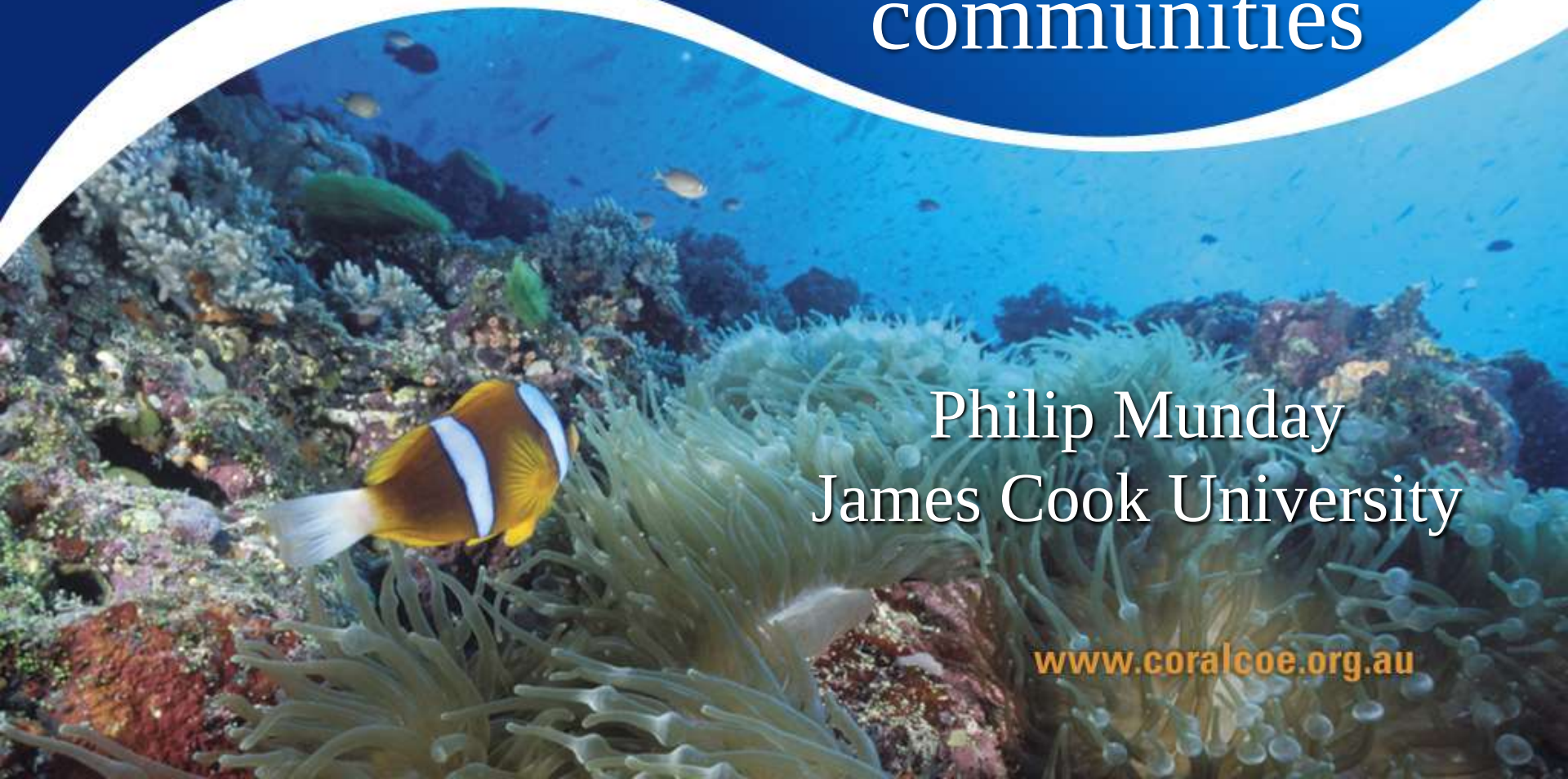
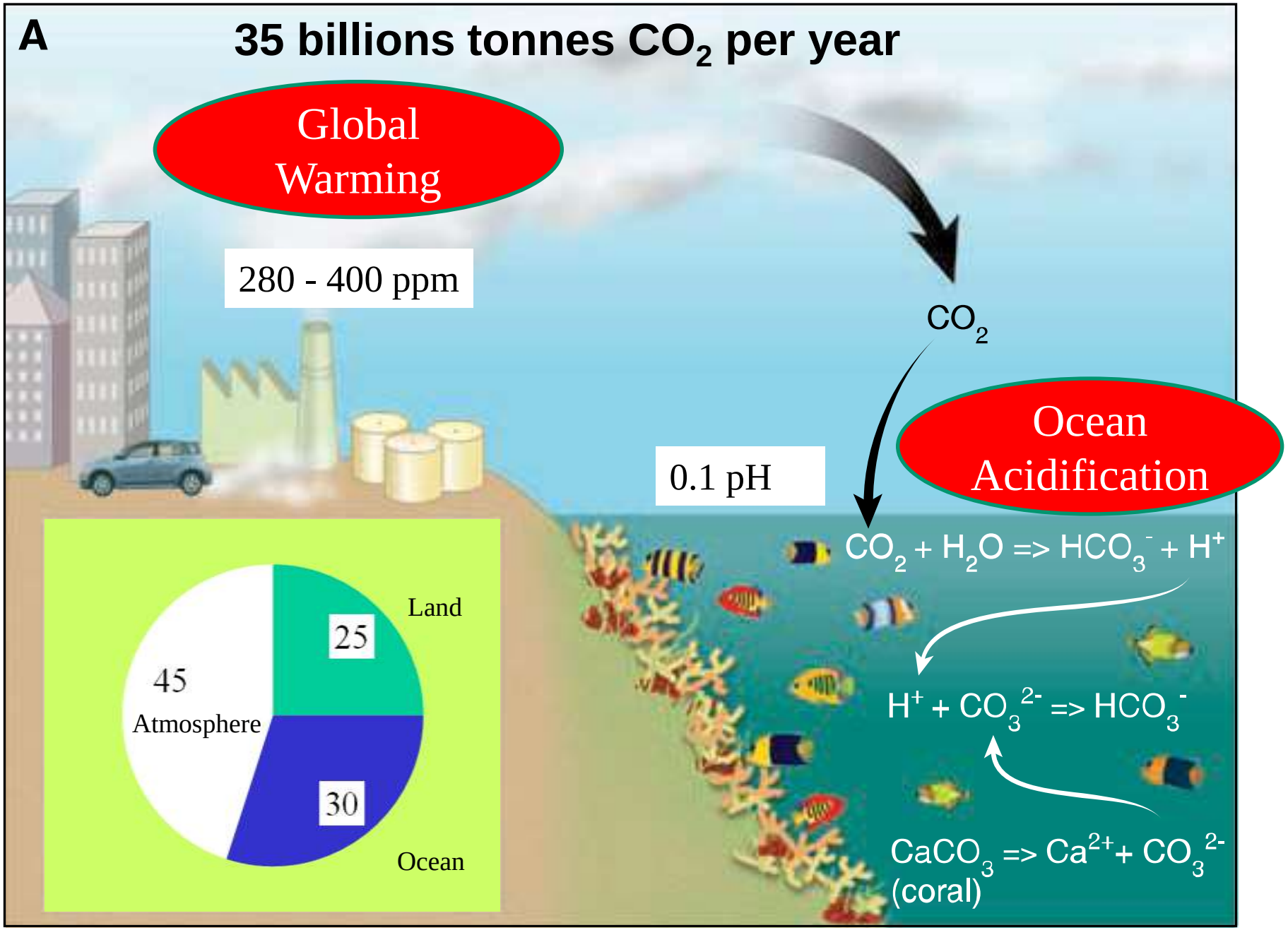
ARC Centre of Excellence
Coral Reef Studies

Ocean acidification and coral reef communities



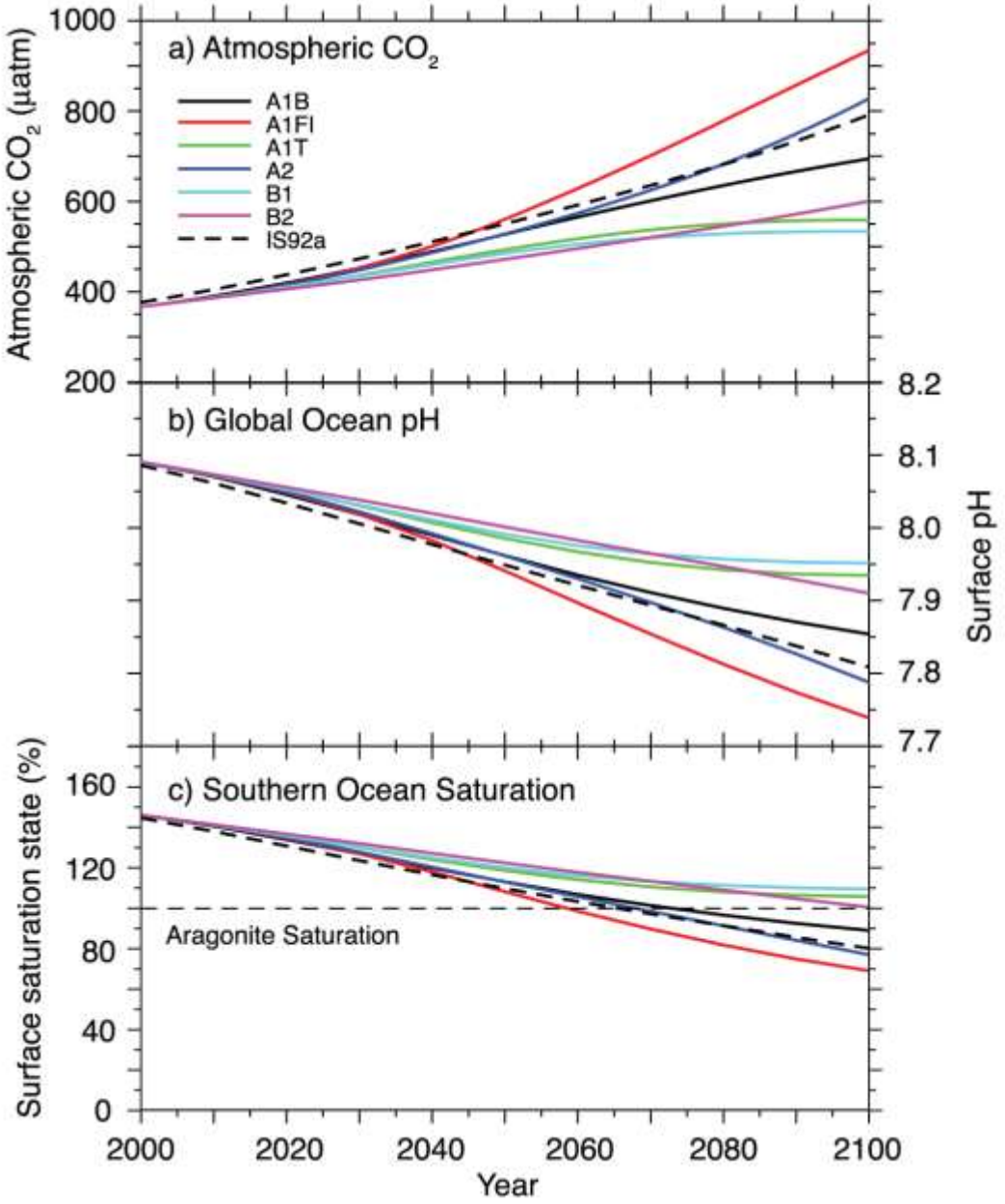
Philip Munday
James Cook University

www.coralcoe.org.au


A
35 billions tonnes CO_2 per year
Global Warming
280 - 400 ppm
CO_2
Ocean Acidification
0.1 pH
$CO_2 + H_2O \Rightarrow HCO_3^- + H^+$
$H^+ + CO_3^{2-} \Rightarrow HCO_3^-$
$CaCO_3 \Rightarrow Ca^{2+} + CO_3^{2-}$
(coral)
Land
25
45
Atmosphere
30
Ocean

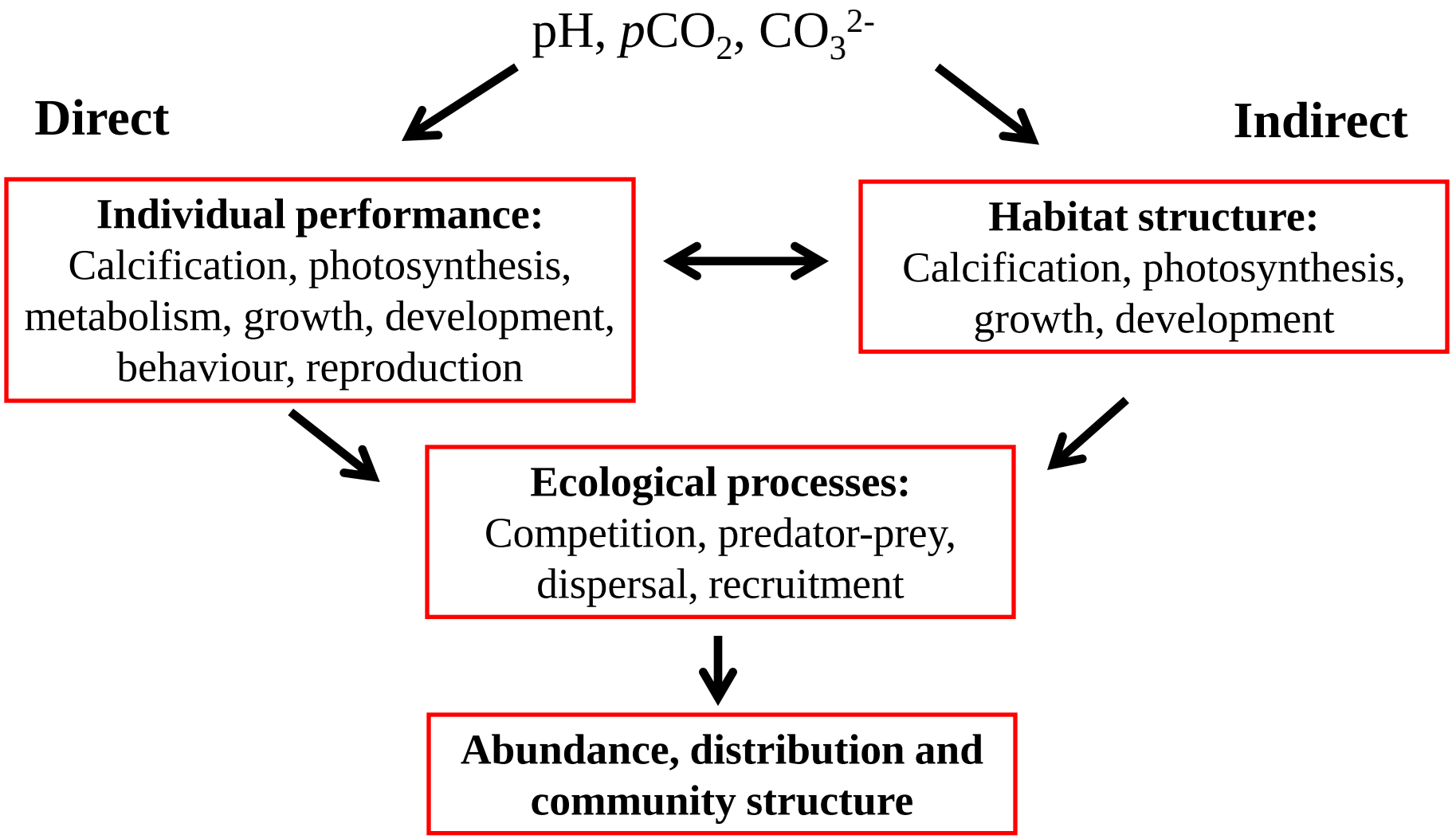
Projections

- Atmospheric CO_2 >500ppm by 2050
- >900ppm by 2100
- pH drop 0.3-0.4 units
- Problem for marine calcifiers

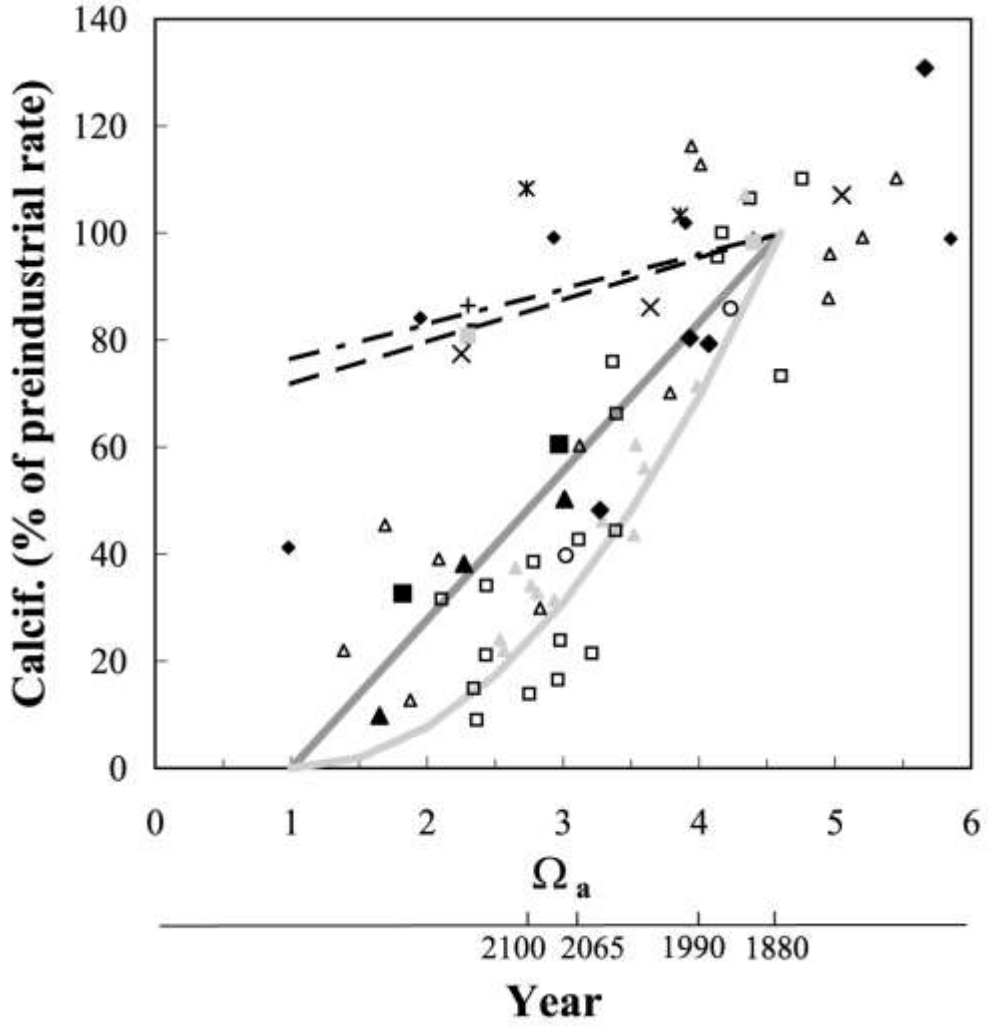


IPCC 2007 Chapter 10 Global Climate Projections

Effects on reef organisms



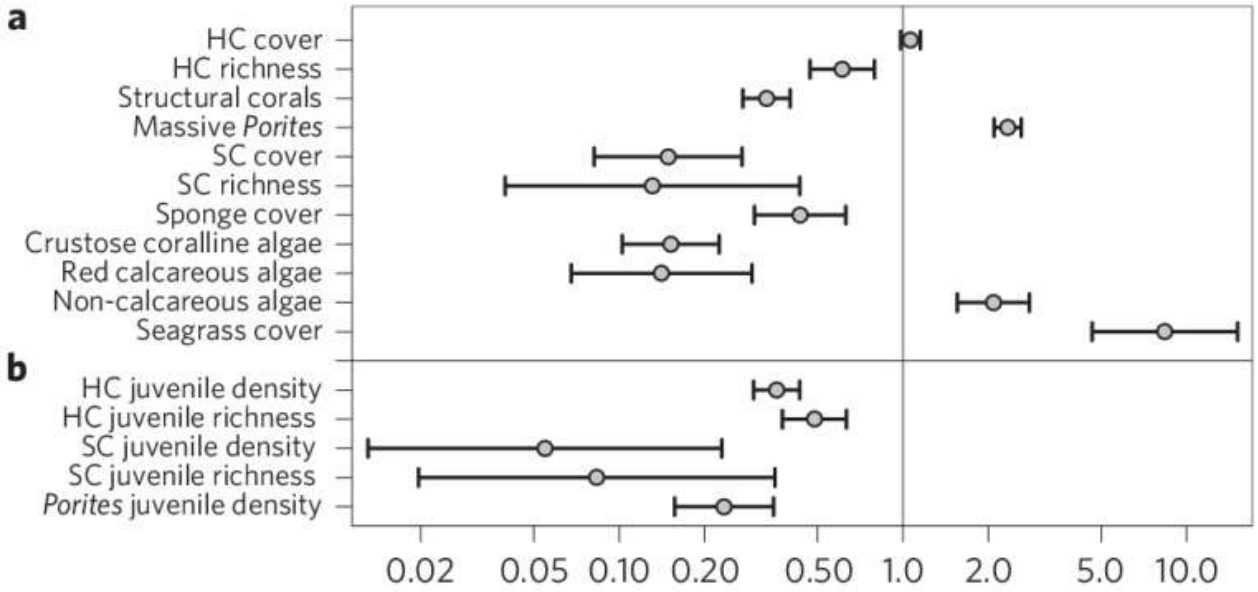
Corals – habitat forming calcifyers



~10-30% reduction in calcification rate with doubling of CO_2

Langdon and Atkinson 2005. Journal of Geophysical Research 110. C09S07

PNG CO_2 seeps

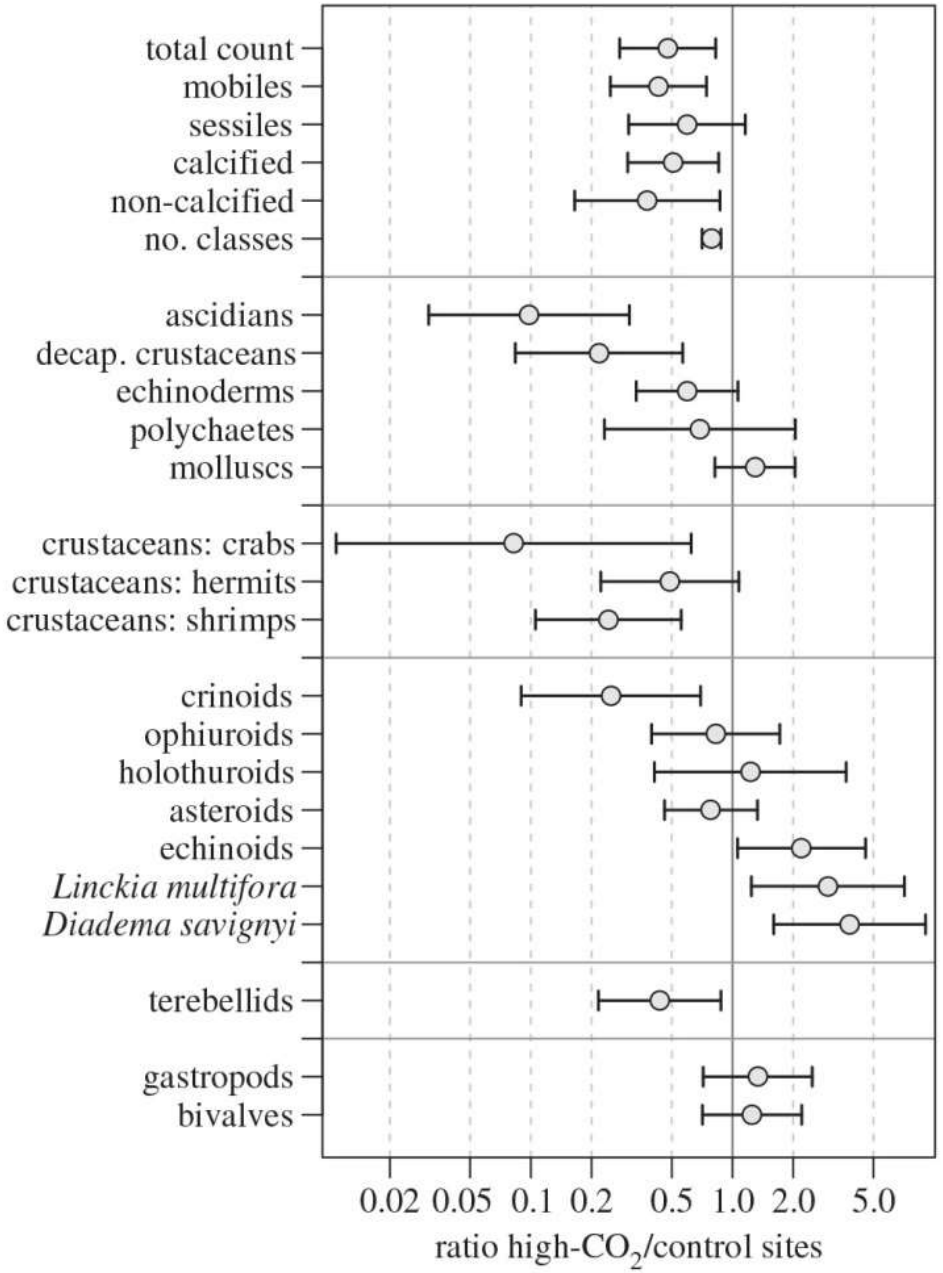


Coral cover unchanged but shift in community structure from branching coral and soft coral to massive coral and non-calcareous algae

Fabricius et al. 2011. Nature Climate Change, 1: 165-169

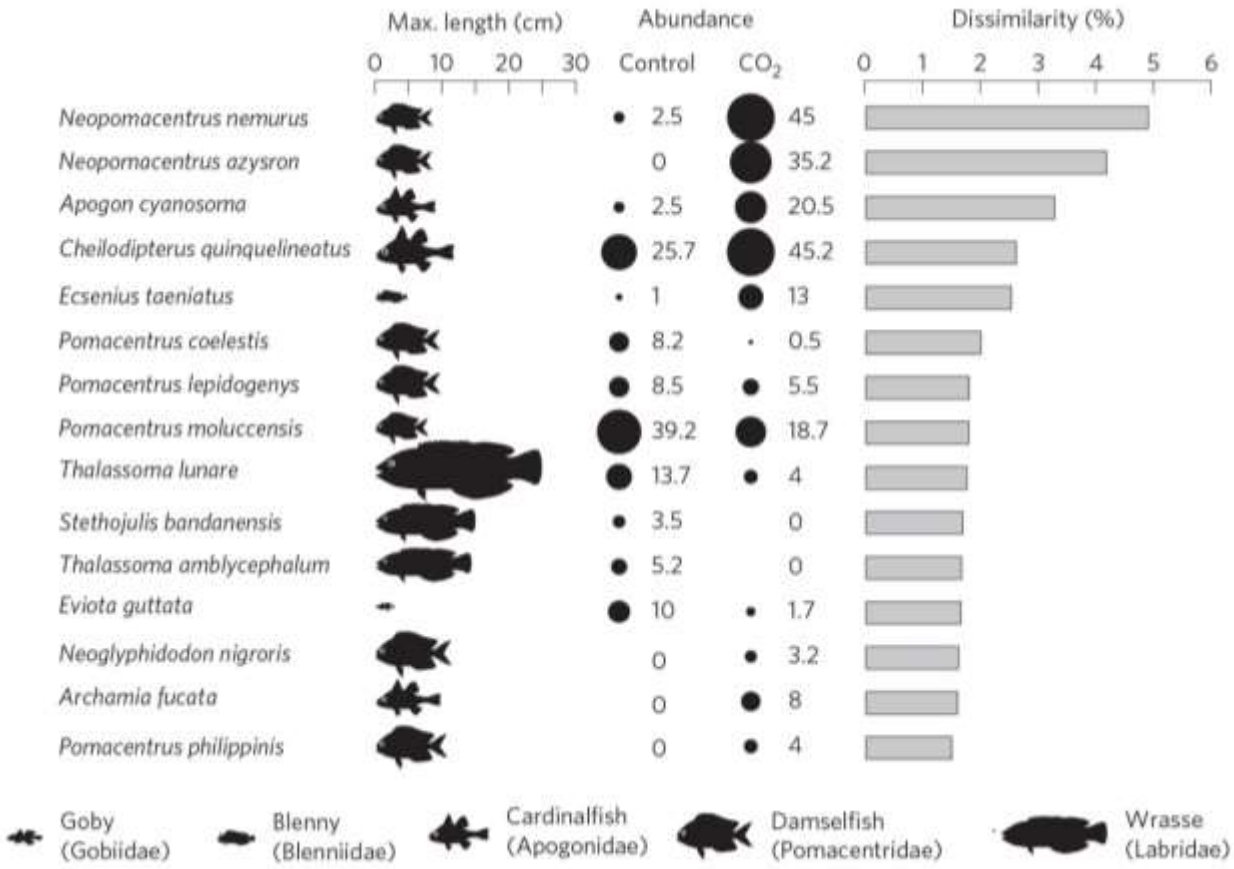
PNG CO_2 seeps

- 48% decline in density of macro-invertebrates
- Not linked to physiological tolerance
- Loss of complex habitat structure
- Predation prone taxa most susceptible



Fabricius et al. 2014. Proc R Soc Lond B. 281: 20132479

PNG CO_2 seeps

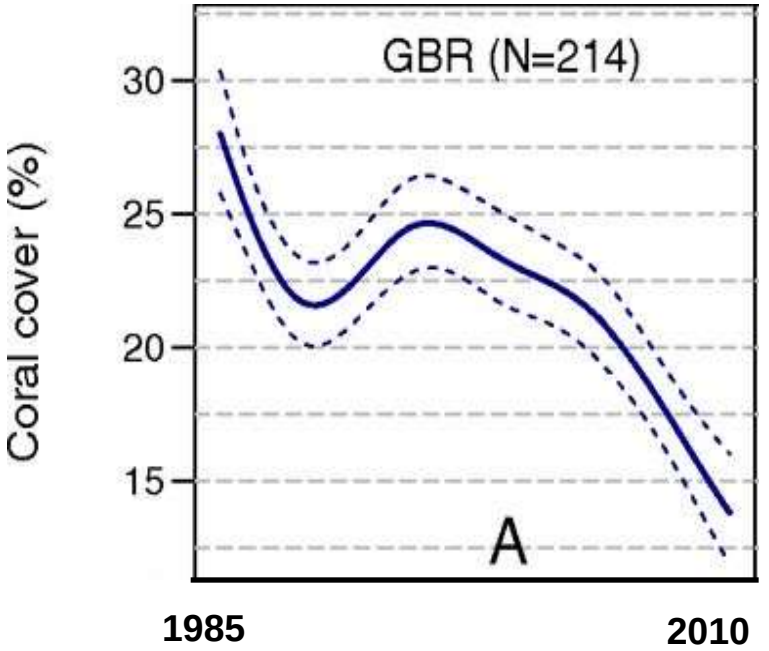


Little change in diversity and abundance, but significant changes in community structure. Fewer large predatory fishes

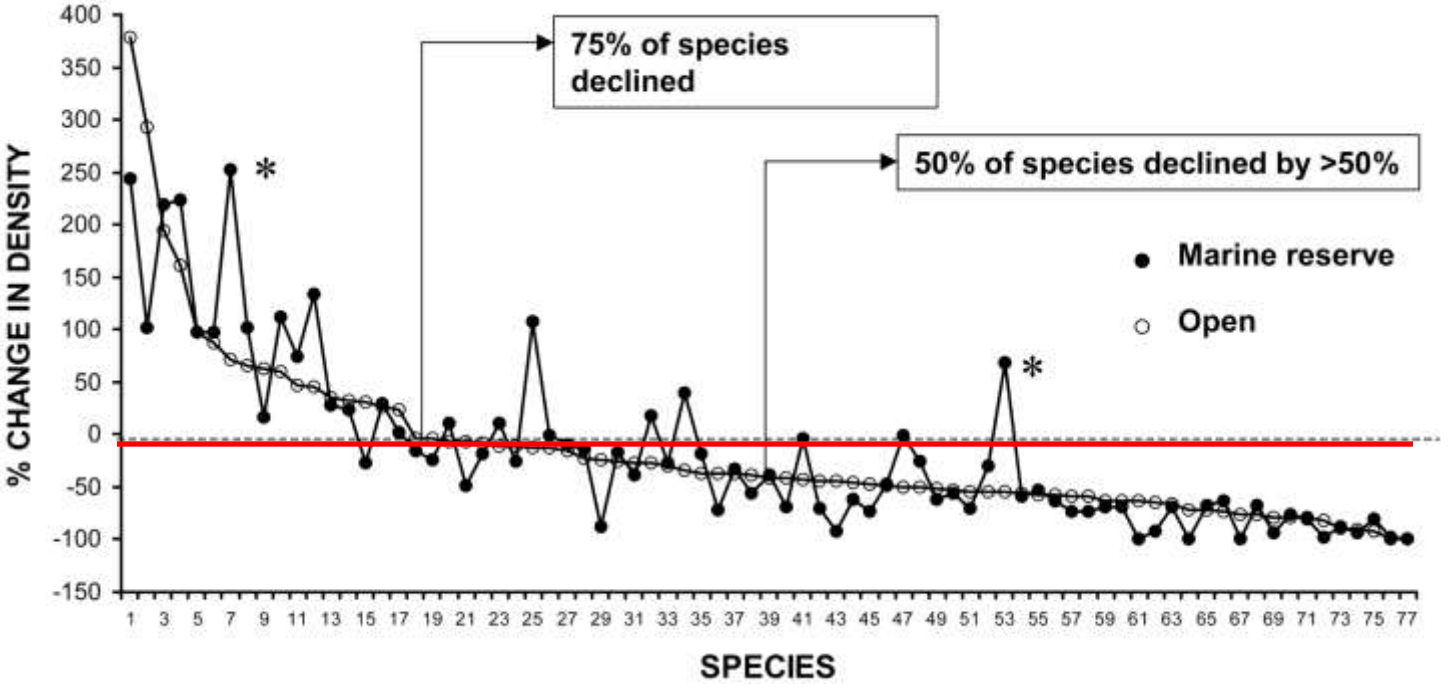
Munday et al. 2014. Nature Climate Change

Ocean acidification and global warming

- OA will interact with warming and coral bleaching
- Increased frequency of strong storms
- Reduced coral cover and declining reef complexity



Effects of coral loss on reef fish

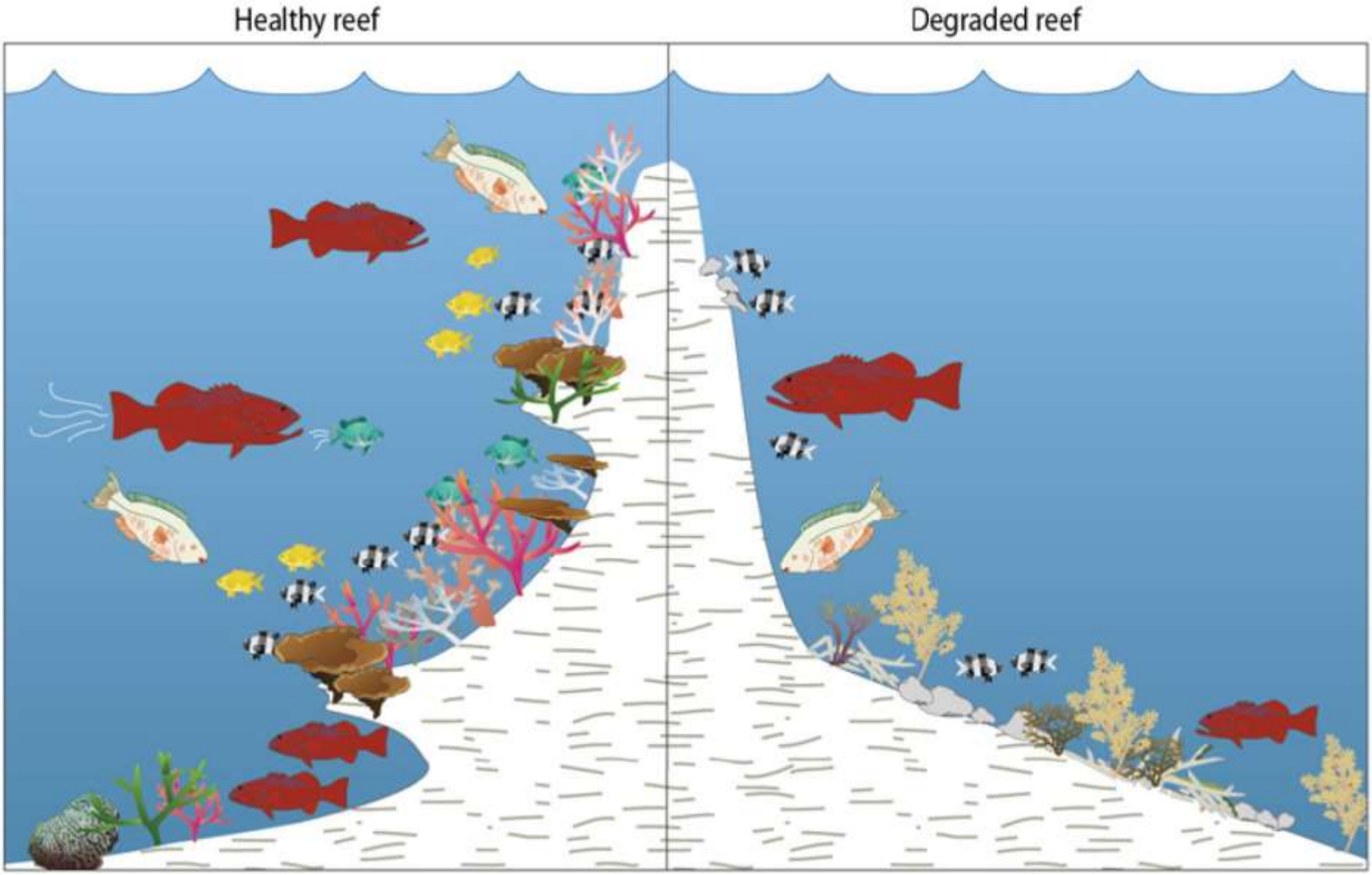


- Decline in diversity and abundance
- Live coral a key settlement habitat
- Change in fish community structure

Jones et al. 2004. PNAS. 101: 8251-8253

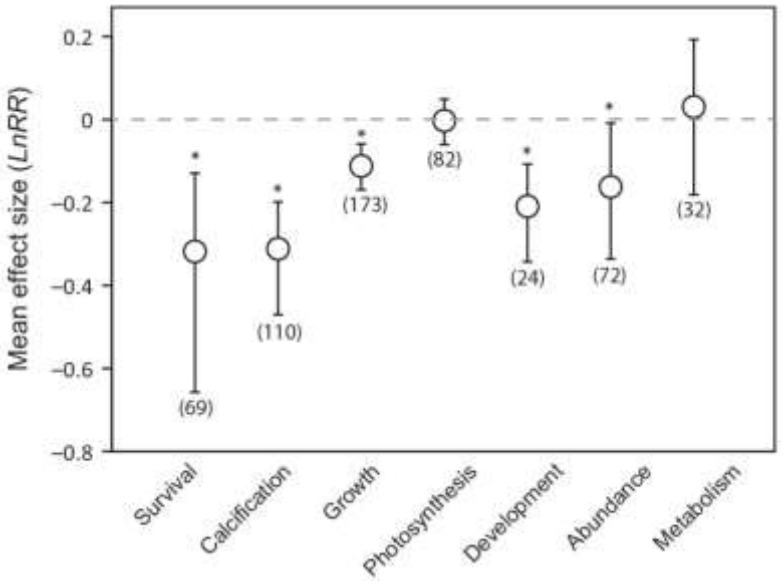
Structural complexity



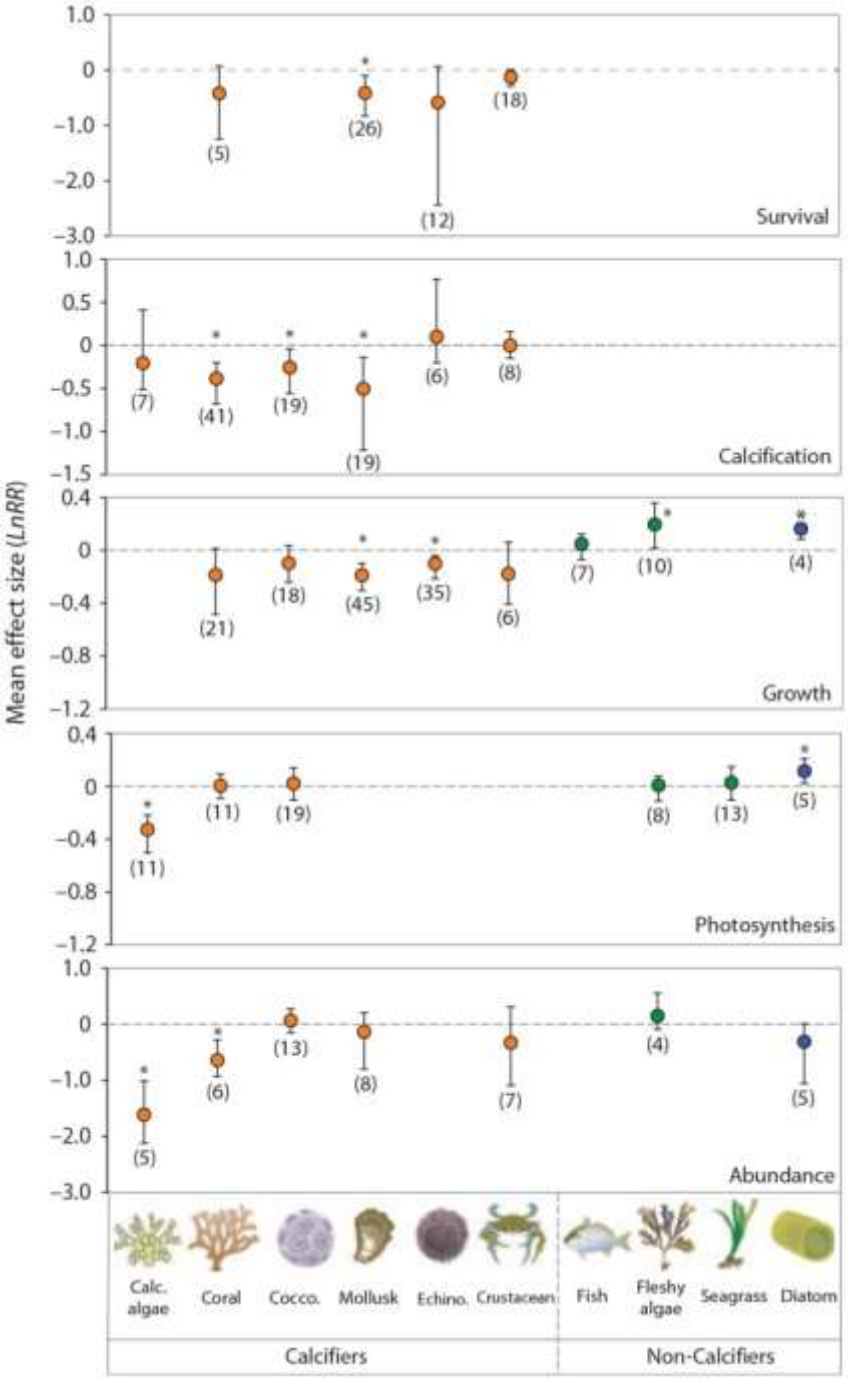



Pratchett et al. 2011. Chapter 9 in: Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change. SPC

Direct effects



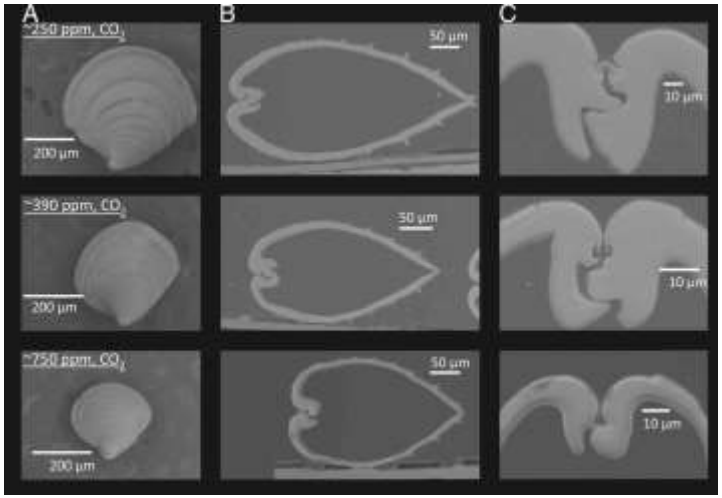
- Variable, but calcification generally affected
- Mollusks susceptible



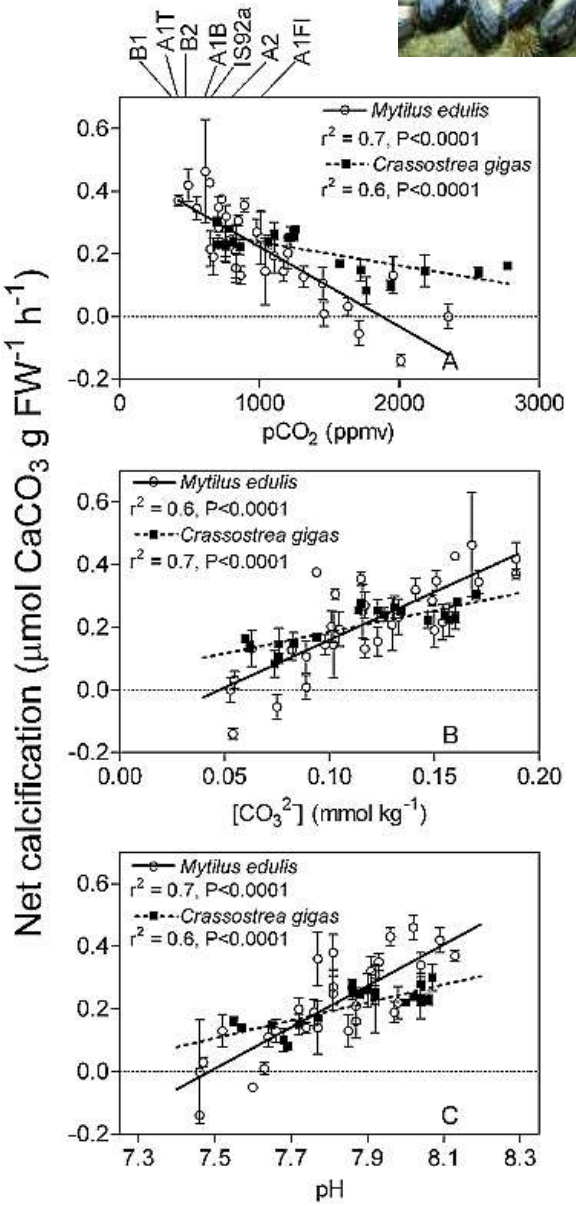
Kroeker et al. 2013 Global Change Biology 19: 1884-1896

Mussels, Oysters and Clams

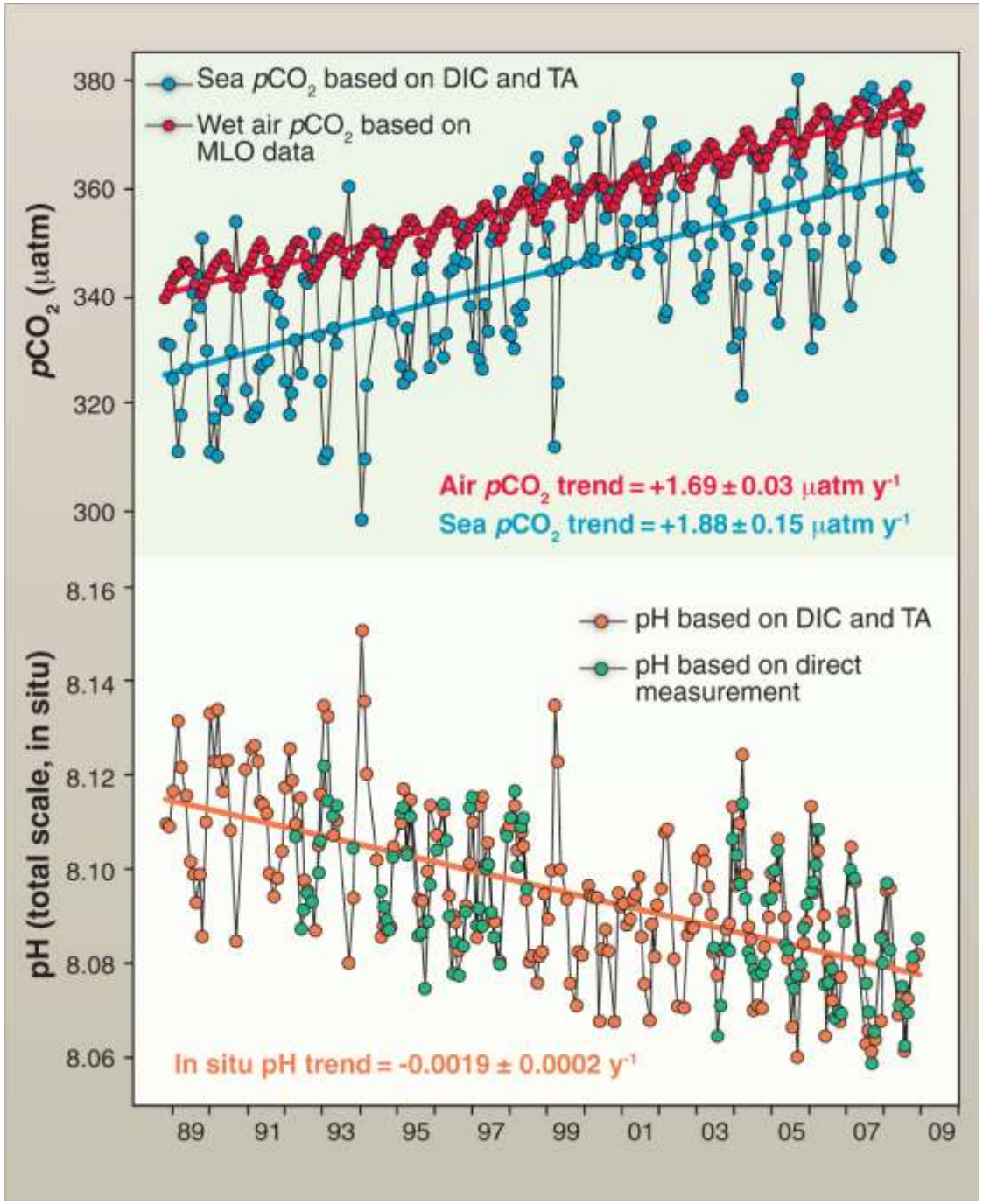
- Reduced shell and soft tissue growth
- Thinner shells and weaker hinges
- Larval survival reduced



Talmage and Gobler PNAS 2010



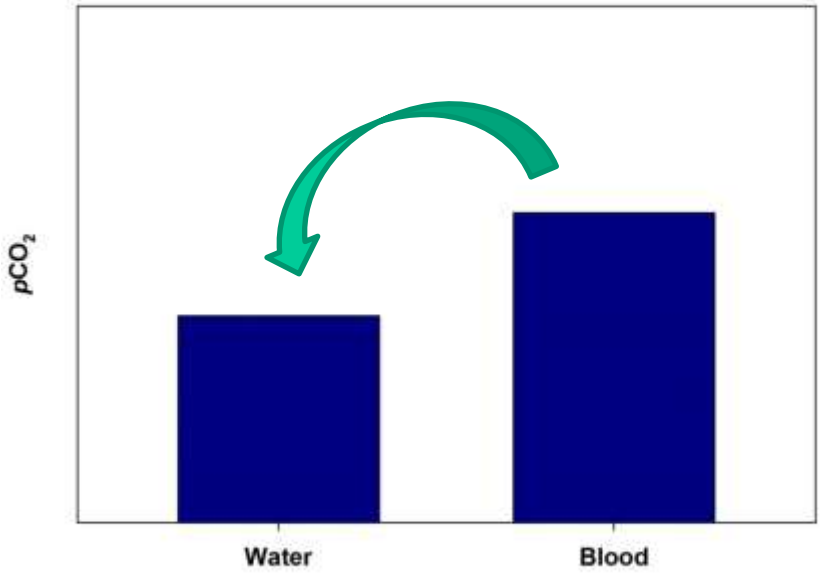
Gazeau et al. 2007 Geophysical Research Letters 34 LO7603



Doney et al. 2010 Science

Effects of increased CO_2

- Alters CO_2 gradient between environment and tissues
  - Water breathers sensitive because blood pCO_2 close to ambient



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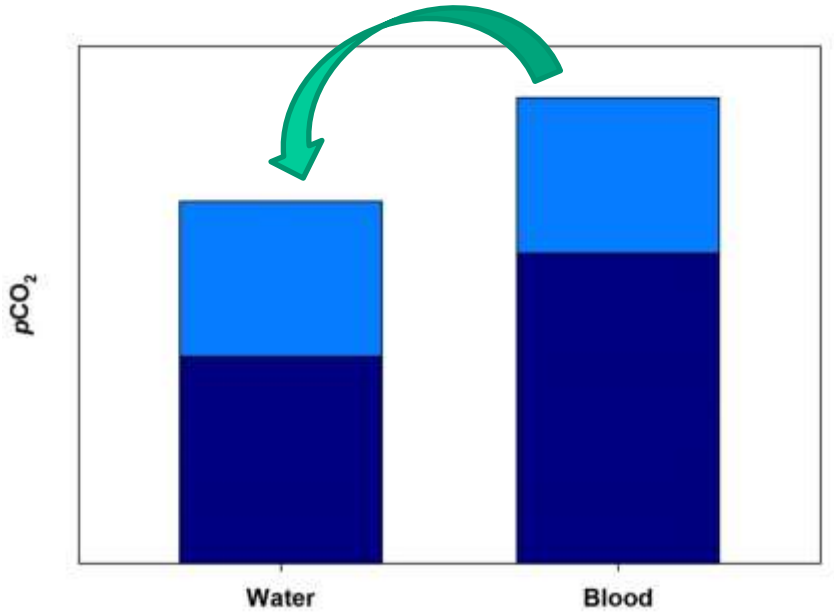
  - Higher ambient CO_2 raises blood and tissue CO_2
  - Acts to acidify the tissues



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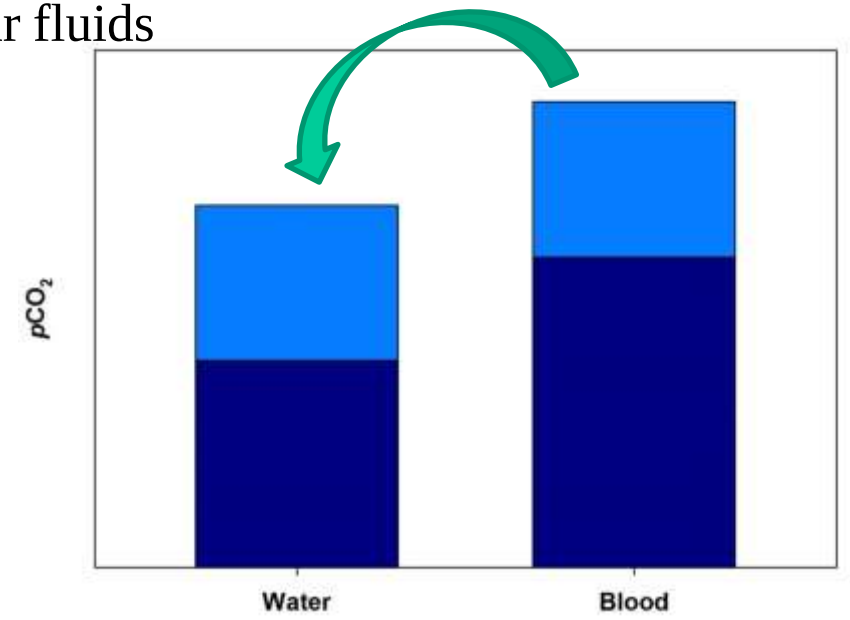
- Counteracted by physiological processes
  - Buffering of extra- and intra-cellular fluids
  - Ion exchange (e.g. via gills)



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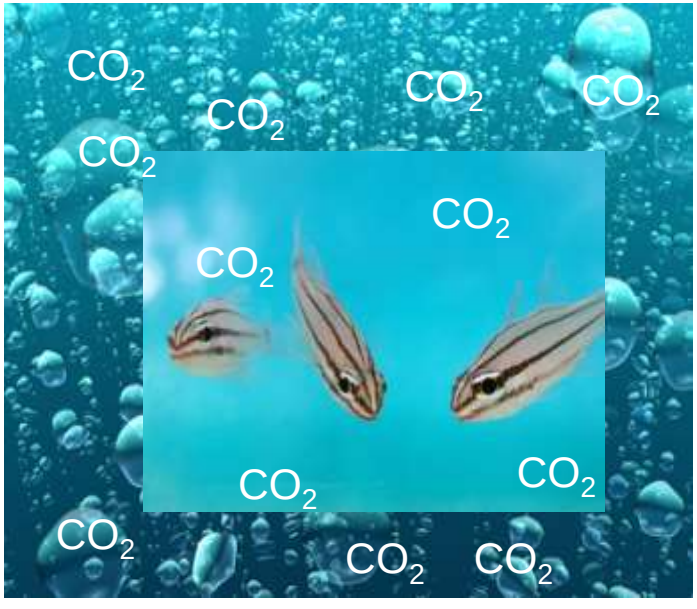
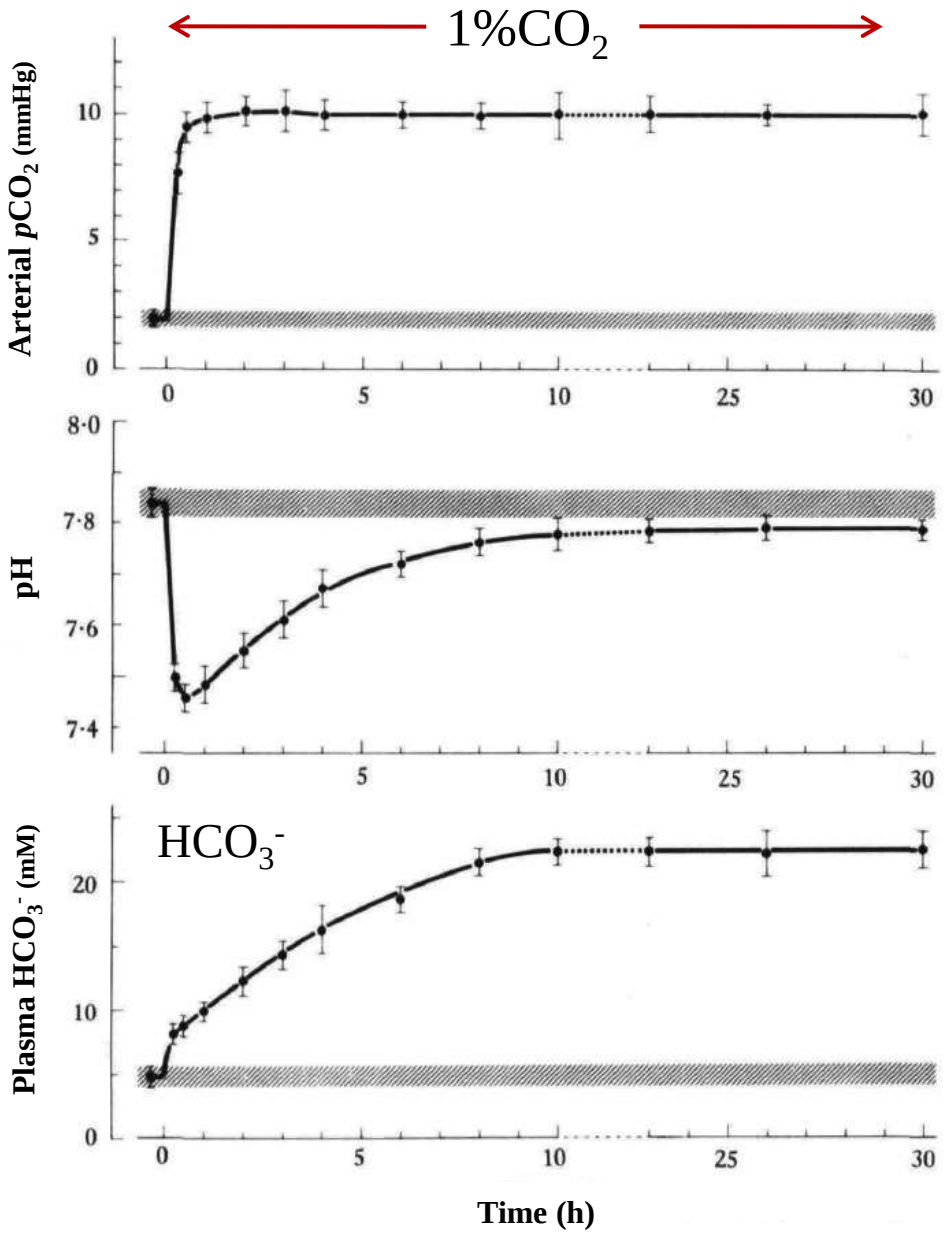
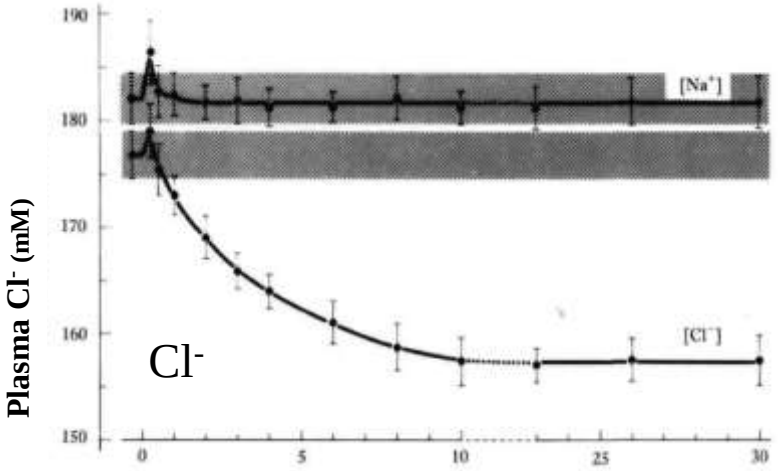
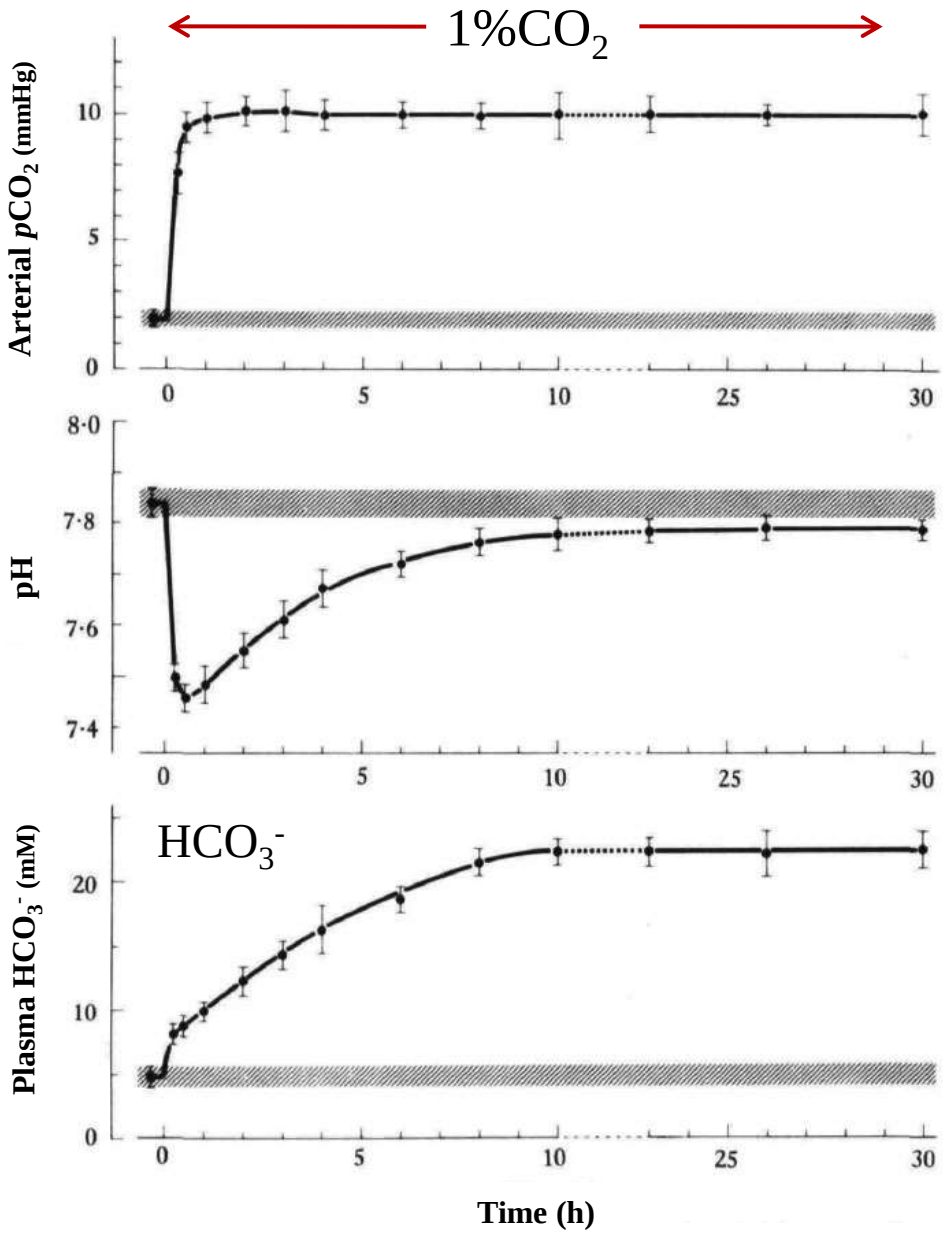
Fish good at regulating acid-base balance







Toews et al. 1983 J Exp Biol



LC_{50} generally >10,000 ppm CO_2 for adult fishes

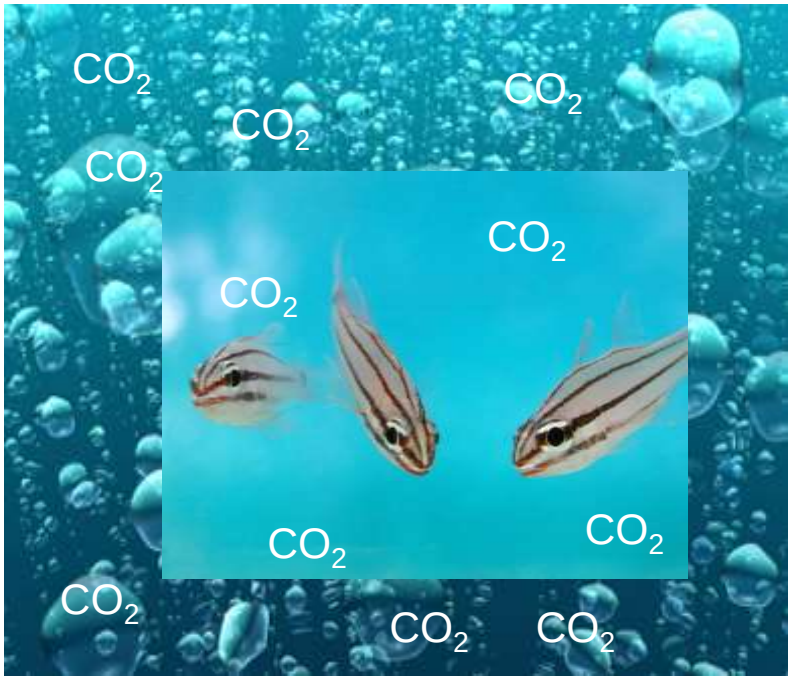
Energetic cost of acid-base regulation?

Toews et al. 1983 J Exp Biol

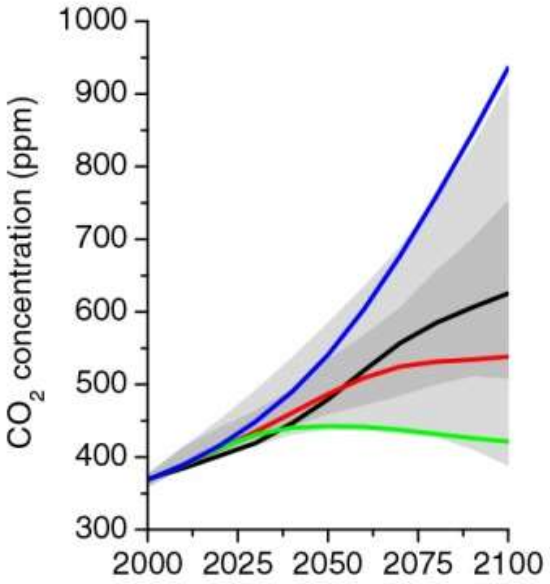
Sub-lethal effects of increased CO_2

- Affect on growth, development, reproduction, behaviour
- CO_2 levels relevant to climate change

- Early life history stages most susceptible
  - large surface area to volume ratio
  - homeostasis not fully developed



Early life history development



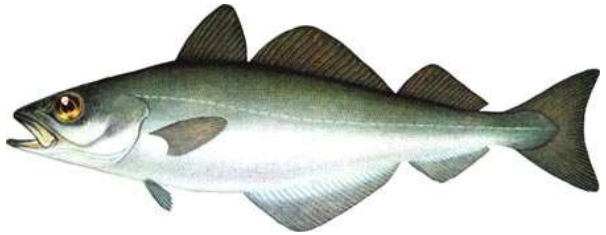
- 390-450ppm
- 550-600ppm
- 700-750ppm
- 850-1050ppm

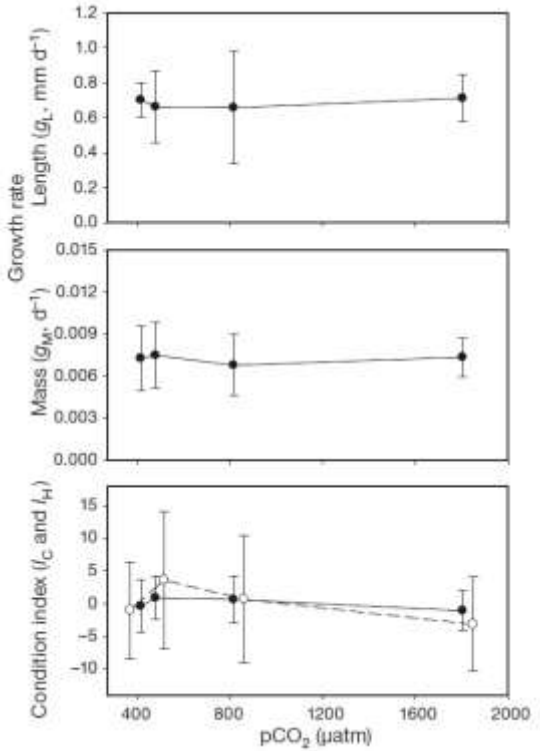
Early life history development

- Limited effects on:
  - Egg survival
  - Size at hatching
  - Development
  - Growth
- Up to 1000ppm CO_2

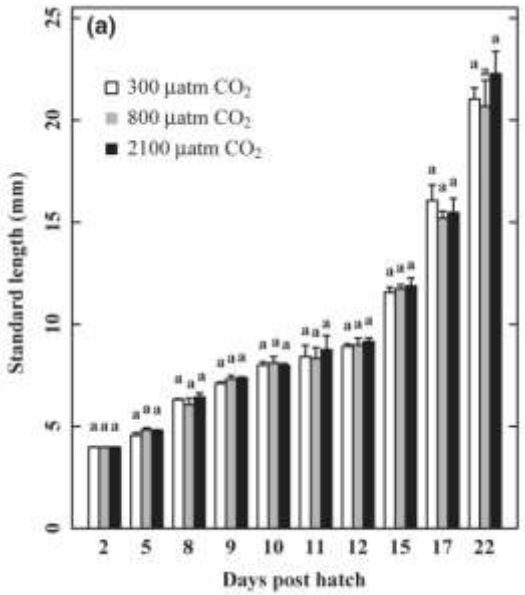
Early life history development

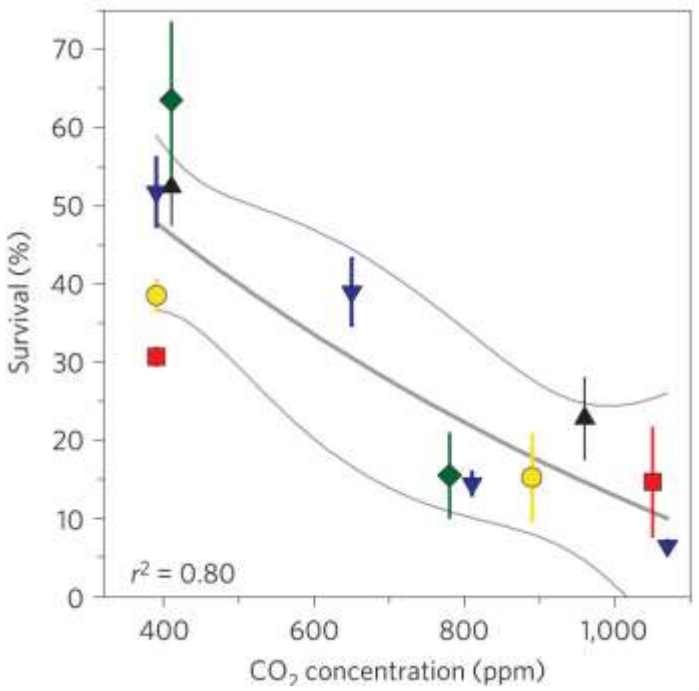
Pollock (Hurst et al. 2012 Aquatic Science)

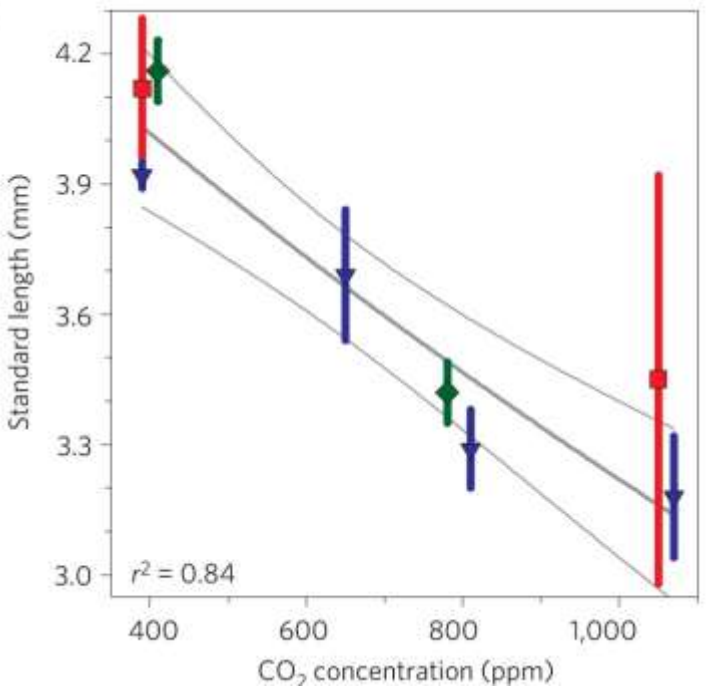


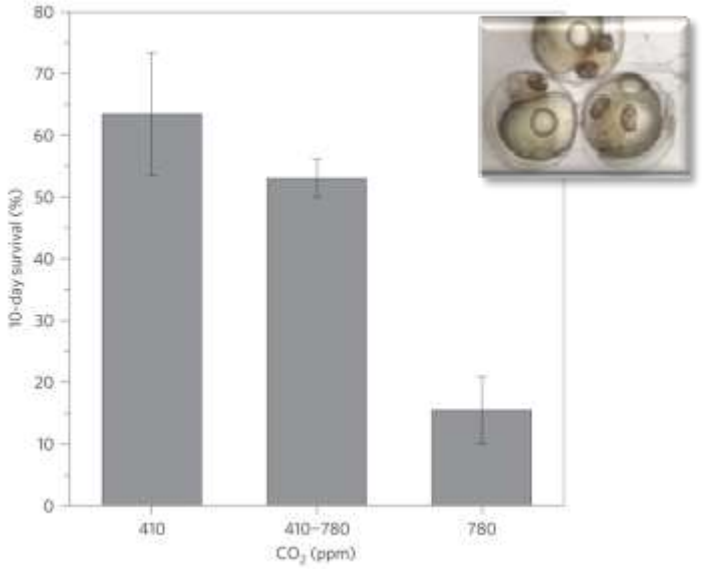


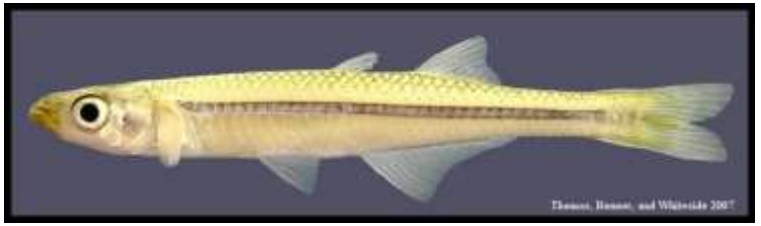
Cobia (Bignami et al. 2013 Global Change Biology)





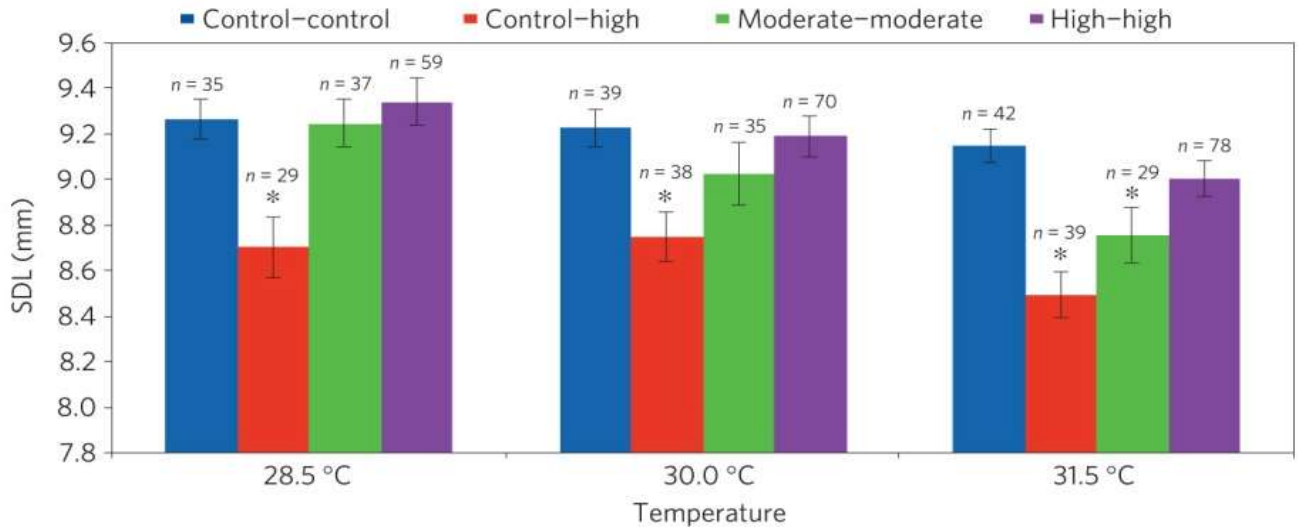


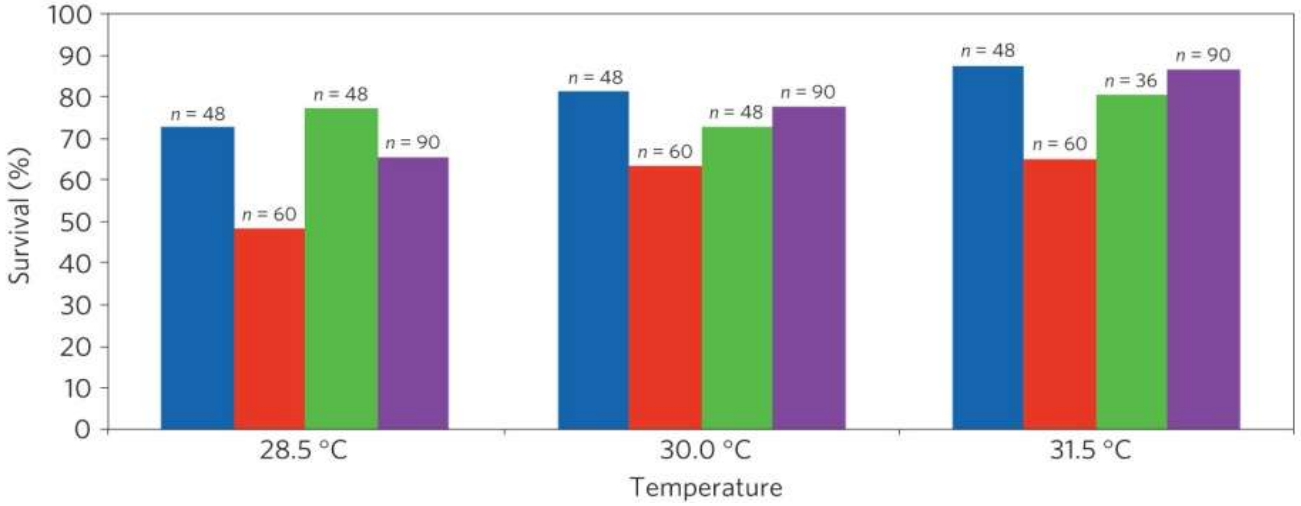




Baumann et al. 2012 *Nature Climate Change*

Parental exposure ameliorates impact of increased CO_2





Miller et al. 2012 Nature Climate Change 2: 858

Life-history summary

- Limited effects on early life history growth, development of most fishes tested to date
- Few species tested - broadcast spawners with small, poorly developed larvae could be more susceptible (e.g. tuna)
- Parental effects critical in projecting future impacts

Sensory ability and behaviour

- Impaired ability to discriminate between chemical cues
  - Settlement habitat
  - Kin v non-kin
  - Predators v non-predators

PNAS

Ocean acidification impairs olfactory discrimination and homing ability of a marine fish

Philip L. Munday[a,b,1], Danielle L. Dixson[a,b], Jennifer M. Donelson[a,b], Geoffrey P. Jones[a,b], Morgan S. Pratchett[a], Galina V. Devitsina[c], and Kjell B. Døving[d]

[a]Australian Research Council Centre of Excellence for Coral Reef Studies, [b]School of Marine and Tr
4811, Australia; [c]Ichthyology Department, Faculty of Biology, Moscow MV Lomonosov State Unive
Institute of Molecular Bioscience, University of Oslo, N-0316 Oslo, Norway

Edited by David M. Karl, University of Hawaii, Honolulu, HI, and approved December 29, 2008 (rec

ECOLOGY LETTERS

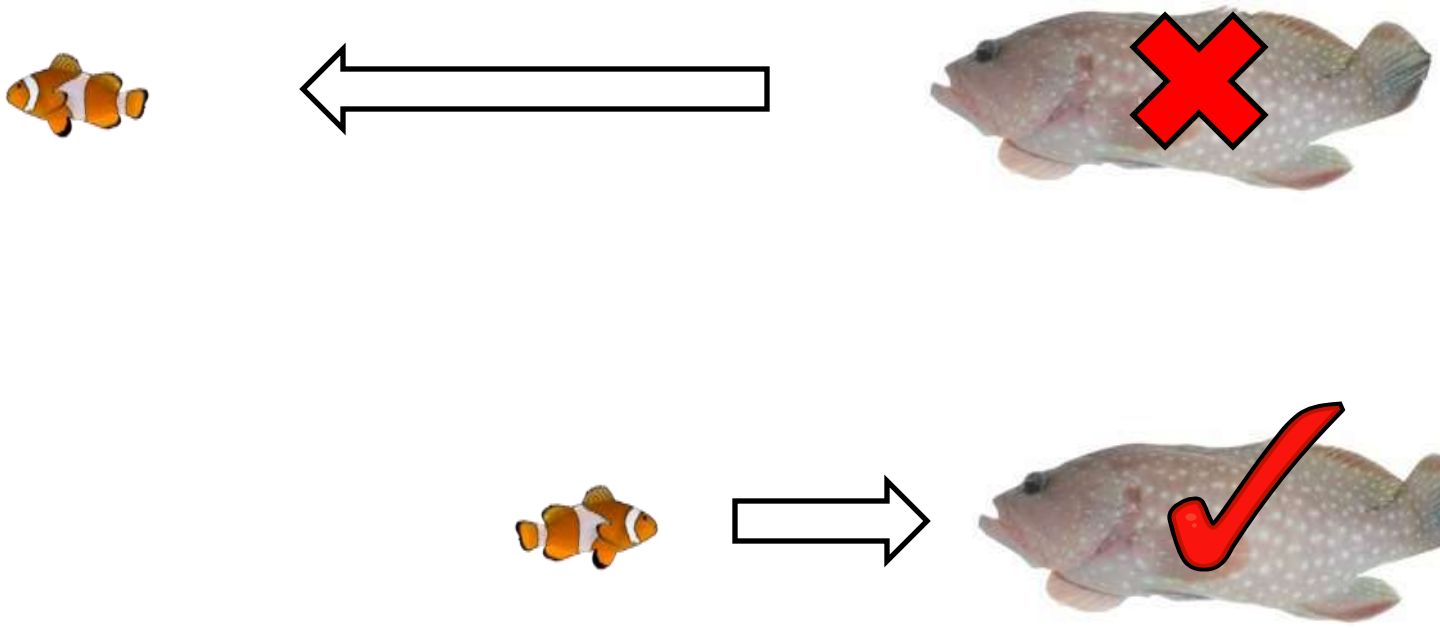
Ecology Letters, (2010) **13**: 68–75 doi: 10.1111/j.1461-0248.2009.01400.x

LETTER

Ocean acidification disrupts the innate ability of fish to detect predator olfactory cues

Munday et al. 2009. *PNAS*, 106: 1848

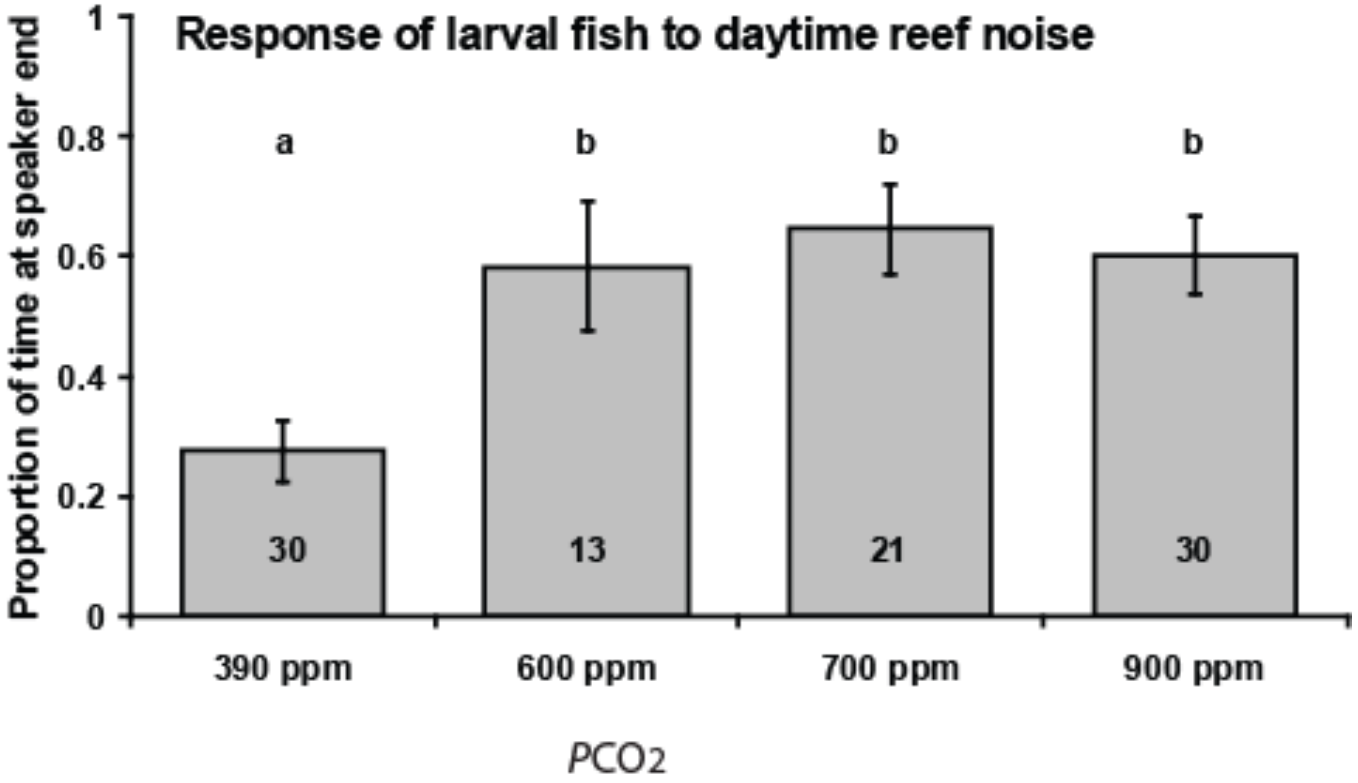
Attracted to predator odour



Dixson et al. 2010. *Ecology Letters*, 13: 68

Hearing

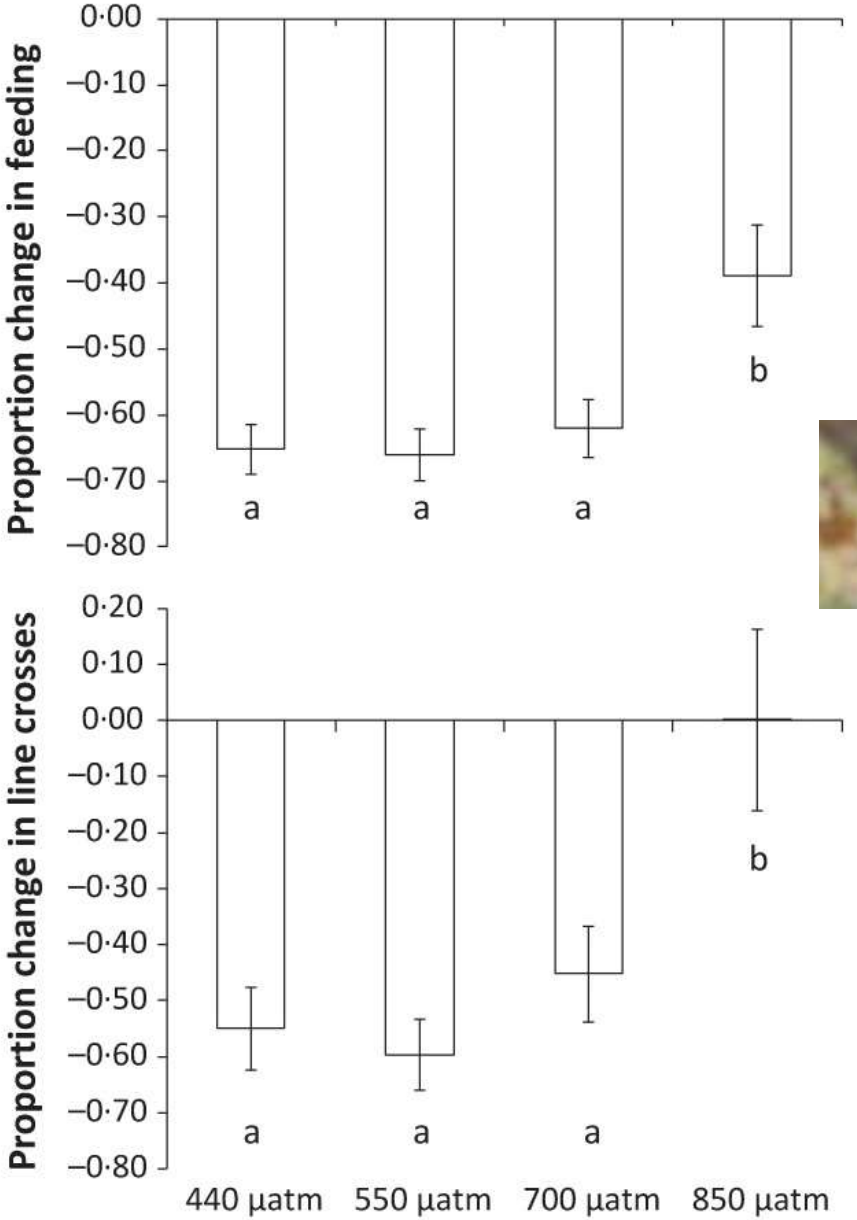
- Altered auditory preferences



Simpson et al. 2011 *Biology Letters*

Vision

- Reduced response to visual threat



Ferrari et al. 2012 *Functional Ecology*

Learning

alarm cue

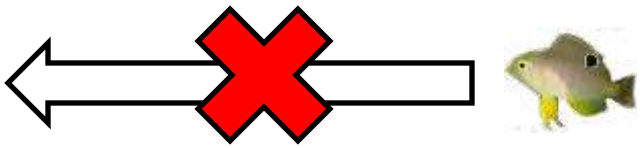
Ferrari et al. 2012 *PLoS One*

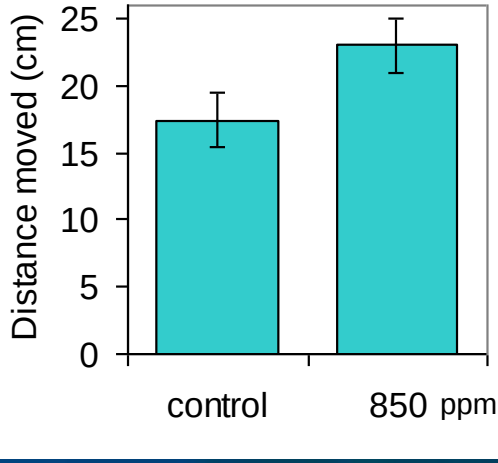
Learning

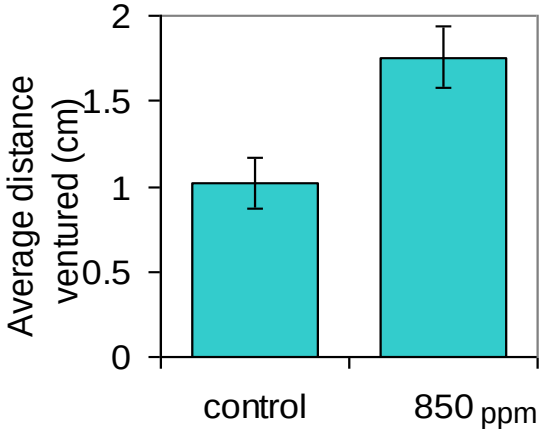
- Inability to learn

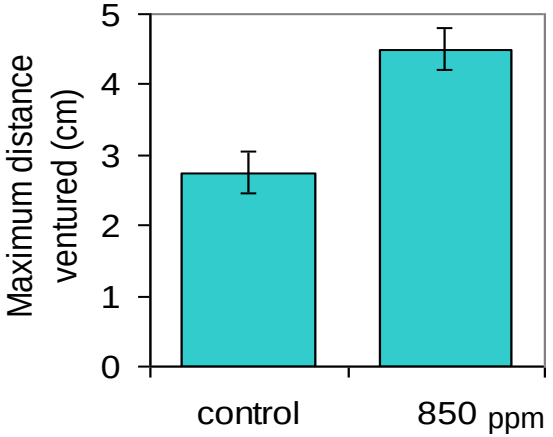
alarm cue

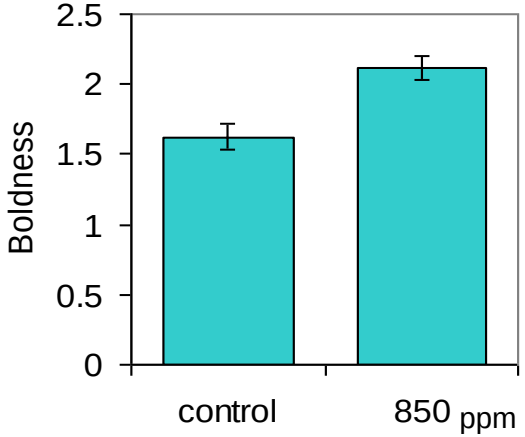
High CO_2

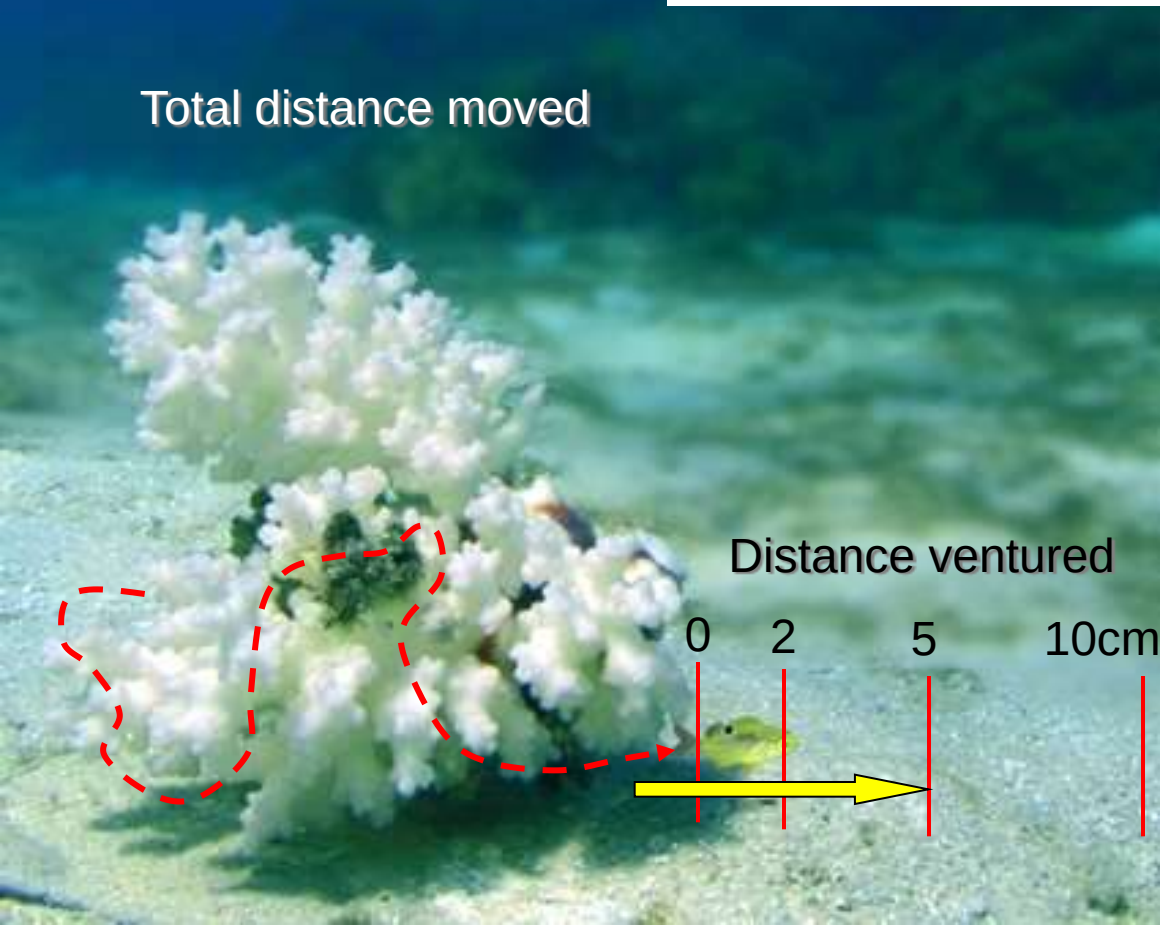












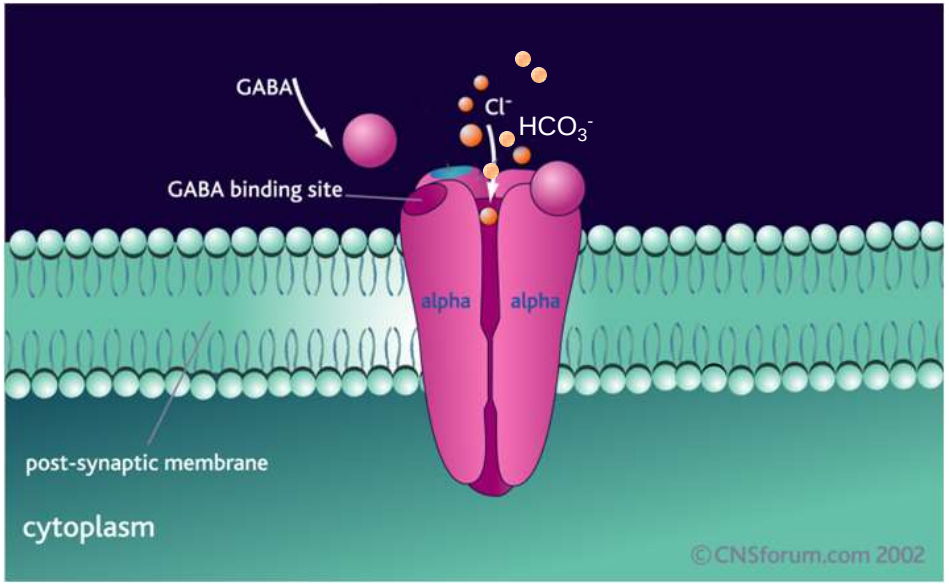
More active and riskier behaviour

Predator & prey

Coral Trout

Juveniles more active and attracted to odours they normally avoid

High CO_2 interferes with GABA neurotransmitter receptor function



Ecological consequences

- Predator-prey interactions
- Population replenishment
- Habitat selection
- Navigation
- Recruitment

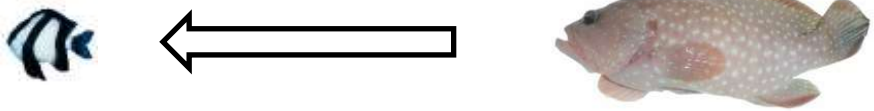
600-850 µatm CO_2

Summary

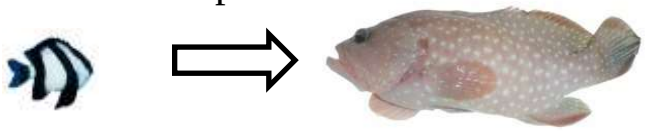
- Ocean acidification will interact with warming, leading to loss of coral cover and decline is habitat complexity
- Loss of biodiversity and abundance in reef communities
- Reef species also directly affected by rising CO_2
- Long-term physiological/energetic costs
- Behavioural effects recently discovered
- Implications for population and communities
- Strong interacting effects with warming
- Adaptation?

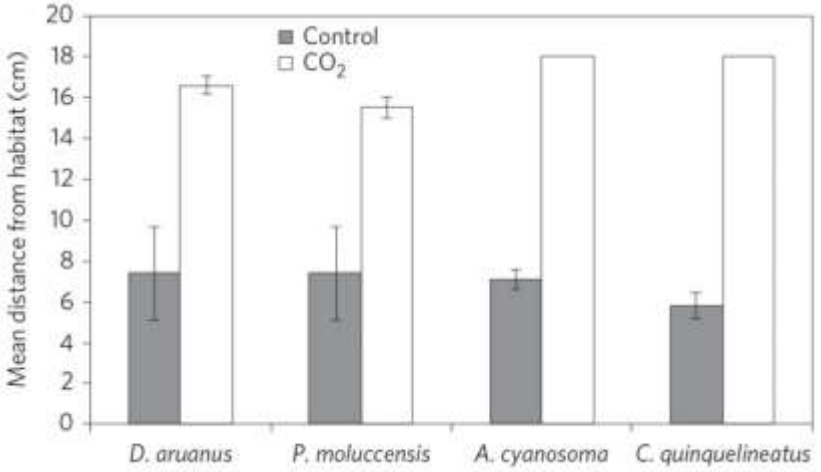
PNG CO_2 seeps

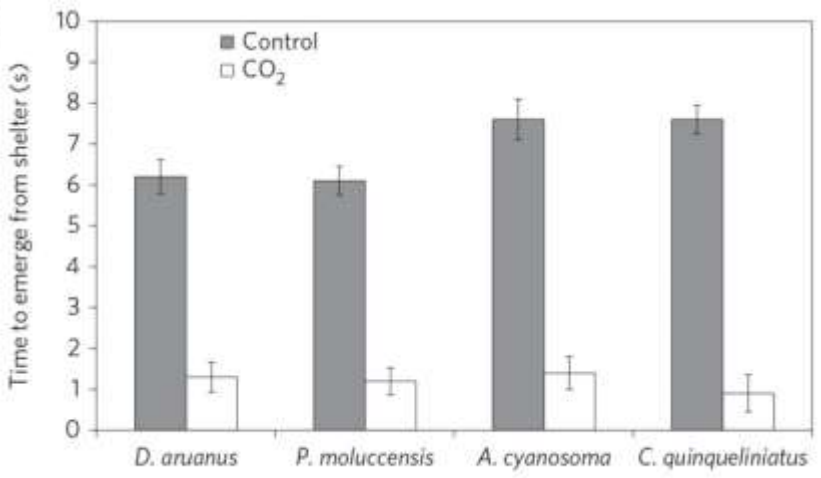
control reef



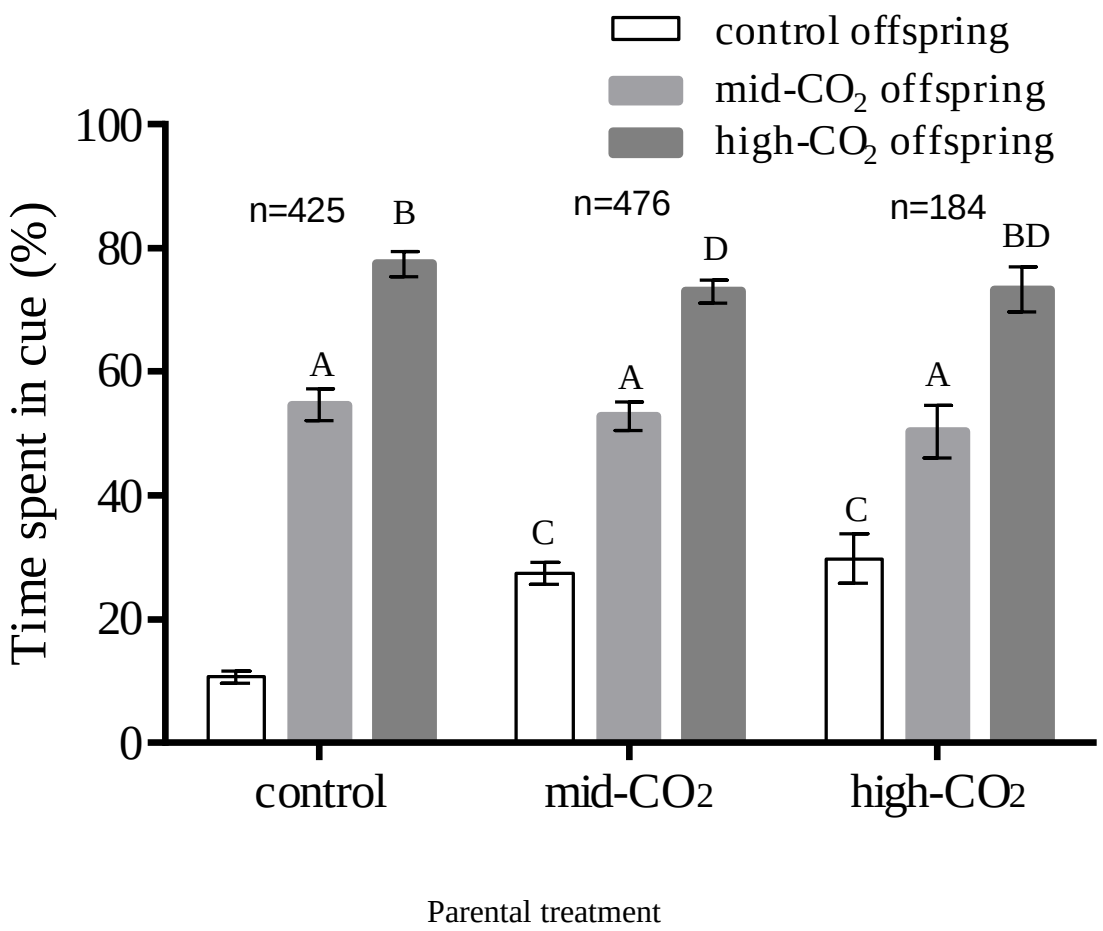
CO2 seep







Transgenerational acclimation



Welsh et al. in review