Use of natural marine CO_2 gradients to evaluate the effects of ocean acidification

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1. Five examples of marine areas with high pCO_2, low Ω and low pH
2. Data on ecosystem responses in areas with high pCO_2, low Ω and low pH
3. Certainties and limitations

Over the past few years many studies in aquaria and mesocosms have revealed the mechanisms by which acidification affects growth, reproduction, embryo development, physiology, immunology and species interactions.

BUT

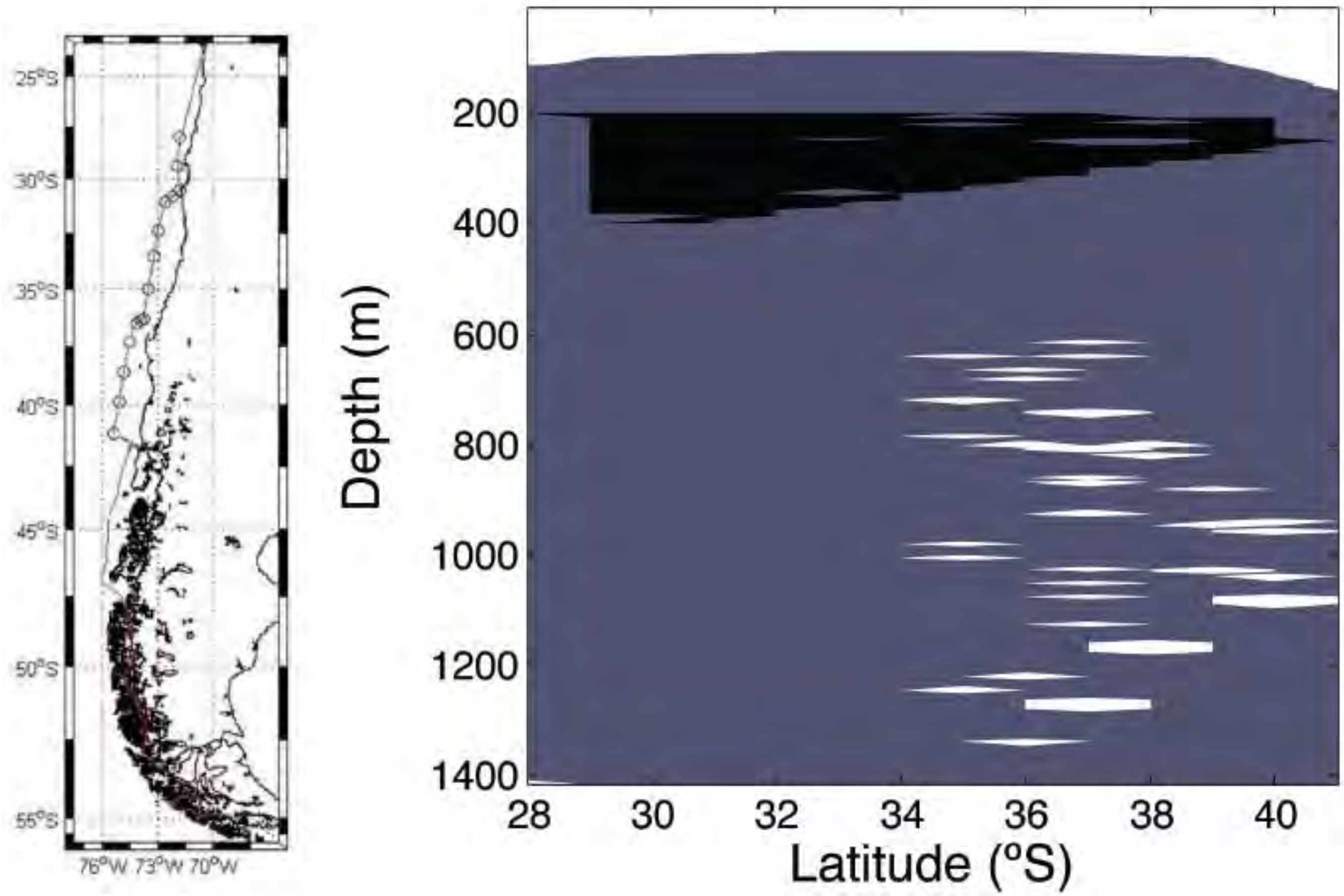
It is difficult to scale-up from these studies as we can not imitate ocean acidification conditions *in situ* for sufficient periods to affect whole marine communities

Solution..

Areas with naturally high CO_2 may help show ecosystem responses to ocean acidification.

I'll show 5 examples

There are steep natural gradients in carbonate chemistry with depth



Measurements off Chile indicate areas where aerobic respiration and biocalcification (Ω <2) are compromised by high CO_2 and low O_2 levels (in black). White area = no compromises, blue area biocalcification compromised.

Mayol et al. 2010 BGD 7, 8895-8918

There are also steep natural gradients in seawater carbonate chemistry between biogeographic areas e.g. between ocean basins, in upwelling areas, in coastal seas and at the poles. These natural gradients are starting to be used to investigate biological responses to increasing CO_2 levels.

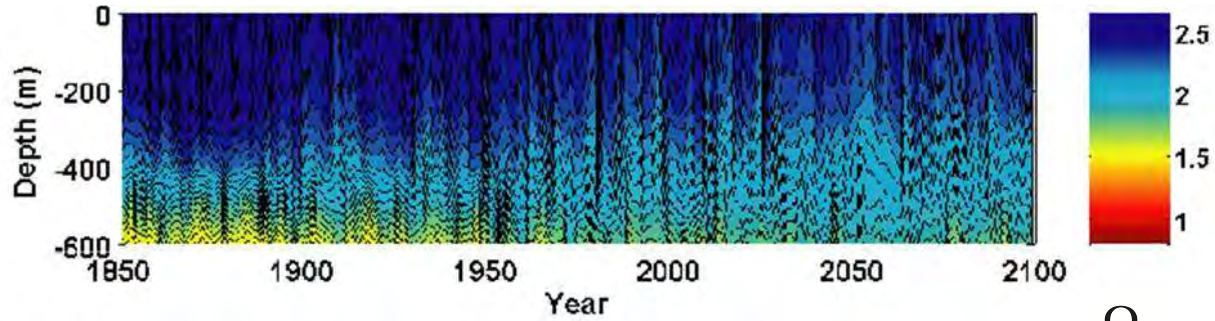
- The aragonite saturation horizon is shoaling rapidly
- Polar waters absorb more CO_2 and have lower carbonate levels than warm waters
- Models predict that aragonitic deep sea corals are at risk

Guinotte & Fabry 2008 Ann NY Acad Sci; Tittensor et al. 2010 Mar Ecol

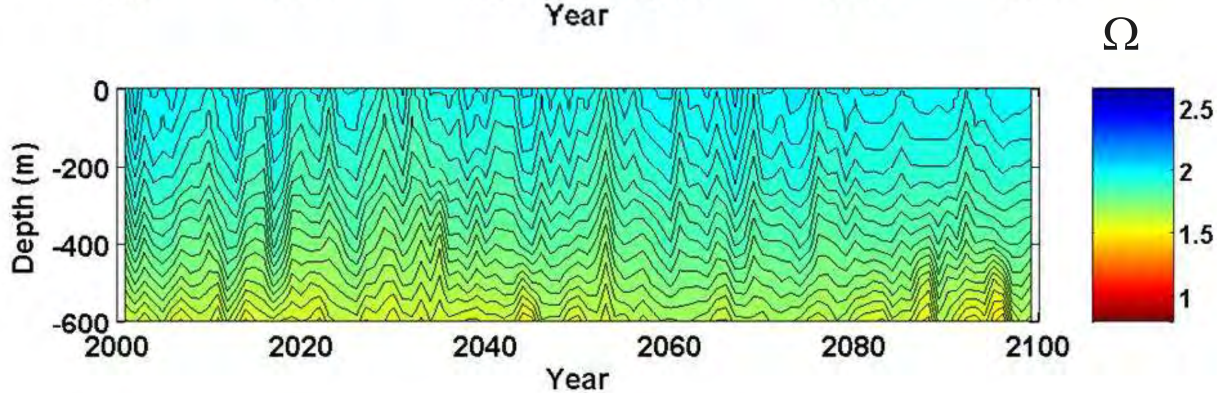
Example 1 Models show that Rost reef has already been exposed to a large shift in carbonate chemistry

Ω_{Arag} at Røst Reef

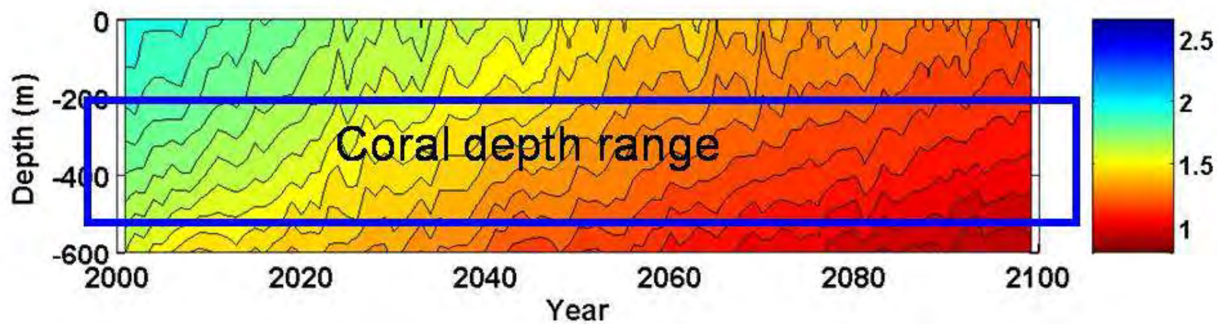
Preindustrial - no anthropogenic carbon release



Atmospheric CO_2 at year 2000 levels: we are already out of the natural state



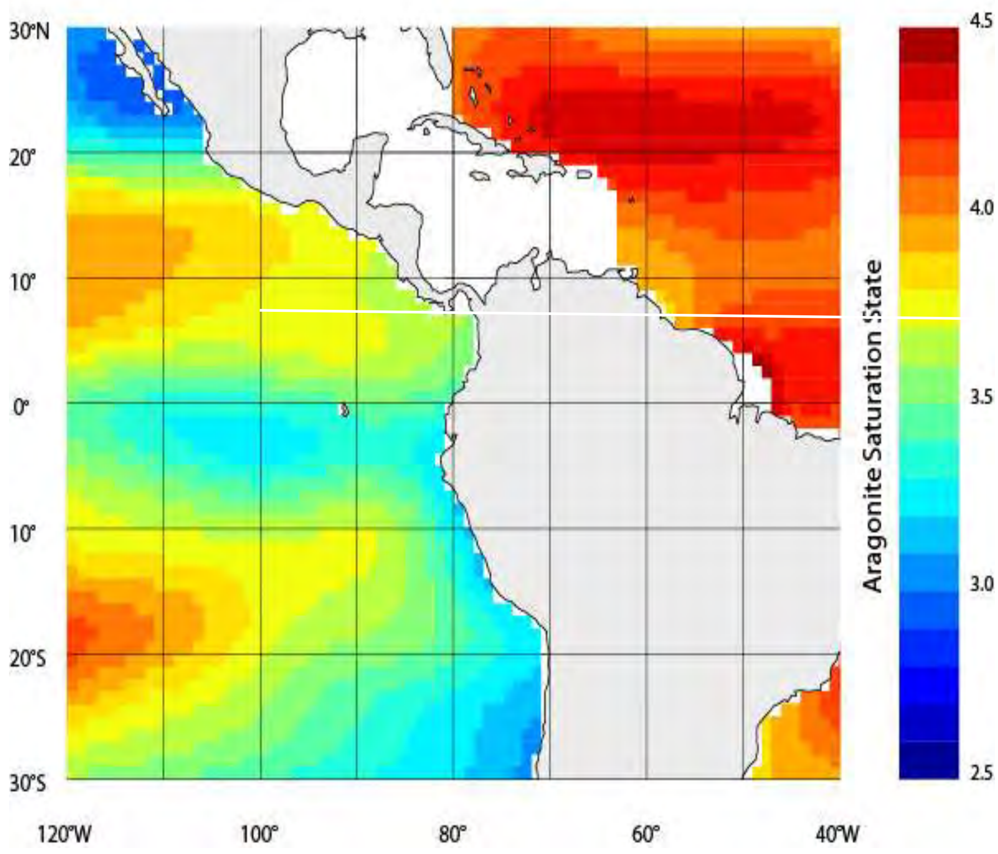
Atmospheric CO_2 to increase by $1\%.yr^{-1}$ until 2100



Bjerknes Centre for Climate Research

Bellerby in prep

Example 2: use of differences in surface water carbonate chemistry between basins. Eastern Pacific reefs show what coral reef growth is like in low Ω, high-CO_2 seawater.

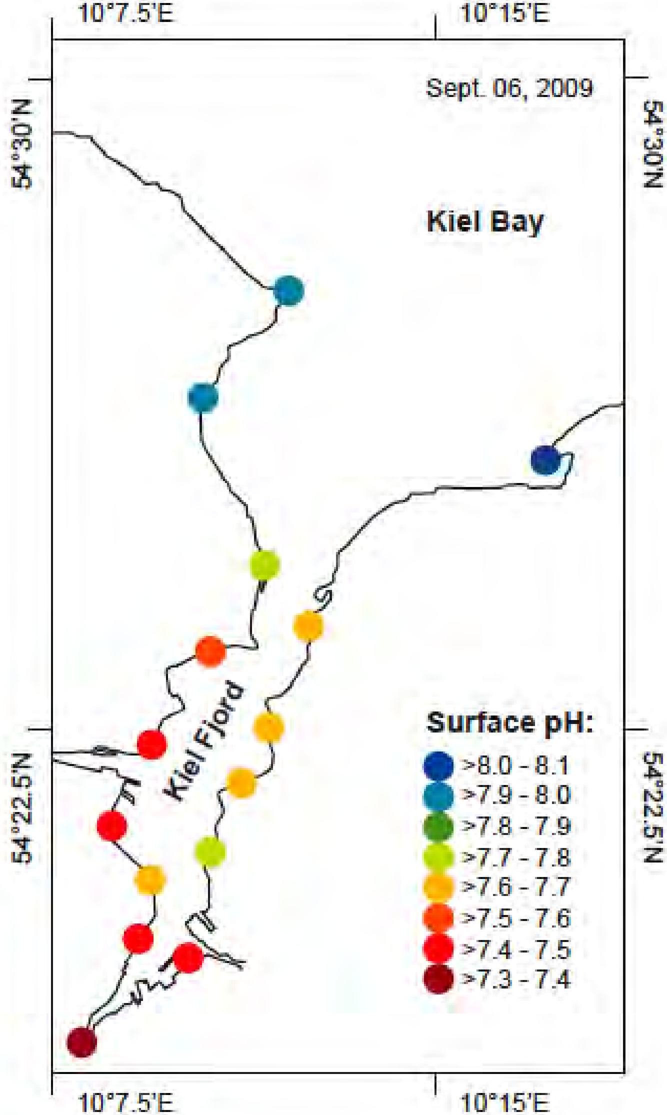


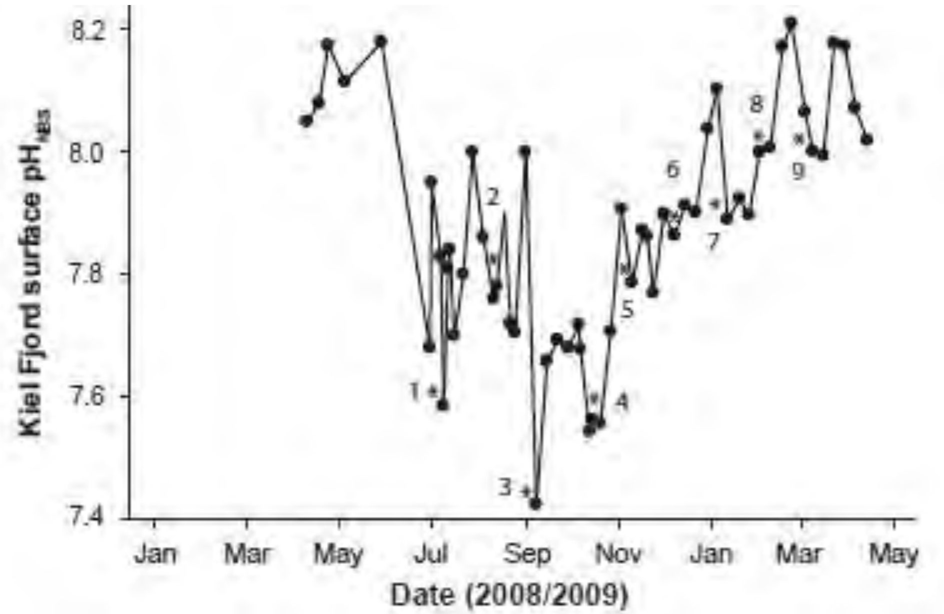
High Ω
high cementation
low bioerosion

Low Ω
no cementation
high bioerosion

Manzello 2008 *PNAS*

Example 3: use of seasonal pH variability
In this case due to upwelling of high CO_2 water





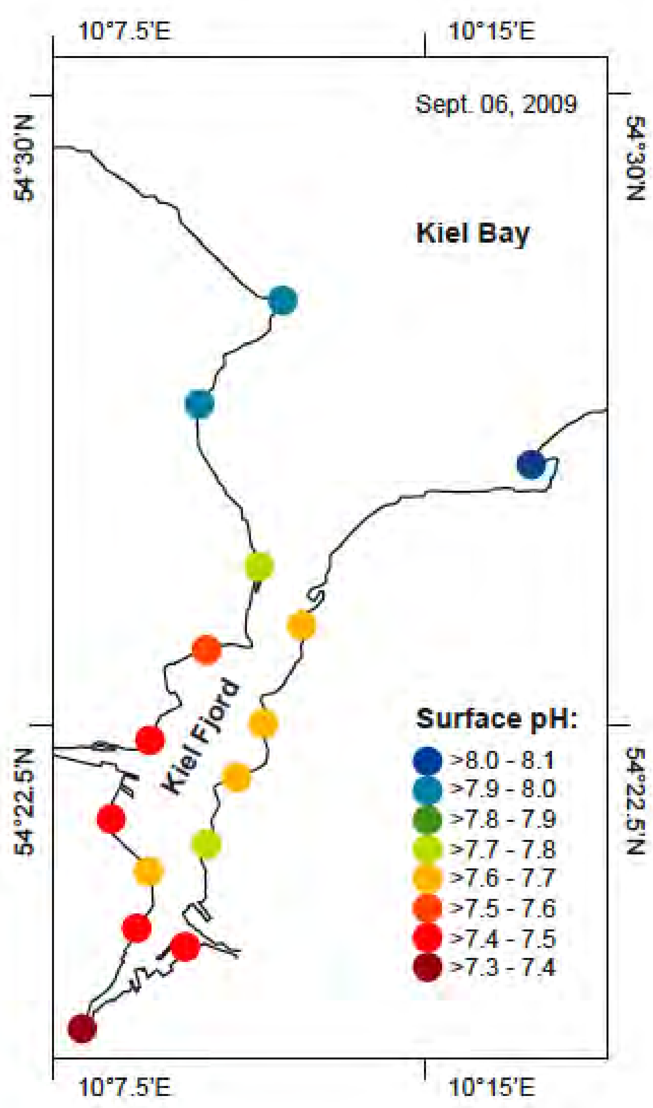
Upwelling in summer and autumn

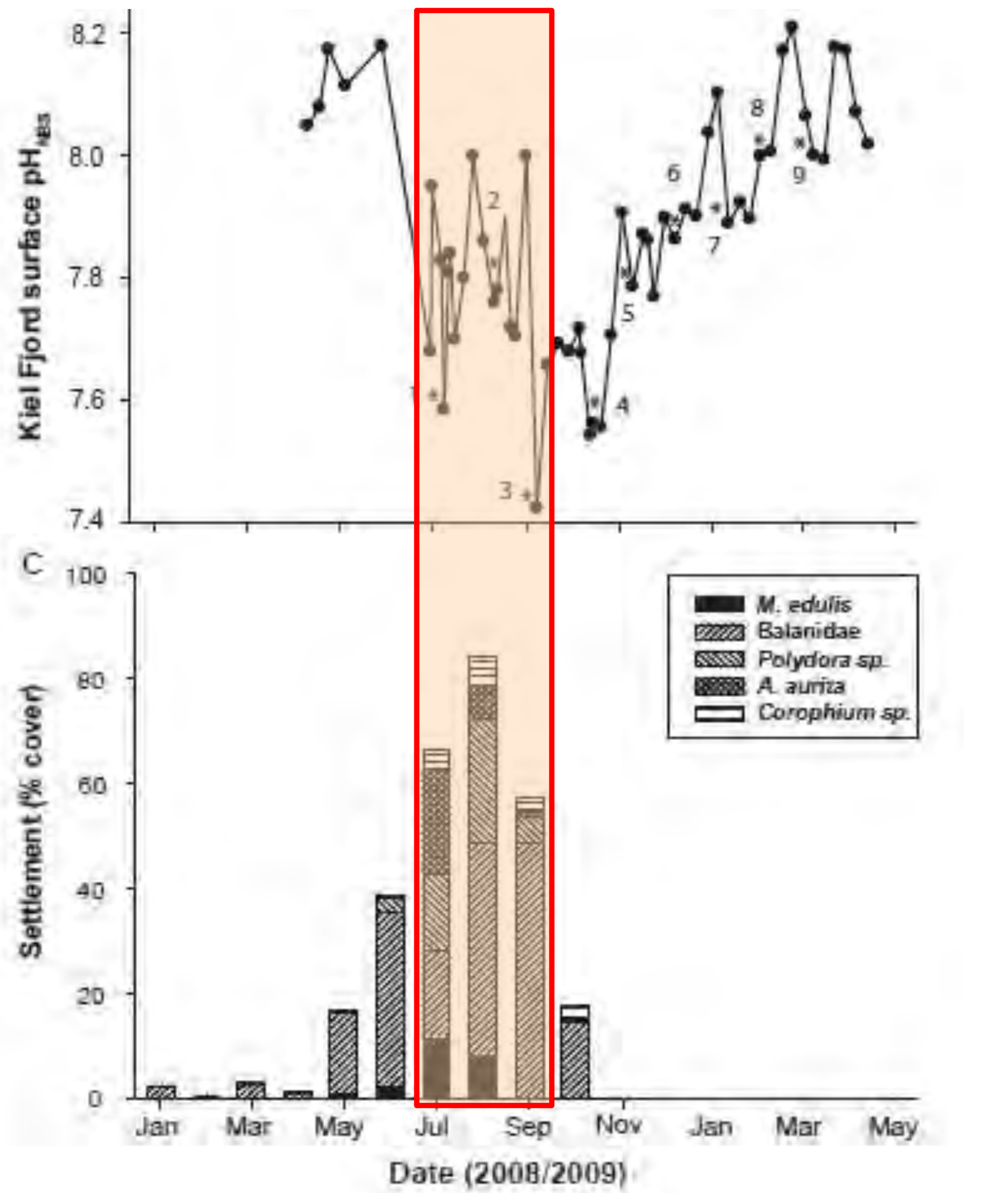
Average pCO_2 in 2008/2009 ~ 700 µatm
Average pCO_2 July-August ~ 1000 µatm
Maximum pCO_2 >2000 µatm

NB also a gradient along the estuary

Thomsen et al. 2010 BGD

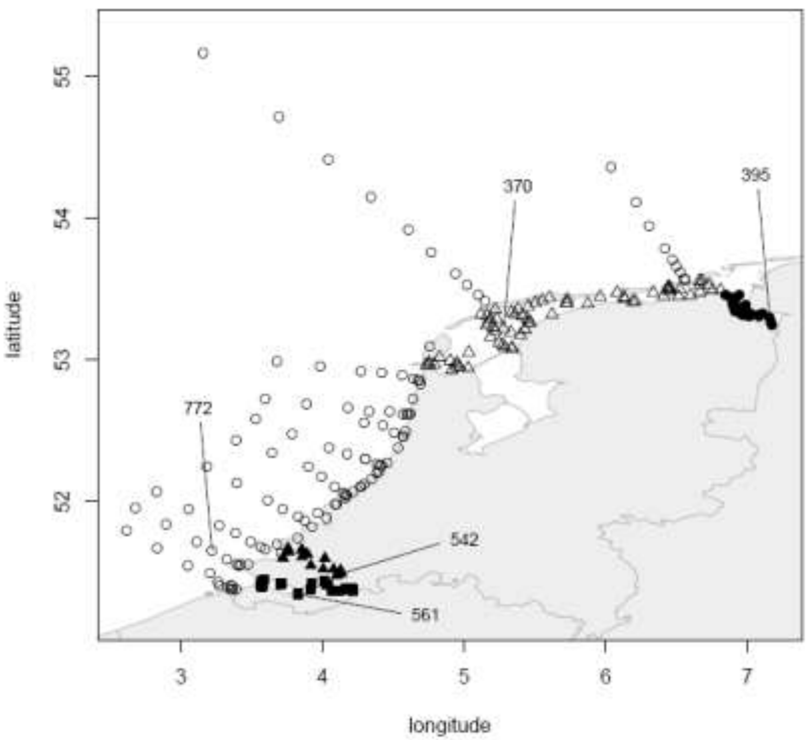
Calcification and settlement of calcifiers continues despite high CO_2 levels. Submitted work relates this to food intake – well fed animals can calcify despite low Ω levels.

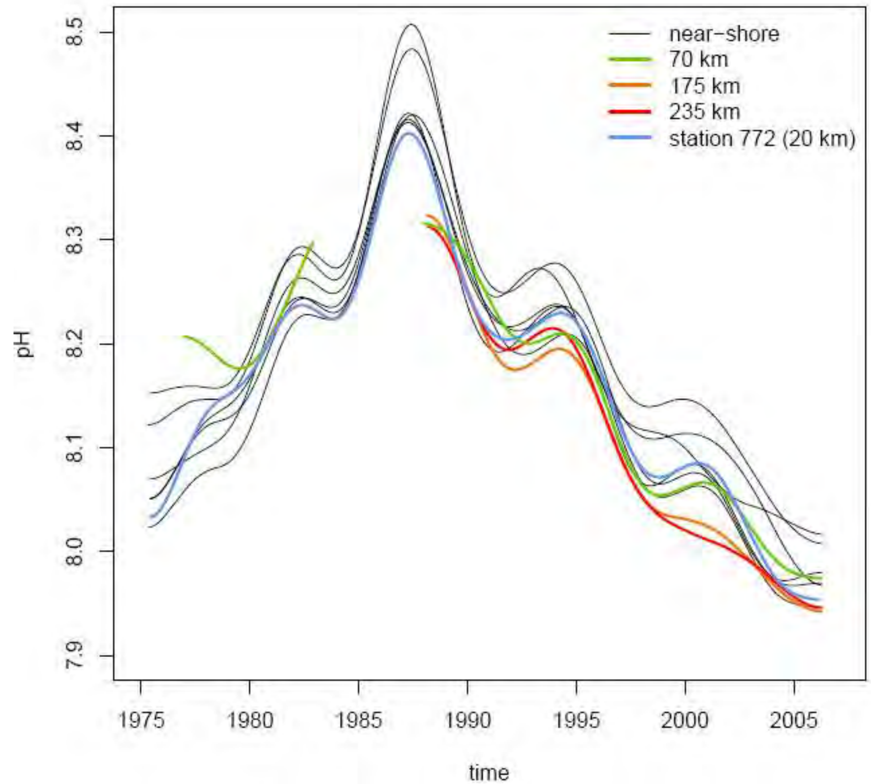




Example 4

In some places the pH of coastal waters is falling faster than predicted globally



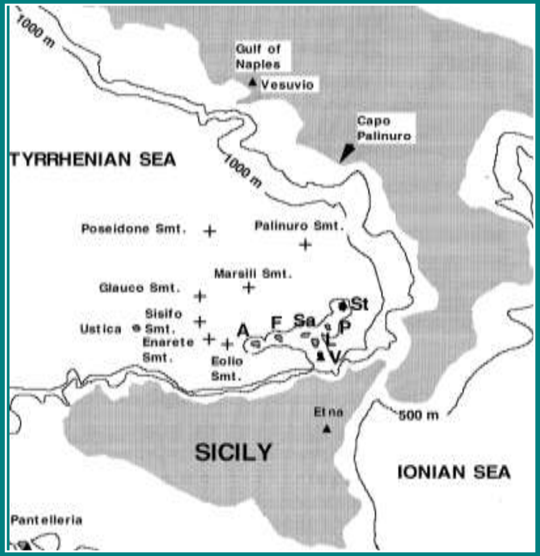


Long term fluctuation in pH off the Dutch coast – Provoost et al. (2010 Biogeosciences) think it was rising due to greater phytoplankton growth caused by eutrophication and is now falling rapidly due to lower nutrient inputs thanks to river catchment clean-up policies

Example 5: use of gradients in CO_2 levels caused by volcanoes

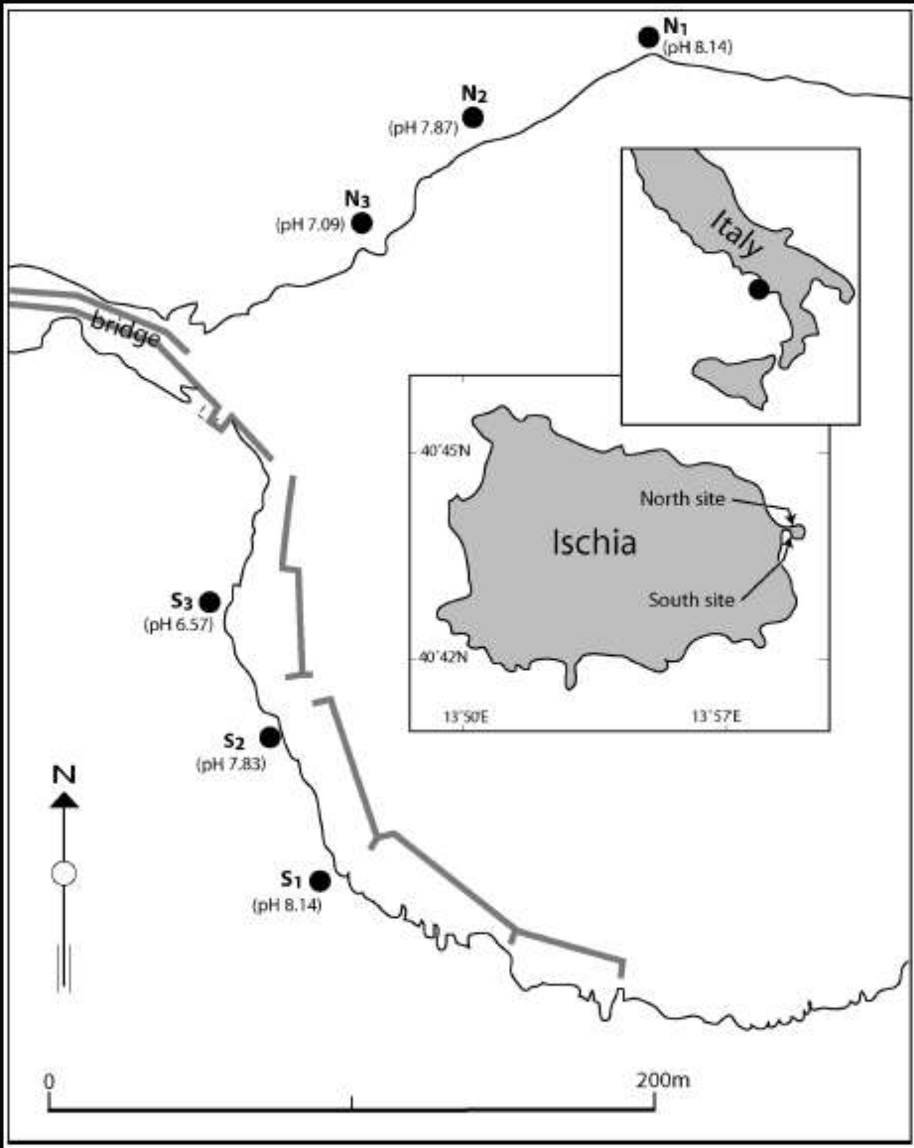
European volcanoes are of global significance in geological CO_2 flux…..*ca* 10^8 kg d^{-1}

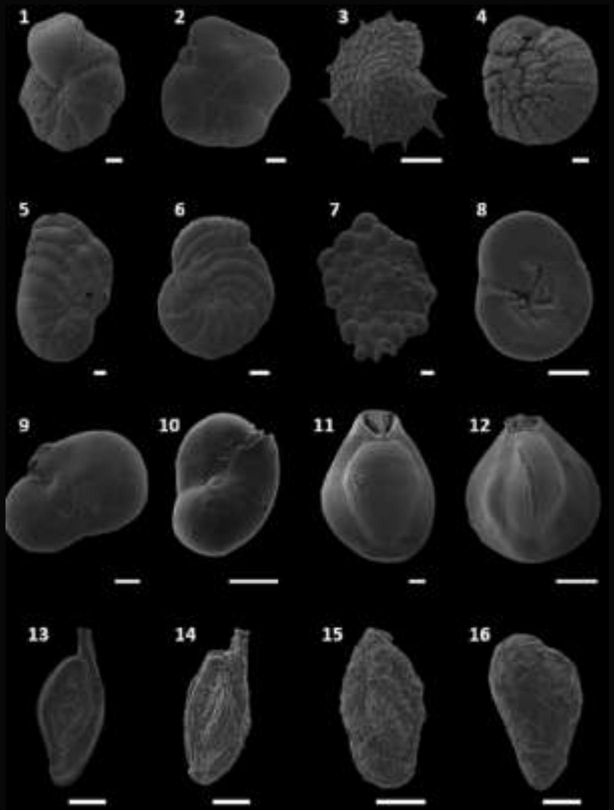
Etna alone produces 10% of annual global flux from sub-aerial volcanoes.



Only a few vent systems are well suited to OA studies as most have confounding gradients in temperarture, total alkalinity and toxic chemicals such as H_2S

Sediment has significant reductions in foraminiferan diversity along CO_2 gradients





Dias B et al. 2010 J Geol Soc Lond

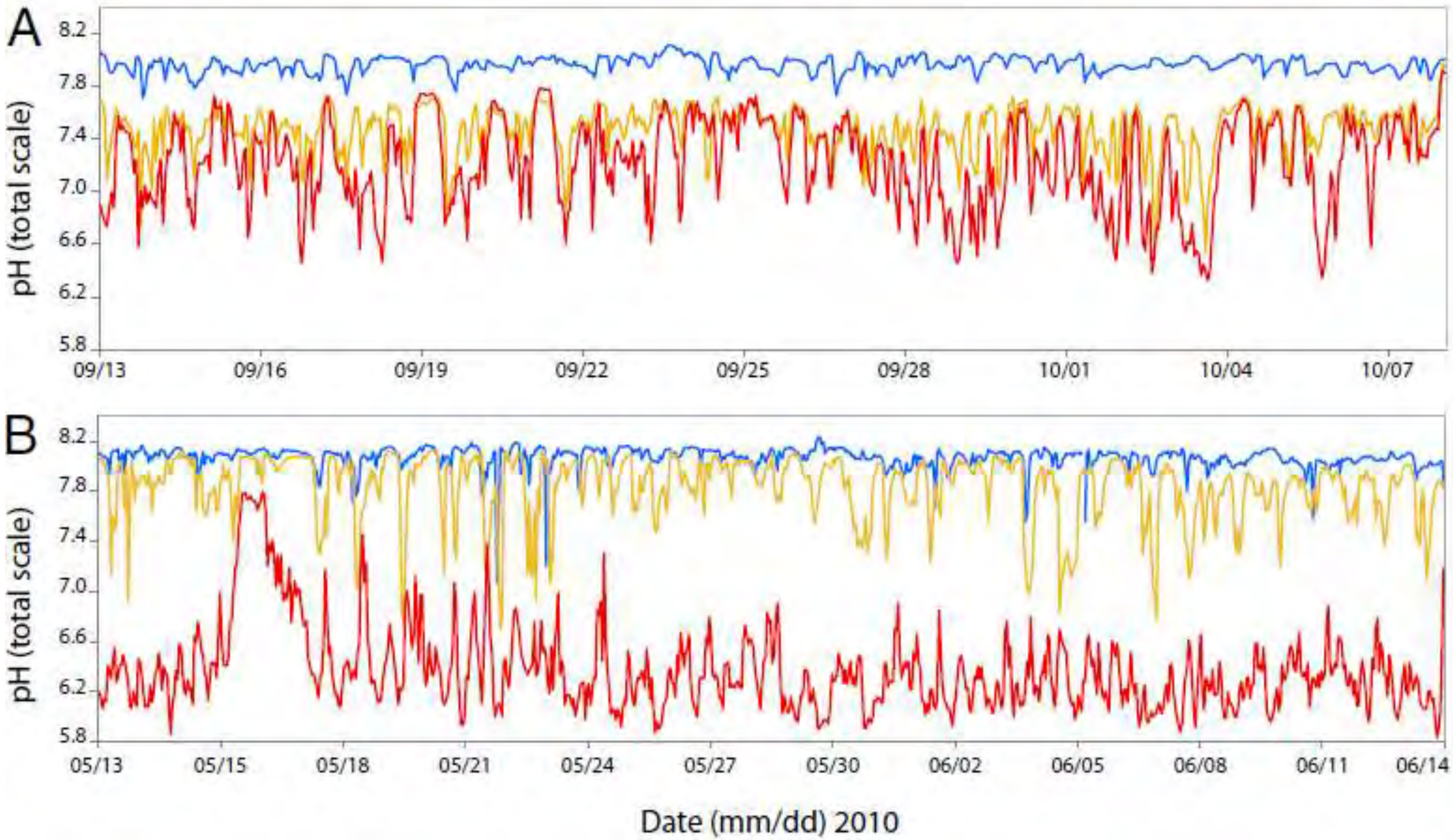
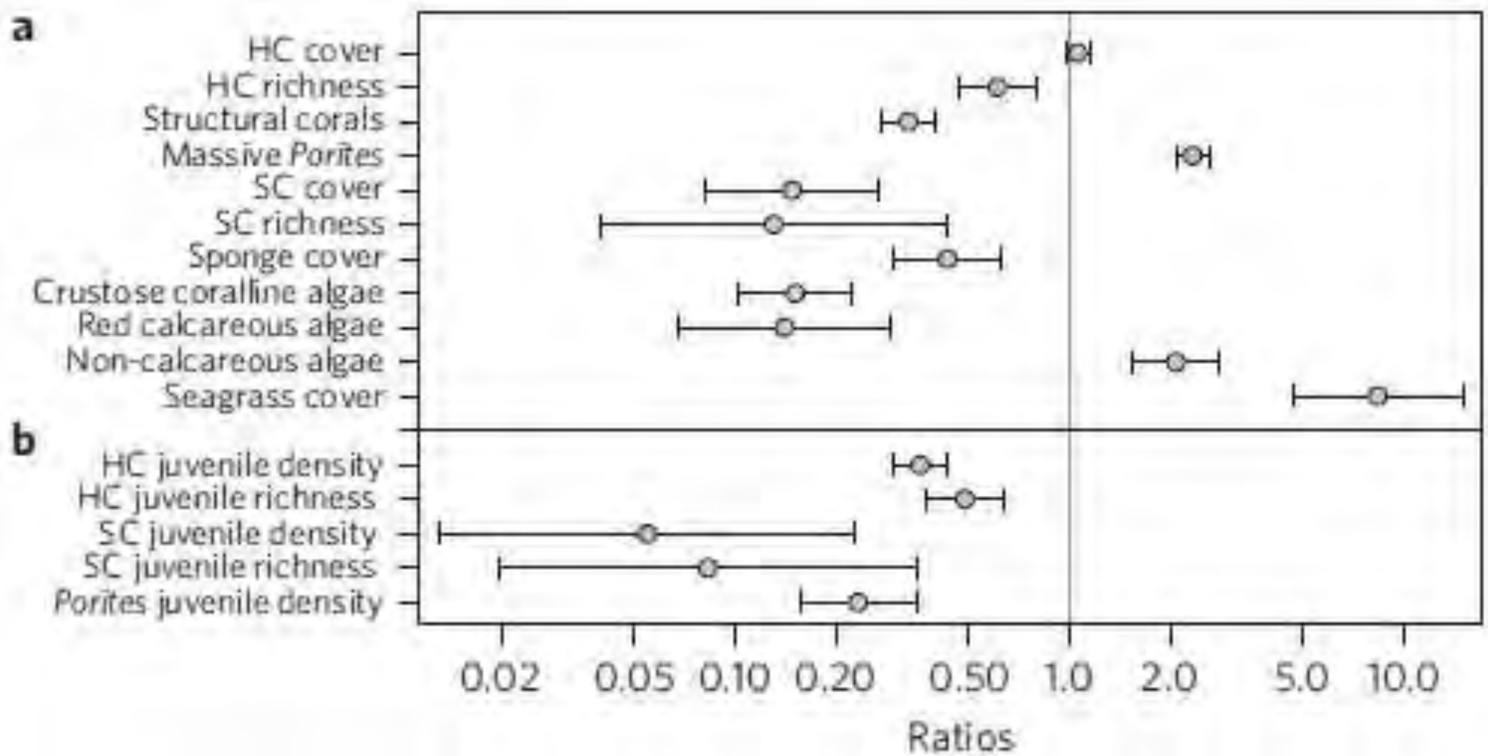


Fig. 1. Representative time series of hourly seawater pH_T values for (*A*) northern and (*B*) southern sites at Castello Aragonese d'Ischia in the ambient (blue), low (yellow), and extreme low (red) pH zones. Time series for (*A*) the northern site is from September 13 to October 8, 2010, and time series for (*B*) the southern site is from May 12 to June 14, 2010.

Kroeker et al. 2011 PNAS

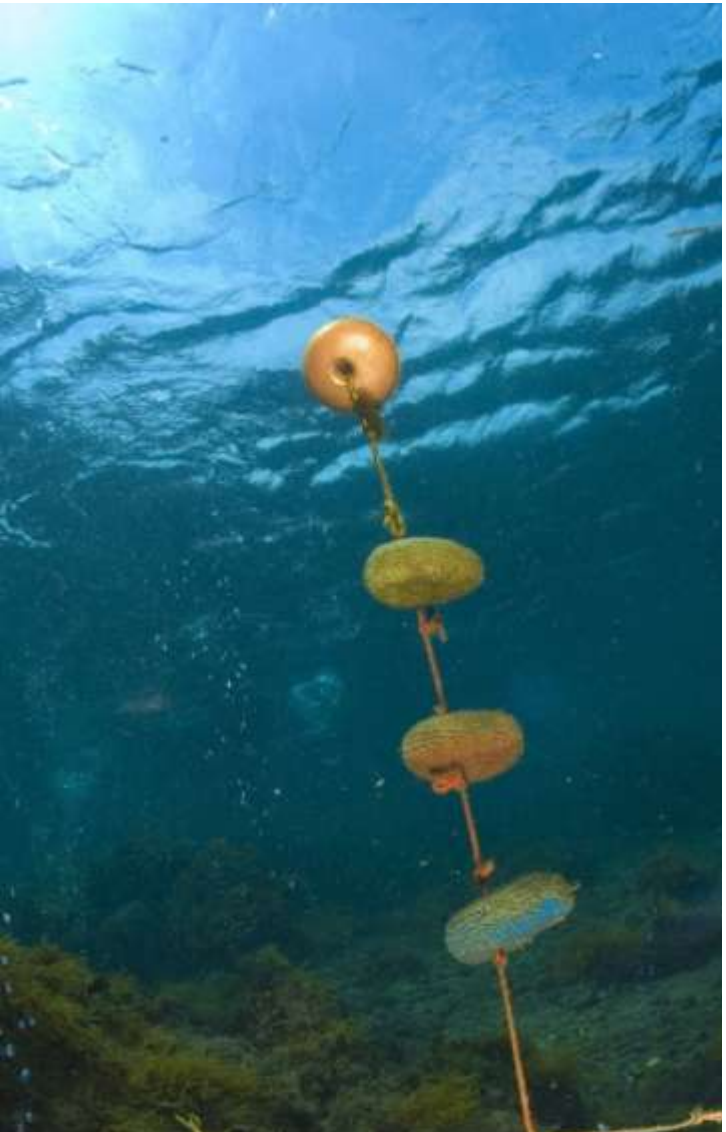
Inside the vents, almost no calcifiers, fleshy algae and invasive species dominate

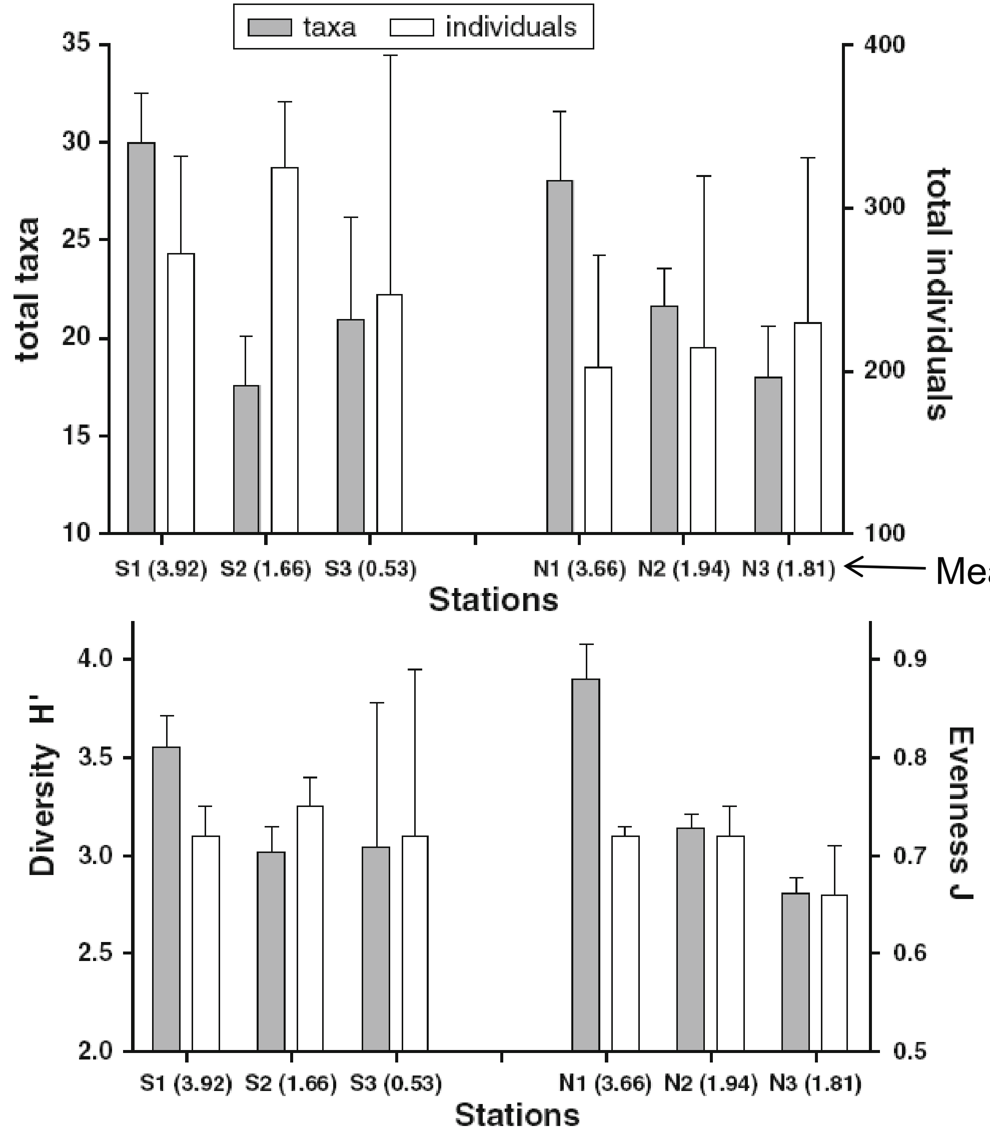
250 taxa now examined including macroalgae (Porzio et al. 2011, JEMBE) , seagrasses, foraminifera, sponges, nematodes, polychaetes, molluscs, crustaceans, chaetognaths, bryozoans.



Fabricius et al.
2011 Nature
Climate Change

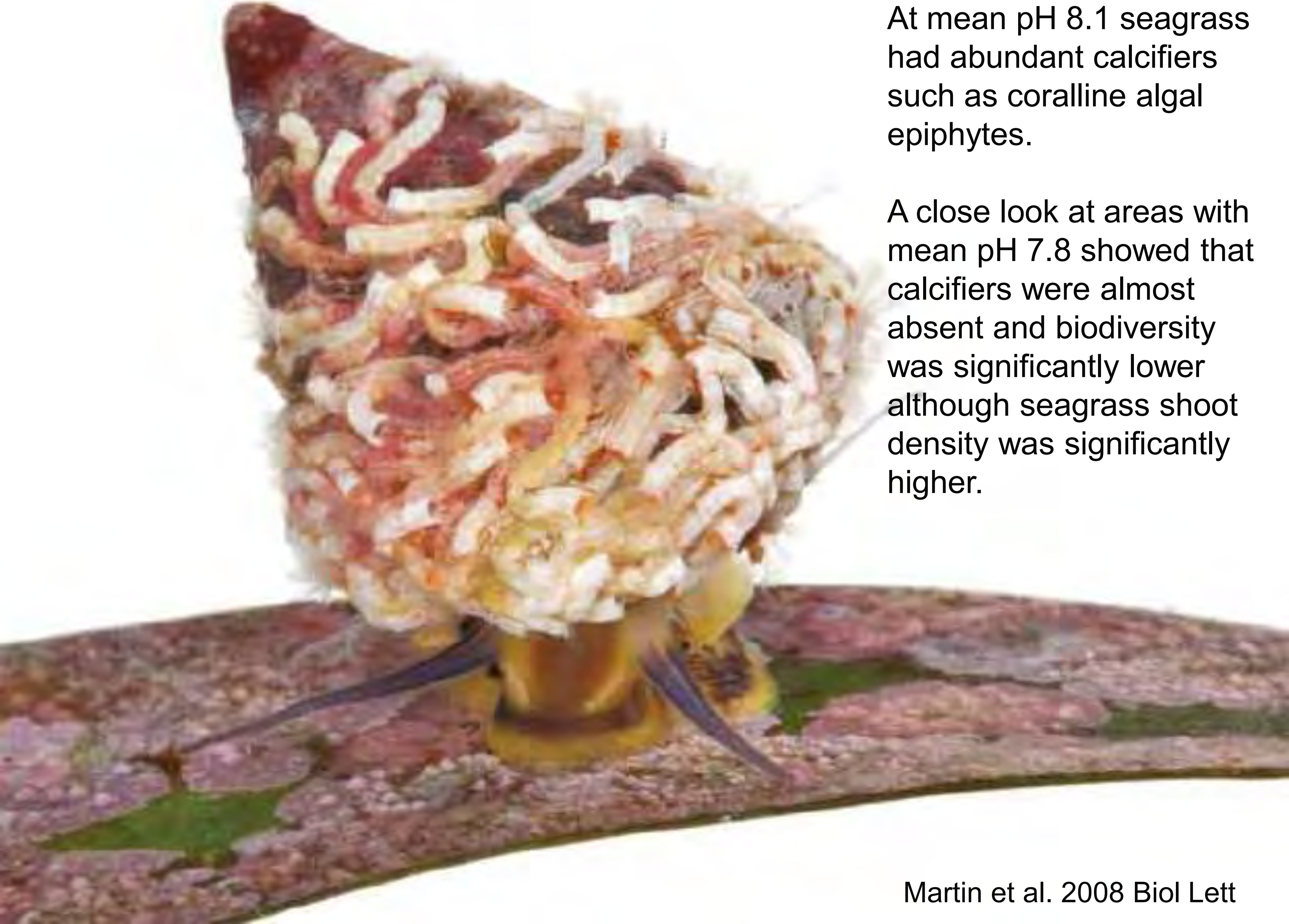
Colonization experiments show increased CO_2 levels have major effects on invertebrate recruitment





Mean Ω arag

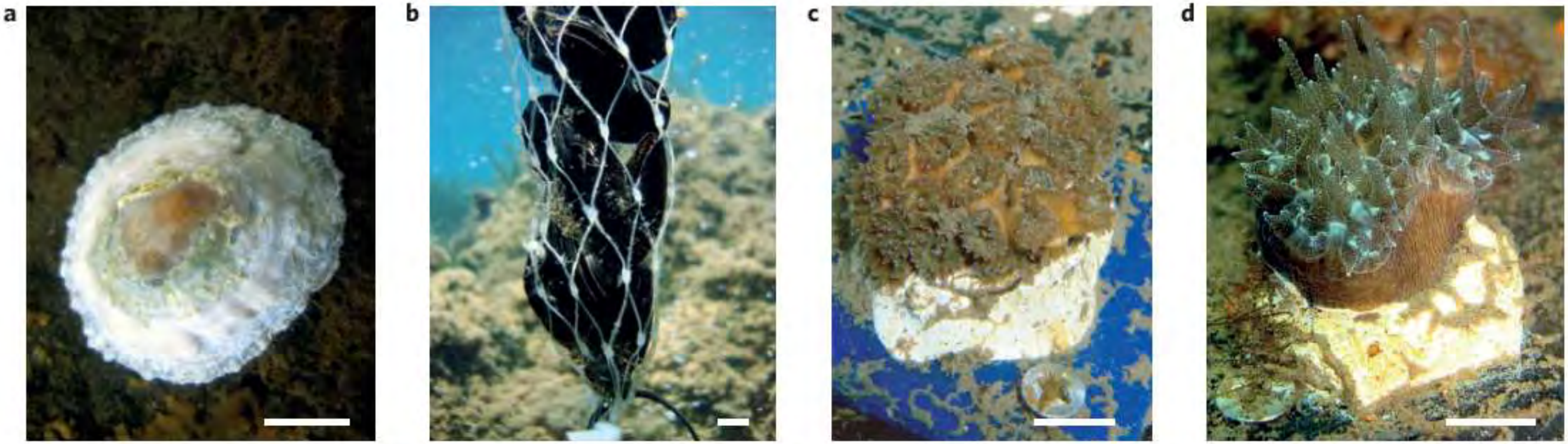
Cigliano et al. (2010) *Marine Biology*



At mean pH 8.1 seagrass had abundant calcifiers such as coralline algal epiphytes.

A close look at areas with mean pH 7.8 showed that calcifiers were almost absent and biodiversity was significantly lower although seagrass shoot density was significantly higher.

Martin et al. 2008 Biol Lett



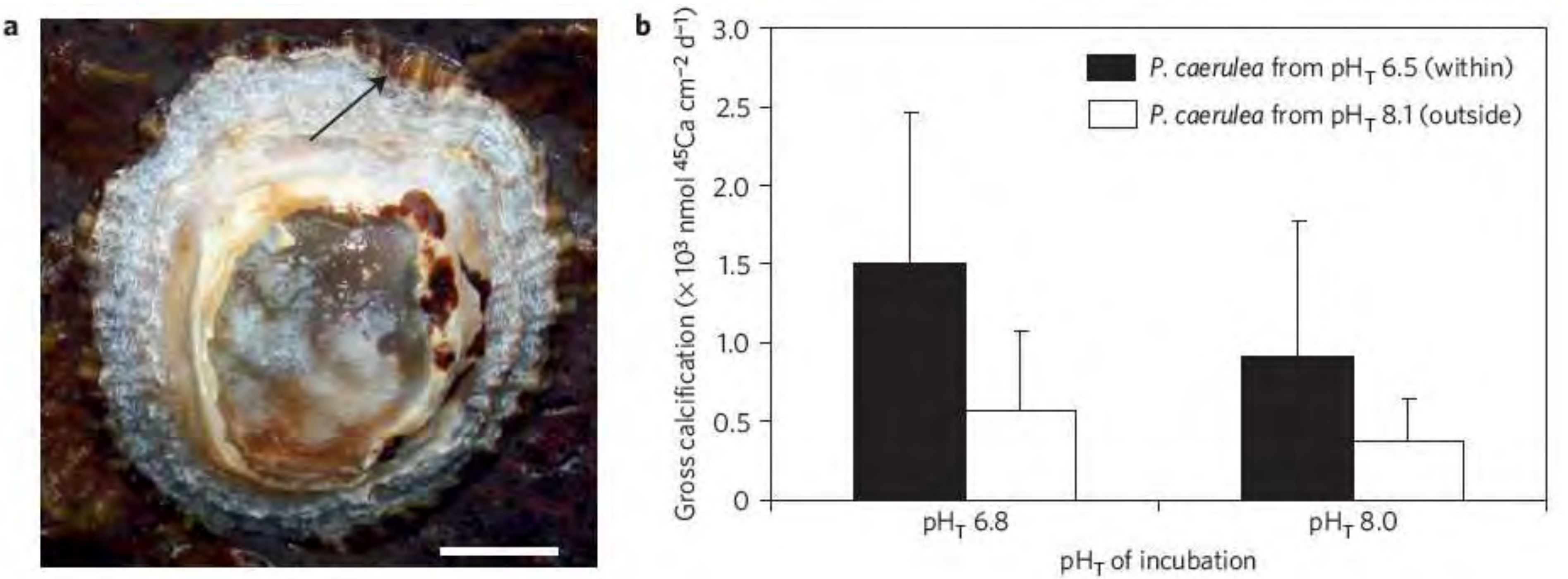
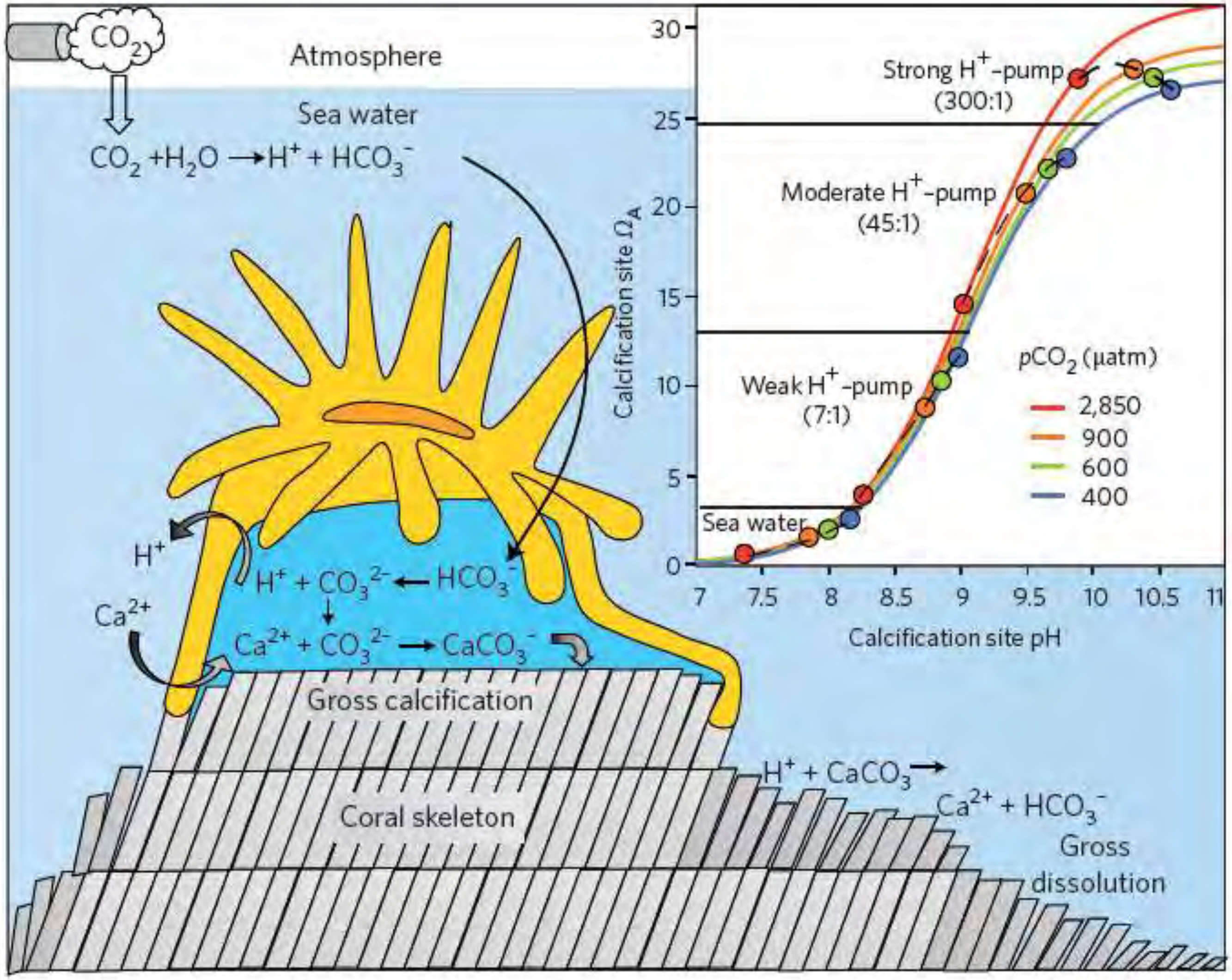
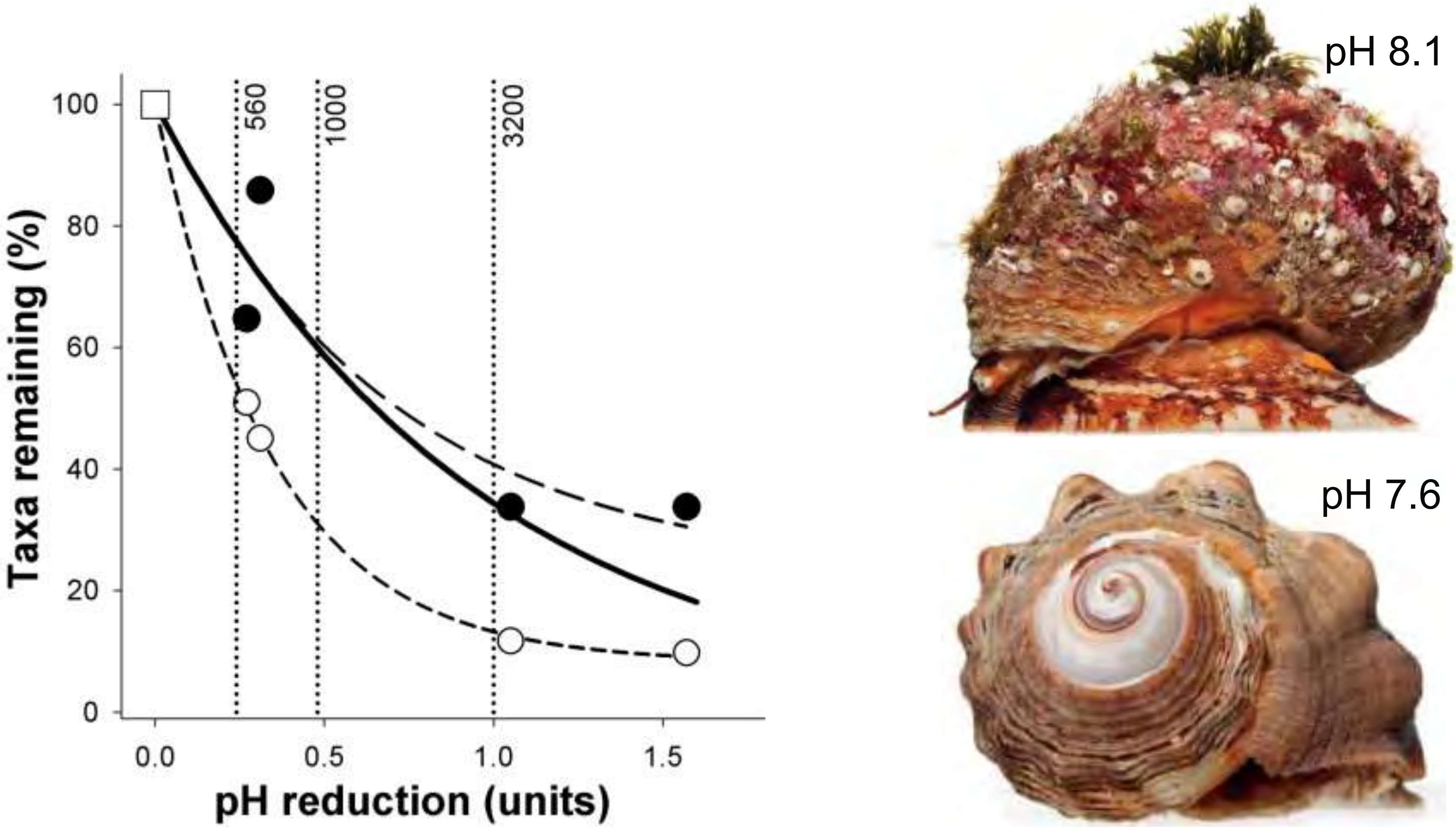


Figure 3 | Calcification of *P. caerulea* measured in aquaria at pH_T 6.8 and 8.0. a, Limpets collected at mean pH_T 6.6 and transplanted at the same pH. The arrow shows new brown shell secreted one week after transplantation. Scale bar = 1 cm. **b**, Gross calcification of *P. caerulea* collected within and outside volcanic CO_2 vents and incubated in aquaria with ^{45}Ca-labelled sea water both at pH_T 6.8 and 8.0 (Supplementary Tables S2c and S3). Data are means ± s.d. ($n = 14$).



Gross rate of calcification for strong H+ pumping corals could increase under increased CO2 levels via bicarbonate utilization. This increase is offset on a net basis by increased dissolution of unprotected skeleton. See Rodolfo-Metalpa et al. (2011) Nature Climate Change & Ries (2011) Nature Climate Change



% taxa that occur in areas with no pH reduction (open square) for calcifiers (51 taxa, white circles) and non-calcifiers (71 taxa, black circles). Vertical lines show atmospheric ppm CO_2 required to cause pH changes observed along the pH gradients. Photographs of molluscs collected at mean pH 8.1 and mean pH 7.6 showing reduced biodiversity and shell dissolution in the acidified area.

In summary - naturally high CO_2 areas

- integrate the long-term effects of ocean acidification
- can test models and scale-up lab. and mesocosm experiments
- identify 'winners' e.g. seagrass and invasive algae
- show under what conditions major ecological tipping points occur along gradients of increasing CO_2 levels
- Can be used to investigate the combined effects of ocean acidification with other common stressors (e.g. low oxygen & warming)
- I hope we can save time, money and effort by engaging with the fresh water 'acid rain' ecologists

Marine Institute
UNIVERSITY OF PLYMOUTH

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