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journal or publication title	Journal of Integrated Field Science
volume	6
page range	59-70
year	2009-03
URL	http://hdl.handle.net/10097/48783

Relationships between Land Use and River Nutrient in the River Basins of Kitakami River and Ishikari River Using Remote Sensing and GIS

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Keywords: Land use, River nutrient, River basin, Remote sensing, GIS

Received 4 March 2009; accepted March 23 2009

Abstract

Land uses of the Kitakami River and Ishikari River basins were determined using remote sensing and GIS, and the relationships between land uses and the nutrient concentrations of river water were investigated. The classes of land uses were as follows, coniferous forest (C-forest), broad-leaved forest (B-forest), paddy field (Paddy), cultivated field or grassland (Culti or Grass), low vegetation or bare soil (Low Vege or Soil), urban area (Urban Area) and water body (Water Body). There were positive correlations between the area rate of Paddy, Culti or Grass and Urban Area and, total nitrogen (T-N) and total phosphorus (T-P), and between Low Vege or Soil and T-N. There were negative correlations between B-forest and, T-N and T-P. The results suggested that N and P in the river water were mainly supplied from agricultural area and urban area more than forest. We compared the elemental ratio of the river nutrients with Redfield ratio, using existing report. The Si ratio was high in the both river comparing with Redfield ratio. Therefore, it was considered that the red tide of dinoflagellate was not caused easily in the coastal ocean near the mouth of the Kitakami River and the Ishikari River. It was suggested that the nutrients supplied from agricultural area and urban area were not cause of red tide and contributed to the growth of diatoms.

Introduction

Phytoplankton is a primary producer in the sea. The production is bigger in the coastal ocean than in the middle of ocean. Nitrogen (N), phosphorous (P) and silica (Si) are essential nutrients for phytoplankton, especially for diatom. In the coastal ocean, the main supply of these nutrients is considered river water. Such nutrients in the river water are influenced by the land use of the river basin. Therefore the relationships between land uses of river basin and the nutrients in the river water are important for the environment and fishery in the coastal ocean.

There are a lot of studies about relationships between land uses and river water or seawater as pollution at coastal ocean. For example these are urbanization (e.g. Yuan, 2008; Tang, 2005), soil erosion (e.g. Ning et al., 2006; Tanaka et al., 2003) and red tide caused by the excess supply of nutrients (e.g. Magnien et al., 1992; Cloern, 1996; Li et al., 2005; Livingston, 2007; Hayashi et al., 2008). However, it is said that the nutrients flowed out from broad-leaved forest are important for the phytoplankton in the coastal ocean. Therefore, it is necessary to study relationships between all land use of whole river basin and river nutrients as for the supply nutrients for phytoplankton from the land into the coastal ocean.

In this paper, we studied the relationships between land uses of whole river basin and the nutrients in the river water. The investigations of river water quality at the main river have been performed by the Ministry of Environment of Japan. We can use the results of those investigations. Therefore we use the concentrations data of T-N and T-P in the results. We analyzed land use of river basin using remote sensing and GIS.

Dinoflagellate is the main cause of the red tide that gives fishery damages. It is considered that diatom is dominant phytoplankton in the ocean when Si is rich, and the red tide that is the cause of dinoflagellate is not generated. However, when N or P is excess, dinoflagellate is dominant and causes red tide. The nutrients balance is important in the ocean. Therefore, we discussed that the nutrient contributed to growth of diatom or whether it caused the red tide.

Target Area

The target areas of the study were the river basins of the Kitakami River and the Ishikari River (Fig.1). The Kitakami River passes through in Iwate and Miyagi Prefecture in the northeast of Japan, and the river has the biggest river basin in Tohoku district of Japan. The distance of north-south and east-west is about 190 km and 100 km, respectively, and the area of the river basin is about 10,200 km^2. Most part of the Kitakami River basin is included in Iwate Prefecture. The annual average temperature is 10.0 centigrade and the annual precipitation is 1,254 mm in Morioka city that is the prefectural capital of Iwate Prefecture (Morioka meteorological observatory HP, 2008). The Ishikari River passes through the west of Hokkaido, and the river has the biggest river basin in Hokkaido. The distance of north-south and east-west is about 170 km and 200 km, respectively, and the area of the rive basin is about 14,500 km^2. The annual average temperature is 8.5 centigrade and the annual precipitation is 1,100 mm in Sapporo that is the prefectural capital of Hokkaido (Sapporo city office HP, 2008).

Used Data

The used satellite data are listed in Table 1. Landsat/TM or Terra/ASTER images observed in two seasons were used to make land use maps. The 50 m resolutions digital elevation model (DEM) was used to calculate the whole river basin and the river basin at each sampling point of river nutrients. The DEM data were produced by Geographical Survey Institute. The DEM of the Kitakami River basin was edited by Dr. Yokoyama of Iwate University. The river basin polygons separated into some small river basin were used to modify the river basin made from the DEM.

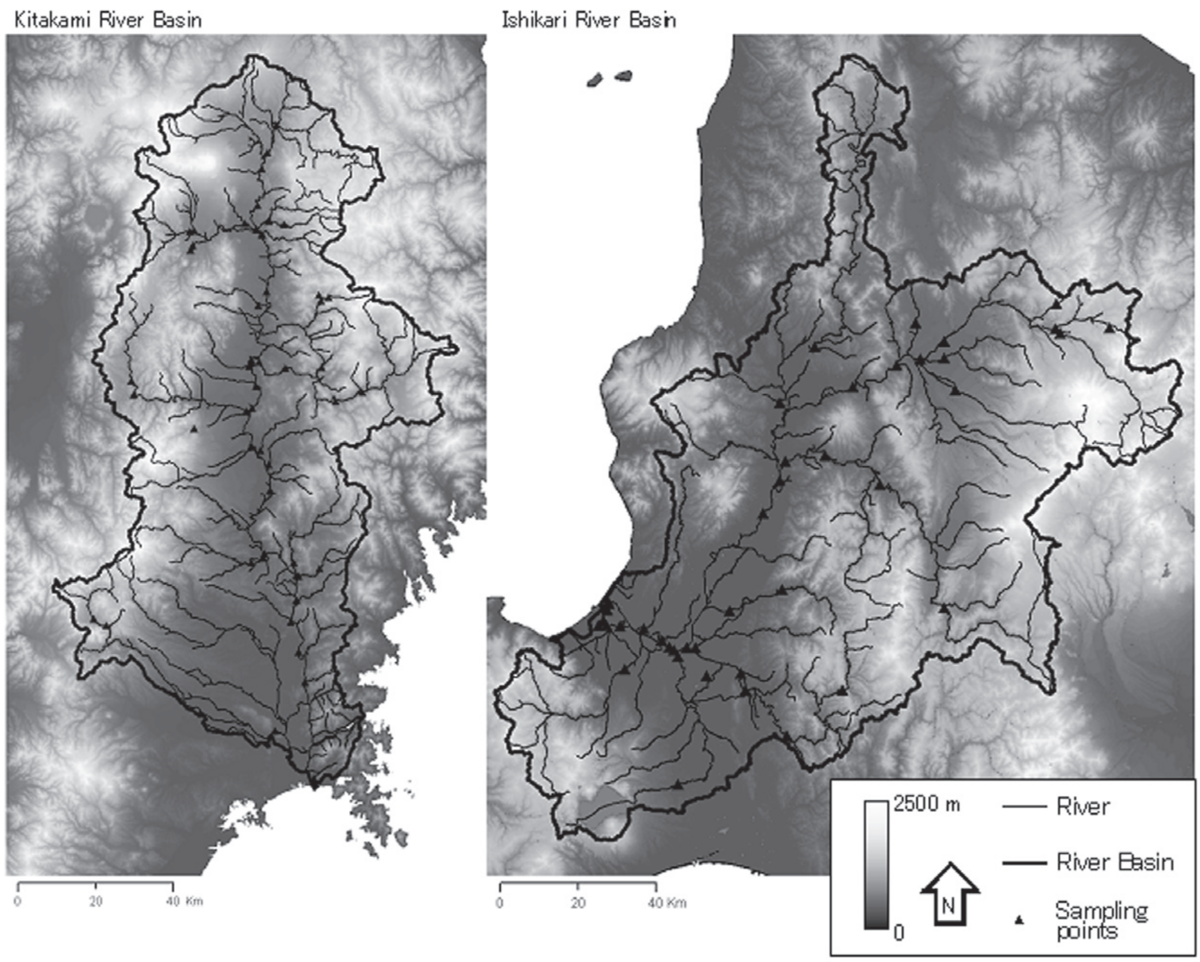

Fig.1. Location of the Kitakami River Basin and the Ishikari River Basin
The sampling points of river water were 55 points in the Kitakami River and 26 points in the Ishikari River.

Table 1. The used satellite data to make land use maps

	satellite/sensor	observed date	using band
Kitakami River Basin	LANDSAT/TM	11-Jul-00	1 - 4
	Terra/ASTER	21-Sep-00	1 - 9
		24-Oct-00	
		7-Jun-02	
		2-May-03	
		7-Jul-04	
Ishikari River Basin	LANDSAT/TM	12-Jun-95	1 - 4
		11-Jul-00	
	Terra/ASTER	18-Oct-04	1 - 9
		2-Jul-06	

That polygon data were downloaded from the website of Ministry of Land, Infrastructure, Transport and Truism in Japan (Ministry of Land, Infrastructure, Transport and Truism, 2007). The concentration data of total-nitrogen (T-N) and total-phosphorous (T-P) were downloaded from Ministry of Environment in Japan (Ministry of Environment in Japan, 2007). The river nutrients were investigated once in two months in the Kitakami River and once a month in the Ishikari River. There were 55 sampling points in the Kitakami River and 26 points in the Ishikari River. The points were listed in Fig.1.

Methods

Process of the methods was showed in Fig.2. First, Unsupervised classification was performed on the satellite images to make land cover maps. We interpreted the classes of land cover using spectral information. The land use maps were produced by the overlay method using the land cover maps of two seasons. We classed the land use map into 7 classes. They were coniferous forest (C-forest), broad-leaved forest (B-forest), Paddy field (Paddy), cultivated field or grassland (Culti or Grass), low vegetation or bare soil (Low Vege or Soil), urban area (Urban Area) and water body (Water Body). Culti or Grass included the vegetation area of riverside. Low Vege or Soil included the vegetation area around top of mountains. Second, river basins at each sampling point were produced using 50 m resolutions DEM and were modified using the polygon data of small river basins and a 1:25,000 topographic map. Third, the land use map was extracted by the basins of each sampling point and the area rate of land use of each river basin was calculated. Finally, the coefficients of correlation between the area rate of land use and the concentrations of T-N and T-P were calculated.

Results

The land use maps of the Kitakami River basin and the Ishikari River basin were showed in Fig.3 and Fig.4, respectively. The area rates of land use in the whole river basin of Kitakami River and Ishikari River were showed in Fig.5. In the Kitakami River basin, forest covered 68 %. C-forest was 30 % and

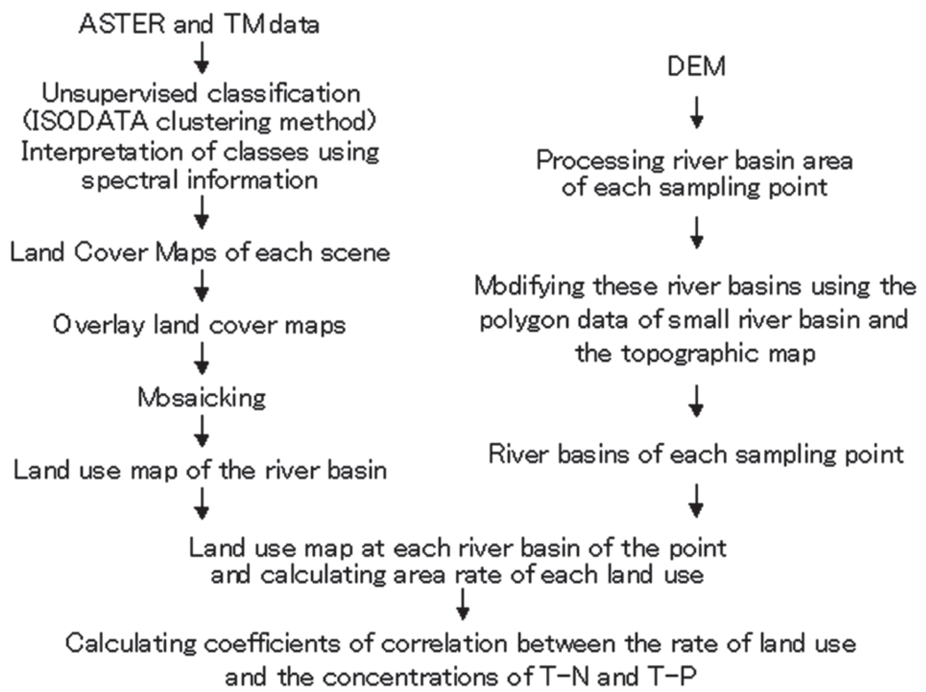

Fig.2. Flowchart of procedure

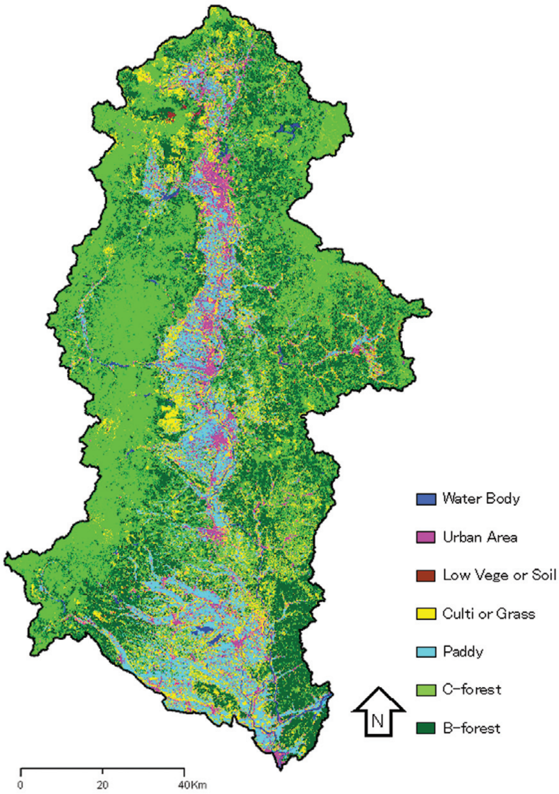

Fig.3. The land use map of Kitakami River Basin
The land use map was classed into 7 classes.

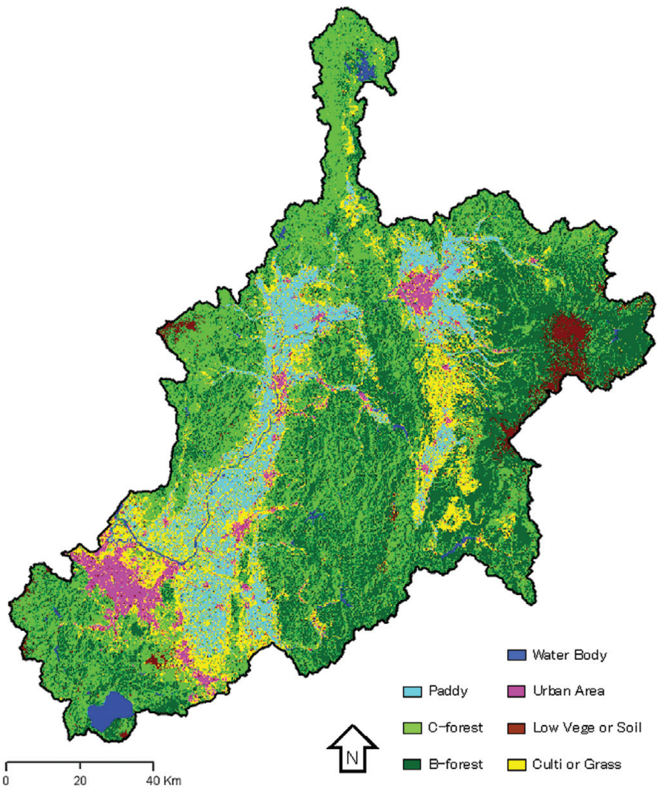

Fig.4. The land use map of Ishikari River Basin
The land use map was classed into 7 classes.

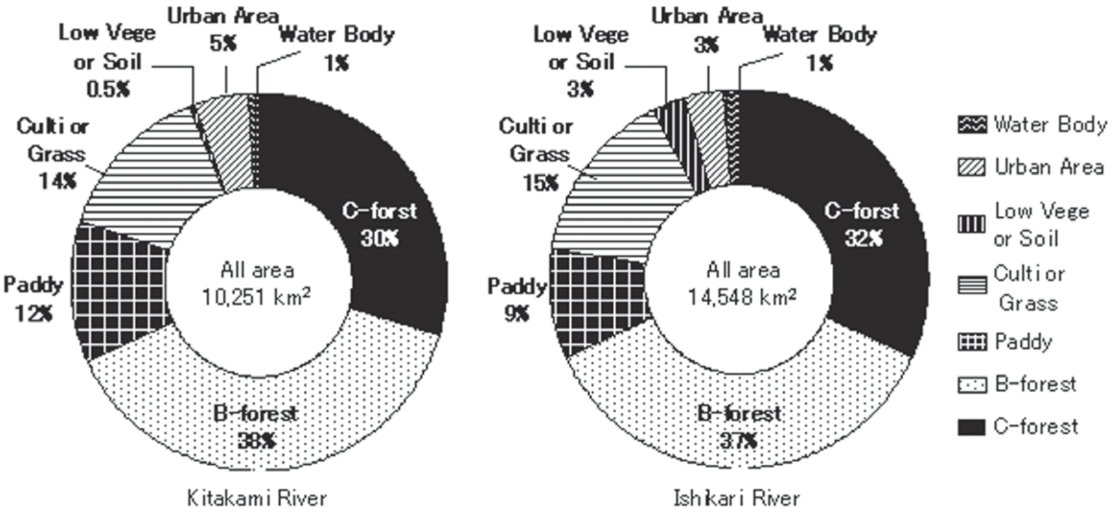

Fig.5. Area rate of land use in the Kitakami River basin and the Ishikari River basin

B-forest was 38 % in the river basin. Paddy, Culti or Grass, Low Vege or Soil, Urban Area and Water Body covered 12 %, 14 %, 0.5 %, 5 % and 1 %, respectively. Paddy and Urban Area are located in the middle part of river basin. Paddy and Urban Area were along the Kitakami River and were low and flat area. In the Ishikari River basin, the forest covered 69 %. C-forest was 32 % and B-forest was 37 %. Paddy, Culti or Grass, Low Vege or Soil, Urban Area and Water Body covered 9 %, 15 %, 3 %, 3 % and 1 %, respectively.

The relationships between the area rate of land use and, the elevation and slope were investigated (Fig.6). In the Kitakami River basin, most part of the Paddy and Urban Area distributed at 0-200 m of elevation and 0-5 degree of slope. The Culti or Grass distributed at 0-400 m of elevation and 0-10 degree of slope. The low elevation area was used to urban area and agricultural area, and the flat area more than 70 % in the low elevation was used as agricultural area. Culti or Grass of high elevation area was mostly used as pasture field. The area rate of B-forest increased with increasing of elevation and slope. However, the area rate of C-forest peaked at 201-400 m of elevation and 11-20 degree of slope. In the Ishikari River basin, most part of the Paddy and Urban Area also distributed at 0-200 m of elevation and 0-5 degree of slope. The Culti or Grass distributed at 0-400 m of elevation and 0-10 degree of slope. The Low Vege or Soil over 801 m of elevation and 21 degree of slope was considered the area around top of mountains. The B-forest distributed as same rate at 51-800 m of elevation and over 1 degree of slope. The area rate of C-forest increased with increasing of elevation and slope.

The coefficients of correlation between the area rate of land use and concentrations of T-N and T-P were showed in Table 2 and Table 3. The concentrations of T-N and T-P were the average concentrations of each period from 2001 to 2005 in Kitakami River and from 2003 to 2005 in Ishikari River. In the Kitakami River basin, there were positive significant correlations between the area rate of Paddy, Culti or Grass and Urban Area and, T-N and T-P. There were negative significant correlations between B-forest and, T-N and T-P. In the Ishikari River basin, there were also positive significant correlations between the area rate of Paddy, Culti or Grass and Urban Area and, T-N and T-P. There was negative significant correlation between B-forest and T-N. The Fig.7 and Fig.8 showed the relationships between the area rates of major land use and the concentrations of T-N and T-P in the Kitakami River and the Ishikari River basin. The concentrations showed the average at all periods in the Kitakami River and the Ishikari River. In the Kitakami River, there were high positive correlations between Culti or Grass and Urban Area and, T-N, Paddy and Urban Area and, T-P. There was high negative correlation between B-forest and T-N. In the Ishikari River, There were high positive correlations between Paddy, Culti or Grass and Urban Area and, T-N, and Paddy and Culti or Grass and, T-P.

Discussion

The positive correlations suggested that the concentrations of T-N and T-P were increased with in-

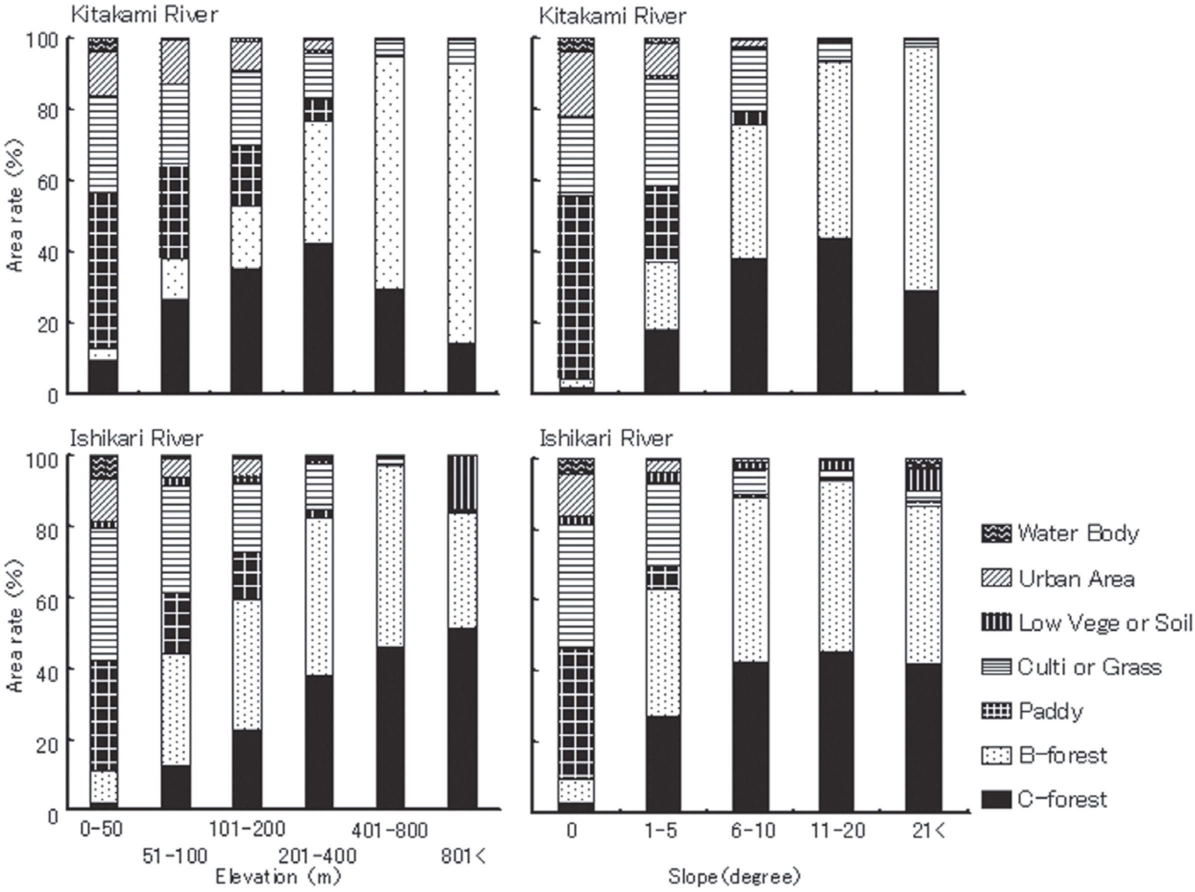

Fig.6. The relationships between the area rate of land use and the elevation and slope
The slope was calculated by the 50m DEM.

creasing the area rate of Paddy, Culti or Grass and Urban Area in both rivers. It was considered that the origin of the nutrients from the agricultural area was fertilizer, plant residual and livestock manure, and the origin from the urban area was domestic and industrial drainage.

At the Kitakami River, the negative correlations suggested that the concentrations of the T-N decreased with increasing the area rate of B-forest. It has been reported that the concentration of nitrogen in run-off water was lower than in the precipitation, that was because it was considered that nitrogen was used by trees and adsorbed to soil (Tokuch et al., 1991). Therefore, in our study, the nutrients of river water were decreased by the utilization of vegetation in a broad-leaved forest. On the other hand, at the Ishikari River, there was no correlation between the area rate of B-forest and the concentration of T-N. The B-forest distributed at low elevation and low slope area (Fig.6). B-forest, Paddy and Culti or Grass were mixed at the low elevation and low solpe. Therefore, it was considered that the effect of absorption of nutrients by B-forest was denied by the effect of these agricultural areas.

It has been reported that the concentration of T-N in the river water decreased with increasing of forest area in the region of subtropical monsoon climate in China (Yang et, al., 2007), and the nitrate levels decreased with increasing of the forest area or decreasing of agricultural land in the subtropical region of USA (Basnyat et al., 1999 and Basnyat et al., 2000). In those researches, they did not divide forest into coniferous forest and broadleaved forest. In our study, there were different results of correlations between B-forest and C-forest. There was negative correlation between B-forest and, T-N and T-P, but there was no correlation between C-forest and, T-N and T-P, in the Kitakami River (Table 2 and Fig.7). About 99 % of the broadleaved forest in Iwate and Miyagi prefecture was a natural forest and more than 90 % of the coniferous forest in these prefectures was an artificial forest (Ministry of Agriculture, Forestry and Fisheries, 2005). The C-forest distributed in lower area of slope and elevation than B-forest (Fig.6). The coniferous

Table 2. The coefficients of correlation between the area rate of land use and concentrations of T-N and T-P at the Kitakami River Basin

		C-forest	B-forest	Paddy	Culti or Grass	Low Vege or Soil	Urban Area
T-N	Apr-May	0.25	-0.65**	0.31*	0.62**	0.31*	0.61**
	Jun-Jul	0.30*	-0.48**	0.19	0.32*	0.45**	0.30*
	Aug-Sep	0.29*	-0.68**	0.39**	0.56**	0.39**	0.55**
	Oct-Nov	0.23	-0.72**	0.52**	0.63**	0.20	0.64**
	Dec-Jan	0.13	-0.67**	0.54**	0.64**	0.12	0.75**
	Feb-Mar	0.13	-0.69**	0.54**	0.68**	0.14	0.71**
T-P	Apr-May	-0.26	-0.43**	0.69**	0.56**	0.04	0.76**
	Jun-Jul	-0.11	-0.44**	0.65**	0.49**	0.02	0.47**
	Aug-Sep	-0.18	-0.38**	0.68**	0.45**	-0.05	0.44**
	Oct-Nov	-0.13	-0.43**	0.65**	0.51**	-0.10	0.52**
	Dec-Jan	-0.33*	-0.26	0.62**	0.39**	-0.09	0.62**
	Feb-Mar	-0.25	-0.39**	0.68**	0.52**	-0.04	0.63**

The sampling points were 55. The concentrations were the average from 2001 to 2005.
* 95% significant level, ** 99% significant level

Table 3. The coefficients of correlation between the area rate of land use and concentrations of T-N and T-P at the Ishikari River Basin

		C-forest	B-forest	Paddy	Culti or Grass	Low Vege or Soil	Urban Area
T-N	Apr	-0.08	-0.51**	0.57**	0.62**	-0.08	0.54**
	May	-0.23	-0.46*	0.76**	0.76**	-0.15	0.50**
	Jun	-0.06	-0.54**	0.61**	0.62**	-0.07	0.50*
	Jul	-0.30	-0.34	0.57**	0.71**	-0.16	0.64**
	Aug	-0.12	-0.49*	0.64**	0.68**	-0.11	0.53**
	Sep	-0.17	-0.33	0.52**	0.60**	-0.20	0.57**
	Oct	-0.19	-0.34	0.55**	0.63**	-0.19	0.59**
	Nov	-0.13	-0.50**	0.59**	0.63**	0.01	0.58**
	Dec	-0.13	-0.45*	0.57**	0.66**	-0.16	0.56**
	Jan	-0.18	-0.35	0.60**	0.58**	-0.13	0.53**
	Feb	-0.19	-0.33	0.60**	0.56**	-0.14	0.57**
	Mar	-0.25	-0.37	0.72**	0.69**	-0.20	0.53**
T-P	Apr	-0.16	0.00	0.18	0.32	-0.30	0.27
	May	-0.37	-0.04	0.44*	0.44*	-0.23	0.72**
	Jun	-0.49*	-0.06	0.54**	0.60**	-0.19	0.65**
	Jul	-0.58**	0.08	0.45*	0.59**	-0.28	0.57**
	Aug	-0.44*	0.04	0.46*	0.50*	-0.32	0.53**
	Sep	-0.10	0.13	-0.02	0.14	-0.37	0.26
	Oct	-0.37	-0.02	0.40*	0.55**	-0.32	0.52**
	Nov	-0.32	-0.13	0.42*	0.57**	-0.24	0.56**
	Dec	-0.21	-0.17	0.36	0.41*	-0.19	0.65**
	Jan	-0.31	-0.18	0.49*	0.47*	-0.10	0.73**
	Feb	-0.31	-0.18	0.51**	0.47*	-0.12	0.74**
	Mar	-0.30	-0.19	0.60**	0.47*	-0.16	0.64**

The sampling points were 56. The concentrations were the average from 2003 to 2005.
* 95% significant level, ** 99% significant level

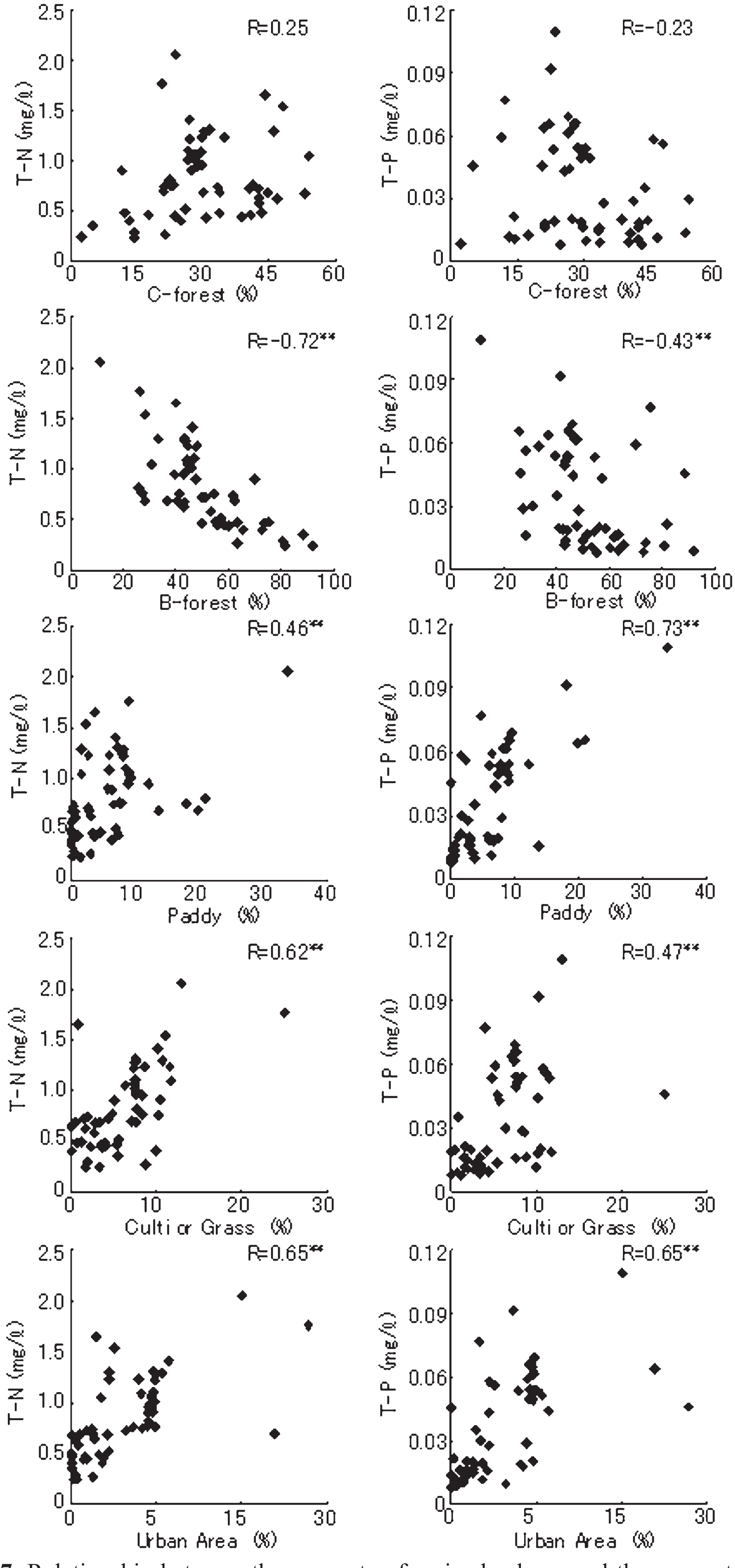

Fig.7. Relationship between the area rate of major land use and the concentrations of T-N and T-P at the Kitakami River Basin

The sampling points were 55. The concentrations were the average in all period from 2001 to 2005. * 95% significant level, ** 99% significant level

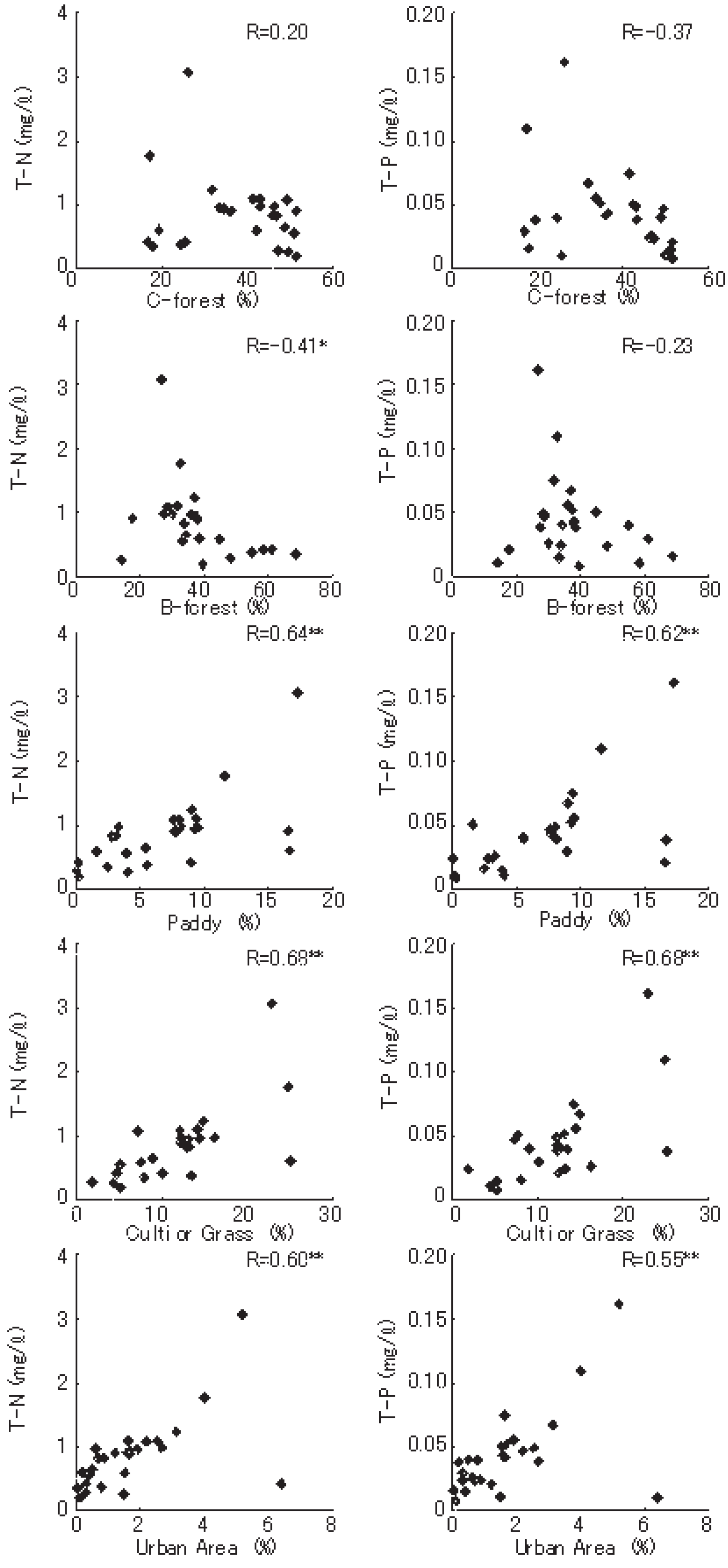

Fig.8. Relationship between the area rate of major land use and the concentrations of T-N and T-P at the Ishikari River Basin

The sampling points were 26. The concentrations were the average in all period from 2003 to 2005. * 95% significant level, ** 99% significant level trees are planted for timber production. Therefore the coniferous forest was afforested in the area of easy management. However, the artificial forest has not been managed and that caused the degradation of the coniferous forest, because of low price of the timber. It is suggested that the uptake of nitrogen by the coniferous tree is decreased and the nitrogen flows out to the stream in older coniferous forest (Ohrui et al., 1997). In the degraded coniferous forest, it was considered that the manure or compost was applied to the artificial coniferous forest for fertilizer and the uptake of nitrogen by the coniferous trees decreased, and the nitrogen flowed out to the stream.

The Redfield ratio is famous ratio of the nutrient balance for diatom. That is C : N : P = 160 : 16 : 1(Redfield et al., 1963). The growth of diatom is limited by the nutrient that is smaller than that ratio. We used the Redfield ratio including Si and Fe (Redfield et al., 1963; Martin et al., 1989; Harashima, 2003) for the nutrients balance and compared the Redfield ratio with elemental ratio in the Kitakami River and the Ishikari River water. We could not get the Si and Fe data of both river water, and we used the data reported by Kobayashi (1961). Two sampling points in the Kitakami River and four sampling points in Ishikari River in the Kobayashi's paper were the near points in this study. The Eai River is a branch of the Kitakami River, and the Yuubari River, Chitose River and Toyohira River are branches of the Ishikari River. The concentrations of nutrients and elements ratio were showed in Table 4. In the 1950s, the P ratio was lower than the Redfield ratio. Although N and P concentration have been increased in the 2000s, especially P increased, the P ratio was also lower than the Redfield ratio. In the 2000s, the Si ratio has been tenth than a part of the 1950s ratio. Nevertheless, Si ratio in the 2000s has been higher than the Redfield ratio's. Therefore, it was considered that the dinoflagellate did not easily caused red tide in the coastal ocean near the mouth of the Kitakami River and the Ishikari River.

Conclusion

The relationships between area rate of land uses and river nutrients were investigated in the Kitakami River and the Ishikari River basin. There were positive significant correlations between the area rate of Paddy, Culti or Grass and Urban Area and, T-N and T-P. There were negative significant correlations between B-forest and, T-N and T-P. It was suggested that the concentrations of the nutrients increased with increasing the area rate of agricultural area and urban area, and the concentrations decreased with increasing the area rate of broad-leaved forest. There were different results of correlations between B-forest and C-forest, because C-forest was an artificial forest and degraded. The results suggest that N and P in the river are mainly supplied from agricultural area and urban area more than forest. We compared the elemental ratio of the river nutrients with Redfield ratio, using existing report. The P ratio was lower than the Redfield ratio both in 1950s and 2000s. The Si ratio was high in the both river comparing with the Redfield ratio. It was considered that diatom was dominant species in the coastal ocean into which the Kitakami River and the Ishikari River flow. Therefore, it was suggested that the nutrients supplied from agricultural area and urban area were not a cause of red tied but also contributed to the growth of diatoms.

Table 4. The concentrations and elemental ratio of the nutrients in the Kitakami River water in 1950s and 2000s.

		1950s				2000s			
		NO_3-N + NH_4-N	PO_4-P	SiO_2-Si	Fe*	T-N	T-P	SiO_2-Si	Fe*
concentration (mg/ℓ)	Kitakami river	0.34	0.003	9.1	0.48	0.52	0.043	-	-
	Eai river	0.14	0.003	15.6	0.32	0.96	0.049	-	-
	Ishikari river	0.71	0.006	9.8	1.17	0.84	0.055	-	-
	Yuubari river	0.75	0.003	5.8	0.25	0.61	0.057	-	-
	Chitose river	0.12	0.006	15.6	0.01	1.70	0.076	-	-
	Toyohira river	0.25	0.003	9.8	0.22	0.40	0.055	-	-
elemental ratio	Kitakami river	229	1	3071	87	26	1	227	6
	Eai river	94	1	5233	58	42	1	339	4
	Ishikari river	238	1	1637	106	33	1	190	12
	Yuubari river	504	1	1943	45	23	1	109	3
	Chitose river	40	1	2624	1	48	1	221	0
	Toyohira river	168	1	3274	40	16	1	198	2
	Redfield ratio	16	1	16-50	0.003-0.035	16	1	16-50	0.003-0.035

*Fe shows the total Fe.
The concentrations of nutrients in 1950s were quoted from Kobayashi (1961), the concentrations of Si and Fe in 2000s were quoted from Kobayashi (1961). The concentrations of T-N and T-P were the average of all period from 2001 to 2005. The ratio of N and P were quoted from Redfield et al., 1963, Fe was quoted from Martin et al,. 1989 and Si was quoted from Hirashima, 2003. The Eai river is a branch of the Kitakami River. The Yuubari river, Chitose river and Toyohira river are branches of the Ishikari River.

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