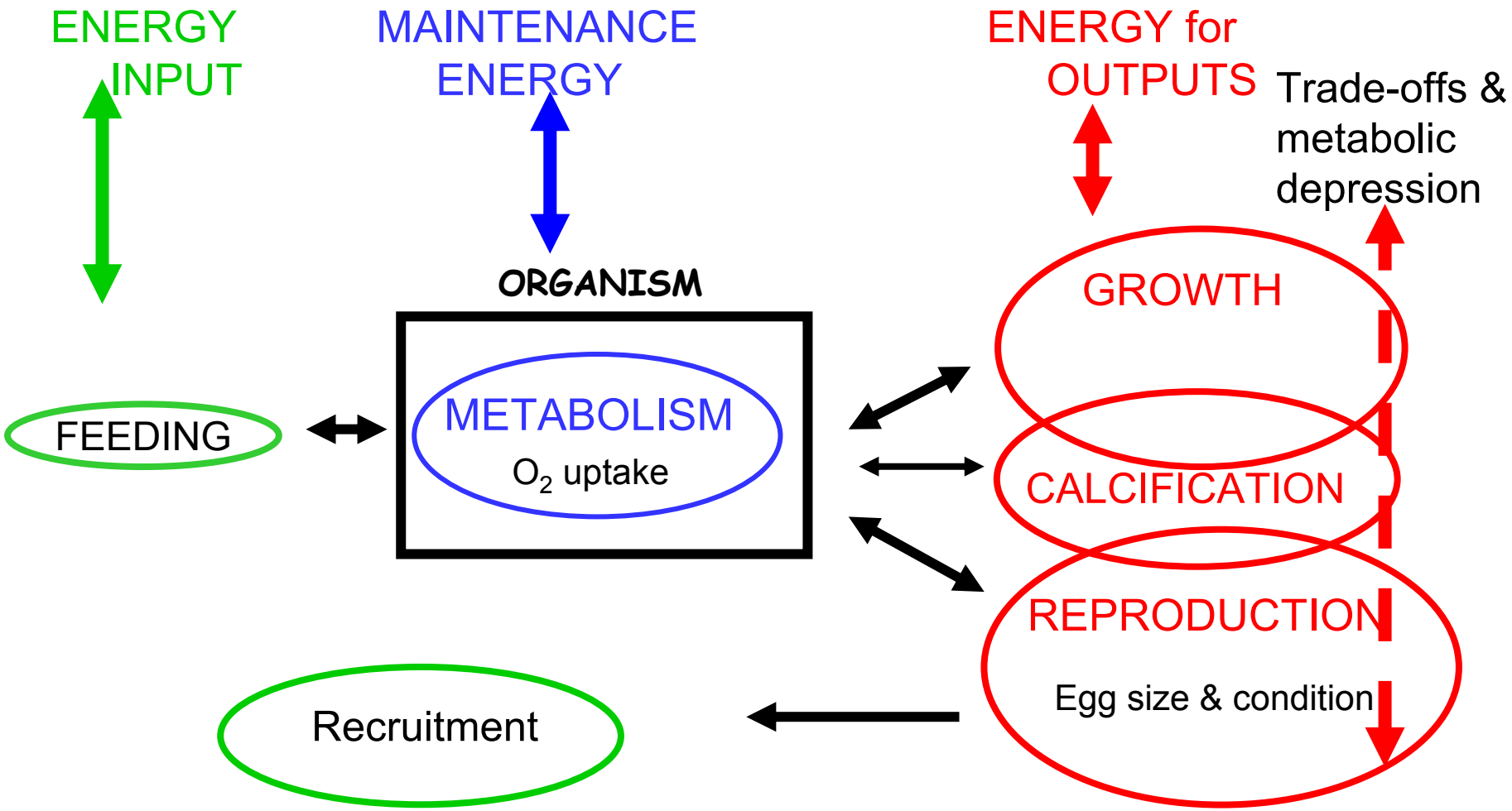
- Some species more sensitive to others
- Differences found in one species of oysters in Australia – so there may be some gene strains more resistant – new area of research

Gazeau 2007



- **Increasing CO_2 results in slower growth and lower final weight,**
- **These are adults but what about spats and juveniles, recruitment and settlement?**

Key Survival Processes in the Life Cycle and Physiology of an Organism

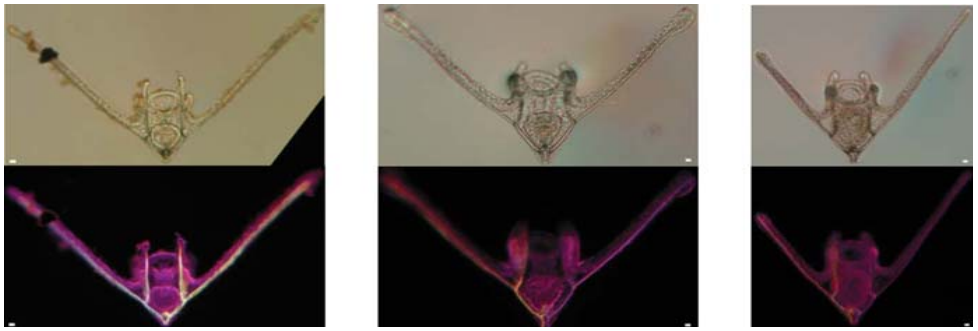


Schematic adapted by C Turley from H Wood (PML)

Examining the Full Life Cycle to Find the Weakest Link

Dupont et al. 2008

Declining pH



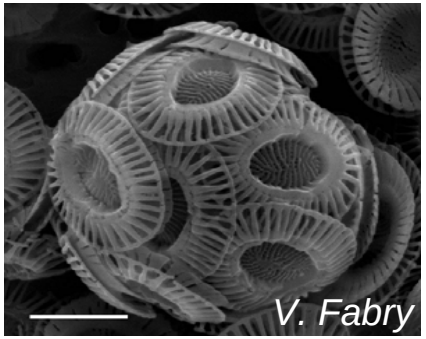
Padstow National Lobster Hatchery

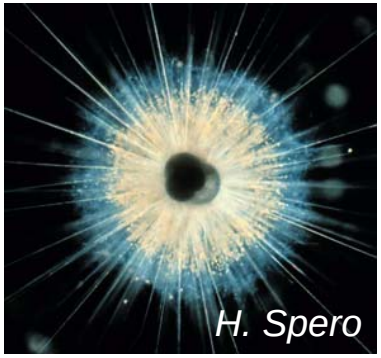
Egg Development

Larval Development

- Some early life stages are very sensitive to ocean acidification
- Impacts vary with species
- Some more tolerant than others

Experiments on Major Planktonic Calcifiers



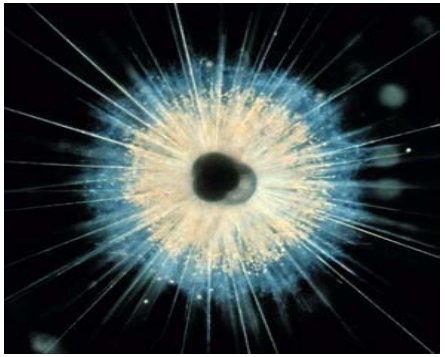


	# Extant species	Mineral form	Generation time
Coccolithophores (autotrophs)	~ 250	calcite	days
Foraminifera (heterotrophs)	~ 50	calcite	weeks
Euthecosomatous Pteropods (heterotrophs)	~ 32	aragonite	months to year?

- CO_2 sensitivity experiments limited to a few species
- Majority show decrease in calcification – but not all – we need to understand if this is “real” or artefacts of different experimental design

Will Understanding the Mechanisms of Calcification Help us Understand Varied Response to CO_2?

Calcifiers are Living Organisms Protected by Membrane – so why worry?



- They have different mechanisms to control the pH of the microenvironment of calcification
- But despite this the majority show sensitivity to lower pH or carbonate ion concentration
- The mechanisms are different and may help explain the variation seen in lab experiments
- Understanding the generic mechanisms of calcification in the different groups of calcifiers may help us predict future responses to ocean acidification

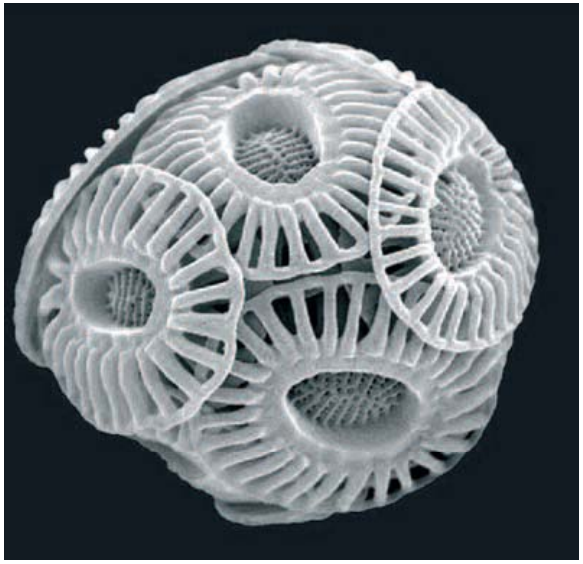
Controlled Laboratory Experiments….

•Mainly short term experiments on single species

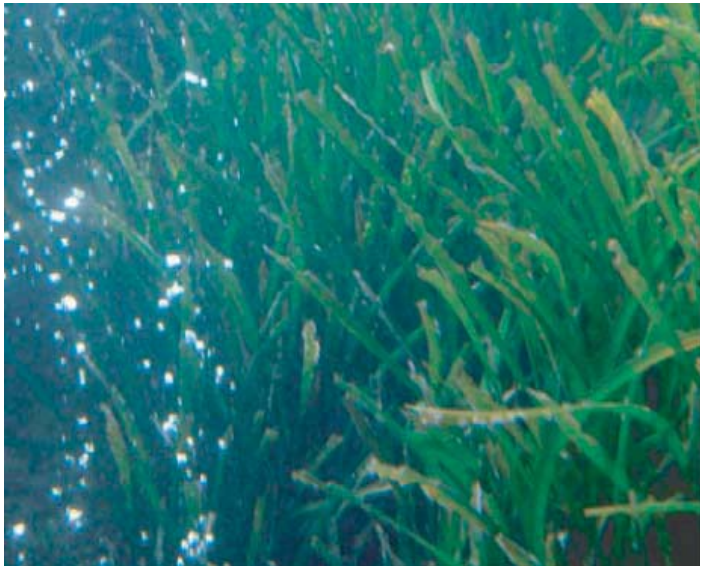
•Longer, multi-generation experiments now emerging but show no adaptation to high CO_2 after 150 generations

•Multiple species experiments showing complex interactions

•How do we interpret these for the real world of the oceans?



CO_2 Vents: "Windows" into a Future High CO_2 Ocean



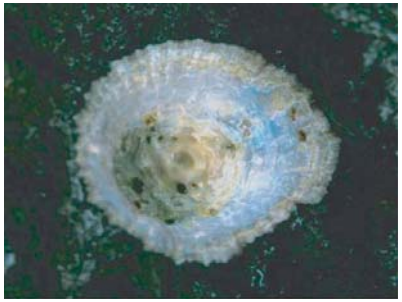
Hall-Spencer et al. Nature (2008)

Studies in the shallow waters of the Mediterranean and deep-sea CO2 vents may help assess future ecosystem level impacts? Preliminary studies show:

- total loss of some species (supporting lab. experiments)
- reduced biodiversity
- "regime shifts" to totally different ecosystems

e.g. Sea grass benefit but so do invasive species

Will there be more jellyfish and Harmful Algal Blooms? We don't know yet.

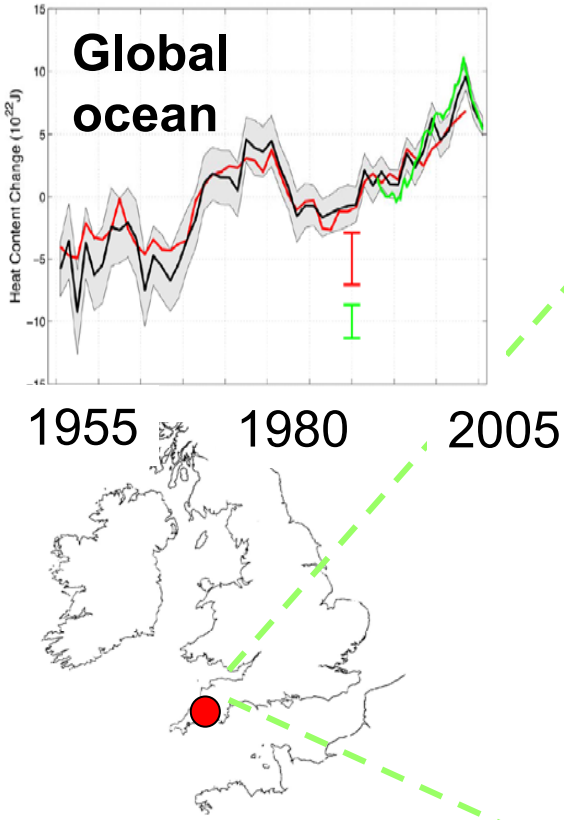


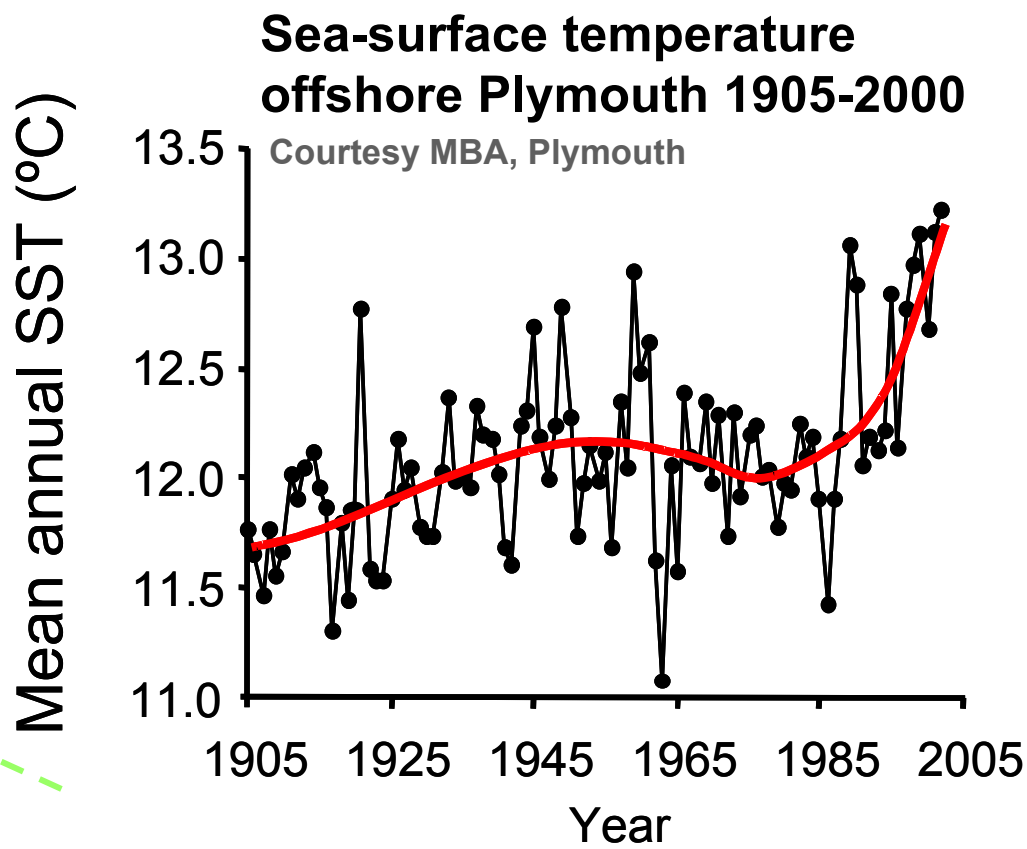
……Windows into High CO_2 Ocean

- Natural CO_2 Vents at ambient temperature (shallow and deep ocean)
- Regions with naturally gradients from low to high CO_2 e.g. Baltic Sea, Benguela upwelling, E. tropical Pacific
- These regions generally show change in biota, especially calcifiers and other CO_2 sensitive species with changing pH, erosion>calcification
- May be useful future natural laboratories

Our Oceans and Seas Are Already Warming ……

IPCC 2007





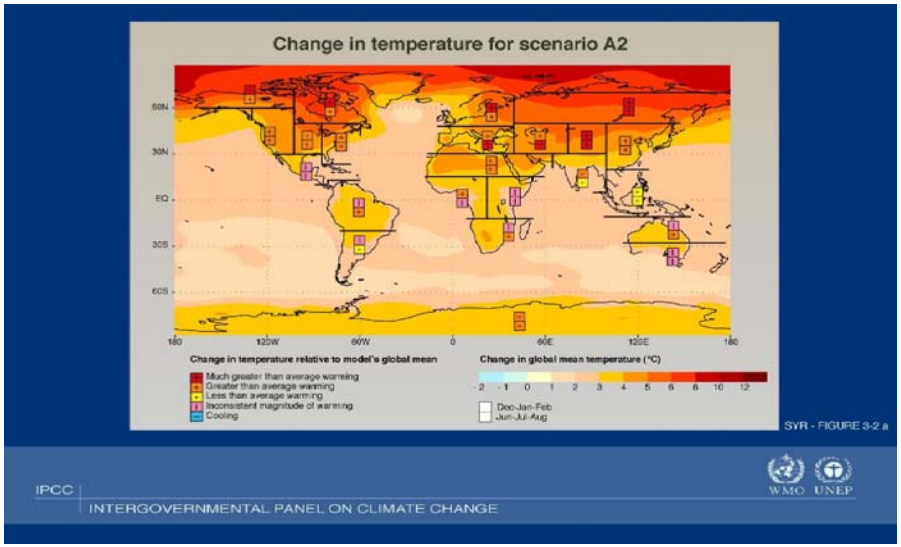
Data source: Met Office Hadley Centre
Grid square 50-51ºN, 4-5ºW

Combined Impacts of ocean Acidification and Warming of Oceans

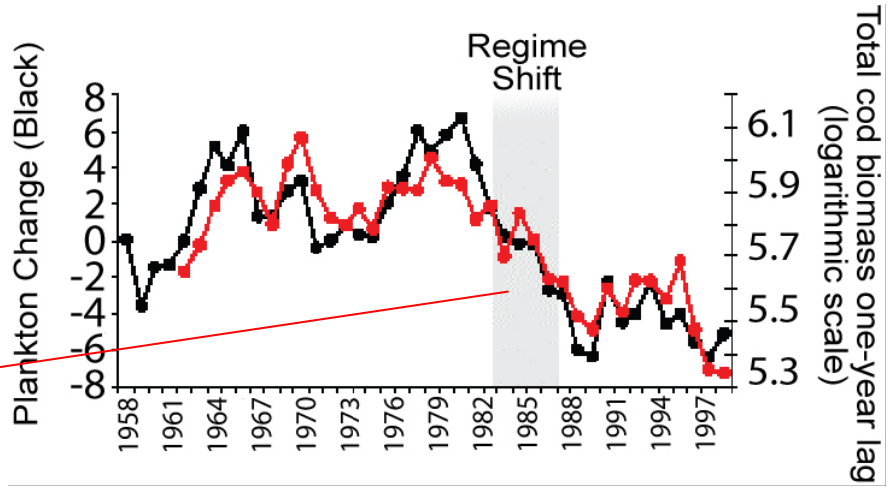
Emerging evidence of enhanced combined impact of higher temperature and higher CO_2 on:

- Pteropod calcification
- Sea urchin gonad development
- Coral reef calcification 50% slower
- Barnacles (growth and settlement)
- Temperature thresholds for animals ("thermal window") shrinks in a high CO_2 ocean e.g. thermal stress elevated at higher CO_2 in crabs

- Changes in geographic distribution of predators and prey - poleward migration: regime shifts due to warming waters



Change in annual mean surface temperature between year 2000 and 2100 based on IPCC scenario A2.



Changes in zooplankton (black line) and cod biomass (**red line**). Sir Alister Hardy Foundation for Ocean Science.

Marine Food Webs - Highly Complex

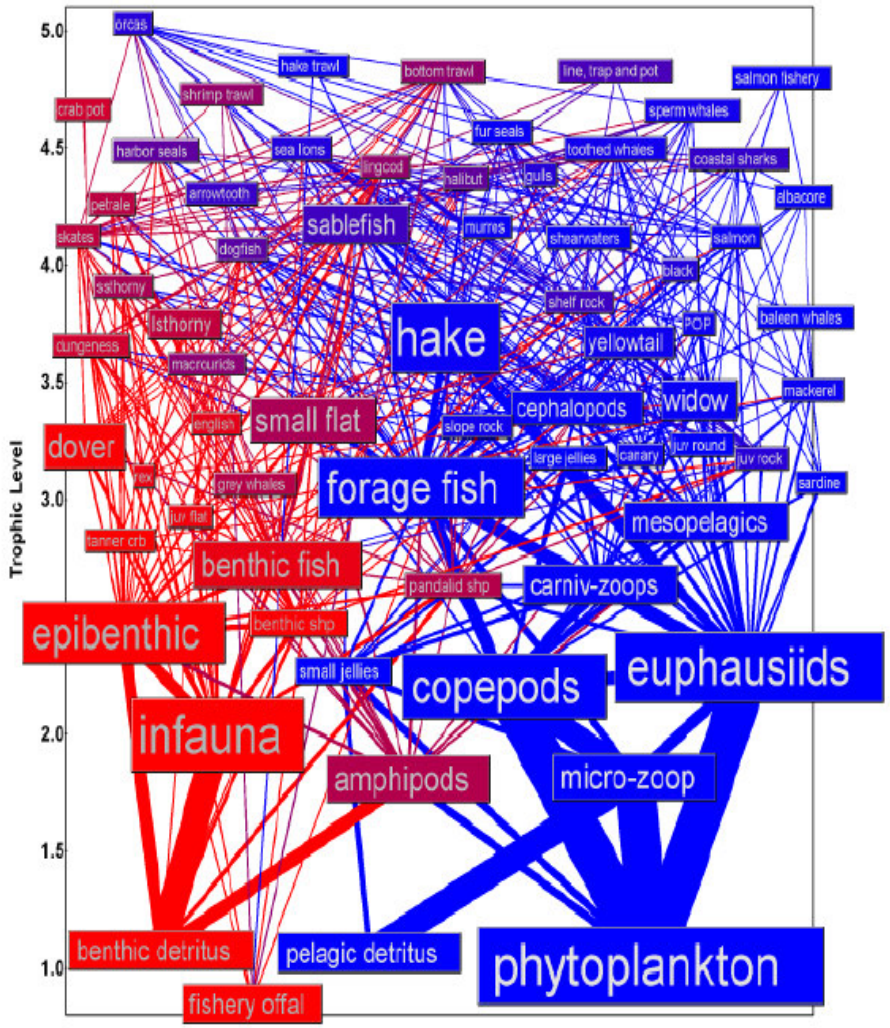
- Every species lost causes a faster unravelling of the overall ecosystem

- So impacts of ocean acidification and temperature on fisheries can be indirect

- We are likely to see changes to ecosystems but predicting what future ecosystems look like and whether they will carry out the same roles is difficult

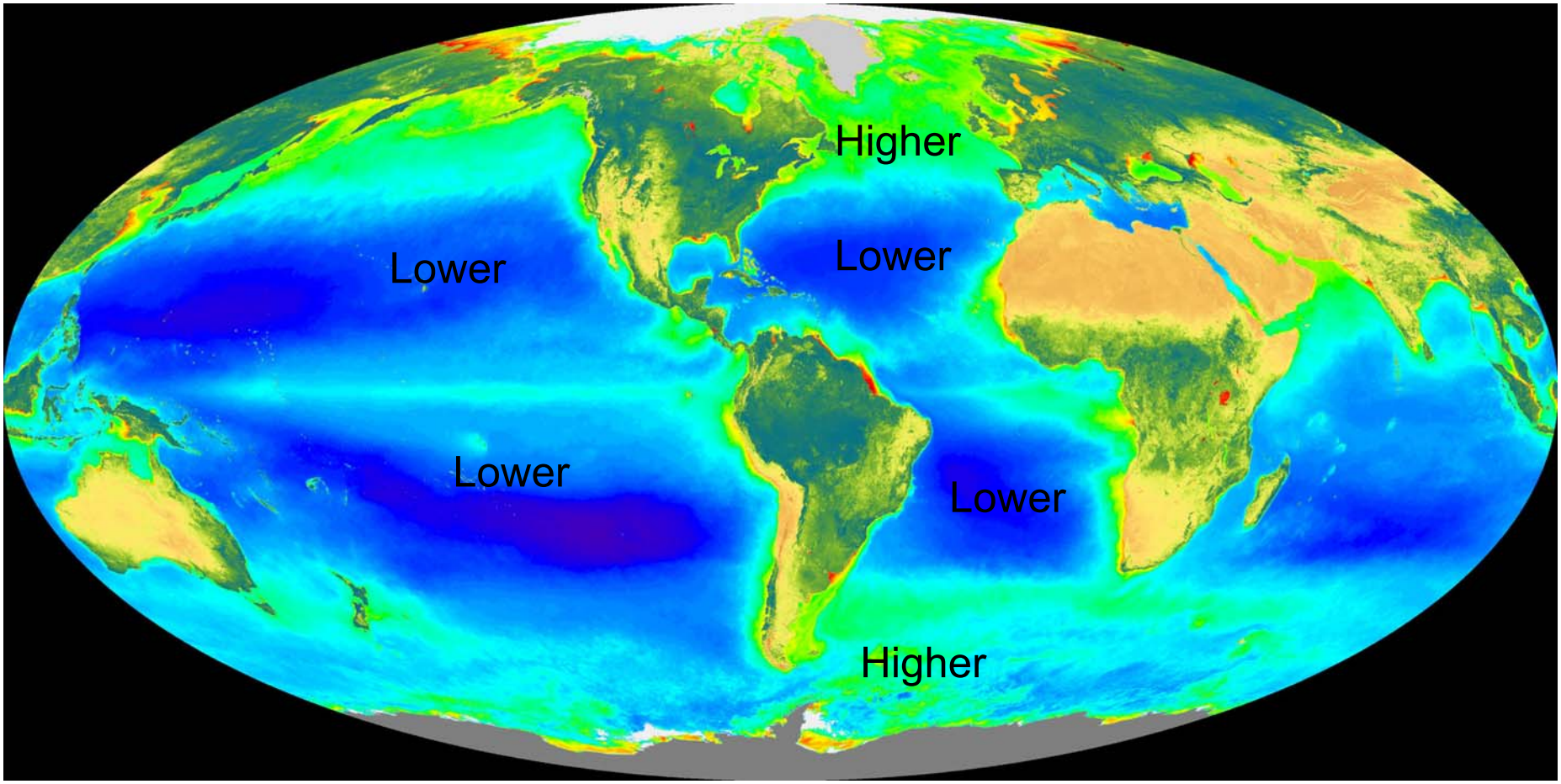
- Collapse of many fisheries associated with higher temperature (as well as over fishing)

- Ocean acidification is another stressor on already stressed fish stocks



California Current Food Web
Field and Francis 2004

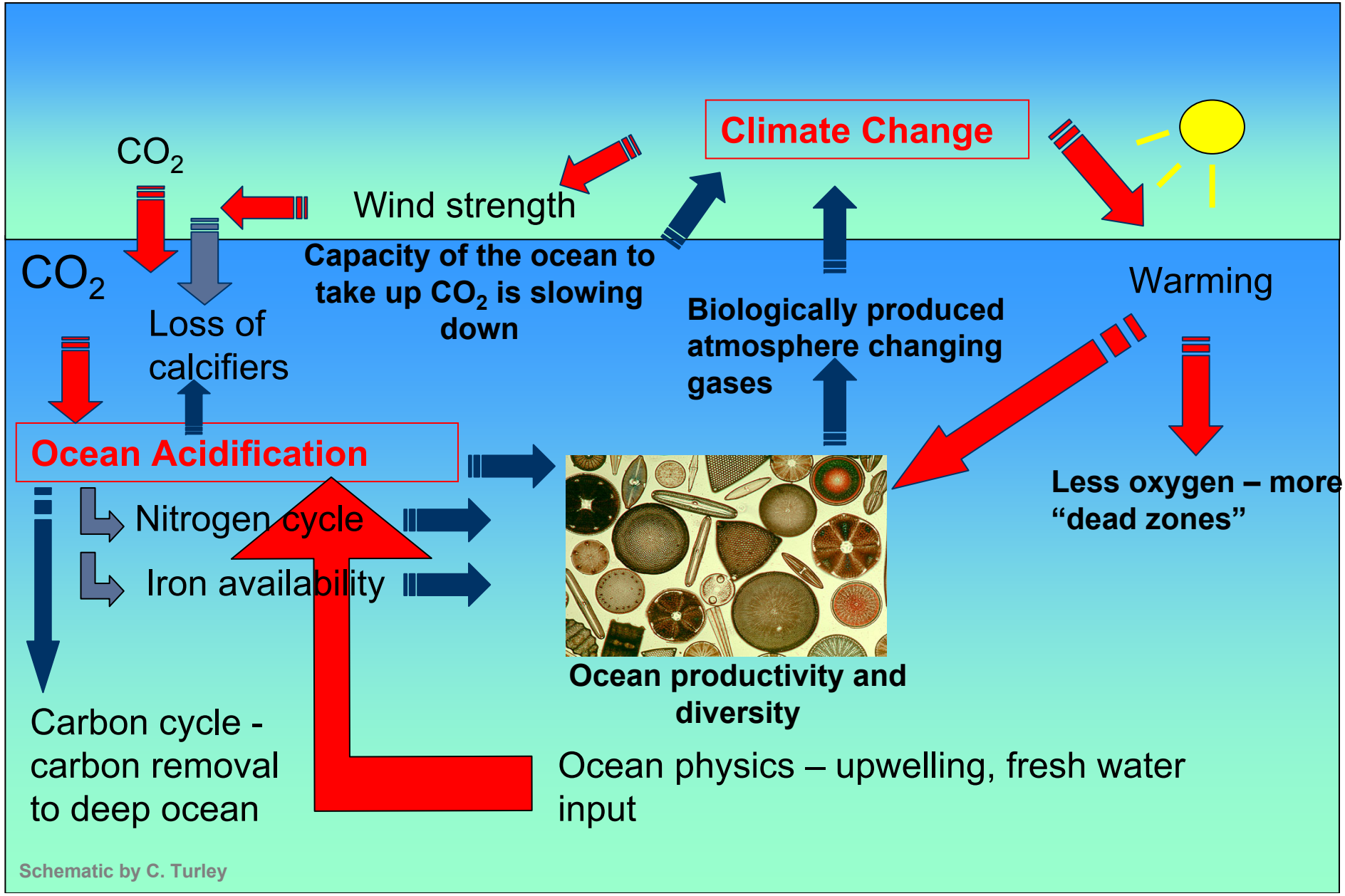
Will Ocean Productivity Increase due to Warming? Predictions are ….



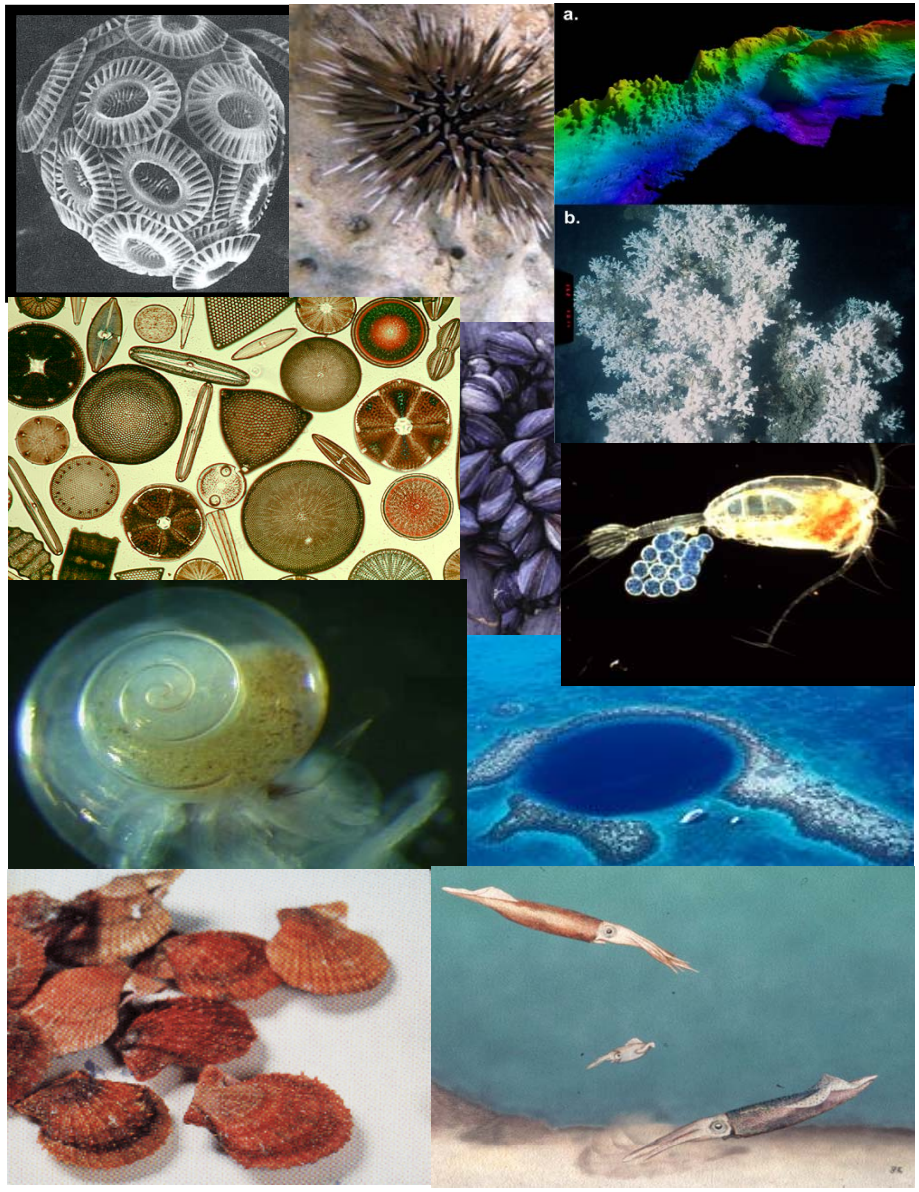
Will this be passed on to higher trophic levels?

Will this draw down more CO_2 or less?

Interactions between Ocean Acidification and Climate …….. Possible Important Feedbacks?



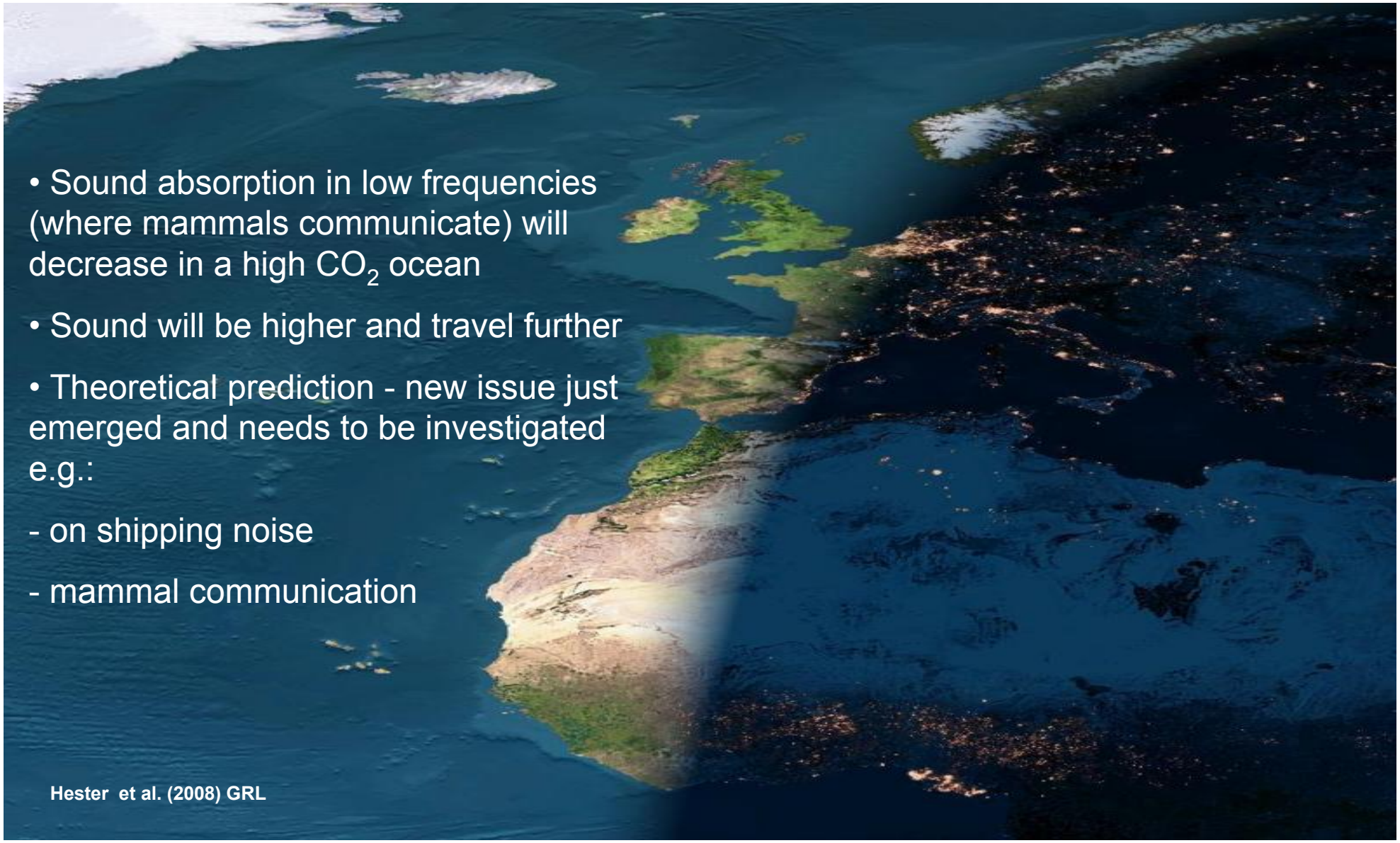
Concern for Many Marine Organisms and Ecosystems ……..



- Reduced calcification rates
- Reduced growth, production and life span of adults, juveniles & larvae
- Reduced tolerance to other environmental fluctuations
- Combined impacts of ocean acidification and warming seas
- Changes to fitness and survival
- Changes to species biogeography
- Changes to biodiversity
- Changes to food webs
- Changes to ecosystem & their services
- Changes to feedbacks between ocean acidification and climate change and vice versa
- Uncertainities great – research required

C. Turley

A Noisier Future Ocean at Low pH?



- Sound absorption in low frequencies (where mammals communicate) will decrease in a high CO_2 ocean
- Sound will be higher and travel further
- Theoretical prediction - new issue just emerged and needs to be investigated e.g.:

- on shipping noise

- mammal communication

Hester et al. (2008) GRL

Sunset Over an Ocean with Man's Footprint Now Detectable – Warmer, More Acidic, Less Diverse and Over Exploited

Oceans will become more acidic – very high certainty.

The Oceans are sick and it could be serious. It needs our help!

The only way of reducing the impact of global ocean acidification is a substantial and urgent reduction in CO_2 emissions – very high certainty.

Mitigation will make a difference – ocean acidification argues for stabilizing CO_2 *lower* than 450 ppm

C. Turley