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

Modulating factors

Ocean acidification is too complex to answer with one experiment

Each experiment is an abstraction of reality
modulated by

- ✓ Experimental design
  - Confounding factors
  - Practical limitations

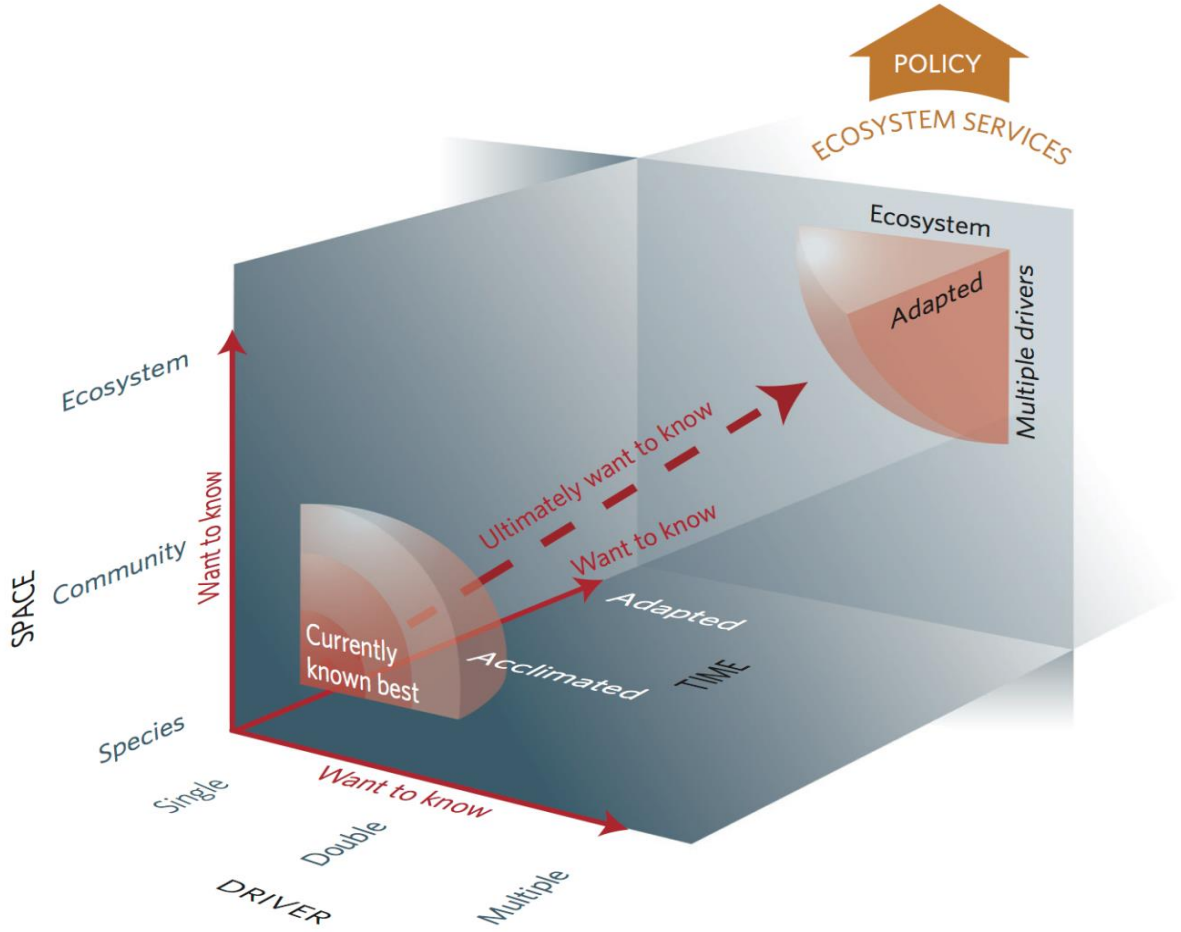
Ocean acidification is too complex to answer with one experiment

Each experiment is an abstraction of reality
modulated by

- ✓ Experimental design
  - Confounding factors
  - Practical limitations

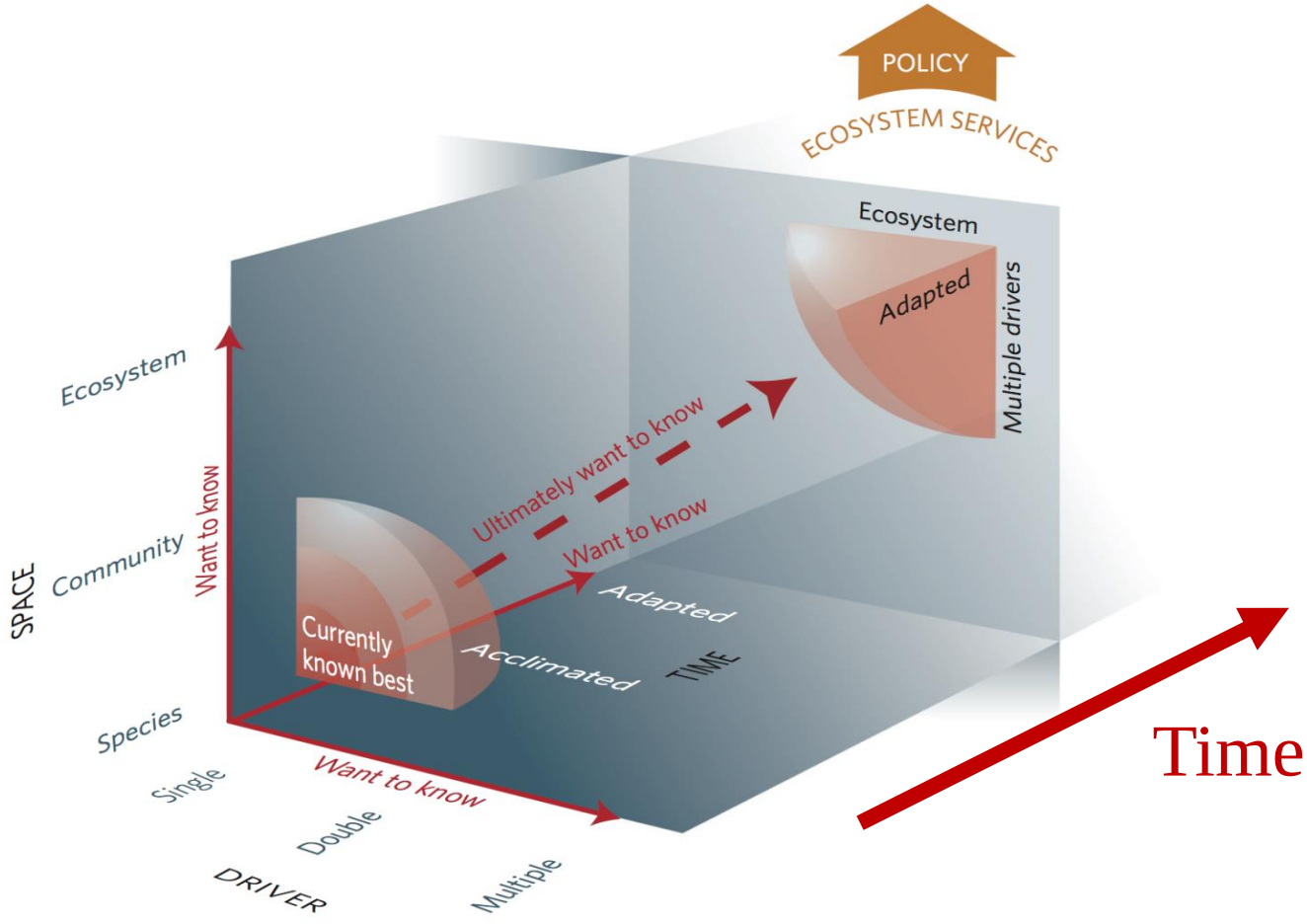
- ✓ Lack of realism

Ocean acidification is too complex to answer with one experiment



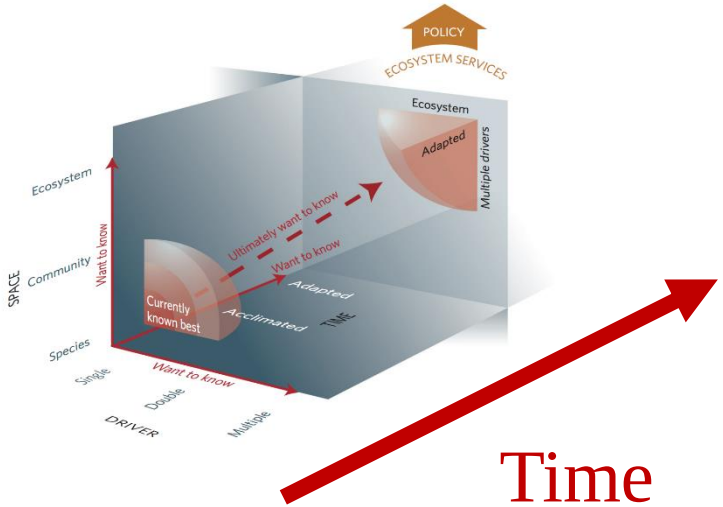
Complex ! Would requite a module for each factor

Ocean acidification is too complex to answer with one experiment



Time: Acclimation / Evolution

Ocean acidification is too complex to answer with one experiment



Time

Short term experiments neglect:

- ✓ Acclimation
- ✓ Carry-over
- ✓ Selection
- ✓ Etc

and then lead to over- or under-estimation of the ocean acidification effect

Field of (marine) evolution

Review

Cell PRESS

Evolution in an acidifying ocean

Jennifer M. Sunday[1,2], Piero Calosi[3], Sam Dupont[4], Philip L. Munday[5,6], Jonathon H. Stillman[7,8], and Thorsten B.H. Reusch[9]

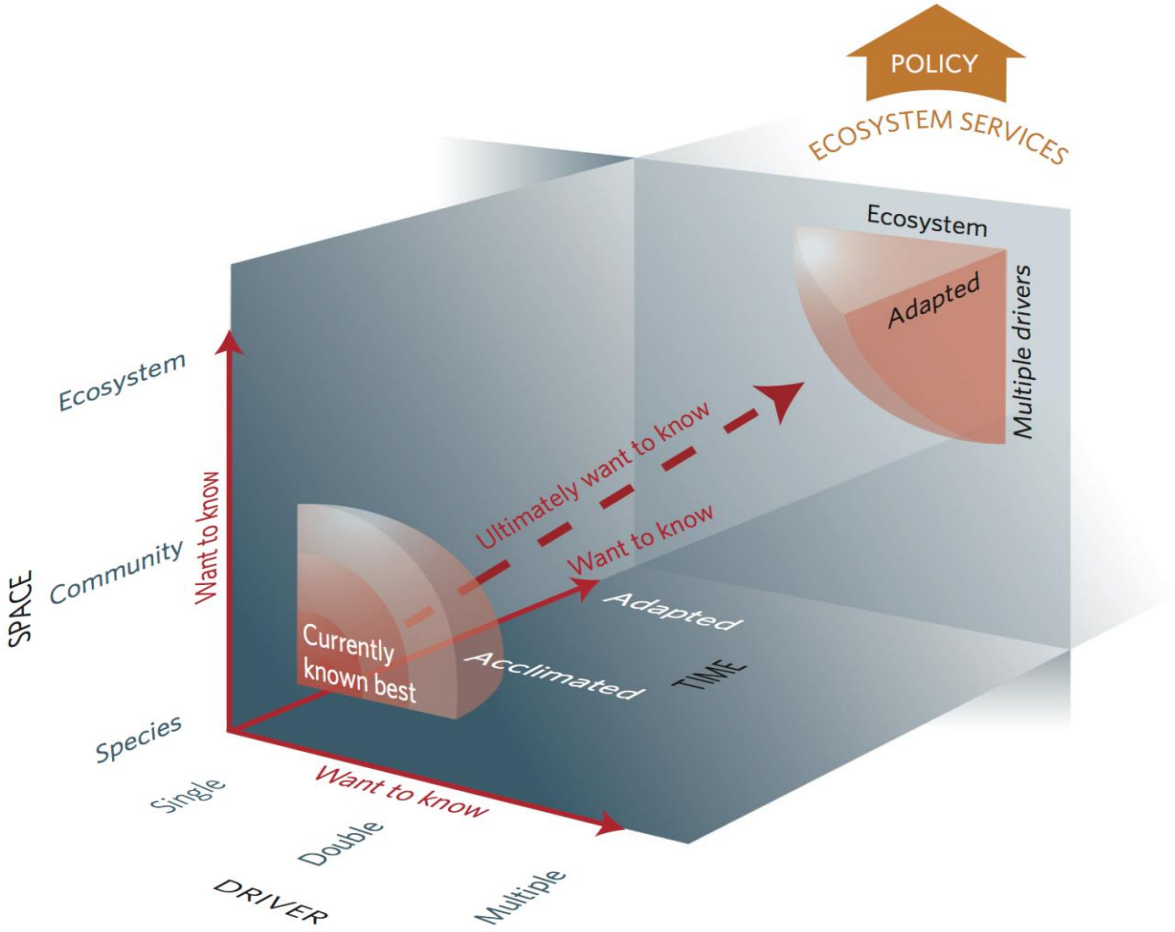
Evolutionary Applications ISSN 1752-4571

ORIGINAL ARTICLE

Will life find a way? Evolution of marine species under global change

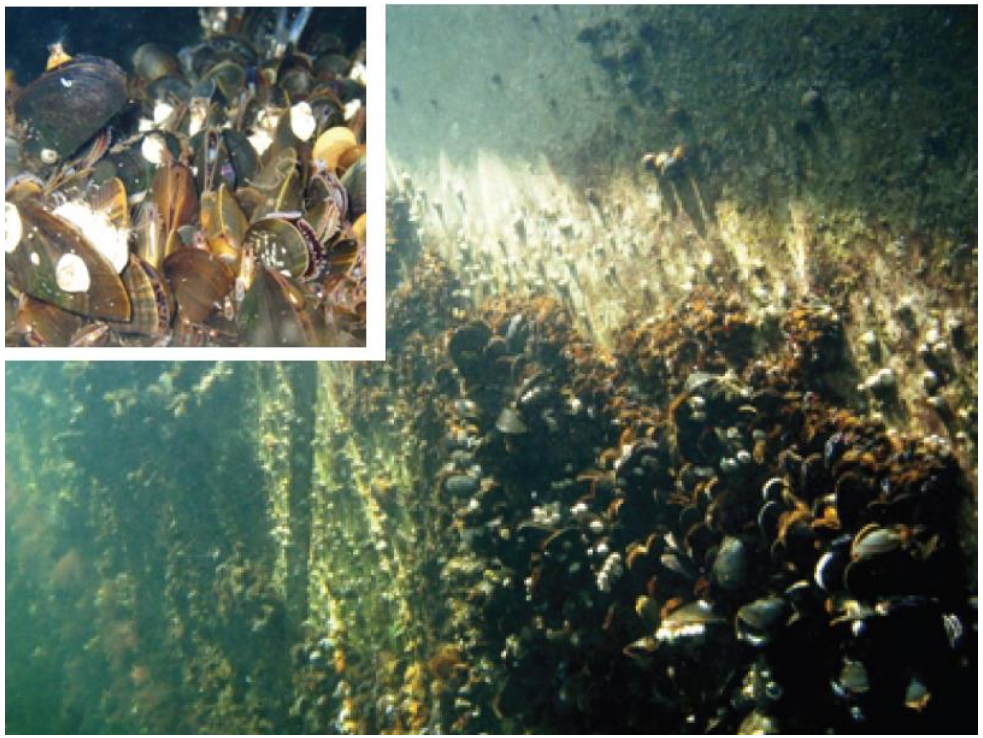
Piero Calosi,[1] Pierre De Wit,[2] Peter Thor[3] and Sam Dupont[4]

Ocean acidification is too complex to answer with one experiment



Space: Interactions, Ecology

Single species – lack modulating role of trophic interactions

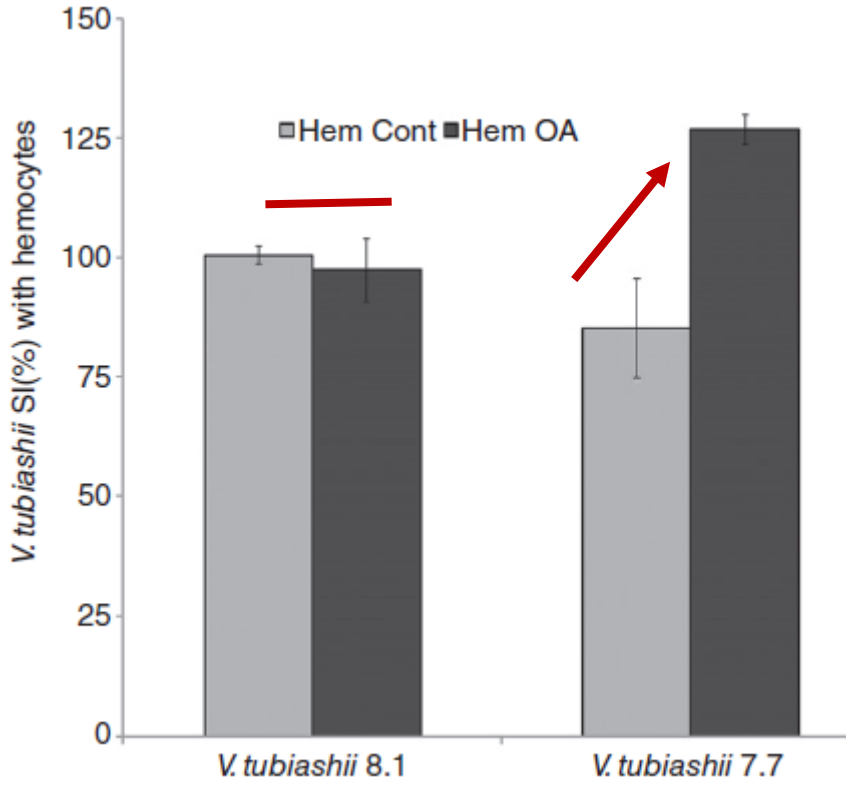


pH 7.5, Ωara=0.35

(Thomsen et al. 2010)

”Low” level of food can over-estimate the impact

Single species – lack modulating role of species interactions (e.g. parasite)



environmental microbiology
Environmental Microbiology (2013)
doi:10.1111/1462-2920.12307

Ocean acidification and host–pathogen interactions: blue mussels, *Mytilus edulis*, encountering *Vibrio tubiashii*

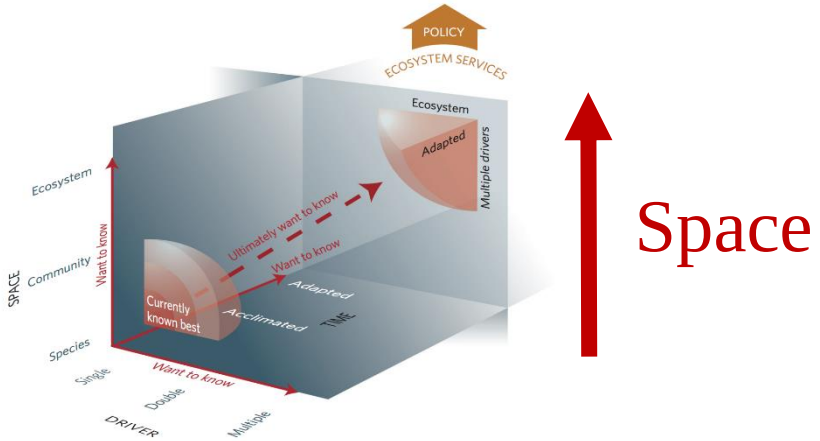
Maria E. Asplund,[1*] Susanne P. Baden,[1] Sarah Russ,[1] Robert P. Ellis,[2] Ningping Gong[3] and Bodil E. Hernroth[4,5]

viability when exposed to haemocytes of OA-treated mussel. Our findings suggest that even though host organisms may have the capacity to cope with

Increased sensitivity to parasite if both cultured under low pH

Effect neglected in single species studies leads to under-estimation of effect on host

Ocean acidification is too complex to answer with one experiment



Space

Single species experiments neglect intra- and inter-specific interactions and then lead to over- or under- estimation of the ocean acidification effect

Field of (marine) ecology

ESA CENTENNIAL PAPER

Ecology, 96(1), 2015, pp. 3–15

Ocean acidification through the lens of ecological theory

Brian Gaylord,[1,14] Kristy J. Kroeker,[1] Jennifer M. Sunday,[2] Kathryn M. Anderson,[2] James P. Barry,[3] Norah E. Brown,[2] Sean D. Connell,[4] Sam Dupont,[5] Katharina E. Fabricius,[6] Jason M. Hall-Spencer,[7] Terrie Klinger,[8] Marco Milazzo,[9] Philip L. Munday,[10] Bayden D. Russell,[4] Eric Sanford,[1] Sebastian J. Schreiber,[11] Vengatesen Thiyagarajan,[12] Megan L. H. Vaughan,[2] Steven Widdicombe,[13] and Christopher D. G. Harley[2]

nature climate change

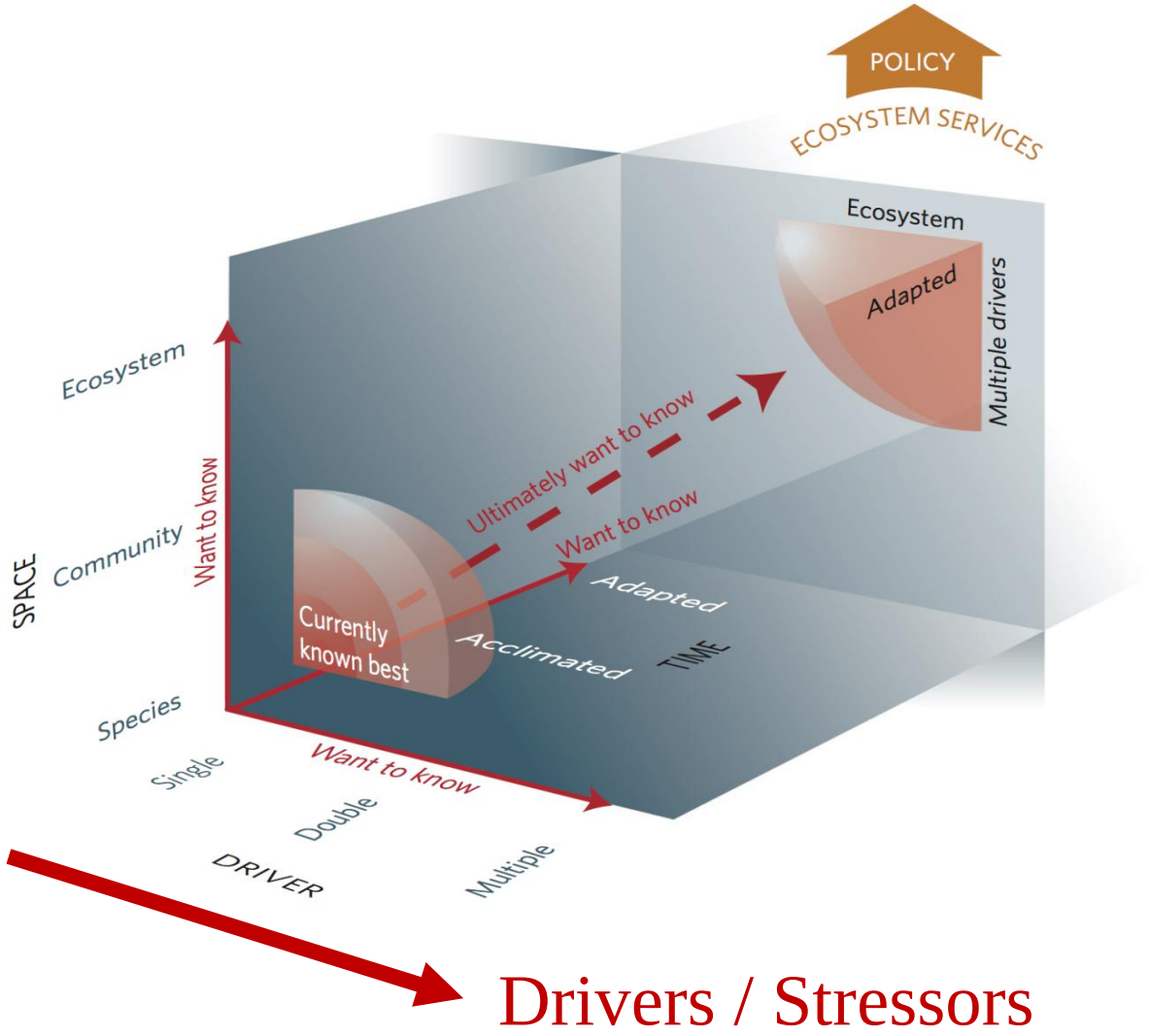
ARTICLES

PUBLISHED ONLINE: 21 NOVEMBER 2016 | DOI: 10.1038/NCLIMATE3161

Ocean acidification can mediate biodiversity shifts by changing biogenic habitat

Jennifer M. Sunday[1*], Katharina E. Fabricius[2], Kristy J. Kroeker[3], Kathryn M. Anderson[1], Norah E. Brown[1], James P. Barry[4], Sean D. Connell[5], Sam Dupont[6], Brian Gaylord[7], Jason M. Hall-Spencer[8,9], Terrie Klinger[10], Marco Milazzo[11], Philip L. Munday[12], Bayden D. Russell[13], Eric Sanford[7], Vengatesen Thiyagarajan[13], Megan L. H. Vaughan[1], Stephen Widdicombe[14] and Christopher D. G. Harley[1]

Ocean acidification is too complex to answer with one experiment



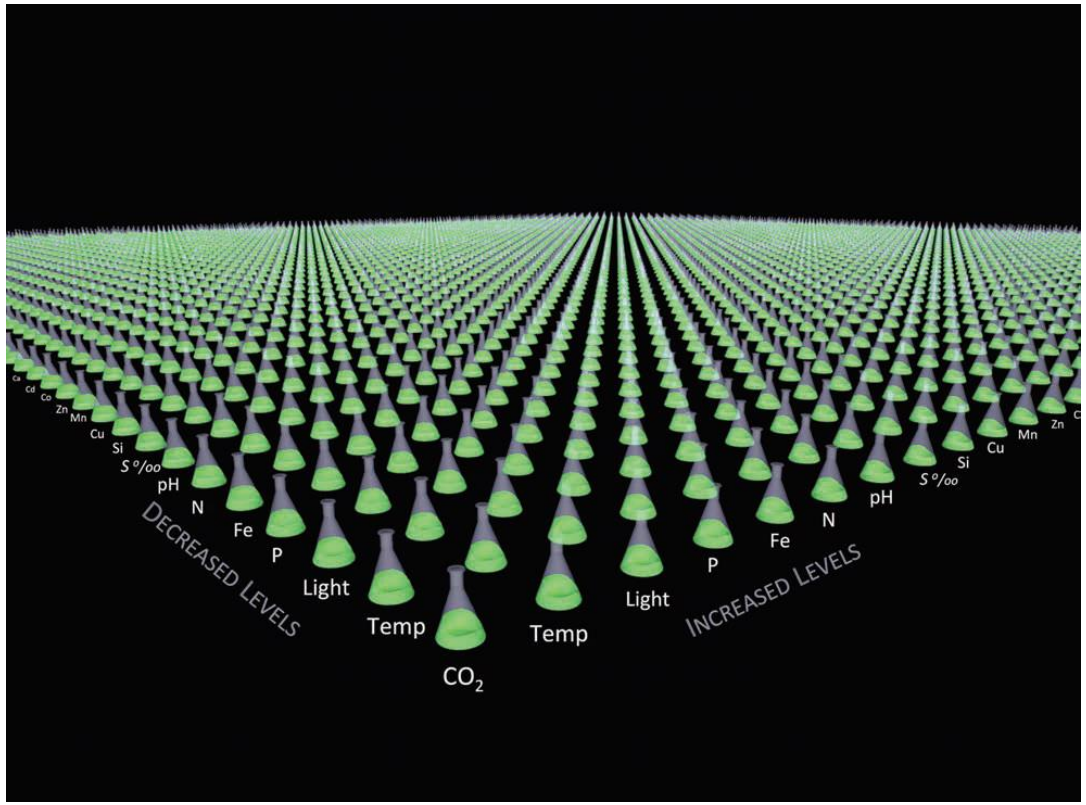
THE question

Multiple drivers/stressors
(A, B, C, D, etc.)

What is the effect of A+B+C+D+etc.

How to answer this question

Multiple stressors experiments



- ✓ Many stressors
- ✓ Many scenarios

Complex to perform

Complex to interpret !

Part 1 – Importance of definitions

”She was here on earth to grasp the meaning of its wild enchantment and to ***call each thing by its right name****.”*

(Pasternak, 1957 - Doctor Zhivago)

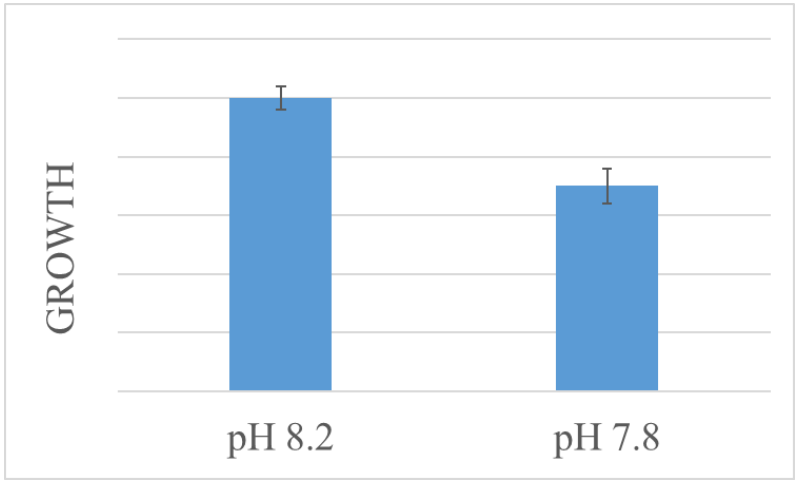
Case study #1: impact of OA on mussels

Shengsi island, China

Exposure: Monitoring - pH variability = 8.2 – 7.6

Effect? Experiment – two scenarios

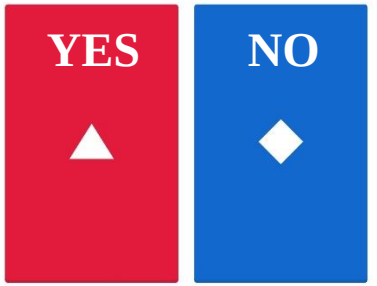
- pH 8.2
- pH 7.8 (=8.2-0.4, IPCC)



Significant 15% decrease in growth

Question #1

You want to study the impact of ocean acidification (ΔpH=-0.4 pH unit) on mussels collected in the tidal zone of Shengsi island where the pH varies between 8.2 and 7.7. In the laboratory, you test pH 8.2 and pH 7.8 (8.2-0.4) and see that it leads to a decrease in growth by 15% when they are exposed to pH 7.8 as compared to 8.2

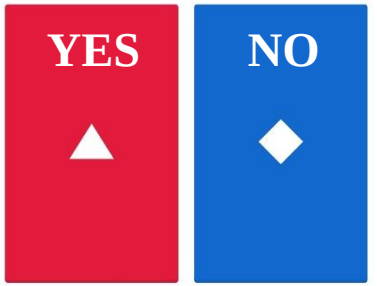


Can you reach the following conclusions?

1. Mussel growth decreases by 15% under ocean acidification YES/NO

Question #2

You want to study the impact of ocean acidification (ΔpH=-0.4 pH unit) on mussels collected in the tidal zone of Shengsi island where the pH varies between 8.2 and 7.7. In the laboratory, you test pH 8.2 and pH 7.8 (8.2-0.4) and see that it leads to a decrease in growth by 15% when they are exposed to pH 7.8 as compared to 8.2

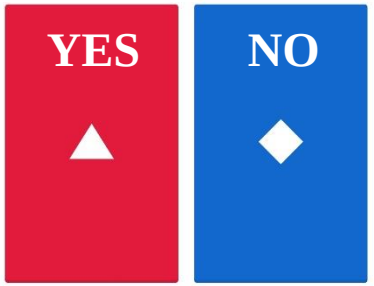


Can you reach the following conclusions?

2. Mussels are stressed when exposed to pH 7.8 YES/NO

Question #3

You want to study the impact of ocean acidification (ΔpH=-0.4 pH unit) on mussels collected in the tidal zone of Shengsi island where the pH varies between 8.2 and 7.7. In the laboratory, you test pH 8.2 and pH 7.8 (8.2-0.4) and see that it leads to a decrease in growth by 15% when they are exposed to pH 7.8 as compared to 8.2



Can you reach the following conclusions?

3. Our results show that pH is a stressor for these mussels YES/NO

Definitions

- *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.*

A driver can become a stressor

Small dose

Increase longevity

High dose

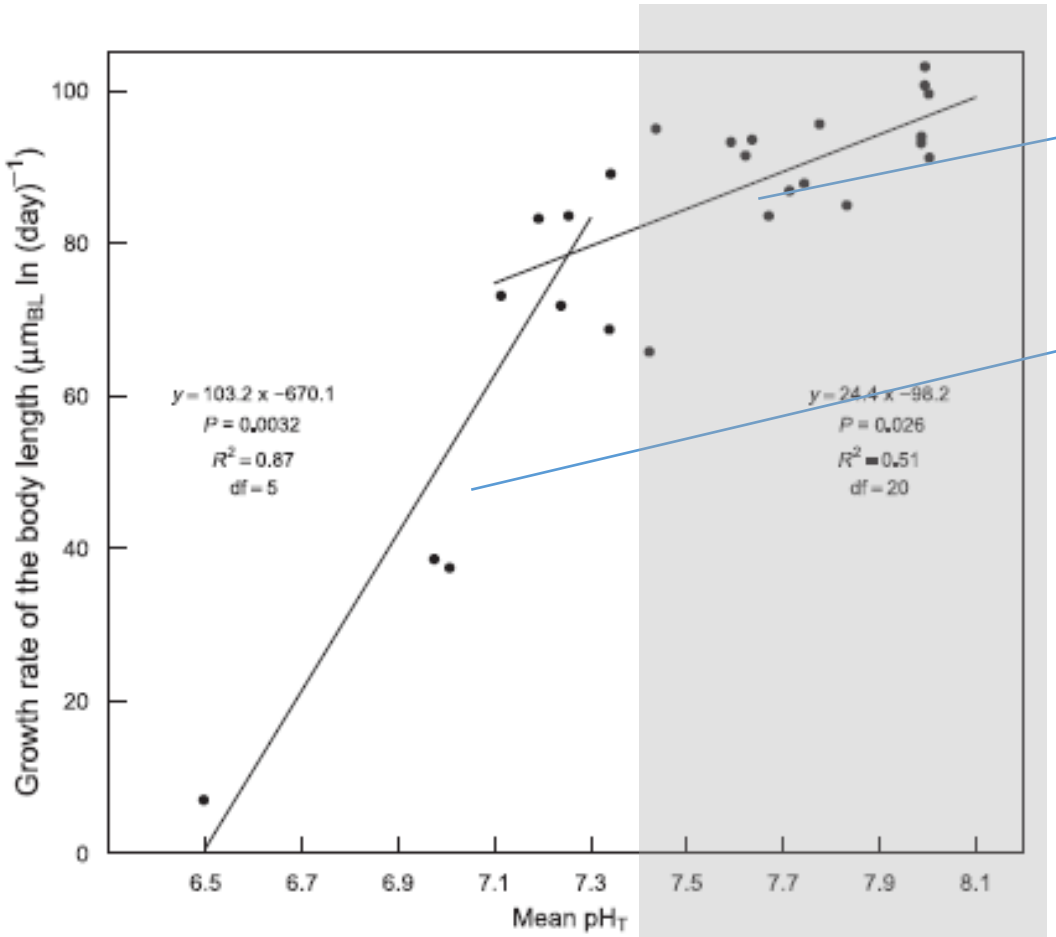
Acute

Stress (Hangover)

Chronic

Death

A driver can become a stressor



Today

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

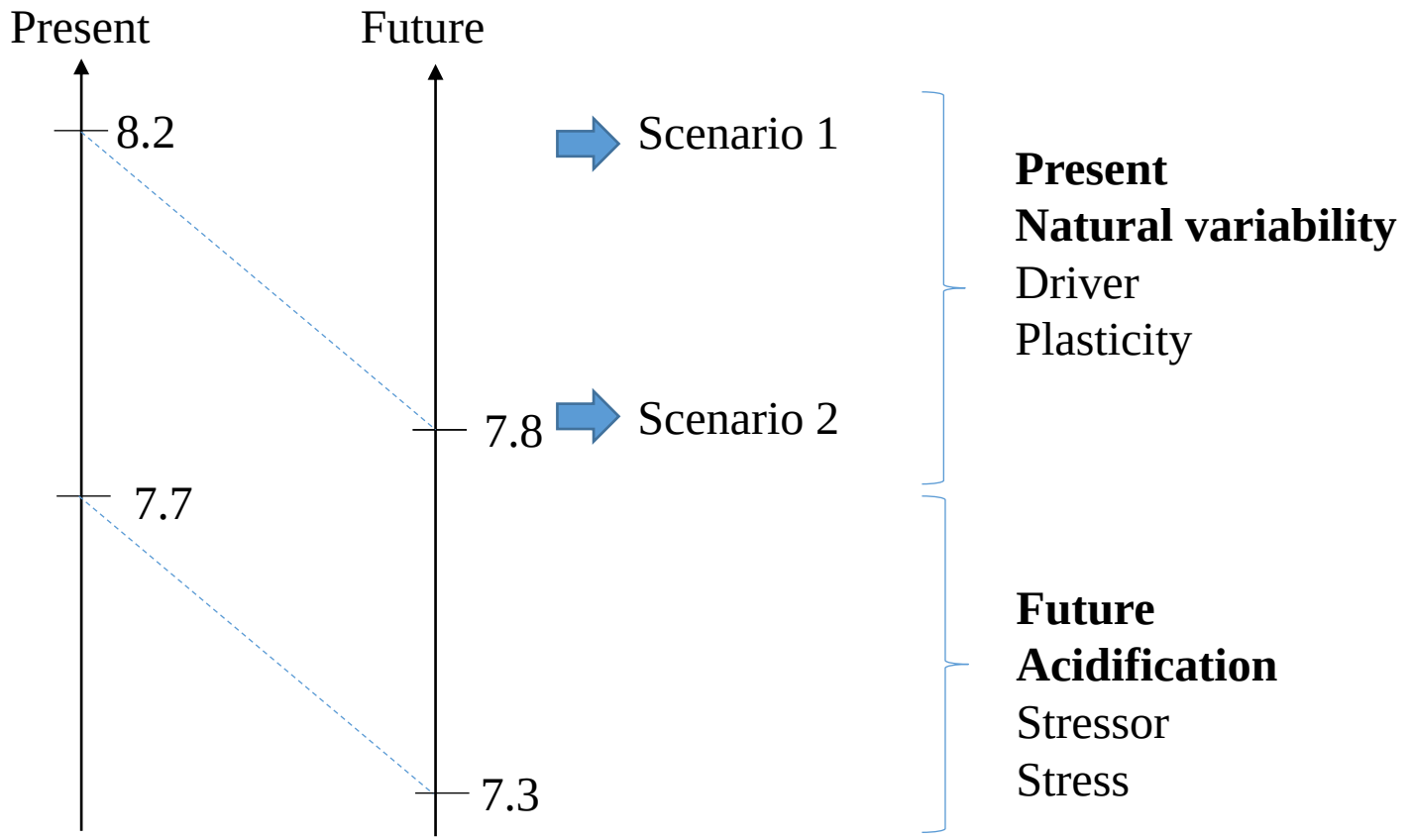
Global Change Biology (2013), doi: 10.1111/gcb.12276

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

Case study #1: impact of OA on mussels



Question #1-3

You want to study the impact of ocean acidification (ΔpH=-0.4 pH unit) on mussels collected in the tidal zone of Shengsi island where the pH varies between 8.2 and 7.7. In the laboratory, you test pH 8.2 and pH 7.8 (8.2-0.4) and see that it leads to a decrease in growth by 15% when they are exposed to pH 7.8 as compared to 8.2

Can you reach the following conclusions?

1. Mussel growth decreases by 25% under ocean acidification YES/NO
2. Mussels are stressed when exposed to pH 7.8 YES/NO
3. Our results show that pH is a stressor for these mussels YES/NO

Question #4

Is the following sentence correct?

Combining two stressors always lead to more stress than the individual effect of each stressor?

- Yes
- No
- It depends

Question #4

Is the following sentence correct?

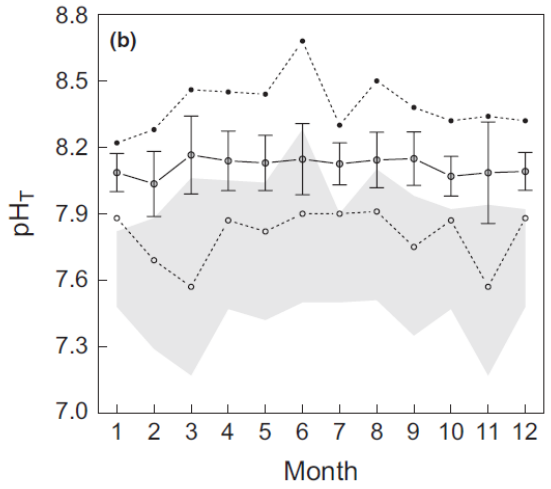
Combining two stressors always lead to more stress than the individual effect of each stressor?

- **Yes**
- No
- It depends

By definition: more stressors = more stress (negative effets)

Part 1 – Importance of definitions

Use the right terminology (and underlying concepts)

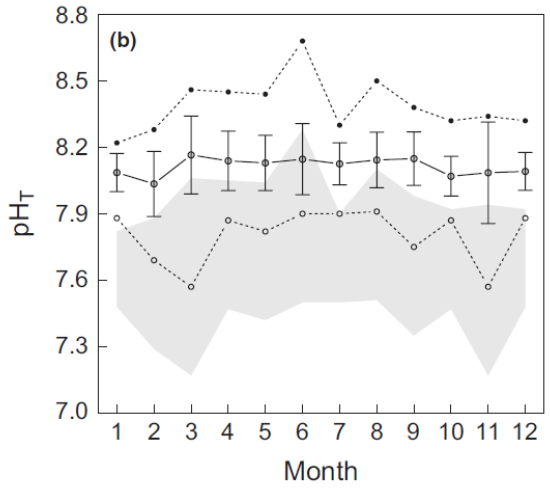


- pH 8.1 = control
- pH 7.6 = ocean acidification (IPCC scenarios)

Part 1 – Importance of definitions

Use the right terminology (and underlying concepts)

*Important to **consider present variability** in defining tested scenarios (monitoring the weather)*



- pH 8.1 = control (present, average)
- pH 7.6 = control (present, extreme) – ocean acidification (future, average)
- pH 7.4 = ocean acidification (future, extreme, out of range)

Part 2 – Importance of concepts

Additive

Synergism/Synergistic

Antagonistic

Case study #2: impact of OA and oil on sea urchin larvae

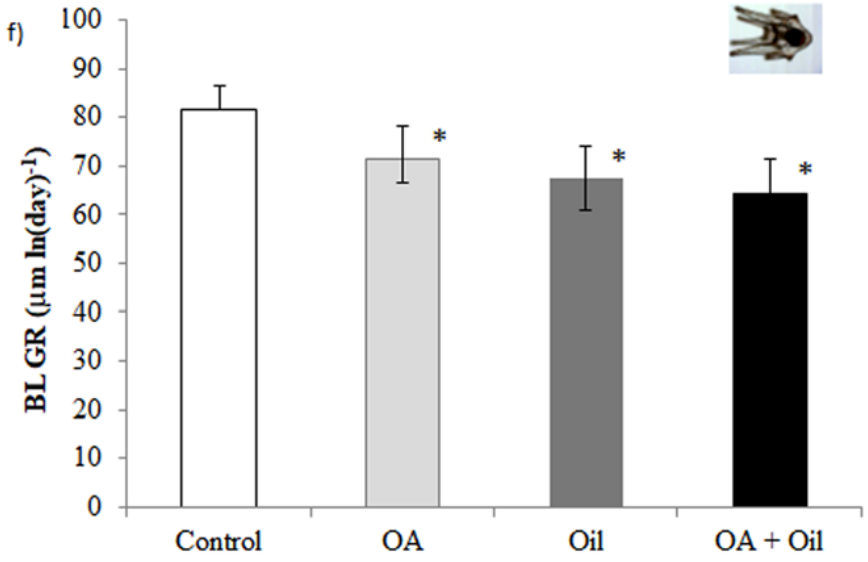
SCIENTIFIC REPORTS

OPEN

Effects of oil and global environmental drivers on two keystone marine invertebrates

Received: 8 October 2015
Accepted: 8 November 2018
Published online: 26 November 2018

Maj Arnberg[1,2], Piero Calosi[2,3], John I. Spicer[2], Ingrid C. Taban[5], Shaw D. Bamber[1], Stig Westerlund[1], Sjur Vingen[2], Thierry Baussant[1], Renée K. Bechmann[1] & Sam Dupont[4]



Effect on growth:

OA: -7%

Oil: -11%

Oil+OA: -18%

Question #5

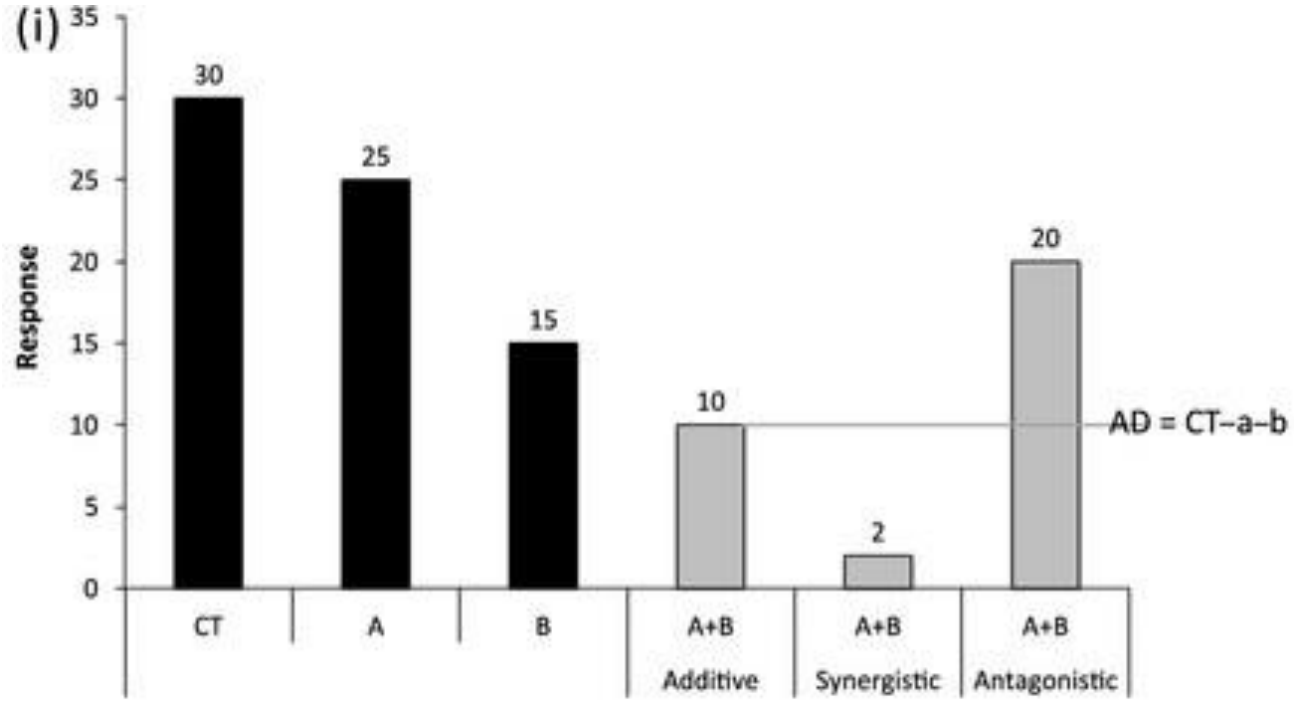
In this experiment, we saw that the

Effect of Oil+OA = effect of oil + effect of OA.

Is the following sentence correct:
Oil and OA are additive environmental parameters

- Yes
- No
- Not possible to know

In the literature…



Ecology and Evolution
Open Access

Reconceptualizing synergism and antagonism among multiple stressors

Jeremy J. Piggott, Colin R. Townsend & Christoph D. Matthaei
Department of Zoology, University of Otago, P.O. Box 56, Dunedin 9054, New Zealand

Based on that definition:

- Yes

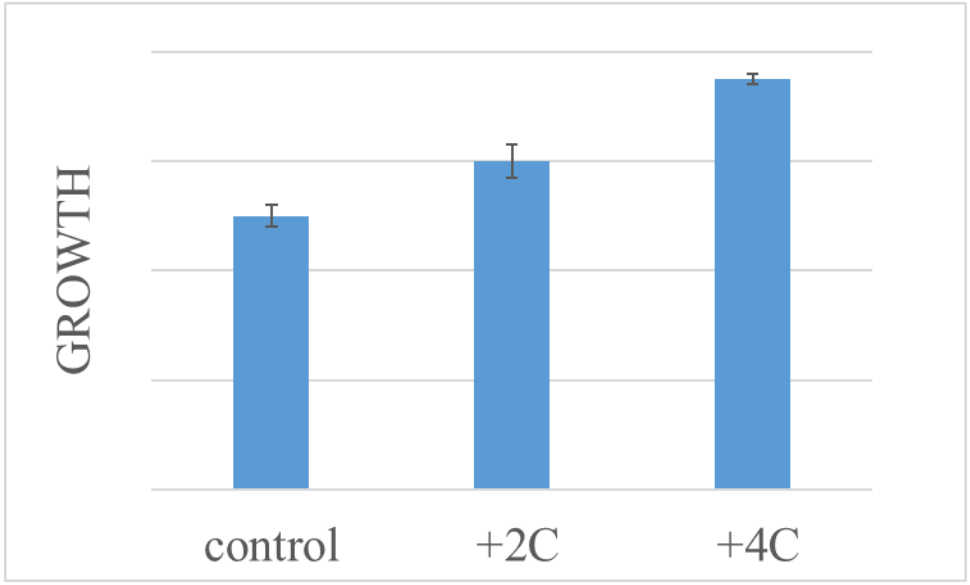
BUT…

Does additivity at the effect level = additivity at the stressor level?

Case study #3: impact of temperature on mussels

Ultimate additive stressors:
Temperature + Temperature

Case study #2: impact of temperature on mussels



Effect on growth:

+2C (A): +10%
+4C (B): +15%
+6C (A+B): ?

Ultimate additive (multiple stressors): Temperature + Temperature

Question #6

You do an experiment testing the impact of temperature on mussel growth.

An increase by 2C = 10% increase in growth
An increase by 4C = 25% increase in growth
What is the % of increase in growth after a 6C increase in temperature?

- 35%
- <35%
- >35%
- It depends

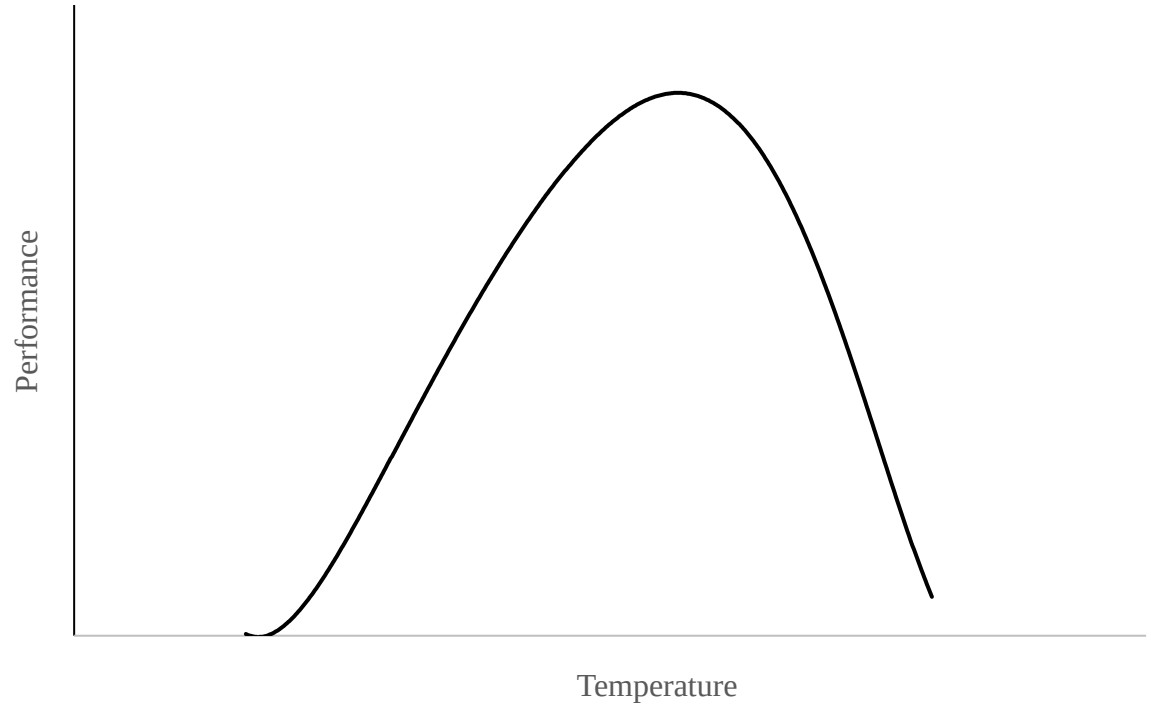
Question #6

You do an experiment testing the impact of temperature on mussel growth.

An increase by 2C = 10% increase in growth
An increase by 4C = 25% increase in growth
What is the % of increase in growth after a 6C increase in temperature?

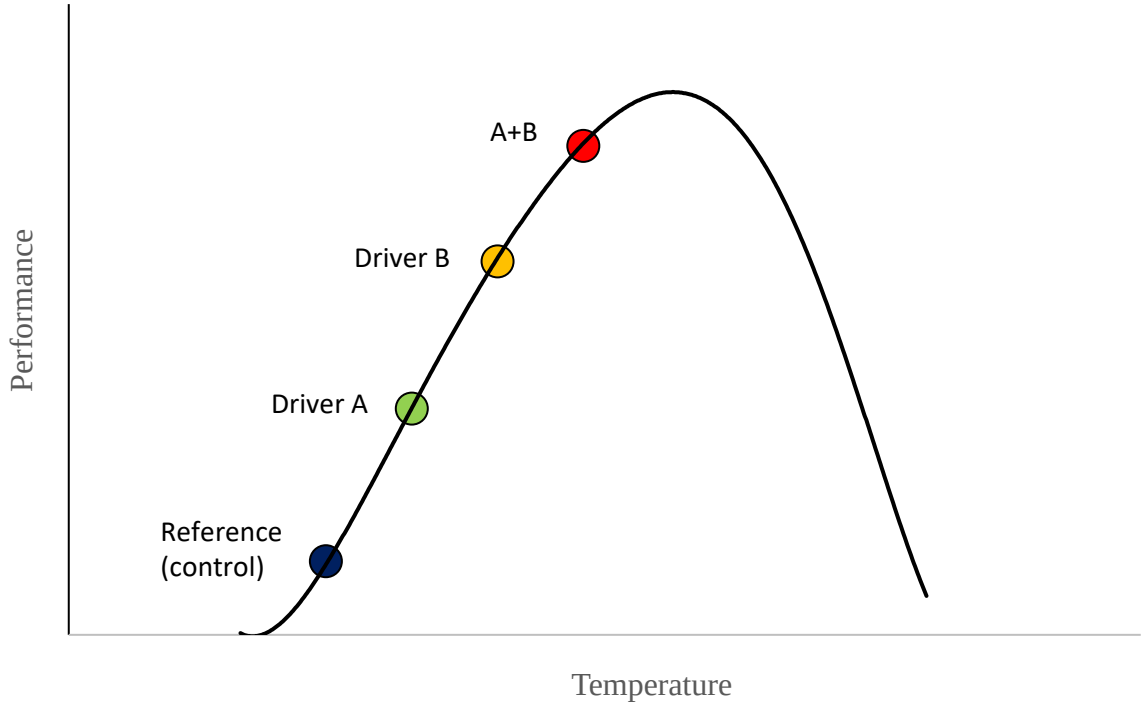
- 35%
- <35%
- >35%
- It depends

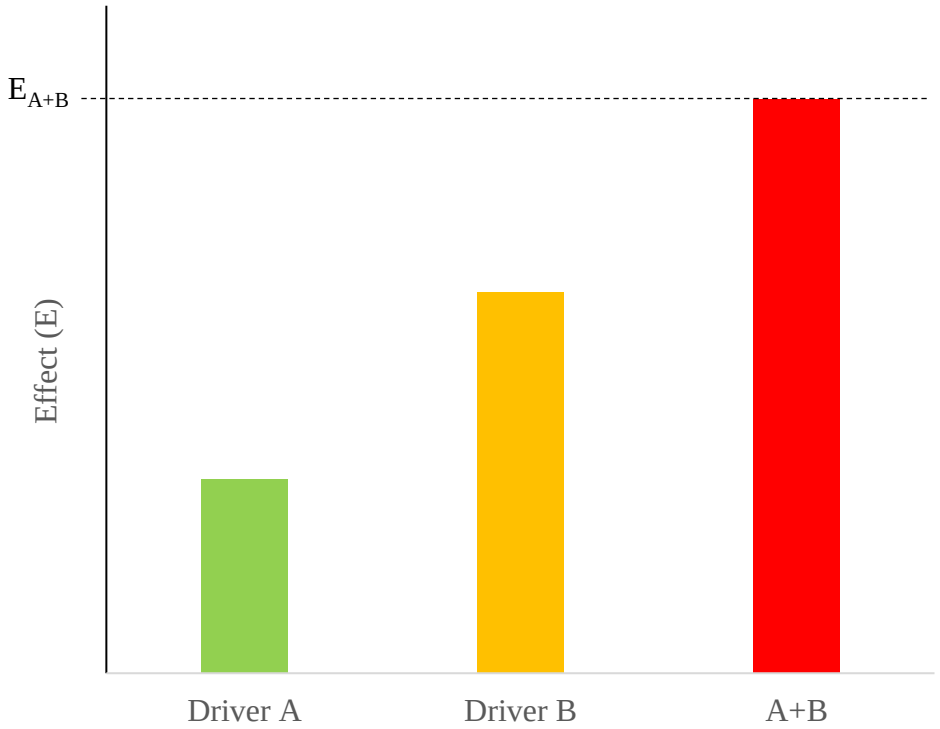
Why does it depend?



Performance curves are not linear

For additive driver, the effect depends on the shape of the curve and starting point



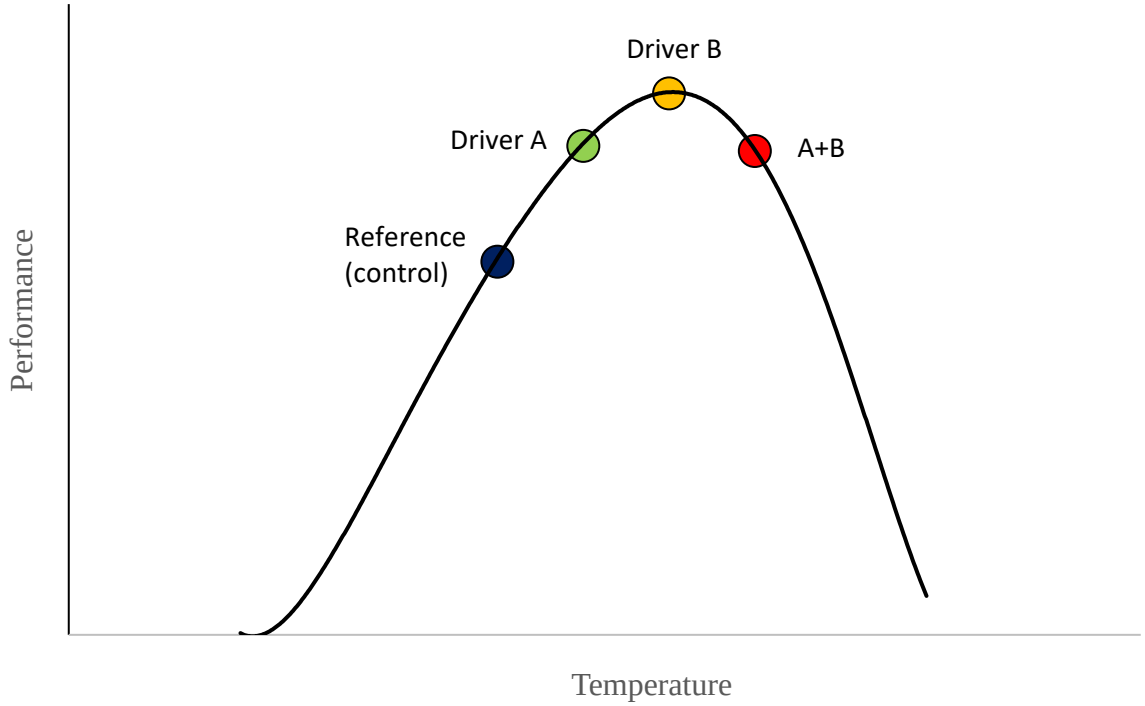


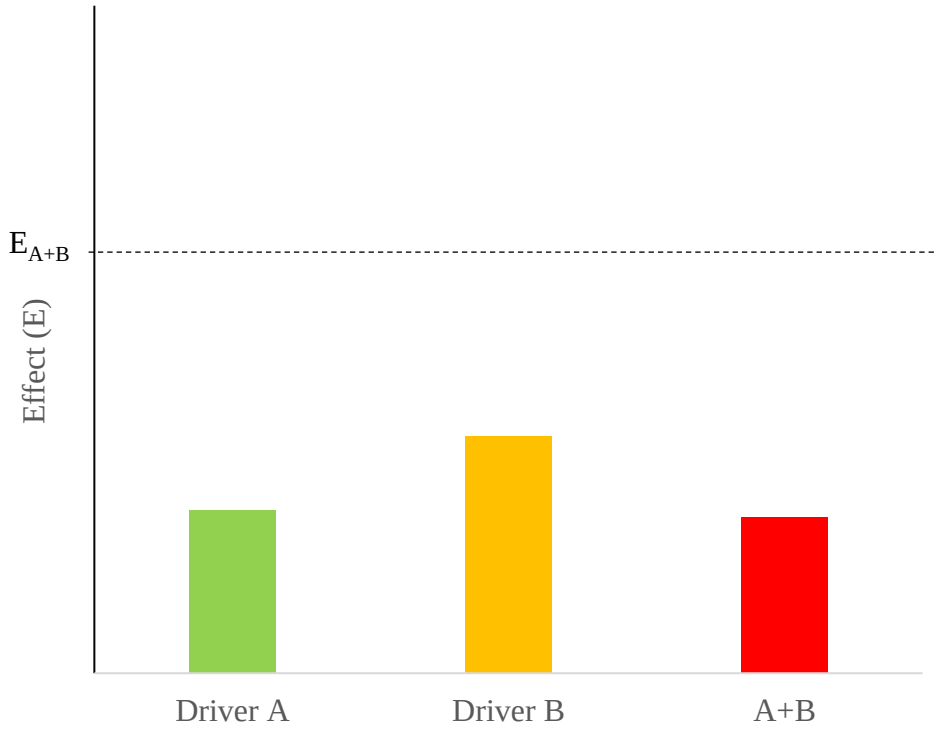
Additive drivers

Additive effect

$$Ea+b = Ea + Eb$$

For additive driver, the effect depends on the shape of the curve and starting point

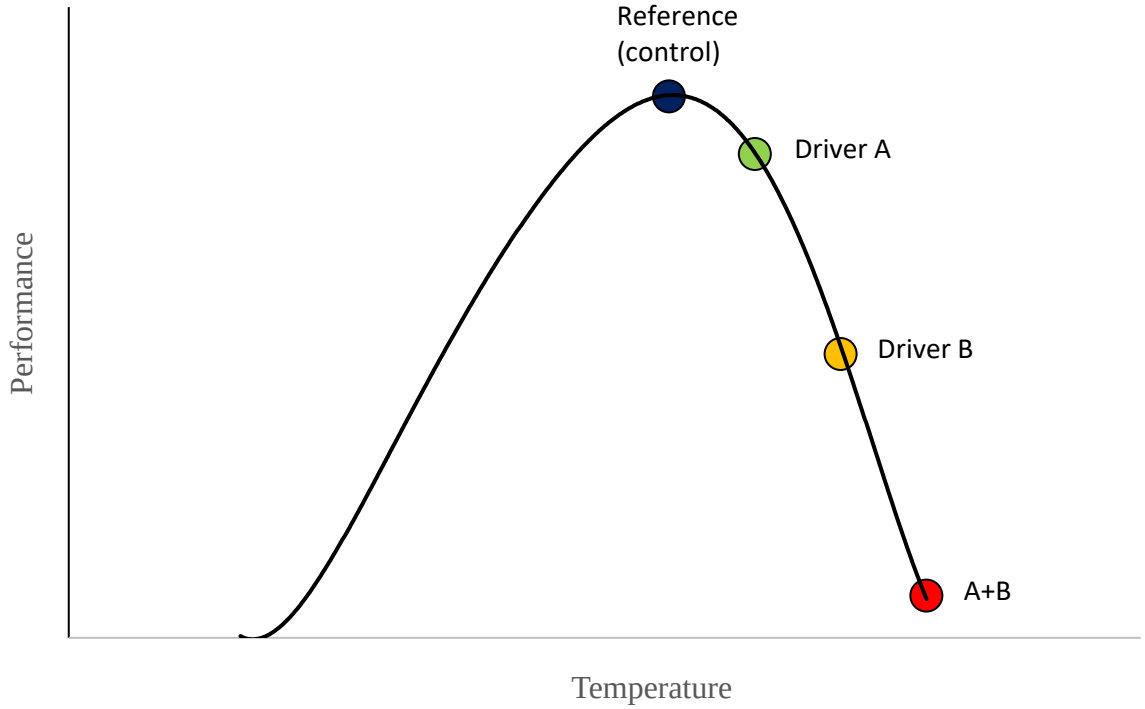


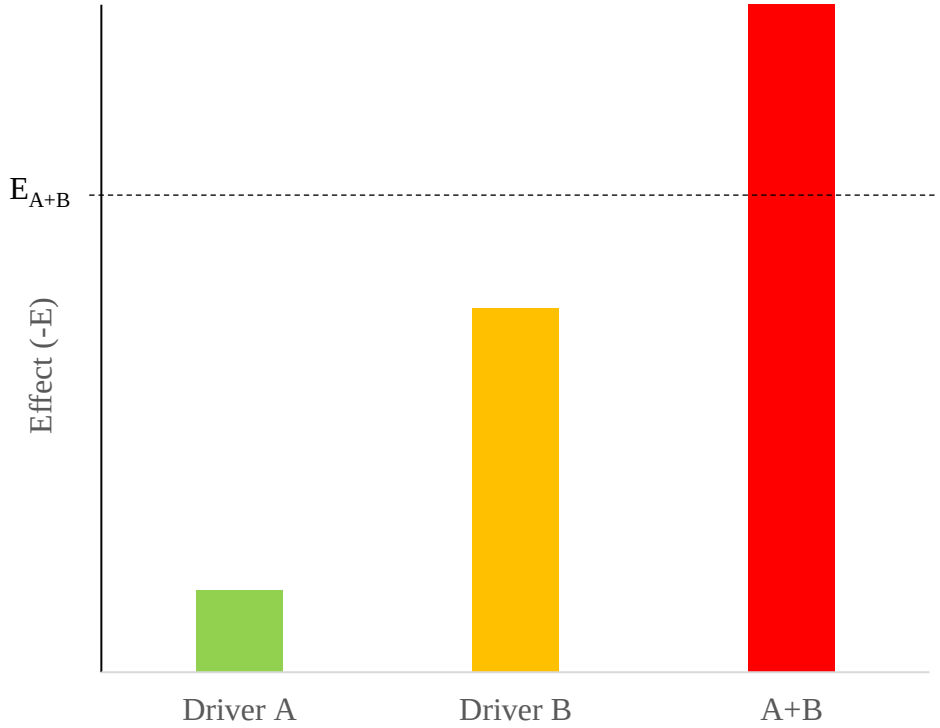


Additive drivers
Antagonistic effects

$$Ea+b < Ea + Eb$$

For additive driver, the effect depends on the shape of the curve and starting point





Additive drivers
Synergistic effects

$$Ea+b > Ea + Eb$$

Additive stressors add in a non-linear way (depends on the shape of the curve) so it does not translate into an arythmetic mathematical addition at the effect level

As a consequence:

1. What you see at the effect level does not say anything on the additivity of stressors

2. Multiple stressors experiments have limited potential to resolve how stressors work in combination

Question #5

In this experiment, we saw that the

Effect of Oil+OA = effect of oil + effect of OA.

Is the following sentence correct:
Oil and OA are additive environmental parameters

- Yes
- No
- **Not possible to know**

To understand how two stressors work in combination you need the mode of action

Mode of action and interactions

Driver 1 = beer

Driver 1 = wine

Driver 1 = drugs

No interaction / Additive

Interaction

Mechanistic studies

Definitions

https://kahoot.it/

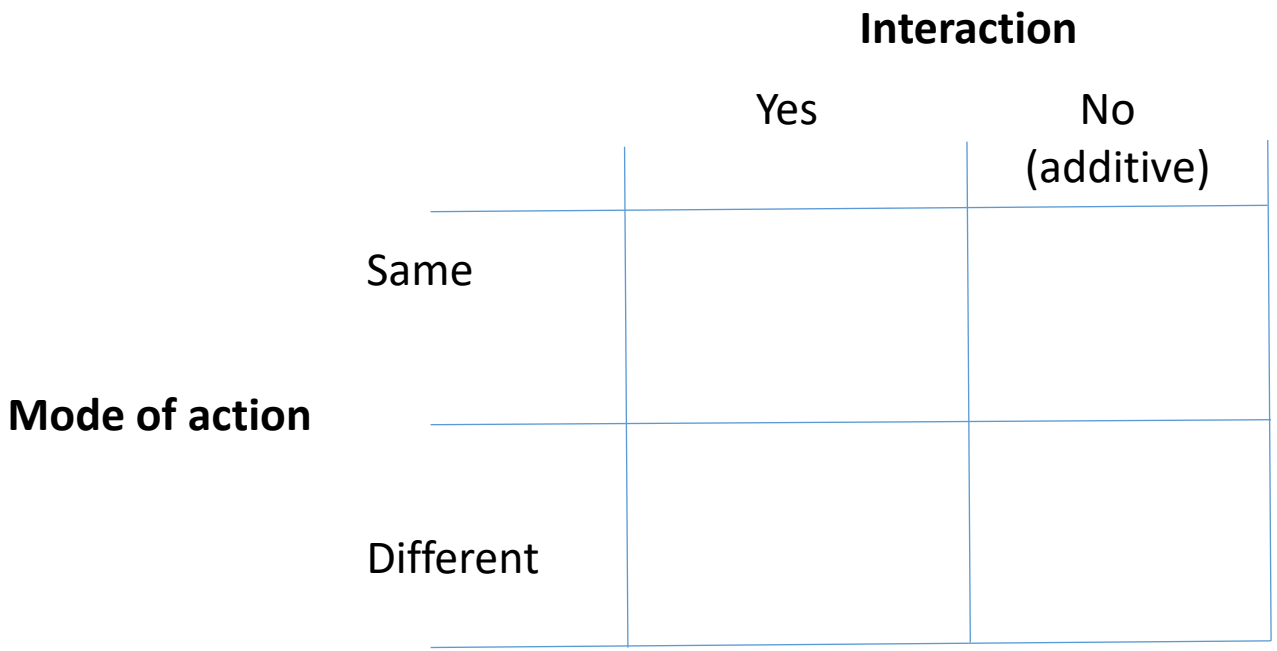
Code: 2051639

- *Additive* — ***Absence of interaction*** *between drivers/stressors (dose-addition)*
- *Synergism/Synergistic*
- *Antagonistic*

Interactions *between drivers/stressors*

Four options

- *Same or different mode of action*
- *Interactions or no interactions*



Case study #4: warming and over-fishing

Global warming (A): kills 50% of fish

Fishing (B): kills 50% of fish

A+B?

Question #7

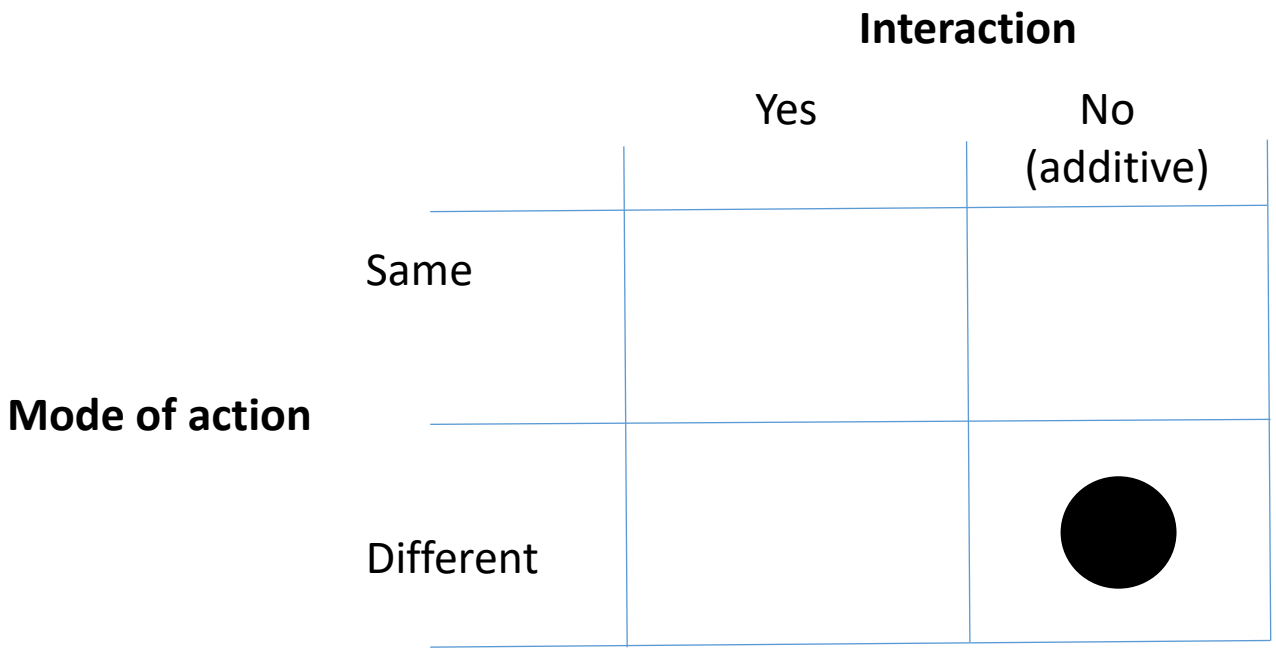
You want to understand the combined effect of global warming and fisheries on a local population of fish. You know that:

- Global warming with kill 50% of the fish
- Fishing pressure will remove 50% of the fish

What will be the combined impact of global warming and fisheries?

- 25% of the fish will die
- 33% of the fish will die
- 75% of the fish will die
- 100% of the fish will die

Different mode of action and no interactions



Different mode of action and no interactions

Stressor 1 = overfishing (50%)

Stressor 2 = Global warming (50%)

Stressor 1 + Stressor 2 = ???

Different mode of action and no interactions

Stressor 1 = overfishing (50%)

Stressor 2 = Global warming (50%)

Stressor 1 + Stressor 2 = ???

Different mode of action and no interactions

Stressor 1 = overfishing (50%)

Stressor 2 = Global warming (50%)

Stressor 1 + Stressor 2 = ???

$$R_{A+B} = R_A + R_B - R_A x R_B = 75\%$$

Question #7

You want to understand the combined effect of global warming and fisheries on a loca population of fish. You know that:

- Global warming with kill 50% of the fish
- Fishing pressure will remove 50% of the fish

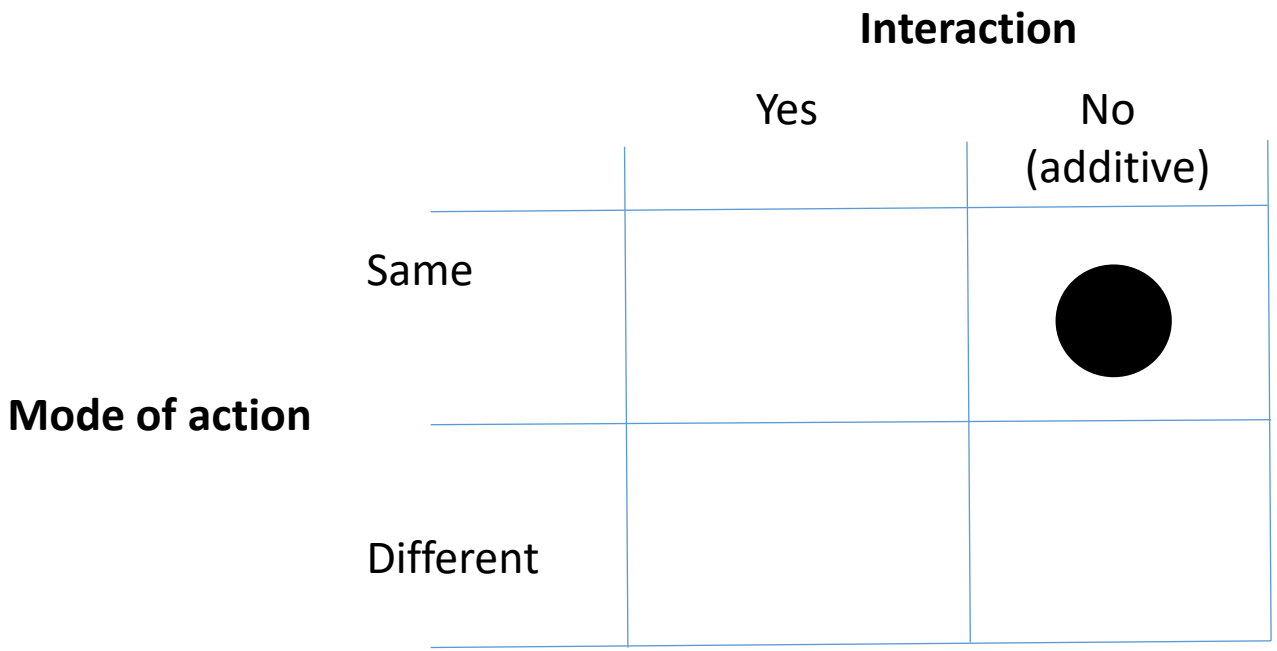
What will be the combined impact of global warming and fisheries?

- 25% of the fish will die
- 33% of the fish will die
- **75% of the fish will die**
- 100% of the fish will die

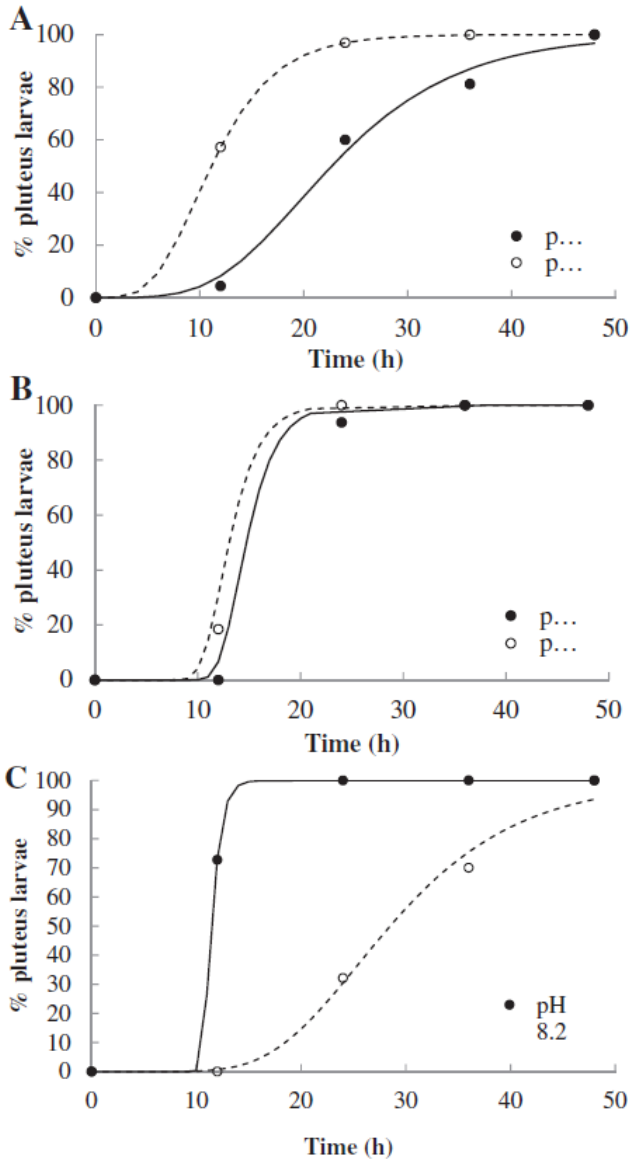
Different mode of action
No interaction

Additive stressor, Antogonistic effects

Same mode of action and no interactions



OA + temperature



Low temperature
Positive effect of OA

Mid temperature
No effect of OA

High temperature
Negative effect of OA

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Temperature modulates the response of the thermophilous sea urchin *Arbacia lixula* early life stages to CO_2-driven acidification

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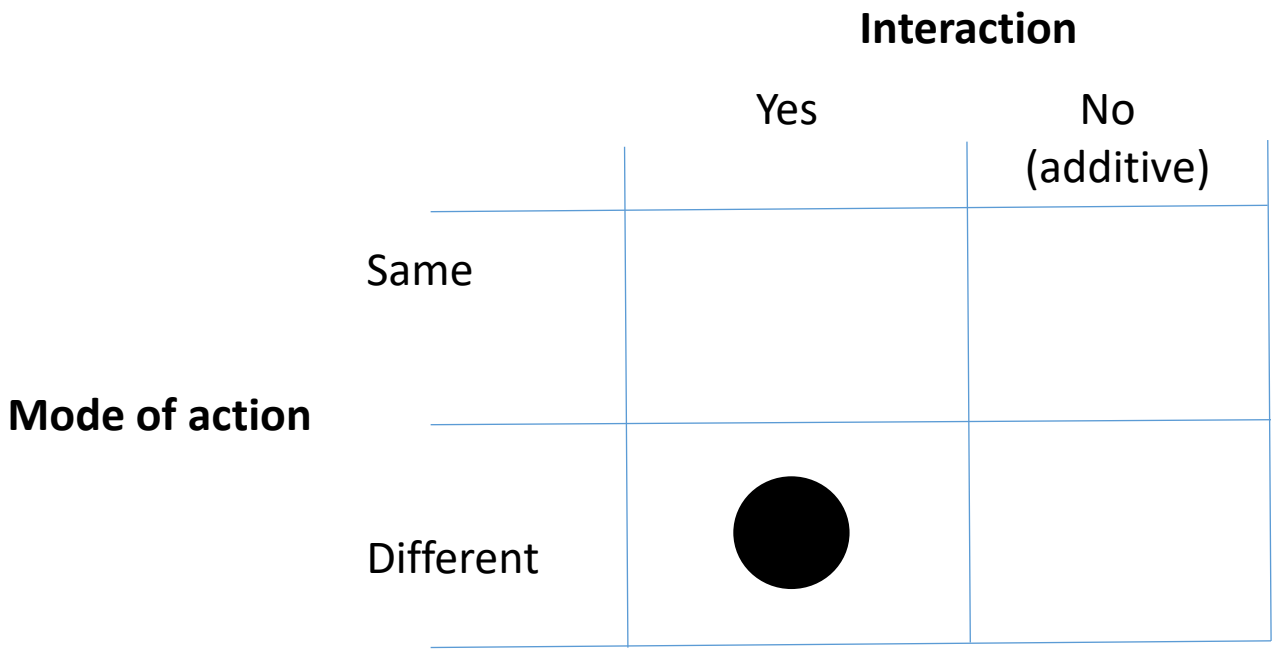
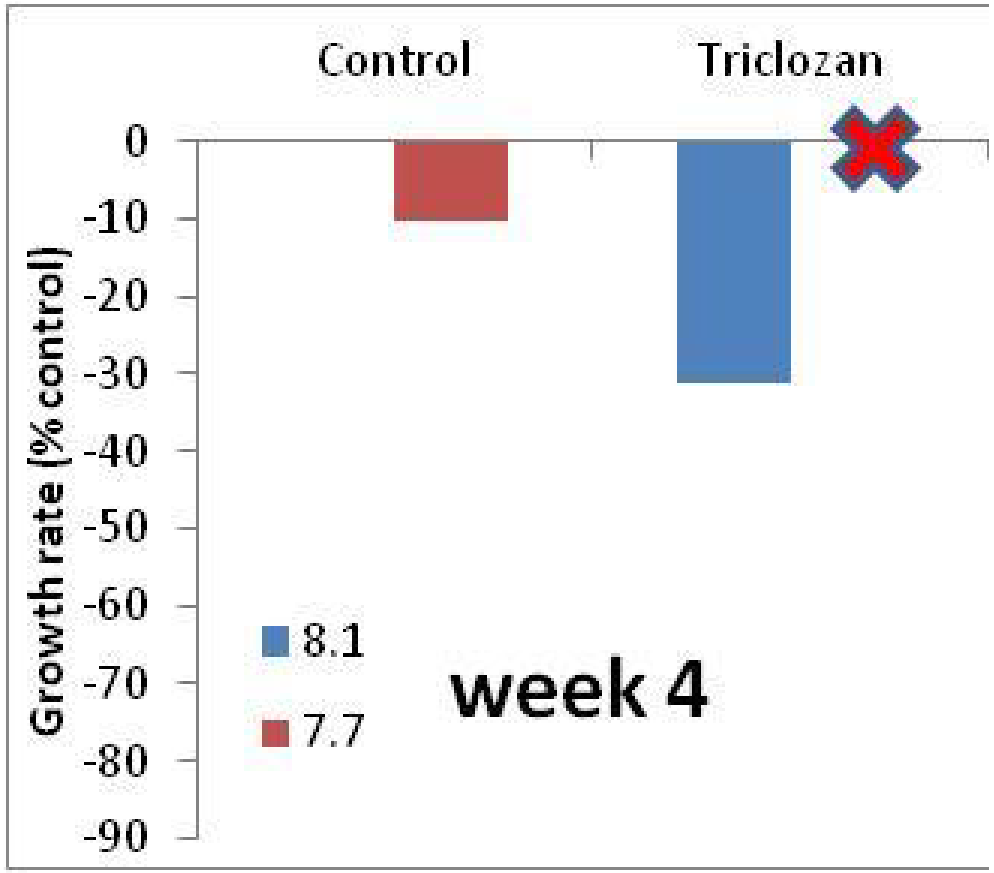
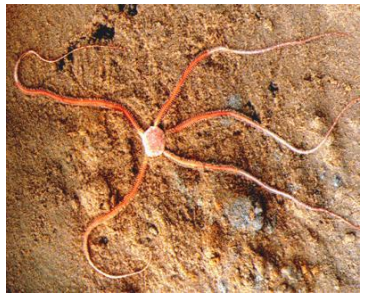
Additive stressor,
Depends on effects

Different modes of action and interactions



Ocean acidification with toxicants





Complex interactions

Need a deeper mechanistic understanding

Take home messages

- ✓ *It is not possible to understand the combined effects from a simple multi-stressor experiment !*

- ✓ *You need a strategy combining different approaches (mechanisms, performance curves, models and statistics, multi-stressor experiments)*

Research strategy

1. *List your drivers/stressors*
   (intensity, duration, etc.)

Research strategy

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   (intensity, duration, thresholds, etc.)

2. *Understand the mode of action and interactions*

Research strategy

1. *List your drivers/stressors*
(intensity, duration, thresholds, etc.)
2. *Understand the mode of action and interactions*
3. *Understand your performance curves*
4. *Model*
5. *Test your model*

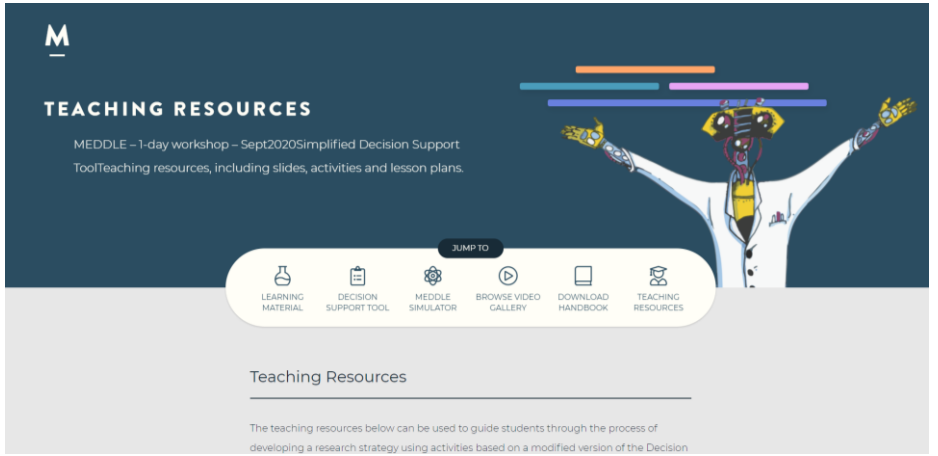
Monitoring

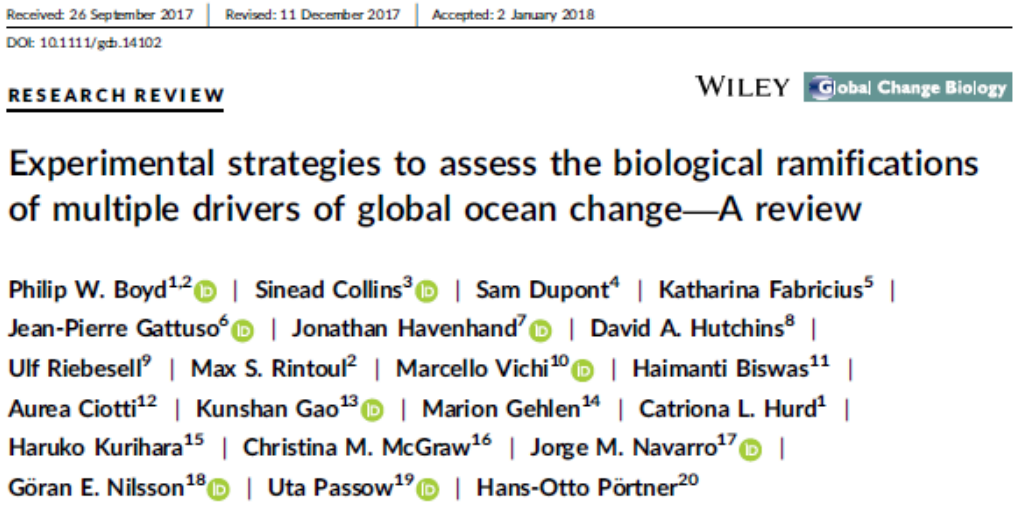
Single stressor experiments

Modeling

Multiple stressors experiments

To go further





Received: 26 September 2017 | Revised: 11 December 2017 | Accepted: 2 January 2018

DOI: 10.1111/gcb.14102

RESEARCH REVIEW

WILEY Global Change Biology

Experimental strategies to assess the biological ramifications of multiple drivers of global ocean change—A review

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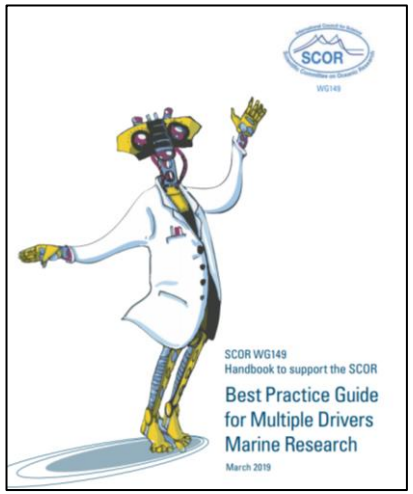

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