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U.S.-Japan-Hong Kong Planning Visit: Long Term Collaborative Research Studying Fe Effects on Ecosystem Structure in the Subarctic Pacific

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Final Report for Period: 08/2003 - 07/2005

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Principal Investigator: Wells, Mark L.

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Organization: University of Maine

Title:

U.S.-Japan-Hong Kong Planning Visit: Long Term Collaborative Research Studying Fe Effects on Ecosystem Structure in the Subarctic Pacific

Project Participants

Senior Personnel

Name: Wells, Mark

Worked for more than 160 Hours: Yes

Contribution to Project:

Post-doc

Graduate Student

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Other Collaborators or Contacts

We have collaborated closely with Dr. S. Takeda, Dr. A. Tsuda (University of Tokyo) and Dr. H. Saito (University of Hokkaido) on planning and conducting experiments, and in a detailed summary workshop discussing the findings from our joint oceanographic experiment.

Our collaborators total nearly 40 other Japanese scientists who were directly involved with the mesoscale iron enrichment study.

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:

There are no direct teaching skills that evolved from this project. The research skills obtained dealt more with learning in more detail the alternate viewpoints of our Japanese colleagues than laboratory practices or analytical skills.

Outreach Activities:

The public outreach activities on this project include presentations in local K-6 schools, discussions with journalists for local newspapers (Maine, California, Ontario), participation in national and international radio broadcasts, an article in the University of Maine, Alumni publications.

Journal Publications

Books or Other One-time Publications

Web/Internet Site

Other Specific Products

Contributions

Contributions within Discipline:

None with direct respect to the planning project here.

Contributions to Other Disciplines:

Nothing with direct respect to the planning project here.

Contributions to Human Resource Development:

The project has facilitated long term interactions and scientific collaboration among scientists from Japan, Canada, and U.S.A.

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

The major findings of the SEEDS II mesoscale iron enrichment demonstrated that these large scale manipulations general inconsistent increases in phytoplankton production and carbon export to deep waters. These results, along with those of mesoscale Fe enrichment studies done in other ocean regions raise significant question about the efficacy of iron-induced carbon sequestration into the ocean as a practical geo-engineering practice to mitigate current increases in atmospheric carbon dioxide.

Categories for which nothing is reported:

Organizational Partners

Any Journal

Any Book

Any Web/Internet Site

Any Product

Contributions: To Any Resources for Research and Education

Major Findings

The joint mesoscale iron enrichment experiment was successfully performed, with efficient overlap of the multi-vessel operation. Japanese scientists (8) participated on the US vessel (R/V Kilo Moana) and 2 U.S. scientists participated on the Japanese vessel (R/V Hakuho Maru). Because of the overlap in vessels, it was possible to extend observation of the biological and geochemical changes associated with iron enrichment for 32 days; one of the longest observation periods ever attained among the mesoscale enrichment studies to date. The major findings of the experiment were:

In-patch Observations

1. The iron infusion was performed successfully, yielding ~2 nM total iron concentrations during the first and second infusions. Iron concentrations decreased extremely rapidly after the first infusion, and much slower after the second infusion. The majority of the iron added during the first infusion remained in the dissolved state (<0.2) immediately after infusion, but iron existed largely in the acid-labile (pH 3.2, unfiltered) form following the second infusion. The patch remained coherent and was tracked for 25 days.
2. The iron infusion generated a significant increase in phytoplankton biomass, including picoplankton and diatoms, within the patch. However, increases in production (Chl a biomass) were small (3 x ambient) and only minor decreases in macronutrient concentrations were observed.
3. The outcome differed dramatically from that of SEEDS I, despite the fact that two infusions were applied in SEEDS II (vs. one in SEEDS I), and that the two experiments were conducted in the same general geographical region and oceanographic conditions (high nitrate low chlorophyll).
4. Deckboard incubation studies on both the Hakuho-Maru and the Kilo Moana show that iron amendments consistently increased phytoplankton production (Chl a) relative to the controls in the large size fraction (>10-20 μm). These findings show unequivocally that iron still was limiting the in-situ phytoplankton assemblage within the patch despite iron concentrations being significantly elevated.
5. Carbon fixation (^{14}C) vs. irradiance (P vs. E) data show that phytoplankton within the patch had poor physiological capabilities for growth between Day 7 and Day 13 (the period of observation), and that this condition was substantially improved over short time scales (≤ 2 days) by the addition of iron to the cultures. The cause for the poor ambient physiology on Day 7 may be related to the shallowing of the mixed layer on Day 6 from 30 to 20 m, which may have resulted in short term light stress of the surface phytoplankton.
6. Control bottles in deckboard iron enrichment experiments (Hakuho-Maru and Kilo Moana) also showed significant increases in Chlorophyll a that was not seen in-situ, indicating that surface waters in the bottles experienced higher iron availability. This apparent increase might be attributed to one of three reasons.

- a. Contamination: This is an unlikely reason here given the trace metal clean precautions taken, the comparatively elevated iron concentrations in the in-patch surface waters used to initiate the experiments, the fact that at least one size class showed no increased growth during the bioassays until late into the experiment, and that multiple experiments from two groups showed similar changes.
- b. Grazing: If microzooplankton grazing of picoplankton was enhanced in the culture bottles by exclusion of mesozooplankton, then recycling rates of iron would have been higher than in-situ which might influence iron availability. However, control incubations on the Hakuho-Maru on Day 11 show a substantial increase in chlorophyll a ($\sim 6 \mu\text{g/L}$) split roughly equally between picoplankton and diatoms. That is, the change is not simply a shift in biomass (iron) from small to large cells. Net increases in chlorophyll of this magnitude are unlikely attributable to changes in iron recycling *rates* and instead suggest there was an increase in total available iron in the culture vessels.
- c. Photochemistry: Photochemical cycling of the organically-complexed iron phase, releasing iron to inorganic chemical species is 1) known to occur, and 2) to increase the availability of iron to eukaryotic (e.g. diatom) species. Placement of the experimental bottles in shallow incubators would enhance photochemical processes relative to that in surface waters having 20 m mixed depth (due to higher UV exposure).

Summary

Surface waters of this HNLC region are iron limited, and in-situ additions of iron increased phytoplankton biomass and shifted the phytoplankton assemblage towards a higher proportion of large ($> 10 \mu\text{m}$) pennate diatom species, primarily of the genus *Pseudo-nitzschia*. However, the increase in phytoplankton biomass was small ($\sim 3 \times$ ambient) and substantially less than occurred in SEEDS I in this region. This outcome was not due to rapid disappearance of infused iron (values remained elevated for a major period of time). Even so, deckboard iron addition experiments demonstrated that diatom biomass was limited by iron availability. There also was a significant decrease in the chemical lability of iron (dissolved iron:acid-labile iron ratio) between the first and second infusions, suggesting that less of the iron added the second time may have been available to diatoms. Even so, there was a significant shift in the picoplankton assemblage as the bloom evolved resulting in marked increases in the proportion of *Synechococcus* spp. and Cryptophytes relative to other pico and nanoplankton. This marked shift remained a signature of the patch waters beyond the 25-day period of observation. In other words, the system did not return to the ambient conditions within the period of observation.

“Natural Bloom” Observations

1. A low pCO_2 , elevated chlorophyll region of surface waters was observed adjacent to the iron-fertilized patch, although it did not impinge or interfere with the patch.

2. Nutrient depletion at this site was significant, although nutrients still remained high. The depletion of nutrients (particularly Si) at this natural “bloom” site was greater than occurred within the iron-infused patch. The silicate drawdown (~10 μM) indicated that diatom production in particular had been enhanced. (Do we have preserved phytoplankton samples from this site?)

Summary

The “natural” enhanced production in this adjacent region had been larger, and had a greater proportion of diatom growth, than was generated by artificial infusion with iron.

Research and Education Activities

This project funded three planning visits with Japanese scientists at several oceanographic Institutions to organize a joint mesoscale iron enrichment experiment in the subarctic Pacific Ocean. These visits were designed to align an independent NSF-funded research project with the independent Japanese research program to provide enhanced research opportunities for both projects. The planning visits included up to 40 Japanese scientists with the three US PI's. The major goals of the planning grant were to:

1. Detail any significant scientific overlaps between the NSF project and their program goals for the 2004 Fe enrichment experiment.
2. Identify synergistic linkages between the planned NSF research that could be facilitated by sharing individuals or expertise among the three vessels.
3. Finalize new research questions that could be addressed during the experiment with the broadened pool of equipment and expertise. (For example, our project will have a flow cytometer on board that could be used to address questions not normally possible on typical research cruises.) This aspect is particularly difficult to accomplish by e-mail because of the complex ship and personnel logistics.
4. Finalize the logistical plan for coordinating the research vessels. This aspect is particularly time-sensitive because the UNOLS ship schedule for the 2004 season will be finalized shortly.
5. Finalize the broader collaborative research goals that could be addressed cooperatively during our 2005 cruise to Ocean Station PAPA. It will be important to have this settled at this early date because comparing data between the eastern and western Subarctic Pacific gyres will require unification of sampling/methodological plans. These plans may alter how we prepare for 2004 cruise.
6. Arrange any inter-lab exchanges of personnel who will be working together on the 2004 experiment so that methods and protocols are well established beforehand.

The lasting effect of the planning visits was an efficiency of scale. We were able to collaboratively structure a broad framework for joint research on the effects of Fe on the marine biogeochemistry of Subarctic Pacific waters beyond these two NSF cruises. These collaborations continue today in the form of:

1. Japanese participation in our research cruises,
2. Joint presentations at national and international meetings,
3. A planned joint editorship for a special issue in an international journal covering up to 20 papers dealing with the outcome of the joint mesoscale experiment,
4. Planned exchange of graduate students

Overall, the major objectives of the planning project have been met.