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Seasonal and Long-term Changes of the Nutrients in the Middle-reach of the Yahagi River, Central Japan

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The environmental quality of the middle-reach of the Yahagi River has deteriorated in recent years. The nutrient dynamics within the reach were investigated to explain the changes. Seasonal pattern of NO_3^--N concentration tended to stay low from April or May through July or August and then increased till winter or early spring, although there were peaks during high flow periods in mid-September, 2000 and late-August, 2001. No clear seasonal changes were observed in PO_4^{3-}-P concentration. In the bimonthly records from 1980-2002, the DIN concentrations on January and March were higher than other months whereas the average daily flows on January and March were lower than they were in other months. The mean DIN concentration showed a high negative correlation with the median of average daily flow. In the past 50 years, the average concentration of DIN (excluding nitrite) was 0.21 mg L^{-1} in 1952-1953. The concentration was about twice this high around 1980, and it is about three times this high at present. On the other hand, the average concentration of PO_4^{3-}-P was below the limit of detection in 1952-53. However, it increased to almost 0.03 mg L^{-1} around 1980, then decreased to approximately 0.016 mg L^{-1} at present. Our results suggest that the increasing DIN concentration is one of the causes of environmental change in the Yahagi River. We conclude that controlling the DIN concentration is essential for improving the river environment.

Key words : Long-term changes, nutrients, DIN, Yahagi River

INTRODUCTION

Water quality is one of the indicators for understanding the environmental changes in the river (Turner and Rabalais, 1991). The main causes of changes in water quality are human disturbances such as urbanization and farming (Allan, 1995). The Yahagi River is the only large river situated in the western part of the Mikawa area, which has been developed heavily for industry and agriculture. It has a 1,830 km^2 drainage basin and a population of about 1.17 million. The rate of river water utilization has been constantly over 40% in recent years (Imai, 1997), so that human disturbance in the watershed is severe.

In the middle-reach of the Yahagi River, there have been various indications that the river environment has changed in recent years. These include stabilization of the river-bed, a poor catch of ayu, *Plecoglossus altivelis*, and extensive growth of filamentous green algae, *Cladophora glomerata* (Yamamoto, 2000). One of the crucial changes is assumed to be a change in water quality. Few studies have examined long-term chang-

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es of water quality in the Yahagi River, so the long−term changes are unclear. In this study, we attempted to understand the long−term changes of nitrogen and phosphorus since excess amounts of these nutrients reflect human disturbance and are causes of eutrophication. In addition, seasonal patterns of nutrients in recent years and in long−term are discussed.

MATERIALS AND METHODS

The study site is located in the middle−reach of the Yahagi River (35° 06′N, 137° 11′E), ca. 44 km from the mouth (site A in Fig. 1) and 2 km downstream of Koshido Dam. A field survey was carried out almost every two weeks from August 1999 through March 2002. Water samples were taken from the surface water at the study site for analysis of the concentrations of nitrate (NO_3^-−N), nitrite (NO_2^-−N), ammonium (NH_4^+−N), organic nitrogen (Org−N), total nitrogen (T−N), phosphate (PO_4^{3-}−P), organic phosphorus (Org−P), and total phosphorus (T−P). Dissolved inorganic nitrogen (DIN) was calculated as the sum of NO_3^-−N, NO_2^-−N, and NH_4^+−N. NO_3^-−N, NO_2^-−N, NH_4^+−N, T−N, PO_4^{3-}−P, and T−P were analyzed spectrophotometrically after Japanese Standards Association (1999). Org−N and Org−P were determined by subtracting inorganic from total contents (Japanese Standards Association, 1999). Turbidity was measured on site with a HORIBA Water Checker U−10. The average daily discharge from Koshido dam (Nishi−Mikawa Agriculture, Forestry and Fisheries Office, Aichi prefecture, 1981−2003) was regarded as the daily flow of the study site since there are no tributaries between the dam and the study site (Fig. 1).

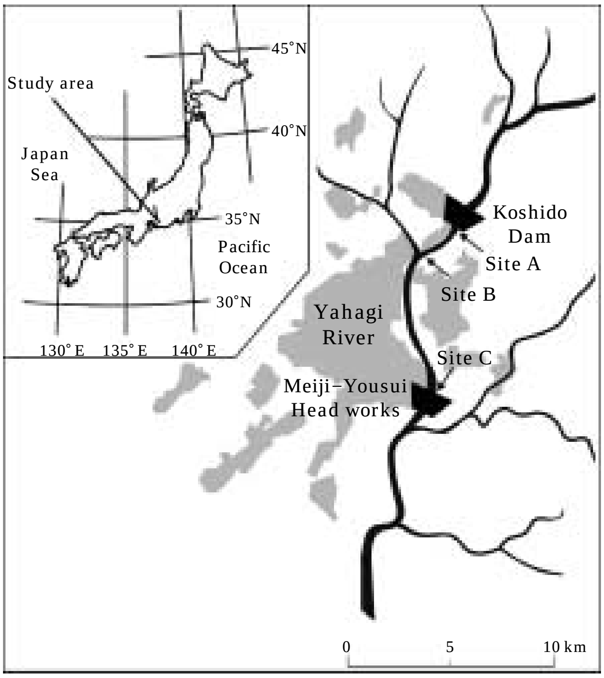

Fig. 1. Water sampling sites in the middle−reach of the Yahagi River. Sampling periods: A) August 1999−March 2002, B) 1952−53, C) 1977−2002. Shaded areas indicate the urban area of Toyota city.

Data for long−term changes of nutrients were collected for 1952−53, 1977−79, and 1980−2002. In 1952−53, 12 water samples were taken at ca. 42 km from the mouth (site B in Fig. 1) and NO_3^-−N, NH_4^+−N, and PO_4^{3-}−P were analyzed colorimetrically (Kobayashi, 1960). In 1977−79, 12 water samples were taken at ca. 35 km from the mouth (site C in Fig. 1) and NO_3^-−N, NO_2^-−N, NH_4^+−N, and PO_4^{3-}−P were analyzed electro-photo−colorimetrically (Chaya *et al.*, 1980). Bimonthly samplings were conducted from 1980 through 2002 (excluding 1984−86) at ca. 35 km from the mouth (site C in Fig. 1; Department of the Environment, Aichi Prefecture, 1981−2003) and NO_3^-−N, NO_2^-−N, NH_4^+−N, and PO_4^{3-}−P were analyzed spectrophotometrically (Japanese Standards Association, 1980−2002). Comparing the present nutrient levels at the sites A and C (site B is not available), there is a little difference (see Fig. 2 and Fig. 4). However, since the Toyota city had not urbanized in 1952−53, we considered that the difference in nutrient levels between these sites would be smaller and can be ignored at that time. And also, as NO_2^-−N was not analyzed in 1952−53, we regarded the sum of NO_3^-−N and NH_4^+−N as DIN. It must be no problem because the NO_2^-−N level is very low. In order to compare the long−term DIN concentrations with the flow regime, we used the discharge data from Koshido Dam (Nishi−Mikawa Agriculture, Forestry and Fisheries Office, Aichi prefecture, 1981−2003).

RESULTS AND DISCUSSION

Seasonal patterns of physical and chemical variables

Average daily flow peaked every August or

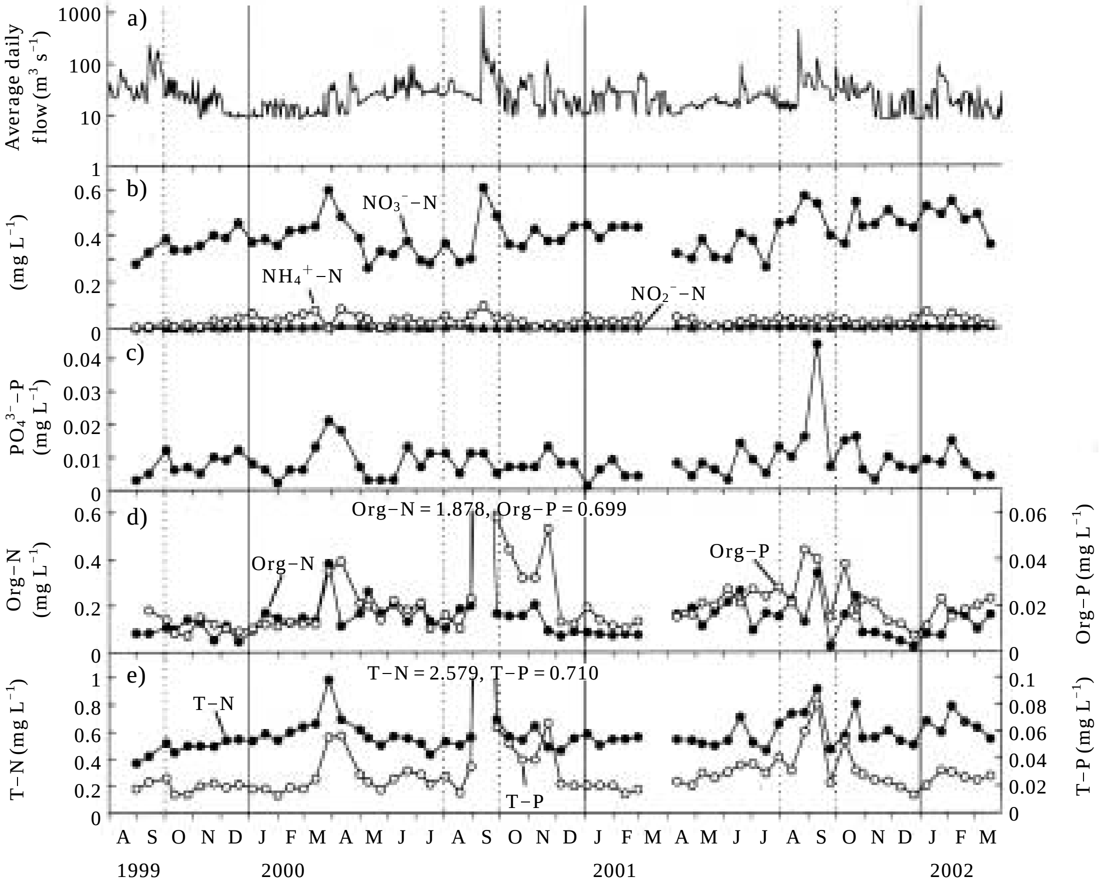

Fig. 2. Seasonal variations of a) average daily flow, b) NO_3^-−N, NO_2^-−N, NH_4^+−N, c) PO_4^{3-}−P, d) Org−N, Org−P, e) T−P, T−N concentrations from August 1999 through March 2002. The vertical solid lines indicate the end of years and the dashed lines indicate the period of high water discharge (August and September).

September during the study period (Fig. 2a). On September 11−12, 2000, there was a heavy rainfall (called "Toukai gouu") and the average daily flow was over 1,200 $m^3 s^{-1}$. The NO_3^-−N concentration tended to stay low from April or May through July or August and then increased till winter or early spring. In addition to the pattern, there were peaks during the high flow events in mid−September 2000 and late−August 2001 (Fig. 2b). A day after the heavy rain, the NO_3^-−N and NH_4^+−N concentrations were at maximum and Org−N and Org−P concentrations also reached their maximal values, which are more than 10 and 30 times higher than normal, respectively (Fig. 2d). Throughout the study period, the NO_3^-−N concentration increased gradually (Fig. 2b). No clear seasonal changes were observed in the concentration of PO_4^{3-}−P (Fig. 2c). T−N and T−P also did not show any conspicuous changes except for the time after the heavy rain (Fig. 2e), when the highest concentrations of Org−N and Org−P were observed (Fig. 2d).

Water flow might be a cause of the seasonal variation in the DIN concentration, although it is difficult to prove this hypothesis from the few years data collected from our field survey. So, we compared the bimonthly records of the concentrations of DIN (Department of the Environment, Aichi Prefecture, 1981−2003) with average daily flow data (Nishi−Mikawa Agriculture, Forestry and Fisheries Office, Aichi prefecture, 1981−2003) from 1980 to 2002 (excluding 1984−86). The DIN concentrations of January and March were higher than other months (Fig. 3a) whereas the average daily flows of January and March were lower than other months (Fig. 3b). The mean DIN concentration showed a high negative correlation with the median of average daily flow

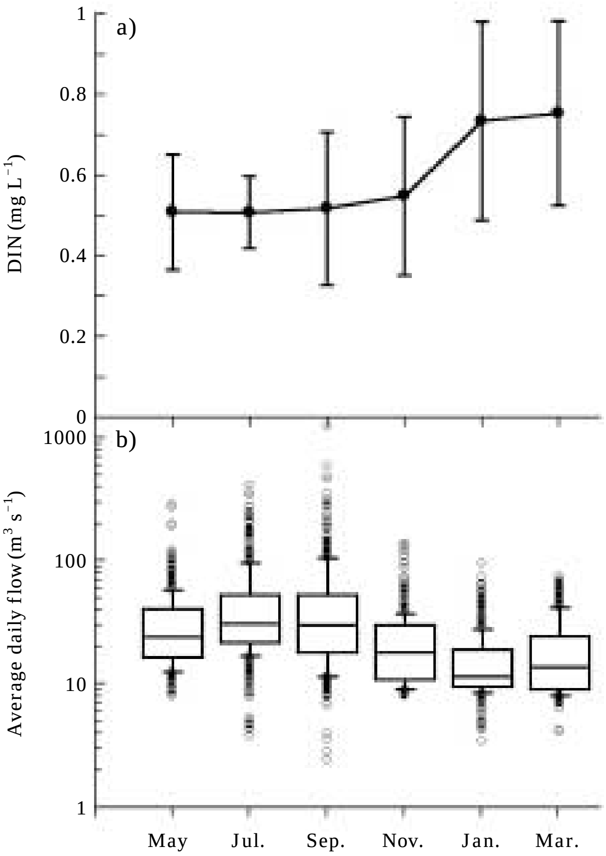

Fig. 3. Long-term seasonal variations of a) DIN (NO_3^--N, NO_2^--N, and NH_4^+-N) concentrations (mean ± 1 SE) (Department of the Environment, Aichi Prefecture, 1981–2003) and b) average daily flow from 1980 through 2002 (Nishi-Mikawa Agriculture, Forestry and Fisheries Office, Aichi prefecture, 1981–2003). The central line of each box is the median, the outer edges of each box are the 25th and 75th percentiles, and the whiskers are the 10th and 90th percentiles.

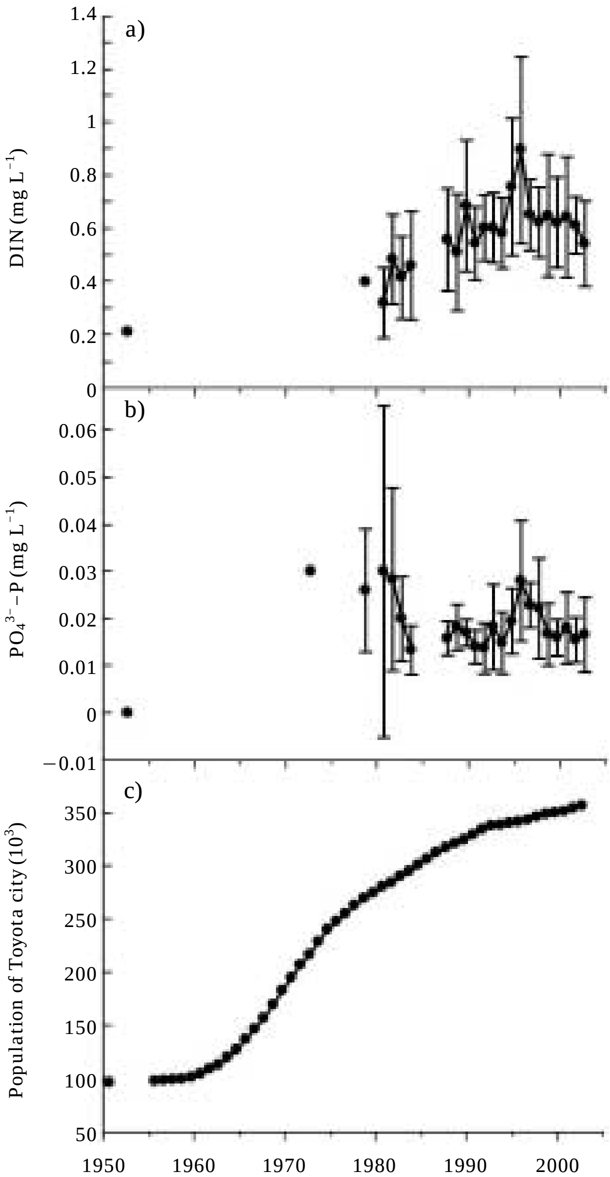

Fig. 4. Long-term variations of a) DIN (NO_3^--N and NH_4^+-N) and b) PO_4^{3-}-P concentrations in 1952-53 (N = 12, at ca. 42 km from the mouth; Kobayashi, 1960), 1977-79 (N = 12, at ca. 35 km from the mouth; Chaya *et al.*, 1980), and every year from 1980 to 2002 (N = 6/year, at ca. 35 km from the mouth; Department of the Environment, Aichi Prefecture, 1981-2003). Mean$\pm$1 SE are shown. c) shows the population growth of Toyota city (Department of the Statistics, Aichi prefecture, 2003).

($y = -0.012x + 0.859$, $p < 0.001$, $r^2 = 0.755$). Therefore, it is considered that the seasonal variation of DIN concentrations is due largely to dilution and condensation effects by flow fluctuation.

Long-term changes of DIN and PO_4^{3-}-P concentrations

The average concentration of DIN was 0.21 mg L^{-1} in 1952–1953, and then increased to about 0.4 mg L^{-1} around 1980 (Fig. 4a). The DIN concentration has generally continued to increase to the present, although very high concentrations were observed in 1994 and 1995. On the contrary, the average concentration of PO_4^{3-}-P was below the limit of detection in 1952–53 (Fig. 4b). However, it increased to almost 0.03 mg L^{-1} around 1980, then decreased to approximately

0.016 mg L^{-1} after the mid−1980s. The concentration of PO_4^{3-}−P, like the concentration of DIN, became very high in the mid−1990s. However, except for that period, the PO_4^{3-}−P concentration has not changed much from its concentration in the mid −1980s.

The early 1950s was before the period of high economic growth. At this time, river pollution by household and industrial effluents was not noticeable in the Yahagi River. Kobayashi (1960) reported that in 1952−53 the concentrations of dissolved major ions and nutrients in the Yahagi River were relatively low among 225 Japanese rivers.

The population of Toyota city, the largest city in the catchment area of the sampling sites (Fig. 1), has grown considerably since the 1950s (Fig. 4c; Department of the Statistics, Aichi prefecture, 2003). A strong relationship between the mean annual values of DIN concentration and the population in the past 50 years was found ($y = 2.029 \times 10^{-6}x - 0.078$, $p < 0.001$, $r^2 = 0.587$). In contrast, the cultivated land of Toyota City has dropped from 9,930 ha to 4,700 ha in the past 40 years (Toyota statistics & information branch, Tokai agricultural administration office of Japan, 1995; Department of the Statistics, Aichi prefecture, 2003), which suggests that the rate of nitrogen loading from fertilizer use is much lower than before. Furthermore, an expansion of the public sewage system began in 1988 and today the sewage system covers more than 50% of Toyota city (Water and sewer commission, Toyota City, 2001). However, the capacity and performance of the system have not been sufficient to reduce the nitrogen loading into the Yahagi River. These results suggest that the population growth has mainly contributed to the increase in the DIN concentration in the watershed.

The concentration of PO_4^{3-}−P was highest around 1980, then decreased from mid−1980s and remained low thereafter. After the Lake Biwa Eutrophication Avoidance Act was established to prevent phosphorus loading in 1979, the production and use of phosphorus detergent had decreased drastically (Sato, 2003). Around the same time, an environmental group asked the government to encourage the use of non−phosphorus detergents in the Yahagi River watershed (Conference on conservation of water quality of the Yahagi River, 1999). Therefore, the decrease in the concentration of PO_4^{3-}−P appears to be due to the decrease in phosphorus detergent use.

Nitrogen loading into the Yahagi River has gradually increased in the past 50 years while phosphorus loading has decreased from the mid−1980s and has remained low thereafter. After a study conducted by Sakamoto (1966) in Japanese lakes, studies of eutrophication of inland waters have been paid much more attention to phosphorus loading than to nitrogen loading. There is general agreement that eutrophication in lakes can be controlled by elimination of phosphorus (Inamori etc., 1993). This idea was quickly adapted for the regulation of water quality in rivers. As a result, the regulation seems to have decreased the PO_4^{3-}−P concentration in the Yahagi River. However, the concentration of DIN has still been increasing in recent years. The increase of local economic activity and lack of appropriate environmental administration appear to be the cause of the DIN increase in the Yahagi River. Our results suggest that the increasing DIN concentration is responsible for environmental changes in the middle−reach of the Yahagi River. We conclude that controlling the DIN concentration is essential for improving the river environment.

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