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Nutrient Release from Sediment in the Changjiang Estuary

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Abstract

Modifications in the Changjiang River supply, land use changes, and industrial development in the catchment area are expected when China's Three Gorges Dam is completed. Changes in nutrient supplies may influence primary production and the ability of the environment to biodegrade pollutants. To forecast the ecosystem's response to the new conditions, it is essential to understand the processes and exchanges of nutrients at the sediment–water interface.

The sediment appears to be in continuous interaction with the water column in the Changjiang estuary. Processes involved in nutrient transfer are reversible and quick, and differ with season and sediment type. The release of phosphorus from the sediment to the water column is highlighted by both direct sampling measurement and bottle experiments. These preliminary results can be used in the modeling of this ecosystem.

Introduction

An ecosystem's nutrient status greatly affects algal growth, the microbial community, fisheries resources, and aquaculture production. The consequences of nutrient imbalance include red tides and associated shellfish poisoning, and changes in the capacity of the environment to biodegrade pollutants, economics, human health, and quality of life.

In the East China Sea ecosystem, most nutrients are supplied by the Changjiang River, although marine currents also influence the region. The Changjiang flow shows a high seasonal variability, although inter-annual variation is low. The construction of the Three Gorges Dam may lead to a drastic change in the river's flow in the near future. To forecast the response of the East China Sea ecosystem to the changes in flow, we have to determine the present state of the marine ecosystem.

My work is part of the "China–Japan Co-operative Study—Environmental capacity and effects of pollutants on the marine ecosystem in the East China Sea", conducted by the Environment Agency of Japan, the State Oceanic Administration of China, and the National Institute for Environmental Studies of Japan. Other contributions to the project are focusing on water column processes.

The phosphorus (P) cycle in marine ecosystems includes the processes at the bottom in addition to those in the water column. Sediment can act as a sink or a source according to the conditions at the sediment–water interface. My role is to determine the importance of the processes and exchanges at the water–sediment interface in the nutrient status of the East China Sea ecosystem. Focus was given to P for two reasons:

- P has an important role in the control of eutrophication and red tides in coastal waters of the East China Sea (Wu *et al*., 1992).
- P behavior is closely linked with exchangeable pollutants, including Fe, Cu, Zn, Mn, Pb, and As. Therefore, knowing the exchange, flux, and fate of P can help us estimate exchanges in those pollutants too.

The study area (lat. 31° to 32°N, long. 122° to 124°E) (Fig. 1) is shallow, with depths from 20 to 50 m. Storms resuspend sediment particles, particularly in winter (Xie and Li, 1990). To study the water–sediment interface, it is therefore necessary to investigate the seasonal effects of the different water mass conditions above the sediment as well as the hydrodynamic and biological features.

On a more global scale, an understanding of the ecosystem's behavior is needed to help policymakers emphasize the need for management of watersheds and for waste treatment.

Materials and Methods

The water column was sampled with Go-Flo® bottles; samples were immediately filtered (Nucleopore® 0.4-µm pore size; 47 mm) and frozen. From the Chinese boat "Kaikan 49" tubes gravity cores at stations A1, A3, B1, C1, and C3 and the mesocosm area (Fig. 1) were sliced directly after sampling and frozen. At stations B1, C1, and C3 and mesocosm area, the interstitial water of the sediment was obtained by compressing the gravity core without contact with air in a specially designed system (Fig.1). The interstitial water was filtered through a Millipore Millex® FG PTFE 0.2-µm filter, and samples were frozen. The compressed sediment was then sliced and frozen.

In addition to the sampling, on-board experiments to simulate sediment–water resuspension were run (Fig. 1; Table 1).

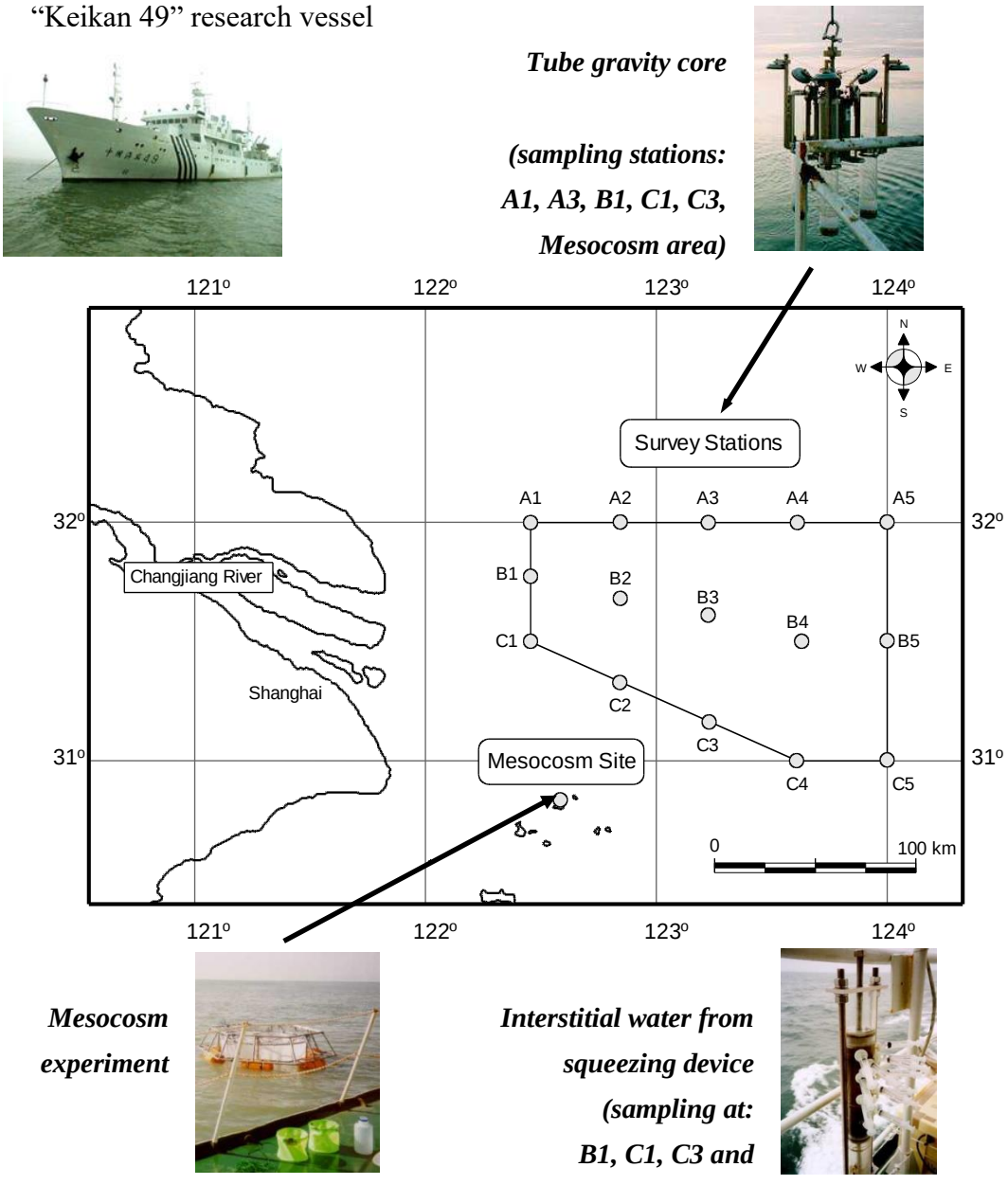
Table 1: Characteristics of the resuspension simulation experiment.

Season and sediment type:	Autumn 1997, muddy sediment (mesocosm area)	Spring 1998, sandy sediment (Station A1)
Sediment characteristics	Al = 8.2%, Ca = 1.9%, Fe = 4%	Al = 5.5%, Ca = 2.4%, Fe = 5.5%
Sediment inorganic P, $\mu mol \cdot g^{-1}$	13.3	14.5
Dissolved inorganic P, water samples, $\mu mol \cdot L^{-1}$	Surface water (0 m) = 0.78 Overlying water (20 m) = 0.78	Surface water (0 m) = 0.25 Bottom water (24 m) = 0.18 Overlying water (25 m) = 0.15
Experimental conditions	Sediment weight = 20 g Volume of water = 250 ml Stirring 14 h, total contact 18 h	Sediment weight = 6.5 g Volume of water = 200 ml Stirring 20 h, total contact 24 h

The first 2 cm of the sediment was homogenized, and a few grams was introduced in a dark bottle (to avoid light effects). A Teflon® bar magnet in the bottle was used to stir the sediment in contact with samples of water from different depths (surface, bottom, and overlying waters, Table 1) to simulate the plunging of the water that can occur on windy days and to simulate new conditions of concentration and physico-chemical proprieties which might occur in the future at the sediment–water interface in addition to simple resuspension with the existing water above the sediment. The suspension was incubated at the in-situ temperature for at least 15 hours to get a steady equilibration of concentration between the water and the sediment (Andrieux-Loyer, 1997). Two sediments types were investigated, one in autumn and one in spring (Table 1) in two parallel sets, one to

investigate the total processes occurring during physical resuspension, and one after biological activity in the sample was reduced by ultrasound (lyse of cells).

Figure 1: Study area and sampling devices at the Changjiang estuary mouth.



Extraction of inorganic and organic P from the sediment was done according to Slomp *et al.* (1993). The sediment extracts and the dissolved inorganic P (DIP) from the

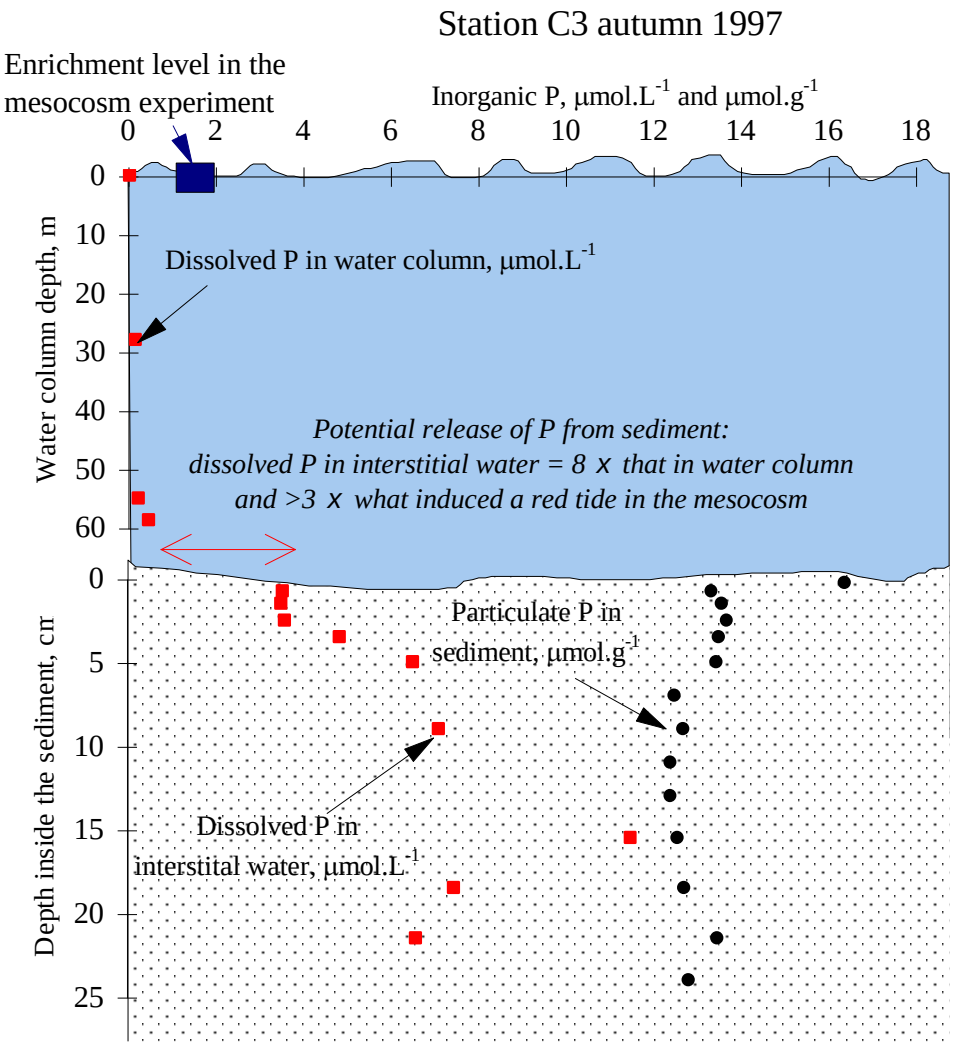
seawater samples and the interstitial water of the sediment were determined with an auto-analyzer. To check the extractions and accuracy of analysis, a certified reference sediment (MESS-2 from the Beaufort Sea provided by National Research Council Canada)was treated in the same way as the other samples. For the water samples, blank samples were also run on board to check background levels and contamination.

Results and Discussion

Potential P release

The dissolved interstitial P concentration of the sediment was higher than the concentration measured in the water column by a factor of 1.4–65 (according to location and sediment layers). The maximum interstitial concentration found was 13 $\mu mol \cdot L^{-1}$ at station C3 in autumn (Fig. 2).

Figure 2: Dissolved, interstitial, and particulate inorganic P at station C3 in autumn 1997.



Through exchanges at the sediment–water interface and migration of the interstitial water, some P should be able to be released to the water column. Autumn seems to be more favorable than spring for P release because the interstitial concentrations were a little higher then. As resuspension from the seabed is a winter feature, the water column may gain P from the sediment then. On the other hand, spring and summer exhibit higher biological activity and more probably a higher bioturbation. Exchanges at the interface from the bioturbation would compensate for the less marked resuspension at the bottom during these warmer months.

An in-situ mesocosm experiment was also conducted at sea in autumn and spring. The mesocosm equipment, designed by Dr. M. Watanabe's team, is unique and represents a great tool for understanding the ecosystem shift. Phytoplankton blooms in the mesocosm were induced after P enrichment of 1.5–2 and 3 $\mu mol \cdot L^{-1}$ for the three experiments conducted during the two surveys. Thus the concentrations in the interstitial water of 1–13 $\mu mol \cdot L^{-1}$ would be able to induce phytoplankton growth.

Depending on the concentrations in the interstitial water and water column and on the local conditions (bottom resuspension, bioturbation, changes in the water column), the sediment would be both a sink and a source of P. The flux of nutrients released to the water column through the interstitial water of the sediment should be high enough to increase the dissolved concentration of the water body to induce a phytoplankton bloom.

Release of P from sediment after simulation of bottom resuspension

To estimate the release of nutrients from the sediment to the water column when sediment is resuspended, on-board experiments were conducted immediately after the core sampling to simulate physical resuspension (but not the deep bioturbation by worms and shells).

The DIP content was measured in the initial water samples (Table 1) and in the water after resuspension (Table 2).

Table 2: Dissolved inorganic P content after simulation of bottom resuspension.

Water source	DIP in the water above the sediment after simulation, $\mu mol \cdot L^{-1}$			
	Muddy sediment, autumn		Sandy sediment, spring	
	raw sample	after ultrasound	raw sample	after ultrasound
Surface water	1.35	1.40	0.34	0.64
Bottom water			0.39	0.27
Overlying water	1.34	1.24	0.56	0.30

The simulation of a muddy sediment resuspension in autumn produced a similar DIP content in the water from both sets of experiment with and without ultrasound action to depress biological activity. The release of P in this particular case seems to be governed only by physical processes. The calculated percentage of IP removed from the sediment is small, <0.1%, although the increases in the DIP content in the water in contact with the sediment were from 59% to 80%. The IP was also measured in the interstitial water of the sediment after the resuspension experiment. A ratio of 0.85 was reached between the interstitial DIP of the sediment and the water column above the sediment for all results in the muddy sediment in autumn. Because of the stability of this ratio, it would be possible to use it in a predictive model of sediment–water interface exchanges. But extrapolation of the interstitial DIP : water column DIP ratio of 0.85 to other seasons and sediment types was not verified. The concentration equilibration at the sediment–water interface from physical processes emphasizes a quick and reversible response of the sediment to the water column changes.

In spring and for a sandy, slightly muddy sediment, the DIP concentration in the water after stirring was highly variable. Under the experimental conditions, the resuspension led to a DIP increase of 40% to > 100%. No real trend can be drawn from the results. This contrasts with the autumn experiment for a muddy sediment. The differences in results between ultrasound and non-ultrasound treatments would support a key but variable role for biological processes in the exchanges during spring. The main conclusion would be that for spring and a sandy, slightly muddy sediment, P exchange at the sediment interface is highly reversible, quick, and variable.

In both sediment resuspension simulations, a release of IP from the sediment was marked by an increase in DIP in the water in contact with the sediment. This highlights active or passive exchanges, or both, at the sediment interface during resuspension. The sediment seems to be potentially in continuous interaction with the water column above it. The sediment compartment plays a role in the water column P content and should be considered a buffer able to both store and release P according to conditions.

Potential for release of nitrogen from the sediment

Other nutrients were also analyzed. The concentrations of NO_3^-, NO_2^-, NH_4^+, and PO_4^{3-} in interstitial water were higher than those in the water column, except sometimes for NO_2^-. The NH_4^+ concentrations were 50 to 190 times higher in the sediment than in the water column. This is likely due to organic matter degradation and mineralization within the sediment. As a general feature, the interstitial nutrient concentrations increased with sediment depth at all stations. This characteristic can be explained by degradation in

deeper and less oxygenated sediment. An alternative explanation is a release from the sediment to the water column and either nitrification or denitrification. The NO_2^- concentrations of the water column at mid depth and above the sediment interface were higher than at the sea surface. This would suggest nitrification or release from the sediment to the water column. Simulation of bottom resuspension also highlighted the release of nutrients from the sediment to the water column.

To forecast the ecosystem response to changes in water column composition and quality, the sediment compartment has to be included in predictive models. Results from this preliminary study can be used in models.

Conclusions

Most of the P stored in the sediment of the studied area is in inorganic form. Results of the resuspension simulation experiment, the vertical profile of nutrients trends in the sediment, and the interstitial water content support potential release of P. From the results, the sediment could be continuously in dynamic exchange with the water column. The water column composition would therefore be related to the sediment composition. Exchange processes differ according to sediment type and season. The release is likely to involve migration and equilibration exchanges between the interstitial water of the sediment and the water column. The IP concentration found in the interstitial water of the sediment varied from < 1 to $\mu mol \cdot L^{-1}$. Release of P from the interstitial water would be able to induce a phytoplankton bloom if the flux was great enough.

But the extent to which a release from the sediment will modify the concentration in the whole adjacent water column still requires further investigation. By taking representative cores of the different sediment types and by determining the biological activity over the seasons, we should be able to get a more global idea of the exchange flux. Benthic chamber measurement of the flux at the sediment–water interface would give key parameters for a predictive model of the nutrient state of the area, to complement our understanding of the water column behavior. This study is a first step in this approach.

The sampling and bottle experiment results suggest a seasonal effect that will have to be taken into account in predictive models. A ratio of equilibrium of 0.85 for inorganic P was found between the interstitial water and water in contact with the sediment in the muddy sediment in autumn. This highlights the physical processes involved in the exchange. Other nutrients and pollutants should be analyzed to set their specific ratios for predictive models. It appears that in spring, biological activity is more stressed, and a steady equilibrium cannot be reached.

Some exchangeable pollutants, such as Fe, Cu, Zn, Mn, Pb, and As, which are linked with the P cycle, may also follow the same trend. Special focus should be given to their study in relation to P behavior to assess their exchange at the sediment–water interface.

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