CHANGES OF NUTRIENT LOADING CAUSED BY CLEAR-CUTTING OF A DECIDUOUS BROADLEAF FOREST AND PLANTING OF JAPANESE CEDAR

Takao Kunimatsu*, Yoshihumi Hida*, Etsuji Hamabata** and Miki Sudo*

**School of Environmental Science, University of Shiga Prefecture, Hassaka, Hikone, Shiga 522-8533, Japan*
***Lake Biwa Research Institute, Utidehama, Otu, Shiga, 520-0022, Japan*

ABSTRACT
Two adjoining small forested watersheds having weirs were prepared to evaluate changing in the loading rate of nutrients caused by clear-cutting. One of the experimental watersheds (Kutsuki-L, 1.09 ha) was clear-cut from December 1996 to May 1997, and young Japanese cedars (*Cryptomeria Japonica* D. DON.) were planted in April 1998. The other (Kutsuki-R, 1.92 ha) has been conserved. Before clear-cutting, the annual average concentrations of total nitrogen (TN), total phosphorus (TP) and potassium ion (K^+) of the stream water of Kutsuki-L were 0.145, 0.010 and 0.16 mg l^{-1}, respectively. After the clear-cutting practice, abrupt and short-term increasing of TN, TP, and TOC concentrations was occurred. It seemed to result from disturbance of surface soils by the practice. TN increased to around 0.5 mg l^{-1} after about one year from the event, and began decreasing gradually in 2000. However in 2002, it maintained yet slightly higher level than that of conserved Kutsuki-R. The high concentration was mainly due to increasing discharge of nitrate. TP and TOC did not show such delayed and prolonged effect. K^+ decreased concentration slightly for two years and then recovered the level before cutting. The averages of output fluxes of TN, TP and K^+ were 2.18, 0.15 and 2.67 kg ha^{-1} y^{-1}, respectively, before clear-cutting. After that, TN increased to the maximum in the third year, which was 5.6 times of the above value, and TP to 1.3 times in the first year. These results indicated that clear-cutting of the large area might give serious effect on eutrophication of lakes and bays in the lower reaches, and that it is necessary to develop logging techniques to limit the draining of nitrate.

Keywords clear-cutting, forest, nutrients

INTRODUCTION
Nutrient concentrations of stream water draining from a forest are usually low. However, it is well known that the concentration of nitrogen rises when the trees of the forest are clear-cut. The results obtained on the Hubberd Brook Experimental Forest, which is one of the most famous experiments, showed that the concentration of nitrate increased to 38.4 mg/l in the first year and 52.9 mg/l in the second year after clear-cutting in 1965 (Likens et al., 1973). The amounts of substances discharging from the soil ecosystem of a forest are strongly affected by geological and geographical features, soil, climate, vegetation, etc. (Kunimatsu, 2001). Since there are so many parameters participating in stream water draining from forest ecosystem, that it has not fully succeeded in construction of any mathematical models forecasting the concentrations and/or loading rates of nutrients from forests (Kawara et al., 2001). Therefore, the results obtained on some areas are not applied directly on forests in another region, and it is necessary to measure at appropriate numbers of forest sites in order to evaluate the nutrient loads in a certain region. Experiments have not yet reported on the mountain forests in the monsoon climatic zone in Asia. In this research, the influences of clear-cutting the deciduous broad-leaved forest on the stream-water quality were investigated over 12 years.

METHODS
Study Area
Two small experimental watersheds were set in a temperate deciduous broadleaf secondary mountain forest in around the central part of the main island of Japan. The catchment areas are 1.09 and 1.92 ha called Kutsuki-L and Kutsuki-R, respectively, and adjoin with each other, as shown in Figure 1. They are located at 35 22' 14" N in latitude, 135 54' 45"E in longitude, and 290-496 m in altitude. The dominant species are chestnut (*Castanea crenarta SIEB. et ZUCC.*), white oak (*Quecusserrata THUNB.*), containing a few small stands of Japanese red pines (*Pinus desiflor* SIEB. et ZUCC). From a tree census curried out in summer 1996, the rate of breast height basal area of white oak to that of total trees were 32%, red pain 22%, and chestnut 10%, and biomass of Kutsuki-L was 89 ton/ha and Kutsuki-R 99 ton/ha. For long time before around 1950, the broadleaf trees used to harvest about every 20 years in preparation of charcoal and fire wood.

After the census, clear-cutting of Kutsuki-L was carried out on about 80 % of the total area from mid-December 1996 to the beginning of January 1997, and the residual area in the following March. Almost all of trunks and all of branches, leaves, and grasses were left in the watershed, and used for hillside wicker work in making terraces like stripes (see Photo 1), where three thousands of young Japanese cedars (*Cryptomeria Japonica* D. DON.) per ha were planted throughout the watershed in May 1998. The underbrush was cut down through the area every June and August since then to 2000, and every August after 2001. The first pruning of the cedars was curried out in October 2002, after the last cutting of underbrush. In contrast, Kutsuki-R has been conserved as a control.

The watersheds lay on sandstone bedrock, and the soil is a brown forest soil according to the Japanese classification system, or Cambisol in FAO classification. The headwater streams draining the watersheds are perennial and not polluted by any anthropogenic sources except for forest workings. The annual mean value of air temperature was 12.2^{o}C and that of precipitation 2265 mm/y. There is considerablly heavy snow fall between January and March with 50-100 cm of lying snow, but the soil under the snow is not frozen.

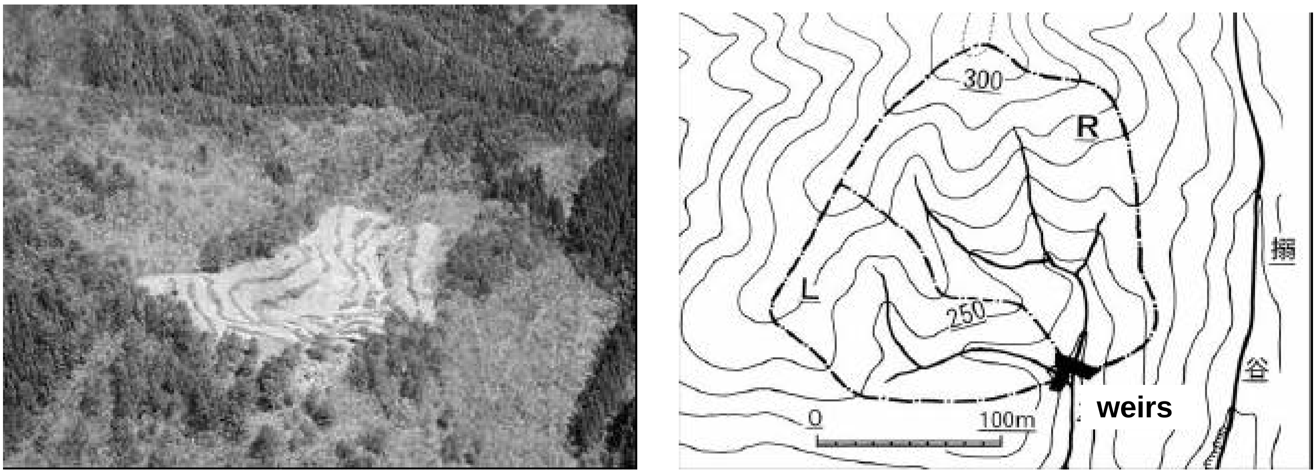

Figure 1 *Experimental forest watersheds.*

Water chemistry

Stream-water draining from each watershed was collected periodically once a week from July 1990 to December 2002, after monitoring once a month on non-rainy days from July 1988. Water samples were directly collected in clean 2-liter polyethylene (PE) bottles at the points pouring into the weirs from upstream. Atmospheric wet and dry depositions were collected by a set of two PVC-deposit gauges consisting of a 30-cm diameter funnel and 20-liter reservoir, and drains from the rain-snow gauge were collected in a reservoir during winter. One of them contained 5 ml of conc.-H_2SO_4. Waters in the gauges were measured the volumes and sampled once a month from 1989 to 2002.

One liter of the sample was filtered through a 1-µm glass fiber filter with a 45-mm in diameter, from which particles larger than about 1-mm were picked up with tweezers and discarded. Suspended solids (SS) were measured by weighing the filter before and after the filtration after overnight drying at 105 °C. The total amounts of nitrogen (TN), phosphorus (TP), organic carbon (TOC), and chemical oxygen demand by potassium permanganate ($TCOD_{Mn}$) were obtained by analysis of non-filtered waters, and the dissolved components (DN, DP, DOC, $DCOD_{Mn}$) by analysis of the filtered samples. The concentrations of particulate forms (PN, PP, POC, $PCOD_{Mn}$) were obtained from the differences between the total concentrations and the dissolved concentrations. Chemical analyses were carried out by Japan Industrial Standard Methods (1986).

Hydrology and atmospheric deposition

The same scale of right-angle V-notch weirs (W 2.00, L 5.00, D 1.50 m) lay at the ends of the watersheds. Water levels were continuously recorded at the weirs. The water levels were also measured by a ruler, when the water samples were collected. The flow rates were calculated using the following equation.

$$Q=Ch^{5/2} \quad (1)$$

$$C=1.354+0.004/h(0.14+0.2D^{-1/2})(h/B-0.09)^2 \quad (2)$$

where h, B, and D are the water levels over the weir, the width of the weir, and the height from the canal bed to the apex of V-notch.

Rain-snow gauges standardized by the Japan Weather Bureau with a 20.3-cm orifice were placed on the open space about 400m south-west from the weirs and at Forest Environmental Research Institute located about 750 m south-west of the watersheds.

RESULTS AND DISCUSSION

Stream-water chemistry of the conserved forest

In order to assess the influence of clear-cutting on the stream-water quality, we have first to understand the ranges of the usual fluctuation and trend of concentrations shown by the conserved experimental forest as a control. Chemographs of the stream water discharging from the conserved Kutsuki-R Experimental Forest, and hyetographs were drawn in Figures 2 and 3, based on the periodical weekly data and the daily data, respectively.

Changes for short duration. Many sharp peaks were found on the chemographs. It has been shown that the concentrations of the materials containing particulate components, such as TN, TP, and TCOD, rapidly increased with increasing discharge (Kunimatsu and Sudo, 1999). It is then easy to expect that the sharp peaks found in these Figures resulted from sampling during storm-runoff events. However, the shapes of the peaks changed with substances (Kunimatsu et al, 2001).

Namely, materials such as phosphorus, which discharges mainly in the form of particulate, showed simple needle-like peaks. In contrast, materials such as nitrogen and organic carbon, which contain considerable amounts of dissolved substances as well as particulate ones, draw rather broad peaks following a number of small sharp peaks. The patterns of dissolved ions were characteristic of each, and reflected seasonal changes of biogeochemical process in the forest ecosystem.

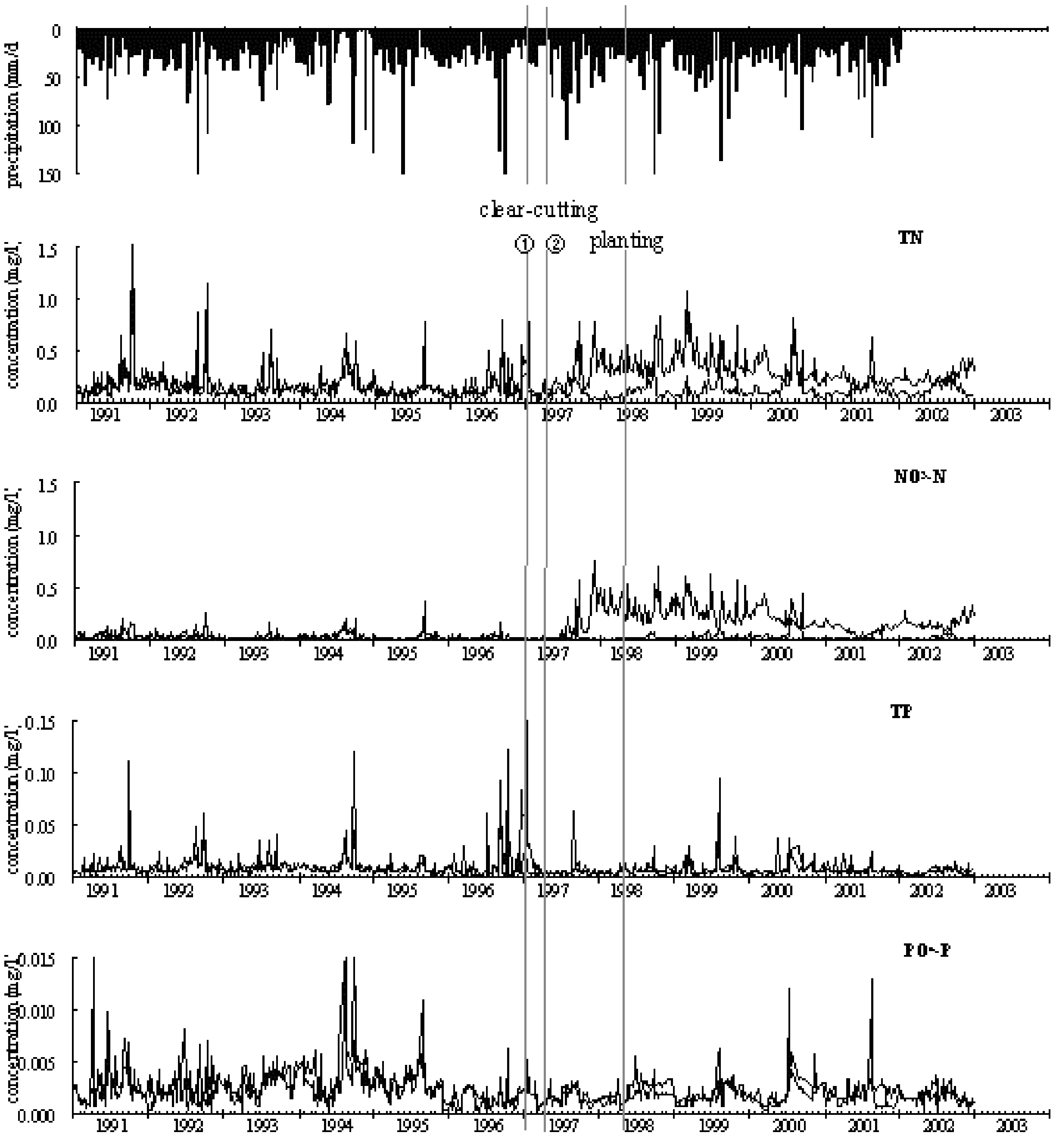

Figure 2 *Changes in the concentration of nitrogen and phosphorus in the stream water from Kutsuki-L and Kutsuki-R. The former watershed was clear-cut about 80 % of the total area from mid-December 1996 to the beginning of January 1997, and the residual area in the following March. Three thousands of young Japanese cedars per ha were planted throughout the watershed in May 1998. The latter watershed has been conserved as a control. Chemographs were drawn by using the data obtained once a week and hyetographs daily data.*

However, numbers of discrepancies between the peaks of the Chemographs and those of the hyetograph were found on the figures. It was because the Chemographs were drawn from the data obtained by periodical sampling (every 7 days), whereas the hyetograph was from the daily data, and because the concentration data were obtained from spot samples which were taken up at a moment on a periodical day from the stream flow, though the concentrations drastically changed in a short time during rain.

Seasonal Changes. Although the wet or dry season generally is not distinct in Japan, it is rainy from early summer to early autumn (from June to September), and rains exceeding 100mm by a typhoon

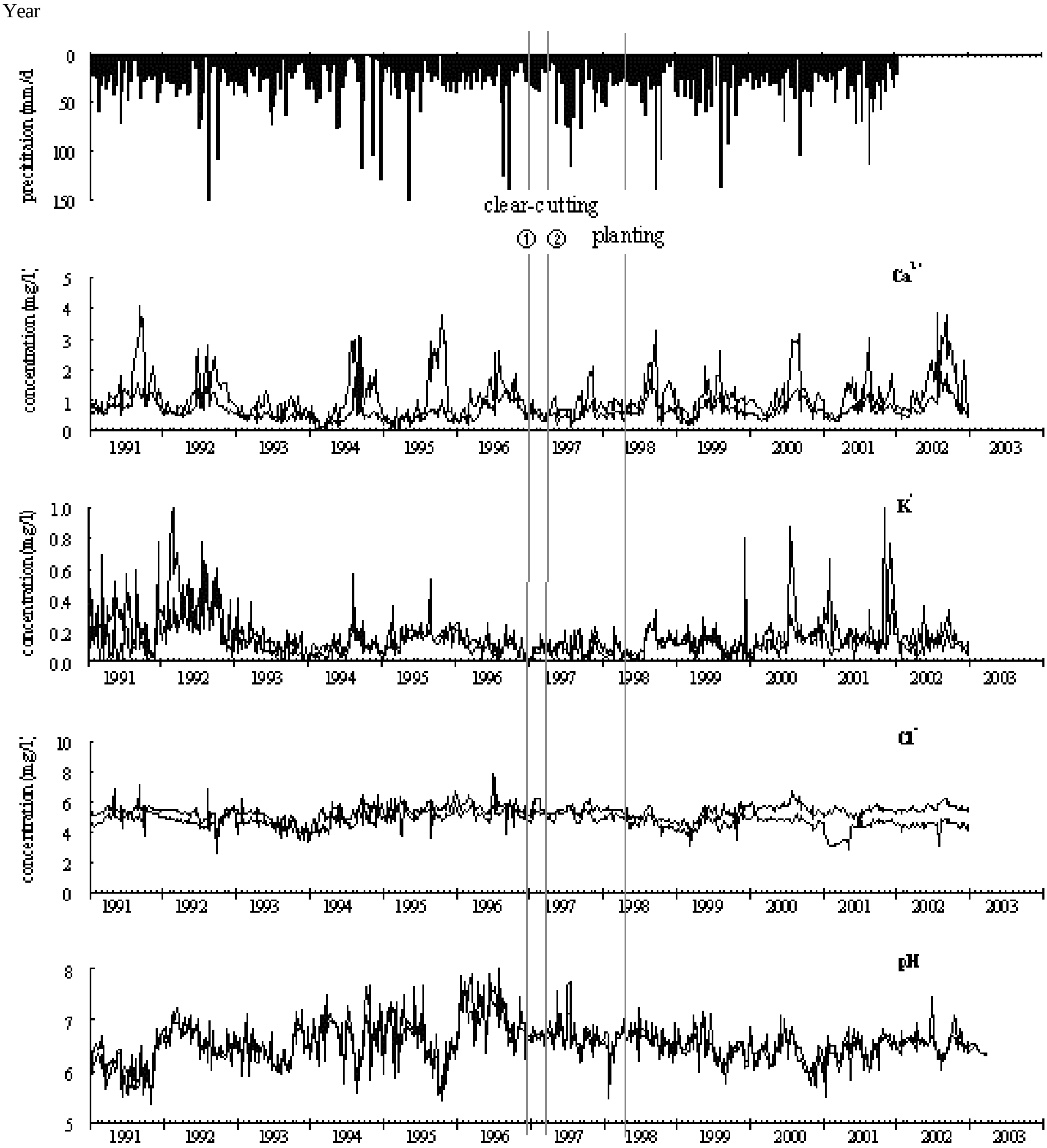

Figure 3 *Changes in the concentration of Ca^{2+}, K^+, Cl^- and pH in the stream water from Kutsuki-L and Kutsuki-R. The experimental conditions were the same as Figure 2.*

occasionally fall, which come from Pacific Ocean. Normally the snow pack persists from mid-December to mid-April, which is transported by north-west window from the Sea of Japan. Since the climatic variation affects almost all of biogeochemical process, the chemistry of stream water and precipitation shows a certain seasonal fluctuation. In addition, the pattern of the seasonal fluctuation usually varies considerably with years due to yearly changes of hydrologic conditions. Figure 2 and 3 distinctly showed that the concentrations of TN, NO3-N and Ca^{2+} gradually increased from early summer and decreased in autumn after reaching the maximum of a year at August. It can be checked on Figure 4, which was drawn with monthly average values calculated from all the data 1991-2002. Phosphorus and Mg^{2+} showed the same sort of pattern as those of nitrogen and Ca^{2+}. Consequently these seasonal patterns closely resembled that of precipitation. Na^+ also showed the same kind pattern despite narrow range fluctuation, but Cl^- did not show any seasonal variation. In addition, the standard deviations of Na^+ and Cl^- were extremely small.

Long-term change and Mean concentrations. Figure 2 and 3 plotted the periodical data show characteristic shot-term variations as well as seasonal changes, but is not necessarily suitable for the purpose in finding some long-term changes or trends. Therefore, the annual arithmetic and weighted mean concentrations of the stream waters and atmospheric deposition calculated from the data for 11 years (1991-2001) were shown in Table 1, and Figure 5.

The annual precipitation was an average of 2265 (CV 11 %) mm/y, which fluctuated from 1788 mm/y in 1994 to 2527 mm/y in 1992. Judging from average values, the concentrations of TN as well as TP were not high, compared with the stream water in another region (Kunimatsu et al, 2001). It can see from the arithmetic mean data that TN and TP slightly increased concentrations in a droughty year such as 1994 and 1996 as well as a year with much rainfall such as 1992 and 1999. It seems that nitrogen and phosphorus has shown slightly decreasing trends on Figure 5, which were drawn by the arithmetic mean data. Nitrite and ammonium ions always occurred in very low concentrations and did not show any characteristic tendencies.

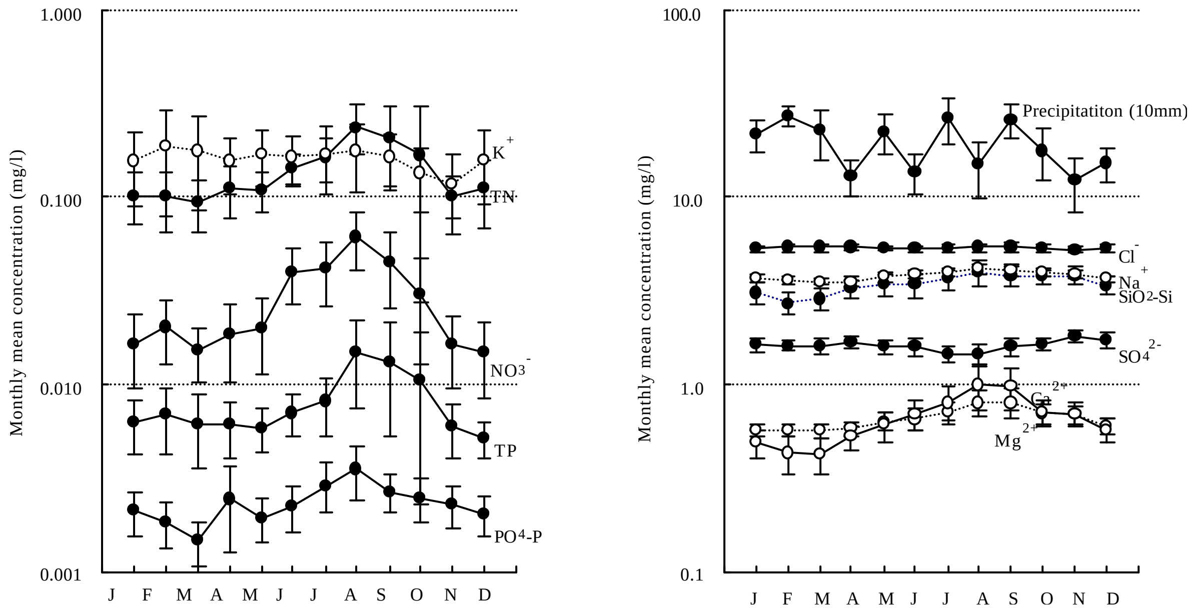

***Figure 4** Seasonal changes of concentrations in the stream water. Monthly average values calculated from all the data 1991-2002 were used, and ranges of deviation were shown by 1/2 s.*

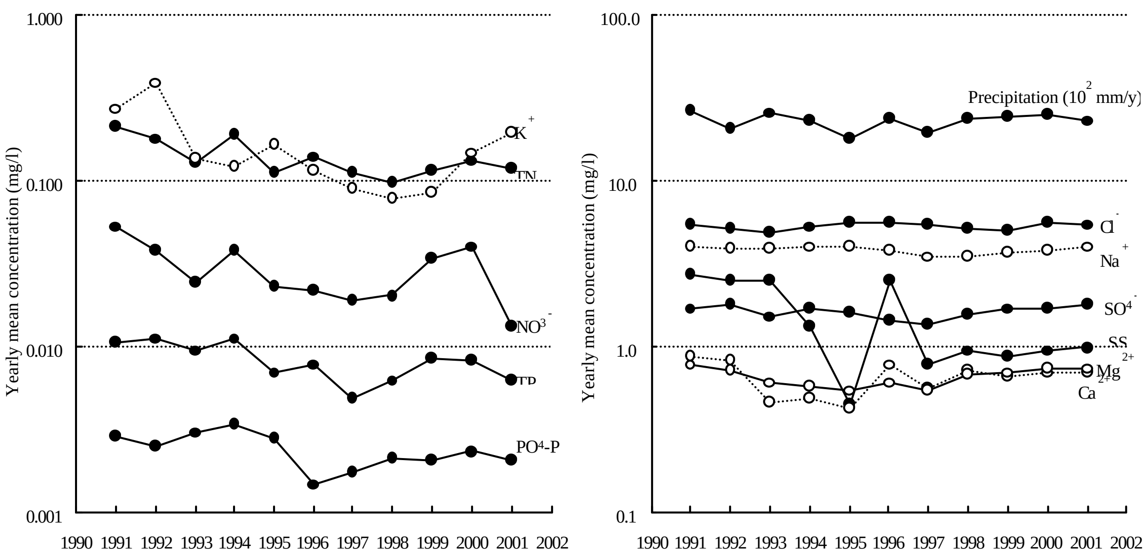

***Figure 5** Changes of yearly concentrations in the stream water. Yearly arithmetic mean values of the periodical data were used.*

Effects of Clear-cutting

The changes of concentrations in the stream draining from the clear-cut Kutsuki-L Experimental Forest were also shown in Figure 2 and 3. TN and TP concentrations increased abruptly by the clear-cutting practice carried out in mid-December 1996, and then early in January 1997 decreased to almost the same levels as those of Kutsuki-R shortly after the practice. The similar behavior was also found on the profile of SS. It suggests from the results that disturbances of forest ecosystem by the practice facilitated the outflow of some components on soil surface by small rains or snows, and that the following snow pack restrained those from flowing out by covering the soil surface. Since then substantial differences in TN, TP, and TOC concentrations between the two experimental watersheds were not found despite having planted trees in April, except for a short-duration concentration peak much higher than that of Kutsuki-R, which was caused by continuous rains in September 1997.

Since mid-November 1997, about eleven months after the clear-cutting, nitrogen independently increased the concentration again, and then had maintained and fluctuated around 0.5 mg/l for about 2 years. The concentration began to decrease gradually early in 2000, and had returned almost the same level as that of Kutsuki-R in summer 2000. After it till today, however, the new level around 0.3 mg/l has maintained despite further decreasing from autumn to spring as Kutsuki-R. Consequently, the influence has not been lost yet about 6 years after the clear-cutting practice. It was no doubt from Figure 2 that the source was increasing discharge of nitrate.

Table 1 Annual mean concentrations in the stream water discharging from Kutsuki Experimental Forests. R: Kutsuki-R. Observation period was 11 years (1991-2001). L: Kutsuki-L. Observation period was 6 years (1991-1996) before clear-cutting. TCOD was measured from 1991 to 1996, and TOC from 1996 to 2001.

Items	Stream Water – All data								Atmospheric deposition			
	arithmetic mean				Weighted mean				arithmetic mean		weighted mean	
	R	CV %	L	L/R	R	CV %	L	L/R		CV %		CV %
pH	6.59	6	6.60	1.00	6.47	4	6.42	0.97	4.7	6	4.6	6
EC (mS/m)	3.37	21	3.87	1.15	3.10	10	3.18	1.03	2.61	22	2.62	25
SS	1.49	273	2.18	1.46	2.4	71	2.3	0.99	3.27	26	2.72	36
TCOD	1.81	96	1.71	0.94	1.91	27	1.44	0.76	2.9	33	2.6	26
TOC	1.92	103	2.37	1.23	1.79	26	2.08	1.16	-	-	-	-
TN	0.139	94	0.151	1.08	0.136	44	0.138	1.02	0.698	28	0.622	27
NO_2-N	0.002	111	0.002	1.19	0.002	40	0.002	1.15	0.002	143	0.002	148
NO_3-N	0.029	100	0.032	1.08	0.026	55	0.032	1.23	0.261	37	0.235	29
NH_4-N	0.017	110	0.023	1.34	0.014	50	0.021	1.44	0.186	63	0.175	63
DON	0.051	101	0.046	0.89	0.042	42	0.033	0.78	0.181	60	0.147	61
PN	0.040	200	0.048	1.20	0.053	60	0.051	0.97	0.092	24	0.083	34
TP	0.0082	114	0.0100	1.22	0.0090	38	0.0095	1.05	0.0280	28	0.6216	27
PO_4-P	0.0024	65	0.0028	1.17	0.0020	28	0.0024	1.15	0.0122	36	0.0108	36
DOP	0.0020	104	0.0026	1.30	0.0020	51	0.0024	1.22	0.0053	104	0.0046	90
PP	0.0038	214	0.0046	1.21	0.0050	56	0.0050	1.00	0.0110	29	0.0098	32
K^+	0.16	84	0.15	0.92	0.17	65	0.15	0.90	0.25	34	0.23	33
Na^+	3.81	11	3.59	0.94	3.60	5	3.36	0.93	1.86	15	1.96	25
Ca^{2+}	0.65	51	1.10	1.69	0.49	27	0.69	1.41	0.43	34	0.40	37
Mg^{2+}	0.65	27	0.91	1.40	0.57	13	0.67	1.17	0.24	22	0.25	31
Cl^-	5.34	9	4.86	0.91	5.26	7	4.83	0.92	3.07	11	3.20	20
SO_4-S	1.61	19	1.55	0.96	1.58	9	1.40	0.89	2.16	23	2.08	17
SiO_2-Si	3.46	28	2.77	0.80	3.05	16	2.37	0.78	0.18	94	0.18	103
Rain (mm/y)	2265	11	-	-	-	-	-	-	-	-	-	-
Dischage %	63	17	-	-	-	-	-	-	-	-	-	-

TP and SS seemed to be slightly affected in the similar way as TN in Figure 2 and 3. However the influence was ambiguous, because the changing patterns of concentrations in stream water are affected strongly by hydrologic conditions. Therefore, the ratios of the annual arithmetic mean concentrations of Kutsuki-L to those of Kutsuki-R (L/R ratio) were calculated and shown in Figure 6 and Table 1. Judging from the L/R ratios for the periods before clear-cutting, it was reasonable to think that there were originally no substantial differences in stream water chemistry between these two watersheds except for Ca^{2+}, Mg^{2+} and K^+. It was clearly shown that the concentration of nitrogen discharging from Kutsuki-R was about 4 times higher than that of Kutsuki-R in annual mean during the important 2 years beginning from the second year since the clear-cutting, and that effect continued for over 6 years. The effect increased the concentration of phosphorus to 2.6 times as high as that of Kutsuki-R during only the first year. TOC showed the tendency slightly decreasing the concentration for over 6 years. The other substances observed in this research were not affected by clear-cutting and planting practices.

CONCLUSION

The clear-cutting of deciduous broadleaf forest and planting cedars increased the concentration of nitrogen and phosphorus of discharge to 3.8 and 2.7 times, respectively, as high as those of the conserved forest. The influences on phosphorus continued for only one year. However, nitrogen has been affected over 6 years. Consequently, the clear-cutting of the forests of a vast area all at once has a possibility that down-stream lakes may be induced eutrophication with nitrogen, so that it is necessary to develop the technology of attaining soil preservation and water quality conservation simultaneously.

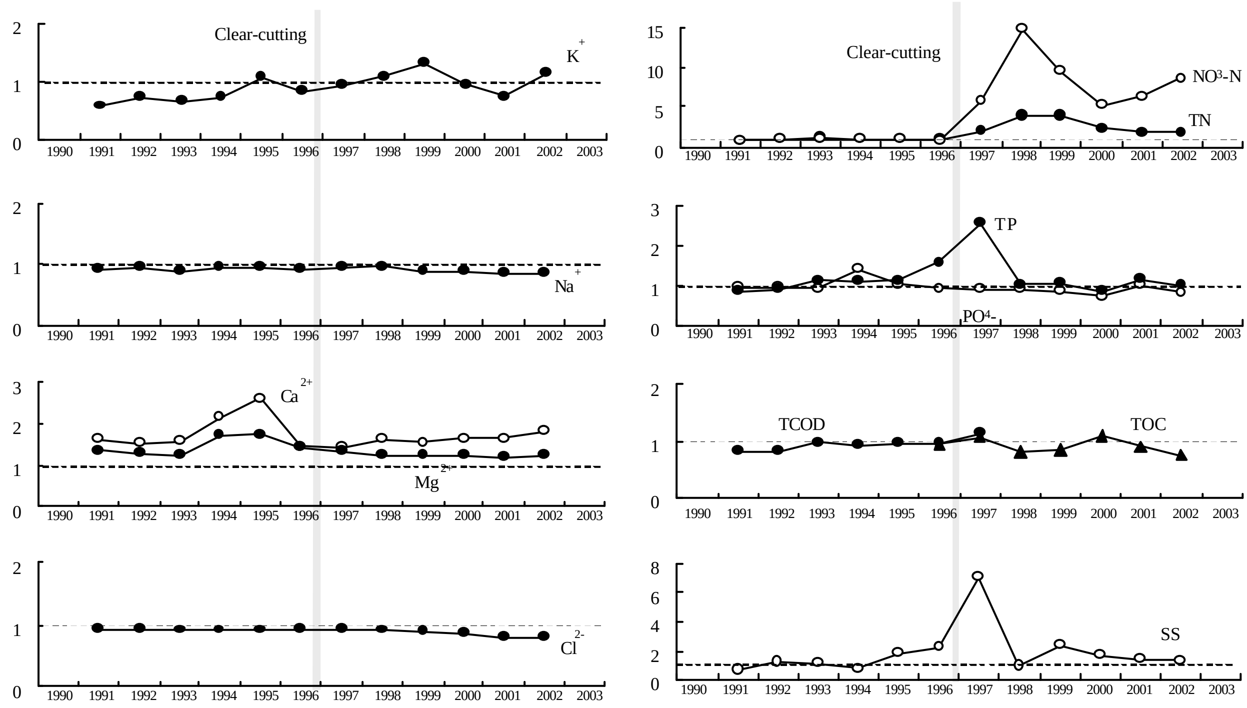

Figure 6 *Changes of the ratio of yearly mean concentrations of Kutsuki-L to Kutsuki-R. Yearly arithmetic mean values of the periodical data were used.*

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