Research article

Water Quality Characteristics of the S River – Effect of Livestock Grazing, Hokkaido, Japan

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Abstract Forest grazing, which uses grassland and woodlands for livestock grazing, is generally considered an environmentally friendly method of livestock management. However, its implementation is rare, and the full extent of its environmental impact is poorly defined. Here, we examined the effect of forest grazing on the current state of river water quality. The study site was the S River, which flows through K Farm, located in eastern Hokkaido, Japan. The K Farm offers forest grazing for its beef cattle. River water was collected at nine points on the main S river and at five tributaries that join the main river near the pastureland and upstream of the dam. The mean ion concentration of river water was 8.1–16.4 mg/L for cations and 6.5–11.5 mg/L for anions. The concentrations were relatively low at all the sampling points. The average total nitrogen (T-N) concentration ranged from 0.18 to 0.75 mg/L, which is below the environmental standard of 1.0 mg/L. In the tributaries, the nitrate nitrogen (NO_3-N) ratio was approximately 45%, which was greater than the main river value of 30%. Regarding the relationship between the first and second principal components of the PCA results, the plot trends differed between the main river upstream and downstream and between the tributaries. The overall ion concentration in the main river upstream was low. In contrast, the five tributaries showed a different trend from the main river; in particular, the overall water quality concentration of tributary T2 was high, and K^+, PO_4^{2-}, and T-N were high. It is necessary to conduct long-term observations of seasonal and temporal fluctuations in the tributaries flowing through grazing areas to investigate the effects of grazing.

Keywords forest grazing, livestock management, T-N concentration, PCA

INTRODUCTION

Grazing livestock farming is attracting international attention as an environmentally friendly method of food production that may help solve future food problems associated with population growth and climate change. However, several studies have reported the recognition of the evolving emphasis on improving management methods that have less adverse impact on the environment (Agouridis et al., 2005; Hubbard et al., 2004). For example, Chaubey et al. (2010) used a water quality assessment model to simulate the effects of different grazing management methods on water quality in the United States. They showed that nitrogen and phosphorus runoff increased with grazing density. They also showed that nitrogen and phosphorus runoff varies with changes in weather conditions.

In Japan, there are few examples of grazing livestock farming. The environmental impact of livestock grazing has not been thoroughly investigated. Our study, which analyzed the quality of river water at K Farm, aims to shed light on the impact of beef cattle grazing livestock farming on river water quality. This study reports on the few water quality survey results available for grazing lands, which is an issue that has been highlighted internationally. (Agouridis et al., 2005). This study provides important basic information for considering grazing management methods for water quality conservation in Japan.

METHODOLOGY

Study Sites

The research site was the S River, which flows through K Farm in eastern Hokkaido. K Farm is a 100-hectare (ha) ranch where beef cattle are grazed year-round in the pastures and forests. The farm raises Aberdeen Angus cattle, and as of 2019, it had a stock of approximately 80 head. The pasture is open from April to November, and grass harvested from the K Farm's meadows is fed from December to March, as snow cover prevents grass from being foraged on the pasture. During the survey period of this study (May to October 2019), the precipitation and average temperature at the weather station closest to the grazing area were 851 mm and 11.6 to 20.2°C, respectively.

The S River, a class B river in Japan, has a channel length of 19.0 km and a catchment area of 2,029 km^2. We surveyed nine sites from the upper to lower reaches of the S River and five tributaries that flow into the S River. A flood control dam is located in the downstream area of the pasture, and the S River flows through the pasture and into the flood control dam before continuing downstream to the residential area and emptying into the Pacific Ocean. Fig.1 shows the locations of the sampling points. M1, the point on the main river, is located upstream of the pasture. M2 and M3 were sampling points within the pasture, and M4 was located downstream of the pasture. Five water sampling points (M5–M9) were established on the main river downstream of the dam. Of the five tributaries, T1 to T4 are tributaries that flow through the pastureland and into the main river. T1 flows through the uppermost part of the pastureland, and T2 flows through the pastureland on the north side, where beef cattle are grazed in winter. T3 and T4 flow through pastureland used for grazing cattle from May to November, excluding the snow season. T5 flows downstream from the lower reaches of K Farm and was determined to be unaffected by K Farm.

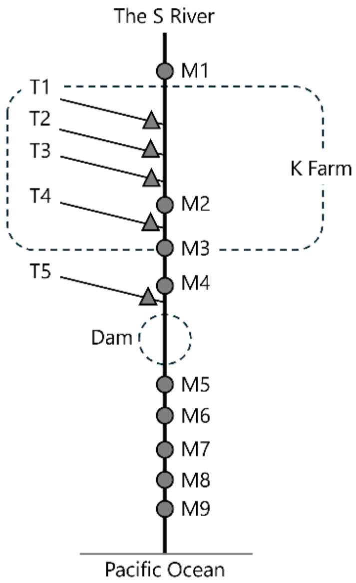

Fig. 1 Sampling points

Water Quality Investigation

River water was sampled at nine sites on the main S river and five sites on its tributaries during periods of low water flow when the water was not affected by flow fluctuations due to the rainfall. The river water was directly collected into clean, dry plastic bottles, stored in a cool, dark container, and immediately transported to the laboratory for analysis. Water was sampled once a month from May to October 2019, for a total of six samples. Using liquid chromatography and well-established protocols, we analyzed the following ion components in each sample: F^-, Cl^-, Br^-, NO_3^-, NO_2^-, PO_4^{2-}, SO_4^{2-}, Na^+, K^+, NH_4^+, Ca^{2+}, and Mg^{2+}. Total nitrogen (T-N) was mineralized using the alkaline potassium peroxydisulfate decomposition method and measured using a UV-visible spectrophotometer. Organic nitrogen (Org.-N) was calculated by subtracting ammonia (NH_4-N), nitrite (NO_2-N), and nitrate nitrogen (NO_3-N) from T-N.

Principal Component Analysis

We used the scikit-learn package in Python (Python3) to perform principal component analysis (PCA) of the water quality. The PCA was performed using two data types: 1. the average ion and T-N concentrations and 2. ion and T-N concentrations for all sampling dates. However, NH_4-N and NO_2-N were excluded from the PCA because they were below the detection limit of liquid chromatography (NH_4-N < 0.05 mg/L, NO_2-N < 0.02 mg/L) on most of the sampling dates.

RESULTS AND DISCUSSION

Average Ion Concentration and Ion Composition Ratio at Each Sampling Point

Figure 2 (a) and (b) show the average cation and anion concentrations, and Figure 2 (c) and (d) show the ion composition ratios. The average ion concentration was 8.1–16.4 mg/L for cations and 6.5–11.5 mg/L for anions. Cation concentrations tended to increase from upstream to downstream in the main river. In the tributaries, concentrations were similar to those in the downstream section of the main river, with the highest concentration recorded at T2 in the tributary. There were no significant differences in the anions in the main river, but as with cations, T2 in the tributary had the highest concentration. Regarding the ion composition ratio, Na^+ and Ca^{2+} were the primary ions, accounting for approximately 30% and 50% of the cations, respectively, while Cl^- and SO_4^{2-} were the primary anions, accounting for approximately 45% of each. Although there were differences in the ion concentrations at each sampling point, the ion composition ratios showed a similar trend.

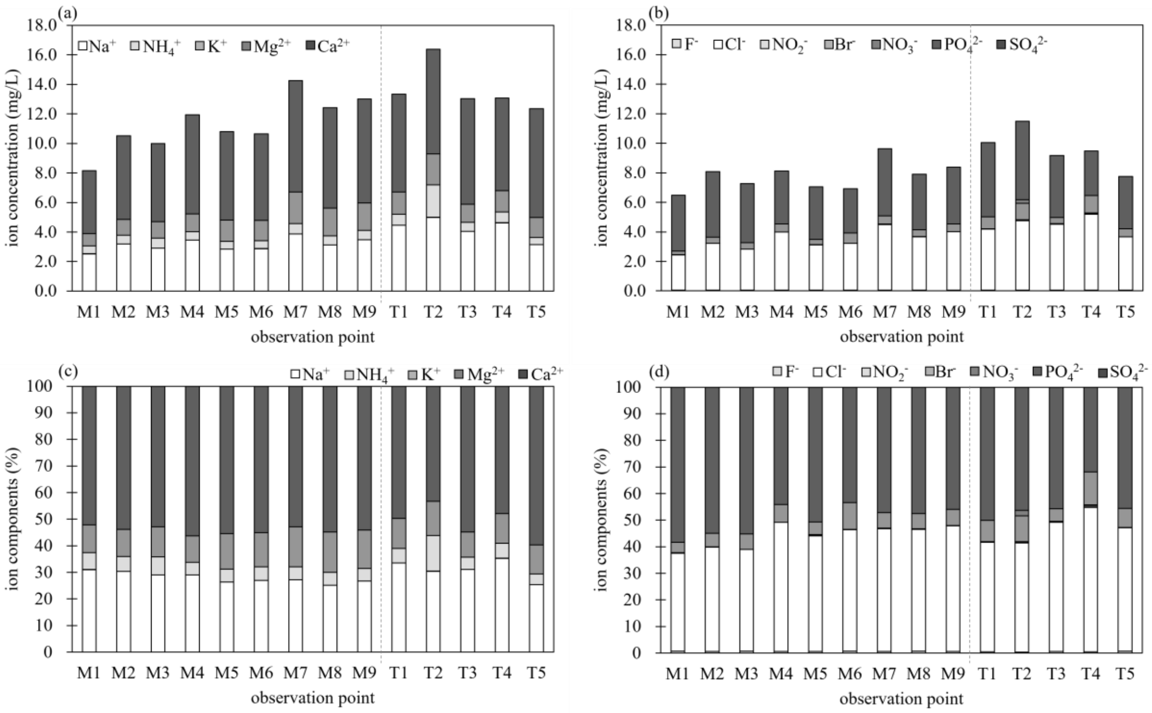

Fig. 2 Average ion concentration and ion composition ratio (a) to (d)

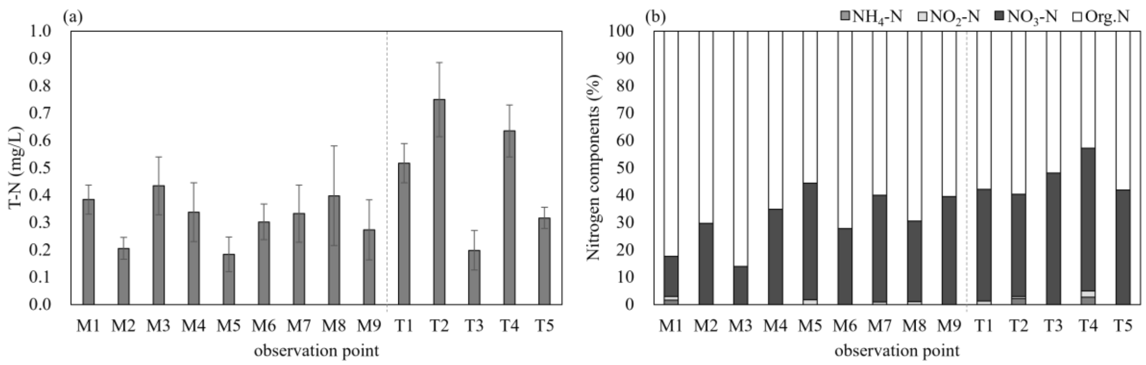

Fig. 3 T-N concentration and nitrogen composition ratio (a) and (b)

T-N Concentration and Nitrogen Composition Ratio at Each Sampling Point

Figure 3 (a) and (b) show the average T-N concentration and nitrogen component (NH_4-N, NO_2-N, NO_3-N, and Org.-N) composition ratios. The average T-N concentration ranged from 0.18 to 0.75 mg/L, which was below the environmental standard of 1.0 mg/L. There were no significant differences in the T-N concentrations in the main river. The T-N concentrations of tributaries T1, T2, and T3 tended to be greater than those of the main river. Regarding the composition ratio of nitrogen components, organic nitrogen accounted for approximately 70% and NO_3-N for approximately 30% in the main river. In the tributaries, the ratio of NO_3-N was approximately 45%, which was greater than that of the main river.

Correlation Matrix of Nitrogen Components

Figure 4 (a) shows the correlation matrix of the average concentrations of each nitrogen component (NH_4-N, NO_2-N, NO_3-N, and Org.-N) between the sampling points. The correlation coefficients between the concentrations of each nitrogen component were very high, indicating that the nitrogen composition ratios at all sampling points were similar. However, the correlation coefficients of T3 and T4 in the tributaries were lower than those at the other sampling points.

Figure 4 (b) shows the correlation matrix for the T-N concentration between the sites on each sampling day. The correlation coefficients between the four sites in the upper reaches of the main river (M1 to M4) were high, ranging from 0.82 to 0.99. The correlation coefficients between the four sites in the upper reaches of the main river and the five sites in the lower reaches of the main river (M5–M9) tended to be low. Conversely, the correlation coefficients between the upstream sites of the main river and the tributaries were high. In contrast, the correlation coefficients between the downstream sites and the five sites on the tributaries were low. In other words, the seasonal variation in T-N concentration showed a similar trend at the upstream sites of the main river and tributaries.

(a)

r	M1	M2	M3	M4	M5	M6	M7	M8	M9	T1	T2	T3	T4	T5
M1		0.98	1.00	0.96	0.91	0.99	0.94	0.98	0.94	0.93	0.94	0.88	0.82	0.92
M2			0.98	1.00	0.98	1.00	0.99	1.00	0.99	0.98	0.99	0.96	0.91	0.98
M3				0.96	0.91	0.98	0.93	0.98	0.93	0.92	0.94	0.87	0.81	0.92
M4					0.99	0.99	1.00	1.00	1.00	0.99	1.00	0.98	0.94	0.99
M5						0.97	1.00	0.98	1.00	1.00	1.00	1.00	0.98	1.00
M6							0.98	1.00	0.98	0.98	0.99	0.95	0.90	0.98
M7								0.99	1.00	1.00	1.00	0.99	0.97	1.00
M8									0.99	0.98	0.99	0.96	0.92	0.98
M9										1.00	1.00	0.99	0.97	1.00
T1											1.00	0.99	0.97	1.00
T2												0.99	0.96	1.00
T3													0.99	0.99
T4														0.97
T5														

(b)

r	M1	M2	M3	M4	M5	M6	M7	M8	M9	T1	T2	T3	T4	T5
M1		0.82	0.99	0.87	-0.09	0.10	0.03	0.41	-0.52	0.70	0.95	0.78	0.90	0.98
M2			0.85	0.96	0.33	0.64	0.47	0.48	-0.11	0.49	0.81	0.73	0.51	0.80
M3				0.89	0.01	0.14	0.13	0.45	-0.42	0.71	0.96	0.76	0.85	0.95
M4					0.33	0.47	0.44	0.65	-0.12	0.39	0.91	0.87	0.61	0.83
M5						0.53	0.90	0.51	0.89	-0.30	0.06	0.13	-0.46	-0.22
M6							0.61	0.09	0.34	0.01	0.09	0.20	-0.27	0.13
M7								0.62	0.78	-0.17	0.21	0.14	-0.32	-0.09
M8									0.30	-0.23	0.66	0.68	0.29	0.29
M9										-0.55	-0.35	-0.27	-0.77	-0.63
T1											0.51	0.11	0.62	0.71
T2												0.85	0.85	0.90
T3													0.68	0.76
T4														0.91
T5														

Fig. 4 Correlation matrix of nitrogen components (a) and (b)

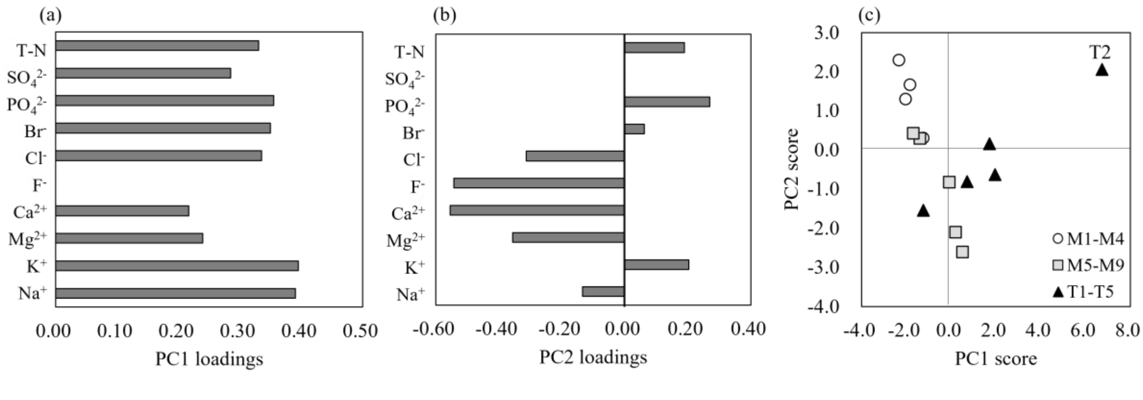

Fig. 5 PCA loadings and relationship between PC1 and PC2 of the average ion and T-N concentration (a) to (c)

PCA of Average Ion and T-N Concentrations

Figure 5 (a) and (b) show the PCA loadings for the average ion and T-N concentration values. The contribution ratio of PCA using the average values was 53% for the first principal component, PC1, and 21% for the second principal component, PC2; therefore, it was judged that two principal components, PC1 and PC2, could explain the 10 water quality items. The loadings of PC1 were positive for all water quality parameters; therefore, the higher the value of PC1, the higher the overall water quality concentration. On the other hand, K^+, Br^-, PO_4^{2-} and T-N showed positive values for the PC2. K^+, PO_4^{2-}, and T-N were considered potential indicators of livestock manure inputs.

Figure 5(c) shows a scatter diagram with PC1 on the x-axis and PC2 on the y-axis. Related to the relationship between the first and second principal components, the plot trends differ for the main river upstream, downstream, and the tributary. The plot of the main river showed a linear transition from the second quadrant to the fourth quadrant. The nine points on the main river had negative values or values close to 0 for PC1, indicating a low overall water quality concentration. In addition, PC1 for the main river increased as it flowed downstream, and the water quality concentration increased slightly downstream. In contrast, PC2 showed positive values at the upper sites of the main river and 0 or negative values at the lower sites of the main river. From this, K^+, PO_4^{2-}, and T-N tended to be higher at the upper sites of the main river than at the lower sites. The five sites on the tributary river showed a different trend from the main river, with a linear transition from the first to the third quadrant. In particular, T2 was plotted in a position separate from the other four tributary sites, indicating that the overall water quality concentration was high and that K^+, PO_4^{2-}, and T-N were high.

PCA of Ion and T-N Concentrations for All Sampling Dates

Figure 6 (a) and (b) show the PCA loadings for the ion and T-N concentrations for all sampling dates. The contribution ratios of principal component analysis were 44% for PC1 and 18% for PC2, so PC1 and PC2 could explain the 10 water quality items. The results for the principal component loadings for PC1 and PC2 were similar to those of the PCA using the average values of the ion and T-N concentrations described above.

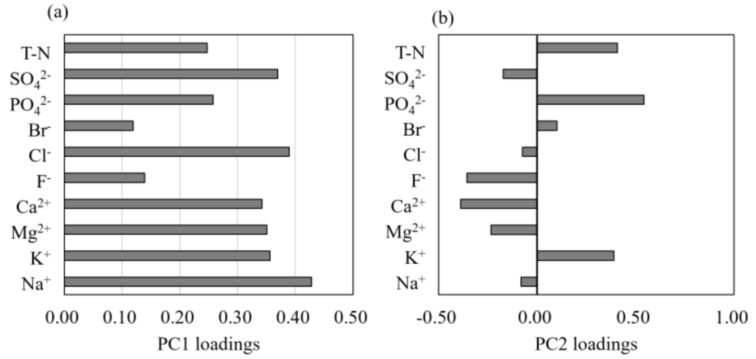

Fig. 6 PCA loadings of the average ion and T-N concentration for all sampling dates (a) to (b)

Figure 7 (a) shows the results for the four sampling points, M1 to M4, in the upper reaches of the main river, Fig.6 (b) for the five sampling points, M5 to M9, in the lower reaches of the main river, and Fig. 6 (c) for the five sampling points, T1 to T5, in the tributary. In terms of the relationship between PC1 and PC2, the main river showed a linear transition from the second to the fourth quadrant. Although there were no significant differences in the principal component scores for any of the sampling points or dates, the PC2 scores were high for M1 and M2 in the upper reaches of the main river only in May. For the tributaries, T1, T3, and T5 showed similar trends, with no significant differences between the sampling points or dates. In contrast, T2 was plotted in a position distant from the other sites, and in particular, as T2 showed positive values for both the first and second principal components in May, it can be seen that the overall water quality concentration was high and that the K^+, PO_4^{2-}, and T-N concentrations were higher than in the other months when the water was sampled.

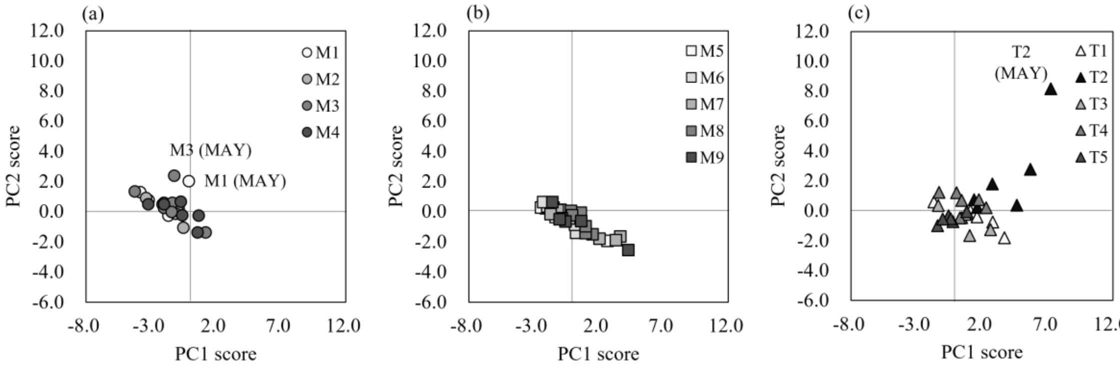

Fig. 7 Relationship between PC1 and PC2 of the ion and T-N concentration on all sampling dates (a) to (c)

CONCLUSION

The ion and T-N concentrations were low at all the sampling points. When comparing the main river and the tributary near the pasture, the tributary tended to have higher water quality. The cation composition ratio was similar at all sites, but the proportion of NO_3-N was high among the nitrogen components in the tributaries. In addition, a strong positive correlation was observed between the upstream section of the main river and the tributary in terms of T-N concentration from May to October. In the PCA of ion and T-N concentrations, the tributary's overall water quality was higher than that of the main river, with particular characteristics in K^+, PO_4^{2-}, and T-N concentrations. The tributary T2 flowing by the pasture during the snow season showed a distinct water quality trend, with particularly high overall water quality in May, which was also observed at the main river sites M1 and M3. The beef cattle grazing livestock farming does not significantly impact the river water quality; however, water quality fluctuations after snowmelt indicate the need for long-term monitoring of seasonal and temporal variations in tributaries within the grazing area.

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