Coastal Futures 2014 | UK Ocean Acidification Research Programme | London: 23 January

Ocean acidification update

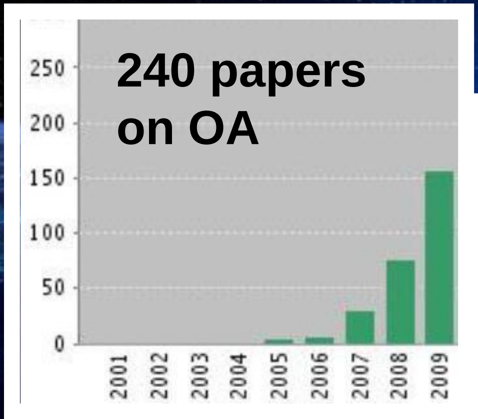
"After much research effort, we now know a lot more than when we started – although it is mostly knowing how little we now know"

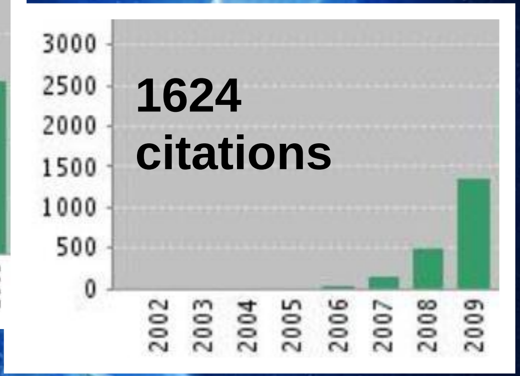
Phil Williamson
Science Coordinator (NERC/UEA)
UK Ocean Acidification research programme

Department for Environment Food & Rural Affairs
NERC SCIENCE OF THE ENVIRONMENT
DEPARTMENT OF ENERGY & CLIMATE CHANGE

Scientific interest in ocean acidification began to 'take off' around 5 years ago

up to end of **2009**





Scientific interest in ocean acidification began to 'take off' around 5 years ago

since then there has been a six-fold increase in OA publications

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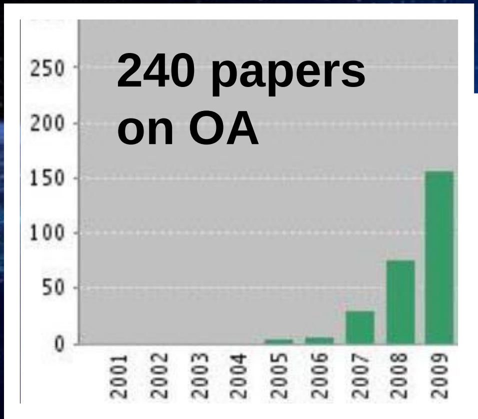
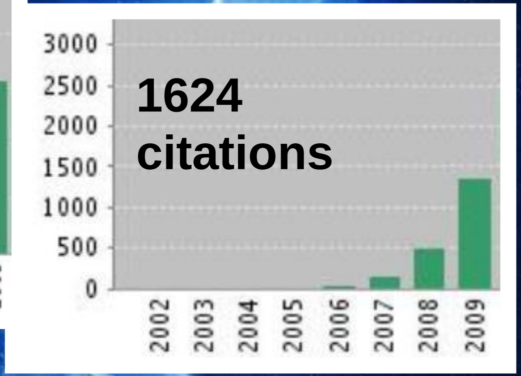
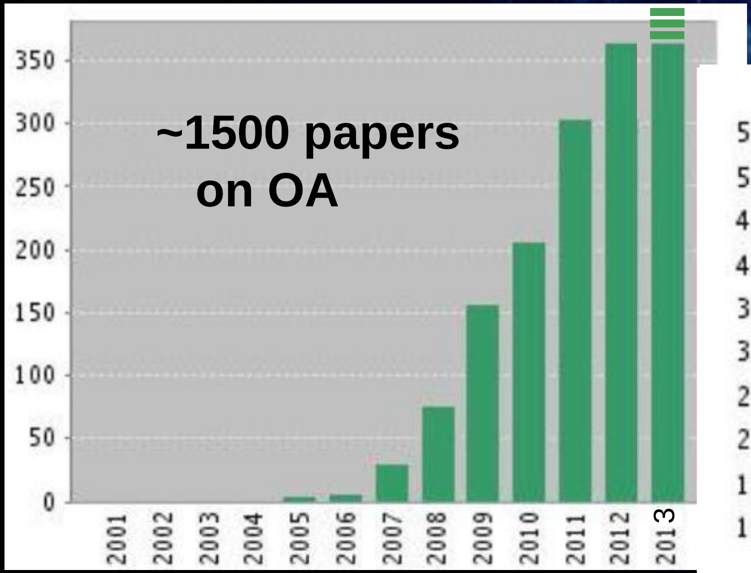
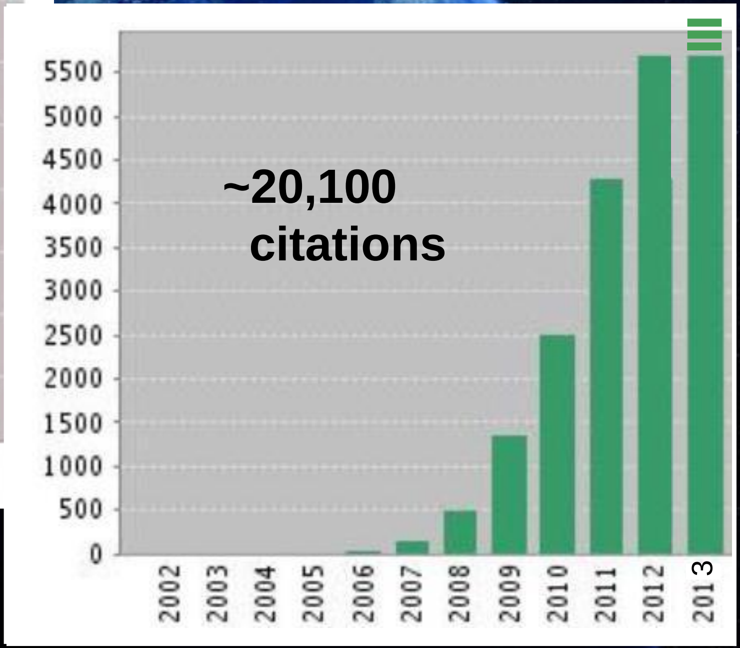




up to end of **2013**



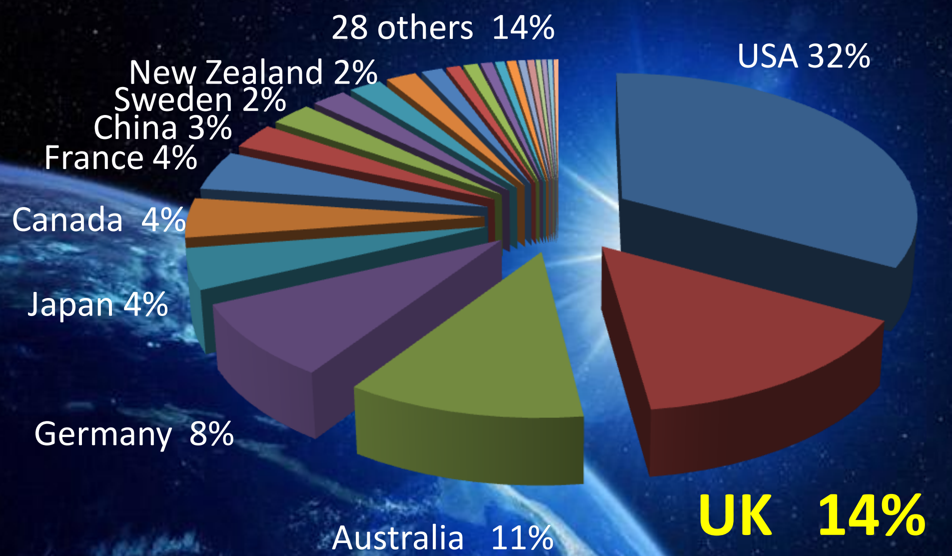


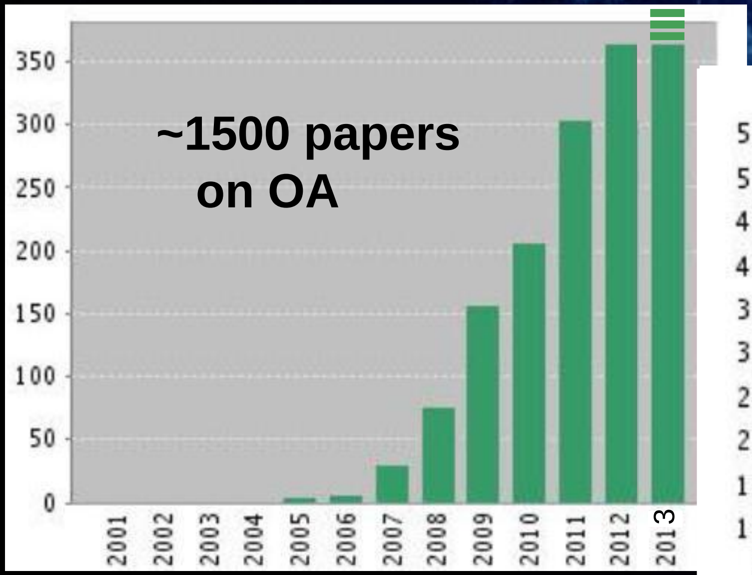
ISI World of Science data (provisional for 2013)

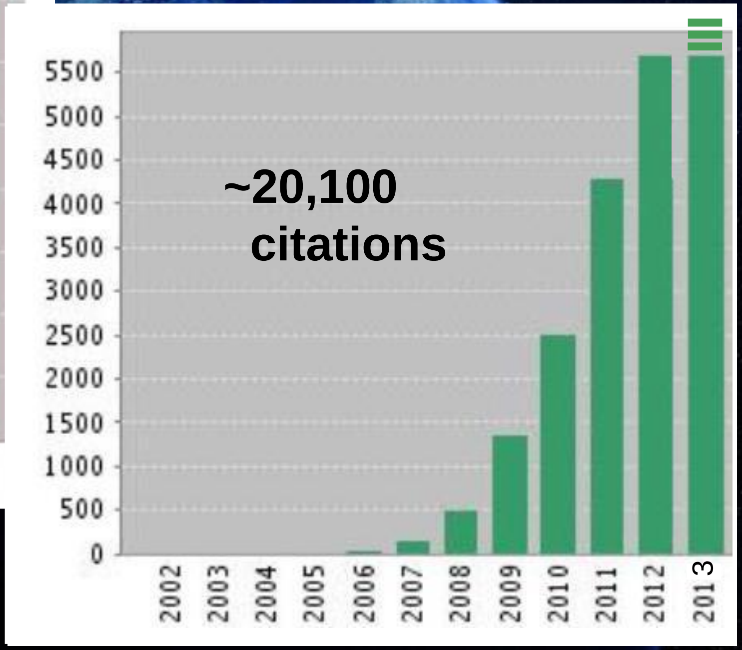
Scientific interest in ocean acidification began to 'take off' around 5 years ago

since then there has been a six-fold increase in OA publications with a major UK contribution

First authorship of OA publications 2005-11

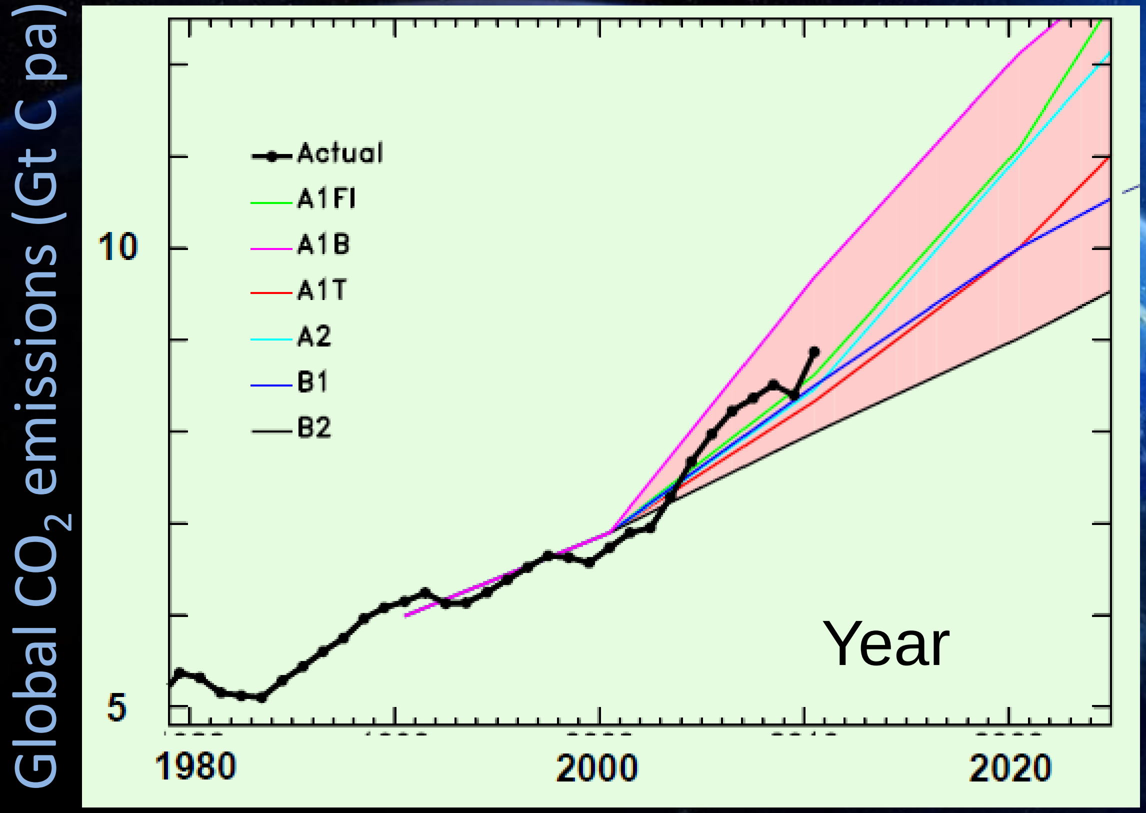




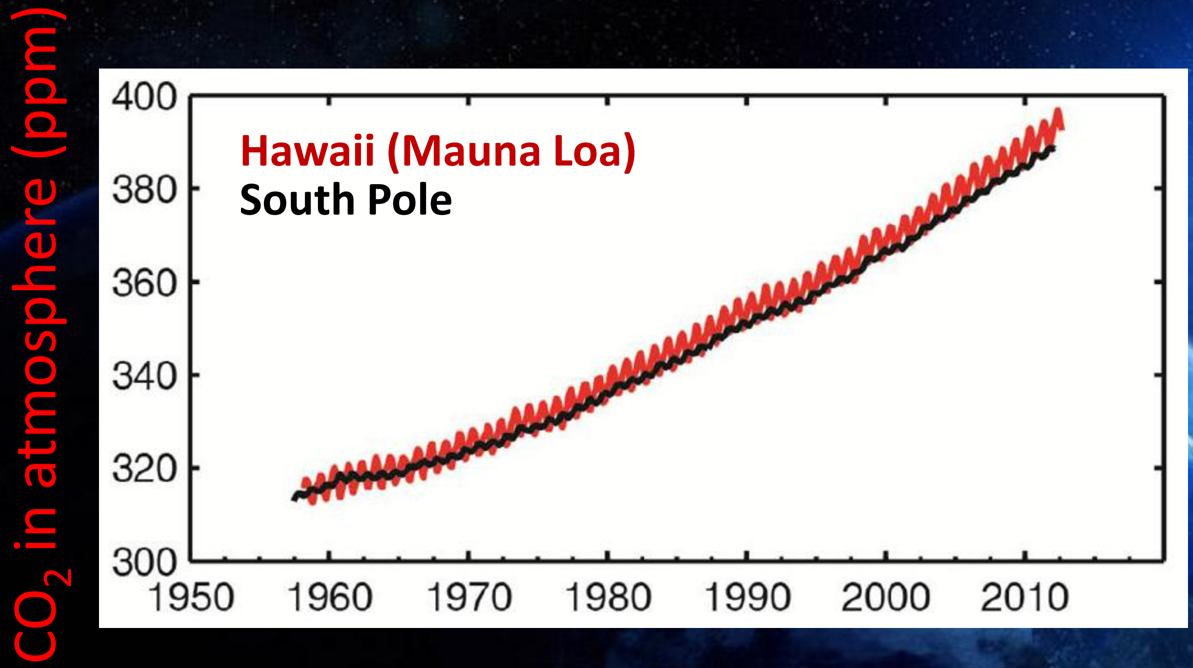


ISI World of Science data (provisional for 2013)

The driver for ocean acidification: increasing CO_2 emissions due to human activities

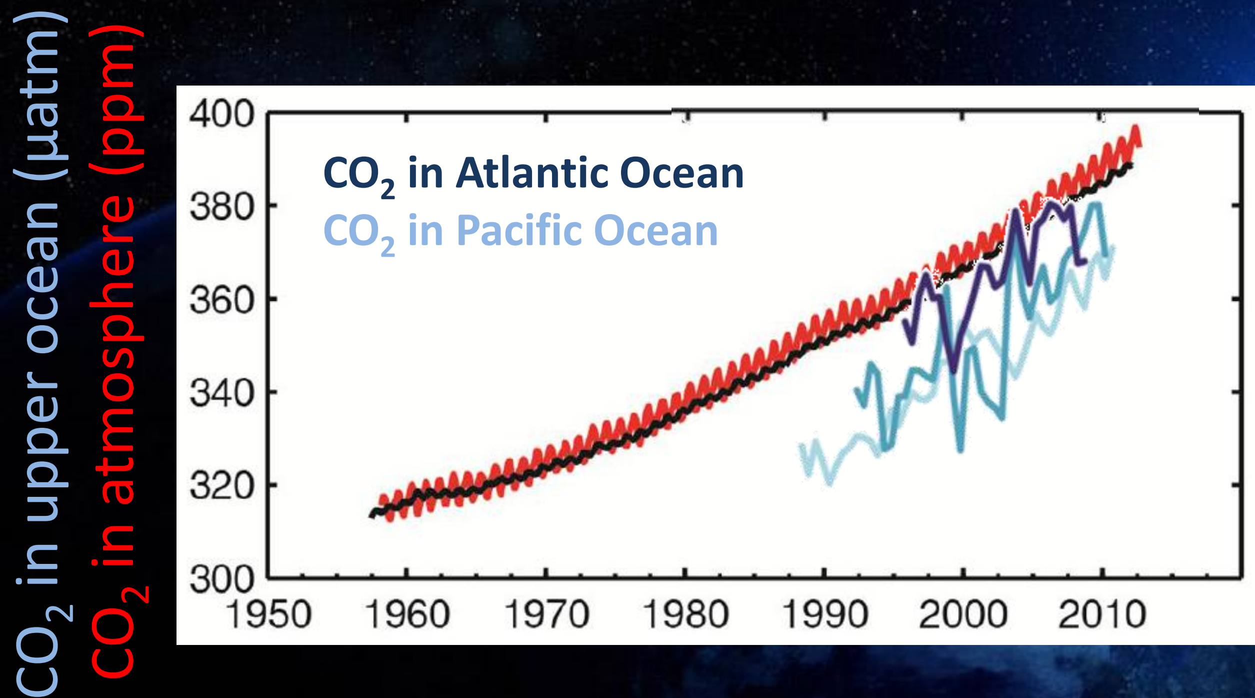


hence increased CO_2 in the atmosphere…



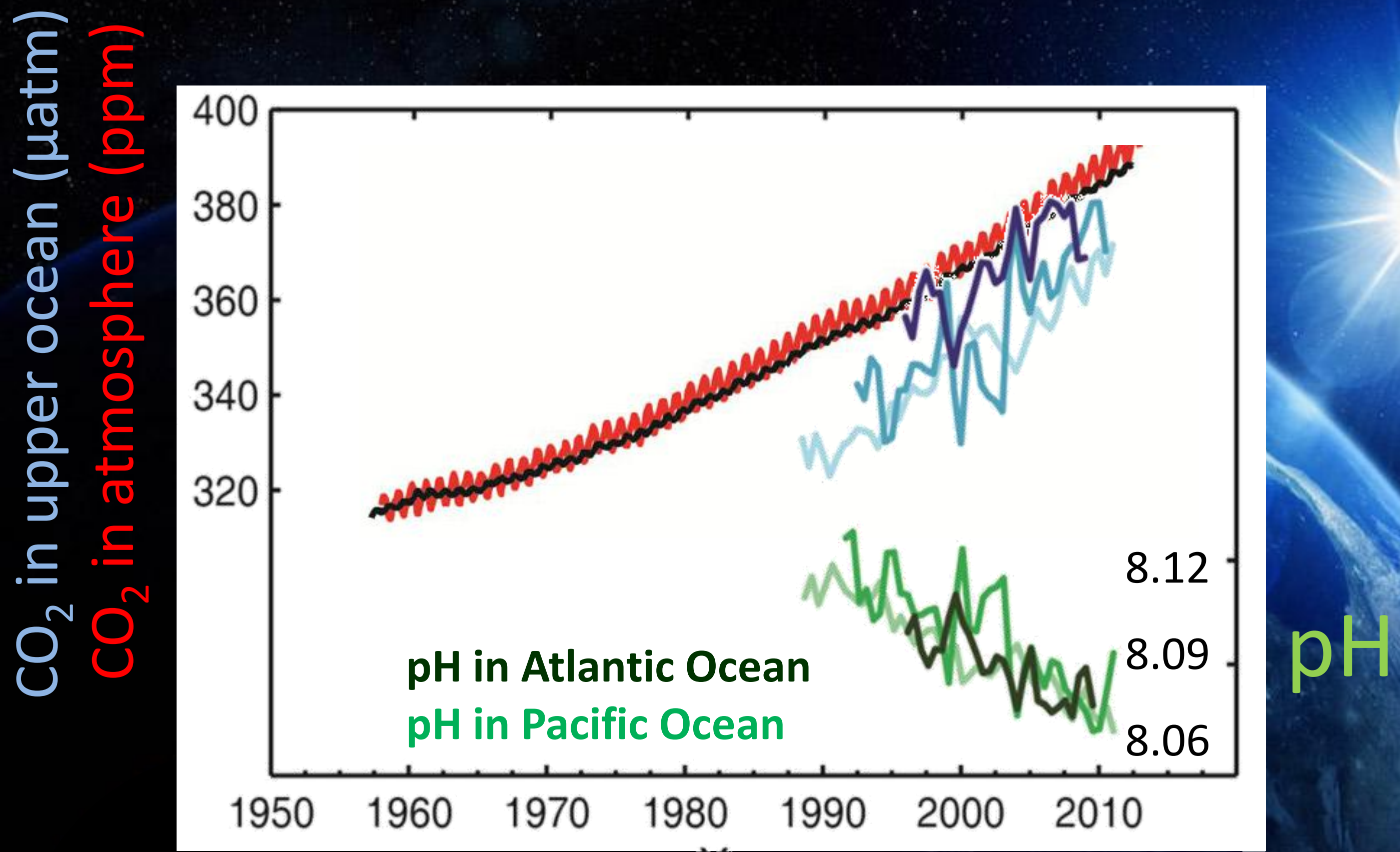
IPCC (2013) WG I, Summary for Policymakers, www.ipcc.ch

… and increased CO_2 in the upper ocean



IPCC (2013) WG I, Summary for Policymakers, www.ipcc.ch

… and decreased upper ocean pH *(increased H^+)*



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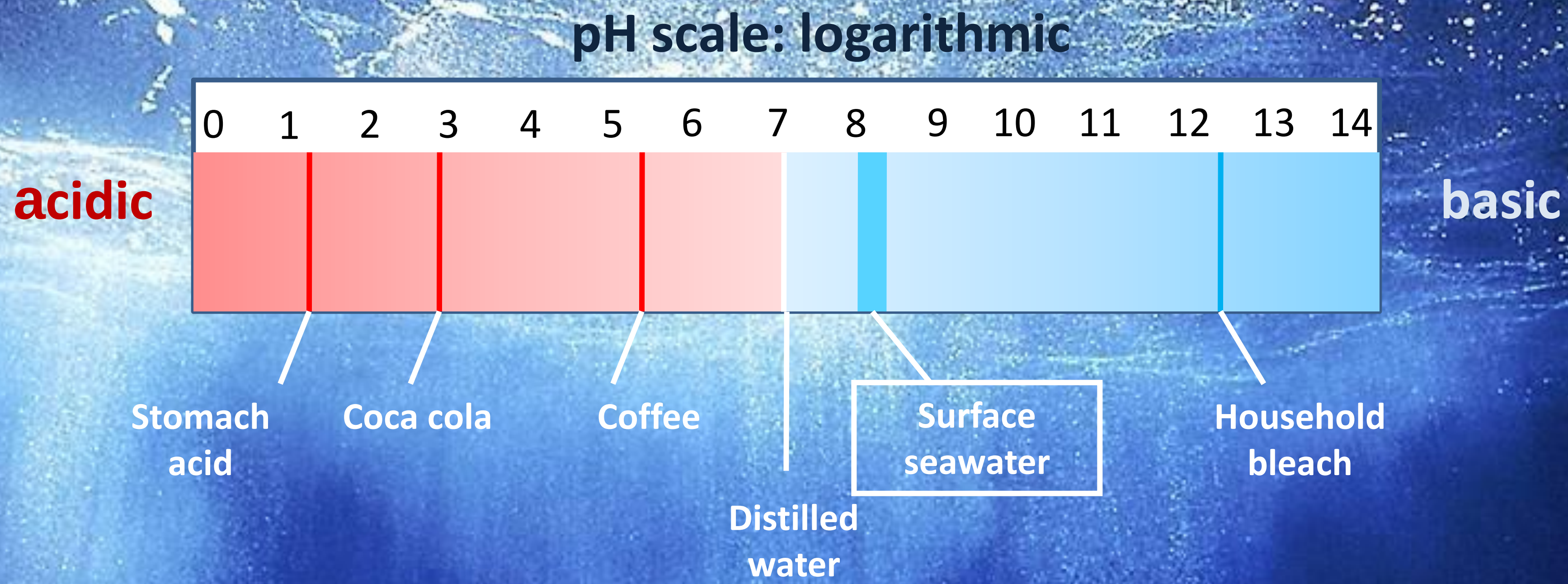
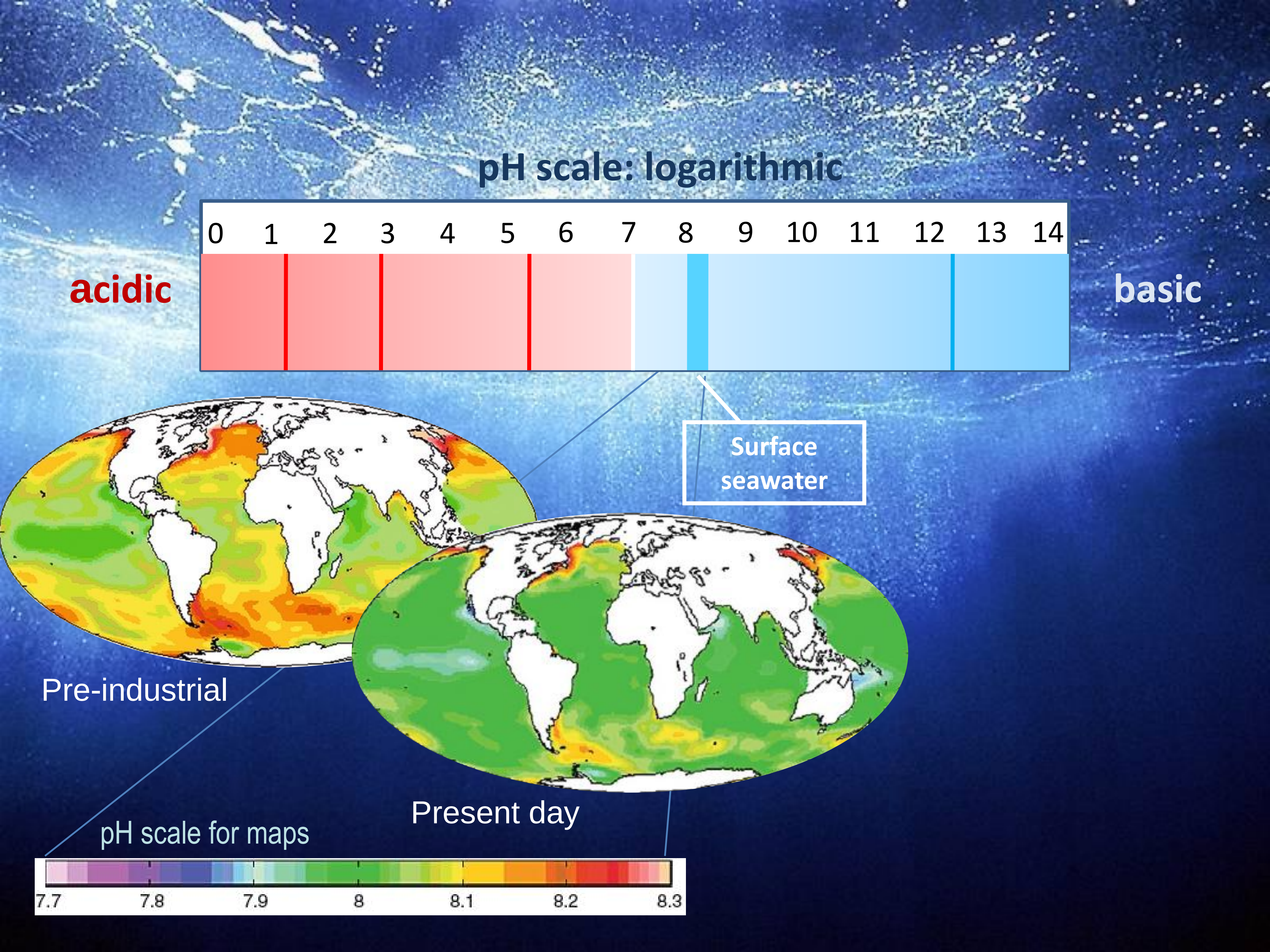
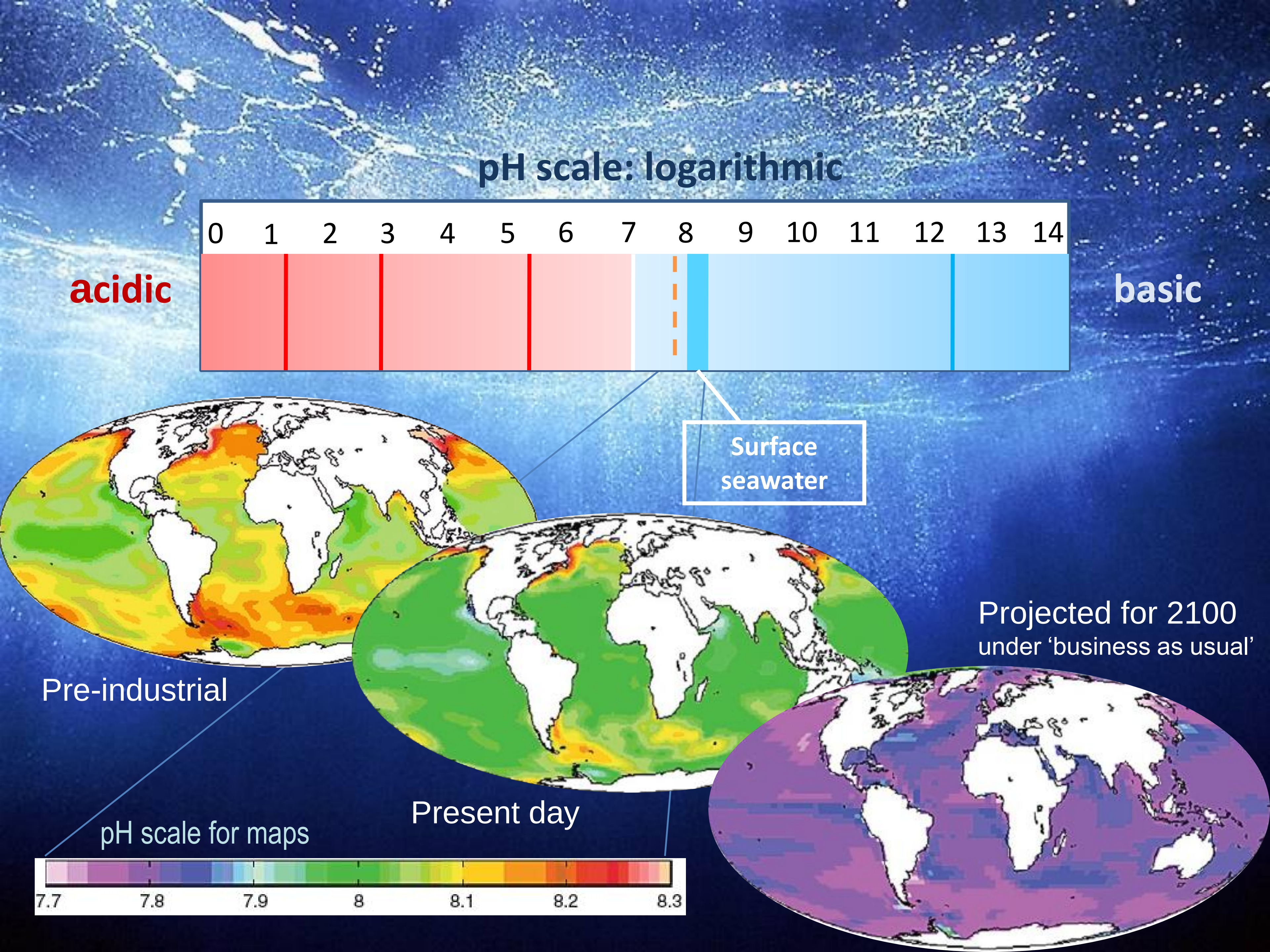


0.3 decrease in pH = doubling of H^+ concentration

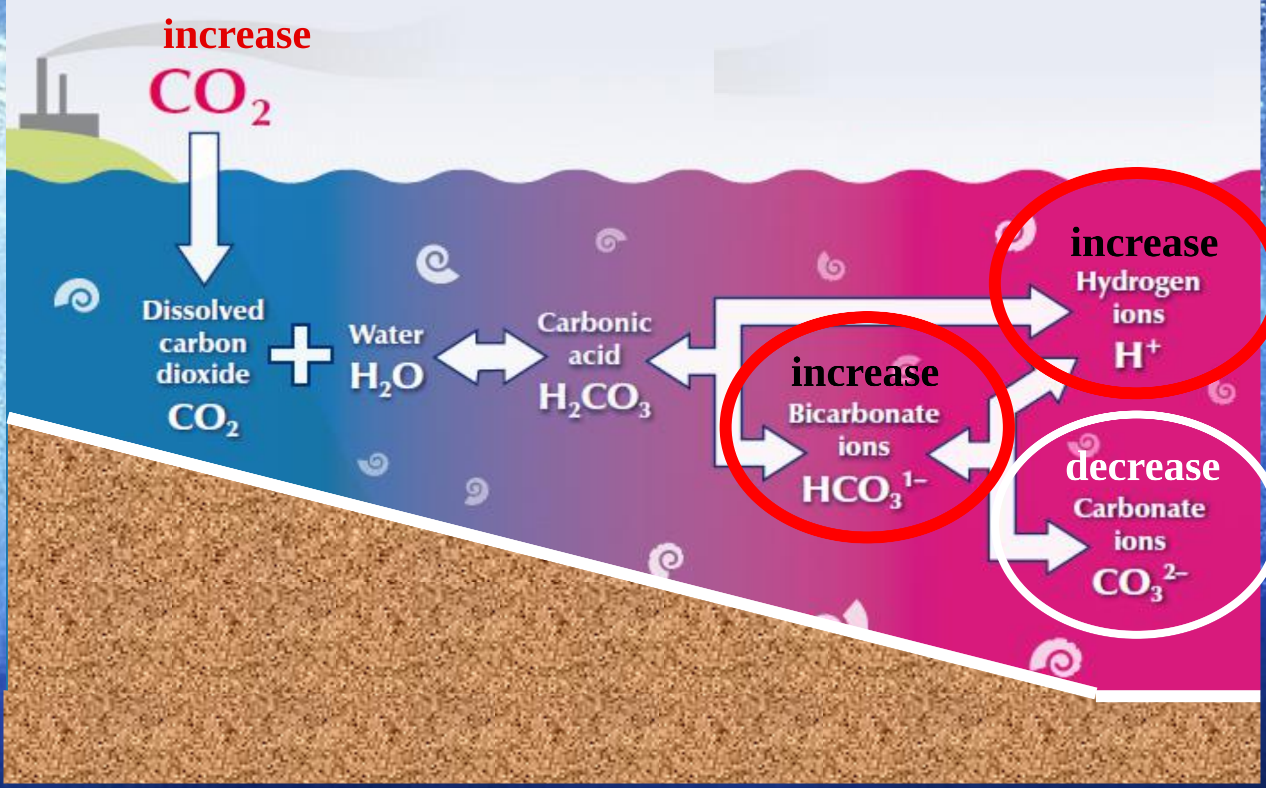
(decrease is considered to be "acidification", wherever on the scale it occurs)



pH scale: logarithmic
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
acidic
basic
Surface seawater
Pre-industrial
Present day
pH scale for maps
7.7
7.8
7.9
8
8.1
8.2
8.3


pH scale: logarithmic
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
acidic
basic
Surface seawater
Pre-industrial
Present day
Projected for 2100
under ‘business as usual’
pH scale for maps
7.7 7.8 7.9 8 8.1 8.2 8.3

Increased H^+ is not the only change involved in ocean acidification



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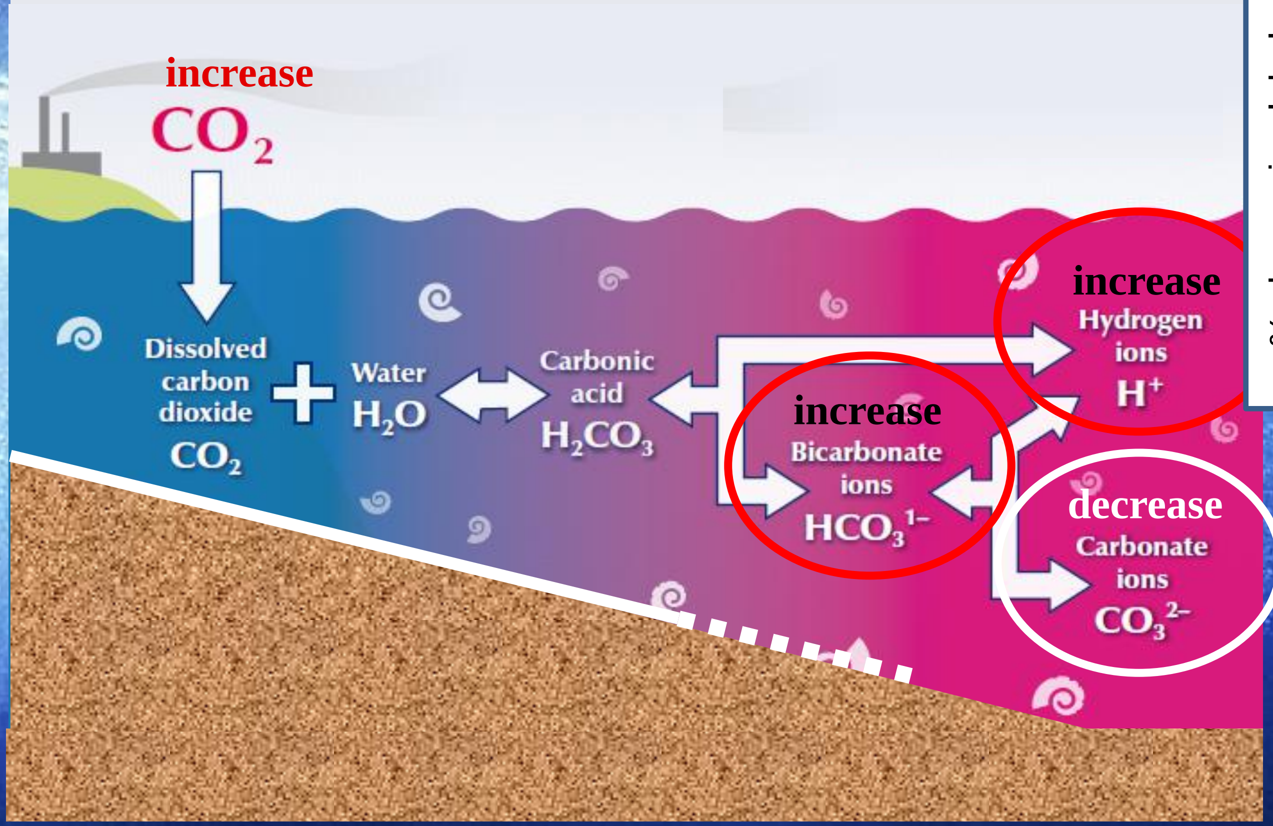
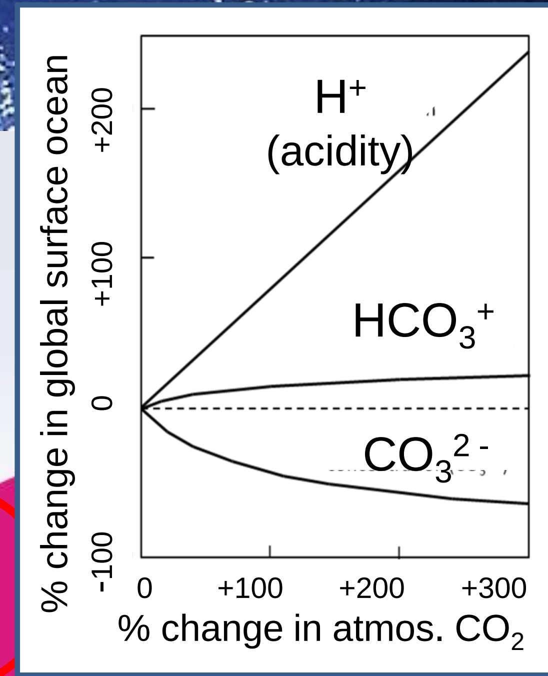
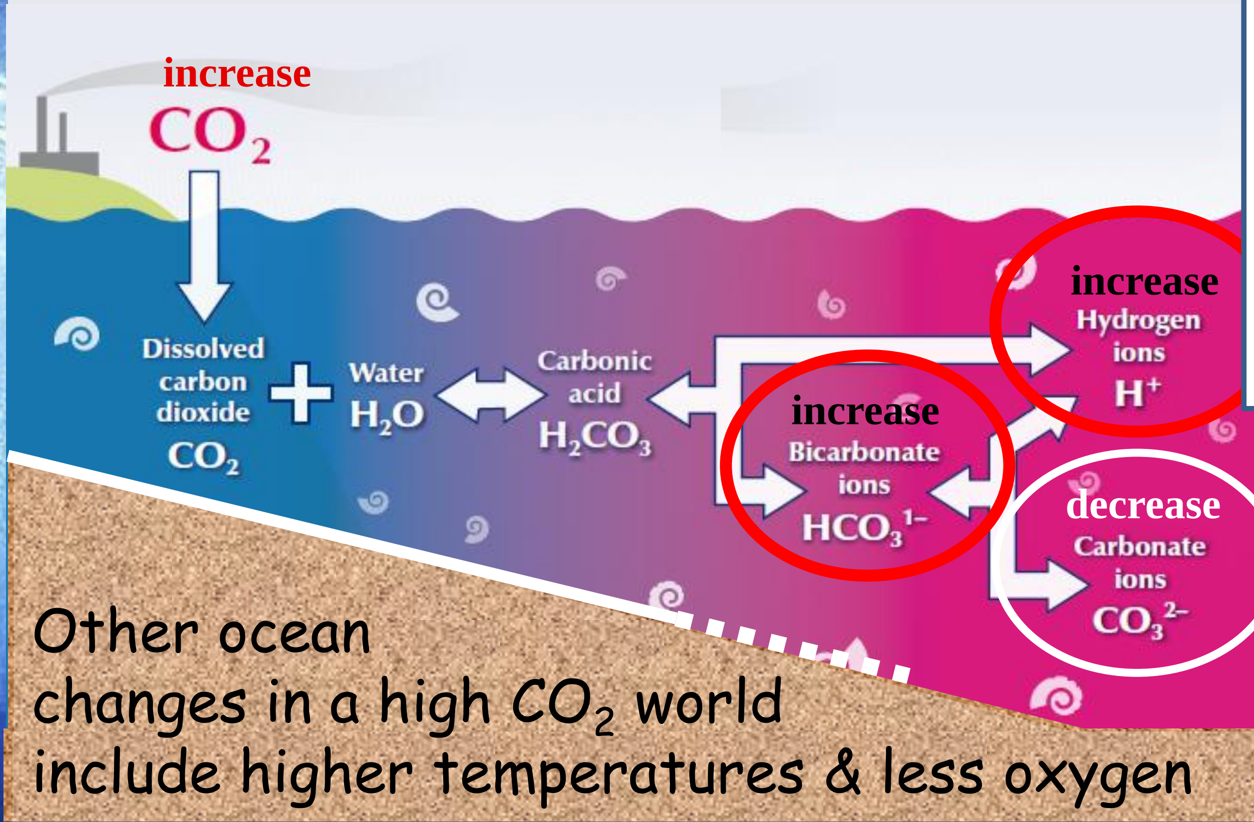


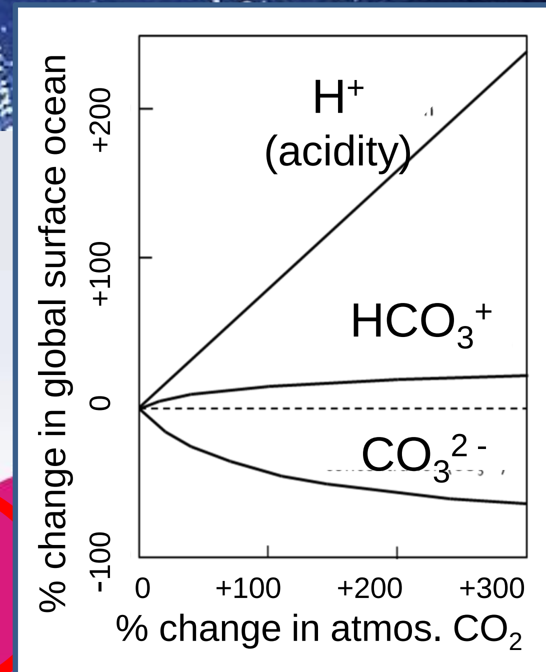


Affects calcium carbonate saturation state (Ω): when Ω < 1.0, unprotected $CaCO_3$ dissolves

Increased H^+ is not the only change involved in ocean acidification



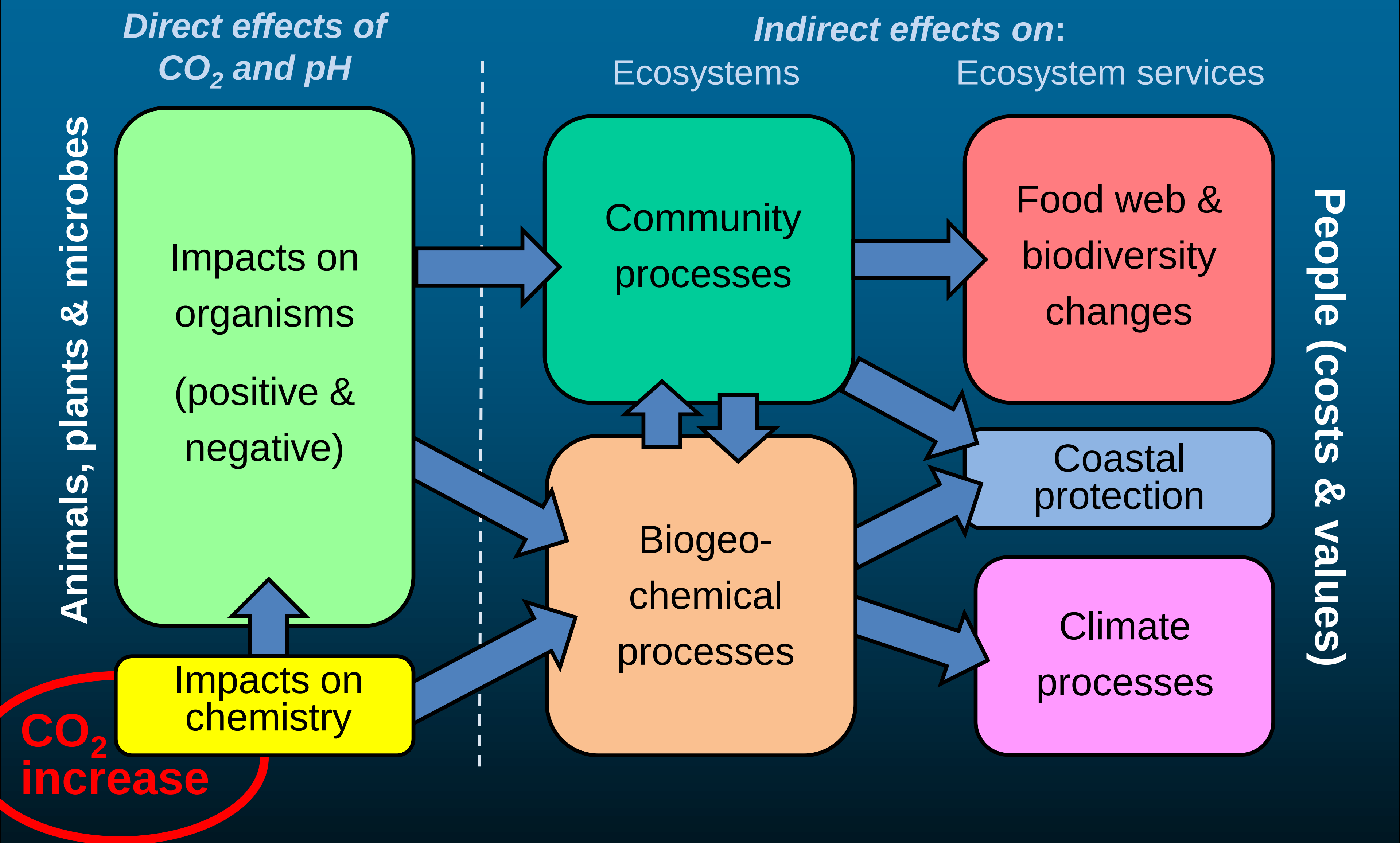
Other ocean
changes in a high CO_2 world
include higher temperatures & less oxygen



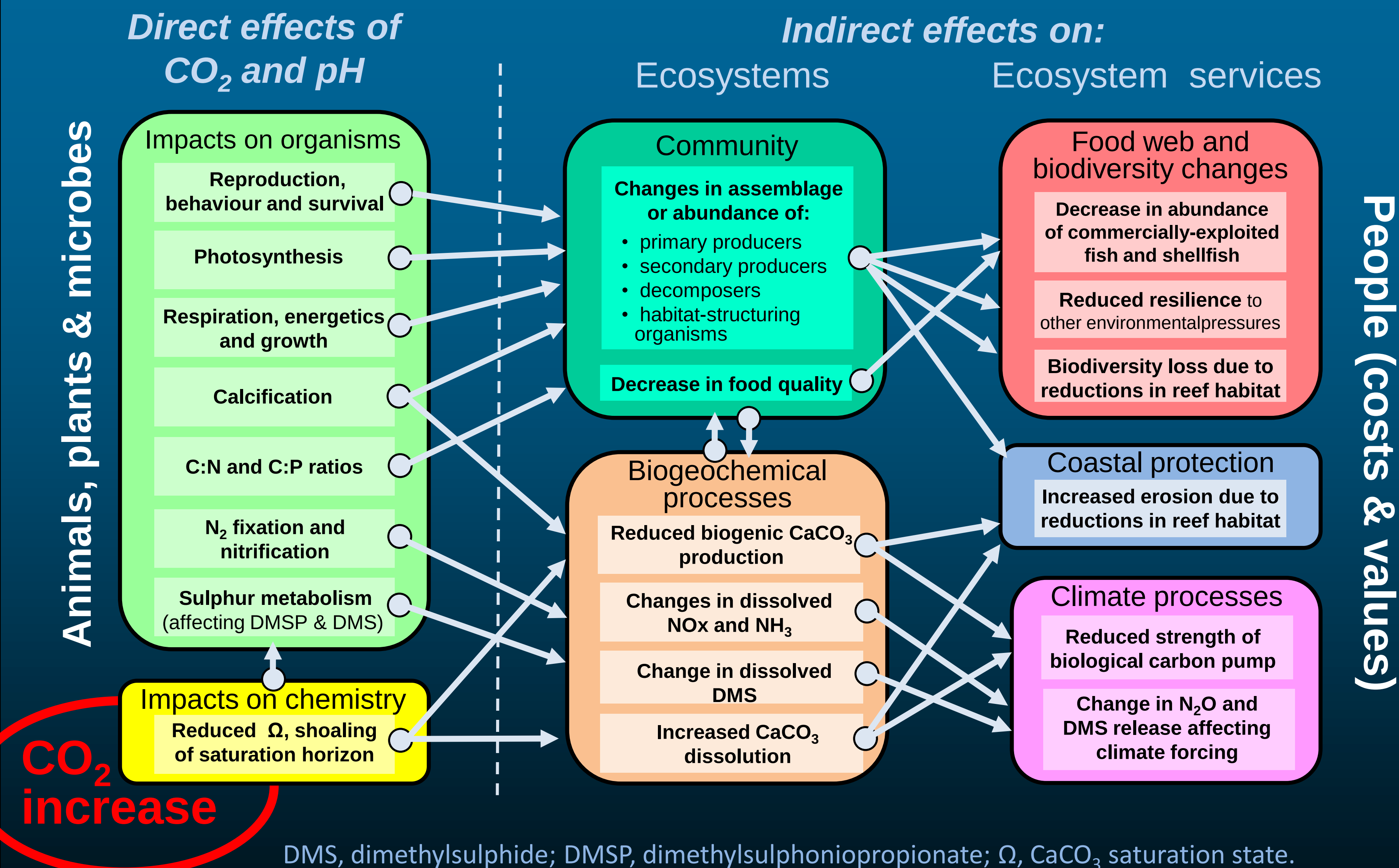
Affects calcium carbonate saturation state (Ω): when Ω < 1.0, unprotected $CaCO_3$ dissolves

Organisms (and ecosystem processes) may respond to any one - or all - of these interacting variables

Overview of ocean acidification impacts #1



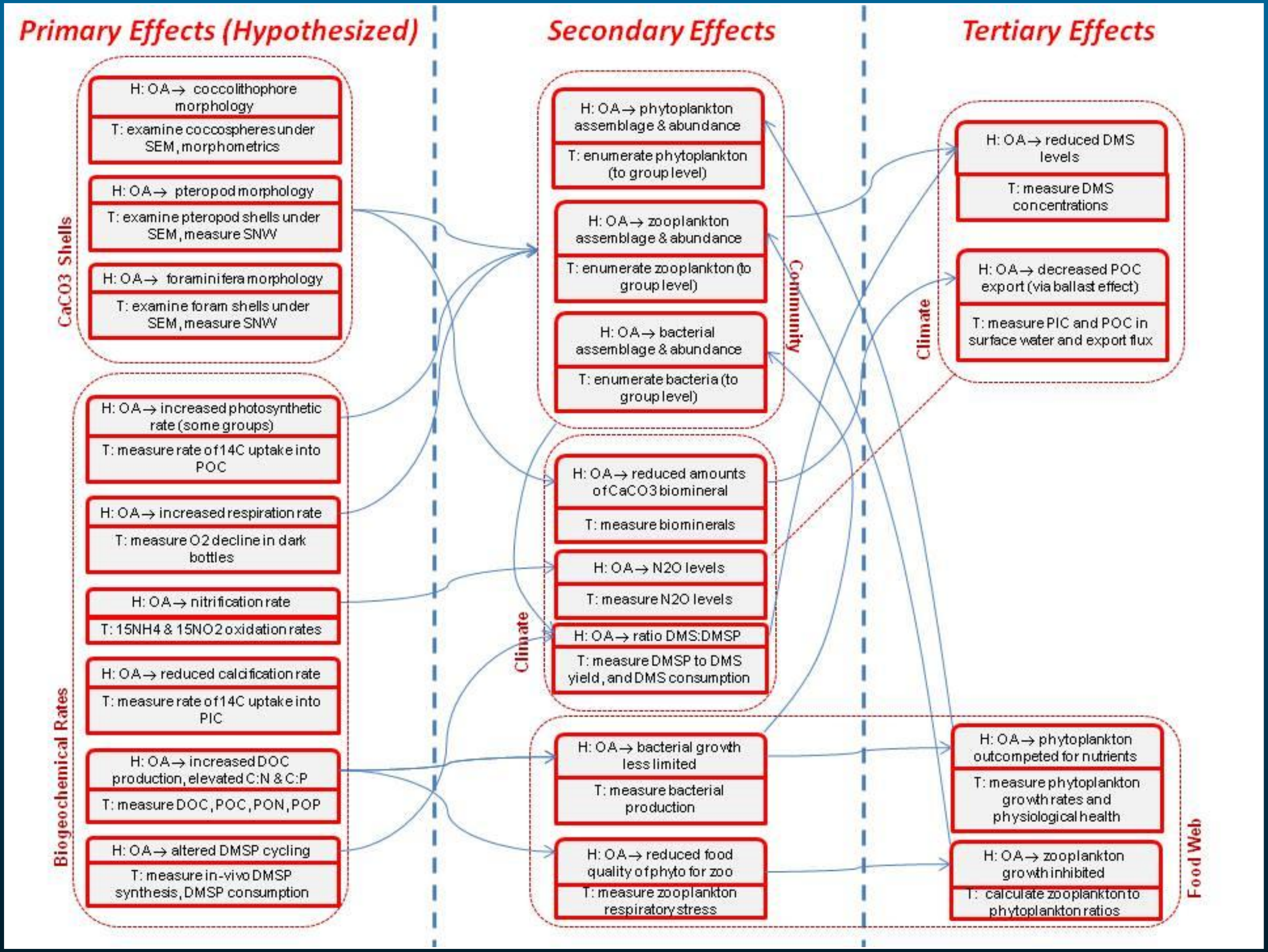
Overview of ocean acidification impacts #2



DMS, dimethylsulphide; DMSP, dimethylsulphoniopropionate; Ω, $CaCO_3$ saturation state.

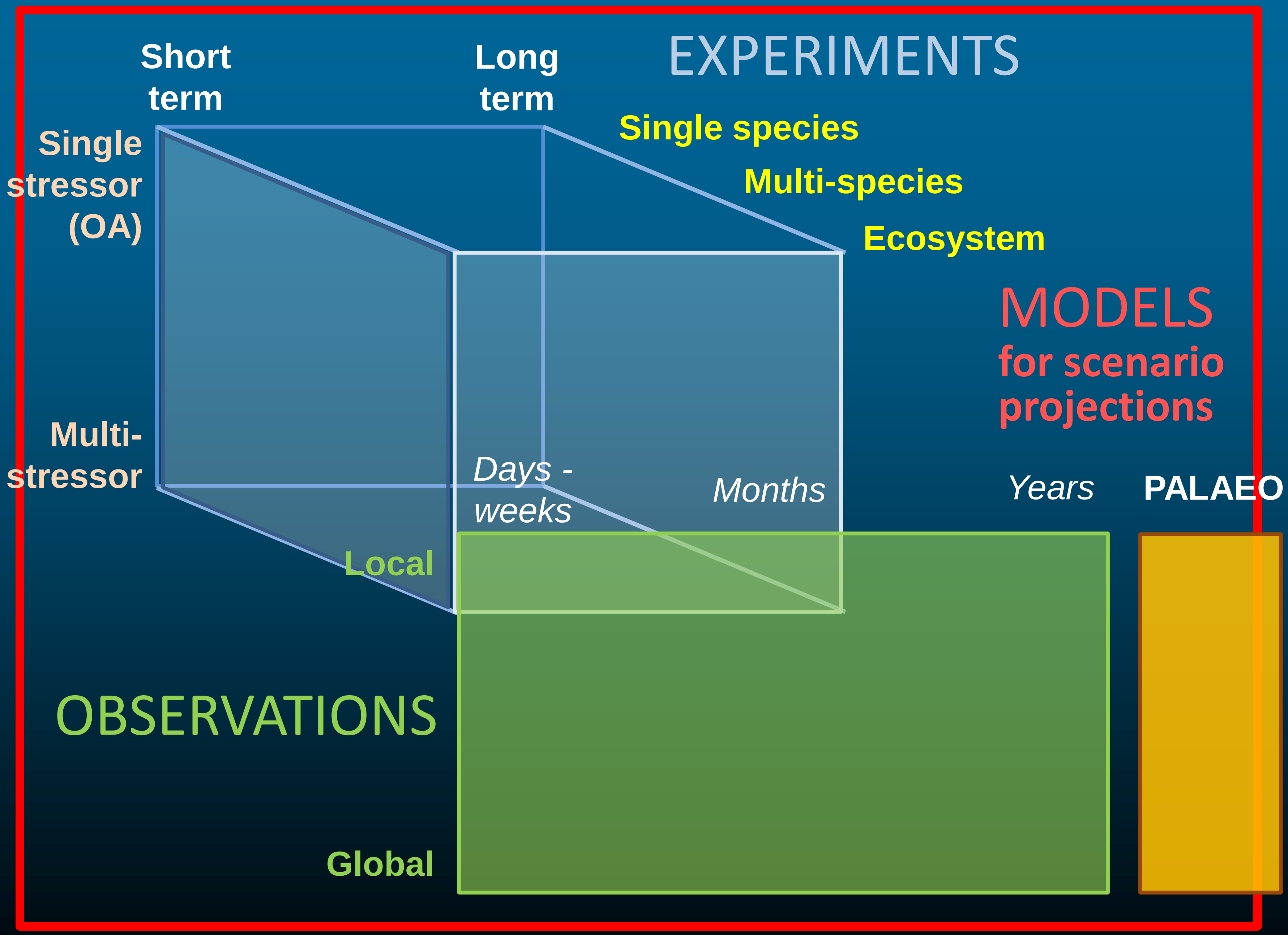
Williamson & Turley (2011), after Tyrrell

Overview of ocean acidification impacts #3



(original version of this diagram)

Evolving framework for OA research



Evolving framework for OA research

	Short term	Long term
Single stressor (OA)	*Days - weeks*	*Months*

EXPERIMENTS

Single species

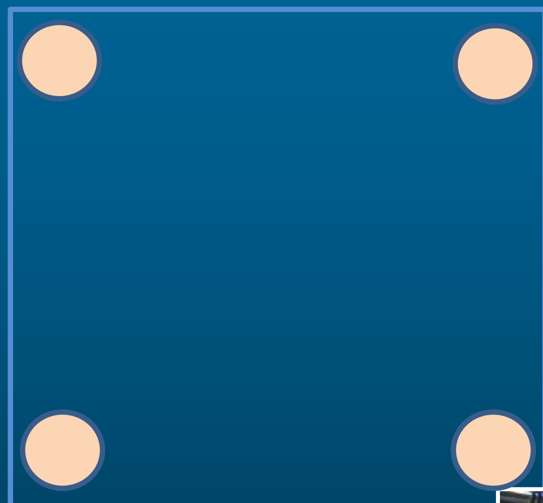
Evolving framework for OA research

Short term

Long term

Single stressor (OA)

Multi-stressor

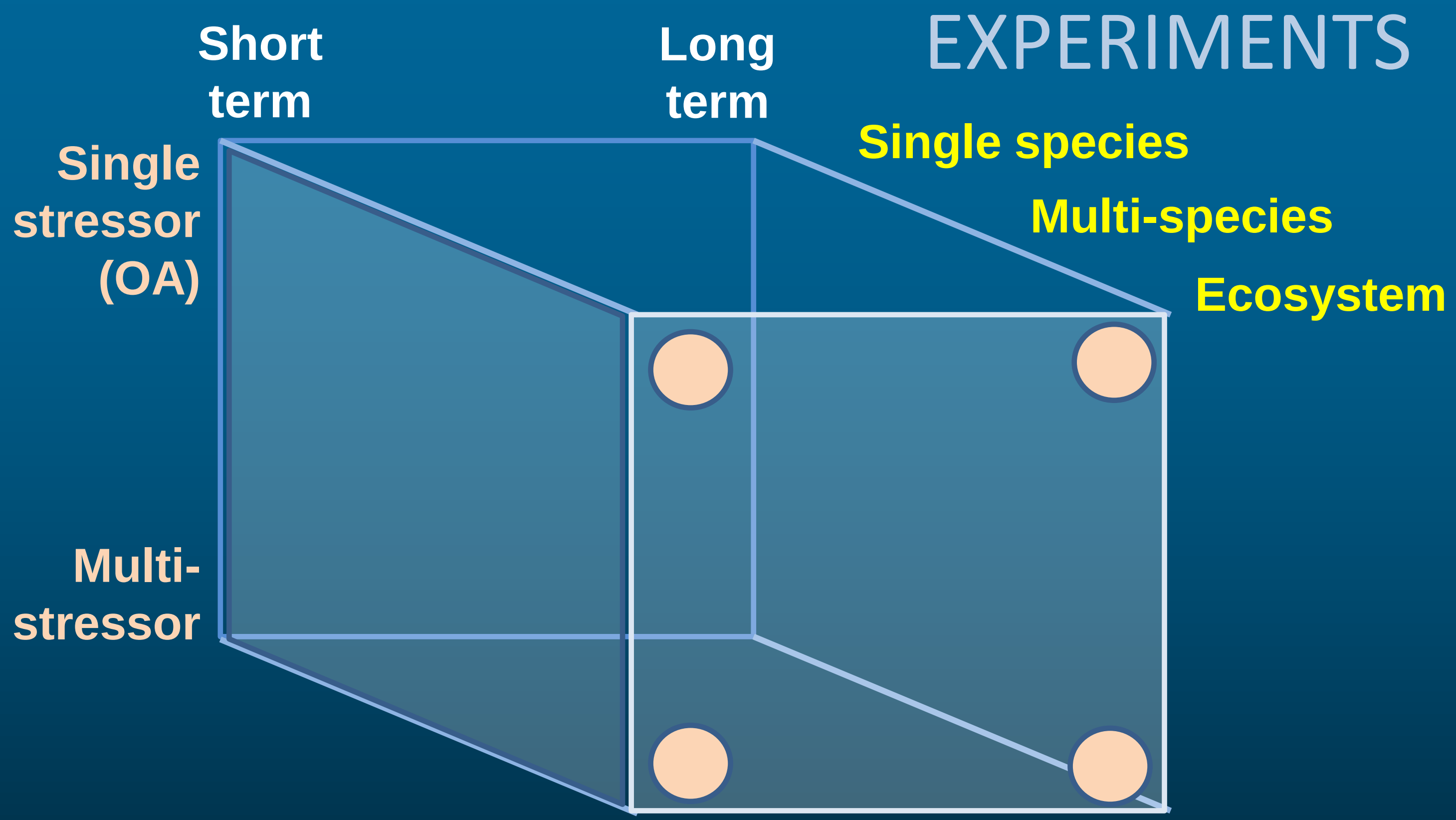


EXPERIMENTS

Single species

Other relevant variables include temperature, oxygen & food/nutrients:

Evolving framework for OA research



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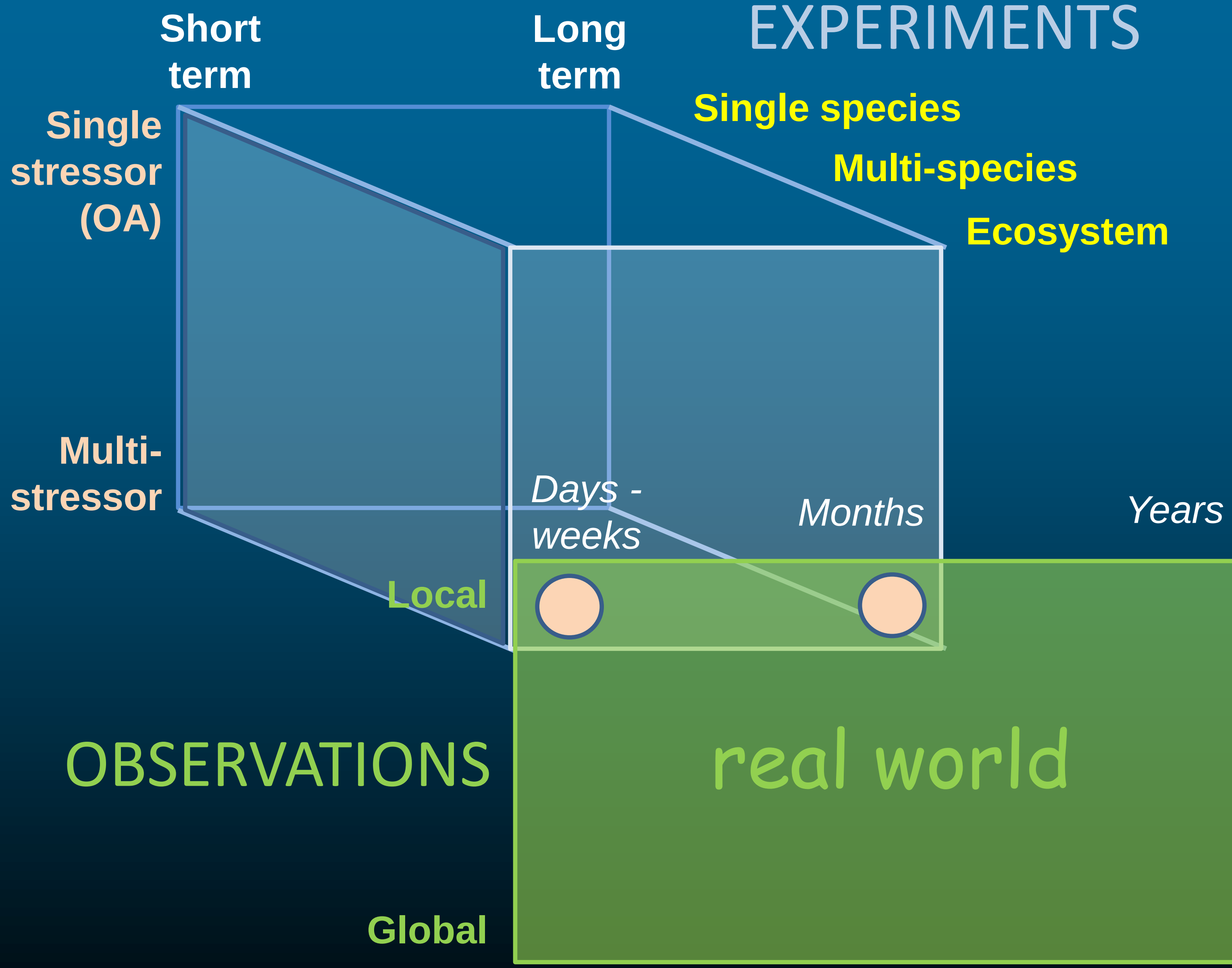

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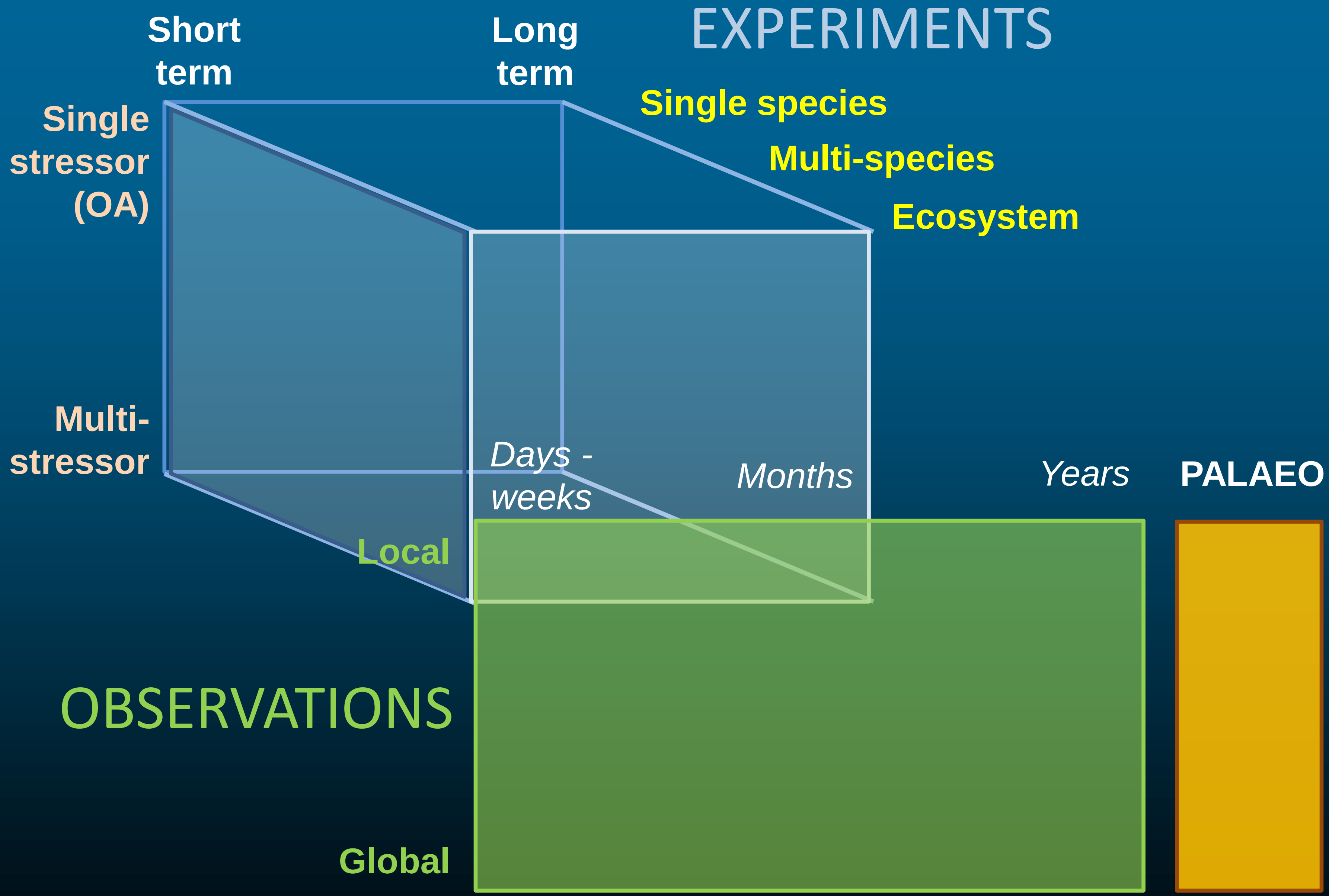

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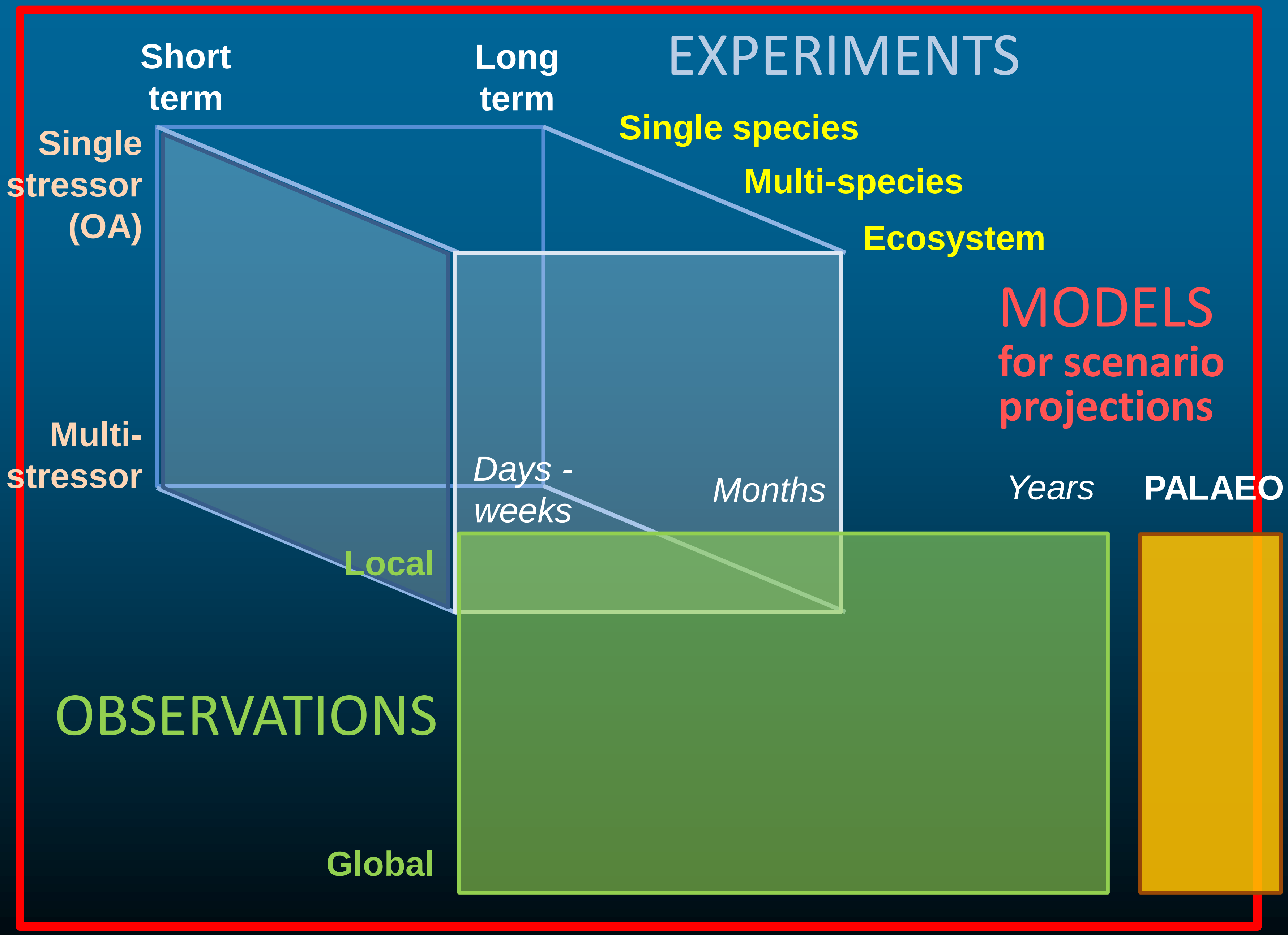
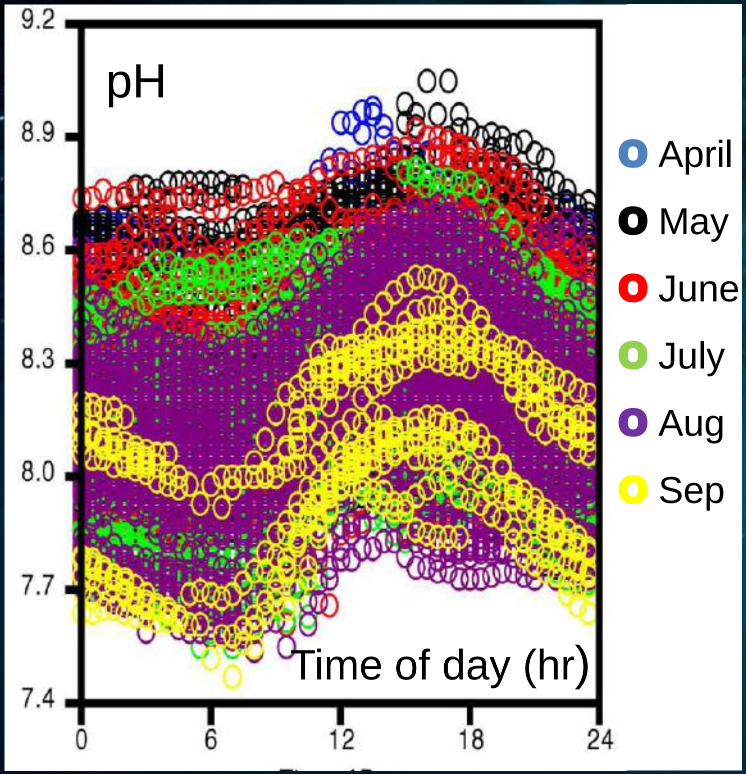


Physico-chemical variability

In coastal waters and shelf seas, pH (and other carbon chemistry parameters) can vary greatly on daily and seasonal basis

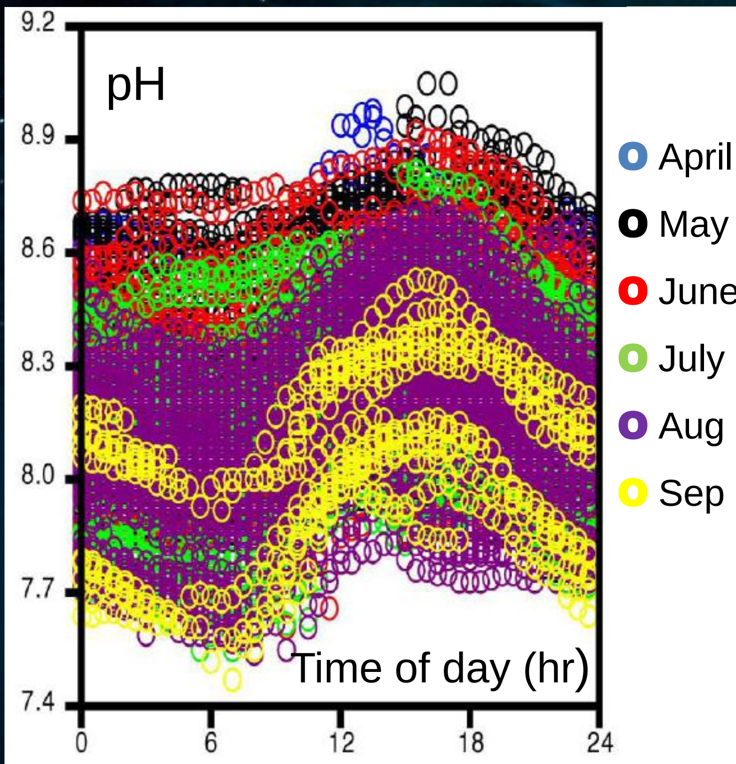


Diurnal and seasonal pH variability at Tatoosh Island WA, 2000-2007.
Wootton et al (2008)

Photo: Jason Hall-Spencer

Physico-chemical variability

In coastal waters and shelf seas, pH (and other carbon chemistry parameters) can vary greatly on daily and seasonal basis – also spatially



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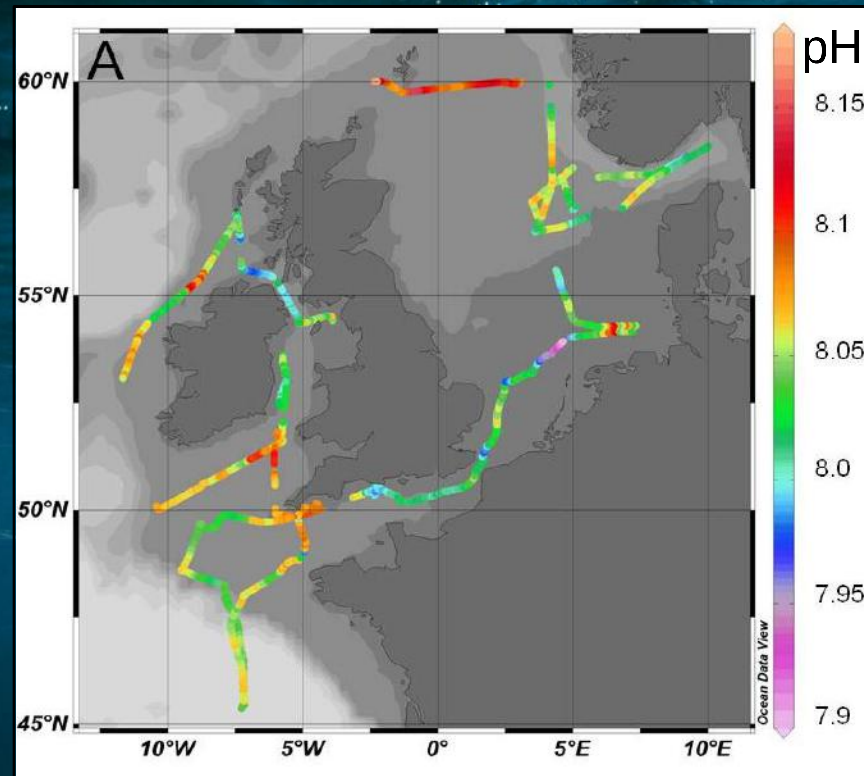


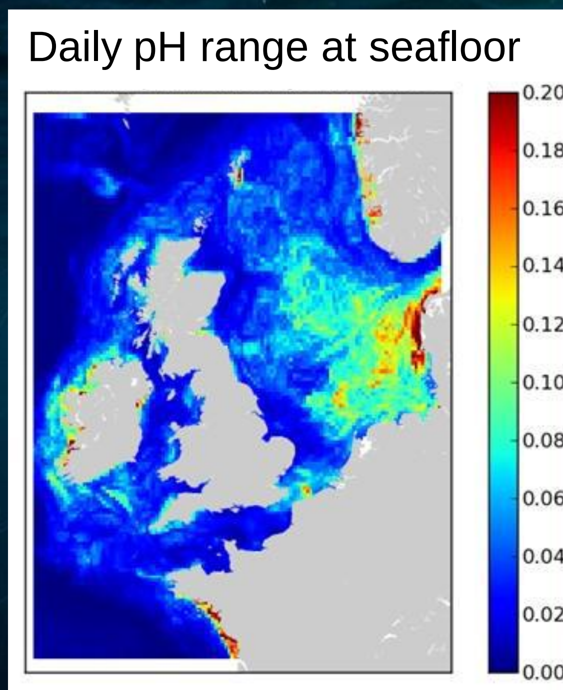
UKOA research cruise data 2011: underway near-surface pH (*Rerolle et al*)

Photo: Jason Hall-Spencer

Physico-chemical variability

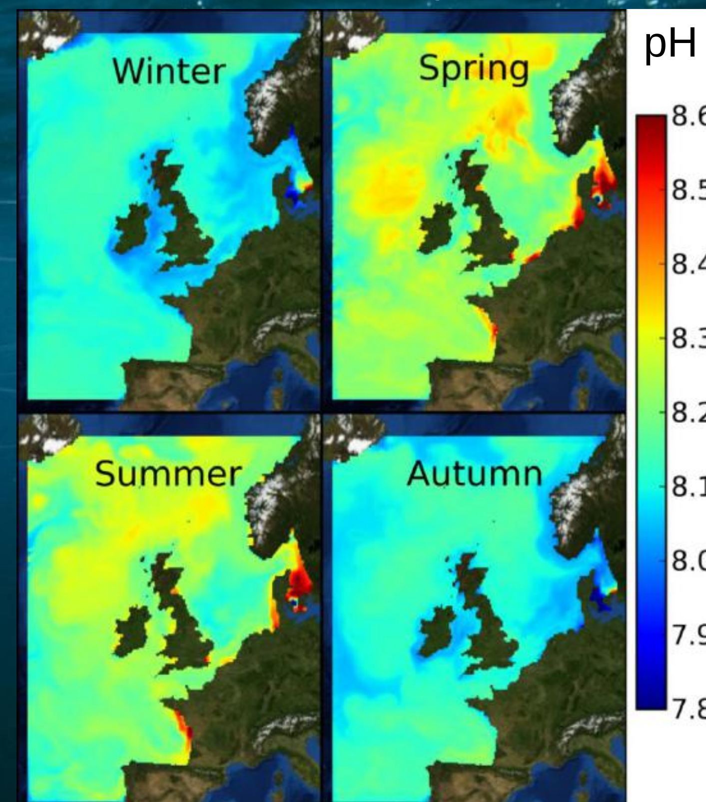
In coastal waters and shelf seas, pH (and other carbon chemistry parameters) can vary greatly on daily and seasonal basis – also spatially

This variability can now be simulated in high resolution models



Blackford et al; Artioli et al (2012)

Present day : sea surface



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Physico-chemical variability

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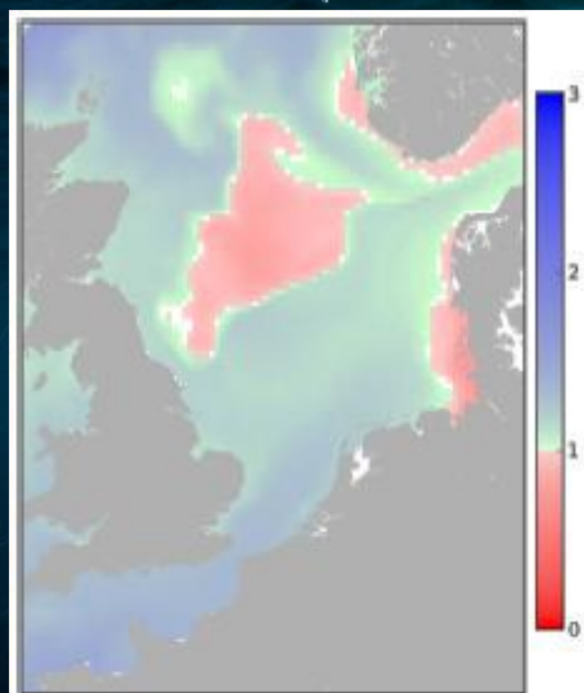
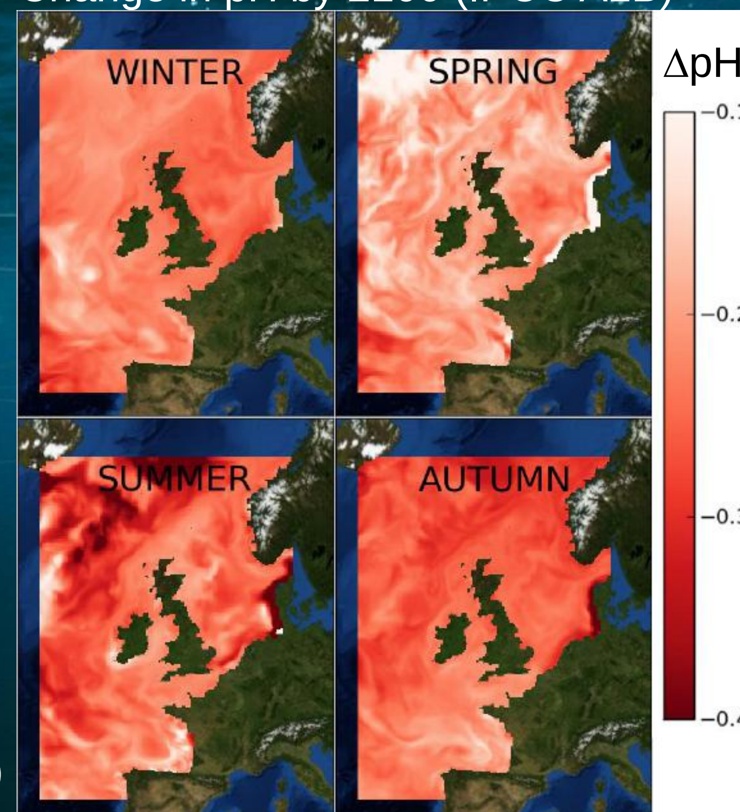
Aragonite saturation at sea floor by 2100 (IPCC A1B scenario)

Artioli et al (2013)



Change in pH by 2100 (IPCC A1B)

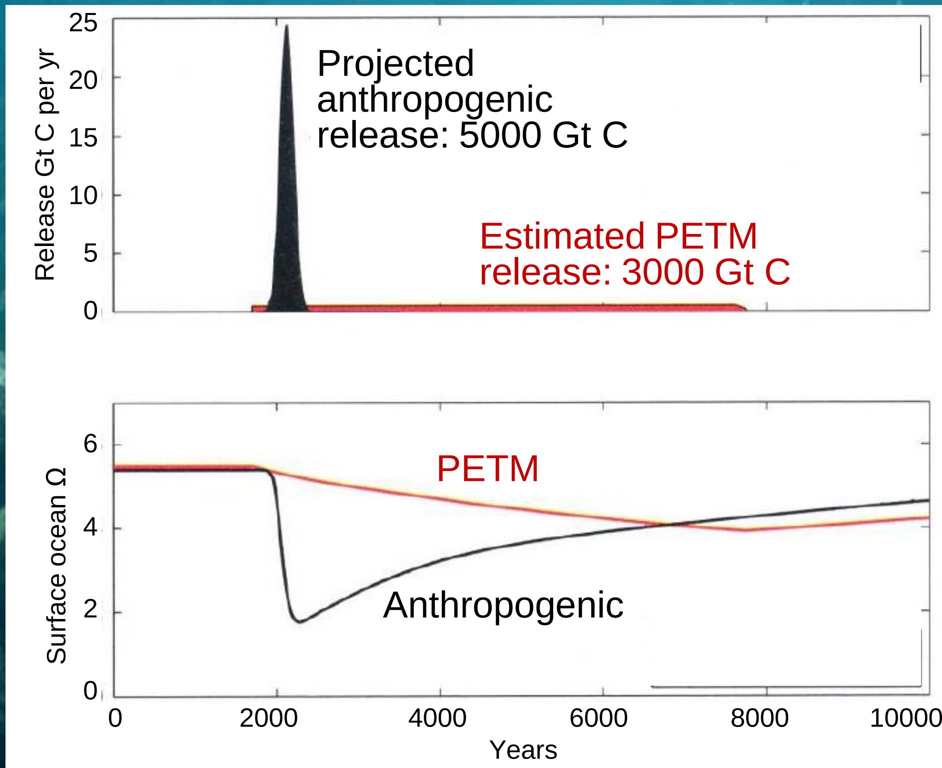


Artioli et al (2012)

Photo: Jason Hall-Spencer

Palaeo- studies: global OA has happened before

E.g. at Palaeocene-Eocene Thermal Maximum (PETM)



Zeebe & Ridgwell, 2011

At PETM onset, ~35% of benthic foraminifera became extinct

Note: i) rate of OA change was then 10 times slower than now; ii) recovery time was ~10,000 yr

Foster et al 2013

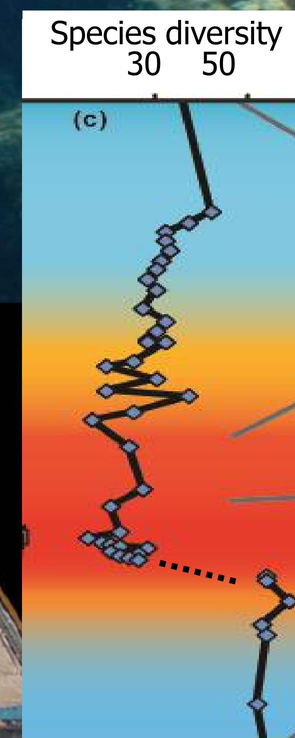
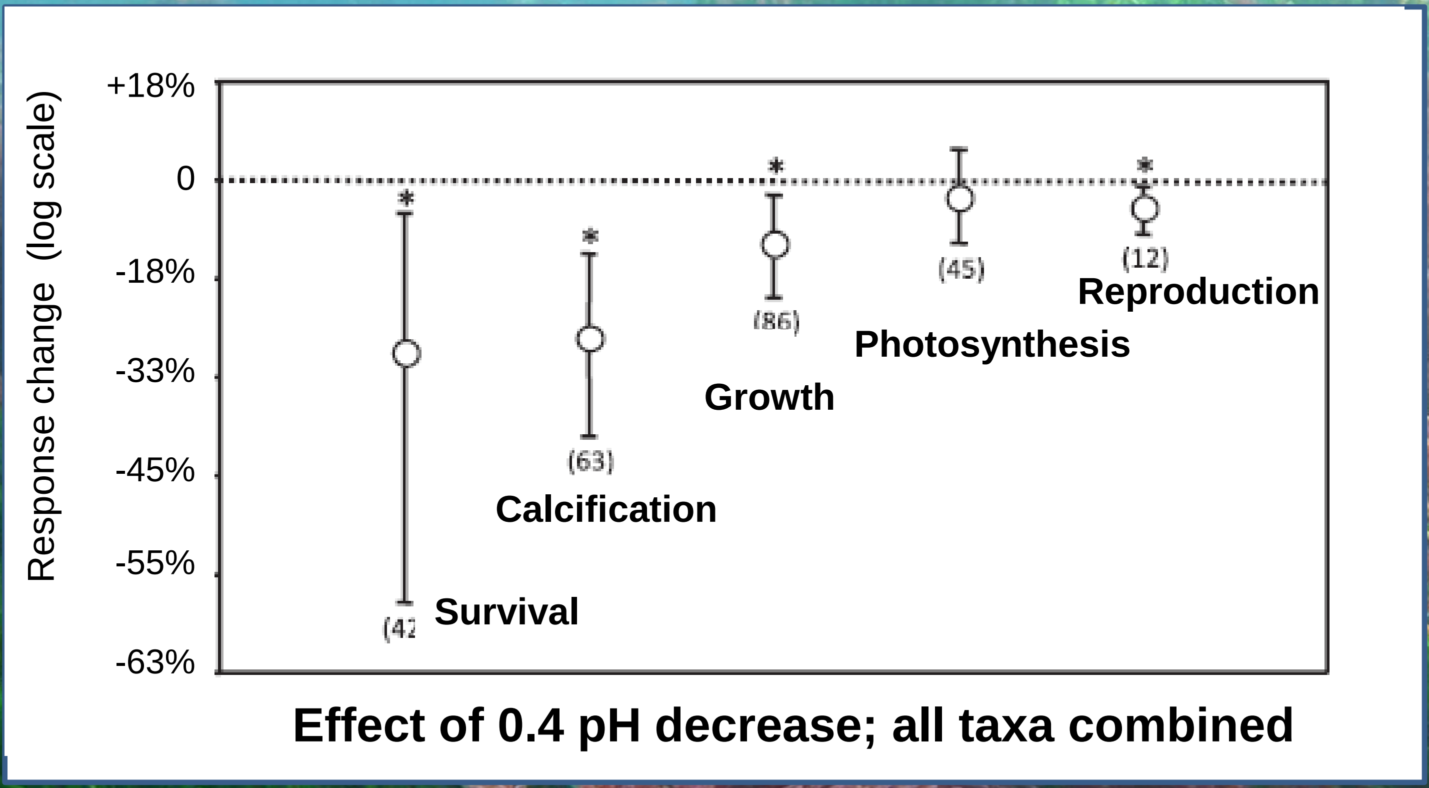


Photo: Jason Hall-Spencer

Metadata analysis based on single-species studies



Kroeker et al. 2010

Photo: Jason Hall-Spencer

Metadata analysis based on single-species studies

Kroeker et al. 2013

- Not tested or too few studies
- Enhanced <25%
- 95% CI overlaps 0
- Reduced <25%
- Reduced >25%

Taxa	Response	Mean Effect
Calcifying algae	Survival	
	Calcification	
	Growth	
	Photosynthesis	-28%
	Abundance	-80%
Corals	Survival	
	Calcification	-32%
	Growth	
	Photosynthesis	
	Abundance	-47%
Coccolithophores	Survival	
	Calcification	-23%
	Growth	
	Photosynthesis	
	Abundance	
Molluscs	Survival	-34%
	Calcification	-40%
	Growth	-17%
	Development	-25%
	Abundance	
Echinoderms	Survival	
	Calcification	
	Growth	-10%
	Development	-11%
	Abundance	

Taxa	Response	Mean Effect
Crustaceans	Survival	
	Calcification	
	Growth	
	Development	
	Abundance	
Fish	Survival	
	Calcification	
	Growth	
	Development	
	Abundance	
Fleshy algae	Survival	
	Calcification	
	Growth	+22%
	Photosynthesis	
	Abundance	
Seagrasses	Survival	
	Calcification	
	Growth	
	Photosynthesis	
	Abundance	
Diatoms	Survival	
	Calcification	
	Growth	+17%
	Photosynthesis	+12%
	Abundance	

Photo: Jason Hall-Spencer

Metadata analysis based on single-species studies

Kroeker et al. 2013

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	Abundance	
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	Development	-11%
	Abundance	

Crustaceans	Survival	
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	Growth	
	Development	
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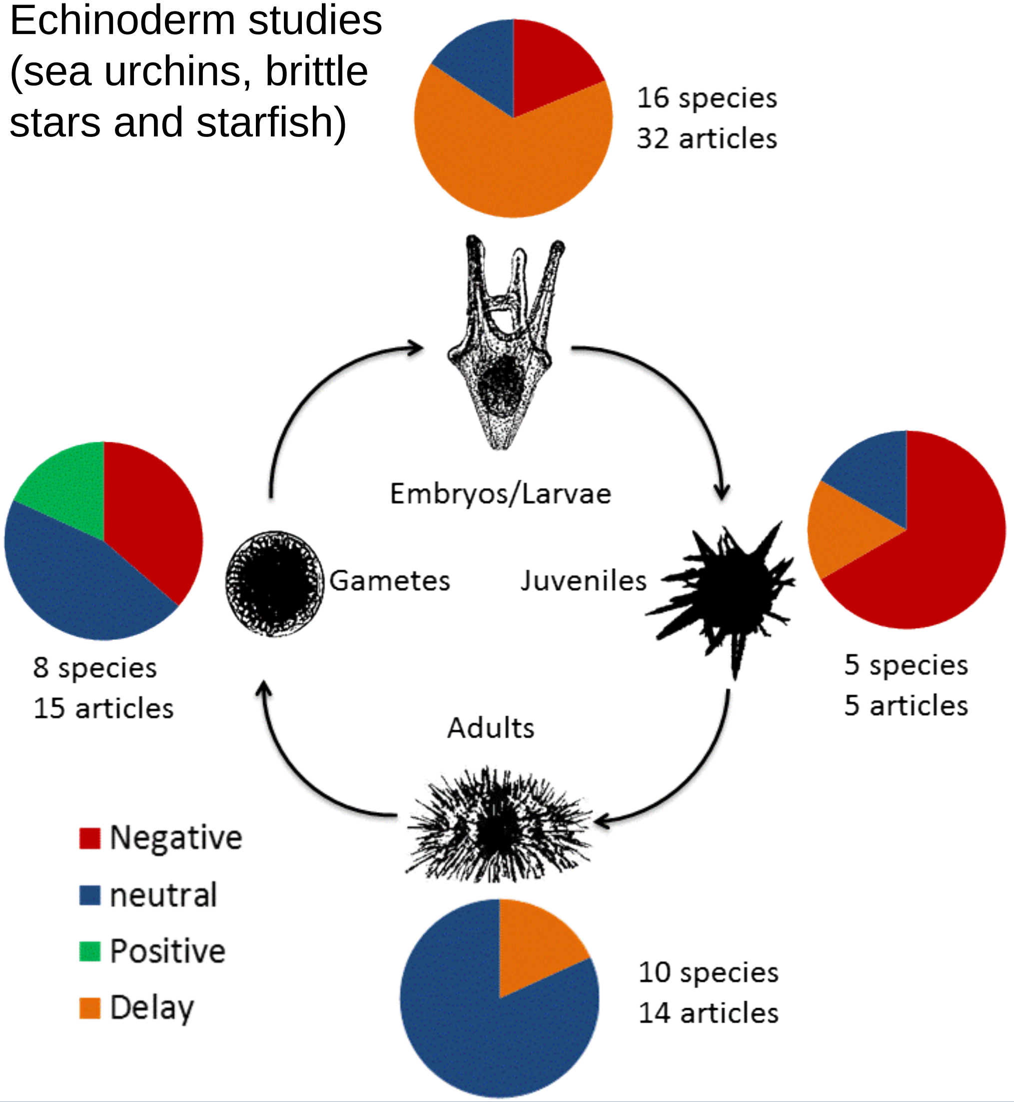
Such analyses need to be carefully interpreted!

Photo: Jason Hall-Spencer

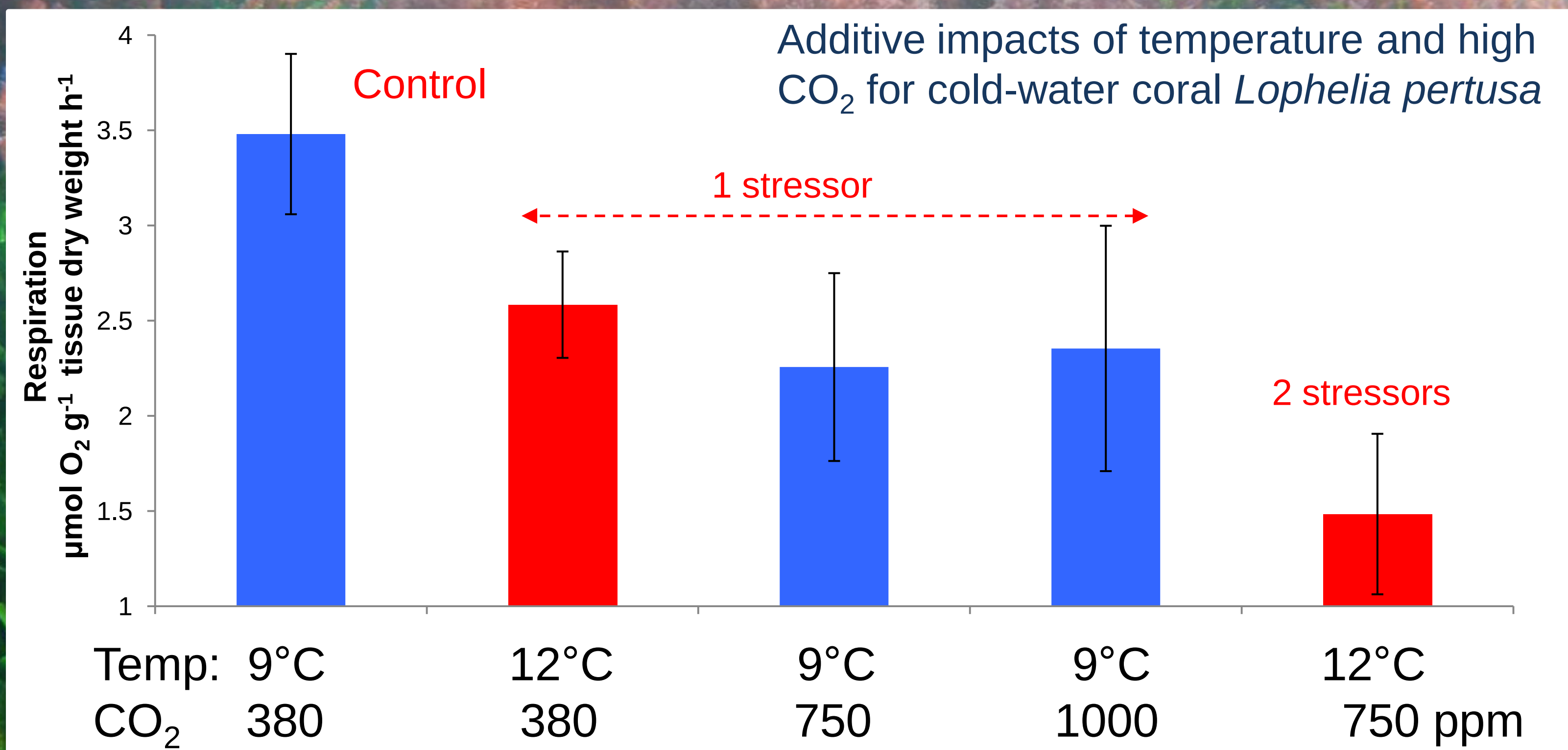
Intra-taxon variability in response to OA

Echinoderm studies (sea urchins, brittle stars and starfish)



Early life stages – embryos, larvae and juveniles – are much more sensitive to OA than adults

Multi-stressor studies show that interactions can be additive/synergistic or antagonistic

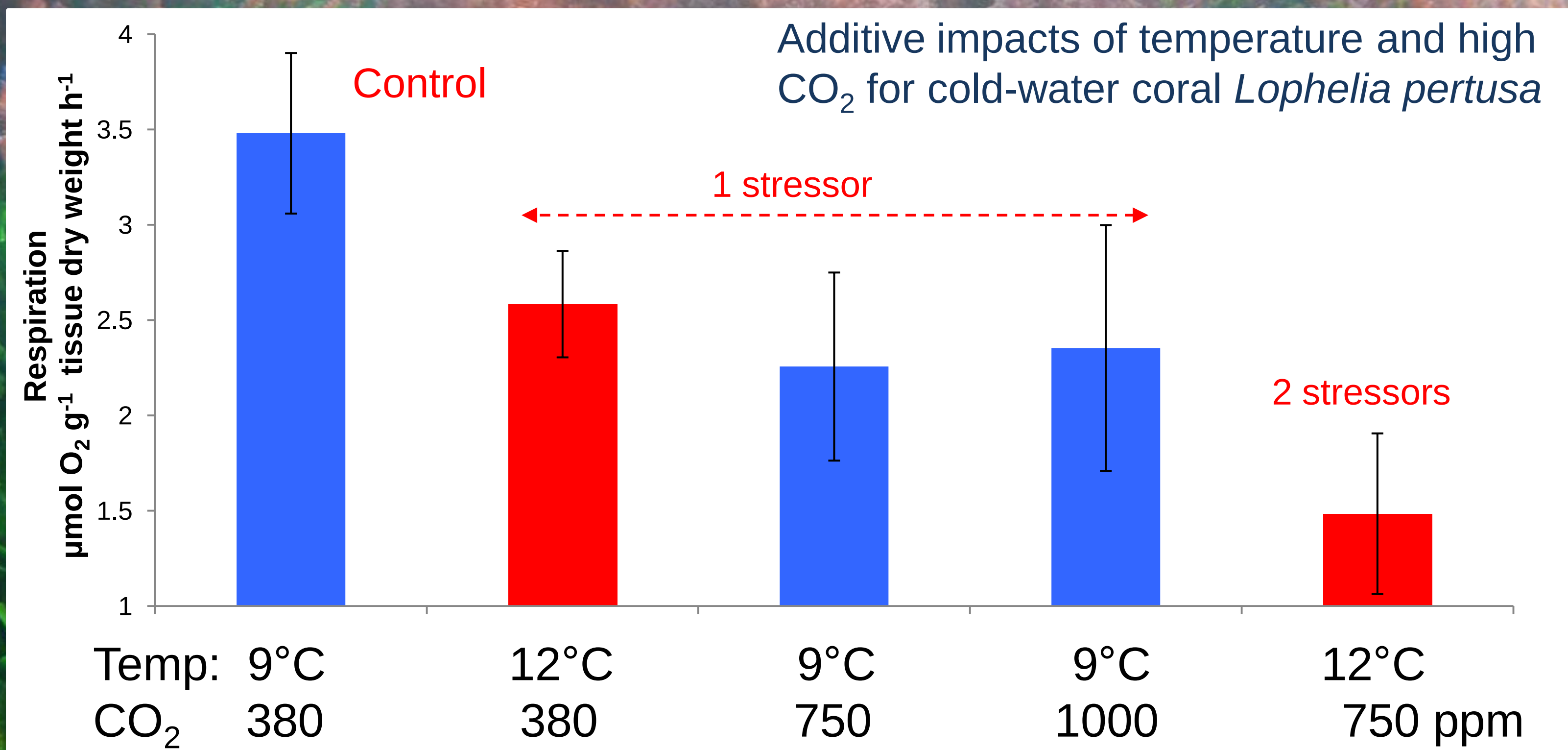


Preliminary data: Hennige & Murray

Photo: Jason Hall-Spencer

Multi-stressor studies show that interactions can be additive/synergistic or antagonistic

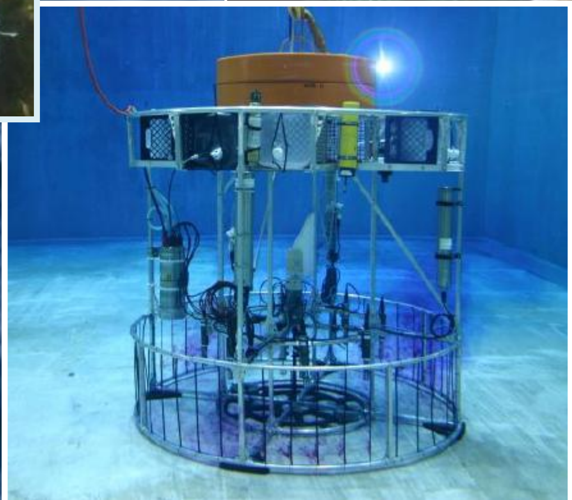
But multi-factor experiments are complex (and food quality/quantity may be critical)



Preliminary data: Hennige & Murray

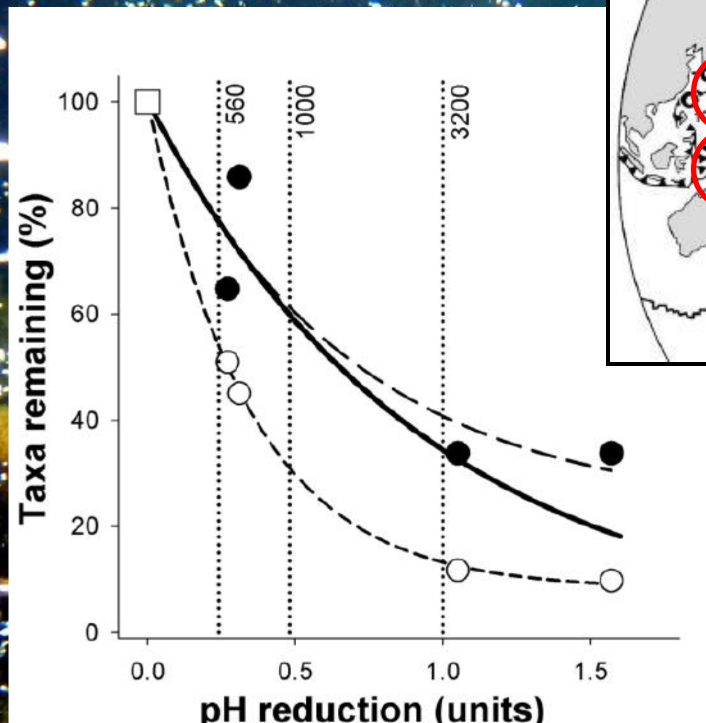
Photo: Jason Hall-Spencer

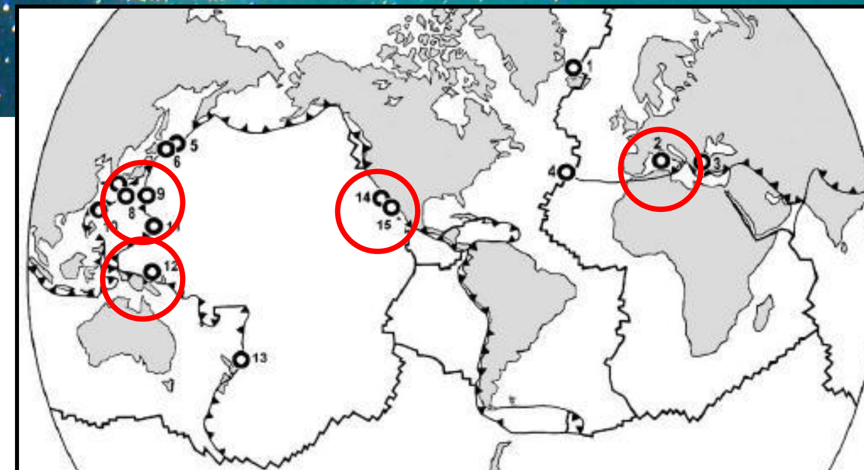
Multi-species and ecosystem-scale experiments



Mesocosms and Free Ocean CO_2 Enrichment (FOCE) studies: *ecologically more realistic, but high cost for multi-factor replicates*

Natural experiments at ecosystem-scale





High CO_2 vents (in the Mediterranean, USA, Japan, and Papua New Guinea) show dramatic biodiversity loss and community shifts, favouring seagrasses and non-calcified algae

Photo: Jason Hall-Spencer

Impact of OA on ecosystem function

Ecosystem services and socio-economics:

Loss of tropical coral reefs is likely to be the greatest societal impact of ocean acidification, with costs estimated at ~ US $1,000 billion per year *(Brander 2012)*

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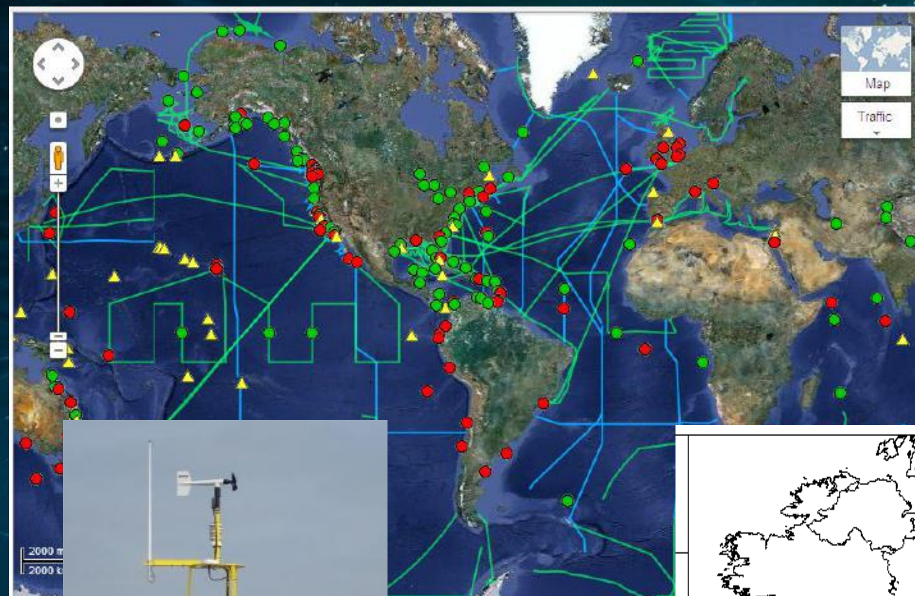
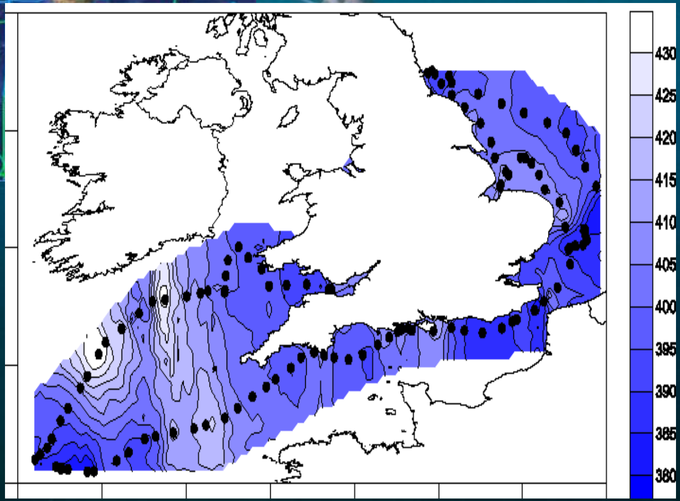
Costs of other OA impacts – on fisheries, aquaculture, food web structure and climate regulation – are not yet well-defined

Observational requirements

Urgent need to develop global observing network for OA and ecosystem response, linked to existing observing systems



UK work by Cefas, Marine Scotland, NOC, PML and university research groups



Coastal Futures 2014 | UK Ocean Acidification Research Programme | London: 23 January

Main recent achievements

- Importance of multiple stressors
- Improved techniques
- Awareness of biological variability
- Awareness of chemical variability
- Importance of scope for adaptation
- Insights from palaeo- studies
- Development of ecosystem-level studies

Phil Williamson

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with acknowledgements to UKOA researchers, funders & others