RELATIONS BETWEEN LAND USE AND STREAM NUTRIENT CONCENTRATIONS FOR SMALL WATERSHEDS IN THE GEORGIA PIEDMONT

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Abstract. We have been sampling nutrient concentrations in 17 headwater streams within the South Fork Broad River (SFBR) watershed on a monthly basis since November 2001. The streams were classified as either developed (n=4), agriculture/pasture (n=4), mixed land use (n=6) or forested (n=3) based on information from the National Land Cover Data (NLCD) database. The lowest mean nitrogen concentrations were observed in streams draining forested watersheds. A set of landscape indicators explained 93 % of the spatial variability in the total nitrogen concentrations which suggests that watershed land use has an important effect on stream nitrogen levels. Total phosphorus varied seasonally at some of the sites, with high concentrations observed during the summer and low concentrations in winter. Only 4 out of 14 non-forested sites showed higher mean total phosphorus concentrations and no relationships were found between the landscape indicators and the total phosphorus concentrations in the streams. We suggest that, in contrast to what was observed for nitrogen, in-stream sources (e. g. decaying plant material), in-stream cycling, or strong pollution sources (e. g. manure, septic tanks) are more important than watershed land use in determining the total phosphorus concentrations in these small streams.

INTRODUCTION

Eutrophication results from an increase in the rate of nutrient supply to aquatic ecosystems and leads to a wide range of undesirable effects (see Smith et al., 1999). Excess nutrients accounted for almost 50 % of the impaired lakes and 30 % of the impaired river and stream reaches in the US in 1998 (US EPA, 2000). The concept of nutrient limitation is the keystone of eutrophication research and it implies: (1) that one key nutrient is limiting the growth of plants in a ecosystem, that (2) the growth of plants is proportional to the rate of supply of this nutrient, and (3) that the control of eutrophication should be accomplished by restricting the loading of this key nutrient to the ecosystem (Smith, 1998).

Empirical models that relate nutrient loads to land use are useful in predicting the nutrient load to a water body (NRC, 2001). Empirical models are derived by statistical inference from a set of observations. Also, they are easily understood and implemented and their uncertainty can be estimated from the statistical methods employed. Empirical models have been applied with success to explain the spatial differences in stream nitrogen and phosphorus export and/or concentrations among watersheds at local and regional scales (e.g., Jones et al., 2001).

The objective of this work was to see if watershed land use and some easy-to-calculate landscape indicators derived from satellite imagery and other geographic databases could be used to explain the spatial differences in the nitrogen and phosphorus concentrations among small headwater streams in the SFBR watershed. Headwater streams frequently exhibit high rates of nutrient cycling (Peterson et al., 2001) and provide valuable ecosystem services by reducing transport of various pollutants to downstream ecosystems (Meyer and Wallace, 2001). However, their ecosystem function is easily impaired by human disturbance of their catchment, riparian zone, and channel (Meyer and Wallace, 2001).

The use of remote sensing and landscape analysis is an appropriate tool for the assessment of low order streams due to their spatial extent within the drainage system. However, some uncertainties exist in the use of satellite imagery and other sources of geographical data to study small watersheds as they are collected with different scales of resolution. We hope that a better knowledge of the linkages between small headwater streams and their watersheds and better assessment tools will enhance the protection of this valuable portion of river networks.

STUDY AREA

The Broad River is located in northeast Georgia and flows from the Appalachian mountains to its confluence with the Savannah River. The SFBR is a tributary of the Broad River that is 128 km in length. The SFBR watershed is primarily rural and remains in a largely undeveloped state. Agriculture is the main land use throughout the valley and also includes some managed forests. Industrial use in the watershed is mainly limited to a few granite quarries.

METHODS

Seventeen headwater watersheds within the SFBR watershed ranging from 0.5 to 3.4 km^2 were selected. We have been monitoring concentrations of nutrients (nitrate, nitrite, ammonia, orthophosphate, dissolved organic nitrogen and phosphorus, total nitrogen and phosphorus) and other parameters (temperature, conductivity, dissolved oxygen, alkalinity, pH, DOC, flow rate, trace gases) on an approximately monthly basis since November 2001 at the outlets of the watersheds. Nitrate was measured by UV detection (Crumpton et al., 1992). Nitrite was measured by the diazotization method in a HAACH spectrophotometer. Ammonia was determined potentiometrically with an Accumet ammonia selective electrode (APHA, 1998). Orthophosphate was determined by the molybdenum blue method with ascorbic acid as the reducing agent (APHA, 1998). Organic and particulate fractions of both elements were measured by digestion of filtered and unfiltered samples with persulfate, followed by either UV detection or colorimetry (Valderrama, 1981).

Percentages of forested land, agricultural and pasture land, residential areas, wetlands and open water surfaces within each watershed were calculated from the National Land Cover Data (NLCD 92, USGS) database in a geographical information system (GIS). The study sites were then classified as either forested, agricultural and pasture land, residential/developed or mixed land use depending on the land uses observed within the watershed. Also, land uses were estimated along a 30 m width buffer strip surrounding each stream.

Nutrient data were log transformed for normality and a subset of indicator variables was selected among the landscape indicators by stepwise regression.

RESULTS AND DISCUSSION

Total nitrogen concentrations varied over more than one order of magnitude across land use categories. Nitrogen concentrations were generally below 0.5 mg N L^{-1} in the forested sites. (Figure 1). Mixed land use sites exhibited higher nitrogen concentrations than the forested sites, within the 0.5-1.5 mg N L^{-1} range. Two of the developed sites and two of the pasture sites showed very high nitrogen concentrations, usually over 2 mg N L^{-1}. The other developed and pasture sites showed much lower values that didn't differ from the mixed land use sites.

Spatial and temporal variability in total phosphorus concentrations was somewhat higher than that of nitrogen as they varied over two orders of magnitude. Phosphorus concentrations were similar in the forested and mixed land use sites and rarely exceeded 0.10 mg P L^{-1}. Two of the developed sites and two of the pasture sites had phosphorus concentrations as low as the forested and mixed land use sites. The other developed and pasture sites showed higher total phosphorus concentrations with one of the developed sites exceeding 1 mg P L^{-1}.

Nitrogen concentrations didn't show a clear temporal trend. Nitrogen concentrations clearly peaked during the summer in only 3 out of the 17 sites. Total phosphorus showed a clearly seasonal trend at some of the sites, with higher concentrations during the summer and early autumn and a sharp decline during winter, after the end of the drought. This trend was observed in about half of the sites. A period of very low flows which ranged from July to mid-September had a limited and variable impact on the concentrations of both nutrients.

Discharge and nitrogen concentrations were inversely correlated in 2 sites. The same relationship between discharge and phosphorus concentrations was observed in 5 sites. This relationship usually reflects low nutrient concentrations in the groundwater input to the stream and a point source with higher nutrient concentrations. Also, two developed sites, D06 and D79 and one pasture site P38, showed high DOC concentrations and low oxygen concentrations which suggest that a strong pollutionsource (e. g. septic tank leakage or animal manure) is affecting these sites.

In-stream sources of nitrogen and phosphorus also need to be considered. In autumn, a significant build-up of leaf packs was observed in most of the streams. In summer, dense stands of grasses and aquatic vegetation

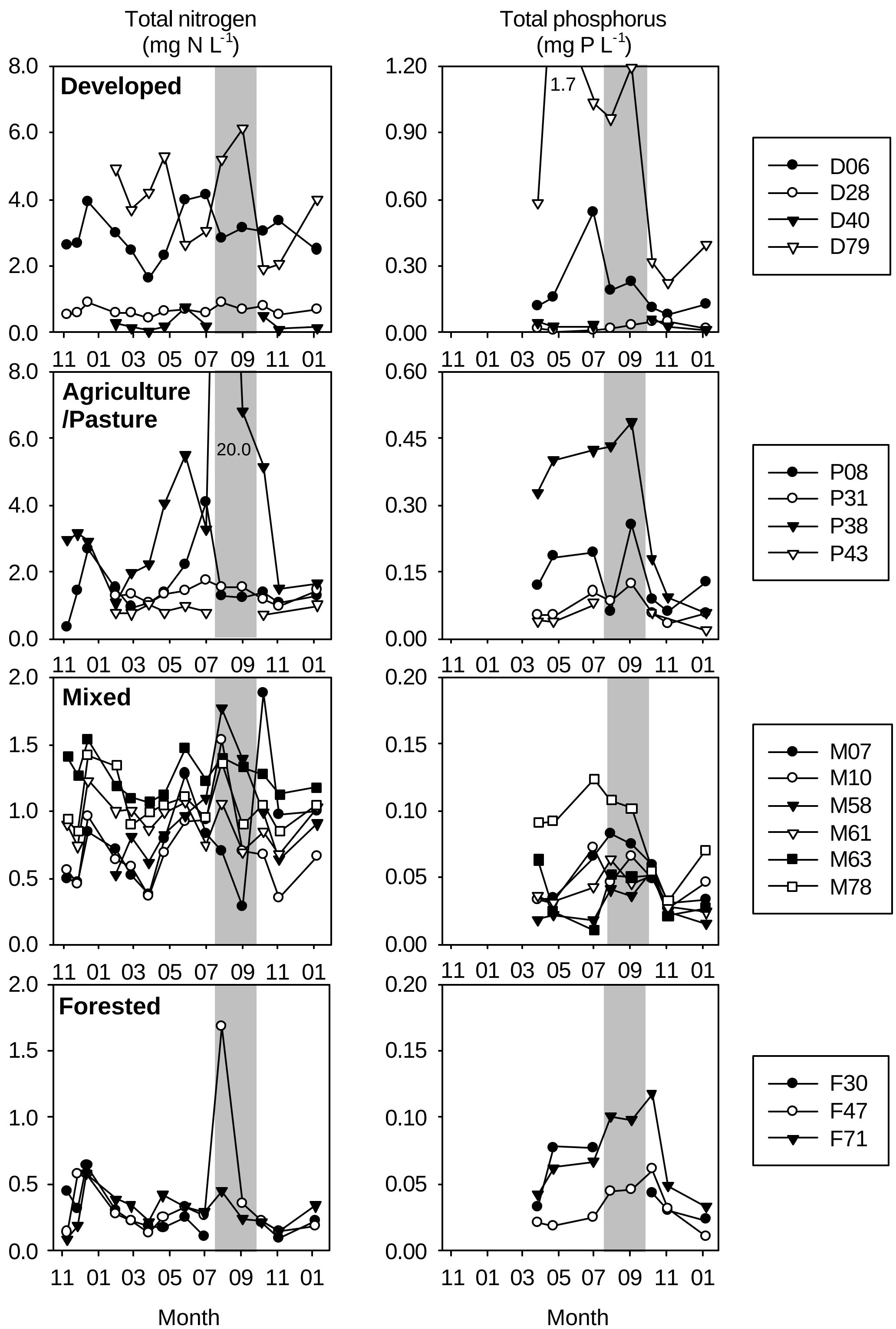

Figure 1. Total nitrogen (mg N L^{-1}) and phosphorus (mg P L^{-1}) concentrations in the studied streams (D, developed sites; P, agricultural/pasture sites; M, mixed land use sites; F, forested sites). The grey band in the graphs indicates very low flows in all the streams. Three of the sites (F30, P43 and D40) were dried during this period.

Table 1. Results of the stepwise regression on the total nitrogen (mg N L^{-1}) concentrations

Variable	) R^2	R^2
Wfor	0.55	0.55
Wdev	0.06	0.61
Wwet	0.04	0.65
Bfor	0.01	0.66
Bdev	0.27	0.93

Wfor, percentage of forest in the watershed; Wdev, percentage of developed land in the watershed; Wwet, percentage of wetlands in the watershed; Dfor, percentage of forest in the buffer strip; Bdev, percentage of developed land in the buffer strip.

clogged the channel in 6 sites. Decaying plant material can be a source of both elements in dissolved and particulate form. In the forested sites, total phosphorus concentrations clearly increased as the amount of leaves in the stream was increasing, but they diminished in winter when the leaf packs were washed downstream after some heavy rains.

One half of the sites showed N:P ratios higher than 40, and only 4 sites had an N:P ratio below 16, which is considered the theoretical optimum ratio for phytoplankton growth. As phosphorus is in short supply compared to nitrogen in most of the streams, we think that this element is being cycled more efficiently than nitrogen.

Up to 93 % of the spatial variability in total nitrogen concentrations was explained by the landscape indicators (Table 1), which implies a direct effect of the land uses within the watershed on the nitrogen levels in the streams. No such relationship with landscape indicators was found for total phosphorus concentrations. We suggest that either in-stream nutrient sources and/or processes or strong pollution sources (e. g. manure, septic tanks) are masking the effect of the watershed land uses on the total phosphorus concentrations.

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LITERATURE CITED

APHA,1998. Standard methods for the examination of water and wastewater, 20th edition. United Book Press Inc.

Crumpton, W. G., T. M. Isenhart & P. D. Mitchell, 1992. Nitrate and organic N analyses with second-derivative spectroscopy. *Limnology and Oceanography,* 37: 907-913.

HAACH. Nitrite, LR. Diazotization method. For water, wastewater and seawater. Method 8507.

Jones, K.B., A.C. Neale, M.S. Nash, R.D.Van Remortel, J.D. Wickham, K.H. Ritters, R.V. O'Neill,2001. Predicting nutrient and sediment loadings to streams from landscape metrics: A multiple watershed study from the United States Mid-Atlantic Region. *Landscape Ecol.* 16: 301-312.

Meyer, J. L., J. B. Wallace, 2001. Lost linkages and lotic ecology: rediscovering small streams. In: Press, M. C. et al. (Eds.) *Ecology: Achievement and Challenge*, pp. 295-317, Blackwell Science.

National Research Council, 2001. Assessing the TMDL approach for water quality management. National Academic Press.

Peterson, B. J., W. M. Wolheim, P. J. Mulholland, J. R. Webster, J. L. Meyer, J. L. Tank, E. Marti, W. B. Bowden, H. M. Valett, A. E. Hershey, W. H. McDowell, W. K. Dodds, S. K. Hamilton, S. Gregory, D. D. Morrall, 2001. Control of nitrogen export from watersheds by headwater streams. *Science* 292: 86-90.

Smith, V. H., 1998. Cultural eutrophication of inland, estuarine, and coastal waters. In: Pace M. L. & P. M. Grofman (Eds.) *Successes, Limitations and Frontiers in Ecosystem Science*, pp. 7-49. Springer.

Smith, V. H., G. D. Tilman, J. C. Nekola, 1999. Eutrophication: impact of excess nutrient inputs on freshwater, marine and terrestrial ecosystems. *Environmental Pollution* 100: 179-196.

US EPA, 2000. A summary of the National Water Quality Inventory: 1998 Report to Congress (US EPA 841-S-00-001). Office of Water.

USGS. National Land Cover Datasets 1992. A U.S. land cover classification product based primarily on 1992 Landsat Thematic Mapper (TM) data. http://edc.usgs.gov/products/landcover.html.

Valderrama, J. C., 1981. The simultaneous analysis of total nitrogen and total phosphorus in natural waters. *Marine Chemistry*, 10: 109-122.