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Listen to the ocean

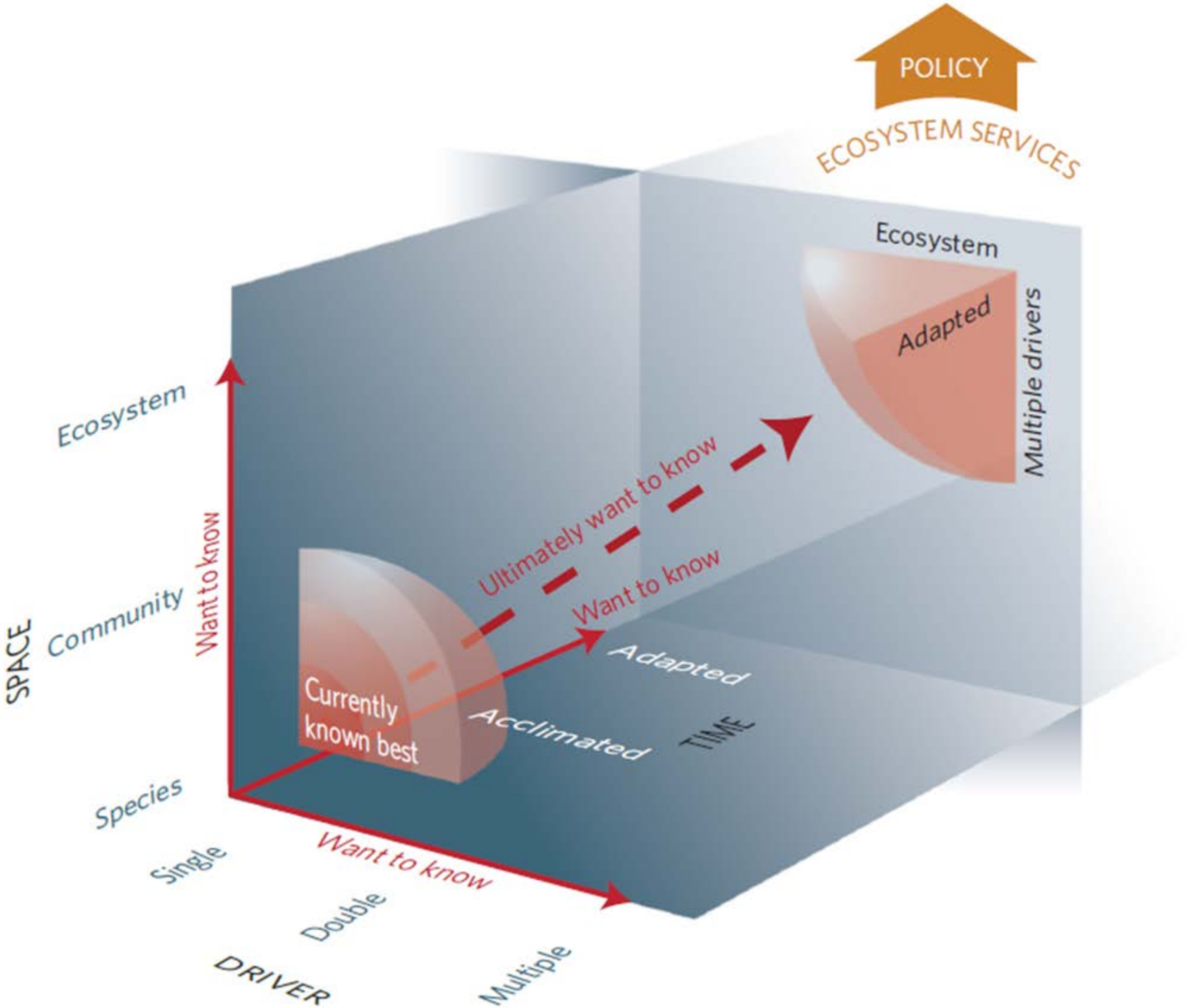
How do we put all the pieces together to appreciate the bigger picture?

Steve Widdicombe

Session 11: Benthic and Pelagic system responses in a Changing Ocean: From Genes to Ecosystem Level Functioning

4th International Symposium on the Effect of Climate Change on the World's Oceans (ECCWO) , 4th – 8th June, 2018, Washington D.C., USA

Shifting Objectives – Individuals to Ecosystems

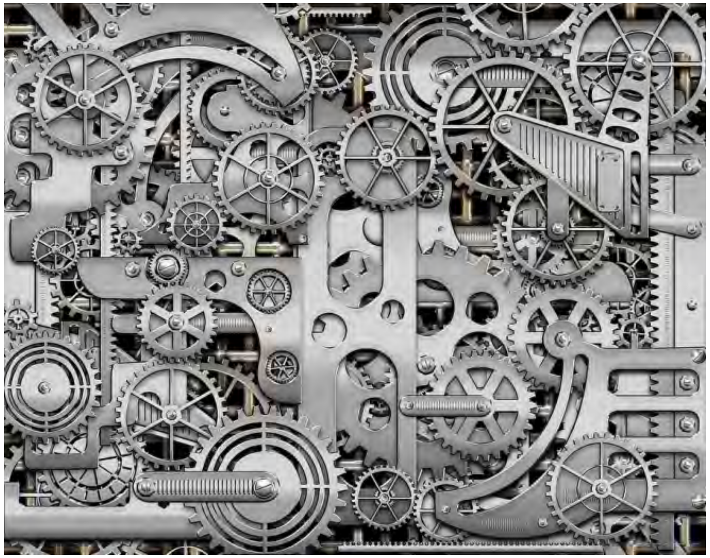


U Riebesell, J-P Gattuso (2015) Lessons learned from ocean acidification research. *Nature Climate Change* 5: 12–14.

Two Major Challenges

Time

- Climate is changing over years and decades
- Experiments are generally short in duration; days, weeks; months
- Shock response vs long term acclimation adaptation



Complexity

- Multiple stressors
- Interactions occur between species, but also within species (between populations) and within individuals
- Climate vs weather

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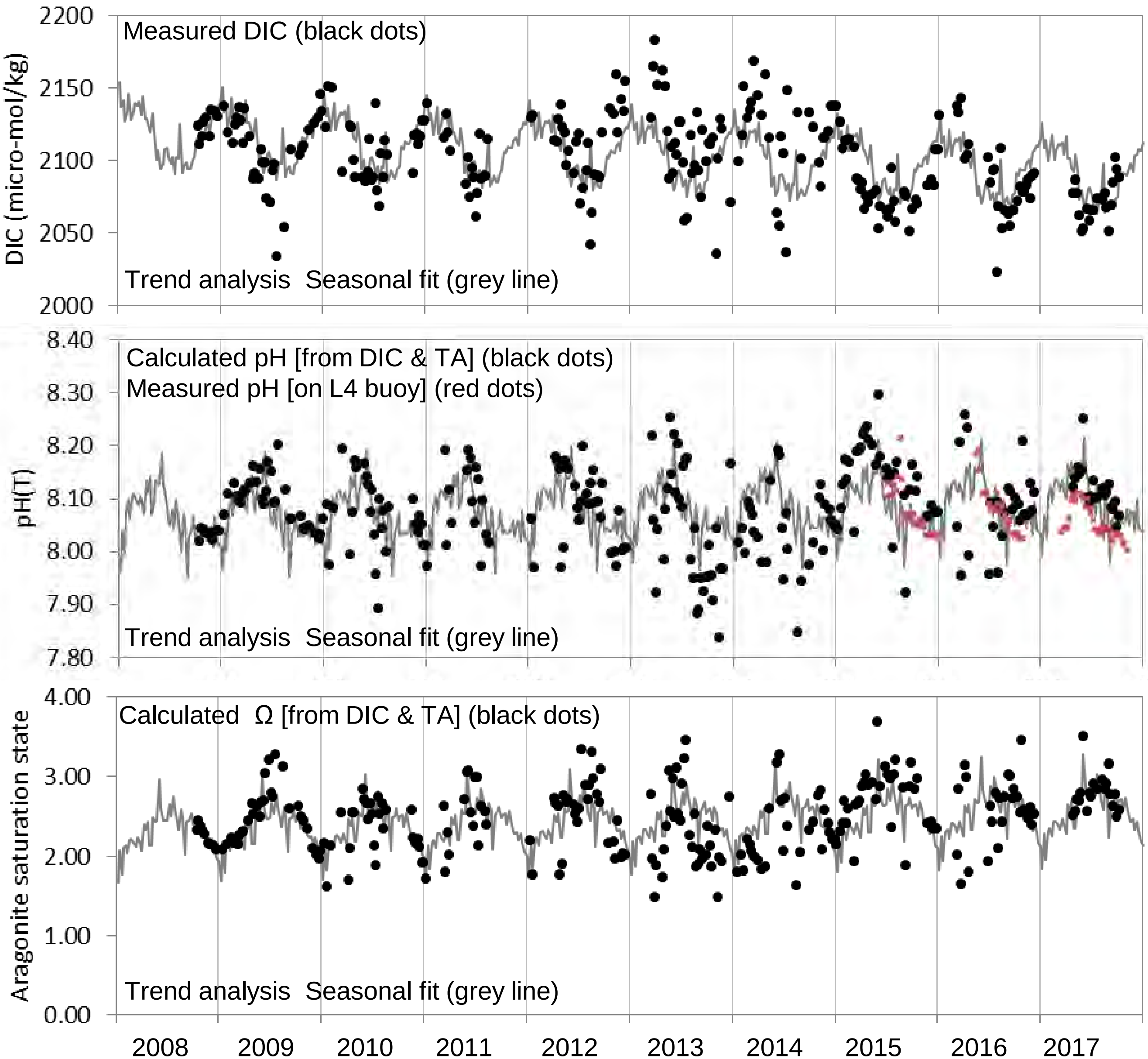
Climate vs Weather



Extreme events are really important but gradual (chronic) change can have impacts across life times & generations

"Weather" "Climate"

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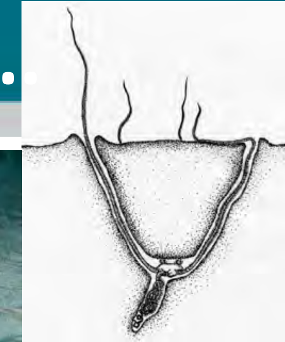
A story 10 years in the making……

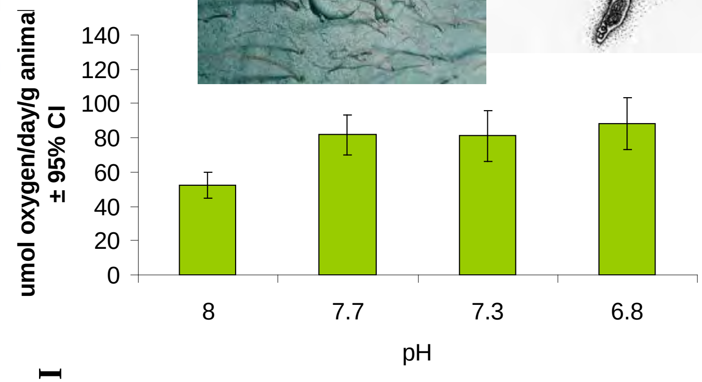


PROCEEDINGS OF THE ROYAL SOCIETY B | BIOLOGICAL SCIENCES

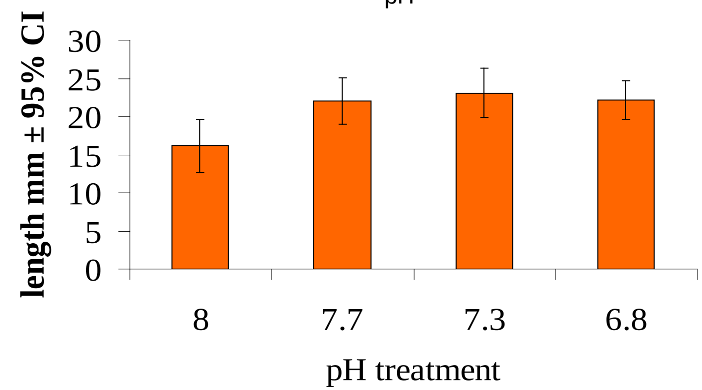
Ocean acidification may increase calcification rates, but at a cost

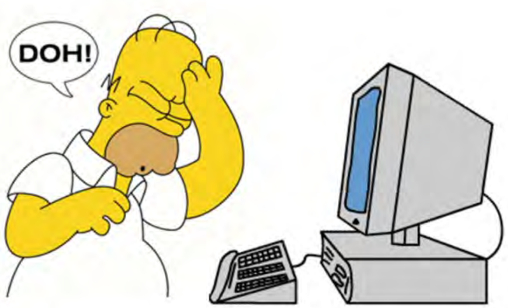
Hannah L Wood, John I Spicer and Stephen Widdicombe

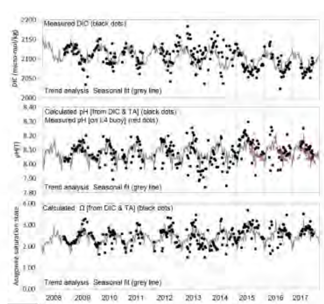
Proc. R. Soc. B 2008 **275**, 1767-1773



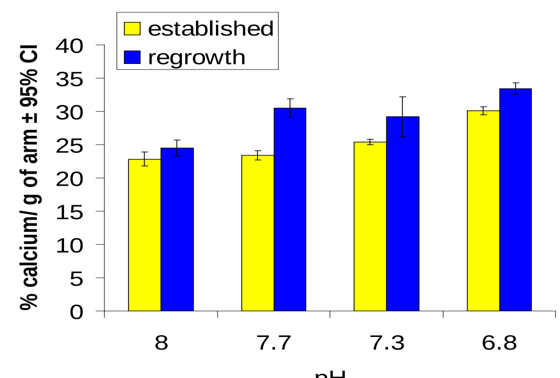
- Lowered pH causes significant increase in respiratory rate
- Regrowth significantly longer at lowered pH
- pH significantly affects calcium content in arm regrowth
- Arm regrowth has significantly higher calcium content than established arms







What's the cost?



The payoff

control

7.7

7.3

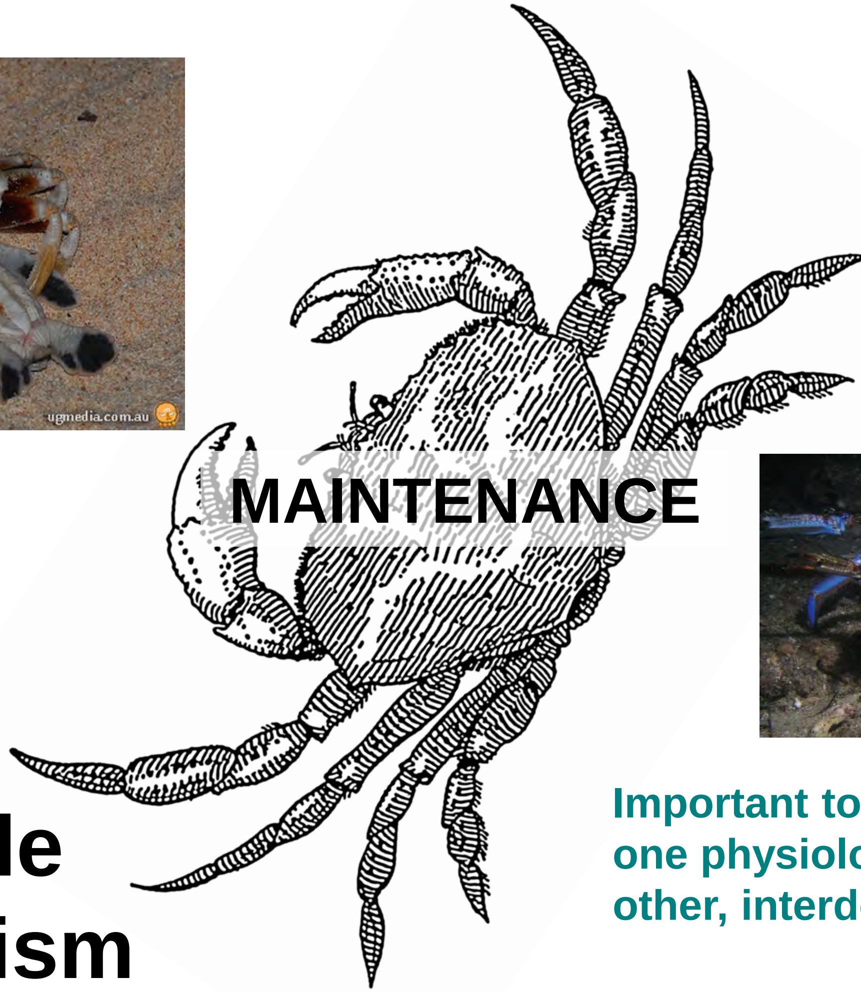
6.8

Energetic Trade-offs Within Individuals

FEEDING

GROWTH

REPRODUCTION



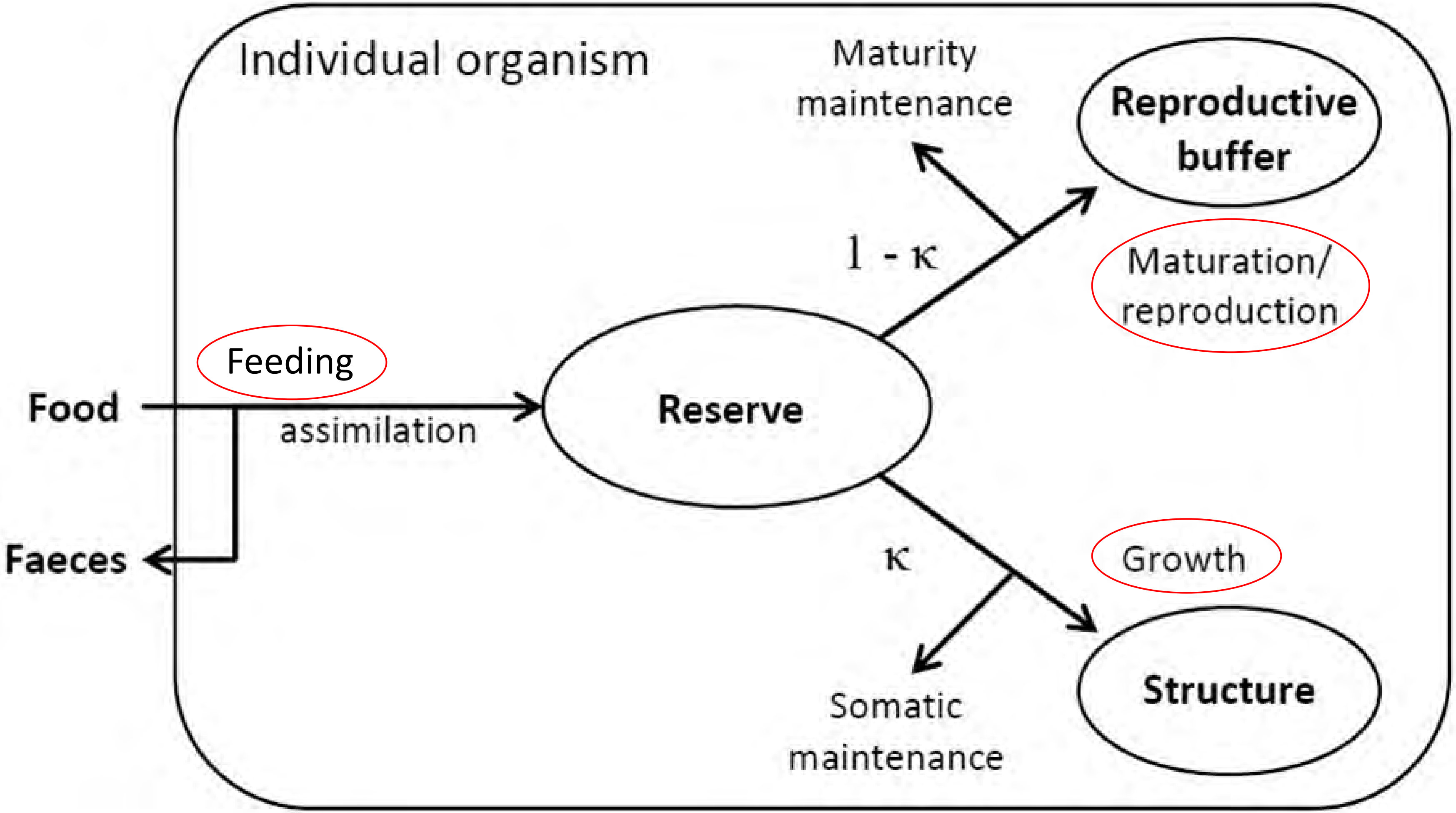
MAINTENANCE

Whole Organism Approach

Important to consider how changes in one physiological process can affect other, interdependent process.

Physiological Trade-Offs

Dynamic Energy Budget Models a link to populations



Ecological and ecosystem level processes

Once you know the response of key ecological processes you can project the consequences for populations and distributions……

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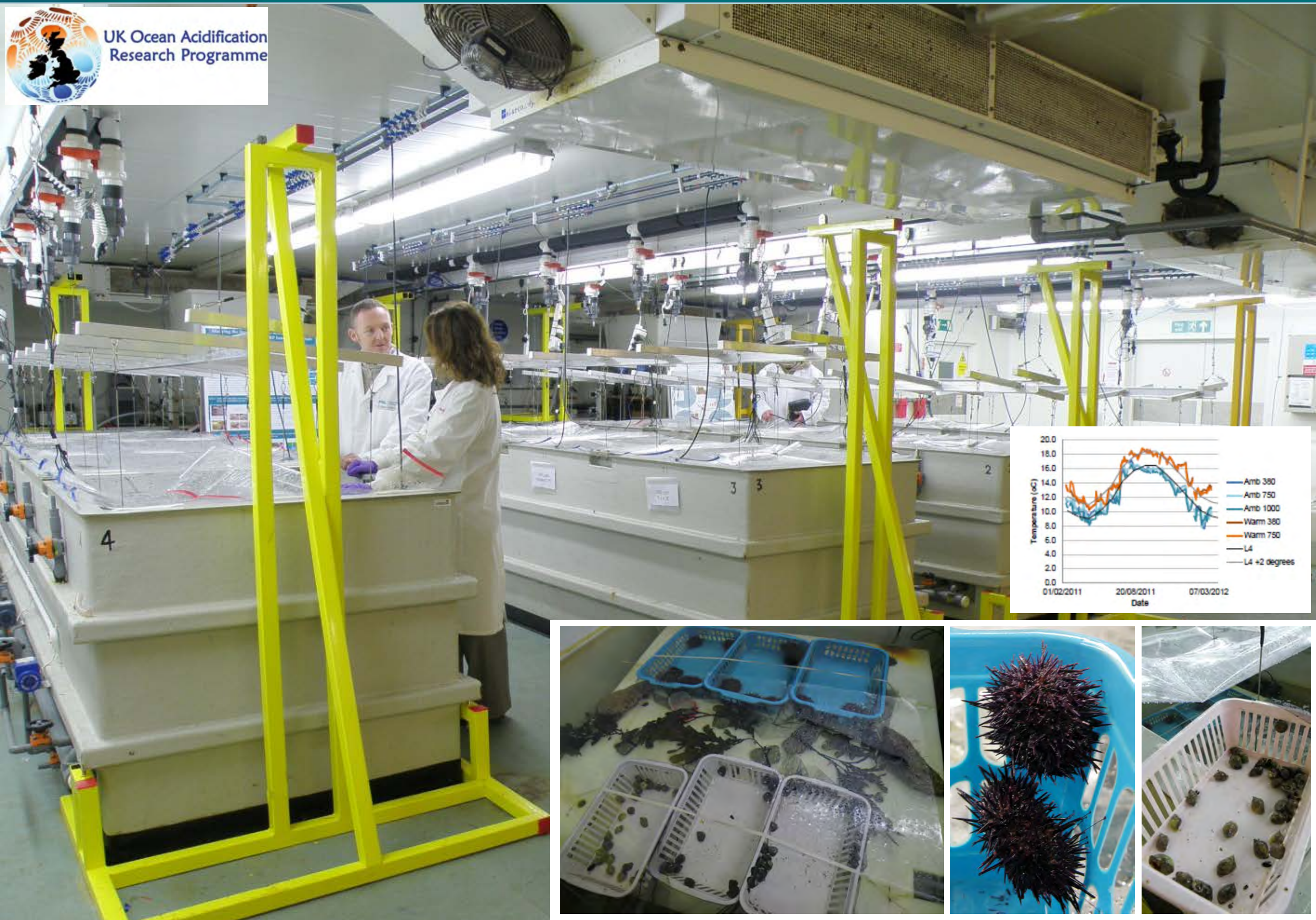
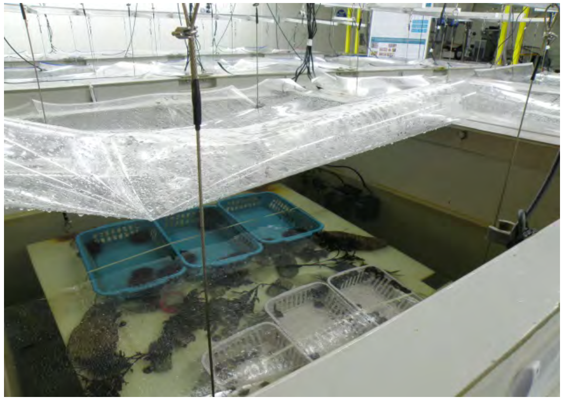
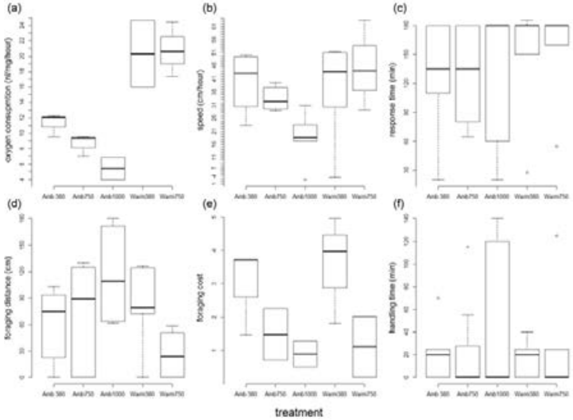
Long-term Ocean Acidification Experiment

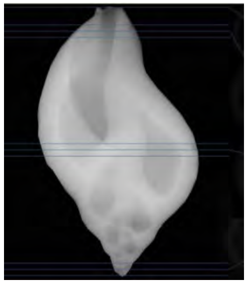
UK Ocean Acidification Research Programme

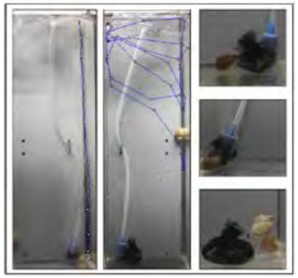


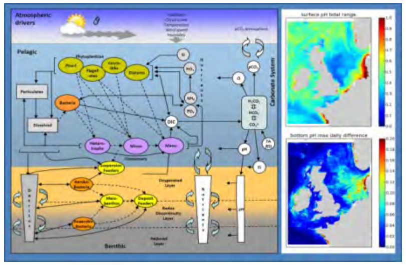
Blending together the knowledge

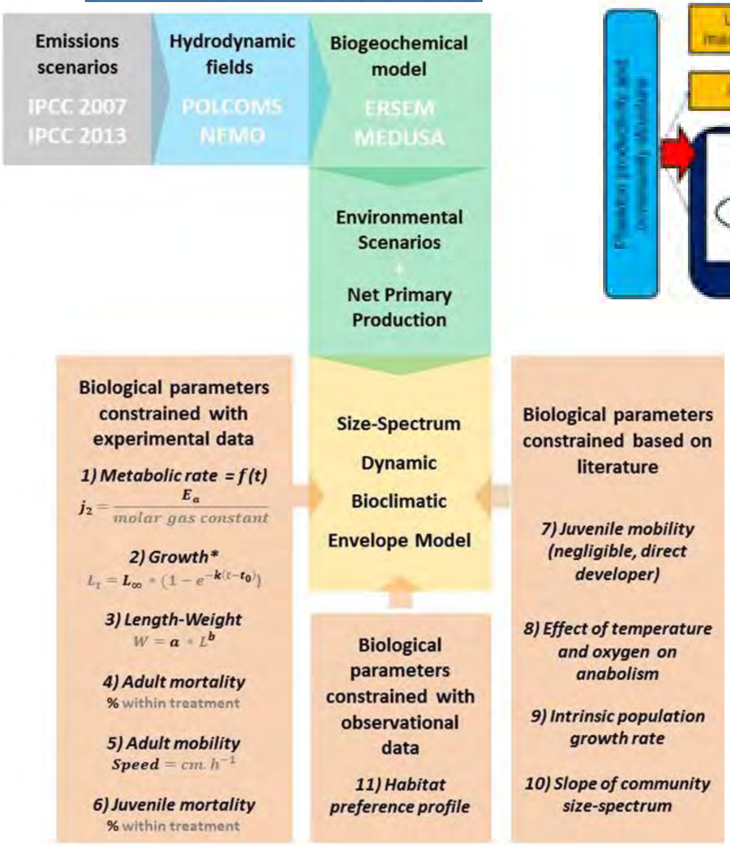


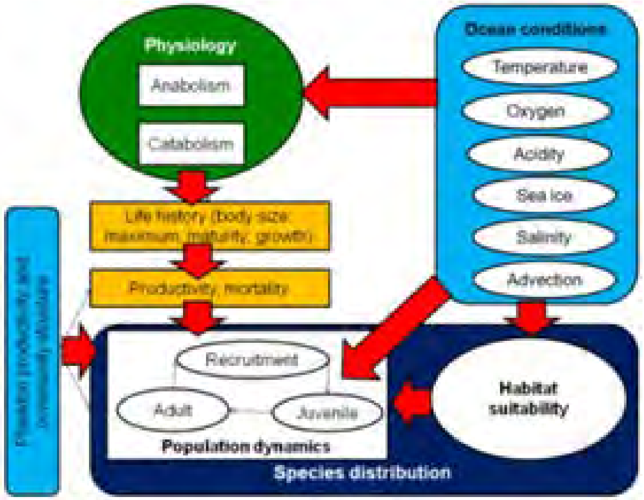













Plastic and Heritable Components of Phenotypic Variation in *Nucella lapillus*: An Assessment Using Reciprocal Transplant and Common Garden Experiments

Sonia Pascoal, Gary Carvalho, Simon Creer, Jenny Rock, Kei Kawai, Sonia Mendo, Roger Hughes

Functional Ecology 1991, 5, 461–475

Optimal foraging decisions by dogwhelks, *Nucella lapillus* (L.): influences of mortality risk and rate-constrained digestion

M. T. BURROWS & R. N. HUGHES

Oecologia (1994) 100: 439–450

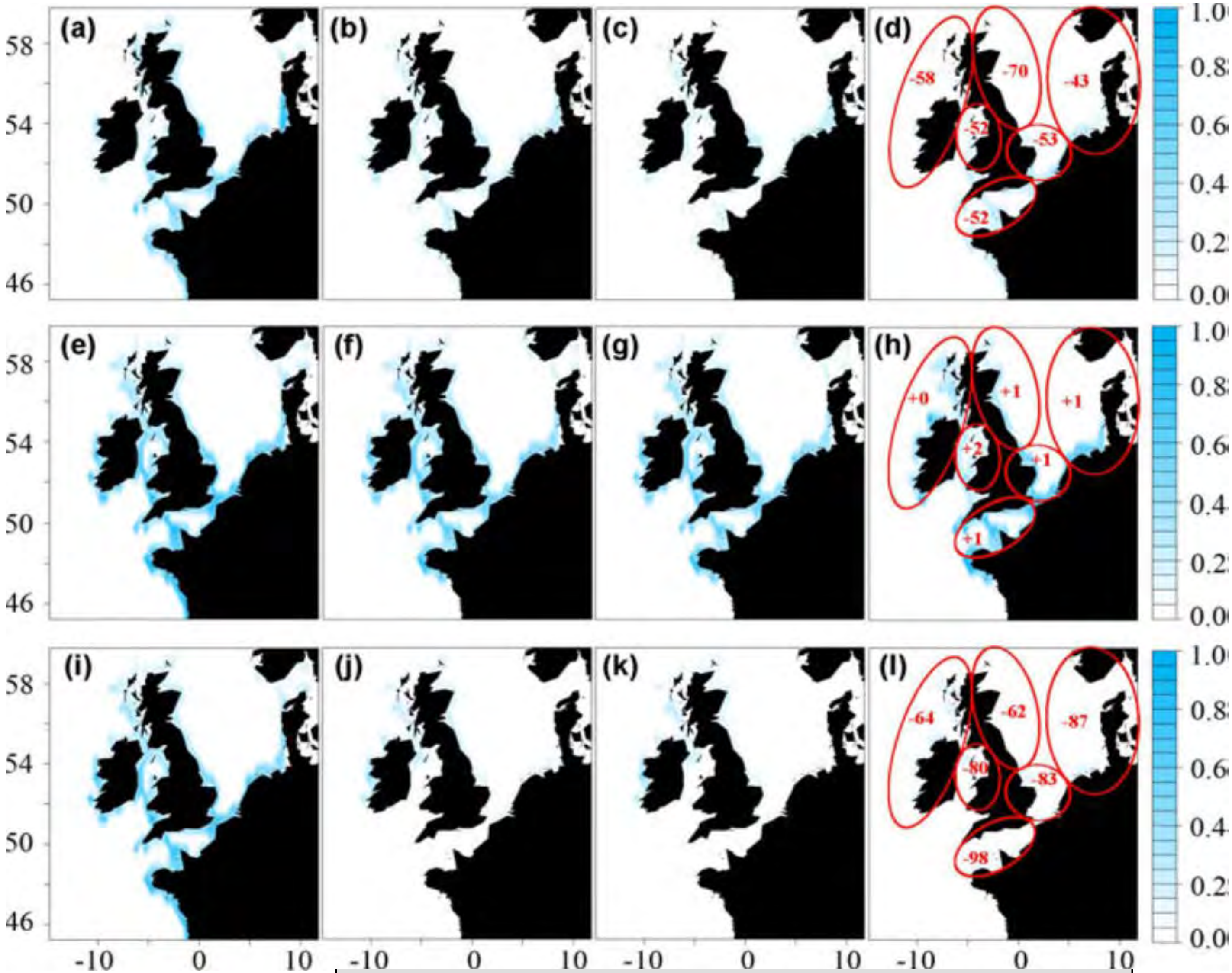
ORIGINAL PAPER

R. L. Vadas Sr · M. T. Burrows · R. N. Hughes

Foraging strategies of dogwhelks, *Nucella lapillus* (L.): interacting effects of age, diet and chemical cues to the threat of predation

% Change in *Nucella lapillus* abundance

Warm | OA | Warm + OA



1986-2000

2086-2100

4th IPCC Business-as-usual

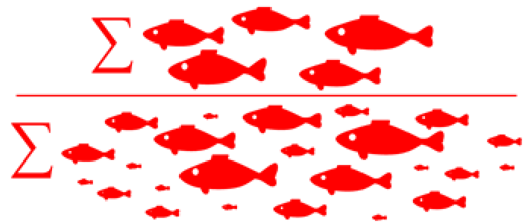
5th IPCC “lower emissions”

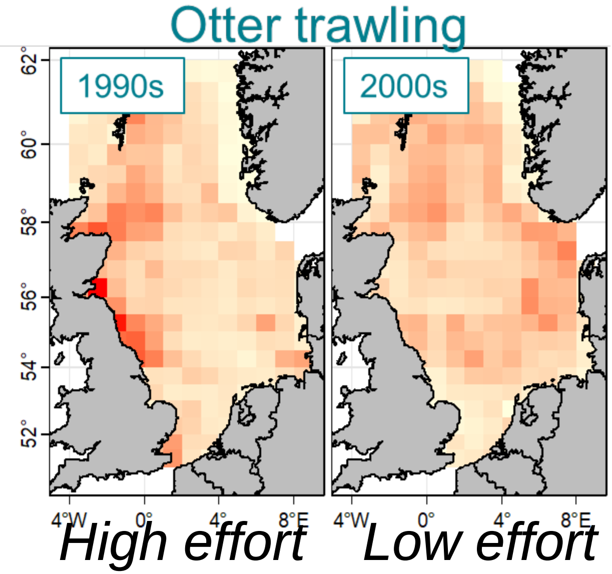
5th IPCC “higher emissions”

AM Queirós, et al. (2015) Quantifying ecosystem-level consequences of ocean acidification and warming by scaling up individual level responses of a predator snail and its trophic interactions. **Global Change Biology 21(1): 130–143.**

Large Fish Index

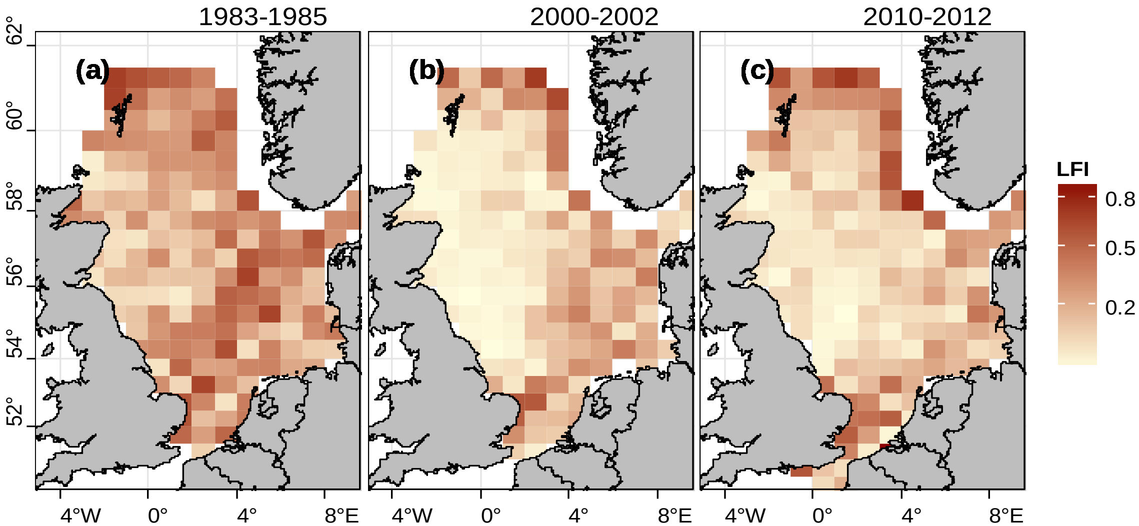
LFI =





Where fishing effort was reduced in the 2000s (along the UK coast) relative to the 1990s the **LFI had *begun* to improve** (with an expected time lag). But………

LFI



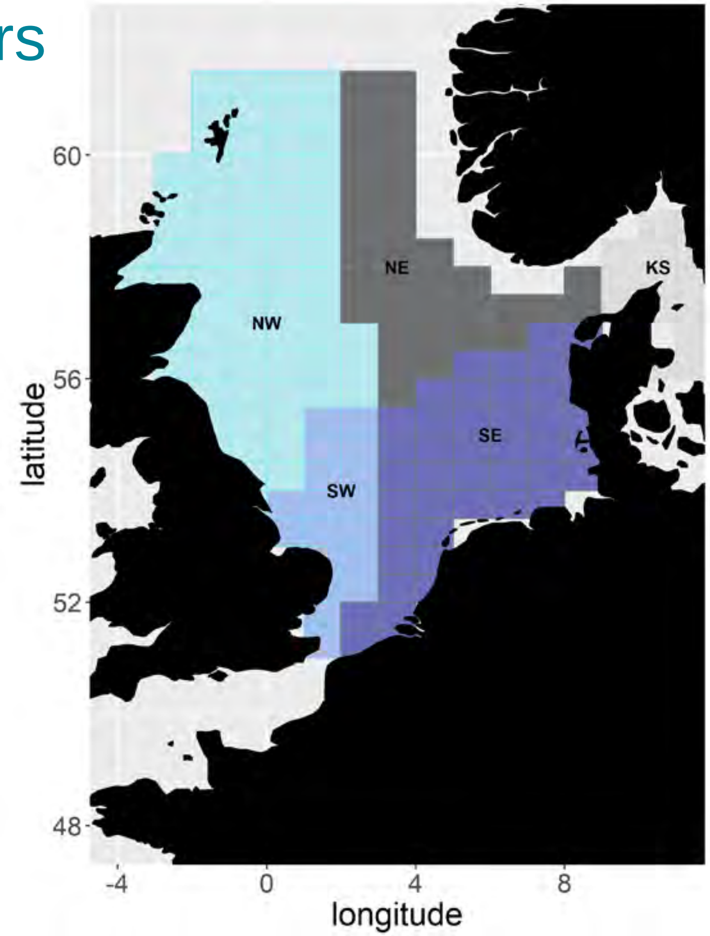
High LFI *Low LFI* *Recovering*

Recovery wasn't happening as fast or as completely as expected in some areas…..Why?

Engelhard et al (2015) Effort reduction and the large fish indicator: spatial trends reveal positive impacts of recent European fleet reduction schemes. Environmental Conservation 42: 227-236 doi: 10.1017/S0376892915000077

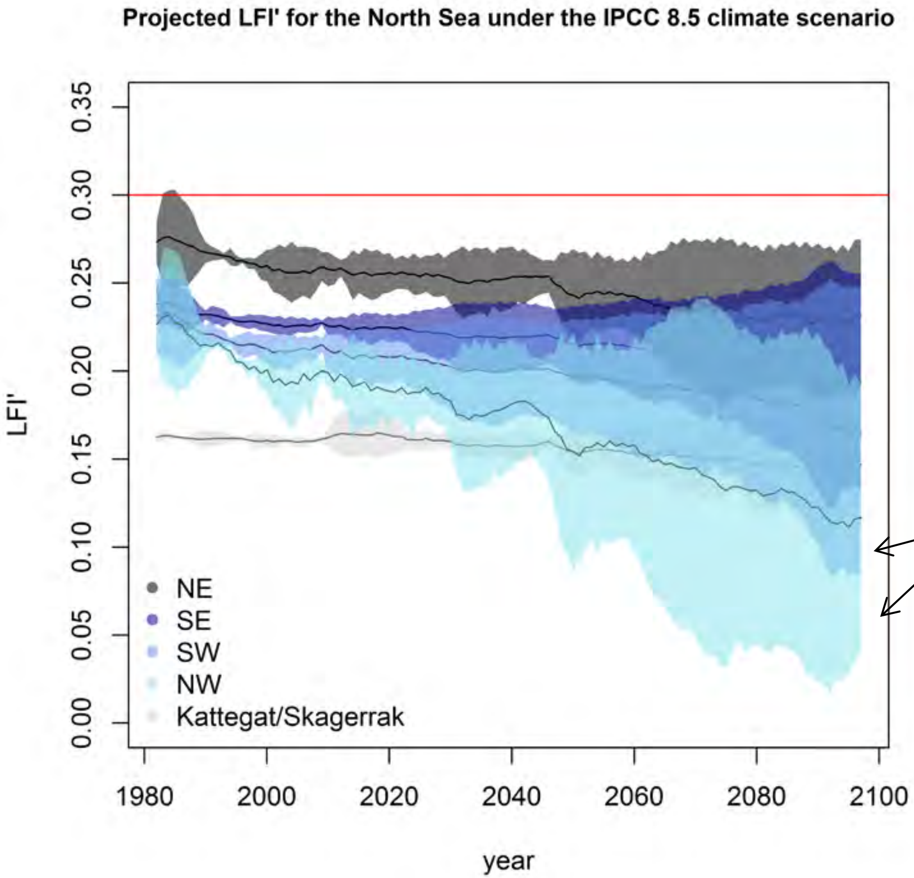
Queirós et al (2018) Climate change alters fish community size-structure, requiring adaptive policy targets. ***Fish & Fisheries*. 00:1–9.**
https://doi.org/10.1111/faf.12278

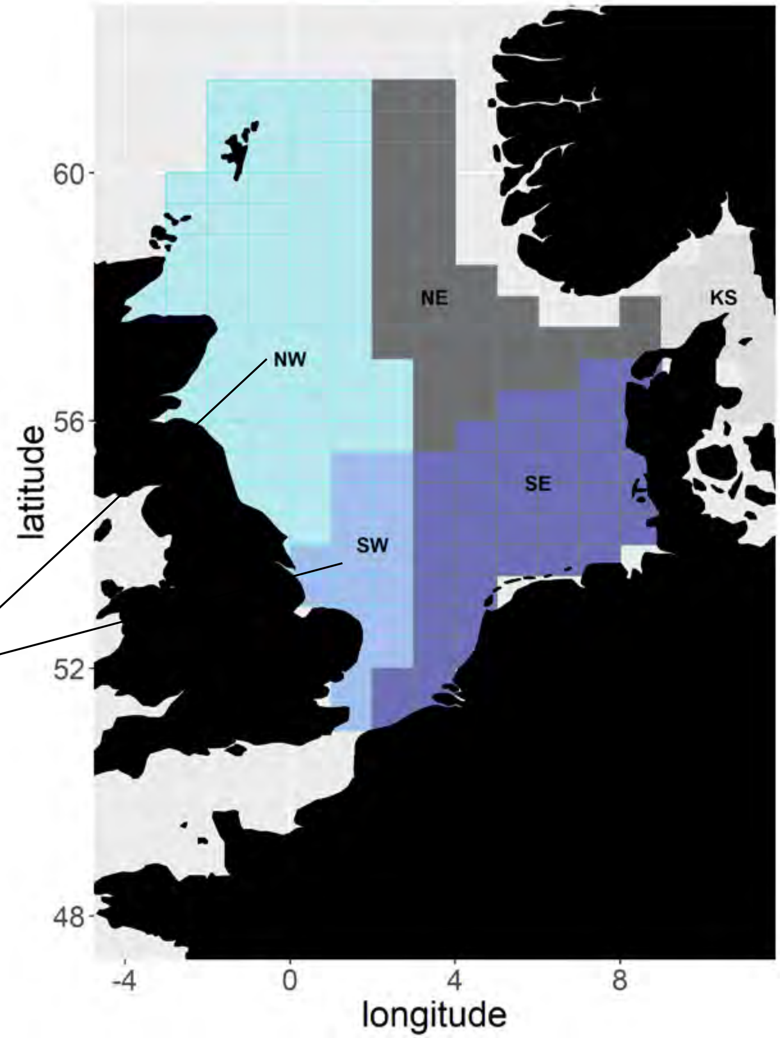
Used a size-spectrum dynamic bioclimate envelope model (SS-DBEM, *Fernandes et al., 2013*) to project the response of 7 species of fish to climate change in 5 areas of the North Sea.



This model considers how species physiology, growth, population dynamics and dispersal potential respond to temperature, oxygen, salinity, depth, pH and primary production; how each species is able to compete for basal resources within the simulated species assemblage; and the effect of food and temperature on the size-structure of individual populations.

In some places targets could become impossible to meet!





BUT Not all populations are the same!

- Integrated population genetics with experimental data for growth and mineralisation, physiology and metabolomics.
- The sensitivity of populations of the gastropod *Littorina littorea* to future OA was shaped by regional adaptation.
- Populations towards the species range edges exhibited greater shell dissolution and the inability to upregulate their metabolism when exposed to low pH, thus appearing most sensitive to low seawater pH.
- Future levels of OA could mediate temperature-driven shifts in species' distributions, thereby influencing future biogeography and the functioning of marine ecosystems.

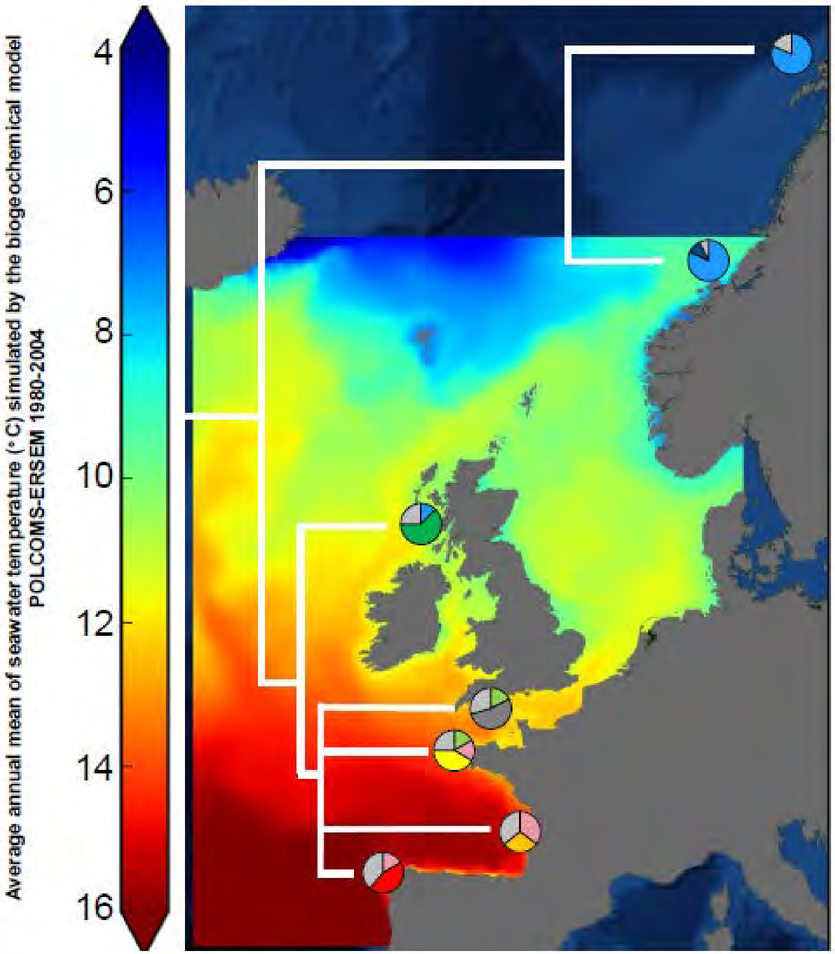


Figure 1: Genetic structure of *Littorina littorea* populations. Thermal map of Europe from the POLCOMS-ERSEM biogeochemical model showing sampling locations and genetic structure of the six different populations of *L. littorea* sampled across the Northwest Atlantic latitudinal gradient (from 42° to 70°). Pie charts = proportion of common haplotypes (grey), shared between climatic regions (pastel colours, northern = blue, mid = green, southern = pink), private to individual sites (primary colours).

P Calosi et al (2017) Regional adaptation defines sensitivity to future ocean acidification. *Nature Communications* 8: 13994.
DOI 10.1038/ncomms13994

Local adaptation is driven by local environmental variability

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- Explored the highly varied conditions across the he coastal ecosystems of the Humboldt Current System (HCS) off Chile

- A meta-analysis revealed adaptive intraspecific variability in the response of individuals to pCO_2 changes among local populations.

Taxa	Environment	Mean ± SD environmental pCO_2 levels (µatm)	Control pCO_2 levels (µatm)	Experimental pCO_2 levels (µatm)	Response	Mean effect	Reference
	Coastal ocean	555.6 ± 157.5	380	1500	Respiration	+ 213%	32
	Estuarine	623.42 ± 233.68	380	1500	Respiration	+147%	32
	Coastal ocean	555.6 ± 157.5	376	980 -1100	Ingestion	-47%	33
	Estuarine	623.42 ± 233.68	376	980 -1100	Ingestion	-33%	33
	River-plume area	811.0 ± 185.7	376	980 -1100	Ingestion	-17%	33
	Estuarine	623.42 ± 233.68	365 - 398	979 - 1077	Larval survival	-60%	38
	River-plume area	811.0 ± 185.7	365 - 398	979 - 1077	Larval survival	-17	38
	Estuarine	623.42 ± 233.68	347 - 377	910 - 960	Ingestion	-60%	33
	River-plume area	811.0 ± 185.7	347 - 377	910 - 960	Ingestion	-13%	33
	Tidal inlet	500.8 ± 140.2	388	979	Calcification Growth	-37% -35%	34
	Freshwater-influenced tidal inlet	608.9 ± 319.3	388	979	Calcification Growth	-4% -13%	34
	Coastal ocean	405.9 ± 95.4	398 - 405	1255	Ingestion	-72%	37
	Estuarine	623.42 ± 233.68	398 - 405	1255	Ingestion	+ 5%	37

- This variability in response leads to inter- populations variability that reveals the potential role of local adaptation and/or adaptive phenotypic plasticity in increasing resilience of species to environmental change.

CA Vargas et al (2017) Species-specific response to ocean acidification should account for local adaptation and adaptive plasticity. *Nature Ecology and Evolution* 1(4): UNSP 0084. DOI 10.1038/s41559-017-0084

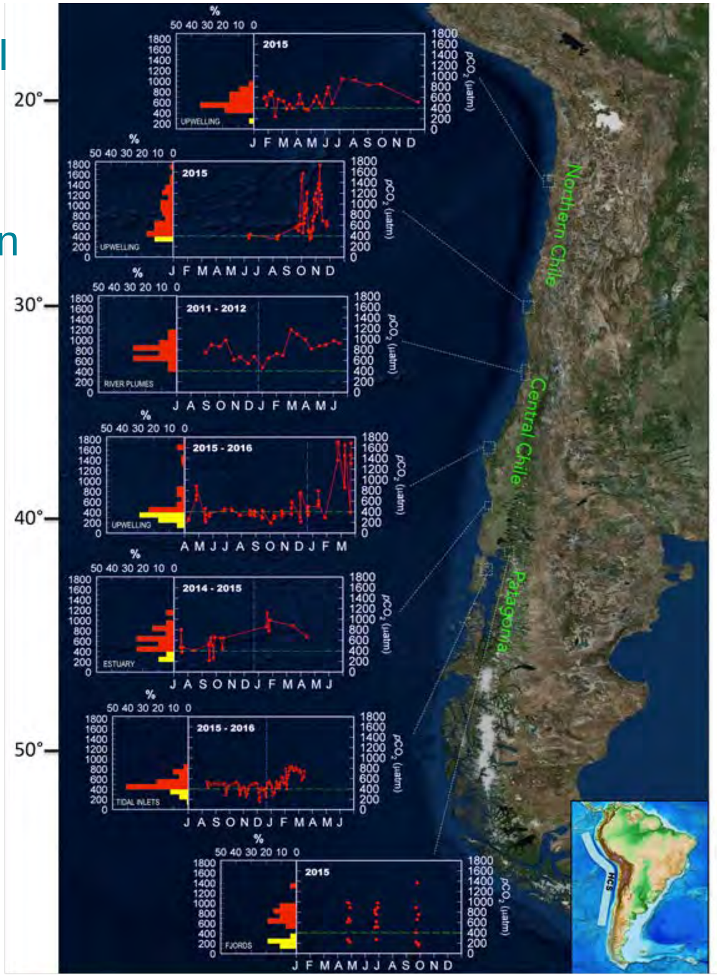


Figure 1 | Temporal series (line plots) and frequency analysis (bars plots) of surface (upper 10 m depth) pCO_2 (µatm) for different coastal environments along the Chilean coast.

We largely neglect differences between individuals

- Studies are heavily biased towards survivors
- More consideration should be given to the range of responses rather than the mean
- Ultimately, variability at the level of the individual will drive localised adaption

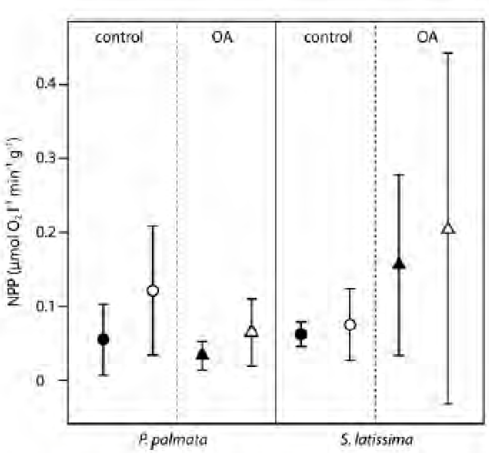


Figure 1. Mean ± SD Net Primary Production, NPP, of *P. palmata* and *S. latissima* under control and acidified (OA) treatments. Black symbols represent T_0, white symbols represent T_4.

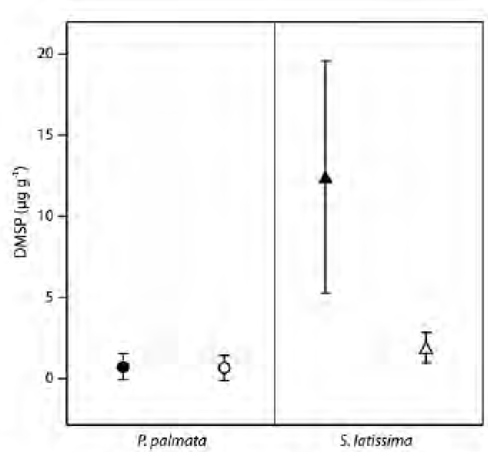


Figure 3. DMSP concentration (mean ± SD) of *P. palmata* and *S. latissima* at the base (black symbols) and tip (white symbols) of the frond.

ICES Journal of Marine Science Advance Access published May 11, 2015

ICES Journal of Marine Science

ICES CIEM

ICES Journal of Marine Science; doi:10.1093/icesjms/fsv081

Two intertidal, non-calcifying macroalgae (*Palmaria palmata* and *Saccharina latissima*) show complex and variable responses to short-term CO_2 acidification

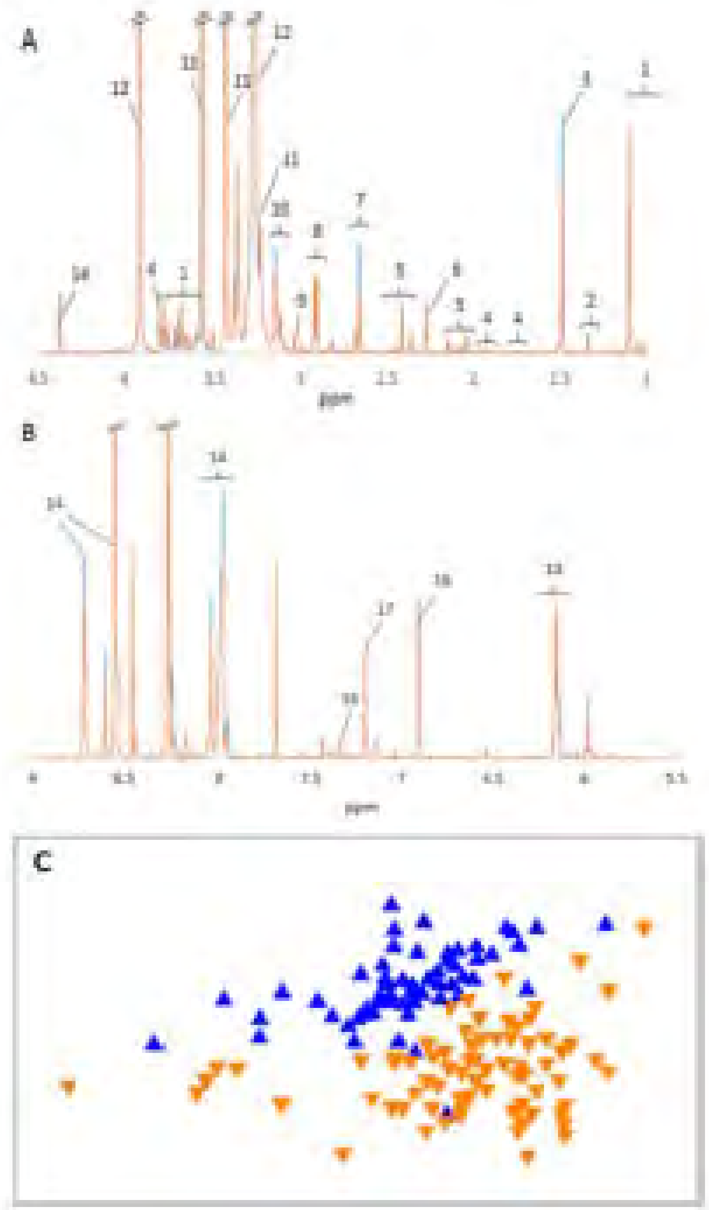
Joana Nunes[1]*, Sophie J. McCoy[1], Helen S. Findlay[1], Frances E. Hopkins[1], Vassilis Kitidis[1], Ana M. Queirós[1], Lucy Rayner[2], and Stephen Widdicombe[1]

The importance of gender

Environmental Science & Technology
Article
pubs.acs.org/est

[1]H NMR Metabolomics Reveals Contrasting Response by Male and Female Mussels Exposed to Reduced Seawater pH, Increased Temperature, and a Pathogen

Robert P. Ellis,*[†,∥] John I. Spicer,[‡] Jonathan J. Byrne,[§] Ulf Sommer,[§] Mark R. Viant,[§] Daniel A. White,[†] and Steve Widdicombe[†]



- Individuals of blue mussels were exposed to elevated temperature and pCO_2. Then also exposed to a pathogen.
- The metabolites produced in response to these stressors were determined.
- Large difference in response observed between males and females

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The Importance of Sex

- Differences between ♂ and ♀ response to elevated pCO_2 investigated in < 4 % of studies to date, often being precluded by the difficulty of determining sex non-destructively, particularly in early life stages.
- But, sex significantly impacts organism responses to OA, differentially affecting physiology, reproduction, biochemistry and ultimately survival.
- Impacts do not always conform to ecological theory based on differential resource allocation towards reproduction, which would predict females to be more sensitive to OA due to the higher production cost of eggs compared to sperm.
- Non-sex specific studies may overlook subtle but ecologically significant differences in the responses of males and females to OA, with consequences for forecasting the fate of natural populations in a near-future ocean.

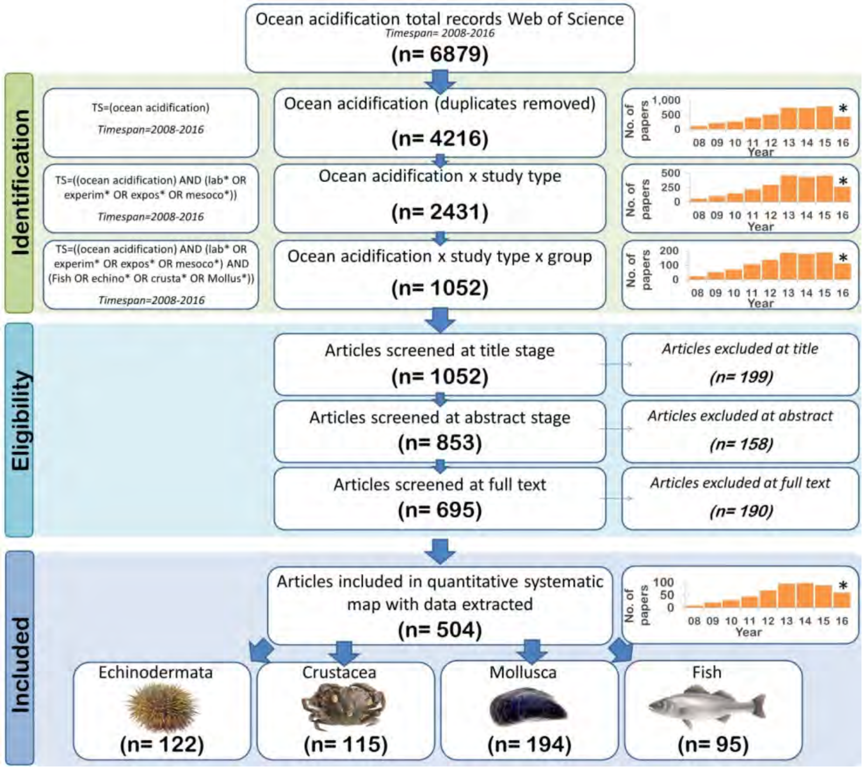

Figure 1. Overview of the systematic map process. Values (n = x) are the number of studies at each stage. Asterisk indicates partial record for number of papers published in 2016 as literature sourced on 22/06/2016..

RP Ellis et al (2017) Does sex really matter? Explaining intraspecies variation in ocean acidification responses. *Biology Letters* 13(2): 20160761. DOI 10.1098/rsbl.2016.0761

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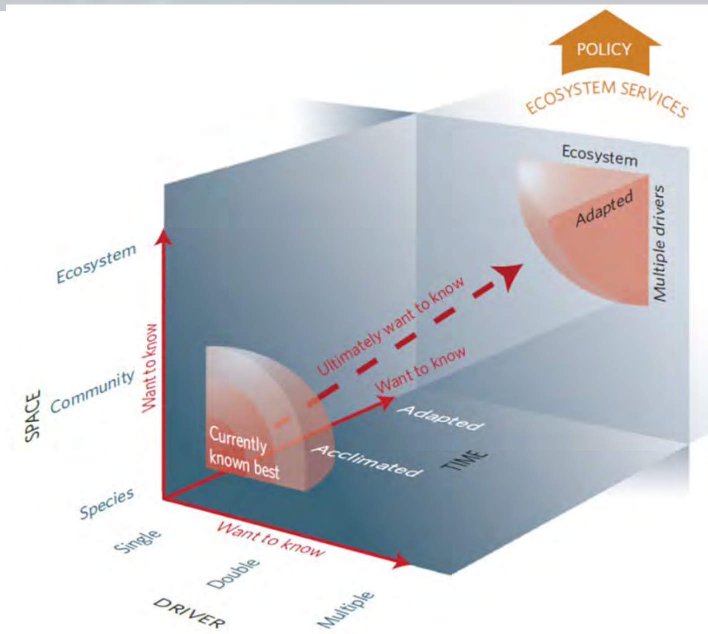
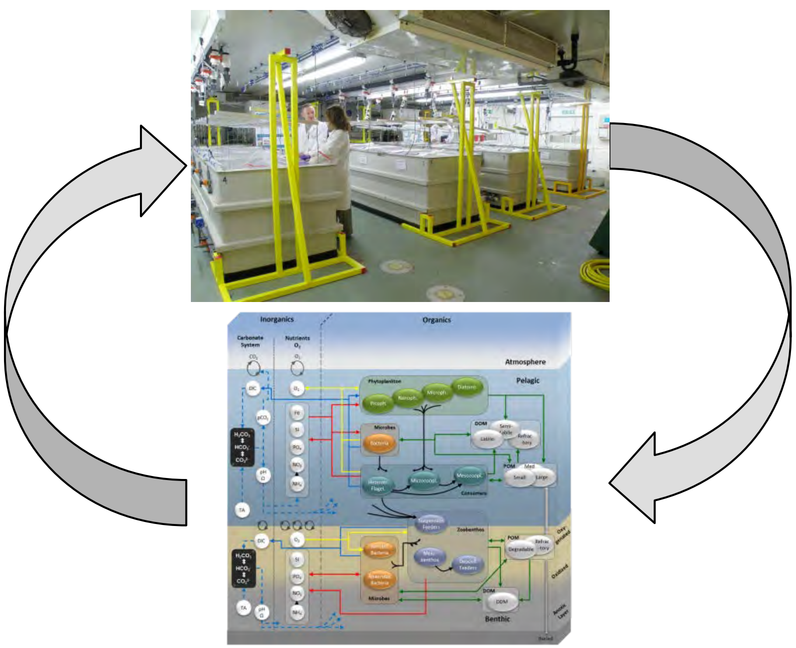
Summary





- No experiments or studies are a perfect mimic for climate change. Except 1!!!
- Complexity and variability are all around us, and increases as we move across spatial, temporal and organisational scales. We need to except this and work with it.
- Appreciate where the system has been, in order to understand where it is going.
- Find ways to pull knowledge together to conceptually understand, but also challenge, the system and its response.
- Models and experiments need to **co-evolve**.

Thank you