Ocean Acidification: A Global Problem With Local Impacts

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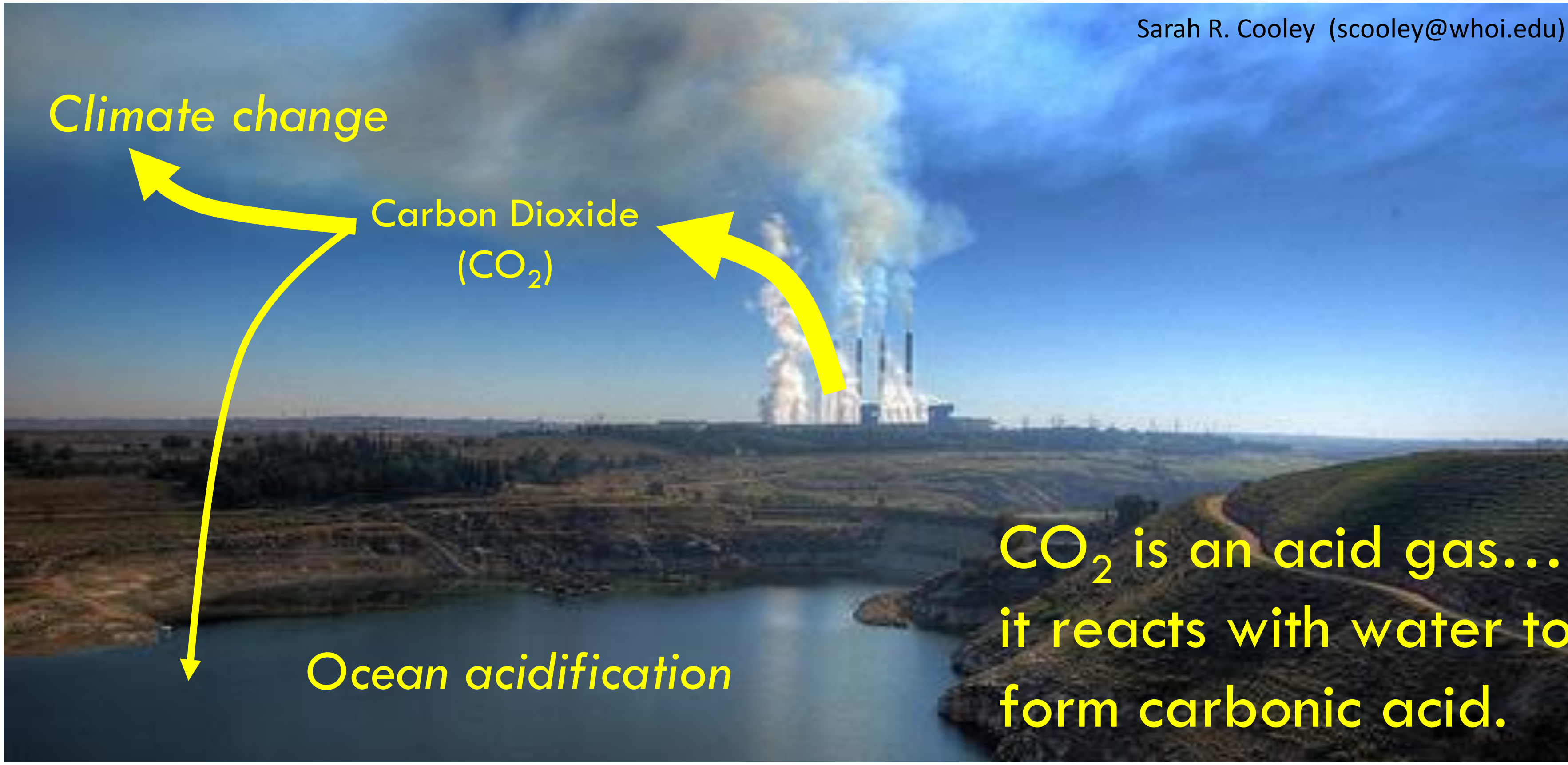
Outline

- Physical/Chemical Oceanography
- Marine Biology Including:
  - Phytoplankton, Zooplankton (oyster larvae, pteropods) and Salmon

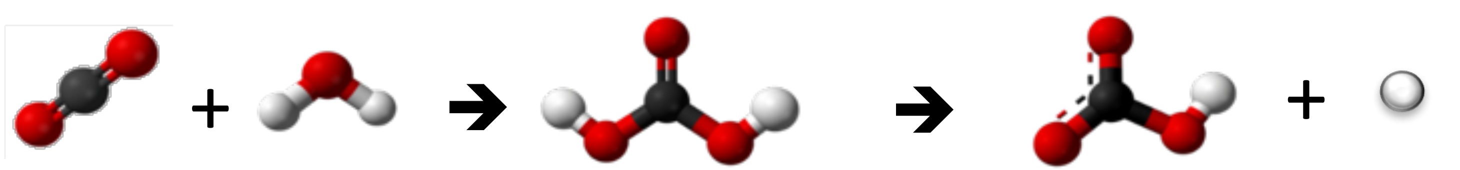
Ocean Policy Research Institute
Sasakawa Peace Foundation
International Symposium on Ocean Acidification
28 October 2018

Photo credit: Meghan Shea

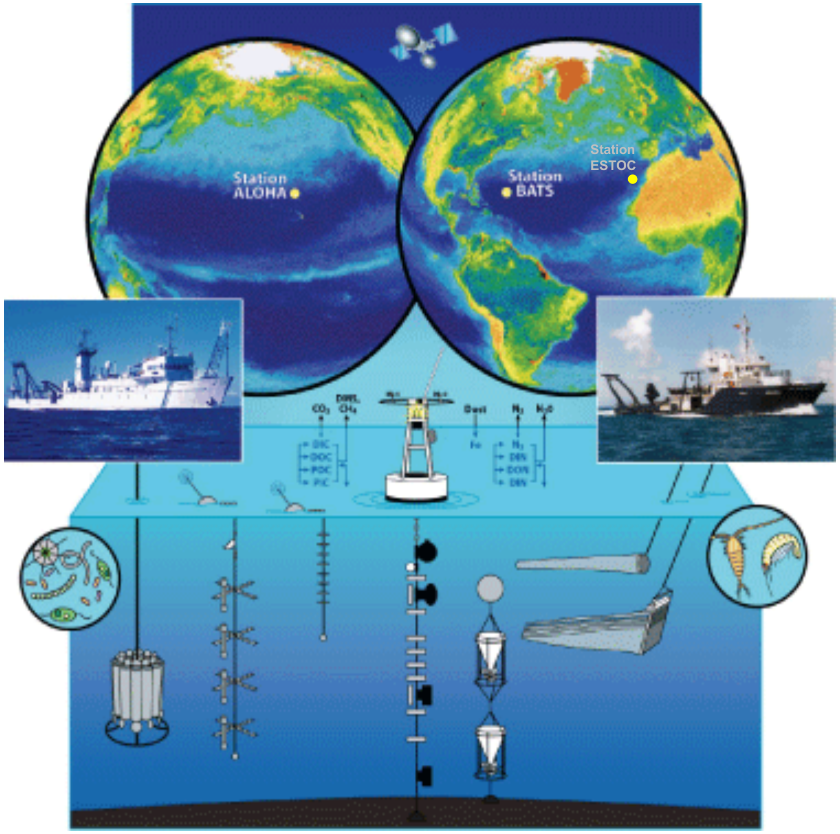
Ocean Acidification: the other CO_2 problem

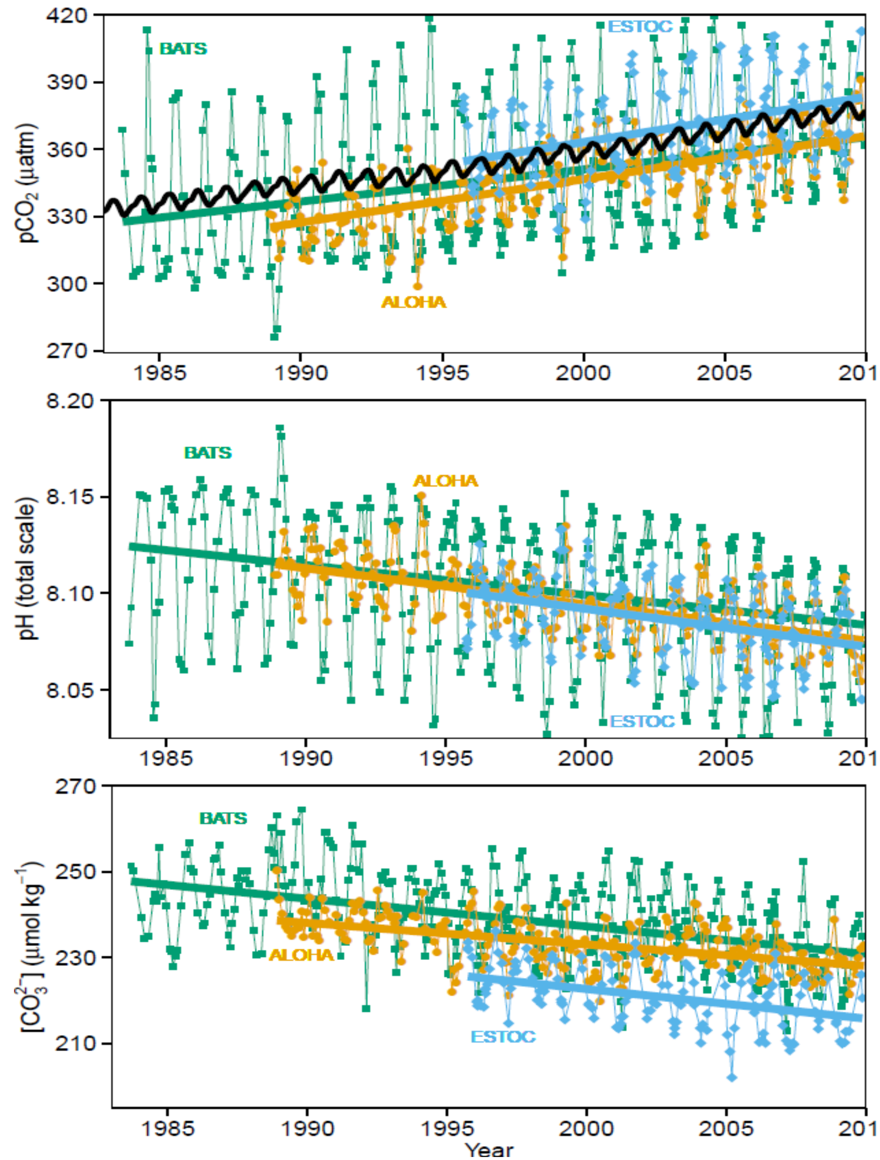


$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+$$



Change in pH from ocean acidification already measurable





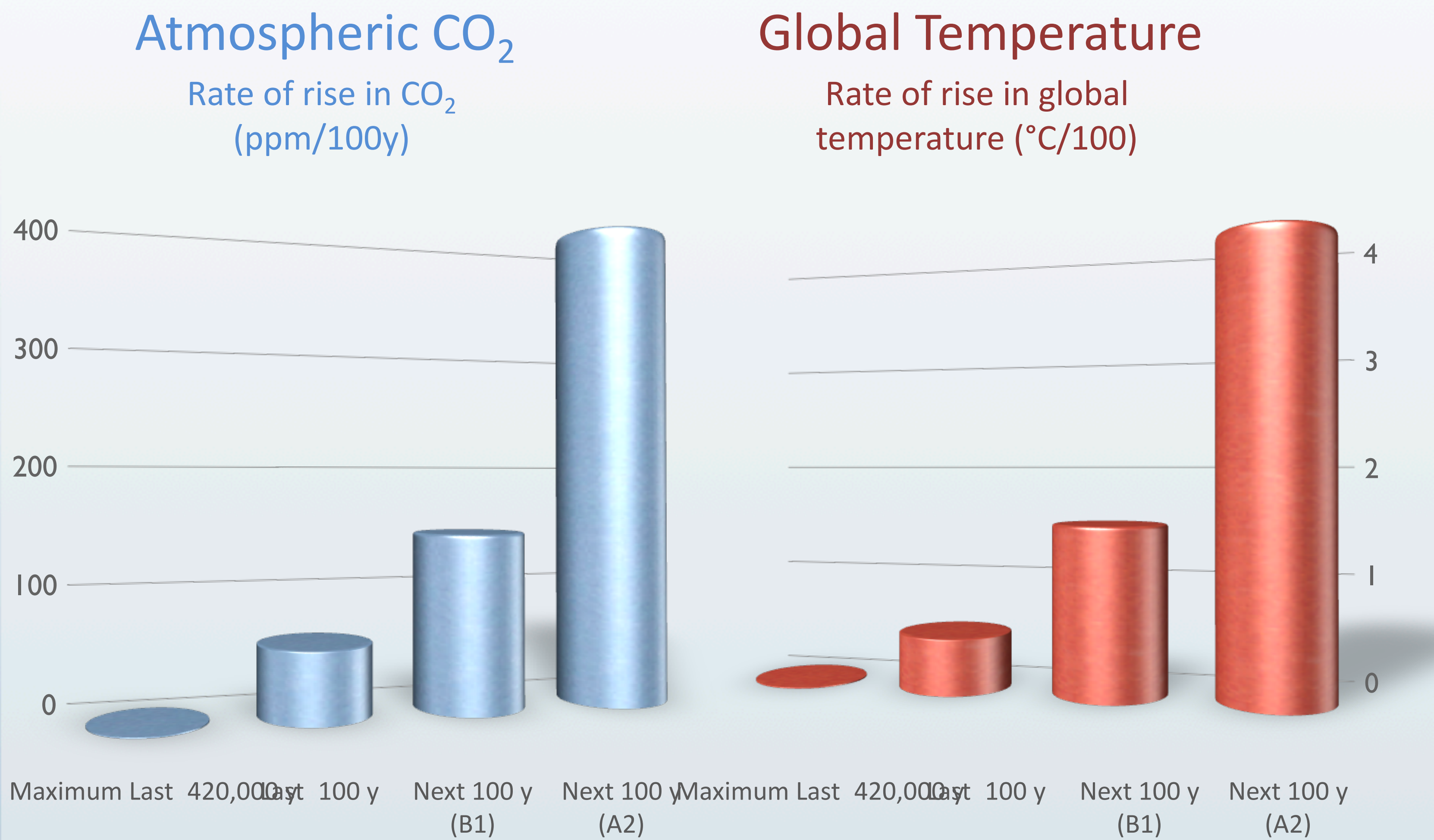
<u>Data</u>:
Bates (2007)
Dore et al. (2009)
Santana-Casiano et al. (2007)
Gonzàles-Dàvila et al. (2010)

IPCC AR5 WG1 Report, Chap. 3 (2013)

In-situ pH change = -0.0019 ± 0.0002 yr^{-1}

Rates of increase are important

Ocean CO_2 Chemistry



Hoegh-Guldberg et al. 2007, Science

Saturation State

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$$

calcium | carbonate | calcium carbonate

Saturation State

$$\Omega_{phase} = \frac{[Ca^{2+}][CO_3^{2-}]}{K^*_{sp,phase}}$$

$\Omega > 1$ $CaCO_3$ precipitates

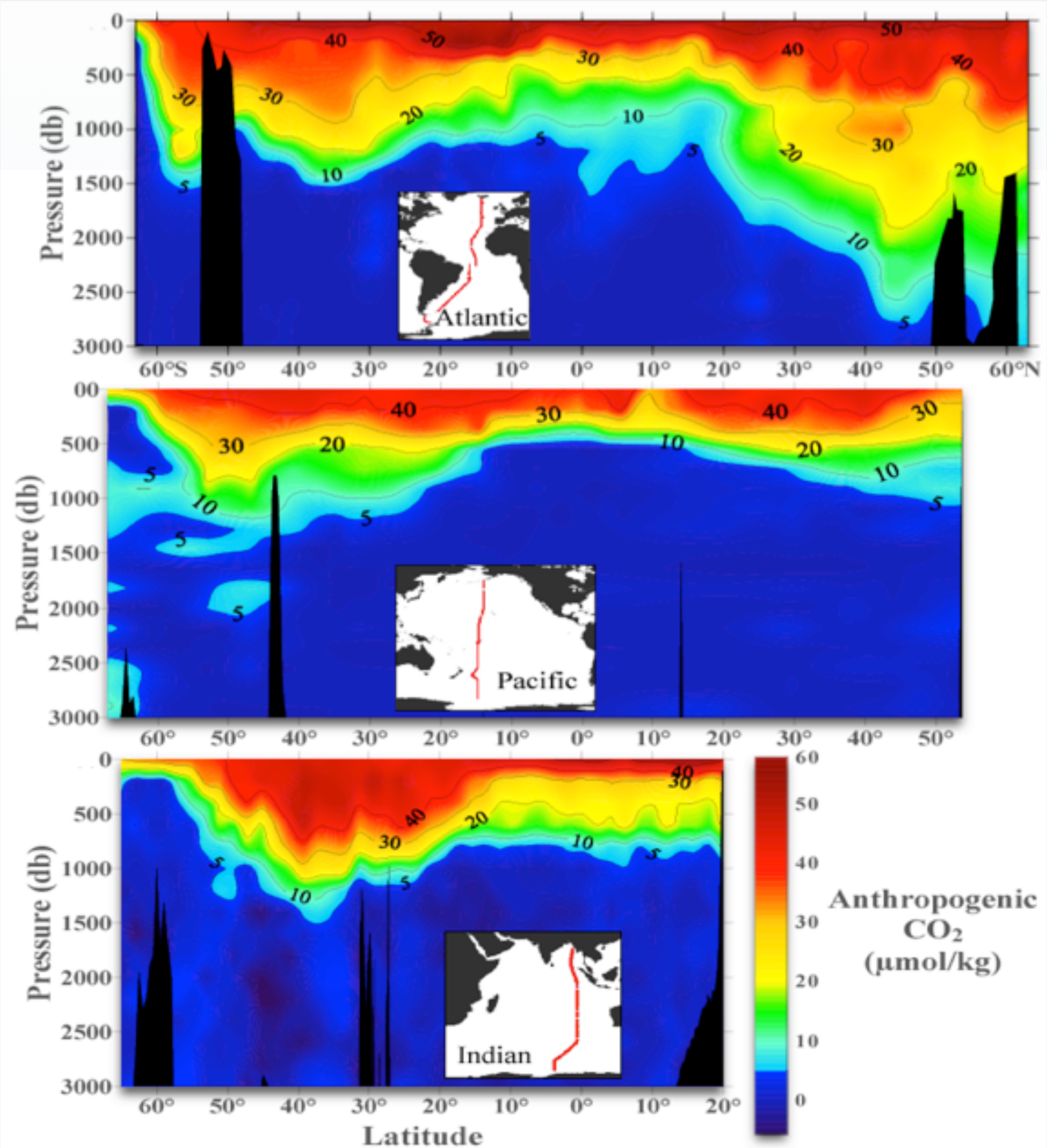
$\Omega = 1$ equilibrium

$\Omega < 1$ $CaCO_3$ dissolves

Common carbonate minerals:

aragonite (more soluble) and calcite (less soluble)

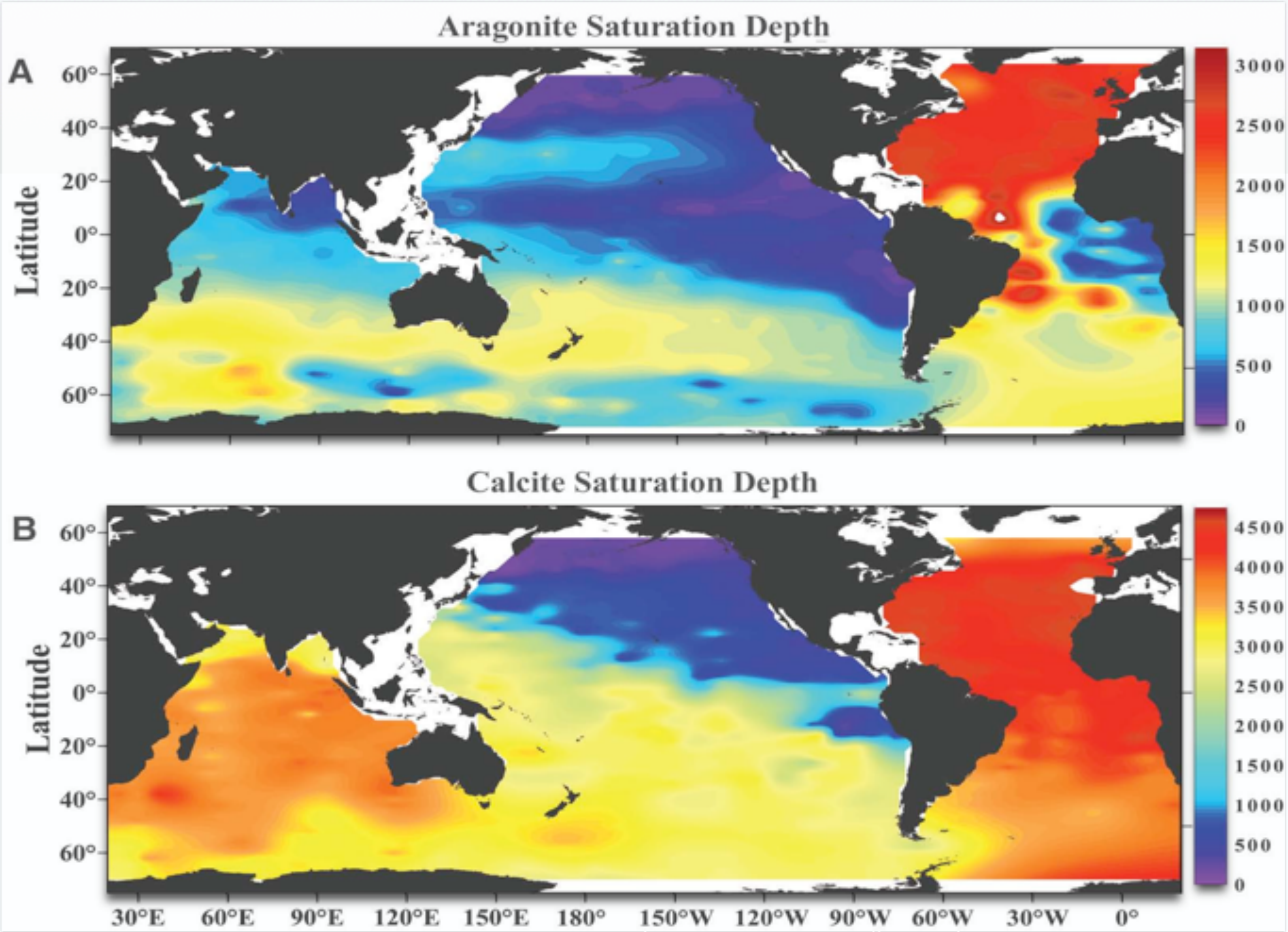
Penetration of Anthropogenic CO_2 into Ocean



- Difference of present-day levels minus pre-industrial (year 1800)
- Half trapped in upper 400 m
- Equivalent to about a third of all historical carbon emissions
- 150 Pg C since the beginning of the industrial era have accumulated in the oceans

Sabine et al. Science 2004

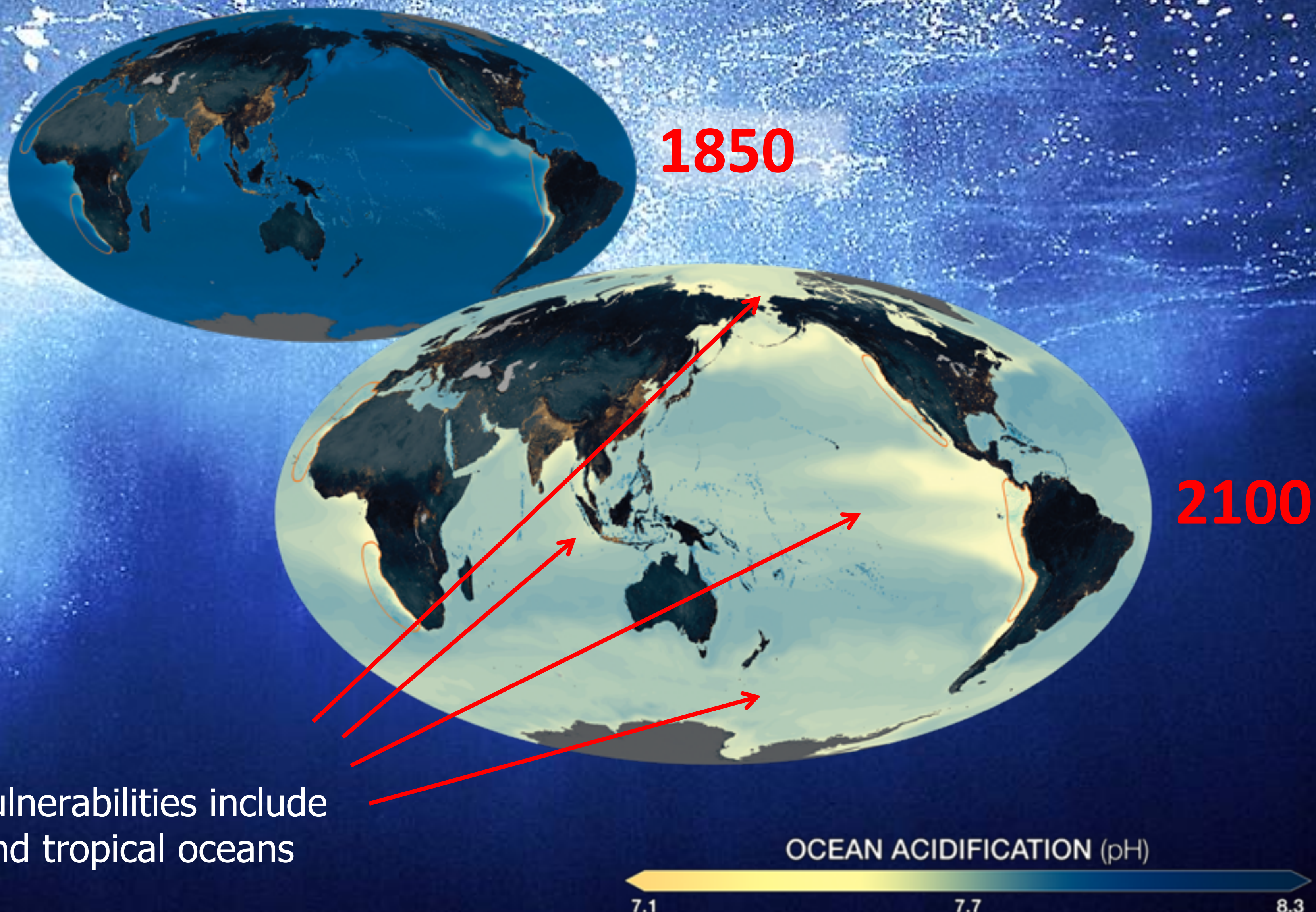
Observed aragonite & calcite saturation depths



Feely *et al.* (2004)

The **aragonite saturation state** migrates towards the surface at the rate of 1-2 m yr^{-1}, depending on location.

Surface ocean pH change since the industrial revolution



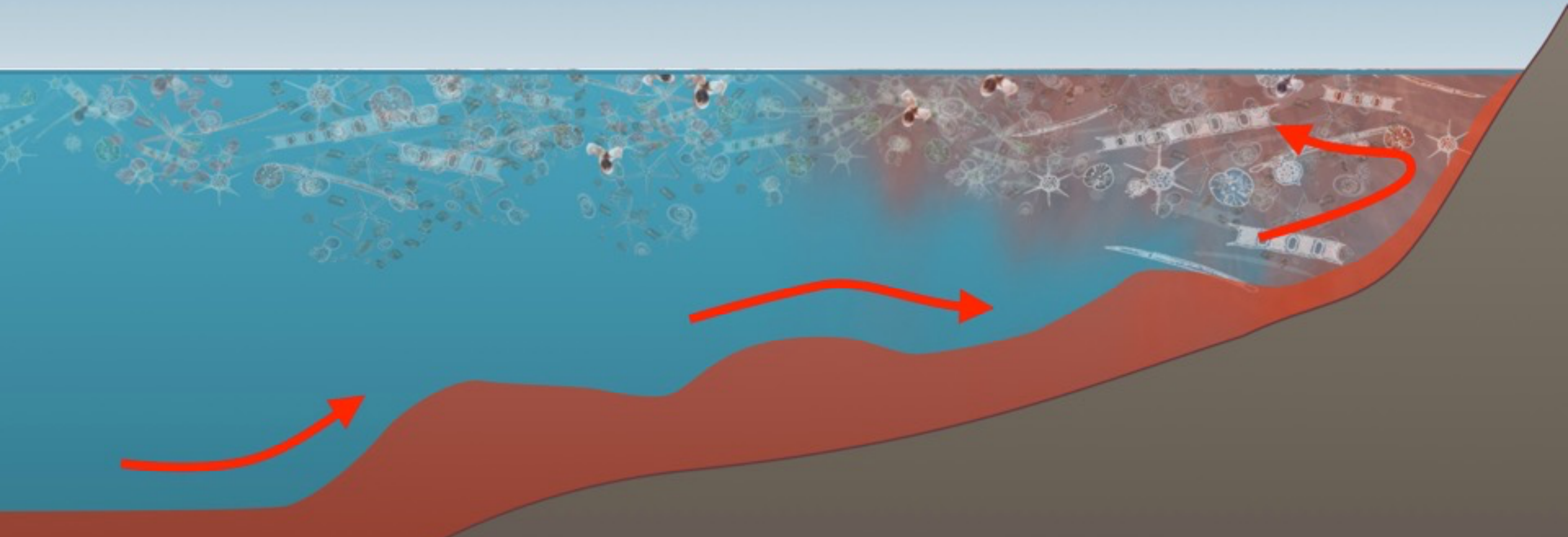
Early vulnerabilities include polar and tropical oceans

IGBP, IOC, SCOR (2013) Ocean Acidification Summary for Policy Makers

Ocean Acidification is Occurring Rapidly

- Approximately 28% of the CO_2 generated by human activities since the mid-1700s has been absorbed by the oceans.
- Ocean acidity has increased 30% since the start of the industrial age.
- Ocean acidity is projected to increase 100-150% percent by 2100.
- Current rate of acidification is nearly 10x faster than any period over the past 50 million years.

Seasonal invasion of corrosive upwelled water on the west coast of North America



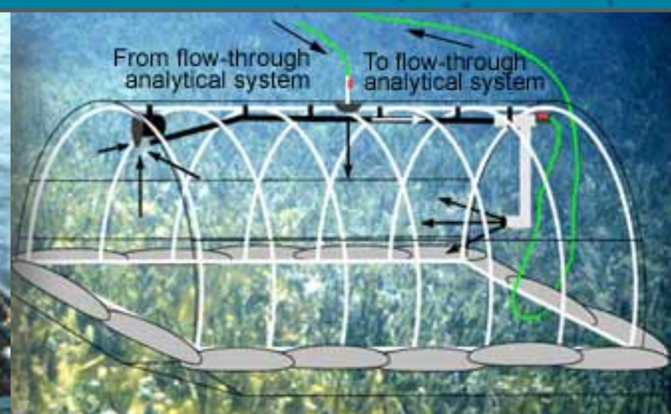
- Upwelling of CO_2-rich intermediate waters, undersaturated with aragonite (Ω_{arag}), onto continental shelf from a depth of 150 – 200m
- Exposure of productive coastal ecosystems to corrosive upwelled water

The Effects on Marine Organisms

Experiments on *many scales*

Biosphere 2
(provided by Mark Eakin)

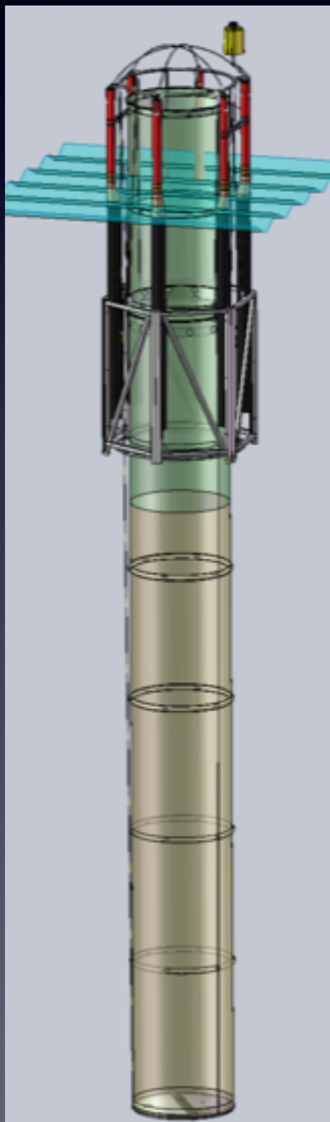
Aquaria
& Small Mesocosms

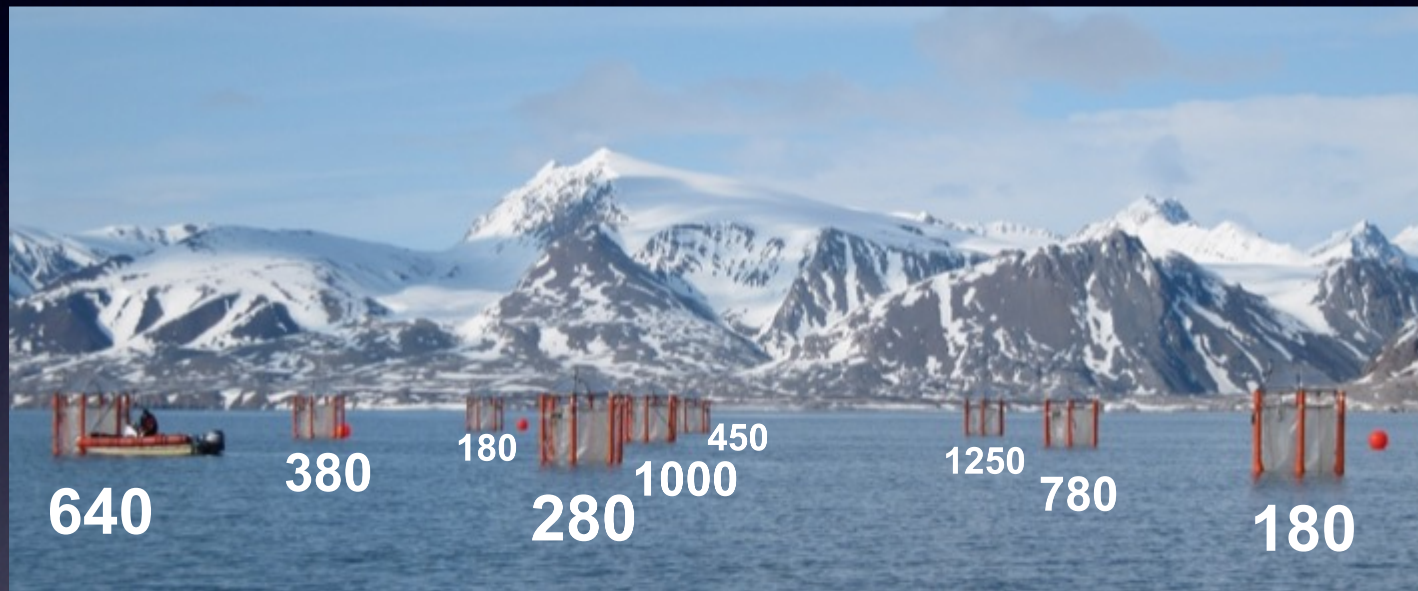


USGS
science for a changing world

SHARQ
Submersible Habitat for Analyzing Reef Quality

Svalbard 2010: CO_2 Enriched Mesocosms

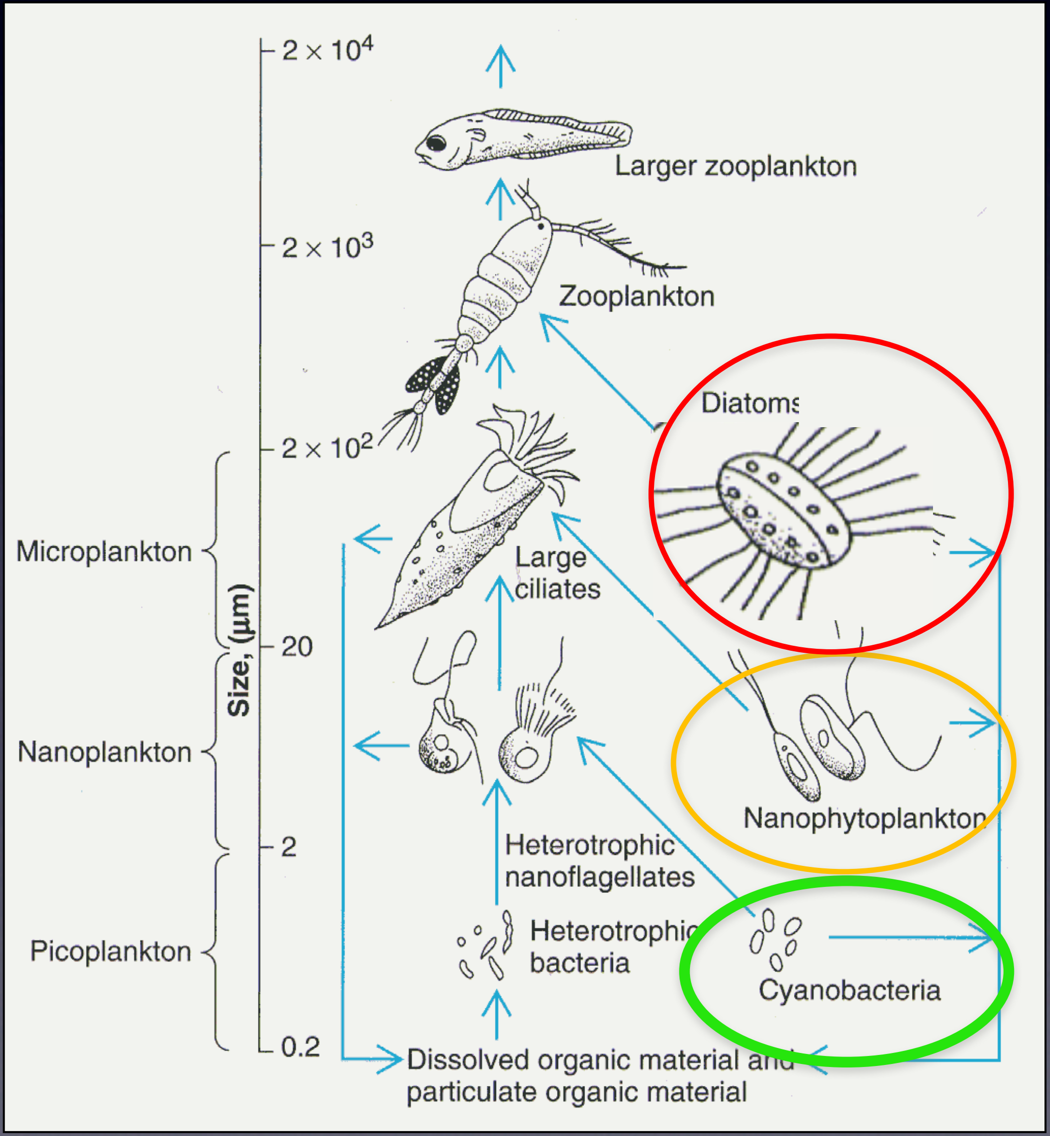




35 participants from 12 partner institutes

EPOCA
European Project on OCean Acidification

Major Changes at the Base of the Pelagic Foodweb



.... with likely consequences for higher trophic levels and foodwebs

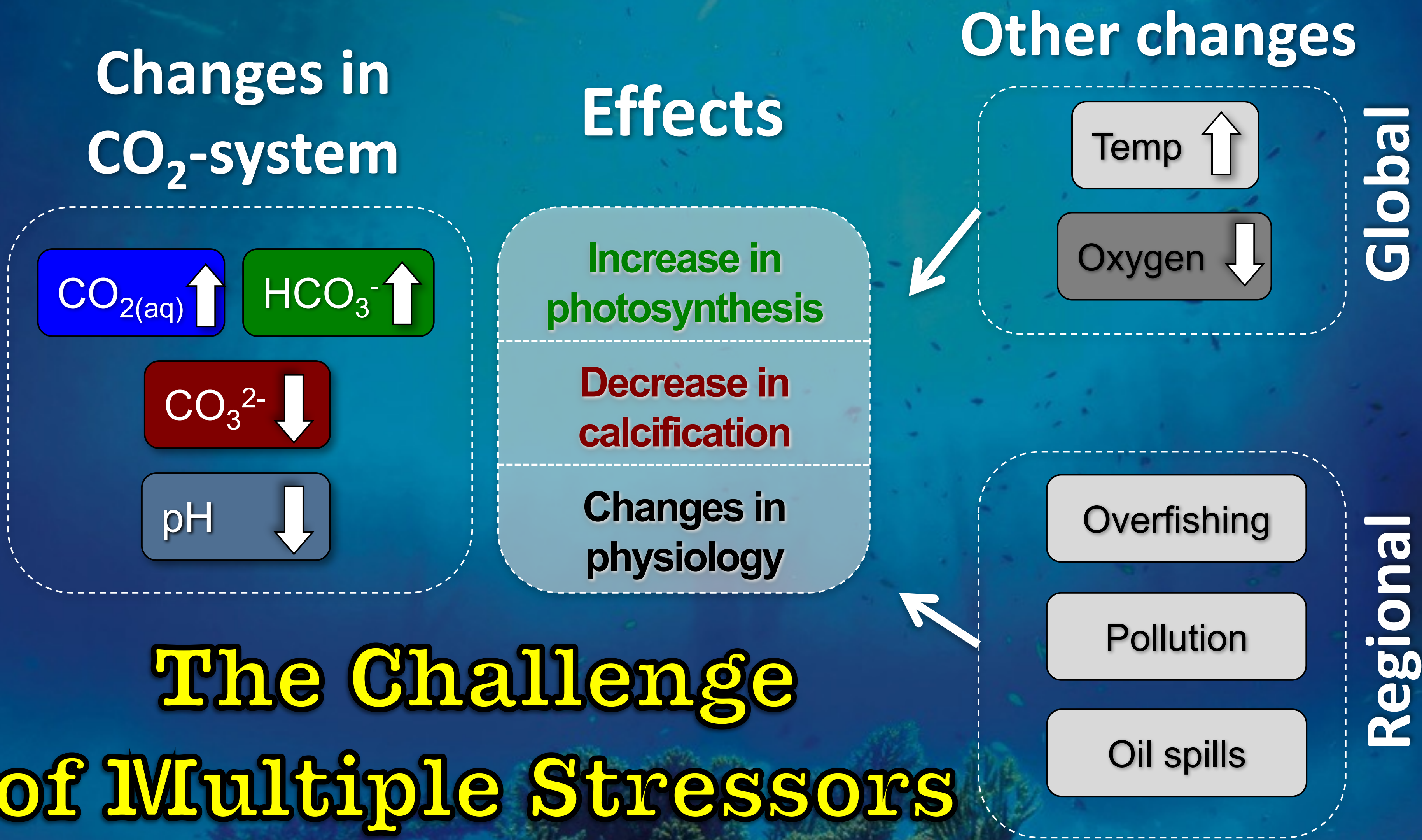
outcompeted at high CO_2

moderately stimulated at high CO_2

strongly stimulated at high CO_2

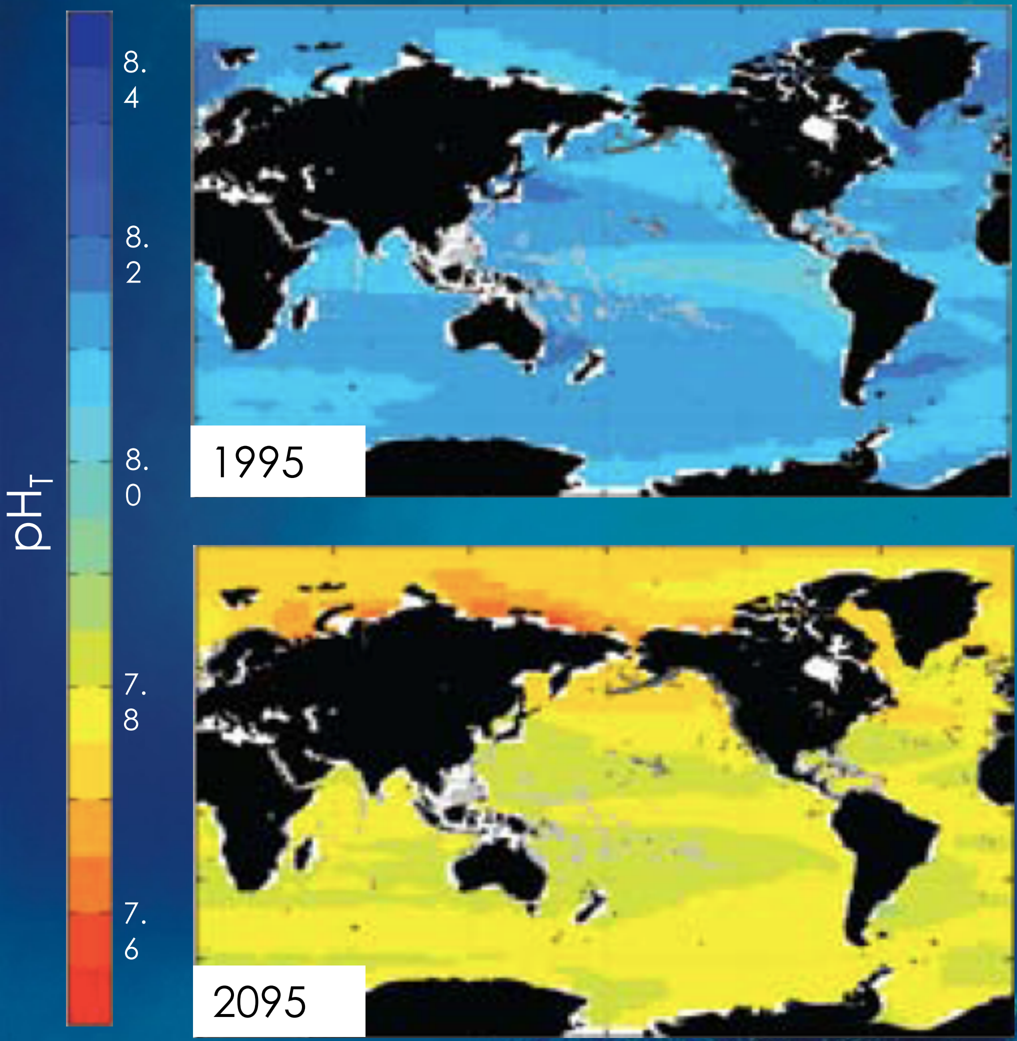
(unpublished data coutesy Ulf Reibesell, BIOACID and EPOCA)

How CO2 in seawater affects marine life



The Challenge of Multiple Stressors

A meta-analytic approach



CC SM3-modeled decadal mean pH (surface)

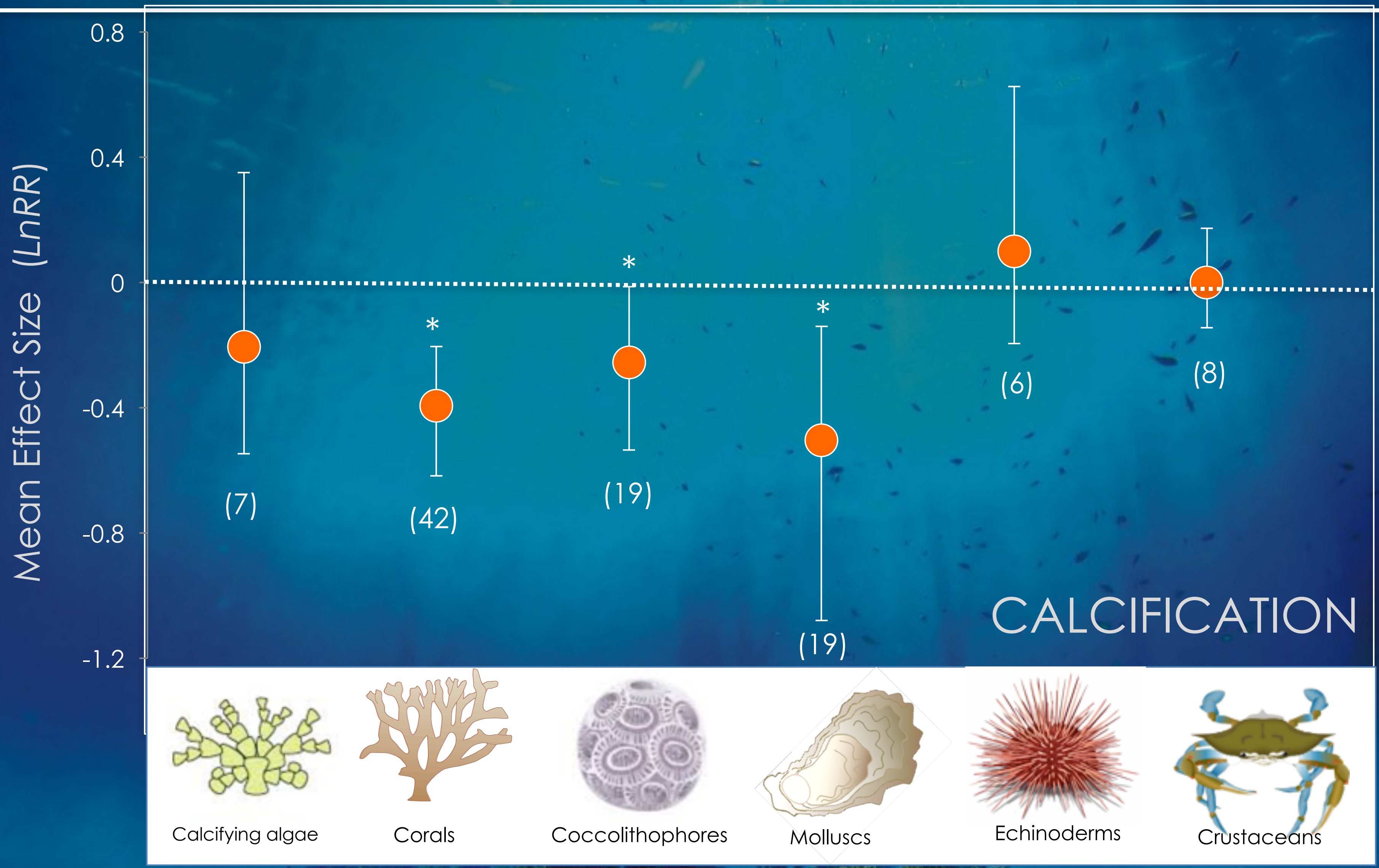
Study criteria:

Δ pH ≤ 0.5 decrease

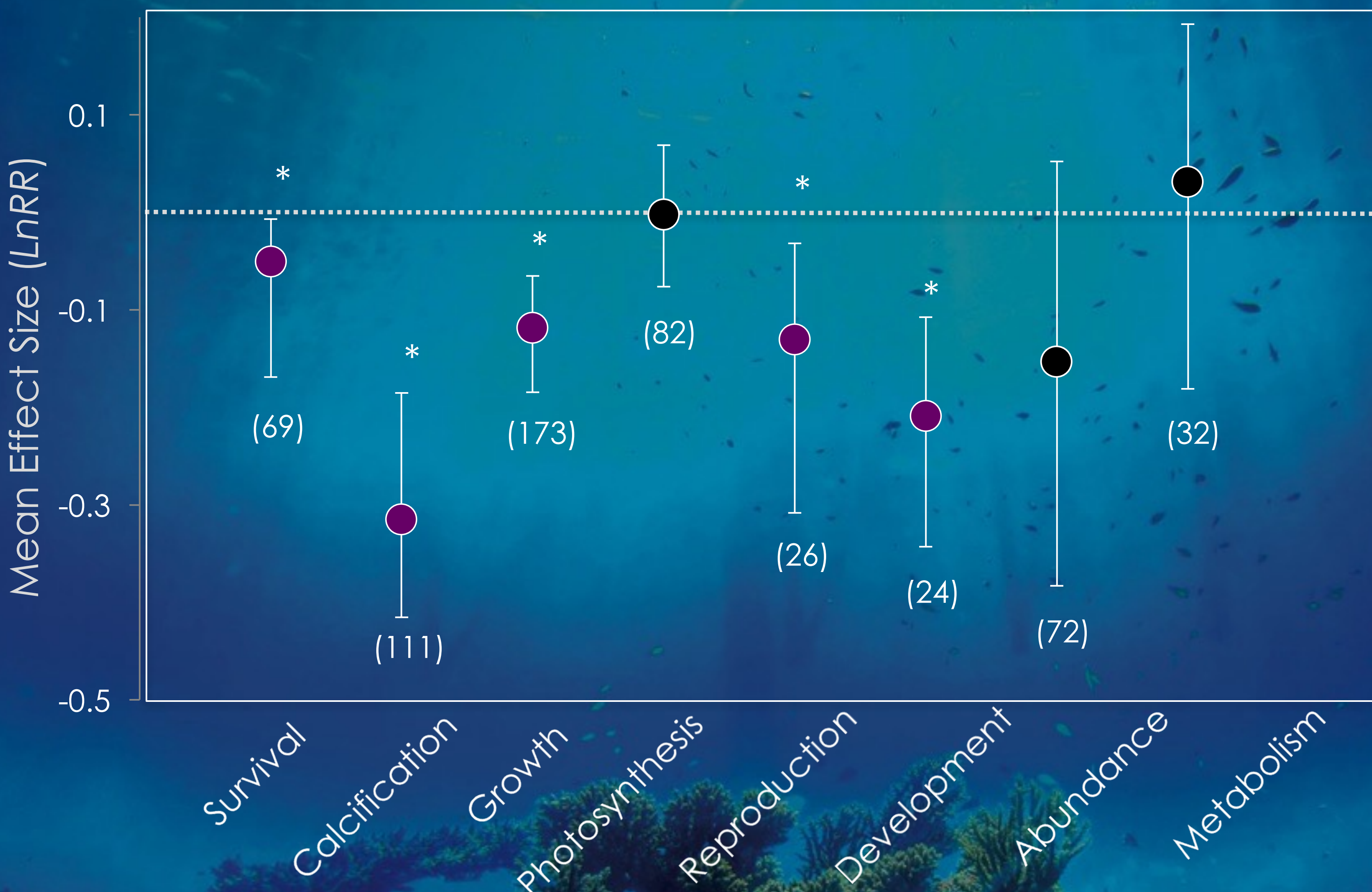
588 unique experiments

Kroeker et al., 2013

Variation in sensitivity among calcifiers



OA has negative effects across a large range of processes

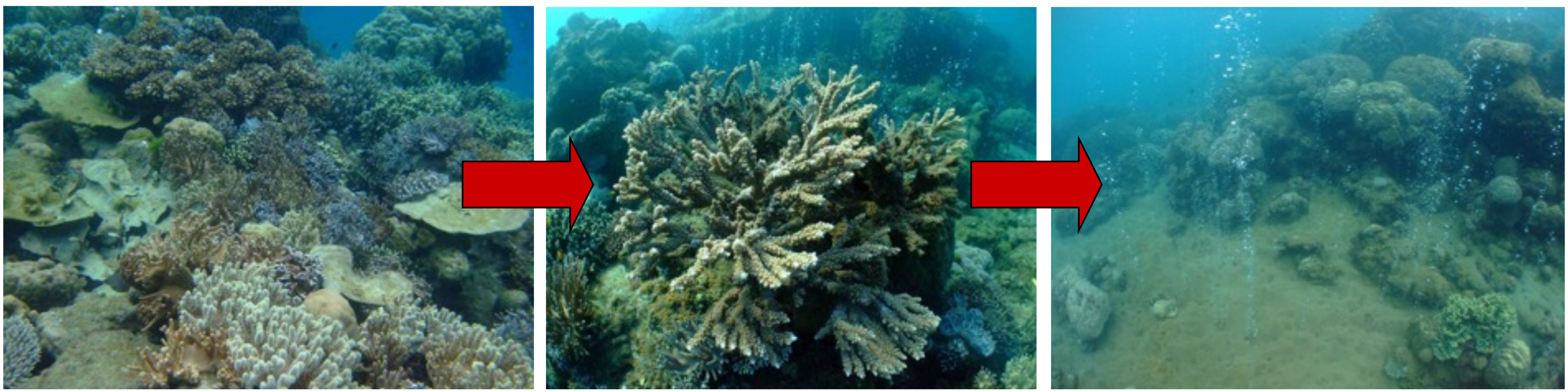


Kroeker *et al.* 2013

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*

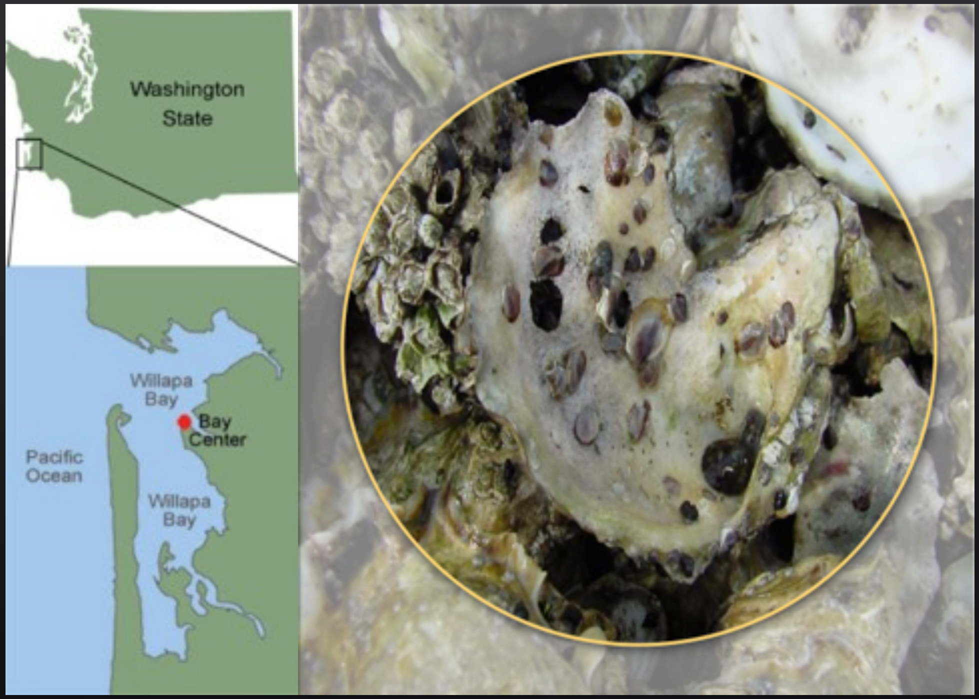
Slide courtesy Katharina Fabricius

Effects on Calcification

Many other species

Pacific Northwest *oyster emergency*

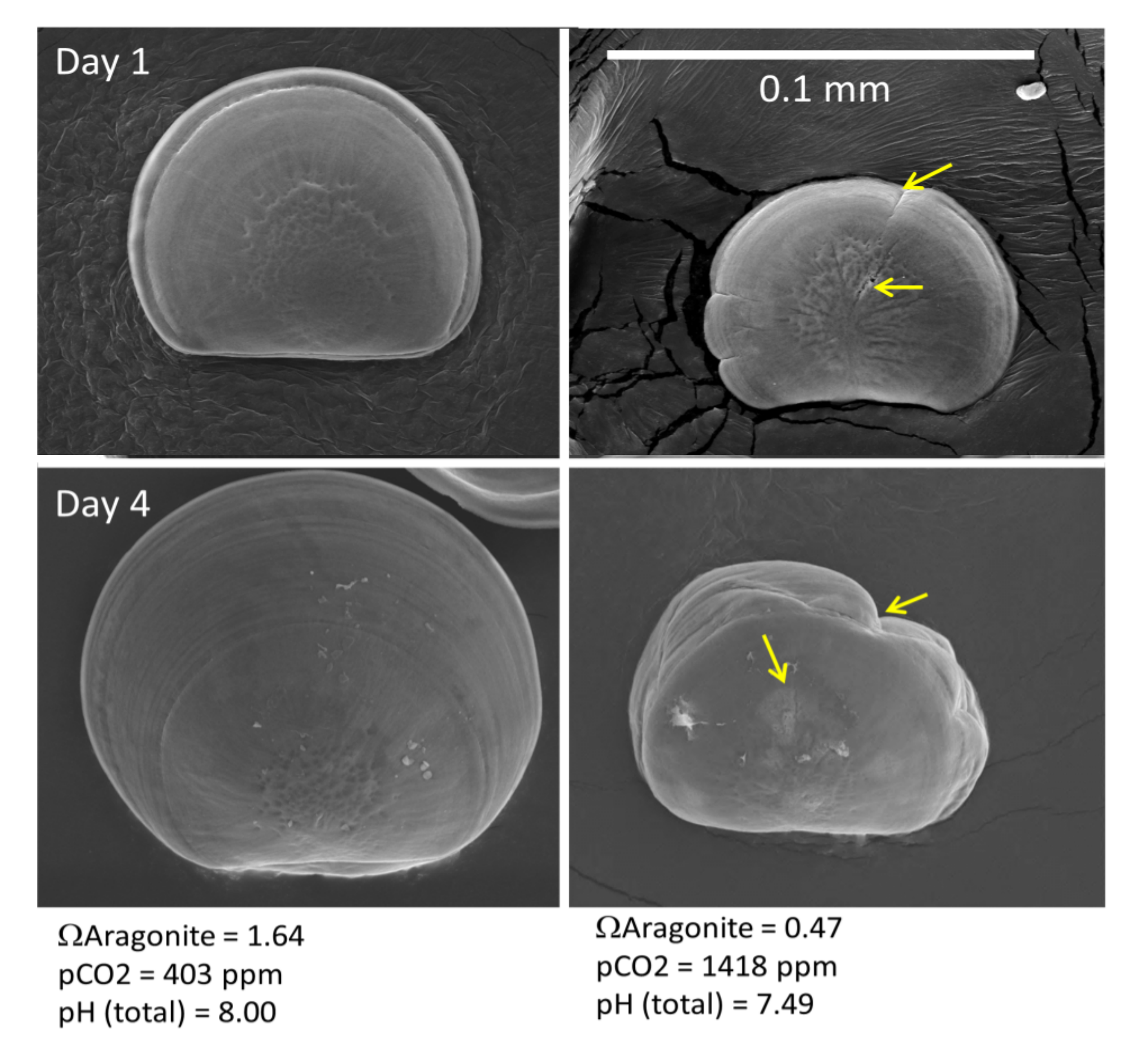
Are larval oysters the “canary in the coal mine” for near-shore acidification?



West Coast Oyster seed crisis

- Failure of larval oyster recruitments in recent years
- Commercial oyster hatchery failures threatens a $110M industry (3200 Jobs)
- Low pH “upwelled” waters a possible leading factor in failures

Oyster Larvae in Peril



Larvae reared in low aragonite saturation state conditions appear able to form their shell, but suffer from major defects that ultimately result in mortality.

Figure source: Elizabeth Brunner and George Waldbusser, Oregon State University

Pteropod Dissolution as an indicator of past, present and future impacts

Pre-industrial level of dissolution due only to upwelling: naturally occurring dissolution (~18%)

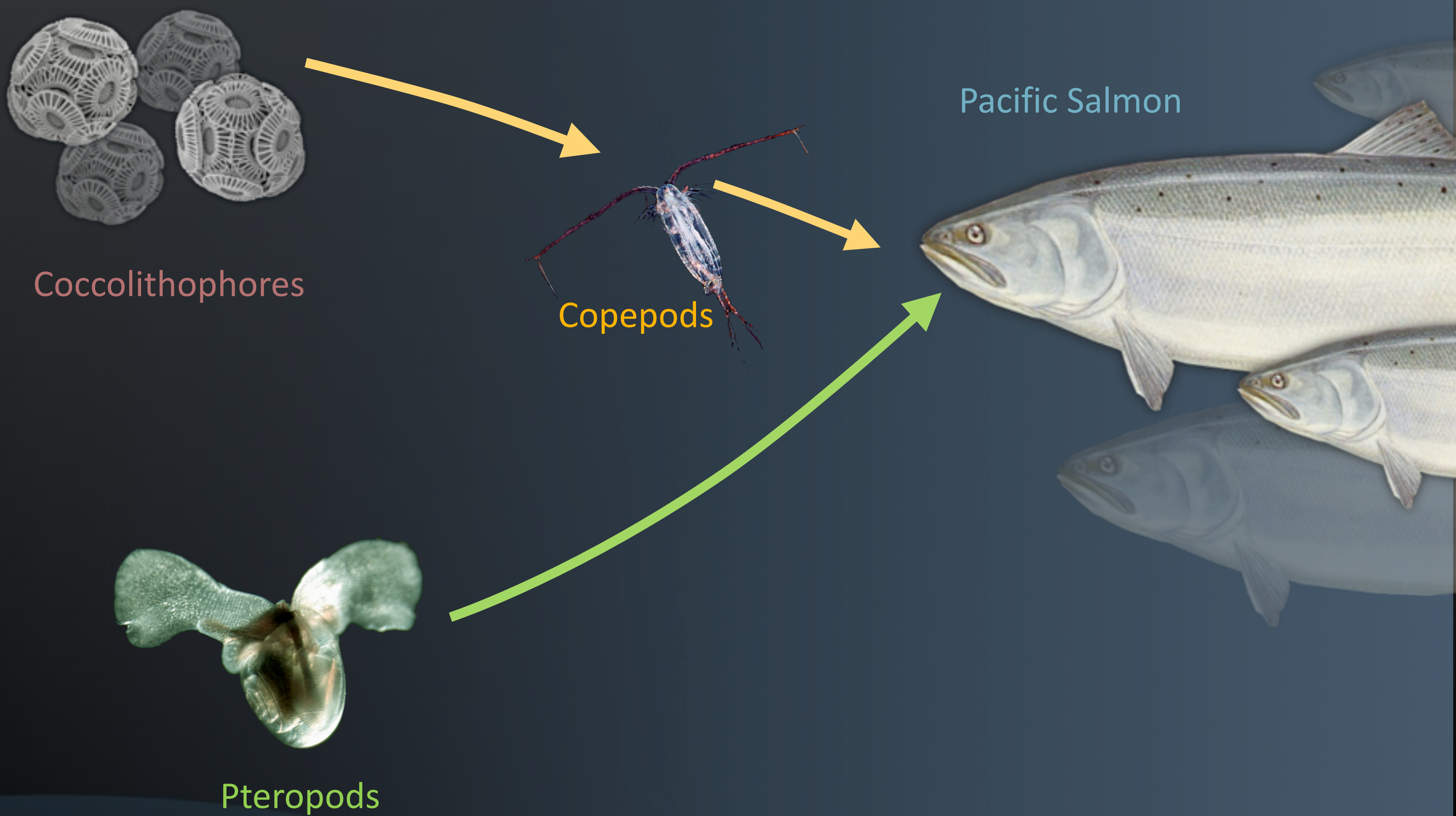


*S*ignificant increase in the current level of dissolution → 53% in the coastal regions with anthropogenic CO_2 contribution in addition to upwelling.

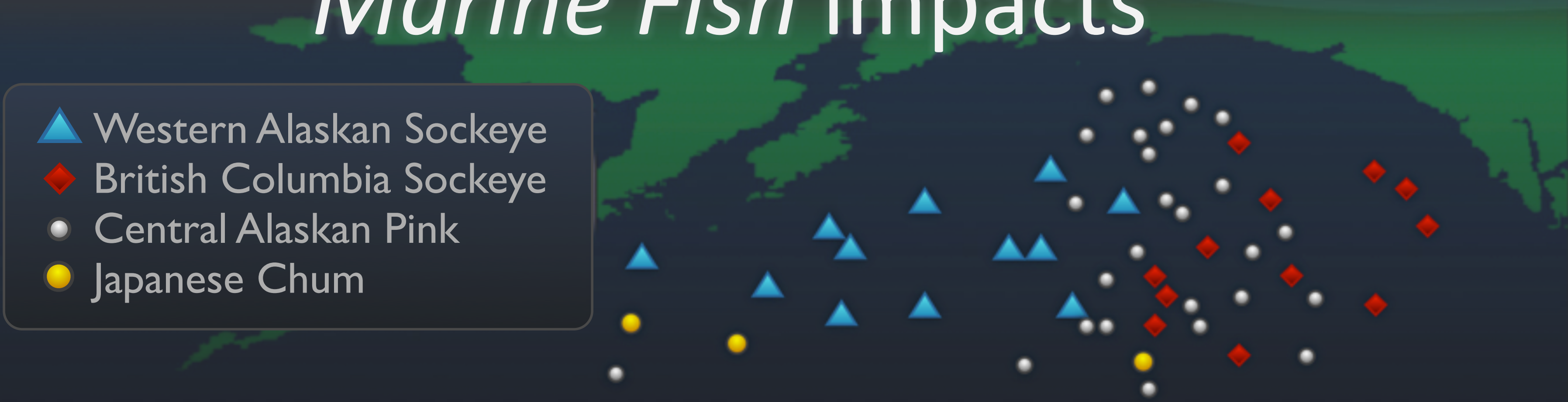
By 2050: ~70% of water column will be undersaturated →70% of pteropods affected by severe dissolution in the coastal regions.

Bednarsek et al 2014

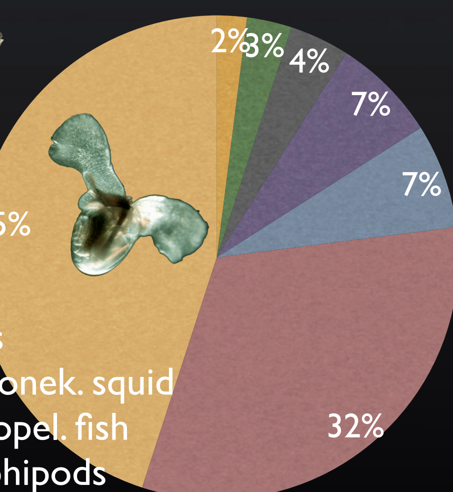
Potential *food web* impacts



Marine Fish impacts



Pink salmon diet

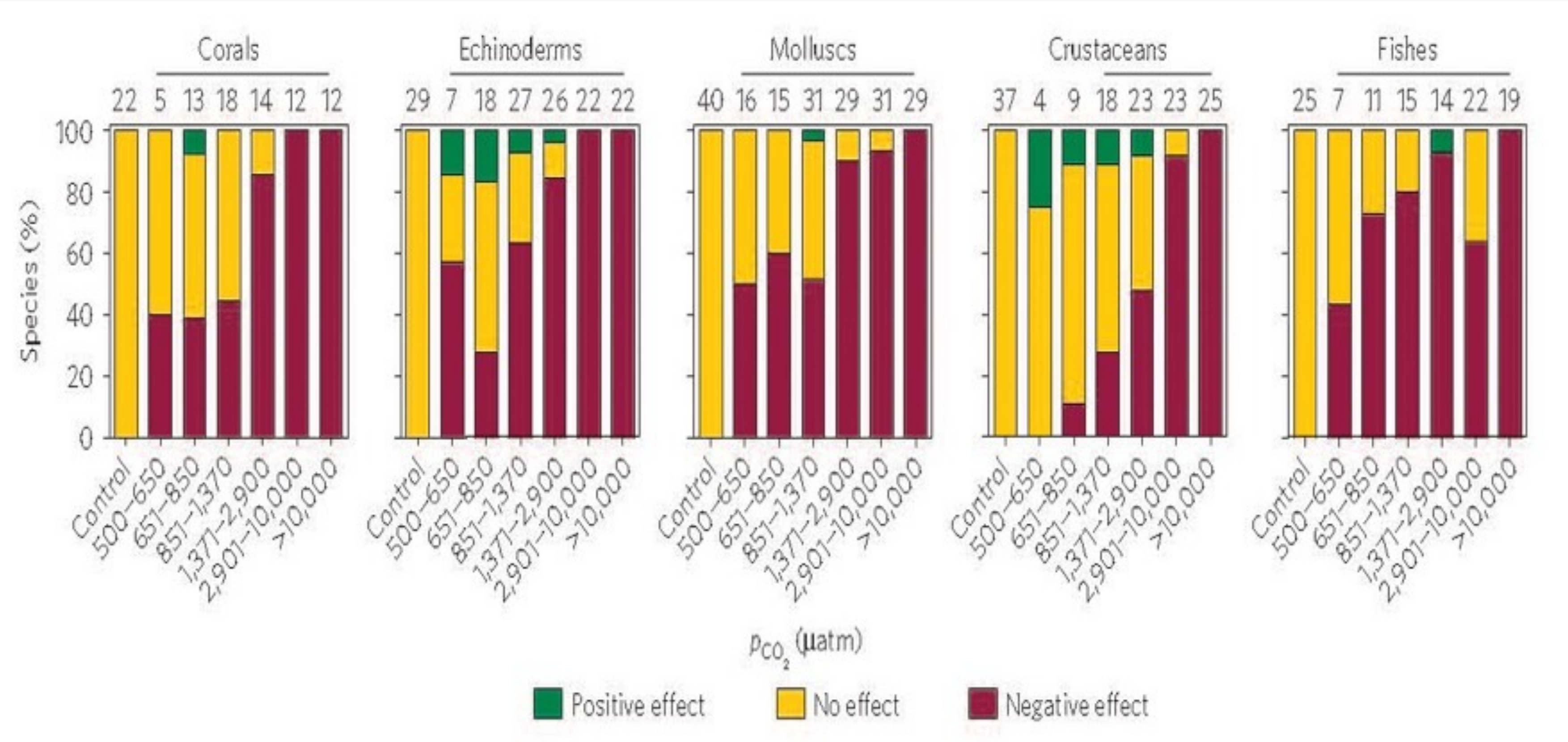


Predicted effect of climate change on pink salmon growth:

- 10% increase in water temperature leads to 3% drop in mature salmon body weight (physiological effect).
- 10% decrease in pteropod production leads to 20% drop in mature salmon body weight (prey limitation).

Aydin et al., 2005

Impacts of Acidification (after Wittmann and Pörtner, 2013)



Corals, echinoderms and molluscs are more sensitive to 936 ppm pCO_2 than are crustaceans. Larval fishes may be even more sensitive than the lower invertebrates, but taxon sensitivity on evolutionary timescales remains obscure. The variety of responses within and between taxa, together with observations in mesocosms and palaeo-analogues, suggest that ocean acidification is a driver for substantial change in ocean ecosystems this century, potentially leading to long-term shifts in species composition.

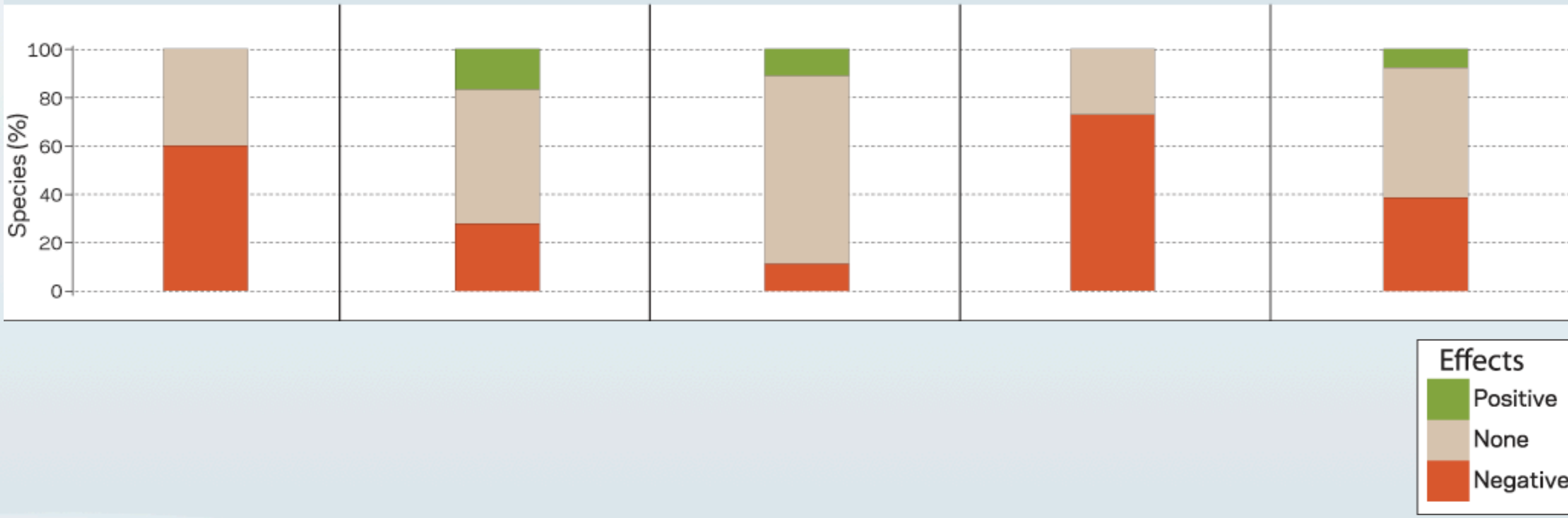
Commercially Important Organisms

GROUPS				
Molluscs	Echinoderms	Crustaceans	Finfish	Corals

Current estimated global commercial value♦

Molluscs	Echinoderms	Crustaceans	Finfish	Corals
$24 billion	$0.7 billion	$37 billion	$65 billion	$30-375 billion◊

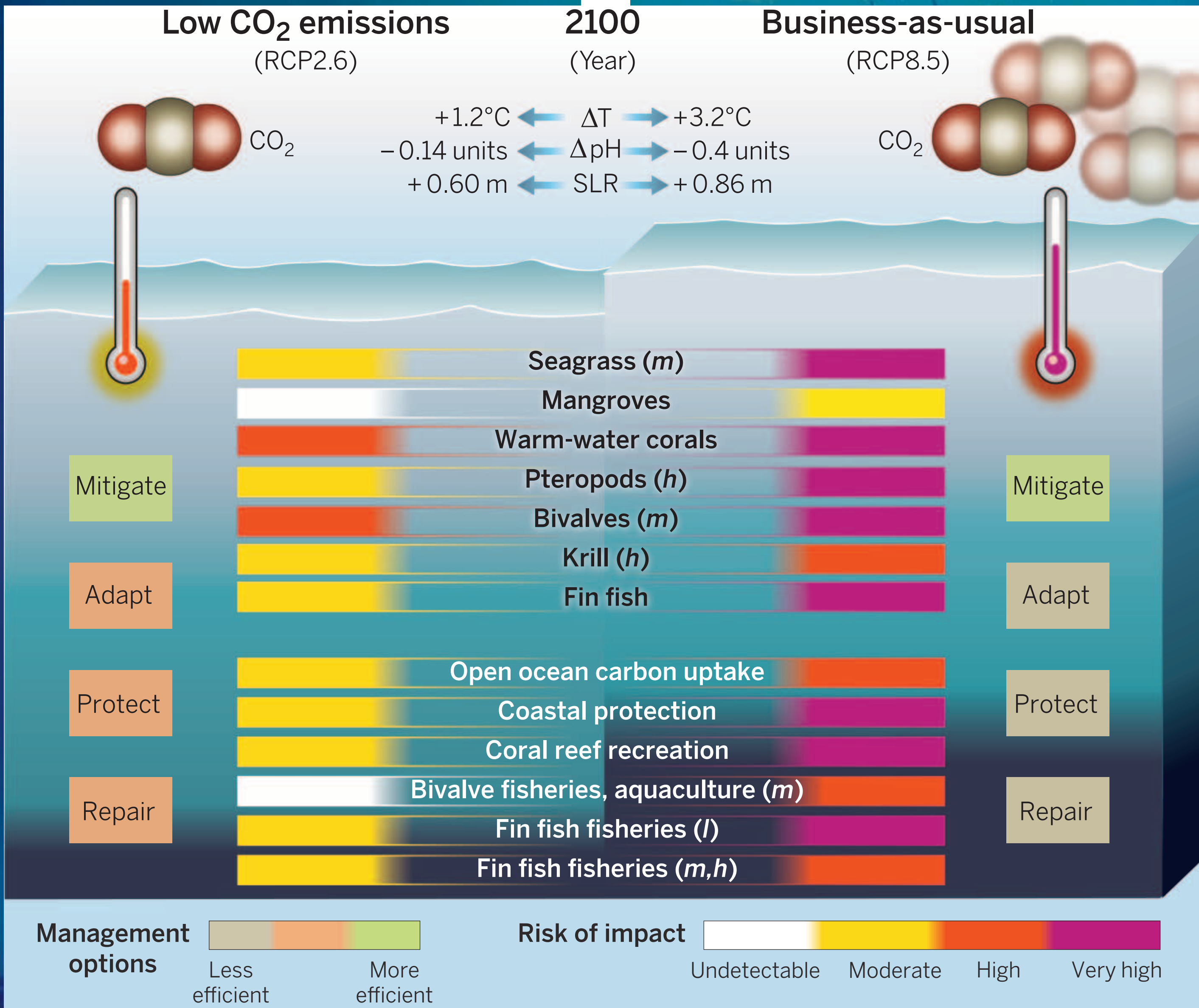
Sensitivity (percent of species affected)△



Concern for Marine Organisms and Ecosystems

- Reduced calcification rates
- Significant shift in key nutrient and trace element speciation
- Shift in phytoplankton diversity
- Reduced growth, production and life span of adults, juveniles & larvae
- Reduced tolerance to other environmental fluctuations
- Changes to fitness and survival
- Changes to species biogeography
- Changes to key biogeochemical cycles
- Changes to food webs
- Reduced sound absorption
- Reduced homing ability
- Reduced recruitment and settlement
- Changes to ecosystem goods & services
- Changes to behavior responses

Future Biological Impacts from CO_2 Emissions

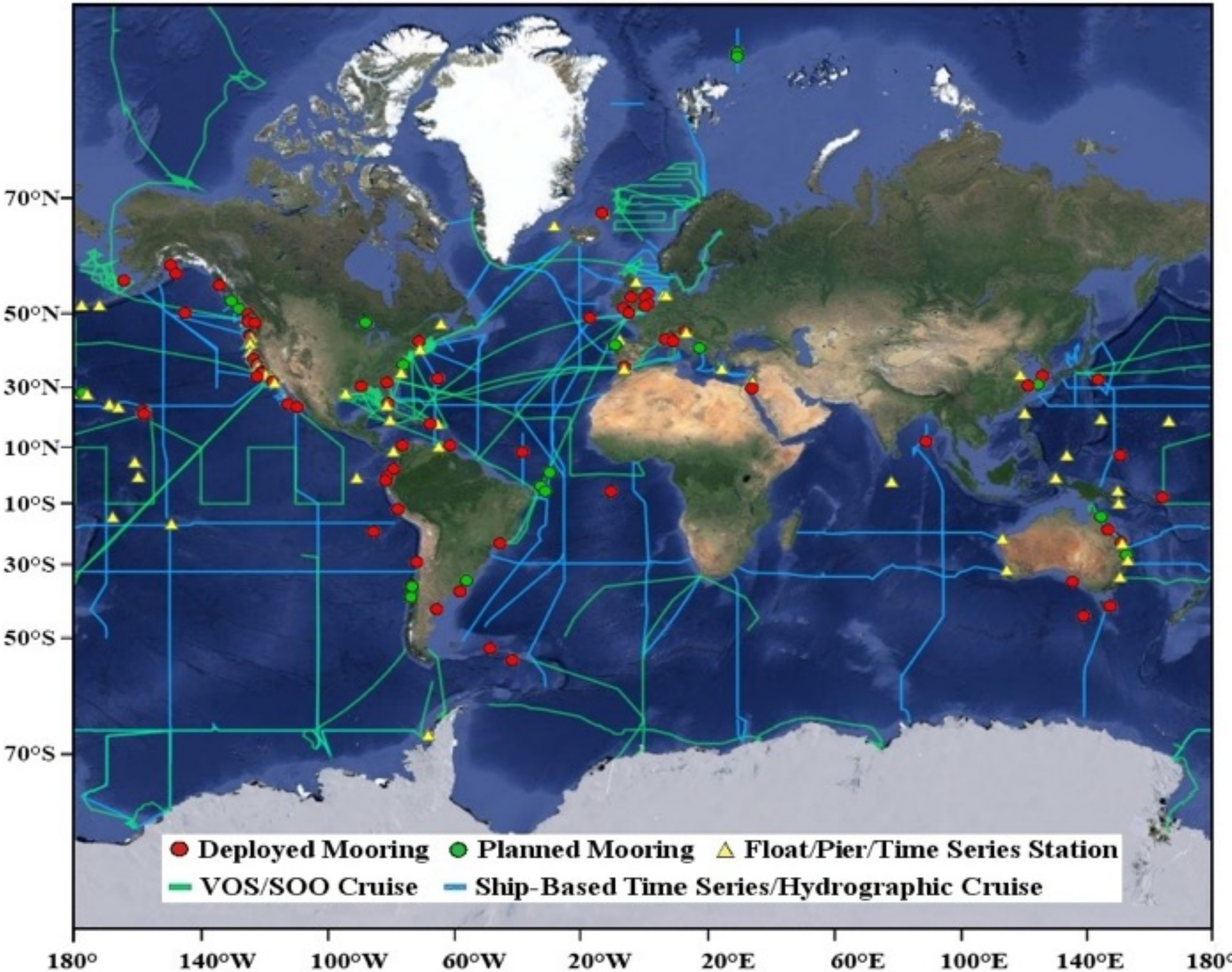


Gattuso et al., Science 2015

Changes in impacts on organisms and ecosystems according to stringent (RCO2.6) and high (RCP8.5) CO_2 emission scenarios.

Global Ocean Acidification Observing Network

GOA-ON
Global Ocean Acidification Observing Network



Provide access to:

- **SOCAT SOOP**
- **Data**
- **GLODAPv2 Repeat Hydrography data**
- **Mooring data**
- **Coastal Data**

Develop

- **seasonal and trend views**
- **synthesis products**
- **model output**

- *www.GOA-ON.org*

Conclusions

- The ocean is acidifying rapidly
- Some species will be sensitive to OA
- Biological responses to OA are variable
- Impacts of OA can transfer through food webs
- Other stressors can exacerbate response to OA
- Economic consequences of OA are significant