IAEA
Ocean Acidification International Coordination Centre
OA-ICC

UNIVERSITY OF GOTHENBURG

KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

Basic training course on ocean acidification

EVT1804704

14-19 March 2022

Scenarios

Take home messages

- ✓ CO_2sw is often different from CO_2atm as many factors create variability

- ✓ Natural variability in relevant carbonate chemistry experienced by an organism should be included in the experimental design

Note: for this lecture we will consider pH but you need first to identify what are the key carbonate chemistry parameter for your species/ecosystem

- ✓ IPCC open ocean scenarios (e.g. pH 8.1 vs. 7.7) are often irrelevant for your experiment and several control pH targets should be considered.

What pH targets to use in an ocean acidification experiment?

- ✓ You have a question / strategy / experiment

- ✓ You want to compare:
    - Control / Present / Ambient
    - Treatment / Ocean acidification / Future / End of the century

When you read the literature…

Methods

Adult *Paracentrotus lividus* specimens (4–6 cm diameter) were purchased from Dunmannus Sea Farm Ltd. in Cork, Ireland. Adult *Mytilus edulis* specimens were collected by hand from the intertidal range of the River Exe estuary, Exmouth, Devon, UK. Individuals were left for 7 days in 30 litre holding tanks at 15 °C in ambient artificial seawater (pH_{NBS} 8.1, 470 µatm pCO_2, salinity = 35) to acclimatise prior to the exposures. Ten individuals per treatment were exposed to one of the following four treatments for 14 days at 15 °C; (1) ambient conditions (pH_{NBS} 8.1) with no added copper; (2) ambient conditions (pH_{NBS} 8.1) with nominal 0.1 µM copper sulphate added; (3) OA conditions (pH_{NBS} 7.7) with no added copper; (4) OA conditions (pH_{NBS} 7.7) with nominal 0.1 µM copper sulphate added.

Seawater pH_{NBS} values of 7.7 were targeted to represent near-future OA treatments as projected according to scenario RCP 8.5 and the 2013 IPCC WGI AR5[4,56]; full seawater chemistry is provided in Tables 1 and 2. Seawater pH in the OA conditions was nominally maintained at pH_{NBS} 7.7 (to a resolution of 0.05 units) using pH computers (Aqua Medic, Bissendorf, Germany) which continually controlled the release of CO_2 gas directly into the header tanks to maintain stable conditions throughout the experimental exposures. Partial water changes (50%) were carried out every 48 hours using temperature equilibrated water of the correct pH and CO_2 level and copper concentrations were re-dosed appropriately. Seawater pH_{NBS} (Metrohlm 827 pH lab), temperature, and salinity

Ambient: 8.1

OA: 7.7

When you read the literature…

Methods

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→ Ambient: 8.1

→ OA: 7.7

IPCC scenarios based on open ocean

pH variability in temperate tidal zone : 7.2 – 9.1

Best Practice guide

Part 2: Experimental design of perturbation experiments

3 Atmospheric CO_2 targets for ocean acidification perturbation experiments

James P. Barry[1], Toby Tyrrell[2], Lina Hansson[3,4], Gian-Kasper Plattner[5] and Jean-Pierre Gattuso[3,4]

[1]Monterey Bay Aquarium Research Institute, USA
[2]National Oceanography Centre, University of Southampton, UK
[3]Laboratoire d'Océanographie, CNRS, France
[4]Observatoire Océanologique, Université Pierre et Marie Curie-Paris 6, France
[5]Climate and Environmental Physics, University of Bern, Switzerland

Table 3.3 Key $p(CO_2)_{atm}$ values (ppm) for ocean acidification studies. These $(CO_2)_{atm}$ levels are useful guidelines for perturbation experiments, and can be supplemented with other values of importance for specific studies, such as higher values for evaluating animal performance, or adjustments to correspond to key carbonate system values (e.g. Ω_a or Ω_c ~1).

# of Treatments	Recommended $p(CO_2)_{atm}$ levels
2	present-day (~385), 750
3	280, present-day, 750
4	280, present-day, 550, 750
6	280, present-day, 550, 650, 750, 1000
8	180, 280, present-day, 450, 550, 650, 750, 1000
>8	Add values (e.g. 350, other) to increase resolution

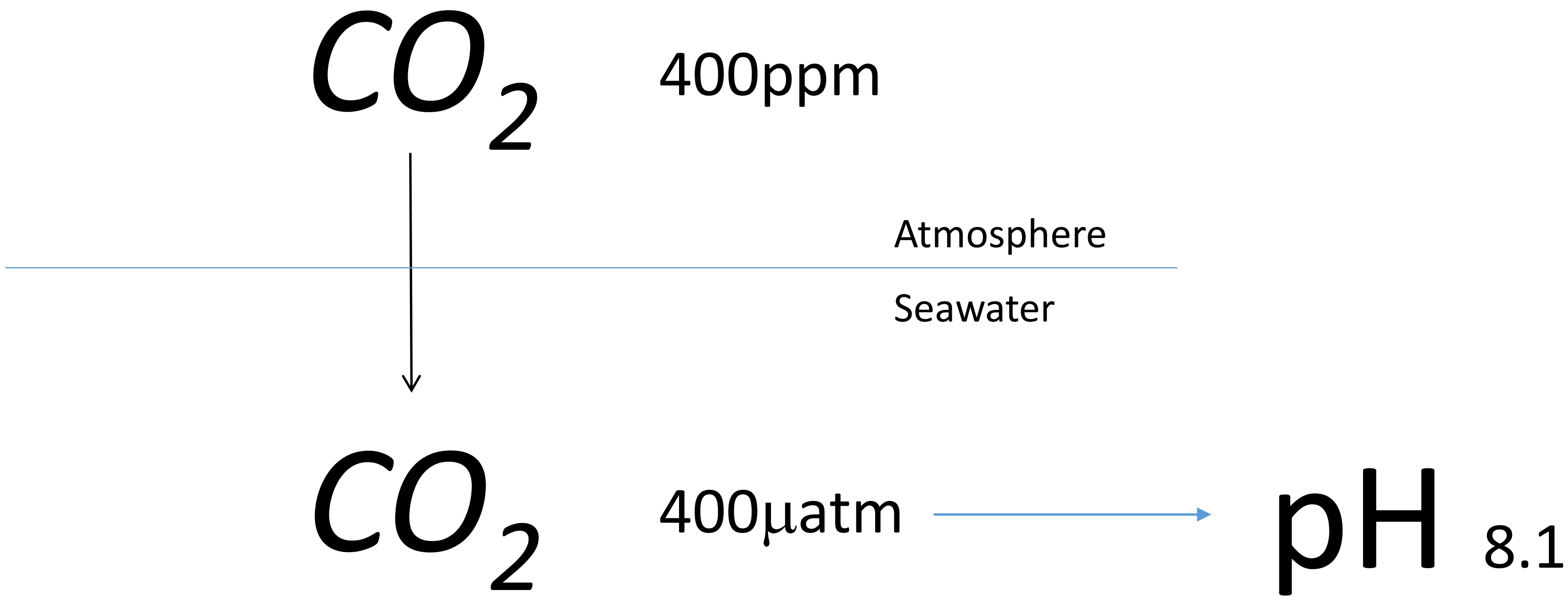
Best Practice guide

$p(CO_2)$**atm**

Table 3.3 Key $p(CO_2)_{atm}$ values (ppm) for ocean acidification studies. These $(CO_2)_{atm}$ levels are useful guidelines for perturbation experiments, and can be supplemented with other values of importance for specific studies, such as higher values for evaluating animal performance, or adjustments to correspond to key carbonate system values (e.g. Ω_a or Ω_c ~1).

# of Treatments	Recommended $p(CO_2)_{atm}$ levels
2	present-day (~385), 750

$$P(CO_2)atm = p(CO_2)sw$$



Equilibrium true for open ocean

Present: 8.1
OA – 2100: 7.7 (ΔpH: 0.4)

Other parameters are influencing the carbonate chemistry in the ocean

- ✓ Mixing/upwelling
- ✓ Interaction with other parameters (e.g. temperature, salinity)
- ✓ Other sources of acidification (nutrients, SOx/NOx)
- ✓ Biology (photosynthesis, respiration, calcification, etc.)

CO_2 ↓ CO_2 ↑ CO_2 ↑

$P(CO_2)atm \neq p(CO_2)sw$ E.g. coastal zone

CO_2 400ppm

Atmosphere

Seawater

CO_2 200-1400 µatm → pH 8.7 - 7.6

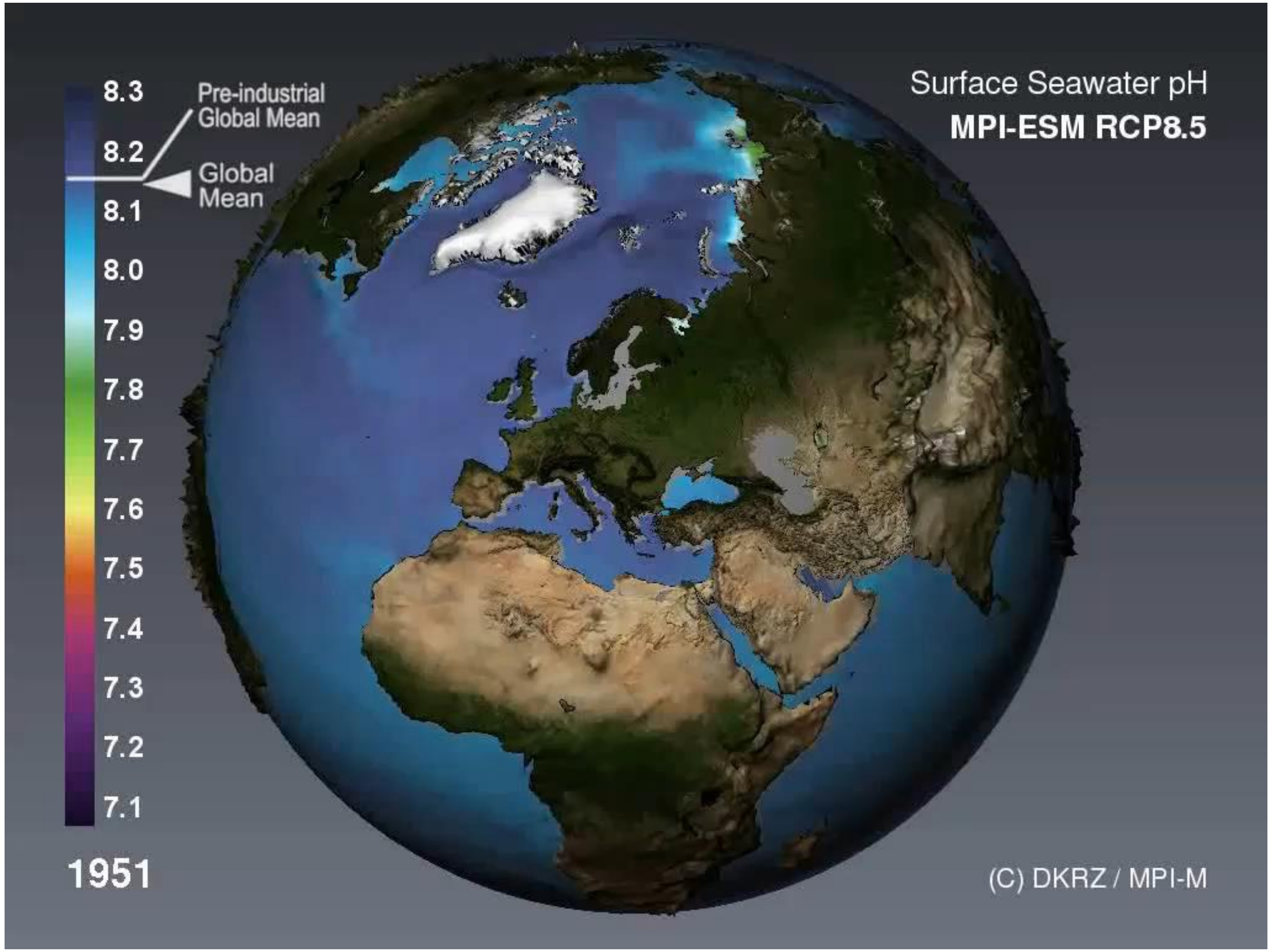
Biology

Not in equilibrium

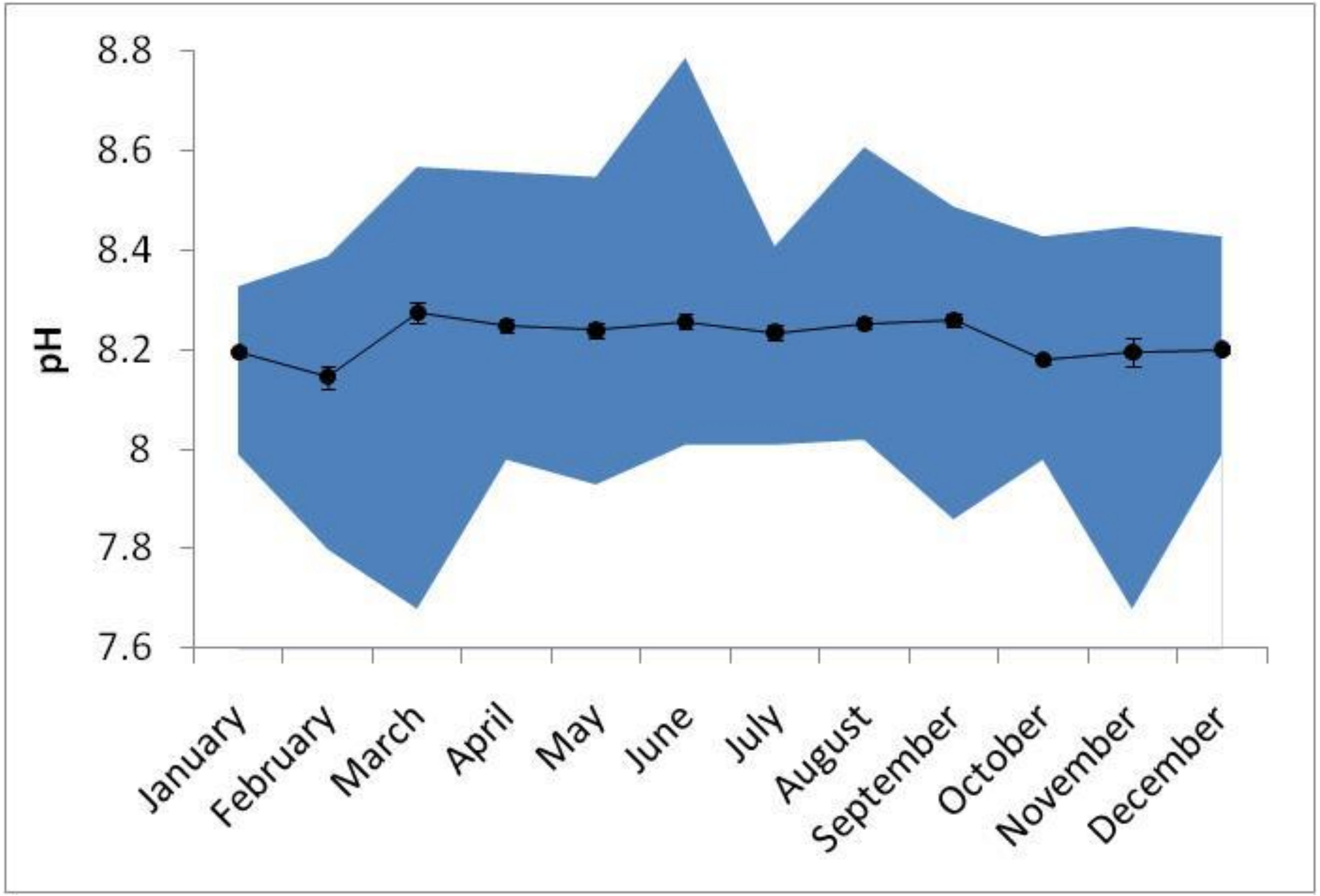
Present: 8.7-7.6

OA – 2100: 8.3-7.2 (ΔpH: 0.4)

Variability in space



Variability in time



All present/Ambient/Control

(Dorey et al. 2013)

Take home messages

- ✓ CO_2sw is often different from CO_2atm as many factors create variability

Why does it matter?

Life adapts to its environment

pH 5.36, Ωara=0.01

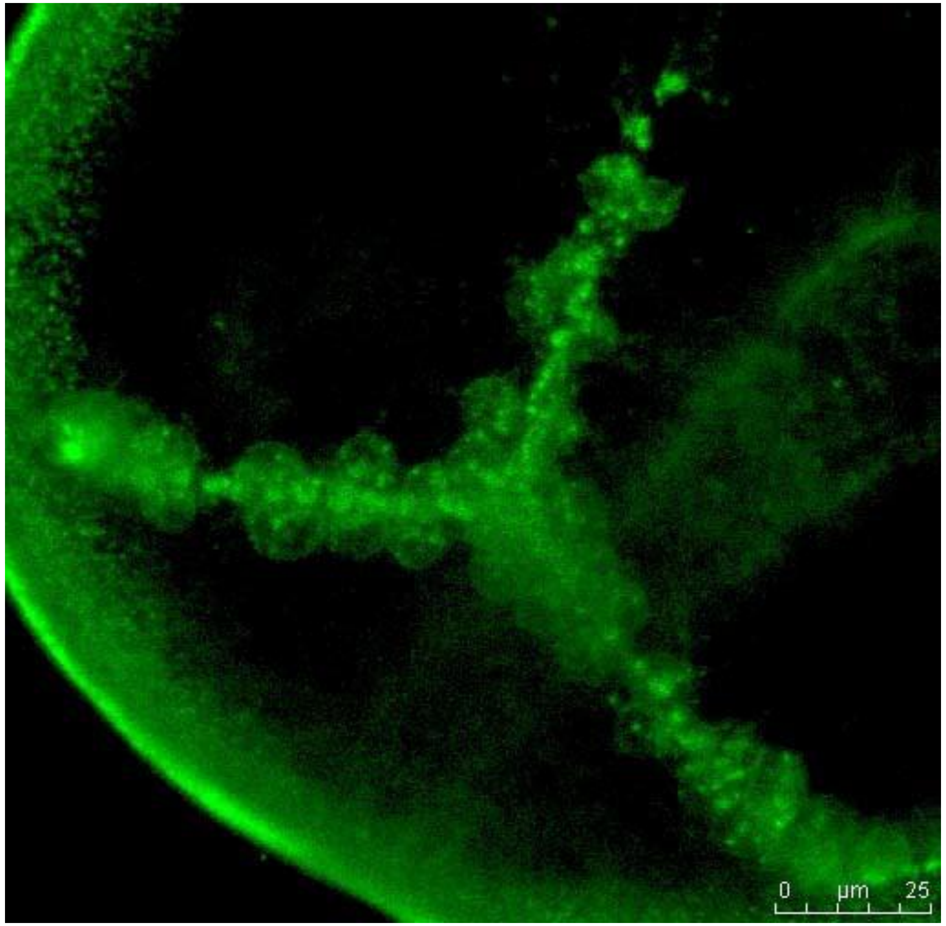
(Tunnicliffe et al. 2009)

How do you make ice at >0°C

A freezer

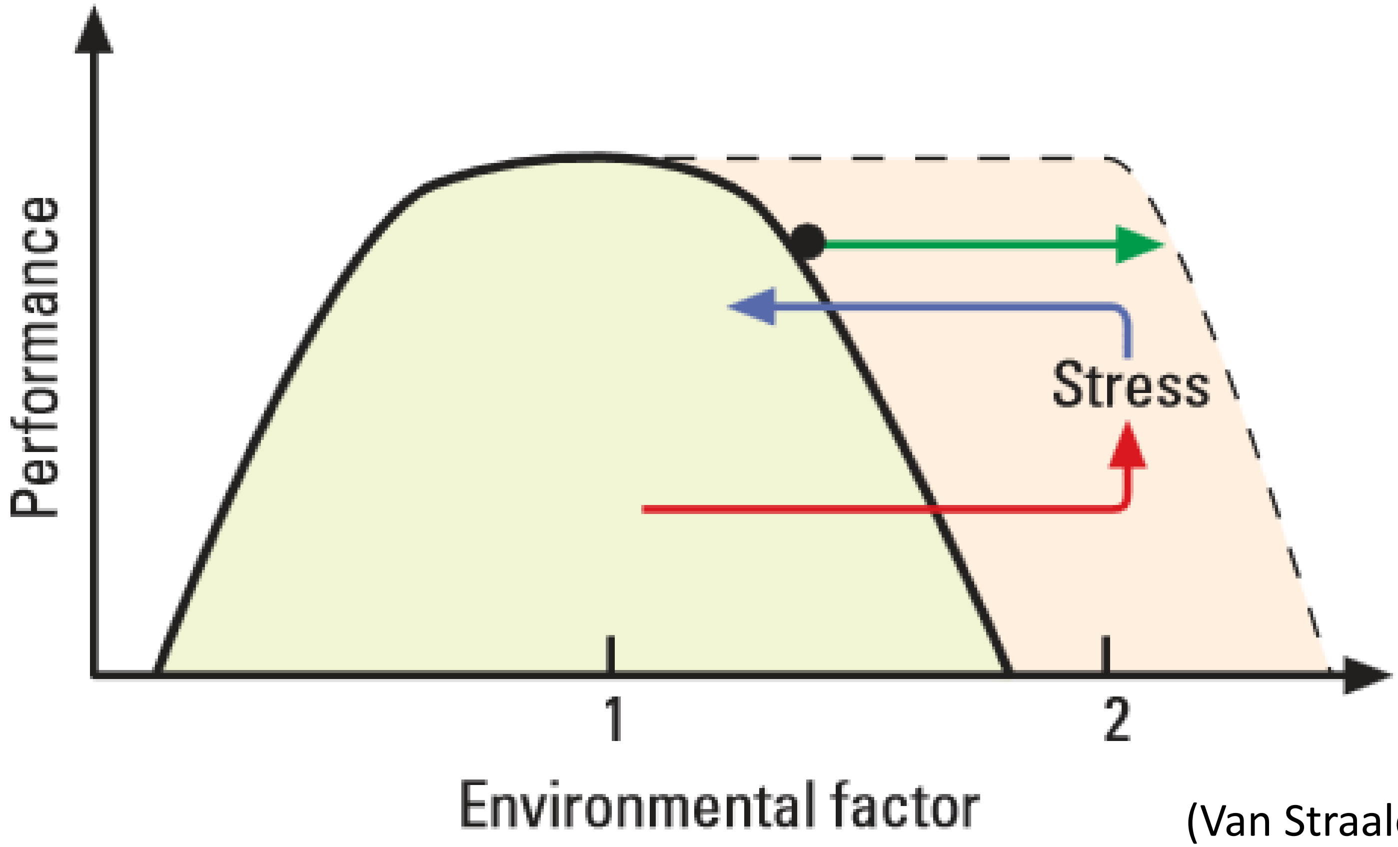
Energy cost

Physiological mechanisms



How to make $CaCO_3$ at $\Omega<1$?
$\Omega>1$ at the calcification site

Adaptation: Biological thresholds different from chemical thresholds



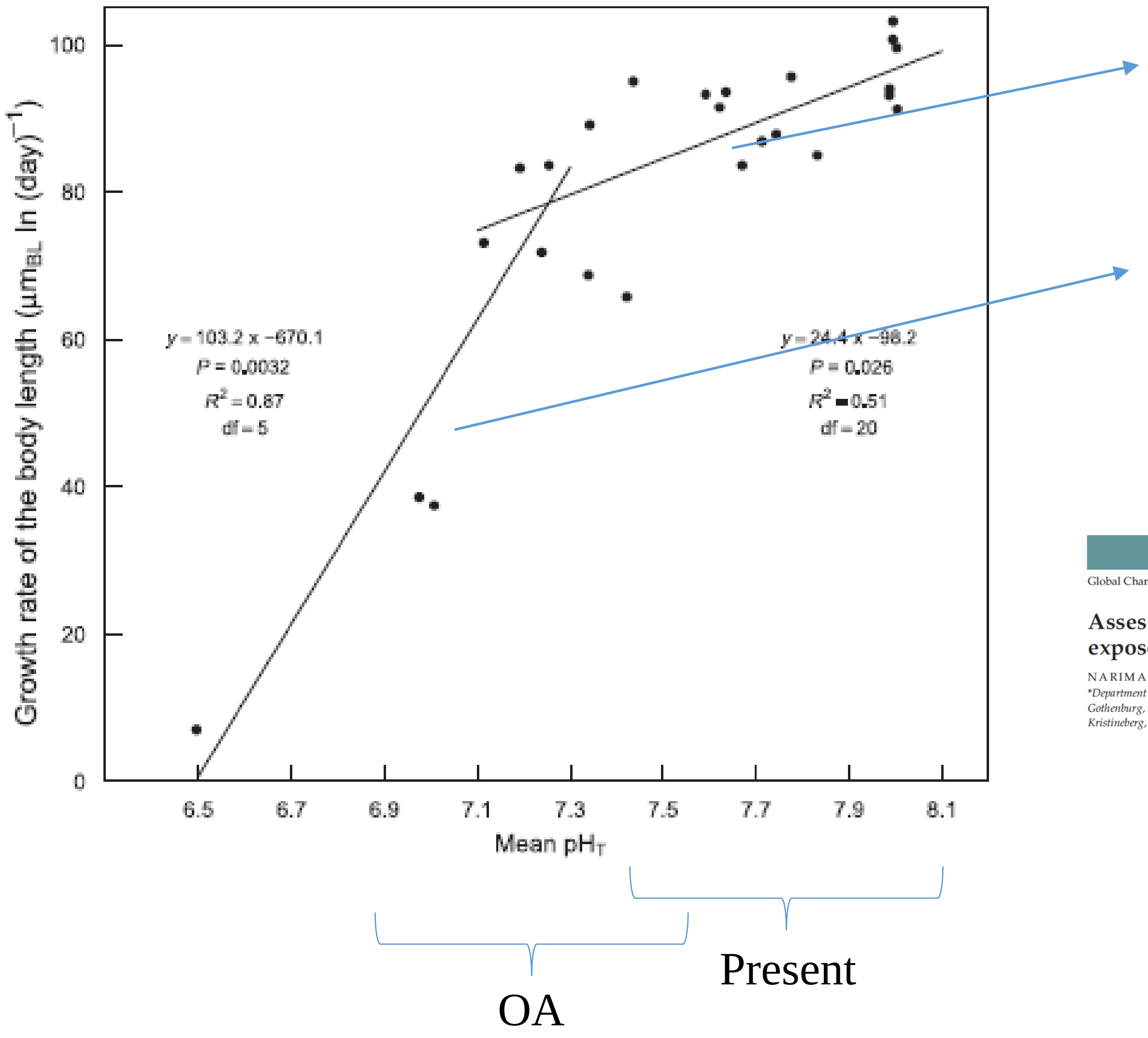
(Van Straalen 2007)

Definitions

Depending on where you are / species you study, a given pH can be:

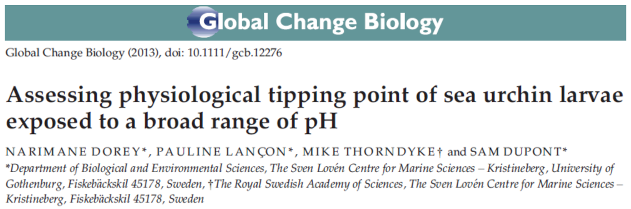
- *Stressor* — *A pressure that causes a quantifiable negative effect on an organism, process or community.*
- *Driver* — *A pressure that causes a quantifiable change (positive or negative) an organism, process or community.*
- *Stress* — *A measurable response that is deleterious to an organism, process or community.*

Response to pH depends on present natural variability: plasticity vs. stress



Within the present range of variability
NOT ocean acidification
NOT stressor / No stress (**plasticity**)

Outside the present range of variability
ocean acidification
stressor / **stress**


Global Change Biology

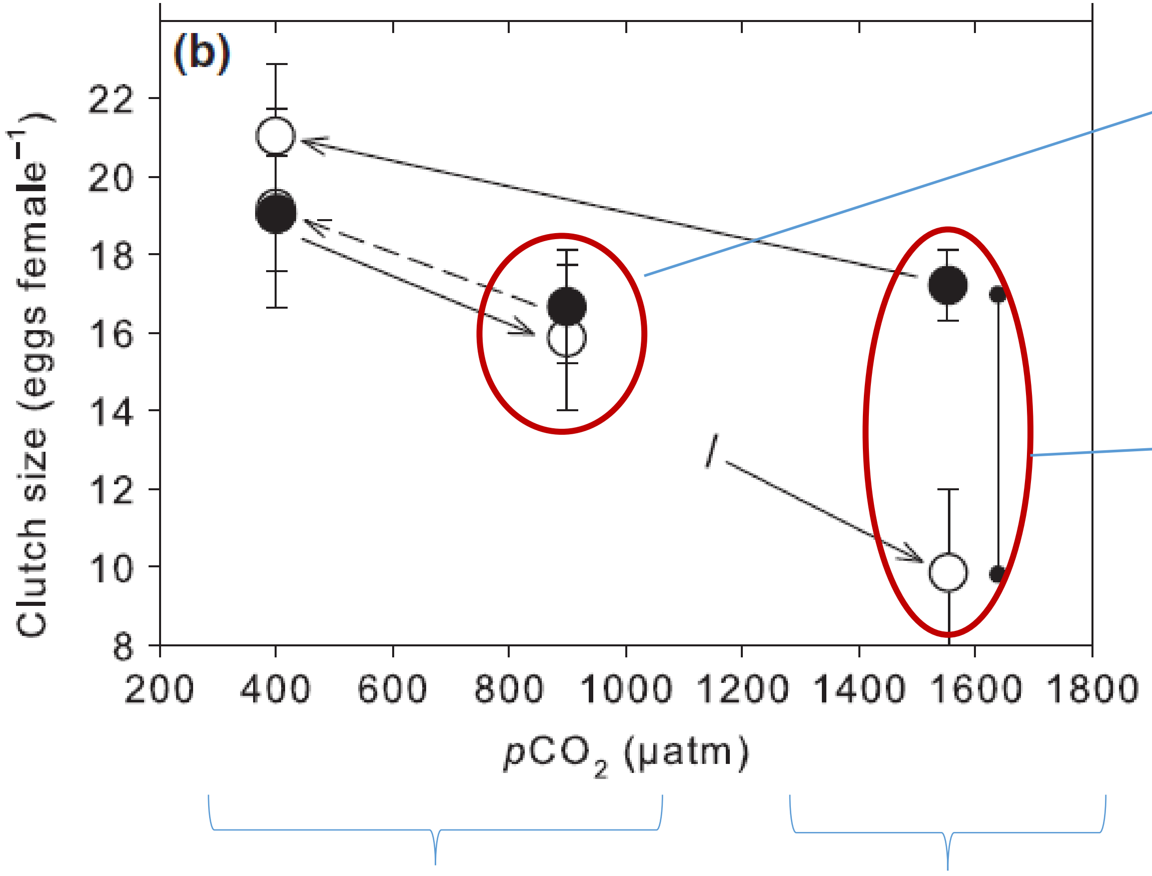
Global Change Biology (2013), doi: 10.1111/gcb.12276

Assessing physiological tipping point of sea urchin larvae exposed to a broad range of pH

NARIMANE DOREY*, PAULINE LANÇON*, MIKE THORNDYKE† and SAM DUPONT*

*Department of Biological and Environmental Sciences, The Sven Lovén Centre for Marine Sciences – Kristineberg, University of Gothenburg, Fiskebäckskil 45178, Sweden, †The Royal Swedish Academy of Sciences, The Sven Lovén Centre for Marine Sciences – Kristineberg, Fiskebäckskil 45178, Sweden

Response to pH depends on present natural variability: plasticity vs. adaptation



Present

OA

Within the present range of variability
NOT ocean acidification
NOT stressor / No stress (**plasticity**)

Outside the present range of variability
ocean acidification
stressor / **adaptation**

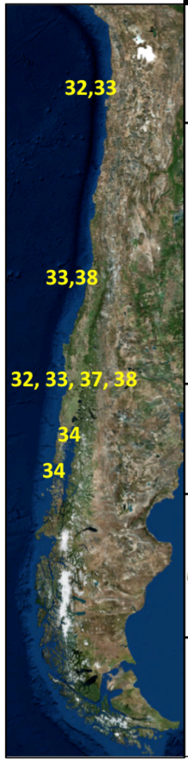
Global Change Biology

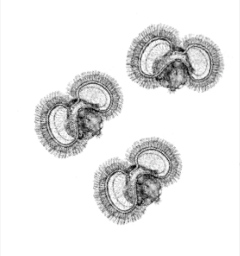
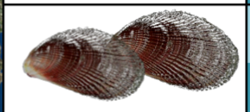
Global Change Biology (2015), doi: 10.1111/gcb.12815

Transgenerational effects alleviate severe fecundity loss during ocean acidification in a ubiquitous planktonic copepod

PETER THOR[1] and SAM DUPONT[2]
[1]*Norwegian Polar Institute, Fram Centre, 9296 Tromsø, Norway,* [2]*Department of Biological and Environmental Sciences, University of Gothenburg, 566 Kristineberg, 45178 Fiskebäckskil, Sweden*

Population sensitivity to pH



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


nature ecology & evolution

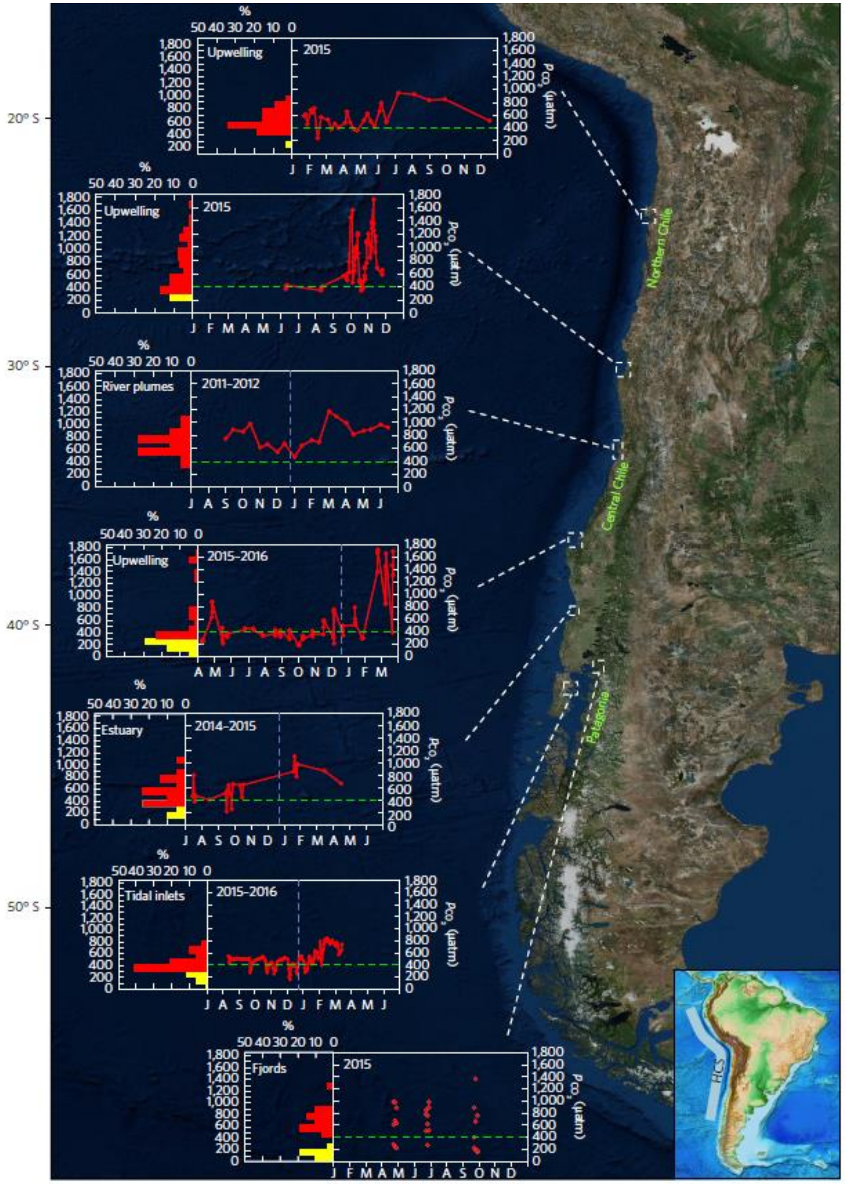
ANALYSIS

PUBLISHED: 13 MARCH 2017 | VOLUME: 1 | ARTICLE NUMBER: 0084

Species-specific responses to ocean acidification should account for local adaptation and adaptive plasticity

Cristian A. Vargas[1,2,3*], Nelson A. Lagos[3,4], Marco A. Lardies[3,5], Cristian Duarte[3,6], Patricio H. Manríquez[7], Victor M. Aguilera[2,8], Bernardo Broitman[3,7], Steve Widdicombe[9] and Sam Dupont[10]

Different variability in pH



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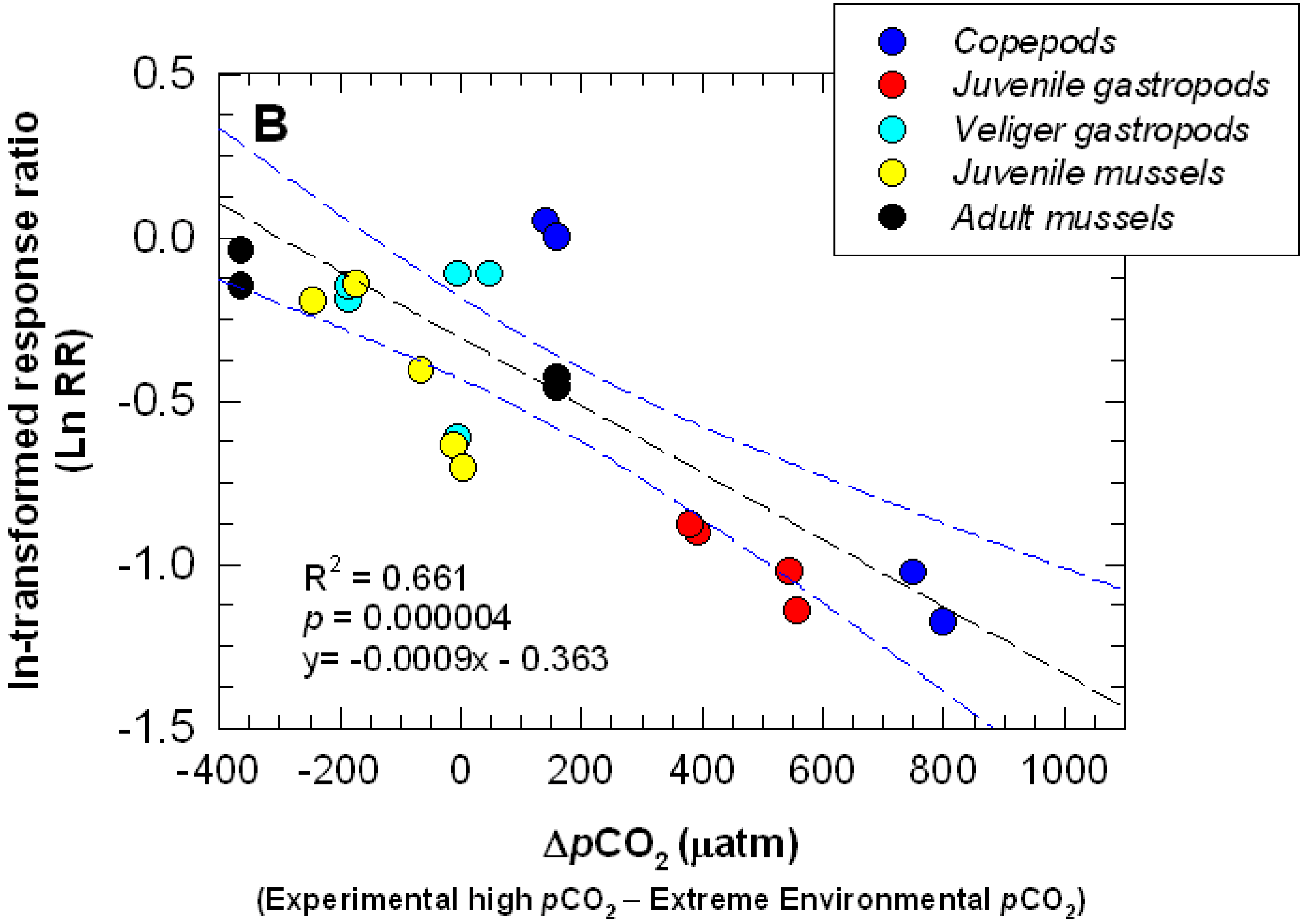
Local adaptation



*The more you **deviate from today**, the more negative impact*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Take home messages

- ✓ CO_2sw is often different from CO_2atm as many factors create variability
- ✓ Natural variability in relevant carbonate chemistry experienced by an organism should be included in the experimental design

Before starting your experiment

What are the physico-chemical conditions experienced by my organism/ecosystem?

Important to take into account:

- ✓ Microhabitats

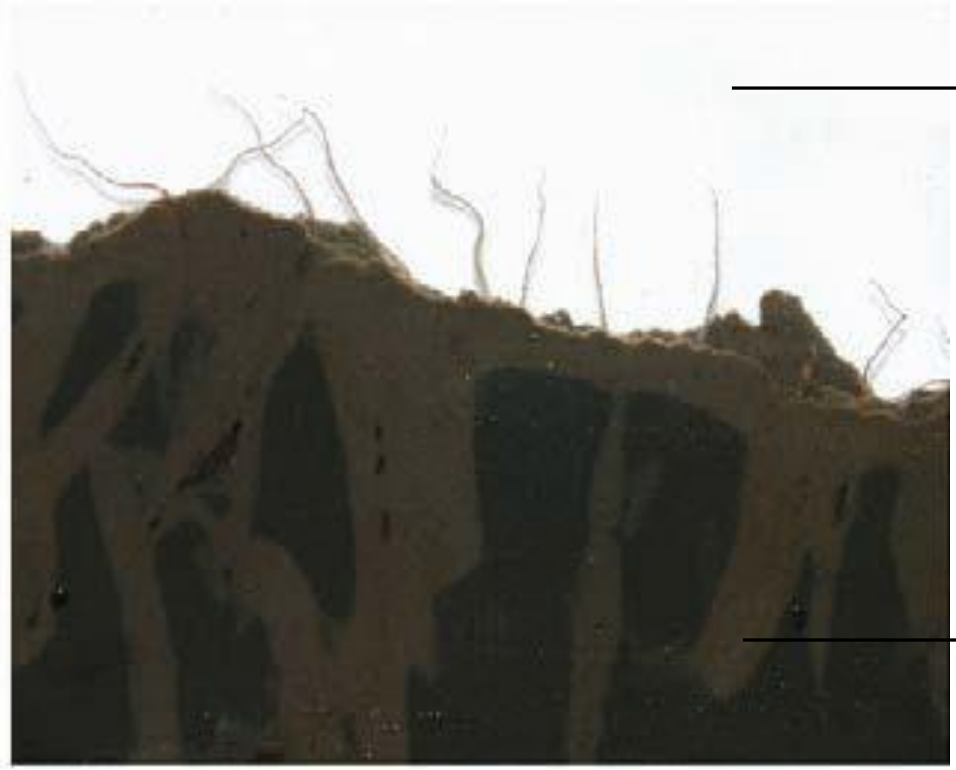
Microhabitats

© 2014. Published by The Company of Biologists Ltd | The Journal of Experimental Biology (2014) 217, 2411-2421 doi:10.1242/jeb.100024

RESEARCH ARTICLE

Energy metabolism and regeneration are impaired by seawater acidification in the infaunal brittlestar *Amphiura filiformis*

Marian Y. Hu[1,2,*], Isabel Casties[1], Meike Stumpp[1,2], Olga Ortega-Martinez[1] and Sam Dupont[1]



250 mmol O_2
pH 8.00

50 mmol O_2
pH 7.67

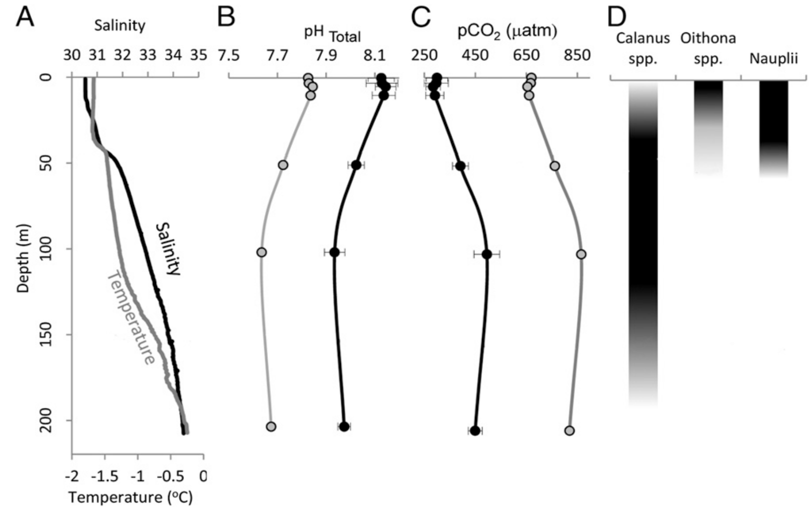
Before starting your experiment

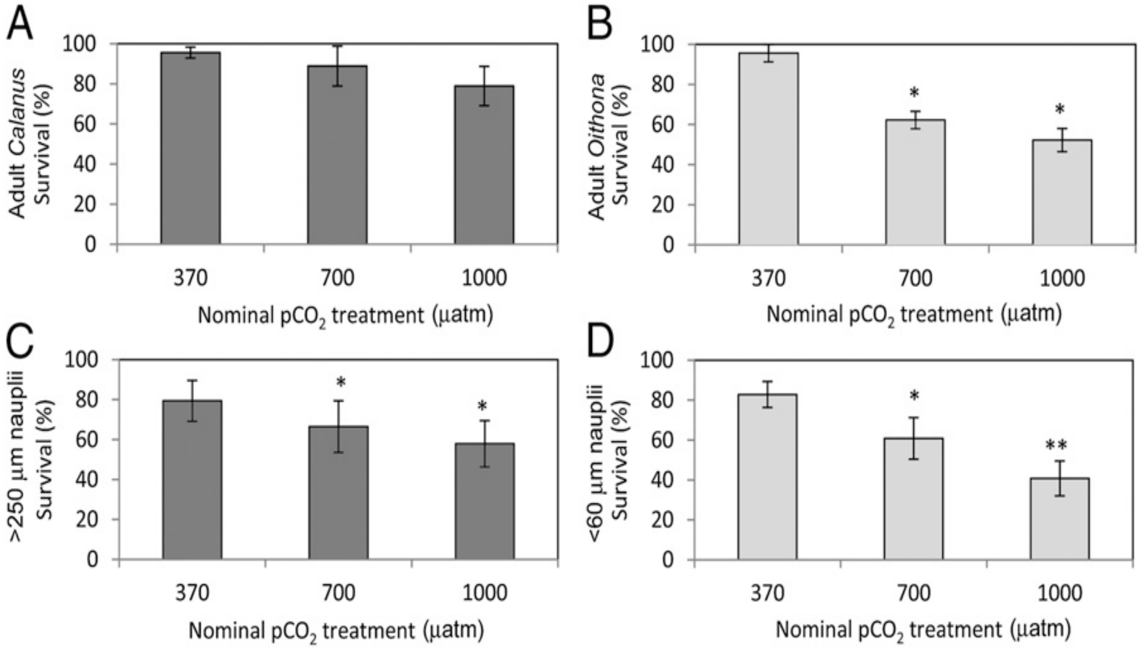
What are the physico-chemical conditions experienced by my organism/ecosystem?

Important to take into account:

- ✓ Microhabitats
- ✓ Behaviour
- ✓ Life-history stages

Behaviour

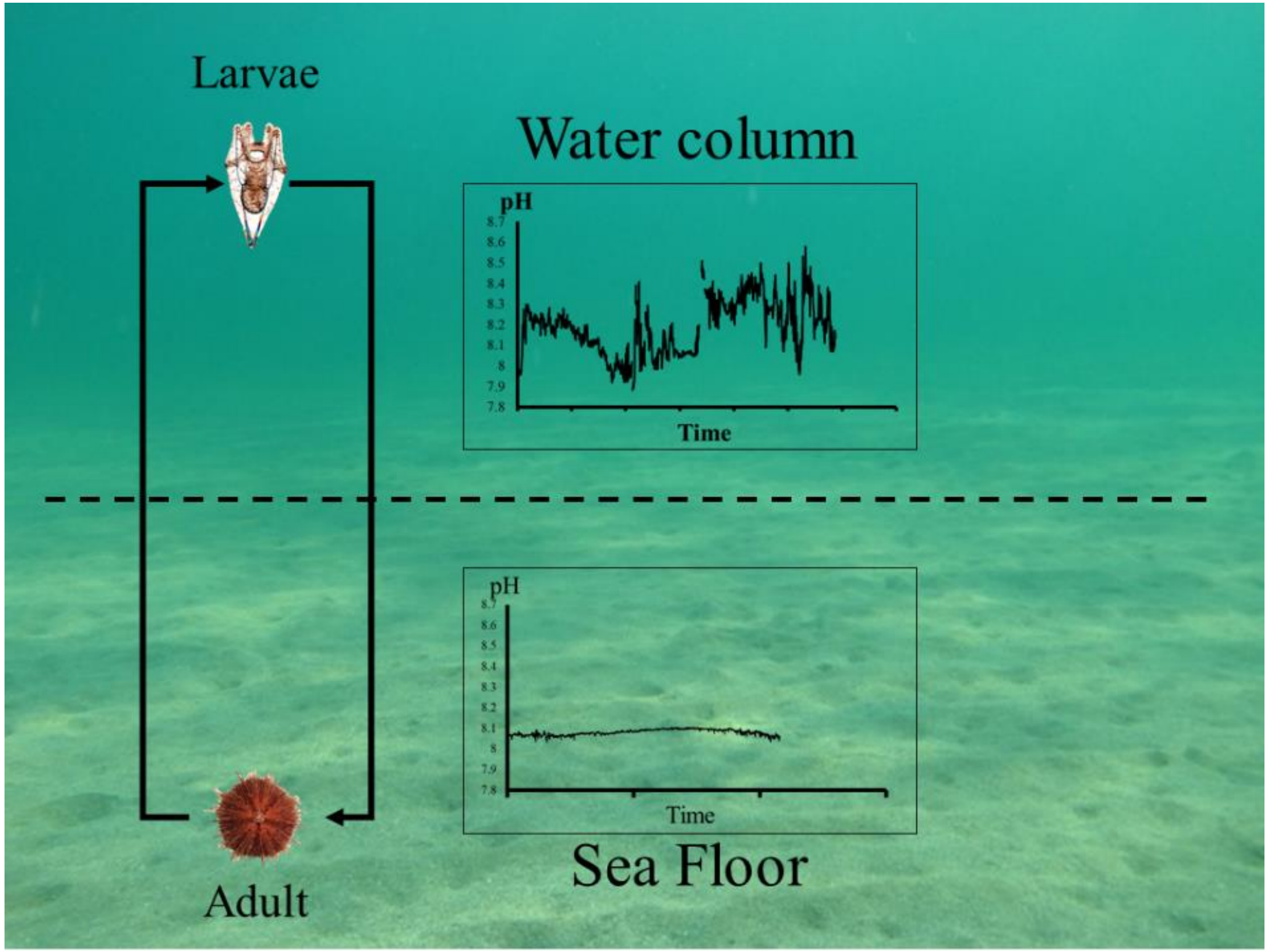




Sensitivity to ocean acidification parallels natural pCO_2 gradients experienced by Arctic copepods under winter sea ice

Ceri N. Lewis[a,1], Kristina A. Brown[b], Laura A. Edwards[c], Glenn Cooper[d], and Helen S. Findlay[e,1,2]

Life-history stages



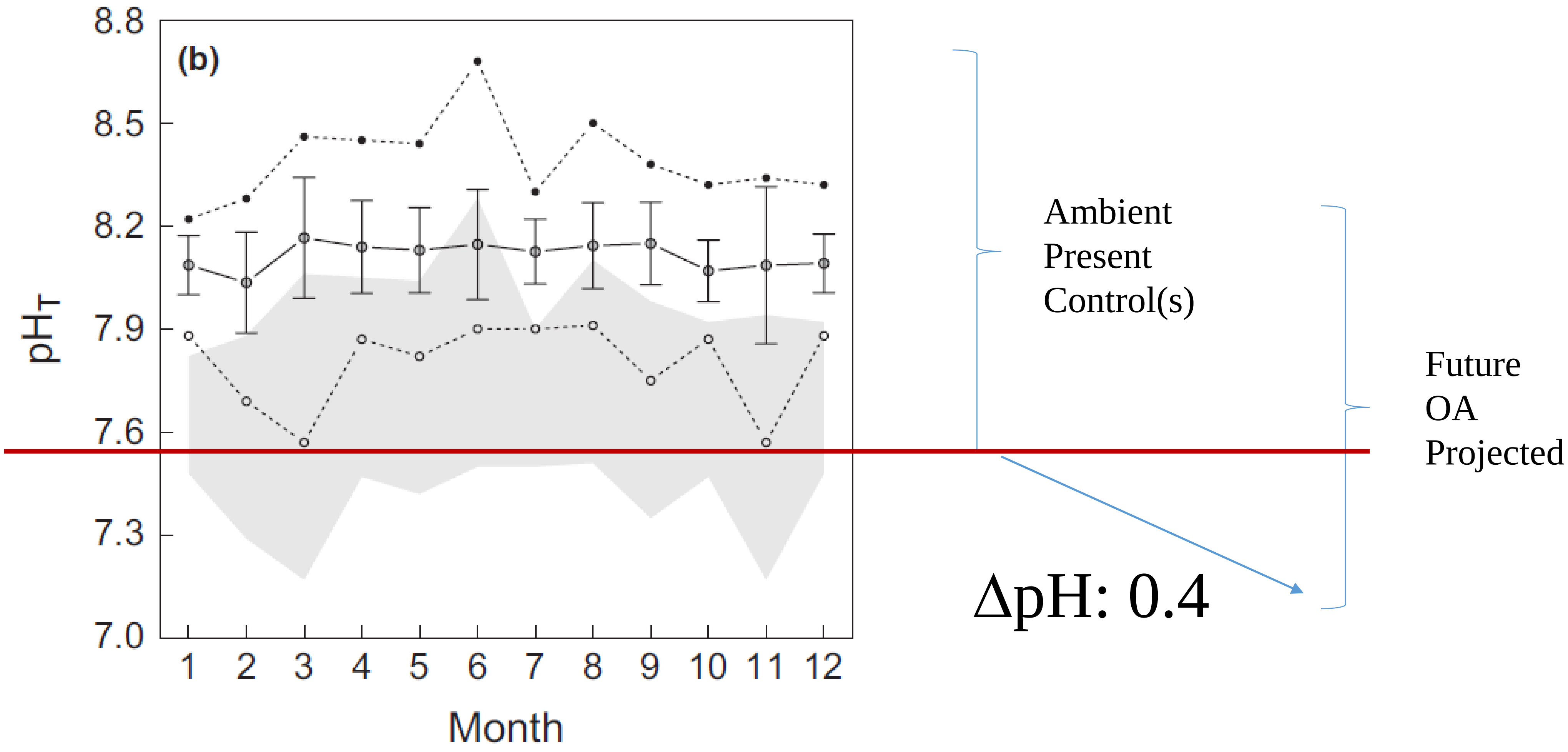
Life-history stages

What are the physico-chemical conditions experienced by my organism/ecosystem?

Three options:

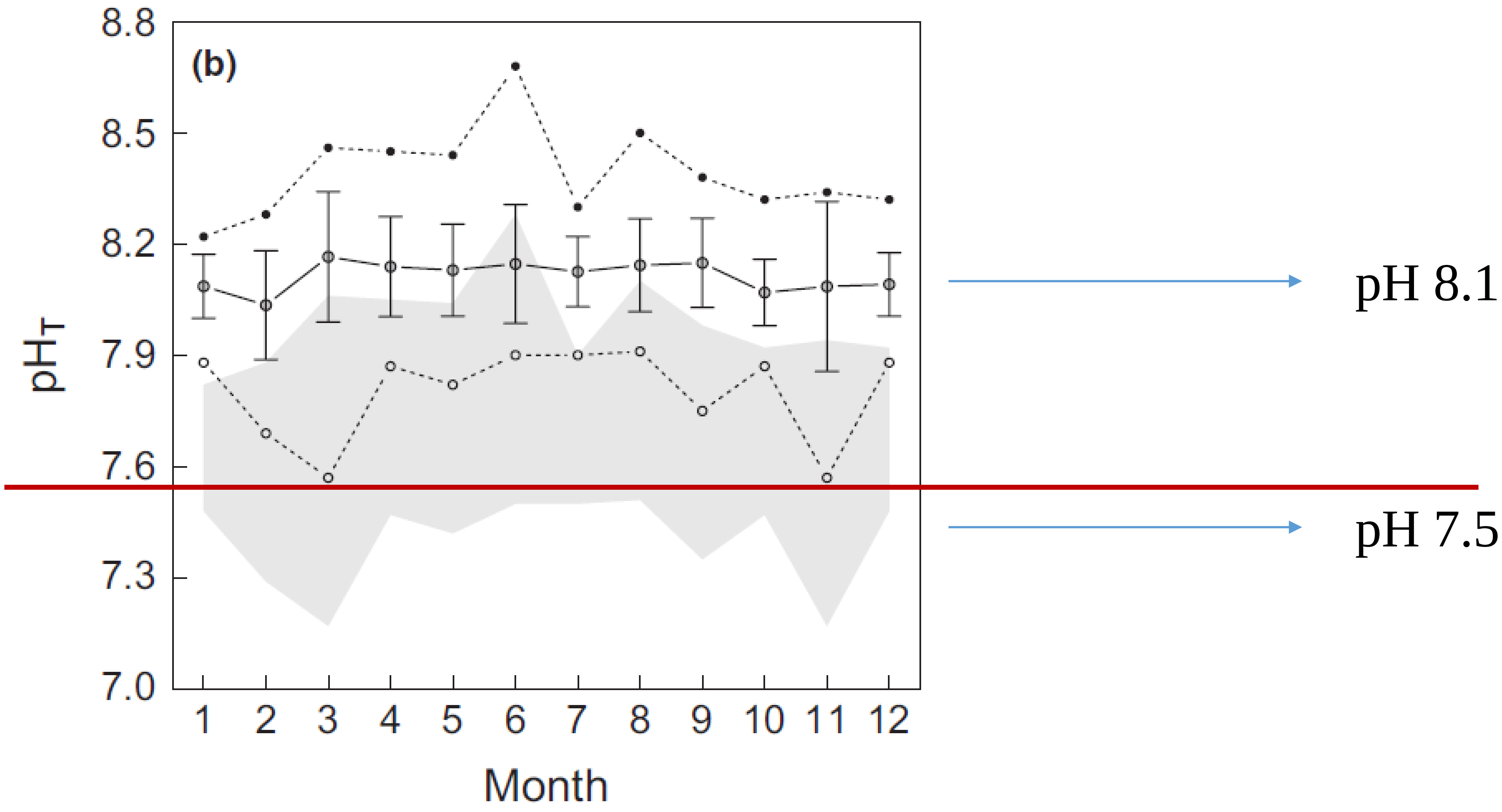
- ✓ Data are available (weather)
- ✓ Data are not available:
  - Collect some data to characterize the variability
  - Use data from a similar environment

Define your scenarios based on the present variability



(Dorey et al. 2013)

Two pH scenarios (example)

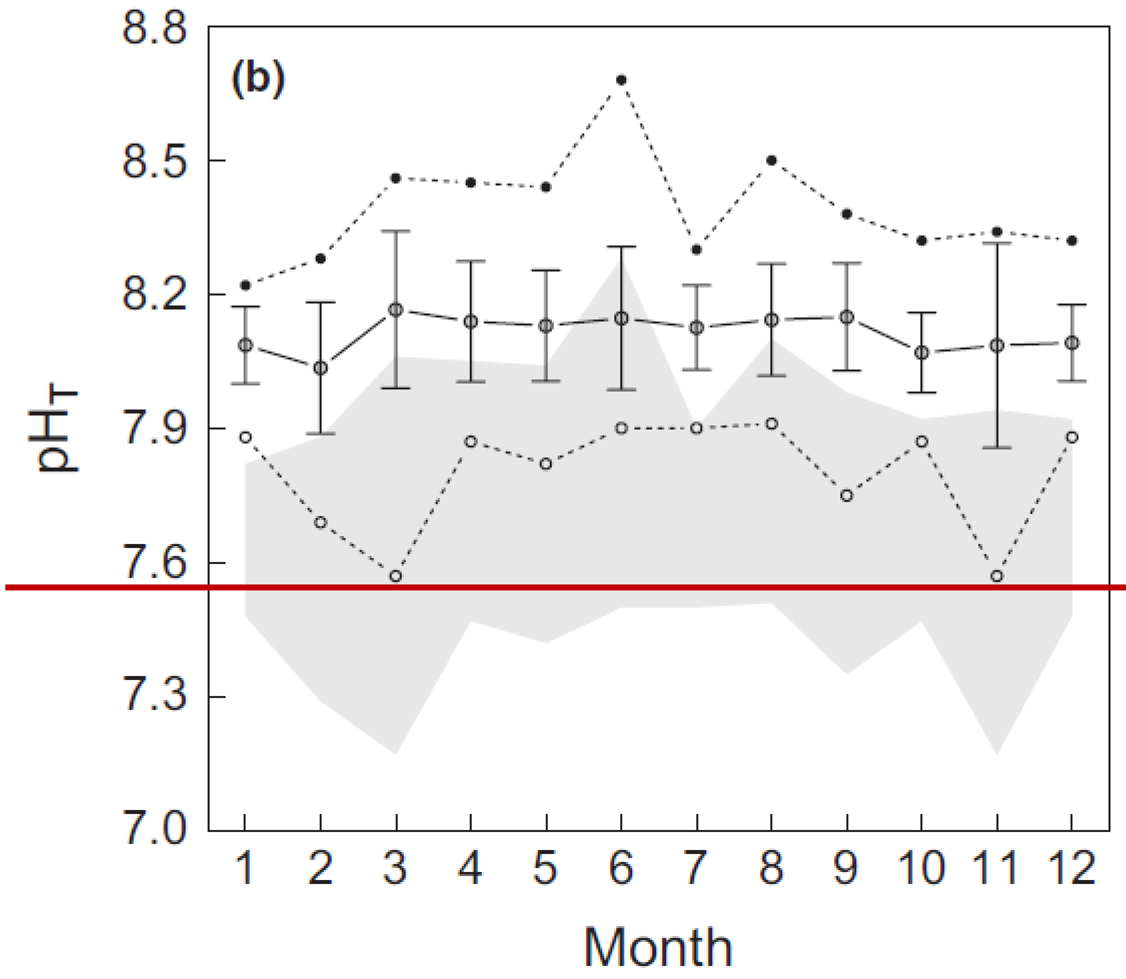


pH 8.1 (present average)

pH 7.5 (outside present range)

(Dorey et al. 2013)

Three pH scenarios (example)



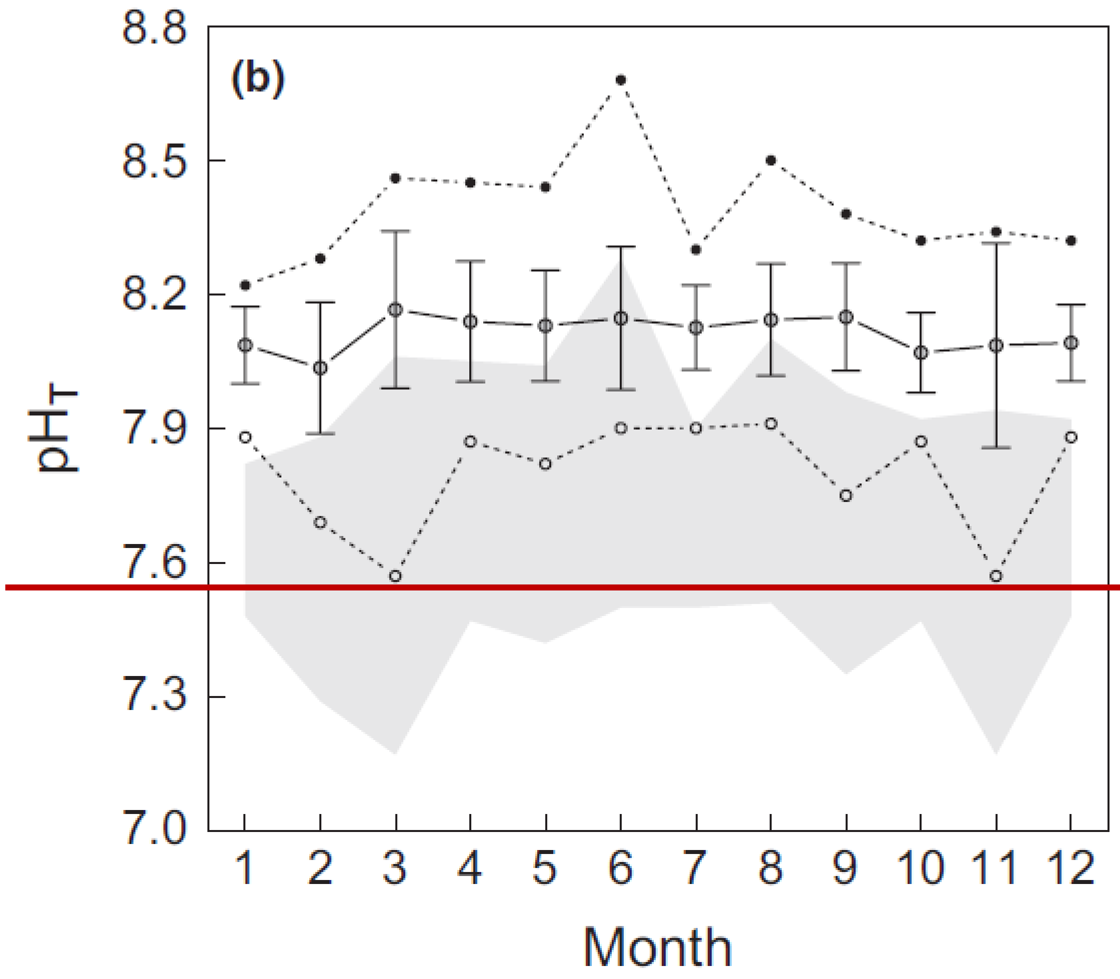
pH 8.1 (present average)

pH 7.6 (extreme of present)

pH 7.4 (outside present range)

(Dorey et al. 2013)

Range of pH scenarios (example)



pH 8.3

pH 8.1

pH 7.9

pH 7.7

pH 7.5

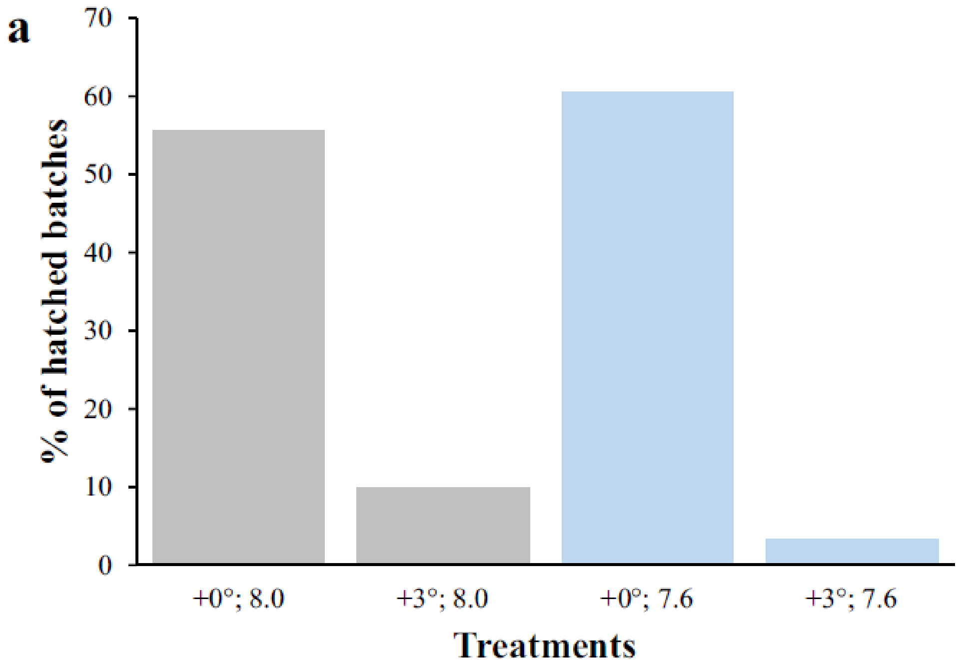
pH 7.3

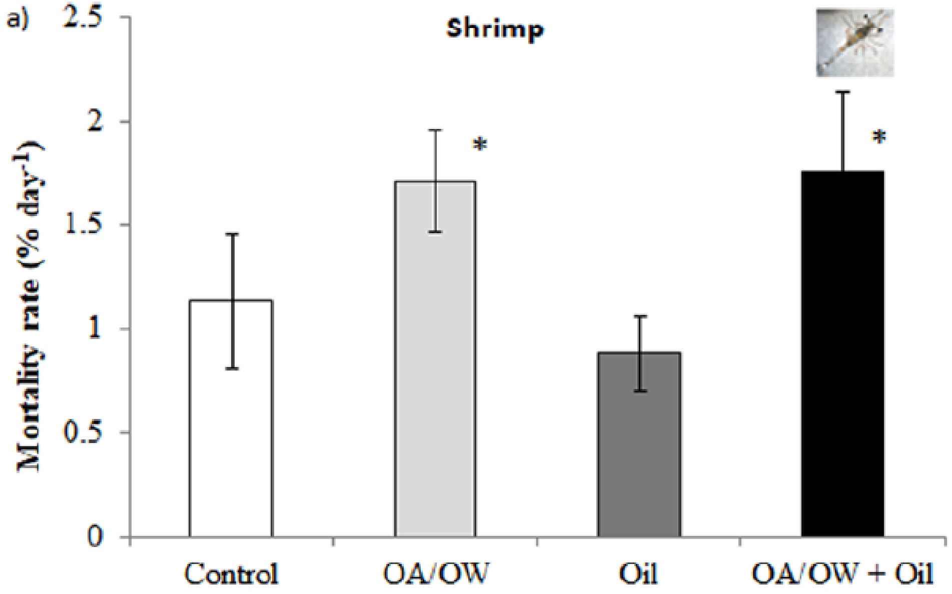
(Dorey et al. 2013)

Recommendations (writing)

- ✓ Use "pH" values in your manuscript as a given pH can be relevant in the context of present natural variability and OA
- ✓ Put tested pH into context of natural variability in the Methods
- ✓ Use the terminology "ocean acidification" in the Discussion

Recommendations (writing)





Take home messages

- ✓ CO_2sw is often different from CO_2atm as many factors create variability

- ✓ Natural variability in relevant carbonate chemistry experienced by an organism should be included in the experimental design

Note: for this lecture we will consider pH but you need first to identify what are the key carbonate chemistry parameter for your species/ecosystem

- ✓ IPCC open ocean scenarios (e.g. pH 8.1 vs. 7.7) are often irrelevant for your experiment and several control pH targets should be considered.

Other parameters

- ✓ All other parameters (not manipulated) should be kept as close as possible to the field (except if testing specific hypotheses)
  e.g. alkalinity, salinity, temperature, food, oxygen, etc.
  Key if you are not using seawater from the sampling site

- ✓ Be careful with interactions !

(Bad) example

Tested factor: temperature

High density
Closed aquarium

Confounding factors: O_2, CO_2

Often require a pilot experiment or working with experts