Research article

Impact of the Land Use Diversity on the River Water Quality in the Agricultural Area

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Abstract Water pollution due to agriculture has become a serious global problem. Also, agricultural development has had major impacts on biodiversity. Impacts on the ecology of a watershed should be considered when proposing changes to land use and management for water quality conservation. Habitat diversity is one of the most important factors for conserving biodiversity in an agricultural landscape. In recent years, several fields of research have shown a positive correlation between a mosaic of land types and species richness. Herein, we evaluated the land use diversity of the Tokachi River basin and examined an appropriate spatial unit to calculate a land cover heterogeneity index for river water quality. The Tokachi River basin is located in the northern part of Japan and plays an important role in a food production area. The main land use types are forest, cropland, pasture, and dairy farming. Here we applied the Satoyama Index (SI) as a land cover heterogeneity index to examine land use diversity. SI evaluates a diverse mosaic of agricultural and non-agricultural land as an index from 0.0 to 1.0 based on Simpson's diversity index. High SI values are an indicator of high habitat diversity. The mean SI value of the Tokachi River basin (No.17) was 0.6, and SI tended to be high in the central basin and low in the headwater of mainstream and tributaries. SI values had negative correlations with total nitrogen, nitrate, and electrical conductivity (EC) of river water. Unified land uses for extensive agricultural land results in increasing nitrogen and EC of the river water and leads to monotonic habitat conditions in the Tokachi River basin.

Keywords Satoyama Index (SI), land use diversity, river water quality, biodiversity, spatial unit size

INTRODUCTION

Ecologically sustainable agriculture is regarded as a strategy to respond to global population growth and food issues, environmental degradation, climate change, and degrading natural resources (Kassam and Friedrich, 2012; Robertson et al., 2014; Bedoussac et al., 2015). The concept of an "ecological farm" is an approach adopted to implementing ecologically sustainable agriculture that is in harmony with nature; it involves the use of cultivation techniques and breeding programs that do not rely on soluble chemical fertilizers, pesticides, herbicides, or artificial genetic modifications. The Food and Health Organisation (FAO) established the Globally Important Agricultural Heritage System (GIAHS) in 2002 to promote traditional agricultural systems and landscapes; these have been created, shaped, and maintained based on diverse natural resources, using locally adapted management practices. However, the agricultural production of eco-friendly agriculture still requires improvement.

In the Tokachi area, which is an important food production area in Japan, nitrogen pollution caused by agriculture has been reported (Yamazaki et al., 2013, 2014, 2015, 2016(a)). Yamazaki et al., 2016(b) showed that it is necessary to control the restructuring of land use to alleviate nitrogen pollution of the Tokachi River basin. Local ecosystems have to be considered when designing an effective layout of land use in an agricultural land to facilitate water quality conservation.

In recent years, several studies have demonstrated a positive correlation between land use diversity and species richness (biodiversity) in an agricultural area (Robinson and Sutherland, 2002; Firbank et al., 2008). Kadoya and Washitani (2011) proposed the Satoyama Index (SI), a biodiversity indicator which is a simple composite index of agricultural landscape heterogeneity and the contribution of nonagricultural land use. They showed that a high SI value is an indicator of high habitat diversity, whereas a low SI indicates a monotonic habitat condition, which is typical of extensive monoculture landscapes.

In this study, we analyzed land use diversity of the Tokachi River basin by SI and examined the relationship between the SI score and the river water quality to design an eco-friendly measure of water quality conservation in the Tokachi region, a large-scale agricultural landscape in Japan.

METHODOLOGY

The Tokachi River basin

This study was conducted in the Tokachi River basin located in the eastern part of Hokkaido, Japan (142.68–144.02 N, 42.55–43.65 E, 0–2,077 m altitude) (Fig. 1 and Table 1). The basin has a total area of 9,010 km^2 and a total stream length of 156 km. According to the Köppen–Geiger climate classification, the Tokachi River basin is characterized as a warm summer continental climate type (Dfb) with an annual mean air temperature of 6.8 °C and an annual precipitation of 887.8 mm/y; these measurements are the means of the recorded values at Obihiro City from 1981 to 2010. The soil types in the Tokachi River basin are volcanic soil, lowland soil, upland soil, and peat soil. In particular, volcanic soil (andosols) is widely distributed in this basin. The main land uses in this river basin are for agriculture and forestry, with 60% of the agricultural land used as cropland and 40% used as pasture. Both chemical fertilizers and livestock manure are applied to the agricultural land.

Water Quality Investigation and Analyses

The river water quality was monitored at 21 sampling points located on the main stream (No.17) and at each tributary (A–T) of the Tokachi River basin in June, in either August or September, and in October from 2007 to 2011 under base flow conditions. Water samples were analyzed for total nitrogen (T-N), nitrate (NO_3-N), total phosphorus (T-P), pH, biological oxygen demand (BOD), suspended solids (SS), and electrical conductivity (EC).

Satoyama Index (SI; Kadoya and Washitani, 2011)

We calculated the SIs of 21 watersheds in the Tokachi River basin. Calculation for SI is shown in Eq. 1 based on the agricultural landscape heterogeneity index (ALHI) using Simpson's diversity index (Lande, 1996; Eq. 2) by ArcGIS Desktop (ver.10, ESRI).

$$\mathrm{SI} = \mathrm{ALHI} \times \frac{p_{other}}{k} \times \frac{k}{k-1} \quad (1)$$

$$\mathrm{ALHI} = 1 - \sum_{i=1}^{S} p_i^2 \quad (2)$$

p_{other} is the number of grid squares of the other land uses, and k is the total number of the grid squares in a spatial unit in Eq. 1. S is the number of different land cover items in a spatial unit, and p_i is the proportion of agricultural land to the total number of grid squares in Eq. 2.

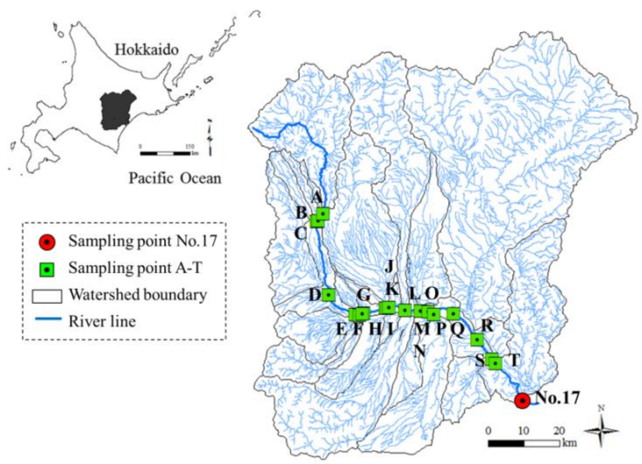

Fig.1 Locations of the 21 sampling points in the Tokachi River basin

In this study, the following were the values used: "land use raster data" (100 m grid size; publication in 2009) published by the National Digital Information and "JAXA High Resolution Land-Use and Land-Cover Map (Ver. 16.02)" (10 m grid size; publication in 2016) published by ©JAXA. The proportion of agricultural land and forest land in Table 1 was calculated by "land use raster data". Also, Kadoya and Washitani (2011) set a spatial unit size of 6 km; however, we set four different spatial unit sizes (500×500 m^2, 1×1 km^2, 5×5 km^2, and 10×10 km^2) to calculate SI of the Tokachi River basin.

RESULTS AND DISCUSSION

Figure 2a, b shows the spatial distribution of SI calculated by a combination of 500 × 500 m^2 spatial unit size and 10 m or 100 m resolution (500 m unit size and 10 m resolution or 500 m unit size and 100 m resolution) in sampling point No.17. SI tended to be low in the center (lowland) of the watershed and high in the headwater of mainstream and tributaries of the watershed. In the Tokachi River basin, the

Table 1 Watershed and land use information for each sampling point

Sampling point	Watershed area km^2	River length km	Proportion (%) Agricultural land	Proportion (%) Forest land
A	23	47	0	98
B	48	27	2	96
C	72	29	2	97
D	337	42	25	68
E	210	25	40	53
F	26	16	73	11
G	35	18	79	18
H	180	38	16	74
I	164	36	73	17
J	33	22	52	44
K	667	67	47	44
L	693	94	18	61
M	197	80	71	70
N	704	43	30	12
O	316	41	65	28
P	127	31	79	12
Q	449	52	70	25
R	2850	150	19	76
S	173	25	23	73
T	66	13	44	51
17	8982	146	31	58

center area is dominated by extensive agricultural land, resulting in monotonic habitat conditions; however, the headwater tributary areas were covered by forests and had rich habitat diversities. The spatial distribution of SI of combinations with other spatial unit sizes (1 × 1 km^2, 5 × 5 km^2, and 10 × 10 km^2) showed the same trend. SI of the 10 m resolution varied between the center area (low SI) and the headwater of mainstream and tributaries (high SI).

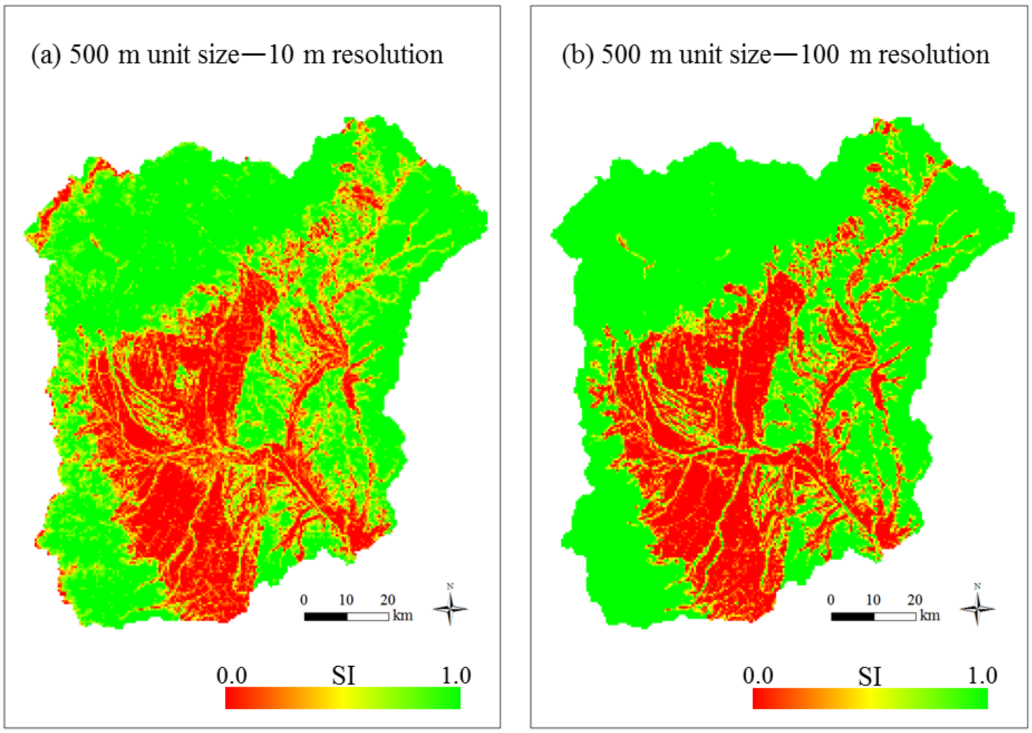

Fig.2a, b Spatial distribution of the Satoyama Index in the sampling point No.17

Fig. 3a, b shows the percentage of each SI value (0.0–1.0) calculated by a combination of four spatial unit sizes (500 × 500 m^2, 1 × 1 km^2, 5 × 5 km^2, and 10 × 10 km^2) and two resolutions (10 m, Fig. 3a; 100 m, Fig. 3b) in the sampling point No.17. SI–1.0 and SI–0.1 were high percentages of 10 m resolution, whereas SI–1.0 and SI–0.0 were high percentages of 100 m resolution. Also, SI–0.2 to SI–0.9 increased with increasing unit size of both resolution types. From this, the land use of the Tokachi River basin is polarized between either agricultural land area or forest area.

We calculated the mean SI of the each watershed of the 21 sampling point of No.17 and A–T. Fig. 4 shows the mean SIs of 500 m unit size–10 m resolution and 500 m unit size–100 m resolution in the sampling point No.17 and A–T as one example. Where the sampling points have less than 0.5 of SI value, Mean SI of the 500m unit size-10 m resolution and 500m unit size -100m resolution showed nearly the same value. However, the mean SI of the 500 m unit size-100m resolution was found to be higher than that of the 500 m unit size-10 resolution at the sampling points has more than 0.5 of SI value. It was considered that minor land use type recognized at 50 m resolution was excluded at 100 m resolution. Habitat diversity of the watershed at the sampling points A–D, H, L, R, and S were comparatively rich since mean SI of these sampling points was higher than SI–0.6. Conversely, the points on the watershed located at F, G, I, M, O, P, and Q were dominated by extensive agricultural land since mean SI of these sampling points was lower than SI–0.2. The same trend was confirmed of a combination with another spatial unit size (1 × 1 km^2, 5 × 5 km^2, and 10 × 10 km^2). However, SI tended to decrease with increasing unit size.

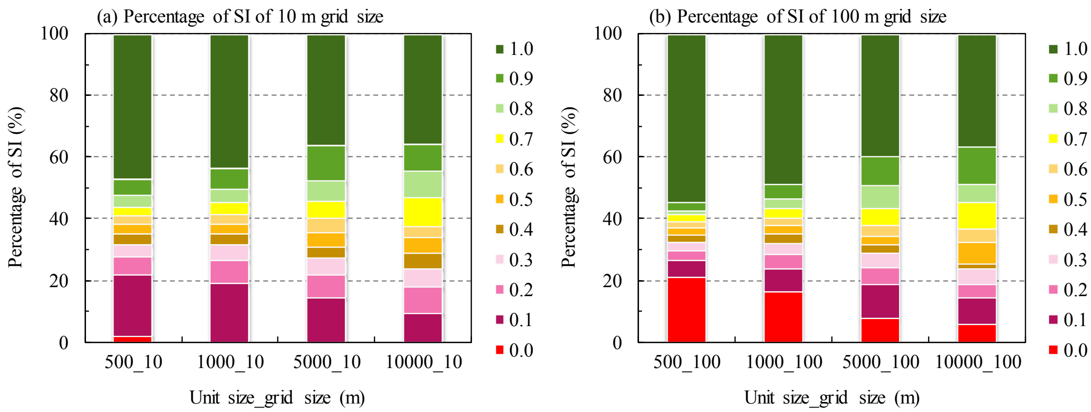

Fig.3 Percentage of Satoyama Index (SI)–0.0 to SI–1.0

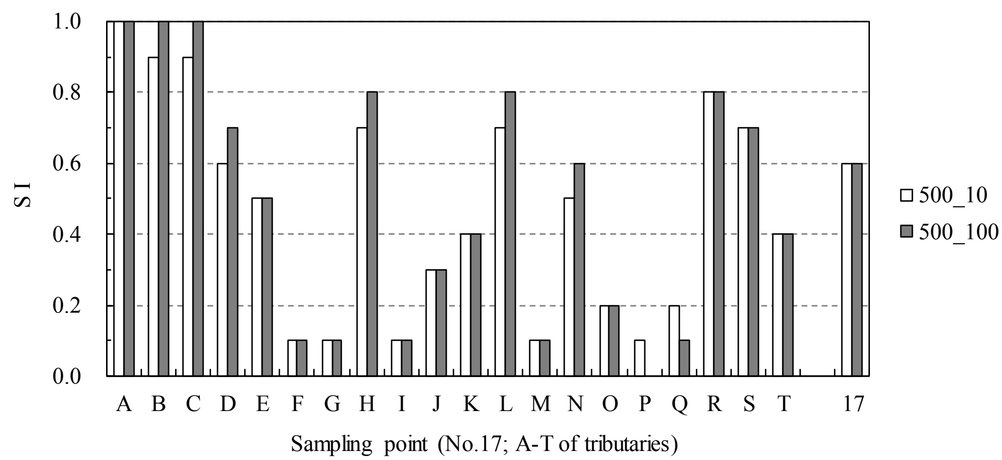

Fig.4 Mean Satoyama Index (SI) of the watershed in the 21 sampling point of No.17 and A–T

Table 2 shows the correlation coefficients of the relationships between seven river water quality variables (T-N, NO_3-N, T-P, pH, BOD, SS, and EC) and mean SI. The mean SI of 21 sampling points had a negative correlation with T-N, NO_3-N, and EC. This implies that nitrogen concentration and dissolved matter tended to increase with low SI (unified to agricultural land). When we compared the correlation coefficients of T-N, NO_3-N, and EC with each combination of unit size and resolution, the correlation coefficients tended to be higher in 10 m resolution than in 100 m resolution, and also tended to be higher in the small unit size.

Table 2 Correlation coefficients of the relationships between water quality and mean Satoyama Index (SI). ** shows significance level ($p < 0.01$).

Water quality index		SI_ 10 m grid size Unit size				SI_ 100 m grid size Unit size			
		500 m	1 km	5 km	10 km	500 m	1 km	5 km	10 km
T-N	(mg/L)	-0.82**	-0.81**	-0.78**	-0.69**	-0.82**	-0.80**	-0.75**	-0.69**
NO_3-N	(mg/L)	-0.81**	-0.79**	-0.76**	-0.68**	-0.80**	-0.79**	-0.73**	-0.68**
T-P	(mg/L)	-0.32	-0.37	-0.34	-0.36	-0.36	-0.34	-0.33	-0.34
pH		0.18	0.12	0.10	0.01	0.14	0.15	0.13	0.03
BOD	(mg/L)	-0.41	-0.42	-0.42	-0.42	-0.41	-0.43	-0.38	-0.35
SS	(mg/L)	-0.06	-0.09	-0.07	-0.06	-0.05	-0.08	-0.06	-0.03
EC	(mS/m)	-0.83**	-0.84**	-0.79**	-0.73**	-0.82**	-0.81**	-0.75**	-0.69**

CONCLUSION

Herein, we analyzed the habitat diversity of 21 sites in the Tokachi River basin using the Satoyama Index (SI) and examined the relationships between the river water quality and SI. In the Tokachi River basin, the center (lowland) area had low SI and was dominated by extensive agricultural land, whereas the headwater of mainstream and tributaries had high SI and had rich habitat diversity. Mean SI of the 21 sampling points showed a negative correlation with T-N, NO_3-N, and EC. The nitrogen concentration and dissolved matter of the river water tended to increase in the sampling points dominated by extensive agricultural land. Also, it was suggested that the combination of 500 m unit size and 10 m resolution was optimal for explaining the relationships between SI and the river water quality.

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