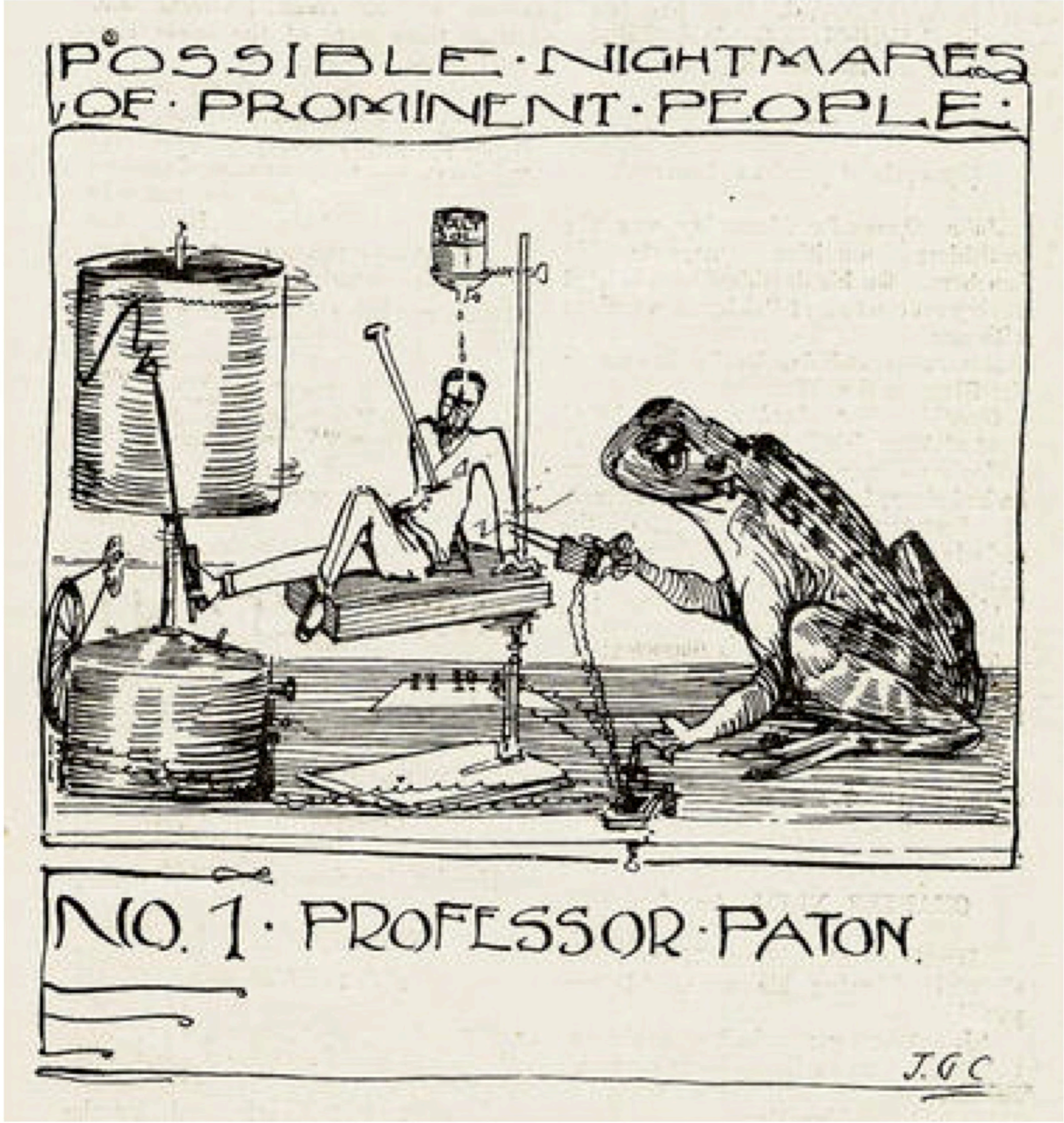
Physiological Responses

- Unicellular/Algae -



John Gallagher, DVM

Physiological Responses

- Unicellular/Algae -

PHYTOPLANKTON

En-Gen: A functional genomic analysis of how a major calcifying phytoplankter [*E huxleyi*] responds to ocean acidification predicted for the end of the century (Ed Carpenter)

A systems biology approach of diatom responses to ocean acidification and climate change (Orellana/Ashworth/Lee/Armbrust/Baliga)

Effects of pCO_2 and pH on photosynthesis, respiration and growth in marine phytoplankton (Hopkinson/Morel)

Effects of ocean acidification on nutrient availability and requirements in phytoplankton (Morel)

Changing phytoplankton trace metal requirements in a high CO_2 ocean (Fu)

CO_2 control of oceanic nitrogen fixation and carbon flow through diazotrophs (Hutchins/Mulholland/Warner)

Oceanic diazotroph community structure and activities in a high CO_2 world (Church/Letelier)

Structural, functional, and ecological characterization of the *Prochlorococcus* carboxysome, the ocean's primary molecular module for carbon fixation (Kerfeld/Salmeen/Ting/Heinhorst/Cannon)

Experimental studies to understand and evaluate acclimation of marine plankton assemblages to increased CO_2 and temperature (Schnetzer)

Physiological Responses
- Unicellular/Algae -

Interactive effects of temperature, nutrients, and ocean acidification on coral physiology and calcification (Warner/Grottoli/Cai)

Influence of temperature and acidification on the dynamics of coral co-infection and resistance (Harvell/Burge/Mydlarz/Weil)

Phytoplankton nutritional value for fishery-based food webs (King/Wikfors/Meseck)

BENTHIC FORAMS & MACROALGAE

Experiments to determine the impacts of a high CO_2 world on high latitude, temperate and tropical benthic foraminifera (Bernhard)

Effects of increased CO_2 on calcification and carbonate sediment contributions of *Halimeda* and larger foraminifera (Robbins/Knorr/Harries/Hallock/Wynn)

Long-term monitoring of coral and algal calcification in the Florida Keys, U.S.A. (Kuffner/Hickey/Poore)

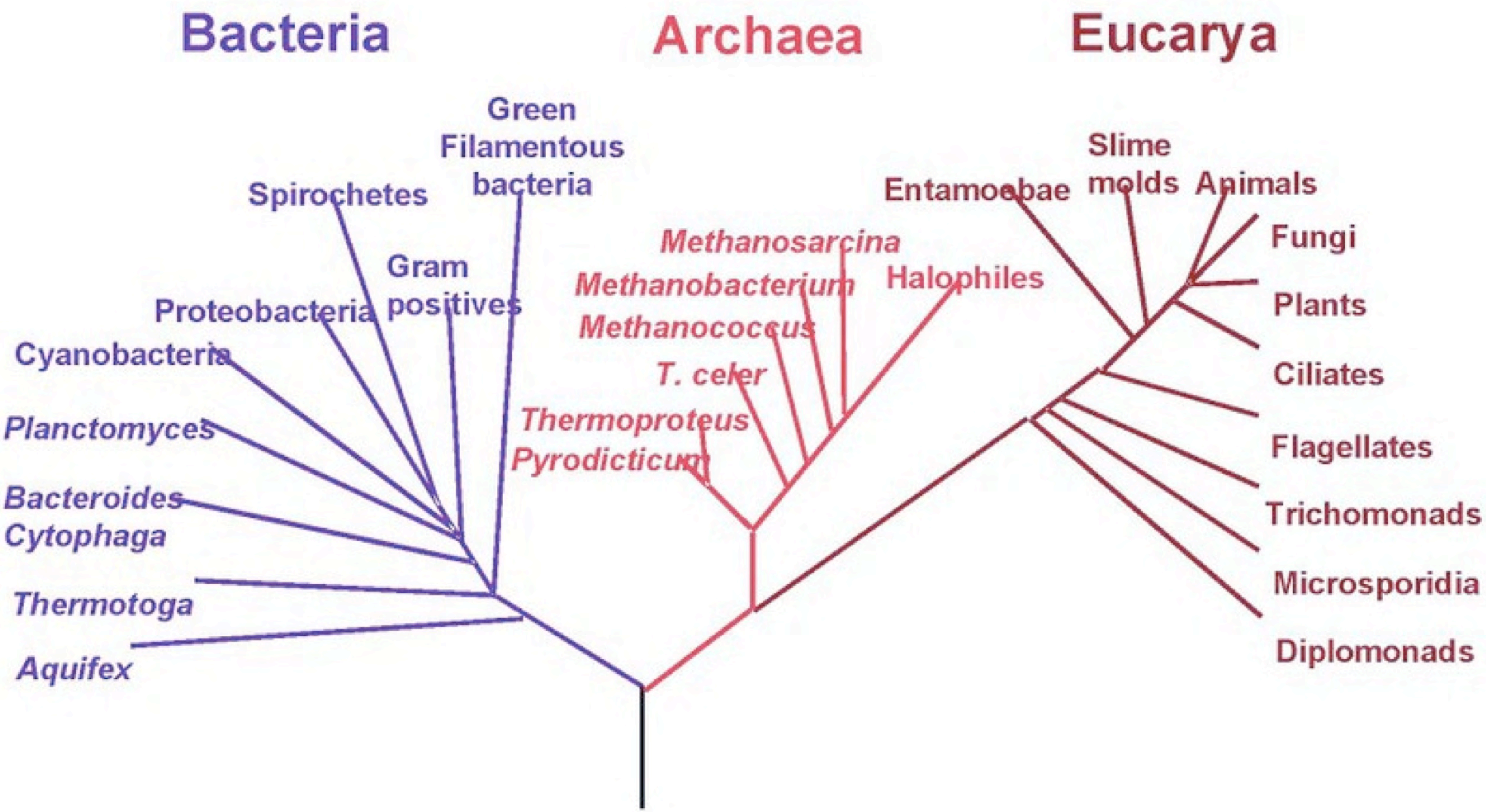
No title - preliminary work on Temp+CO_2 exposures on early life stages of spawners, and macroalgae (Miller)

Physiological response of benthic algae to ocean acidification (Price/Smith)

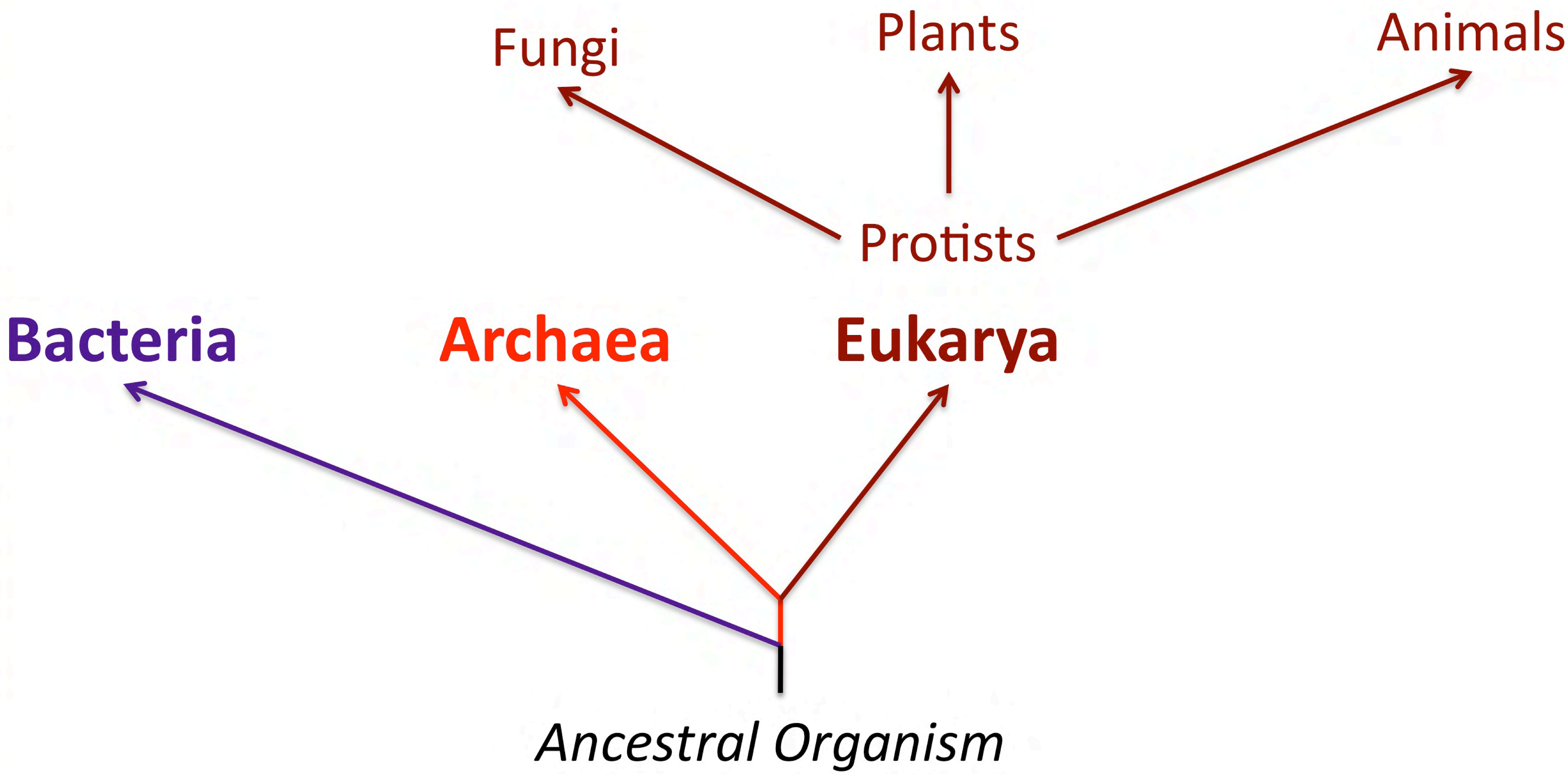
Investigation of the effects of $CaCO_3$ saturation state & temperature on the calcification rate & skeletal properties of benthic marine calcifiers (Ries)

Effects of ocean acidification on coastal organisms: an ecomaterials perspective (Carrington/Summers/O'Donnell/Martone)

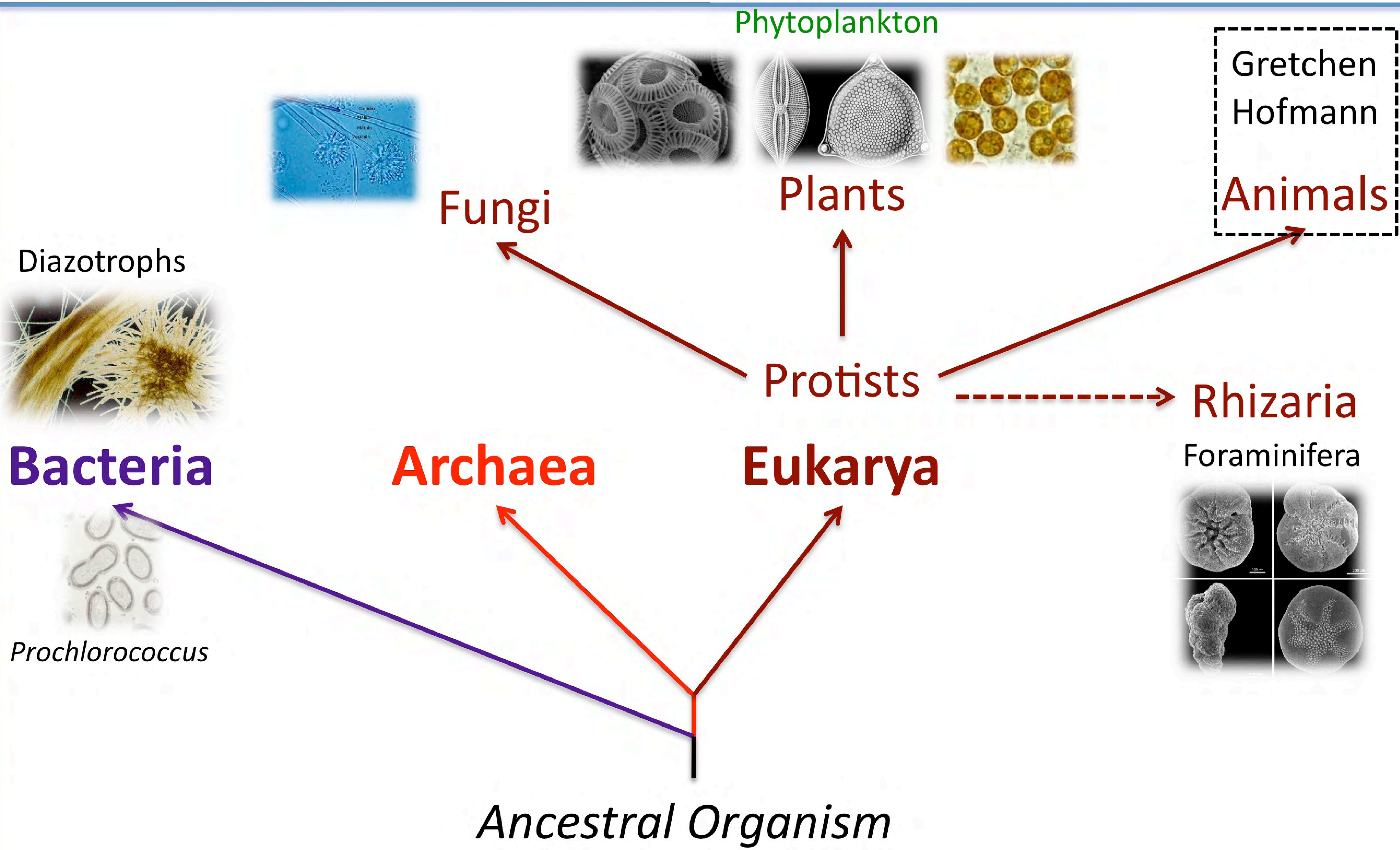
BASIC TREE OF LIFE



VERY BASIC TREE OF LIFE



VERY BASIC TREE OF LIFE



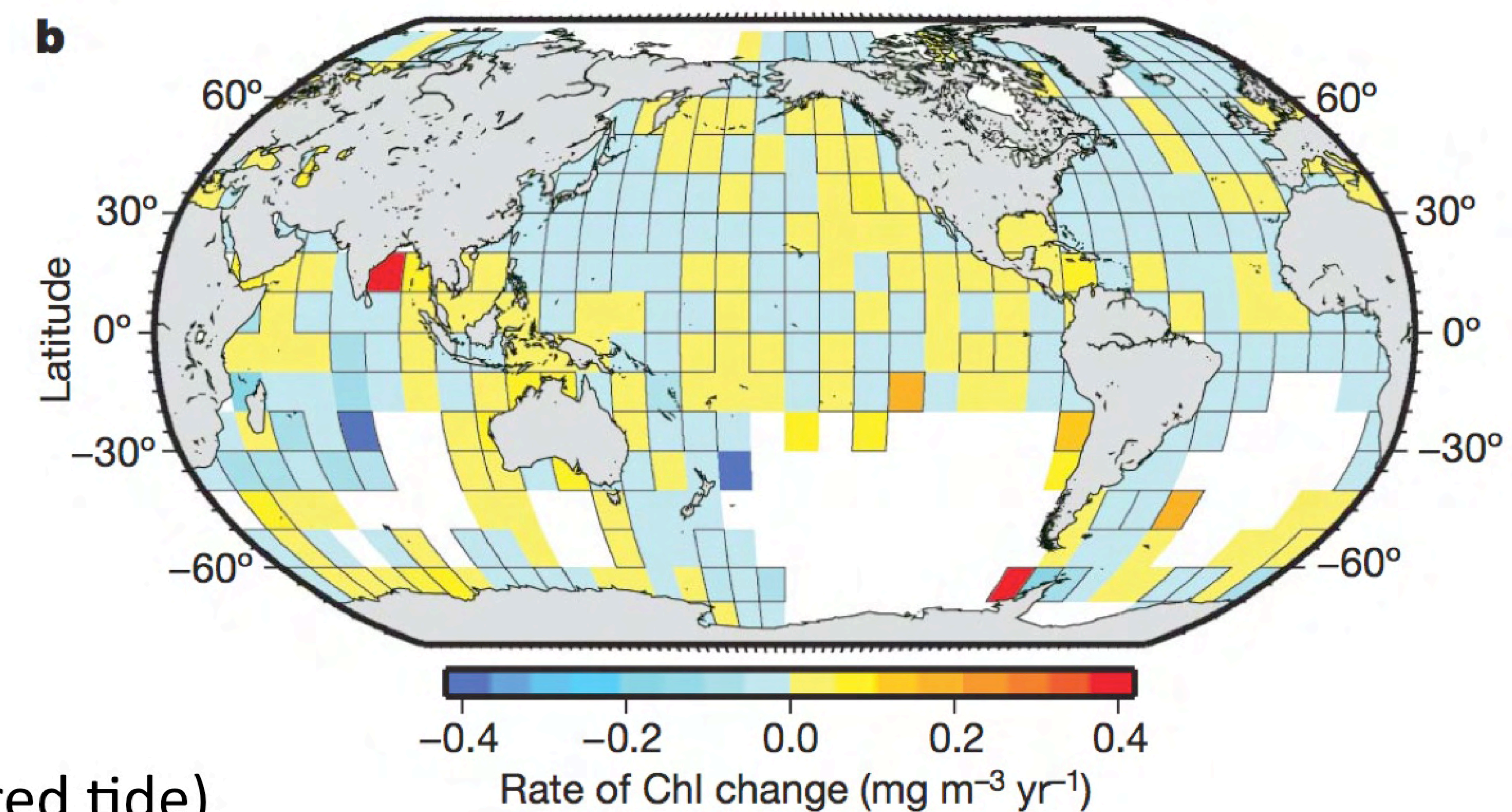
PHYSIOLOGICAL RESPONSES

PHYSIOLOGICAL RESPONSES

Main Groups

Phytoplankton:

Diatoms	*Thallassiosira oceanica*
Coccolithophores	*Emiliania huxleyi*
Cyanobacteria	*Prochlorococcus* *Synechococcus* *Trichodesmium* *Crocosphaera watsonii*
Dinoflagellates	*Alexandrium fundyense* (red tide) *Symbiodinium* (coral endosymbiont)



Boyce et al. 2010 *Nature*

Fungi:

Aspergillus (sea fan pathogen)

Benthic forams

Benthic macroalgae:

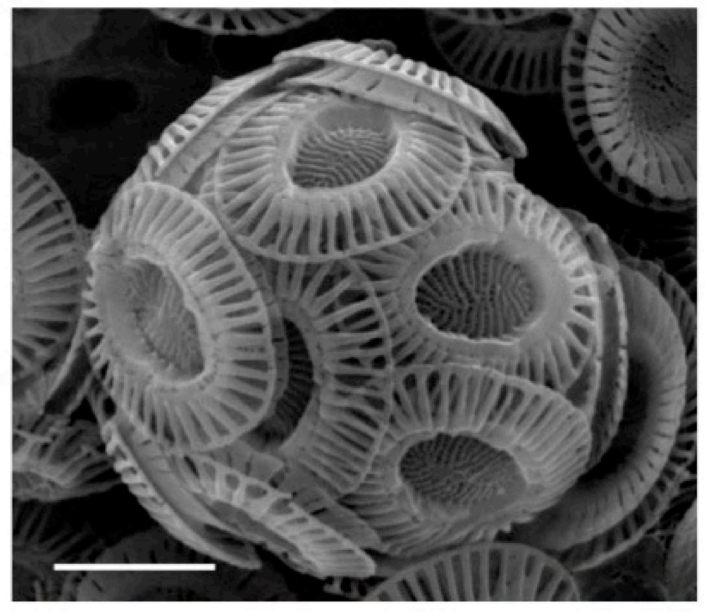
Halimeda

Coralline red algae

Coccolithophores

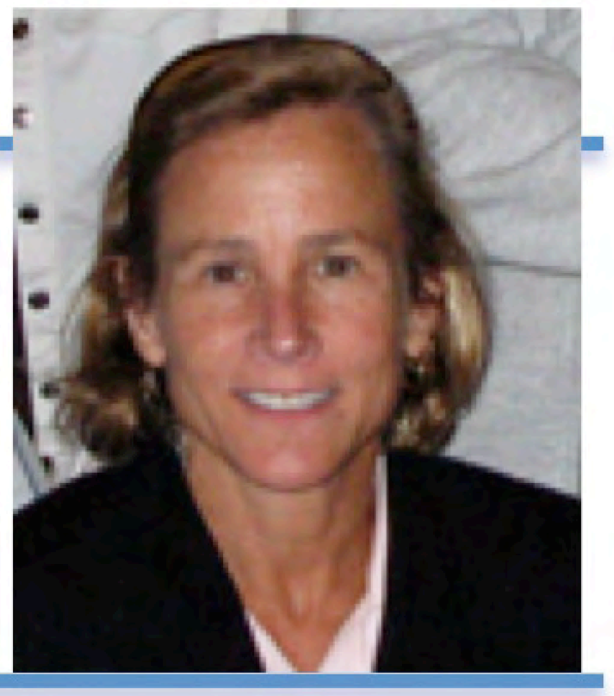
Ed Carpenter (with Jonathan Stillman and Tomoko Komada)

- Functional genomic analysis of genetically distinct ecotypes exposed to 2100 conditions for 2 weeks AND 2 years
- Use the *E. huxleyi* microarray.
- Generate biomarker genes for analyzing environmental physiology
- Ability of *E. huxleyi* to adapt to pH and pCO_2 conditions expected at the end of the century



- Ammonium concentration expected to rise in the future
  - increased N deposition
  - increased N2 fixation
  - decreased nitrification
- Maintain cultures for 2000 generations under different pCO_2 and nitrogen
- Ammonium depresses calcification, alters assimilation of N, alters coccocolith size/shape, increases primary production
- N-source and pCO_2 synergistically drive growth rates, cell size and PIC:POC

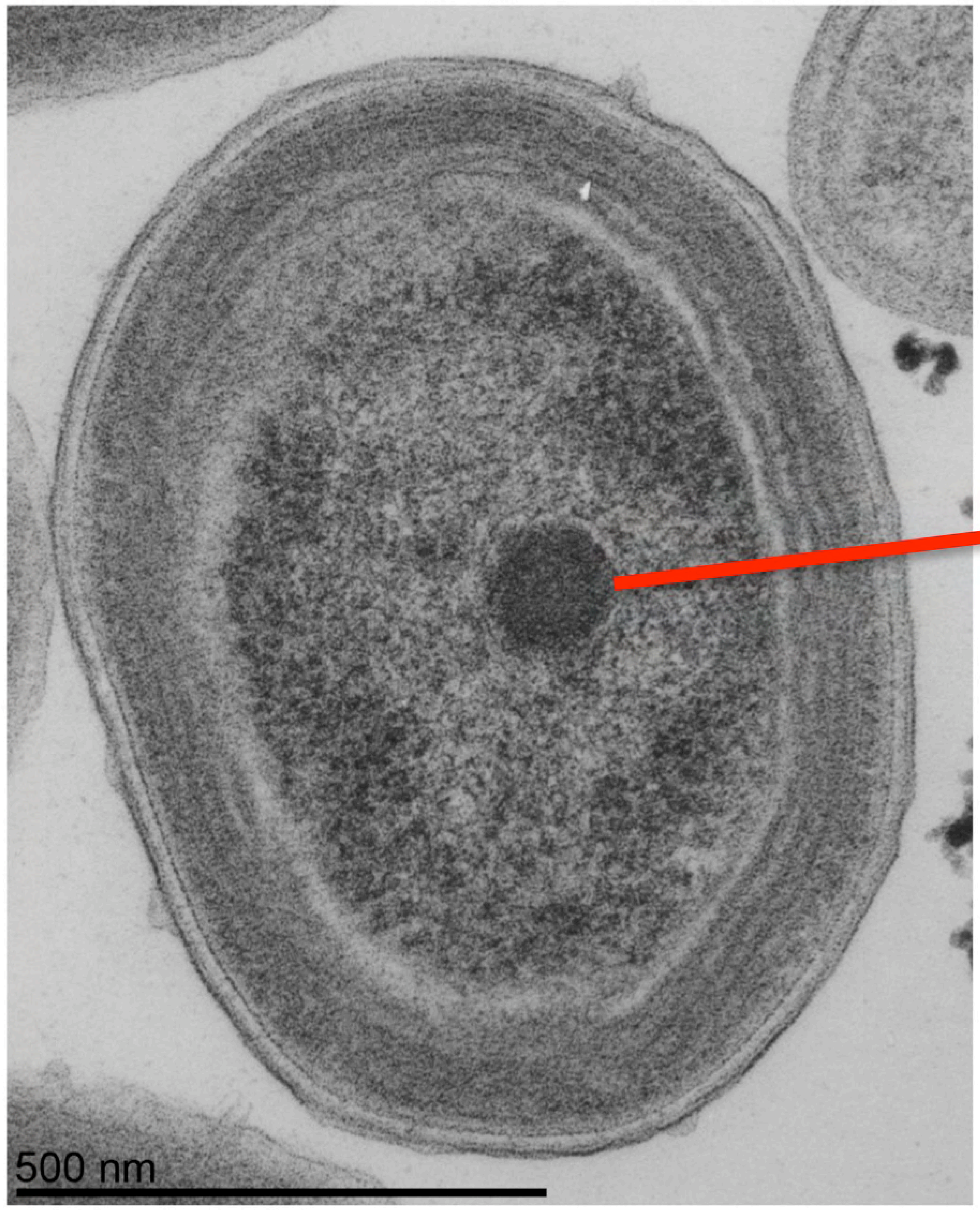
CCM in Bacteria



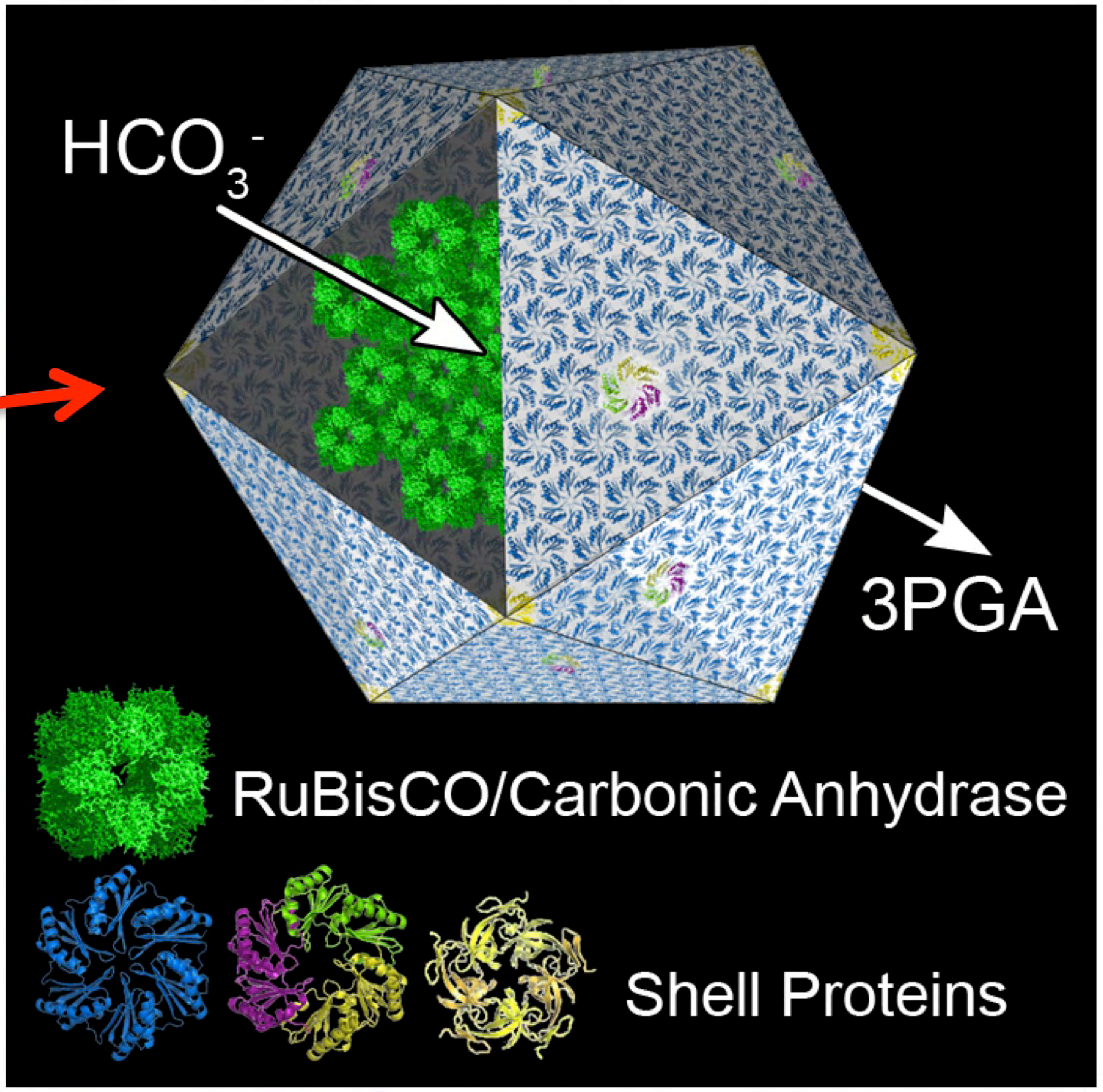
Kerfeld/Salmeen: *Structural, Functional, and Ecological Characterization of the Prochlorococcus Carboxysome, the Ocean's Primary Molecular Module for Carbon Fixation*

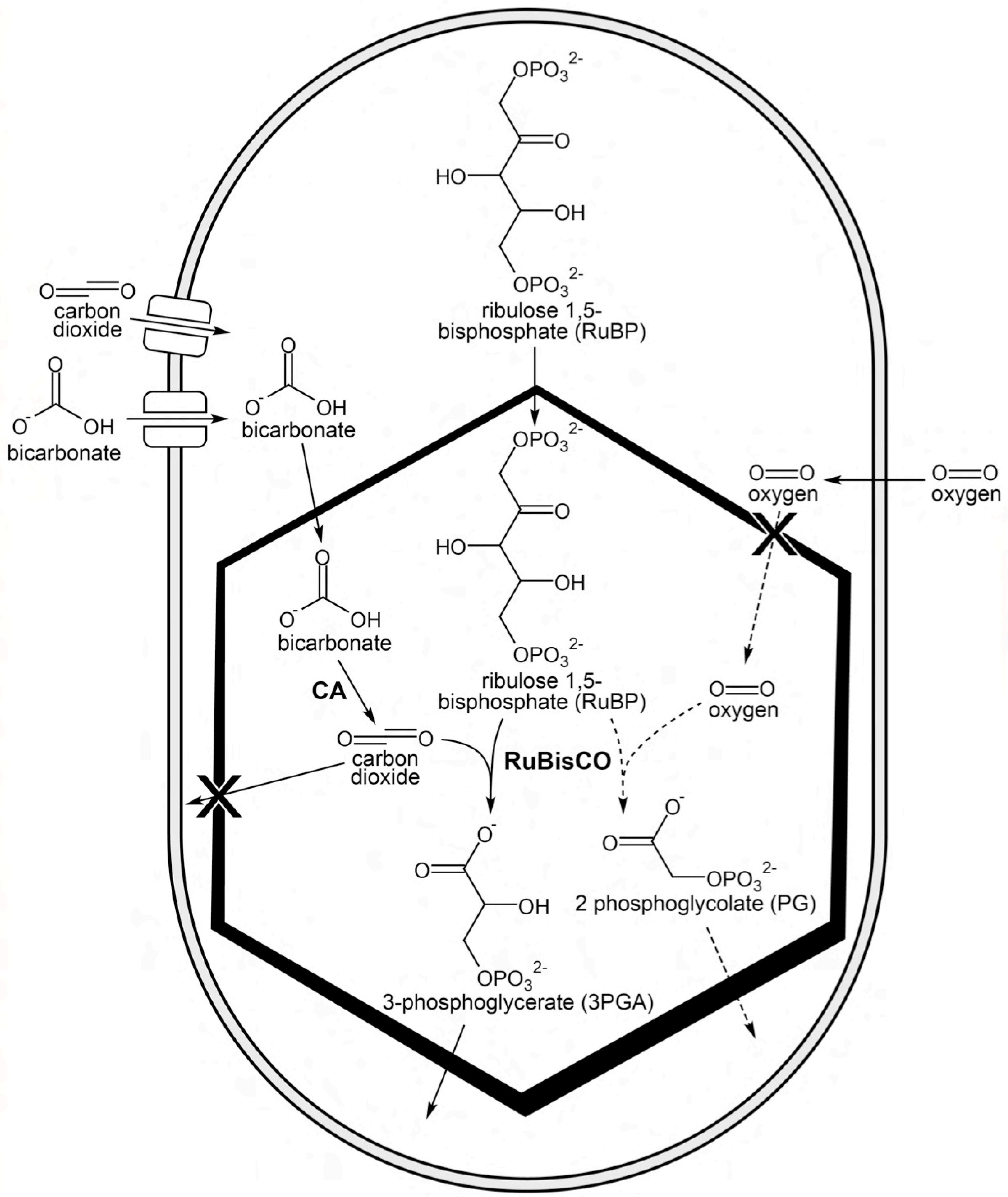
Characterize the structure and function of marine cyanobacterial carboxysome and bioinformatically examine the distribution of the cyanobacterial CCM in the open ocean

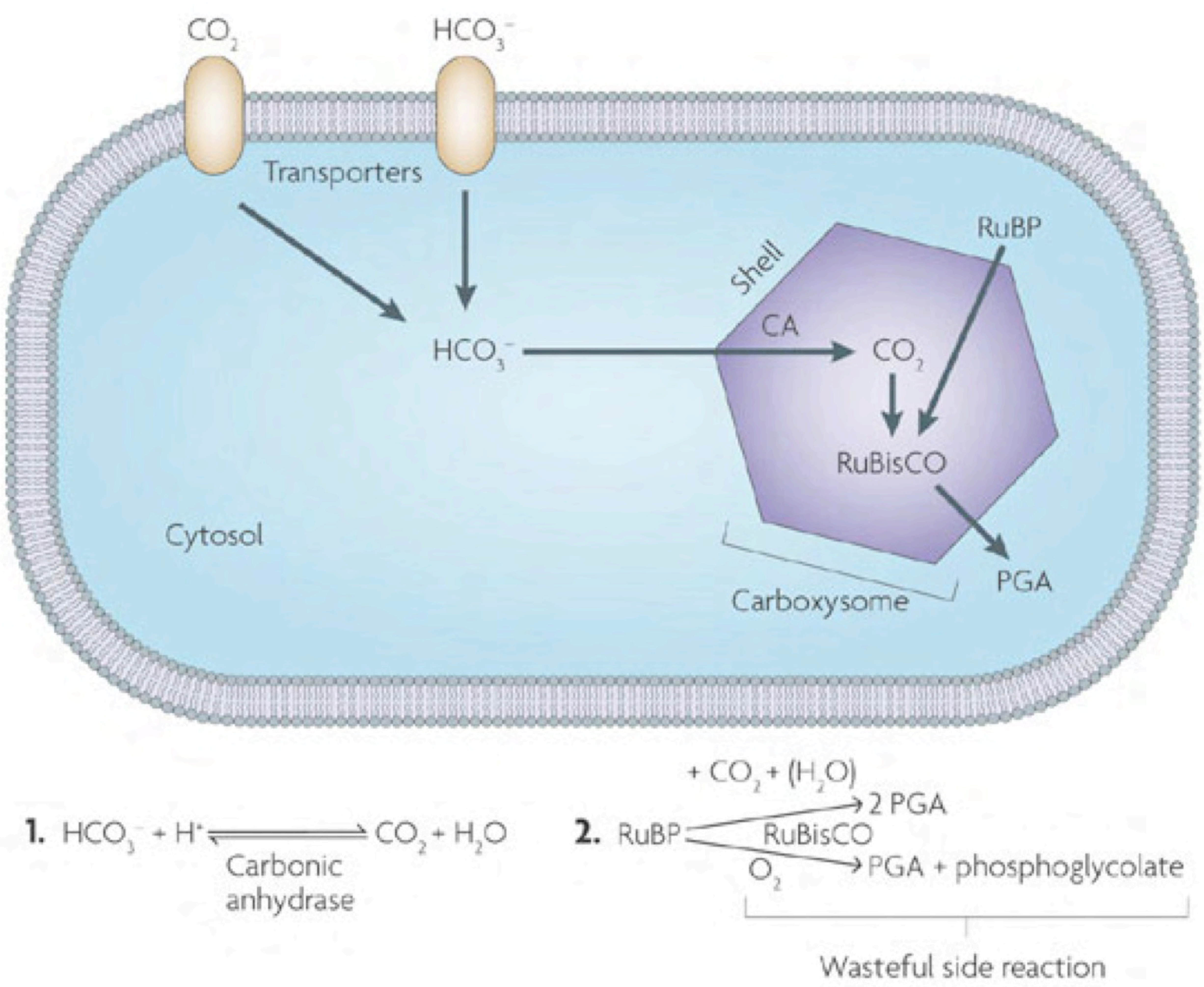
TEM image of Prochlorococcus MED4 with a single carboxysome



Schematic model of carboxysome structure and function







Nature Reviews | Microbiology

Changes in Trace Metal Chemistry

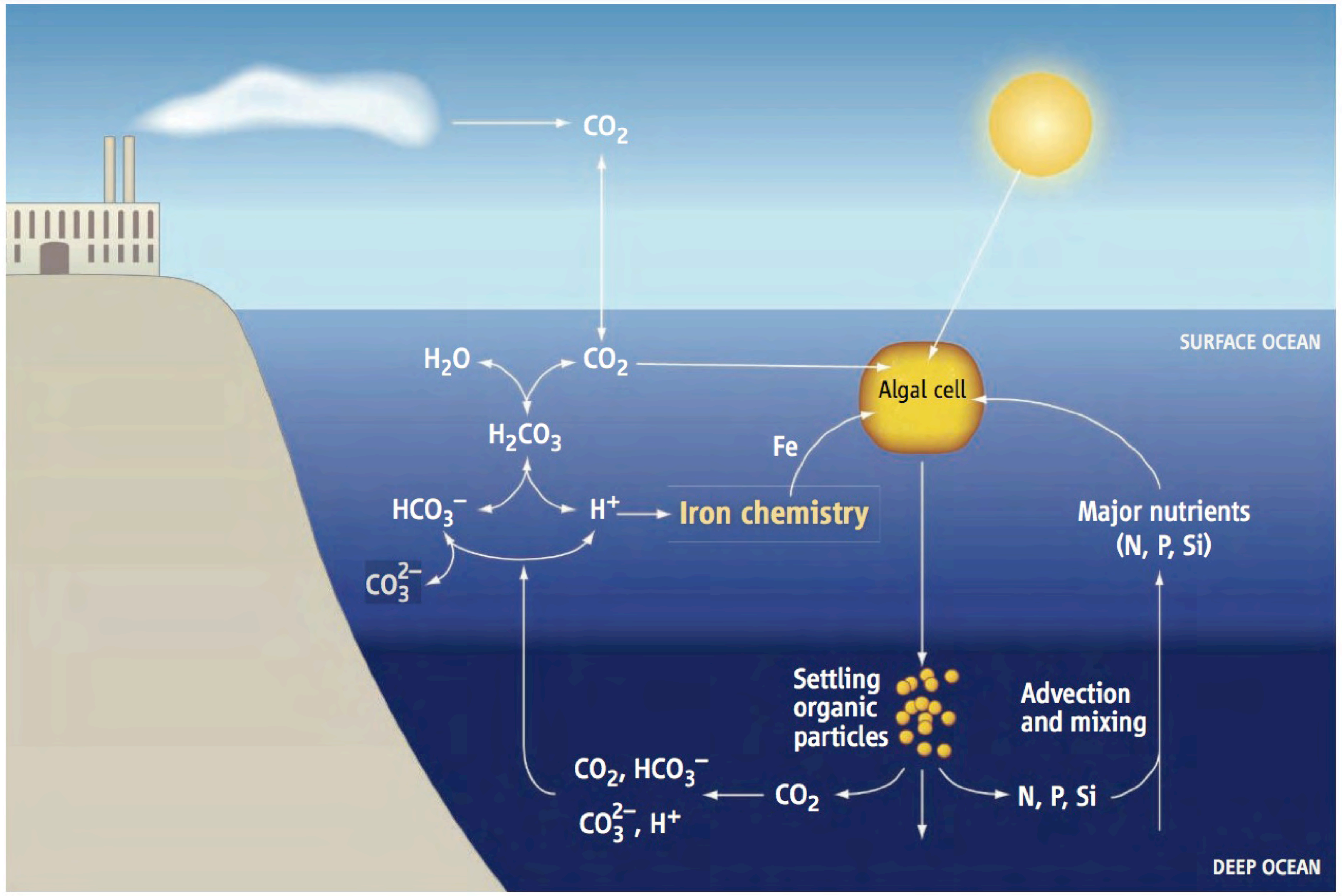
PHYSIOLOGICAL RESPONSES

F. Morel: *Effects of ocean acidification on nutrient availability and requirements in phytoplankton*

H1: acidification lowers the rate of Fe uptake by photoplankton (due to low pH) and simultaneously increases their Fe use efficiency (because of high CO2)

H2: acidification increases the C:N ratio of N-limited phytoplankton because of an increase in N use efficiency and the storage of C-rich compounds

H3: acidification decreases the ability of phytoplankton to use organic sources of P because of a decrease in the specific activity of alkaline phosphatase and in Zn availability.

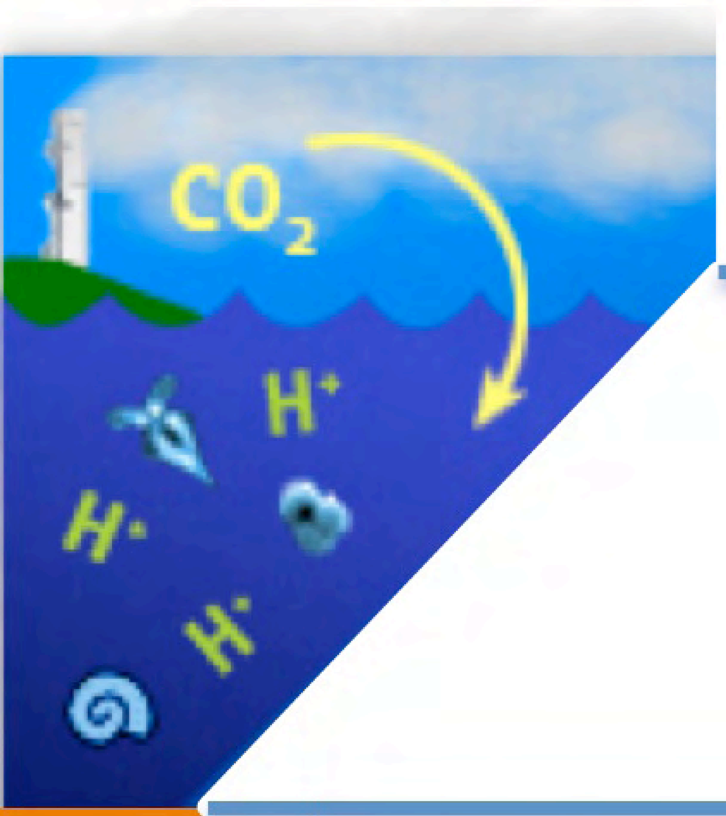


From Sunda 2010 *Science*
Commentary on Shi et al. 2010 *Science*

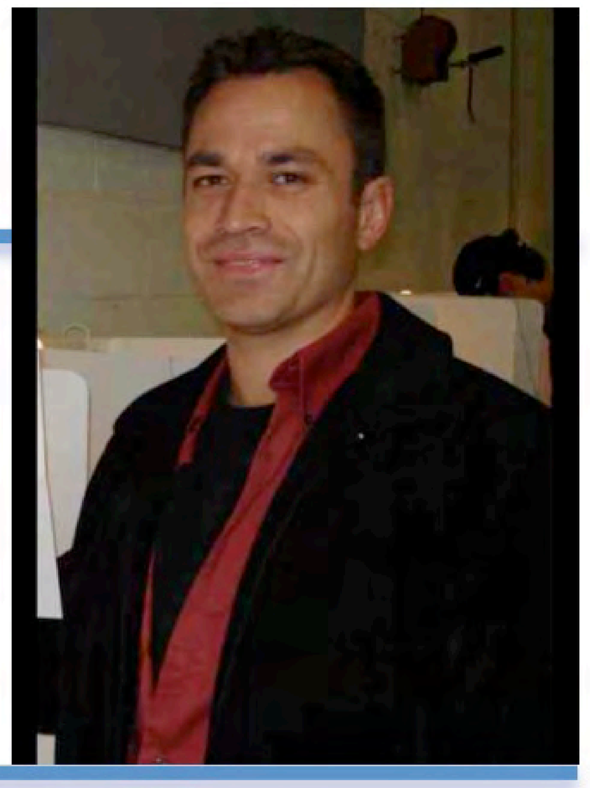
F.-X. Fu: *Changing phytoplankton trace metal requirements in a high CO_2 ocean*

1) Lab experiments to measure trace metal quotas of key groups (diatoms, coccolithophores *Phaeocystis*, cyanobacteria) under different conditions of iron, T, light

2) Field studies of trace-metal stoichiometry of natural communities across a range of pCO_2 conditions



N_2-fixation - Diazotrophs



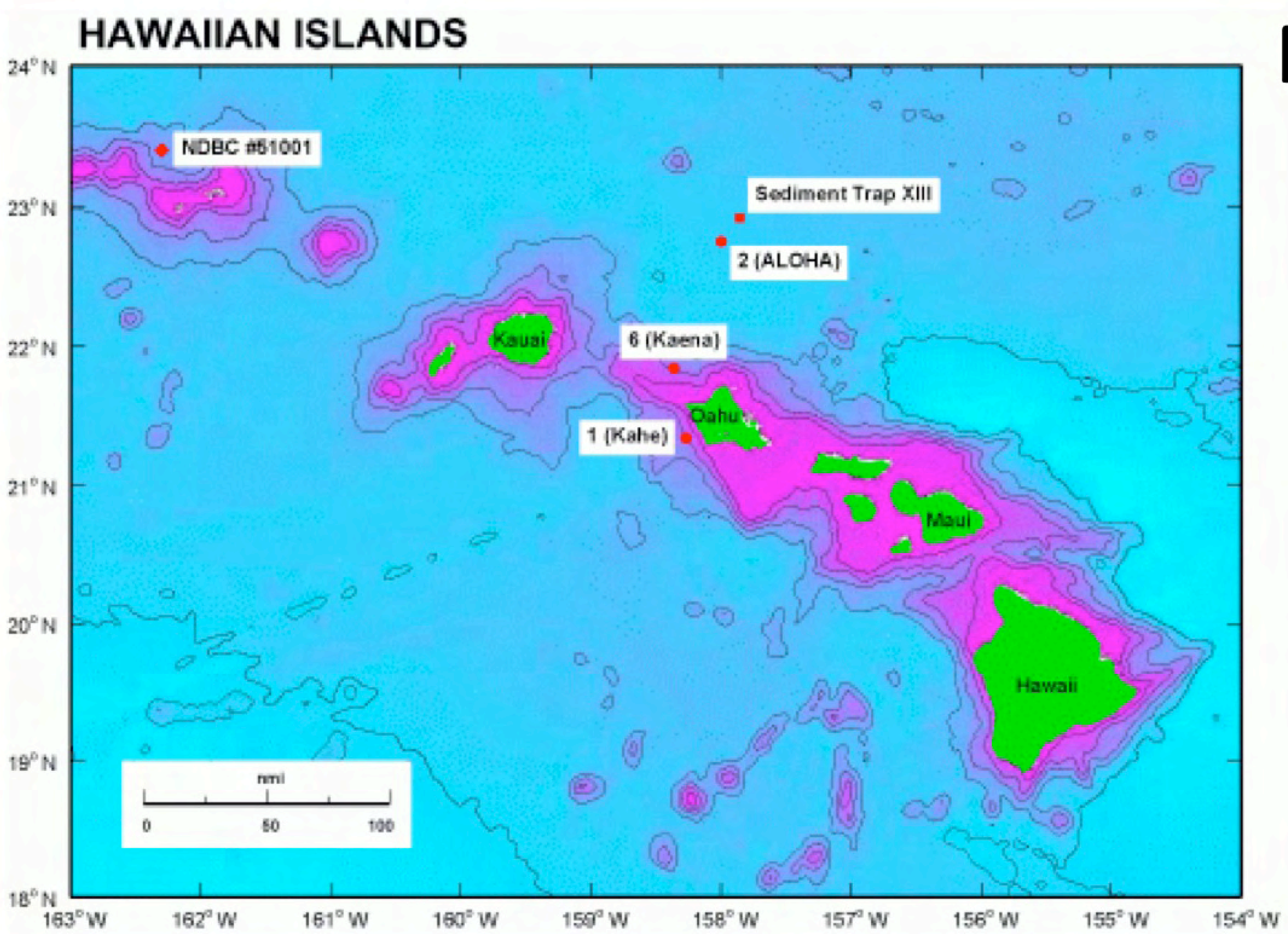
PHYSIOLOGICAL RESPONSES

Nathan Garcia (Hutchins) *CO_2 control of oceanic nitrogen fixation and carbon flow through diazotrophs*

Physiological rate responses to:

1) combined effects of elevated pCO_2 and PO_4 limitation in *Crocosphaera*
2) combined effects of elevated pCO_2 and Fe limitation in *Trichodesmium*
3) CO_2 response curves of diverse N_2 fixers
4) CO_2 effects on N_2 fixation and physiology in acclimated cultures.

See Nathan's poster

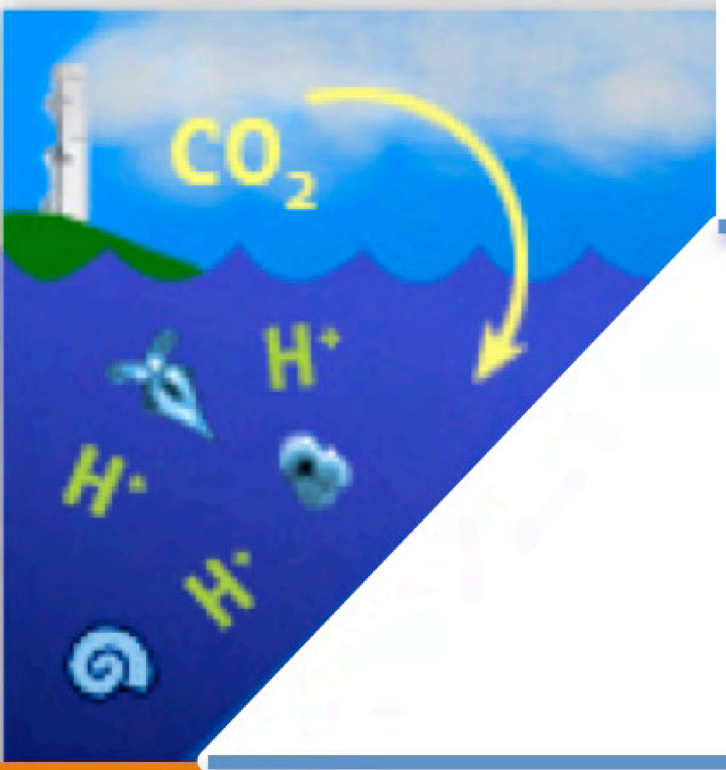


Matt Church/Ricardo Letelier: *Oceanic diazotroph community structure and activities in a high CO_2 world*

1) Quantify responses to pCO_2 on growth and community structure of natural diazotroph assemblages

2) Identify why and how changes influence growth and C-acquisition in *Trichodesmium* and *Crocosphaera*

3) Quantify temporal variability in diazotroph community structure



CCM in Phytoplankton

PHYSIOLOGICAL RESPONSES

Brian Hopkinson/Morel: *Effects of pCO_2 and pH on photosynthesis, respiration and growth in marine phytoplankton*

H1: elevated CO_2 -> higher photosynthetic efficiency because the CCM can be down-regulated
H2: lower pH -> decreased respiration because less energy needed to maintain normal internal pH

Looking at a variety of phytoplankton species
Tools: Molecular markers to trace C and O metabolism; Mass Spectrometry

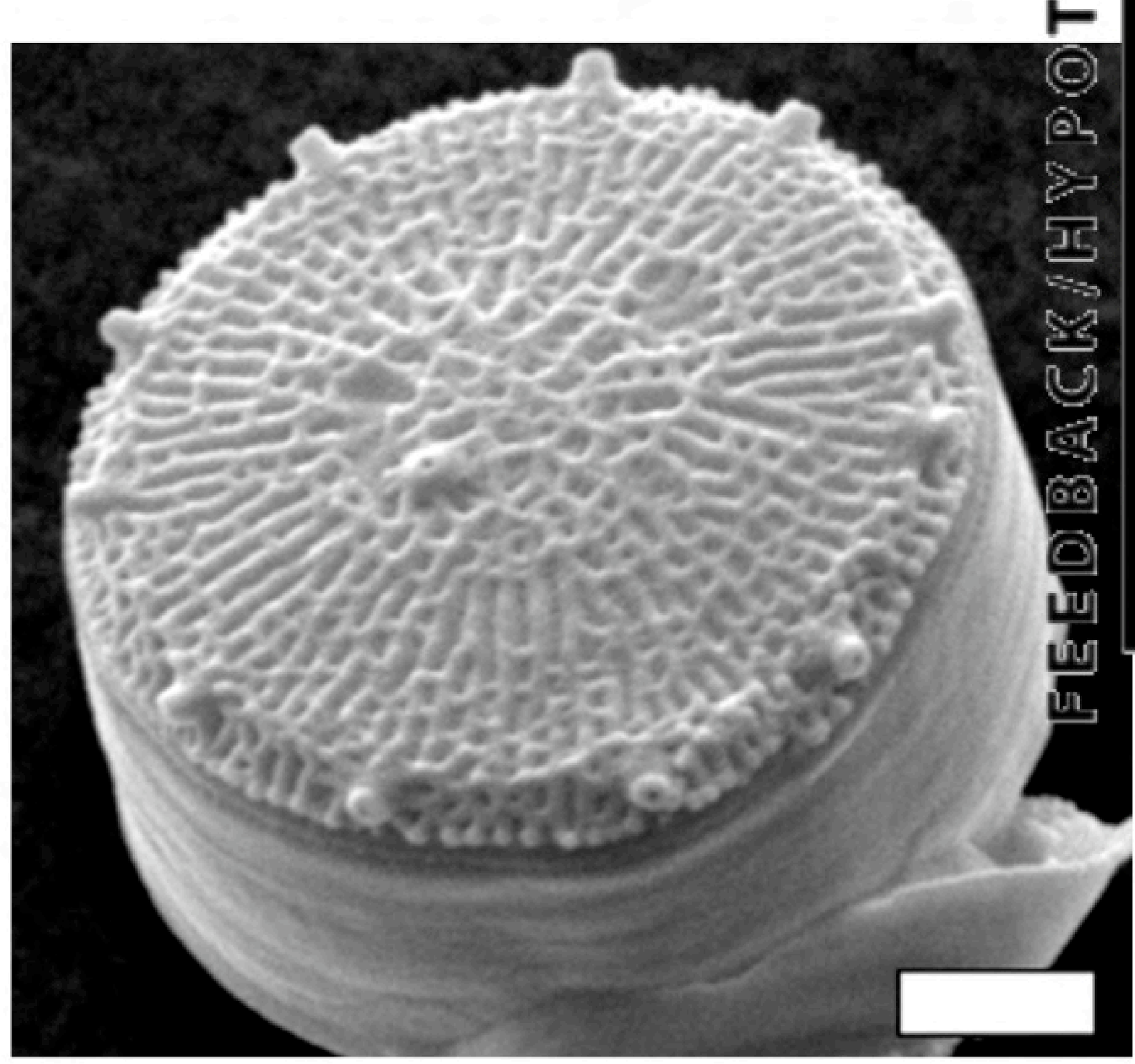
Diatoms:
- molecular basis of the CCM in model diatoms
- manipulating putative CCM genes to determine if their repression or overexpression alters CCM function
- using newly developed membrane inlet mass spectrometry to understand diatom C-cycling

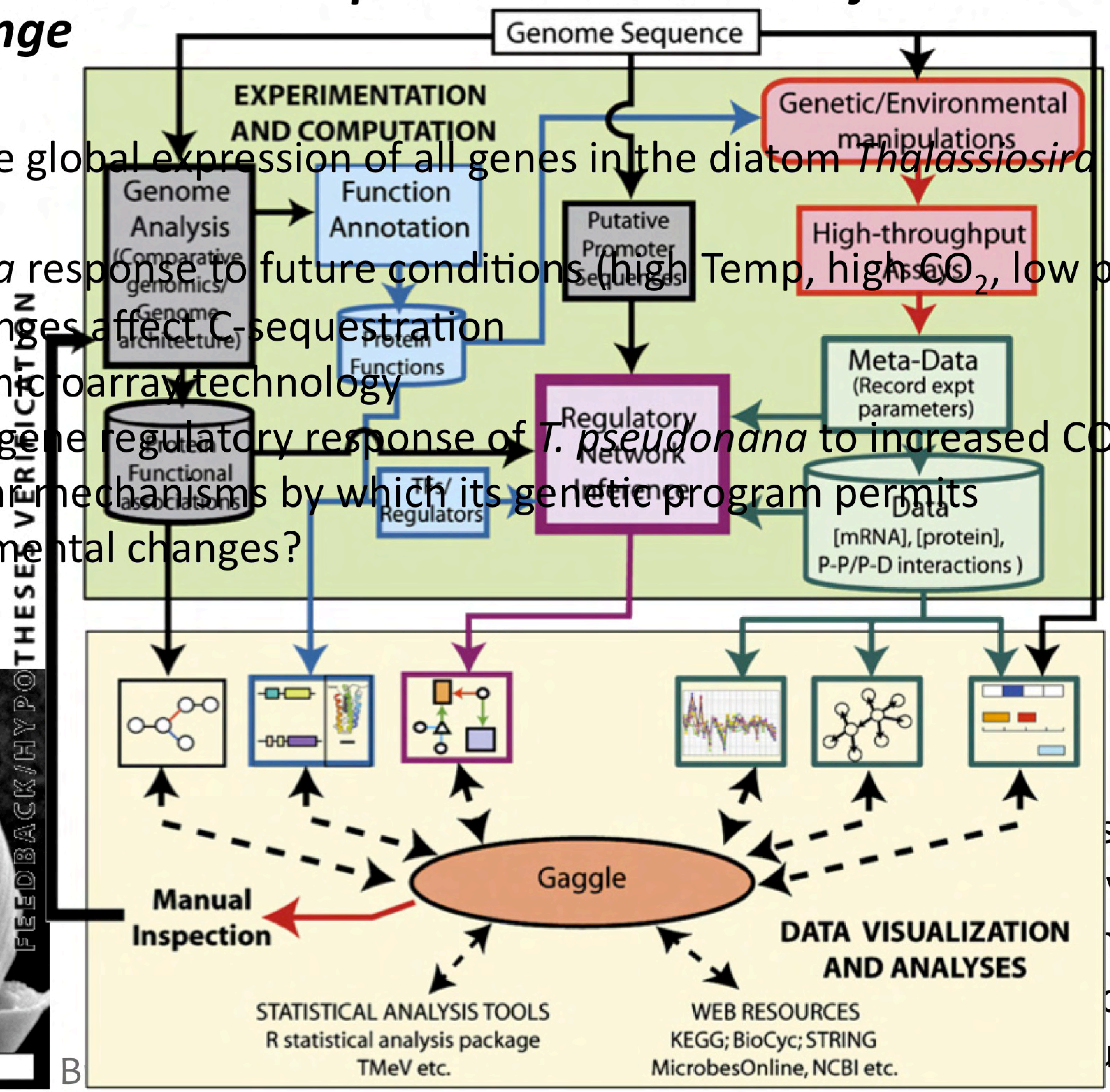
Diatoms

PHYSIOLOGICAL RESPONSES

Mónica Orellana/Justin Ashworth (Lee, Armbrust, Baliga): ***A Systems Biology Approach to Diatom Responses to Ocean Acidification and Climate Change***

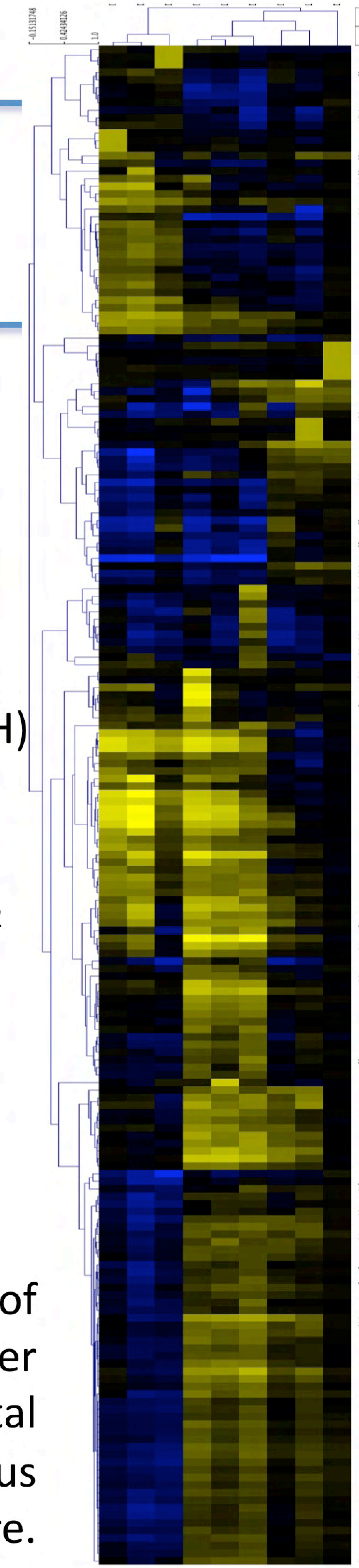
- Predictive model of the global expression of all genes in the diatom *Thalassiosira pseudonana*
- Forecast *T. pseudonana* response to future conditions (high Temp, high CO_2, low pH)
- Predict how these changes affect C-sequestration
- Use high-throughput microarray technology
- Measure the dynamic gene regulatory response of *T. pseudonana* to increased CO_2
- What are the molecular mechanisms by which its genetic program permits adaptation to environmental changes?





B

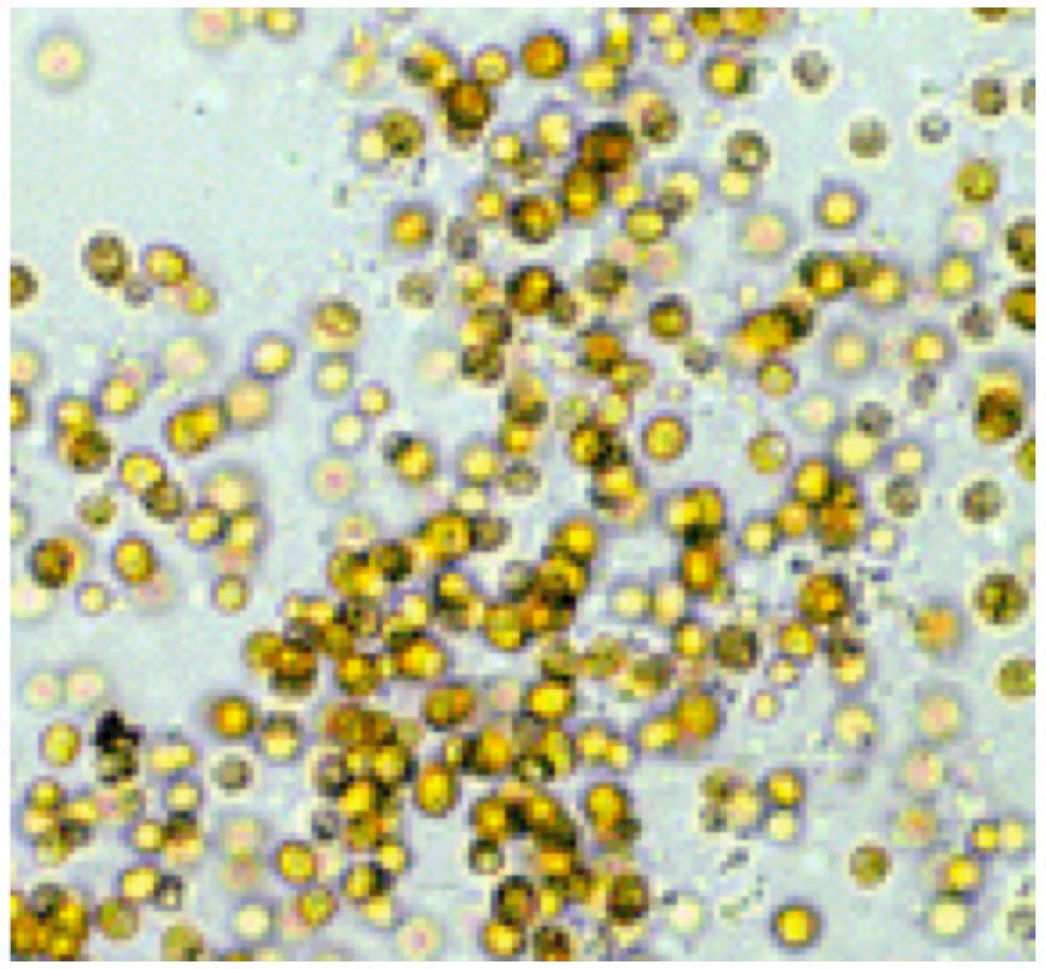
s of
ver
ntal
ous
ure.



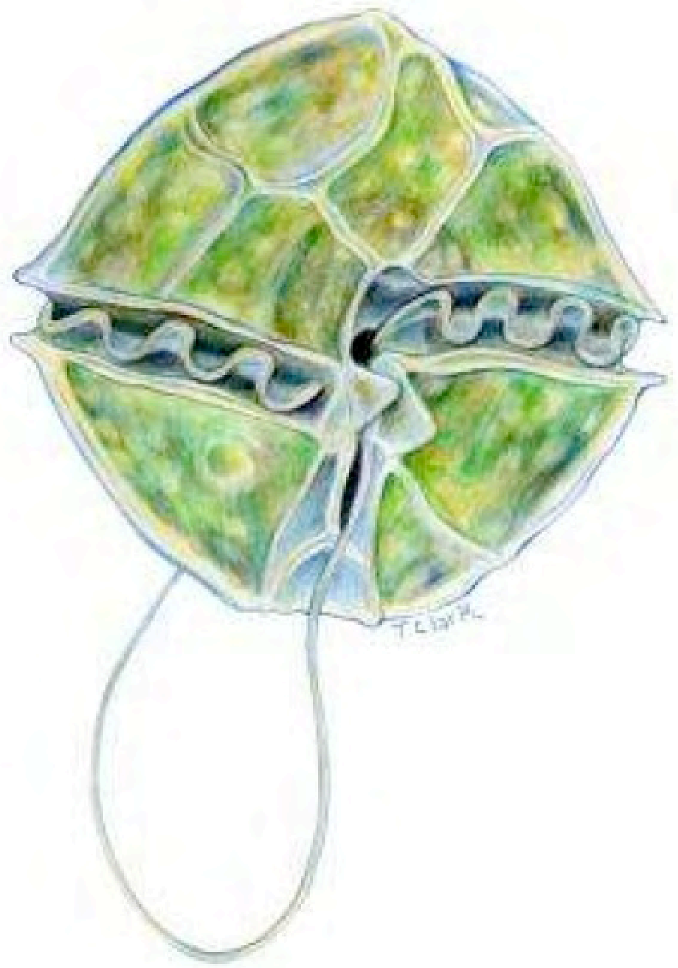
PHYSIOLOGICAL RESPONSES

Dinoflagellates

- Coral Symbionts (*Symbiodinium*):
  - Mark Warner (Impacts of altered pCO_2 on cellular physiology and ecology of microalgae, including different *Symbiodinium* clades)
  - Clay Cook



- Shannon Meseck: *Alexandrium fundyense*



- Astrid Schnetzer and Dave Hutchins: *Experimental studies to understand and evaluate acclimation of marine plankton assemblages to increased CO2 and temperature*

Nutritional value of Phytoplankton

Shannon Meseck: *Phytoplankton nutritional value for fishery-based food webs*

- Key players in the northern Atlantic planktonic food webs:
- *Thalassiosira pseudonana* & *T. oceanica* (omega-3, omega-6 PUFAs)
- *Alexanderium fundyense* (potentially toxic toxic)
- *Emiliania huxleyi*

Pathogens

PHYSIOLOGICAL RESPONSES

Colleen Burge (Harvell, Mydlarz)

Influence of Temperature and Acidification on the Dynamics of Coral Co-infection and Resistance

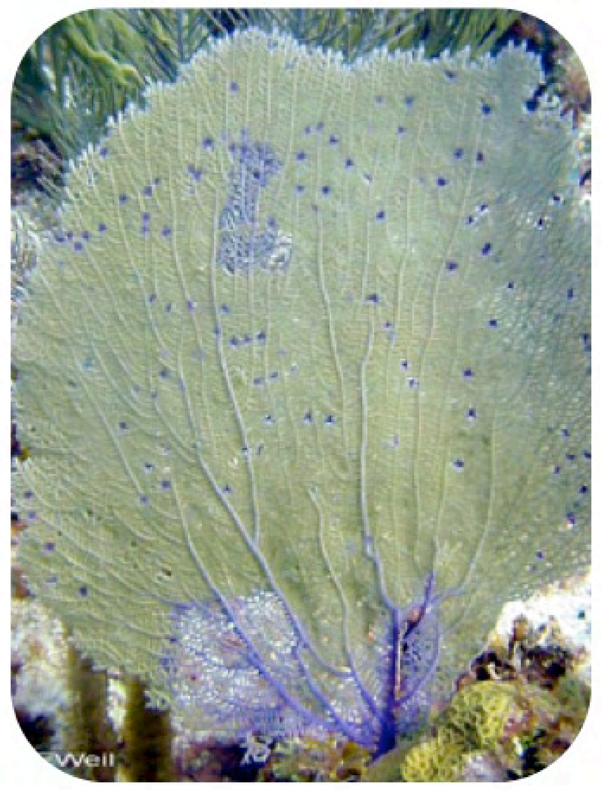
Influence of temperature and acidification on:

- Pathogen virulence
- Underlying host resistance
- Dynamics of single and co-infections

Second Project: Assess how CO_2, temperature, and N and P can impact coral-algal symbioses and calcification

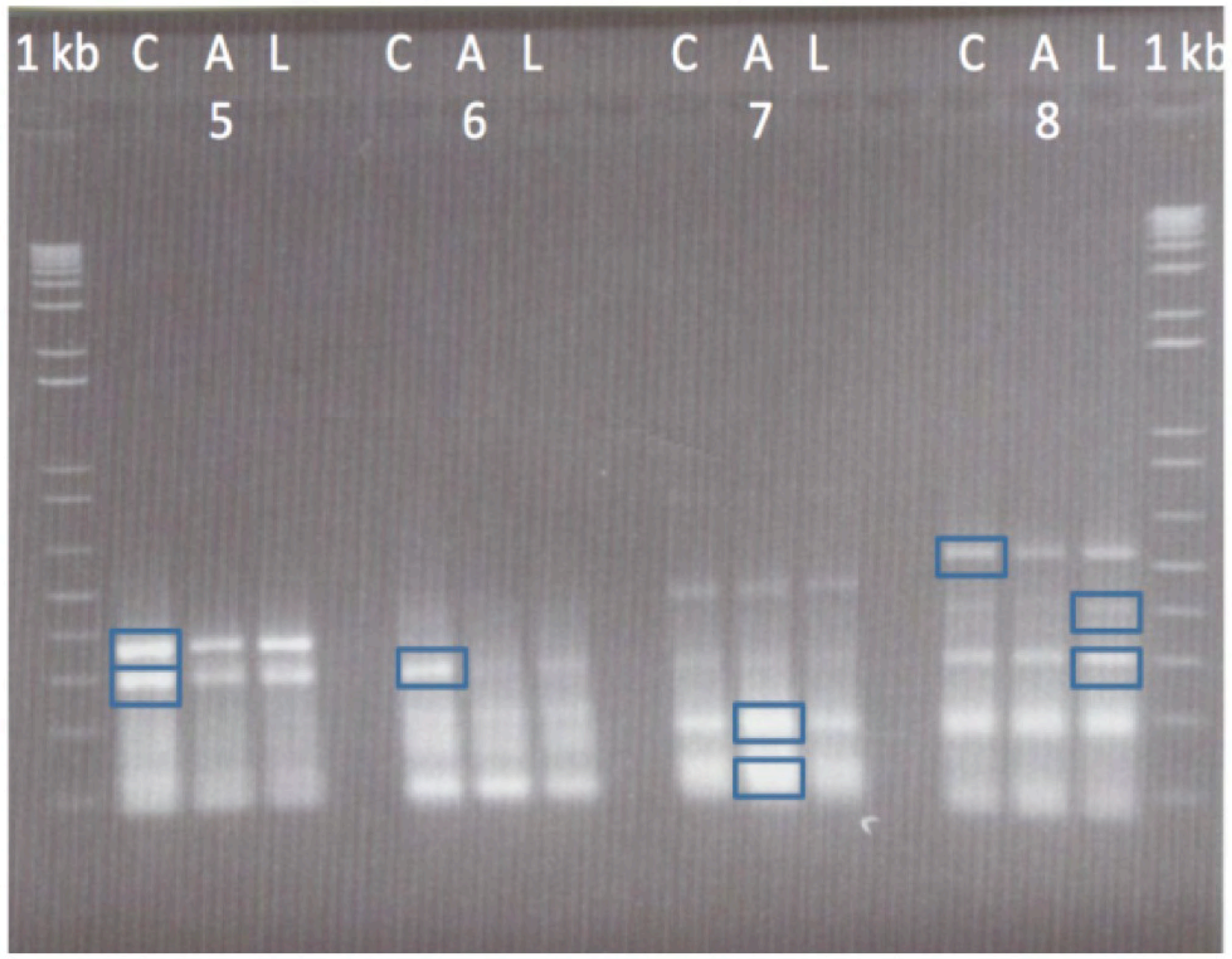
Visual observations of disease in sea fans

Aspergillus sydowii



Labyrinthulid protozoan

Photos: E. Weil



Potential differentially expressed genes (blue boxes) in sea fans exposed to *A. sydowii* (A), a Labyrinthulomycota (L), or control media.

Benthic Foraminifera

- *PETM studies highlight high extinction rates of benthic foraminifera*
- *Used as proxies for environmental conditions*
- *Sediment production*

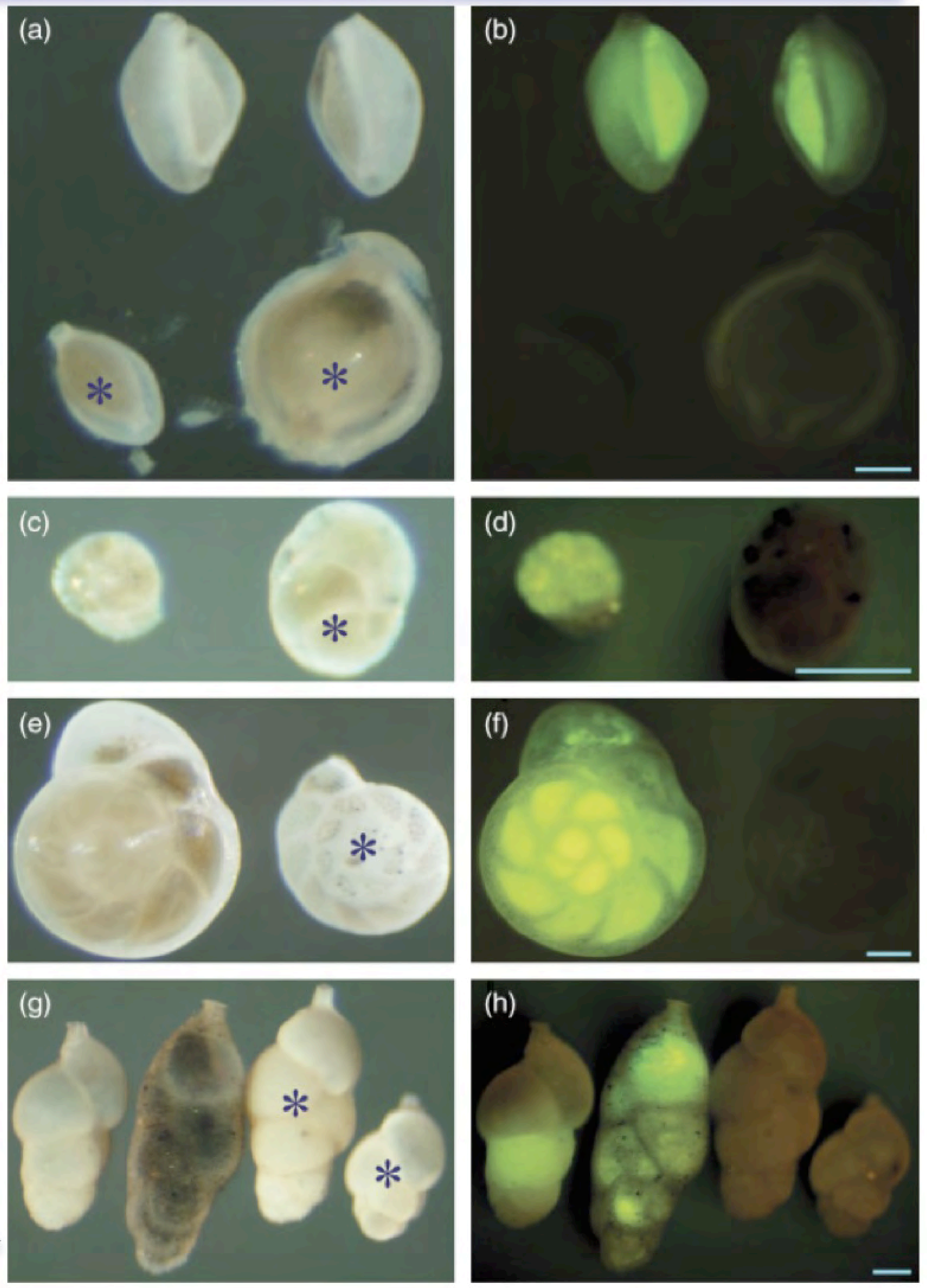
Joan Bernhard: *Impacts of a high CO_2 world on high latitude, temperature, and tropical benthic foraminifera*

high latitude (Swedish fjord)

temperate (off Cape Cod)

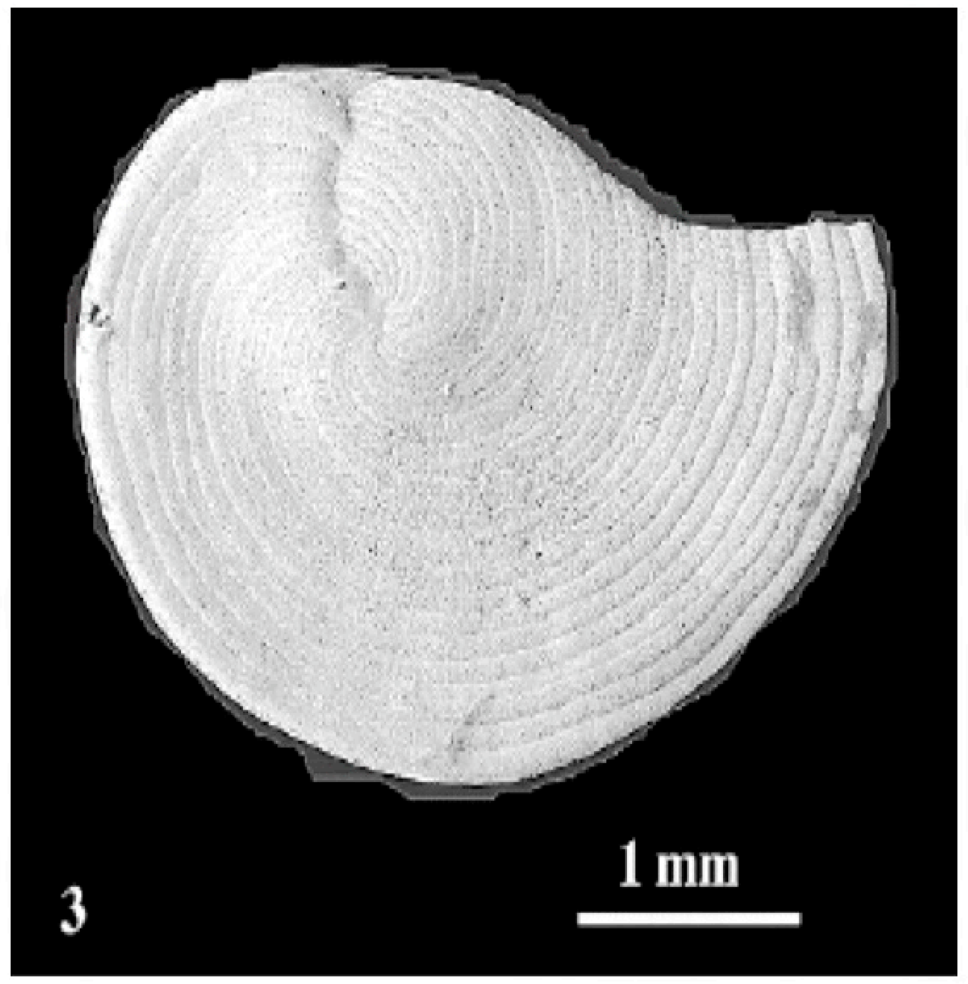
tropical (Florida reef)

- Early results: no effect on survival; some effects on test microstructure
- Calcite being used to calibrate pH proxies (B/Ca and δ^{11}B)
- Also studying effects of CO_2 disposal in the deep ocean -> calcareous forms affected; non-calcareous forms were not



Lisa Robbins (Paul Knorr) *Effects of increased CO_2 on calcification and carbonate sediment contributions of <u>Halimeda</u> and larger foraminifera*

- pH-stat experiments
- Analyze ultrastructure and isotopes



PHYSIOLOGICAL RESPONSES

Benthic Macroalgae

Lisa Robbins (Paul Knorr) *Effects of increased CO_2 on calcification and carbonate sediment contributions of Halimeda and larger foraminifera*

– pH-stat experiments
– Analyze ultrastructure and isotopes

Nichole Price (Jen Smith) *Physiological response of benthic algae to OA*

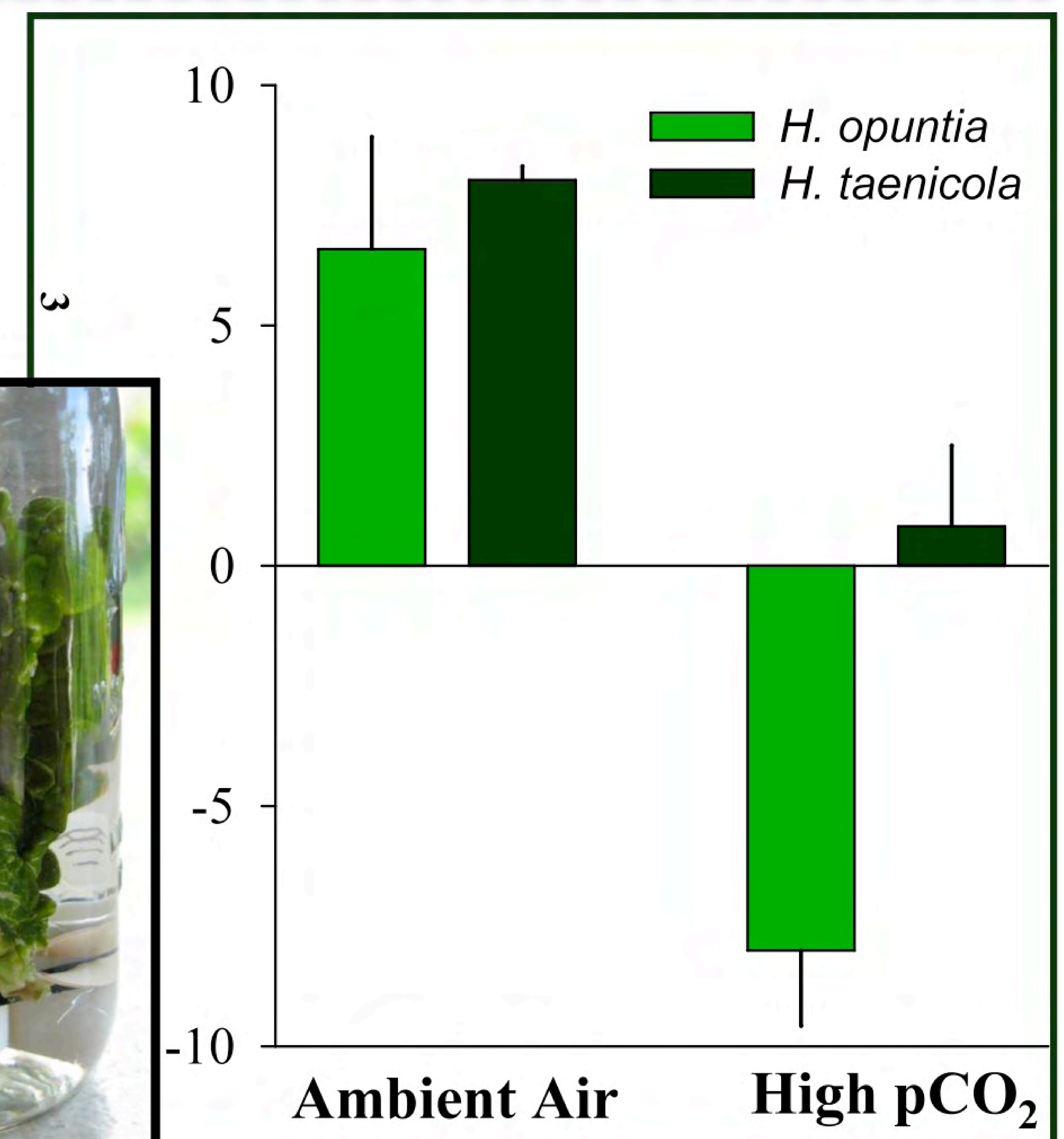
H1: C-limited algae will benefit from high-CO2

H2: Calcifying algae will experience reduced calcification rates

– Photo-physiology
– Respiration
– Growth
– Morphology
– Mineralogy
– Calcification

CO_2 bubbling experiment with 2 species of *Halimeda.* *Price et al. (in review)*

Similar species can have different responses

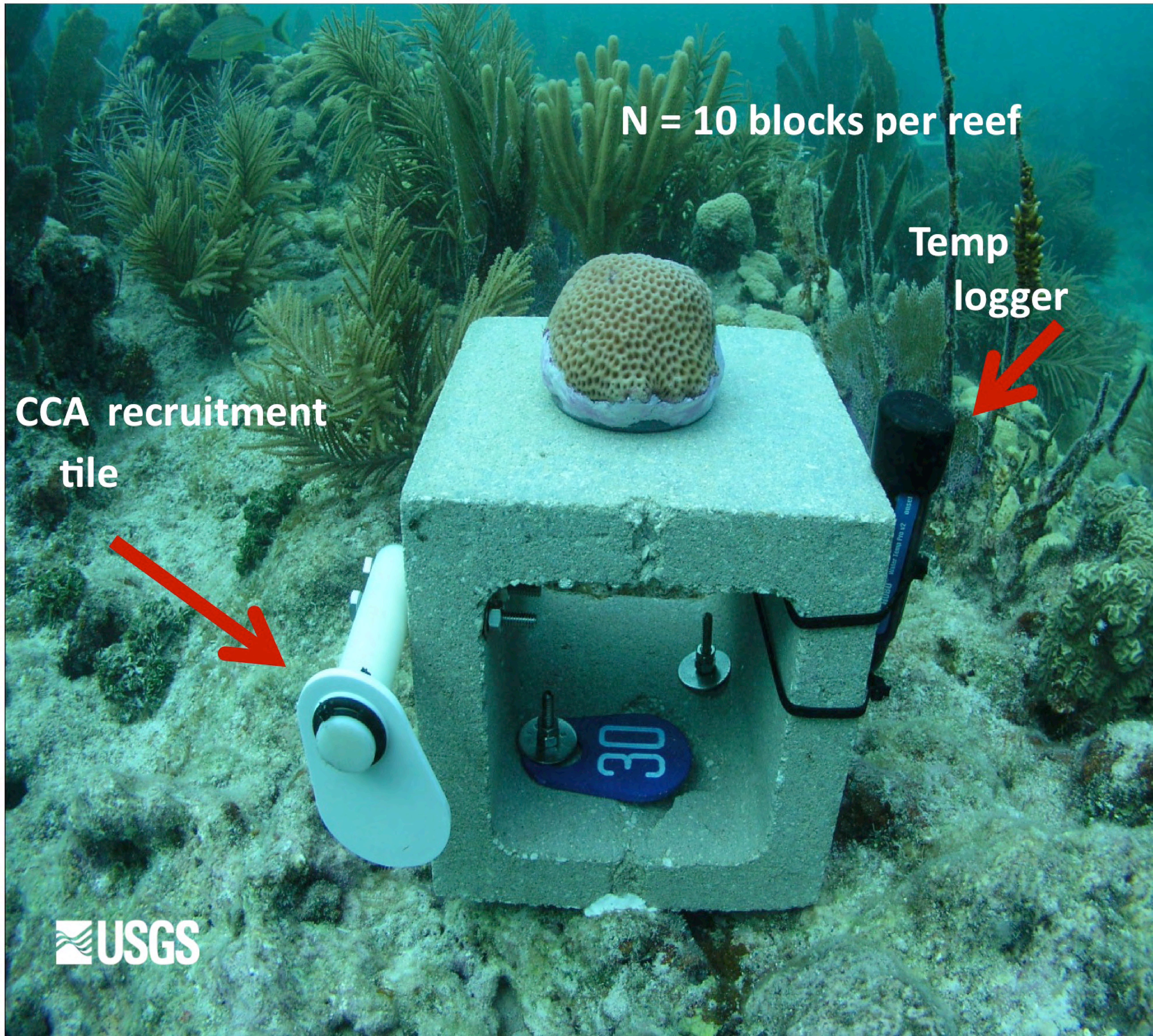


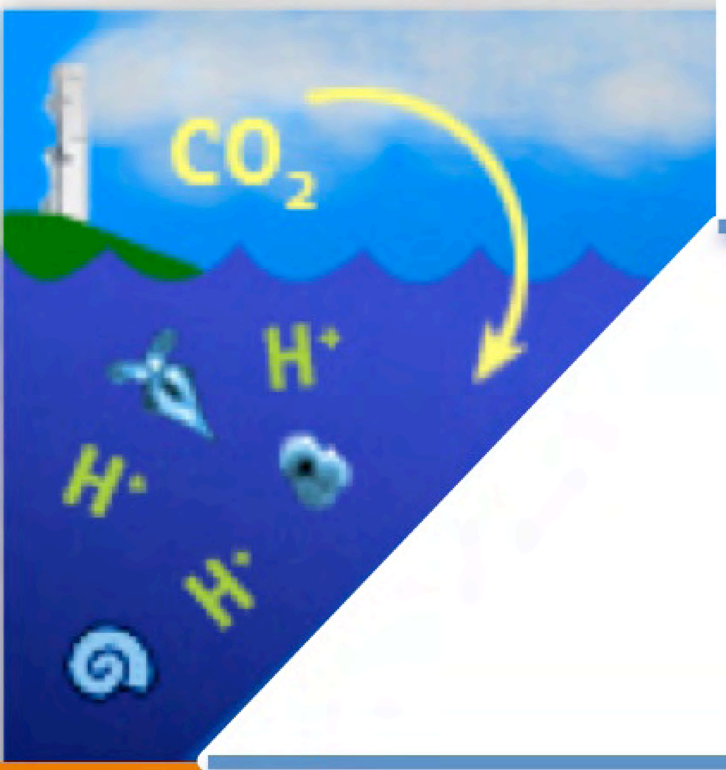
Benthic Macroalgae

PHYSIOLOGICAL RESPONSES

Ilsa Kufner (Hickey, Poore) *Long-term monitoring of coral and algal calcification in the Florida Keys, U.S.A.*

- ✓ Establish stations (N = 40)
- ✓ *In-situ* temperature & SEAKEYS oceanographic data
- ✓ Two years of growth data, *Siderastrea siderea* & CCA
- Correlate calcification with temperature, modeled carbonate system parameters, and other variables
- High-resolution Sr/Ca temperature proxy calibration



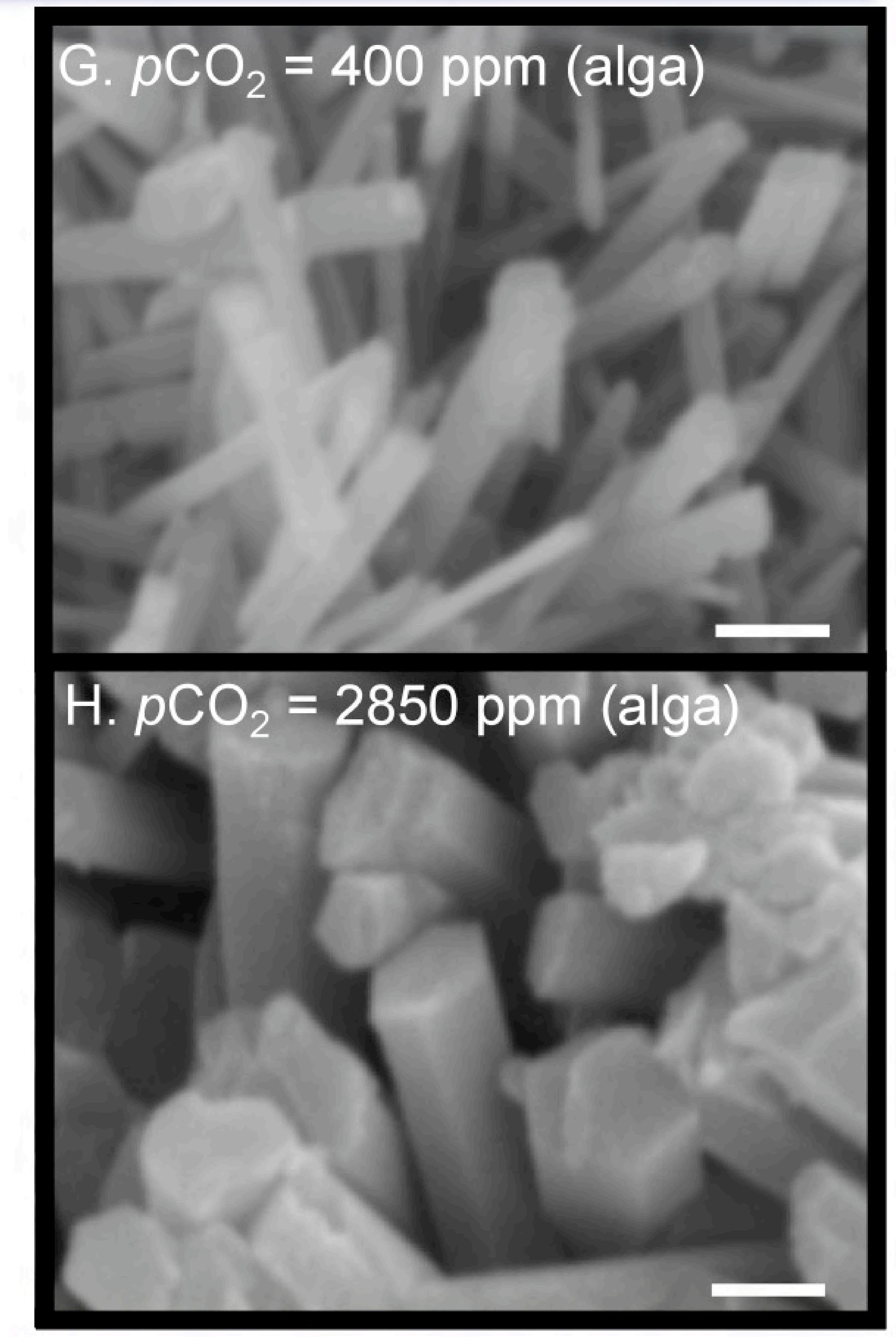


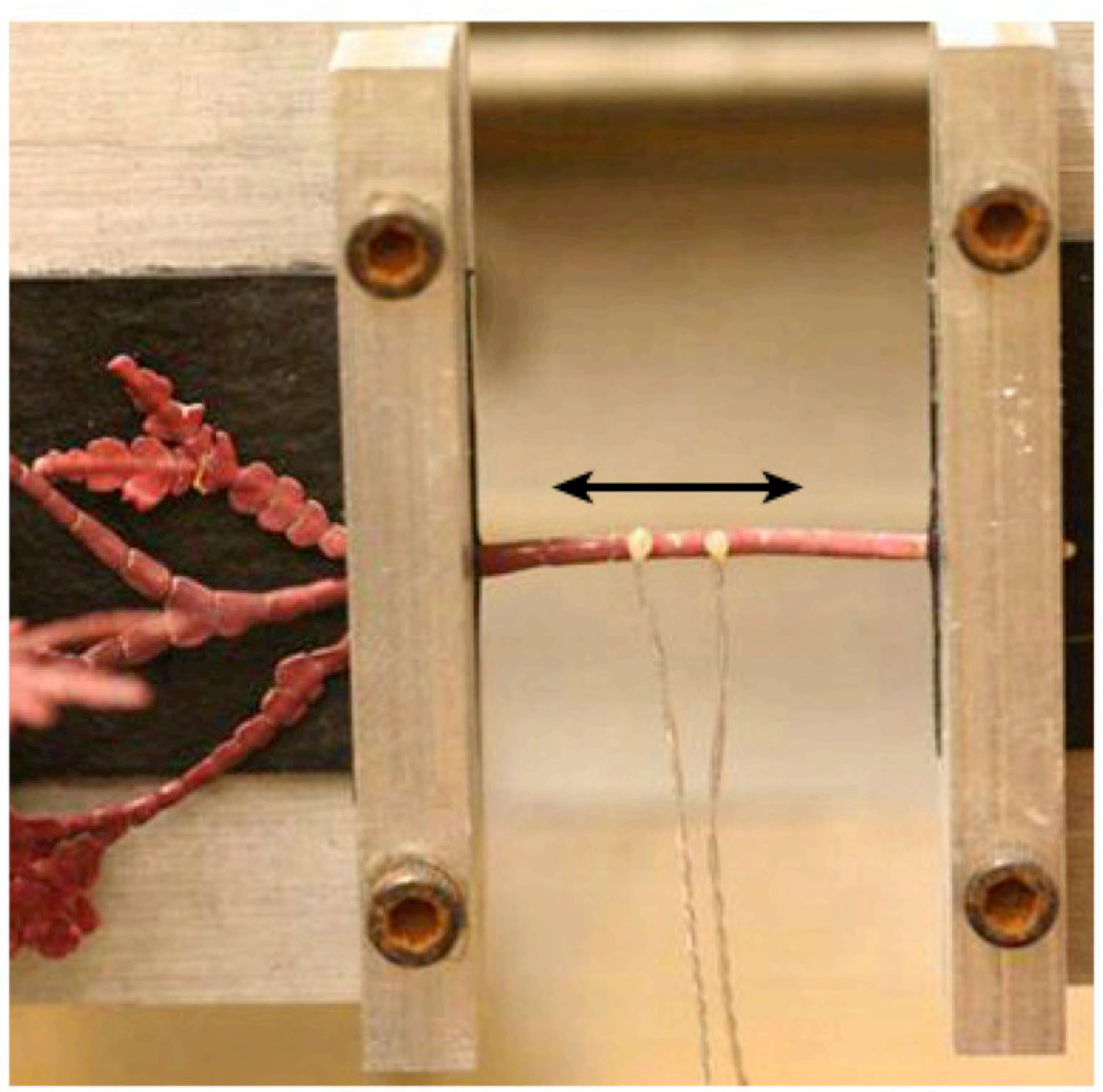
PHYSIOLOGICAL RESPONSES

Benthic Macroalgae

Justin Ries *Effects of $CaCO_3$ saturation state and temperature on the calcification rate and skeletal properties of benthic calcifiers*

- Calcification rate
- Elemental composition
- Mineralogy
- Biomechanical properties
- <u>Geological perspective</u>

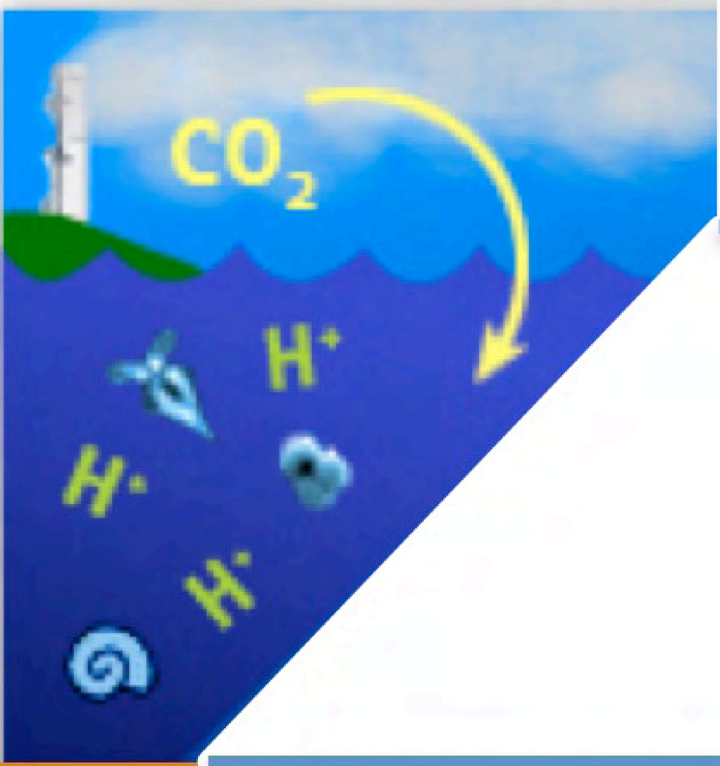




Testing the integrity of structural components

Emily Carrington (Summers, O'Donnell, Martone) *Effects of ocean acidification on coastal organisms: an ecomaterials perspective*

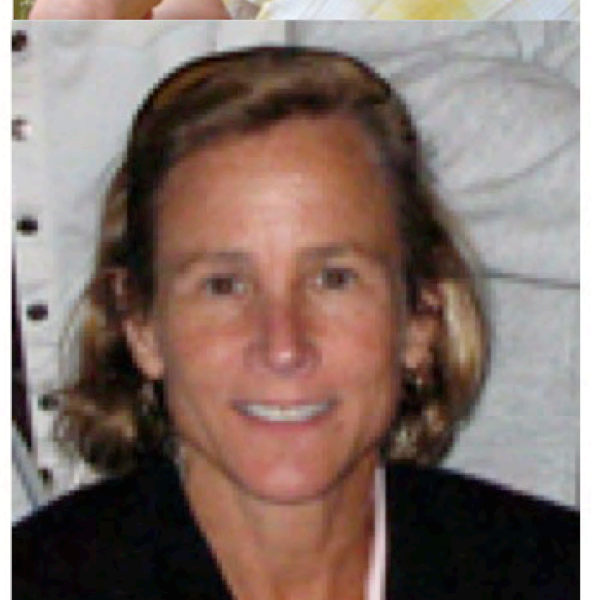
- Tissue composition
- Materials properties
- Effects on organism performance



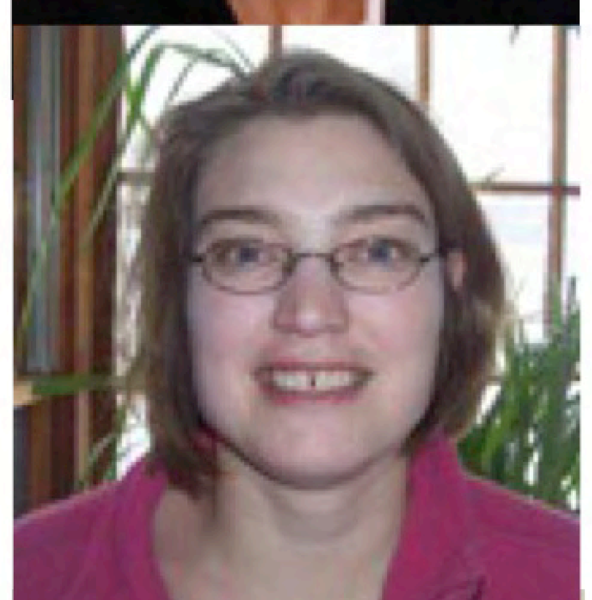
Panelists

PHYSIOLOGICAL RESPONSES

Brian Hopkinson
Univ. Georgia



Cheryl Kerfeld
Joint Genome Institute/UC Berkeley



Shannon Meseck
NOAA/NMFS, Connecticut

Mónica Orellana
Inst. Systems Biology, Seattle

Mark Warner
Univ. Delaware

Example Questions

What science needs to be done (how can we use these other sciences to enlighten our understanding of how organisms/ecosystems respond to OA)

- Physiological sciences, systems biology, evolutionary biology, etc.
- OMICs
- Biological/chemical monitoring; What tools are ready for moorings, gliders, floats, AUVs, proxy approaches
- Adaptation studies
- Evolution studies
- Paleobiology, paleoecology, proxies
- Biogeochemistry and the interactions with all of the above

What can we learn from these fields as they've been applied in terrestrial sciences?

What are the barriers to using some of these approaches?

- Natural research (disciplinary) barriers (different languages, interests, motivation)
- Funds
- Agency/university structures

How to facilitate that science through:

- Collaborations (cross-agency, cross-disciplines, public-private collaborations; policy world international)
- Synthesis & modeling – what information is out there already that can be useful

How to support that science through:

- Data management – what data are most important to collect? - links to other data centers or information outlets (e.g., economic and other societal data)
- Facilities

Building capacity

What actions should be done immediately to get this going?

- Recommend new research directions?
- OCB support on specific activities? (meetings, data support, synthesis)