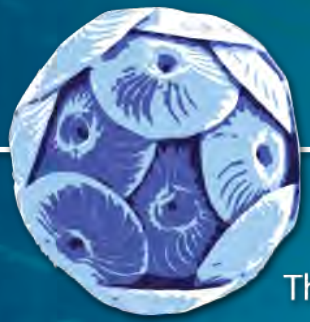

The Ocean in a High-CO_2 World

Ocean Acidification

Third Symposium • Monterey • California • 24-27 September • 2012

Ocean Acidification – an update –

Joanie Kleypas
National Center for Atmospheric Research
Boulder, CO

… with help from everybody …

The Ocean in a High CO_2 World II

6 - 9 October 2008

Musée Océanographique, Monaco
under the High Patronage of His Serene Highness Prince Albert II

~220 participants

The Monaco Declaration, 2008

PRINCE ALBERT II OF MONACO FOUNDATION

PRINCIPAUTÉ DE MONACO

Prince Albert of Monaco

© Photo Palais Princier de Monaco

To avoid severe and widespread damages, all of which are ultimately driven by increasing concentrations of atmospheric carbon dioxide (CO_2), we call for policymakers to act quickly to incorporate these concerns into plans to stabilize atmospheric CO_2 at a safe level to avoid not only dangerous climate change but also dangerous ocean acidification.

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The Ocean in a High CO_2 World III

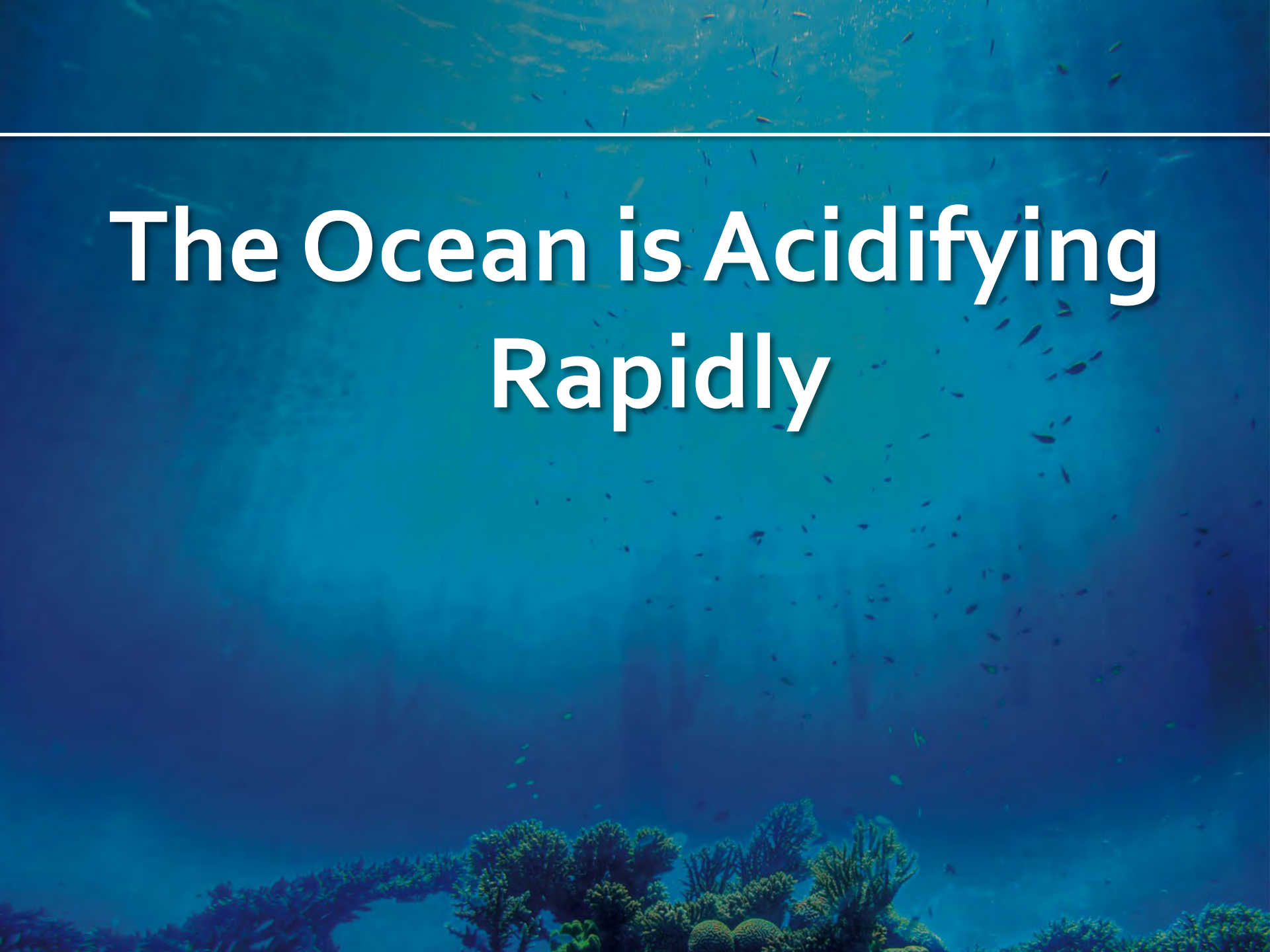
540 participants

37 countries

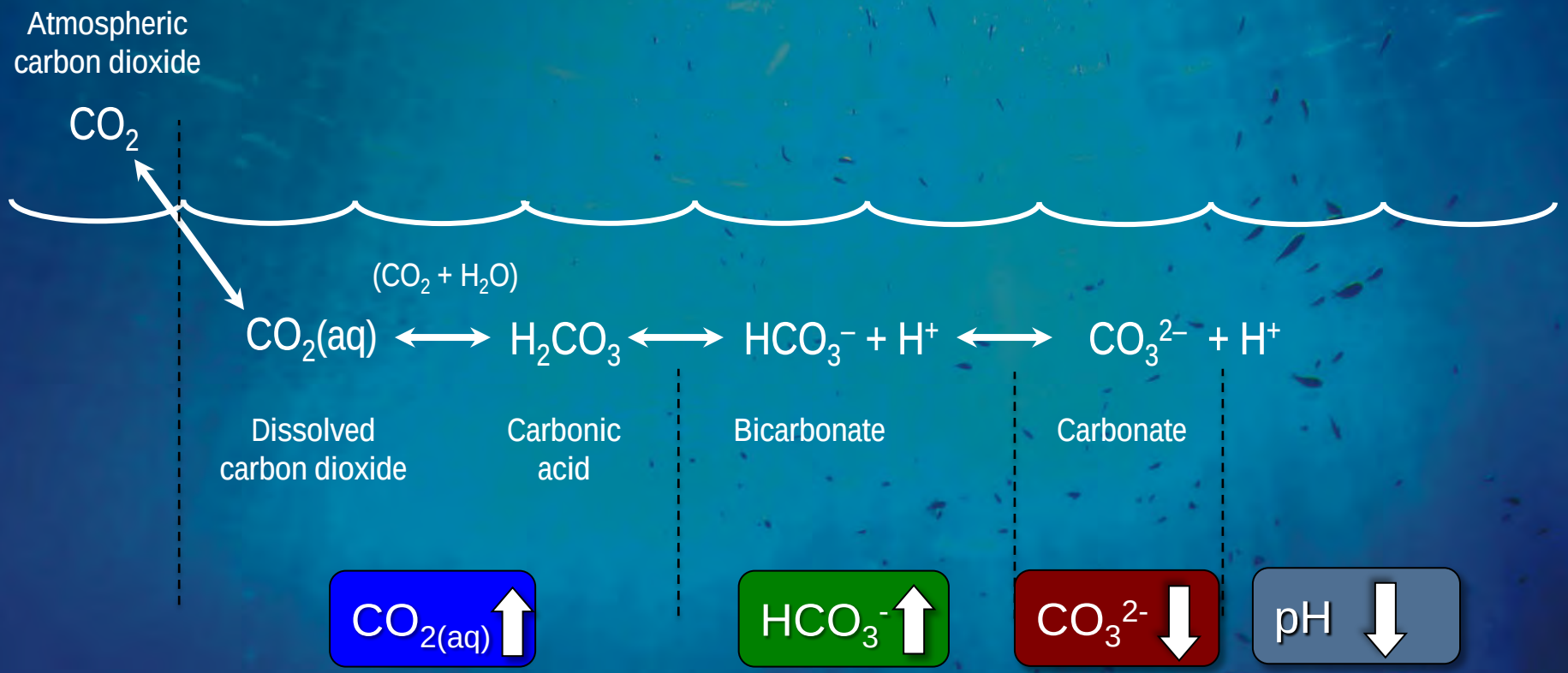
40% female speakers

Sep 24-26 2012

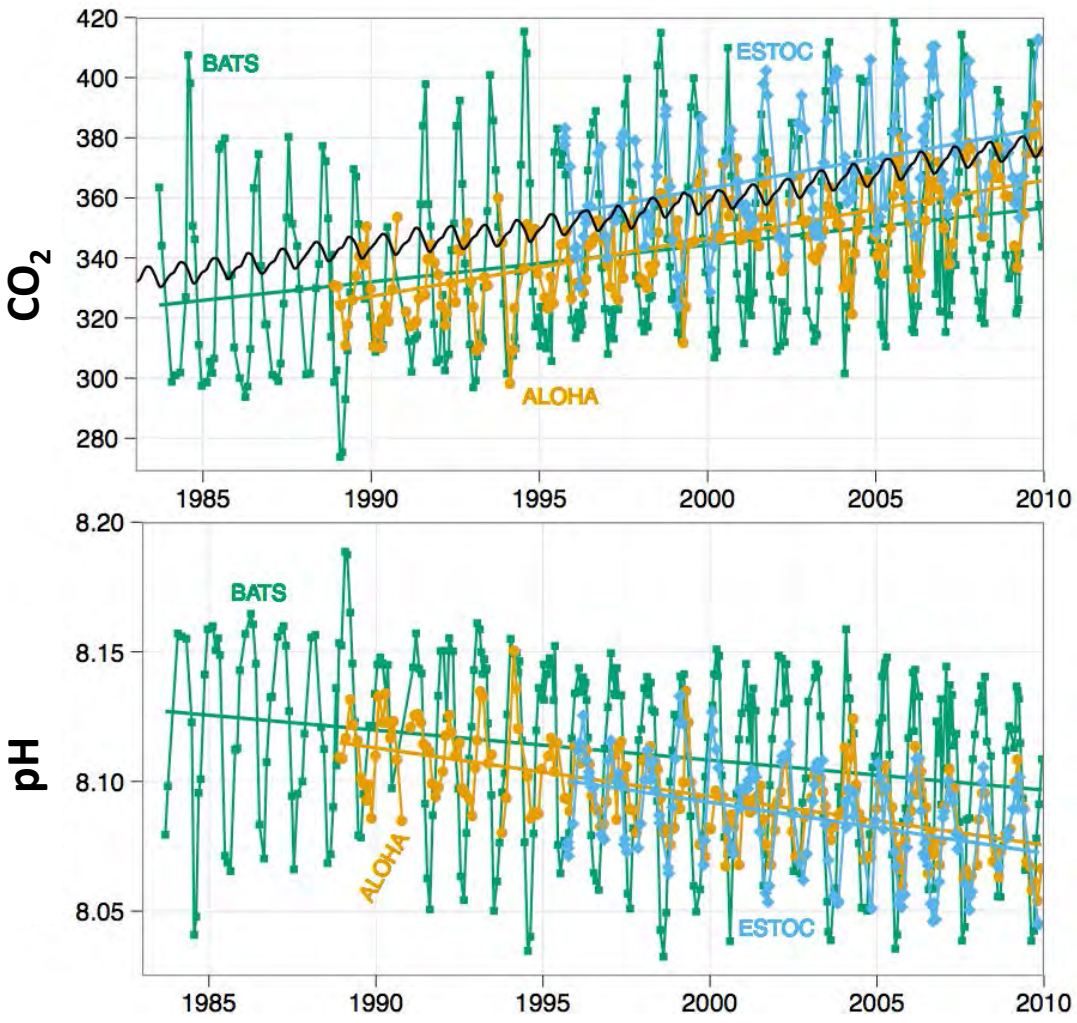
The Ocean is Acidifying Rapidly

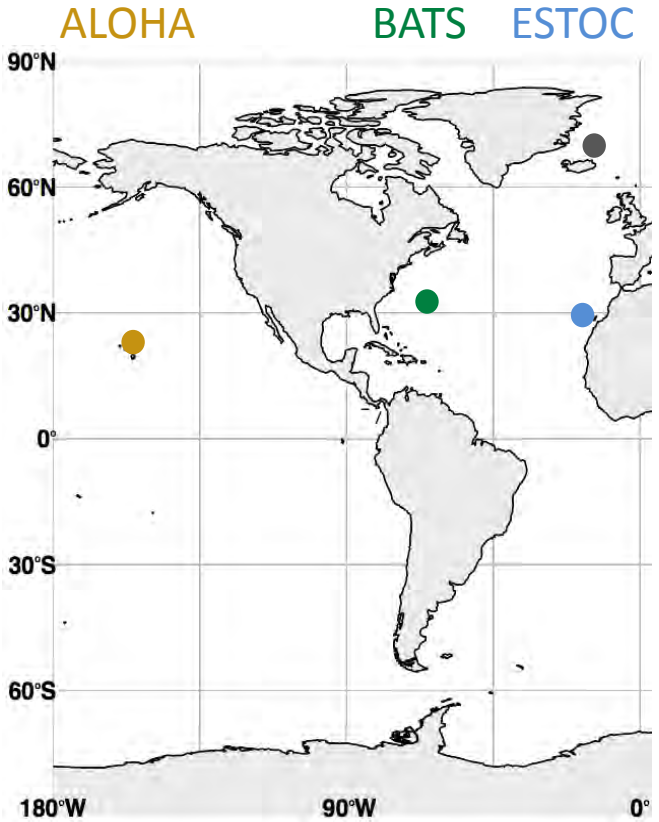


OA is a direct result of CO_2 emissions



30 Years of Measurements

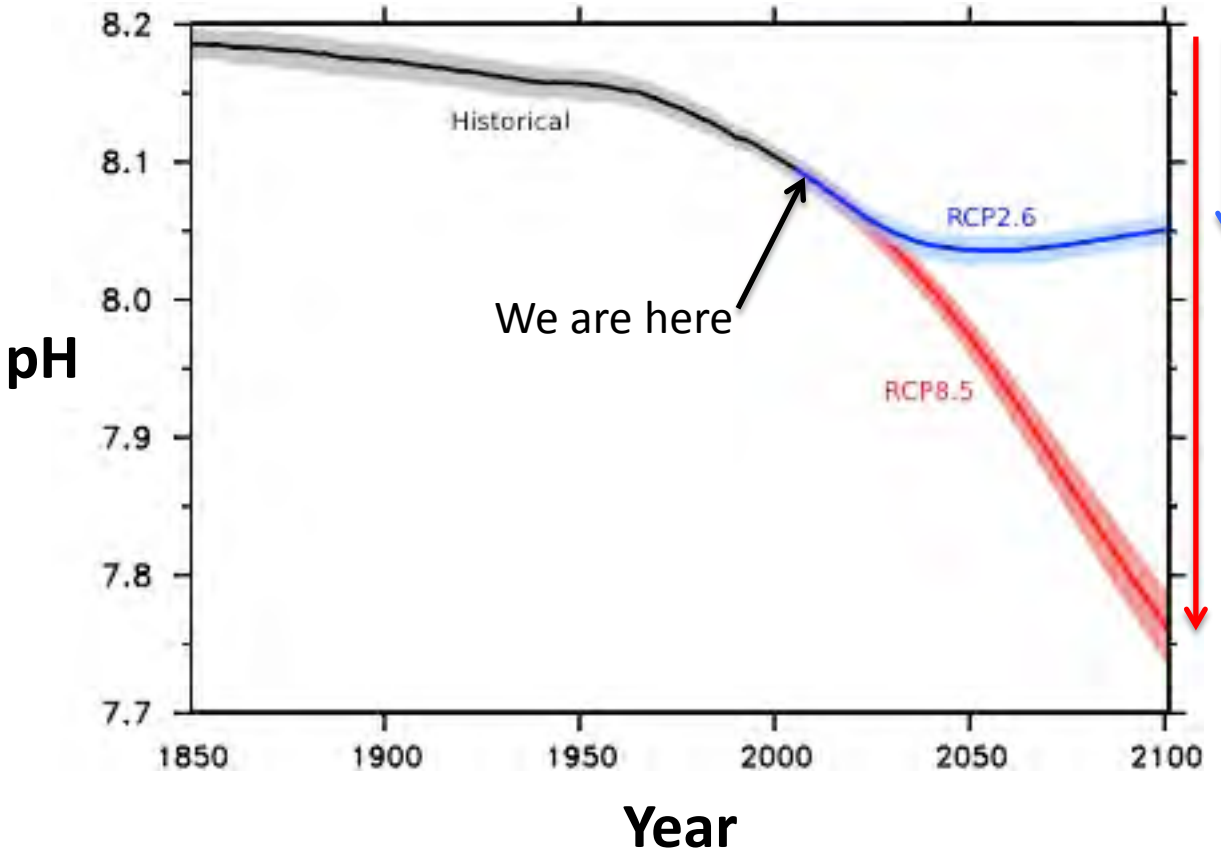




Jim Orr, 2010

The ocean is acidifying rapidly

Average pH of the ocean surface

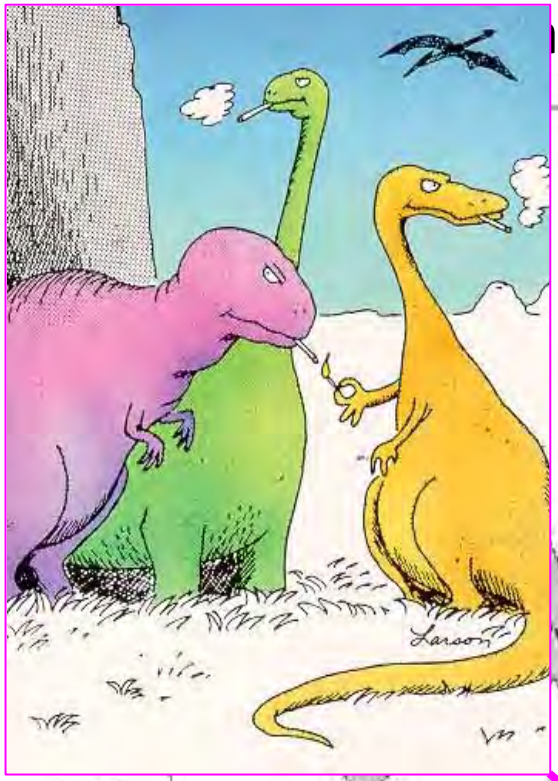


RCP2.6
pH change = –0.13
"What we hope for"

RCP8.5
pH change = –0.42
"Where we're headed"

Figure courtesy of Jim Orr

The ocean is acidifying rapidly



st

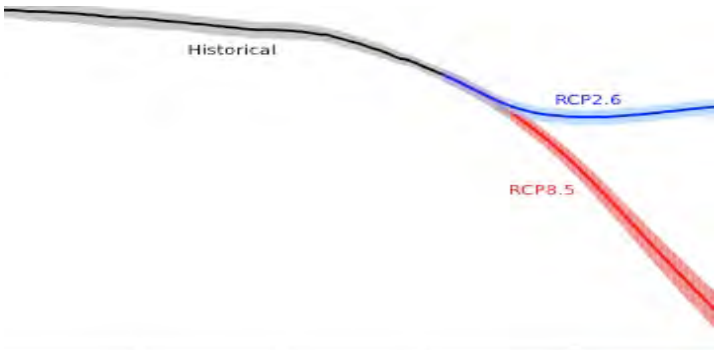
7.4

7.2

250 200 150 100 50 0

250 MILLION Years

Present



1850 2100

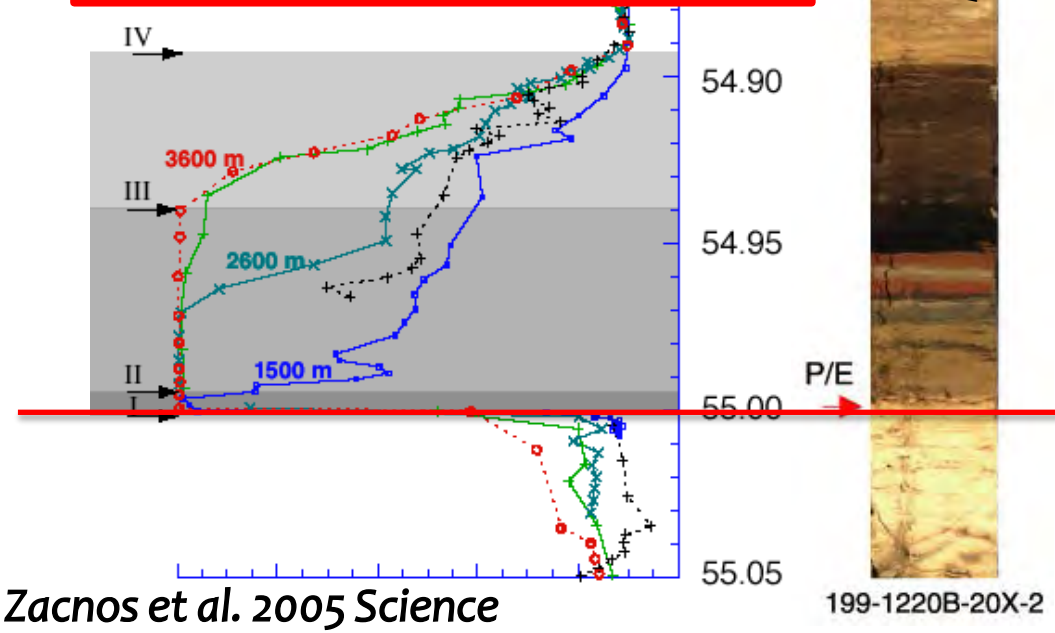
250 Years

Ridgwell & Schmidt, 2010

Orr, 2012

The Last Big Acidification Event (55 M years ago)

The current rate of CO2 increase is at least 10X faster than it was 55 million years ago



Zacnos et al. 2005 Science

Physical changes:

- Acidification
- Warming: 5-8°C
- Deoxygenation

Biological responses:

- Plankton blooms
- Extinctions
- Species turnovers
- Changes in calcification

55 Millions of Years Ago

The Ocean is Acidifying Rapidly

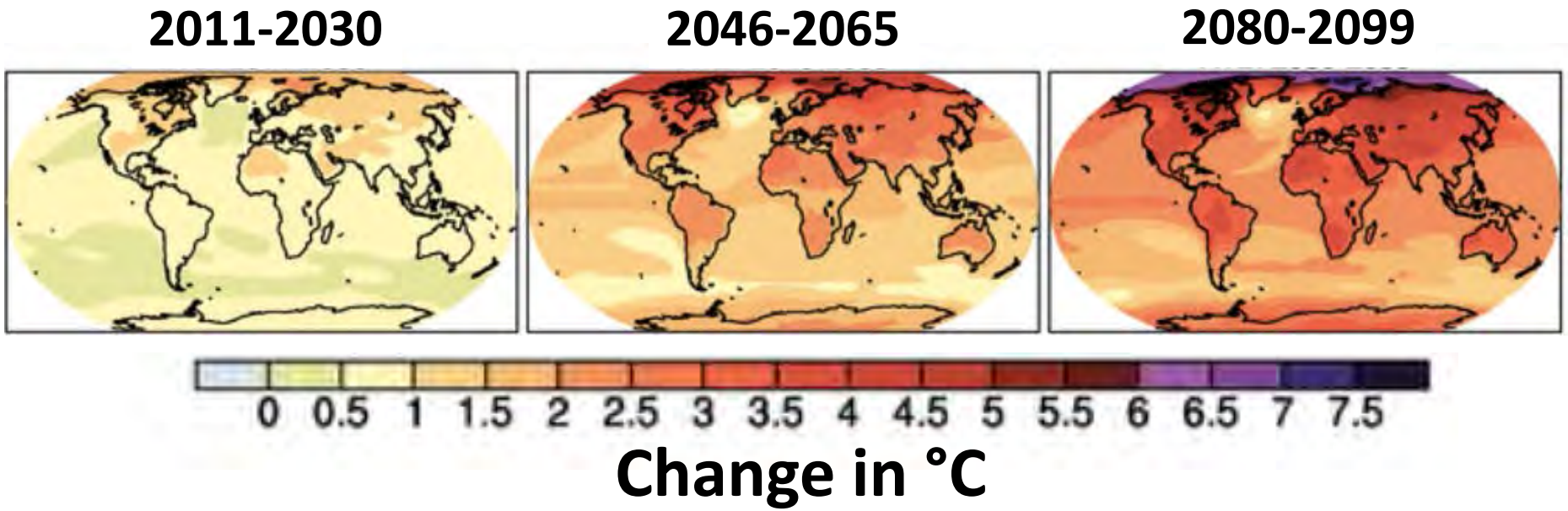
"The outcome is very clear that we are in uncharted territory in the entire span of Earth history. The primary cause of this is simply the rate of change; we are changing Earth far, far faster than any recorded geologic shift ever."

- Peter Brewer, MBARI

Partners in CO_2 Crime

Rising Temperature

Projections – "business as usual"

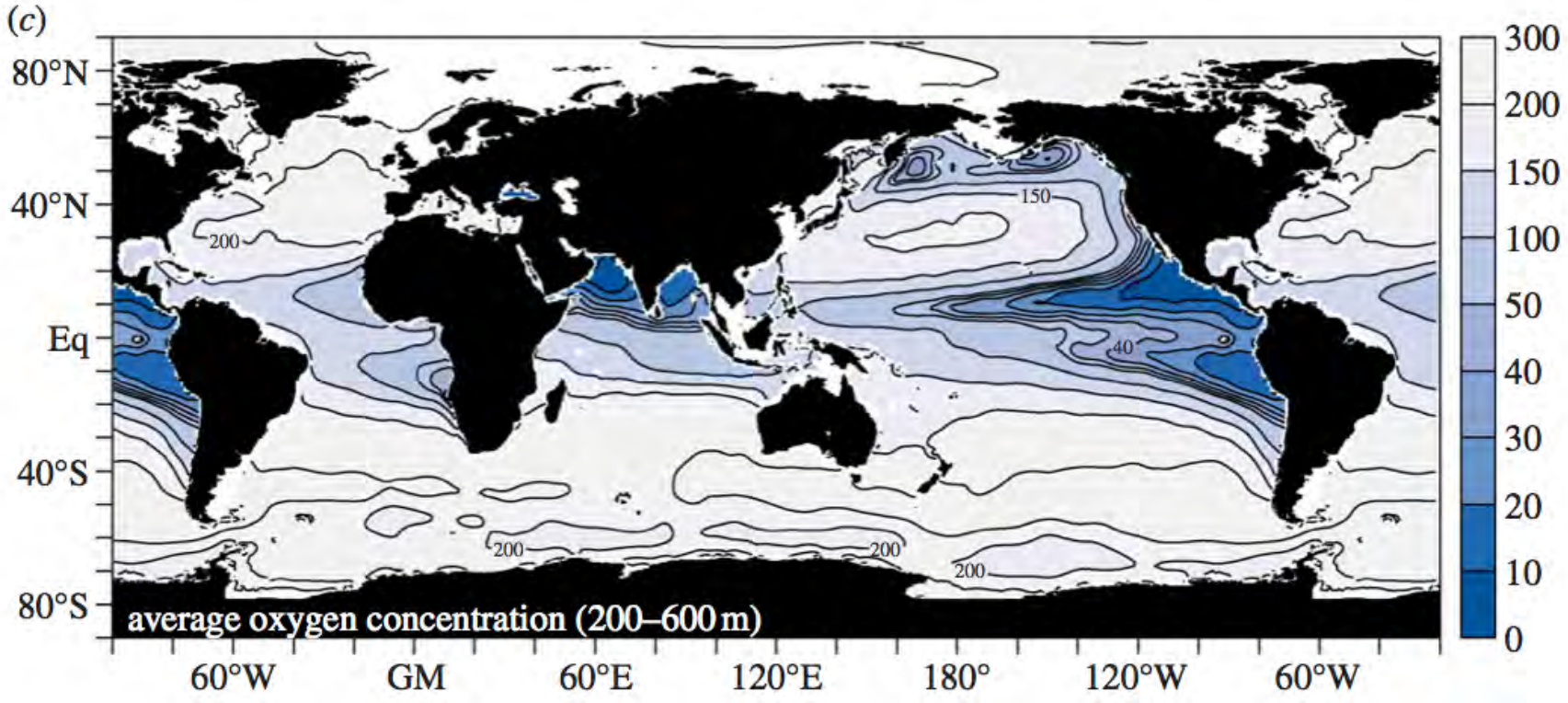


IPCC, 2008

Partners in CO_2 Crime

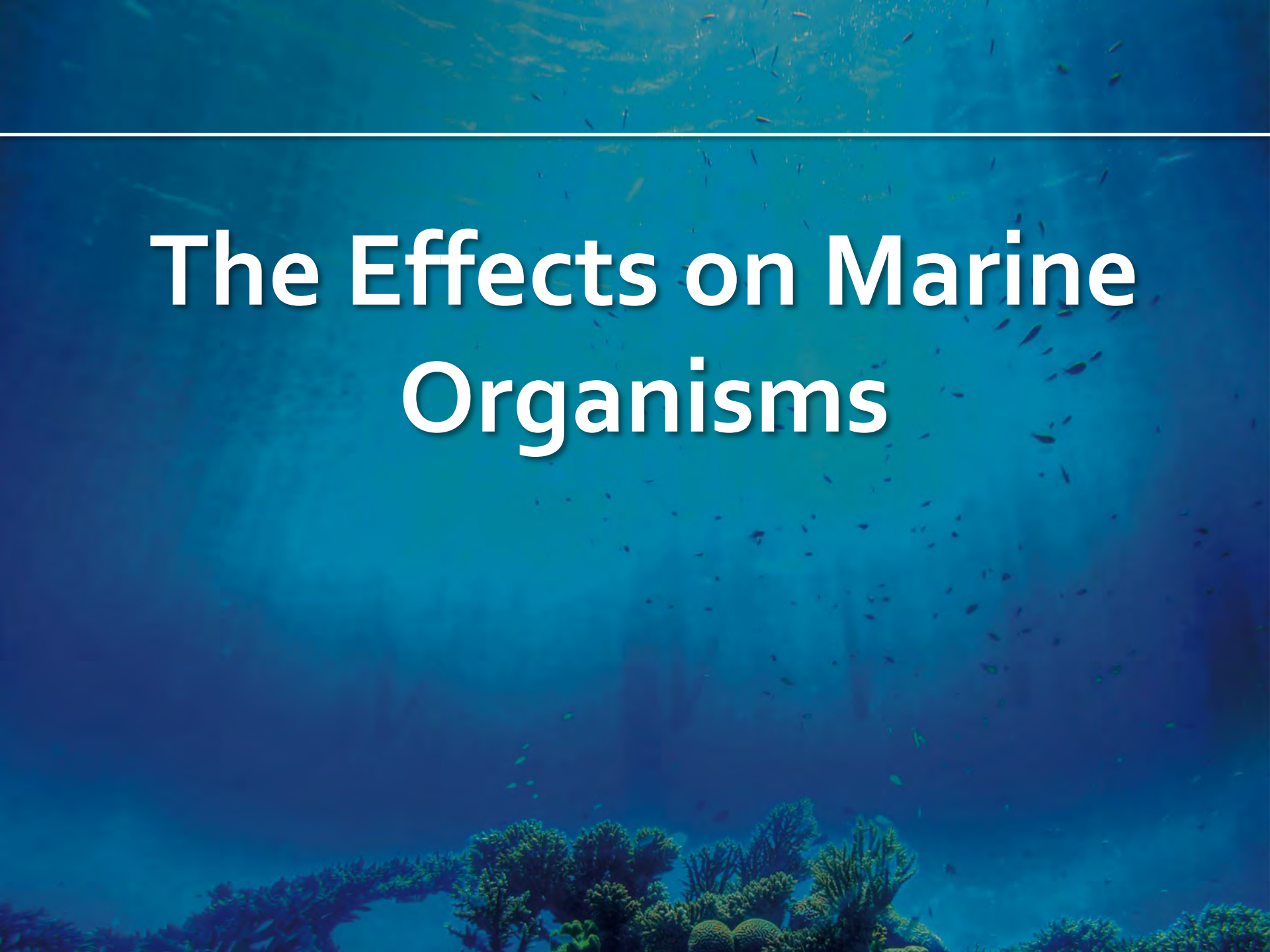
Deoxygenation

Areas of low oxygen are expanding

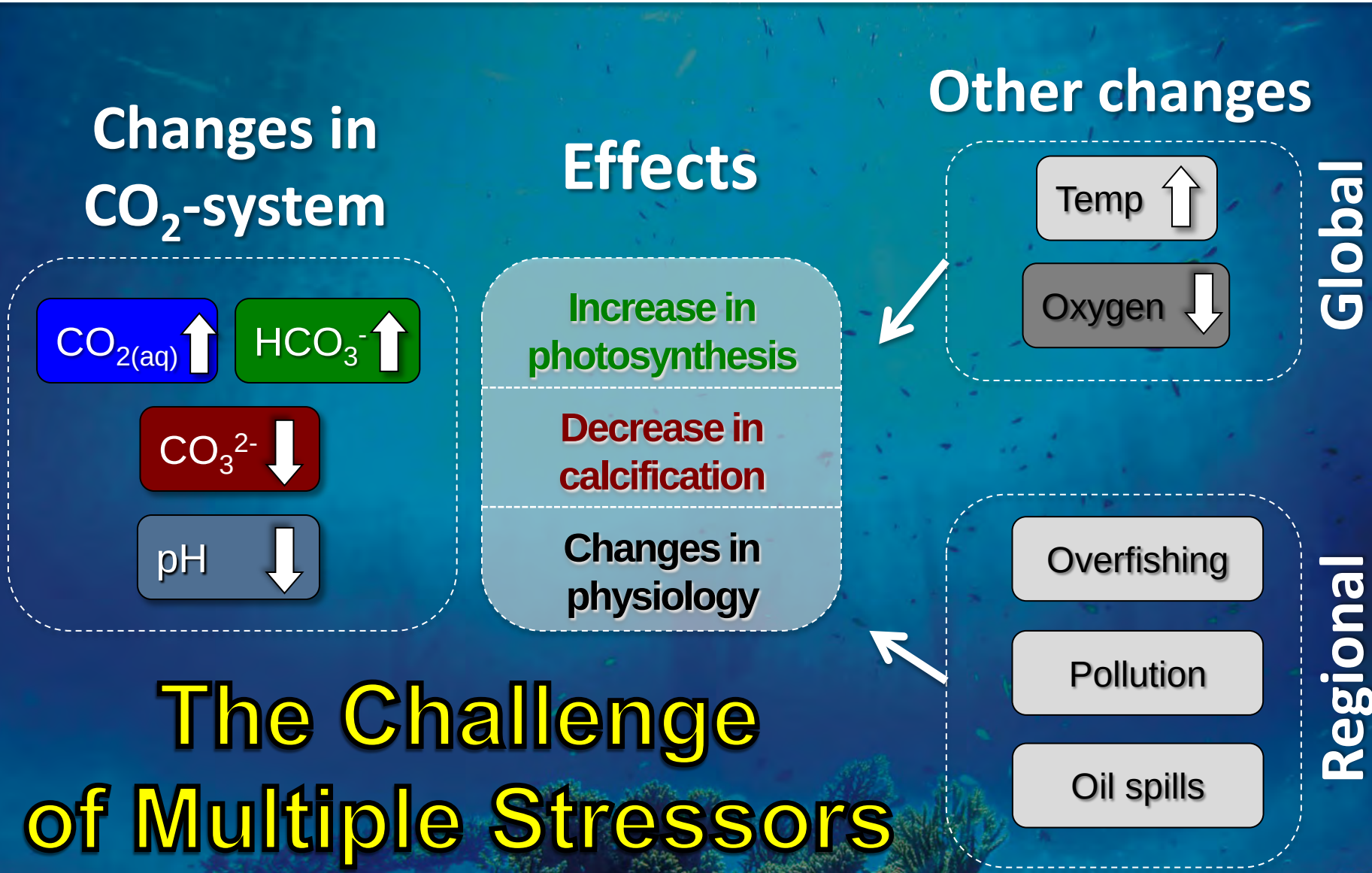


Gruber (2012) Phil Trans. Roy Soc. A (2012)

The Effects on Marine Organisms



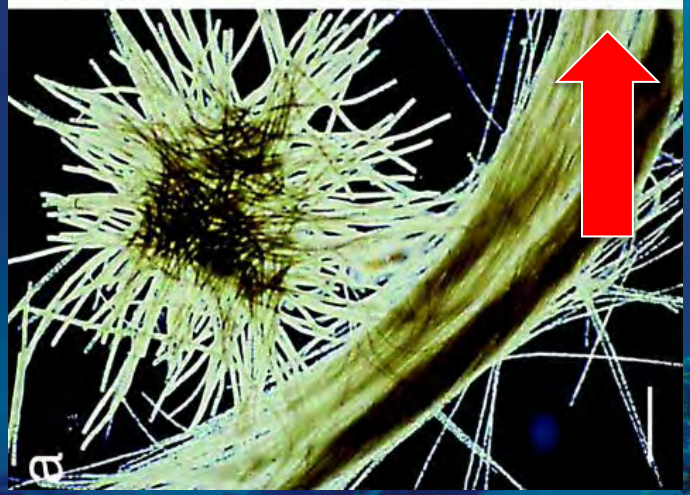
How CO_2 in seawater affects marine life



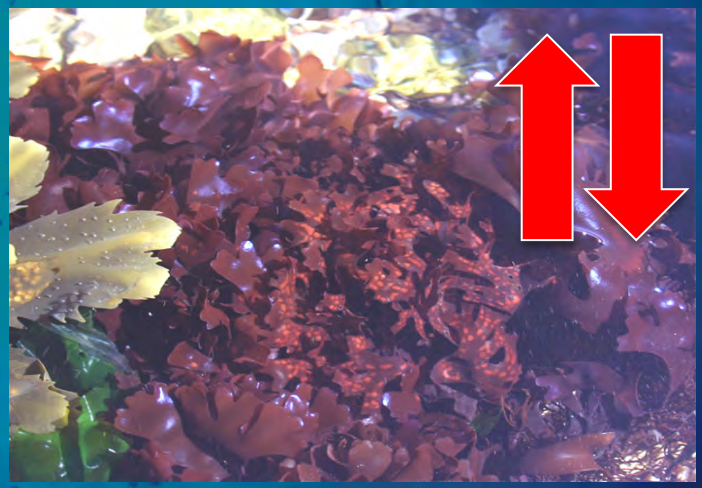
Marine Primary Production

"CO_2 fertilization"

Phytoplankton



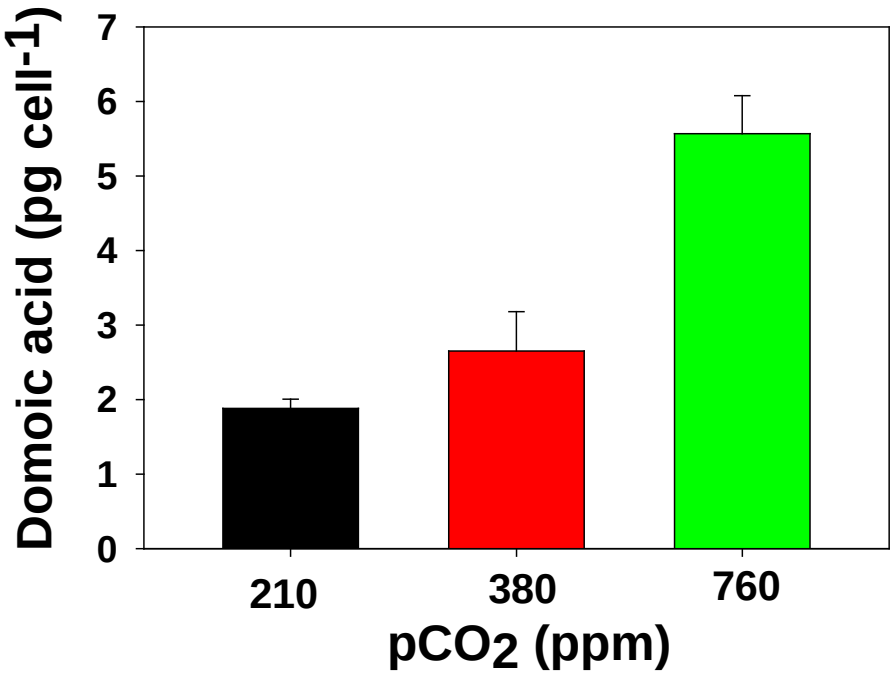
Macroalgae & Seagrasses



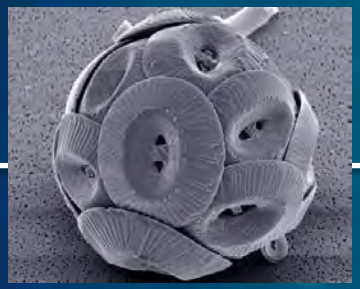
Harmful algal blooms

Harmful Algal Bloom in California: Pseudo-nitzschia Spread Along Coast Causing Massive Mortalities of Marine Life in Spring 2007

High CO_2 increases toxicity of the harmful bloom diatom *Pseudo-nitzschia*

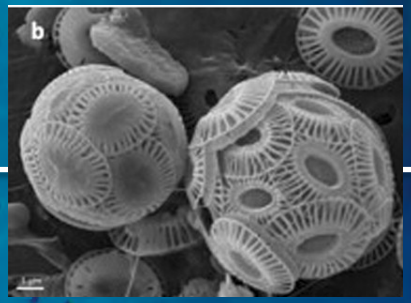


Tatters, Fu, & Hutchins (2012) *PLoS One*



Effects on calcification

The coccolithophore story

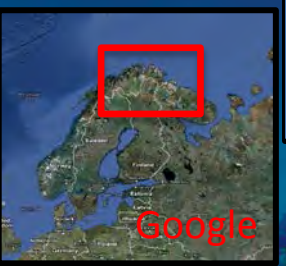


Global picture:

Coccolithophores calcify more in high pH waters and less in low pH waters

Experiments:

Large amount of variation across and within species



Evolution in the lab

Multiple genotypes

Selection

Single genotype

Mutation

Increasing CO_2

See paper by: Lohbeck et al (2012) *Nature Geoscience*, DOI: 10.1038/NGEO1441

Effects on calcification

Tropical Corals

OA causes calcification to decline in most species – but some species are tougher than others

Cold water corals

Ocean acidification causes calcification to decline, made worse by elevated temperature

Effects on calcification

Many other species

Bottlenecks in the life cycle

A tweet from the meeting

"It is not birth, marriage, or death, but gastrulation which is truly the most important time in your life”

Lewis Wolpert, developmental biologist

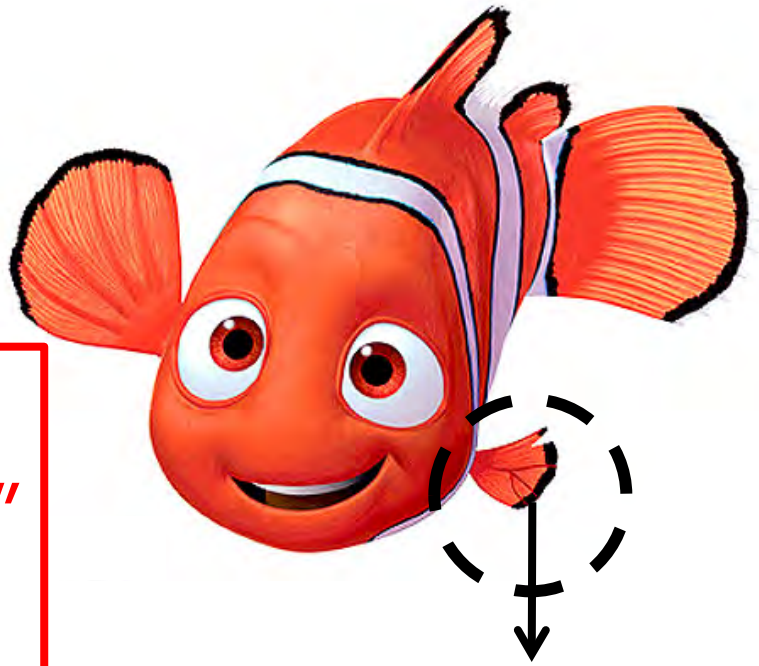
The Whiskey Creek Story

Failure of the Pacific Oyster Hatchery at Netarts Bay, Oregon

Credit: Photos by Lynn Ketchum, OSU

Effects on animal behavior

Acidification impairs the ability of juvenile clownfish to detect predators



Probably NOT due to ocean acidification

Quote from the Conference:

We know the film "Nemo-2" is coming out, but what we really need is the "Nemo-2100" sequel.

- Carol Turley

Research by Phil Munday

Surprise!

There are many ways that OA affects organisms!

The responses vary a lot!

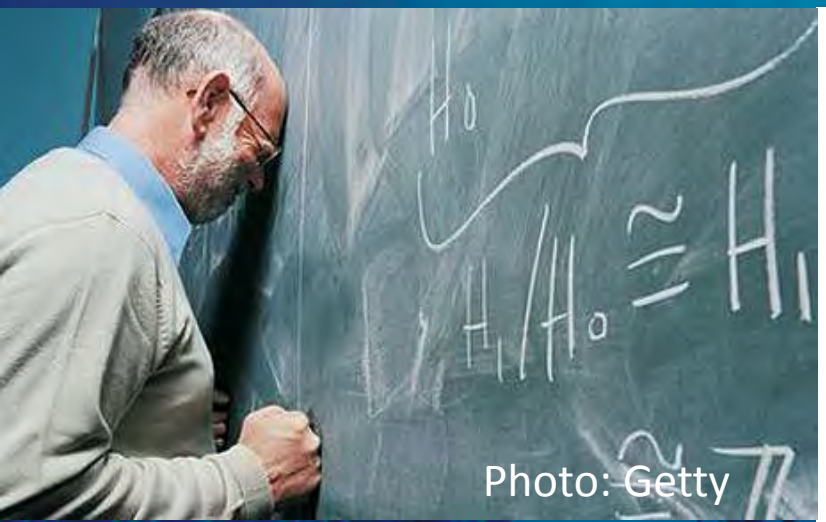
Marine organisms are exposed to many changes at once:

- Acidification causes a suite of changes
- The oceans are also warming and losing oxygen

Marine organisms have complex biology:

- Multiple life stages
- Capacity to adjust to change (physiology) – one lifetime
- Capacity to adapt (genetically) – across generations

The Effects on Marine Organisms



This makes predicting their fate much harder but …

… it gives us some hope

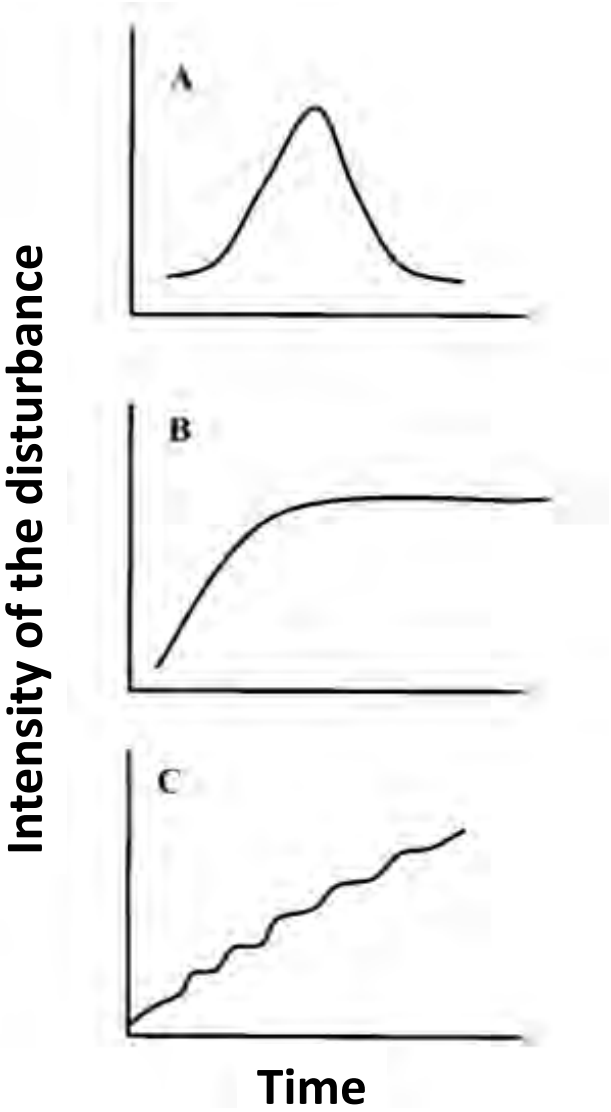
… it gives us some clues

The Effects on Marine Ecosystems

"Predicting how whole ecosystems will change in response to rising levels of CO_2 is enormously challenging"

- Steve Widdicombe

The stresses ecosystems feel



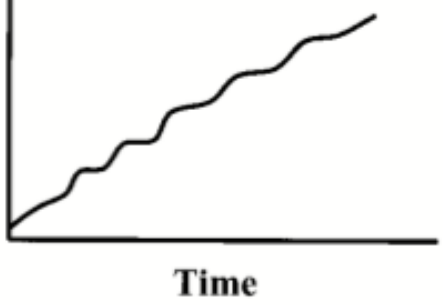
"Pulse" disturbance storms

"Press" disturbance overfishing

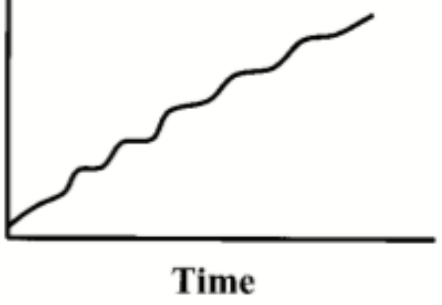
"Ramp" disturbance acidification
global warming
deoxygenation

The new world order

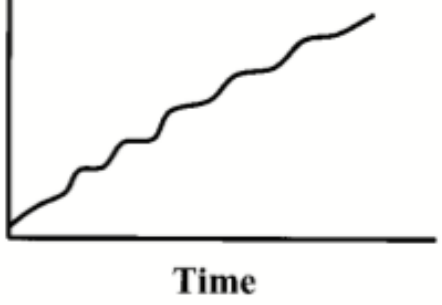
Ocean Acidification



Temperature



Other Stressors



Expect change!

Effects on Ecosystems


Italy


Papua-New Guinea

"Champagne Sites"

CO_2 bubbles up naturally due to underlying volcanism

Ecosystems show big changes

Effects on Ecosystems

A window into the future of coral reefs?

pH 8.05: Today **pH 7.95: ~ year 2050** **pH 7.8: ~ year 2100**

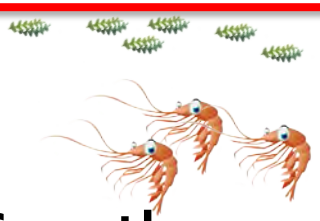
Fabricius et al. (2010) *Nat Clim Change*

Slide courtesy Katharina Fabricius

Simulating the Future

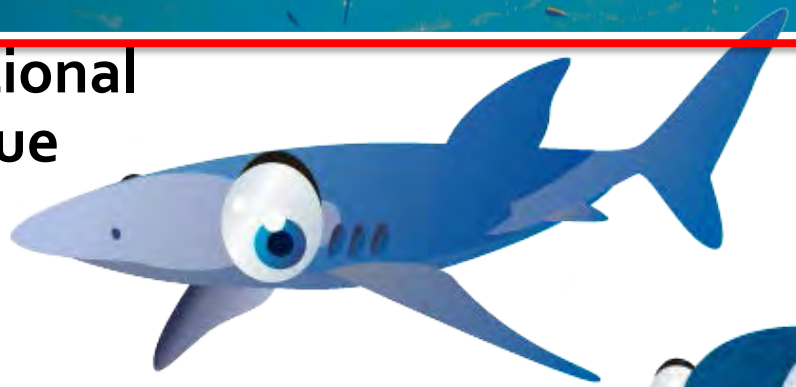
The Effects on Fisheries

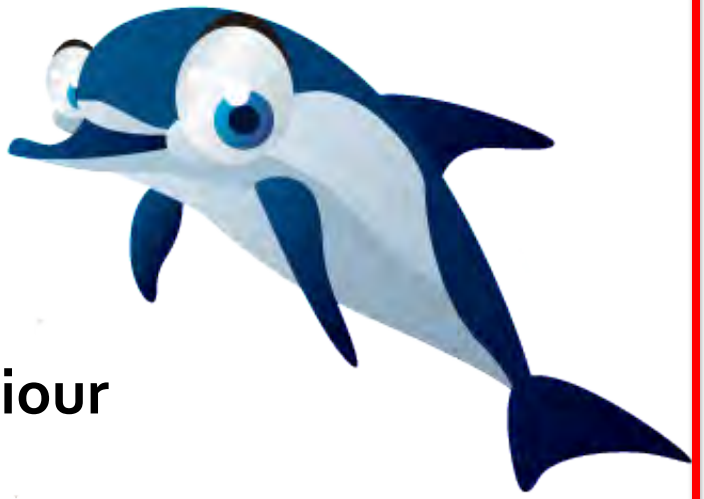
Fisheries



Growth

Nutritional value



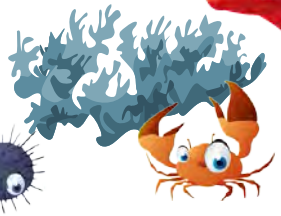


Temperature tolerance

Behaviour

Calcification

Mortality

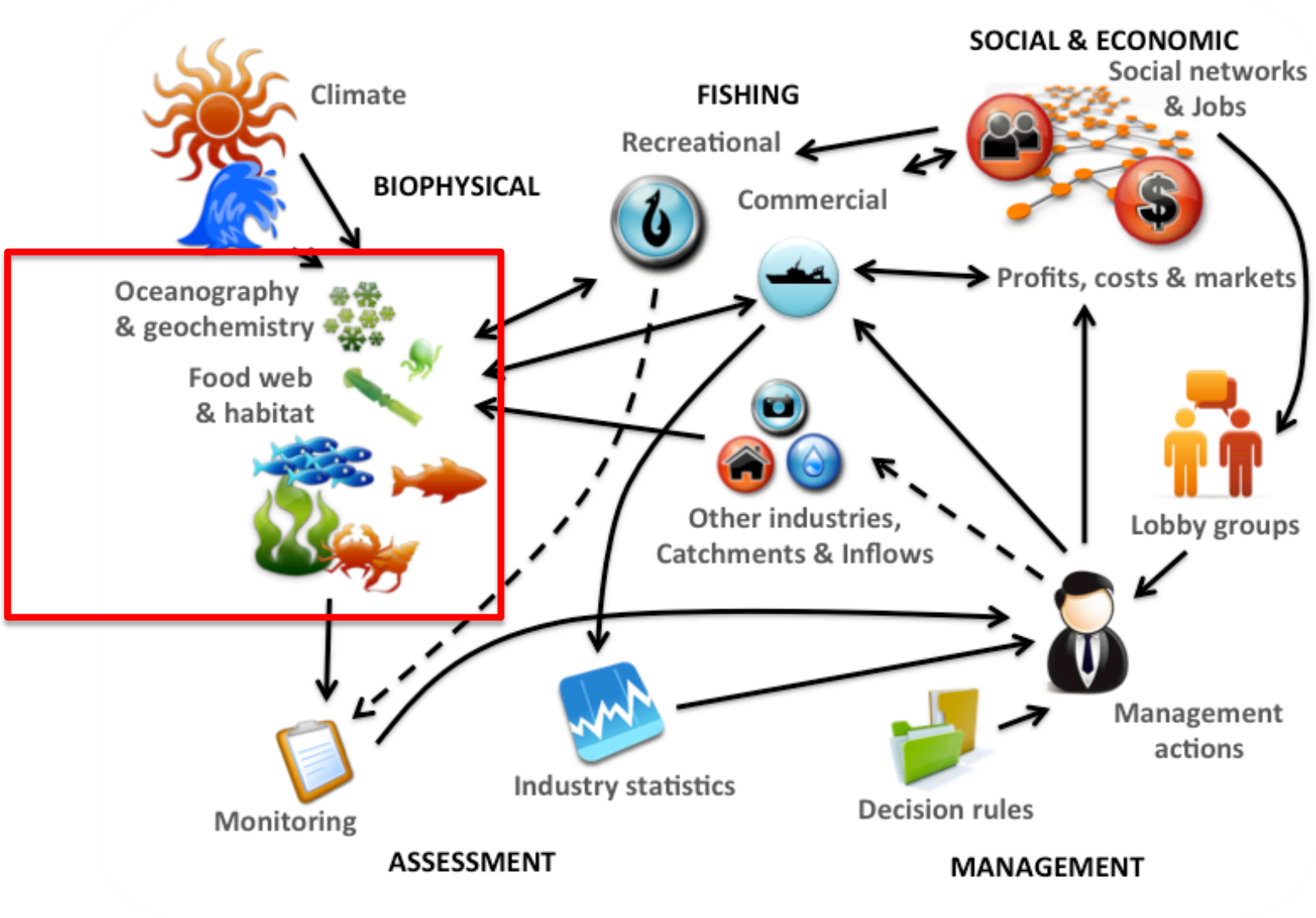


Fecundity

Denitrification

Slide courtesy of Beth Fulton

Fisheries



Slide courtesy of Beth Fulton

The Effects on Fisheries

Some species will decline, others will increase, with net loss of biodiversity

"We will still have fisheries – if we're willing to eat different fish"

– Beth Fulton, CSIRO

Socio-economic impacts

$ Fisheries

$ Tourism

★ Human health and well-being

★ Ecosystem services

"Just because something is hard to measure doesn't mean it's not important"

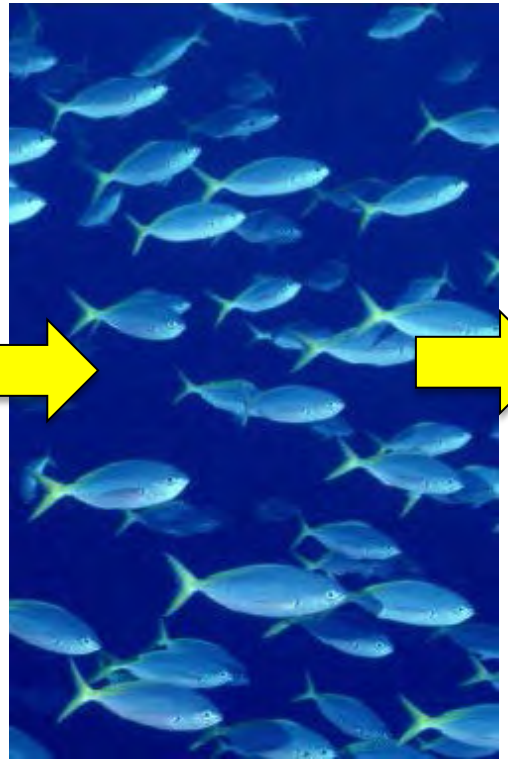
Socio-economic impacts

Ocean Acidification

Marine Ecosystems

Loomis/LA TImes

Ecosystem Services



ARC

Socio-economic impacts

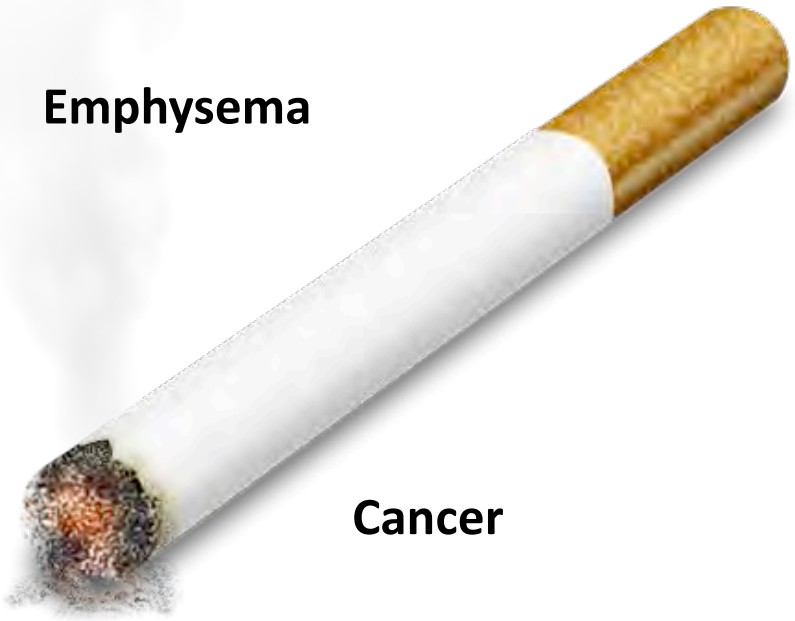
Zabur Karuru

From Luke Brander, grossly simplified by me

"Multiple stresses – one root cause"

High blood pressure

Emphysema



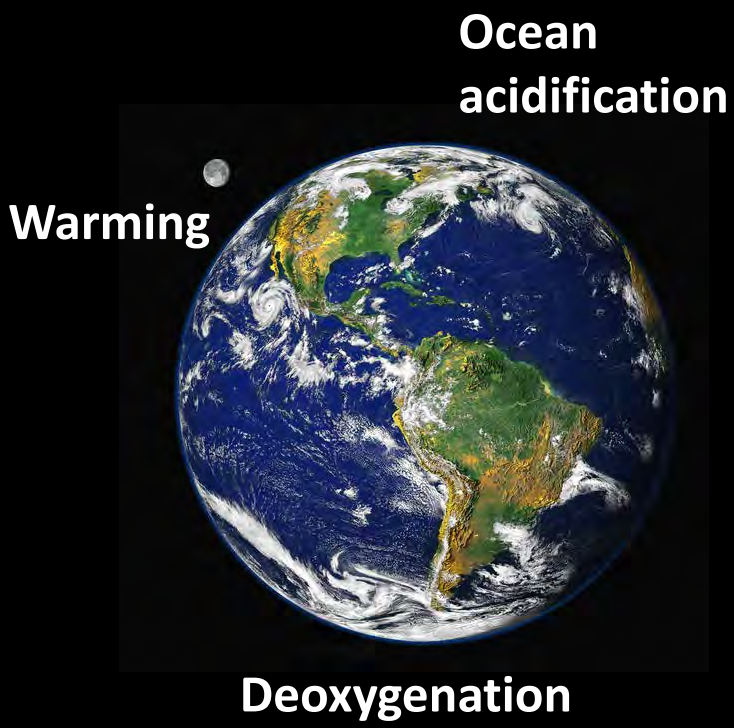
Cancer

Smoking causes multiple health issues in the human body

Until the smoker can kick the habit:

1) Treat the symptoms rather than the cause
2) Ask the patient to eliminate other stresses, such as drinking, eating poorly, etc.

"Multiple stresses – one root cause"

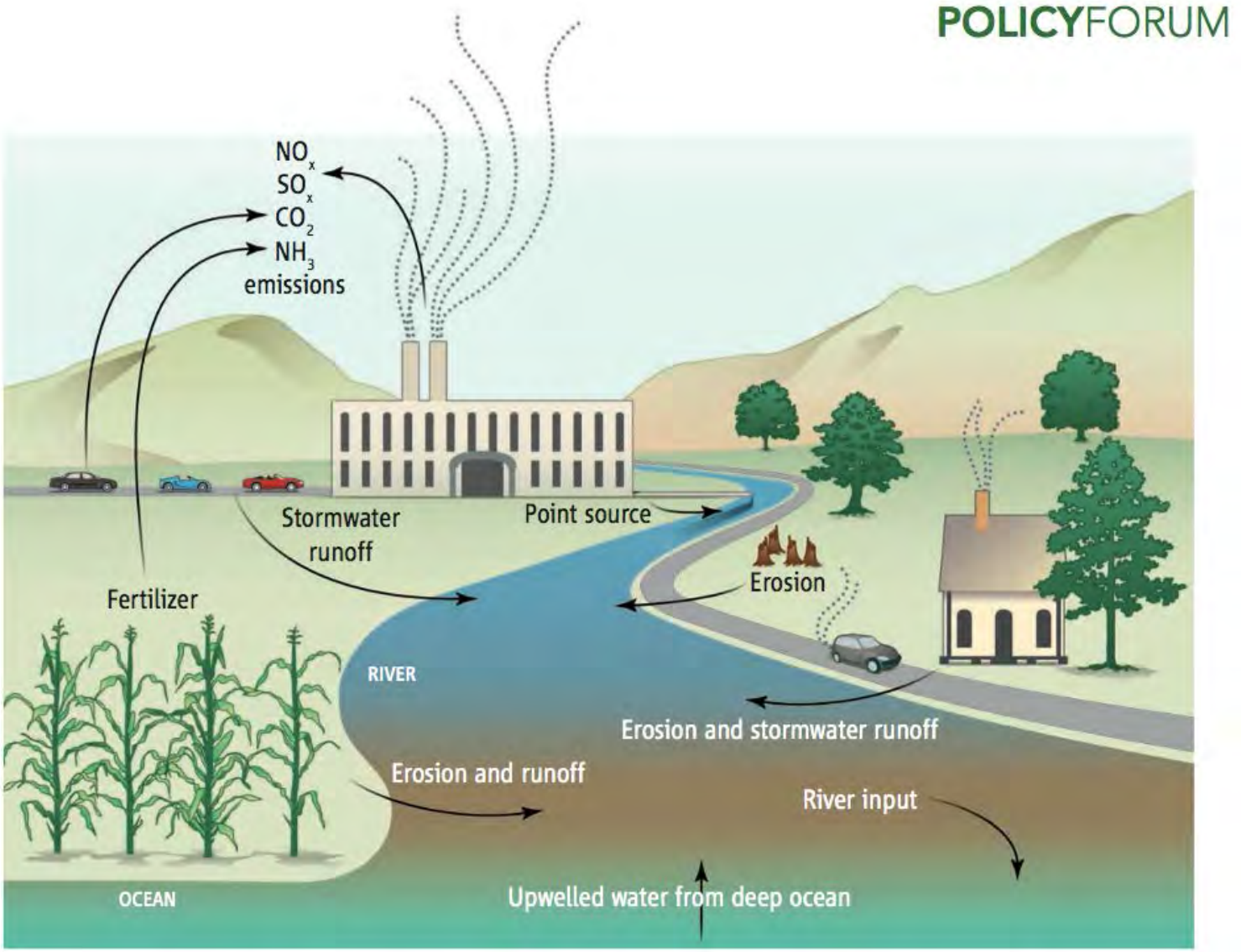


Rising atmospheric CO_2 causes multiple health issues in the oceans

Until we can kick the CO_2 habit

1) treat the symptoms rather than the cause
2) Ask the patient to eliminate other stresses, such as pollution, overfishing, etc.

Reduce other stressors



Kelly et al. (2011) *Science*

Washington State's

Blue Ribbon Panel on Ocean Acidification

Source: L. Whitely Binder, CIG

Protect State's marine resources by:

- **Strengthening linkage between science and actions.**
- **Developing recommendations to reduce harmful effects on shellfish industry and other marine resources.**
- **Improving coordination, strengthening partnerships, raising public awareness.**

The C40 Cities Climate Leadership Group

C40 is a network of the world's megacities committed to addressing climate change

C40 CITIES

MAKE A DIFFERENCE

Each city in the C40 is unique in its infrastructure and progress in addressing climate change. C40 works to empower cities to connect with each other and share technical expertise on best practices.

"While international negotiations continue to make incremental progress, C40 Cities are forging ahead. Collectively they have taken more than 4,700 actions to tackle climate change, and the will to do more is stronger than ever. As innovators and practitioners, our cities are at the forefront of this issue – arguably the greatest challenge of our time'

—Mayor Michael R. Bloomberg

We know enough to act

We KNOW that a major catastrophic event is coming

We KNOW how to prevent it

We CANNOT PREDICT exact costs, casualties and damages

But… uncertainties are NOT an excuse for inaction

- Sam Dupont

The Declaration Stands

PRINCE ALBERT II OF MONACO FOUNDATION

PRINCIPAUTÉ DE MONACO

Prince Albert of Monaco

© Photo Palais Princier de Monaco

To avoid severe and widespread damages, all of which are ultimately driven by increasing concentrations of atmospheric carbon dioxide (CO_2), we call for policymakers to act quickly to incorporate these concerns into plans to stabilize atmospheric CO_2 at a safe level to avoid not only dangerous climate change but also dangerous ocean acidification.

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