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Original Research

Comparative Study of Nitrogen Dynamics of Three Wetlands in the Higashi-Hiroshima Area, Western Japan

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Abstract

In a watershed, wetlands may function either as a nutrient sink or as a source and net transformer of nutrients. One of the most widely recognized functions of wetlands is the ability to reduce or remove nutrients from surface water passing through the wetland. In order to compare nitrogen retention capacity, we investigated the ability of three wetlands to reduce or remove dissolved nitrogen from the surface water that passed through them. Although the three wetlands were located within one watershed, their surrounding land uses were significantly different. In this study, the surface water of each of the three wetlands was sampled from five points (the main inlet, outlet and three points inside the wetland) during the second week of every month, from December 2005 to December 2006, in order to measure dissolved nitrogen concentrations and their components (nitrate, nitrite, ammonium, and dissolved organic nitrogen). During the growing season (June-July), a vegetation census was conducted in each wetland that included an estimation of the percent of coverage and a survey of the diversity of vegetation. Investigation into the seasonality of the source or sink function indicated that wetland A had a source-role in three seasons (winter, spring, and summer) and a sink role during the autumn season. Wetland B had a sink-role during two seasons (winter and summer), a source-role in the spring, and a neutral role in autumn. Wetland C had a sink-role for dissolved nitrogen in surface water during all seasons of the study period. Results from the vegetation census indicated that *Typha latifolia* was the dominant species for wetland A, *Potamogeton cristatus* was dominant for wetland B, and *Ischene globosa* was dominant for wetland C. The percentage of vegetation cover was estimated as 83%, 35%, and 53% in wetlands A, B, and C, respectively. The results of this study indicated that the surrounding land use and human alterations to the environment had played a significant role in determining the function of each wetland as a sink, source or transformer for dissolved nitrogen in surface water passing through the wetlands. It emerges from this study that the seasonal changes in the function of the wetland for dissolved nitrogen as well as variations in vegetation cover (%) and dominant plant species, were affected by the composition of the surrounding lands. This study revealed not only that the role (as source, sink or transformer) that the wetland plays for dissolved nitrogen might change because of the above-mentioned factors, but also that this role could either be stable, or that it could change seasonally. Finally, an investigation of the components of total dissolved

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nitrogen in these three wetlands showed that under the influence of the surrounding land use, NH_4^+ was the dominant form in wetland A (with a high percentage of urban area), and (NO_3^-+NO_2^-) were sub-dominant in wetland B (with a high percentage of agricultural area). Dissolved organic nitrogen was the dominant form in wetland C (with 0% of urban area and a high percentage of forest area). According to the results, dissolved organic nitrogen was not always the dominant component of the dissolved nitrogen, so that with an increase in the percentage of urban area, DIN was the dominant form and vice versa. Based on the results, the retention capacity of the wetlands for dissolved nitrogen in surface water increased in conjunction with a decrease in the level of urban land use.

Keywords: nitrogen, wetlands

Introduction

Wetlands are multifunctional in the sense that they provide several ecosystem services such as supplying habitat for many plants and animals; recharging aquifers; and improving water quality by removing organic and inorganic nutrients and toxic metals from the water that flows across the wetlands [1]. There are several reasons why elevated concentrations of nitrogen in fresh water are a matter for public concern [2]. Nitrogen (N) plays a prominent role in the euthrophication of aquatic systems [3]. Rising nitrate (NO_3^-) concentrations are also of particular concern because of an associated human health risk [e.g. 4]. Given the negative impact of increasing nitrogen (N) loads, the mechanisms by which fresh water systems can reduce local and downstream N concentrations are becoming increasingly important [2]. Wetlands may play an important role in the N cycle through retaining N by denitrification and transformation of N solutes between inorganic and organic fractions (NO_3^-, NH_4^+ and DON), and being a net sink or source of N due to vegetation uptake and organic matter accumulation [5]. Transformation, retention or mobilization of N in wetlands can regulate N concentration at watershed outlets [6]. Therefore, determining the functional role of the wetlands in a given watershed could help water resource planners manage the quality of water resources downstream.

McHale et al. [6] noted that total dissolved nitrogen (TDN) concentrations in groundwater would change more than the TDN concentrations in stream water through the wetlands; the study found that wetland groundwater contributed minimally to stream flow, and concluded that N chemistry in surface water was affected more by N transformation in stream water than by N transformation in groundwater, since N changes in stream water, although small, affected a much greater volume of water. In addition, one of the most widely recognized functions of the wetlands is the ability to reduce or remove nutrients from surface water passing through the wetland. Therefore, our study focused on the dynamics of nitrogen in wetland surface water in order to investigate the ability of wetlands to reduce nitrogen from the water that flows across the wetlands.

Haidary and Nakane [7] investigated the relationship between total dissolved nitrogen concentration and vegetation composition for 24 wetlands in this area; this study classified these wetlands into three groups based on the kinds of land use in their watershed. This classification has indicated a particular pattern of changes in nitrogen concentrations as well as a pattern to the changes in plant species composition within three groups of wetlands. In the present study, one wetland was selected from each group in order to compare the role that the wetlands played for dissolved nitrogen. The nitrogen retention capacities of these three sample wetlands were measured.

Objectives of this study were:

1) to compare the function of the three wetlands for dissolved nitrogen in surface water and to quantify the N retention capacity of each of the wetlands;
2) to investigate the role the wetlands played over time in order to determine whether or not there was seasonality to their role;
3) to study the factors that affect wetland function, particularly the role of surrounding land use, and the role of human alterations; and
4) to determine the dominant form of dissolved nitrogen in each wetland.

Material and Methods

Study Site

The study was conducted in the Higashi-Hiroshima watershed, which is located between 132º 36' 23" E - 132º 51' 19" E and 34º 15' 19" N - 34º 34' 58" N with a 635 km^2 area (Fig. 1). Annual mean temperature was 14.1ºC with a monthly mean ranging from 2.3ºC in January to 26.8ºC in August as minimum and maximum values, respectively. Annual mean rainfall was on average 160 mm/month with a maximum value of 304 mm/month in July, and a minimum value of 19 mm/month in October. Granite and alluvial sand are the main geological formations in the catchment areas of the wetlands and yellow soil and grand lowland soil were observed as dominant and subdominant soil types.

The location of the three wetlands in various landscape settings is illustrated in Fig. 1. Wetlands A, B and C are located in (34° 25′ 41.7″, 132° 41′ 43.6″); (34° 24′ 47.6″, 132° 40′ 37.2″); and (34° 25′ 47.8″ , 132° 42′ 16.8″) N latitude and E longitude, respectively. Area of the wetlands varied between 1.01 ha. (wetland B) to 8.1 ha. (wetland A). This value for wetland C is 2.5 ha. These wetlands had different water depths; 1.1 m (wetland A), 1.2 m (wetland B) and 1.5 m (wetland C). It should be noted that while these wetlands have similar geographic features, their catchment areas have different physical features. Shimoda [8] suggested that there are about 1,100 water bodies (ponds) in the study area. Haidary and Nakane [7] studied twenty-four out of these 1,100 wetlands, and for the present study three out of the twenty-four were chosen as our study sites, The selection was made with the use of a topographical map (1:50,000) (Japan Geographical Survey Institute). The contributing catchment areas of these wetlands were then checked by field observation in order to obtain a variety of landscape setting-related data for future analysis. The maximum water level of the water bodies was considered in order to meet the definition of a wetland based on the Ramsar Convention on Wetlands (http://www.ramsar.org/ris/key_ris_types.htm) (5/3/2006).

Materials and Methods

In each of the three wetlands, surface water from the wetlands was sampled from five points (main inlet, outlet and three points inside of the wetland) in 500 ml bottles (in the second week of every month from December 2005 to December 2006), which were immediately transported to a laboratory for analysis of total dissolved nitrogen concentration (TDN) and its components (NO_2^-, NO_3^-, NH_4^+, and dissolved organic nitrogen (DON)). The Ion Chromatography Method was used for NO_2^- and NO_3^-, the Ultraviolet Spectrophotometric Screening Method was applied for NH_4^+. DON was determined by subtracting DIN (DIN= NH_4^++NO_3^-+NO_2^-) from TDN.

A census of the vegetation in the wetlands was conducted by the line-transect method during the growing season (June-July, 2006) in order to determine the variety of plant species and estimate the percentage of coverage.

The Friedman test was applied to specify the significant difference between data related to the three wetlands, since the initial requirements of a parametric statistical test (normality and inequality in the variance) were not observed in the data set. A Pearson correlation coefficient test ($P<0.05$) was used to determine the relationship between concentrations of TDN and its components.

The watershed boundaries of the three wetlands were hand digitized, using 1:25,000 topographic quadrangle maps (Japan Geographical Survey Institute, 2000). The land cover map [9] was then superimposed on the watershed boundaries of the wetlands map in order to calculate the real extent of each land use type within the watershed;

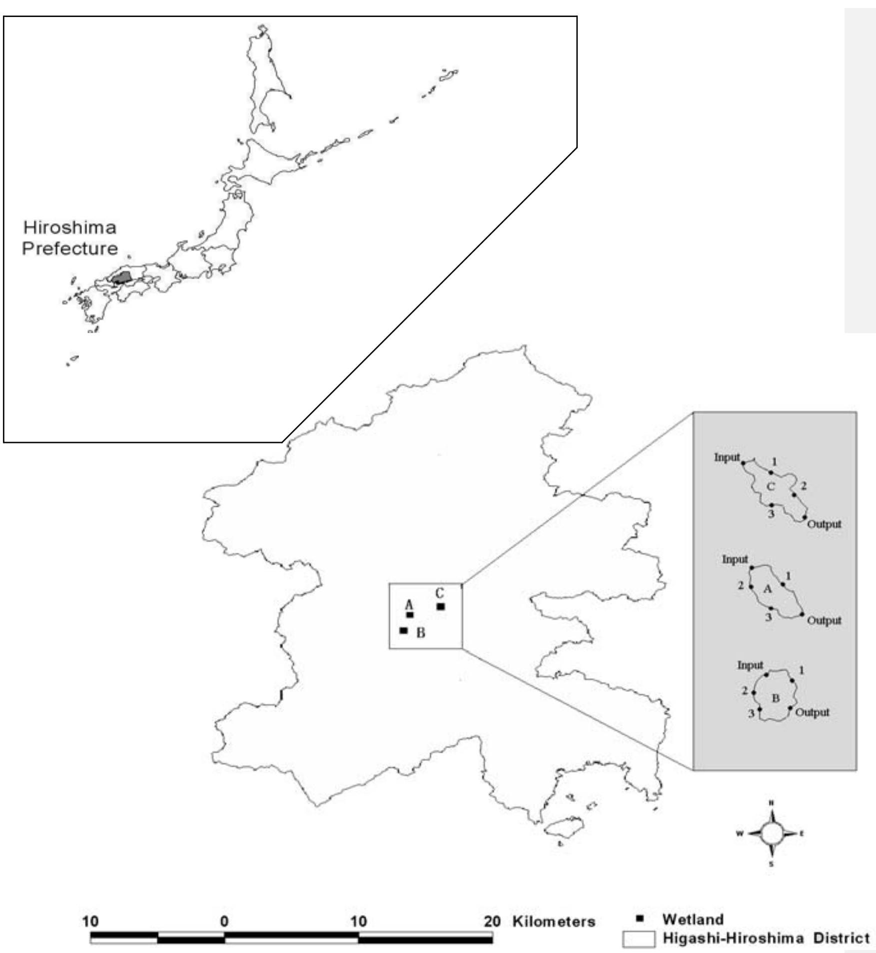

Fig. 1. Geographical position of the study area.

Table 1. Proportion (%) of land use in watershed of the three wetlands.

Wetland	Land use			
	Urban	Agriculture	Forest	Grassland
A	**<u>40.73</u>**	59.27	0.00	0.00
B	4.16	**<u>77.06</u>**	18.78	0.00
C	0.00	30.86	**<u>53.63</u>**	15.51

Bold and underline: Dominant land use.

the result of this calculation was then subsequently divided by the area of the watershed in order to determine the percentage of the watershed covered by each type, using the Geographical Information System [10]. All databases were transformed into a common digital format and projected onto a common coordinate system (UTM, zone 53).

Results

Land Use and Vegetation Composition of the Wetlands

Table 1 indicates the percentage of different land use types surrounding each wetland. As shown in this table, the percentage of urban area decreases from wetland A to wetland C, and the extent of forested area increases in inverse proportion.

The results of the investigation of plant species revealed that 27 plant species were observed in the three wetlands (6 species in wetland A, 7 species in wetland B and 18 species in wetland C). There were 4 species common to both wetlands B and C; other plant species were considered as exclusive species for each wetland (Table 2).

Typha latifolia, *Potamogeton cristatus* and *Ischane globosa* were the dominant species in wetlands A, B, and C, in that order. Vegetation cover (%) in the summer (June to July) was estimated to be 83%, 35% and 53% in wetlands A, B, and C, respectively. Table 2 shows that wetland C (with 18 plant species) had a higher plant species diversity.

Concentration of TDN and Components

Fig. 2 indicates the maximum and minimum values of TDN concentration and its components in the three wetlands (data which was obtained from monthly data collection). The maximum values for each factor were observed in wetland A and the widest range of variations in concentrations for each factor were also observed in wetland A. These values showed a decreasing trend from wetland A to wetland C, via B. On the other hand, the annual mean of TDN concentration and its components listed in Fig. 2 shows a decreasing trend from wetland A to C (except DON and NO_3^-). Fig. 2 also indicated that the dominant form of TDN was DIN in wetland A, in particular NH_4^+.

Table 3 indicates seasonal fluctuations in TDN concentrations and its components, including whether there was a seasonal increase or decrease in TDN concentration. The maximum extent of seasonal fluctuations in both TDN concentration (a 0.967 unit decrease from winter to spring) and DIN concentration (a 1.277 unit decrease from winter to spring) were recorded in wetland A. The minimum values for seasonal fluctuations in both TDN concentration (a 0.01 unit increase from spring to summer) and in the concentration of DIN (a 0.001 unit decrease from winter to spring) were observed in wetland C. Table 3 also indicates seasonal fluctuations in the components of the DIN (NH_4^+, NO_3^-, NO_2^-) and DON for each wetland. The maximum extent of seasonal fluctuation in DON concentration (0.42 unit increase from autumn to winter) was recorded in wetland B.

Seasonal Functions of the Wetland for TDN in Surface Water

In order to determine the function of the wetland as a source or a sink for dissolved nitrogen, N retention needs to be calculated. The following formula (Eq. 1), which was suggested by Devito and Dillon [11], was applied for calculating N retention in each wetland.

$$RS\ (\%) = 100 \times (\text{surface water input} - \text{surface water output})/\text{surface water input} \quad (1)$$

For Eq. 1, concentration of the nitrogen in the wetland intlet and outlet were used as the inlet and outlet values, respectively. Because there was not a significant difference between inflow and outflow discharge during sampling time. This initiative facilitates comparison among the wetlands without the discharge to be applied for standardization of the nitrogen load and retention [2].

The results shown in Tables 4-6 indicate that wetland A released N into surface water and functioned as an N source during the winter, spring and summer. During autumn it played a sink role by retaining N from surface water. Wetland B had a sink role during the winter and summer through retention of nitrogen. The data suggested that during the spring wetland B played a source role by releasing nitrogen and during the autumn this wetland played a neutral role. Wetland C played a sink role for all the seasons because of its retention of N.

Discussion

Plant Composition

Considering the land use composition surrounding each wetland, it was suggested that plant diversity in a wetland decreased as urban area increased, while the percentage of the vegetation cover in the wetland with the highest area (%) of urban land use (wetland A) was greater than the percentage of the vegetation cover in the wetland with the

Table 2. Plant species in the three wetlands.

Plants Name		Wetland		
		A	B	C
1	*Polygonum thunbergii*	*		
2	*Plogonum lapathifolium*	*		
3	*Polygonum hydropiper*	*		
4	*Phalaris arundinacea*	*		
5	*Typha angustifolia*	*		
6	*Typha latifolia*	O		
7	*Iris ensata*		*	
8	*Chara braunii*		*	
9	*Brasenia schrebri*		*	
10	*Phragmetis autralis*		*	*
11	*Eleocharis kuroguwai*		*	*
12	*Najas* SP.		*	*
13	*Potamogeton cristatus*		O	*
14	*Nymphaea tetragona*			*
15	*Viola verecunda*			*
16	*Schoenoplectus triquter*			*
17	*Sagittaria* SP.			*
18	*Eupatorium lindleyanum*			*
19	*Sarothra laxa*			*
20	*Sphagnum palustre*			*
21	*Juncus wallichianus*			*
22	*Eleocharis wichurai*			*
23	*Potamogeton distinctus*			*
24	*Utricularia vulgaris*			*
25	*Lonicera japonica*			*
26	*Juncus effusus*			*
27	*Isachne globosa*			O

O: Dominant species

Table 3. Seasonal balance of TDN and its components in the three wetlands (mg/l).

Factor		Wetland		
		A	B	C
TDN	1)	0.967	0.478	0.077
	2)	0.692	0.011	-0.010
	3)	-0.963	0.148	-0.450
	4)	-0.697	-0.581	-0.022
DON	1)	-0.304	0.355	0.077
	2)	0.115	-0.015	-0.012
	3)	0.005	0.080	-0.060
	4)	0.184	-0.420	-0.005
DIN	1)	1.277	0.124	0.00ï
	2)	0.577	0.026	0.002
	3)	-0.967	-0.002	0.015
	4)	-0.887	-0.148	-0.016
NH_4^+-N	1)	1.018	0.055	-0.028
	2)	0.492	0.030	0.016
	3)	-0.783	0.023	0.014
	4)	-0.726	-0.108	-0.001
NO_3^--N	1)	-0.181	0.018	0.011
	2)	0.579	0.011	0.567
	3)	-0.230	-0.028	0.007
	4)	-0.168	-0.001	-0.021
NO_2^--N	1)	0.033	0.033	-0.006
	2)	-0.087	0.002	0.004
	3)	0.046	0.002	-0.004
	4)	0.007	-0.038	0.006

1) Balance between winter and spring.
2) Balance between spring and summer.
3) Balance between summer and autumn.
4) Balance between autumn and winter.

highest area (%) of forest land use (wetland C). Shimoda [12] found that wetlands surrounded by a forest area are the most species-rich ones. The *Typha* species was observed as the dominant species in wetland A, a wetland that is surrounded by a high percentage of urban area (nearly 40.73%). On the other hand, in wetland C with 0% of urban development and a high percentage of forest area, vegetation cover (%) was average and plant diversity was high. This indicated the existence of suitable environmental conditions for different kinds of plant species in wetland C. The low plant diversity in wetland A, which is surrounded by a high percentage of urban area, indicated the environmental factors were not well suited to the maintenance of diverse vegetation. On the other hand, plant composition was closely correlated with the level of concentration of TDN and its components, as measured at the inlet. This confirmed the founding of Lopez and Fennessy [13] that a highly-disturbed wetland would not provide desirable habitats for plants. A significant relationship was observed between TDN concentration and type of land use, suggesting that plant diversity declined and vegetation cover (%) increased due to an increase of TDN concentration in the wetlands [7]. In this regard Shimoda [12] found that there is a correlation between nitrogen and phosphorus concentration, and plant distribution in wetland. NH_4^+ was the dominant form of nitrogen in wetland A, where *Typha latifolia* was observed as the dominant species . In this regard, Brix et al. [14] found that *Typha latifolia* was well adapted to growth in wetland soils where NH_4^+ was the prevailing nitrogen compound.

TDN Concentration Fluctuations

Among the three wetlands, the maximum extent of fluctuation in concentrations of TDN and DIN were observed in wetland A. In order to investigate the relationship between changes in TDN concentration and its components and in order to determine which component controlled the changes in TDN concentration, a Pearson correlation coefficient test was applied (Tables 7 and 8).

The results indicated that there was a significant relationship between TDN and DIN ($r=0.97$, $p<0.05$), and between DIN and NH_4^+ ($r=0.96$, $p<0.05$) in wetland A. It might be implied that changes in DIN concentration were controlled by changes in NH_4^+ and that the level of TDN was controlled by changes in DIN concentration. The results mean that although a change in the TDN concentration was

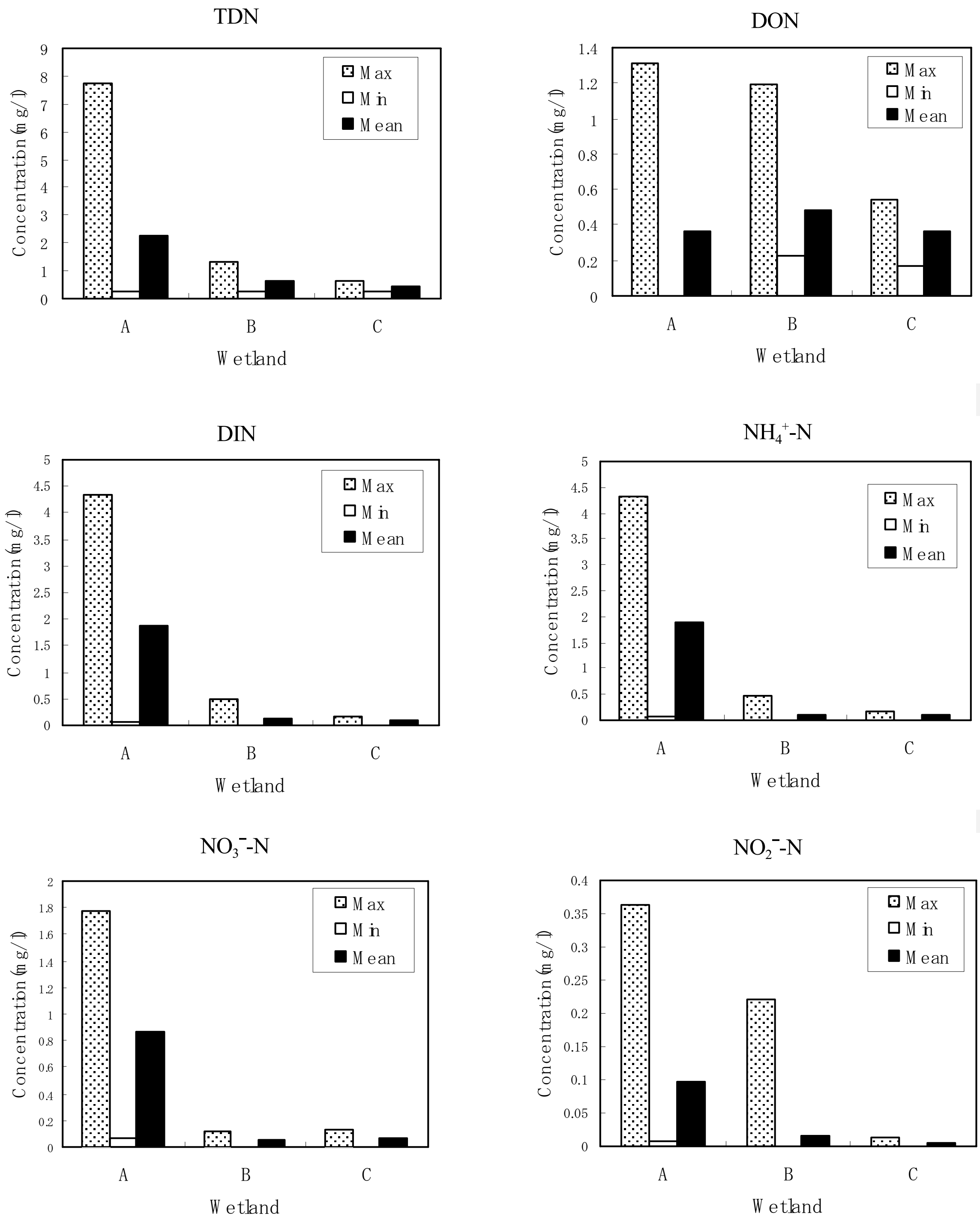

Fig. 2. Maximum, minimum and annual mean values of TDN and its components in the three wetlands (mg/l).

Table 4. Seasonal function of wetland A for TND and its components.

Season		TDN	DON	DIN	NH_4^+-N	NO_3^--N	NO_2^--N
Winter	Inflow	2.837	0.23	2.607	1.456	0.572	0.087
	Outflow	3.58	0.126	3.454	2.538	0.837	0.079
	Difference	-0.743	0.104	-0.847	-1.082	-0.265	0.008
	RS (%)	-26.190	45.217	-32.489	-74.313	-46.329	9.195
	Seasonal Function	Source	Sink	Source	Source	Source	Sink
Spring	Inflow	2.05	0.481	1.569	0.699	0.943	0.53
	Outflow	2.234	0.537	1.698	0.996	1.005	0.047
	Difference	-0.184	-0.056	-0.129	-0.297	-0.062	0.483
	RS (%)	-8.976	-11.642	-8.222	-42.489	-6.575	91.132
	Seasonal Function	Source	Source	Source	Source	Source	Sink
Summer	Inflow	1.885	0.389	1.496	0.299	1.064	0.133
	Outflow	1.369	0.373	0.996	0.324	0.624	0.048
	Difference	0.516	0.016	0.5	-0.025	0.44	0.085
	RS (%)	27.374	4.113	33.422	-8.361	41.353	63.910
	Seasonal Function	Sink	Sink	Sink	Source	Sink	Sink
Autumn	Inflow	2.986	0.389	2.597	1.242	1.251	0.104
	Outflow	1.796	0.359	1.437	0.796	0.573	0.068
	Difference	1.19	0.03	1.16	0.446	0.678	0.036
	RS (%)	39.853	7.712	44.667	35.910	54.197	34.615
	Seasonal Function	Sink	Sink	Sink	Sink	Sink	Sink

Table 5. Seasonal function of wetland B for TND and its components.

Season		TDN	DON	DIN	NH_4^+-N	NO_3^--N	NO_2^--N
Winter	Inflow	1.188	0.965	0.223	0.131	0.061	0.031
	Outflow	1.132	0.772	0.360	0.190	0.087	0.083
	Difference	0.056	0.193	-0.137	-0.059	-0.026	-0.052
	RS (%)	4.714	20.000	-61.435	-45.038	-42.623	-167.742
	Seasonal Function	Sink	Sink	Source	Source	Source	Source
Spring	Inflow	0.500	0.379	0.121	0.058	0.058	0.005
	Outflow	0.570	0.450	0.120	0.061	0.054	0.005
	Difference	-0.070	-0.071	0.001	-0.003	0.004	0.000
	RS (%)	-14.000	-18.734	0.826	-5.172	6.897	0.000
	Seasonal Function	Source	Source	Source	Source	Sink	Neutral
Summer	Inflow	0.490	0.434	0.056	0.020	0.034	0.002
	Outflow	0.483	0.436	0.047	0.023	0.022	0.002
	Difference	0.007	-0.002	0.009	-0.003	0.012	0.000
	RS (%)	1.429	-0.461	16.071	-15.000	35.294	0.000
	Seasonal Function	Neutral	Source	Neutral	Source	Neutral	Neutral
Autumn	Inflow	0.374	0.308	0.066	0.000	0.066	0.000
	Outflow	0.374	0.310	0.064	0.000	0.064	0.000
	Difference	0.000	-0.002	0.002	0.000	0.002	0.000
	RS (%)	0.000	-0.649	3.030	0.000	3.030	0.000
	Seasonal Function	Neutral	Source	Sink	Neutral	Sink	Neutral

Table 6. Seasonal function of wetland C for TND and its components.

Season		TDN	DON	DIN	NH_4^+-N	NO_3^--N	NO_2^--N
Winter	Inflow	0.492	0.419	0.073	0.007	0.065	0.001
	Outflow	0.477	0.368	0.109	0.019	0.089	0.001
	Difference	0.015	0.051	-0.036	-0.012	-0.024	0.000
	RS (%)	3.049	12.172	-49.315	-171.429	-36.923	0.000
	Seasonal Function	Sink	Sink	Source	Source	Source	Sink
Spring	Inflow	0.446	0.341	0.105	0.029	0.071	0.005
	Outflow	0.406	0.293	0.113	0.059	0.045	0.009
	Difference	0.040	0.048	-0.008	-0.030	0.026	-0.004
	RS (%)	8.969	14.076	-7.619	-103.448	36.620	-80.000
	Seasonal Function	Sink	Sink	Source	Source	Sink	Source
Summer	Inflow	0.426	0.352	0.074	0.024	0.048	0.002
	Outflow	0.409	0.306	0.103	0.022	0.078	0.003
	Difference	0.017	0.046	-0.029	0.002	-0.030	-0.001
	RS (%)	3.991	13.068	-39.189	8.333	-62.500	-50.000
	Seasonal Function	Sink	Sink	Source	Sink	Source	Source
Autumn	Inflow	0.499	0.431	0.068	0.011	0.051	0.006
	Outflow	0.398	0.329	0.069	0.006	0.056	0.007
	Difference	0.101	0.102	-0.001	0.005	-0.005	-0.001
	R(%)	20.240	23.666	-1.471	45.455	-9.804	-16.667
	Seasonal Function	Sink	Sink	Source	Sink	Source	Source

a result of a change in its component's concentration, NH_4^+ was in fact the controlling factor. The dominance of NH_4^+ in wetland A, which was related to land use composition (in its adjoining watershed), confirmed the effect of land use and human influence.

As to wetland B, DON was the dominant form of TDN, and, among the three wetlands, the maximum extent of fluctuation in concentration of DON was also observed in wetland B (Table 3). The result of the correlation coefficient test showed that there was a significant relationship between TDN and DIN ($r=0.96$, $p<0.05$), as well as between TDN and DON ($r=0.82$, $p<0.05$), implying that changes in TDN concentration were under the influence of variations in DON and DIN concentrations. An increase in the levels of ($NO_2^-+NO_3^-$), and a corresponding decrease in the levels of NH_4^+ within the components of DIN, imply that the nitrogen concentration of surface water in wetland B has also been affected by surrounding land use.

The minimum extent of fluctuation in concentrations of TDN were observed in wetland C and results of the correlation coefficient test (Table 7) indicated there was a significant relationship between TDN and DON concentrations ($r=0.86$, $p<0.05$). It could be concluded that changes in the concentration of DON were the controlling factor for TDN concentration changes. Therefore, it was the dominant form of TDN (with a magnitude of 81.84%) as well, since it was the controlling component for changes in TDN concentrations based on the result of the correlation coefficient test.

Function of the Wetland for Nitrogen in Surface Water

For wetland A, the sink or source role of the wetland was revealed by the seasonal retention of N based on the result of the correlation test and the contribution of the components of TDN for each season. According to these criteria, wetland A had a source-role in three of the seasons based on the release of NH_4^+ (the prevailing form of DIN) into surface water, while this wetland retained other components of dissolved nitrogen (DON, NO_2^-, and NO_3^-) from surface water. Therefore, it seems that the factor which determines the function of the wetland as a source would be either a fluctuation or an increase in the mean concentration of NH_4^+. Wetland A had a sink role for all components of dissolved nitrogen in the autumn season, which corresponded with a decrease in water velocity and an increase in the residence time when there was a high percentage of plant cover and, finally, an increase in nitrogen retention capacity as a direct or indirect effect of vegetation.

Wetland B could be viewed as playing a source role through the release of DON and DIN (NH_4^+) in the spring. The seasonal function of wetland B and the results of the correlation coefficient test show that the wetland played a sink role in the summer, which was controlled by the retention of DIN (NO_3^-) and DON, while the sink role of the wetland in the winter was controlled by decomposition and the transforming process of DON.

Table 7. Results of the correlation coefficient test between TDN and its components (DIN and DON) in the three wetlands.

	Wetland A	Wetland B	Wetland C
	TDN	TDN	TDN
DIN	0.97	0.82	-0.03
DON	-0.21	0.96	0.86

Table 8. Results of the correlation coefficient test between DIN and NO_3^-, NO_2^- and NH_4^+ in the three wetlands.

	Wetland A	Wetland B	Wetland C
	DIN	DIN	DIN
NH_4^+	0.96	0.79	0.48
NO_3^-	0.41	0.45	0.84
NO_2^-	0.12	0.83	0.37

Wetland C had a sink role for nitrogen in surface water in all seasons because of the retention of DON. Although wetland C released DIN and components into surface water, the results for wetland C revealed that the controlling factor for wetland function was either a fluctuation or a decrease in DON concentration, which suggested it was a result of DON being transformed into DIN form.

Conclusions

It might be mentioned that the effect of the hydrology on the function of the three wetlands was considered slight, since the inlet-discharge and the outlet-discharge of the wetlands were the same or had an insignificant difference during the sampling time from surface water; therefore, the seasonal functions of the wetlands were investigated considering their surrounding land use. The results of this study revealed that the nitrogen retention capacity of the wetland increased in conjunction with a decrease in the area (%) of urban land use and *vice versa*.

Our investigation into the seasonal function of wetlands with regard to the dissolved nitrogen concentration in surface water passing through the wetlands showed that the N retention capacity of a wetland not only increased in conjunction with an increase in the area (%) of forest land use, but that a seasonal change was not observed when the area (%) of forest land use was high, and the role of the wetland as a sink for nitrogen in surface water was stable.

A determination of the dominant component of TDN in each wetland suggested that DON would not always be the dominant form of TDN. The dominant form of TDN was NH_4^+ in the wetland where the watershed had the highest degree of human influence (a high percentage of urban land use), and the levels of DON were highest in the wetland which had the greatest area (%) of forest land use (and where human influence was minimal).

Wetland C, whose watershed was dominated by a high area (%) of forest land use, functioned as a sink for nitrogen in surface water by retaining DON during all four seasons. It suggested that there were suitable conditions for the transformation and mineralization processes of DON. These processes were completed during two seasons, when DON was transformed into NO_3^-. During the two other seasons, these processes were not completely performed, so that DON was changed into NH_4^+ and NO_2^-. Therefore, this wetland released DIN into surface water in spite of there being minimal agricultural land use and other human influence in the adjoining watershed.

The decrease in NO_3^- concentrations in the summer and autumn in wetland B, in spite of a high percentage of agricultural land use, is most probably related to the relatively high (%) of coverage by *Phragmetis australis*. Assimilation, which is carried out by plants, especially by *P. australis*, has been shown to contribute to a decrease in NO_3^- concentrations [15].

Based on the results, it could be concluded that although hydrology is a significant factor in determining the role that the wetland plays as a sink, source, or transformer for nitrogen in surface water passing through the wetlands, other factors such as the surrounding land use and the extent of human alterations are important because they re-inforce or weaken this role. This means that when there is an increase in the inlet inflow from agricultural and urban land use into the wetland, the wetland would not be able to retain a considerable amount of the nitrogen in spite of low water discharge.

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