Physiological Responses
- Unicellular/Algae -

John Gallagher, DVM
Physiological Responses
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**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
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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 CO₂ world on high latitude, temperate and tropical benthic foraminifera (Bernhard)

Effects of increased CO₂ 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+CO₂ 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 CaCO₃ 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

- Bacteria
  - Spirochetes
  - Proteobacteria
    - Cyanobacteria
  - Planctomyces
  - Bacteroides
  - Cytophaga
  - Thermotoga
  - Aquifex
  - Gram positives

- Archaea
  - Green Filamentous bacteria
  - Methanosarcina
  - Methanobacterium
  - Methanococcus
  - Thermoproteus
  - Pyrodictium
  - T. celer
  - Halophiles
  - Entamoebae

- Eucarya
  - Slime molds
  - Animals
    - Fungi
    - Plants
    - Ciliates
    - Flagellates
    - Trichomonads
    - Microsporidia
    - Diplomonads
VERY BASIC TREE OF LIFE

Ancestral Organism

Bacteria

Archaea

Eukarya

Protists

Plants

Animals

Fungi
VERY BASIC TREE OF LIFE

- Ancestral Organism
  - Archaea
    - Prochlorococcus
  - Bacteria
  - Diazotrophs
  - Protists
  - Plants
    - Fungi
  - Animals
    - Phytoplankton
    - Rhizaria
      - Foraminifera
  - Gretchen Hofmann
Main Groups

**Phytoplankton:**
- Diatoms: *Thalassiosira oceanica*
- Coccolithophores: *Emiliania huxleyi*
- Cyanobacteria: *Prochlorococcus*, *Synechococcus*, *Trichodesmium*, *Crocosphaera watsonii*
- Dinoflagellates: *Alexandrium fundyense* (red tide), *Symbiodinium* (coral endosymbiont)

**Fungi:**
- *Aspergillus* (sea fan pathogen)

**Benthic forams**

**Benthic macroalgae:**
- *Halimeda*
- Coralline red algae

Boyce et al. 2010 Nature
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 N$_2$ 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

NOTE: Coccolithophore studies by Barney Balch & Benjamin Twining will be addressed in Ecology Synthesis
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
physiological responses

1. HCO₃⁻ + H⁺ ⇌ CO₂ + H₂O
   Carbonic anhydrase

2. RuBP + CO₂ → 2 PGA
   + CO₂ + (H₂O) → 2 PGA + phosphoglycolate
   Wasteful side reaction

Nature Reviews | Microbiology
Changes in Trace Metal Chemistry

**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.

**F.-X. Fu:** *Changing phytoplankton trace metal requirements in a high CO2 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 pCO2 conditions
N$_2$-fixation - Diazotrophs

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.

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

See Nathan’s poster
CCM in Phytoplankton

Brian Hopkinson/Morel: *Effects of pCO₂ and pH on photosynthesis, respiration and growth in marine phytoplankton*

H1: elevated CO₂ -> 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

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 (e.g., Temp, high CO₂, 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 CO₂
- What are the molecular mechanisms by which its genetic program permits adaptation to environmental changes?
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)
  - *Emiliania huxleyi*
Pathogens

**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 CO₂, temperature, and N and P can impact coral-algal symbioses and calcification

Photos: E. Weil

Visual observations of disease in sea fans

*Aspergillus sydowii*

Labyrinthulid protozoan

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 CO₂ 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 δ¹¹B)
  - Also studying effects of CO₂ disposal in the deep ocean → calcareous forms affected; non-calcareous forms were not

Lisa Robbins (Paul Knorr) *Effects of increased CO₂ on calcification and carbonate sediment contributions of Halimeda and larger foraminifera*

  - pH-stat experiments
  - Analyze ultrastructure and isotopes
Benthic Macroalgae

Lisa Robbins (Paul Knorr) Effects of increased CO₂ 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

Similar species can have different responses

CO₂ bubbling experiment with 2 species of Halimeda. Price et al. (in review)

Ambient Air | High pCO₂
**Benthic Macroalgae**

**Ilse 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
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
- Geological perspective

**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

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)