[i]Relationship between the riverine nitrate-nitrogen concentration and the land use in the Teshio River watershed, North Japan

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Abstract: The present research investigated the relationship between nitrate-nitrogen (NO_3-N) in river water and the land use/land cover (hereafter land use) in Teshio river watershed located in northern Hokkaido island to understand the effect of human activities such as agriculture, forestry, industry and urbanization in the drainage basin on the river ecosystem quality and services. River water was sampled at nine points seasonally during a two-year period and nutrients concentration was measured. Land use profiles were estimated at two spatial scales-riparian and sub-catchment for each sampling station. The spatial pattern of water quality in the Teshio River showed increased NO_3-N levels associated with the agriculture and urban expansion, and forest reduction in the watershed. Land use at the riparian scale closely reflected that at the sub-catchment scale, which masked the unique riparian buffer effect on the river water condition. The high agricultural and reduced forest area in the riparian zone, especially in the upper middle reach, could be a possible reason for the decline of ecosystem service for provisioning of clean water and habitat for aquatic organisms. Measures towards sustainable and more nature-friendly agricultural management are necessary in the area to protect the Teshio river ecosystem and its ecosystem services.

Key words: GIS, NO_3-N, land use, Teshio basin, ecosystem services.

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Introduction:

These days, the ecosystem services framework is gaining popularity among scientists studying natural systems, and its principles are widely recognized as a big step on the road to sustainability. Ecosystem services are the environmental processes from which humans benefit and can be generally separated into the following categories: provisioning, regulating, supporting and cultural (Millenium Ecosystem Assessment, 2003). Some examples of these services are: provisioning clean air and water, moderating weather extremes, pollinating crops and natural vegetation, controlling pests and other disease-carrying organisms, maintaining biodiversity. Often it is assumed that these life-supporting ecosystem services are granted and everlasting. However, wide spread anthropogenic activities like agriculture, urbanization, industry, and deforestation have already negatively impacted the functioning of diverse ecosystems world-wide, and thus are corrupting the services they provide along with the human benefits associated.

Like all ecosystems, rivers and streams provide bundled ecosystem services such as purifying water, maintaining cycling of nutrients, providing habitat for the aquatic organisms, pollution dilution, flood control, food provision, sediment transport and recreation. At the same time running water has been most frequently a subject to human exploitation and alteration. Rivers are open ecosystems, which depend unequally on their surrounding terrestrial landscape. That is why, the river ecosystem condition can be dramatically affected by land use changes and its consequent decline leads to a decline in the services it provides. This is the reason why it is essential to re-consider the actual value of the ecosystem services and consciously look after and maintain them, so that both human benefits and nature systems health can be sustained. Understanding the dynamics of ecological processes associated with ecosystem services is essential in helping the decision makers move towards management solutions in a more practical and sustainable way.

Anthropogenic activities most often altering the rivers are connected with release of polluted water, channelization, water extraction and construction of impoundments. Pollution can have point and non-point (diffuse) sources. Problems caused by the former one can be easily solved with the building of adequate waste water treatment plants. However, the struggle with the diffuse source pollution is difficult and focused on land and run-off management practices (Campbell et al., 2004) and it remains a major environmental topic in most developing and developed countries.

Agricultural runoff is one of the major sources of pollutants to the aquatic habitats (Allan, 1995). Agricultural areas are usually characterized with elevated concentrations of aquatic nutrients and sediments(Bellos et al., 2004; Johnson et al., 1997; Osborne and Wiley, 1988), increased soil and river bank erosion, as well as disconnection and reduction in riparian forests within the drainage area(Stauffer et al., 2000), which all lead to a decline in the water quality. Although NO_3-N in the natural waters is the most abundant nitrogen species and usually has low concentrations (Basnyat et al., 2000), agricultural activities, which are often related to excess fertilizer application lead to increased levels of this nutrient in-stream (Basnyat et al., 2000; Bellos et al., 2004; Herlihy et al., 1998; Johnson et al., 1997). In rural areas like this study site, the Teshio river basin, agricultural land use can be of a great importance to the aquatic ecosystems condition. Nakamura and Yamada (2005) already have reported that one of the main sources of water pollution in Hokkaido are cattle manure and pasture fertilization.

Nutrient export to running waters is conditional on landscape features like hydrology, climate, underlying bedrock, topography, soil type and land management practices. However, within the annual natural cycle, the land use within the catchment is of the greatest significance when considering diffuse source pollution effect (Worrall and Burt, 1999).

The fast development of the Geographic Information System (GIS) and the ready availability of land use data favored their incorporation into a large number of environmental studies; predominantly studies investigating the relationship between land use and water quality (Allan et al., 1997; Basnyat et al., 2000; Herlihy et al., 1998; Maillard, 2007; Pan et al., 2004; Rodriguez et al., 2007; Wang and Yin, 1997; Williams et al., 2005). Landscape indicators at the scale of the local riparian zone, as well as the scale of the entire catchment have been proven to be useful predictors of water chemistry variables (Ahearn et al., 2005; Johnson et al., 1997; Osborne and Wiley, 1988; Strayer et al., 2003; Williams et al., 2005). The ecological stream variables are controlled by diverse processes operating at different spatial and temporal scales, and thus could be expected to have different reaction depending on the landscape factors` scales. Each water quality factor can have a distinct pattern with respect to distance from water course (Maillard, 2007). Land use throughout the entire catchment rules stream hydrology, and it has a strong impact on the nutrients in river water. On the contrary, while emphasizing the disproportionately large role of the riparian zone for the stream conditions some authors maintain that when examining water quality-watershed characteristics relationship only near stream land use should be considered (Osborne and Wiley, 1988). In accordance with this statement, often in studies investigating the response of the aquatic biota (fish populations, macroinvertebrates integrity etc.) or in-stream habitat condition, the land use in the local riparian zone was the leading factor (Inoue et al., 1997; Pan et al., 2004; Stauffer et al., 2000). However, when investigating water chemistry and particularly nutrients, the watershed scale seems to be more appropriate (Williams et al., 2005). Several researchers reported the almost equal ability of both- riparian and entire sub-catchment scales to predict nitrate-flux, while the local reach area (riparian buffer zone limited from hundred meter to several kilometers upstream a study point) were poor predictors (Dow et al., 2006; Dow and Zampella, 2000). Based on these grounds, we investigated the land use at two spatial scales: riparian and sub-catchment.

There are now few world rivers which remain unregulated by various water works along their water course. Dams affect the river condition for some distance downstream, and convert the naturally free-flowing running water ecosystem into discontinuous segments, which disturbs the populations of all aquatic organisms, especially migratory fish (i.e. affecting the local biodiversity) (Allan, 1995).

The object of the present study was to examine the relationship between the stream nutrient concentrations (particularly NO_3-N) and the land use in the Teshio River basin by comparing the spatial pattern of aquatic chemistry and land-use at two different spatial scales (riparian and sub-catchment). For this rural watershed we expected that the agricultural activities would produce a detectable variation in nutrient concentrations in an otherwise homogenous landscape.

Materials and methods:

Study area

The Teshio river system drains an area of 5,590 km^2 in the northern part of Hokkaido Island, Japan (Fig. 1). It is the fourth longest river in Japan (256 km) and has an average discharge of 176 m^3/s. The Teshio basin is one of the least densely populated (17.7 no/km^2) in the country and its river water quality is very high among the major Japanese rivers (data: Ministry of Land, Infrastructure and Transport of Japan, 2003 http//:www.mlit.go.jp/river/jiten/nihon_kawa/index.html cited by Yoshimura et al., 2005)

The majority of previous studies on large rivers have focused on polluted river ecosystems; nevertheless studies in less affected rivers such as the Teshio River can be important for future sustainability-oriented management decisions and thus contribute towards conservation of the river ecosystem services. The river takes its source from the Mt Teshio (1,558 m a.s.l.) and starts flowing through a steep mountainous relief. The middle reach drains mountain forests as well as some even areas, where agriculture has been developed (Kenbuchi area, Shibetsu area, Nayoro area). The lower reach runs through a wide valley with pasture and agricultural land and finally mouths into the Sea of Japan.

The climate in the area is cool and relatively humid with an annual average temperature of 5.2 °C and the amount of precipitation at around 1,100 mm (>30 % snow)(measured at Bifuka station (part of the Automated Meteorological Data Acquisition System) as representative of the study region (1979-2000); (data: Japan Meteorological Agency, http://www.data.jma.go.jp) . The driest period of the year is the summer. Hokkaido rivers which flow into the Sea of Japan have annual flow regimes that can be characterized by one main flow peak in the spring during the snow-melt, and a second smaller peak which may occur between late summer to early autumn (Sakaguchi, 1986). The dominant soil types in the whole Teshio watershed are Dystric Cambisols with Haplic Podzol patches followed by

Eutric/Dystric Fluvisols close to the water course. In the upper middle reach there is a wide spread area with Eutric/Dystric Fluvisols, Dystric Gleysols and Haplic Alisols. Eutric/Dystric Fluvisols can be seen in the lower reach as well, together with Fibric Histosols (The group of Japanese Pedologists 1990).

The vegetation in the region is geobotanically regarded as a mixed forest, changing from a deciduous forest of the cool temperate zone to an evergreen coniferous forest of the boreal zone. The dominating species are *Abies sachalinensis, Picea jezoensis, Quercus crispla, Acer mono, Tilia japonica, Betula sp. and Sasa sp..* In the serpentine area of the mountainous region *Picea ghlenii* is dominating (Nakata and Kojima, 1987).

The Teshio river system provides a habitat for three species of salmon: masu (*Oncorhynchus masou masou*), pink (*O. gorbuscha*) and chum salmon (*O. keta*). As with most rivers in Japan, a viable fish population can only be sustained if large numbers of young fish are introduced every year (Yoshimura et al., 2005). The salmon populations are declining in the rivers of northern Hokkaido. Inoue et al (1997) investigated the relationship between the abundance of juvenile masu salmon and the stream habitat condition in two tributaries of the Teshio river network. The two limiting factors – high water temperature and cover availability- were strongly associated with the presence of riparian forest, highlighting its importance for the salmon population. Masu salmon spawn in headwater tributaries and this makes them highly dependent on the river habitat, and in this way very sensitive to any human-induced disturbances in the catchment. Inoue et al (1997) concluded that the elimination of riparian forests in northern Hokkaido is expected to negatively affect residual masu salmon populations to a large extend.

In 1970 Iwaonai dam was constructed in the upper reach of the Teshio River. It drains an area of 331 km^2 and has an effective capacity of 96,300 x10^3 m^3. It is a multipurpose dam that serves for flood control, irrigation, city and industrial water supply and electrical power generation (http://www2.river.go.jp/dam/index.html).

Water sampling and chemical analysis

During a two year period (2006, 2007) river water was sampled seasonally (May, July, October and December) at 9 stations in the Teshio river network. Seven of the sampling sites were situated on the main stem (from the headwaters-st.1 downstream to st.7 near the estuary) and the rest two sites were located at two of the main tributaries (st.8 at Kenbuchi River and st.9 at Nayoro River). River water was sampled from the surface water column in the mid-channel using a plastic bucket. Both the bucket and the sample polyethylene containers were pre-rinsed with river water twice and then the samples were collected. Water temperature

(Compact thermometer, Horiba Co. Ltd.,Japan), pH (Twin PH B-213, Horiba Co. Ltd., Japan) and electric conductivity (Twin Cond B-212, Horiba Co. Ltd., Japan) were measured on site at each station. Immediately afterwards they were cool stored and transported to the local laboratory in Nayoro city. After freezing at -20 °C, samples were transported to the Sapporo laboratory and thawed at room temperature. After pressure filtration through a 0.45 µm membrane Millipore filter (Millipore Corporation, Billerica, USA) the water samples were analyzed for NO_3-N, NO_2-N, NH_4-N and PO_4 using Flow Injection Analyzer (FI-5000V FIA, SNK, Japan). Stream nutrient concentrations have shown to be more appropriate than nutrient loadings (Osborne and Wiley, 1988), when the focus is on the water quality. That is why our data is reported as in-stream concentrations (mg L^{-1}).

Land use

Land use data for the study area was obtained from the National and Regional Planning Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan based on National Land-related Information (1997) Land-use 3rd mesh. The mapping resolution for this data is 100m. Based on a Digital Elevation Model (50 x 50 m resolution; Geographic Survey Institute 1999), the sub-catchment areas for each sampling station (i.e. the drainage area upstream each station) were delineated and clipped onto the land use map. In the beginning the data included information from 11 land use categories (Fig. 2) and namely ocean, barren land, coast, forest, urban area, farm land, paddy field, water body, roads, golf course and others. Because of their small area the ocean, coast, water body, golf course and others categories were merged into class “others”. Farm land and paddy fields were unified to a single “agriculture” class based on their close characteristics. Finally we had 5 land use classes: forest, barren land, agriculture, urban and others, which were used (except “others”) in the statistical analyses. We picked out the total area of each land use type as the simplest metrics to characterize the landscape (Rodriguez et al., 2007). Using ArcView 9.0 (ESRI Co. Ltd, Redland, CA, U.S.A.), the area of each land use type within the sub-catchments and its percentage were calculated. Buffer analysis was performed to extract the land use profiles in a 200 m zone along both sides of the river within each sub-catchment and the percentages for each land use type were calculated (Johnes and Heathwaite, 1997; Williams et al., 2005). This made possible the comparison between the land use pattern at two spatial scales- sub-catchment and riparian. We used 1997 land use due to the data availabilities. The time lag between the land use and stream chemistry may cause uncertainties for the actual land area in each land-use, but should not be misleading for the general spatial pattern in the whole basin in our results.

Estimation of Residual N

According to Mishima et al. (2001) the surplus nitrogen from the Japanese agriculture brings potential of environmental risk for eutrophication of groundwater and river water. As an estimation of the surplus nitrogen from farmland Mishima utilizes the term “residual nitrogen (residual N)”, which is defined by the difference between the nitrogen inputs into a farmland (manure, chemical fertilizers, nitrate from rain, irrigation and nitrogen-fixation) and the nitrogen outputs through crop harvest, crop by-products and denitrification. By means of a mass balance model using data in 1997 (Mishima et al., 2001) the residual-N amounts (MgN) for the major areas in the Teshio basin were calculated.

Statistical analyses

One-way analysis of variance (ANOVA) was applied to compare the NO_3 –N means between the sampling stations and between the sampling seasons. The similarity between land use profiles for the riparian and sub-catchment scales was examined using correlation analysis. The same was done for the sub-catchment profiles between all land use types. Again, Pearson product-moment correlation coefficients for each sampling station were calculated between the mean NO_3-N concentrations and each land use type percentage to estimate the linear relationships between water chemistry and landscape characteristics and pair-wise comparison among them was made. The grouping among the sampling stations according to their water chemistry was investigated with the help of Hierarchical cluster analysis.

Results:

I. River quality

During the investigated period, the water temperature varied from 0 °C in December to 24 °C in July. In general, the upper reach stations (st.1 and st.2) showed lower values than the middle and lower reach stations. This difference can be distinctly seen in summer (July months during both investigated years). The EC ranged between 39 µS/cm at st.1 (headwaters) in May 2007 and 4,000 µS/cm at st.7 (estuary) in July 2006. Generally, EC had its peaks at the estuary station (st.7), but other smaller peaks could be observed at st.3 in December (2006, 2007) and July (2007). In all cases pH was within the values favorable for the aquatic organisms (6.5-8). Higher pH was measured in July and lower during December for both years.

As for other rivers, NO_3-N was the most abundant inorganic form of nitrogen in the Teshio river water (Figures 3 and 4). NO_3-N concentrations in the river water ranged between 0.08 mg L^{-1} at the estuary station (st.7) in July 2007 and 1.54 mg L^{-1} at the upper reach station (st.2) in October 2006. The lowest mean NO_3-N concentration of 0.17 mg L^{-1} was estimated for the headwaters st.1. Then downstream up to st.3 the concentration increased abruptly and reached its peak mean value (0.6 mg L^{-1}). Further down the peak station 3, the mean NO_3-N values gradually decrease up to the estuary (0.38 mg L^{-1}, st.7) The NO_{3-}N concentrations at st.2 also showed high values with the largest temporal fluctuation during the sampling period with extreme maximums in May (2007) and October (2006,2007). Since these large fluctuations decreased the significance of the statistical analysis for temporal and spatial NO_3-N pattern for this station, st.2 was excluded from all the statistical analyses (the reason for which is discussed later). We applied one-way ANOVA to explore the spatial variation of NO_{3-}N means. It resulted in significant difference between the stations means ($F_{7, 53}$=2.466, p<0.05). Tukey-Kramer HSD test showed that the mean of st. 1 is significantly lower than that of st.3 (p<0.05).

Basically, the seasonal pattern was governed by higher mean concentrations in October and December and the lowest in July (Fig. 3). The mean NO_3-N concentrations for the different seasons were significantly different ($F_{3, 57}$=12.269, p<0.0001) and as follows: May-0.3 mg L^{-1}, July-0.2 mg L^{-1}, October-0.6 mg L^{-1} and December-0.54 mg L^{-1}. All pairs Tukey-Kramer HSD test denoted that the October and December means were significantly higher than those in May and July (p<0.05).

NO_{2-}N was present in the river water in very low concentrations averaging at 0.008 mg L^{-1}. Similar to NO_{3-}N concentrations, higher NO_{2-}N concentration values can be noticed at st.3.

Even though the NH_4-N and PO_4 concentrations were often below the detection limit some peak NH_4-N values were still detected at st.3 especially in December.

Estimation of Residual-N

The residual-N estimates for the headwaters area (around st.1) were as low as 108 MgN y^{-1}. High residual-N values were found downstream in the upper middle reach area (close by st.3 and st.8), where the agriculture and especially paddy fields are well developed (reaching a maximum at 1,113 MgN y^{-1}). In the lower reach region where less portion of agriculture is concentrated near the stream, the residual-N values decrease to 77 MgN y^{-1}. In the estuary section (st.7 area) with extending farmland and pastures defined by the flat topography with cool and wet climate a slight increase in estimated residual-N was located.

Land use profiles

GIS analysis at the sub-catchment scale showed that the major land use types in the Teshio River watershed were forest (56-80 %), agriculture (0-31 %) and barren land (7-22 %) (Fig. 2), which appears to be common for other river basins as well (Herlihy et al., 1998; Xie et al., 2005). For the riparian zone, the percentages were only slightly different and as follows; forest (41%-83 %), agriculture (0-45 %) and barren land (5-17 %). Riparian urban area was small (2 %), but higher than the sub-catchment one (1%). Comparison of the land use profiles between the two spatial scales showed an increase in the agricultural and urban area in the ecotone riparian zone at the expense of decrease in forest and barren land, which illustrates the tendency for anthropogenic activities to concentrate near the water course.

For the upper reach stations (st.1 and 2), the forest and barren land (i.e. natural land cover types) spread over almost the entire landscape with negligible anthropogenic activities (agriculture and urban less than 3% at st.2). A big change in the land use pattern is typical around st.3, where forest was still the prevailing land use type, but the cultivation and settlements increased significantly especially in the riparian zone (36 % and 2 % respectively). Downstream the st.3 the land use analysis showed slightly varying and less human-impacted profiles,; however in general the land use pattern remained the same with average of 19 % (sub-catchment) and 31 % (riparian) for the agriculture. Opposite from the main stream the landscape attributes between the two investigated tributaries contrasted within both spatial scales. Particularly at the riparian buffer scale, the upper middle reach tributary (st.8) had the highest agricultural percentage (45 %) for the entire study basin as opposed to the 18% of agriculture for the lower reach tributary (st.9). On the contrary, the forest percentage for st.8 (41%) was much lower than the one for st.9 (37%).

A comparison of the land use profiles between the entire sub-catchment and local riparian zone by Pearson product-moment correlation analysis showed a significant correlation between them ($r=0.96$, $p<0.0001$, $n=43$). In other words, the riparian buffer mirrored closely the land use pattern of the sub-catchment scale as also reported for other river basins (Johnson et al., 1997). As a consequence of this, further statistical analyses using each scale produced almost identical outcomes and only the results using the sub-catchment scale will be presented. A correlation matrix between each pair of land use types revealed that each of the "natural" land uses (forest and barren land) are significantly and negatively correlated to the anthropogenic land use types (agriculture and urban). A strong positive correlation($r=0.95$, $p<0.001$) also existed between the anthropogenic land use types themselves (i.e. between agriculture and urban area).

Relationship between land use and water quality

The relationship between land use and NO_{3}-N was determined by Pearson correlations. Multiple comparisons among the calculated correlation coefficient showed that the highest positive correlation was between the NO_{3}-N and the agricultural land in the sub-catchment ($r=0.92$, $p<0.01$) (Fig.5). Similar was the magnitude of the NO_{3}-N -urban area correlation ($r=0.86$, $p<0.01$). Negative correlation was characteristic between the NO_{3}-N and the forest percentage ($r=-0.86$, $p<0.01$). Only the negative correlation with the barren land was insignificant.

After one-way ANOVA showed significant difference between the NO_{3}-N means among the different sampling stations, we explored further the spatial pattern in NO_{3}-N concentration with the help of Hierarchical cluster analysis (Fig. 6). The analysis resulted in the formation of three distinguished clusters. The headwater station (st.1) together with the lower reach tributary (st.9) constituted the first cluster. The second cluster comprised of the upper middle reach stations (st.3 and st.8). The rest of the middle and lower reach stations (st.4, 5, 6 and 7) were combined in the third cluster.

Discussion:

The highest NO_{3}-N concentrations were detected in the upper middle reach area (st.3 and 8) which has the highest percentage of agricultural area. The cultures there are mostly paddy fields and farmland, which are developed in the region because of the appropriate topography and soils. Tabuchi and Ogawa (1995) discussed that rice fields often contribute to the NO_{3}-N (nutrients) concentrations in the receiving river ecosystems due to the large amounts of excess fertilizer and waters released. Excess fertilization in farmland has also been shown to affect in-stream conditions (Johnson et al., 1997, Osborne and Wiley, 1988). Most probably the agricultural practices in the st.3 and st.8 region were also associated with excess fertilizer application as implied from their high values of residual-N estimates, which were washed into the nearby river at the appropriate hydrological conditions. This resulted in an increase in the aquatic $NO_{3-}N$ concentrations, which is threatening for the river ecosystem health (Matson et al., 1997). Another fact that might contribute to the increased $NO_{3-}N$ in the upper middle reach section is the spatial arrangement of the agriculture near the water course (O`Neil et al., 1997 cited by King et al., 2005) and the proximity of st3, in particular, to the confluence of the tributary with highly developed agriculture (st.8) . Other water quality parameters such as Electric conductivity, NO_2-N and NH_4-N also showed high concentrations at st.3, which illustrated once again the strong agricultural impact on the water quality in this area (Johnson et al., 1997). Downstream of st.3 the $NO_{3-}N$ concentrations slightly decreased in according with the slight decrease in the agricultural and increase in the forest percentage.

Pasture land is widely spread in the large estuary plain of the Teshio River in conformity with the lowland topography and soil. Interesting for this region is that the estimated residual-N does not affect the river $NO_{3-}N$ concentrations the same way it affected them in the upper middle reach, Possible mechanisms working towards decreasing the in-stream $NO_{3-}N$ concentrations in this area could be the river self-purification ability, which is supported by the increased retention time (slower water current) and the dilution caused by the large amounts of water mass typical for the lower reaches. Another reason could be the great number of wetlands in the estuary region, which also have water clarifying and retaining nutrients effect (Johnston et al., 1990). Another important phenomenon detected for the estuary area (st.7) is the strong influence of the sea. The mixing of sea water with the river fresh water, especially profound in the summer (July), caused huge peaks in the dissolved salts concentration (measured by electric conductivity).

According to the NO_3-N data from the sampling period, st.2 had very unstable behavior. Extreme peaks were detected in May (2007) and October (2006, 2007). The station was suggested to be influenced by the Iwaonai dam, which is situated several kilometers above. The dates with abrupt NO_3-N concentration maximums corresponded to zero discharges from the dam; i.e. no water was released from the dam on these days, which caused the increase of riverine NO_3-N. During the rest of the sampling events there were normal water discharges coming from the reservoir, which exerted a diluting effect on the aquatic NO_3-N concentrations at the below river station (st.2). Based on these analyses, it was suggested that the high temporal fluctuation in NO_3-N concentrations at st.2 was governed by the above reservoir operation manner, which obscured the land use influence and reasoned the exclusion of st.2

from the above-mentioned statistical analyses. The small peak of the water temperature observed at this site could also be associated with the near dam effect.

Many researchers have reported that river chemistry is highly related to the land use characteristics of the drainage area (Johnson et al., 1997; Maillard, 2007; Williams et al., 2005). In accordance with previous researches (Basnyat et al., 2000; Harding et al., 1999), our results showed that along the river water course, forested and lacking human impact headwater areas contribute clean river water with low concentration of NO_3-N, while the agricultural areas downstream impact the river water quality with contributing water with increased NO_3-N levels. The main agricultural activities along the Teshio basin are rice and vegetable production in the middle reach section and pastures in the downstream areas.

Even though the urban area portion is very low, it exerts a disproportionately large impact detected by its high correlation with the NO_3-N concentration. The nutrient retaining and water purifying function of the forest was suggested by the strong negative correlation between its percentage and the NO_{3-}N concentration.

In our study, the land use in the riparian zone had similar pattern with the land use in sub-catchment, which led to their similar effect on the NO_{3-}N spatial change. Possible explanation for this resemblance is that the natural underlying template determines the respective land use. In other words, the land use is indicative for other environmental factors such as the underlying topography, geology, soils and hydrology. As a result, the unique effect of the riparian zone on the responsible variable remained indistinguishable from the sub-catchment scale effects (Johnes and Heathwaite, 1997). Another reason for the similarity between the riparian and sub-catchment land use might be the coarse resolution of the available land use data.

Another spatial consideration that should be mentioned when interpreting the results is the autocorrelation within the land use types. Usually, the different land use types are summarized using percentages summing up to 100%, which inevitably leads to their inter-dependence (King et al., 2005). As a result, several land use types may predict the stream condition equally well (Herlihy et al., 1998). The same statement is applicable for our study. Indeed, in the Teshio basin the increase of anthropogenic land use types - agriculture and urban- led to the decrease of the "natural" forest and barren land types; i.e. they had a negative correlation. Thus the effect on NO_{3}-N concentrations should be shared between both these factors (Strayer et al., 2003).

Most of the studies dealing with the land use-river condition relationship contrast varying extents of agricultural, urban and natural land (Rodriguez et al., 2007). On the contrary, the

Teshio basin did not have a steep land use gradient and the agricultural land use is around 20% for most of the river landscape. On the other hand, Fitzpatrick (2001) cited by Allan (2004) described that a decline in fish IBI occurs at >30% agriculture in the catchment and only 10 %-20 % for the riparian buffer area. In the Teshio River basin most of the land use profiles at the riparian buffer scale had much higher percentage of agriculture than the designated by FitzPatrick (2001), with an average of 31 %, and having its peak-45 % at st.8. This high agriculture percentages that we ascertained together with the forest decrease reported for Hokkaido from other authors as well (Nakamura and Yamada, 2005) is already threatening the ecosystem services like provisioning habitat for salmon (Inoue et al., 1997).

Significantly higher October and December values along with the lowest values detected in July define the seasonal pattern of NO_3-N concentration in the study area. Surface runoff is the major source of non-point pollution which makes hydrology the leading factor controlling the linkages between a drainage basin characteristics and in-stream condition. During high precipitation runoff periods a strong hydrologic connectivity exists between the landscape and the river flowing through it, which makes the effect of land use more evident (Johnson et al., 1997). For the present study, such high run off periods were the October and December months which had significantly higher NO_{3}-N concentrations. The reason for this most likely is the flushing of excess fertilizers, mineralized organic matter (plant die back), and the low biological activity typical for this season (Bellos et al., 2004). Low water flow in December, when most of the precipitation is snow, may explain the increase of aquatic NO_{3}-N concentrations in winter. The spring snow-melt run off, which may wash out over-wintering products could explain the higher May than July NO_{3}-N concentrations. Similarly to previous studies that attributed the low inorganic N concentrations during the growing season to the more active bioprocesses of vegetation uptake and denitrification in soil, streams and riparian zones, the Teshio River`s low July NO_3-N levels can also be partially due to the same phenomenon (Arheimer and Liden, 2000) together with the low precipitation.

The results from the station clustering according to their mean NO_{3}-N concentrations illustrated once again the connection between the river chemistry and agricultural activities (or forest decrease). The areas with the most intensive agriculture, consequent high residual-N and NO_3-N values- st.3 and st.8 formed the first cluster. The second cluster combined the stations with the cleanest water (st.1, st.9-low residual-N and NO_{3}-N level), which correspond to their “natural” landscape. All the other middle and lower reach stations (st.4, 5, 6 and 7) comprise the third cluster, united by their moderate anthropogenic impact and consequent moderate nitrogen levels.

Conclusion:

Based on our results we can conclude that there is a strong relationship between the riverine NO_3-N concentration and the land use pattern in the Teshio River watershed. The increased agriculture and reduced forest cover were associated with increase in the NO_3-N concentration in the river water. The land use profiles of the riparian buffer in the Teshio River basin closely reflected those of the sub-catchment spatial scale. This masked the unique effect, which the riparian zone exerts on the river ecological condition. In the upper reach, another type of anthropogenic activity-a dam operation manner strongly influenced the river water quality at the station several kilometers below the dam. Our study showed that the agricultural development in the Teshio River is critical for the river ecosystem condition and services. Measures towards sustainable and more nature-friendly agricultural management are necessary to secure the conservation of the Teshio river ecosystem and the related ecosystem services.

Acknowledgements:

We thank Dr. Takashi Denboh, Ms. Ikuko Endoh, Mr. Toshiyuki Hirata and all of the technical staff of Northern Forestry Research and Development Office, Forest Research

Station, Field Science Center for Northern Biosphere, Hokkaido University for field research and chemical analysis. We also thank Ms. Jun Yokoyama and the last Dr. Yoshiyuki Ikegami for GIS analysis. This study was conducted as a part of research program of North Hokkaido Experimental Forests, a core-site of Japan Long-Term Ecological Research Network (JaLTER). This study was supported partly by grant in Aid for Scientific Research (A) (18208017) from the Japanese Society for the Promotion of Science to H. U.

Reference:

Ahearn DS, Sheibley RW, Dahlgren R A, Anderson M, Johnson J, Tate KW (2005) Land use and land cover influence on water quality in the last free-flowing river draining the western Sierra Nevada, California. Journal of Hydrology 313(3-4): 234-247.

Allan JD (1995) Stream Ecology. Kluwer Academic Publishers, Dordrecht.

Allan JD (2004) Landscapes and riverscapes: The influence of Land Use on Stream Ecosystems. Annu. Rev. Ecol. Evol.Syst. 35: 257-284.

Allan JD, Erickson DL, and Fay J (1997) The influence of catchment land use on stream integrity across multiple spatial scales. Freshwater Biology 37(1): 149-161.

Arheimer B and Liden R (2000) Nitrogen and phosphorus concentrations from agricultural catchments - influence of spatial and temporal variables. Journal of Hydrology 227(1-4): 140-159.

Basnyat P, Teeter LD, Lockaby BG and Flynn KM (2000) The use of remote sensing and GIS in watershed level analyses of non-point source pollution problems. Forest Ecology and Management 128(1-2): 65-73.

Bellos D, Sawidis T and Tsekos I (2004) Nutrient chemistry of River Pinios (Thessalia, Greece). Environment International 30(1): 105-115.

Campbell N, D`arcy B., Frost A, Novotny V and Sansom A (2004) Diffuse pollution an introduction to the problems and solutions. IWA Publishing, London, UK.

Dow CL, Arscott DB and Newbold JD (2006) Relating major ions and nutrients to watershed conditions across a mixed-use, water-supply watershed. Journal of the North American Benthological Society 25(4): 887-911.

Dow CL and Zampella RA (2000) Specific conductance and pH as indicators of watershed disturbance in streams of the New Jersey Pinelands, USA. Environmental Management 26(4): 437-445.

Fitzpatrick F, Scudder B, Lenz B and Sullivan D (2001) Effects of multi-scale environmental characteristics on agricultural stream biota in eastern Wisconsin. J. Am. Water Resour. Assoc. 37: 1489-507.

Geographical Survey Institute of Japan (1999) Digital map 50 m mesh (elevation), Geographical Survey Institute of Japan, Tokyo, Japan (CD-ROM, in Japanese)

Harding JS, Young RG, Hayes JW, Shearer KA and Stark JD (1999) Changes in agricultural intensity and river health along a river continuum. Freshwater Biology 42(2): 345-357.

Herlihy AT, Stoddard JL and Johnson CB (1998) The relationship between stream chemistry and watershed land cover data in the mid-Atlantic region, US. Water Air and Soil Pollution 105(1-2): 377-386.

Inoue M, Nakano S, and Nakamura F (1997) Juvenile masu salmon (Oncorhynchus masou) abundance and stream habitat relationships in northern Japan. Canadian Journal of Fisheries and Aquatic Sciences 54(6): 1331-1341.

Japan Meteorological Agency, http://www.data.jma.go.jp.

Johnes PJ and Heathwaite AL (1997) Modelling the impact of land use change on water quality in agricultural catchments. Hydrological Processes 11(3): 269-286.

Johnson LB, Richards C, Host GE, and Arthur JW (1997) Landscape influences on water chemistry in Midwestern stream ecosystems. Freshwater Biology 37(1): 193-&.

Johnston CA, Detenbeck NE, and Niemi GJ (1990) The Cumulative Effect of Wetlands on Stream Water-Quality and Quantity - a Landscape Approach. Biogeochemistry 10(2): 105-141.

King RS, Baker ME, Whigham DF, Weller DE, Jordan TE, Kazyak PF, Hurd MK (2005) Spatial considerations for linking watershed land cover to ecological indicators in streams. Ecological Applications 15(1): 137-153.

Maillard P and Pinheiro Santos NA (2007) A spatial-statistical approach for modeling the effect of non-point source pollution on different water quality parameters in the Velhas river watershed-Brazil. Journal of Environmental Management. DOI:10.1016/j.jenvman.2006.12.009

Matson PA, Parton WJ, Power AG, and Swift MJ (1997) Agricultural intensification and ecosystem properties. Science 277(5325): 504-509.

Millenium Ecosystem Assessment (2003) Ecosystems and Human Well-Being , A Framework for Assessment, Millenium Ecosystem Assessment.

Ministry of Land, Infrastructure and Transport, Japan, Database of Dams, http://www2.river.go.jp/dam/index.html

Mishima S (2001) Recent trend of nitrogen flow associated with agricultural production in Japan. Soil Science and Plant Nutrition 47 (1): 157-166.

Nakamura F and Yamada H (2005) Effects of pasture development on the ecological functions of riparian forests in Hokkaido in northern Japan. Ecological Engineering 24(5): 539-550.

Nakata M and Kojima S (1987) Effects of Serpentine Substrate on Vegetation and Soil Development with Special Reference to Picea-Glehnii Forest in Teshio District, Hokkaido, Japan. Forest Ecology and Management 20(3-4): 265-290.

O`Neill RV, Hunsaker CT, Jones KB, Riiters K H, Wickham JD, Schwartz PM, Goodman IA, Jackson BL, and Baillargeon WS (1997) Monitoringenvironmental quality at the landscape scale. BioScience 47: 513-519.

Osborne LL and Wiley MJ (1988) Empirical Relationships between Land-Use Cover and Stream Water-Quality in an Agricultural Watershed. Journal of Environmental Management 26(1): 9-27.

Pan YD, Herlihy A, Kaufmann P, Wigington J, van Sickle J, and Moser T (2004) Linkages among land-use, water quality, physical habitat conditions and lotic diatom assemblages: a multi-spatial scale assessment (vol 515, pg 59, 2004). Hydrobiologia,523(1-3): 237-237.

Rodriguez W, August PV, Wang YQ, Paul JF, Gold A, Rubinstein N (2007) Empirical relationships between land use/cover and estuarine condition in the Northeastern United States. Landscape Ecology 22(3): 403-417.

Sakaguchi Y (1986) Rivers in Japan. Iwanami Shoten, Tokyo

Stauffer JC, Goldstein RM, Newman RM (2000) Relationship of wooded riparian zones and runoff potential to fish community composition in agricultural streams. Canadian Journal of Fisheries and Aquatic Sciences 57(2): 307-316.

Strayer DL, Beighley RE, Thompson LC, Brooks S, Nilsson C, Pinay G, Naiman RJ (2003) Effects of land cover on stream ecosystems: Roles of empirical models and scaling issues. Ecosystems 6(5): 407-423.

Tabuchi T and Ogawa Y (1995) Environmental characteristics of paddy fields. In: T Tabuchi and S Hasegawa (Editors), Paddy fields in the world. Japanese society of irrigation, drainage and reclamation engineering, Tokyo.

Takeda, I. and Fukushima, A., 2006. Long-term changes in pollutant load outflows and purification function in a paddy field watershed using a circular irrigation system. Water Research, 40(3): 569-578.
The group of Japanese Pedologist (1990) Soil Map of Japan 1:1,000,000, Naigai Chizu Co. Ltd. Tokyo, Japan.
Wang XH and Yin ZY (1997) Using GIS to assess the relationship between land use and water quality at a watershed level. Environment International 23(1): 103-114.
Williams M, Hopkinson C, Rastetter E, Vallino J. and Claessens L (2005) Relationships of land use and stream solute concentrations in the Ipswich River basin, northeastern Massachusetts. Water Air and Soil Pollution 161 (1-4): 55-74.
Worrall F and Burt TP (1999) The impact of land-use change on water quality at the catchment scale: the use of export coefficient and structural models. Journal of Hydrology 221(1-2): 75-90.
Xie XD, Norra S, Berner Z and Stuben D (2005) A GIS-supported multivariate statistical analysis of relationships among stream water chemistry, geology and land use in Baden-Wurttemberg, Germany. Water Air and Soil Pollution 167 (1-4): 39-57.
Yoshimura C, Omura T, Furumai H and Tockner K (2005) Present state of rivers and streams in Japan. River Research and Applications 21 (2-3): 93-112.

Figures legends:

Figure 1. Teshio basin: the numbers denote the number of each sampling station;

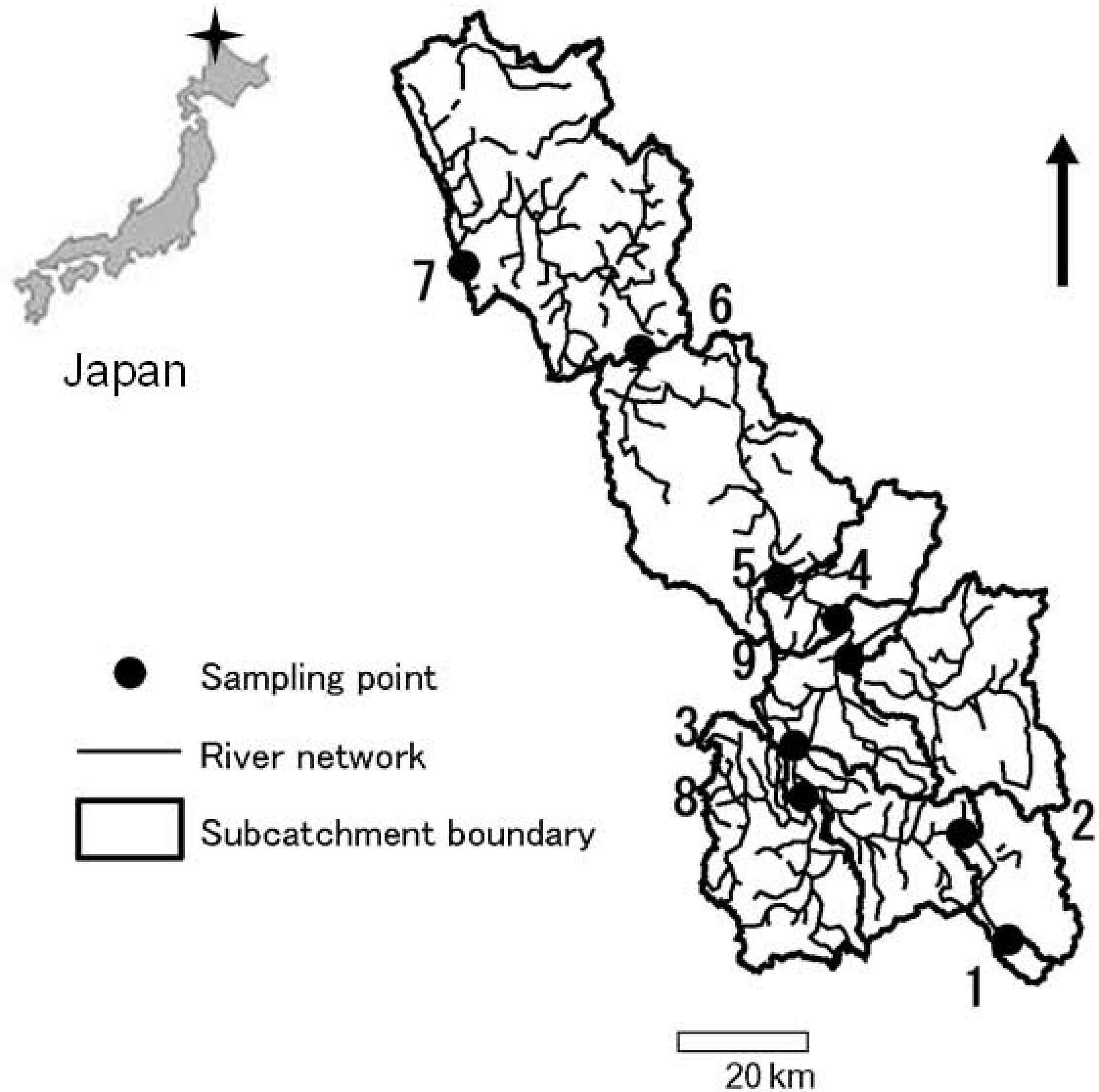
Figure 2. Teshio basin land use pattern. Forest is the predominating land use type. Agriculture is concentrated near the water course and in the upper middle and lower reach of the river network.

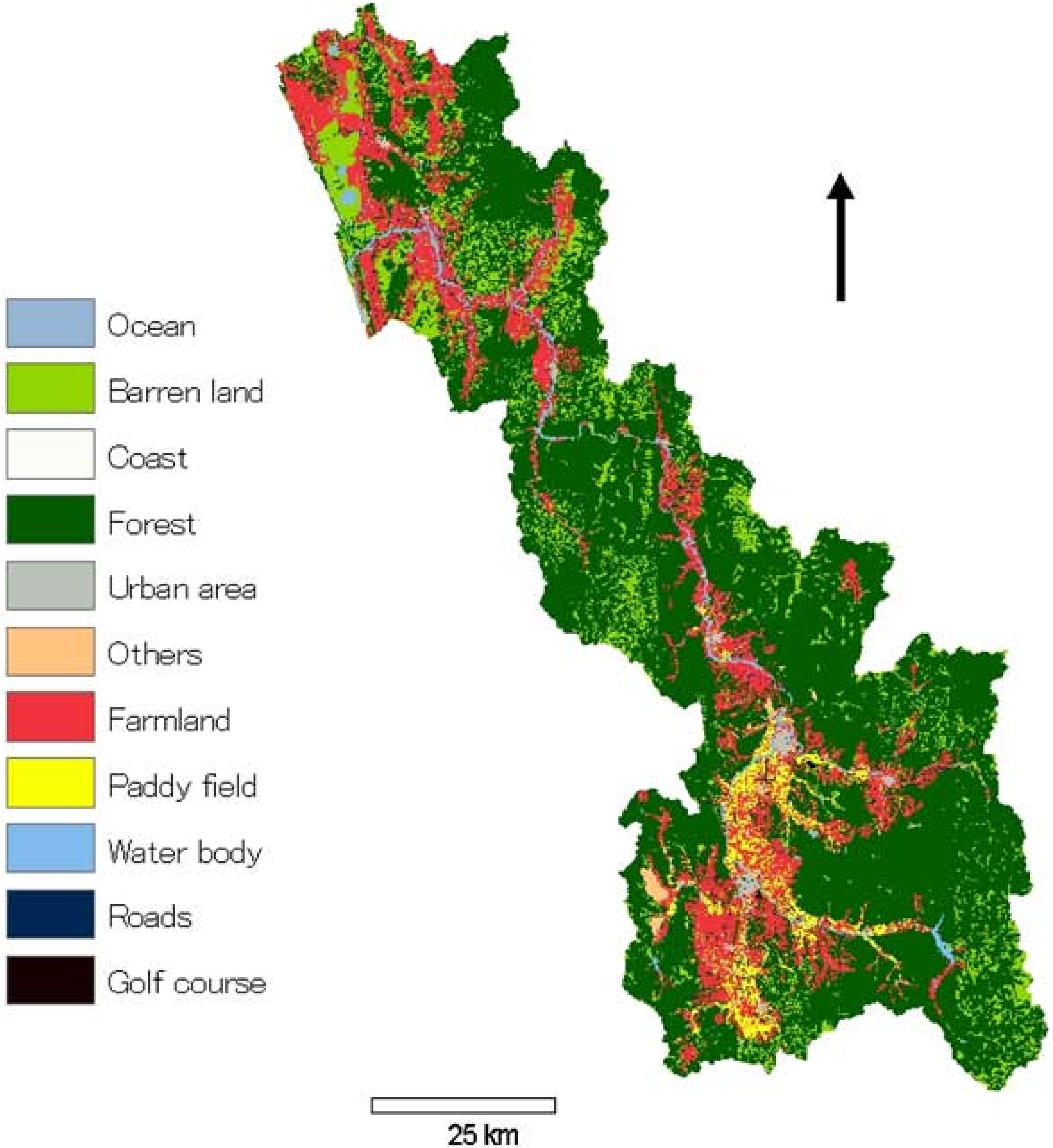
Figure 3. Bar chart showing the seasonal change in the mean NO_3-N concentration. The October and December concentrations were significantly higher than the rest of the sampled months.

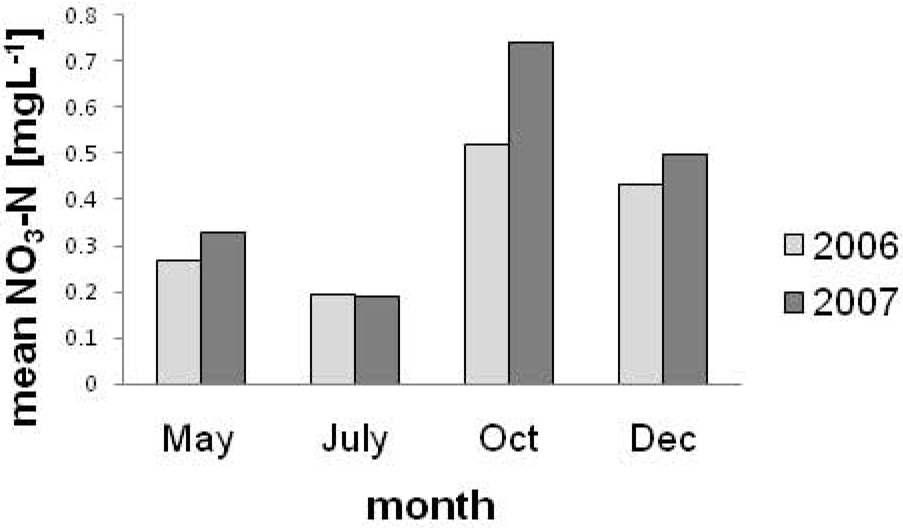
Figure 4. Boxplot of NO_3-N concentrations at all sampling stations. The boxes limit the first and third quartile, notches give the idea of the 95% confidence intervals for the difference between two neighboring medians, whiskers depict the values within 1.5 times the hinges. Circles are outliers.

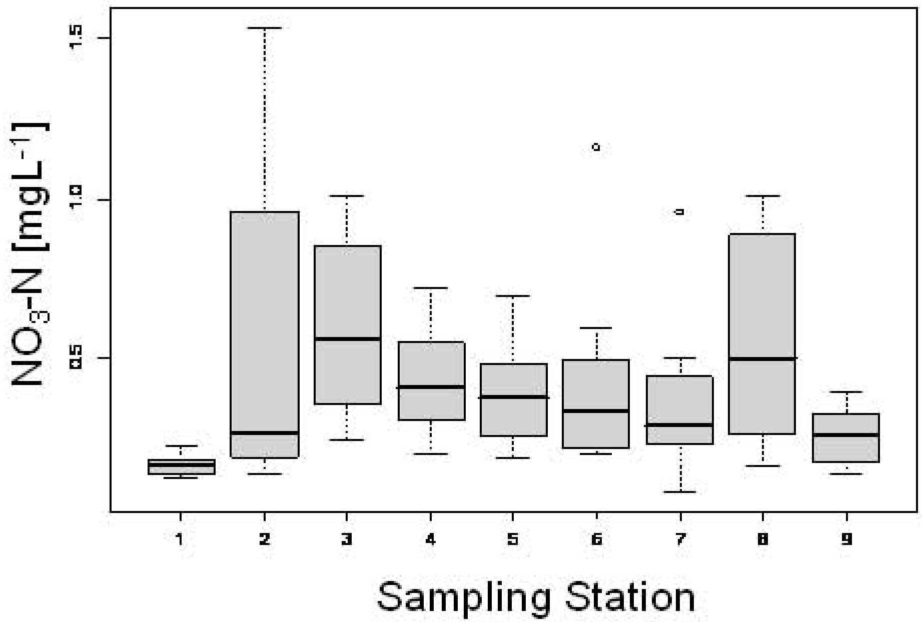
Figure 5. Relationship between the in-stream NO3-N and agriculture percentage in the drainage area. The outlier is the unstable st.2, which was excluded from the statistical tests.

Figure 6. Cluster dendrogram showing the grouping of stations according to their mean NO_3-N concentrations. The numbers denote the station number. The upper cluster constitutes of st.1 and st.9, which are the least anthropogenically impacted, middle cluster-st.3 and st.8 - presenting the areas with highest human influence, and the lower cluster includes the remained moderately impacted middle and lower reach stations - st.4, st.6, st.5 and st.7.

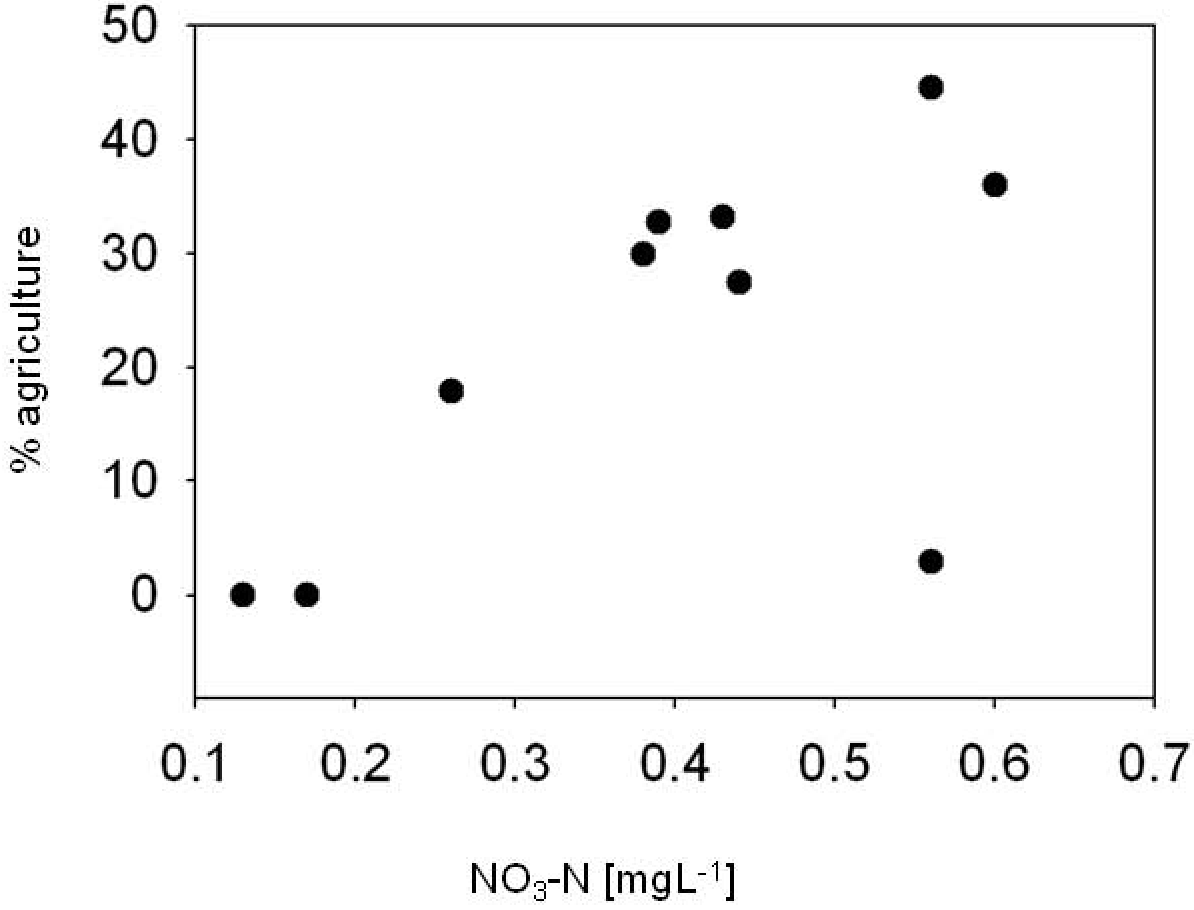

Japan
7
6
5
4
9
3
8
2
1
Sampling point
River network
Subcatchment boundary
20 km

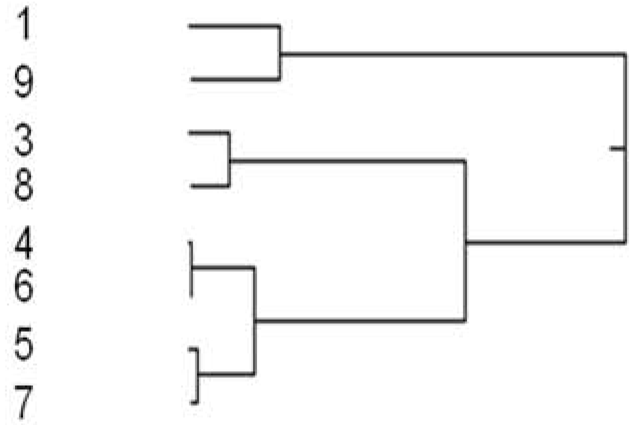

Ocean
Barren land
Coast
Forest
Urban area
Others
Farmland
Paddy field
Water body
Roads
Golf course
25 km


mean NO_3-N [mgL^{-1}]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
May
July
Oct
Dec
month
2006
2007



1.5
1.0
0.5
NO3-N [mgL-1]
1
2
3
4
5
6
7
8
9
Sampling Station


% agriculture
50
40
30
20
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
NO3-N [mgL-1]


1
9
3
8
4
6
5
7