Doctoral Thesis

Reconstruction of phosphorus accumulation and recirculation in coastal sediment controlled by hydrological processes and human impacts, based on the sediment core information in central Seto Inland Sea, Japan

Digest

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Contents

Abstract

This paper evaluated the nutrient accumulation process in Kojima bay, Kojima Lake and Hiuchi-Nada Bay in central Seto Inland Sea area, by using chemical profile data of surface sediment and core samples, combined with dating information and sedimentation calculation from ^{210}Pb and ^{137}Cs as well as the mass balance model. The historical variations of phosphorus accumulation and its recirculation in coastal sediment was established. This thesis indicates the possible impacts by hydrological processes, climate change, submarine groundwater discharge, and severe-eutrophication on phosphorus accumulation and recirculation in coastal sediment.

I evaluated the nutrient concentration in sediment pore water, estimated the upward nutrient flux, and evaluated the effects of submarine groundwater discharge (SGD) on nitrogen (N) and phosphorous (P) supply into coastal areas of the Seto Inland Sea, Japan. I compared the vertical distribution of nutrient concentration in two offshore sediment pore water samples: one from a coastal bay area (Kojima Bay) influenced by river discharge and the other from a semi-enclosed bay area (Hiuchi-Nada Bay) influenced by SGD. The salinity in the pore water was high and varied little in Kojima Bay, but it varied by a large amount (17–36‰) in Hiuchi-Nada Bay, which suggests that there were different contributions from freshwater sources between the two sites. Conversely, N:P molar ratios in the pore water were significantly different between the two study sites. Kojima Bay had high N:P ratios with an average of 322:1, while Hiuchi-Nada Bay had lower N:P ratios with an average of 26:1. Nitrogen fluxes including ammonium and nitrate showed higher levels in Kojima Bay. The phosphate and silicate

diffusion fluxes were higher in Hiuchi-Nada Bay than in Kojima Bay. These results suggest that the offshore SGD is an active source that can substantially influence sediment nutrient dynamics in Hiuchi-Nada Bay.

In Kojima Lake, the P discharge was reconstructed for the last 100 years, using the ^{210}Pb and ^{137}Cs radio activities to date a core sample. The total phosphorus (TP) and the total inorganic phosphorus (TIP) in the sediment showed a slightly decreasing trend with depth and a peak of P content at the depth with an age of around 1970s. This suggests eutrophication in Kojima Lake during the last century and a peak of nutrient load around the 1970s affected the sediment P accumulation process. In addition, TP and TIP contents in the sediment indicated yearly variations. These variations are not affected by annual precipitation, local population, and paddy field area, but, in contrast, they are related to the annual number of rainstorms with daily rainfall over 100 mm. This suggests that most of the TP load is transported in storm flows during extreme rainstorms. An increase in the number of torrential rainstorms is assumed to increase the P that is transported to the ocean.

Both in Kojima Bay and Kojima Lake, I investigated the effects of dam construction on sediment P concentrations and its related potential activities. Long sediment core samples spanning over 100 years were collected from the bay, and their P fractions were analyzed. Sediment P concentrations and the P accumulation rate in an artificial lake increased after the construction of a coastal dam in 1959. The amount of P accumulated in the 60 years after the dam construction was ~1.7 times that prior to the dam construction. Moreover, concentrations of mobile forms of P, primarily redox-sensitive P species, were higher in freshwater sediments above the dam than in saline sediments below the dam. The redox-sensitive forms of P in freshwater sediments increased sharply after the dam construction, from 100 to ~900 μg/g, accompanied by a decrease in chloride (Cl^-) concentrations to <2000 mg/l. In the artificial lake, the maximum values of TP and redox-sensitive P concentrations were ~1200 μg/g and ~900 μg/g at depths of 23 cm and 3 cm, respectively. Smaller peaks observed in the TP and redox-sensitive P concentration values likely corresponded to the recycled P released from sediments. The maximum values corresponded to hypereutrophic conditions that were caused by extensive discharges of sewage during the 1970s. The lake has been gradually recovering from these hypereutrophic conditions, as observed from the trophic state index. However, despite a substantial decrease in P loading after the 1980s, the lake still has a high trophic level. The presently high mobile P concentrations in surface sediments may lead to high-magnitude P releases with environmental changes in the future.

In order to clarify the historical change of nutrient load and its pathway, the mass balances of TN and TP for Lake Kojima and Kojima Bay was calculated. I estimated the P flux by the comparison of sediment nutrient data and a mass balance model approach from 1980 to 2008. The P flux from inflowing rivers is dominant in summer period (June to August) which contributes the 43% of annual P input, and lowest at 9 % in winter (December to February). The P retentions determined by using mass balance calculations were lower than those calculated by multiplying sediment total P concentrations and sediment accumulation rates. Results show around 393 tons of P

(11% of total inflow flux discharged into Kojima Lake) was trapped by the lake sediment. The sediment core data shows that the sediment P accumulation is about 3 times of that, at 1288 tons. It may mean the regenerated P from sediment before 1980 contributed to the recent sediment P cycle in lake, which means the high accumulated P in sediment was affected by the severe lake eutrophication history in 1970s. The sediment P accumulates in all seasons except winter. The dominant period is in spring (March to May), which contributes 57% of annual averages trapped P. In winter, average about 8% of annual trapped P was discharged from sediment to the Kojima Bay. The annual P budget in lake sediment calculated by model is decreasing from around 15 g/m^2/year in 1980 to around minus value in 2008. This shows the decreasing trend of the excess nutrient flux into the lake sediment by the recovery of eutrophication, especially after 1990s. The relatively high P accumulation value calculated by sediment core profile indicates the recycled P from old sediment to the new accumulated ones.

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