COMPARATIVE EVALUATION ON NITROGEN SATURATION OF FOREST CATCHMENTS IN JAPAN AND NORTHEASTERN UNITED STATES

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Abstract. To analyze the differences in the status and processes of nitrogen saturation in Japan and northeastern United States, we examined the hydrobiogeochemistry of nitrogen of forested watersheds in these regions. Two distinct differences were found between watersheds in Japan compared with those in US. 1) In Japanese watersheds, marked decreases of NO_3^- concentration in surface waters during the summer growing season were not found and NO_3^- concentrations sometimes increased especially in the summer at nitrogen saturated sites. This contrast with watersheds in US where decreases in NO_3^- concentration during the summer are commonly observed except those watersheds in advanced stages of nitrogen saturation. These differences in NO_3^- concentration relationships can be attributed to climatic differences, with Japan having high precipitation and high discharge during the summer, while in many regions of North America lowest discharges are found in the summer. The climatic regime in Japan leads to high rates of mineralization and the rapid transport of NO_3^- to streams in summer. 2) Japanese watersheds, even those with high NO_3^- concentrations in surface waters, show little evidence of acidification. This is in contrast to sites in US where increased NO_3^- concentrations, especially during episodic events, result in surface water acidification.

Keywords: nitrogen saturation, nitrogen dynamics, climatic indices, hydrological processes

1. Introduction

Evaluating the effects of nitrogen saturation on surface water quality has been a major concern of biogeochemical researchers in North America (Stoddard, 1994) and Europe (Skeffington, 1990). Quantifications of N atmospheric deposition and the role of N biogeochemistry in affecting acidification have been important research topics. Various definitions of N saturation have been proposed (e.g. Agren and Bosatta, 1988; Aber *et al.*, 1989; Tamm, 1991).

In Japan atmospheric N inputs are currently elevated, especially in urban regions. The recent decreases in SO_2 emissions and hence reductions in H_2SO_4 deposition have contributed to the relatively greater importance of NO_3^- in contributing to "acid rain" in Japan (National Environmental Agency, 1997). Ohrui and Mitchell (1997) showed that several forest watersheds in north central Japan had high NO_3^- discharges that may be indicative of N saturation.

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The major objective of this study was to analyze the difference in the status and processes of N saturation in Japan and eastern North America. We examine seasonal patterns of streamwater NO_3^- concentrations, which have been used to detect stages of N saturation of watersheds, and discuss the factors affecting the seasonality in the discharge of NO_3^-. For the evaluation on N saturation status, we mainly used the definition by Aber *et al.* (1989), describing nitrogen leaching from the catchment through out the year. Results from these Japanese watersheds were compared to watersheds in the northeastern US (Mitchell *et al.*, 1996a).

2. Site Characteristics

Japanese watersheds are located over a wider range of latitude (~8°) from 35°17'N to 43°46'N compared to the sites in the United States (~4°) (Table I). The Moshiri site (MO) located in Hokkaido of northern Japan is much cooler than the three other Japanese sites, which are much warmer than the US sites.

The US sites all have large inputs of snow in winter (relatively high precipitation in Dec., Jan., and Feb. with subfreezing air temperature) while in Japan only MO has significant snow inputs (Fig. 1). Precipitation inputs show little seasonal differences in the US sites while in Japan high precipitation inputs are commonly observed during summer (June-September) due to the Asian monsoon and frequent typhoons. Even though the MO site has similarity in the temperature seasonality and annual precipitation, high precipitation is usually observed during summer.

Vegetation in the US sites is composed of mixed deciduous-conifer forests, which is most common in this region, while the sites in Japan include coniferous stands (OS), mixed deciduous-conifer forests (TB and MO) and deciduous forests (YT). OS in Japan is planted coniferous forest, which is one of the most common types of forests in Japan. As Mitchell *et al.* (1997) noticed, various climatic and geological factors can confound comparisons among the watersheds, but this variation can provide us with the opportunity to examine the effect of the various factors on the N biogeochemistry.

3. Results and Discussion

3.1. Nitrogen Budgets

Bulk N precipitation inputs of the Japanese and the US ranged from 4.5 to 9.6 kg ha $^{-1}$ yr^{-1} and 4.3 to 9.7 kg ha^{-1} yr^{-1}, respectively (Table II). There were no marked differences in N inputs between the two regions. All sites had N retention, except Japanese OS and TB (for MO, tentatively estimated from input N, stream N concentration and runoff data with some absent period). These two sites are located within 100 km of metropolitan Tokyo area and thus likely subjected to high levels of dry N deposition from NO_x (National Environmental Agency, 1997). As Ohrui and Mitchell (1997) pointed out, high N drainage losses in OS may also be a function of the low N increment of the old forest stands in this area that would diminish the ability of the vegetation to retain N. European researchers (e.g. Wright *et al.*, 1995) have suggested that atmospheric inputs greater than 10 kg N ha^{-1} yr^{-1}

may lead to N saturation. The N input to TB was close to this level. All sites in the Northeast US exhibit net N retention even at CK and HF in which input N is close to 10 kg N ha^{-1} yr^{-1}.

TABLE I
Site characteristics

Site (abbrev.)	Location	Elevation (m), size (ha)	Mean temp. (°C)	Dominant species in overstory and stand age	Site history (e.g., cutting, chemical treatment, etc.) and references
Japan					
Yanagatani (YT)	135°50'E 35°17'N	366-815 70	13.0	Deciduous hard wood, secondary.	Not available (Igaki, 1983).
Tsukuba (TB)	140°09'E 36°12'N	200-380 67.5	13.1	Conifer, partly deciduous hardwood	Not available (Hirata and Muraoka, 1991).
Ohyasan (OS)	139°22'E 36°34'N	765-835 1.80	13.2	Conifer, 90.	Plantation after clearcutting, which was thinned 10% of total volume in March 1983 (Toda, unpublished data).
Moshiri (MO)	142°00'E 43°46'N	290-540 128	2.5	Conifer and deciduous hard wood, partly secondary.	Natural forest with occasional light thinning (Shibata, unpublished data).
United States					
Hubbard Brook (HB)	71°45'W 43°56'N	490-775 13.1	5.9	Deciduous hard wood and conifer, 80-90.	Logged in 1910-1919, Damaged by a hurricane in 1938 (Mitchell *et al.*, 1996a).
Bear Brook (BB)	68°06'W 44°51'N	265-475 10	4.9	Mixed northern deciduous hard wood and conifer, 40-60.	Major logging to about 1945 (Norton *et al.*, 1999).
Catskill (CK)	74°25'W 41°59'N	628-1128 960	5.2	Deciduous hard wood and conifer, secondary.	During 1840-90, *Tsuga canadensis* dominated (Mitchell *et al.*, 1996a).
Huntington Forest (HF)	74°14'W 43°59'N	513-701 309	5.2	Deciduous hard wood and conifer.	Some selective timber removal up to 1961 (McHale *et al.*, 2000).

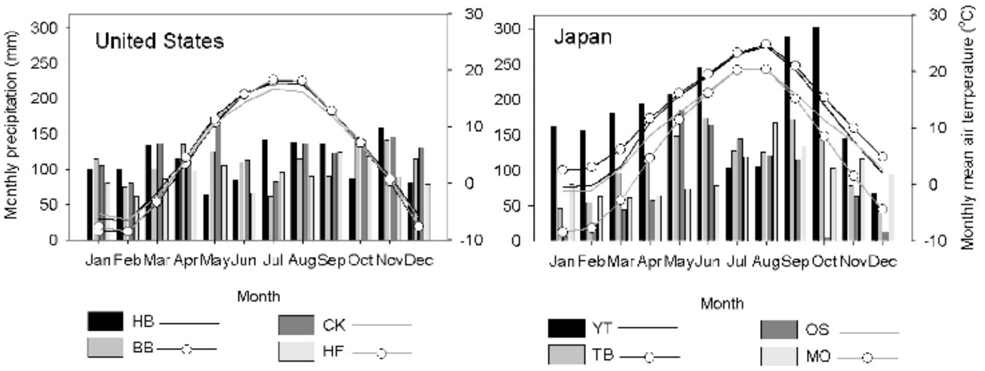

Figure 1. Monthly precipitation (columns) and mean air temperature (lines) of the sites. Site names are listed in Table I.

3.2. Seasonal Patterns of NO_3^- Concentration in Stream Water

As suggested by Mitchell *et al.* (1997), the seasonality in stream NO_3^- of Japanese watersheds is generally characterized by high concentration in the summer growing season. In Figure 2 this pattern was found at both low N output watersheds (YT and MO) that retain the major part of N input, and high N output sites (OS and TB) that may be exhibiting N saturation. For MO in Japan NO_3^- concentrations appear to be affected by both spring snowmelt and early summer high flow. In contrast, the US watersheds show clear depression of stream NO_3^- concentration during the growing season and high concentrations with snowmelt discharge.

Although there are striking differences in the seasonal pattern of NO_3^- concentration between two regions, correspondence of runoff rate and NO_3^- concentration is commonly found. High concentration appeared with the high flow in the snowmelt season for US sites, and in the summer rainy season for Japanese sites. Low concentration was found with low runoff rate during the dry summer for US sites, and the dry winter for Japanese sites. In the case of Japan, two factors likely contribute to this relationship: 1) high rates of N mineralization and nitrification in the warm, wet summer generate high concentrations of NO_3^- in forest floor and mineral soil water; and 2) high precipitation inputs in the summer result in movement of N solutes to surface waters from both soil and ground waters. This type of hydrologic control has been used to explain the patterns of solutes in surface waters (Muraoka and Hirata, 1988; Rice and Bricker, 1995).

TABLE II

Precipitation inputs and discharge outputs and streamwater pH for selected sites

Site	Annual precipitation (mm yr^{-1})	Annual runoff (mm yr^{-1})	Inorganic N input (kg N ha^{-1} yr^{-1})	Inorganic N output (kg N ha^{-1} yr^{-1})	Mean conc. NO_3^- of streamwater (μmol l^{-1})	Stream water pH	Period
Japan							
YT	2059	1621	5.2	1.4	4.5	6.3	1979-1980
TB	1587	721	9.6	13.1	126	6.9	1985-1989[1]
OS	948	502	6.7	8.5	102	7.0	1997
MO	1638**	1113*	6.2**	NA	8.9*	7.3*	*1997-1998 **1998-1999
United States							
HB	1372	890	7.3	0.66	3.6	4.9	1992-1993[2]
BB	1422	930	4.3	3.0	12.2	5.4	1988-1990[3),4]
CK	1679	1118	9.7	3.4	22.6	5.8	1985-1986[5]
HF	1112	639	8.4	1.2	12.2	6.2[7]	1983-1992[6]

[1] Hirata and Muraoka (1991), [2] Likens and Bormann (1995), [3] Kahl *et al.* (1993), [4] Norton *et al.* (1994), [5] Stoddard and Murdoch (1991), [6] Mitchell *et al.* (1996b), [7] Mitchell *et al.* (2000), averaged 1983-1999. NA: not available due to no NH_4^+ data for MO.

3.3. Impacts of Nitrogen Saturation

pH of the Japanese watersheds ranges from 6.3 to 7.3, while the pH of American sites ranges below 6.2 (Table II). Even for OS and TB having the high stream NO_3^- concentration, any symptoms of acidification of stream waters were not found. The high pH with high stream NO_3^- concentration has been reported for several sites in Japan (e.g. Ohrui and Mitchell, 1996; Baba and Okazaki, 1998).

Comparisons using proton budget estimation by Tokuchi and Ohte (1998) indicated that proton production by the N transformation in the Japanese forests was higher than for forests in Europe and Northeast US, but proton consumptions by weathering and cation exchange were also markedly higher. Extensive comparison in acid buffering of the worlds forested watersheds by Ohte and Tokuchi (1999) also showed that alkalinity of Japanese sites was generally higher than that in the Europe and Northeast US sites. This high level of proton consumption may result in little fresh water acidification in Japanese forest watersheds even those with high levels of N saturation.

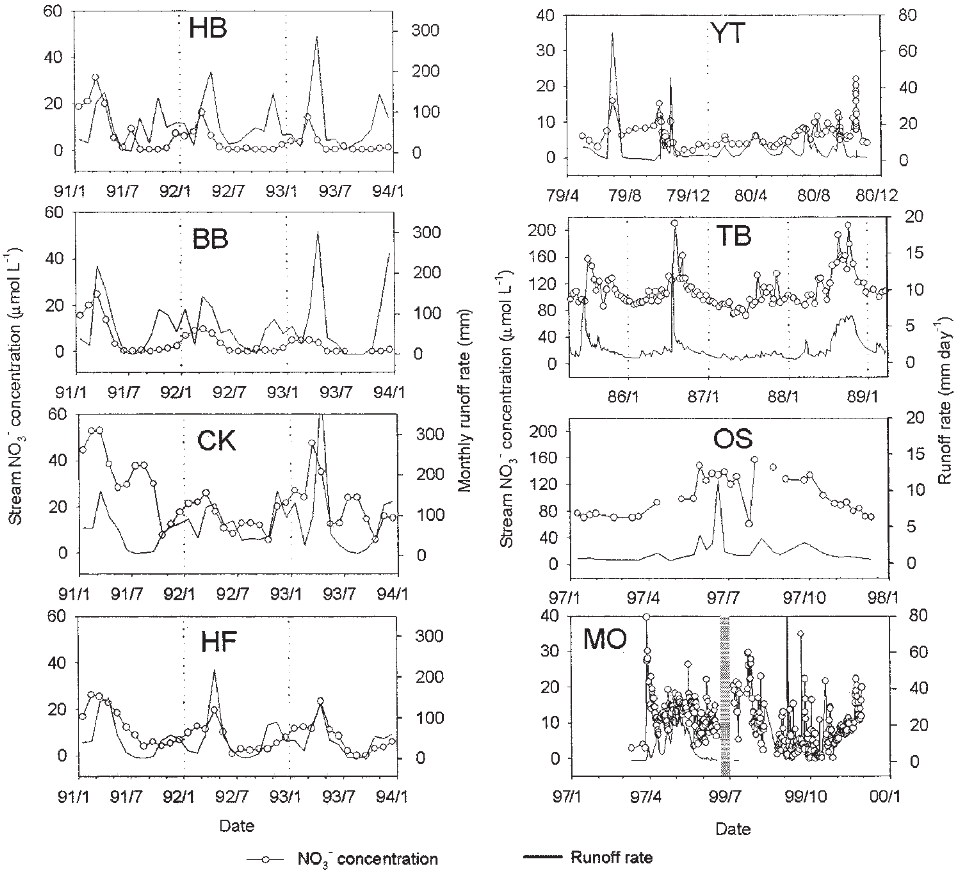

Figure 2. Seasonal variations of NO_3^- concentration and runoff rate.

4. Conclusions

Differences in NO_3^- concentration relationships between Japanese and some US watersheds can be attributed to climatic and hydrological differences. The climatic regime in Japan leads to high rates of N production and the rapid transport of NO_3^- to streams in summer. Thus, rise of NO_3^- concentration during low flow season (winter) and the excess of N output in annual budget are more visible symptoms of the nitrogen saturation in the Japanese watersheds.

Japanese watersheds treated in this paper, even those with high NO_3^- concentrations in surface waters, show little evidence of acidification. This is in contrast to some sites in US and Europe where increased NO_3^- concentrations, especially during episodic events, result in stream acidification (Skeffington and Wilson, 1988; Murdoch and Stoddard, 1992). This difference needs to be examined by more systematic comparison with extensive data sets.

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