

(updated 01/10/00)

## **Workshop Prospectus: Ecological Determinants of Oceanic Carbon Cycling**

Report from First Organizing Committee Meeting

The first meeting of the organizing committee for EDOCC took place on 24 May 1999 at the National Science Foundation. Initial comments by P. Taylor concerning the genesis of this activity, its antecedents and current related activity with regard to the developing Carbon Cycle Science Plan (CCCP), and related Federal and international program. Capone discussed the immediate task of the committee with respect to helping identify critical issues in the realm of biological and ecological processes that would substantively improve our understanding of the oceanic C cycle. This would be accomplished through the organization of an intensive workshop involving a broad range of participants in biological oceanography, biogeochemistry, ecology and allied disciplines, and through solicitation of comment from the broader biological oceanographic community. The inputs received would be used to help craft a science plan for biologically mediated carbon cycling for the next decade.

These introductions were followed by an extended discussion among the committee during the morning on our current understanding of the role of the ocean biota in the global C cycle, and critical gaps in our understanding. Falkowski stressed the urgency, from a human perspective, of fostering a better understanding the biotic role in the oceanic C cycle. Unprecedented increases occurring in atmospheric CO<sub>2</sub> from fossil fuel use over the last century may be reinforced by suite of positive oceanic feedbacks through a lowering of oceanic pH, increased upper ocean stratification and reductions in oceanic N<sub>2</sub> fixation and export production. **Understanding feedback mechanisms at different spatial and temporal scales between marine biological communities and the physical and chemical environment was the broad theme encompassing the rest of the discussion.**

A major question/ challenge looms before us: Is the oceanic biota as inconsequential in the global C cycle? Recent evidence suggests otherwise. However, our current understanding of the role of the upper ocean biota remains very poorly constrained, particularly in comparison to terrestrial C cycling. What are the controls and feedbacks on CO<sub>2</sub> fixation? We have little current basis by which to predict near term responses of the upper ocean biota to a warming surface ocean and shifts in oceanic circulation and stratification.

The Discussion ultimately turned to the identification of several key themes that are the central issues in our current understanding of the role of ocean biology in carbon cycling and that might provide a focus for roundtable discussions at a Workshop. Two broad Key Questions in the realm of ocean biogeochemistry identified in the OEUVRE report were reviewed to provide a framework for targeting research areas. They are:

*#1 How do environmental and biotic factors determine the distributions and activities of key species or functional groups important to biogeochemical cycles in space and time?*

#2 *What are the important interactions among marine biota, global climate and biogeochemistry?*

Our discussion sought to make a first cut at refining these questions. A set of 4 themes were proposed and considered:

### **1. The Functional Groups Concept [Falkowski]**

Advances in remote sensing and optical oceanography provide us with an unprecedented opportunity to observe and define dynamics (e.g. with resolution of trends in space and time not previously attainable) of several groups of plankton in the upper ocean. Current capabilities provide limited means to observe several broad groups with unique optical signatures and biogeochemical impact: e.g. diatoms, important primary producers associated with high potential for export production and for Si test formation; coccolthophorids, primary producers of additional significance due to their precipitation of  $\text{CaCO}_3$ ; *Trichodesmium*, planktonic marine autotrophic cyanobacteria which fix  $\text{N}_2$ , and *Phaeocystis*, an important primary producer in high latitudes. Simultaneously, molecular approaches have provided us with the capability for tracing and identifying populations and subpopulations. Is there a link between, or effect of, populations and functionality?

#### **Specific questions/ issues:**

*Is the Functional Group concept useful in advancing our understanding of marine C cycling? In other words, do species differences and shifts matter with respect to ecosystem function?*

*How do we observe or discern biodiversity (and shifts therein) within functional groupings?*

*How does biodiversity relate to functional redundancy of biogeochemical and ecological function?*

*What is the significance of the level of redundancy (e.g. diverse species involved in  $\text{CO}_2$  fixation compared to few species involved in  $\text{N}_2$  fixation) within different functional groups?*

*How have the functional groups, or composition of the functional groups in biogeochemical cycles evolved (and coevolved with the biota) in the sea over geological time scales?*

*How do we assess “key” functional groups that are difficult to observe or not directly observable by remote sensing (e.g. picoplankton, viruses, heterotrophic bacterioplankton, nitrifiers, denitrifiers, and various grazing populations).*

## **2. Time Scales of Response of the Marine Biota: From Nanoseconds to Millennia [Letelier]**

The role of the biota in the carbon cycle is certainly a function of the factors controlling the growth and activity of organisms. The environmental factors controlling growth vary temporally as a result of natural daily and seasonal cycles, but also due to global change and the long term evolution of biological systems. The time scales of these natural perturbations and environmental variation vary greatly. Plankton population responses to daily and seasonal variability forced by natural fluctuations in light, temperature, physical stability and nutrients have been well-studied and characterized. Biological accommodation and adaptation occur at many levels of biological organization and often involve integrated cell responses (e.g. endogenous rhythms, vertical migration) to optimize daily growth potential. The sequential succession of populations over the season in boreal through sub-tropical (and even tropical) oceanic ecosystems also reflect organismal adaptations to light, temperature, turbulence and nutrients.

In contrast, little is known about natural cell and integrated population responses to high frequency (seconds- minutes) variability in nutrient and light fields often effected by physical variability. Similarly, the underlying factors promoting major population shifts over interannual, decadal and millennial time scales remain in the realm of speculation. Understanding these responses is critical for assessing the role of the biota in carbon cycles, as well as developing predictive models.

### **Specific questions/ issues:**

*Does steady state have meaning in the oceans?*

*How do high frequency variation in environmental parameters (e.g. temperature, light, nutrients) affect the structure of plankton communities and plankton diversity?*

*Can variability be considered a resource?*

*What are the forcing of decadal scale shifts?*

*Can we resolve the interactions between glacial/ interglacial climatology and plankton population dynamics?*

*Can we improve our understanding of the fossil record in this regard, and how might this be done?*

*Do time scales of ocean mixing set constraints on population responses?*

*What temporal scales of upper ocean environmental variability are relevant to deep ocean biota and elemental burial?*

## **3. Biological Transformations and Ocean Geochemistry [Zehr]**

Biological transformations play a key role in controlling the fluxes of C and many key elements. Furthermore, many geochemical inferences are dependent upon parameters interpreted in terms of biological processes. However, while we have a firm qualitative understanding of the importance of biotic processes in marine biogeochemistry, our

quantitative understanding of many processes is minimal, and our ability to predict the biogeochemical response of oceanic biota to perturbations rudimentary.

The recent improvement in the ability to analyze the chemical signatures of natural populations and their physiological status using novel tools of molecular chemistry and biology provide important means of better defining the biotic underpinnings to important geochemical parameters.

### **Specific questions/ issues:**

*What are the biotic controls and feedbacks on C processing and nutrient dynamics: can we improve our mechanistic understanding?*

*Although limiting factors are central concepts in biological and chemical oceanography, we still do not understand the variability in limiting factors as a function of time and space. What are the time and space scales of variability in limiting factors and how do these influence carbon cycling?*

*Can molecular biological analysis provide insights in paleoecology?*

*The Redfield ratio is a constant in elemental composition that was observed early in the study of the link between biology and chemistry of the oceans.*

*Perhaps there are other such ratios in biological composition that set constraints on growth and growth rates. For example, do plankton protein/DNA ratios set primary constraints on growth, growth rates or production? (Inferences from Ecological Stoichiometry)*

*Can isotope fractionation be used to learn more about past and present biogeochemical cycles constraining carbon flux?*

## **4. Food Web Structure, Physical Process, Carbon Export and Fate**

The classical image of carbon export from the surface ocean has been shaped by the fact that the export of particles is governed ultimately by gravitational settling, so it follows that larger particles, and the organisms that produce them, have the strongest immediate influence on export processes. Conversely, it follows that small organisms, and processes that reduce particle mass, will decrease the flux, and determine the balance between dissolved and particulate export. But the export flux is really a function of the collective behavior of the entire food web, which is intertwined in a complex network of interactions which are difficult to describe using traditional modeling techniques. In the end, however, the amount of export in any region will be largely set by inputs of new nutrients, driven by physical processes (vertical mixing, upwelling, horizontal advection, aerial deposition). Physical processes in turn influences the size structure of foodwebs, and other qualitative aspects of foodweb structure. Finally, vertical mixing and advection transport dissolved organic matter and small particles from the upper ocean. Dissecting the relationships between foodweb structure (including genetic diversity), physical processes and export carbon is a major requirement for better predictive understanding of the changing carbon cycle in the ocean. In particular we need to understand how individual “keystone” species, and biological variability at the molecular

to ecosystem scale influence carbon and associated cycles in different biogeochemical/physical ocean regimes. Furthermore, a mechanistic understanding of what controls the fate of exported C is necessary to better define the role of biology in past C burial records.

**Specific questions/ issues:**

- What are the foodweb structures (size spectra, dominant species, limiting nutrients) characteristic of the major ocean biomes?*
- How is net ecosystem production (=export production) related to the structure of the food web? Can it be related to specific components, or is it a property of the system as a whole?*
- Over what temporal and spatial scales does net ecosystem production have meaning in terms of the annual global ocean carbon cycle?*
- How do physical processes influence plankton community succession over event scales (bloom), to seasonal and longer (ENSO) time scales?*
- What is the role of the microbial loop in regulating particle and dissolved exports?*
- What are the roles of temperature, turbulence, stability, etc., in regulating foodweb structure and export?*
- Is there a relationship between physical stability and species/ecotype diversity, and what influence does this diversity have on biogeochemical cycles?*
- How will foodwebs and exports change under global warming in the next two centuries?*
- What are the major marine keystone species, their population dynamics and roles in ocean ecosystems?*
- What role does sexual reproduction play in phytoplankton species dynamics? Is it a regular occurrence or a response to stress?*

While not extensively discussed in our first meeting, Jon Zehr proposed considering limitations in our concepts, methodologies and technologies and our ability to assimilate and synthesize data. Substantive advances in knowledge and understanding are often constrained by available approaches and technologies. Copious examples of innovative conceptualization and new methodologies propelling fields are available. In marine ecology, the influx of molecular approaches has revolutionized our understanding of biodiversity, remote sensing and moored arrays are etc. etc. And these areas are not static. Rapid development of new advances in gene sequencing (DNA chip technology), remote sensing (hyperspectral sensors) of the biota and autonomous probes are underway and challenging our ability to make the most effective use of data streams.

What do we need for breakthroughs in understanding the role of the biota in ocean C cycling? What factors are holding us back? Where can we profit from enlisting the expertise of other disciplines? How do we most effectively make new information available to the broader community?