Prospects for Marine Ecosystems with Ocean Acidification

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NCAR

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Ocean Acidification

The Problem

The CO_2 we put in the atmosphere

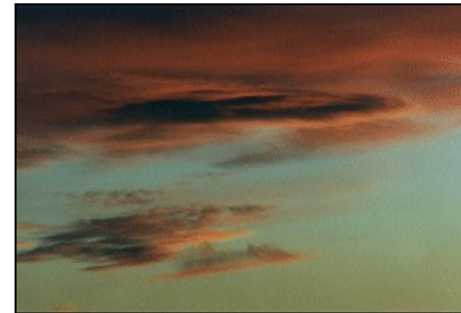
1.5 Pg C y^{-1}

7.5 Pg C y^{-1}

Where it ends up

46%

4.2 Pg y^{-1}



29%

2.6 Pg y^{-1}

25%

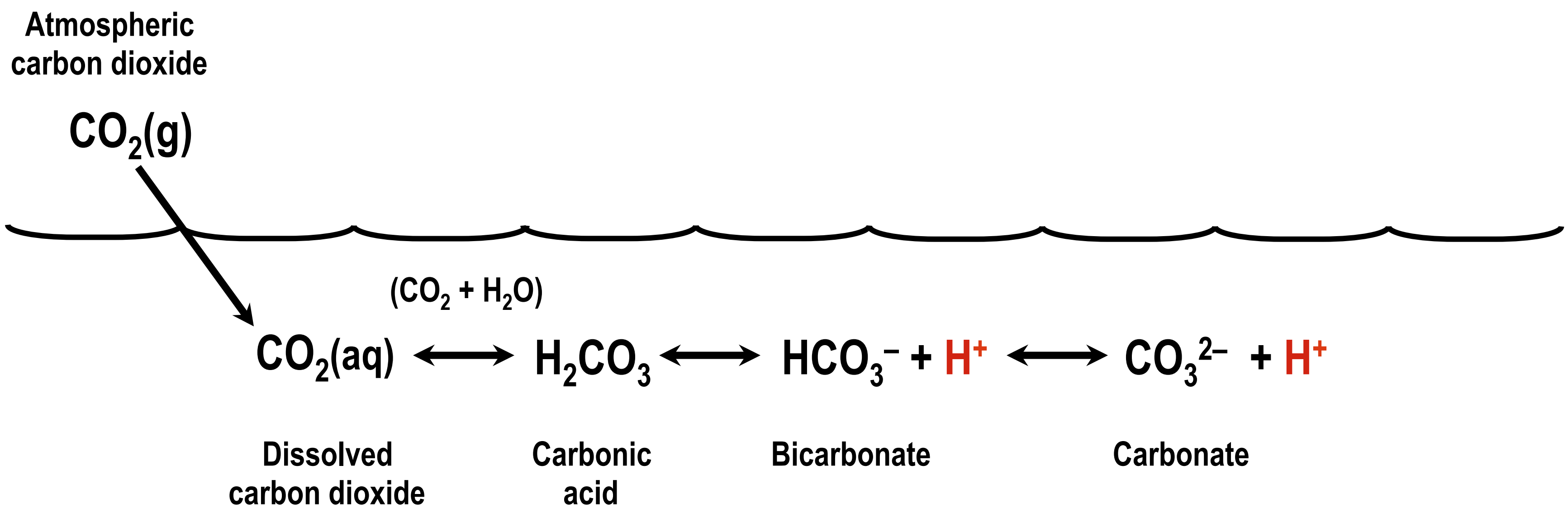
2.3 Pg y^{-1}

Years 2000-2007

Slide modified from GCP - Global Carbon Budget Team

Canadell et al. 2007, PNAS (updated)

Ocean Acidification



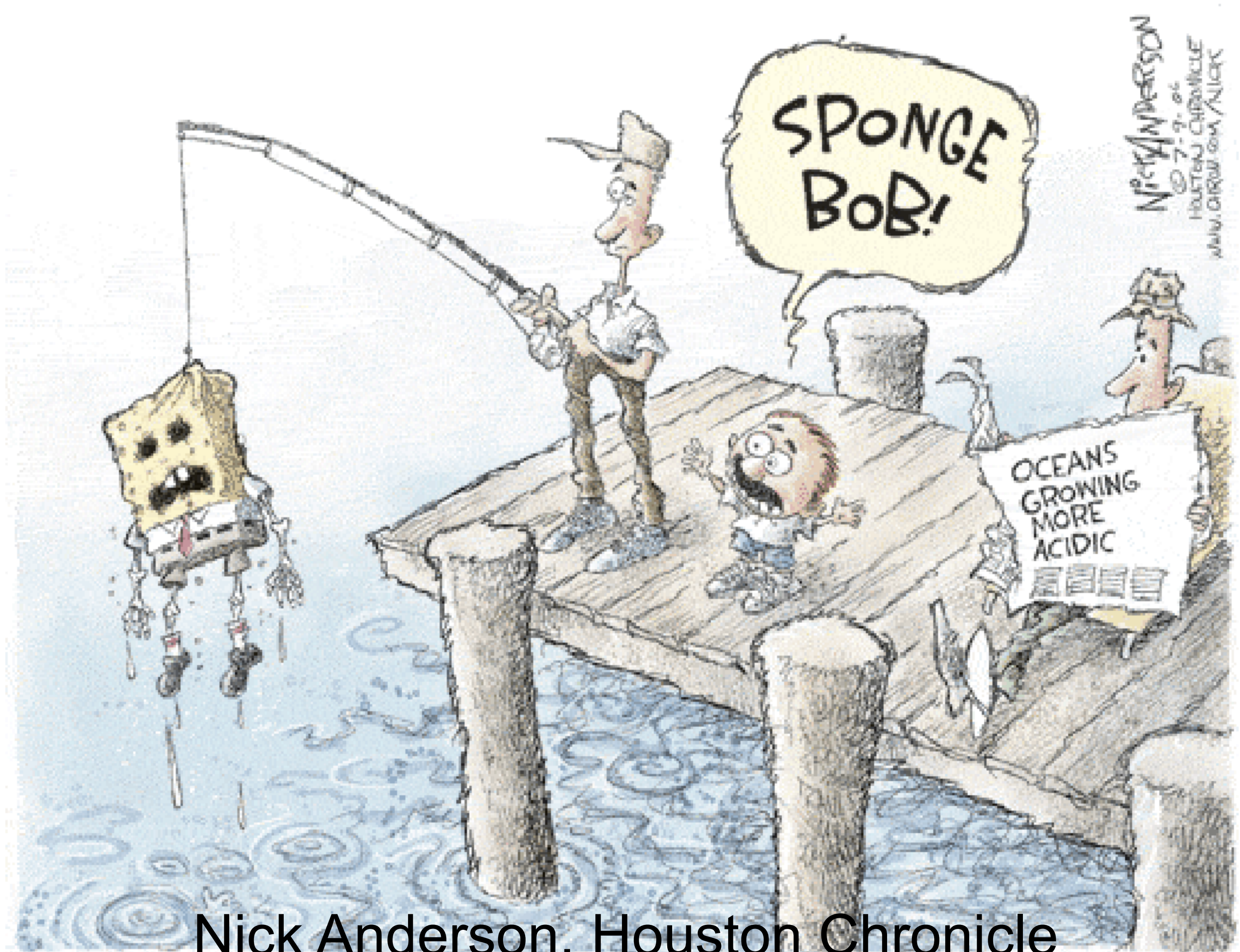
Preindustrial versus doubled preindustrial CO_2 concentrations

$CO_2(g)$ ppmv	$CO_2(aq) + H_2CO_3$ µmol kg^{-1}	HCO_3^- µmol kg^{-1}	CO_3^{2-} µmol kg^{-1}	pH
280	8	1635	272	8.11
560	16	1867	177	7.93

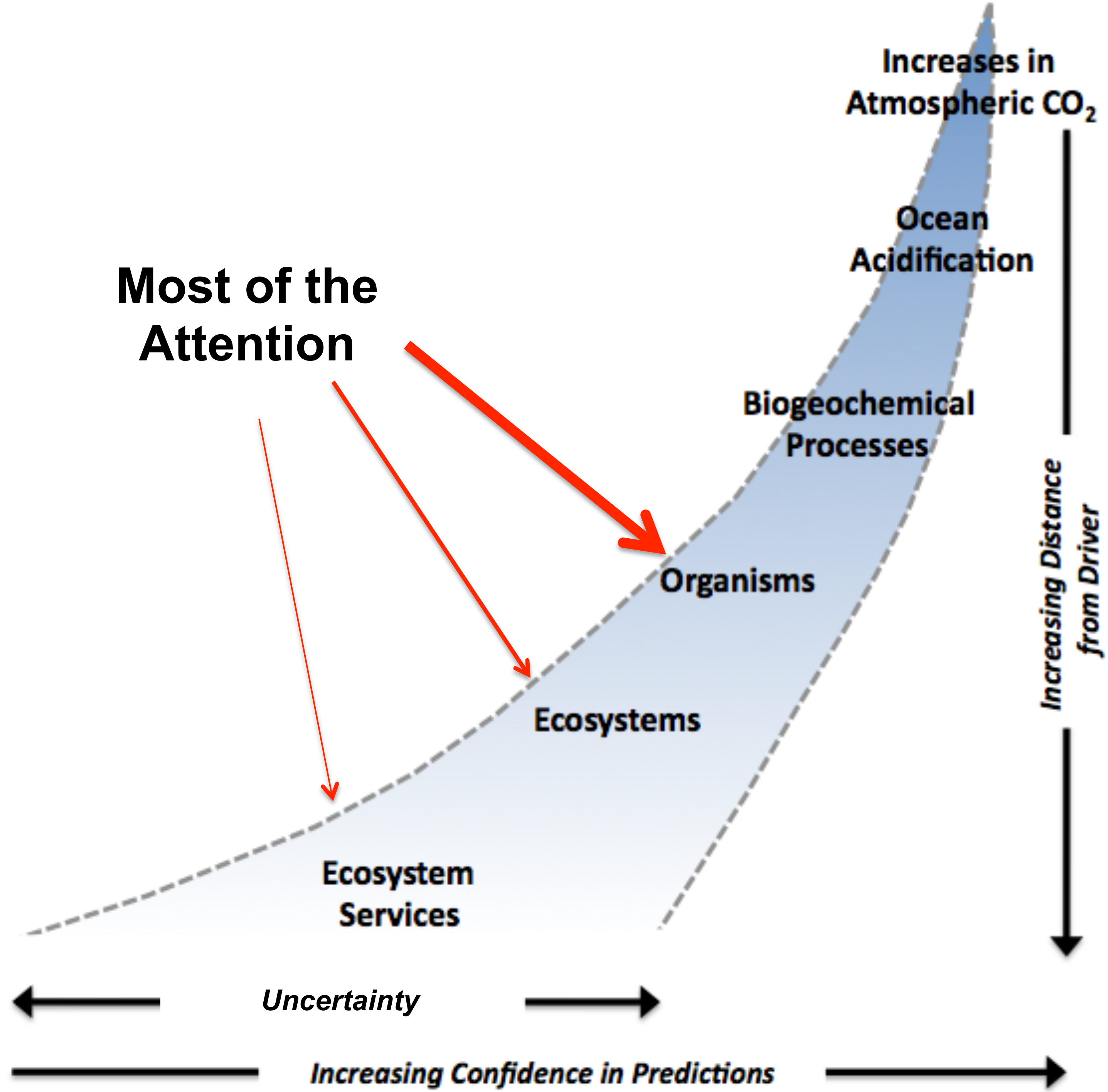
Ocean Acidification

A Suite of Changes
A Suite of Impacts

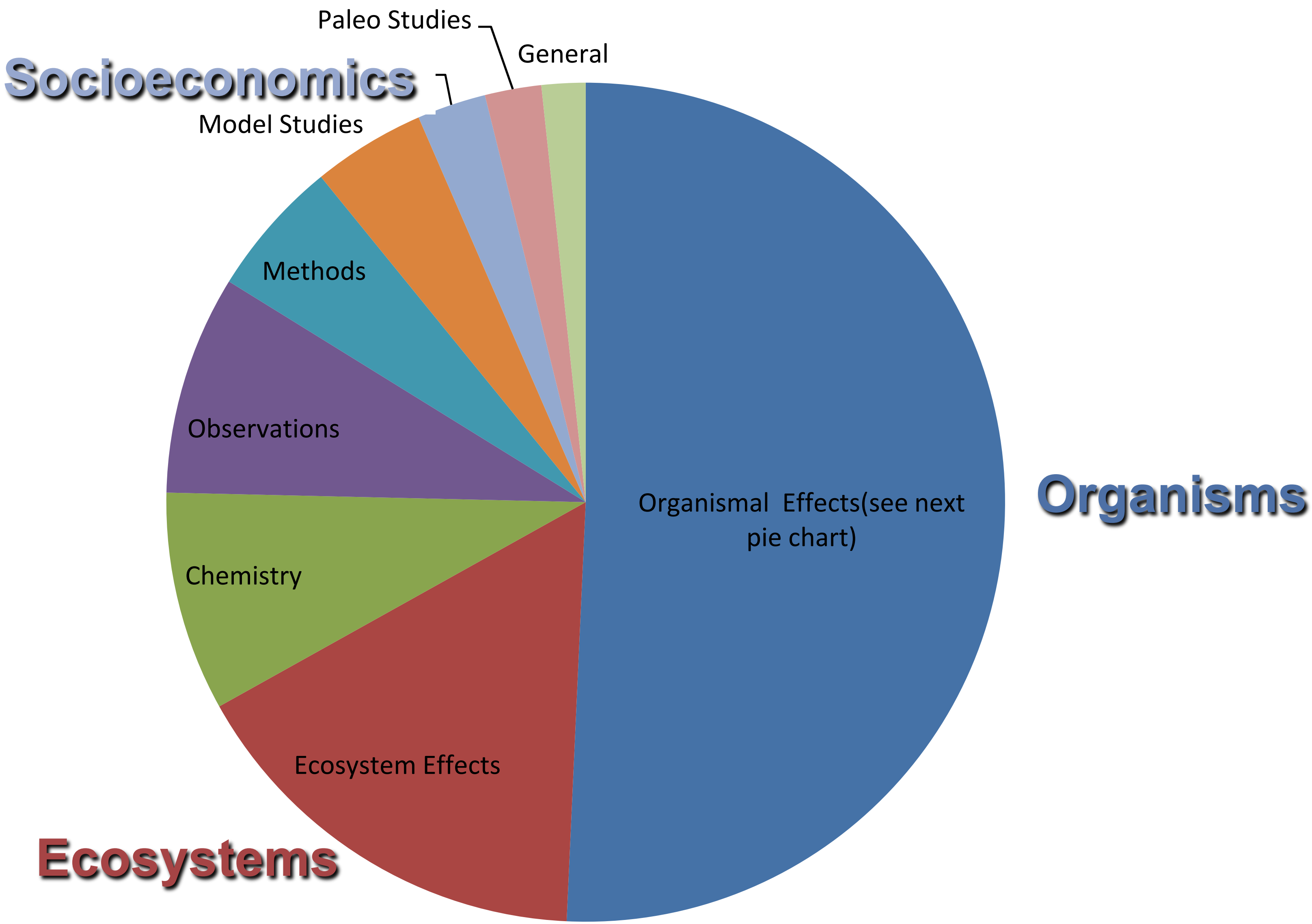
How Bad Will it Be?



Nick Anderson, Houston Chronicle

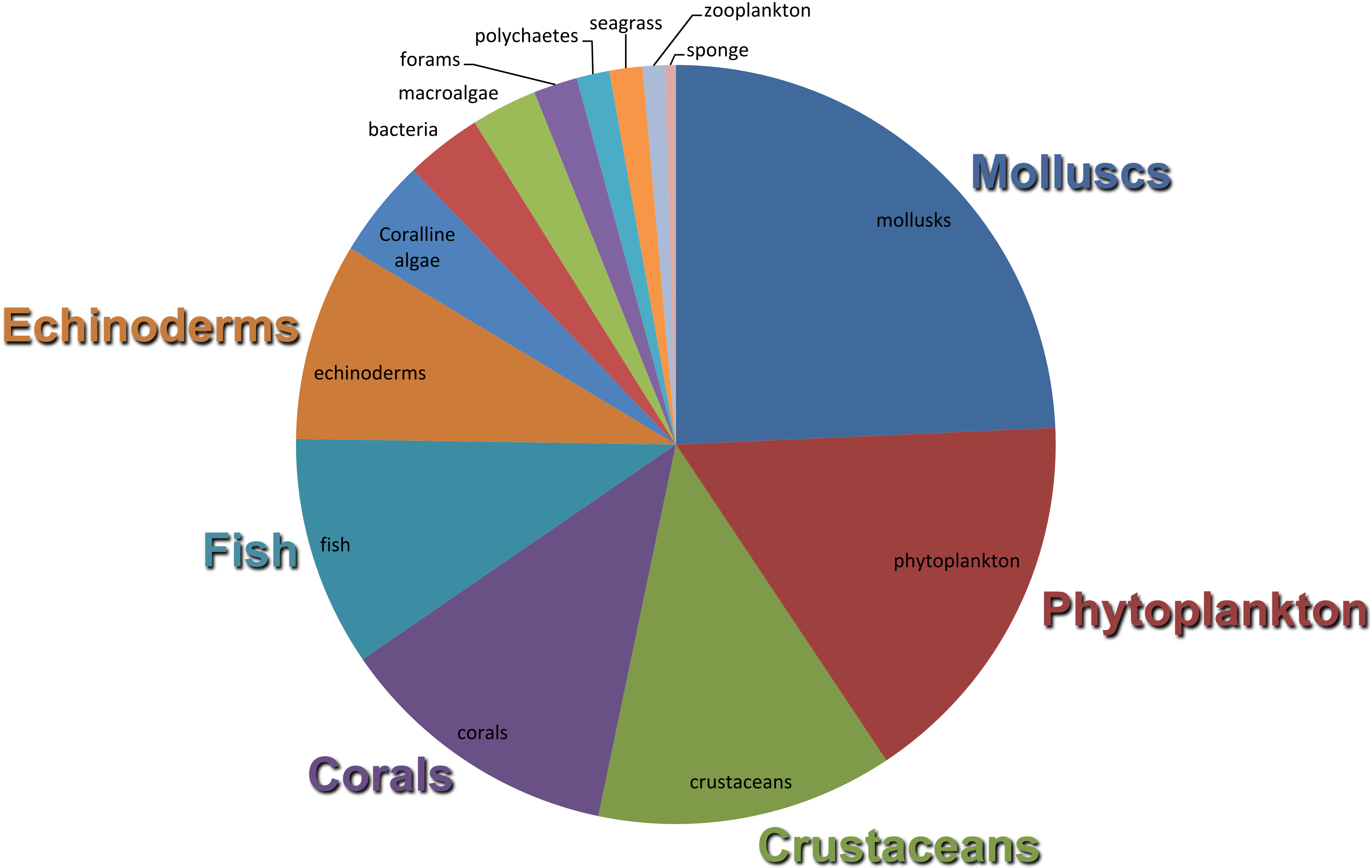

Increases in Atmospheric CO_2
Ocean Acidification
Most of the Attention
Biogeochemical Processes
Organisms
Ecosystems
Ecosystem Services
Increasing Distance from Driver
Uncertainty
Increasing Confidence in Predictions

Abstracts at the *Ocean in a High CO_2 World III*



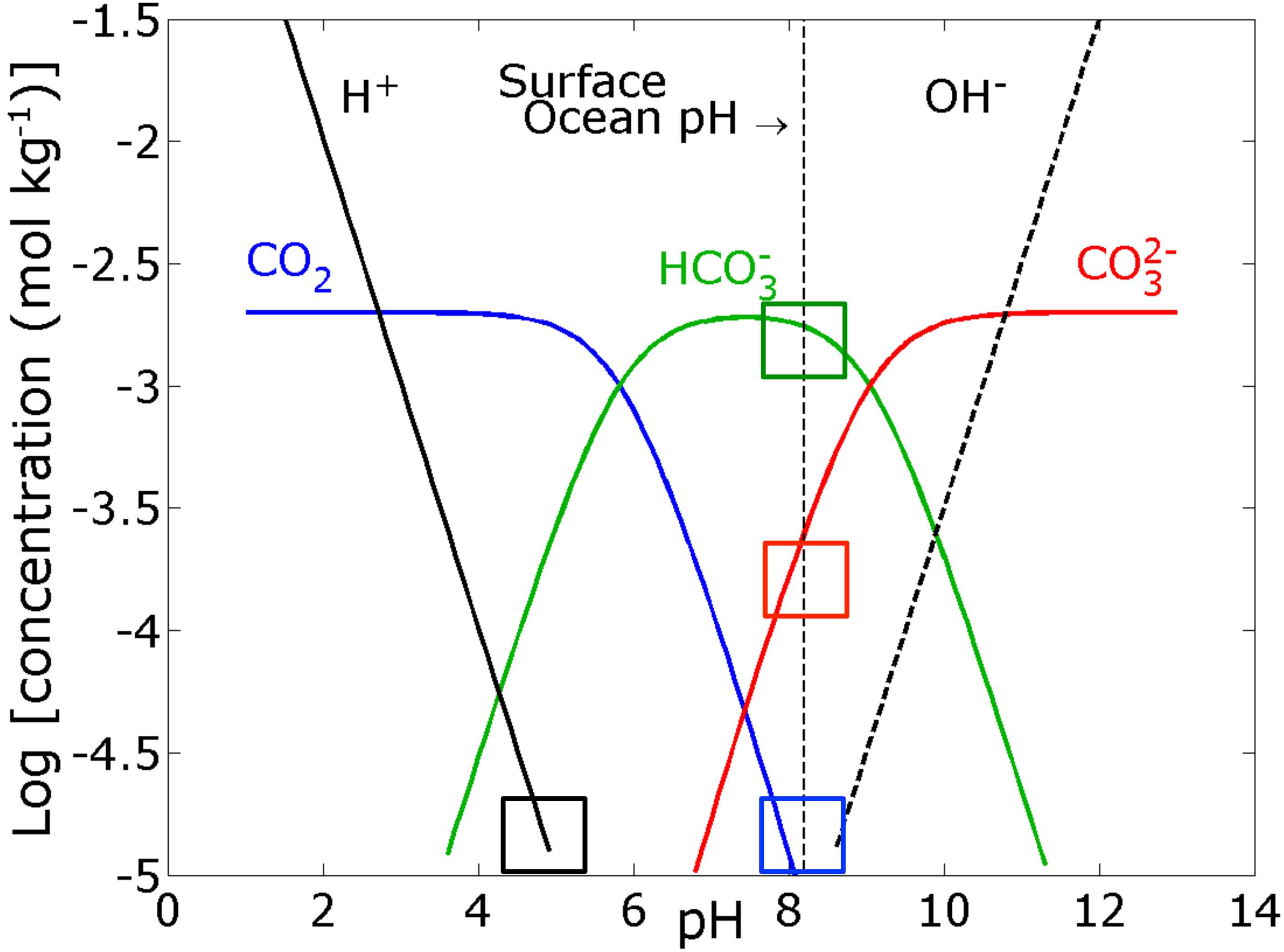
Compiled by Ed Urban

Breakdown by Taxon



Compiled by Ed Urban

Multiple Changes in the CO_2 System



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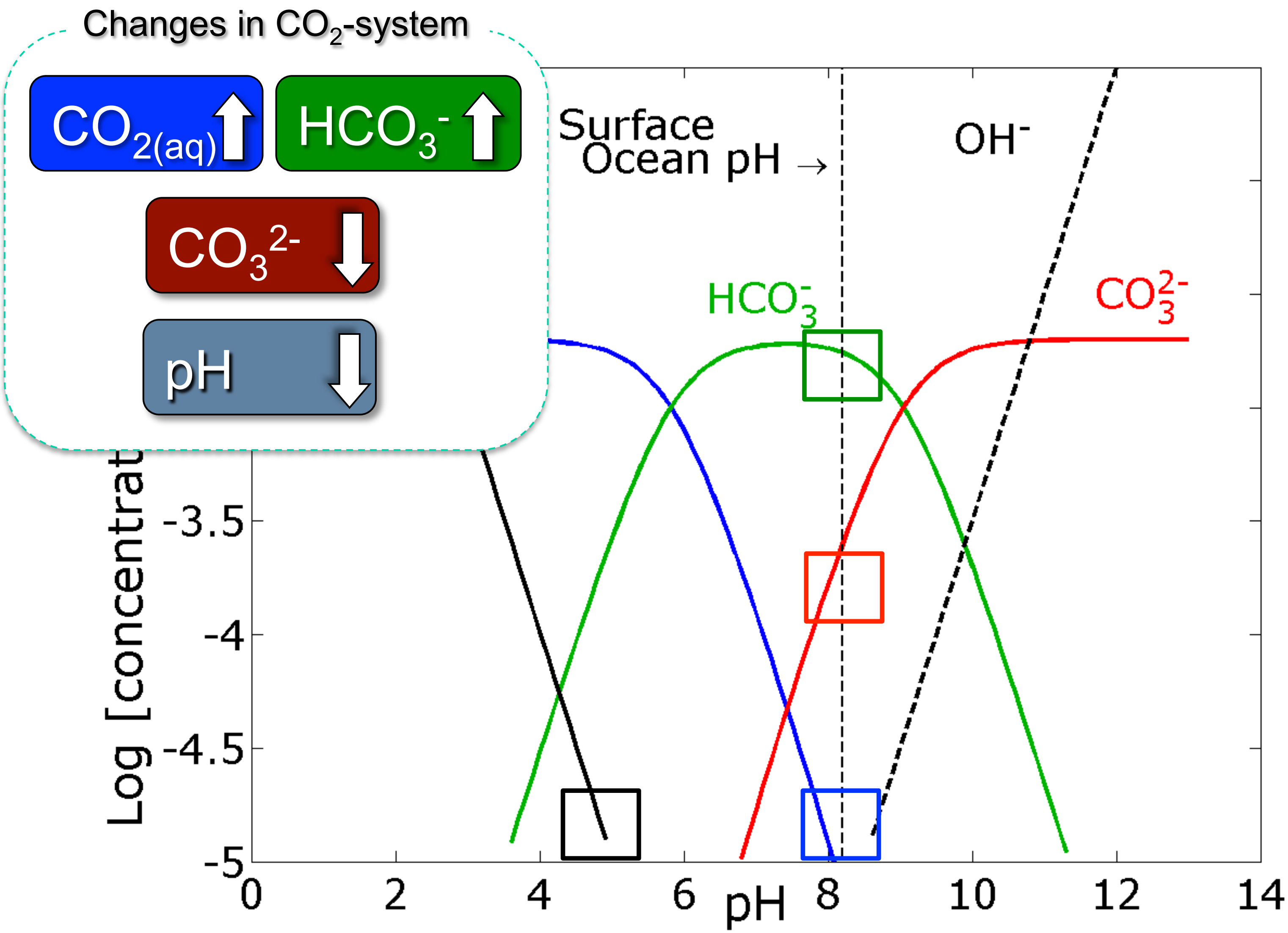


Multiple Effects on Marine Life

Changes in CO_2-system

- $CO_{2(aq)}$ ↑
- HCO_3^- ↑
- CO_3^{2-} ↓
- pH ↓

Direct Effects

Increase in photosynthesis

Decrease in calcification

Chemical speciation
Physiology

Indirect Effects

Biogeochemistry

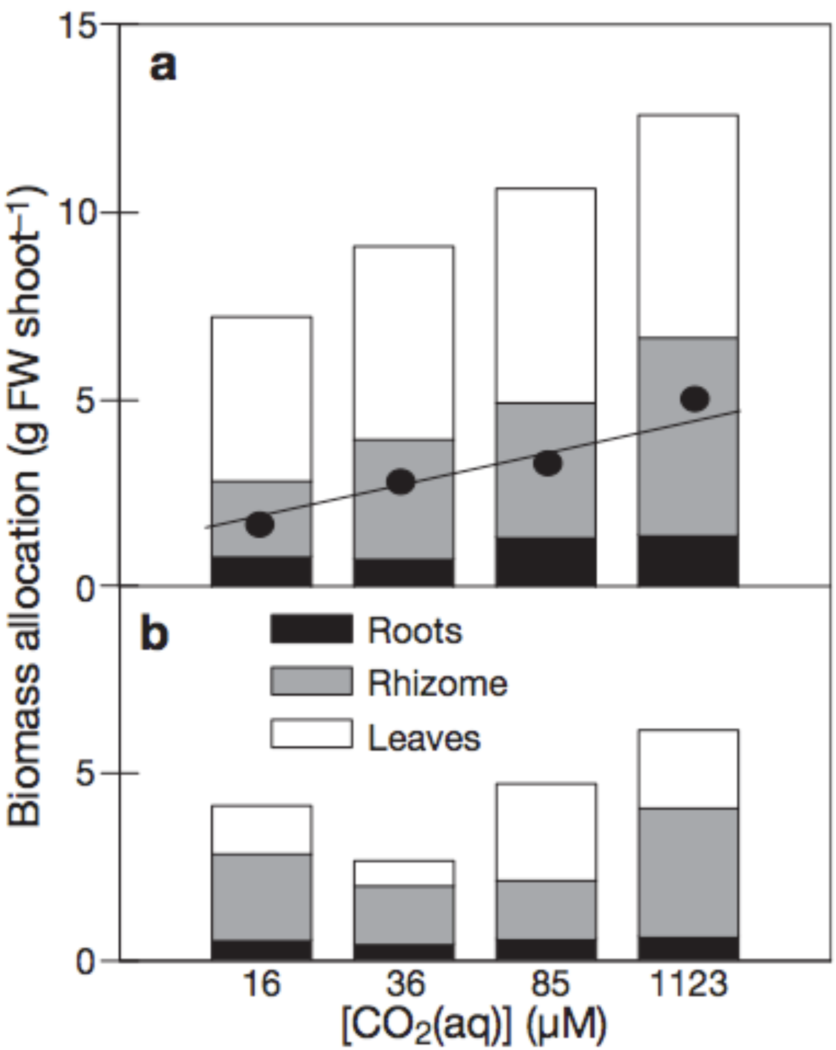
Food webs

Animal behavior

Ecosystem Engineering

$CO_{2(aq)}$ ⇧ HCO_3^- ⇧

Increased Biomass in Seagrasses



Light replete

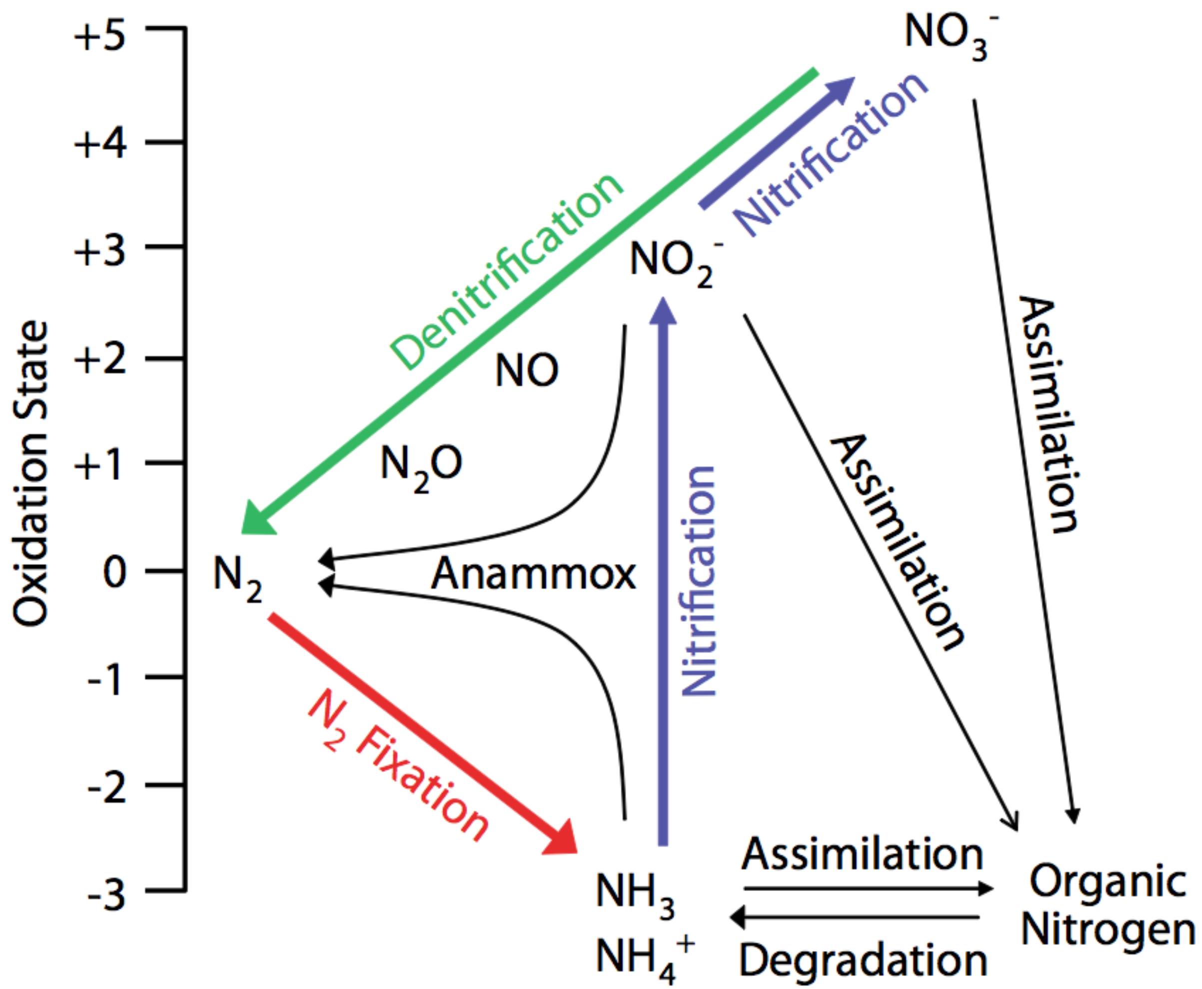
Light limited

Photo credit: NOAA

Palacios & Zimmerman (2007) *MEPS*

$CO_{2(aq)}$ ↑ HCO_3^- ↑

Effects on the Nitrogen Cycle



Hutchins et al. 2009 *Oceanography*

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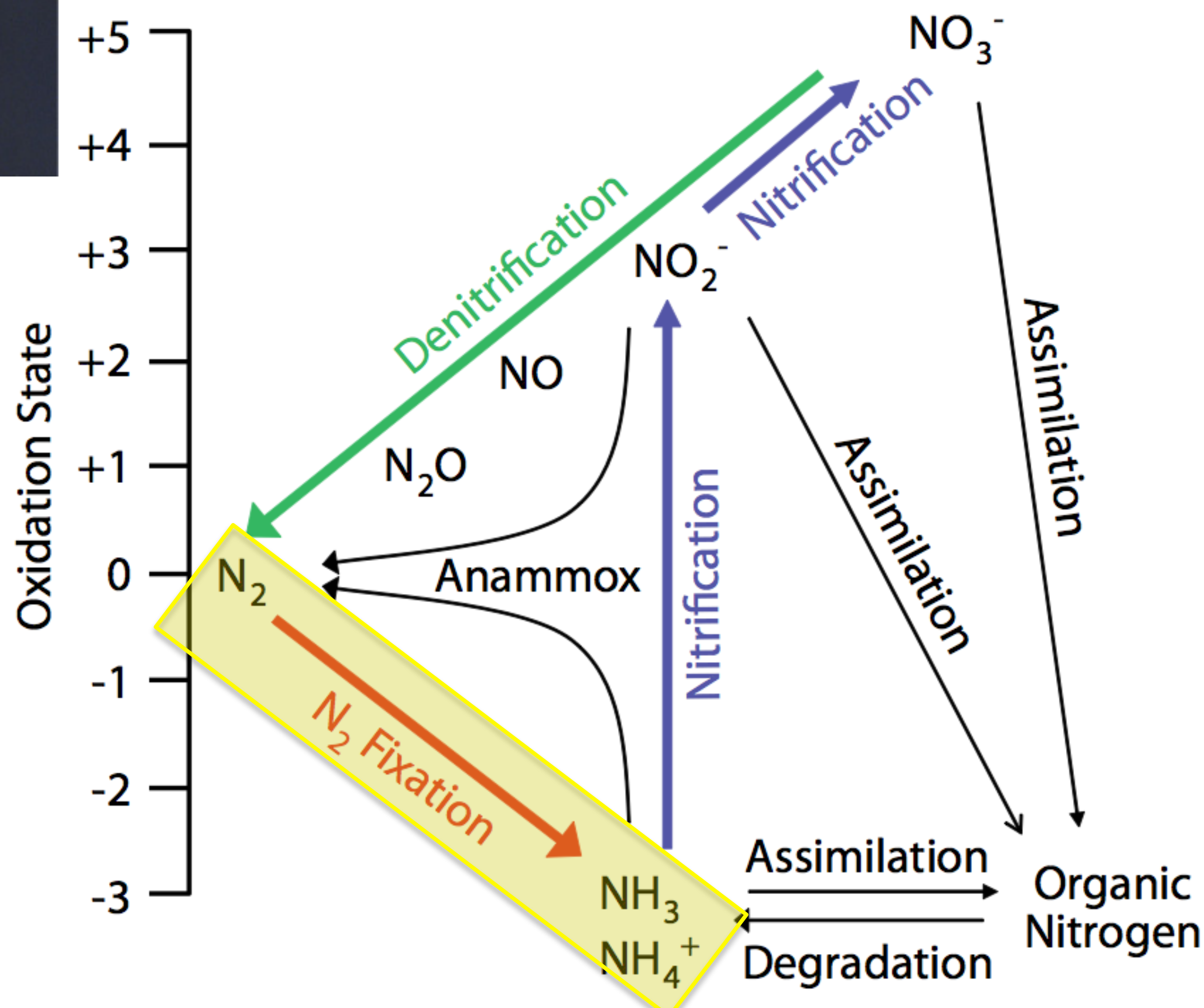

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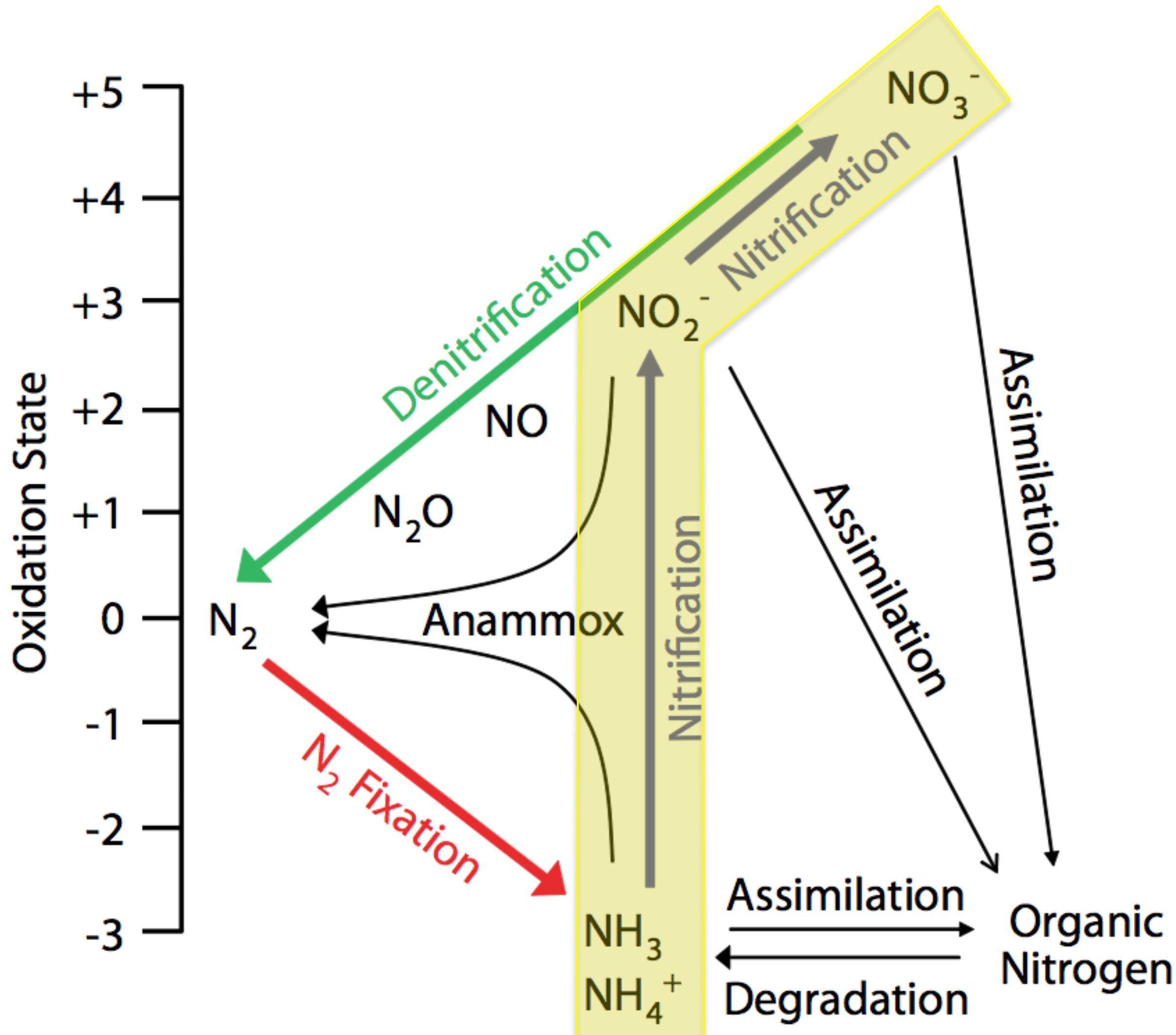

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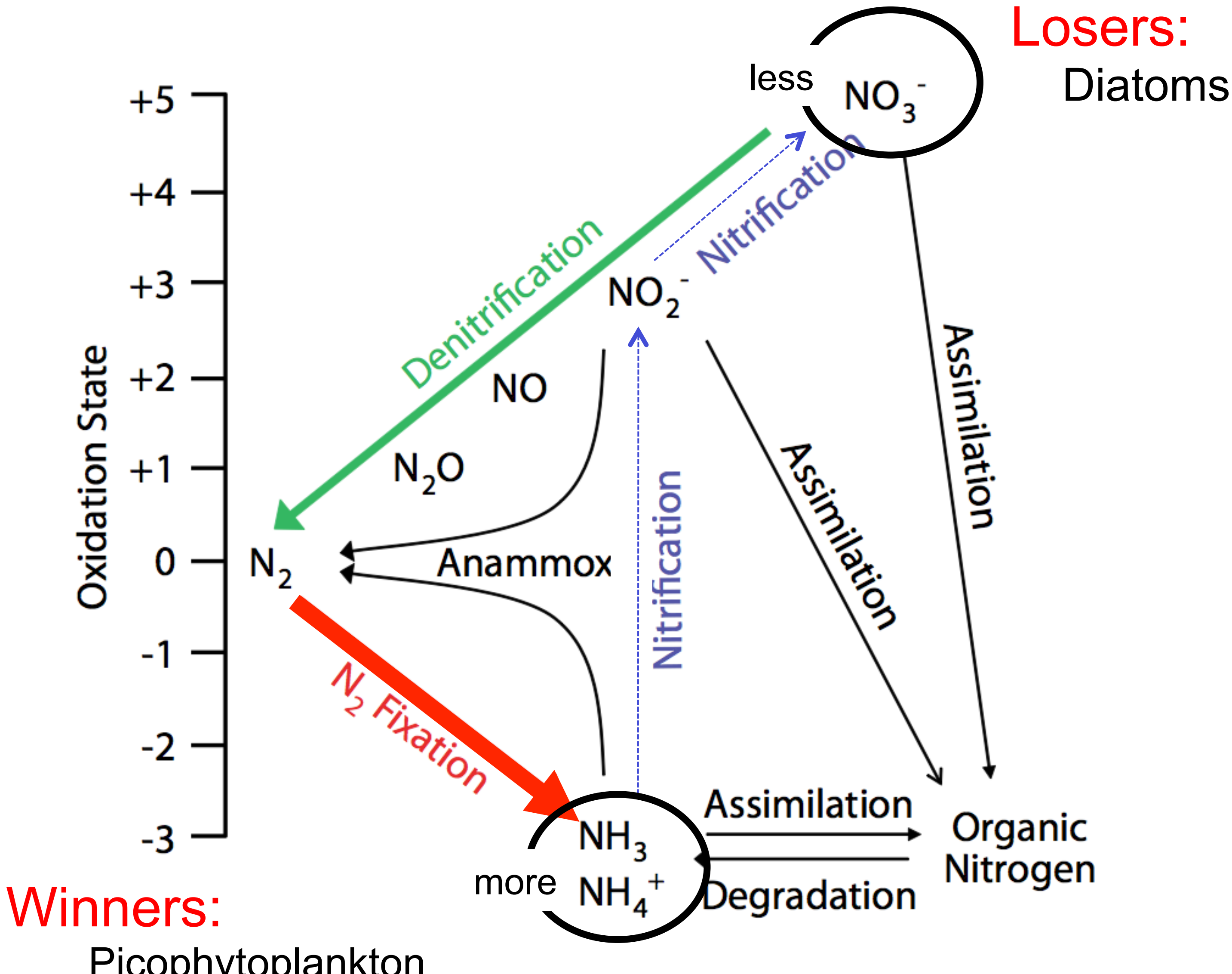
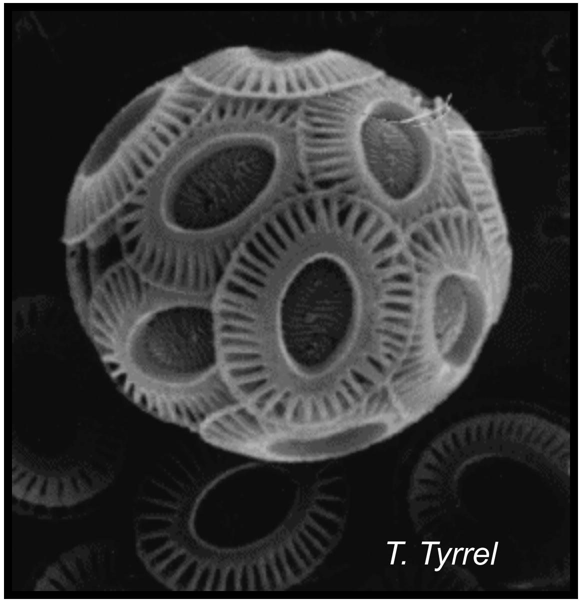
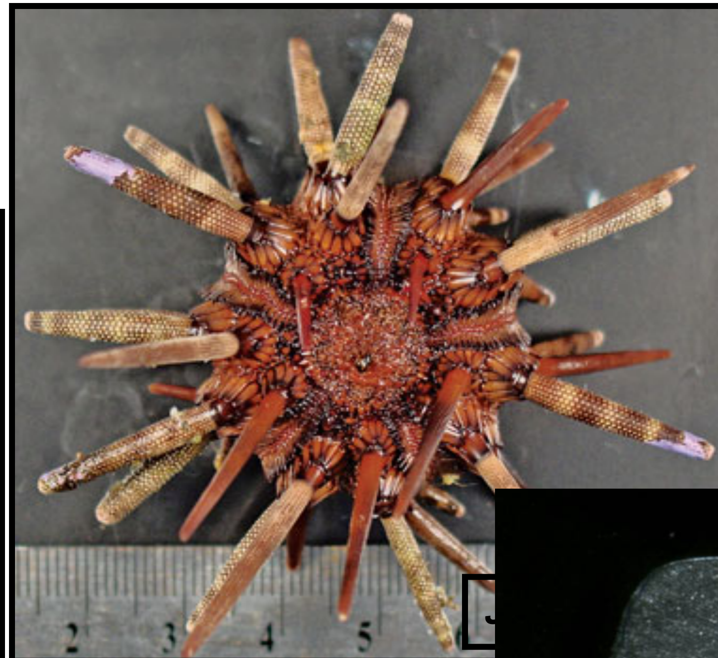
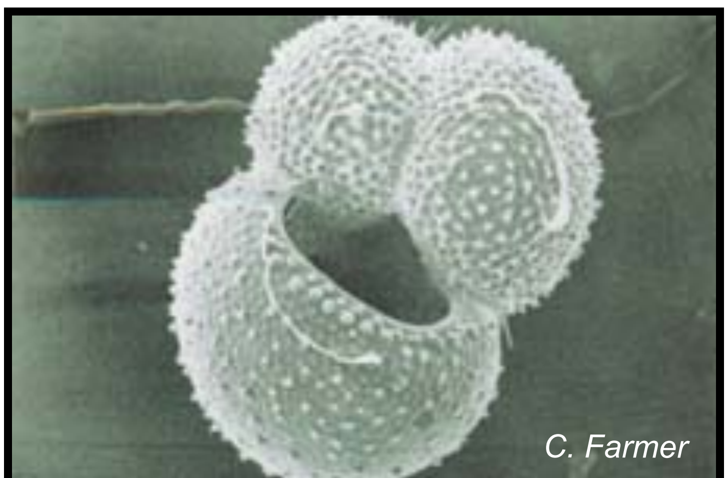


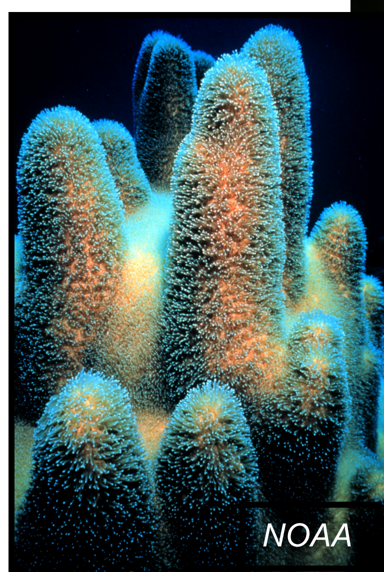
Hutchins et al. 2009 *Oceanography*

CO_3^{2-} ↓









CO_3^{2-} ↓ Effects on Calcification in Organisms

Calcification rate DECREASES in:

Tropical coralline algae
Some coccolithophores
Foraminifera
Scleractinian corals
Some echinoderms
Some mollusks (pteropods, some bivalves)

Calcification rate INCREASES in:

Some coccolithophores
Some echinoderms
Some crustaceans

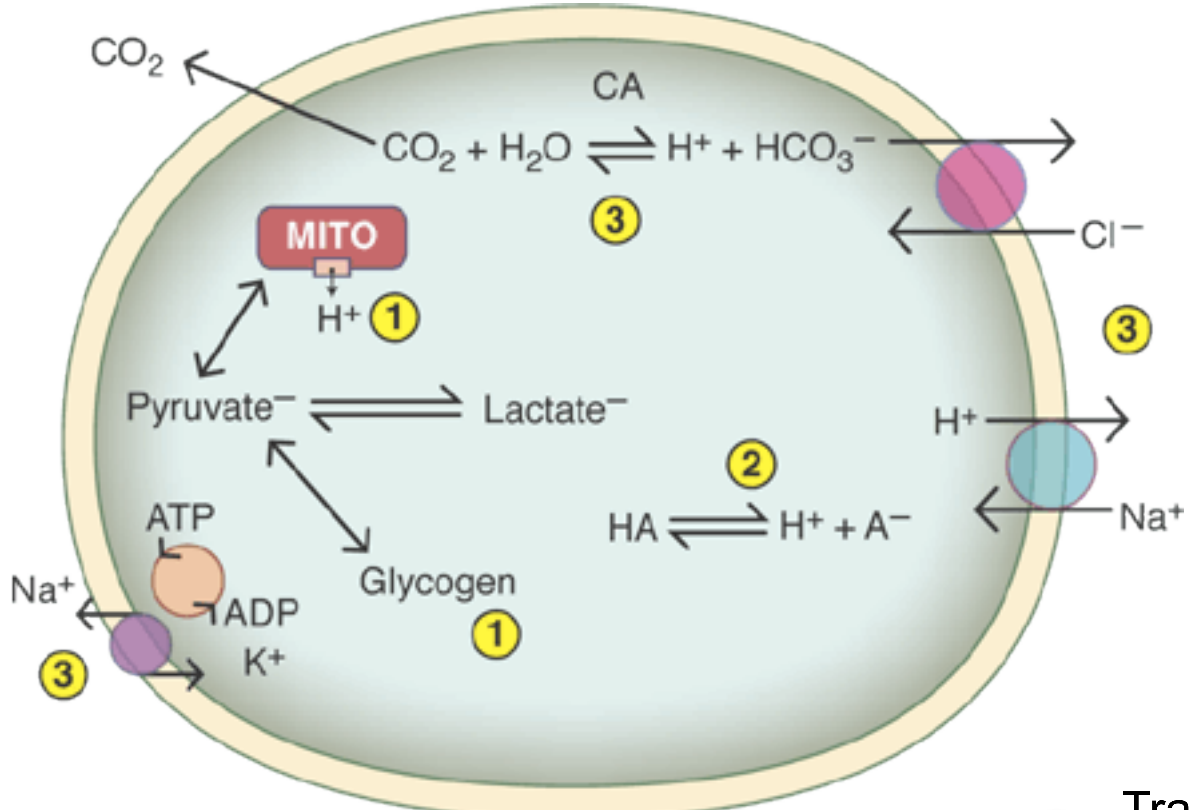
It's Complicated

- Mechanisms of calcification
- Mineralogy
- Presence of protective organic coatings
- Photosynthesis
- Feeding

pH ↓

Decreasing pH

Most organisms maintain internal pH



1 Metabolic interconversion of acids and bases

2 Buffering

3 Transport of acids and bases across cell membranes

Figure from Siebel & Walsh 2001, *Science*

pH

Decreasing pH

The master variable in biochemistry

Organisms spend energy to maintain internal pH

- ocean acidification will either affect:
  - an organism's internal acid-base balance
  - their metabolic costs to maintain it (Fabry et al. 2008)

Abilities of organisms to buffer pH changes varies widely

- effects of ocean acidification on organism physiology will also vary

Decreasing pH poses several important *indirect* effects on organisms

- bioavailability of trace elements (Shi et al. 2010)
- increases in respiratory CO_2 (Brewer & Peltzer 2009)
- increased toxicity of copper (Millero et al. 2009)

Changes in CO_2-system

$CO_{2(aq)}$ ↑

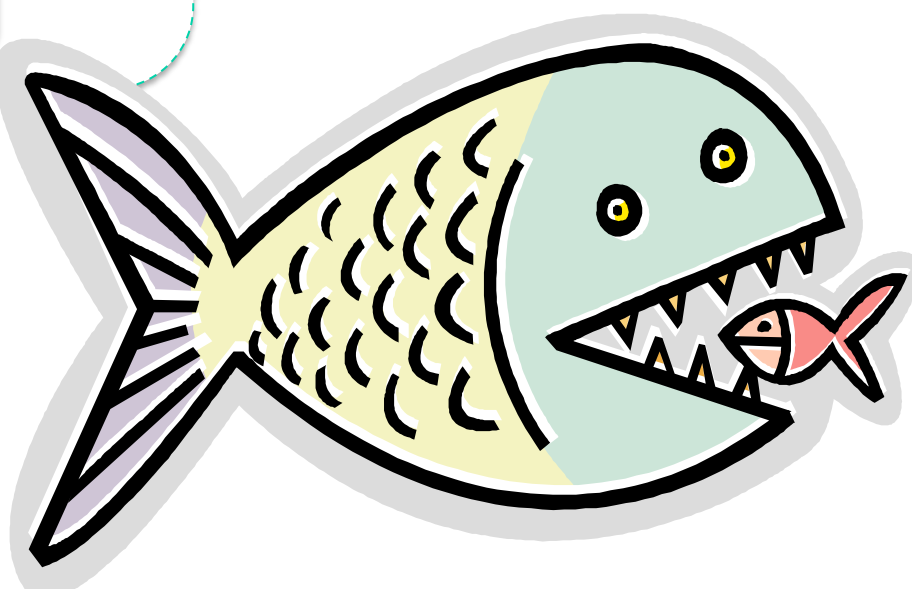
HCO_3^- ↑

CO_3^{2-} ↓

pH ↓

Multiple Effects

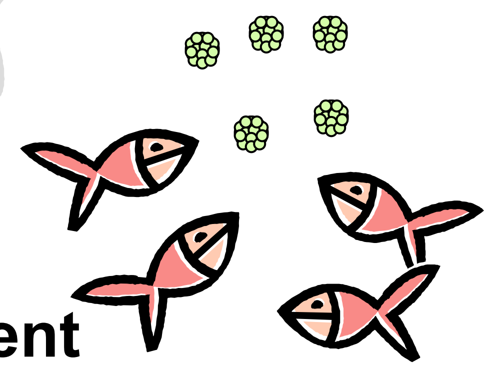
- Acting simultaneously -



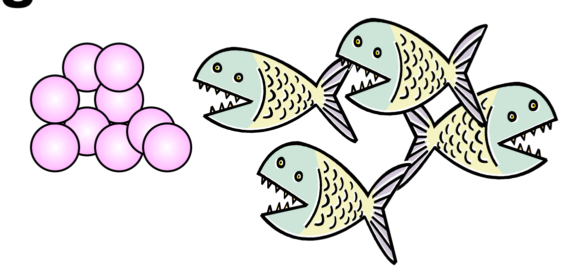
Physiology:

Respiration rate
Blood chemistry
Energy allocation
Photosynthesis
Calcification
Reproduction
Chemoreception

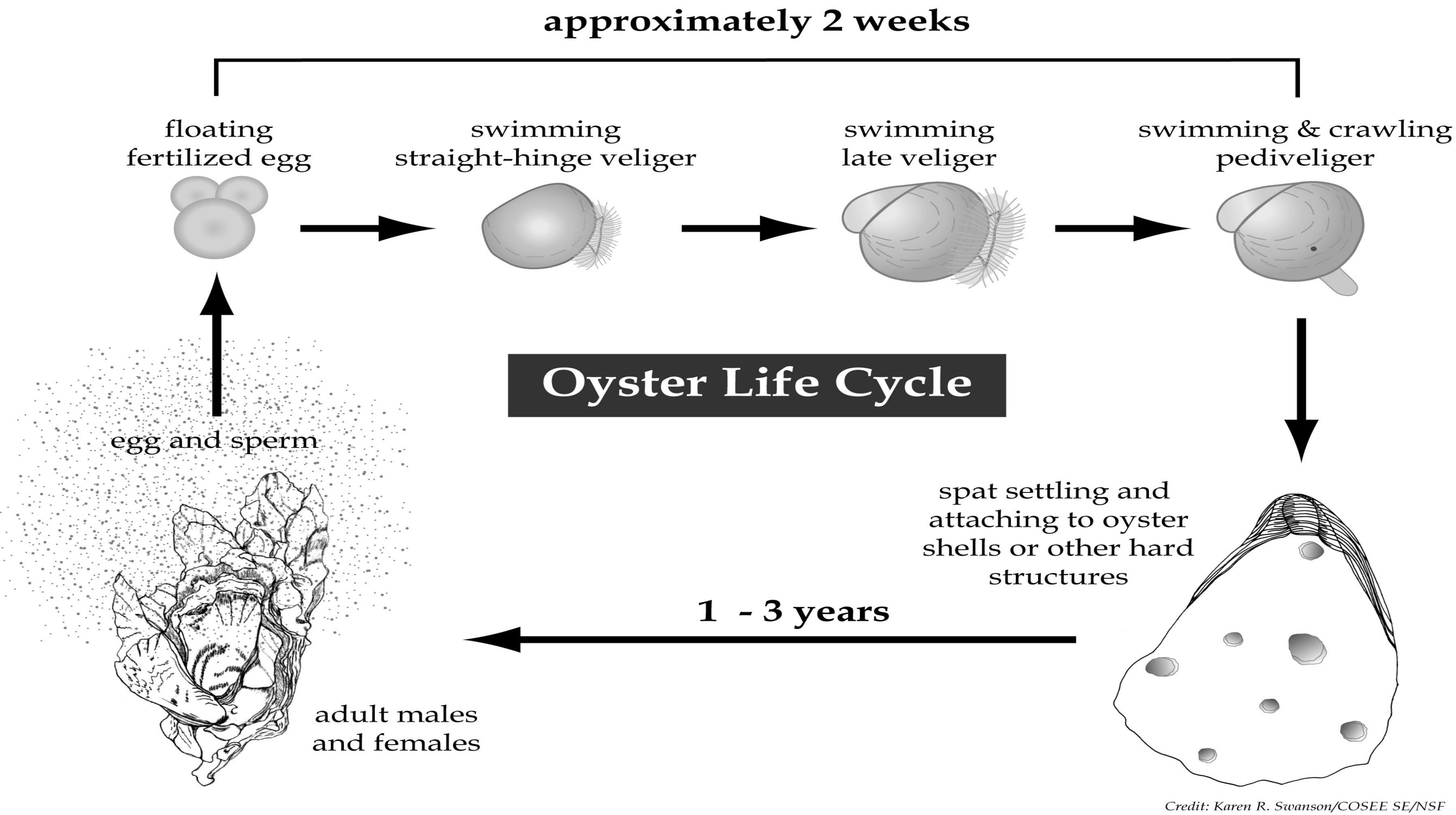
Food Supply



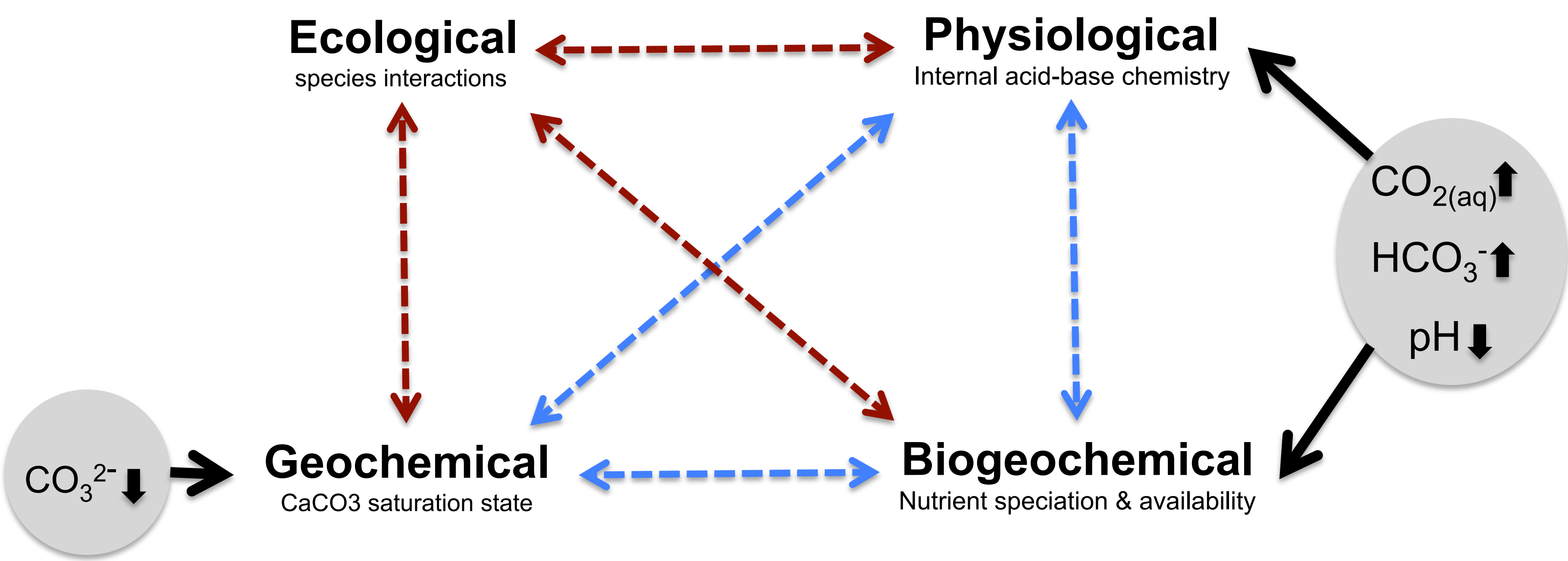
Eggs – Larvae – Recruitment



Life Cycle Effects



Multiple Changes
Direct & Indirect Effects



Predicting impacts is taking time:

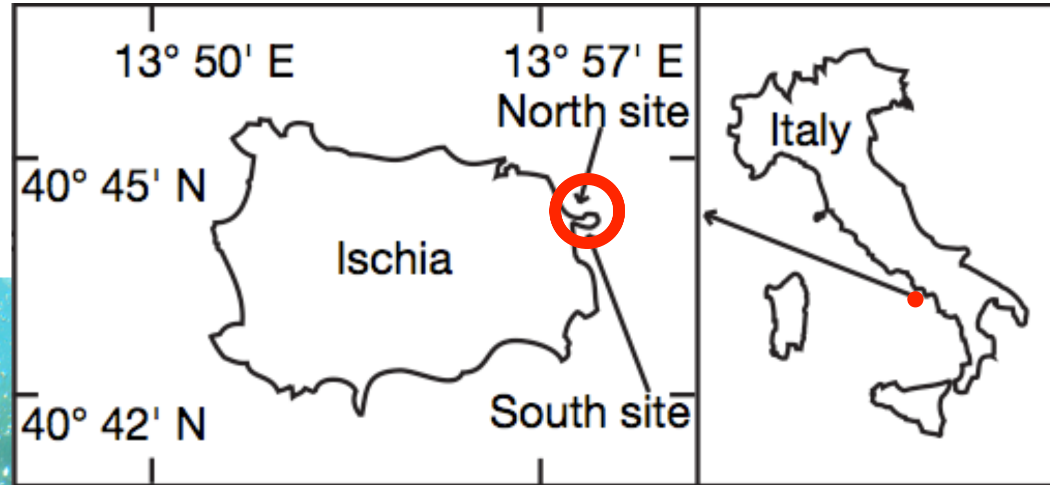
Complex life cycles
Generational effects
Adaptation (or not)
Multiple stressors
Ecosystem complexity (species interactions)
Our plain old ignorance of the ocean

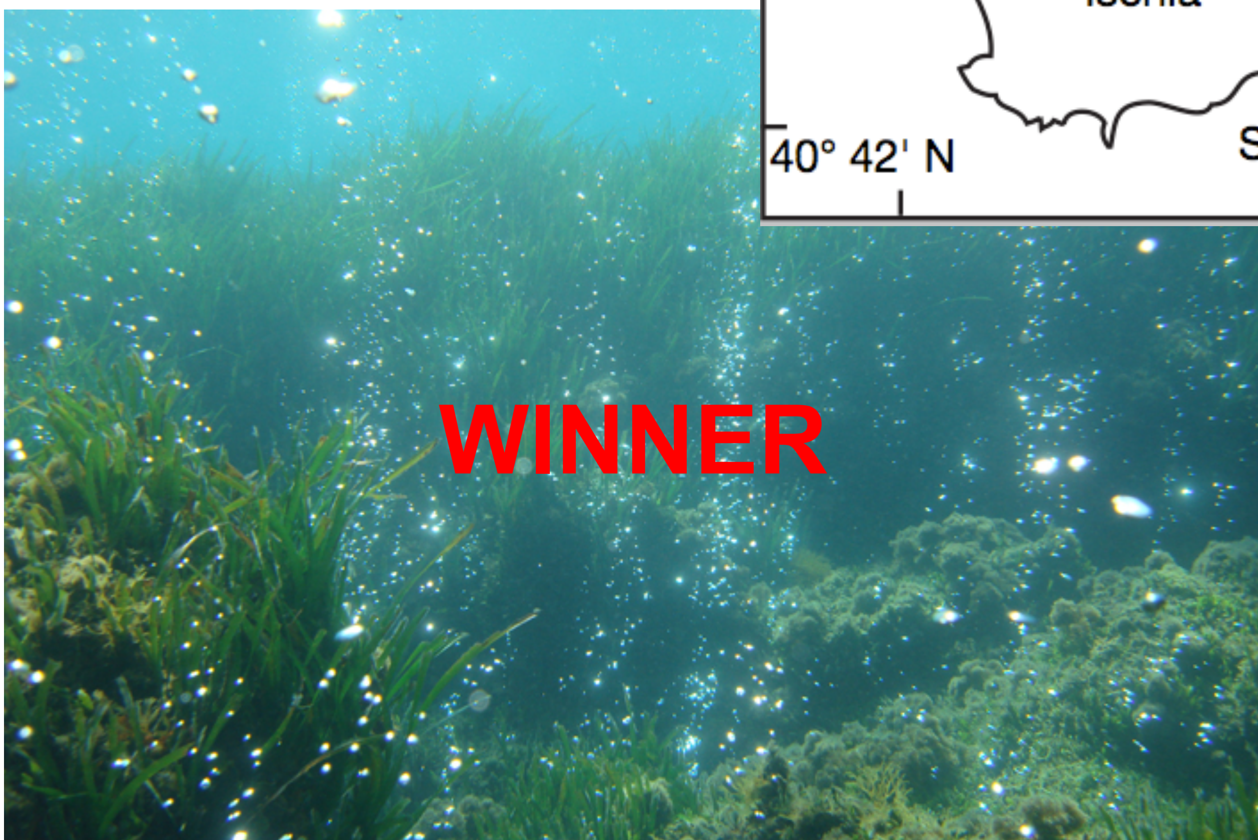
Ocean Acidification

Ecosystems

Natural ocean acidification

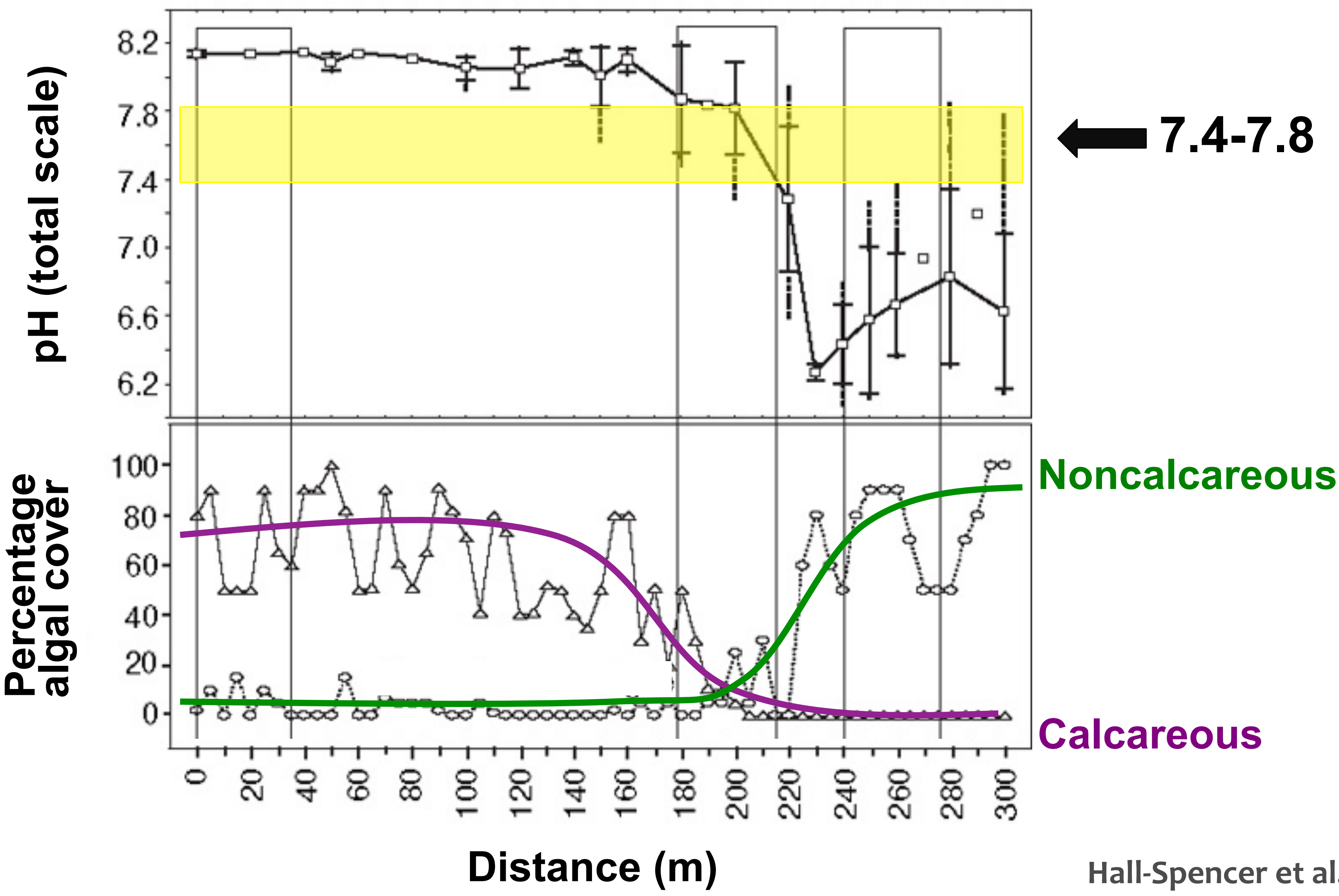
CO_2 vents off Italy





Hall-Spencer et al.
(2008) *Nature*

Community Shifts with Decreasing pH



Hall-Spencer et al. (2008) *Nature*

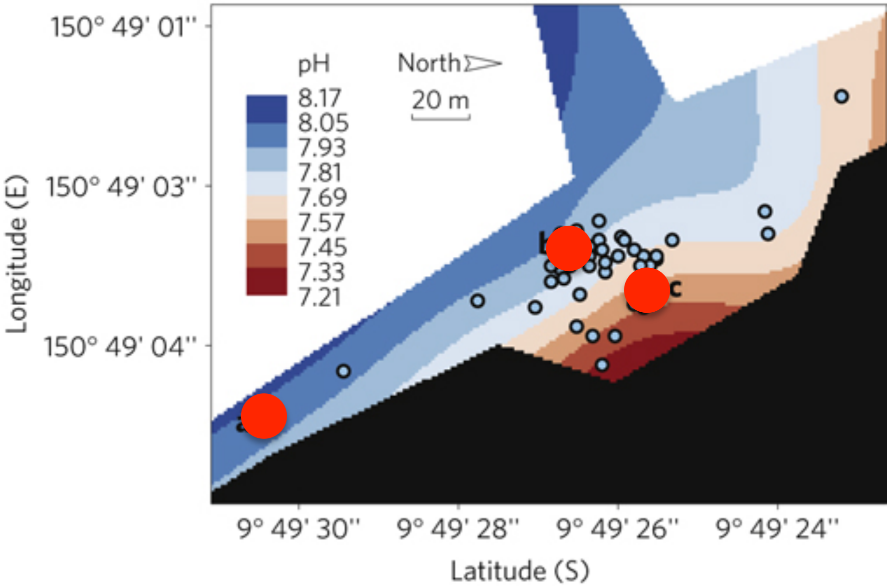
Natural ocean acidification

CO_2 vents off Papua New Guinea

a

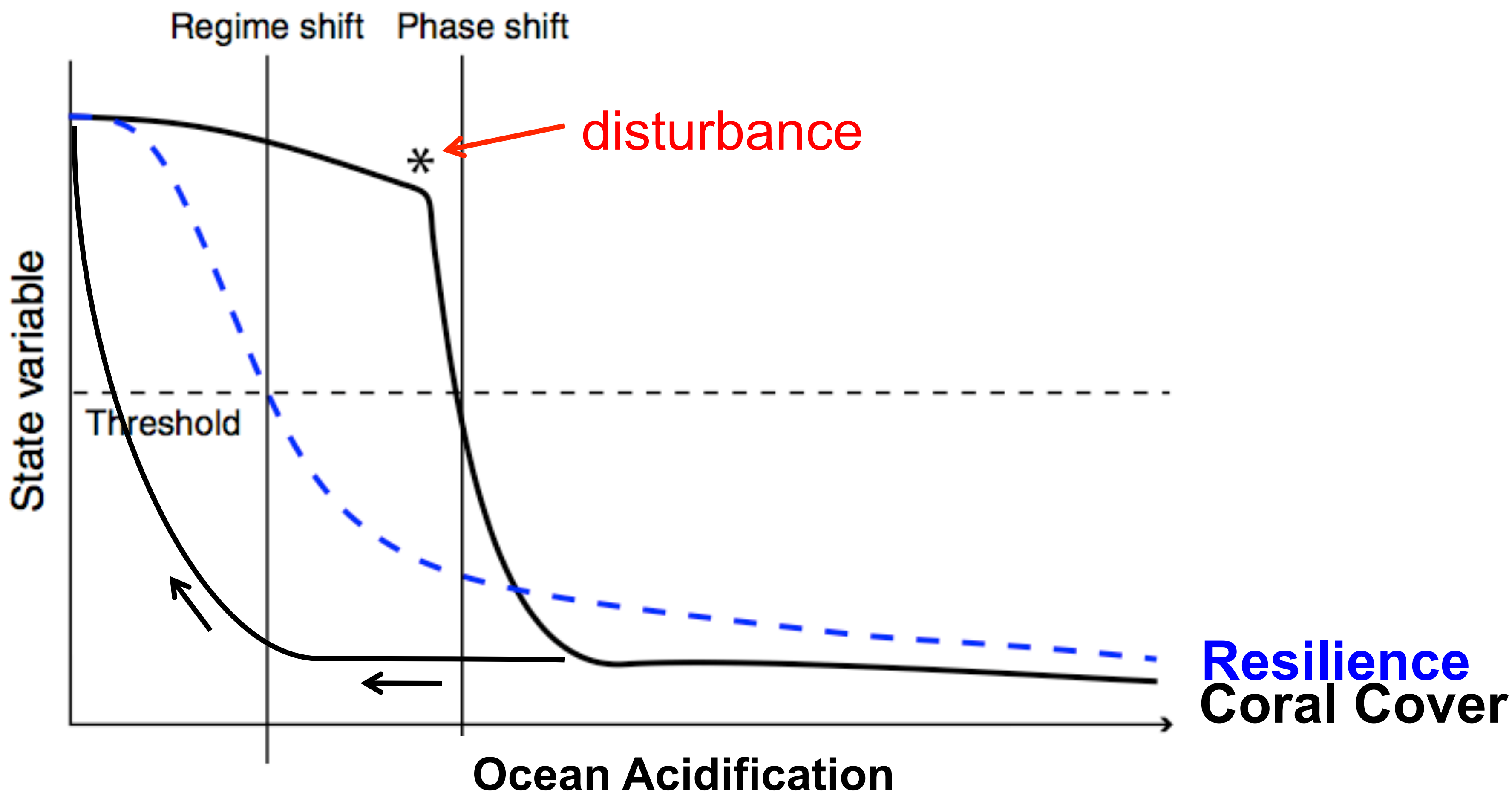
b

c



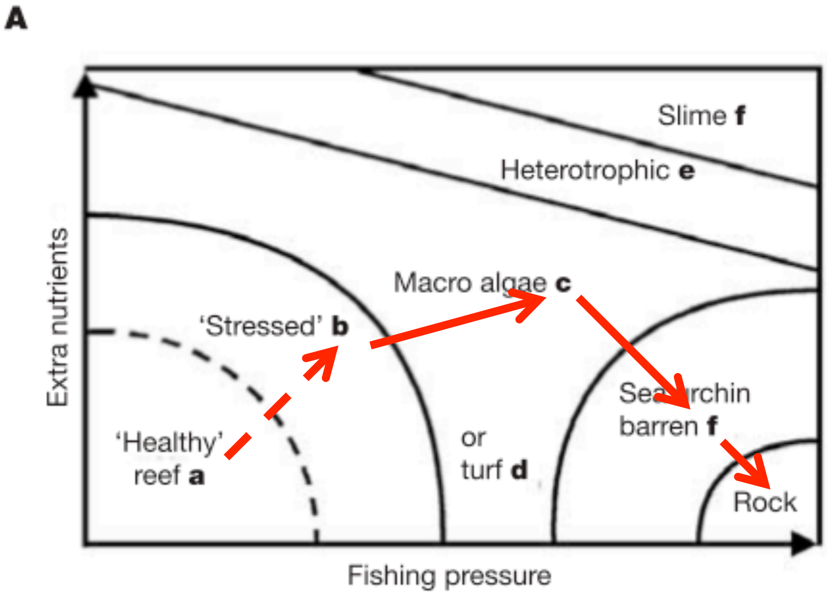
Fabricius et al. 2011 *Nature Climate Change*

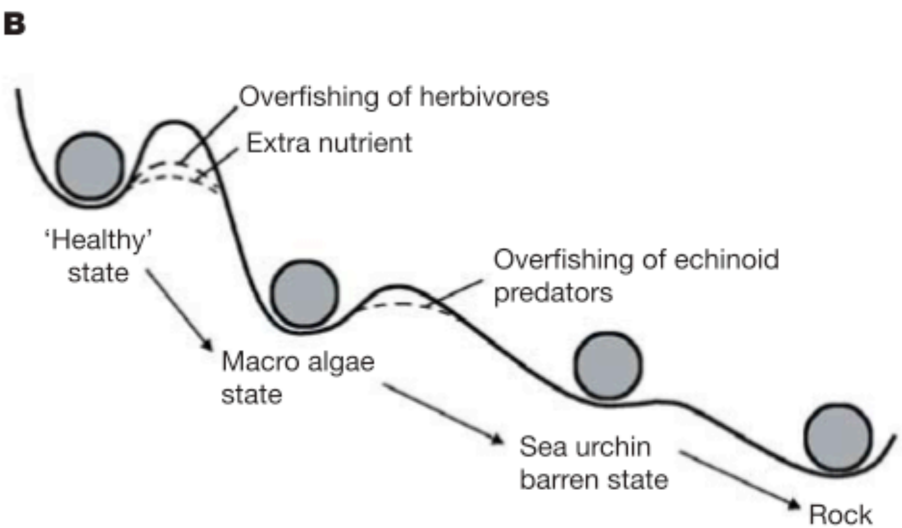
Resilience, Thresholds
Phase Shifts and Regime Shifts

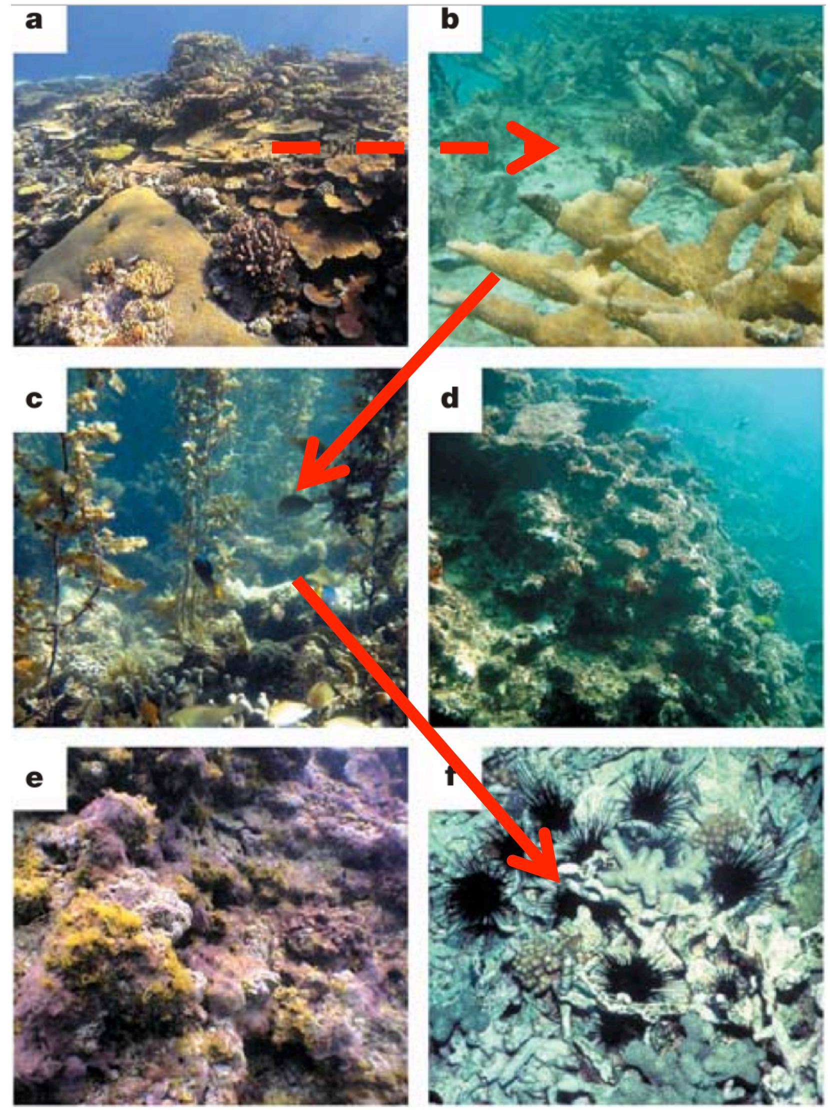


Nyström et al. (2008)
Coral Reefs

Alternative Stable States in Coral Reefs







Bellwood et al. (2008)
Nature

Can We See A Regime Shift Coming?

DETECTION / PREDICTION

1. **Increased variance**

2. **Slower recovery following disturbance**

3. **Monitoring resilience:**
   a) functional groups (e.g. grazers)
   b) demographic skewness in populations
   c) discontinuities (e.g. redundancy)

4. **Indicators**

   e.g. ratios of “good” colonizers versus “bad” colonizers

5. **Tracking local phase shifts within an ecosystem network**

Reviewed by

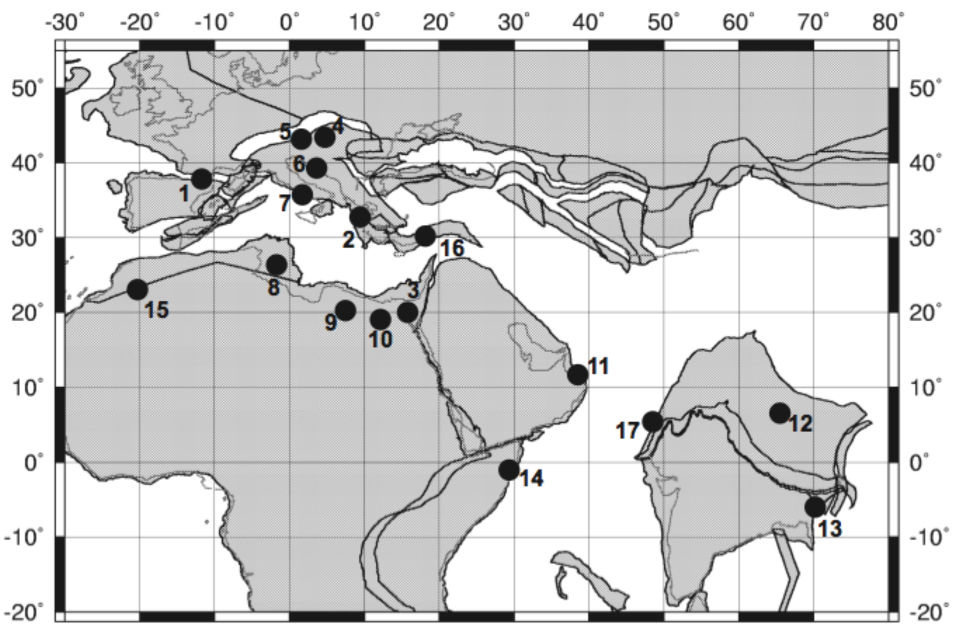
Nyström et al. (2008) *Coral Reefs*

Scheffer et al. (2009) *Nature*

Ocean Acidification

Has this Happened Before?

Late Paleocene Reefs



Reefs were already declining due to warming temperatures

Reefs were replaced by foraminiferal facies at the PETM boundary

No.	Area	Paleo-latitude	Paleocene: P. stage I	Paleocene: P. stage II	Eocene: P. stage III
5	N Calcareous Alps	43°N	coralgal reefs	coralgal reefs	larger foraminifera, individual corals
4	W Carpathian	43°N	coralgal reefs	coralgal reefs	destruction of platform
6	N Adriatic Platform	38°N	coralgal reefs	coralgal reefs	larger foraminifera, individual corals
1	Pyrenean	38°N	coralgal reefs	individual corals, larger foraminifera	larger foraminifera, coralgal reefs
7	Maiella	35°N	coralgal reefs	coralgal reefs, destruction of platform	larger foraminifera, individual corals
2	Ionian Island	32°N	coralgal reefs	coralgal reefs	larger foraminifera
8	Tunisia	26°N	shales, evaporates, phosphates	shales, evaporates phosphates	larger foraminifera
15	W Morocco	23°N	oysters	oysters, bryozoans, echinoids	oysters, bryozoans, echinoids
3	Galala (Egypt)	20°N	coralgal reefs	larger foraminifera	larger foraminifera
9	Sirte Basin (Libya)	20°N	coralgal reefs	coralgal reefs ?, larger foraminifera	larger foraminifera
10	W. Desert (Egypt)	19°N	coralgal reefs	individual corals, hemipelagic sediments	larger foraminifera, individual corals
11	Oman	12°N	no information?	larger foraminifera, individual corals	larger foraminifera, individual corals
13	NE India	5°S	larger foraminifera	larger foraminifera	larger foraminifera, individual corals
12	Tibet	5°N	coralgal reefs, larger foraminifera	larger foraminifera	larger foraminifera
17	NW India	5°N	coralgal reefs	coralgal reefs, larger foraminifera	larger foraminifera
14	NW Somalia	0°	coralgal reefs	individual corals, individual corals, larger foraminifera	larger foraminifera, individual corals

Latitude markers: 45°, 30°, 20°, 0°

Legend: coralgal reefs; individual corals; larger foraminifera; oysters; bryozoans; echinoids

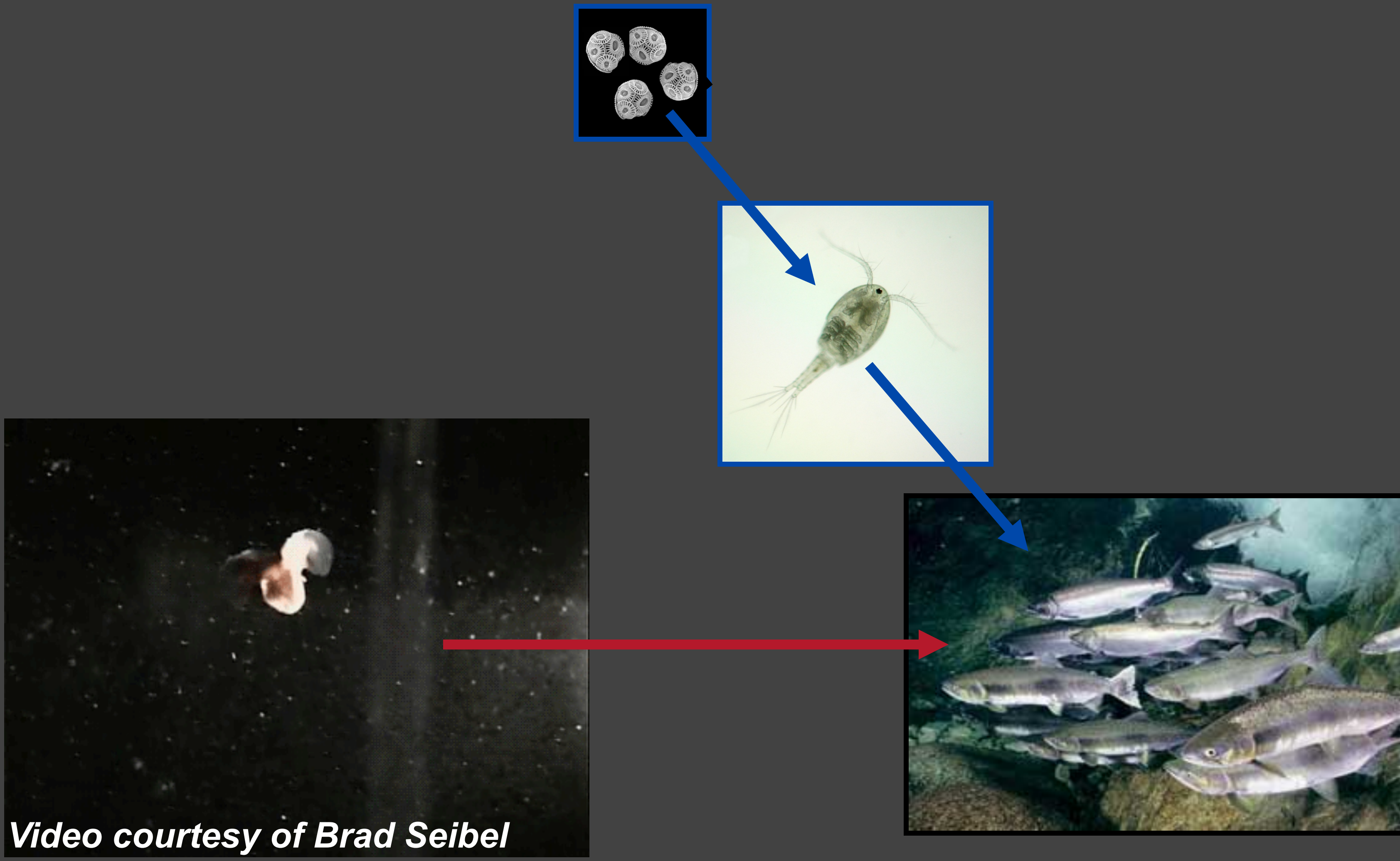
Facies colours: coralgal reefs | larger foraminfera I | larger foraminfera II | exceptional facies

Scheibner & Speijer *eEarth* 2008

Ocean Acidification

What Provokes Attention?

Effects on Fish



Effects on Fisherman

Homer Alaska: commercial fishermen, mariners and others spelled out ‘SOS’ to protect jobs and fisheries from the threat of ocean acidification.

‘Voices for the Ocean’ hosted by the Alaska Marine Conservation Council (AMCC) and the Sustainable Fisheries Partnership (SFP).

Commercial Hatcheries

Paleocene-Eocene Thermal Maximum

Physical changes:

Ocean temperature ↑ 5-8ºC

Marine and terrestrial C Isotopes ↓ 3-8‰

Calcium Carbonate Compensation Depth ↑ 2 km

Biological responses:

Dramatic reorganization of marine and terrestrial ecosystems

marine: benthic foraminifera - 35-50% of deep-water species went extinct (Thomas 1998)

plankton - high species turnover (Gibbs et al 2006)

REEFS: demise of coral-algal reefs, large calcitic foraminifera flourished (Scheibner & Speijer Earth Sys. Rev. 2008)

land: Mammalian radiation

Reorganization of terrestrial plant communities (Wing et al. *Science* 2005)