D-061 Study on the Ecological Deterioration of East Asian Marginal Seas due to the Anthropogenic Change in the Effluent Nutrient Ratio of N: P: Si (Abstract of the Final Report)

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[Abstract] Among several possible causalities between the anthropogenic perturbations and the ecosystem deteriorations such as the increase of harmful algal blooms (HAB) and jellyfishes taking place in the east Asian coastal and/or marginal seas, we verify the process originated from the changes in composition of nutirents via river such as follows. While the loadings of nitrogen (N) and phosphorus (P) are enhanced by the human activities, dissolved silicate (DSi) supplied by naturally tends to be trapped in the still waters behind the dams. The consequent change in the N: P: Si ratio of the river water may be advantageous to flagellates (nonsiliceous and potentially harmful) but not to diatom (siliceous and mostly benign) in the coastal seas. This is the "silica deficiency hypothesis". We try to develop it further to the "extended silica deficiency hypothesis" as follows. Whereas the diatoms effectively draw down the substances from the upper layer with their sinking after the spring bloom (biological pump), other algae do not. This will cause the retention of the surplus nutrients and biogenic substances in the upper layer and lead further to eutrophication of upper layer substantially. A simplified ecosystem model for the Changjiang Estuary was developed. The results showed that the smaller the DSi/DIN discharge is the larger the Nutritions Export from the estuary is, which implies the increase of jellyfish with the supportive consideration of other factors. One of the scientific points that the seasonality in the model results and observation coincide was the consideration of the autonomous sinking of diatom when DSi was depleted, after which the nutritional substances are not drawn down by diatom but exported outward and transformed to the carnivore's biomass.

Key Words Silica Deficiency, Diatom, Autonomous Sinking, Nutritions Export, Jellyfish

1. Introduction

In recent years, the Asian marginal seas suffer the ecosystem deterioration such as the increase of blooms of jellyfish[1)] as well as the harmful algae. Possible causal relationships between the anthropogenic factors (the low in the left-hand side of Fig.1) and the two phenomena mentioned

above (upper right-hand side) are shown as a flow diagram. Among them, the factors related to the variations in the discharge of land-based matters to the sea via rivers are particularly important in order to construct the environmental measures from now on. The general term "eutrophication" caused by too much discharges of organic pollutants (COD), nitrogen (N) , phosphorus (P) has long been discussed intensively. Furthermore, it is noteworthy that the stoichiometric ratio including silicon (Si) is crucial due to the fact that diatom's activity is the primary driving factor in the marine biogeochemical processes.

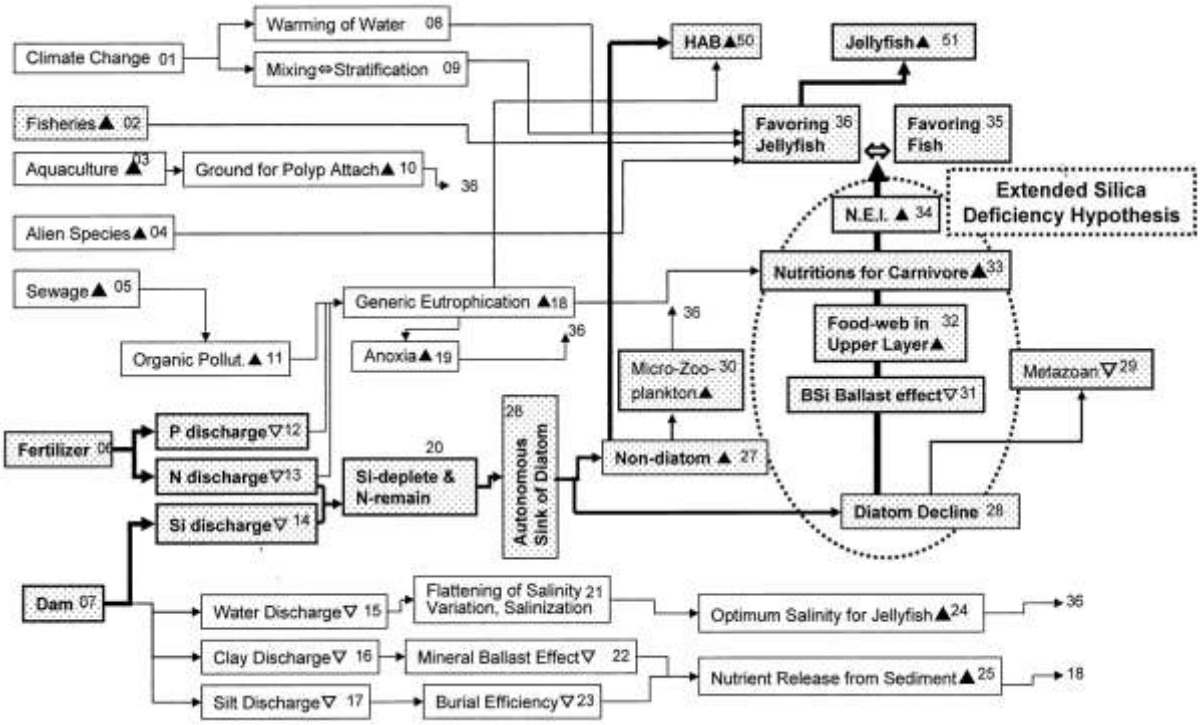

Fig.1 Possible causal relationships between the anthropogenic factors (left-hand side) and the marine ecological deteriorations represented by the increase of the number of harmful algal blooms (HAB) and jellyfish obtained from extensive review of relating papers. The phenomenon and the possible cause-result relation are referred in the text with the number in the right-hand side of each phenomenon such as [nn] or [nn-mm].

Among them the causalities [06-12&13] and [07-14] are our concerns. While the loadings of nitrogen (N) and phosphorus (P) are enhanced by the human activities, dissolved silicate (DSi) supplied by natural weathering of minerals tends to be trapped in the eutrophicated still waters such as dammed reservoirs, which are also increasing in number globally (Fig.2). The consequent decrease in the ratio of Si/(N, P) of the nutrients flowing into the coastal is advantageous to flagellates, which is nonsiliceous and potentially harmful, but not to diatoms, which is siliceous and mostly benign[2]. This is the "silica deficiency hypothesis".

The land-based portion of the hypothesis mentioned above has certainly taken place in the watershed of Changjiang Rivers, where DIN and DIP have increased due to the increase in

fertilizer uses and DSi has decreased due to the past construction of dams. Concerning the marine portion, Wang *et al.* [3] showed a positive view on the anthropogenic effects on the changes in the riverine nutrients' composition, estuarine nutrients' composition and the number of HABs. However, Zhang *et al.* [4] showed rather modest view and the whole part of the silica deficiency hypothesis could not so firmly and straightforwardly verified as was shown in Harashima *et al.* [5] based on the time series characteristics in the Lake Biwa, Yodo River and Seto Inland Sea system.

2. Research Objective

The main purpose of this research is to evaluate the causalities between the anthropogenic riverine inputs and the marine ecological deteriorations such as the increase of jellyfish blooms by developing above hypothesis further to the "extended silica deficiency hypothesis" as follows. While the diatoms effectively draw down the substances from the upper layer with their sinking after the spring bloom (biological pump), other algae do not. This will cause the retention of the surplus nutrients and nutritional substances in the upper layer and lead further to eutrophication of upper layer substantially (Fig.2(a) , (b)).

If verified, this hypothesis will lead to construct a measure such as the regulation of N and P loadings and total quantity of hydrological alterations of major catchments. Considering this, we organized this program, which consists of the following three sub-themes (Fig.3). Since lots of processes are involved in this hypothesis, a weight is put on the review of existing papers following the methodology of IPCC reports, as well as our own in situ observation, experiments and the ecological modeling in order to reduce the scientific uncertainty gradually and comprehensively.

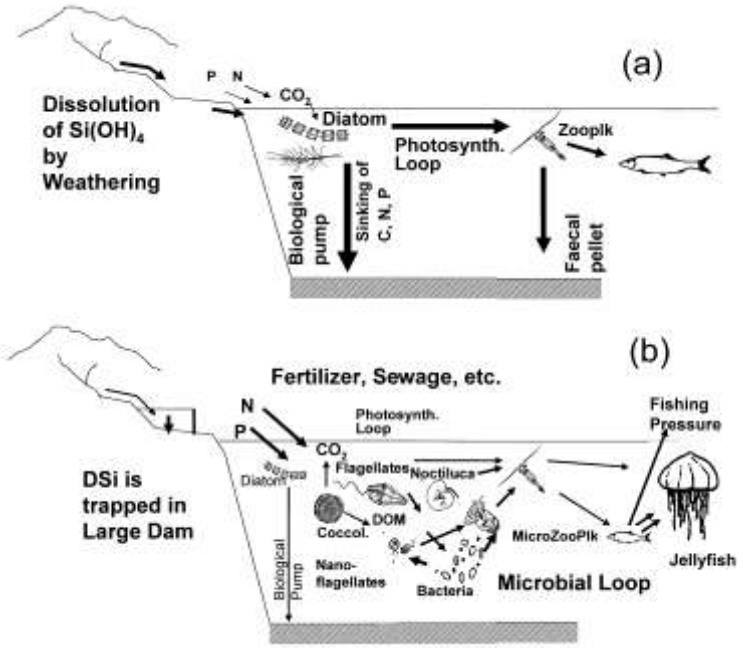

Fig.2 A schematic diagram of the (a) natural and (b) anthropogenically perturbed river-estuary system based on the "Extended Silica Deficiency Hypothesis".

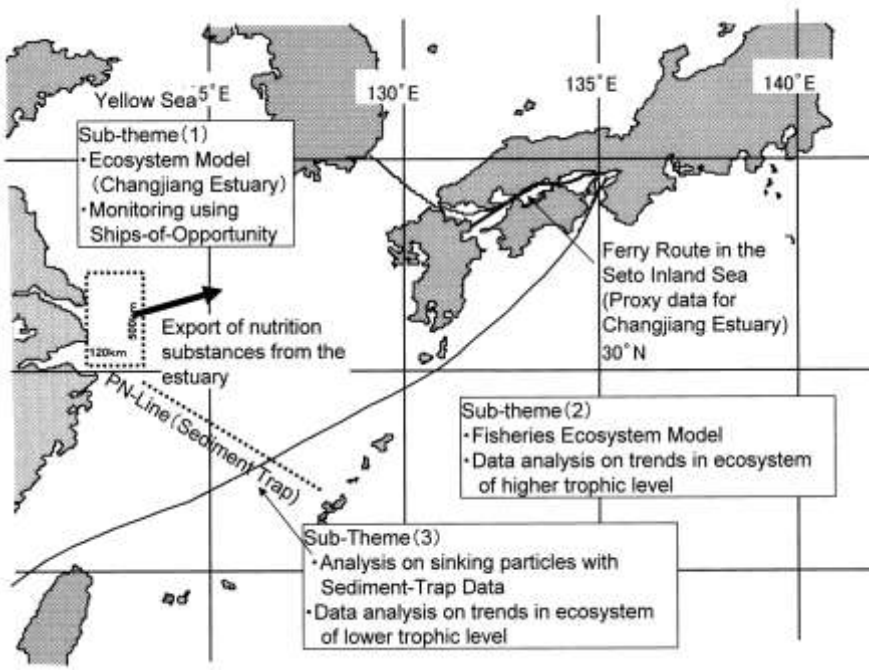

Fig.3 Sharing of the researches by the sub-themes (1), (2) and (3). The dotted rectangle is the region of ecosystem modeling (Changjiang Estuary) performed by (1).

3. Methods and results of each sub-theme

(1) Comprehensive analysis on the marine ecosystem deterioration due to the anthropogenic change in the inflow ratio of N: P: Si (National Institute for Environmental Studies)

We developed an ecosystem model named MSFTM (Marine Stoichiometry and Functional Types Model) with the configuration of two boxes applied to the upper and lower layer of the Changjiang Estuary (Figs. 3 and 4). Here we consider two functional types: siliceous and non-siliceous phytoplankton for diatom and phytoplanktons other than diatom.

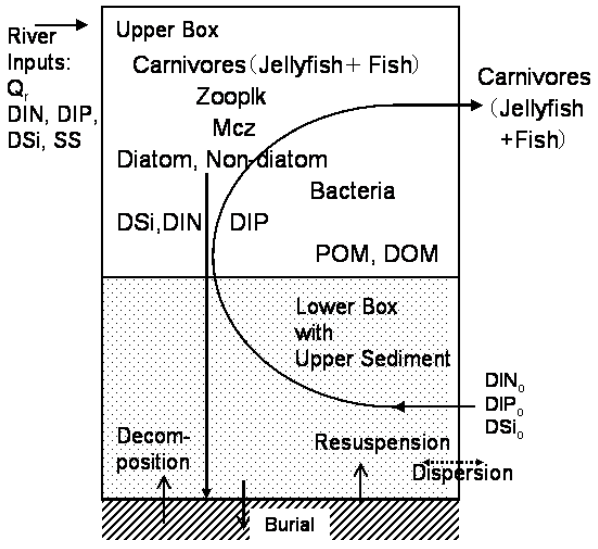

Fig.4 Configuration of MSFTM (Marine Stoichiometry & Functional Types Model).

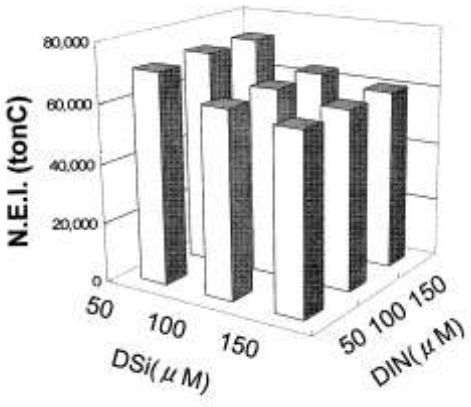

Fig.5 Simulated dependence of Nutritions Export Index (N.E.I.) on the concentration of DSi and DIN of the Changjiang river water.

Starting the simulation from the initial condition of early spring when nutrients are replete, spring bloom of diatom occurs first. When DSi or DIN depletes, the spring bloom ends and diatom decreases. After diatom decreases, DSi recovers to a certain extent because of the absence of diatom. Even though the DSi recovers diatom does not increase again. Then non-diatoms increases and it is maintained through summer. Such a seasonality is consistent with the time series observational results from ferries only when considering the autonomous sinking of diatom, which means the diatom sinks faster than usual in the depletion of nutrients particularly of DSi as was shown by the experiment of Biengfang[7]. In the sinking process, cell wall of diatom (biogenic silica) functions as a ballast [8] to avoid the rather inappropriate condition in the upper layer.

After the sinking of diatom due to DSi depletion, no organisms effectively draw-down the nutritional substances (living non-diatoms, detritus, unused nutrients, zooplanktons, microzooplanktons, bacteria, etc.) and therefore these substances remain in the upper layer and are exported from the estuary. In the case of N-depletion (and Si-excess), diatom also autonomously sinks but above tendency does not take place so remarkably because the non-diatoms, and other organisms feeding on them cannot grow remarkably.

To evaluate how such a tendency depends on the riverine N and Si, we define "Nutritions Export Index (N.E.I. for short)" as the assumed biomass of carnivores (fish + jellyfish) transformed from the exported nutritional substances, namely,

N.E.I. = Seasonal Integration of

$$[\ (\text{Zooplankton} \times \text{Tref} + (\text{Phytoplankton} + \text{Microzooplankton}) \times \text{Tref}^2 + \text{Bacteria} \times \text{Tref}^3 + \ldots) \times \text{Estuarine Circulation Magnitude}\ ],$$

where Tref is the transfer efficiency between the inter-trophic levels. Sensitivity of N.E.I. on the riverine DIN and DSi concentrations showed that the smaller the DSi/DIN ratio is, the larger the N.E.I. is (Fig.5) implying that biomass of fish + jellyfish generated from the exported nutritional substances will be elevated. Considering other anthropogenic factors such as [02] or [03], it is predicted that this elevated biomass will contribute to the biomass of jellyfish than fish.

(2) Evaluation of the effect of stoichiometrical change of nutrients to the higher trophic level of marine ecosystem based on the fisheries ecosystem model. (National Research Institute of Fisheries and Environment of Inland Sea)

Shifts in seawater quality and fisheries landings were accompanied by modifications in structure of marine communities. Alteration of resource availability represents a "bottom-up" perturbation of marine ecosystems, whereas removal of consumer biomass through fishing represents a "top-down" perturbation. Therefore, an understanding of how bottom-up and top-down processes influence the structure and dynamics of marine communities is necessary for effective management of marine ecosystems in the face of environmental variability and human impacts.

In this study, we addressed the question of bottom-up versus top-down control of marine

ecosystem trophic interactions by using field data and previous long-term data in the Seto Inland Sea of Japan. A positive relationship was found between mean annual phytoplankton biomass, annual zooplankton biomass and annual yield of pelagic plankton feeders. These results demonstrate close linkages between phytoplankton, zooplankton and pelagic plankton-feeding fishes, suggesting that bottom-up control regulates ecosystems in the Seto Inland Sea of Japan during recent decades.

The use of ecosystem models also provides a framework to understand the observed structural changes in the ecosystems. A balanced model for Harima Nada, located in the eastern part of the Seto Inland Sea of Japan, was built using the Ecopath with Ecosim software and the carbon flows in this area were estimated using this model. Furthermore, analysis of the trophic interactions indicated that decrease in fisheries production and massive development of jellyfish could be explained not only by overfishing (top-down control) but also by the change in community structure of phytoplankton (bottom-up control).

The present study demonstrates that the changes in community structure of phytoplankton can cause important alterations in the structure and dynamics of a large marine ecosystem. These findings may provide insights for ecosystem management in East Asian marginal seas, suggesting that the comprehensive management throughout land-sea continuum can contribute greatly to sustaining viable marine ecosystems.

(3) Evaluation of effect of stoichiometrical change of nutrients to the lower trophic level of marine ecosystem based on the inter-annual data analysis. (Hiroshima University)

Detecting the land-based effect on the sinking of biogenic particles is a key process as a component of the "extended silica deficiency hypothesis". This study examined how their inter-annual changes are detected by the analysis of sinking biogenic particles from the preserved samples of sediment trap as well as the nutrients and phytoplankton composition in the seawater mainly focusing on the East China Sea and its outer rim (Okinawa Trough). Also, existing scientific papers and data including the characteristic area in the world ocean (North Atlantic, Bay of Bengal, etc.) were reviewed to make out analysis comprehensive.

At Okinawa Trough (outer rim of the East China Sea), sinking particulate fluxes (dry weight, major biogenic constituents, and phytoplankton) observed in 1993 increased noticeably with depth and a benthic diatom *Paralia sulcata* (dominant at inner shelf) was occasionally found in the sinking particles, mostly collected in the deepest sediment trap (50m above bottom). In a spring experiment of 1995, phytoplankton fluxes near bottom on the shelf showed a significant decrease from the inner shelf to the shelf edge and the *Paralia sulcata* was dominant in diatom. In May of 1998, at the Changjiang estuary a high flux of *Prorocentrum donghaiense* (which is similar to *P. dentatum* occurring in Japan and Korean waters) was observed. Further, in June cruise of 2007, diatom abundance significantly decreased from the central shelf to the shelf edge but *P. sulcata* was almost constant and dominant in diatom.

These results indicate that the near-bottom transport is a key process for export of biogenic and lithogenic particles from the inner shelf to the shelf slope facing Okinawa Trough. Also, there is a possibility that phytoplankton species composition may change at the inner shelf to a central shelf

areas since the late 1990's.

4. Discussion and Conclusions

1) Based on the simplified ecosystem model for the Changjiang estuary, it is predicted that the increase of DIN and decrease of DSi in the Changjiang River lead to the increase in the export of nutritional substances from the estuary, which would further contribute to the increase in the biomass of carnivores (fish and jellyfish). The other anthropogenic factors such as overfishing or increase of aquaculture would favor jellyfish than the fish. The point to make the model and observation results consistent is to include the diatom's autonomous sinking when DSi is depleted in the end of spring bloom, after which scarcity of diatom in the upper layer diminishes their function of drawing down the nutrients from the upper layer, which is in the same time intensifying the export of nutrition substances. Thus "extended silica deficiency hypothesis" could deduce more general conclusions than the "silica deficiency hypothesis".

2) Based on the fisheries ecosystem model and existing data analysis, it is confirmed that the bottom-up control is equally important in the trophic relationship with respect to the jellyfish in the Seto Inland Sea.

3) The sediment trap results showing the characteristic inner shelf diatom *Paralia sulcata* at the shelf break imply the existence of flow from the inner shelf to the shelf break via the lower layer. Also, the change in the phytoplankton species composition was implied since the 1990's at the inner shelf to the central shelf of the East China Sea based on the existing data.

4) It could be suggested from our results that certain environmental policy makings should be promoted such as checking and regulating the hydrological alterations such as the construction of dams that hinder the Si supply to the coastal seas as well as regulating the N and P discharges. The continuous marine monitoring using ferries and other ships of opportunities [6),9)] would be a strong tool for the conservation of coastal environment. Also, the mooring of sediment traps [10)] at the shelf break would be an efficient tool to indirectly monitor the environmental changes in the inner shelf.

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