ORGANIC WASTE CONTAMINATION INDICATORS IN SMALL GEORGIA PIEDMONT STREAMS

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Abstract. We monitored concentrations of dissolved organic carbon (DOC) and dissolved oxygen (DO), and other parameters in 17 small streams of the South Fork Broad River watershed on a monthly basis for 15 months. We observed a strong inverse relationship between mean DOC and mean DO, and low DO concentrations (2 mg/L) during summer in some of the streams. Elevated DOC levels and corresponding low DO may result from watershed sources of organic wastes and/or nutrients. Potential sources of watershed organic wastes include animal manure applied to the land and/or human wastes from wastewater treatment plants or septic tanks. Here we present estimates of the amounts of organic waste input to these watersheds and evaluate the possible impact of the waste on stream DOC concentrations. Our results suggest that application of poultry litter at recommended rates may impact stream DOC levels if applied to a high enough percentage of the watershed land area. We also present a few measurements of the stable nitrogen isotope ratio of plants growing in the channel and of potential denitrification rate in the sediments of a few of these streams on a few dates shortly after the monthly monitoring ended. These preliminary results suggest that stable nitrogen isotope ratios and potential denitrification rates are positively correlated with estimates of stream watershed human waste loading and thus are potentially effective indicators of waste contamination in these watersheds. In some cases, stable isotopic, potential denitrification rate, and other biogeochemical indicators of organic waste and/or nutrient contamination may be useful to regulators and managers charged with protecting water quality.

INTRODUCTION

Small streams and their watersheds are critical components of river networks that provide valuable ecosystem services such as organic matter and nutrient processing which, in turn, provide important water quality protection and food resources to downstream ecosystems. Because of their small size, headwater stream ecosystem function may be easily impaired by land use changes and organic waste inputs associated with agricultural, residential, or industrial development. Organic wastes from urban and agricultural watersheds can alter organic matter and nutrient processing and lead to oxygen depletion in small streams.

Small streams draining minimally disturbed Georgia Piedmont watersheds tend to have low dissolved organic carbon (DOC) concentrations (Molinero and Burke, 2003a). This is likely because: (1) the soils have high concentrations of clay and iron oxides (Mulholland and Lenat, 1992), which are known to retain DOC strongly (Qualls et al., 2002); and (2) organic-rich wetlands, which are generally an important source of stream DOC (Hemond, 1990), are uncommon in Georgia Piedmont watersheds (Mulholland and Lenat, 1992). Highly efficient processing of labile organic waste in the terrestrial environment resulting from the relatively warm temperatures and abundant rainfall of the area contributes to low DOC concentrations in those streams draining moderately-impacted watersheds. Elevated DOC in streams likely reflects either direct organic waste inputs or organic waste applied in excess of the processing capacity of the terrestrial environment.

Denitrification is a key aquatic ecosystem service because it contributes to the permanent removal of N. Factors that control denitrification include redox status, and availability of nitrate and labile organic matter. Land clearing and agricultural practices of the late nineteenth and early twentieth centuries, combined with the intense rainfall, steep slopes, and erodible soils of the region, led to accelerated soil erosion and deposition of fine-grained sediments in Georgia Piedmont stream channels (Ruhlman and Nutter, 1999). Fine sediment deposition would be expected to lower redox status. Combined with inputs of labile organic wastes and nitrate, these conditions could lead to enhanced rates of denitrification in stream channel sediments.

The stable nitrogen isotope ratio ($^{15}N/^{14}N$) of plants reflects the $^{15}N/^{14}N$ of their source and provides an indicator of organic waste contamination in aquatic environments (e.g., McClelland et al., 1997; Wigand et al., 2001). Organic waste-derived N is typically more ^{15}N-enriched than N derived either from fertilizer or atmospheric deposition (Heaton, 1986). A large isotope fractionation effect is also associated with the process of denitrification (Heaton, 1986), which leaves the remaining nitrate, and any plants that subsequently fix it, relatively ^{15}N-enriched.

This research is part of an ongoing program to identify, develop, and apply biogeochemical indicators (e.g., stable isotope ratios, denitrification rate measurements) of small stream ecosystem condition and function. Increasing urban development of watersheds may lead to over application of animal wastes to ever shrinking available land areas. If the capacity of the land to process these wastes is exceeded, small stream ecosystem condition and function may be impaired.

STUDY AREA

The South Fork Broad River (SFBR) is a tributary of the Broad River that drains an area of about 556 km^2 mostly within Oglethorpe and Madison counties. The SFBR watershed is primarily rural and largely undeveloped although the human population has rapidly increased in recent years (U.S. Census Bureau (http://quickfacts.census.gov/qfd/). Industrial use in the watershed is mainly limited to a few granite quarries. Forestry and agriculture are the main land uses throughout the watershed. Agriculture consists mainly of grass cultivation for hay production or grazing, and poultry operations. Northern Georgia is a major area of US poultry production. In terms of broiler production, Georgia is the number one ranked state in the US, and Madison and Oglethorpe are the second and thirteenth ranked counties within Georgia (USDA, 2004). Massive amounts of poultry litter are produced as a consequence, most of which is disposed of by land application to pastures near the production site.

METHODS

Seventeen subwatersheds, ranging in size from 0.5 to 3.4 km^2, were selected from within the SFBR watershed. We monitored concentrations of DOC and dissolved oxygen (DO) and other parameters on an approximately monthly basis from January 2002 until March 2003 at the outlets of the watersheds. DOC concentrations were determined by high temperature combustion and DO concentrations were determined with a portable field meter (American Public Health Association, 1998). Denitrification potential was estimated by a modification of the method of Martin et al. (2001). Denitrification rates determined by this technique may be much higher than *in situ* rates because anoxic conditions are imposed in the assay. Neither nitrate nor a labile carbon source, which might have further artificially elevated the rates, were added. Stable nitrogen isotope ratios of plant materials were determined by stable isotope ratio mass spectrometry (McClelland et al., 1997). Stable nitrogen isotope ratios of samples are expressed relative to air in the del notation:

$$^{15}N\ (‰) = [[(^{15}N/^{14}N)_{sample}/(^{15}N/^{14}N)_{standard}] - 1\ ] \times 1000$$

Percentages of forested land, agricultural land, residential areas, wetlands and open water surfaces within each watershed were estimated from the National Land Cover database (see Molinero and Burke, 2003b). The study sites were classified as forested, agricultural, developed, or mixed land use.

Human population in each small watershed was estimated from 2000 US Census data. Human waste production was calculated by assuming that each person excretes 23.2 kg C yr^{-1} (United States Department of Agriculture (USDA), 1992). Animal waste inputs to the watersheds were calculated by assuming that UGA-recommended rates of poultry litter (2 tons $acre^{-1}$ yr^{-1} or about 4.5×10^5 kg yr^{-1} km^{-2}) were applied to all the pastures and hay fields in a given small watershed and that poultry litter inputs far exceed other potential animal waste inputs. Our assumed rate of poultry litter application falls within the range of 2 to 4 tons $acre^{-1}$ yr^{-1} that is typically recommended for southeastern US pastures (Casey Ritz, UGA Cooperative Extension Service, personal communication). Estimated inputs of poultry litter are much higher than inputs of human wastes in all of the subwatersheds, by 3 to 300 fold. The poultry litter was assumed to be 22% carbon (North Carolina State University (NCSU), 2001), so the UGA-recommended rate of input would be about 10^5 kg C yr^{-1} km^{-2}. Waste loading is expressed on a watershed area basis.

RESULTS AND DISCUSSION

We observed a significant ($p < 0.01$) inverse linear correlation between mean DOC and mean DO concentrations (Figure 1). None of the mean DO values were below the generally accepted water quality criteria of 5 mg/L; however, several of the streams with elevated DOC concentrations had DO concentrations of 2 mg/L or less on a few dates during the low flow and high temperature conditions of summer. The inverse correlation of DOC and DO, together with the low summertime DO levels in some of the streams, suggest that inputs of organic wastes from impacted watersheds can create in-stream conditions that are not suitable for all forms of aquatic life during at least part of the year.

Estimated total watershed waste input and mean stream DOC concentrations are also significantly ($p < 0.01$)

correlated (Figure 2) providing further evidence that organic wastes may impact stream chemistry. The two streams with direct waste water treatment (WWTP) inputs were excluded from this correlation. Our data suggest that organic waste inputs to the watershed above about 8 X 10^4 kg C yr^{-1} km^{-2} may begin to influence stream DOC levels. Our data further suggest that, on a per capita basis, WWTP inputs may have more impact on stream DOC concentrations than wastes applied to the land. This is because WWTP effluents are direct inputs to the streams and not attenuated by the natural biological degradation and geochemical adsorption processes associated with transport through the soil. The impact of human waste on DOC concentration in areas without sewer service is likely to be highly variable and depend on factors such as the extent and proximity of development to the stream and septic system performance.

The impact of pasture-applied poultry litter on stream chemistry is likely to be highly variable due to variations in proximity of the pastures to the streams, slope, etc. Further, some areas classified as grassslands based on the remote sensing data are hayfields whereas others are grazed by animals. Grazed pastures may have variable animal stocking rates as a result of food subsidies. Cattle may have direct access to the streams in which they may directly deposit waste which, like WWTP effluents, would not be influenced by natural soil purification processes.

Our paired potential denitrification rate and plant stable isotope measurements are significantly ($p = 0.02$) correlated (Figure 3). The positive correlation between potential denitrification rate and ^{15}N could reflect plant uptake of nitrate that became ^{15}N-enriched as a result of

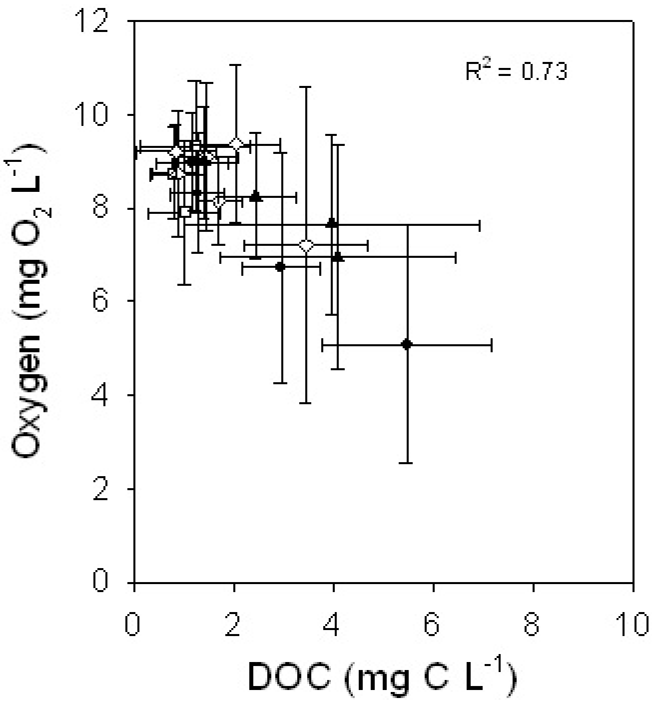

Figure 1. Mean DOC vs mean DO values for the period January 2002 to March 2003 (Molinero and Burke, 2003a). Symbols: closed circles - developed; closed triangles - pasture; open diamonds - mixed; open squares - forested

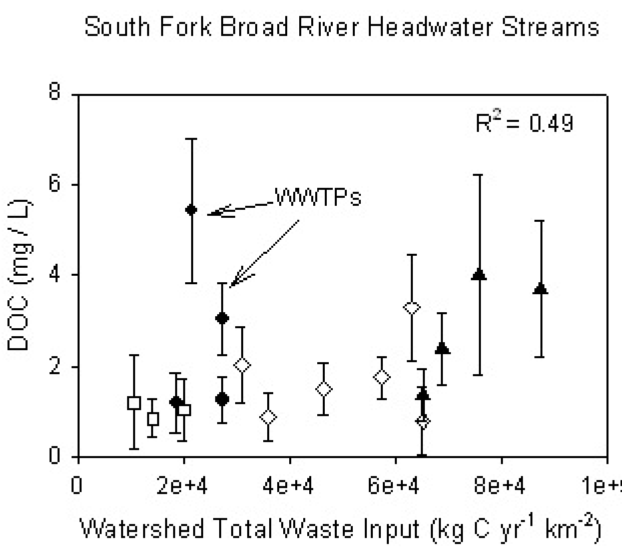

Figure 2. Estimated total watershed waste inputs vs. mean DOC (± one standard deviation) from January 2002 to March 2003. Symbols same as in Figure 1.

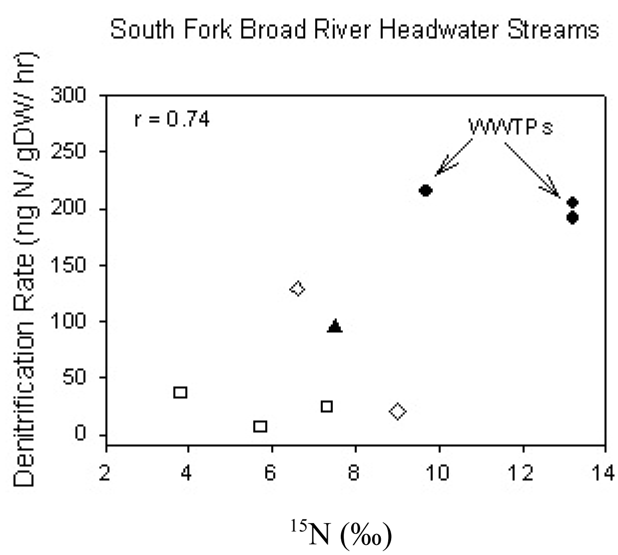

Figure 3. Potential denitrification rate vs. plant stable nitrogen isotope ratio for selected sites. DW - dry weight sediment. Symbols the same as in Figure 1.

denitrification, or both parameters could be independently responding to other factors such as watershed organic waste loading. Potential denitrification rates vary in response to parameters such as nitrate and organic C concentration (e.g., Martin et al., 2001) and thus appear to be useful for comparing relative N and organic C availability and capacity for denitrificaiton among streams. We observed 30-fold variation in potential denitrification rate (Figure 3), which was positively correlated with estimated watershed human waste loading ($R^2 = 0.71$; $p = 0.02$) but not total watershed waste loading. Mean total N values for these streams ranged from 0.3 to 4 mg/L (Molinero and Burke, 2003b). Plant ^{15}N varied by approximately 10 ‰ in our samples and was also positively correlated with estimated watershed human waste loading ($R^2 = 0.67$; $p = 0.02$) but not total watershed waste loading. These correlations suggest that organic waste inputs are enhancing the sediment denitrification potential and increasing plant ^{15}N in these streams. Other studies (e.g., McClelland et al., 1997; Wigand et al., 2001) have shown positive correlations between plant ^{15}N and wastewater N inputs in esturarine systems and suggested that plant ^{15}N might be an effective indicator of relatively low rates of wastewater loading. The observations that sediment potential denitrification rate and plant ^{15}N are highly correlated to human waste loading but not total waste loading suggest that direct (e.g., waste water effluents) or near-stream (e.g., septic tanks) inputs of organic wastes are more likely to impact stream chemistry than are organic wastes dispersed throughout the watershed. Potential denitrification rate, plant ^{15}N, and mean DOC were elevated and mean DO was depressed (Figures 1 and 3) in a stream to which cattle had direct access. This suggests that waste inputs from cattle may also perturb carbon and nutrient cycling in small streams.

In summary, the results presented here suggest that Georgia Piedmont watersheds have a large but finite capacity to process organic wastes and protect small streams from impairment by those wastes. Further, our results suggest that N stable isotope ratios, potential denitrification rate, and other biogeochemical parameters may have value as indicators of the impact of organic waste and/or nutrient contamination on stream ecosystem condition and function. These indicators may be particularly useful to regulators and managers charged with protecting water quality in situations in which watersheds may be threatened by development and/or land application of organic wastes.

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