

DISCOVERING URBAN ECOSYSTEMS: NITROGEN CYCLING IN URBAN RIPARIAN FORESTS

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Abstract. Land disturbances as a result of urbanization have the potential to greatly modify soil processes. In the nitrogen cycle, soil biota converts nitrogen (N) from organic to inorganic compounds making it useable for plants. Denitrification, the conversion of nitrate (NO_3^-) to nitrogen gas (N_2), is an essential step in the nitrogen cycle. If not efficiently converted to N_2 gas, NO_3^- can become a waterway pollutant and an agent of eutrophication. Riparian forests can affectively reduce the amount of NO_3^- in runoff and shallow groundwater. If urbanization alters groundwater flow in urban watersheds riparian forests cannot function as “sinks” for NO_3^- . Mineralization and nitrification, both aerobic processes in the nitrogen cycle, are sources of N. Measuring the rates of mineralization, nitrification, and denitrification determined that high levels of N were found in the urban riparian forests in the Gwynns Falls watershed in Baltimore, Maryland. Low groundwater tables resulted in aerobic environments that increased nitrification. Urban riparian forests along the Gwynns Falls watershed can be a source of N in the summer months.

INTRODUCTION

Only in recent decades have ecologists begun to consider cities as ecosystems. About three quarters of the people in the United States live in metropolitan areas and ecologists now realize the importance of understanding the ecosystems of cities and suburban areas (www.beslter.org/frame4-page_3a.html). Therefore, it is the present challenge of ecologists to explore the nature of human impact on urban ecosystems as our presence has greatly affected the environments of these areas. Pollution from transportation and industry contributes oxides of carbon, nitrogen and sulfur, heavy metals, particulate matter, and an array of allopathic and aromatic hydrocarbons to urban environments (White and McDonnell 1988). These pollutants, along with physical disturbance to the landscape from construction, greatly alter a wide range of ecosystem processes.

The transformation of landscapes from primarily agricultural and forest uses to urbanized landscapes has the potential to greatly modify soil properties and processes. The cyclical processes facilitated by microorganisms and other soil fauna are invaluable to human life. The most universal of these functions is the processing and storage of the organic matter produced by plants. More than 50% of the organic material fixed by primary producers flows to soil-based “detrital” food chains (organisms living in the soil). As organic matter is processed by soil biota, nutrients are released to the environment and become available for recycling back to primary producers. Organic residues from decomposition become part of the stable pool of soil organic matter that plays an important role in moderating soil physical and chemical conditions. Soil microorganisms carry out functions, which are important at micro, ecosystem, landscape, and global scales (www.beslter.org/frame4-page_3a.html).

Nitrogen has been subjected to the most study of the various essential soil elements. This element is a vital component of enzymes, amino acids, and compounds necessary for growth and nutrition. The interaction among the various forms of nitrogen in soils, plants, and animals in the atmosphere constitute the *nitrogen cycle* (Brady 1990). Denitrification, the anaerobic microbial conversion of NO_3^- to N gases is one component of this cycle (Groffman and Crawford, Unpublished).

Nitrate is the most common drinking water pollutant in U.S. groundwater and is an agent of eutrophication in costal and marine waters (Groffman et al. 1992, Groffman and Crawford, Unpublished). Denitrification in soil

can be used to control nitrate levels in waterways in areas positioned to function as “sinks” for this compound. Studies of natural stream-side (riparian) forests have shown that the amount of nitrogen in runoff and shallow groundwater can be reduced by as much as 80% after passing through these ecosystems (Welsch 1991). Past studies have shown (Groffman et al. 1992, Groffman and Crawford, Unpublished) that the ability of soil to convert NO_3 to N_2 gas is directly related to the position of the groundwater table. *Riparian Ecosystem Function in Urban Watersheds*, a previous study of riparian forests in Baltimore, Maryland, noted that urban riparian sites can have significant denitrification if soils are wet. The study also noted that urban riparian zones are often characterized by dry soils and low water tables due to increases in upland surface runoff and downcutting of streams associated with increases in impervious surfaces in urban watersheds (www.beslter.org/frame4-page_3a.html).

In addition to denitrification, it is important to understand the nitrogen cycle processes of mineralization and nitrification. Mineralization, the release of organically bound nitrogen from the tissues of plants and animals, returns nitrogen to its inorganic mineral forms (ammonium- NH_4^+ and nitrate- NO_3^-) for reentry into the nitrogen cycle. Nitrification is the process of enzymatic oxidation of ammonia (NH_3) to nitrates by certain microorganisms in the soil. Nitrification can only take place if there is ammonia to be oxidized. In contrast to denitrification, mineralization and nitrification are dominantly aerobic processes (Brady 1990). While high rates of denitrification allow an ecosystem to function as a sink for nitrate, high rates of mineralization and nitrification can cause an ecosystem to be a source of nitrate.

In this study, we evaluated the levels of denitrification, nitrification, and mineralization in urban riparian soils in relation to water table levels. There are several factors associated with urbanization that can alter riparian water table levels and nitrogen cycling in urban watersheds (Groffman and Crawford, Unpublished). Hydrologic flow paths in these watersheds are altered, with large amounts of water moving from uplands to streams as surface runoff rather than infiltrating groundwater. High urban stream flows can lead to stream incision, which leads to lower riparian water tables. Low water tables prevent interaction of groundwater-borne NO_3^- with near surface soils that have the highest denitrification potential (Groffman et al. 1992, Simmons et al. 1997). Our hypothesis was that hydrologic changes that lead to low water tables cause urban riparian forests to be sources rather than sinks of nitrate.

This information will contribute to ongoing soil research as a part of the Baltimore Ecosystem Study (BES). Funded by the National Science Foundation and the Environmental Protection Agency, BES is a long-term ecological research project focused on a wide range of habitats in urban environments. These studies will help ecologists to understand the city as an ecosystem.

EXPERIMENTAL APPROACH

Sites

Sites used in this study are a part of the ongoing Baltimore Long Term Ecological Research Project focusing on the Gywnns Falls Watershed, a 17,150 ha catchment which lies in Baltimore City and County, Maryland, and drains into the Chesapeake Bay (www.beslter.org/frame4-page_3a.html). Four sites in the watershed were used to determine if incised streams, induced by urbanization, cause N levels to increase in riparian forests. Pond Branch, a completely forested reference is located in a state park. Sites in Glyndon and Gwynnbrook represent rural and old suburban land use. Cahill, an urban site, is located in the core of the city.

MATERIALS AND METHODS

July 9-10, 2001, soil core samples were taken at each site from 0-10 cm, 10-30 cm, 30-50 cm, 50-70 cm, and 70-100 cm depths. Each site had two plots, one located upstream and the other downstream. Using random numbers

to determine the distance of the sampling site from existing wells, two field replicates were taken in each plot. Soil samples were hand sorted and stored at 4°C before analysis.

Soil moisture content was determined by drying at 80°C for 24 hours. Organic matter content was determined by loss on ignition at 500°C for 1 hour. Inorganic N was extracted with 2 M of KCl followed by colorimetric analysis with a Perstorp Flow Solution Analyzer.

Rates of mineralization, nitrification, denitrification and soil respiration were measured by incubating soil samples in 1 L (mason) jars for 10 days. Respiration was quantified by measuring CO₂ accumulation in the headspace of the jars, mineralization was measured from the accumulation of total inorganic N (NH₄⁺ plus NO₃⁻) and nitrification was measured from the accumulation of NO₃⁻ alone. At the end of the 10-day incubation, 100 mL of acetylene was added to each jar and denitrification was quantified by measuring N₂O accumulation over a 24-hour period (Groffman et al. 1999). Concentrations of CO₂ were quantified by thermal conductivity gas chromatography and concentrations of inorganic N were quantified as described above. Concentrations of N₂O were quantified by electron capture gas chromatography.

The denitrification enzyme assay was used to measure denitrification potential as described by Groffman et al. (1999). This assay allows for the quantification of denitrification by measuring the production of N₂O in the presence of 10% acetylene. Samples were amended with NO₃⁻ (100 mg/kg), dextrose (40 mg/kg), and chloramphenicol (10 mg/kg) and acetylene (C₂H₂, 10 kPa) and incubated under shaken anaerobic conditions for 100 minutes. Soils were made anaerobic by repeated evacuation and flushing with O₂ free gas. Gas samples were taken at 40 and 100 minutes and stored in evacuated glass vials. Samples were analyzed for N₂O as described above.

STATISTICAL ANALYSIS

Data were analyzed by one-way analysis of variance with a Fisher's protected least significant difference test to determine specific differences between sites.

RESULTS AND DISCUSSION

Pond Branch (reference forest) had the lowest levels of N as depth increased (-0.03~0.00 mg N kg⁻¹) and Cahill had the highest (Figure 1). These data were consistent with our original hypothesis that the urban sites would have higher levels of N than the reference site. We hypothesized that N levels would be high in the urban sites due to low denitrification rates. Pond Branch was expected to have the highest rate of denitrification (ug N kg⁻¹). However, Pond Branch had denitrification rates similar those of Glyndon, Gwynnbrook, and Cahill (Figure 2). Clearly, differences in denitrification rates did not cause the differences in soil nitrate levels that we observed.

Nitrification rates (mg N kg⁻¹ d⁻¹) were much lower at Pond Branch than at the urban sites (Figure 3). Low levels of soil nitrate are the result of little N production by nitrification, especially at Pond Branch. Glyndon, Gwynnbrook, and Cahill also had varying nitrification suggesting that small amounts of nitrate were being produced.

The differences in nitrification that we observed may be related to differences in carbon availability among the sites (Figure 4). High respiration rates signal high carbon (C) availability to microbes in the soil (Figure 4). Low nitrification at Pond Branch may be a result of competition for NH₄⁺ between nitrifiers and other soil microorganisms. When carbon availability is high soil microorganisms take up NH₄⁺, a process called immobilization. Once NH₄⁺ is immobilized, it is no longer available for nitrification.

The differences in carbon availability and nitrogen cycling that we observed among the sites were likely related to differences in water table depth. At Glyndon, Gwynnbrook, and Cahill the water table is more than 70 cm below

the soil surface (Figure 5). As a result, surface soils at these sites are dominantly aerobic, leading to depletion of available carbon and increases in nitrification. Therefore, NO_3^- is produced in an environment with limited capabilities to consume it. These changes cause the urban riparian zones to be sources, rather than sinks of NO_3^- .

Denitrification rates can vary throughout the year. During summer, denitrification rates can be lower than other seasons. Higher rates of denitrification may be observed during winter when water tables are higher. At this time, soils are more anaerobic and favorable for denitrification. Possibly, Pond Branch will have higher denitrification rates during winter.

Hydrolic changes as a result of urbanization decrease the ability of riparian forests to absorb N. Altering water flow and allowing N to reach streams can have detrimental, long-term effects on coastal waterways. Elevated N levels can destroy aquatic ecosystems, which will directly affect the livelihood of urban cities. Further, long term studies on urban riparian forests are necessary to determine the effects of urbanization and the human responsibility to protect terrestrial and aquatic urban ecosystems.

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation under Grant No. DBI 9988029 and the Environmental Protection Agency as a part of the Baltimore Long Term Ecological Research Project and a contribution of the Andrew W. Mellon Foundation to the Research for Undergraduates (REU) program at the Institute of Ecosystem Studies (IES). The author would like to thank: Dr. Peter Groffman, Soil Microbiologist for his mentorship through the REU program, Amanda Thimmayya, Sabrina Polcek, Emilie Stander, Evan Grant and Groffman Lab Research and Project Assistants for their gracious efforts in the field and in laboratory.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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APPENDIX

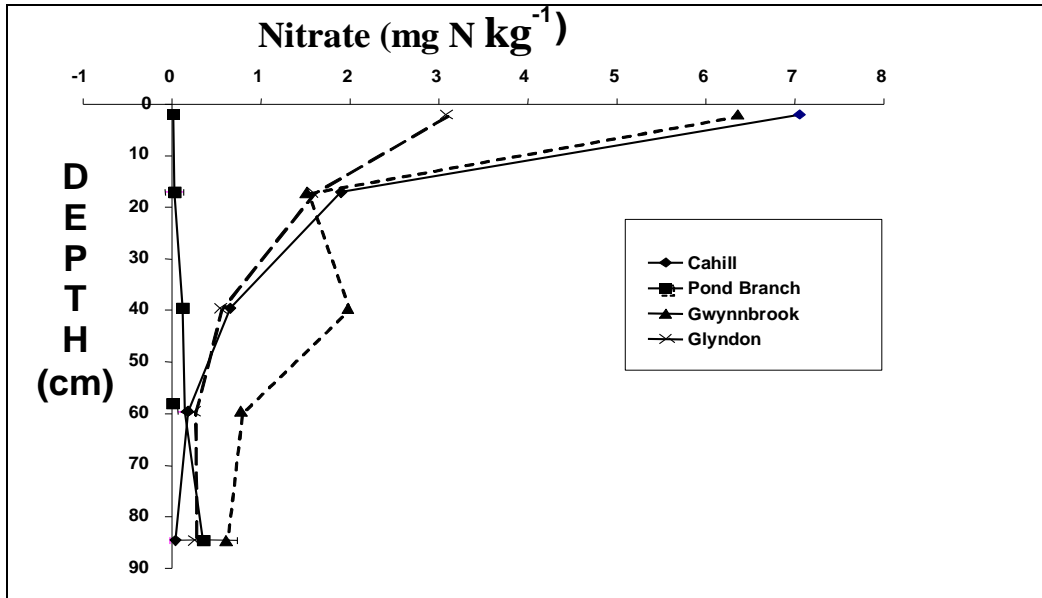


FIGURE 1. Graph of nitrate as depth increases. Pond Branch (reference forest) had the lowest level of N and Cahill had the highest.

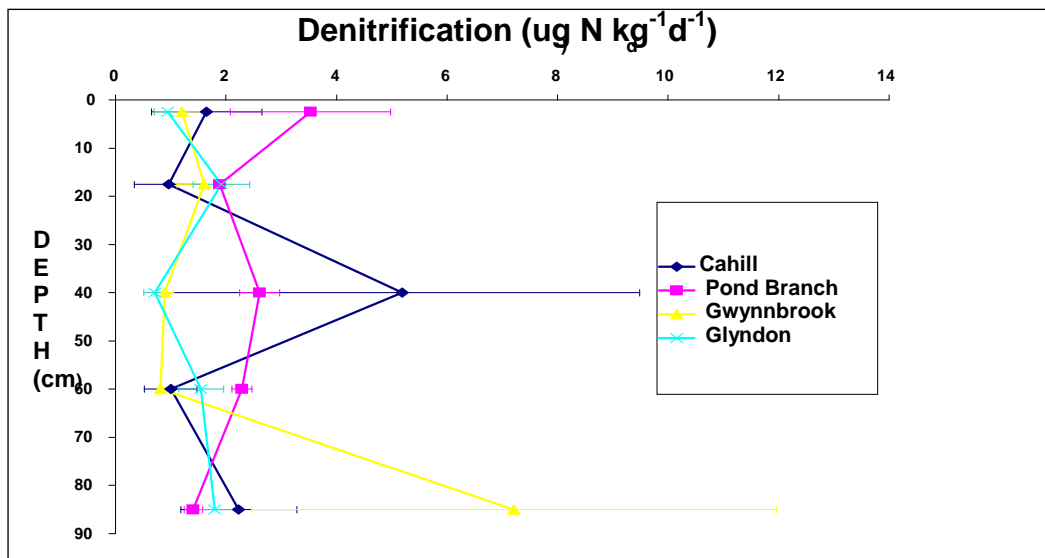


FIGURE 2. Graph of denitrification rates as depth (cm) increases. Pond Branch (reference forest) had rates similar to those of Cahill (urban), Glyndon (suburban), and Gwynnbrook (suburban).

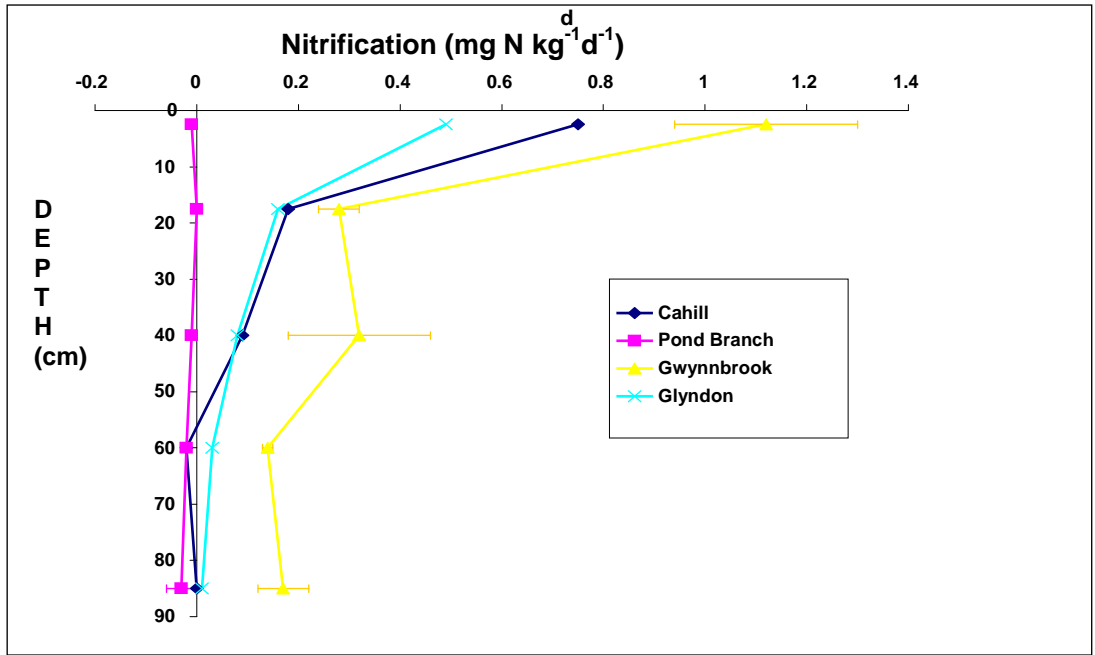


FIGURE 3. Graph of nitrification rates as depth (cm) increases. Pond Branch (reference forest) had very low rates as compared to Cahill, Glyndon, and Gwynnbrook.

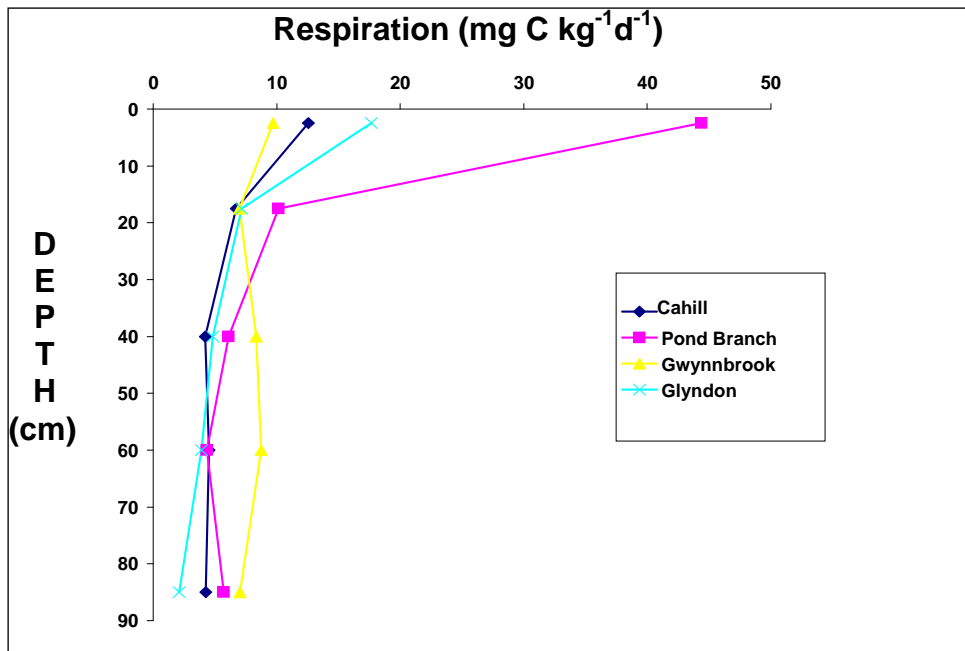


FIGURE 4. Graph of respiration rates as depth increases. Pond Branch (reference forest) had high rates as compared to Cahill, Glyndon, and Gwynnbrook.

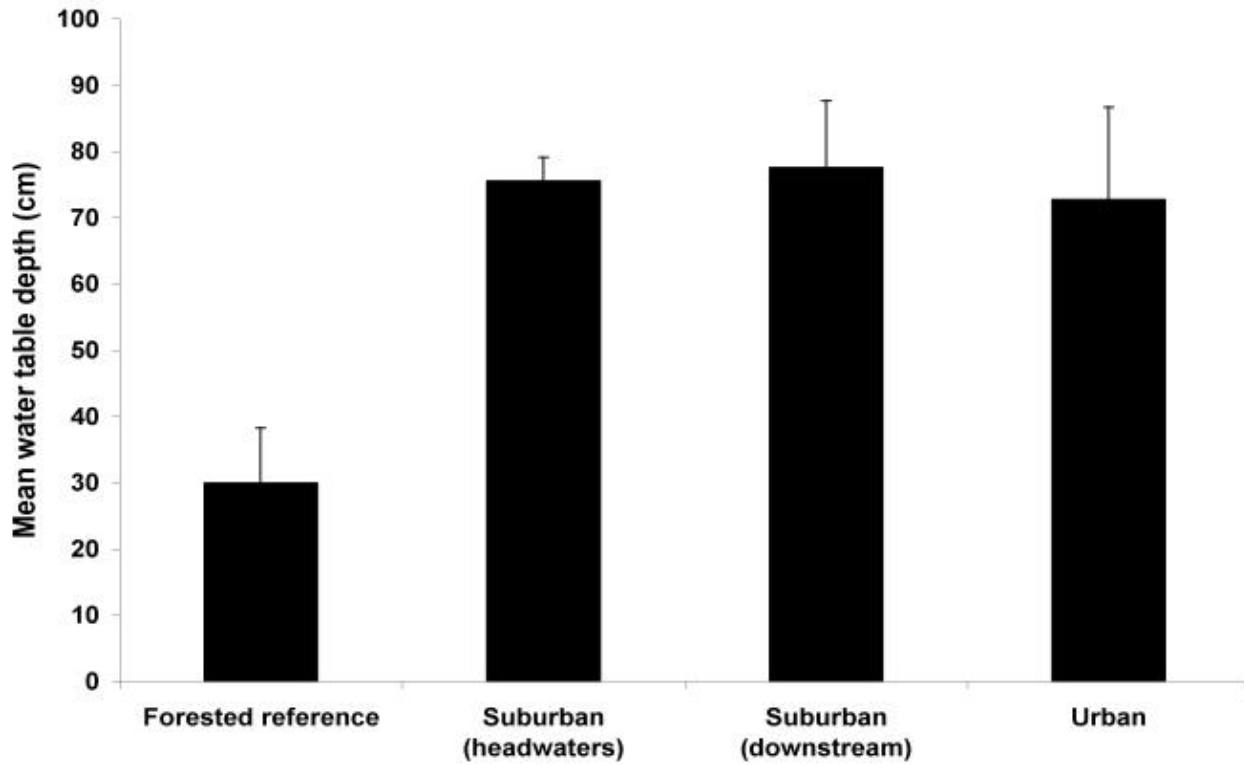


FIGURE 5. Mean water table depth (cm) at Pond Branch, Glyndon, Gwynnbrook, and Cahill.