Note

Changes in Water Quality via the Metabolic Process While Penetrating a Sandy Shore in a Shallow, Eutrophic Lake

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Abstract

Lake water swashing up onto a sandy beach area penetrates the sandy layer before returning to the lake shore zone. As a result, materials contained in the lake water are metabolized, and the water quality of the penetrating water improves. To clarify the process involved, water samples were collected in collection vessels buried at locations 0.2, 0.5, 0.8 and 1.1 m from the shoreline, and seasonal changes in water quality were observed. Organic materials in the lake water were seen to decompose in the sandy beach zone with the organic phosphorus turning into inorganic phosphorus, and to then return almost completely to the lake shore zone. Organic nitrogen was turned mostly into nitrate with the concentration of total nitrogen decreasing as the sample site moved farther from the shoreline. The reduced N/P ratio in water penetrating toward the shoreline suggests the possibility of denitrification as the cause for the decrease in nitrogen concentration as the lake water swashed in and was filtered through the sandy layer.

Key words : sandy shore, penetrating water, recycling system, nitrogen

1. Introduction

In the process of wind waves forcing lake water onto surrounding sandy beaches, that water returns to the shore zone through the sandy layer. Repeated swashing onto the beach results in offensive materials in the lake water being metabolized in a circulation process. The sandy shore not only has a great influence on the environment of the shore zone but, in some cases, also on that of the entire lake. The present study is an attempt to elucidate the changes involved in water quality during the penetration process.

2. Methods

We selected a sandy beach with a slope of 9 : 100 and medium grain size of 0.52 mm, around the central area of the shoreline on the north shore of Lake Kasumigaura, Japan (Fig. 1). The research was carried out for approximately one year from June 1990 to August 1991. We

Fig. 1. Study site and vessels for experiments. A: Filtered water collection vessel. B: Vessel for the penetrating water flow rate.

adopted as the collection vessels 2 l polyethylene bottles, the lateral faces of which were provided with holes of 2×10 cm and then covered with a stainless steel net (0.25 mm mesh) as shown in Fig. 1, (A). The vessels were buried with the upper edge of the holes at water surface level. In this way, filtered water from the surface to a 10 cm depth in the sandy layer was collected. This depth was determined after measuring the flow rate of filtered water in relation to the sandy layer. The water flow rate itself was determined using vessels with 20 mm diameter holes on both lateral faces at different heights from the bottom of the vessel. The water volume entering the vessel was established using the dye dilution method reported in a previous paper (HAMADA *et al.*, 1970, 1995) where five ml of a one percent fluorescein sodium solution was added through a glass tube attached at the shoulder of the vessel (Fig. 1, B). The water volume entering the vessel through the hole represented the relative penetrating flow rate, thus determining the water collecting depth. Ten ml of filtered water was removed from each vessel through the glass tube with a syringe. The vessels were buried at sites 0.2, 0.5, 0.8 and 1.1 m from the shoreline on the sandy slope with the open area of the vessel facing the shoreline so that filtered water would flow into the vessels. To ensure collection of filtered water before it reached the shore water, the collection vessels were buried at 20 cm intervals along a line perpendicular to the shoreline. When the water surface level changed more than one centimeter, the vessels were dug up and reburied. As the water volume entering the vessel buried at the shoreline had already been estimated to be approximately 50 liter per day under ordinary conditions (HAMADA *et al.*, 1995), the penetrating water collection vessel buried there filled with newly generated filtered water. Since the penetrating flow rate was shown to be reduced exponentially at a rate of approximately 2.5% per centimeter as the sampling site moved farther from the shoreline (HAMADA *et al.*, 1995), each vessel including the one 1.1 m from the shoreline was completely replenished with penetrating water

more than once a day. At the same time, shore water was collected for comparison 3.0 m from the shoreline. Analysis of lake water was carried out using the method of STRICKLAND and PARSONS (1972).

3. Results

3-1. Determination of the water collection depth in the sandy layer

The results of observation for penetrating water flow rates are shown in relation to the sand depth in Fig. 2. The relative penetrating water flow rate at 4 cm depth in the sandy layer was $97.3 \text{ ml} \cdot \text{hr}^{-1}$. This reduced exponentially with the increase in depth, reaching $3.03 \text{ ml} \cdot \text{hr}^{-1}$ at 20 cm. The relationship between the relative penetrating water flow rate (Q) and the depth of the sandy layer (D) is given by the following equation.

$$Q (\text{ml} \cdot \text{l}^{-1}) = 209.97 \exp(-0.214 D) \dots\dots (1)$$

We obtain 98 ml per liter as the total relative penetrating flow rate in the vertical direction by integrating equation (1), and 644.5, 865.2 and 967.2 $\text{ml} \cdot \text{l}^{-1}$ for the 0-5, 0-10 and 0-15 cm layers,

Fig. 2. Relationship between sand depth and relative water flow rate.

respectively. The relative penetrating flow rate from the water surface to 10 cm depth is equivalent to 90% of the total rate. Thus, as mentioned above, we decided on 10 cm as the collection depth.

3-2. Changes in water quality in relation to the distance from the shoreline

The concentration of total nitrogen and phosphorus in the shore water ranged from 0.32 to 2.5 and from 0.064 to 0.51 $\text{mg} \cdot \text{l}^{-1}$ respectively. The average relative values of total nitrogen and phosphorus (penetrating water/shore water ratio) observed eight times during the summer of 1990 are shown in Fig. 3. The average relative values of total nitrogen at the sites of 0.2, 0.5, 0.8 and 1.1 m from the shoreline were 0.86, 0.59, 0.56 and 0.47, respectively, decreasing

proportionally with the distance from the shoreline. This result shows that the farther the water filtered from the shoreline, the greater was the change in water quality. The phosphorus concentration in the filtered water showed a different trend from that found for nitrogen, and was not always lower than the concentration in the shore water.

In the nitrogen detected, nitrate occupied a large ratio, ranging from 0.39 to 0.50. This nitrate decrease of approximately 0.20 with a slight $\text{NH}_4\text{-N}$ increase 0.2 m from the shoreline as shown Fig. 3 in remarkable. The concentration of inorganic nitrogen increased as the collection sites moved away from the shoreline, reaching about half of the total nitrogen. The N/P ratio of total nitrogen to total phosphate proved to be 15.0 in the shore water. However, the penetrating water at 0.2, 0.8 and 1.1 meters showed clearly lower values of 9.2, 10.3 and 9.7, respectively.

3-3. Seasonal changes in water quality of filtered water

We observed seasonal fluctuations in total nitrogen and total phosphorus in the filtered water before it passed through the shoreline. The results are shown in Fig. 4. The relative values of the concentration of filtered water to that of shore water was used as the measure for evaluating the filtered water quality. The relative values of nitrogen were in the range of 0.35 to 0.82 from June until the middle of August 1990. This suggested that nitrogen could be removed at 15% maximum and 20% minimum during the summer season as water penetrated into the sandy layer after swashing and flowing back to the lake shore zone. The relative value of nitrogen was approximately 1.0 during the winter season when the water temperature was below 15°C. It began to decrease in June 1991, and ranged from 0.5 to 0.8 thereafter.

As described above, the total nitrogen concentration in the filtered water was almost always lower than that of the shore water except in winter, suggesting that nitrogen was removed from the sandy shore zone. No such trend showing a consistent fall in concentration below the value of the shore water could be recognized

Fig. 3. Composition of total nitrogen and phosphorus, relative values of total nitrogen and total phosphorus concentration, and N/P ratio in filtered water in relation to distance from the shoreline. Relative values (penetrating water/shore water) of total nitrogen (●) and total phosphorus (○) are also shown.

Fig. 4. Time-series changes in concentrations of total nitrogen, total phosphorus and N/P ratio, and in relative values (penetrating water/shore water) of nitrogen, phosphorus and N/P ratio.

in total phosphorus in the filtered water. Although there was fluctuation, the indicated values remained close to or slightly lower than the value of the lake shore water. Figure 4 also shows changes in relative value of the N/P ratio, a value which was almost always below 1.0, except in the winter season, and in some cases, during June and August 1991.

As described above, total phosphorus in the filtered water proved comparable to that of the shore water on average throughout the research period. This suggests that phosphorus flows back into the lake without being removed.

4. Discussion

No trend was recognized where phosphorus was removed from the water zone through fixation in the land area during a filtering process. In contrast to this, nitrogen concentration was seen to decrease in sites distant from the shoreline. One cause for such a decrease in

nitrogen concentration would be filtration of the shore water through the sandy layer. However, changes in composition show that decomposition of organic materials in activated, and that the denitrification is from another source since the concentration of nitrate rises. The structure of material recycling in the sandy shore is complex even when limited to nitrogen. Denitrification is suspected to be one of the causes. The fluctuation in total nitrogen on a sandy beach can be thought of as resulting from a combination of decomposition and denitrification. OLIFF *et al.* (1975, 1976) pointed out that a low oxygen condition is stable in the filtered water along a sea shore. It is reported that the oxygen concentration of penetrating water in Lake Kasumigaura is always below 3.0 mg·l⁻¹ (TONO-OKA *et al.*, 1991), suggesting that denitrification is active in a sandy layer.

The relative value of nitrogen, *i.e.*, the total nitrogen value of filtered water against the total

nitrogen of shore water is shown in Fig. 4. This demonstrates how the percentage of nitrogen removed from the sandy beach zone rises as this value falls. In June and July 1990, 20 to 65% of the total nitrogen of the shore water was seen to be removed.

This study has shown that a sandy beach can have the function of decomposing organic phosphorus into inorganic phosphorus while, in the case of nitrogen, not only does it decompose organic nitrogen but it also removes nitrogen from the lake water. It is well known that the N/P ratio exerts an influence on plankton species (COOPER, 1937; PARSONS *et al.*, 1961; NAKANISHI *et al.*, 1975). This suggests the possibility that, if the sandy beach zones disappear, an increased N/P ratio in the lake water would have an adverse influence on the ecology of the entire lake system through the succession of phytoplankton.

摘 要

富栄養湖において湖水が砂浜を 浸透する過程における水質変化

波浪によって砂浜に打ち上げられた湖水が、砂層に浸透して再び湖岸水域に戻る過程で起こる浸透水中の窒素及びリンの変化を霞ヶ浦湖岸の砂浜に浸透水採取用容器を埋設して周年にわたって観測し、砂浜における物質循環を検討した。浸透水中には、硝酸態窒素、アンモニア態窒素及びリン酸態リンが豊富に含まれており、分解が活発に行われていることが示唆された。全窒素濃度は、夏季には波浪によって砂浜へ打ち上げられる直前の湖岸水の35-80%に低下した。全リンは浸透の過程で無機化されたが、濃度の顕著な低下は認められなかった。こうした窒素とリンの浸透過程における物質代謝の差を反映して N/P 比は浸透過程で低下した。

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