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Open ocean enclosure experiment in the North Pacific Ocean

The Processes of the Ocean's Biological Pump and CO_2 Sequestration

— Exploring Ways to Suppress Global Warming —

The Carbon cycle via the biological pump
Stimulating the biological pump by supplying iron
Development of a biological carbon transport model
Brief Note: Jun Nishioka, Research Scientist, Biology Department, Abiko Research Laboratory

The Carbon cycle via the biological pump

Approximately 70 percent of the Earth's surface area is covered by ocean. Since the start of the industrial revolution, it is believed that oceans have absorbed approximately 30 to 40 percent of anthropogenic carbon dioxide (CO_2). Recent concern about increased levels of atmospheric CO_2 and Global warming have led to studies of the ocean's role in the global carbon budget and also increased interest in the variability of oceanic biological production. In recent years, scientists have been investigating the biological activity of the oceans in order to estimate the absorbed atmospheric CO_2 by phytoplankton ecosystem.

To clarify the role of the oceans' phytoplankton ecosystem in the global carbon cycle, CRIEPI is working on research which investigates the mechanism of the oceans' biological carbon transport processes.

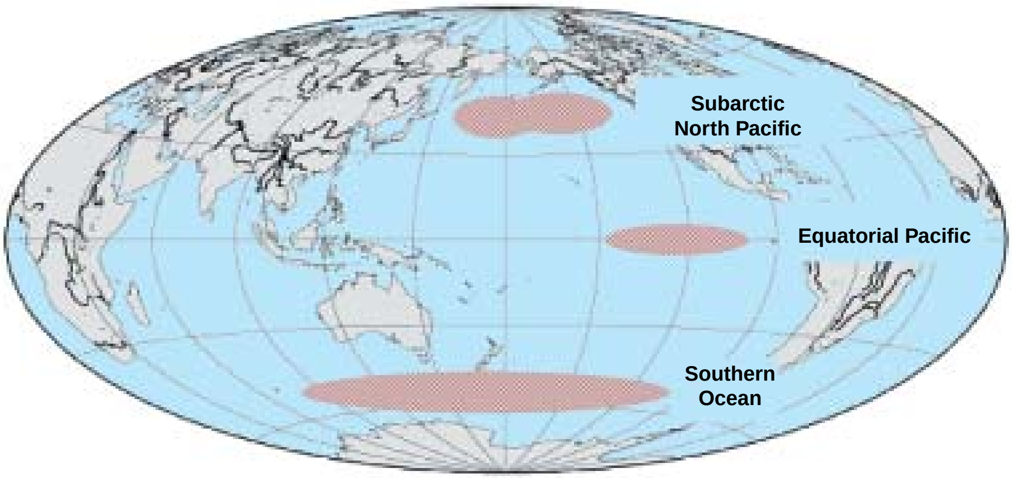
What is the biological pump?

The biology of the ocean, in particular the number of floating plants or phytoplankton, can significantly affect one greenhouse gas -- CO_2. Phytoplankton produces organic matter by the photosynthetic uptake of CO_2 and dead organisms sink away from the surface. In this biological process, there is a net movement of CO_2 from surface water into the deeper parts of the ocean. Major part of the organic carbon is decomposed during sinking and can be returned to the surface by the upwelling of deep water. However, other portions of the organic carbon is sequestrated into the deep-ocean. This movement of CO_2 toward deep water and back to the surface again is called the biological pump. The biological pump is very important to determine and quantitatively understand the global carbon cycle.

CO_2 transfer efficiency by the biological pump

Although major nutrients for phytoplankton such as nitrate, phosphate, and silicate, are present in high concentrations in the Southern Ocean, the equatorial Pacific and the subarctic North Pacific Ocean, phytoplankton biomass (Chla) is lower than expected. These oceans are called High Nutrient Low Chlorophyll (HNLC) regions. In recent years, micronutrient iron has been shown to play a key role in limiting phytoplankton growth rate, nutrient utilization and the structuring of plankton communities in the HNLC regions. It has become known that carbon transfer efficiency via the biological pump varies significantly depending on the oceanic region and the biological pump might be controlled by iron availability.

Additionally, an idea has been proposed to fertilize the oceans by adding small amounts of iron to stimulate the biological pump in order to remove large amounts of CO_2 from the atmosphere.



High nutrient and low chlorophyll regions in the ocean

Stimulating the biological pump by supplying iron

The role of iron in the oceans' biological pump

To investigate the effects of iron supply on phytoplankton growth and changes in species composition, we conducted an onboard incubation experiment in the eastern subarctic North Pacific, where nutrient remains in high concentrations. In this region, small size phytoplankton which uses ammonium is dominant. Organic carbon produced by small size phytoplankton is easily decomposed at the surface and a negligible amount is transported to the deep layer. On the other hand, the results of our experiments showed that the addition of iron to ambient phytoplankton assemblages stimulates the growth of larger diatoms and the utilization of excess nutrients. We also observed that the production of particulate organic carbon also increased during the growth of large diatoms.

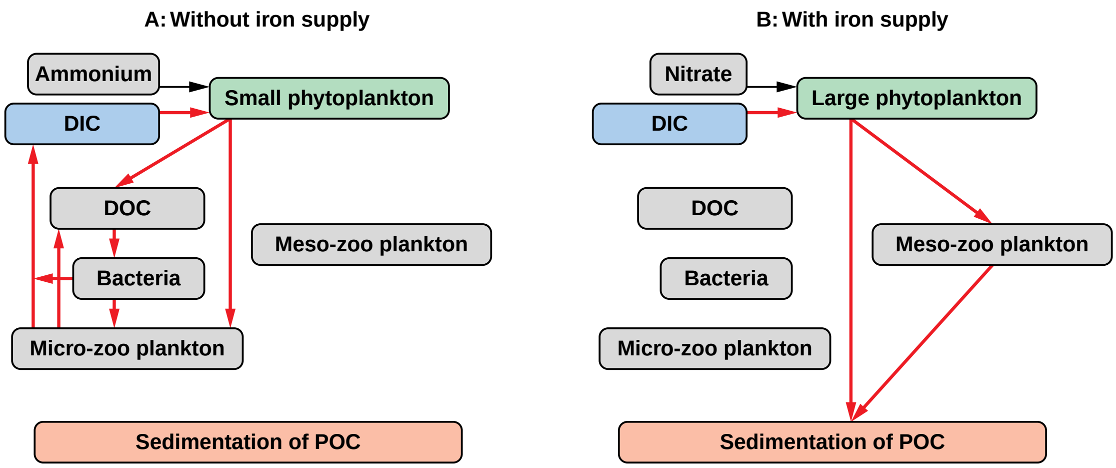
Furthermore, we conducted ecosystem enclosure experiments wherein an oceanic ecosystem was enclosed in a plastic bag, and we have observed chemical and biological parameters. This experiment showed that particulate organic carbon, which was produced by large diatoms in the surface layer, sank to deeper layers immediately after nitrate was depleted in the surface layer.

These findings show that iron is an important factor controlling the oceans' biological pump.

Iron and glacial Southern Ocean

In addition to the experiments in the subarctic North Pacific, we also conducted incubation experiments in the equatorial Pacific Ocean and the Southern Ocean. These experiments showed that the limitation of iron affects the ratio of consumed silicate to nitrate and phosphate. In iron-limited water from the aforementioned environment, adding iron to phytoplankton assemblages in incubation bottles halved the silicon: nitrate and silicon: phosphate consumption ratios, in spite of the preferential growth of diatoms.

On the other hand, Southern Ocean sedimentary records show a nonlinear relationship between organic carbon flux and the opal accumulation rate. This decoupling of organic carbon and opal records can be explained to some extent by the iron-induced change in the diatom nutrient consumption ratio observed in the CRIEPI study.

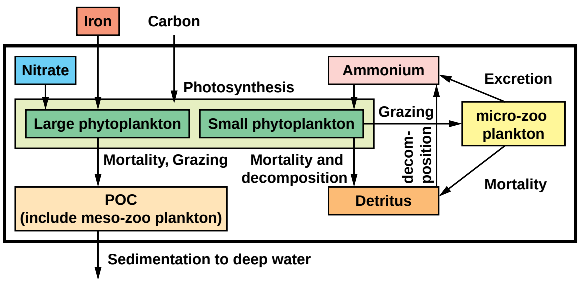


Carbon flow in a plankton ecosystem in the eastern subarctic North Pacific with and without iron supply (DIC: Dissolved Inorganic Carbon, DOC: Dissolved Organic Carbon, POC: Particulate Organic Carbon)

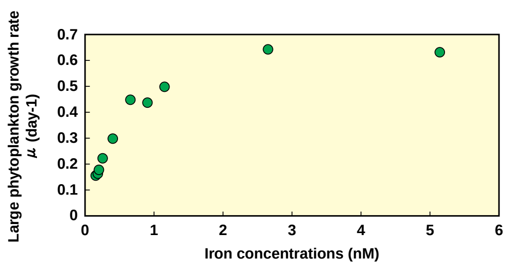
Development of a biological carbon transport model

An ecosystem model expressing the CO_2 sequestration level

We developed an ocean plankton ecosystem model in order to evaluate the CO_2 absorption level in the eastern subarctic North Pacific through a numerical simulation. In the model, the carbon flow regenerated by small size phytoplankton was expressed in four divisions (small size phytoplankton, micro-zoo plankton, ammonium, and detritus). In addition, the carbon flow during the large size phytoplankton blooming regulated by nitrate and iron concentration was expressed in three divisions (large phytoplankton, iron, and nitrate). In the biological carbon transport model, the formula of iron concentration versus large phytoplankton growth rate was used for expressing the effect of the variation of iron concentration to phytoplankton growth and CO_2 transportation.



Parameters and structure of a biological carbon transport model in the eastern subarctic North Pacific



Relationship between iron concentration and the large phytoplankton growth rate

Future study

At this moment, we have observed only that iron supply induces an increase of phytoplankton biomass and ocean primary production. There is still a need for further research to determine how the oceanic carbon cycle is changed after phytoplankton blooming, how much carbon is sequestered in the ocean as organic matter, and to what extent the environment is impacted. In our future study, we will investigate these problems with in situ experiments and an improved ecosystem model.

Brief Note

Jun Nishioka
Research Scientist,
Biology Department,
Abiko Research Laboratory

Understanding the ecosystems of the oceans requires much time and effort. Knowledge of various specialized fields and international collaboration are also indispensable. CRIEPI collects scientific data through international collaboration with organizations such as the Institute of Ocean Science in Canada and the Netherlands Institute for Sea Research.
In addition, we are engaged in international joint projects with research institutions in Japan and abroad, and are starting in situ iron addition experiments to study responses of whole phytoplankton ecosystems. Our future study will focus on quantitatively evaluating the role of oceanic ecosystems on the global carbon cycle.

Central Research Institute of Electric Power Industry

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Central Research Institute of Electric Power Industry
Public Communications Division
1-6-1 Ohtemachi, Ciyoda-ku, Tokyo 100-8126 JAPAN Phone: +81 3 3201 6601 FAX: +81 3287 2863
E-mail : www-pc-ml@criepi. denken. or. jp http : //criepi. denken. or. jp