Annual Report for Period:01/2002 - 01/2003
Submitted on: 06/10/2003
Principal Investigator: Michaels, Anthony F.
Award ID: 9981545
Organization: U of Southern California
Title:
Biocomplexity: Collaborative Research: Oceanic N2 Fixation and Global Climate

Project Participants

Senior Personnel

Name: Michaels, Anthony
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Capone, Douglas
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Haug, Gerald
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Subramaniam, Ajit
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Name: Mahaffey, Claire
Worked for more than 160 Hours: Yes
Contribution to Project:
Postdoctoral Fellow, support from USC. Nitrogen isotope studies of N2 fixation.

Name: Shipe, Rebecca
Worked for more than 160 Hours: Yes
Contribution to Project:
Postdoctoral Fellow, support from USC. Si uptake studies.

Graduate Student

Name: Sohm, Jill
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Finzi, Juliette
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Burns, Jay
Worked for more than 160 Hours: Yes
Contribution to Project:

Undergraduate Student

Name: Jaeger, Stephanie
Worked for more than 160 Hours: Yes
Contribution to Project:
Undergraduate assistant/ volunteer on 2 cruises. Operations coordination, CTD deployments.

Technician, Programmer

Name: Neumann, Michael
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Protopopadakus, Lia
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Gunderson, Troy
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Schimmoeler, Reni
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Smith, Gerry
Worked for more than 160 Hours: Yes
Contribution to Project:
Research support on cruises

Other Participant

Research Experience for Undergraduates

Organizational Partners

NASA

1. We have a NASA contract under their SIMBIOS program which provides us with LAC SeaWiFS coverage during our research cruises.

NASA, SIMBIOS (MTPE). 'Varied waters and Dusty Skies: Validation of Ocean Color Satellite Products in under-Sampled Marine Areas'. 3 y 1 Dec 2000-30 Nov 2003, Co-PI, 1 mo/y.

2. Also- Earth System Science Fellowship to S. Cooley (doctoral student with P. Yager). Quantifying the role of the Western Tropical Atlantic Ocean in global carbon budgets: the intersection of physics, chemistry, and biology. (O25074-01). $72K, 3 yr.

NOAA Office of Global Programs
Global Carbon Cycle Program. Underway pCO2 Measurements in the Western Equatorial North Atlantic and Subtropical North Pacific: The Importance of Synchronous Supporting Measurements (GC02-373). $127K, 3 yr.
(to P. Yager)

DOE Ocean Carbon Sequestration Research
To P. Yager. The impact of nitrogen fixation on carbon sequestration: a reassessment of the inorganic carbon system in LNLC regions

Other Collaborators or Contacts

There are co-PIs from other institutions that have their own NSF grants to cover their effort. These include:

Ed Boyle, MIT
Dave Karl, U Hawaii
Danny Sigman, Princeton
Dave Siegal & Natalie Mahowald, UCSB
Scott Doney, NCAR
Ron Siefert, UMd
Ed Carpenter, SFSU
Gerald Haug, ETH
Patricia Yager, U.Ga.

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

Findings: (See PDF version submitted by PI at the end of the report)

Training and Development:

(Also see activities section)

Training Activities included participation of several undergraduates and numerous graduate students and postdoctoral students on our cruises and workshops. Besides the substantial involvement of 7 graduate students and 3 postdocs at USC, through Co-PIs we have had direct involvement of students from SUNY-Stony Brook (6 graduate students, 2 postdocs), SFSU (4 graduate students, 2 undergraduates, 1 postdoc), U Maryland (1 post doc, 1 grad student), U Ga. (1 grad. student), Oregon State U. (1 grad. student), MIT (2 grad students, 2 postdoc), Rutgers (1 postdoc), U Hawaii (2 grad student), UCSC (1 grad student), UCSB (1 grad student), UCLA (1 grad student), Scripps (1 grad student & 1 postdoc). Several students are performing their PhD thesis research under our Biocomplexity program (J. Sohm, J. Finzi, I. Hewson and J. Steele at USC, S. Cooley at UGa, Y. Chen at UMCES, Westerberry at UCSB.

We were also lucky in receiving funding for a COSEE Center to enhance K-12 science and math education in this area. The Biocomplexity faculty have been quite involved in this effort. Michaels has given numerous lectures in the teacher training sessions and has been active in knitting this content into the curriculum development areas. Capone has been involved with the strategic retreats. This program reaches teachers of schools that are primarily composed of under-represented ethnic groups and we hope it will become an important conduit for increasing the diversity of marine scientists. The larger goal is to enhance the general science backgrounds of ethnic minorities so that they may have a higher chance of moving into any kind of field of science.

Our faculty have been able to create an REU site program. This started the summer of 2003, but the biocomplexity PIs were very involved in the grant proposal and will be key players in that program.

We have five graduate students (Jay Burns, Juliette Finzi, Jill Sohm, Ian Hewson, Josh Steele) who are now working on this project as a major part of their dissertations. Burns just recieved his Ph.D. We have a postdoctoral fellow (Rebecca Shipe)who contributing to the project goals and have just hired two more postdoctoral associates who will be involved (Mahaffey, now Burns).

Michaels continues to teach part of a graduate seminar where the complexity ideas were developed as one of the student discussion topics. Michaels and Capone have also given public seminars on the topic. The hypotheses and results of this research also figure prominently in the undergraduate Biological Oceanography course taught each year by Capone. Michaels also teaches a graduate training program in the professional aspects of being a professor in ocean sciences. He used a number of the biocomplexity ideas in developing that class.

The field activities have provided four of our science technicians with the opportunity to expand their technical and seagoing skills. These three have begun to develop management and leadership skills as they organize significant parts of the cruises and then coordinate the deployment of our sediment trap moorings at sea.

Outreach Activities:

Michaels has given public talks on the climate feedbacks associated with nitrogen fixation as part of hosting the public at the Wrigley Marine Science Center on Catalina Island and in presentations to Rotary clubs, Yacht clubs and other venues in Los Angeles. These groups have

included a number of leaders in business including the CEOs and Presidents of companies large and small. Some of these companies are directly involved in the energy industry and have a stake in understanding the future fate of CO2. We also have convened a group of business leaders as an advisory board for the USC Wrigley Institute and one of their mandates is to aid us in making the business community understand complexity issues in general and how ocean science can enhance the decisions that businesses make about environmental issues. Michaels and Capone are involved in creating a partnership of businesses and academic groups with interests in carbon sequestration. This has resulted in a proposal to the Department of Energy, however, the group activities will continue regardless of funding. The corporate partners include Fluor Corporation, Southern California Edison, Southern California Gas Company and others.

Journal Publications

Karl, D., A.F. Michaels, B. Bergman, D. Capone, E. Carpenter, R. Letelier, F. Lipschultz, H. Paerl, D. Sigman & L. Stal., "Dinitrogen fixation in the WorldÆs Oceans", Biogeochemistry, p. , vol. , ( ). Accepted

Capone, D.G., "Marine Nitrogen Fixation: what's the fuss?", Current Opinion in Microbiology, p. 341, vol. 4, (2001). Published

Subramaniam, A., C. W. Brown and D.G. Capone, "Dynamics of a coastal Trichodesmium bloom 1: Detection", Deep-Sea Res. Part II, p. 107, vol. 49/1-3, (2001). Published

Michaels, A.F., D.M. Karl and D.G. Capone, "Element stoichiometry, new production and nitrogen fixation", Oceanography, p. 68, vol. 14, (2001). Published

Hood, R.H., A. Subramaniam, L.R. May, E.J. Carpenter and D.G. Capone, "Remote estimation of nitrogen fixation by Trichodesmium", Deep-Sea Res. Part II, p. 123, vol. 49/1-3, (01). Published

C. Luo, N. Mahowald, J. del Corral, "Sensitivity study of meteorological parameters on mineral aerosol mobilization, transport and distribution ", JGR-atmospheres, p. , vol. , ( ). Accepted

C. Jones, N. Mahowald, C. Luo, "The role of easterly waves in African desert dust transport ", J. Climate, p. , vol. , ( ). Submitted

N. Mahowald, C. Luo, J. del Corral, C. Zender, "Interannual variability in atmospheric mineral aerosols from a 22-year model simulation and observational data ", JGR, p. , vol. , ( ). Accepted

C. Mahaffrey, R. G. Williams, G. A. Wolff, N. Mahowald, W. Anderson, "Isotopic signals of nitrogen fixation over the eastern North Atlantic", GRL, p. 1300, vol. 40, (2003). Published

N. Mahowald, R. Bryant, J. del Corral, L. Steinberger, "Ephemeral lakes and desert dust sources ", GRL, p. 1074, vol. 30, (2003). Published

N. Mahowald, C. Zender, C. Luo, D. Savoie, O. Torres, J. del Corral, "Understanding the 30-year Barbados desert dust record", JGR, p. 4561, vol. 107, (2002). Published

Haug, G.H., D. G³nther, L.C. Peterson, D.M. Sigman, and K.A. Hughen, "Climate and the collapse of Maya civilization", Science, p. 1731, vol. 299, (2003). Published

Haug, G.H., K.A. Hughen, D.M. Sigman, L.C. Peterson, and U. Rohl, "Southward migration of the Intertropical Convergence Zone through the Holocene", Science, p. 1304, vol. 293, (2001). Published

Thunell, R.C, D.M. Sigman, F. Muller-Karger, Y. Astor, R. Varela, "The nitrogen isotope dynamics of the Cariaco Basin, Venezuela", Global Biogeochemical Cycles, p. , vol. , ( ). in preperation

Pantoja, S., D.J. Repeta, J.P. Sachs, and D.M. Sigman, "Stable isotope constraints on the nitrogen cycle of the Mediterranean Sea water column", Deep-Sea Research I, p. 1609, vol. 4, (2002). Published

Sigman, D.M., R. Robinson, A.N. Knapp, A. van Geen, D.C. McCorkle, J.A. Brandes, and R.C. Thunell, "Distinguishing between water column and sedimentary denitrification in the Santa Barbara Basin using the stable isotopes of nitrate", Geochemistry, Geophysics, Geosystems, p. 1040, vol. 4, (2003). Published

Casciotti, K.L., D.M. Sigman, and B.B. Ward, "Linking diversity and stable isotope fractionation in ammonia-oxidizing bacteria", Geomicrobiology Journal, p. , vol. , ( ). Accepted

Carillo, J.H., M.G. Hastings, D.M. Sigman, and B.J. Huebert, "Atmospheric deposition of inorganic and organic nitrogen and base cations in Hawaii", Global Biogeochemical Cycles, p. 1076, vol. 16, (2002). Published

Casciotti, K.L., D.M. Sigman, M. Galanter Hastings, J.K. Bohlke, and A. Hilkert, "Measurement of the oxygen isotopic composition of nitrate in seawater and freshwater using the denitrifier method", Analytical Chemistry, p. 4905, vol. 74, (2002). Published

Sigman, D.M., K.L. Casciotti, M. Andreani, C. Barford, M. Galanter, and J.K. Bohlke, "A bacterial method for the nitrogen isotopic analysis of nitrate in seawater and freshwater", Analytical Chemistry, p. 4145, vol. 73, (2001). Published

S. Maritorena, D.A. Siegel and A.R. Peterson, "Optimization of a semianalytical ocean color model for global-scale applications
", Applied Optics-LP
, p. 2705, vol. 41, (2002). Published

Siegel, D.A., S. Maritorena, N.B. Nelson, D.A. Hansell and M. Lorenzi-Kayser
, "Global distribution of colored dissolved and detrital organic materials
", Journal of Geophysical Research, p. 3228, vol. 107, (2002). Published

D.A. Siegel, S.C. Doney and J.A. Yoder, "The North Atlantic spring phytoplankton bloom and Sverdrup's critical depth hypothesis
", Science, p. 730, vol. 296, (2002). Published

Behrenfeld, M.J., E. Maranon, D.A. Siegel and S.B. Hooker
, "Photoacclimation and nutrient-based model of light-saturated photosynthesis for quantifying oceanic primary production
", Marine Ecology Progress Series
, p. 103, vol. 228, (2002). Published

Chomko, R.M., H.R. Gordon, S. Maritorena and D.A. Siegel
, "Simultaneous determination of oceanic and atmospheric parameters for ocean color imagery by spectral optimization: A validation
", Remote Sensing of the Environment
, p. 208, vol. 84, (2003). Published

Shipe, R. F., Carpenter, E. J. Govil, S. R. and Capone, D.G., "Limitation of microplankton production by Si and N in the western Atlantic Ocean
", Marine Ecology Progress Series, p. , vol. , ( ). Submitted

Wu, J., E. Boyle, L.-S. Wen, and W. Sunda, "Occurrence of Soluble and Colloidal Iron in Oligotrophic Oceans", Science, p. 547, vol. 293, (2001). Published

Dupouy, C., J. Neveux, A. Subramaniam, M. Mulholland, J. Montoya, L. Campbell, E.J. Carpenter and D.G. Capone, "Satellite captures summer Trichodesmium blooms in the southwestern Tropical Pacific", EOS, p. 15, vol. 81, (2000). Published

Mulholland, M. and D.G. Capone, "The nitrogen physiology of the marine N2 fixing cyanobacteria Trichodesmium", Trends in Plant Sciences, p. 148, vol. 5, (2000). Published

Hood, R.R., A.M. Michaels and D.G. Capone, "Answers sought to the enigma of marine nitrogen fixation", EOS, p. 138, vol. 81, (2000). Published

Mulholland, M.R. and D.G. Capone, "Stoichiometry of nitrogen and carbon utilization in cultured populations of Trichodesmium IMS 101", Limnology and Oceanography, p. 436, vol. 46, (2001). Published

Subramaniam, A., C. W. Brown, R. R. Hood, E. J. Carpenter and D. G. Capone, "Detecting Trichodesmium blooms in SeaWiFS imagery", Deep Sea Research Part II, p. 107, vol. 49, (2001). Published

Mulholland, M.R., S. Floge, E.J. Carpenter and D.G. Capone, "Phosphorus dynamics in cultures and natural populations of Trichodesmium spp.", Marine Ecology: Progress Series, p. 45, vol. 239, (2002). Published

Montoya, J.P., E.J. Carpenter and D.G. Capone, "Nitrogen fixation and nitrogen isotope abundances in zooplankton of the oligotrophic North Atlantic Ocean", Limnology & Oceanography, p. 1617, vol. 47, (2002). Published

Mulholland, M.R., K. Ohki and D.G. Capone, "N utilization and N2 fixation by natural and cultured populations of Trichodesmium spp.", J. Phycology, p. , vol. , ( ). Accepted

Kustka, A., S. Sanudo-Wilhelmy, E.J. Carpenter, D.G. Capone, J.A. Raven, "A revised estimate of the Fe use efficiency of nitrogen fixation, with special reference to the marine N2 fixing cyanobacterium, Trichodesmium spp. (Cyanophyta)", J. Phycology, p. 12, vol. 39, (2003). Published

Carpenter, E.J., A. Subramaniam and D.G. Capone, "Biomass and primary productivity of the cyanobacterium, Trichodesmium spp., in the southwest tropical N. Atlantic", Deep Sea Research, p. , vol. , ( ). Submitted

Mulholland, M., D. Bronk & D.G. Capone, "Dinitrogen fixation and release of ammonium and dissolved organic nitrogen by Trichodesmium IMS10", Marine Ecology: Progress Series, p. , vol. , ( ). Submitted

Hewson, I., S. Govil, D.G. Capone, E.J. Carpenter & J.A. Fuhrman, "Cyanophage may cause significant mortality of Trichodesmium spp., a globally important diazotroph", Aquatic Microbial Ecology, p. , vol. , ( ). Submitted

Galloway, J. [and many others], "Nitrogen Cycles: Past, Present and Future", Biogeochemistry, p. , vol. , ( ). Submitted

Books or Other One-time Publications

Sigman, D.M., and K.L. Casciotti, "Nitrogen isotopes in the ocean", (2001). Book, Published
Editor(s): J.H. Steele, K.K. Turekian, and S.A. Thorpe
Collection: Encyclopedia of Ocean Sciences
Bibliography: pp. 2449, Academic Press, London

Sigman, D.M., and G.H. Haug, "Biological Pump in the Past", ( ). Book, Accepted
Editor(s): H.D. Holland, K.K. Turekian, and H. Elderfield
Collection: Treatise On Geochemistry
Bibliography: Elsevier Science, Oxford

Nelson, N.B., and D.A. SiegelIn, "Chromophoric DOM in the open ocean", (2002). Book, Published
Editor(s): D.A. Hansell
and C.A. Carlson
Collection: Biogeochemistry of Marine Dissolved Organic Matter
Bibliography: p547-578, Academic Press

Capone, D.G., "The marine nitrogen cycle", (2000). Book, Published
Editor(s): D. Kirchman
Collection: Marine Microbial Ecology
Bibliography: J. Wiley, NY. Pp. 455-493.

Zehr, J.P. and D.G. Capone, "Oceanic nitrogen fixation: Ecology and molecular biology of Trichodesmium, a marine diazotroph", (2000). Book, Published
Editor(s): E. W. Triplett
Collection: Prokaryotic Nitrogen Fixation: A Model System for the Analysis of a Biological Process
Bibliography: Horizon Scientific Press. Pp. 15-31

Capone, D.G. and J.P. Montoya, "Nitrogen fixation and denitrification", (2001). Book, Published
Editor(s): J. Paul
Collection: Methods in Microbiology, Volume 30: Marine Microbiology
Bibliography: Academic Press, San Diego

Capone, D., "Microbial nitrogen cycling", (2001). Book, Published
Editor(s): S. Newell and R. Christian
Collection: Manual of Environmental Microbiology, Section IV: Aquatic Environments
Bibliography: ASM Press. pp.439-449.

Capone, D., "The nitrogen cycle in the marine environment", (2001). Book, Published
Editor(s): G. Bitton and D. Capone
Collection: Encyclopedia of Environmental Microbiology: Marine Section
Bibliography: Wiley-Liss. pp. 2176-2188.

Zehr, J.P. and D.G. Capone, "Marine nitrogen fixation", (2001). Book, Published
Editor(s): G. Bitton and D. Capone
Collection: Encyclopedia of Environmental Microbiology: Marine Section
Bibliography: Wiley-Liss. Pp. 2211-2221.

Web/Internet Site

URL(s):

http://biology.usc.edu/bc/

Description:

This is a web page for information on our project, coordination of cruise participants and data distribution. As our results emerge, it will become the public face of the project including the public data system.

Other Specific Products

Contributions

Contributions within Discipline:

This is already a very interdisciplinary project, so we will describe its impact on ocean sciences here and on other fields later.

Ocean biology is a critical part of the carbon and nitrogen cycle in the ocean. The traditional paradigm involves a fairly closed system where reactive nutrients are introduced to the surface ocean, incorporated into organisms, then returned to the deep sea as organic detritus. Nitrogen fixation was assumed to be small. Our previous research helped change that perception. N fixation is significant and it opens the carbon and

nitrogen cycles to a new level of dynamic possibility. It changes the role of oceans in the sequestration of the greenhouse gas CO2. It adds an ecological dimension to biological oceanography; it matters which organisms are present for how an ecosystem functions.

Contributions to Other Disciplines:

This project explicitly links the ocean to a variety of other processes in a complex feedback system. The oceans and land are influenced by the physical dynamics of the atmosphere and climate system. The climate changes the patterns of dust production on the continents and the transport of dust to the open ocean. The chemistry of the atmosphere transforms some of this dust making the iron in it more available. This dust and Fe are deposited to the surface ocean where they stimulate nitrogen fixation and the concommitant uptake of atmospheric CO2. This, in turn, changes the climate. It is also affected by human activity as we increase CO2 by combustion of fossil fuel and as we change the sizes of deserts through land use practices.

Contributions to Human Resource Development:

Please see the training section of the report for more details. This project is training students with a whole new appreciation for the interconnectedness of our field and for the role of complex dynamical systems in creating pattern within the coupled ocean-atmosphere-earth system. The PIs have to work hard to create an environment where they can collaborate because we recognize this difficulty and we are all having to build on our more disciplniary backgrounds. We are training a generation of students who don't have those disciplinary histories and for whom this level of interdisciplinary activity is natural and expected. They will lead our field in the future.

Contributions to Resources for Research and Education:

We are creating an online database that will be quite valuable to many other people in our field (see findings section). We are also creating a more general context for the research and education of others in our field. Finally, the marine sciences can be considered as one of the most successful 'environmental' sciences. As such, we have an opportunity and obligation to set an example for how an environmental science can create good basic scholarship at the same time as it creates information of practical value to society. This model may be our most important contribution to academia in general.

Contributions Beyond Science and Engineering:

The mechanism that is at the heart of this project may sequester carbon dioxide in the deep sea. It is a simple step to ask what would happen if humans added Fe to the surface ocean in these same areas. Could we stimulate a drawdown of CO2 by purposeful additions? On the other hand, if our hypothesis is correct, changes in land-use will change sequestration. Thus any future climate treaties that involve indirect sources and sinks or market mechanisms (trading schemes) will have to include these possibilities or deal with the implications of human choices about sequestration. We have started to introduce these ideas into the policy arena. Michaels is a member of the ASLO Public Policy Committee and has been involved in discussions of just this topic. Capone is a member of the NSF Ocean Science committee that is planning the next generation of ocean carbon science projects and these will cover this topic.

Special Requirements

Special reporting requirements: None

Change in Objectives or Scope: None

Unobligated funds: less than 20 percent of current funds

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Any Product

MANTRA Annual Report –

Research and Education Activities

During year 2 of our Biocomplexity project, field efforts were fully initiated. Our first research cruise from 6 to 27 January 2001 aboard RV Seward Johnson successfully deployed deep sediment traps at our two primary Atlantic stations, nominally at 30°N, 45°W and 10°N, 45°W. During time on station, we undertook comprehensive hydrographic and biological characterization of these sites. Sixteen other stations were taken for more limited hydrographic and biological characterization.

A second cruise 9 to 30 April, 2001 aboard RV Wecoma, deployed sediment traps at our 2 Pacific stations at 26°N, 175°W and 28°N, 170°E. Station Aloha (HOT program) is our eastern anchor station. Again, deployments went well on this cruise, and several other stations were picked up during the transit.

A third cruise major cruise was undertaken aboard RV Knorr 25 Jun to 24 Jul, 2001 with the purpose of retrieving and redeploying the 2 Atlantic traps and of comprehensively undertaking biological characterization of the two sites, including process studies and enrichment experiments. Unfortunately, at the first major station (30N, 45W), we encountered problems with the Edgetech acoustic releases for the deep traps which have turned out to be defective (see below). We occupied the station for 3.5 days and, while the traps were not recovered, process studies and experiments were initiated. We quit station prematurely due to a medical emergency and proceeded to Barbados to discharge a sick crew member, before proceeding to our second major station. At that station, we also encountered release failure, and had a second medical emergency and returned again to Barbados having accomplished only limited sampling. After the second medical emergency, there was insufficient time remaining to reoccupy either of the major stations due to the distances, so we occupied a station in waters east of Barbados and conducted experimental studies.

While the failure to recover the 2 Atlantic traps was a serious setback, we collected extensive data sets on the aerosol dust burden, dissolved iron concentrations, diazotroph densities and distributions, nutrient chemistry and hydrography to be used in our global analysis and modeling efforts. Furthermore, we established an experimental mesocosm bioassay system for diagnosing iron limitation in the upper ocean of oligotrophic regions.

We gathered most of the PIs at a 2 day workshop in Hawaii preceding the ASLO/ AGU meeting in Feb 2002. We also organized a 'Biocomplexity' poster session during the meeting where some of the preliminary results from our modeling and field work were presented.

Field activities continued apace during year 3 of this project. A cruise aboard RV Endeavor 9 Apr to 3 May 2002 was mounted on short notice in April 2002 to attempt recovery of our two Atlantic moorings. Limited research was also undertaken on that cruise. However, major equipment failures on board (improperly configured and inoperative trawl winch- fully reported on in cruise report) precluded recovery of either mooring.

We were originally slated for a major (>40 day) cruise on RV Kilo Moana departing about 1 Aug 2002. However, problems with the delivery of RV Kilo Moana resulted in our cruise being split into two separate cruises. The mooring recovery leg of our cruise was shifted to RV KOK (U Hawaii) with a planned departure date of 25 Jun 2002 returning 19 Jul. However, RV KOK returned to port from its previous cruise with a disabled engine and our departure was delayed a week, with the overall cruise length reduced. Hence, we only proceeded to our most westerly station and successfully recovered and

redeployed our sediment trap there (26 N, 175 W). Major sampling was undertaken at this station including comprehensive hydrography, optics, in situ productivity, mesocosm experiments and trace metal sampling.

The intensive process component of our field took place from 22 Sep to 16 Oct 2002 aboard RV Kilo Moana. This cruise was highly successful with good SeaWiFS satellite coverage helping guide our cruise track. Dense populations of diazotrophs were encountered and sampled. We took about 20 stations for comprehensive hydrography, optics and chemical and biological characterization, made several successful sediment trap deployments, and accomplished 4 mesocosm experiments.

We convened a three day workshop, coordinated with the PIRANA biocomplexity project Pis, before the ASLO meeting in Salt Lake City in Feb 2003 for project coordination, integration and synthesis.

MANTRA PIs also participated on a final Atlantic cruise from 18 Apr to 23 May 2003 on RV Seward Johnson. Fulfilling MANTRA objectives, 4 mesocosm experiments were undertaken during that cruise. A second rescue mission for recovery of moorings with faulty releases was underway on RV Atlantis concurrently with our RV Seward Johnson cruise. Because of engine difficulties and a schedule disruption, no attempt was made for our southern trap. However, our northern trap was recovered with samples intact.

Sampling Summary and Hydrography:

In eight cruises, the joint MANTRA/PIRANA project has sampled 229 stations in both the Pacific and Atlantic Ocean basins. Approximately 530 CTD cast have been conducted. Table 1 presents a summary of cruise details. Data obtained on each CTD cast includes:

- Temperature
- Salinity
- Density - Sigma Theta
- Beam Attenuation
- Fluorometer
- PAR
- Surface PAR
- Dissolved Oxygen Concentration

TABLE 1 – Cruise Summaries Table

Cruise	Vessel	Date	Ocean Basin	No. of Stations	No. of CTD Casts
MP01	RV Seward Johnson	1/7/2001 to 2/19-2001	Atlantic	51	125
MP02	RV Wecoma	4/9/2001 to 4/30/2001	Pacific	6	21
MP03	RV Knorr	6/26/2001 to 8/15/2001	Atlantic	55	105
MP04	RV Endeavor	3/17/2002 to 4/7/2002	Atlantic	7	6
MP05	RV KOK	6/25/2002 to 7/19/2002	Pacific	20	41
MP06	RV Kilo Moana	9/22/2002 to 10/16/2002	Pacific	20	110
MP07	RV Atlantis		Atlantic	1	1
MP08	RV Seward Johnson	4/18/2003 to 5/22/2003	Atlantic	69	120

Nutrients: For cruises MP1(81 core casts ranging in depth from 3000m to surface), MP2 (15 core casts ranging in depth from 3000m to surface), MP3 (96 core casts ranging in depth from 4000m to surface), MP4 (RV Endeavor, 4 core casts ranging in depth from 200m to surface) have been analyzed. For MP 3, Meso's 1-5 have been analyzed. For MP5, all but 2 casts of 22 core casts ranging in depth from 3000m to surface have been analyzed. The mesocosms nutrient data from MP5 have not been analyzed. All nutrient samples have been analyzed for MP6 including 33 core casts ranging in depth from 1000m to surface with one deep cast to 4000m, 4 process/pico perturbation casts, 2 mesocosm experiments. Similarly all samples from MP8 first leg (20 core casts ranging in depth from 1000m to surface) while leg 2 samples (core casts and mesocosms) remain to be done.

N_2 Fixation: To determine rates of nitrogen fixation, we conducted acetylene reduction assays at 5 standard light levels (100, 50, 25, 10 and 1% of ambient sunlight). On cruise MP1, Leg 1, we were unable to collect sufficient numbers *Trichodesmium* to perform assays. MP1, Leg 2 yielded 26 light depth experiments on *Trichodesmium*. Cruise MP3, Leg 1 yielded 11 light depth experiments on *Trichodesmium* and 4 on Hemiaulus/Richelia. We performed 19 light depth experiments on *Trichodesmium* and 1 on *Hemiaulus/Richelia* during MP3, Leg 2. Cruise MP5 we were able to obtain nitrogen fixation rates of *Trichodesmium* at one station. During cruise MP8, 23 light depth experiments on *Trichodesmium* and 8 on *Hemiaulus*/*Richellia* were performed. All acetylene reduction data for MP1 and MP3 has been analyzed. Nitrogen fixation rates have been determined for cruise MP8 on a per colony or cell basis.

Stable isotope enrichment experiments were conducted on all Biocomplexity cruises, except MP01 (Leg I), MP02 and MP04. The number of experiments performed on "whole water" samples, enriched with $^{15}NH_4/^{15}NO_3$ and incubated over 3-5 timepoints at standard light levels (100, 50, 25, 10, 1 and 0.1% of ambient irradiance), were as follows: 20 on MP01 (Leg II), 3 on MP03 (Leg I), 10 on MP03 (Leg II), 1 on MP06 (Leg I) and 1 on each Leg of MP08. Light-level incubations were also conducted, as follows, for samples enriched with $^{15}N_2(g)/^{13}C$ (sodium bicarbonate): 2 on MP03 (Leg I), 1 on MP03 (Leg II), 6 on MP06 (Leg I), 7 on MP06 (Leg II), 12 on MP08 (Leg I) and 10 on MP08 (Leg II). Nitrogen and carbon fixation rates ($^{15}N_2/^{13}C$) were also measured for perturbation experiments (Fe and PO_4 additions) on *Trichodesmium*, *Hemiaulus* and pico-plankton. *Trichodesmium* perturbation tracer experiments were only done with surface seawater on MP03 (3 on Leg I and 1 on Leg II). One *Hemiaulus* perturbation tracer experiment was done on each Leg of MP03, while 2 were done on MP08 (Leg I) and 1 on MP08 (Leg II). Pico-plankton perturbation experiments were as follows: 4 on MP03 (Leg I), 3 on MP03 (Leg II), 5 on MP05, 3 on MP06 (Leg I) and 2 on MP06 (Leg II). All samples from MP03 $^{15}N_2/^{13}C$ fixation-rate experiments have been analyzed on a continuous-flow mass spectrometer; all other samples are "in prep".

Natural abundance samples were collected from depth profiles on all Biocomplexity cruises. Samples were collected at the following number of stations for the following cruises (Leg I/Leg II): MP01 (11/20), MP02 (all stations [see Neumann's tally]), MP03 (12/15), MP04 (all stations), MP05 (all stations, MP06 (9/9), MP08 (16/16). All samples from MP03 and Leg I of MP01 have been analyzed for del 15N/13C of the particulate size-fraction (>0.7um), however final data analyses have yet to be done.

Mesocosms: To test whether nutrient and dust amendments would stimulate primary production and plankton cell densities, we conducted multi-day 20L mesocosm experiments. Nutrients (Fe and PO_4) and ambient aerosol dust, collected in situ on pre-cleaned, cellulose filters via an underway aerosol sampler,

were added to surface water. We did three mesocosm experiments on the first leg of MP3 (MANTRA) and two mesocosm experiments on the second leg of MP3 (PIRANA). We did two experiments on MP5 (MANTRA) and we did two mesocosm experiments on MP6. Finally, we did four mesocosm experiments on MP8. In each of these experiments we collected samples for nutrient analysis, chl a measurements, Fe measurements, DNA analysis, cell counts. We also set up experiments to measure ^{13}C, ^{14}C, ^{32}Si and $^{15}N_2$ uptake and bacterial production.

Silicon Cycle (R. Shipe): Silicon cycle dynamics were studied during cruises in the North Central Pacific Ocean in the fall of 2002 and the western equatorial Atlantic Ocean in the spring of 2003. Pools of dissolved silicon, particulate silica and rates of biogenic silica production were measured at discrete depths in the euphotic zone, in parallel with other rate process measurements. The effects of iron, phoshphate and dust enrichment on silicon dynamics were also assessed in 5-day mesocosm experiments. In order to identify species-specific as well as bulk processes, we are currently processing samples to determine the species of diatoms which were present at the chlorophyll maximum and in surface waters during both cruises. In addition, the kinetics of biogenic silica production in the various assemblages were determined at sea by serial nutrient enrichment. Some of the dominant diatom species from the Amazon plume were isolated and are being maintained in laboratory culture for further experimental work. Final measurement and analysis of all biogenic silica production rates are pending.

Carbon Dynamics (P. Yager): Additional funding to P. Yager (DOE, NOAA, NASA) for quantifying the inorganic carbon system began in September 2002. Academic year 2002-2003 has been dominated by getting the underway pCO_2 instrument built and deployed on the three planned expeditions, collecting DIC, ^{13}C-DIC, and ALK samples from these expeditions, and processing the samples and data. Sample analyses for MP1 and MP3 are complete; MP2, MP5, and MP6 are nearly complete (expected by the end of summer 2003). MP8 should be finished by Spring 2004. Yager & Cooley also participated in the data workshop in February 2003 (see below) where they presented and compared data from the first few expeditions of this project (funded in part by the USC Biocomplexity grant and also by a UGA Faculty seed grant to P. Yager).

Educational Activities included participation of several undergraduates and numerous graduate students and postdoctoral students on our cruises and workshops. Besides the substantial involvement of 7 graduate students and 3 postdocs at USC, through Co-PIs we have had direct involvement of students from SUNY-Stony Brook (6 graduate students, 2 postdocs), SFSU (4 graduate students, 2 undergraduates, 1 postdoc), U Maryland (1 post doc, 1 grad student), U Ga. (1 grad. student), Oregon State U. (1 grad. student), MIT (2 grad students, 2 postdoc), Rutgers (1 postdoc), U Hawaii (2 grad student), UCSC (1 grad student), UCSB (1 grad student), UCLA (1 grad student), Scripps (1 grad student & 1 postdoc). Several students are performing their PhD thesis research under our Biocomplexity program (J. Sohm, J. Finzi, I. Hewson and J. Steele at USC, S. Cooley at UGa, Y. Chen at UMCES, Westerberry at UCSB. We were also lucky in receiving funding for a COSEE Center to enhance K-12 science and math education in this area. The Biocomplexity faculty have been quite involved in this effort. Michaels has given numerous lectures in the teacher training sessions and has been active in knitting this content into the curriculum development areas. Capone has been involved with the strategic retreats. This program reaches teachers of schools that are primarily composed of under-represented ethnic groups and we hope it will become an important conduit for increasing the diversity of marine scientists. The larger goal is to enhance the general science backgrounds of ethnic minorities so that they may have a higher chance of moving into any kind of field of science.

MANTRA Annual Report for 2002 –

Findings

As we are still in a period of active field work and sample collection, much of the analytical work (e.g. particulate and isotopic anaysis) remains to be done. However, all CTD data have been processed and are available on our Web site (http://biology.usc.edu/bc/). More details and specifics of findings from Co-investigators will be found in the annual reports of Boyle, Doney, Karl, Mahowald, Siegel and Sigman.

Hydrographic Summary:

Pacific Hydrographic Summary

Data exhibit significant seasonal variability in both surface (<25 meters) temperature and mixed layer depth. Winter/Spring station averages for surface temperature and mixed layer depth are 22.81 degrees C and 76 meters, respectively. In contrast, station averages for surface temperature and mixed layer depths for Summer/Fall average 26.31 degrees C and 50 meters, respectively. Seasonal surface salinity variation is less than 1% with Winter/Spring values averaging 35.21ppt and Summer/Fall values averaging 35.14ppt.

Atlantic Hydrographic Summary

Due to the large North/South spatial extent of Atlantic stations and the vastly different physical forcing mechanisms between northern stations and southern stations the following hydrographic summary is categorized into two classes: Northern Stations (>20 N Latitude) and Southern Stations (<20 N Latitude).

Northern Stations

Significant seasonal variation is present in surface temperature, surface salinity and mixed layer depth. Winter/Spring averages for all stations are: surface temperature, 22.88 degrees C, surface salinity, 36.86ppt, and mixed layer depth, 89 meters. Summer/Fall averages, by contrast, are:
surface temperature, 24.47 degrees C, surface salinity, 37.05ppt, and mixed layer depth, 22 meters.

Southern Stations:

As with the Northern Stations, significant seasonal variation is present in the data. Winter spring values average 25.82 degrees C, 35.99ppt, and 73.11 meters, for surface temperature, surface salinity and mixed layer depth, respectively. Summer fall averages are: surface temperature, 28.24 degrees C, surface salinity, 34.25ppt, and mixed layer depth, 31 meters. We attribute the large variability in Southern Stations due to the influence of Amazon and Orinoco river outflow.

N_2 Fixation: Depth integrated nitrogen fixation rates for *Trichodesmium* were highest during the MP1 cruise in the month of February. Depth integrated fixation rates during MP3 were of the same magnitude and range as MP1, however, several stations had very low rates of activity, producing a cruise average nitrogen fixation rate of approximately half of the rate during cruise MP1. Depth integrated nitrogen

fixation rates for *Hemiaulus/Richelia* were highest in July and were within the range of values determined for Trichodesmium on the same cruise. *Trichodesmium* was not present in significant numbers when *Hemiaulus* was present. Depth integrated values for the most recent cruise, MP8, are currently unavailable, however nitrogen fixation rates on a per colony basis appear to be equivalent to those found during cruise MP3. Hemiaulus/Richelia and Trichodesmium were both present and actively fixing nitrogen at 8 stations. Trichodesmium abundance was low on cruise MP5, however for a single station in July, the per colony nitrogen fixation rates were equivalent to rates determined during MP1. Colony specific nitrogen fixation rates on cruise MP6 were the highest relative to all cruises. Daily average rates from several stations are 2 to 10 times higher than rates seen on other MP cruises.

Short term Fe and PO_4 additions were conducted on *Trichodesmium* colonies and *Katagynemene* filaments on MP6. Nutrients were added to experiments and nitrogen fixation measured over the course of the day. With the exception of three stations (one with colonies, two with filaments) all enrichments either showed no effect on nitrogen fixation or the additions inhibited nitrogen fixation. When organisms were incubated for 1 day or longer before measuring nitrogen fixation, positive effects on nitrogen fixation were seen; at one station, Fe increased fixation and at another, Fe and PO_4 together increased fixation.

Mesocosms: The results from the ^{13}C, ^{14}C and $^{15}N_2$ uptake experiments were highly variable. For ^{14}C uptake, all sites demonstrated dust stimulation except for one site. No sites demonstrated dust stimulation for the $^{15}N_2$ uptake. In the Atlantic the simultaneous Fe and PO_4 additions inhibited ^{14}C uptake, while in the Pacific the simultaneous Fe and PO_4 initally stimulated, then inhibited ^{14}C uptake. ^{14}C and $^{15}N_2$ uptake data were presented in a poster at the ASLO 2003 conference.

Modelling: As noted in the previous report, the initial modeling efforts included simulations using global general circulation models and simple box models. In all three cases, the models indicated that Fe inputs to the tropical gyres that caused nitrogen fixation stimulated an atmospheric drawdown of CO2. This drawdown remained in the ocean different amounts of time depending on the model formulation. If the model assumed no change in Antarctic biology, then the CO_2 outgassed after a few hundred years. If the model assumed that the additional reactive nitrogen and Fe in the midwater lead to an increase in Antarctic new production, the CO_2 stayed in the ocean until denitrification removed the nitrate, essentially millenia. Thus, the fate of midwater Fe from diazotrophs is a critical component of the research and we adjusted the sampling to accomodate this new idea.

Silicon Dynamics (R. Shipe): High dissolved silicon inputs from the Amazon shelf in the spring of 2002 and 2003 supported offshore silica biomass and production rates similar to those in coastal upwelling regions. At this time, a large fraction of primary productivity was contributed by diatoms. This is in dramatic contrast to the low nutrient, low siliceous biomass conditions encountered in the Pacific. However, we observed a dramatic increase in diatom dominance over one 5 day mesocosm experiment, indicating that diatoms can become an important component of this system.

Preliminary analyses indicate that substrate limitation of biogenic silica production was widespread at nearly all stations during both cruises. This was not unexpected in the oligotrophic Pacific waters, where biomass-normalized biogenic silica production rates asymptotically approached a maximum rate with increasing dissolved silicon concentration. However, it was surprising in eutrophic Atlantic waters, where biogenic silica production rates increased nearly linearly with increasing dissolved silicon concentrations. Assemblages of diatoms which fit the classical model of succession were observed in the Atlantic, including fast-growing blooms of small cells, mixed diatom assemblages and slow-growing large cells with nitrogen-fixing cyanobacterial symbionts.

We are planning future studies and laboratory experiments to investigate the mechanisms and ecological implications of these unusual uptake kinetics.

Carbon Dynamics (P. Yager): Results from the carbon dynamics study clearly show that the impacts of the Amazon River plume include both dilution effects (lowering pCO_2 below atmospheric equilibrium) and stimulation of biological net production.

Data Management and Data Access: Data is available through the Internet via several portals. A comprehensive project web site for both MANTRA and PIRANA has been constructed and is accessible at http://biology.usc.edu/bc. The web site functions as the primary data gateway and provides data access through interactive plotting and extraction utilities, via password encrypted web directories and by secure FTP (ftp://biosci.usc.edu/Faculty/tricholab/biocomplexity). Additionally, data is available through an interactive web-based GIS (http://catalina01.usc.edu/netviewer.asp?biocomplexity. The project web site also presents a project overview, cruise summaries, logistics information, and contact details for project collaborators. Data available through the various resources portals includes:

- Temperature Profiles
- Salinity Profiles
- Density - Sigma Theta Profiles
- Beam Attenuation Profiles
- Fluorometer Profiles
- PAR Profiles
- Surface PAR
- Dissolved Oxygen Concentration Profiles
- Discrete Sampled Chlorophyll – Bulk
- Discrete Sampled Chlorophyll – 202um Filtered
- Discrete Sampled Dissolved Inorganic Nitrate
- Discrete Sampled Dissolved Inorganic Phosphate
- Discrete Sampled Dissolved Inorganic Silicate
- Mixed Layer Depth
- SeaWiFs Derived Chlorophyll Images
- MODIS Derived SST Images

Data is delivered in-house through a Microsoft access database. We anticipate delivering the Microsoft Access database via the web by August 2003.