Ocean Acidification International Coordination Centre

IAEA 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

Why study ocean acidification? Why now?

The blue planet

Q1: What are the services provided by the ocean?

The blue planet

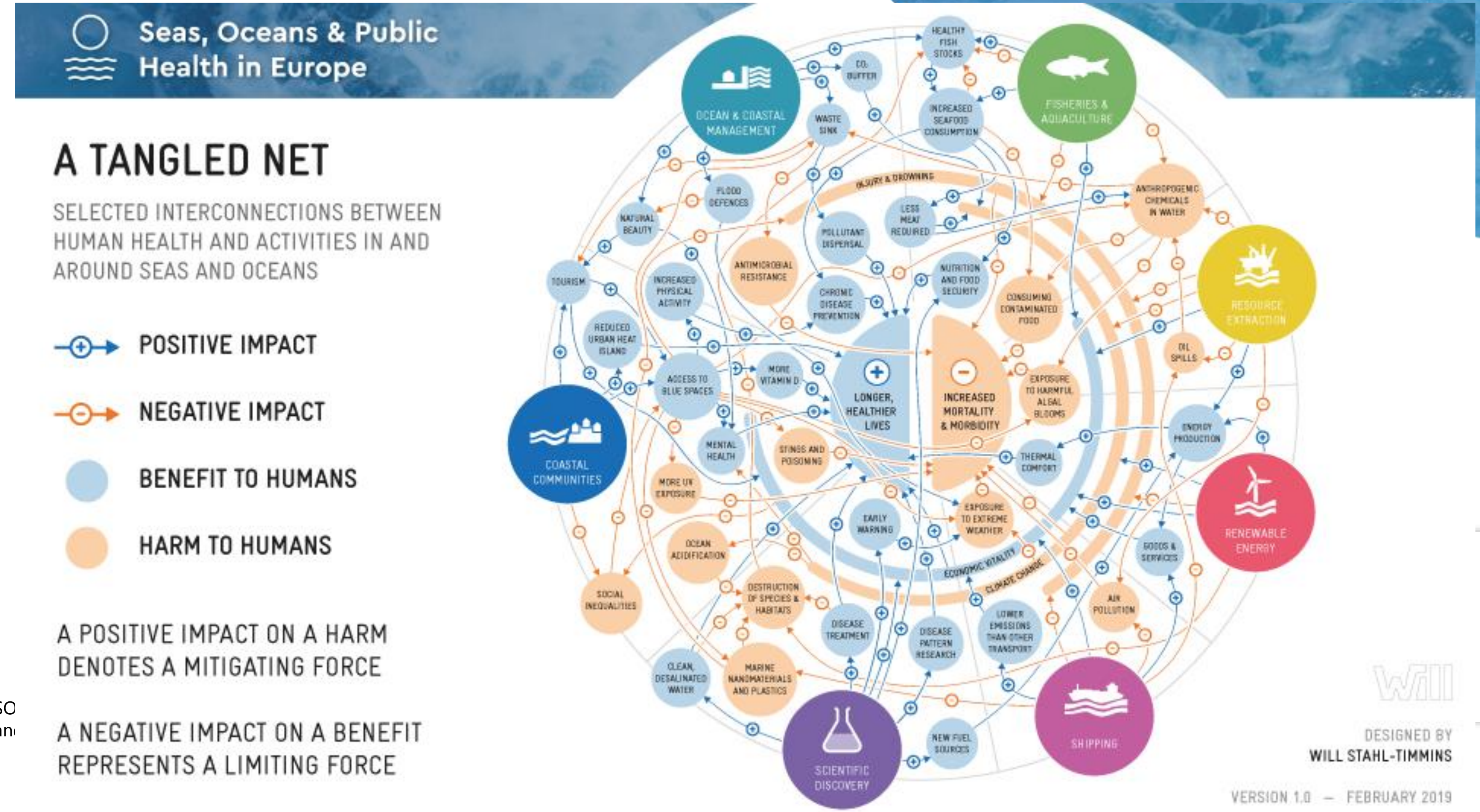







Seas, Oceans & Public Health in Europe

Linking oceans and health research



Ocean Health = Human health

e.g. Chronic disease = main cause of mortality

Obesity caused by:

- Nutrition → Seafood based diet
- Exercise (lack of) → Recreation/biodiver.
- Mental health / Stress → Recreation/biodiver.
- Genetics
- Medication → New medicine
- Culture

Stronger human impacts

INDEPENDENT

JOIN

RT CULTURE VIDEO INDY/LIFE HAPPY LIST INDYBEST LONG READS INDY100 VOUCHERS MINDS

Eight million salmon killed in a week by sudden surge of algae in Norway

Deaths come weeks after similar incident in Scotland: 'We're all pretty worried'

Harry Cockburn | Wednesday 22 May 2019 16:29 |

Like Click to follow The Independent

Growth

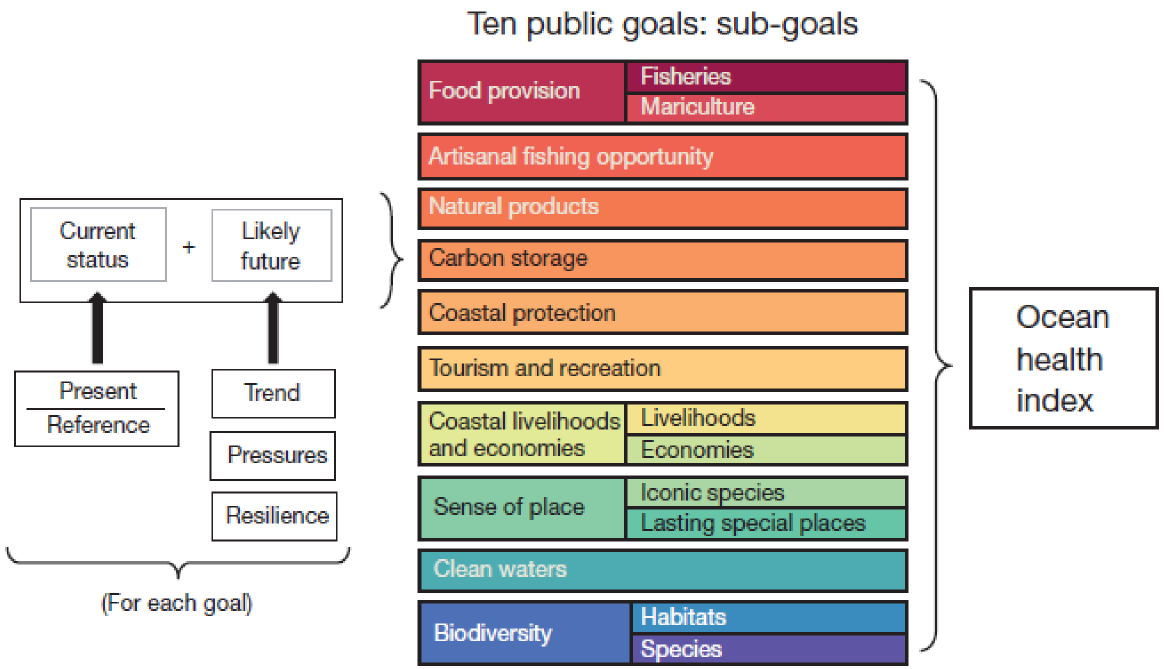
Ocean Health

ARTICLE

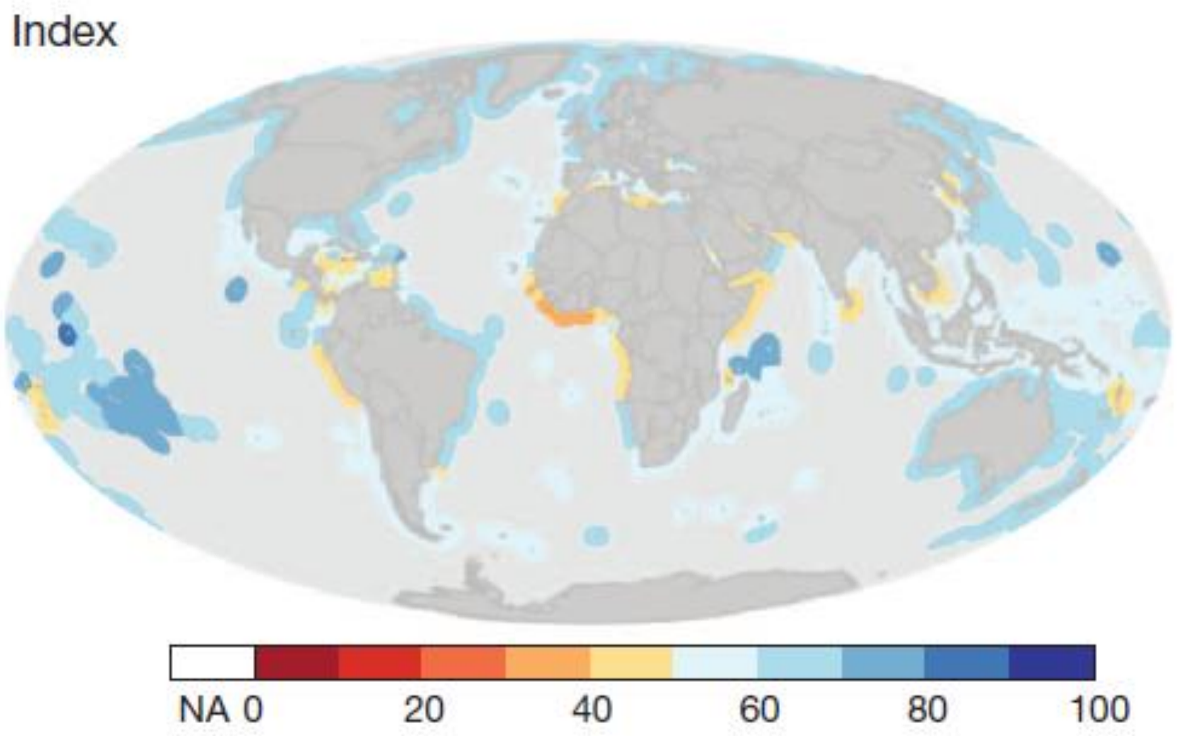
doi:10.1038/nature11397

An index to assess the health and benefits of the global ocean

Benjamin S. Halpern[1,2], Catherine Longo[1], Darren Hardy[1], Karen L. McLeod[3], Jameal F. Samhouri[4], Steven K. Katona[5], Kristin Kleisner[6], Sarah E. Lester[7,8], Jennifer O'Leary[1], Marla Ranelletti[1], Andrew A. Rosenberg[5], Courtney Scarborough[1], Elizabeth R. Selig[5], Benjamin D. Best[9], Daniel R. Brumbaugh[10], F. Stuart Chapin[11], Larry B. Crowder[12], Kendra L. Daly[13], Scott C. Doney[14], Cristiane Elfes[15,16], Michael J. Fogarty[17], Steven D. Gaines[8], Kelsey I. Jacobsen[8], Leah Bunce Karrer[5], Heather M. Leslie[18], Elizabeth Neeley[19], Daniel Pauly[6], Stephen Polasky[20], Bud Ris[21], Kevin St Martin[22], Gregory S. Stone[5], U. Rashid Sumaila[6] & Dirk Zeller[6]



Ocean Health

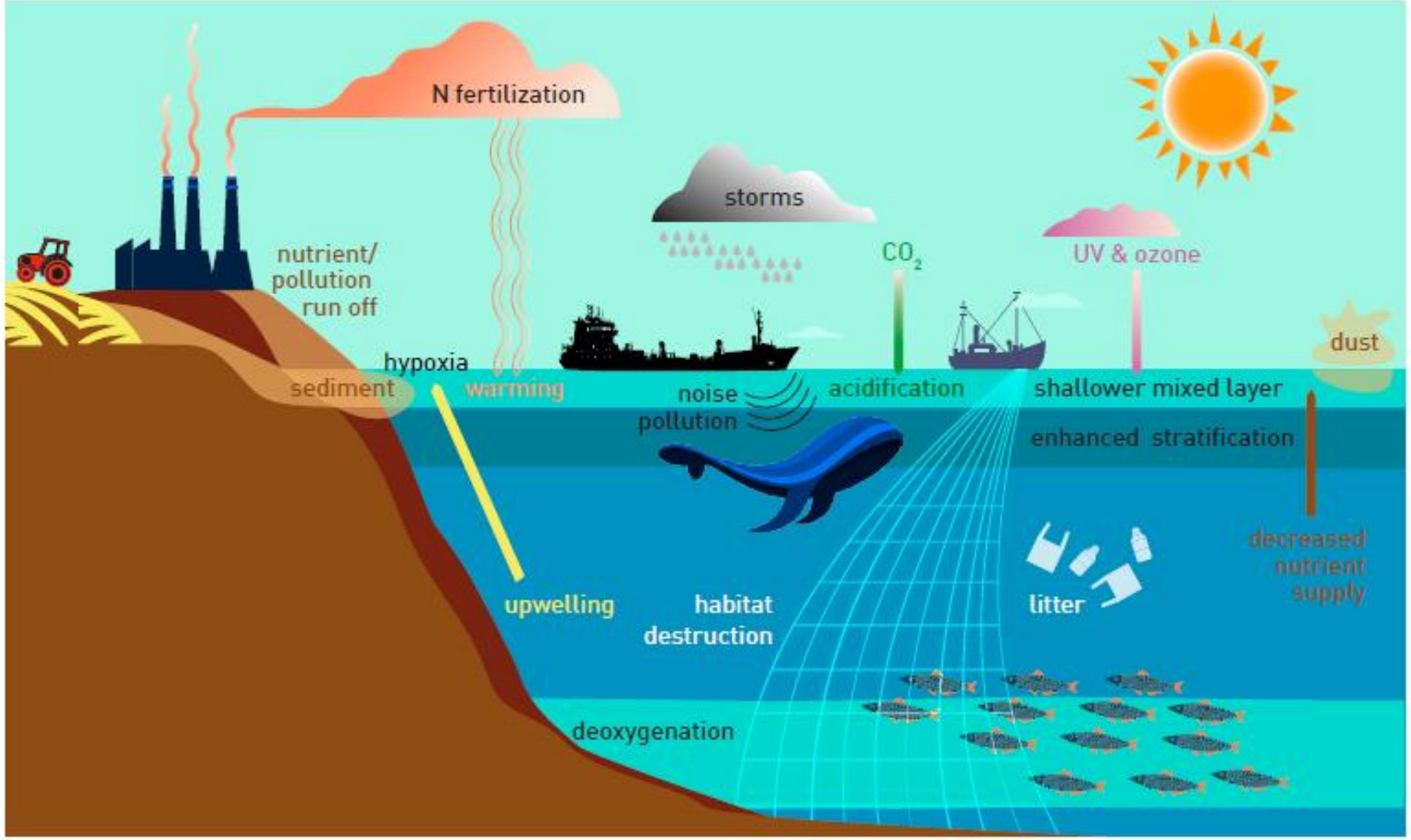


OHi = 60% [36-86]

Changes

Q2: What are the main pressures on the ocean?

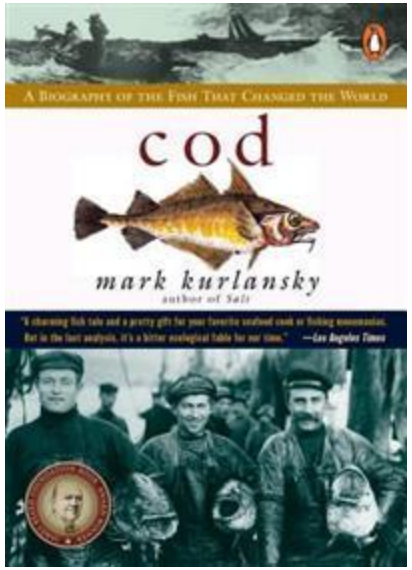
Human threats on the ocean

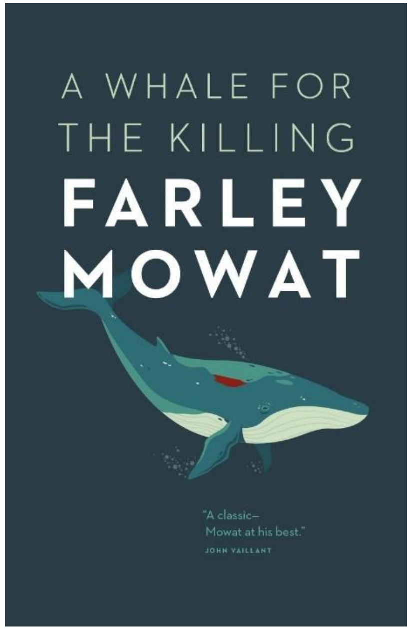


Multiple stressors

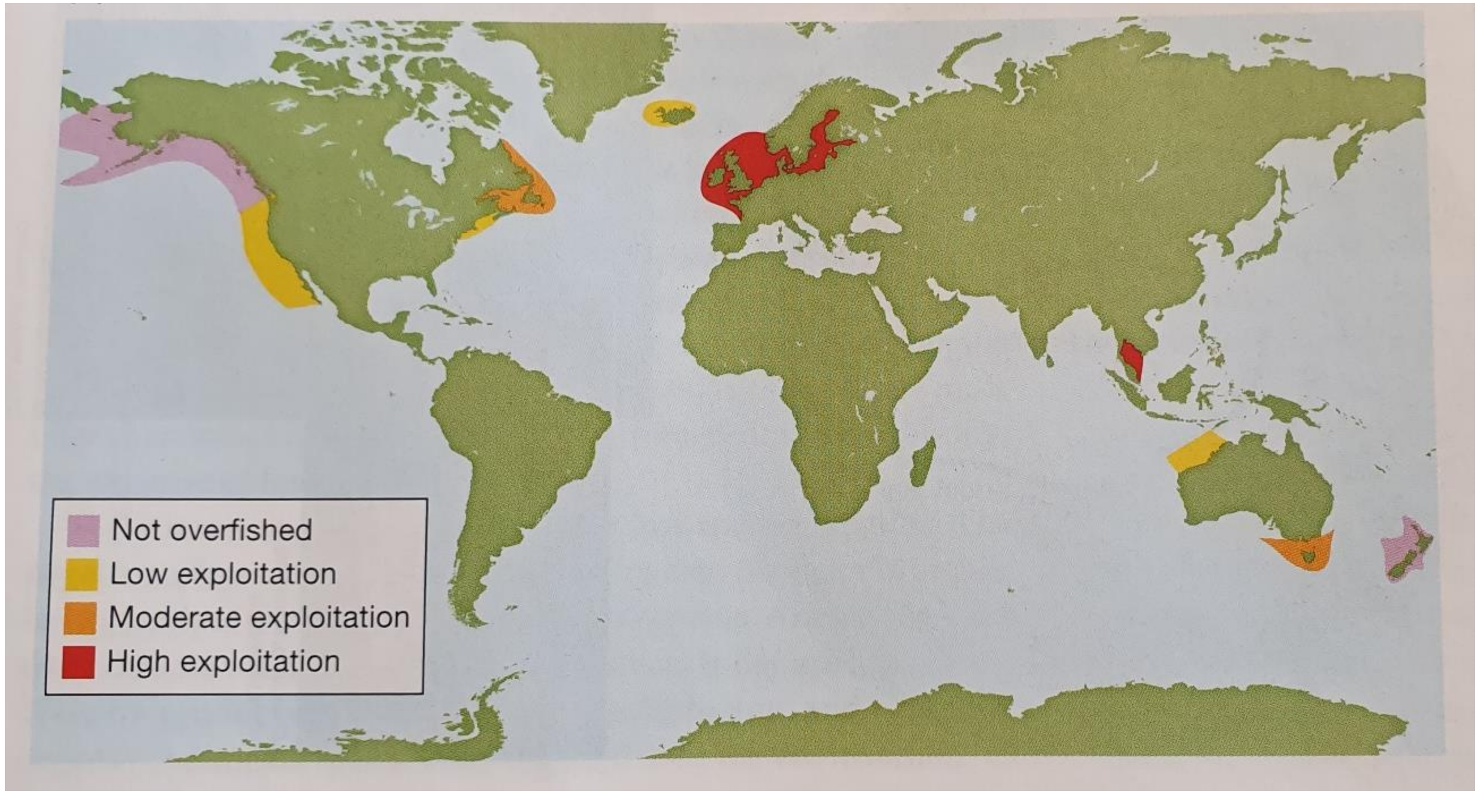
Main pressures: Over-fishing

Humans have fished for 40000 years
Increased efficiency with technology
Market pressure





Main pressures: Over-fishing

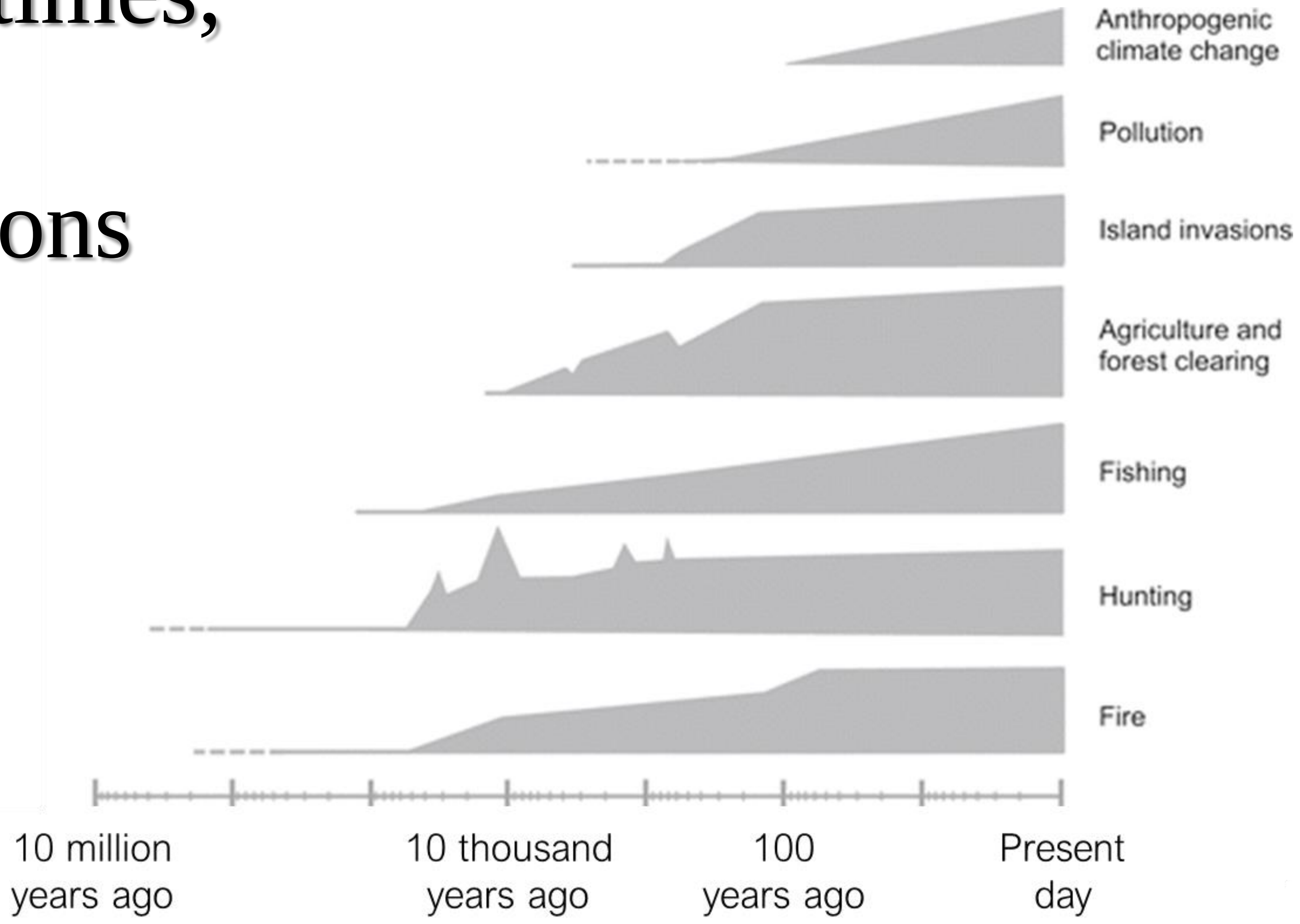


14% exploited fish populations collapsed

e.g. cod, tuna, sardines

Intensity depending on location

Different times, different combinations



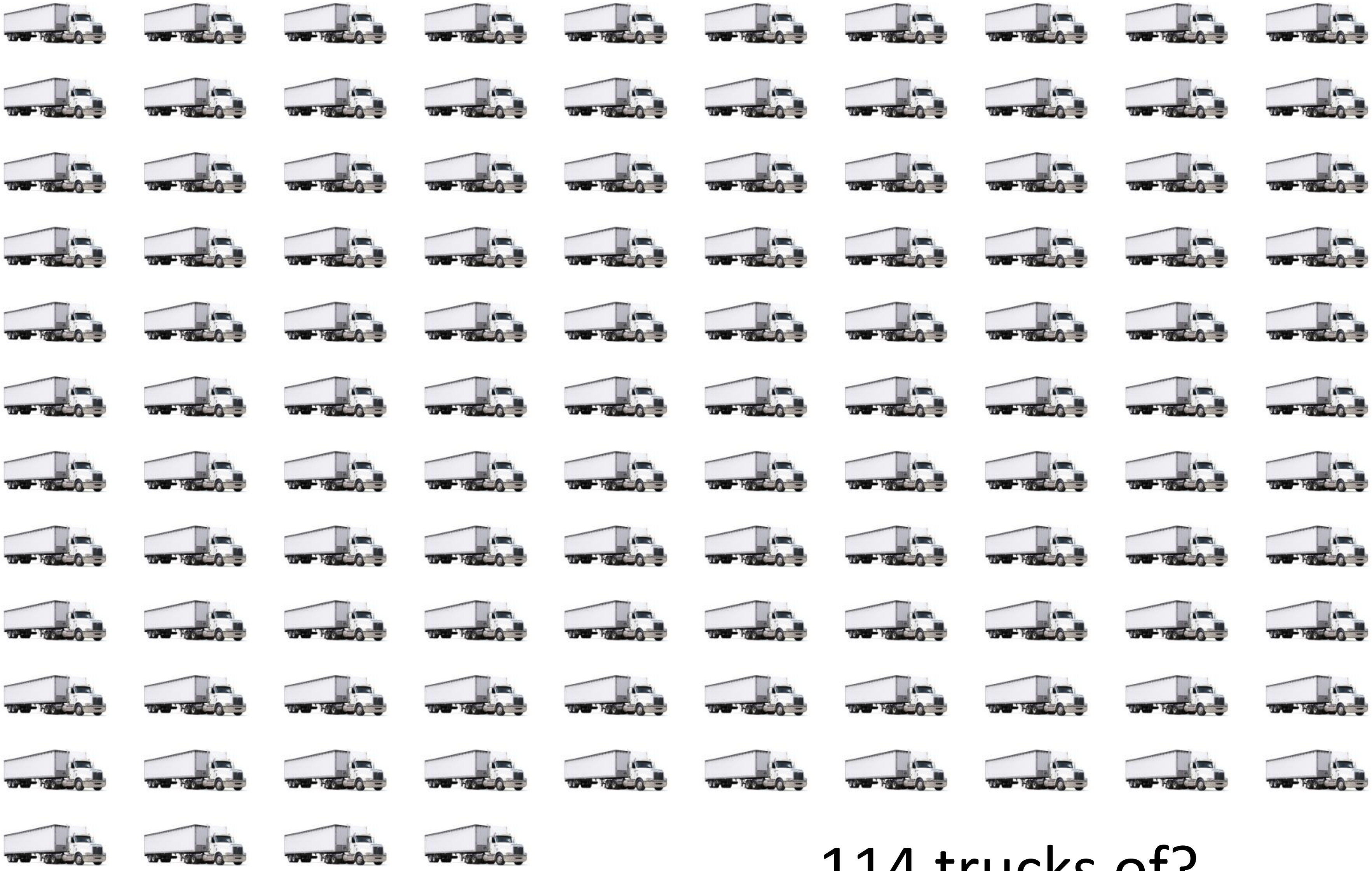
Many consequences

- ✓ Toxicants (>100.000)
- ✓ Over-fishing
- ✓ Warming
- ✓ Deoxygenation
- ✓ Ocean acidification
- ✓ Litters (macro, micro, nano)
- ✓ Etc.


Global impacts

25 million tonnes of plastic packaging

For every truck of plastic in the ocean…

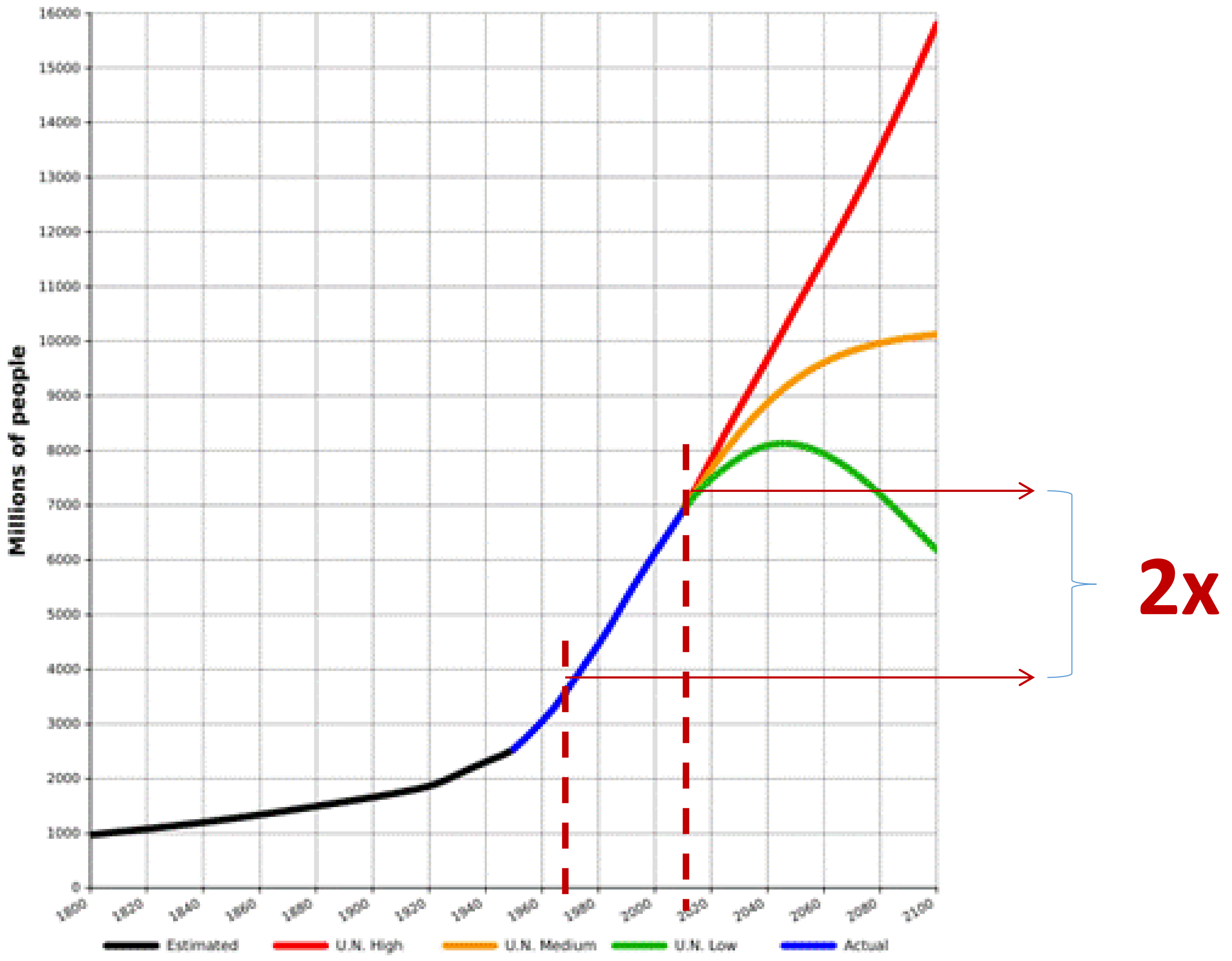


… 114 trucks of?

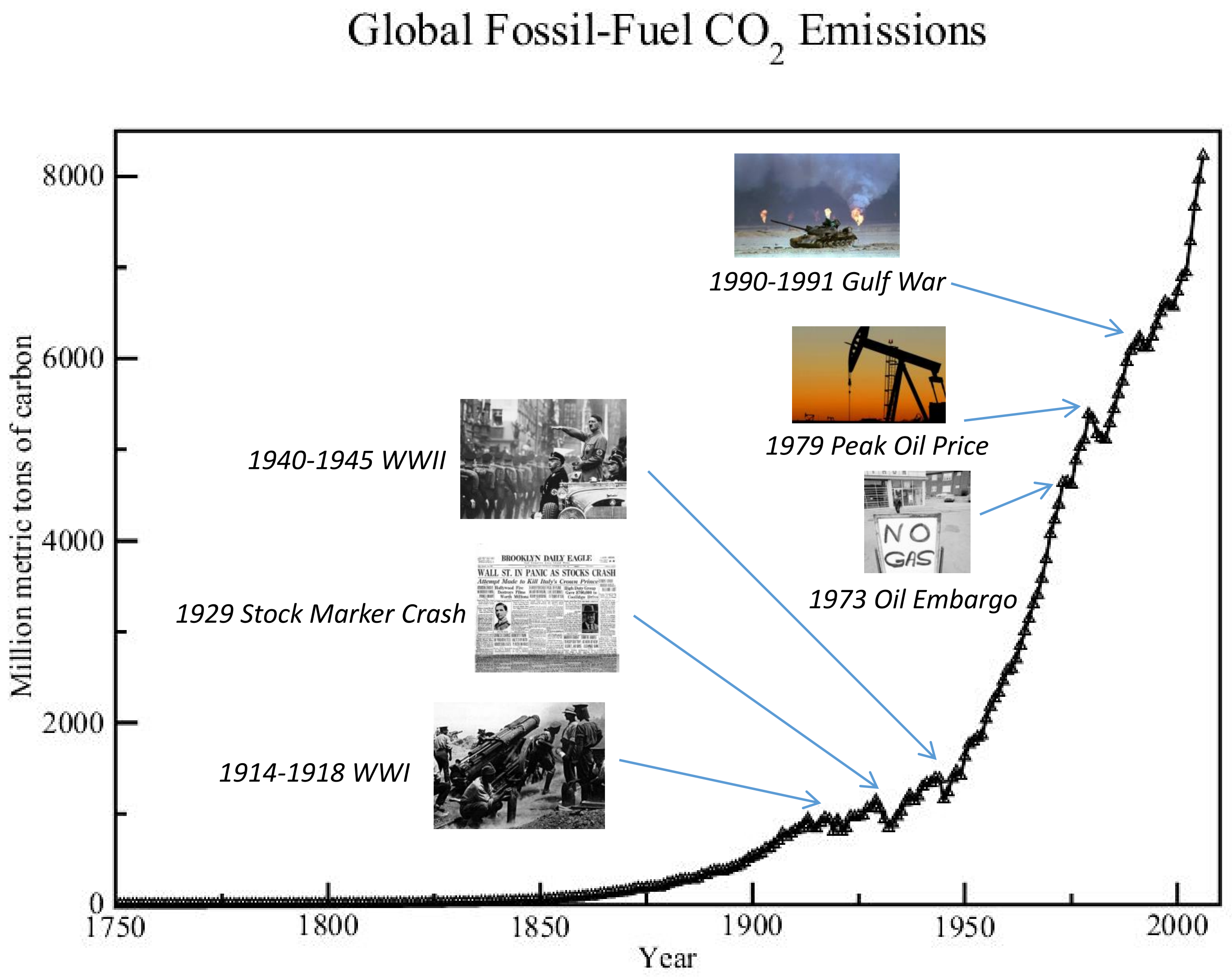

A clue?


CO2

Cause: human demography



Energy = carbon dioxide (CO_2)



Symptoms

Global warming

Catastrophic events

Ice melting

Sea level rise

Hypoxia

Salinity changes

Ocean acidification

Ocean acidification is chemistry…

… not conjecture

CO_2

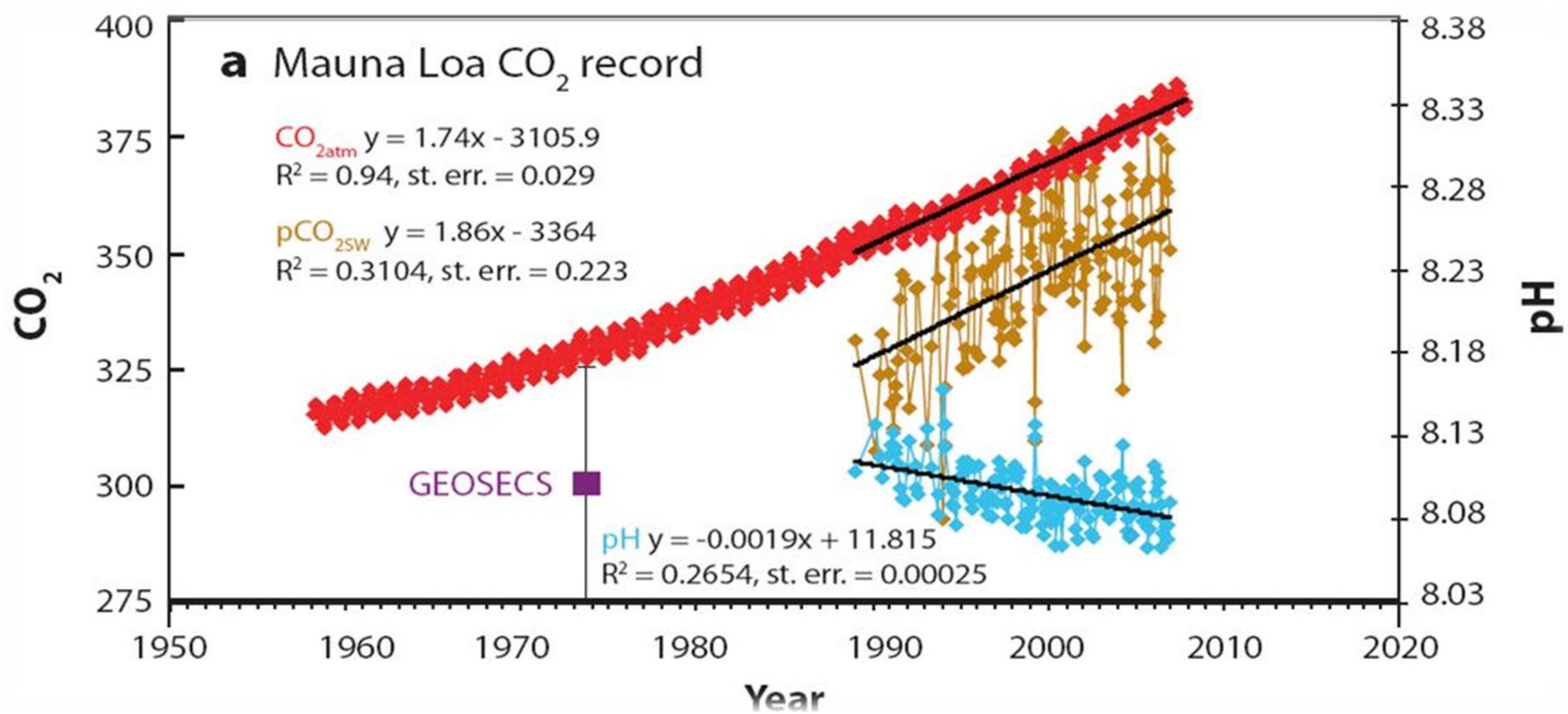
$$CO_2 + H_2O \longrightarrow H_2CO_3$$

Carbon dioxide

Water

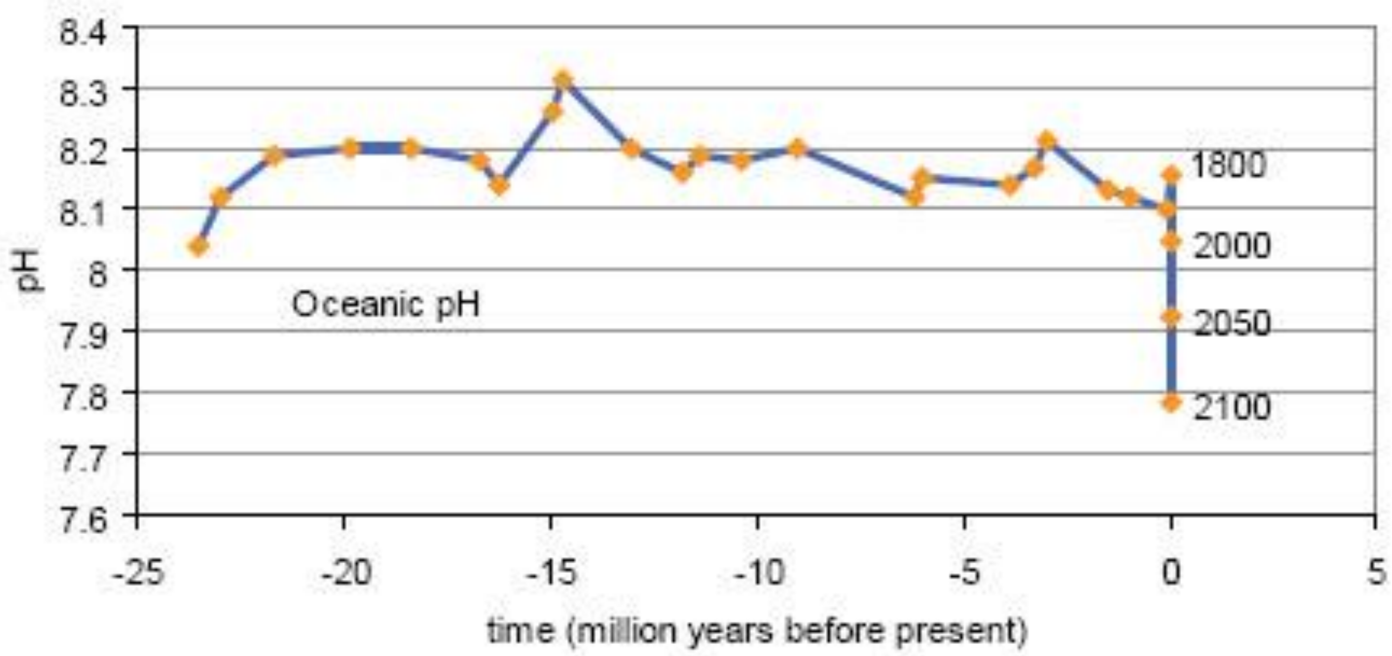
Carbonic acid

Ocean acidification is happening now



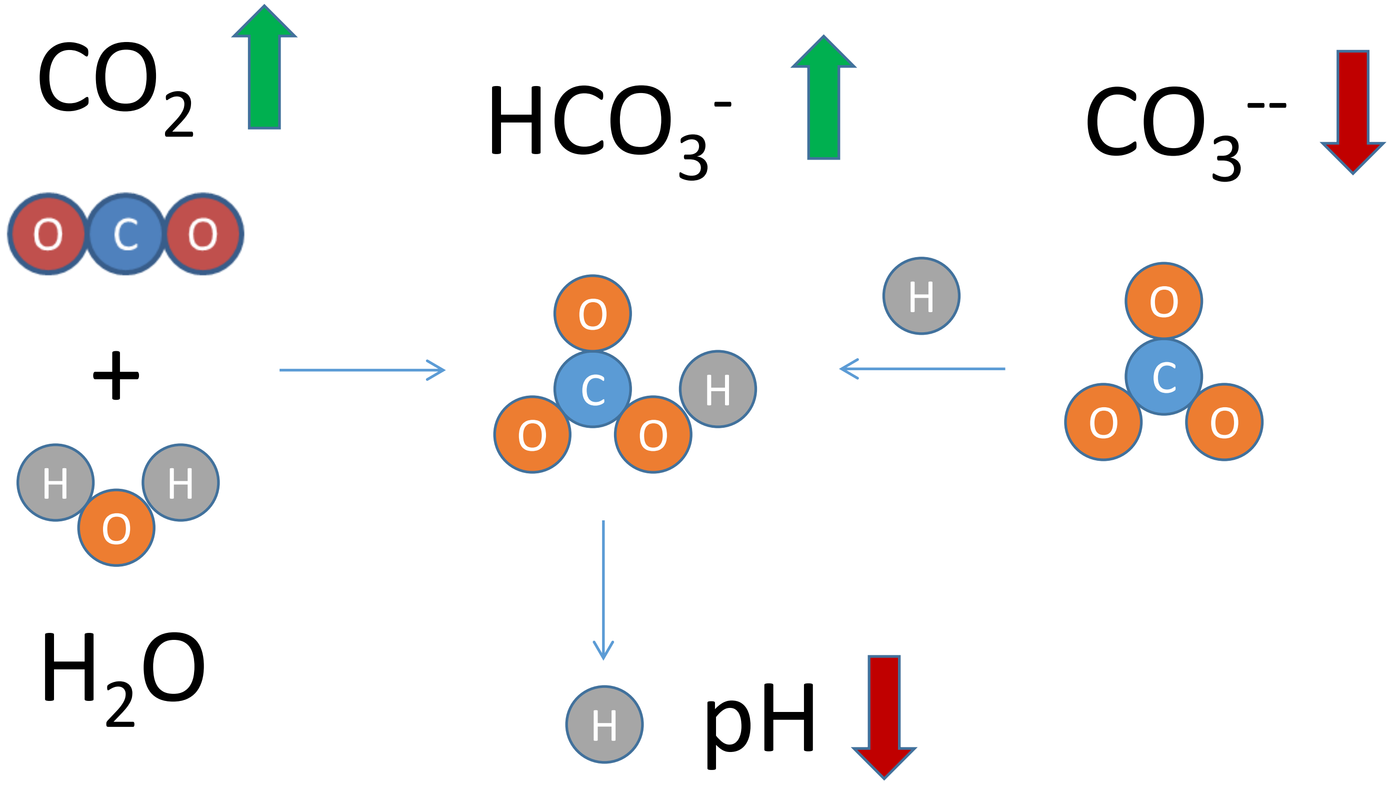
Doney et al. (2009)

Fast and strong



Ocean 2x more acidic by 2100

A little bit more chemistry



Sea water more acidic

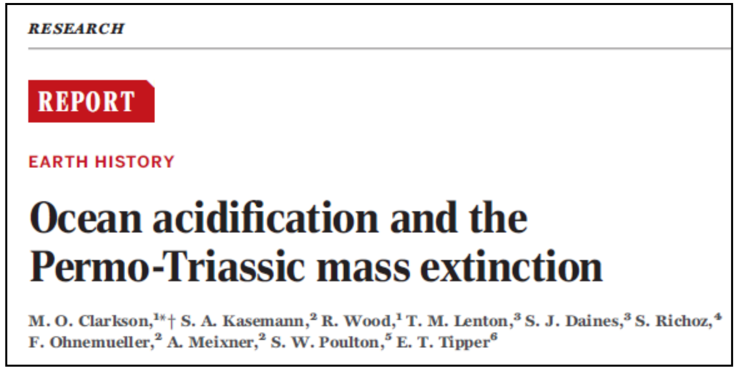
Sea water more corrosive

Decreased carbonate

Calcification?
[$CaCO_3$]

Ocean acidification is a real, fast and directly related to our CO_2 emissions

Last ocean acidification event: the third extinction

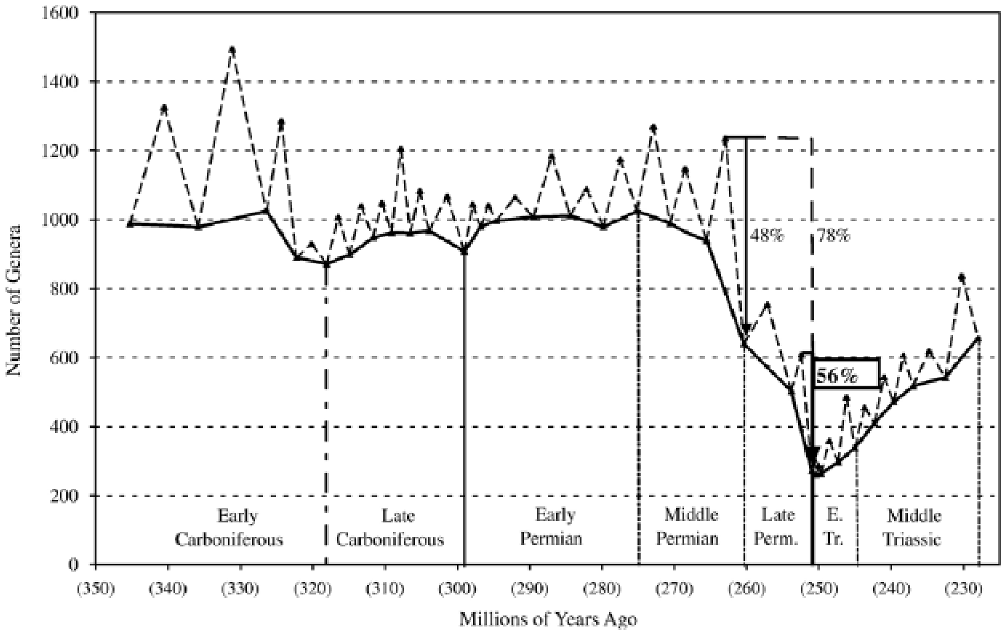

RESEARCH

REPORT

EARTH HISTORY

Ocean acidification and the Permo-Triassic mass extinction

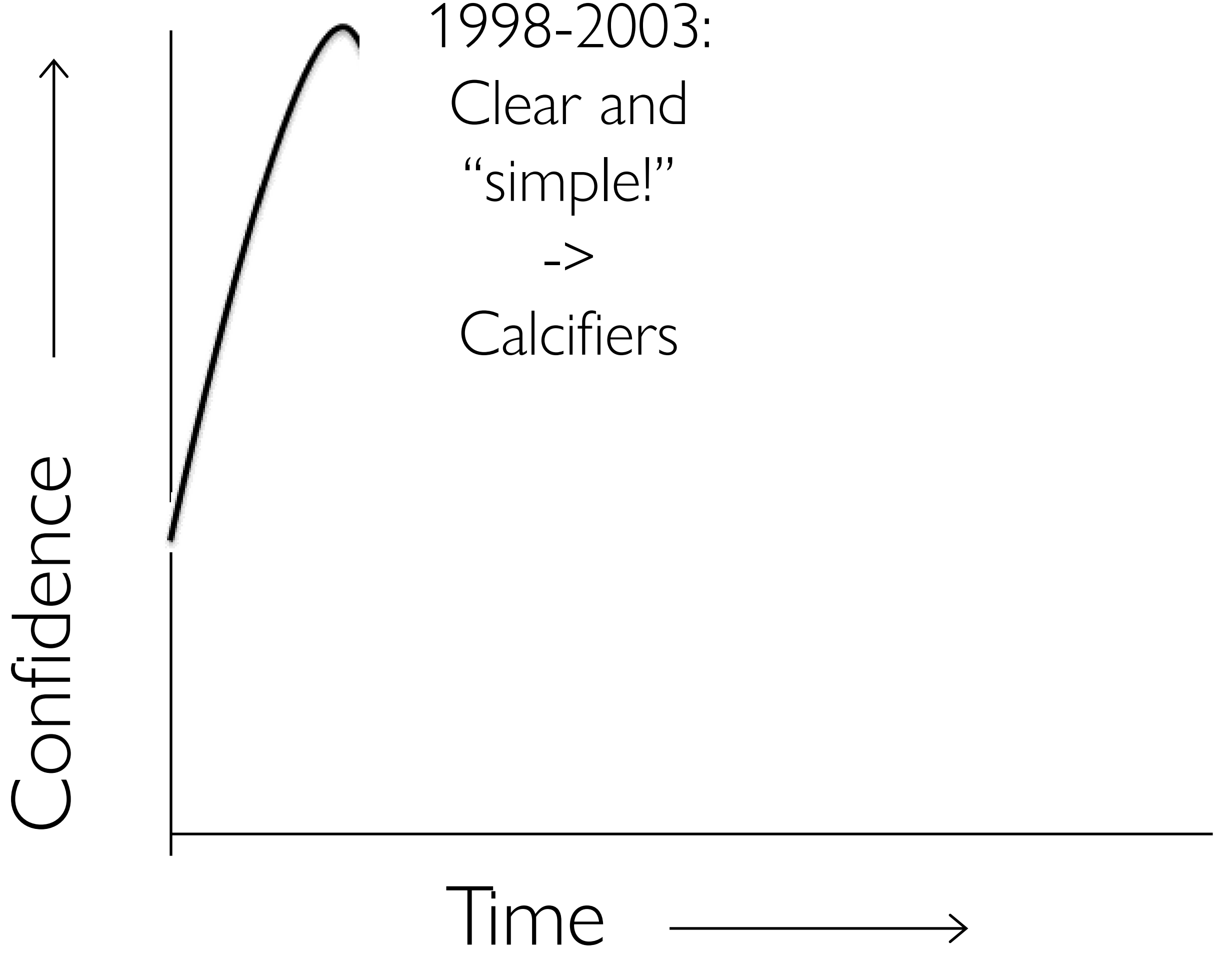
M. O. Clarkson,[1*†] S. A. Kasemann,[2] R. Wood,[1] T. M. Lenton,[3] S. J. Daines,[3] S. Richoz,[4] F. Ohnemueller,[2] A. Meixner,[2] S. W. Poulton,[5] E. T. Tipper[6]



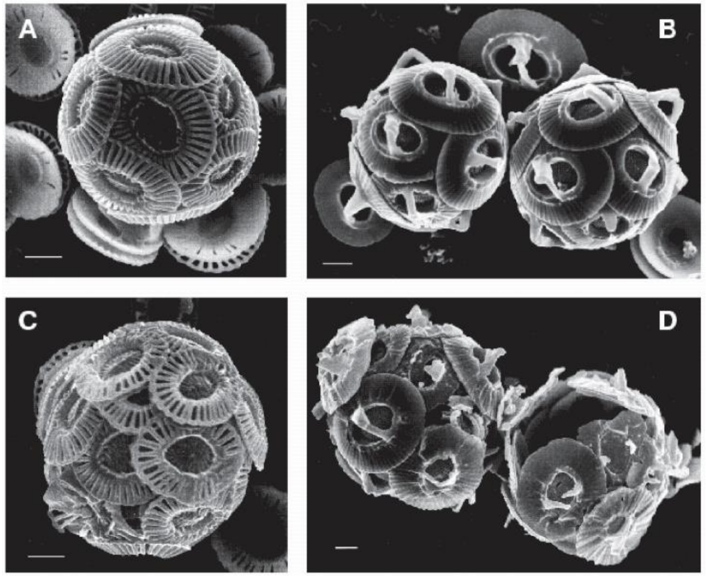
(Knoll et al. 2007)

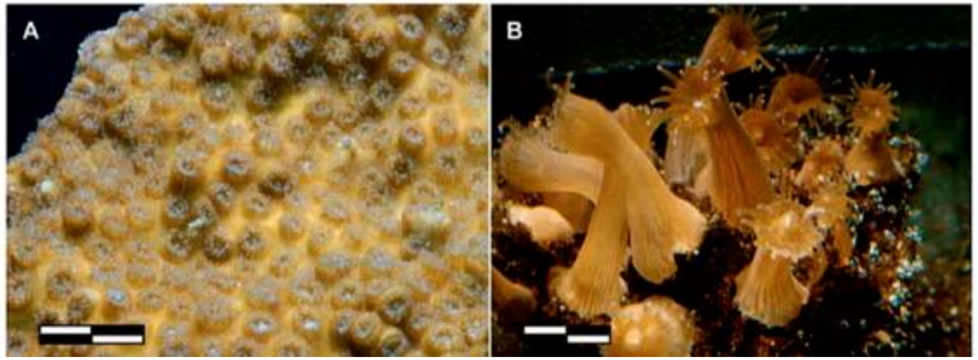
Extinction of 92% of all marine species

The heart beat of ocean acidification



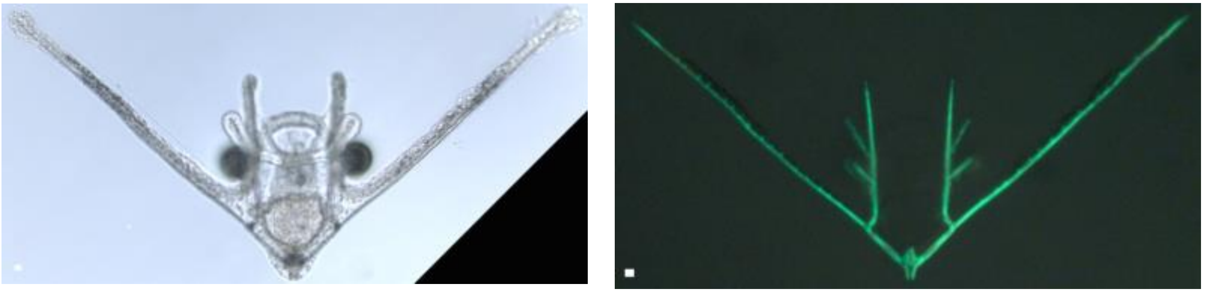
Negative impact on calcifiers



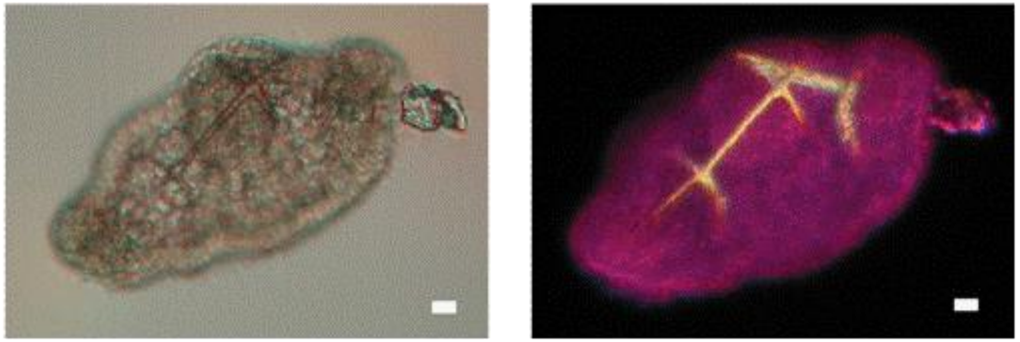


Can lead to species extinction

8.1



7.9



(Dupont et al. 2008)

Challenge marine ecosystems

50% of marine animals threaten by ocean acidification

(Wittmann & Pörtner 2013)

It is already happening

Impact aquaculture and industry

Negative impact on calcifiers

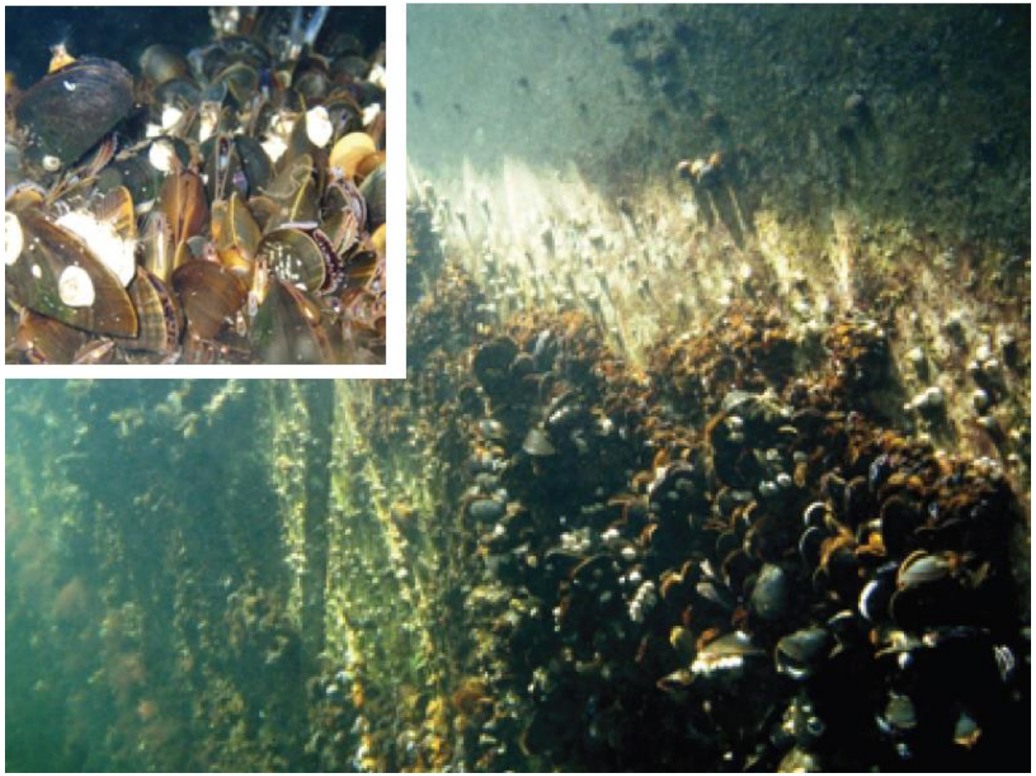
nature climate change
PERSPECTIVE
PUBLISHED ONLINE: 23 FEBRUARY 2015 | DOI: 10.1038/NCLIMATE2508

Vulnerability and adaptation of US shellfisheries to ocean acidification

Julia A. Ekstrom[1*†], Lisa Suatoni[2], Sarah R. Cooley[3], Linwood H. Pendleton[4,5], George G. Waldbusser[6], Josh E. Cinner[7], Jessica Ritter[8], Chris Langdon[9], Ruben van Hooidonk[10], Dwight Gledhill[11], Katharine Wellman[12], Michael W. Beck[13], Luke M. Brander[14], Dan Rittschof[8], Carolyn Doherty[8], Peter E. T. Edwards[15,16] and Rosimeiry Portela[17]

e.g. Threshold: $\Omega < 1.5$

Organisms are not pieces of $CaCO_3$



pH 7.5, Ωara=0.35

(Thomsen et al. 2010)

Local adaptation

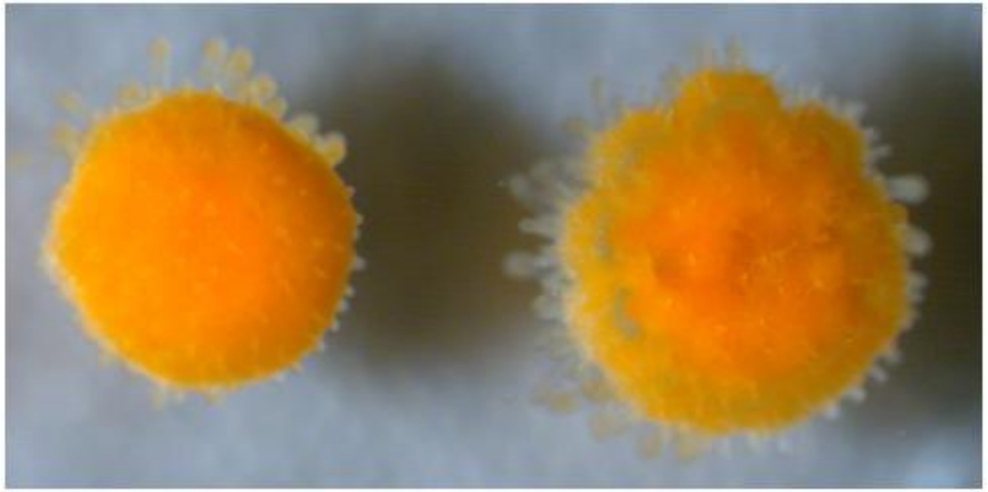
Some calcifiers are winners

RESEARCH ARTICLE

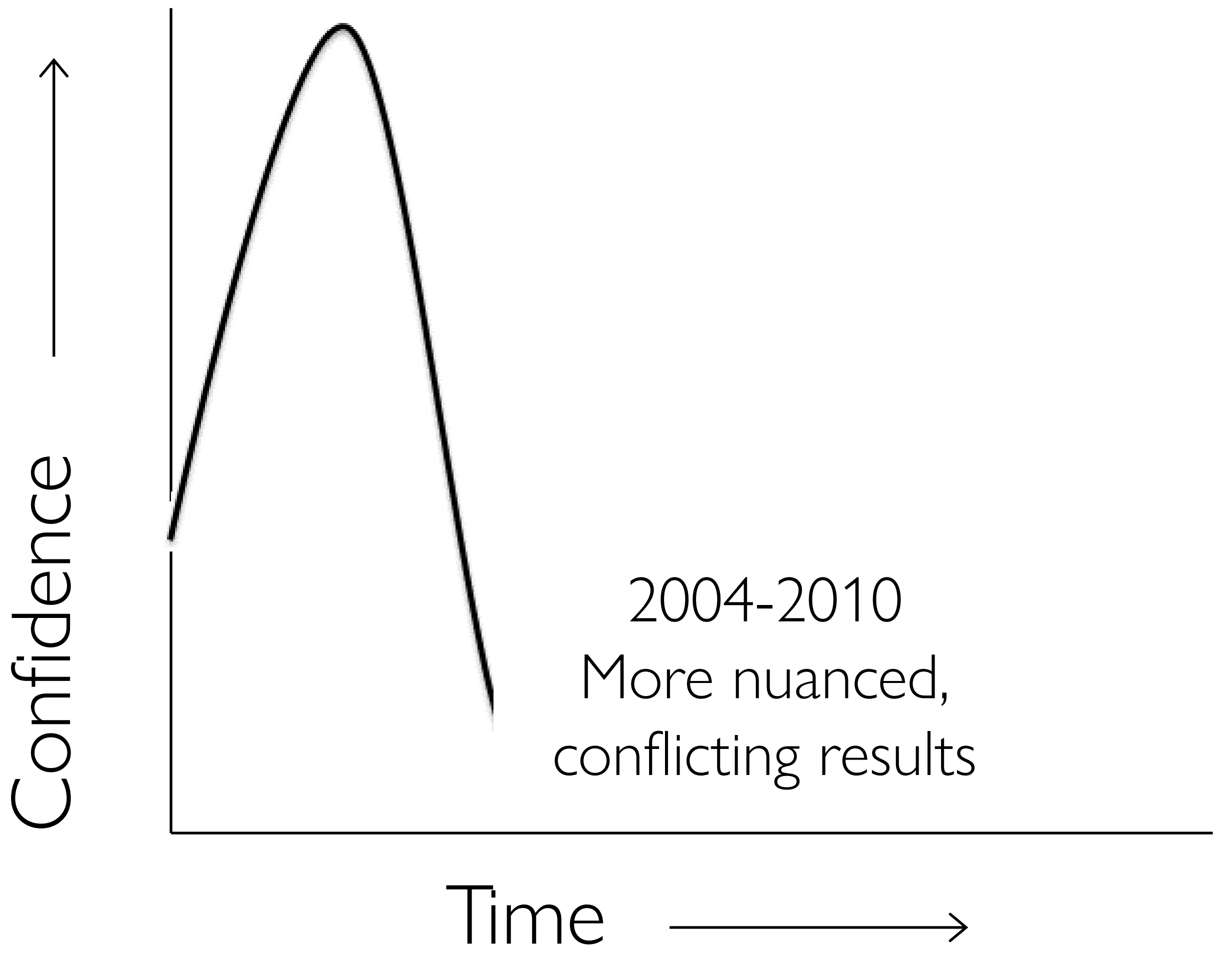
Near Future Ocean Acidification Increases Growth Rate of the Lecithotrophic Larvae and Juveniles of the Sea Star *Crossaster papposus*

SAM DUPONT[1]*, BENGT LUNDVE[1], AND MIKE THORNDYKE[2]

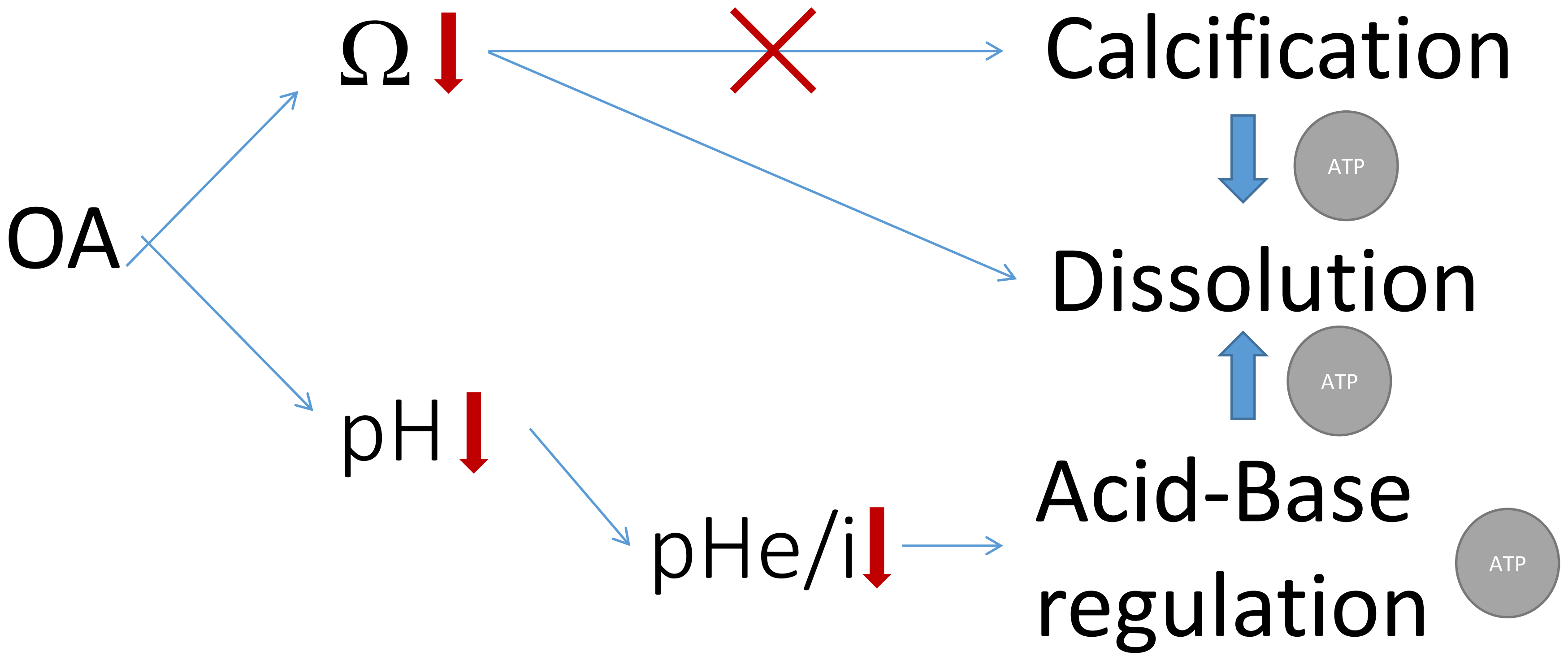
JOURNAL OF EXPERIMENTAL ZOOLOGY
PART B
MOLECULAR AND DEVELOPMENTAL EVOLUTION



The heart beat of ocean acidification

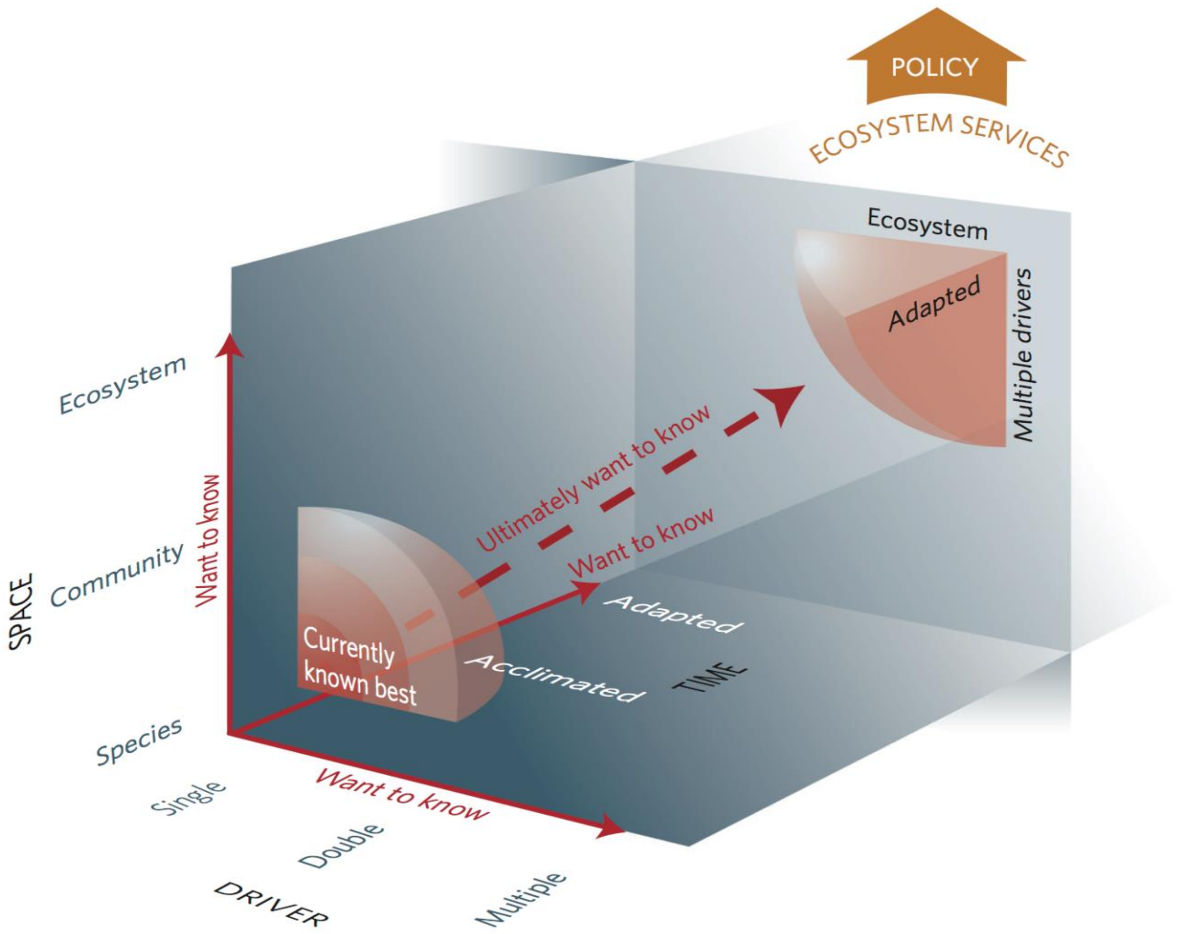


What is happening to an animal exposed to ocean acidification?



Species sensitivity relates to: ability to protect/compensate & energy + local adaptation

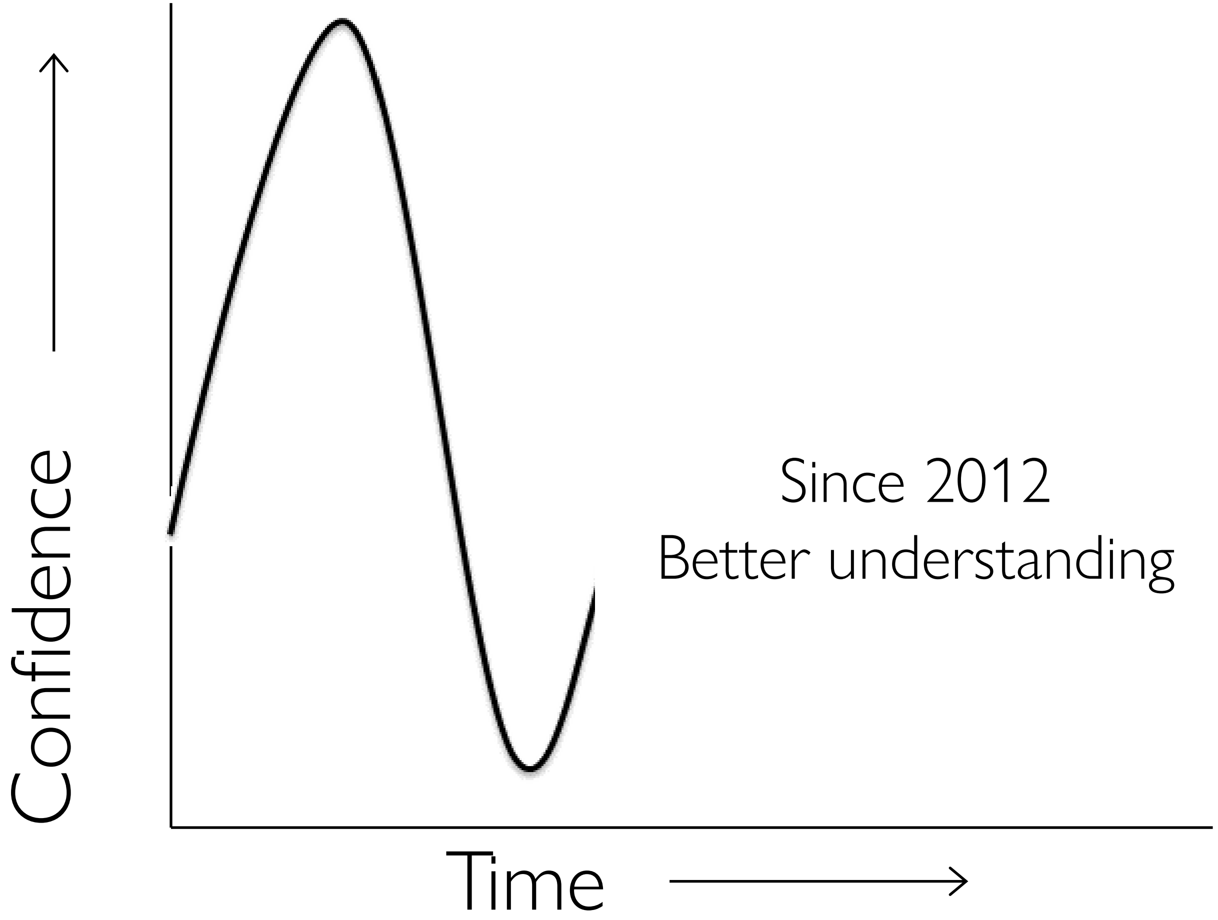
Well, biology is complicated…



… and will always be limiting

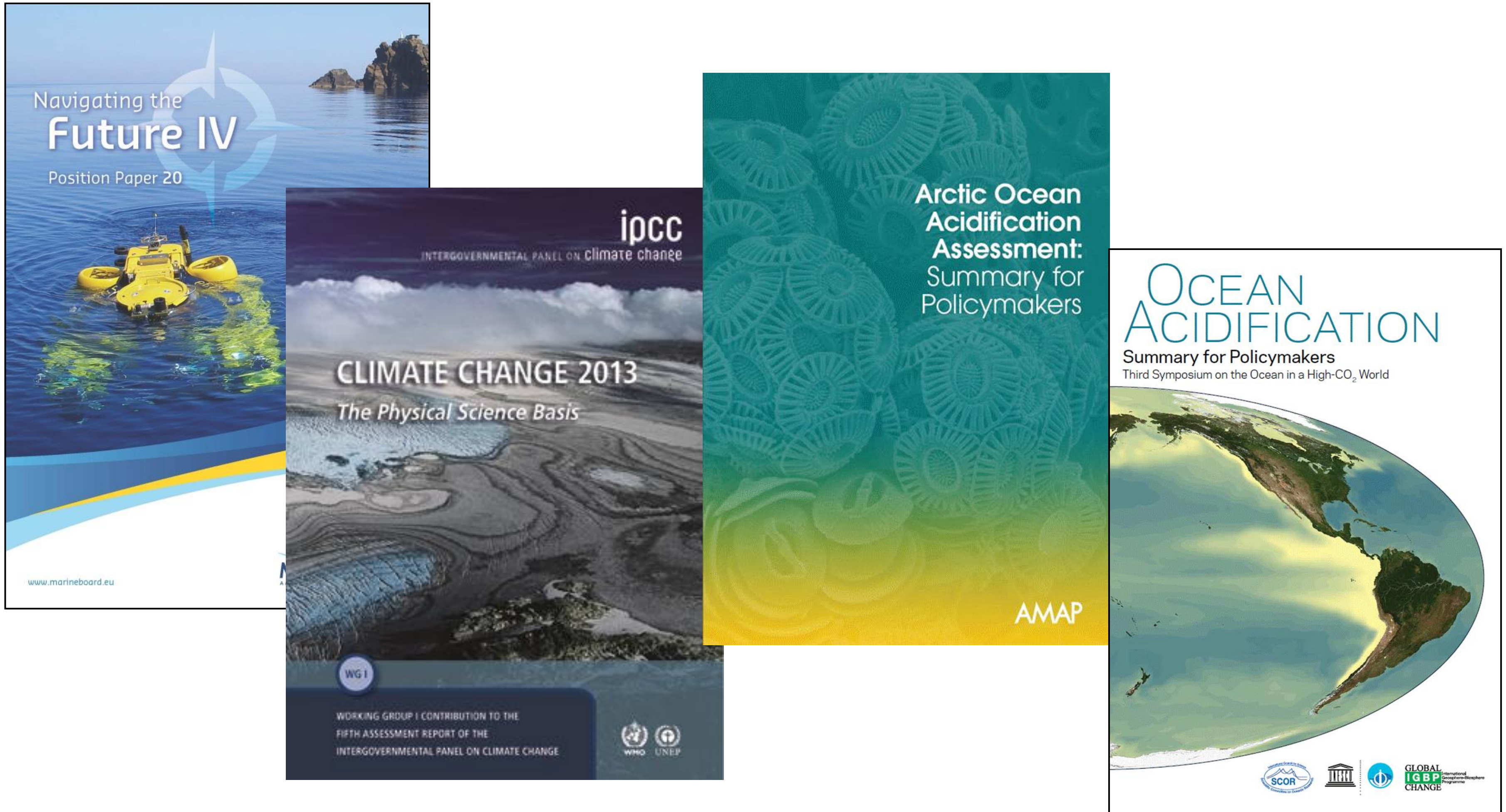
Riebesell and Gattuso (2015) <u>Nature Climate Change</u>

The heart beat of ocean acidification



We know what we don't know

Scientists are “virtually certain” that ocean acidification will lead to dramatic consequences



SUSTAINABLE DEVELOPMENT GOALS

17 GOALS TO TRANSFORM OUR WORLD

1 NO POVERTY

2 ZERO HUNGER

3 GOOD HEALTH AND WELL-BEING

4 QUALITY EDUCATION

5 GENDER EQUALITY

6 CLEAN WATER AND SANITATION

7 AFFORDABLE AND CLEAN ENERGY

8 DECENT WORK AND ECONOMIC GROWTH

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

10 REDUCED INEQUALITIES

11 SUSTAINABLE CITIES AND COMMUNITIES

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

13 CLIMATE ACTION

14 LIFE BELOW WATER

15 LIFE ON LAND

16 PEACE, JUSTICE AND STRONG INSTITUTIONS

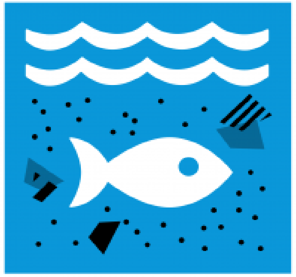
17 PARTNERSHIPS FOR THE GOALS

SUSTAINABLE DEVELOPMENT GOALS

SUSTAINABLE DEVELOPMENT GOAL 14

Conserve and sustainably use the oceans, seas and marine resources for sustainable development

TARGET 14·1

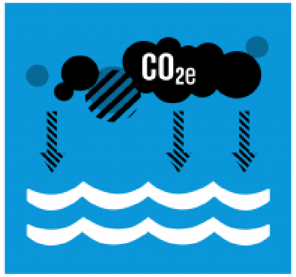


REDUCE MARINE POLLUTION

TARGET 14·2

PROTECT AND RESTORE ECOSYSTEMS

TARGET 14·3



REDUCE OCEAN ACIDIFICATION

TARGET 14·4

SUSTAINABLE FISHING

TARGET 14·5

CONSERVE COASTAL AND MARINE AREAS

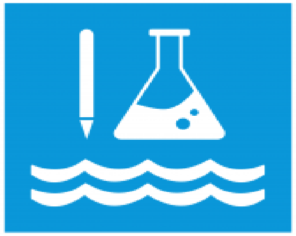
TARGET 14·6

END SUBSIDIES CONTRIBUTING TO OVERFISHING

TARGET 14·7

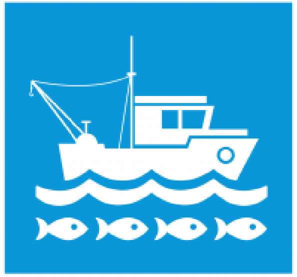
INCREASE THE ECONOMIC BENEFITS FROM SUSTAINABLE USE OF MARINE RESOURCES

TARGET 14›A



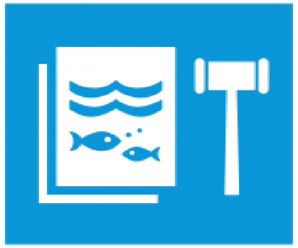
INCREASE SCIENTIFIC KNOWLEDGE, RESEARCH AND TECHNOLOGY FOR OCEAN HEALTH

TARGET 14›B

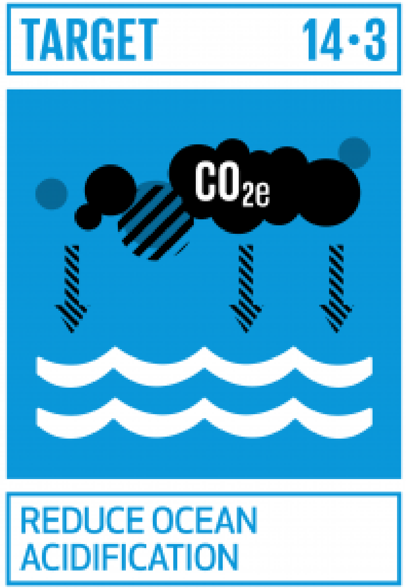


SUPPORT SMALL SCALE FISHERS

TARGET 14›C



IMPLEMENT AND ENFORCE INTERNATIONAL SEA LAW



Target 14.3
Minimize and address the impacts of **ocean acidification**, including through enhanced scientific cooperation at all levels

What can we do?

Fight?

Flight?

or nothing?

- NOTHING: Face to the consequences
- FIGHT: Mitigation - Work on the cause (decrease CO_2)
- FLIGHT: Adaptation - Work on the symptoms (buy some time)

A problem of scale

GLOBAL challenges

GLOBAL options: ↓ CO_2

GLOBAL/LOCAL data

Mitigation

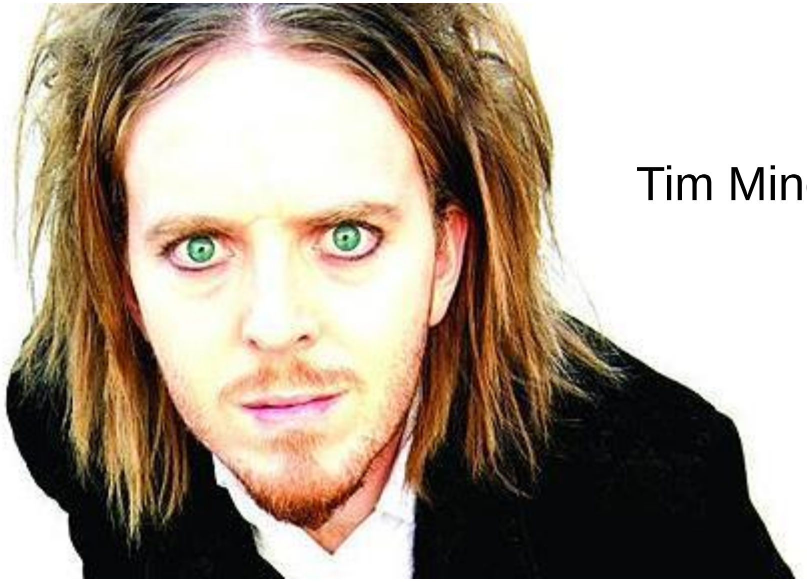
Mitigation: We know what to do

Demography

CO_2 emissions

WHY NO MORE ACTIONS???

A failure to communicate?



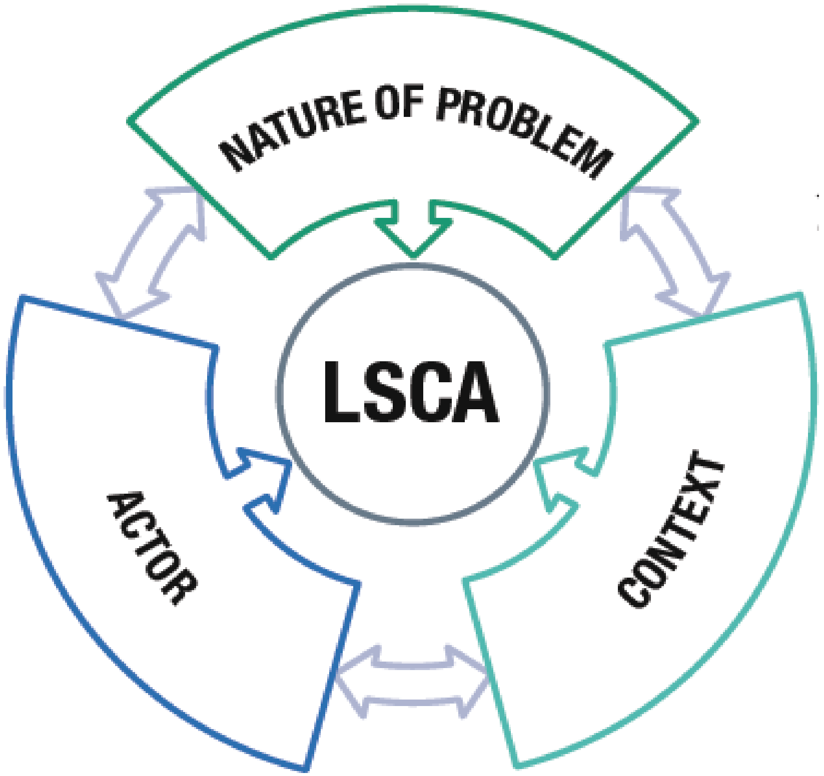
Tim Minchin

The idea that (...) the science of anthropogenic global warming is controversial is a powerful indicator of the extent of our failure to communicate.


KEN CALDEIRA
on Inquiring Minds
"People have to sacrifice a little bit of their short term self interest to help the world be a better place for the long term. And how you get people to do that, I think, is the most important research that can be done."
@inquiringshow

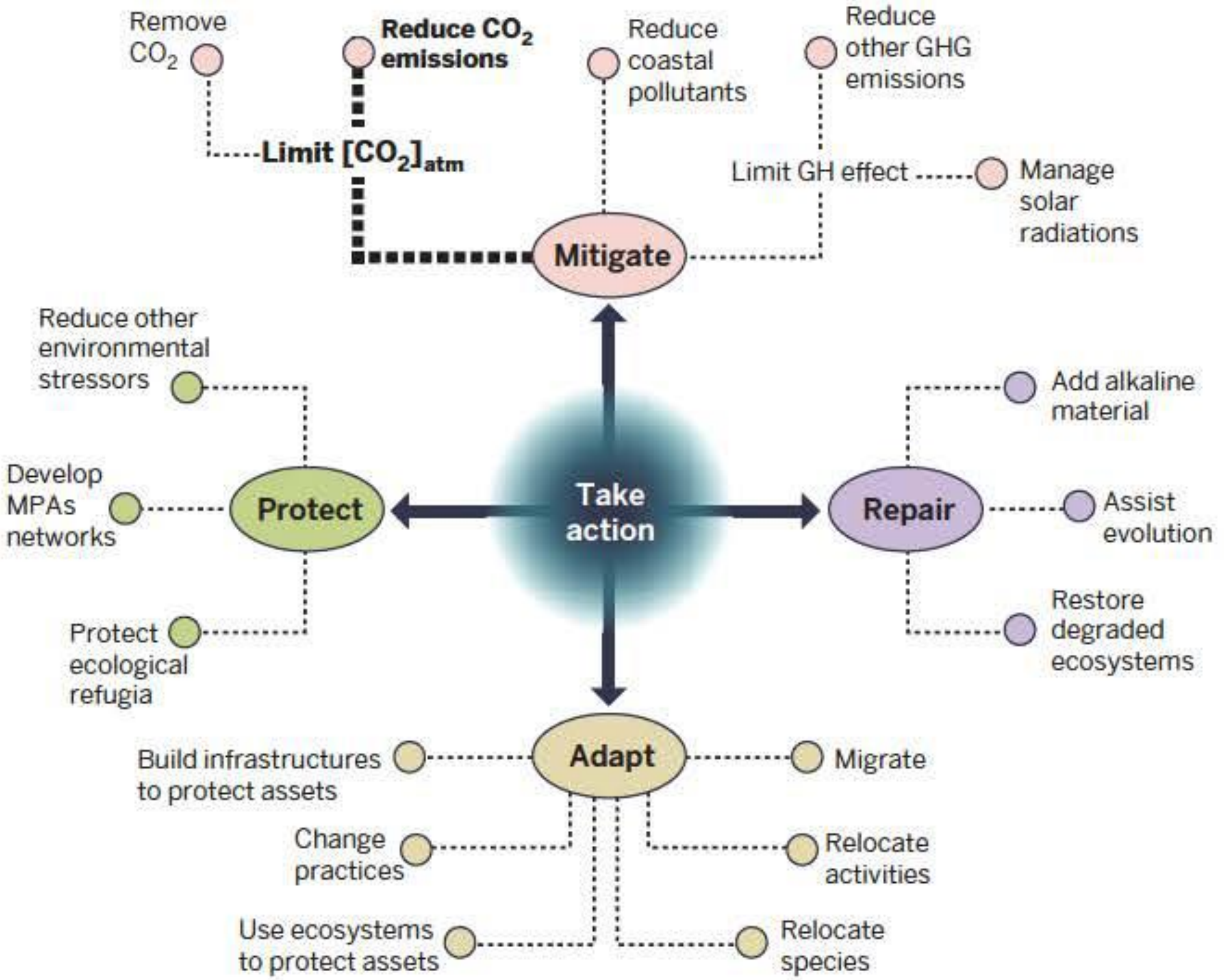
CENTRE FOR COLLECTIVE ACTION RESEARCH

CeCAR



Adaptation

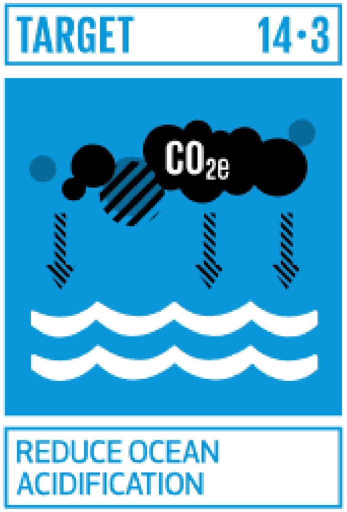
Actions


Remove CO_2
Reduce CO_2 emissions
Limit $[CO_2]_{atm}$
Reduce coastal pollutants
Reduce other GHG emissions
Limit GH effect
Manage solar radiations
Mitigate
Reduce other environmental stressors
Develop MPAs networks
Protect
Protect ecological refugia
Take action
Repair
Add alkaline material
Assist evolution
Restore degraded ecosystems
Adapt
Build infrastructures to protect assets
Change practices
Use ecosystems to protect assets
Migrate
Relocate activities
Relocate species

We need both to address (mitigation) and minimize (adaptation)

- ✓ Mitigation will take some time
- ✓ Adaptation buy some time

What data do we need to address and minimize?



Target 14.3
Minimize and address the impacts of **ocean acidification**, including through enhanced scientific cooperation at all levels

Indicator 14.3.1
Average marine acidity (pH) measured at agreed suite of representative sampling stations

Irrelevant indicator !

- ✓ Does not allow to characterize ocean acidification
- ✓ Would lead to low quality data (no quality control)
- ✓ Biologically irrelevant

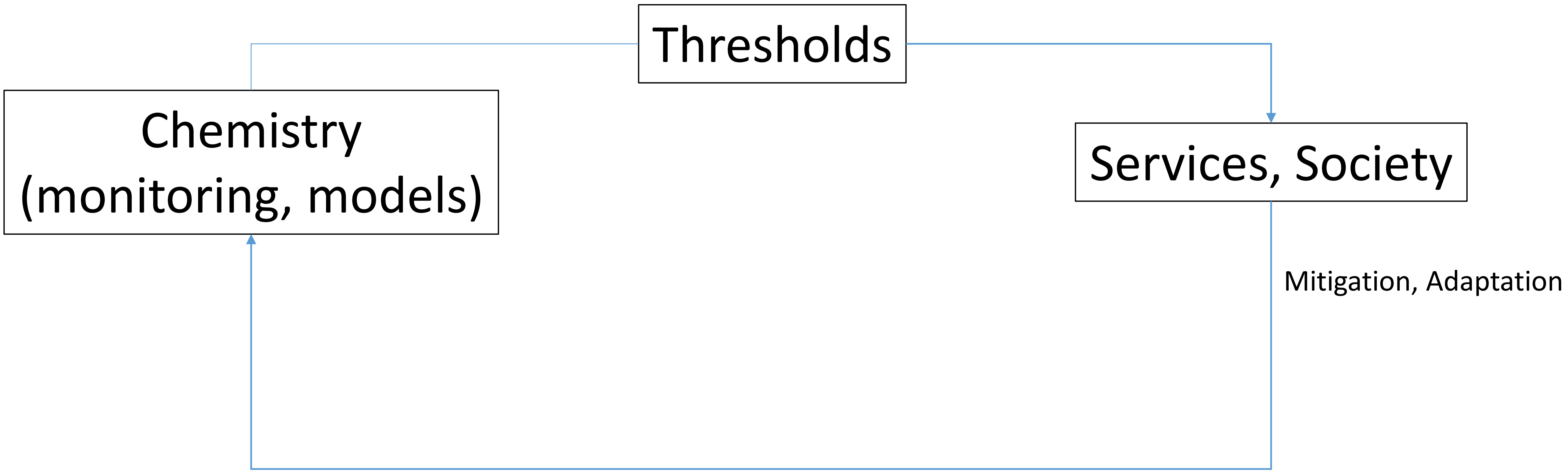
Biology is needed to drive chemistry to services (and for adaptation strategies)

- ✓ Chemical monitoring
  - Rate of chemical change (climate)
  - Ecological niche (weather)

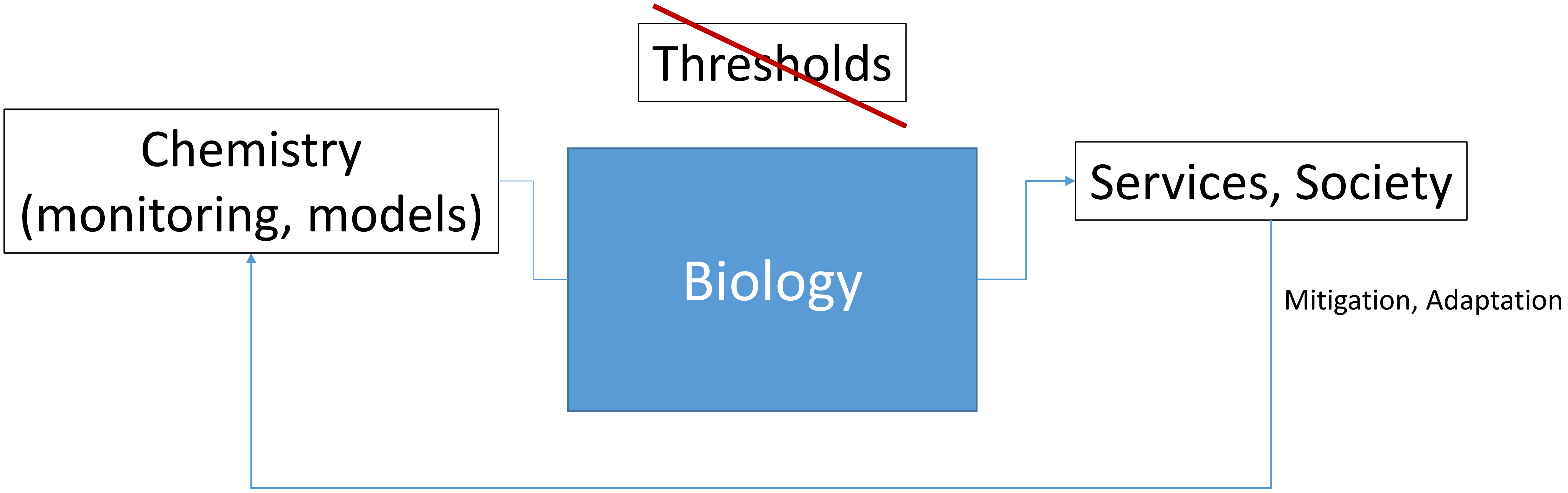
} Models
Experimental design

So what?

Bridge biology to society



Bridge biology to society



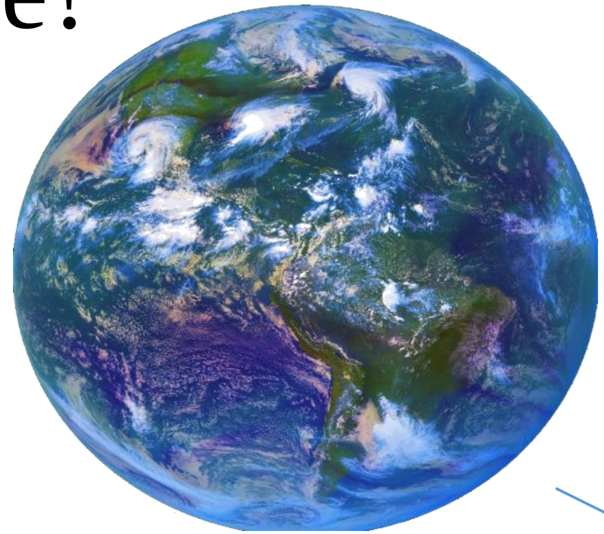
(Chemical) monitoring is not enough

Classic ”ecotoxicology” monitoring approach does not work for ocean acidification

- ✓ CO_2 and pH are not toxicants but natural drivers
- ✓ Lot of variability in space and time
- ✓ Local adaptation by marine life

→ Complex relative thresholds (need experiments!)

What data do we need to address and minimize?



GLOBAL challenges

GLOBAL options: ⬇ CO_2

MITIGATION

GLOBAL & LOCAL

LOCAL challenges

LOCAL options

LOCAL

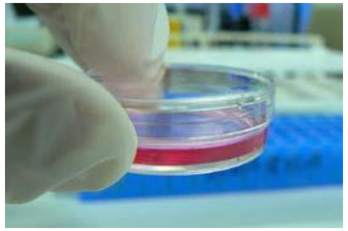
ADAPTATION

How do we collect those data?

- ✓ Monitoring
- ✓ Modeling
- ✓ Paleo
- ✓ Field (e.g. natural analogs, gradients)
- ✓ Field experiments
- ✓ Laboratory experiments
- ✓ Etc.

What is the best approach?

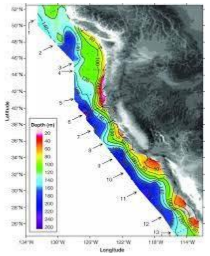
Lab based experiments

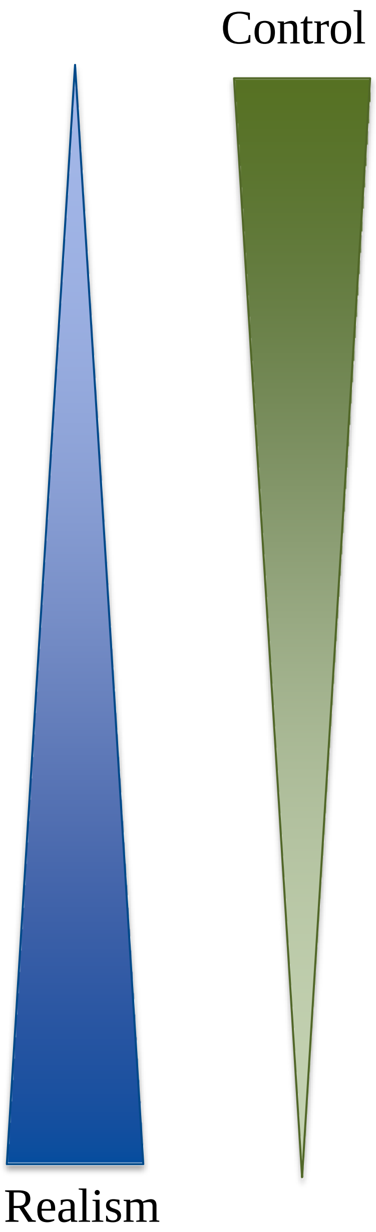


Field based experiments

Natural analogs

Field variability (space for time)



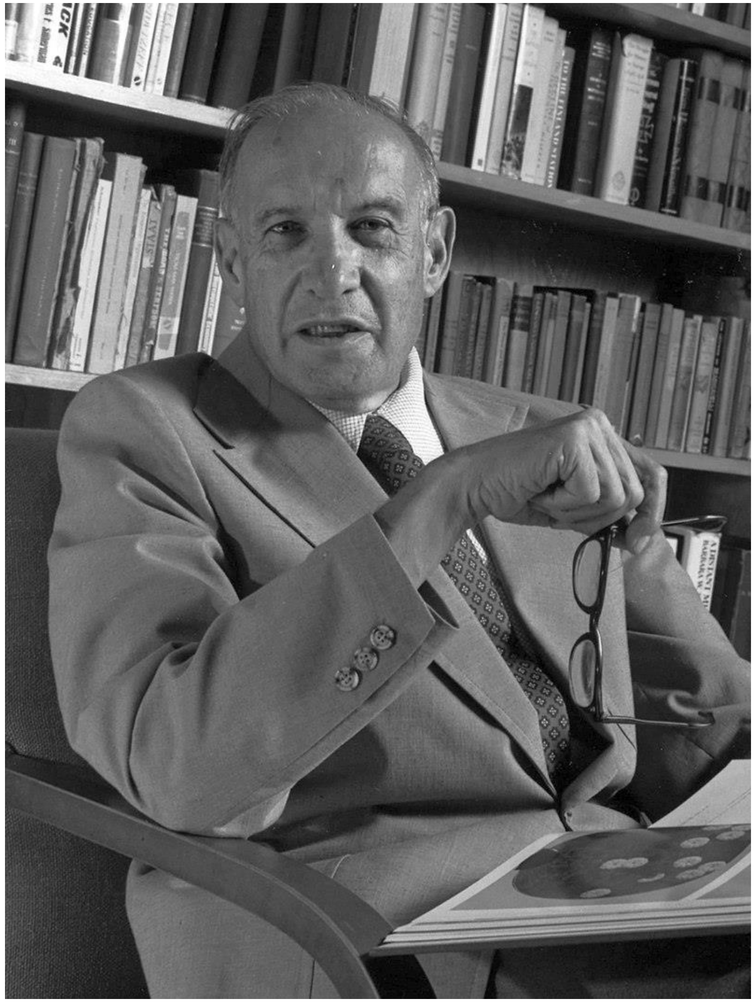


What is the best approach?

- ✓ A good question cannot be answered using only one approach…
  … or one experiment
  ➡ *Importance of a strategy*

- ✓ All experiments are an abstraction of reality (and then ”wrong”)
  ➡ *Importance of diversity (and honnesty)*

Why bother?

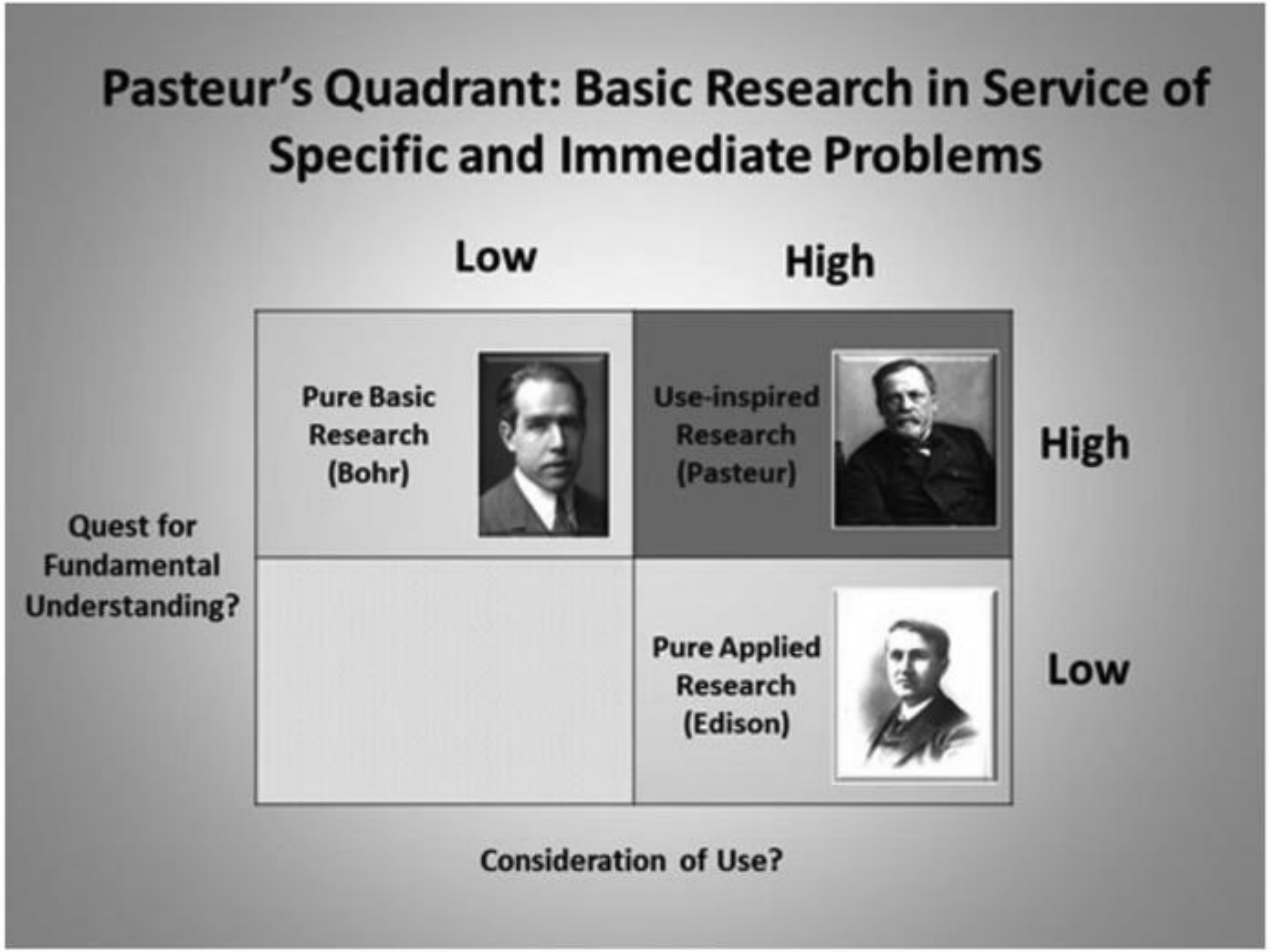


(Peter Drucker)

Effectiveness is doing the right things

Efficiency is doing things right

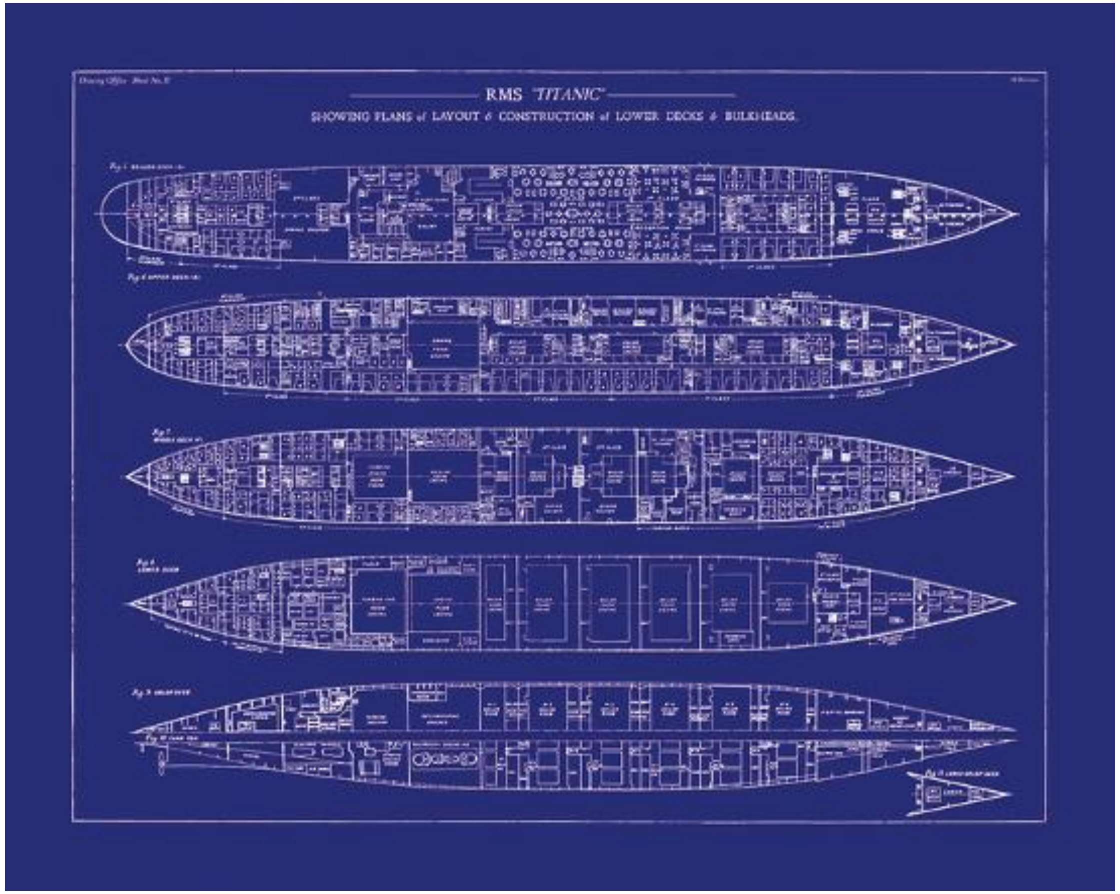
Ocean acidification is mostly an applied science



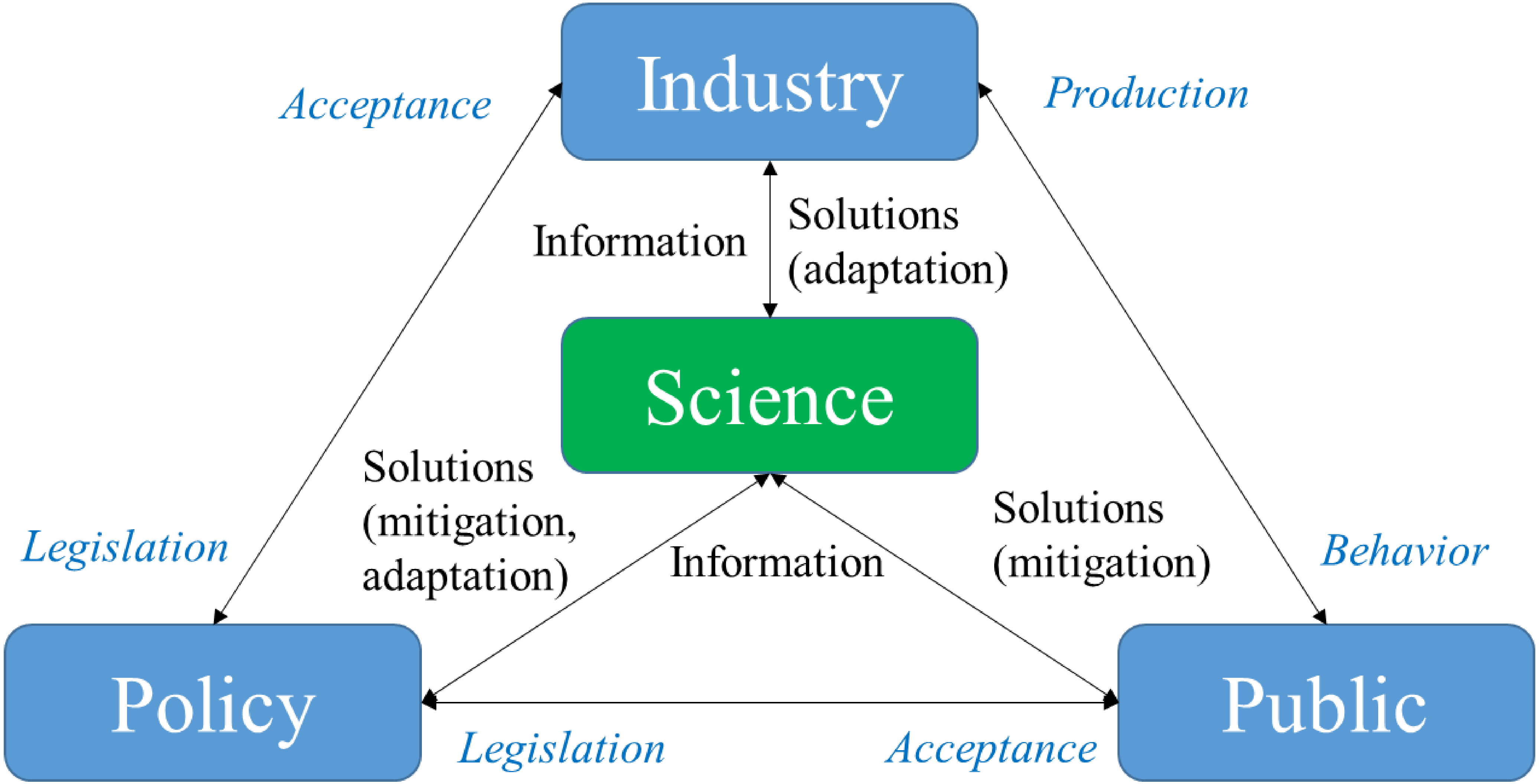
All science is interesting but not all science is useful


House is on fire !
Priorities !

Need to prioritize



What (data) is important FOR YOU?



Read read read

Read the literature ! or ask experts

… not only specific literature…

[Theoretical background, methods, etc.]

Standing on the shoulders of giants

Doing the right thing: What experiment shall I do?

- ✓ What are my local key services challenges by OA
- ✓ What are the solutions to minimize and address?

→ *Question*

Doing the right thing: What experiment shall I do?

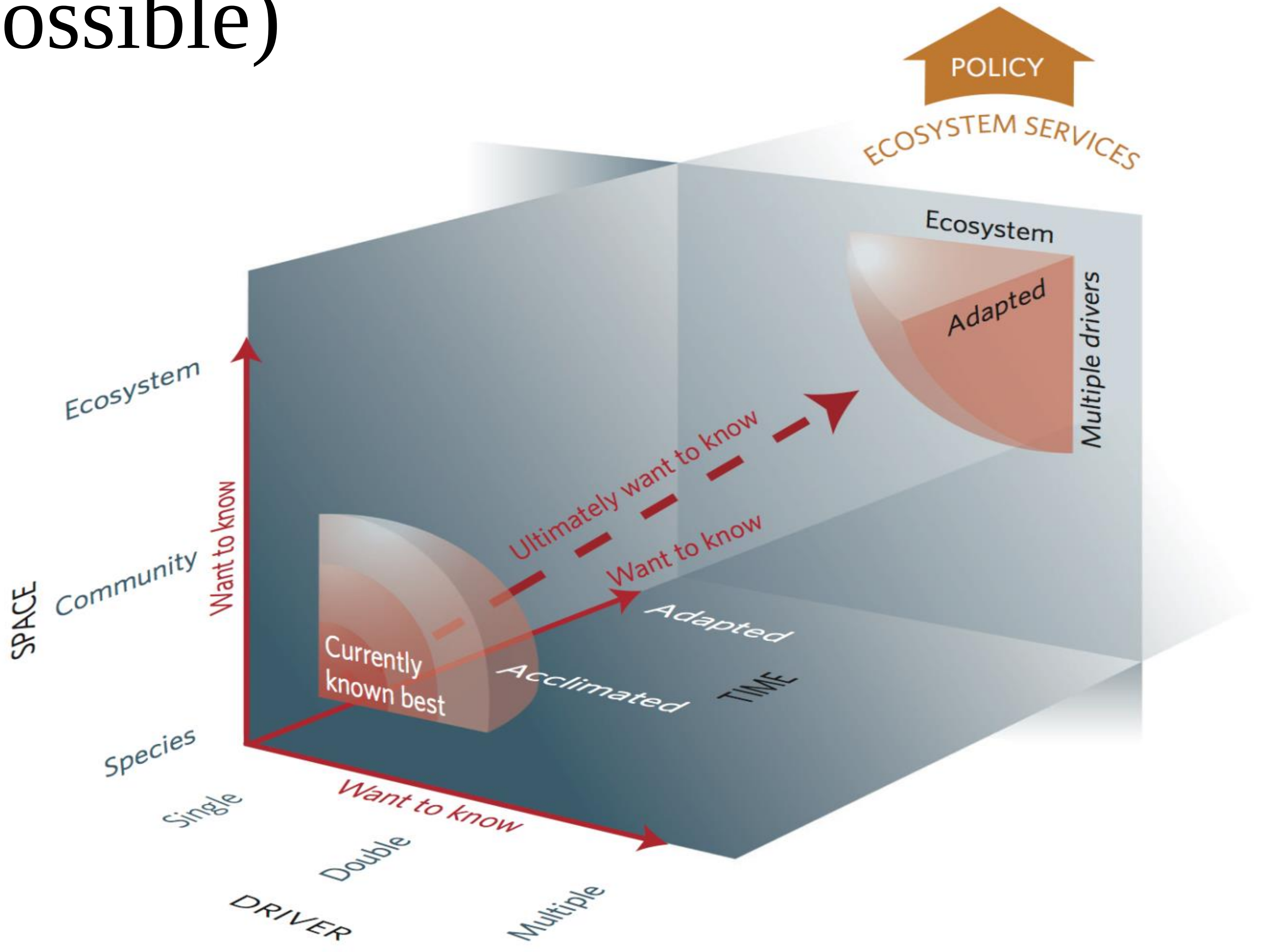
- ✓ What are my local key services challenges by OA
- ✓ What are the solutions to minimize and address?

  → *Question*

- ✓ What data do I need?
- ✓ How can I collect those?

  → *Strategy*

Aspects to consider (simplify as much as possible)



Ecology
Evolution
Multiple stressors

Doing the right thing: What experiment shall I do?

- ✓ What are my local key services challenges by OA
- ✓ What are the solutions to minimize and address?

⇒ *Question*

- ✓ What data do I need?
- ✓ How can I collect those?

⇒ *Strategy*

- ✓ What experiment(s) needs to be done?
- ✓ What is my hypothesis?

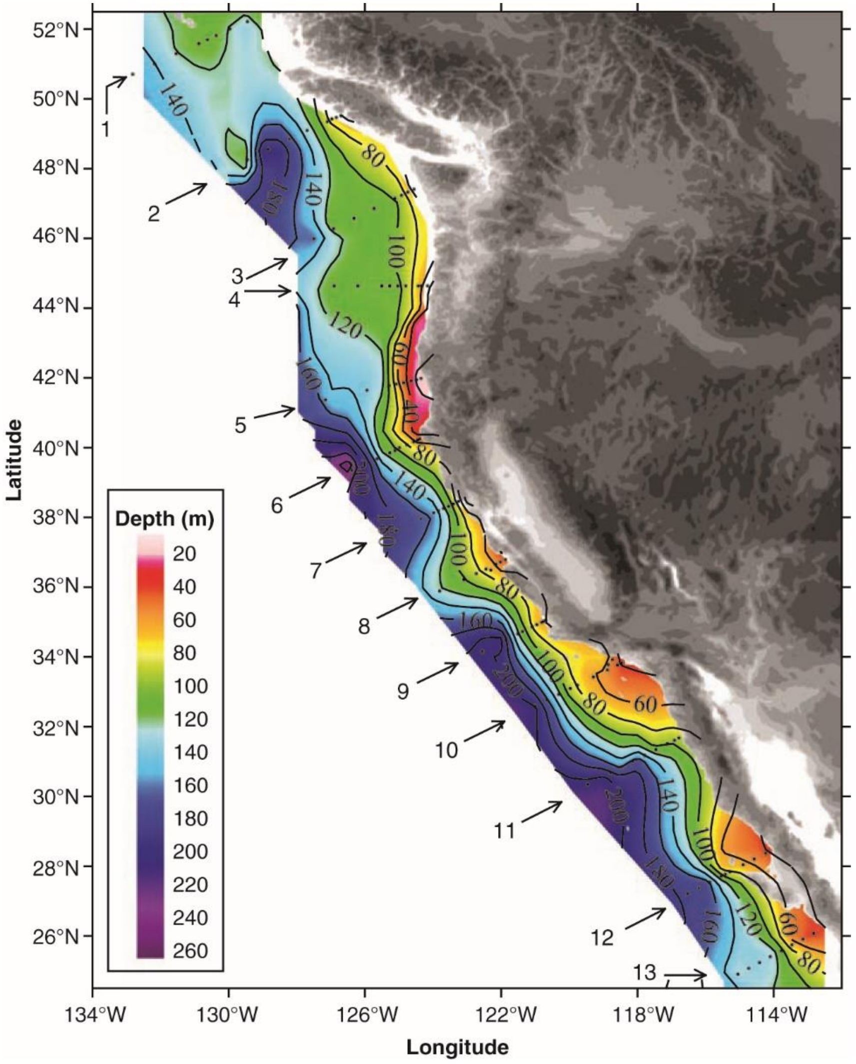
⇒ *Design*

Case study #1 – Oyster aquaculture in the USA

Problem: Not possible to produce spats in hatcheries

-> No production, no money, no jobs

Step 1 – Diagnosis: what is the problem?



Feely et al. 2008

<u>Cause</u>: Ocean acidification

Combined with upwelling

Step 2 – Diagnosis: what is the source?

Environ. Res. Lett. **14** (2019) 124060 https://doi.org/10.1088/1748-9326/ab5abc

Environmental Research Letters

LETTER

Attributing ocean acidification to major carbon producers

R Licker[1], B Ekwurzel[1], S C Doney[2,3], S R Cooley[4], I D Lima[3], R Heede[5] and P C Frumhoff[6]

Cause: CO_2 emissions

Step 3.1 – Diagnosis: What are the solutions?

Solution: *Mitigation*

- ✓ Policy
- ✓ Change
- ✓ Acceptance

} Citizen

Problem: Inefficient (time scale)

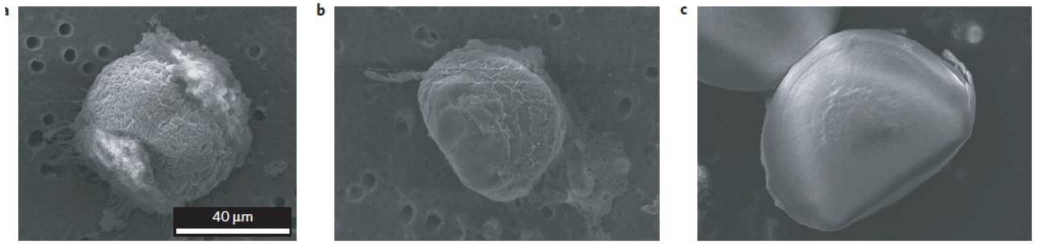
Step 3.2 – Diagnosis: What are the solutions?

Solution: *Adaptation*

= Change aquaculture practices to make it more resilient to ocean acidification

Step 4 – Data collection (experiment)

Window of opportunity
-> keep conditions good
over that period



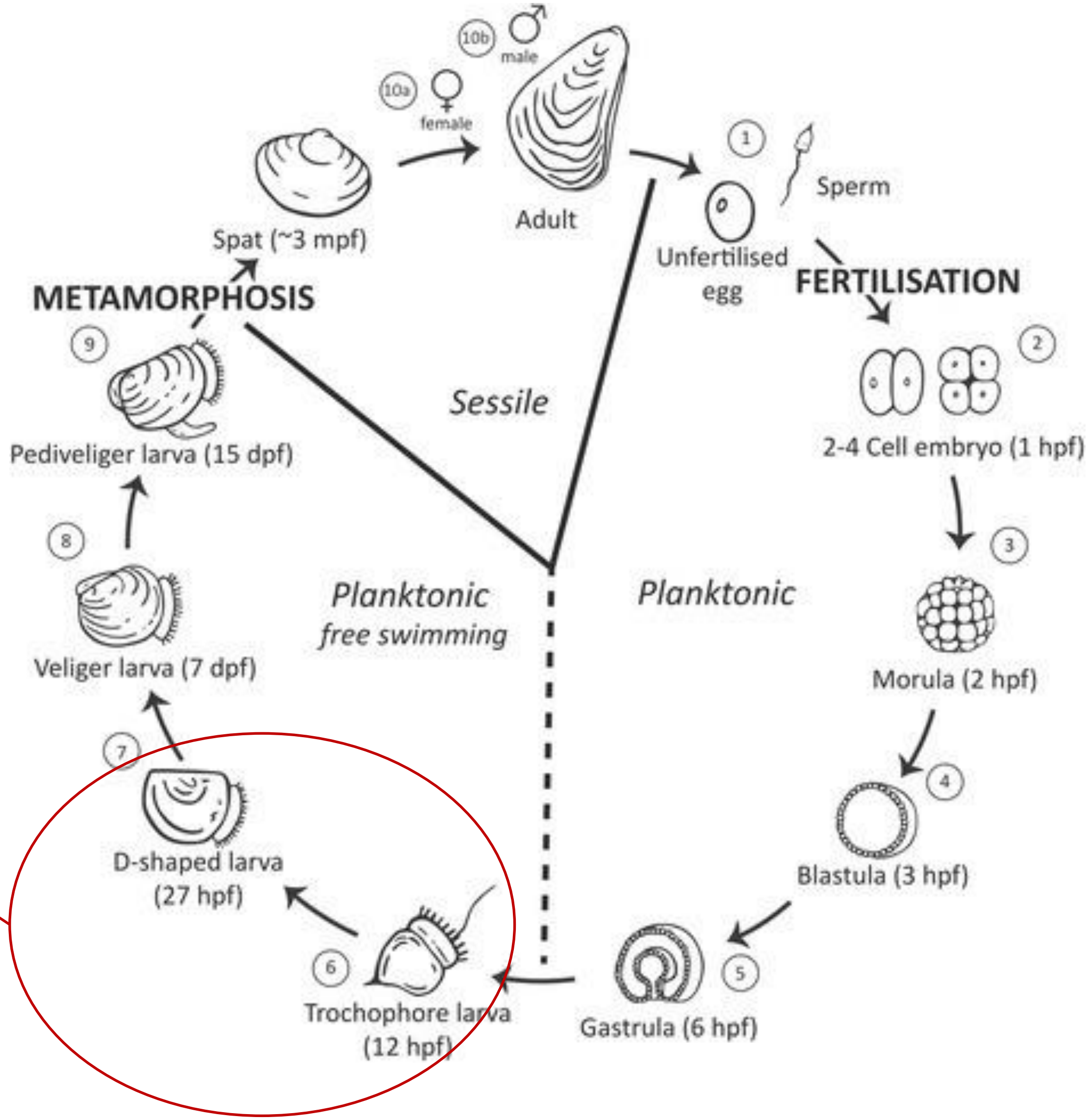
nature climate change

ARTICLES

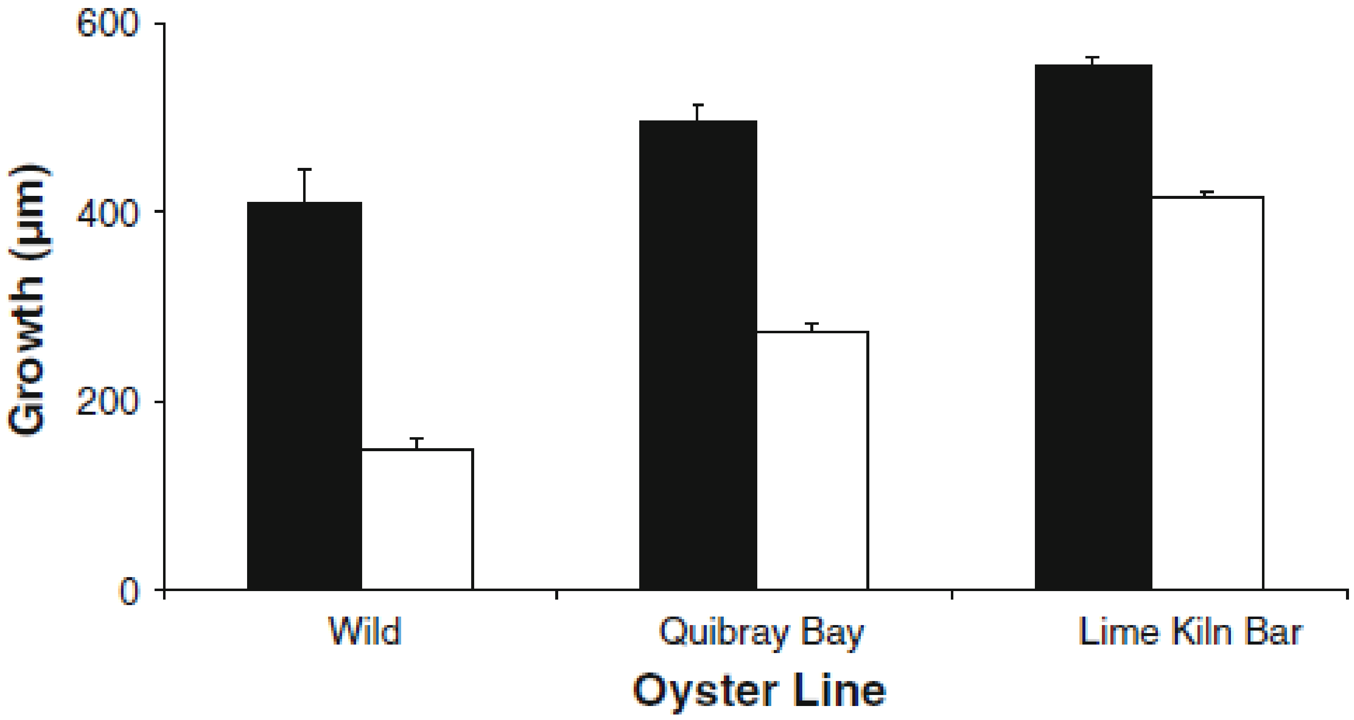
PUBLISHED ONLINE: 15 DECEMBER 2014 | DOI: 10.1038/NCLIMATE2479

Saturation-state sensitivity of marine bivalve larvae to ocean acidification

George G. Waldbusser[1]*, Burke Hales[1], Chris J. Langdon[2], Brian A. Haley[1], Paul Schrader[2], Elizabeth L. Brunner[1], Matthew W. Gray[2], Cale A. Miller[3] and Iria Gimenez[1]



Step 4 – Data collection (experiment)



Positive genetic correlation: fast growing strains are more resilient: -> Use resilient strains

Mar Biol
DOI 10.1007/s00227-010-1592-4

ORIGINAL PAPER

Populations of the Sydney rock oyster, *Saccostrea glomerata*, vary in response to ocean acidification

L. M. Parker · Pauline M. Ross · Wayne A. O'Connor

Case study #1 – Oyster aquaculture in the USA

- ✓Problem: ocean acidification
- ✓ Cause: CO_2 emissions
- ✓ Solution: Mitigation – but need to buy some time
- ✓ Solution: Adaptations – change of practices

Back to business (for now)

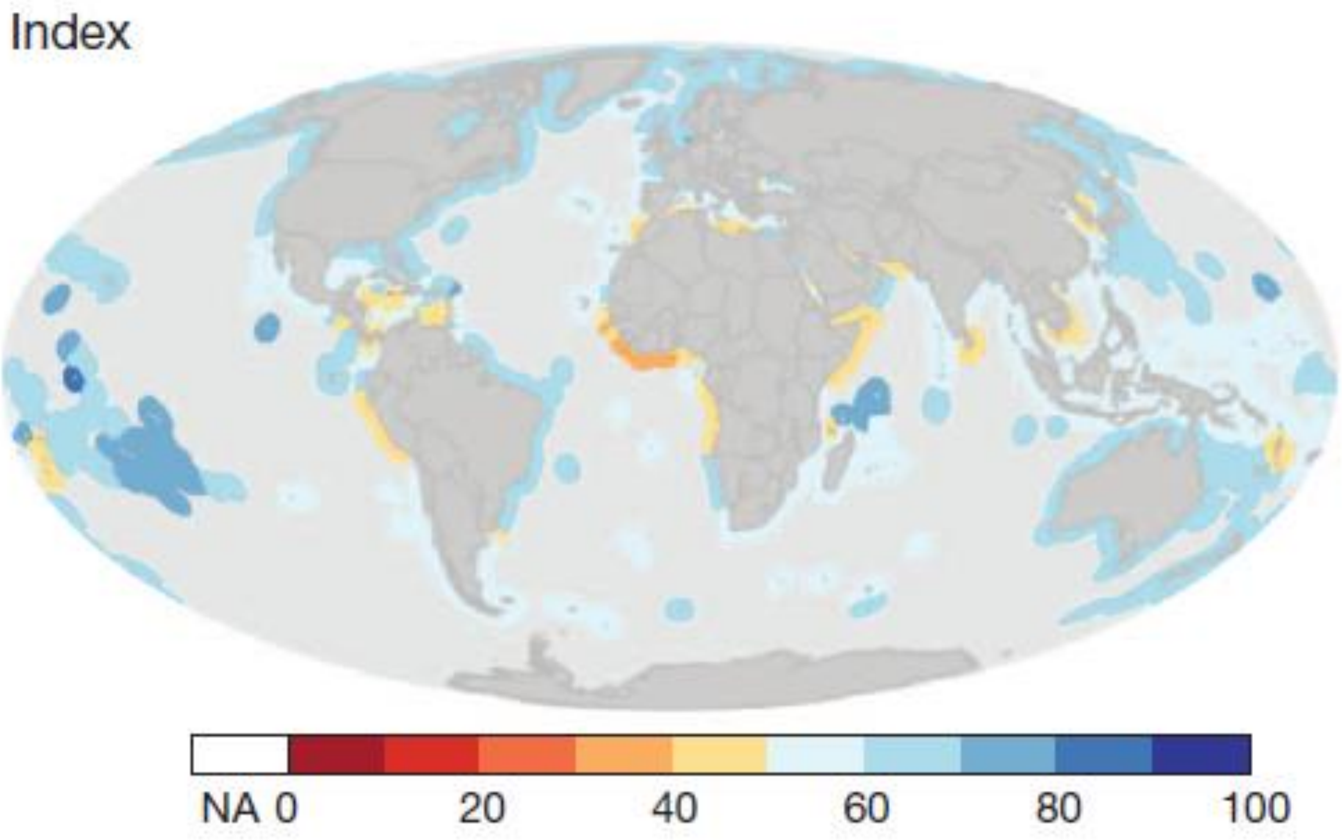
Case study #2 – Global ocean health

ARTICLE

doi:10.1038/nature11397

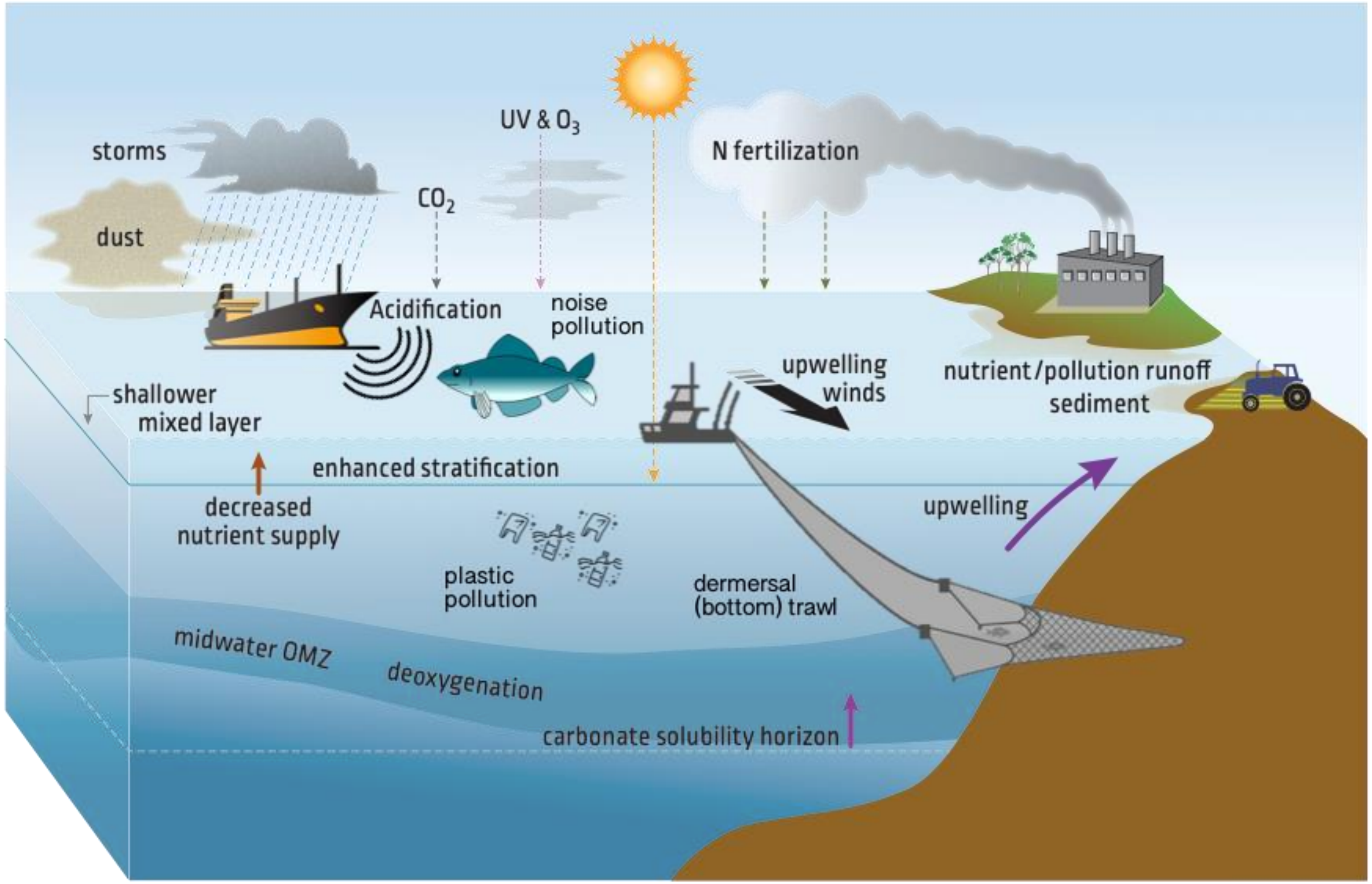
An index to assess the health and benefits of the global ocean

Benjamin S. Halpern[1,2], Catherine Longo[1], Darren Hardy[1], Karen L. McLeod[3], Jameal F. Samhouri[4], Steven K. Katona[5], Kristin Kleisner[6], Sarah E. Lester[7,8], Jennifer O'Leary[1], Marla Ranelletti[1], Andrew A. Rosenberg[5], Courtney Scarborough[1], Elizabeth R. Selig[5], Benjamin D. Best[9], Daniel R. Brumbaugh[10], F. Stuart Chapin[11], Larry B. Crowder[12], Kendra L. Daly[13], Scott C. Doney[14], Cristiane Elfes[15,16], Michael J. Fogarty[17], Steven D. Gaines[8], Kelsey I. Jacobsen[8], Leah Bunce Karrer[5], Heather M. Leslie[18], Elizabeth Neeley[19], Daniel Pauly[6], Stephen Polasky[20], Bud Ris[21], Kevin St Martin[22], Gregory S. Stone[5], U. Rashid Sumaila[6] & Dirk Zeller[6]



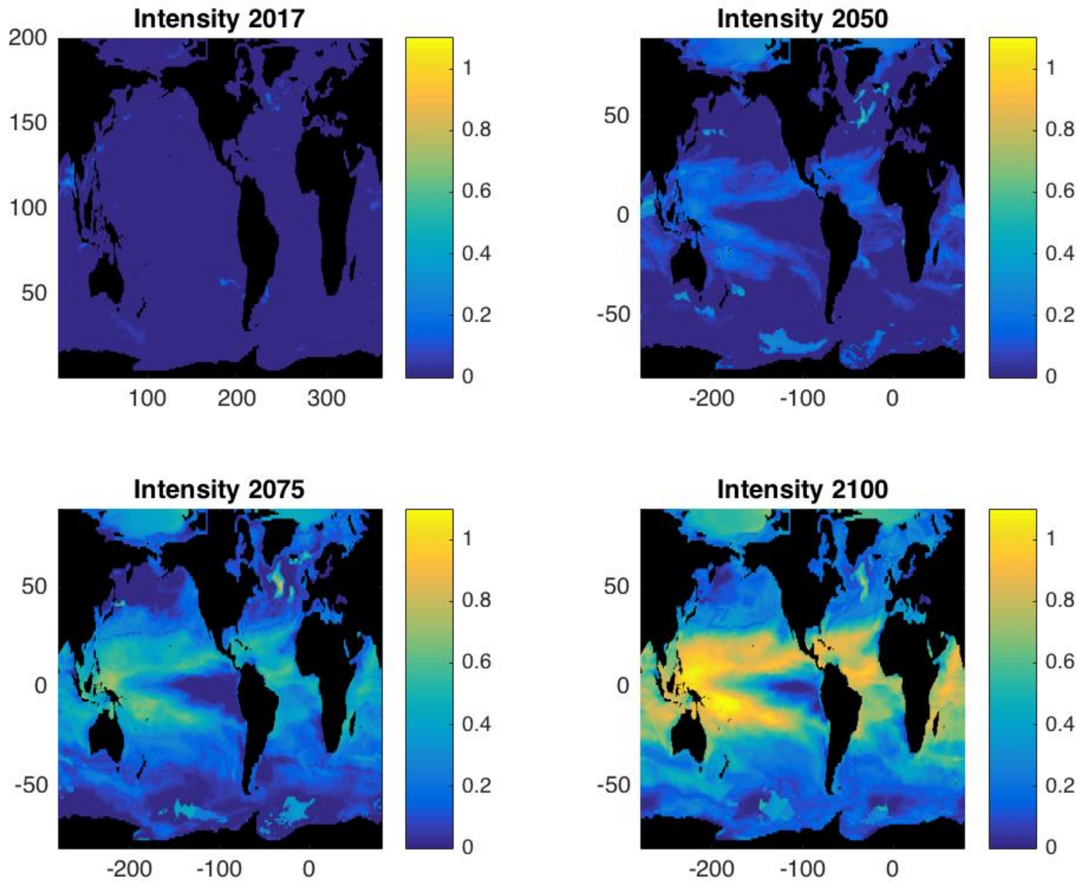
OHi = 60% [36-86]

Step 1 – Diagnosis: multiple stressors

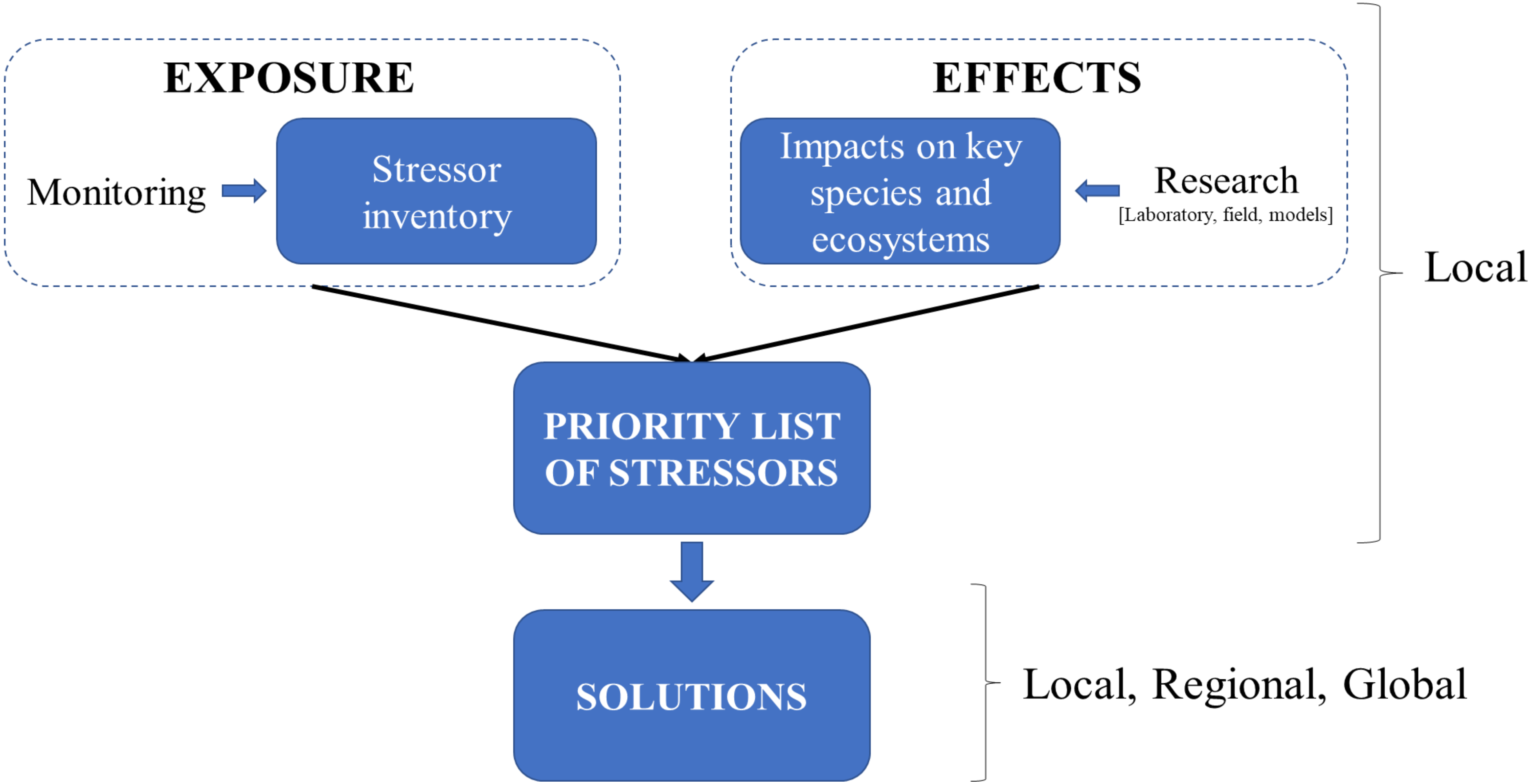


Step 2 – Solution: Science based management

Need to develop projection / forecasting for key regions / services



Step 3 – Data needs: Define (LOCAL) priorities and sources



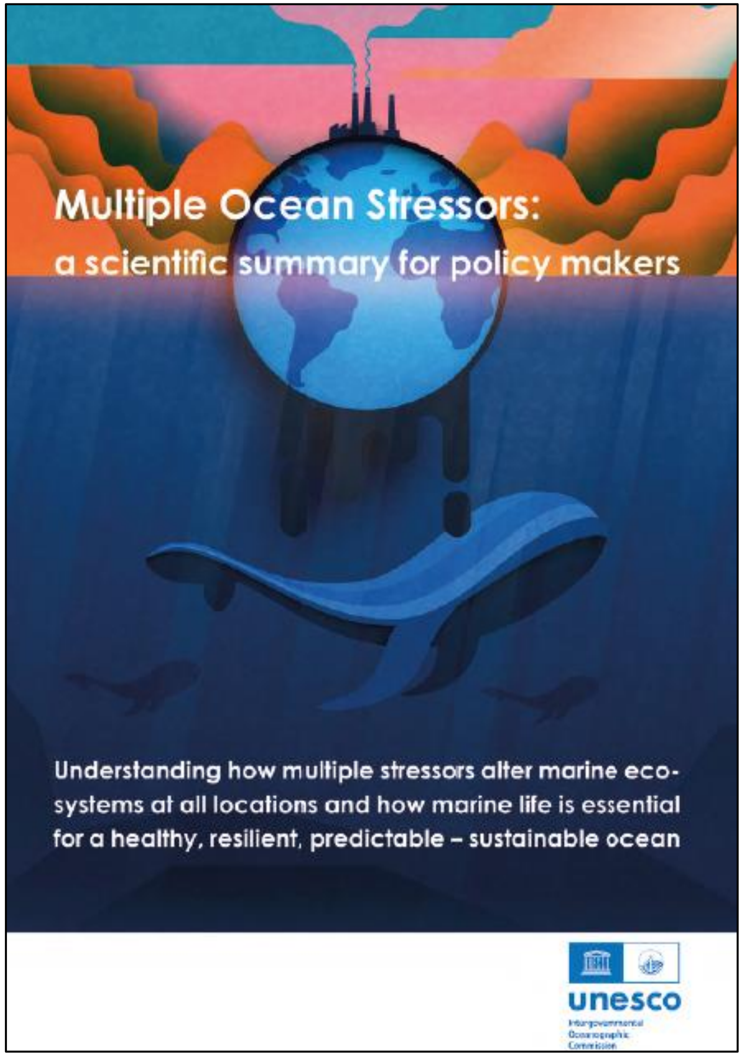
Identify priorities – now and then

Identify priorities – now and then

Step 4 – Diagnosis: poor scientific understanding of combined effects

$$A + B \neq C$$

Step 5 – Solution: multiple stressor understanding



Scientific strategy
(and complex designs)

Case study #2 – Global ocean health

- ✓Problem: Poor ecosystem health
- ✓ Cause: Multiple local and global pressures
- ✓ Solution: Forecasting – Science-based management
- ✓Gap: poor understanding on how drivers work in combination

Research priority & strategy

Case study #3 – Mitigation through societal changes

Demography

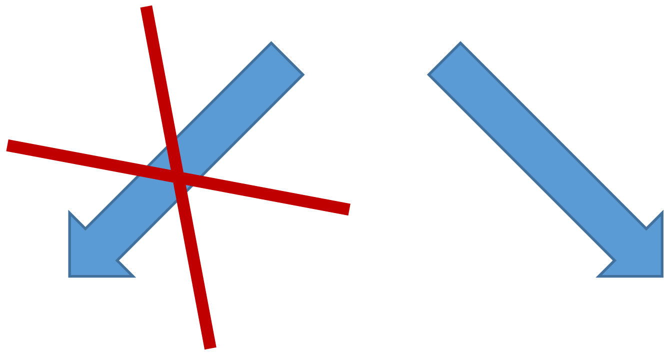
CO_2 emissions

WHY NO MORE ACTIONS???

Step 1 – Diagnosis: science fails to drive change

Information

[e.g. Global changes]



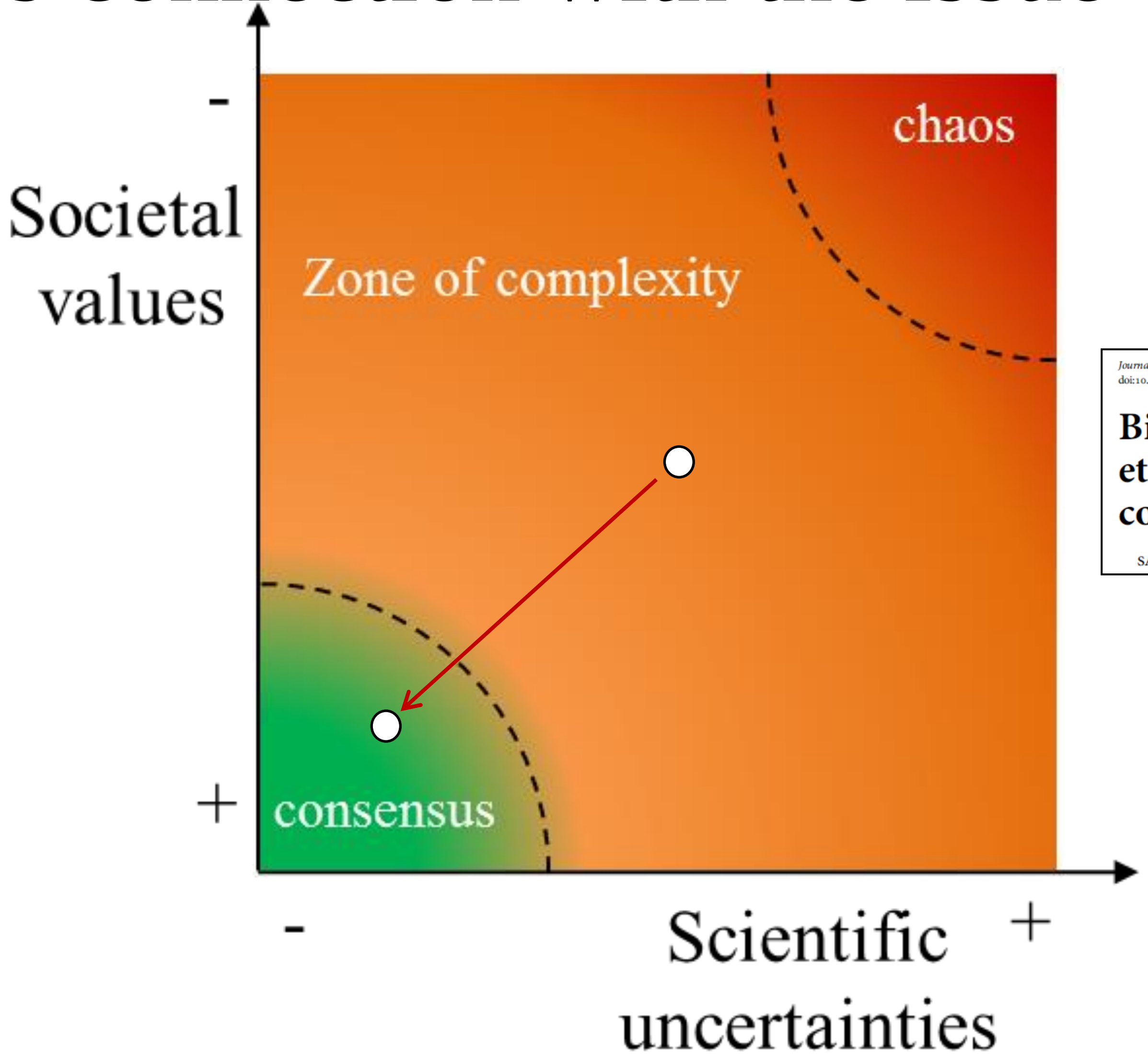
Needed Change

[e.g. cut carbon dioxide emission]

More polarization

(Dupont & Fauville 2017)

Step 2 – Solution: prioritize science that drives connection with the issue



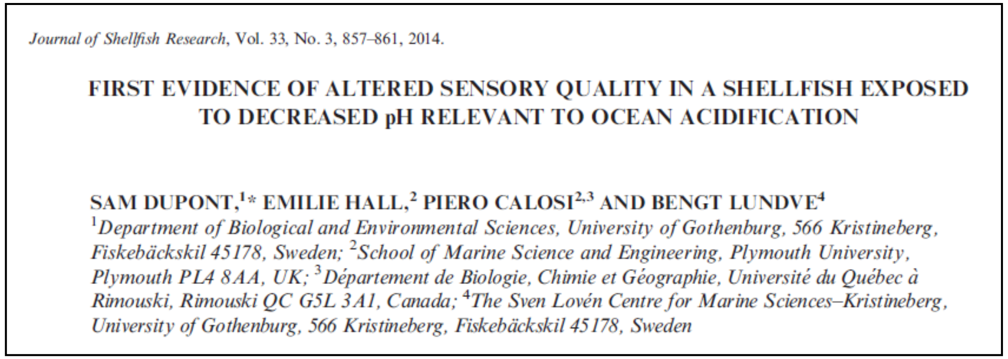
Journal of the Marine Biological Association of the United Kingdom, page 1 of 2.
doi:10.1017/S0025315415000193

Bird is the word – on the importance of ethical and effective scientific communication

SAM DUPONT[1], GREGORY PUNCHER[2] AND PIERO CALOSI[3]

What do you care about? E.g. seafood

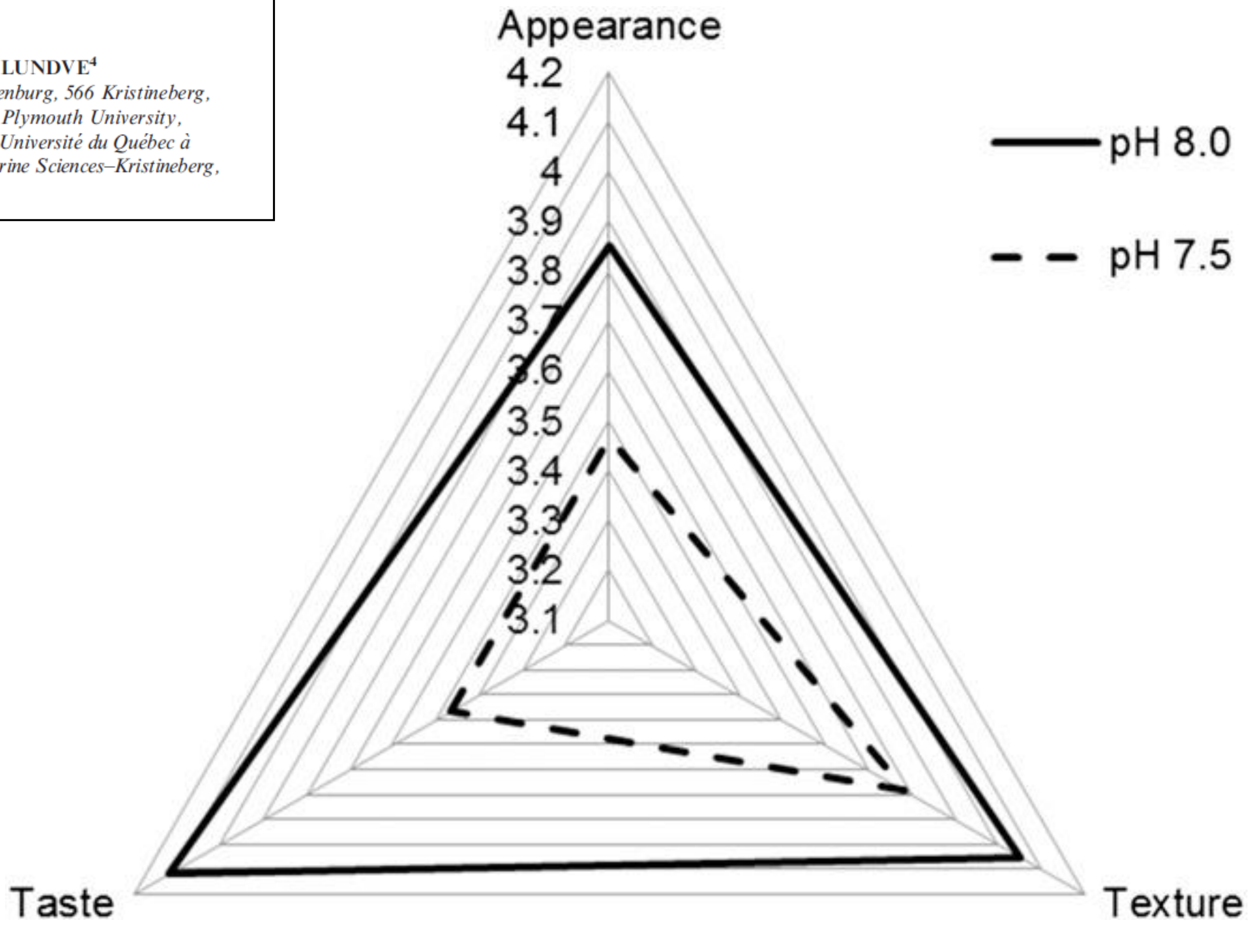
Simple experiment: You can taste ocean acidification



Journal of Shellfish Research, Vol. 33, No. 3, 857–861, 2014.

FIRST EVIDENCE OF ALTERED SENSORY QUALITY IN A SHELLFISH EXPOSED TO DECREASED pH RELEVANT TO OCEAN ACIDIFICATION

SAM DUPONT,[1]* EMILIE HALL,[2] PIERO CALOSI[2,3] AND BENGT LUNDVE[4]
[1]*Department of Biological and Environmental Sciences, University of Gothenburg, 566 Kristineberg, Fiskebäckskil 45178, Sweden;* [2]*School of Marine Science and Engineering, Plymouth University, Plymouth PL4 8AA, UK;* [3]*Département de Biologie, Chimie et Géographie, Université du Québec à Rimouski, Rimouski QC G5L 3A1, Canada;* [4]*The Sven Lovén Centre for Marine Sciences–Kristineberg, University of Gothenburg, 566 Kristineberg, Fiskebäckskil 45178, Sweden*

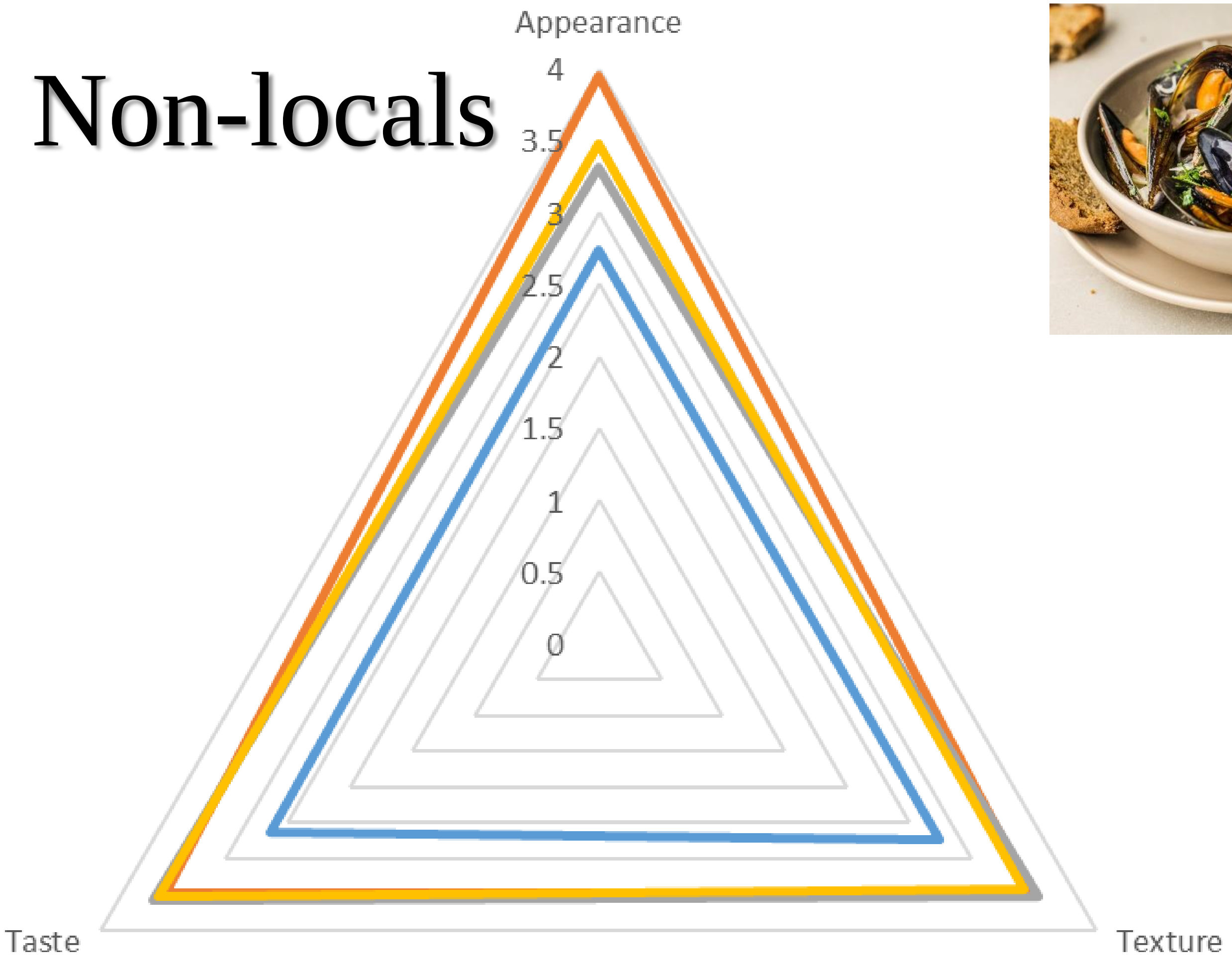


Citizen centered scientific information can drive change

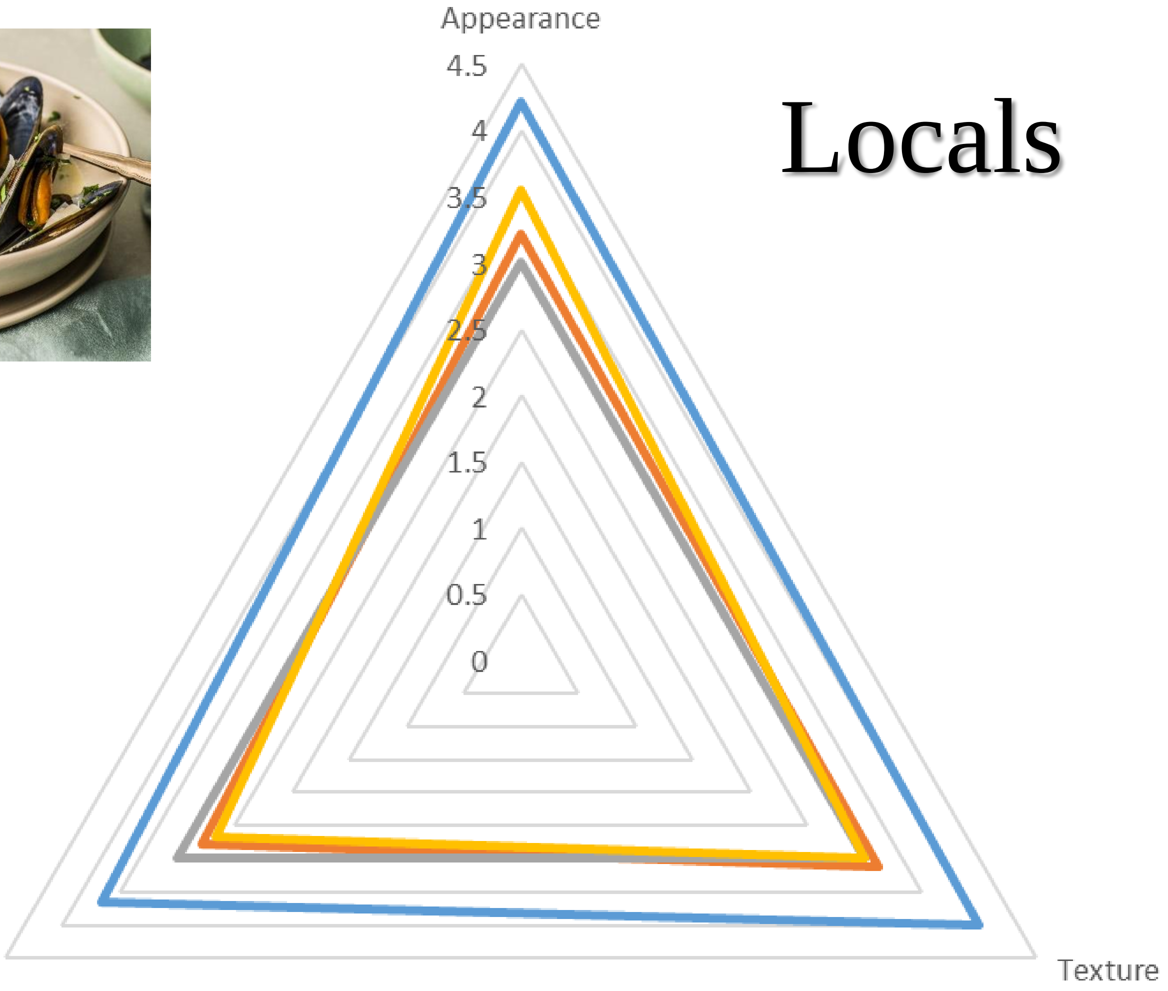
On the importance to think local

Control OA OW OWA

Non-locals



Locals



Case study #3 – Mitigation through societal changes

- ✓Problem: ocean acidification and climate change
- ✓ Cause: CO_2 emissions
- ✓ Solution: Individual change
- ✓Gap: What type of information drivers change?

Priority: natural and social science

Conclusions

- ✓ Ocean acidification is (mostly) **applied science**
- ✓ As “the house is on fire”, it is important to identify **key local questions** based on ocean services under threat from ocean acidification
- ✓ For each question, you should identify the **best solutions** (realistic, relevant time scale, etc.)
- ✓ For each solution, you need to identify the data needs and associated **scientific strategy** and best approach to collect them.
- ✓ **When laboratory experiments are needed, adopt the best design** (best practices)

Do the right thing

Do things right

Why do we need to study ocean acidification?

Need solutions (mitigation, adaptation)

Need better information

Think carefully of your question / scale

Why do we need to study ocean acidification?

This course will provide the tools to find relevant questions, design good experiments, work according to best practices and build a network