Does Biological Community Structure Influence Biogeochemical Fluxes?

JGOFS Says Yes!

Anthony F. Michaels
University of Southern California
Wrigley Institute for Environmental Studies

Roadmap

• What do we mean by community structure?

• Selected survey of community impacts on global carbon cycle
  – HNLC
  – Particulate Inorganic Carbon
  – Nitrogen Fixation
  – Remineralization length-scales
Tension and Balance

- Biologist's love of the details of life
- Biogeochemist's need to simplify in order to model global dynamics

What do we need to get a food web?

- Phytoplankton
- Zooplankton
- Nutrients
- Sinking Particles

Stays Suspended

Sinks
What do we need to get a food web?

Phytoplankton  →  Zooplankton

Nutrients  ↘  Bacteria  ↘  Sinking Particles

Stays Suspended  (Fasham et al., 1990)

P-Z-N Dynamics: Populations Change through Time

Nitrate  

Zoop  

Phyto  

Time
P-Z-N Dynamics: Populations Change through Time

Nitrate

Phyto

Zoop

P-Z-N Dynamics: Populations Change through Time

Nitrate

Phyto

Zoop
So, what are we really asking?
Does it matter what biology is hidden within each box?

Is this level of details necessary to understand the carbon cycle?
Rephrase the Question

Do we need more structure than P-Z-N-B to capture the important carbon dynamics for *global* scales?

(e.g., more phytoplankton, more zooplankton, viruses, marine snow, etc.)

Community Structure and Flux: Circa 1988
Start with big size range of plants

- **Pico-Phyto** (<2 µm)
- **Nano-Phyto** (2-20 µm)
- **Micro-Phyto** (20-200 µm)
Nutrients

Pico-Phyto → Nano-Phyto → Micro-Phyto → Meso-Zoo

Stays Suspended

Bacteria & Nutrients

Sinking Paricles
Foodwebs and Flux - 1988

• Focus on f-ratio and the amount of export from surface waters

• “Ryther-esque” outcome (# trophic steps, transfer efficiency)

• Imply that removal of carbon from surface is directly related to exchange with atmosphere
Ocean biology maintains a vertical DIC gradient: Balance of biology and physics

What Processes Have Significant Affects on Air-Sea Partitioning of Carbon Dioxide?

1. Incomplete Nutrient Utilization (HNLC)
3. Changes in Nitrogen fixation:Denitrification balance (LNLC)
4. Changes in Remineralization Length-scales

Do food webs matter for any of these?
1. Incomplete Nutrient Utilization in the Surface Waters (HNLC)

- Decadal residence times
- Century residence times
- Millennial residence times

Most of the ocean shows near-complete nutrient utilization
Low Nutrient Areas

If nutrient levels stay near detection and if C:N:P stoichiometry is constant,

then P-Z-N might be enough for the global carbon models

– Those are some big “ifs”
– There is more of interest on this planet than just global carbon

HNLC Regions

Changes in net utilization of surface nutrients changes DIC gradient and air-sea partitioning (within limits)

• High-nutrient, low chlorophyll areas (HNLC) in Southern Ocean, Equatorial Pacific, North Pacific and some coastal zones

• Trace nutrient limitation (Fe), Diatom blooms (Si)

• Reduce HNLC area - 15-100 ppm reduction in atm CO₂

• Amenable to direct manipulation (political hot potato)
Nutrient Cycling in the Modern Southern Ocean

Nutrient Cycling in the Glacial Southern Ocean

(Anderson et al., 2002)
Nutrient Cycling in the Glacial Southern Ocean

(Anderson et al., 2002)
1. Incomplete Nutrient Utilization in the Surface Waters (HNLC)
   Influence of Community Structure?
   - Taxa-specific responses to Fe
   - Si+N requirements in diatoms, N requirements in other phytoplankton
   - Taxa-specific grazing responses
   - Ballasting issues

2. Changes in Particulate Inorganic Carbon Flux
   - Archer and Maier-Reimer, 1994
   - Skeletons of coccolithophorids, foraminifera and pteropods
   - Alkalinity change! Increase in PIC flux -> increase in pCO₂
   - Net effect on atmosphere depends on PIC:POC ratio
   - Community structure effects analogous to remineralization length scale
Carbonate Flux Linked to Organic Carbon Flux via Ballasting
(a la Armstrong et al, 2002)

(Klaas and Archer, 2002)
2. Changes in Particulate Inorganic Carbon Flux
Influence of Community Structure?

- Carbonate skeletons found in a subset of taxa: coccolithophorids, foraminifera and pteropods
- Ecosystem dynamics will determine relative contributions of these taxa
- Mix of autotrophs and heterotrophs - must be mix of top-down and bottom-up controls
- Some of these taxa susceptible to creating blooms
- Ballasting link to organic carbon fluxes, stronger for carbonate fluxes than opal (correlation - causation?)

3. Changes in Nitrogen Fixation - Denitrification Balance

- Extra Nitrogen Fixation
- Lower DIC
- Higher DIC

Decadal residence times
Century residence times
Millennial residence times
Dissolved Inorganic Carbon
Nitrate+Nitrite
3. Changes in Nitrogen Fixation - Denitrification Balance

Extra Denitrification

Higher DIC

Lower DIC

Trichodesmium spp.
Best Known Planktonic Diazotroph
Excess Nitrate = NO₃ - 16*PO₄

Data from BATS

N* in the Atlantic Ocean

(Gruber and Sarmiento, 1997)
N* in the Pacific Ocean

(Deutsch et al., 2001)

(Husar et al., 1997)
Key Assumptions and Dynamics:

- Iron from dust limits nitrogen fixation
- Reasonable flexibility in N:P ratios and nutrient controls on N-fixation
- Carbon Modeling
  - NCAR Ocean GCM (Doney)
  - Multi-compartment box model (Sigman)
  - Add adequate N fixation for 1 Gt/y C fixation
  - Restrict N fixation to 10-40° (N and S)
  - C:N=6.6, Assume flexible N:P within N* range
  - 100-300 year runs

(Doney, Moore in prep)
Nitrogen Fixation Feedback Cycle Hypothesis
(as an example)
Two Additional Biological Characteristics:

- Diazotrophs form large surface blooms
Two Additional Biological Characteristics:

- Diazotrophs form large surface blooms
- Nitrogen fixation dynamics seem to change on decadal time-scales (at least in the Pacific Ocean)

Dave Karl and co-workers
3. Changes in Nitrogen Fixation - Denitrification Balance

Influence of Community Structure?

- Diazotrophy found in a distinct subset of all prokaryotic taxa
- Chemical defenses against grazing in some
- Some taxa symbiotic in eukaryotes (esp. diatoms, creates silica requirement)
- Denitrification - special environmental conditions, specific prokaryotes
4. Changes in remineralization length-scales and C-N-P stoichiometry

Changes in remineralization length-scales

- Depends on the depth horizon and ventilation time-scale:
  - Annual: 10-20 Gt C/y
  - Multi-annual (>200 m): 5-10 Gt C/y
  - Multi-Decadal: 2-4 Gt C/y
  - > Centennial: ~1-2 Gt C/y
Larger b value, more POC is recycled in upper ocean
Smaller b value, more POC gets to deep ocean
US-JGOFS Open-Ocean Sites

Exponent, $b$

POC Export at 100 m (mmolC m$^{-2}$ d$^{-1}$)

(Martin et al., 1987)

Berelson (in prep)
Slope’s always positive—
best explanation—
Reactivity
POC >
Reactivity bSi

Can bSi content slow net particle settling rates?
(Hypothesis: Yes)
US-JGOFS EqPac—1992

Settling Velocity (m/day)

El Nino
Non-El Nino

Location (depth, m)  Berelson (2001)

Low Opal
Hi Opal

Eq. (880-2284)  100
Eq. (2284-3618)  150
5°N (1191-2091)  200

0

Eq. (880-2284)  50
Eq. (2284-3618)  100
5°N (1191-2091)  150

0
Salp, copepod, euphausiid

Fecal Pellets

Bacteria & Nutrients

Sinking Particles

Stays Suspended

Nano-Zoo → Micro-Zoo → Meso-Zoo

Pico-Phyto → Nano-Phyto → Micro-Phyto

Bacteria & Nutrients

Sinking Particles

Stays Suspended
Bacteria & Nutrients

Nano-Zoo → Micro-Zoo

Nano-Phyto → Micro-Phyto

Pico-Phyto → Nano-Phyto → Micro-Phyto

Sinking Particles

Twice in a decade!

Enormous Blooms!
Asexual reproduction by budding

The Outer Limits

~ 1 Gt C

~ 0.5 Gt C
Ecosystems and Plankton Blooms

- Ecosystems are complex-dynamical systems
- Bloom dynamics are poorly understood and hard to study
- Top-down vs bottom-up, a debate that is sorely lacking in ocean science
- Blooms created and controlled by internal dynamics of ecosystem, rarely bounded by external controls like nutrients

4. Changes in remineralization length-scales and C-N-P stoichiometry
   Influence of Community Structure?

- Mix of biological and physical sources to different types of sinking particles
- Ballasting signals (mechanisms?)
- Diatom blooms may have non-intuitive impact on remineralization length-scale
- Bloom forming organisms create unique time-space scale issues for remineralization and for science.
Conclusions

• Community structure matters for the partitioning of carbon between ocean and atmosphere.

• JGOFS has clarified some simple issues that now allow us to ask much more sophisticated questions.

• We still lack tools to study these processes on the time, space and taxonomic levels that are required.

• When community structure is important, the outcome is often emergent from internal dynamics.

Future Directions

• Community structure where it matters (HNLC, nitrogen fixation, etc.)

• The “twilight zone” and below

• Bloom dynamics (when they occur and when they matter)

• Complex systems approaches

• Be ready for surprises (viruses, archea, who knows what else).
Thank you!