Research article

Water Quality Preservation Effect of Riparian Forests in Watersheds with Dairy Farming Areas in Eastern Hokkaido

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Abstract The effects of riparian buffer zones consisting of forest and wetland on water quality functions were investigated by comparing the river water quality in two watersheds with dairy farming grassland in a large-scale dairy farming area of Eastern Hokkaido. The nitrogen, phosphorus and suspended solids (SS) components from the two watersheds, one without riparian buffer zones (MB) and the other with riparian buffer zones (HY), were compared at normal flow and at rainfall runoff periods. Total nitrogen (T-N) and NO_3–N concentrations were lower in the water from the river with riparian buffer zones. For the water sampled during the rainfall runoff period, all the water quality indicators showed lower concentrations for the river with riparian buffer zones than for the river without riparian buffer zones. The amount of nitrogen that flowed out of land into the river (nitrogen load) in the watershed with riparian buffer zones was 70% of that of the watershed without riparian buffer zones. The differences in water quality between the two watersheds are assumed to have resulted from water purification by the riparian buffer zones on one of the rivers. It is assumed that the riparian trees adsorbed nitrogen and that the riparian wetlands removed nitrogen and captured suspended solids, both of which contributed to purifying the runoff water. Based on the above findings, it can be determined that the conservation of riparian buffer zones is effective in preserving the river water quality on a watershed-wide scale in watersheds consisting of dairy farming grassland.

Keywords riparian, forest, river, nitrogen, phosphorus

INTRODUCTION

In Japan, measures against river water contamination caused by pollutants including nitrogen (N), phosphorus (P) and suspended solid (SS) from upland fields and dairy farming grassland has been called for since the 1980s. The authors have been examining water quality conservation measures based on land use by conducting studies on the relationship between river water quality and land use in watersheds with upland fields and grassland in Hokkaido, Japan (Okazawa et al, 2010, 2011 and 2012). We have reported that a major factor in river water contamination is the expansion of farmland in agricultural watersheds, that the location and scale of farmlands and forests influence the nitrogen concentration of river water, and that forests and wetlands along rivers, which are called riparian buffer zones, are effective in conserving the quality of river water.

The ability of riparian buffer zones to conserve the water environment has attracted attention in the US and Europe since the 1980s (e.g. Lowrance et al., 1984; Hill et al., 2000). It has been clarified that the nitrogen concentration of runoff from farmlands in the shallow groundwater decreases when it passes through riparian buffer zones. In Japan, Hayakawa et al. (2001) and Kanazawa and Hayakawa (2001) examined the relationship between the topographic linkage and the nitrate nitrogen concentration in groundwater, and clarified that the nitrate nitrogen concentration in runoff water from upland fields decreases when that water passes though grasslands. Nakamura and Ishida (2001) examined the effectiveness of riparian buffer zones in conserving the water quality on a watershed-wide scale in a small watershed with dairy farming grassland in Eastern Hokkaido, and they clarified the relationship between the changes in the water environment by ground freezing and the water quality conservation of buffer zones. In Japan and other regions that experience Asian monsoons, few studies have addressed the functions of riparian buffer zones, and proposals for measures for conservation and restoration of riparian buffer zones are not easily accepted. Even though riparian buffer zones have been recognized as conserving the water quality, few studies have evaluated the phenomenon on a watershed-wide scale.

OBJECTIVE

This study investigated the influence of riparian buffer zones on the water environment of a watershed by examining a dairy farming area with grassland in Eastern Hokkaido, where relatively natural riparian buffer zones consisting of riparian forests and wetlands are found. The river water at the normal flow and rainfall runoff periods was investigated in two watersheds with different conditions of rivers and surrounding areas: The river in one watershed was artificially modified and the areas along it was mainly grassland, and the river in the other watershed was natural, with forests and wetlands along it. By comparing the river water quality of the two watersheds using statistical method, the effects of riparian buffer zones on water quality functions were clarified on a watershed-wide scale.

METHODOLOGY

The subject area

The survey was done in Hamanaka Town (E145°13′, N43°07′), which is in a dairy farming area of Eastern Hokkaido. Hamanaka is located in hills at Konsendaichi in the Nemuro-Kushiro Tableland, which has a geological basement of pyroclastic deposits and a thick surface layer of black volcanic ash soil. The daily mean temperature in Hamanaka averages 4.9 °C; it is -12.3 °C in February and 19.8 °C in August 2003. The annual precipitation in 2003 was 1,178 mm, and rain frequently falls in the period from August to October. The snowfall season is from November to April. On the Konsen Plain (Nemuro-Kushiro Plain), where Hamanaka Town is located, large-scale pilot farms with pasture that are mainly for dairy farming were established during the period from 1950 to 2000. The main agriculture in this area is livestock and dairy farming, with upland cultivation also done in some parts.

The surveys were done on the two tributaries of the Furen River, which flows through Hamanaka Town (Fig. 1, Table 1). The watersheds are indicated as MB and HY. The watersheds are similar in area and in proportions of land uses. The locations of grassland and forest relative to the rivers and the degree of river modification differed between the watersheds. In MB, the grassland comes very close to the riverbanks and 71% of the river has been modified, which is relatively high compared to HY. The riverbed and riverbanks are covered with concrete blocks. In HY, riparian forests of Japanese ash (*Fraxinus mandshurica*) and alder trees (*Alnus japonica*) and wetlands are found along the river. This river remains in its natural, unmodified state. The riparian forests are 30 - 100 m wide. There are livestock barns scattered in both watersheds. The cattle densities are 91 head/km^2 for MB and 85 head/km for HY. The livestock manure is spread on the grasslands after being composted or processed as slurry.

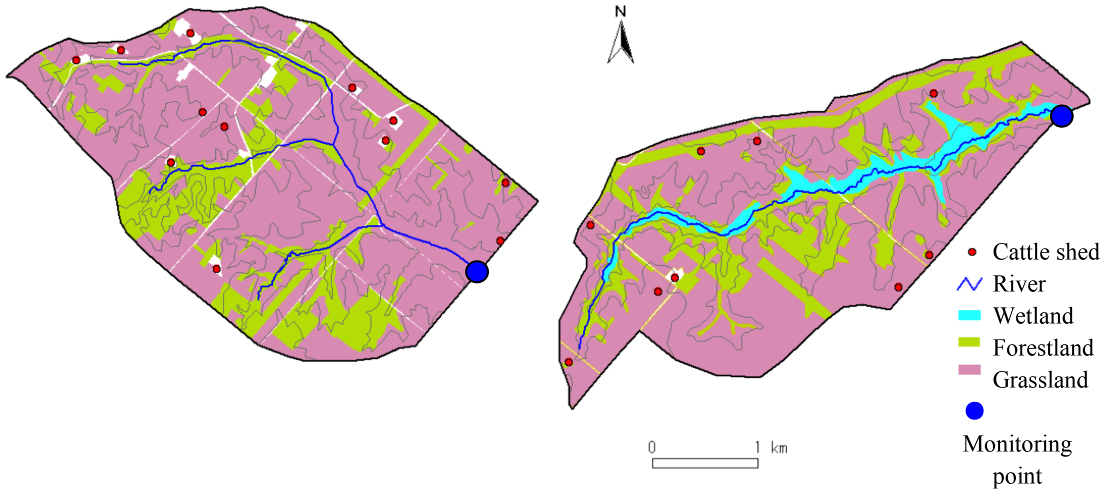

Fig.1 Landuse map of the MB watershed (Left) and the HY watershed (Right)

Table 1 General description of the two watersheds

Name of the watershed	MB	HY
Watershed area (km^2)	10.9	8.9
Land use percentage in the watershed		
Grassland (%)	72	70
Forestland (%)	23	23
Wetland (%)	0	6
Others (%)	5	1
Length of river (km)	8.26	6.23
River density ($km \cdot km^{-2}$)	0.76	0.70
Percentage of improvement length (%)	71	0
Stocking density of cattle ($Head \cdot km^{-2}$)	91	85

Survey technique

The survey periods were from September 5 to November 16 2002 and from June 6 to November15 2003. Continuous monitoring was done for precipitation, river water level and water quality indicators by installing a rain gauge, a water-level gauge and an automatic water sampler at each monitoring point.

River discharges were determined from an H-Q equation obtained from the relationship between the measured discharge (Q) and the water level (H). The continuous values for water levels collected at 10-minute intervals were converted into discharges. The survey periods were classified into that with normal flow (during clear weather) and that with rainfall runoff.

River water was collected using automatic water samplers. Two samples per week were collected from June 6 to August 4 in 2003, and one sample per day (at 12:00 noon) was collected in the survey period in 2002 and from August 5 to November 15 (a period with frequent rainfalls) in 2003. In addition to the regular water sampling, 24-hour continuous sampling at 1-hour intervals was done whenever the rainfall reached 5 mm/h or more. The number of samples collected during the survey periods were 119 (MB) and 109 (HY) for the normal flow period; and 290 (MB), including 10 for flooding, and 340 (HY), including 12 for flooding, for the rainfall runoff period.

The water quality indicators analyzed were T-N (total nitrogen), TON (total organic nitrogen), NO_3-N, NO_2-N, NH_4-N, total phosphorus (T-P), PO_4-P and SS (suspended solids). Ion components were analyzed by ion chromatography, and SS was analyzed by suction filtration. TON was determined by subtracting NO_3-N, NO_2-N, and NH_4-N from T-N.

Calculation method of nitrogen load

The area-specific load of nitrogen flowing out into the rivers in the two watersheds during the period from June 2 to November 14 in 2003 was determined for the normal flow period and the rainfall runoff period (Fig.2). The area-specific load is expressed by Eq. (1).

$$L = (Q \cdot C) / A \tag{1}$$

where L is the Area-specific load ($g \cdot s^{-1} \cdot km^{-2}$), Q is the river discharge ($m^3 \cdot s^{-1}$), C is the concentration (mg/L) and A is the area of watershed (km^2). The area-specific load of nitrogen expresses the flux of nitrogen that flows out of a watershed.

As the changes in nitrogen concentration were smaller during the normal flow period than the rainfall runoff period (see Table 2 and 3), the area-specific load for the normal flow period was obtained by multiplying the average nitrogen concentration of river water at the normal flow period by the discharge. The area-specific load during the rainfall runoff period was obtained based on the water quality data collected every hour and the discharge data collected during the rainfall runoff period. For rainfall events for which water sampling using the automatic water sampler was not done, the load was estimated by obtaining an equation for the relationship between the river discharge (Q) and the load (L) (L-Q formula) from existing data (Fig.2).

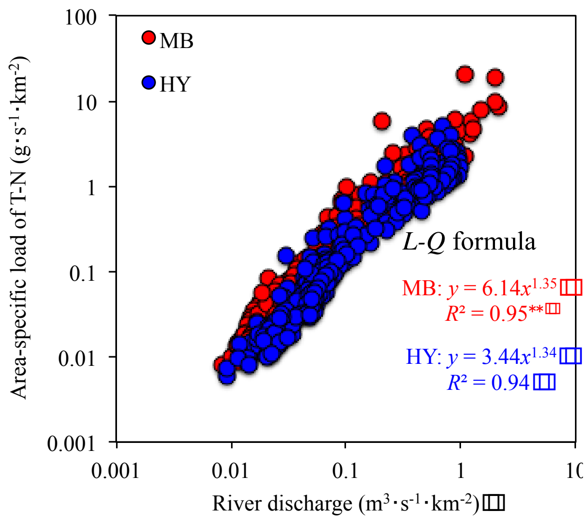

Fig.2 Relationship between specific load of T-N (L) and river discharge (Q) during rainfall runoff period

RESULTS AND DISCUSSION

Characteristics of river water quality at normal flow and rainfall runoff periods

The concentrations of water quality indicators (discharge-weighted average) for the two watersheds during the normal flow period and those during the rainfall runoff period are shown in Tables 2 and 3. During the normal flow period, statistically significant by using t-test statistics differences between the watersheds were found in the concentrations of T-N and NO_3-N, and these concentrations were lower in MB than in HY. For other water quality indicators, the differences in their concentrations between the two watersheds were small, and no significant differences between the two watersheds were found.

Based on the above findings, it can be thought that NO_3-N, which readily eluviates from the grassland soil at normal water level, was purified in the riparian forests, and made the concentrations of water quality components in MB low.

During the rainfall runoff period, the concentrations of all the water quality indicators were higher in MB than in HY. The difference in concentrations of TON, NH_4-N, T-P and SS, which readily flow with the suspended components, were great between the watersheds. During the rainfall runoff period, soil erosion occurs in grassland, and contaminants are adsorbed by sediments and flow out into rivers. That the concentrations of water quality indicators were lower in HY than in MB was attributed to the catching, by the riparian forests and wetlands, of contaminants generated during the rainfall runoff period, which thus kept them from flowing into the river.

Table 2 Mean concentration in normal flow period

MB watershed	T-N	TON	NO_3-N	NO_2-N	NH_4-N	T-P	PO_4-P	SS
M.C.	1.14	0.30	0.80	0.02	0.02	0.08	0.03	12
S.D.	0.35	0.30	0.16	0.02	0.03	0.05	0.02	12
C.V.	31	99	20	122	165	66	52	99
HY watershed	T-N	TON	NO_3-N	NO_2-N	NH_4-N	T-P	PO_4-P	SS
M.C.	0.79	0.30	0.46	0.01	0.02	0.09	0.04	10
S.D.	0.41	0.24	0.30	0.02	0.04	0.06	0.03	11
C.V.	52	80	65	120	181	74	75	109

M.C.:Mean concentration (mg/L), S.D.: Standard division (mg/L), C.V.: Coefficient of variation (%)

Table 3 Mean concentration in rainfall runoff period

MB watershed	T-N	TON	NO_3-N	NO_2-N	NH_4-N	T-P	PO_4-P	SS
M.C.	4.66	3.63	0.63	0.04	0.35	0.61	0.30	204
S.D.	3.05	2.88	0.36	0.06	0.41	1.23	0.20	274
C.V.	66	79	57	139	117	200	68	135
HY watershed	T-N	TON	NO_3-N	NO_2-N	NH_4-N	T-P	PO_4-P	SS
M.C.	2.52	1.89	0.47	0.03	0.14	0.58	0.22	107
S.D.	1.50	1.45	0.15	0.04	0.16	0.53	0.15	110
C.V.	59	77	31	159	118	91	70	103

M.C.:Mean concentration (mg/L), S.D.: Standard division (mg/L), C.V.: Coefficient of variation (%)

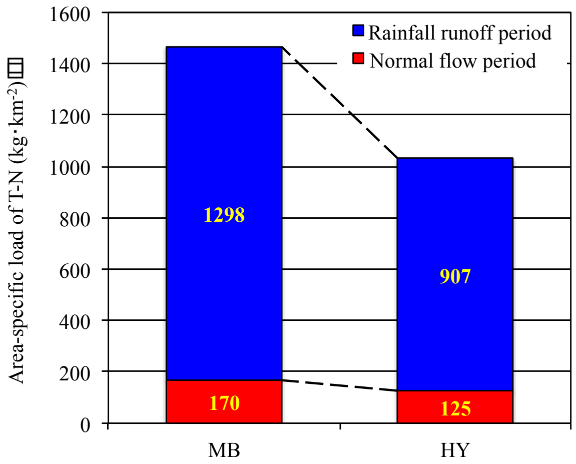

Fig.3 Specific load of T-N during 3 June to 14 November 2003

Nitrogen loading reduction by riparian buffer zones

Figure 3 shows the relationship between area-specific load of T-N in the MB watershed and the HY watershed. The area-specific load of T-N showed lower values in HY than in MB for both the normal flow period or the rainfall runoff period. The two watersheds differed in whether they had riparian forests and wetlands or did not have these. Therefore, the difference in the area-specific T-N between the two watersheds can be attributed to reduction of nitrogen by the riparian forests and wetlands. It can be assumed that the low levels of nitrogen concentration were the result of purification by the riparian forests and wetlands. Because, many researchers reported that the surface water, which contained nitrogen components flowing out from grasslands into the riparian forests and wetlands, was purified when the trees adsorbed nitrogen components and the wetlands removed nitrogen components (e.g. Takahashi et al., 2003). The area-specific load of T-N in HY for the normal flow period was 125 $kg \cdot km^{-2}$, which is 74% that in MB, and for the rainfall runoff period it was 907 $kg \cdot km^{-2}$ which is equal to 70% that in MB. This result clarifies that the riparian forests and wetlands reduced the nitrogen load by 26% during the normal flow period and 30% during the rainfall runoff period.

CONCLUSION

The water conservation effects of riparian buffer zones (riparian forests and wetlands) were examined by comparing the water qualities of rivers in two similar dairy farming grassland watersheds that had different degrees of artificial modification of the rivers and different riparian environments. Data suggest the concentrations of river water quality indicators, including nitrogen, phosphorus and SS, in the water of the river with such zones to be lower than in the water of the river without such zones. The zones were found to significantly reduce such load from grasslands, particularly during the rainfall runoff period. It was clarified that about 30% of the nitrogen load in runoff was reduced by the riparian buffer zones.

This study was able to clarify the water quality conservation effect of riparian buffer zones on a watershed-wide scale. It also clarified that the water quality functions of riparian buffer zones differed for every water quality component by flow regime (normal vs. rainfall runoff).

In recent years degradation of the water environment in agricultural watersheds has been a concern in Hokkaido. It can be said that including the conservation of riparian forests and wetlands in environment improvement plans is effective in conserving the water environment of rivers.

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