ABSTRACTS
(UNDER CONSTRUCTION)

Rising CO_2, Ocean Acidification, and Their Impacts on Marine Microbes

Expert Meeting organised by the Plymouth Marine Laboratory and the Center for Microbial Oceanography: Research and Education (C-MORE)

East-West Center, University of Hawaii at Manoa

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Background to Ocean Acidification

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The relation of the present anthropogenic increase in atmospheric carbon dioxide to changes in the inorganic carbon chemistry and pH of the surface ocean involves relatively simple physical chemistry, with fewer problems in determining the timing and extent of changes than for effects of carbon dioxide on climate. However, there was a significant delay in widespread appreciation of these oceanic effects after Keeling's demonstration (1950s onwards) of increasing atmospheric carbon dioxide. The effects of the dissolution of some of the additional atmospheric carbon dioxide into the surface ocean are to increase the concentrations of dissolved carbon dioxide and bicarbonate (smaller relative, but greater absolute, effect on bicarbonate than on dissolved carbon dioxide), and decrease the carbonate concentration and pH. The most widely recognized biological effects are in decreasing the rate of production, and the possibility of retention, of calcium carbon skeletons, with the distinct possibility of the extinction of some taxa. The inorganic carbon and pH changes increase photosynthetic carbon assimilation in many primary producers, with less effect on growth (as cell division) rates, and also impact negatively on many animals as well as influencing non-photosynthetic micro-organisms. Exacerbating these biological effects is the large extent (greater dissolved inorganic carbon changes and pH decrease than has been seen for at least the last 800,000, and probably many million, years) and rate (much faster than glacial - interglacial variations) of these anthropogenic changes. These factors interact in making difficult any genetic adaptation to the changed inorganic carbon and pH regime, especially for organisms with long generation times. While ultimately these effects on surface ocean chemistry will be largely reversed by natural processes this will take thousands of years and will not save us from changes predicted for 'business as usual' over the next few centuries.

Seawater Carbonate Chemistry - Basics and Outlook

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The oceans have absorbed about 40% of the carbon dioxide emitted by humans over the past two centuries.
As a result, surface ocean pH has already dropped by 0.1 units relative to preindustrial levels and is expected to drop by 0.3 units until year 2100 under business as Usual scenarios. In this presentation, I will give an overview on the basics of seawater chemistry, expected future changes, and other related issues. I will also call attention to a surprising and hitherto largely unknown consequence of ocean acidification.

Variable pH in freshwaters: a model ecosystem to test the ecological impacts of ocean acidification?

Stephen C. Maberly
Centre for Ecology & Hydrology
Lancaster Environment Centre
Lancaster, UK

The talk will describe the extent and causes of variability in pH among and within freshwater systems and the effect this has on the carbonate equilibria. The consequences for the biota, and especially the phytoplankton, will be explored.

The potential of genomics in studies of ocean acidification

Chris Bowler
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and
Stazione Zoologica,
Naples, Italy

Genomic approaches are transforming our knowledge of planktonic life in the oceans. For example, whole genome sequences from representatives of many key functional groups are now available, and metagenomics approaches are being used to explore microbial communities and the expressed gene repertoires of specific environments. In the diatoms, genome sequences have been instrumental in uncovering their responses to bioavailable iron, a major limiting resource in

many oceanic regions. In my laboratory we have used the pennate diatom *Phaeodactylum tricornutum* as a proxy to explore diatom metabolism in iron limiting conditions because of the similarity of its response to iron compared with oceanic diatoms that respond most strongly to iron fertilization, and because of the superior genetic resources that are available for this species. I will summarize these studies, and will show preliminary results using similar approaches aimed at exploring diatom responses to increased carbon dioxide levels. I will also discuss how metagenomics of natural populations can be leveraged to explore responses to ocean acidification in natural environments.

Experimental approaches in ocean acidification research: problems of up-scaling in time and space

Ulf Riebesell
Leibniz Institute of Marine Sciences (IFM-GEOMAR), Kiel Germany

Progress in our ability to make reliable predictions of the impacts of ocean acidification on marine organisms and ecosystems critically depends on our capability of conducting experiments mimicking the 'real world'. Ideally, such experiments should encompass whole ecosystems and last long enough to cover the relevant time-scales of the processes under investigation. In practice, due to logistical, technical, and financial constraints, most experiments represent a compromise between environmental relevance and experimental power. I will present an overview of some of the experimental approaches applied in ocean acidification research and will discuss some of the problems involved in up-scaling experimental results in time and space.

Offered papers

CO_2, acid and microbes: Some thoughts on field observations and experimental design

David M. Karl,
University of Hawaii

To understand the impacts of rising CO_2, increased acidity and other habitat changes that are tied to greenhouse gas induced warming of the sea (e.g., stratification, light and nutrient fluxes) it is critical to mount an integrated, transdisciplinary investigation of marine microbes in their natural environment. This research needs to include: (1) long-term observations in order to separate natural habitat variability from secular changes in key properties, (2) direct experimentation using natural assemblages and that are designed to last for multiple generations of the microorganisms of interest and (3) a range of nested models from those based on metabolism and growth of individual organisms to those based on ecosystem level processes. Comparative ecosystem analyses of marine habitats with different characteristics (pCO_2, pH, nutrient fluxes) may help to identify genomic or metabolic traits that are selected for in more acidic, high pCO_2 environments. Measurement programs and experimental studies should focus on the most fundamental aspects of metabolism possible, such as photosynthesis, respiration, growth rate and cellular bioenergetics (cellular nucleotide pools, ATP turnover), in order to detect changes in solar energy capture and dissipation that serve to structure marine microbial assemblages. The recently established Center for Microbial Oceanography: Research and Education (C-MORE) is uniquely positioned to bring intellectual assets and physical resources to bear on this important climate related research prospectus.

The fate of calcifying phytoplankton and ocean acidification: how to work out the ocean mean?

Debora Iglesias-Rodriguez
National Oceanography Centre, Southampton

Over the last twenty years, the marine science community has combined observational and modeling efforts to diagnose and forecast the reciprocal interactions between the chemical changes due to ocean acidification and marine plants and animals. While we are able to accurately measure changes in the atmospheric carbon dioxide, the processes governing its cycling by marine biota remain largely a mystery. One group of organisms targeted in these studies is the marine calcium carbonate-producing phytoplankton, the coccolithophores. This group produces intracellular calcium carbonate structures, which are extruded to the plasma membrane of the cell in a process called coccolithogenesis. In this biomineralization process, CO_2 is produced and thus it is the balance between photosynthesis and calcification what controls whether coccolithophores act as a source or a sink of CO_2. Laboratory experiments have shown that increasing pCO_2 causes enhanced organic carbon production in coccolithophores and non-calcifying phytoplankton. However, analysis of calcification within and between coccolithophore species has revealed a great deal of variability. The strategies to investigate the effect of ocean acidification at the population and community levels are discussed in an evolutionary context.

Does high CO_2 enhance marine phytoplankton growth?

Ian Joint
Plymouth Marine Laboratory

Several studies have suggested that phytoplankton growth rate is enhanced at higher pCO_2 and lower pH. Data from both laboratory cultures and mesocosm experiments have tended to indicate that there is a fertilization effect of CO_2. However, results are difficult to interpret because of the way in which experiments are done with phytoplankton. The pH of a typical laboratory culture growing in f/2 media will be very much greater than seawater (probably more than pH 9). To control pH in a laboratory culture, either biomass must be kept extremely low (something no physiologist would do) or buffers must be added at high concentration, with the potential changes to cellular biochemistry. Using low biomass, continuous culture, we do not find enhanced growth rate at 750ppm CO_2. Similarly, in a mesocosm experiment, a natural phytoplankton assemblage that was dominated by coccolithophores had significantly lower primary production at 750ppm than at 380ppm.

Physiological and Ecological Responses of Marine Phytoplankton Assemblages to Experimental CO_2 manipulations

Philippe D. Tortell
University of British Columbia

Over the past decade, we have conducted a number of CO_2 manipulation experiments with natural phytoplankton assemblages in various oceanic regions. Our results consistently show large biochemical and physiological changes in response to CO_2 levels ranging from ~100 – 800 ppm. These responses include the regulation of enzymes and transport systems involved in the assimilation of inorganic carbon. By comparison, we typically observe only modest (though often statistically significant) effects of CO_2 levels on bulk phytoplankton growth in our experiments. Yet, when phytoplankton species composition is examined, we find large species shifts in assemblage composition, with large diatoms increasing in relative abundance under higher CO_2 treatments, and smaller diatoms dominating under low CO_2 conditions. Our physiological data provide a mechanism to explain these apparent species shifts, based on surface area to volume considerations and maximum cellular C transport rates. I will discuss these results, with a particular focus on recent experiments conducted in the Ross Sea, Antarctica

Investigating the responses of ocean diazotrophs to variations in seawater pCO_2 in the North Pacific Subtropical Gyre

Matthew J. Church
University of Hawaii

Time series investigations in the North Pacific Subtropical Gyre suggest oceanic N_2 fixing microorganisms (termed diazotrophs) provide a major source of new nitrogen to the oligotrophic waters of the North Pacific Subtropical Gyre, thereby exerting important control on the cycling of bioelements in this ecosystem. Over the 20+ years of observations at Station ALOHA in the NPSG, various lines of evidence suggest the activities of N_2 fixing microorganisms may be increasing. Coincident with such changes, seawater pCO_2 has progressively increased in response to rising atmospheric CO_2 inventories. Over the next 3 years (2009-2012) we plan to investigate possible connections between variations in seawater pCO_2 and the activities and diversity of naturally occurring N_2 fixing microorganisms in this ecosystem. This presentation will provide information on the objectives of the project and describe how we intend to test several hypotheses regarding how alterations in the seawater carbonate system may influence diazotroph physiology.

Alteration of oceanic nitrification under elevated concentrations of carbon dioxide

Michael Beman
University of Hawaii

Nitrification is a biogeochemically important process in the ocean that may be sensitive to changes in ocean chemistry associated with ocean acidification. Based on multiple experiments performed in the Sargasso Sea and Southern California Bight, elevated carbon dioxide concentrations can potentially reduce populations of nitrifying microorganisms in the ocean, increase microbial growth rates, and enhance nitrification rates by 30-40%. These findings suggest that projected increases in pCO_2 may affect microbial biogeochemistry and community structure in the sea, with important implications for the global nitrogen and carbon cycles.

Effects of pH shift on the photosynthetic performance of marine phytoplankton measured by FRR fluorometry

Zbigniew Kolber
Monterey Bay Aquarium Research Institute

In my talk I will describe the design of our experimental setup to continuously measure the effects of the pH shift on the efficiency of photosynthetic light utilization, on the yield of charge separation, and on the kinetics of electron transport between photosystem II and photosystem. I will present some data we have acquired in our laboratory, and during the 2008 OPEREX cruise, and I will discuss the potential difficulties in interpretation of these data.

How do we quantify physiological to ecosystem stress under a Climate Change Scenario?

Ricardo M Letelier
College of Oceanic & Atmospheric Sciences
Oregon State University

A biological system becomes under stress primarily when the environmental conditions change at a rate that is greater than its rate of adaptation. Alternatively, stress can also be experienced when these environmental changes modify the niche beyond a threshold in which a given population or community is able to survive. For this reason, the rate of environmental change relative to the rate of adaptation can be envisioned conceptually as a key non-dimensional indicator of stress. However, can we quantify the potential rate of adaptation in oceanic systems? One possibility is to analyze the response of pelagic ecosystems to natural stochastic or cyclic variations. Another is to assess experimentally how the rate of change of a given environmental parameter, such as pH or CO_2, may affect the long-term evolution of a pelagic community. In the present talk I will try to build on time-series research and conceptual experimental manipulations to explore the possibility of developing an approach to identify and quantify potential environmental stress resulting from ocean acidification.

Ocean acidification: documenting its impact on calcifying phytoplankton at basin scales

William M. Balch[1] and Victoria J. Fabry[2]

[1]Bigelow Laboratory for Ocean Sciences

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We evaluate several approaches to discern the impact of ocean acidification (OA) on calcifying plankton, over basin scales. We focus on estimates of the standing stock of particulate inorganic carbon (PIC) associated with calcifying plankton since it is thought that these organisms will be the most sensitive to OA. Chemical techniques provide the greatest accuracy and precision for measuring the concentration of PIC in sea water but basin-scale chemical surveys are formidably expensive due to the high costs of ship time and analytical instrumentation. Optical techniques, while not yet as precise as chemical methods, provide the opportunity to rapidly sample over much greater spatial scales, with large numbers of samples contributing to each PIC determination (which reduces the standard error about each mean determination). Optical measurements from autonomous platforms (buoys and gliders) will provide important depth resolution of PIC, otherwise not accessible to ocean color satellites. We propose a strategy for future PIC measurements that employs both optical and chemical measurements on the same water samples. This will ensure adequate knowledge of the PIC backscattering cross-section, critical for satellite PIC determinations at basin scales.