DECOMPOSITION AND SOIL PROCESSES IN NATURAL VERSUS ARTIFICIAL PONDS AND RIPARIAN AREAS

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Abstract. The increase in urban land cover over the last 50 years has had detrimental effects on the environment. With an increase in nitrogen levels as well as other chemicals in the environment, ecosystems are suffering from the adverse effects of these pollutants. In addition, the destruction of forests and other natural habitats has displaced some of the natural functions unique to these ecosystems. As a result, humans have found ways to replace processes such as the regulation of runoff water. These measures, otherwise known as stormwater control measures (SCMs), seek to mimic natural ways of controlling runoff water. Nonetheless, the deposition of pollutants in these urban fixes to nature has caused changes in the organisms that live in these artificial environments and the processes that they perform. One of the most important of these processes is decomposition, the process by which microorganisms and invertebrates consume organic matter and releases nutrients such as nitrogen to the environment. We quantified differences between natural and artificial ponds and riparian zones with regards to decomposition, invertebrate abundance and microbial biomass and activity related to nitrogen cycling. We sampled between artificial and natural ponds and riparian zones in the Baltimore, MD USA metropolitan area. We expected to find higher rates of decomposition and macroinvertebrate abundance in the natural areas. Likewise, we hypothesized that the natural areas would have higher amounts of microbial biomass and rates of nitrogen cycle processes such as mineralization and nitrification. Our results showed no difference between artificial and natural environments in terms of macroinvertebrate abundance and decomposition rate. In contrast, natural areas had higher rates of potential net nitrogen mineralization, potential net nitrification, soil nitrate levels, and microbial biomass N. These results suggest that artificial ponds and riparian zones successfully replace some functions lost by urban land use change but that others are not. Artificial ponds, which are very common in urban areas around the world, appear to have particularly high functional potential.

INTRODUCTION

Urban land cover has quadrupled over the last 50 years and covers ~24 million ha of land in the United States (Lubowski et al. 2006). Between 1950 and 2000, the amount of land classified as urban (>1 housing unit per acre) and exurban (between 1 unit per acre and 1 unit per 40 acres) increased 5 fold (Brown et al. 2005). Urbanization increases both the type and amount of pollution that runs off into nearby aquatic ecosystems (US EPA 1993). This runoff includes pollutants such as sediments, road salts, heavy metals, hydrocarbons, and nutrients that are washed off buildings, roads and other areas.

Pollutant loads are higher in urban areas for two reasons; there are more sources in urban areas and there is less opportunity for pollutants to be removed by plants and soil before they reach aquatic ecosystems (Nowak and Walton 2005). As the number of cities and metropolitan areas increase, the number of natural terrestrial and aquatic ecosystems and the natural pollutant removal processes that they support declines. Previous research has shown that urbanization has a particularly significant impact on the nitrogen (N) cycle (Groffman et al. 2006, Bernhardt et al. 2008). This impact is driven by high nitrogen deposition from fossil fuel combustion in urban areas. This deposition aggregates on parking lots, roads, and along gradients away from roadways (Hope et al. 2004, Davidson et al. 2010, Kirchner et al 2005). In the presence of rain, these pollutants enter natural streams and ponds. Other factors like fertilizer additions, septic systems, and ineffective sewer infrastructure are other important sources of nitrogen in urban areas (Kaushal et al. 2011*)*.

In addition to having abundant sources of nitrogen, the ability of urban areas to convert reactive nitrogenous compounds back into environmentally benign forms are diminished compared to non-urban areas. Alterations in the landscape by human activity have reduced connections between riparian zones, the stream, and the uplands, which results in in lower watershed N retention (Hogan and Walbridge 2007). Riparian zones normally function as "sinks" for nitrate (NO_3-), the most common and problematic form of reactive N through the process of denitrification, an anaerobic process that converts NO_3^- into nitrogen gases.

In urbanized areas with impaired streams and riparian zones, engineering solutions have been employed to replace the ecosystem functions previously performed by forests and riparian zones, such as storm water infiltration and N removal. Most of these engineering solutions act to control storm water discharges through the installation of storm water control measures (SCMs). These control measures seek to reduce peak discharge and/or remove pollutants associated with sediments. There are five classes of SCMs: (A) wet ponds, such as shallow marsh and wet ponds, which have a permanent pool of water, (B) dry detention ponds, which have pools that dry out between storms, (C) dry extended detention basins, which are designed to store runoff and then drain over an extended period of time (usually 24 hr), (D) infiltration practices, such as swales, infiltration basins and trenches, which are designed to infiltrate storm water into the soil, and (E) filtering practices such as sand filters and bioretention areas, which are designed only for sediment removal, and do not reduce peak flows (US EPA 1993).

The intermediate disturbance hypothesis states that diversity and species richness are greatest in areas with moderate disturbance. In these areas, the amount of disturbance is enough to change the ecosystem but doesn't cause extinction of species (Stiling, 379). Events of environmental disturbance can cause changes in the properties and functions of ecosystems. Depending on the intensity or the spatial reach, disturbance events can affect a variety of ecosystem properties such as nutrient cycling and the function and structure of plant and soil populations (Wright & Coleman, 2002; Anderson & Rosemond, 2007; Ford & Naiman, 1988; Margolis et al., 2001; Nummi & Kuuluvainen, 2013). An important ecosystem property that is affected by disturbance is decomposition.

Decomposition plays a vital role in the ecosystem in terms of recycling nutrients and energy in ecosystems through the chemical and physical breakdown of dead biomass into forms that are usable to other organisms. Different organisms make up the biotic decomposers in an ecosystem, both macro- and microorganisms. Macro-decomposers include gastropods, insect larvae, amphipods, arthropods, nematodes, and annelids. Micro-decomposers are typically heterotrophic bacteria, fungi, and invertebrates that biodegrade dead or decaying biomass to obtain carbon, nutrients, and energy. Disturbance events affect decomposers differently depending on their functions and niches.

Urban conditions have been shown to affect both decomposers and the process of decomposition (Casas et al., 2000; Anderson & Rosemond, 2007; Gonzalez et al., 2013). Decreases in the macroinvertebrates that occupy aquatic and terrestrial components of urban ecosystems may lead to important changes in ecosystem processes such as decomposition (Christenson et al., 2010). Urban-induced decreases in macroinvertebrate abundance have been shown to affect both aquatic and terrestrial decomposers and decomposition in a range of ways (Anderson & Rosemond, 2007; Margolis et al., 2001; Nummi & Kuuluvainen, 2013).

There is great uncertainty about the decomposer communities that populate the artificial ponds and other SCM that are created in urban areas. Almost nothing is known about the diversity/abundance of detritivores that occurs within these artificial environments and how this influences the amount of decomposition.

In both natural and artificial environments, leaf litter serves as an important source of energy for both terrestrial and aquatic decomposers. Depending on its availability, quality, and type, leaf litter affects decomposer abundance, community composition, and rate of decomposition (Negrete-Yankelevich et al., 2008; Tiegs et al., 2008; Wallace et al., 1999; Lepori et al., 2005;Schädler & Brandl, 2005). However, the fate of leaf litter likely differs greatly between natural and artificial environments.

In this study, our objective was to determine if the artificial environments created as SCMs mimicked natural conditions and supported ecological functions, with a, particular focus on ponds and riparian areas. We measured decomposition and soil processes associated with nitrogen cycling including nitrate and ammonium levels, total inorganic nitrogen levels, respiration, microbial biomass, mineralization, and nitrification in natural versus artificial ponds and riparian areas in Baltimore, MD, USA. We assessed potential responses to the influence of urban conditions on overall decomposition and macroinvertebrate abundance by ambient sampling and the introduction of homogenous leaf litter bags in both aquatic and terrestrial environments. Our objectives were to determine 1) whether decomposition was higher in natural or artificial areas and 2) if soil processes related to the nitrogen cycle were similar in natural areas and artificial areas.

MATERIALS AND METHODS

Study Sites and locations

This study focused on ponds and riparian areas in the Baltimore, Maryland metropolitan area. Within this urban area, 2 natural ponds (Gwynnbrook natural, Pond Branch), 2 artificial ponds (Gwynnbrook detention, Winterset detention) and nearby riparian areas were selected from sites previously studied as part of the Baltimore LTER (Bettez and Groffman 2012). At each site, two zones were sampled, a zone in the pond and an adjacent riparian area. IButton data loggers were placed at three of the eight locations to measure temperature and relative humidity every three hours for the course of 4 weeks.

Pond areas were selected based on sites used for previous research. These ponds were optimal for research for two reasons; they have adjacent riparian areas and they were relatively old, well-established ponds. For the natural ponds, riparian areas were within 10 m of the ponds. Artificial sites were stormwater detention basins that permanently retained water for comparison with the natural ponds. The grassy areas around the artificial ponds were selected as the riparian areas.

Decomposition

Dried red maple (*Acer rubrum*) litter was collected from the Vassar College Ecological Preserve. From this collection, 24 ~7.0g leaf litter samples were placed into 0.5mm mesh bags. These bags were then numbered 1-24 and stapled shut. Bags 1-6 were for the natural ponds, 7-12 for the artificial ponds, 13-18 for the natural riparian areas, 19-24 for the artificial riparian areas. Three replicate bags were placed randomly in each location. IButton loggers were placed a week after the bags, two recording data for the natural sites and one recording data for the artificial sites.

Three macroinvertebrate samples were taken at each location on the day that litter bags were deployed. We will call these the ambient samples. For the terrestrial sites (riparian areas), three leaf litter samples were taken from each site adjacent to where the bags were placed. Aquatic samples were collected using the benthic kick-net method of walking 3-5 meters across the pond with a net to collect macroinvertebrates. Samples were stored in pond water. Altogether, 24 samples were collected, 12 from the terrestrial sites and 12 from the aquatic sites. Terrestrial litter was placed in Berlese funnels taped to containers with 70% ethanol for approximately 2-3 days before analysis and aquatic macroinvertebrates were collected in a sealed container. Collected macroinvertebrates were stored in ethanol or pond water and identified to order using a dissecting microscope.

Bagged samples were collected four weeks (June 10^{th}-July $8^{th)}$ after their deployment. Terrestrial samples were analysed in the same way as the ambient terrestrial litter. Likewise, aquatic were collected and analysed in the same way as the ambient aquatic litter. Litter from the bagged samples were weighed to calculate the mass difference. The mass difference was used as a measure of decomposition. IButton loggers were also removed and recorded data was used to measure average temperature and relative humidity each week for four weeks.

Soil and Microbial Processes

Three soil/sediment cores were collected from each site close to the location of the bagged samples. Samples were stored at 4 degrees C for less than a week and then homogenized by removing large roots and rocks. Soil moisture content was calculated by drying subsamples to a constant weight. Subsamples were analysed for soil NH_4, soil NO_3, soil total inorganic nitrogen (TIN), respiration rates, microbial biomass N, microbial biomass C, potential net nitrogen mineralization, and potential net nitrification according to methods described and referenced in Groffman et al (2003).

Soil NH_4 and NO_3- were extracted with 2 M KCl and analysed with a Lachat flow injection analyser. We measured microbial biomass C using the chloroform fumigation incubation method developed by Jenkinson and Powlson (1976). In this method, we fumigated samples with chloroform to kill and lyse microbial cells, inoculating them with fresh soil, and incubating them for ~10 days. During this period, the dead microorganisms were mineralized to CO_2 and NH_4+ by living microbes in the fresh soil. The amount of CO_2 and 2 M KCl extractable inorganic N produced during the incubation are proportional to the amount of carbon and nitrogen in the microbial biomass. Using a gas chromatograph, we measured CO_2 and then calculated the amount of C through a proportionality constant of 0.45. We also measured the amount of CO_2 and 2 M KCl extractable NH_4+ and NO_3- in unfumigated “control” samples over ~10 day incubations. The amount of CO_2 in these samples was used to calculate microbial respiration. The amounts of NH_4+and NO_3- produced were used to calculate potential net N mineralization, conversion of organic N to inorganic N, and nitrification, the transformation of NH_4+to NO_3-.

Statistical Analysis

The statistical program R was used for all data analysis. We used a one-way analysis of variance (ANOVA) to test for differences between natural areas and artificial areas in leaf decomposition, bagged samples macroinvertebrate abundance, ambient samples macroinvertebrate abundance, respiration rates, potential net nitrogen mineralization, potential net nitrification, soil NH_4, soil NO_3-, soil total inorganic N (NH_4 + NO_3-), microbial biomass C and microbial biomass N. In addition, we used student’s t tests to analyze specific differences among sites for macroinvertebrate abundance, decomposition, microbial biomass C, microbial biomass N, respiration, microbial biomass N. Shannon and Jaccard indices of diversity for macroinvertebrates were calculated in Microsoft Excel.

RESULTS

The mean temperatures were higher in the artificial areas than in the natural areas every week for four weeks (Table 2). There was no significant difference between natural and artificial areas in terms of decomposition (Figure 1) as quantified by mass loss over the four-week incubation.. However, there was statistical support for differences in decomposition rates between ponds and riparian areas. Leaf bag samples placed in ponds lost more mass than samples placed in riparian areas (Figure 1)($P<0.05$).

Macroinvertebrate abundance was not different between the four environments for the ambient samples ($P>0.05$) (Figure 2). Among the bagged samples, there was no significant difference in abundance between the natural and artificial areas. However, the riparian areas had higher number of macroinvertebrates than the ponds ($P<0.05$) (Figure 3), which is the opposite trend that was observed for decomposition.

Microbial biomass C was not significantly different between the different environments ($P>0.05$) (Figure 4). On the contrary, microbial biomass N was higher in the natural riparian areas than in the artificial riparian areas ($P<0.05$) (Figure 5). There was no statistically significant difference between the artificial pond and the natural pond. For soil nitrate, we observed that the natural areas (ponds and riparian areas) had higher concentrations than the artificial areas ($P<0.05$) (Figure 6). Ammonium concentrations in the soil were not different between the four sites ($P>0.05$)(Figure 7). Soil respiration rates and soil total inorganic nitrogen ($P>0.05$) (Figures 8 and 9) also did not differ among sites. Potential net N mineralization and potential net nitrification were higher in natural riparian areas than in artificial riparian areas ($P<0.05$) (Figures 10 and 11). Natural and artificial ponds showed no differences in these variables.

DISCUSSION

Although the average weekly temperature of the artificial areas was higher than the natural areas, this did not appear to influence macroinvertebrate abundance or decomposition rate, as there was no consistent difference in these variables between the artificial and natural areas. It is surprising that we were unable to establish a significant relationship between temperature and these variables given the large temperature range (13.0 °C-23 °C) that we observed. Our results are consistent with Lessard and Hayes (2003) who established that temperature was not significantly related to macroinvertebrate richness but are contrary to other studies that have suggested that temperature changes either increase or decrease macroinvertebrate abundance. According to Li et al. (2012), macroinvertebrate abundance decreased as water temperature increased; a 1 °C increase was associated with an 11% reduction in the winter abundance and richness. In contrast, Arthur et al. (2003) found that total macroinvertebrate density was higher in heated waterways. The effect of varying temperature on macroinvertebrate abundance depends on factors such as season and macroinvertebrate species and these factors appear to be more important than the differences in temperature and relative humidity in this study.

Pond areas had higher rates of decomposition than riparian areas. This may be due to the convenience of finding resources in aquatic areas. Aquatic macroinvertebrates might not have to travel as far to find food compared to terrestrial macroinvertebrates. Somewhat surprisingly, riparian areas had higher macroinvertebrate abundance in decomposition bags than pond areas, the exact opposite of the trend for decomposition. This data suggests that terrestrial macroinvertebrates were better able to colonize the bagged samples, but clearly, their activity was less than those that colonized the bags in the ponds.

Our hypotheses were inconsistent with our results. There was no difference in decomposition rates between the natural versus artificial areas. Also, areas with higher macroinvertebrate abundance and microbial biomass did not have higher rates of decomposition. Still, there were some differences between natural and artificial for some soil processes. Microbial biomass C was not significantly different among the different environments; however, microbial biomass N and several other nitrogen cycling processes were higher in the natural area than the artificial area. Similar to Bettez and Groffman (2012), natural riparian areas had a higher nitrate concentration than artificial areas. These trends suggest that while artificial areas are doing well for decomposition and macroinvertebrate abundance, they are not as effective for soil processes related to nitrogen cycling such as mineralization and nitrification. There is a clear need for more detailed measurements of process rates in natural and artificial features in urban environments.

Investigating the differences between natural environments and constructed environments will give us an idea of how to better mimic natural conditions. For urban places like Baltimore City, NYC, and Washington DC, creating artificial ponds and riparian areas that effectively imitate natural ponds and riparian areas will improve soil/microbial processes and decomposition rates, thereby reducing pollution associated with high levels of nitrogen. Future research should seek to find ways to increase the biodiversity of benthic and terrestrial macroinvertebrates that aid with decomposition. We also need to develop effective approaches to study the relationship between microbial biomass and macroinvertebrate abundance and its effect on the concentration and recycling of organic matter in terrestrial and aquatic ecosystems.

This study aimed to establish whether artificial areas developed to replace natural ecosystem functions lost through urbanization properly mimicked natural conditions and functioned as well as natural areas. Our data was unable to fully conclude that natural areas did better than artificial areas for all of our factors, but we discovered that the success of artificial areas depended on the ecosystem processes we were studying. Future research should study each variable separately to determine how they differ between natural sites and constructed sites.

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APPENDIX

TABLE 1. Experimental Design

Sites	# of Replicates	# of Samples/ Site	Total Samples
Natural Pond	2	3	6
Detention Pond	2	3	6
Natural Riparian Zone	2	3	6
Artificial Riparian Zone	2	3	6

TABLE 2. Mean temperature and relative humidity at the different environments over the course of four weeks.

	Natural Riparian		Artificial Riparian		Natural Pond		Artificial Pond	
Week	Temp (°C)	Relative Humidity	Temp (°C)	Relative Humidity	Temp (°C)	Relative Humidity	Temp (°C)	Relative Humidity
1	23.33	92.21	26.38	86.10	25.24	87.41	26.38	86.10
2	19.82	93.04	21.82	92.79	21.93	91.37	21.82	92.79
3	20.64	98.83	23.12	91.17	22.77	92.03	23.12	91.17
4	23.84	97.98	26.37	91.40	26.03	87.86	26.37	91.40

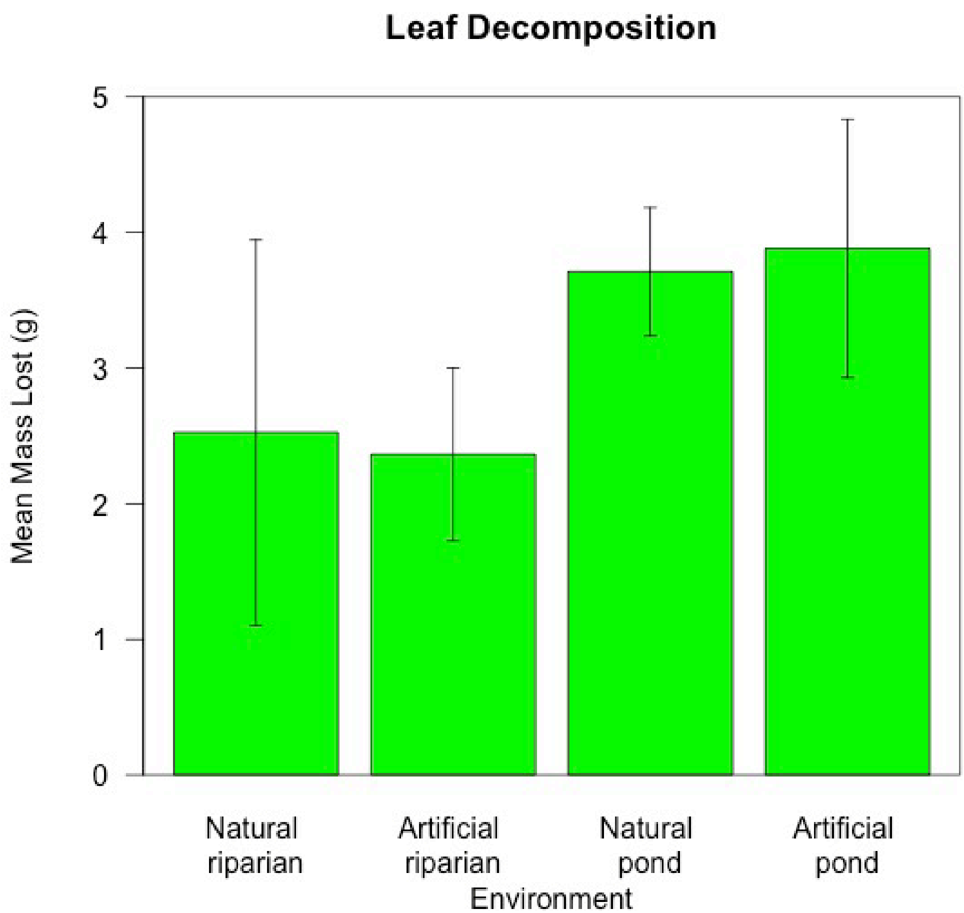

FIGURE 1. Mean percent mass loss in bagged leaf litter samples. Ponds had significantly higher loss than riparian areas ($P<0.05$).

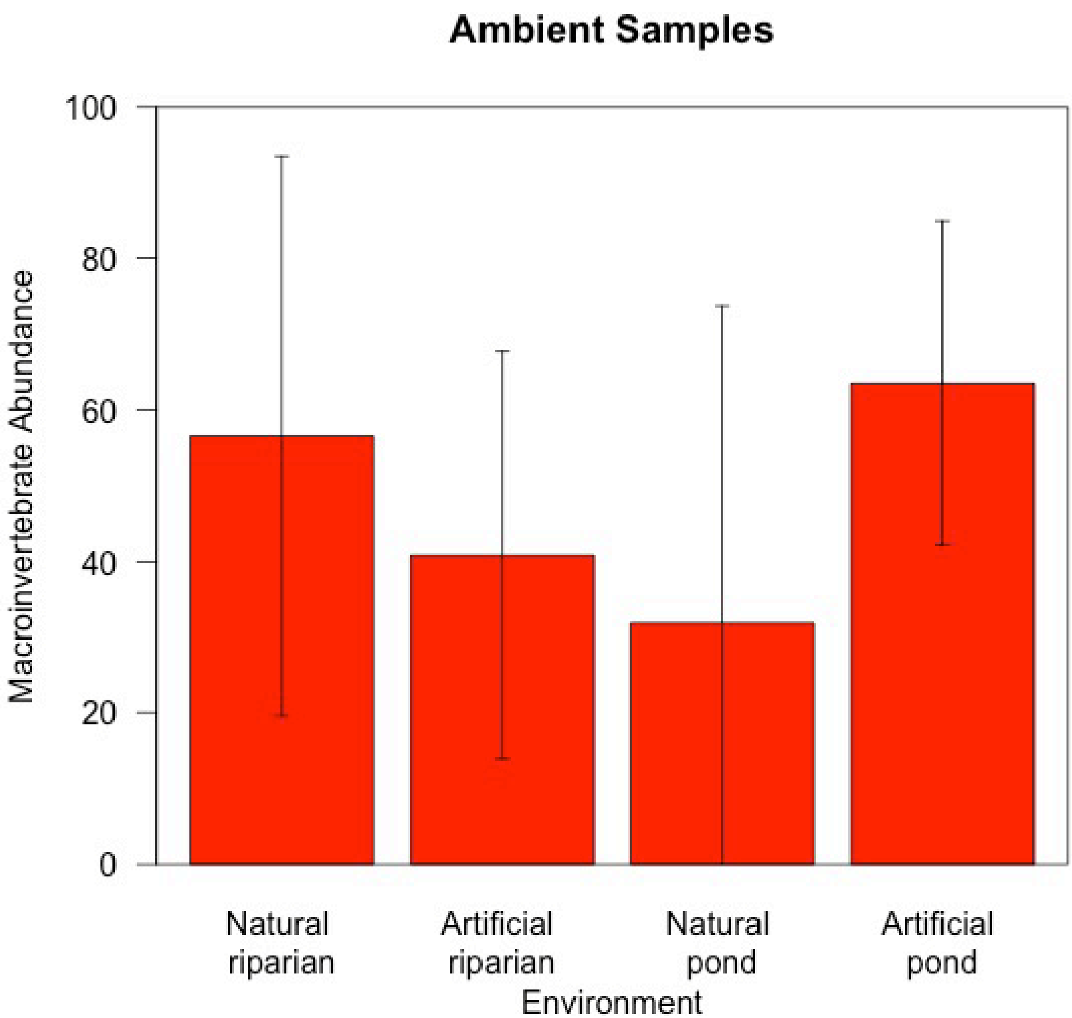

FIGURE 2. Mean macroinvertebrate abundance in ambient leaf litter and benthic samples. There were no significant differences among sites.

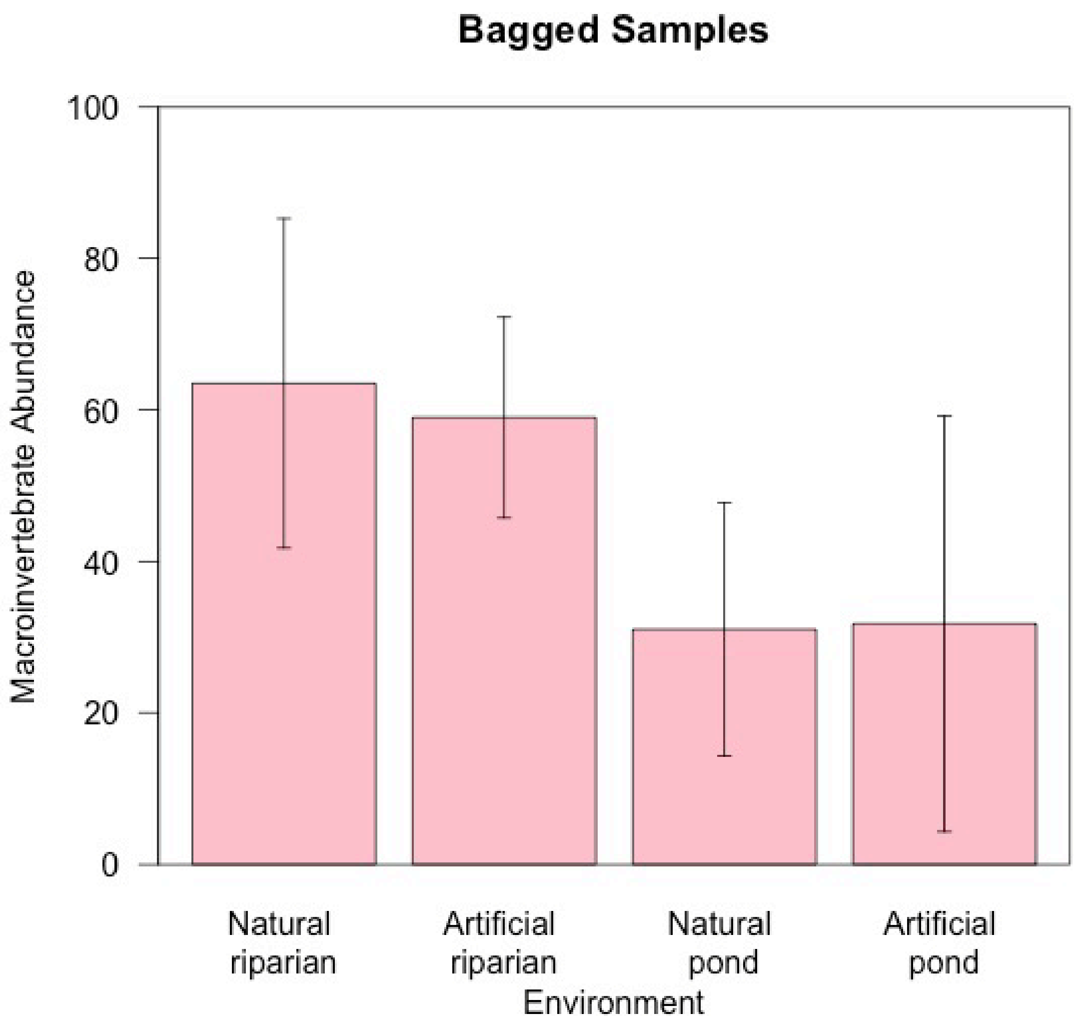

FIGURE 3. Mean macroinvertebrate abundance in bagged leaf litter samples. Abundance was higher in riparian areas than in ponds (P<0.05).

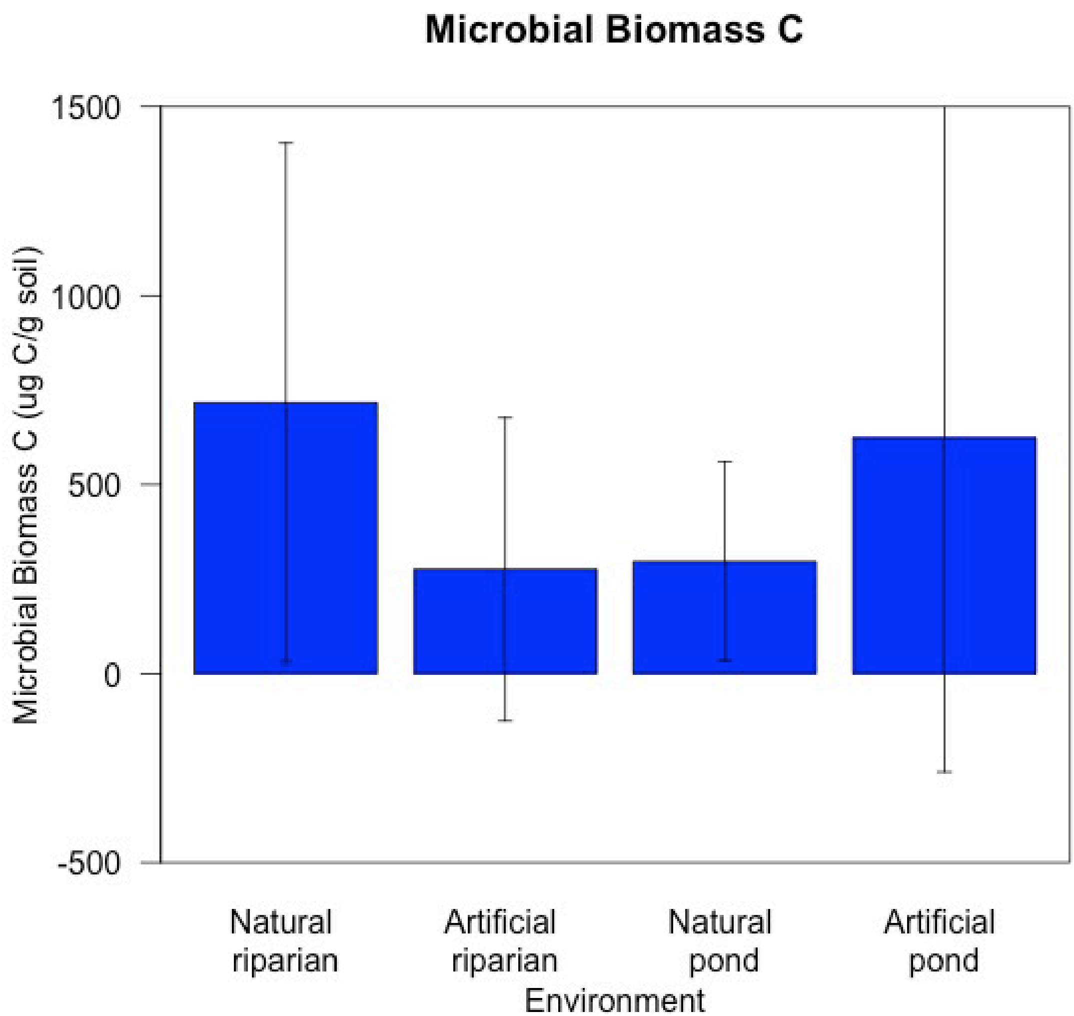

FIGURE 4. Microbial biomass C measures in each of the four environments. There were no statistically significant differences among sites.

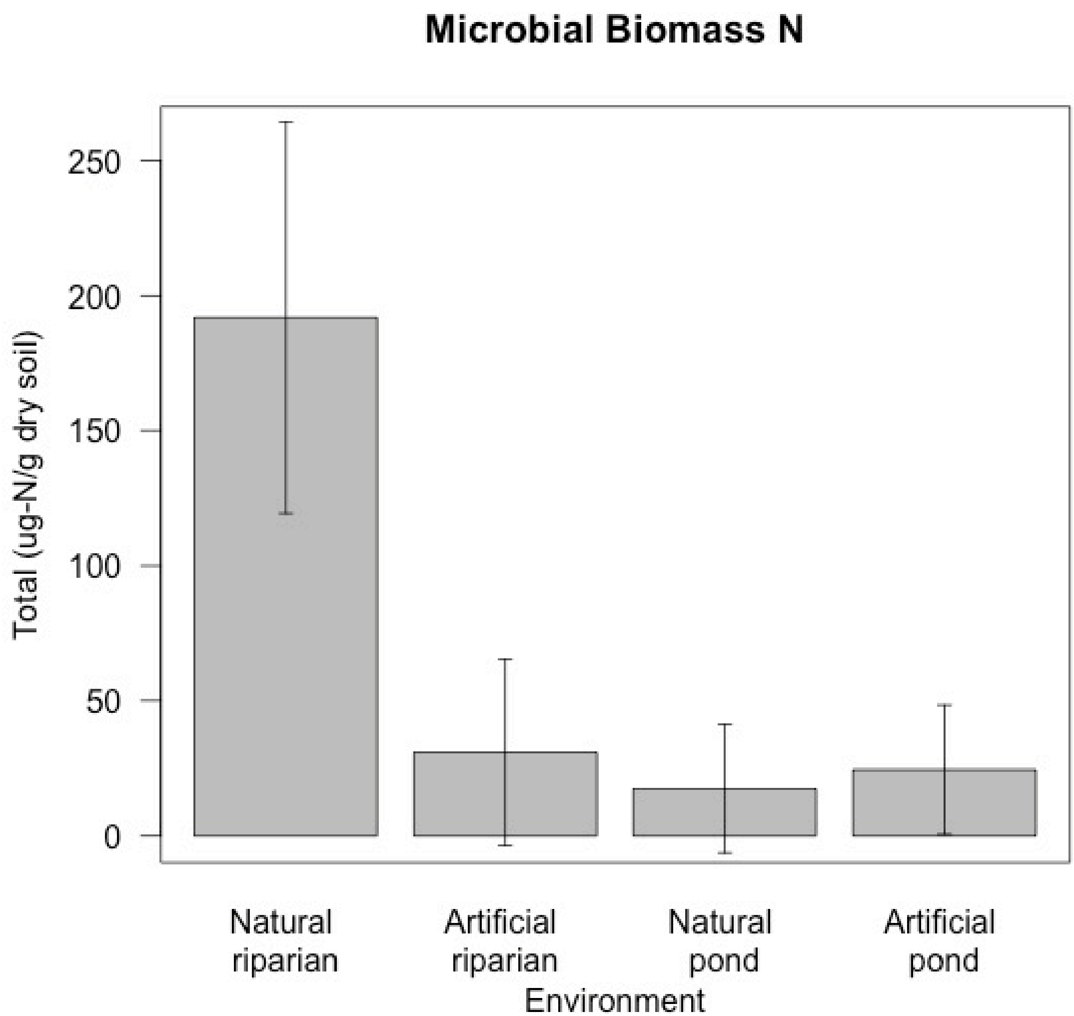

FIGURE 5. Microbial biomass N concentration in each of the four environments. Biomass N was higher in the natural riparian areas than in the artificial riparian areas (P<0.05).

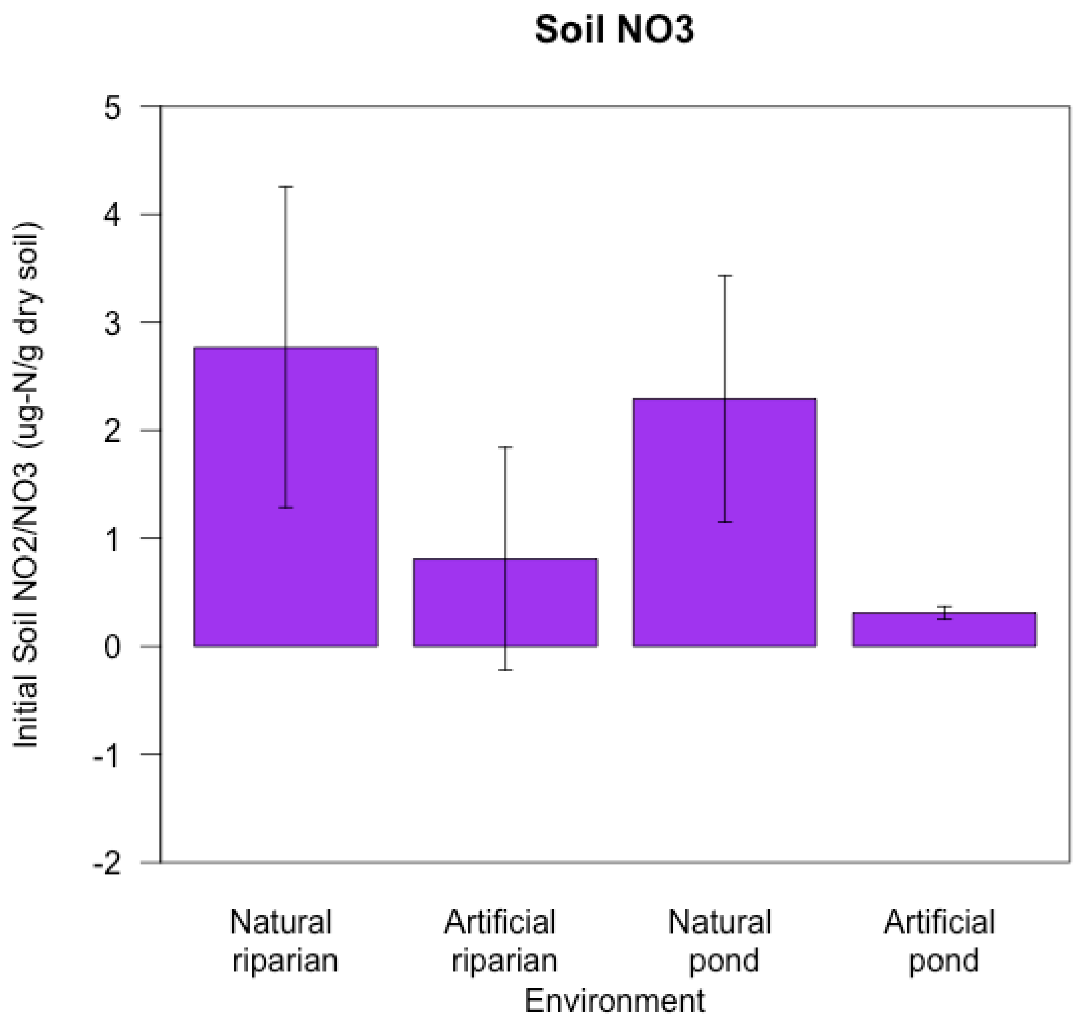

FIGURE 6. Soil nitrate concentration in each of the four environments. Natural areas had higher concentrations than artificial areas (P<0.05).

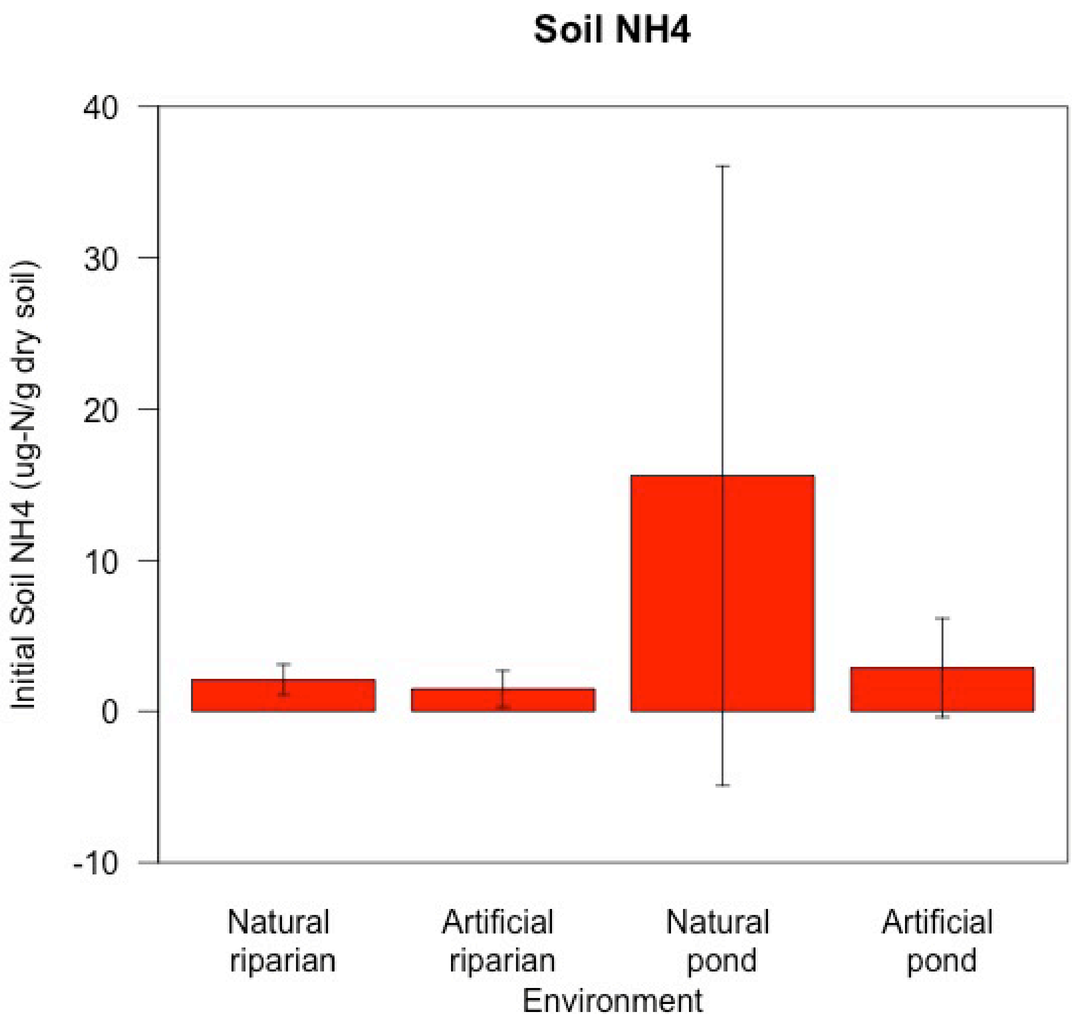

FIGURE 7. Soil ammonium concentration in the four environments. There were no statistically significant differences among sites.

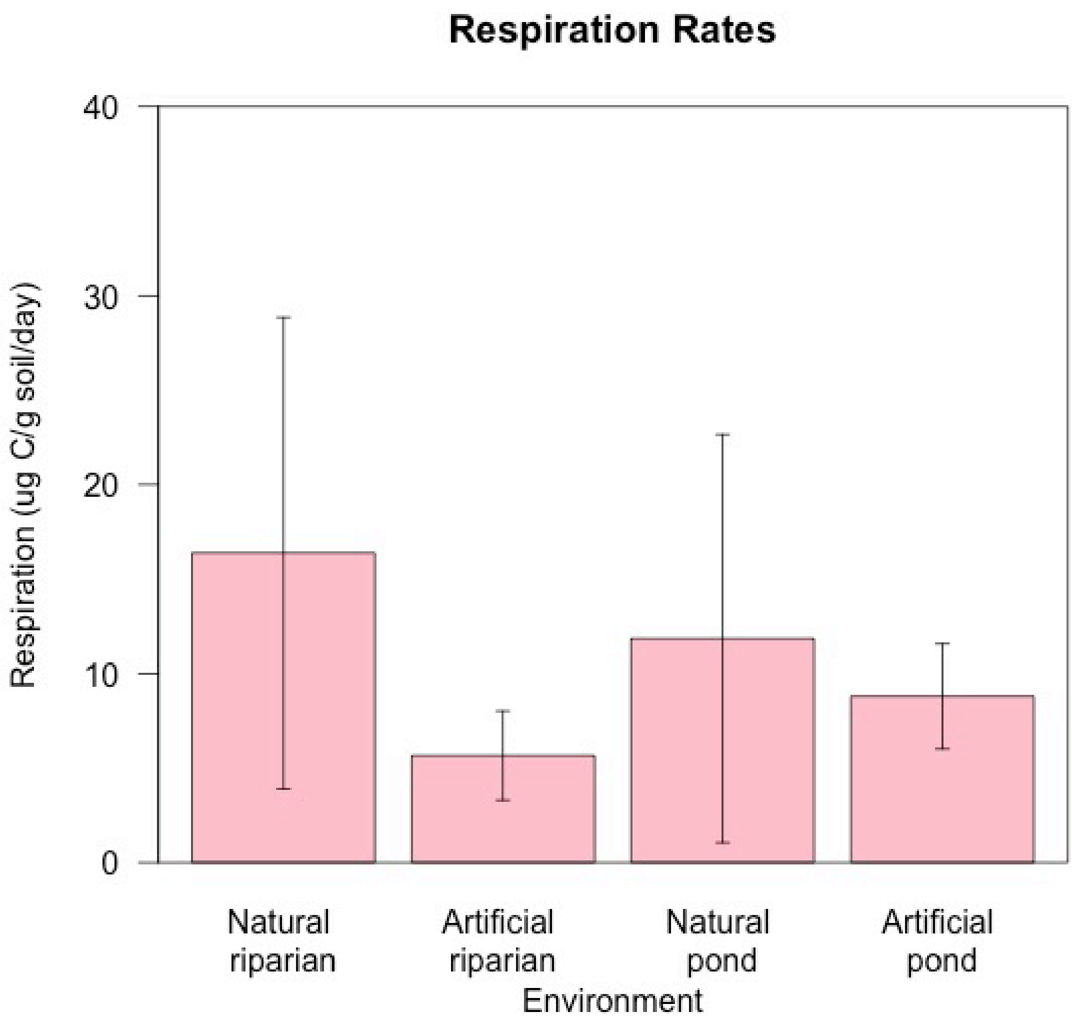

FIGURE 8. Respiration rates in each of the four sites. There were no statistically significant differences among sites.

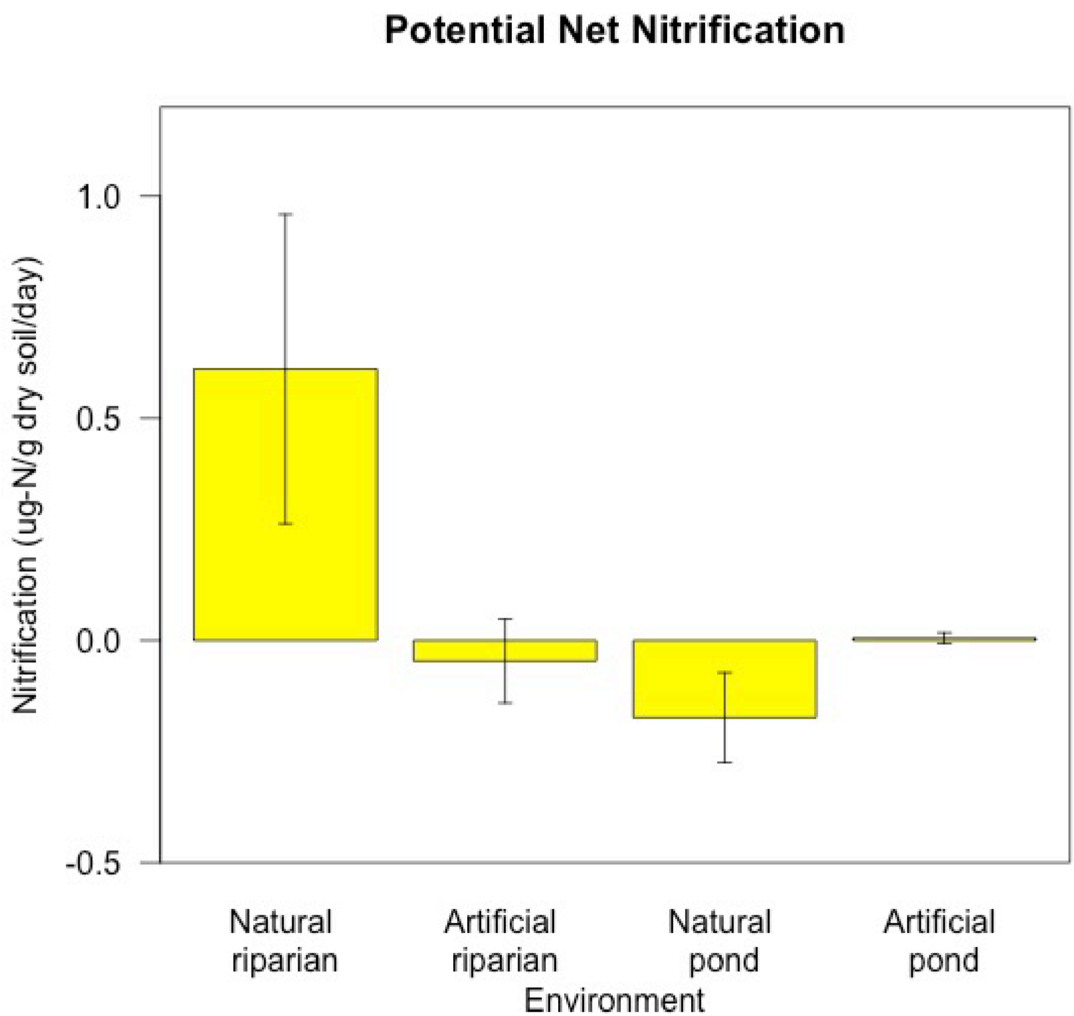

FIGURE 9. Soil total inorganic nitrogen in the four environments. There were no statistically significant differences among sites.

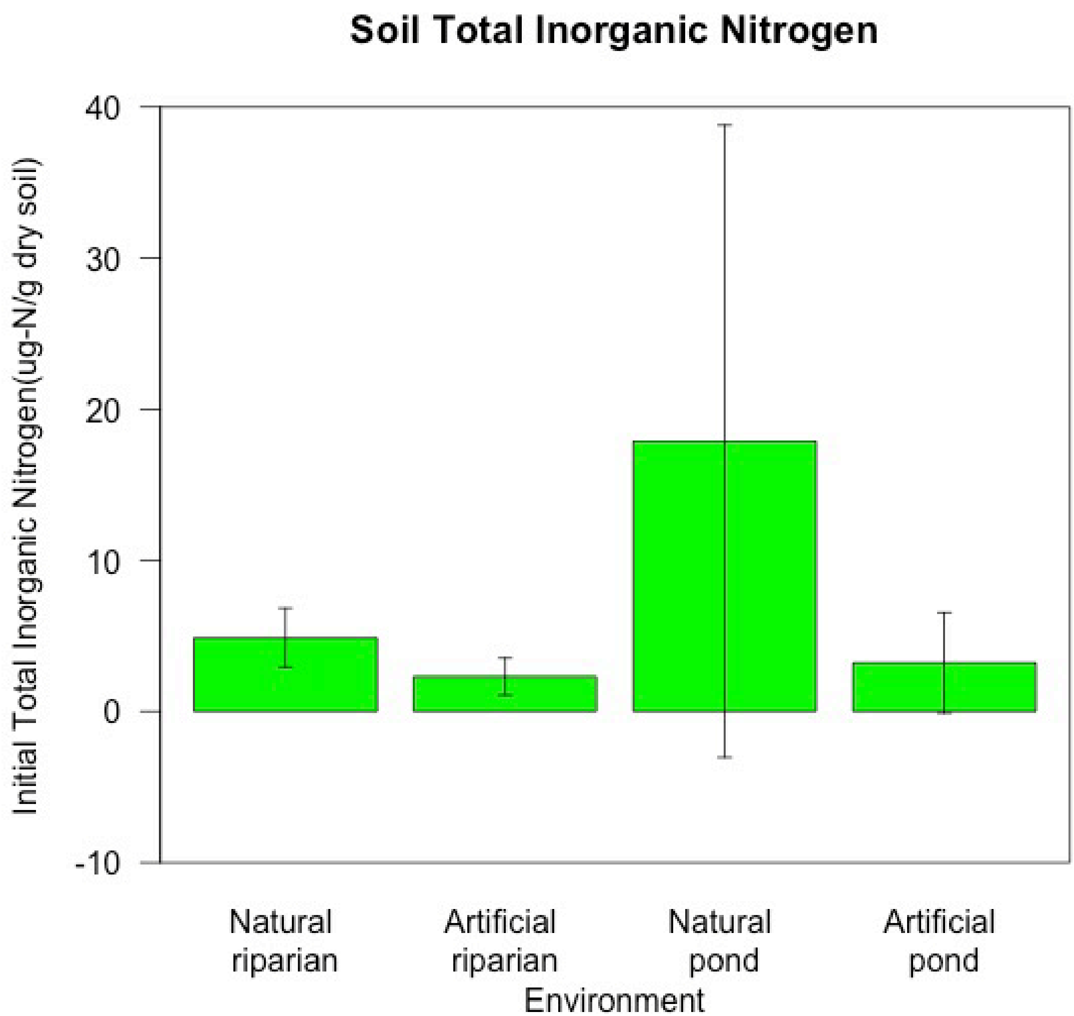

FIGURE 10. Potential net nitrification rates in each of the four environments. Rates were higher in natural riparian areas than in artificial riparian areas ($P<0.05$).

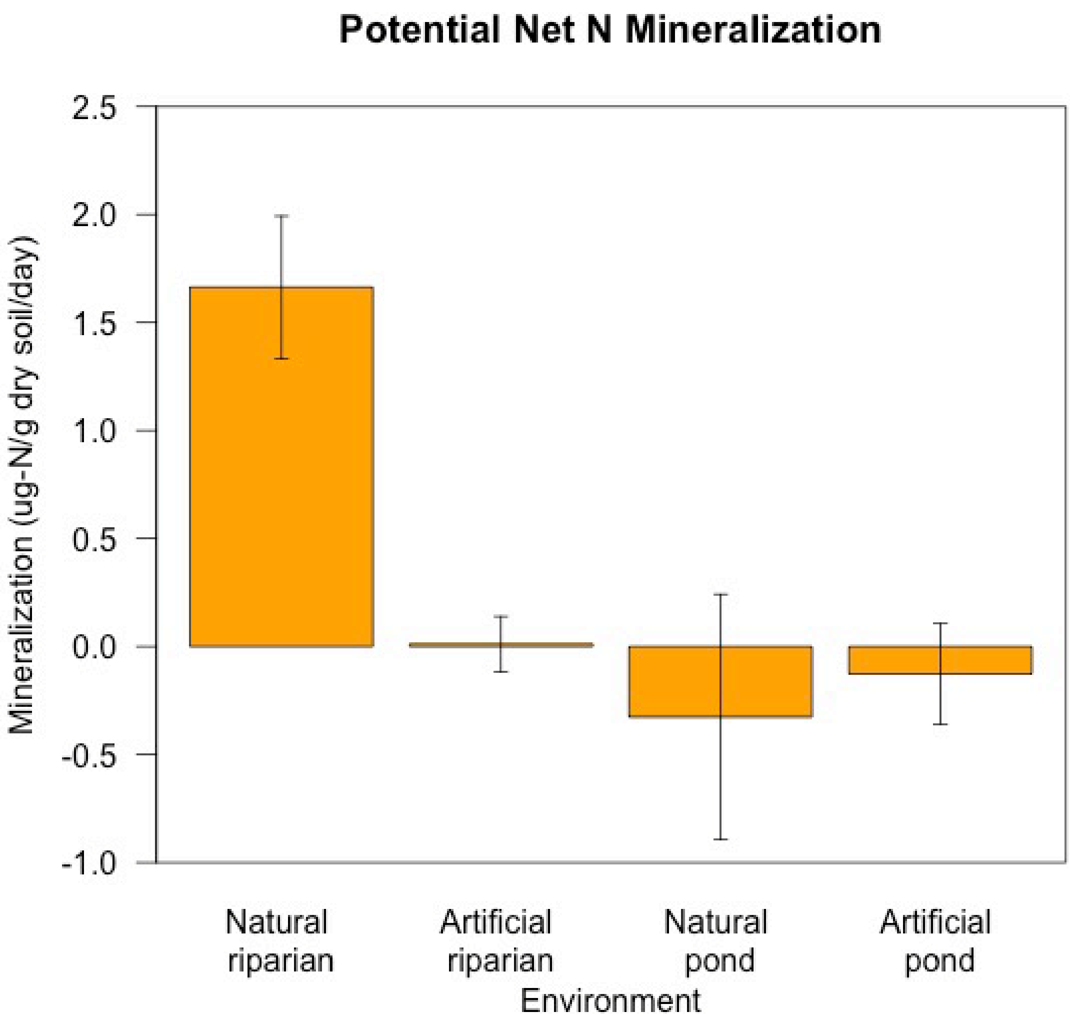

FIGURE 11. Potential net N mineralization in each of the four environments. Rates were higher in natural riparian areas than in artificial riparian areas ($P<0.05$).