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Concentration of Nitrogen in a Forested Headwater Stream in Japan

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Abstract**—**The balance between nitrogen loading and runoff in the forested headwater streams of the Kanna River was estimated to elucidate the current status of nitrogen saturation in a forested watershed. NO_3-N concentration in the study area was far higher than the average value in Japan. Estimated nitrogen runoff accounted for 55–57% of nitrogen loading; suggesting that the forest's nitrogen retention capacity is most likely in decline. Since the 1970s, Japan's forestry industry has been declining due to the decrease in lumber demand and increase in cheap imported materials. Thus, this decline will contribute significantly to further reducing nitrogen saturation in forest ecosystems.

Keywords**—**Dissolved inorganic nitrogen species, Forest management, Nitrogen Saturation, Watershed.

I. INTRODUCTION

DURING the period of high economic growth from the 1950s to the 1960s, rapid industrialization caused serious industrial pollution in Japan. As a means to solve such issues, the Water Quality Prevention Control Act was established in 1970. Owing to the tightening of regulations, emissions from stationary sources were gradually reduced. In addition, a public sewage system and small-scale individual sewage treatment tanks were gradually installed in urban areas, reducing water pollution by sewage contamination. The continuous efforts to reduce emissions have improved water quality considerably, particularly in urban streams.

Recently, there has been a growing concern that nitrogen contamination in forested headwater streams which have no anthropogenic emission source such as industrial, agricultural, or domestic wastewater [1]–[3]. In general, the temperate forest ecosystem is situated under the nitrogen limitation [4]. Therefore, most nitrogen is consumed by plants and microbes or kept in the soil in the form of organic compounds [5]. As a result, nitrogen runoff rarely occurs in the healthy forest ecosystem. However, when nitrogen loading exceeds its retention capacity, the ecosystem will be free from the nitrogen limitation. This situation is referred to as nitrogen saturation and may result in nitrogen runoff [6].

Yoh et al. reported that high NO_3^- concentrations (>70 μmol-N/L) were observed in several mountain streams which run through the western suburbs of the Tokyo Metropolitan Area [1]. They also pointed out the possibility of nitrogen saturation at the forested watershed. In particular, high concentrations of inorganic nitrogen species were typically observed in the headwater streams of the Tone River which supplies water to 27 million people in the Tokyo Metropolitan Area. Hasegawa et al. suggested that the increase in anthropogenic nitrogen deposition via air pollution is one possible cause of nitrogen contamination in the headwater streams [7]. Globally, the amount of nitrogen deposition via atmospheric circulation is expected to increase continuously [8]. This will trigger soil acidification, nutrient imbalance, and nitrogen saturation in forest ecosystems. Changes in the balance of nitrogen cycling are likely to affect all watershed ecosystems [9]. Thus, the forest ecosystem plays an important part in the biogeochemical cycling of nitrogen.

In this study, we estimated the balance between nitrogen loading and runoff in the forested headwater streams to understand the current status of nitrogen cycling in the forested watershed. We then discuss the relationship between the collapse of the forestry industry and nitrogen saturation in terms of forest management.

II. EXPERIMENTAL

A. Observation Sites

Headwater streams of the Tone River (gross length: 322 km; gross basin area: 16,840 km^2; the largest river in Japan) are located in the northwest mountainous areas approximately 100 km from the center of Tokyo. In this study, three monitoring stations (St. 1, St. 2, and St. 3 in Fig. 1) were placed in the upper reaches of the Kanna River (gross length: 87 km; gross basin area: 407 km^2), which is one of the headwater streams flowing into the Tone River. Most of the water catchment area in the upper reaches of the Kanna River is covered with forest (approx. 94%). Large swathes of the forest are artificial and consist of planted cedar and cypress. However, the once-active forestry industry is now following a course of decline due to the falling price of ligneous resources and the serious staff shortages as a result of workforce aging.

B. Chemical Analysis of Dissolved Inorganic Nitrogen Species

Water samples were collected monthly at each monitoring station from March to June, 2012. Approximately 3 L of surface water was collected from the center flow. According to the Japanese Industrial Standard (JIS) method K0102, dissolved inorganic nitrogen (DIN), namely, ammonium ion (NH_4^+), nitrite ion (NO_2^-), and nitrate ion (NO_3^-), was analyzed

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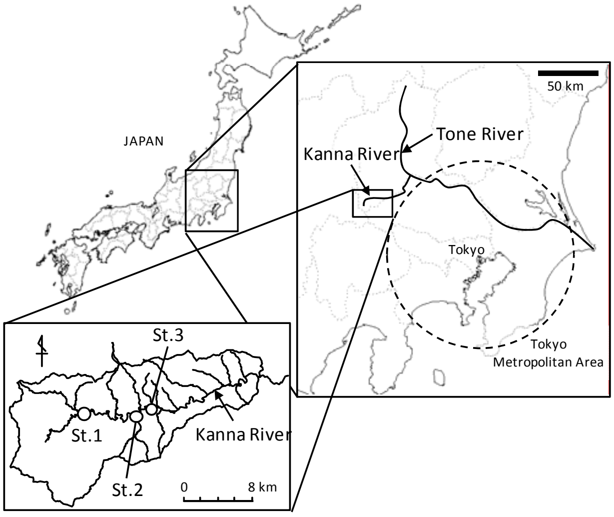

Fig. 1 Location of the upper reaches of the Kanna River

by indophenol blue absorptiometry, naphthylethylenediamine absorptiometry, and naphthylethylenediamine absorptiometry with Zn-catalyzed nitrate reduction, respectively (DPM-MT, Kyoritsu Chemical Check Lab., Co., Tokyo, Japan).

III. RESULTS AND DISCUSSION

A. Water Quality of the Kanna River

In the Kanna River, the water has maintained a very low concentration (<1.0 mg/L) of biochemical oxygen demand during the past decade. Thus, the Kanna River is recognized as one of the best quality reservoirs of the Tone River. This indicates there are no significant anthropogenic sources around the monitoring stations.

Table I summarizes the average concentrations of NH_4-N, NO_2-N, and NO_3-N at each monitoring station. Concentrations of NH_4-N and NO_2-N were below detection limits. In general, the average concentration of NO_3-N in Japanese river water is estimated as 0.4 mg-N/L [10]. Therefore, the current DIN concentration in the upper reaches of the Kanna River is far higher than the average value in Japan. This suggests that the forests in the Kanna River basin are likely facing nitrogen saturation.

TABLE I
CONCENTRATIONS OF DISSOLVED INORGANIC NITROGEN SPECIES

Species	Concentration (mg-N/L)		
	St. 1	St. 2	St. 3
NH_4-N	<0.16	<0.16	<0.16
NO_2-N	<0.0061	<0.0061	<0.0061
NO_3-N	1.0	0.98	0.96

B. Estimation of Nitrogen Leaching from the Forest Ecosystems

Nitrogen loading into the forest ecosystem originates mainly from atmospheric deposition. Therefore, suburban forests are expected to receive relatively large amounts of anthropogenic nitrogen transported from urban areas. In summer, severe air pollution is frequent in the northwest suburbs of the Tokyo Metropolitan Area, which are situated downwind from the industrial hubs [11]. A large portion of annual nitrogen deposition comes from severe air pollution during the summer rainy season. Indeed, Aoi demonstrated that relatively large amounts of nitrogen deposition are observed in the suburban areas compared with the urban areas [12]. In this study, we estimated the amount of nitrogen loading into the forested watershed of the Kanna River using the data on nitrogen deposition at 1.4 t-N/km^2/year previously obtained by Aoi [12].

The water catchment areas of St. 1, St. 2, and St. 3 were calculated as 111.83 km^2, 160.40 km^2, and 197.03 km^2, respectively using the national geographical information system. The amount of nitrogen loading in the respective areas was estimated to be 156.6 t-N/year, 224.6 t-N/year, and 275.8 t-N/year, respectively by multiplying the nitrogen deposition unit (1.4 t-N/km^2/year) by water catchment area.

Next, we estimated the amount of nitrogen runoff at the respective monitoring stations. Water balance in the basin can be expressed as follows.

$$P - E_T \pm \Delta S = R \tag{1}$$

Here P is annual precipitation, E_T is annual evapotranspiration, ΔS is difference in recharge, and R is annual runoff. Under steady state conditions, ΔS is assumed to be 0. Therefore (1) can be simply expressed as (2).

$$P - E_T = R \tag{2}$$

There are several methods to estimate the amount of evapotranspiration. In this study, we adopted Thornthwaite's method, which is a commonly used estimation method. Monthly maximum evapotranspiration E_{max} can be estimated as follows.

$$E_{max} = 16\left(\frac{10T}{I_t}\right)^a \tag{3}$$

$$I_t = \sum_1^{12}\left(\frac{T}{5}\right)^{1.514} \tag{4}$$

$$a = \left(0.675{I_t}^3 - 77.1{I_t}^2 + 17920 I_t + 492390\right) \times 10^{-6} \tag{5}$$

Here T is monthly mean temperature. In this study, E_{max} was estimated for each month from data in the meteorological dataset (summarized in Table II). Annual maximum evapotranspiration was calculated by adding monthly E_{max} values. E_T was obtained by multiplying with 0.7, the typical conversion factor in Japan [13]. Finally, E_T was estimated as 435.8 mm/year. From the data of P (1238.4 mm/year; Table II), R can be estimated as 802.6 mm/year using (2).

TABLE II
METEOROLOGICAL DATA OF THE UPPER REACHES OF THE KANNA RIVER

Month	Mean temperature (°C)	Total precipitation (mm)	Total sunshine (h)
Jan.	0.6	27.6	140.3
Feb.	1.5	28.7	158.4
Mar.	5.1	60.4	175.7
Apr.	10.9	77.1	178.4
May	15.7	95.3	170.7
Jun.	19.2	136.8	128.2
Jul.	22.7	172.0	138.1
Aug.	23.8	208.9	142.7
Sep.	19.8	225.6	104.5
Oct.	13.6	138.7	119.7
Nov.	7.5	45.3	127.2
Dec.	2.6	22.2	128.0
Annual	11.9	1238.4	1712.3

Data acquired from the Japan Meteorological Agency. Monthly statistics are average values of the period from 1981 to 2010.

From the data of R and the water catchment area, the amount of runoff water at St. 1, St. 2, and St. 3 was estimated as 89.8 × 10^6 m^3/year, 129 × 10^6 m^3/year, and 158 × 10^6 m^3/year, respectively. Given the DIN concentration (Table I), these values correspond to 89.8 t-N/year, 126 t-N/year, and 152 t-N/year of nitrogen runoff at the respective stations. Fig. 2 illustrates the relationship between nitrogen loading and runoff at each station.

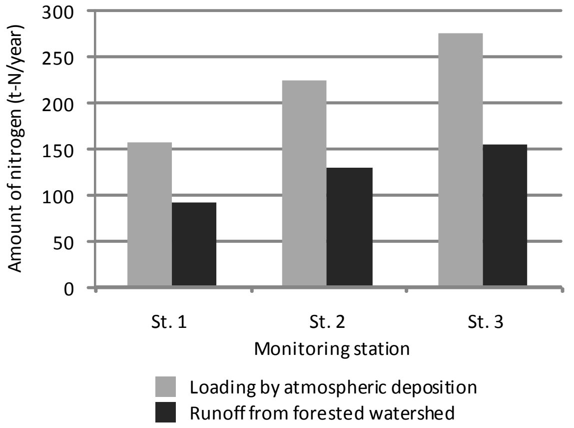

Fig. 2 Relationship between nitrogen loading and runoff estimates

Estimated nitrogen runoff accounts for 55–57% of nitrogen loading. Although the forested watershed of the Kanna River has not been fully saturated with nitrogen, the retention capacity of nitrogen is most likely in decline. In Japan, as is the case with the Kanna River, several other forested headwater streams are also contaminated with a high concentration of DIN. Thus, nitrogen saturation is a growing concern for many forested watersheds in Japan.

C. Forestry Industry Trend in Japan

Many researchers (e.g., [7], [11], [14]) have pointed out that nitrogen saturation is caused mainly by an increase in atmospheric deposition or excess input from agriculture and livestock industries. However, the fact remains that the erosion of the multifunctional role of forests is due to the collapse of forestry, which is another cause of nitrogen saturation.

Japan has one of the highest rates of forest cover of all nations, with greenery covering 66% (251,000 km^2) of the country. Approximately 40% (104,000 km^2) of total land area is artificial forest populated by planted cedar, cypress, and larch. Reclamation projects of artificial forests made rapid progress during 1950s to the early 1970s. These projects were intended to provide ligneous resources to restore the devastated country following World War II. Conifers such as cedar and cypress were selectively planted because their rapid growth rate enables quick reclamation and market supply of ligneous resources. Since the 1970s, however, Japan's forestry industry has been following a course of decline due to the decrease in lumber demand and increase in cheap imported materials, and domestic wood products continue to loose international competitiveness. According to the Annual Report on Forest and Forestry in Japan, 262,000 people were engaged in forestry in 1965, but this number had decreased to 47,000 by 2005 [15]. During the same period, the elderly ratio (ratio of elderly employees ≥65 years old) increased from 4% to 26%. As a result, a tree-planting program to reforest 4,000 km^2/year was carried out at the industry peak, but this has decreased to 240 km^2/year. In contrast, the decrease in domestic demand has caused an overstock of fellable ligneous resources (>50-year-old trees). Fig. 3 shows tree age distribution in the artificial forests in Japan.

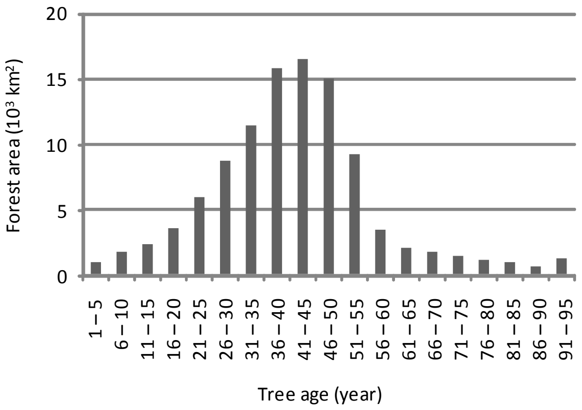

Fig. 3 Tree age in the artificial forests of Japan

In 2007, fellable artificial forest with trees >50 years old accounted for 35% of total artificial forests. If this balance is left unchanged, the rate of fellable artificial forest will reach 60% of the total by 2017. Generally, carbon and nitrogen fixation becomes poor in an aging forest. In addition, forestry collapse has caused serious damage to growing forests by leaving them without management. Abandoning forests not only retards the growth of valuable ligneous resources, but also reduces carbon and nitrogen fixation. Thus, the collapse of forestry will be a significant cause of worsening nitrogen saturation in the forest ecosystem.

D.Current Status of Forest Policies in Japan

Mounting concerns for global climate change and the reduction in biodiversity calls for an enhancement in the multifunctional role of forests, which provide various ecosystem services such as production of ligneous resources, fixation of carbon and nitrogen, recharging of water resources, mitigation of floods, and formation of bountiful soil. Therefore, we can receive several secondary benefits by achieving the primary goal of effective forest management.

Under the Kyoto Protocol, Japan will have to reduce its emissions of greenhouse gas by 6% of its 1990 levels between 2008 and 2012. The Japanese government has planned for a 3.8% reduction by targeting forest management. Since there are few places suitable for planting or replanting in Japan, forest management is the only way to achieve the target. To stimulate the faltering domestic forestry industry, the Japanese government established the carbon credit trading platform. In the forestry industry, carbon credits can be obtained through projects aimed at fuel conversion from fossil fuel to biomass (e.g., forest thinning). Approximately, 313,000 t-CO_2 of carbon credits have been certified as of 2011. Furthermore, since 2008, the platform for carbon offset (Japan Verified Emission Reduction: J-VER) has enabled carbon offset credit by forest management practices such as thinning. Approximately 155,000 t-CO_2 of offset credit have been certified as of 2011.

In addition to these approaches, forest taxation has been introduced for maintaining forest water sources. This tax system shares the burden among all citizens who receive benefits from forest ecosystem. To date, approximately 65% of local governments have adopted this tax system, and the revenue is now used for forest management, campaign promotion, environmental education, and supporting of volunteers.

The Japanese government has introduced several policies to enhance the multifunctional role of forests. These measures seem to be quite effective. The supply of domestic ligneous resources had been on a declining trend since peaking in 1967, but it bottomed out in 2000 before beginning to gradually increase [15]. In the forests surrounding the headwater area of the Kanna River, past discretely-distributed forestry industry has moved into a land-intensive style. Owing to the progress of these projects, domestic forestry has shown recent signs of recovery. To ensure sound nitrogen cycling in the forest ecosystem, it is necessary to ensure further development of domestic forestry.

IV. CONCLUSION

Our findings revealed that in the forested watershed in the upper reaches of the Kanna River, 55–57% of loaded nitrogen has been leached to headwater streams, indicating that the forest’s retention capacity of nitrogen is most likely at the start of a decline. This trend is one factor indicating the decline in the multifunctional role of the forest ecosystem. Forest policies that are focused on climate change and/or biodiversity will gradually contribute to the revival of the domestic forestry industry. We need to monitor continuously the effects of these policies in terms of biogeochemical cycling of nitrogen in the forest ecosystem.

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