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Nitrate attenuation in a small temperate wetland following forest harvest

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ABSTRACT

Elevated nitrate concentrations in streams and groundwater are frequently observed following forest harvest. In addition to depleting nutrients available for forest regeneration, elevated nitrate export following harvest can have deleterious effects on downstream aquatic ecosystems. As part of a forest harvest experiment conducted at the Turkey Lakes Watershed, Ontario, Canada, stable isotope techniques were employed to investigate nitrate attenuation in a natural wetland receiving high concentrations of nitrate as a result of clear-cutting in the catchment. Isotopic analysis of nitrate (δ^{18}O, δ^{15}N) and vegetation (δ^{15}N) demonstrated that both denitrification and plant uptake of nitrate resulted in significantly lower nitrate concentrations in wetland outflow compared to incoming stream water. Although the 0.2-ha forested swamp (4% of catchment by area) was too small to be featured on standard topographic maps, the wetland remove 65–100% of surface water nitrate inputs, thereby protecting downstream aquatic habitats from the full effect of N release from forest harvest. The δ^{15}N enrichment factor associated with nitrate attenuation in wetland surface water was lower than typically observed during denitrification in groundwaters, suggesting that nitrate removal is complete in some areas of the wetland. Plant assimilation of nitrate was also partially responsible for the low observed enrichment factor. Wetland plants recorded the high δ^{15}N associated with denitrification activity in portions of the wetland. Apportionment of nitrate sources using $\delta^{18}O–NO_3^-$ at the outlet weir was unaffected by the wetland nitrate attenuation under pre- and post-harvest conditions due to the mid-catchment position of the wetland. Future forest management practices designed to recognize and preserve small wetlands could reduce the potentially detrimental effects of forest harvest on aquatic systems.

1. Introduction

Under natural conditions, nitrogen (N) is typically the growth-limiting element in terrestrial ecosystems (Tamm, 1991). Annual inputs of new N (deposition, fixation, and mineral weathering) are often insufficient to meet annual biological requirements and therefore forests have evolved efficient methods of recycling available N (Rosswall, 1976). Forest harvest and other disturbances generally result in the loss of N from catchments by decoupling the mechanisms responsible for the tight internal N cycling (Vitousek, 1981). These losses can affect forest regeneration time and species composition as well as impacting downstream aquatic systems (Vitousek et al., 1979). Consequently, the fate of N is particularly important when considering the biogeochemical consequences of forest management practices.

Elevated export of nitrate (NO_3^-), the most mobile form of dissolved inorganic N, has been documented following forest harvest in both hardwood (e.g. Likens et al., 1970; Hornbeck et al., 1986; Gundersen et al., 2006; Wang et al., 2006) and conifer forests (e.g. Tamm et al., 1974; Gundersen et al., 2006). Nitrate export following harvest results from increased ammonification (organic N to ammonium (NH_4^+)) and nitrification (NH_4^+ to NO_3^-) in conjunction with drastically reduced vegetative N uptake (Vitousek, 1981). Atmospheric nitrate deposition can also contribute to increased nitrate export following forest harvest. Decreased interception and retention of precipitation by vegetation, combined with lower infiltration rates in disturbed soils, can result in a greater potential for overland flow in harvested catchments (Elliot et al., 1998). Therefore a greater proportion of atmospheric nitrate may be directly transported to streams following harvest, largely bypassing attenuation by plants and soil microbes.

High nitrate export has detrimental effects on terrestrial and aquatic systems. In order to maintain charge balance, nitrate losses must be accompanied by increased cation leaching from soils. Therefore nitrate export can decrease forest health by concomitant loss of nutrient cations such as calcium and potassium, and lead to acidification of aquatic systems through the export of hydrogen

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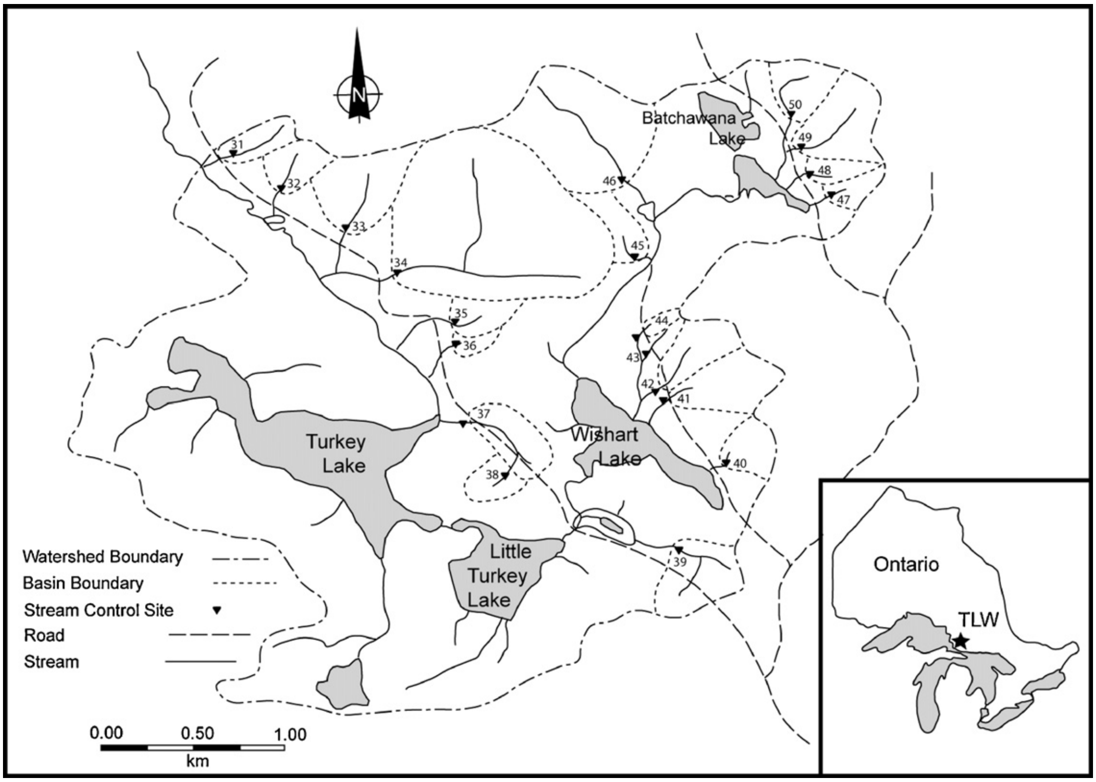

Fig. 1. The Turkey Lakes Watershed, Ontario, Canada.

ions (Aber et al., 1989). Nitrate can be harmful to the aquatic life stages of amphibians, even at relatively low concentrations (Baker and Waights, 1993, 1994; Hecnar, 1995; Marco et al., 1999). Nitrate concentrations resulting from forest harvest can exceed drinking water standards and threaten potable water supplies (e.g. Likens et al., 1970).

In 1997, a forest harvest experiment was initiated at the Turkey Lakes Watershed (TLW), located near Sault Ste. Marie, Ontario, Canada (Fig. 1), to study the effects of current forest management practices on a tolerant hardwood ecosystem. Although not typical of conventional management approaches (selection and shelterwood cuts) in Canadian hardwood forests, a clear-cut treatment was used to provoke a maximum disturbance effect. As part of the TLW harvest experiment, stable isotope techniques were used to trace nitrate sources and cycling in both undisturbed and harvested catchments.

Stream samples for nitrate isotope analysis have been collected regularly at weirs at the catchment outlets since 1995. In May 1999, additional sampling along the length of the stream in the clear-cut catchment revealed a decrease in nitrate concentrations through a small wetland located in the upper part of the catchment. Studies examining wetland responses to harvest have focused on the effects of harvesting the wetland itself (e.g. Shepard, 1994) or on the riparian zone adjacent to the aquatic habitats (e.g. Broadmeadow and Nisbet, 2004). A large body of literature also deals with the effects of draining peatlands to enhance forest growth (e.g. Paavilainen and Päivänen, 1995). We are not aware of previous studies that have investigated wetland attenuation of elevated nitrate concentrations caused by harvesting of the adjacent uplands.

Nitrate removal in the wetlands of clear-cut and undisturbed catchments could affect the interpretation of nitrate isotope ratios in stream water collected at the catchment outlets. Nitrate isotope ratios are frequently used to determine the relative importance of atmospheric versus microbial sources of nitrate in streams and groundwaters of forest catchments (e.g. Durka et al., 1994; Kendall et al., 1996; Spoelstra et al., 2001; Burns and Kendall, 2002; Schiff et al., 2002; Pardo et al., 2004; Hales et al., 2007). However, nitrate attenuation processes such as denitrification discriminate against the heavy isotopes of nitrate, leaving the residual nitrate enriched in both ^{15}N and ^{18}O (Kendall, 1998). Therefore nitrate removal processes could affect the correct interpretation of isotope ratios of nitrate export.

The goals of this study were to: (1) determine the role of a small wetland in buffering downstream areas from the full effects of forest harvest with respect to nitrate export, (2) identify the main mechanisms responsible for declining nitrate concentrations through the wetland, (3) determine if δ^{15}N of vegetation records evidence of denitrification activity in the wetland and (4) determine if nitrate attenuation in the wetland affects nitrate isotope ratios measured at the catchment outlet.

2. Methods

2.1. Study site

Biogeochemical research was initiated at the TLW in 1980 to investigate the effects of acidic deposition on an acid-sensitive Canadian Shield ecosystem (Jeffries et al., 1988; www.tlws.ca). The TLW (47°03′N, 84°24′W; Fig. 1) is a 10.5 km^2 watershed containing a series of five lakes that ultimately drain into Lake Superior. Basin soils are Humo-Ferric podzols (Canada Soil Survey Committee, Subcommittee on Soil Classification, 1978) developed from thin glacial till underlain by Precambrian silicate greenstone bedrock and minor occurrences of granite (Semkin and Jeffries, 1983). Elevation ranges from 630 m at the top of Batchawana Mountain to 340 m at the watershed outlet.

The temperate climate of the area is moderated by the basin's proximity to Lake Superior. The TLW generally receives 1200–1300 mm of precipitation annually (Sirois et al., 2001) with approximately 35% deposited as snow (Semkin et al., 2002). Sea-