D-1.1 Study on the Mechanism of Variation in Ocean Element Cycle Accompanied with the Shifts of Dominant Species (Final Report)

Contact Person Shigeki Harada
Senior Researcher, Ocean Research Team
Global Environment Division,
National Institute for Environmental Studies
16-2 Onogawa, Tsukuba, Ibaraki 305, Japan
Tel: +81-298-50-2509 Fax: +81-298-51-4732
e-mail: sharada@nies.go.jp

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Abstract A mesocosm (marine enclosure; 5m in diameter and 18m in depth) was developed in the Seto-Inland Sea, Japan. Vertical mixing in the upper layer (0-5m) was provided by a circulation system. This system created gentle upward flow and then suspended non-motile phytoplankton species such as diatoms. The dominant phytoplankton species were categorized into centric diatoms, pennate diatoms, dinoflagellates and others. Succession of these species was explained by the changing nutrient (N, P, Si) availability and grazing by zooplankton. Stable carbon isotope tracer experiments were done, using the bottle incubation technique. ^{13}C-DIC or ^{13}C-DOC was added into the bottles in order to know the transformation rates from DIC to >100 μ m POC (through photosynthetic loop) and those from DOC to >100 μ m POC (through bacterial loop). Our results suggested that higher role of bacterial loop than previously reported, especially when Doliollida dominated the zooplankton community.

Key Words Mesocosm, Species Change, Element Cycle, Photosynthesis, Bacterial Loop

1. Introduction

Increasing loads of anthropogenic pollutants such as nutrients, organic matters and toxic chemicals deeply concern the marine element cycles. Because the loads into inland bay and coastal sea zones are large, it is expected to influence the marine environment in the continental shelf zones and thereby affect the global element cycles.

Characterization of carbon cycles based on biochemical processes is essential to understand the cycles of pollutants within marine ecosystems. Especially the characterization of carbon transfer into higher trophic levels through photosynthetic loop (dissolved inorganic carbon: DIC - phytoplankton - zooplankton) and bacterial loop (dissolved organic carbon: DOC - bacteria - protozoa - zooplankton) is important, because the carbon transfer could be linked with the transfer of pollutants within the ecosystems.

Our approach for addressing the characterization of carbon cycles is the use of an *in-situ* mesocosm (marine enclosure). A mesocosm permits the development of a closed and mass-conserved system, but with biochemical and ecological conditions similar to those in nature. The system allows us to sample repetitively the same body of water and then to analyze quantitatively the effects of various physical (e.g. mixing regime of the water column), chemical (e.g. changing nutrient availability), biological (e.g. physiological requirement of the species emerged) and ecological (e.g. grazing interactions between the species) factors.

We have deployed a large-scale mesocosm (5m in diameter and 18m in depth) in the Seto Inland Sea (Japan). The novelty of our mesocosm is the vertical circulation system within the surface (0-5m) layer[2]. This system is expected to provide: 1) turbulence to suspend non-

motile phytoplankton such as diatoms and 2) the ability to control physical conditions (mixing regime) in the water column, both being the major problems of previous mesocosms[3].

2. Research Objective

The final goal of this research is to develop a model of element cycles in coastal zones. This goal requires the analysis of species succession and resulting variations in the carbon cycles. Especially the role of the carbon transfer through bacterial loop should be rapidly understood.

We have conducted ^{13}C tracer experiment to examine the carbon flow both within bacterial and photosynthetic loops. Variations in the ^{13}C transfer efficiency into zooplankton in both loops were analyzed together with the dynamics of the shifts of dominant phyto- and zooplankton species.

3. Research Method

(1) N.I.E.S. Mesocosm

Water column was enclosed cylindrically (5m in diameter and 18m in depth, contains 350m^3 sea water), using five rings made of stainless pipes and ethylenevinylacetate reinforced with polyester grids (Fig.1). This material is extremely strong, flexible, translucent and no elution from the surface. The top rim was fixed to flotation module, and the bottom rim was positioned in the sediment with the aid of scuba driver. The stainless rings were fixed using anchors in order to prevent the mesocosm being moved.

Vertical mixing in the upper layer (0-5m) was provided by a circulating system. Water taken from the surface was discharged through a nozzle of vertical jet which was placed within two PVC pipes submerged in the water column (from surface to 3m depth). Vertical jet entrained the surrounding water in the pipes, and thereby brought over this water from the bottom of the pipe.

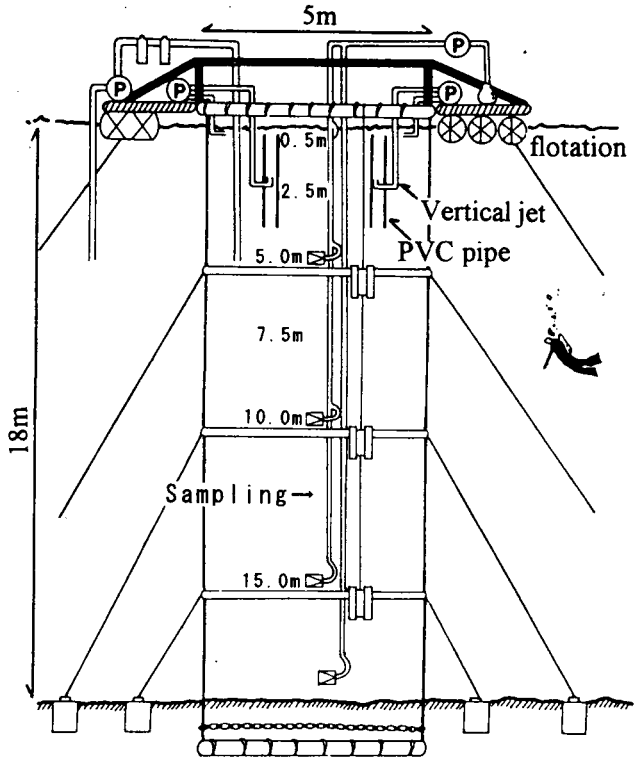

Fig.1 Schematic view of the mesocosm

(2) Experiments and Observation

Just after enclosing the water column on 29 July in 1994, nutrients (500g $NaNO_3$, 60g $NaH_2PO4 \cdot 2H_2O$, 100g $NaSiO_3 \cdot 9H_2O$) were added into the water column uniformly.

The vertical profiles of water temperature, pH, DO, POC, PON, DOC, DIC, nutrient concentrations, pigment concentrations, phytoplankton species and cell concentrations, zooplankton species and concentrations, bacterial numbers, picoplankton numbers, heterotrophic nanoflagellate numbers were observed by one or two days intervals.

Sediment traps were deployed at 5m, 10m and 15m depths, and POC, PON and pigment concentrations within sinking particles were observed every day.

Stable carbon isotope tracer experiments were done, using the bottle incubation technique. Every morning, sea water was sampled at 0.5m and 10m depths, and enclosed within 4.5 litter PC bottles. ^{13}C-DIC (sodium bicarbonate) or ^{13}C-DOC (glucose) was added into the bottles in order to examine the transformation rates of DIC to POC and DOC to POC, in turn. After 4 hours incubation (at the sampling depth), POC was size-fractionated. Transfer efficiency into zooplankton was defined as the percentage of excess ^{13}C in >100 μm POC to the total particulate excess ^{13}C (>0.7 μm POC in the DIC enriched bottles and >0.2 μm POC in the DOC enriched bottles).

4.Results and Discussion

(1) Physical Conditions within the Mesocosm

Vertical distribution of water temperature indicated the development of stratification under the surface (0-5m) mixed layer (Fig.2). Because of this mixing within the surface layer, non-motile species such as centric and pennate diatoms were well maintained. By changing the length of the PVC pipes (Fig.1), it is possible to change the depth of mixed layer.

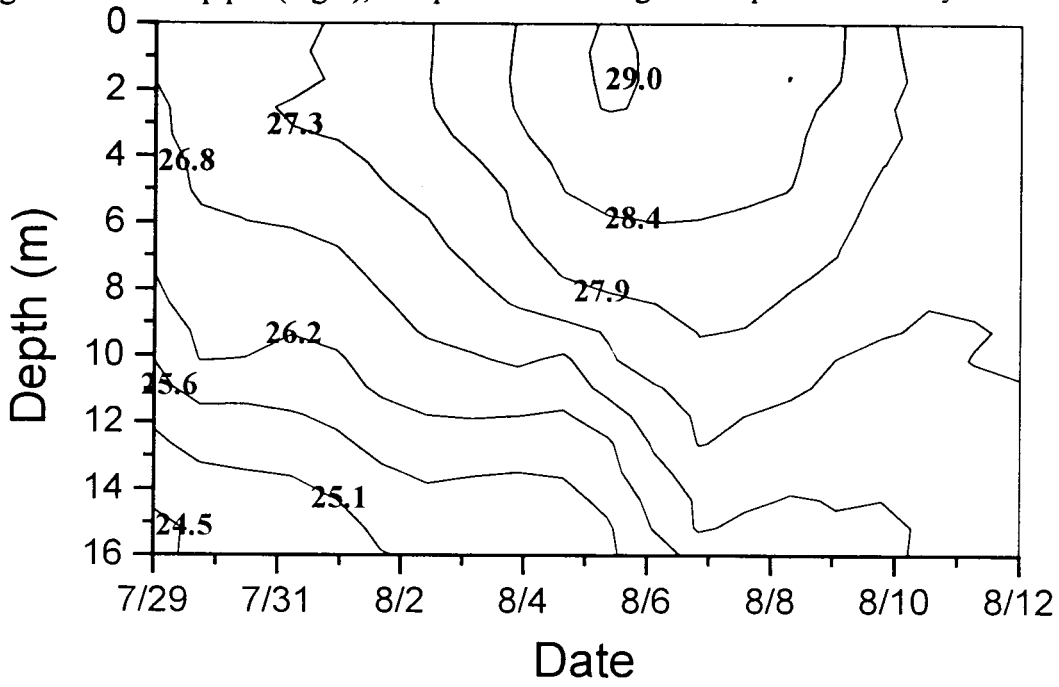

Fig.2 Vertical distribution of seawater within the mesocosm

(2) Phytoplankton Species Succession

Just after the mesocosm deployed, dinoflagellates (especially *Gymnodium mikimotoi*) dominated the phytoplankton community (Fig.3). After that, every category (centric and pennate diatoms and dinoflagellates) increased reflecting the nutrient enrichment. Nutrients decreased quickly due to the uptake by phytoplankton (Fig.4).

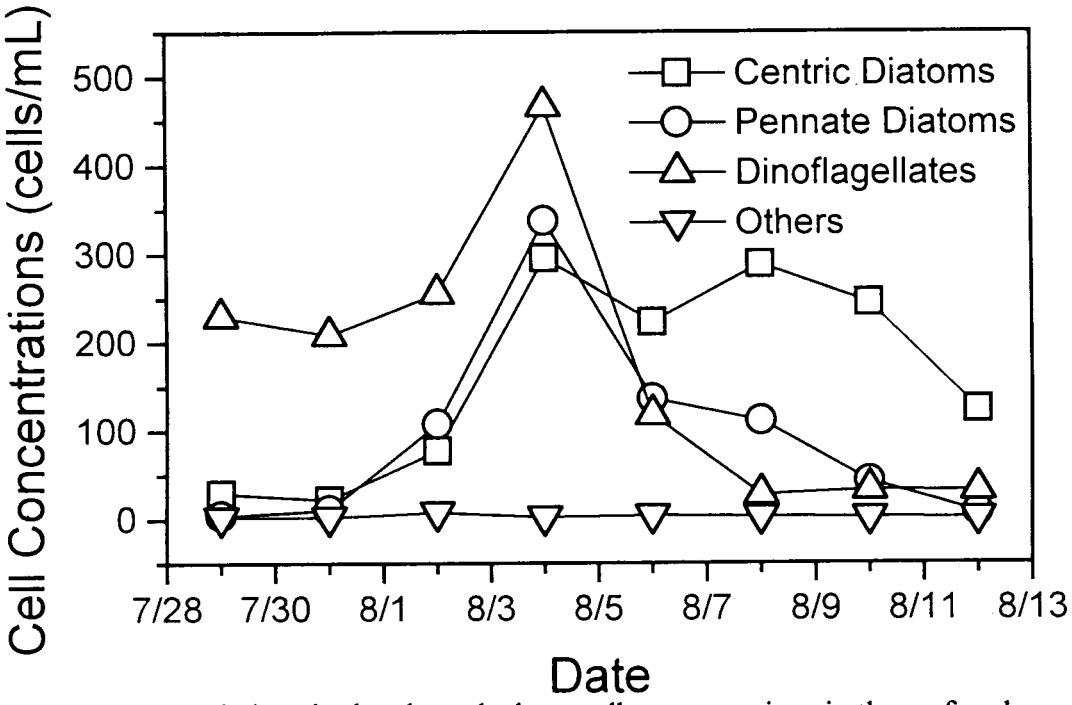

Fig.3 Variations in the phytoplankton cell concentrations in the surface layer

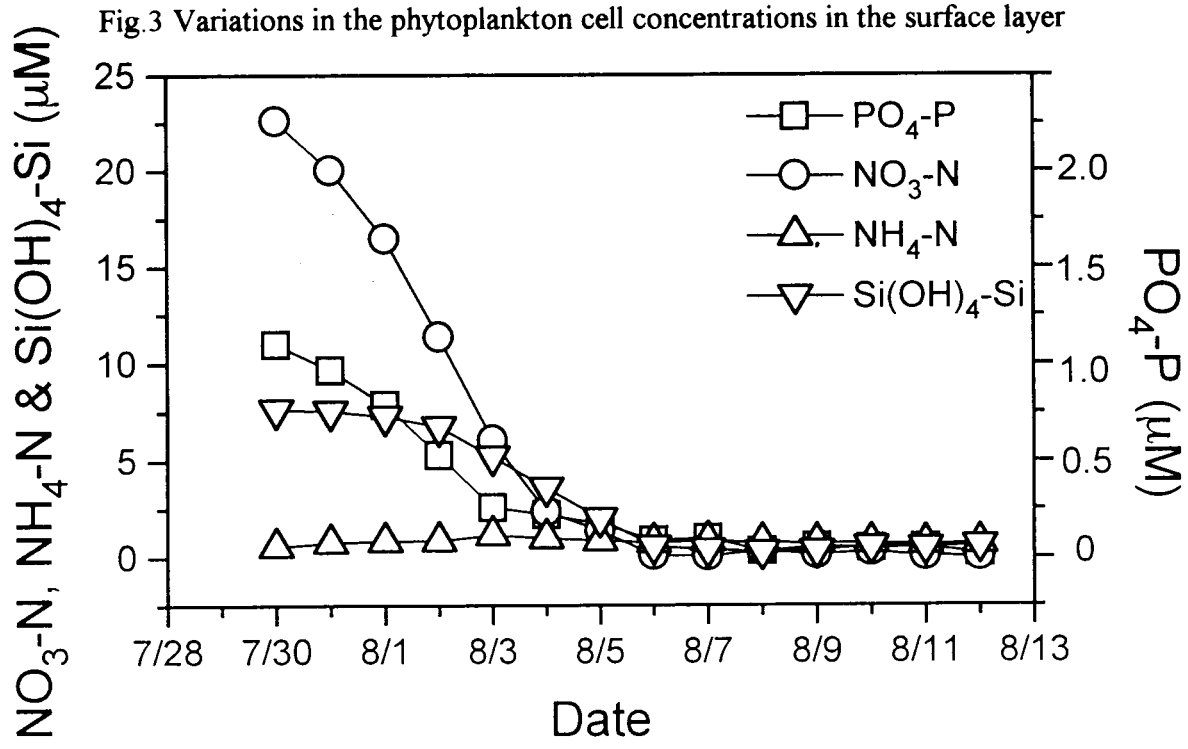

Fig.4 Variations in the nutrient concentrations in the surface layer

From 5 August, every nutrients were depleted (Fig.4), but centric diatoms were maintained till the end of the experiment (Fig.3). This phenomena was dissimilar to the phenomenon observed in our mesocosm experiments in other years. In the experiments conducted in 1989, 1991[5] and 1992, rapid decrease of centric diatoms were observed before the nutrients were depleted. In these experiments, Copepoda dominated the zooplankton community when centric diatoms decreased rapidly. On the other hand, in the experiment in 1994, Doliollida dominated during the period that centric diatoms was abundant (Fig.5).

Results of ^{13}C tracer experiments in 1991[6)7)] and 1992 indicated that Copepoda grazed centric diatoms actively. While the experiments in 1994 indicated the small grazing activity of Doliollida on Copepoda (see Fig.6). These results underline the significance of grazing interactions between different species on the phytoplankton succession.

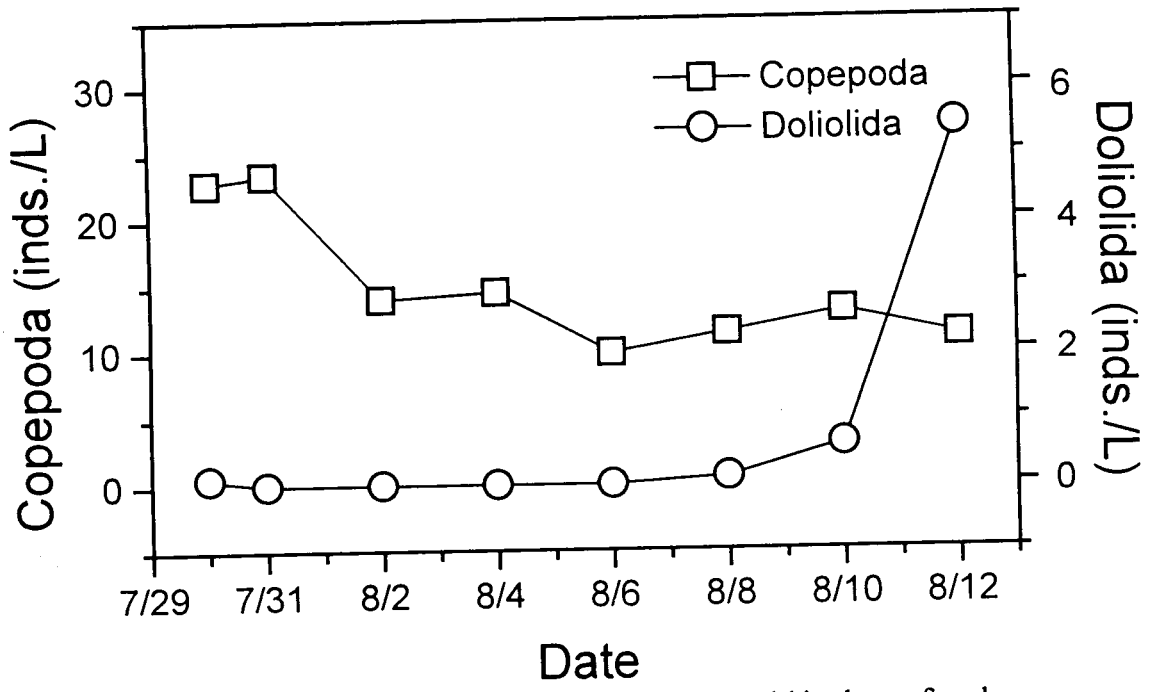

Fig.5 Variations in the zooplankton abundance within the surface layer

(3) Transfer Efficiencies of Photosynthetic and Bacterial Production into Zooplankton

The average transfer efficiencies in photosynthetic and bacterial loop were 0.4 % (range: 0.2-1.0%) and 0.9% (0.2-1.6%), respectively (Fig.6).

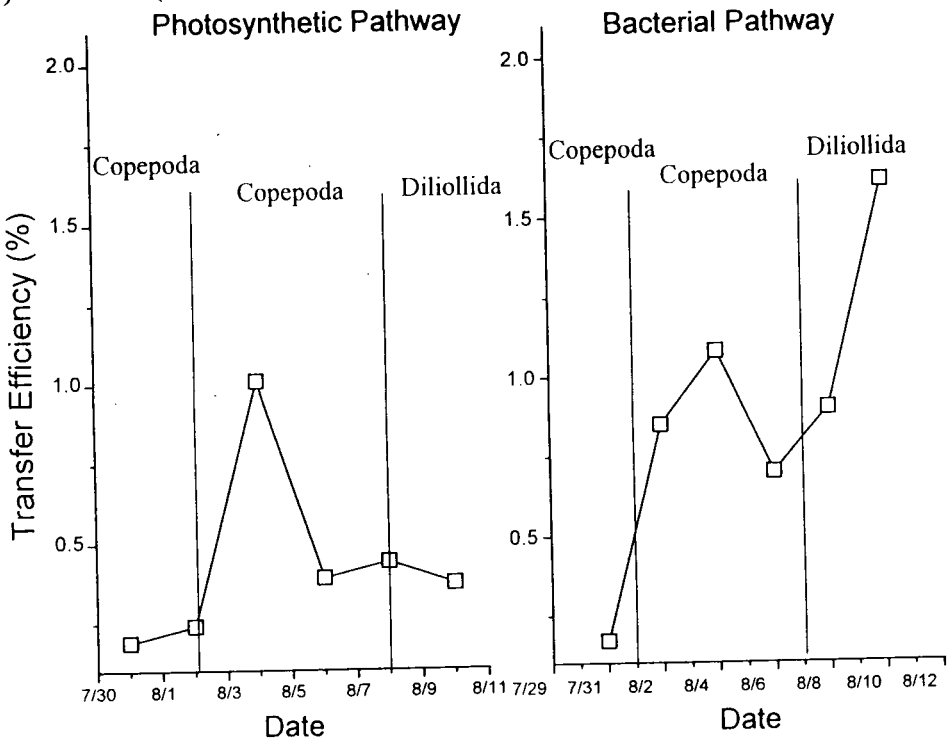

Fig.6 Variations in the transfer efficiency from photosynthetic and bacterial production

Previous report[8] indicated very low transfer efficiency (ca. 0.03%) suggesting that bacterial loop is a respiratory energy sink. However, our results indicated that the transfer efficiency of bacterial production could be higher than that of photosynthetic production in some ecosystems.

Transfer efficiency of bacterial production was higher when Doliollida dominated the zooplankton community. Because Doliollida graze smaller particles (bacteria size) directly[9], the transfer efficiency could be elevated. On the other hand, transfer efficiency of photosynthetic production was smaller in the ecosystem comprised of Copepoda and dinoflagellate (at the initial stage) and that of Doliollida and centric diatoms (at the final stage). These results underline the potential effects of species succession on the variation of ocean element cycles.

References

1) Grice, G. D., R. P. Harris, M. R. Reeve, J. F. Heinbokel, and C. O. Davis. 1980. Large-scale enclosed water-column ecosystems. An overview of foodweb I , the final CEPEX experiment. J. mar. biol. Ass. U. K. **60:** 401-414.

2) Watanabe, M., K. Kohata, T. Kimura, T. Takamatsu, S. Tamaguchi, and T. Ioriya. 1995. Generation of *Chattonella antiqua* bloom by imposing a shallow nutricline in a mesocosm. Limnol. Oceanogr. **40:** 1447-1460.

3) Guanguo, L. (1990). Different types of ecosystem experiments. In: Enclosed Experimental Marine Ecosystems: A review and Recommendations, Lalli, C. M. (Ed.), Springer-Verlag, New York, pp.7-19.

4) Hama, T., T., Miyazaki, Y. Ogawa, T. Iwakuma, T. Takahashi, A. Otsuki, and S. Ichimura. 1983. Measurement of photosynthetic production of a marine phytoplankton population using a stable ^{13}C isotope. Mar. Biol. **73:** 31-36.

5) Harada, S., M. Watanabe, K. Kohata, T. Ioriya, M. kunugi, T. Kimura, T. Fujimori, H. Koshikawa, and K. Sato. 1996. Analyses of planktonic ecosystem structure in coastal seas using a large-scale stratified mesocosm. Wat. Sci. Tech. inpress.

6) Koshikawa, H., S. Harada, M. Watanabe, and K. Sato. 1996. Relative contribution of bacterial and photosynthetic production to metazooplankton as carbon sources. J. Plankton Res. submitted.

7) Harada, S., H. Koshikawa, M. Watanabe, K. Sato. 1995. Variations in the transfer efficiency from photosynthetic and bacterial carbon production into zooplankton during a shift of zooplankton dominance from Copepoda to Doliollida. North Pacific Marine Science Organization 4th Annual Meeting, Qingdao.

8) Ducklow, H. W., D. A. Purdie, P. J. Leb. Williams, and J. M. Davies. 1986. Bacterioplankton: a sink for carbon in coastal marine plankton community. Science. **232:** 865-867.

9) Crocker, K. M., A. L. Alldredge, and D. K. Steinberg. 1991. Feeding rates of the *Dolioletta gegenbauri* on diatom and bacteria. J. Plankton Res., **13:** 77-82