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Water resource management in Japan: Forest management or dam reservoirs?

Hikaru Komatsu [a,*], Tomonori Kume [b], Kyoichi Otsuki [a]

[a] Kasuya Research Forest, Kyushu University, 394 Tsubakuro, Sasaguri, Kasuya, Fukuoka 811-2415, Japan
[b] School of Forestry and Resource Conservation, National Taiwan University, 1 Sec. 4, Roosevelt Road, Taipei 106, Taiwan

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ABSTRACT

Researchers and journalists in Japan recently proposed forest management as an alternative to dam reservoir development for water resource management. To examine the validity of the proposal, we compared the potential low-flow increase due to forest clearcutting with the increase due to dam reservoir development. Here, we focused on forest clearcutting as an end member among various types of forest management. We first analyzed runoff data for five catchments and found a positive correlation between annual precipitation and the low-flow increase due to deforestation. We then examined the increase in low-flow rates due to dam reservoir development (dQ_d) using inflow and outflow data for 45 dam reservoirs across Japan. Using the relationship between annual precipitation and the low-flow increase due to deforestation, we estimated the potential increase in the low-flow rate for each dam reservoir watershed if forests in the watershed were clearcut (dQ_f). Only 6 of the 45 samples satisfied $dQ_f > dQ_d$, indicating that the potential increase in the low-flow rate due to forest clearcutting was less than the increase due to dam reservoir development in most cases. Twenty-five of the 45 samples satisfied $dQ_f < 0.2\ dQ_d$, indicating the potential increase in the low-flow rate due to forest clearcutting was less than 20% of the increase due to dam reservoir development in more than half the cases. Therefore, forest management is far less effective for water resource management than dam reservoir development is in Japan.

1. Introduction

Despite higher precipitation in Japan than in other temperate regions (National Astronomical Observatory, 2001), water shortages frequently occur in Japan (Ministry of Land, Infrastructure, Transport and Tourism, 2009a) owing to the country's large population relative to the land surface area (127,000,000 people in an area of 378,000 km^2).

A total of 2738 dams have been developed in Japan, and a further 331 are now under construction or have been proposed (Tonegawa Integrated Dam and Reservoir Group Management Office, 2009). One purpose of dam reservoir development is to increase low-flow discharge to secure water resources. Most dam reservoirs are located in forested areas upstream of metropolitan and agricultural areas (Ministry of Land, Infrastructure, Transport and Tourism, 2009b).

Recently, dam reservoir development has drawn criticism from the viewpoints of biological and environmental conservation (Harada and Yasuda, 2004). There are frequent campaigns opposing proposed dams (e.g., Hoyano, 2001), and the removal of existing dams is also debated (e.g., Amano and Igarashi, 2004).

Some researchers and journalists (e.g., Tsukamoto, 1998; Yorimitsu, 2001; Kuraji, 2003; Amano and Igarashi, 2004) have proposed forest management, such as patch clearcutting and thinning of coniferous plantation forests and conversion to broadleaved forests, as a possible alternative to the development of dam reservoirs. Japan has developed large coniferous plantation forests for timber production, and there was active management of forests before the 1970s (Fujimori, 2000). However, forest management has not been economically viable in recent years because of the relatively low price of timber and has not been actively performed for several decades (Fujimori, 2000). Researchers and journalists have proposed that low flow could be increased by forest management because forest management could reduce leaf area and hence evapotranspiration. This proposal is widely believed to be valid and many local governments have thus introduced taxes to aid forest management (e.g., Yorimitsu, 2001; Imawaka and Sato, 2008).

Researchers in Japan have reported an increase in low flow due to forest management such as forest clearcutting (e.g., Tamai et al., 2004; Maita et al., 2005). On the other hand, researchers in Japan developed a method to evaluate the increase in low flow due to dam reservoir development (e.g., Kume and Kubota, 1998; Komatsu

* Corresponding author. Tel.: +81 92 948 3109; fax: +81 92 948 3119.
E-mail address: komatsu@forest.kyushu-u.ac.jp (H. Komatsu).

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et al., 2009b). Komatsu et al. (2009b) applied the method to evaluate an increase in low flow for seven existing dam reservoirs located upstream of the Tokyo metropolitan area. They reported an increase in low flow due to the dam reservoir development. However, researchers in Japan have not compared the increase due to forest management with that due to dam reservoir development. Thus, the effectiveness of forest management in increasing low flow relative to dam reservoir development has not been evaluated. Consequently, the validity of the proposal of forest management in Japan has not been determined (Komatsu et al., 2009a).

This study compares the increase in low flow due to forest management with that due to dam reservoir development to evaluate the effectiveness of forest management. Among various types of forest management, we focused on forest clearcutting as an end member. Changes in a flow regime due to forest clearcutting are generally greater than changes due to other forest management practices such as patch clearcutting and thinning of coniferous plantation forests, and conversion to broadleaved forests (e.g., Bosch and Hewlett, 1982; Scott and Lesch, 1997; Komatsu et al., 2009a,c).

Though our analysis focuses on Japan, our results are of use to researchers in other countries. Many dam reservoirs have been developed to secure water resources in other countries. However, the construction of dam reservoirs is criticized because it greatly changes natural flow regimes and therefore affects biodiversity in river and riparian ecosystems (Poff et al., 1997, 2007; Lytle and Poff, 2004). Forest management might be an alternative to the construction of dam reservoirs in securing water resources.

2. Materials and methods

This study comprises three parts. First, we examined the differences in low-flow rates between forested and deforested periods using catchment runoff data obtained where deforestation and/or afforestation occurred in Japan. Second, we examined the increase in low-flow rates due to dam reservoir development using inflow and outflow data for dam reservoirs across Japan. Third, we calculated the potential increase in the low-flow rate if forests in a dam reservoir's watershed were clearcut and compared it with the increase due to the dam reservoir development.

2.1. Catchment runoff data

We obtained daily runoff data for five catchments where deforestation and/or afforestation had occurred. There are several other catchments such as Kamabuchi I and Jozankei catchments where deforestation and/or afforestation had occurred (Maita, 2005) but for which we could not obtain daily runoff data, and thus we did not use data for these catchments.

Fig. 1 shows the locations of the five catchments and Table 1 briefly describes the catchments. The catchments are located in western or central Japan, where water shortages are more frequent than in northern Japan. Thus, the results of our analysis are more reliable for these regions than for northern Japan. In northern Japan, catchment runoff is often influenced by snowmelt (Komatsu et al., 2008a; Shinohara et al., 2009), which contrasts to the case in western and central Japan.

2.1.1. Sarukawa I and III catchments

The Sarukawa I and III catchments are adjacent catchments. The mean annual precipitation for 1959–2000 in these catchments was 3032 mm and the standard deviation was 704 mm. Fig. 2a is a histogram of annual precipitation for 1959–2000. The annual precipitation ranged between 1913 and 5710 mm. Fig. 3a shows the seasonal variation in precipitation based on data for 1967–1972 and 1994–1999. Precipitation amounts and their variations were greater in summer than in winter.

Broadleaved forests in Sarukawa I and III catchments were clearcut in 1967. Coniferous trees (*Chamaecyparis obtusa* and *Cryptomeria japonica* for Sarukawa I and III catchments respectively) were planted just after the clearcutting and broadleaved trees naturally regenerated in the catchments. Thus, the catchments have been covered by coniferous plantation and broadleaved forests since the late 1970s (Shimizu et al., 2008). Daily runoff data for 1968–2000 were available from the Forest Influences Unit Kyushu Branch Station (1982), Takeshita et al. (1996) and Shimizu et al. (2008). Thus, 1968–1972 data for the deforested period and 1994–1999 data for the forested period were used in evaluating the difference in low-flow rates between the forested and deforested periods. Note that some data for 1997 were missing and therefore data for this year were not used in the analysis. More complete descriptions of the catchments were given by Shimizu et al. (2008).

2.1.2. Tatsunokuchi-Kita and Tatsunokuchi-Minami catchments

The Tatsunokuchi-Kita and Tatsunokuchi-Minami catchments are adjacent catchments. The mean annual precipitation for 1937–2000 in these catchments was 1232 mm and the standard deviation was 221 mm. Fig. 2b is a histogram of annual precipitation for 1937–2000. The annual precipitation ranged between 499 and 1680 mm. Fig. 3b shows the seasonal variation in precipitation based on data for 1971–1980. Precipitation amounts and their variations were greater in summer than in winter.

Coniferous forests, comprising *Pinus densiflora*, in the Tatsunokuchi-Kita catchment were clearcut in 1937. Broadleaved trees naturally regenerated and the catchment has been covered with broadleaved forests since the 1960s (Goto et al., 2006). Daily runoff data for 1937–2000 were available from the Forestry and Forest Products Research Institute (1961), the Forest Influences Unit Okayama Experimental Site Kansai Branch Station, 1979) and Goto et al. (2005). Thus, 1947–1951 data for the deforested period and 1993–1999 data for the forested period were used to evaluate the difference in low-flow rates between forested and deforested periods. Note that some data for 1995 and 1996 were missing and therefore data for these years were not used in the analysis. A more complete description of the catchment was given by Goto et al. (2006).

The Tatsunokuchi-Minami catchment was deforested by forest fire in 1959. Coniferous trees (*Pinus sylvestris*) were planted immediately after the forest fire and the catchment was covered with coniferous plantation forests in the 1970s. However, there was an insect infestation around 1980 and the coniferous forests of the catchment were completely destroyed. Broadleaved trees naturally regenerated and the catchment has been covered with broadleaved forests since the 1990s (Goto et al., 2006). Daily runoff data for 1937–2000 were available from the Forestry and Forest Products Research Institute (1961), the Forest Influences Unit Okayama Experimental Site Kansai Branch Station (1979), and Goto et al. (2005). We performed three comparisons for this catchment to evaluate the differences in low-flow rates between forested and deforested periods: (i) 1960–1964 for the deforested period versus 1973–1977 for the forested period; (ii) 1973–1977 for the forested period versus 1980–1984 for the deforested period; and (iii) 1980–1984 for the deforested period versus 1993–2000 for the forested period. The comparisons evaluate changes in low-flow rates due to coniferous afforestation, coniferous deforestation, and broadleaved afforestation respectively. Note that some of the data for 1995, 1996, and 1997 were missing and therefore data for these years were not used in the analysis. A more complete description of the catchment is given by Goto et al. (2006) and Komatsu et al. (2009c).