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Runoff Loadings and Chemical Forms of Soil Phosphorus from Rivers in Japan during the High Flow Stages

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Abstract

The processes of soil phosphorus runoff into Hiroshima Bay via the Ohta River and composition of phosphorus forms in suspended matter in several major rivers in Japan during the high flow stages were investigated. In the Ohta River, the majority of soil runoff occurred as a result of terrestrial soil erosion due to heavy rainfall over several days of a year. In major rivers in Japan, phosphorus content in suspended matter ranged from 20 μmol/g (Yoshino River) to 71 μmol/g (Tone River) in which inorganic phosphorus accounted for over 50%. Potentially reactive inorganic phosphorus (CDB-P) accounted for 25 to 56% of the total phosphorus contained in sus pended matter during the high flow stages, suggesting that the CDB-P load from rivers equals of exceeds that of organic phosphorus. The higher ratios of CDB-P in large rivers such as Shinano Rivers such as Shinano River and Tone River may be caused by the erosion of phosphorusrich soil from large agricultural fields in drainage basin areas. In Hiroshima Bay, particulate phosphorus and CDB-P loads under flush conditions were estimated to be 2,600 t/yr and 880 t/yr, respectively. CDB-P load from soil substances discharged during the high flow stages was considered to be the main source of phosphate eluted from coastal marine sediments.

Discipline: Fisheries
Additional key words: soil erosion, suspended matter, eutrophication of marine environments

Introduction

It is well known that phosphorus is very important in the process of eutrophication in coastal marine environments and that the major sources of phosphorus are inputs from rivers and release from coastal marine sediments. Although few case studies have been carried out regarding inflow of phosphorus from rivers in Japan, it is generally recognized that most of the phosphorus runs off in the form of particulate phosphorus during the high flow stages[5]. At flooding time, rivers discharge terrestrial soil substances which originate from the erosion of forests and farmlands and contain large amounts of inorganic phosphorus together with organic phosphorus[9,12].

On the other hand, the release of phosphorus from sediments under anaerobic conditions in eutrophic coastal waters has been investigated experimentally in order to elucidate the origin of eluted phosphate[6,7,15]. Results have indicated that such phosphorus is inorganic rather than organic in origin. Therefore, the phosphorus cycle relating to sediments and loading processes can not be fully understood without the information on runoff loadings and chemical composition of soil phosphorus in drainage basin areas.

In this study, the runoff behavior of soil substances was investigated in the Ohta River and Hiroshima Bay (Seto Inland Sea) during the rainy season, and phosphorus forms contained in the suspended matter were examined in several major rivers in Japan during the high flow stages.

Materials and methods

The Ohta River (Fig. 1), which flows through the western part of Hiroshima Prefecture into Hiroshima Bay, was observed for runoff loading of suspended matter during the rainy season. Samples of suspended matter were taken for chemical analysis

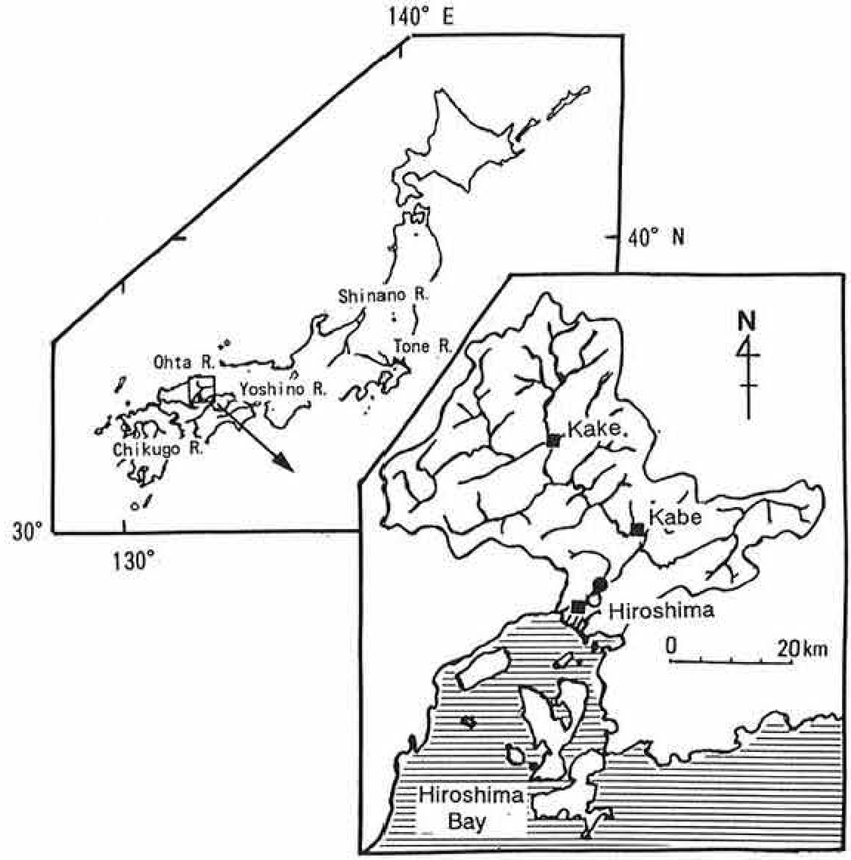

Fig. 1. Locations of several major rivers in Japan where water sampling was conducted during the high flow stages and sampling stations in the drainage area of the Ohta River for measurement of turbidity (○), discharge (●), and precipitation (■)

during high discharge periods. The drainage basin covers 1,690 km^2, and includes the urban areas of Hiroshima, agricultural fields, and forest lands. Average discharge is approximately 70 m^3/s and domestic wastewater and drainage from the fields flow into the Ohta River as in the case of many rivers in Japan.

During the 1991 rainy season from June 11 to July 21, runoff processes of suspended matter from the Ohta River were monitored at the water inlet of the Hesaka Water Purification Plant (Fig. 1) with a light scattering type turbidimeter (ALEC electronics MTB-16K) calibrated according to the concentration of suspended solids (SS) in Ohta River. A stream flow recording gauge (government operation) provided time series data for discharge in the vicinity of Hesaka every 15 min. Precipitation data in the drainage basin of the upper reaches (Kake), middle reaches (Kabe) and lower reaches (Hiroshima) were collected from the Automated Meteorological Data Acquisition System (AMeDAS) of the Meteorological Agency.

During the high flow stages in 1990–1992, suspended soil substances were collected from the Ohta River and several other major rivers in Japan; samples were concentrated by centrifugation and frozen at $-20°C$ until freeze-drying. They were then gently crushed using a pestle and mortar into a uniform fine composition suitable for chemical analysis.

The procedures of Williams et al.[14] were adopted for serial extraction of the inorganic soil phosphorus to be separated into the following three fractions:

1) Phosphorus extracted by citrate - dithionite - bicarbonate procedure (CDB-P): forms extracted included most of the iron phosphate minerals and adsorbed phosphate by iron oxyhydride. Since CDB-P is dissolved under anaerobic conditions[6,13,15], and if the concentration of dissolved phosphorus is low, adsorbed phosphate is rapidly desorbed via the phosphate buffer system[2].

2) 1N-sodium hydroxide solution extractable

phosphorus (NaOH-P): forms extracted included aluminium phosphorus and any iron-bound phosphorus not extracted in the CDB treatment.

3) 1N hydrogen chloride extractable phosphorus (HCl-P): forms extracted included varieties of apatite (calcium phosphate).

Total phosphorus content (Total-P) was determined by the methods of Andersen[1] and organic phosphorus content (Org-P) was estimated by the difference between the amount of Total-P and that of total inorganic phosphorus (CDB-P + NaOH-P + HCl-P).

Results

1) Runoff processes of suspended matter from the Ohta River

Fig. 2 shows the time series records of suspended

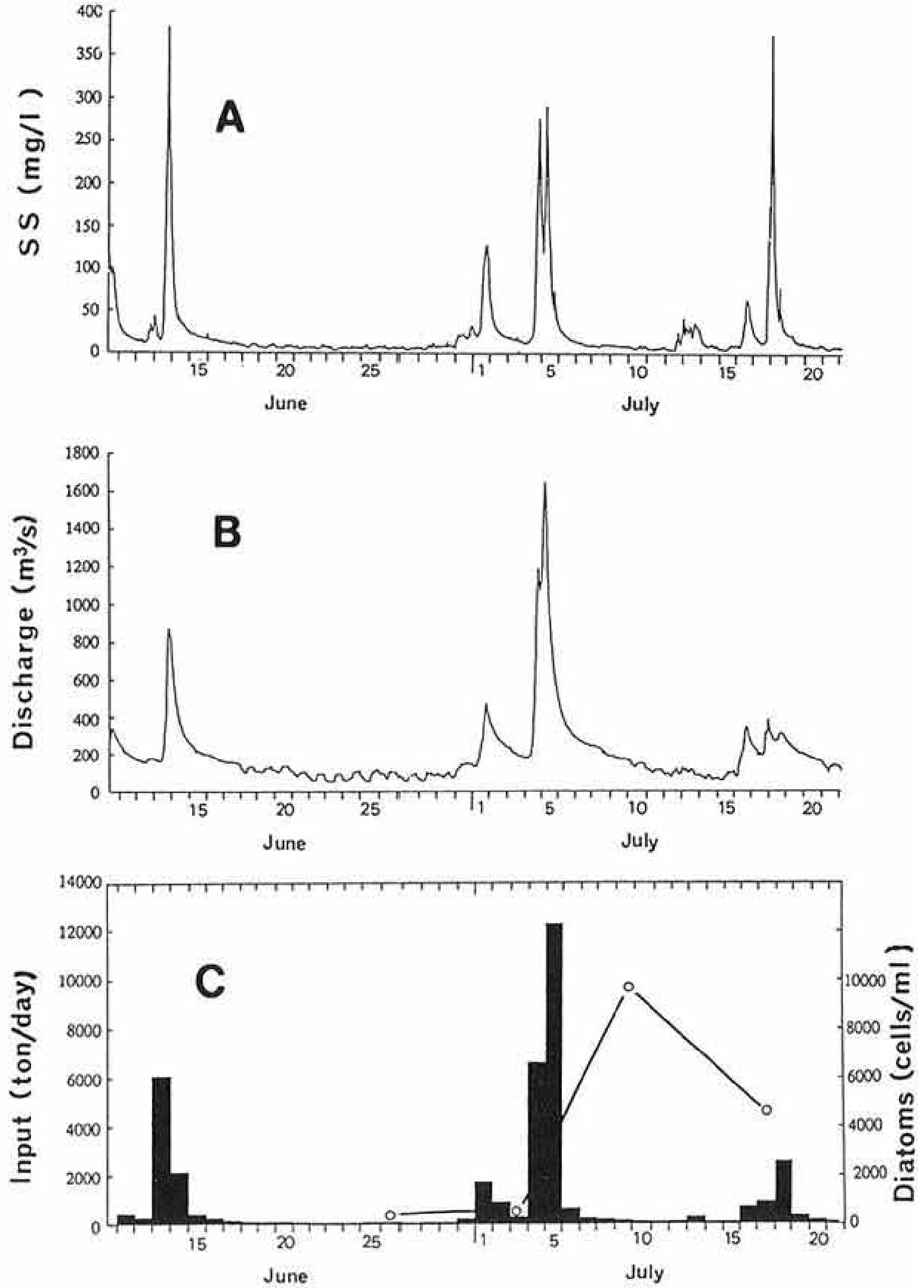

Fig. 2. Time series records of concentration of suspended solids (A), discharge of water (B) and input of suspended solids (C) during the rainy season in Ohta River at Hesaka in June-July, 1991
Changes in diatom cell number (open circles) in Hiroshima Bay after maximum input are also shown in (C).

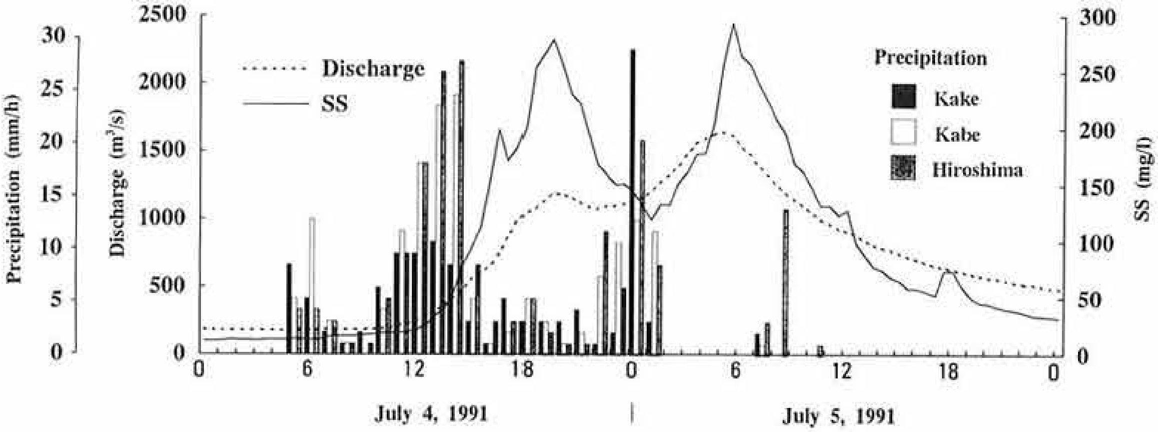

Fig. 3. Time series records of concentration of suspended solids (SS), discharge, and precipitation in the Ohta River drainage basin during the period July 4–5, 1991

solids (SS), discharge and the daily input (flux) of SS for each day. There were three major high flow stages during the observation periods (June 13–14, July 1–5 and July 16–20). Although the SS concentration increased during the high flow stages, the values of SS peaks were almost unrelated to the peak values of discharge. For example, the marked increase in the SS concentration on July 18 was not accompanied by a remarkable increase in discharge.

Up to half of the total SS flux in the rainy season was concentrated during the period July 4–5, suggesting that most of the runoff occurred within several days of a year[4]. There were two peaks of SS concentration during the period July 4–5, although the peaks of discharge were less evident. Fig. 3 shows the changes in the SS concentration and discharge during this period together with precipitation at the upper reaches (Kake), middle reaches (Kabe) and lower reaches (Hiroshima) of the river. Concentrated rainfall above 25 mm/h was observed 5 to 6 hours prior to the peaks of SS (19:30, July 4 and 05:30, July 5), whereas the fluctuations in the discharge were less related to the fluctuations of SS. From these observations, it appears that the concentration of suspended sediments was more affected by the rainfall intensity in the drainage basin than by the river discharge. Fig. 4 shows the relationships of peak SS concentration to discharge and to peak precipitation occurring several hours prior to SS peaks. Concentration of SS was significantly correlated with that of precipitation ($r = 0.91$), suggesting that the suspended matter originated from terrestrial soil substances eroded by intense rains rather than from resuspension associated with the flow of sediments on the riverbed.

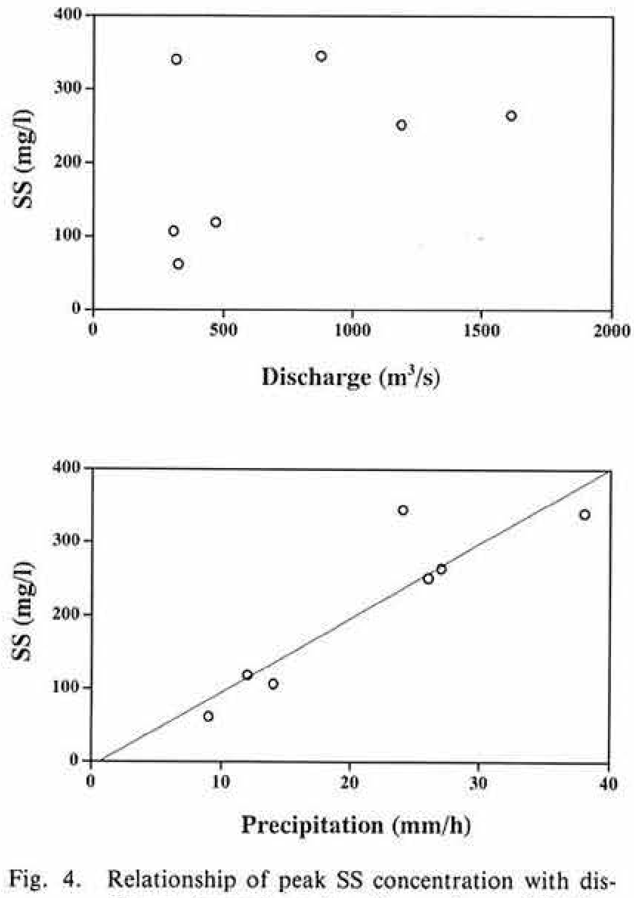

Fig. 4. Relationship of peak SS concentration with discharge (upper), and with peak precipitation occurring several hours prior to the appearance of SS peaks (lower)

2) Phosphorus forms of suspended matter in rivers

Phosphorus composition of suspended matter in several major rivers in Japan is summarized in Fig. 5 together with the average data of the Ohta River. Total-P content in suspended matter ranged from

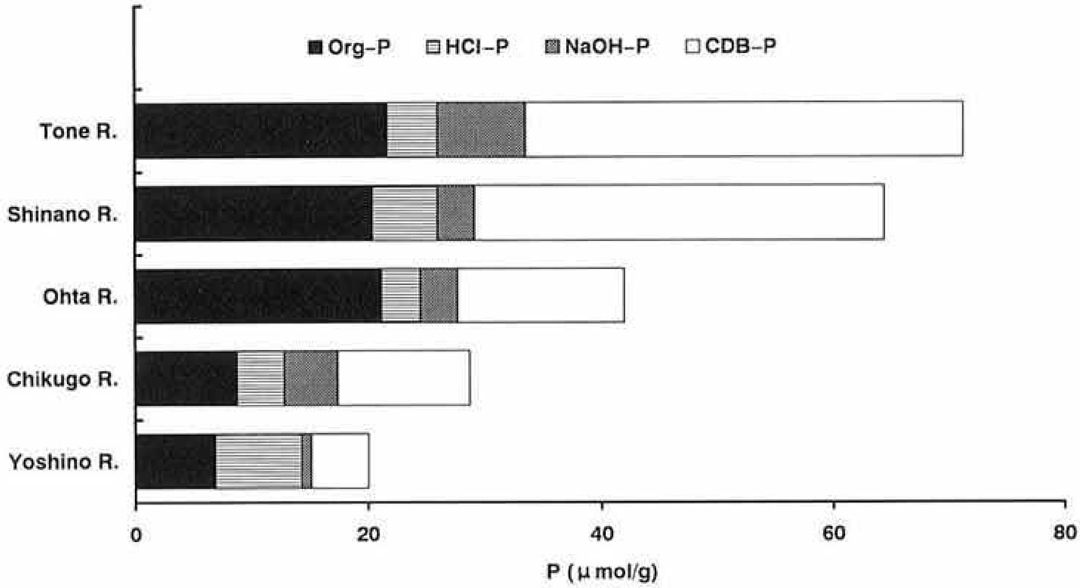

Fig. 5. Phosphorus fractions of suspended matter during the high flow stages in several major rivers in Japan

20 μmol/g (Yoshino R.) to 71 μmol/g (Tone R.) in which inorganic phosphorus, the sum of the three serial extractions, accounted for over 50%. CDB-P, potentially reactive phosphorus, was the major component of inorganic phosphorus except in the case of the Yoshino River in which HCl-P was the major constituent. The ratios of CDB-P were higher in large rivers such as the Tone and Shinano Rivers.

Discussion

During the observation periods, the Ohta River discharged about 40,000 t of suspended solids (SS) in which almost half was concentrated during the period July 4-5. The particulate phosphorus load during the period July 4-5 was estimated to amount to 26 t from the phosphorus content of the suspended matter (42 μmol/g : Fig. 5) which corresponded to a 65-day load of the daily average total phosphorus input (including dissolved and particulate forms) by Ohta River at Hesaka Water Purification Plant[3].

Although the maximum discharge reached a volume of 1,600 m^3/s in the 4-5 June period (over 20 times that of normal discharge), in many cases a much higher discharge was recorded (e.g. 6,800 m^3/s in 1972). Therefore, the case observed in this study is not exceptional and it is concluded that most of the phosphorus load is concentrated within several days of high discharge in a year.

The impact of particulate phosphorus load to estuaries during high discharge periods is considerable. In fact, diatom cell number increased drastically after July 4-5 in Hiroshima Bay as shown in Fig. 2 (Itakura, S. unpublished). According to Kamiyama (1994)[8], the phosphate level in the Ohta River estuary was low from May through June 1991, suggesting that the particulate phosphorus load may have played an important role in the diatom bloom occurring in the inner part of Hiroshima Bay.

In several major rivers in Japan, 25 to 56% of the phosphorus contained in suspended matter during the high flow stages consists of CDB-P, suggesting that the CDB-P load is equivalent to or exceeds that of Org-P. These results indicate that CDB-P in coastal marine sediments is mainly derived from riverine suspended matter discharged during the high flow stages. The relationship between the SS concentration and precipitation in the Ohta River indicates that suspended matter during high flow stages originated from soil substances eroded by intense rainfall. In general, a large amount of inorganic phosphorus is accumulated in soil substances in farmlands in Japan as a result of fertilizer applications[9]. Consequently, the higher ratios of CDB-P in large rivers such as the Shinano and Tone Rivers may be caused by the erosion of phosphorus-rich soil substances from the large agricultural fields in the drainage basins.

Simulated calculations of annual inputs of phosphorus in Hiroshima Bay are presented in Fig. 6. Inputs for precipitation and mariculture for Hiroshima Bay are based on the reports of Yuasa

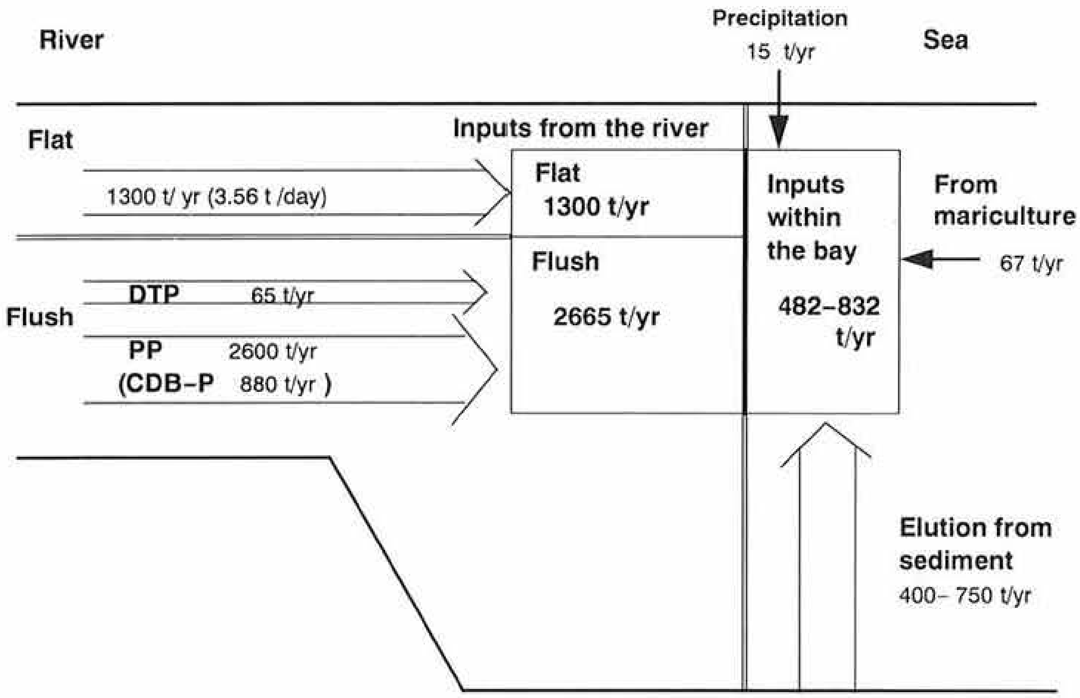

Fig. 6. Annual inputs of phosphorus into Hiroshima Bay
DTP: Dissolved total phosphorus,
PP: Particulate phosphorus.

and Sakamoto (1986)[10], respectively. Assuming that the phosphorus composition and content of the riverine suspended matter discharged into Hiroshima Bay are equivalent to those of the Ohta River, particulate phosphorus and CDB-P loads under flush conditions are estimated to be 2,600 t/yr and 880 t/yr, respectively, using the estimation of SS inputs during high flow stages from sedimentary loads[4]. On the other hand, the phosphorus loads under flat conditions were estimated to be 1,200 t/yr based on the data of Hiroshima Prefecture by summing up the daily load of each source unit in the drainage basin. These estimates indicate that a great part of the phosphorus input is due to the erosion of soil substances by flush water during the rainy and the typhoon seasons.

According to Shiozawa et al. (1984)[11], the annual load of phosphorus eluted from bottom sediments in Hiroshima Bay was estimated to be 400–750 t/yr, which is equivalent to a CDB-P load from rivers during high flow stages. Thus, the CDB-P load from the soil substances discharged during high flow stages is considered to supply the phosphate eluted from the sediments in Hiroshima Bay.

These results indicate the importance of the runoff of soil substances in the phosphorus cycle in the coastal marine environments in connection to phosphate elution from the deposited CDB-P in the sediments. Consequently, development activities in the upstream areas of rivers including logging may damage coastal environments due to soil runoff, eutrophication, and red tide. Therefore, it appears that attempts to conserve industrial and domestic waste water are not sufficient for the preservation of coastal marine environments. Further attention must be paid to the effects of soil erosion on eutrophication in marine environments.

References

1) Andersen, J. M. (1976): An ignition method for determination of total phosphorus in lake sediments. *Water Res.*, **10**, 329–331.
2) Froelich, P. N. (1988): Kinetic control of dissolved phosphate in natural rivers and estuaries: A primer on the phosphate buffer mechanism. *Limnol. Oceanogr.*, 33, 649–668.
3) Hashimoto, T., Izawa, H & Nakatomi, F. (1990): Pollutant load under rainy condition in Ohta River. *J. Environ. Lab. Assoc.*, **15**, 17–23 [In Japanese].
4) Hoshika, S. & Shiozawa, T. (1988): Mass balances of heavy metals and suspended substances in the Seto Inland Sea, Japan. *Rep. Gov't Industr. Res. Inst., Chugoku*, **34**, 77–88 [In Japanese with English summary].
5) Inoue, T. & Ebise, S. (1991): Runoff characteristics

of COD, BOD, C, N and P loadings from rivers to enclosed coastal seas. *Mar. Poll. Bull.*, **23**, 11-14
6) Izawa, H. & Seiki, T. (1983): Evaluation of CDB (Citrate, Dithionite, Bicarbonate) extraction on behavior of phosphorus in coastal marine sediments. *Bull. Hiroshima Pref. Center Envir. Sci.*, **5**, 44-47 [In Japanese with English summary].
7) Joh, H. (1982): Fractionation of phosphorus and releasable fraction in sediment mud of Osaka Bay. *Bull. Japan. Soc. Sci. Fish.*, **49**, 447-454 [In Japanese with English summary].
8) Kamiyama, T. (1994): The impact of grazing by microzooplankton in northern Hiroshima Bay, Seto Inland Sea, Japan. *Mar. Biol.*, **119**, 77-88.
9) Nanzyo, M. (1989): Chemi-sorption of phosphate on soils and soil constituents. *Bull. Inst. Agro-Environ. Sci.*, **6**, 19-73 [In Japanese with English summary].
10) Sakamoto, I. (1986): N and P load control from the view point of pisciculture. *In* Regulation of nitrogen and phosphorus pollution load into partially enclosed marine fishing grounds for the development of fisheries. ed. Murakami, A., Kouseishakouseikaku, Tokyo, 96-133 [In Japanese].
11) Shiozawa, T. et al. (1984): Distribution of pollutant in sea water and its dissolution out of bottom sediment in the Seto Inland Sea I. phosphorus and nitrogen. *Rep. Gov't Industr. Res. Inst.*, **21**, 13-43 [In Japanese with English summary].
12) Tanaka, K. (1993): Effects of riverine suspended matter loading on the forms of phosphorus and the phosphorus cycle in coastal marine sediments. *Bull. Japan. Soc. Fish. Oceanogr.*, **57**, 345-352 [In Japanese with English summary].
13) Tanaka, K. (1995): Effects of soil substance on the phosphorus cycle in estuarine and coastal marine environments. *Bull. Nansei Natl. Fish. Res. Inst.*, **28**, 73-119 [In Japanese with English summary].
14) Williams, J. D. H., Jaquet, J- M. & Thomas, R. H. (1976): Forms of phosphorus in sediments of Lake Erie. *J. Fish. Res. Bd. Can.*, **33**, 413-429.
15) Yamada, H & Kayama, M. (1987): Distribution and dissolution of several forms of phosphorus in coastal marine sediments. *Oceanol. Acta*, **10**, 311-321.
16) Yuasa, I . (1991): Influence of rain for the eutrophication of estuary and coastal embayment. *Man & Environ.*, **16**, 161-164 [In Japanese].

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