CAUSES AND EFFECTS OF POLLUTION “HOT SPOTS” IN THE FALL KILL CREEK

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Abstract. The impacts of urbanization on ecosystems is largely understudied. In an effort to ameliorate the lack of attention paid to urban streams, areas in the Fall Kill Creek in Dutchess County, New York, with high concentrations of chloride and nitrate were studied to determine some of the causes of pollution “hot spots” and to investigate the effects of hot spots on the rest of the ecosystem. Five sites of varied pollution levels were chosen for experimentation. Macroinvertebrates that are sensitive to high levels of pollution were used as indicator species and were counted at each test site, as is commonly done in stream health surveying. Data suggest that the difference in relative abundance of indicator macroinvertebrates at hot spots versus non-hot spots is not statistically significant. Further, leaf mass was measured then leaves were placed in the stream at each site for three weeks and their final mass was measured to determine the percentage of mass lost by leaves at each site. While there was a significant difference in mass loss among sites, it was not related to chloride or nitrate concentration. Finally, the percentage of impervious cover within one half mile radius of each site was calculated to determine if a higher percentage of impervious cover correlated with higher chloride concentrations at each site and the relationship was found to be non-significant. These results suggest that stream conditions in the Fall Kill are able to support the macroinvertebrate community and leaf decay and that pollution levels are not yet detrimental but should continue to be monitored.

INTRODUCTION

Urban land use and the concentration of human populations in cities is recognized to have an effect on ecosystems. The ecology of urban streams is particularly interesting as these streams are both a resource and a necessity in city environments. Urban stream research is largely focused on the impacts of human action and on strategies for remediation, both natural and human-made. The effects of road salt on streams is a continuing line of inquiry and the effects of surrounding land use, especially around mines and agricultural areas, is a global interest (Miserendino et al. 2011, Findlay and Kelly 2011). After more than 14 years of studying the Fall Kill Creek, one question still remains about this New York stream flowing into the Hudson River: what causes pollution “hot spots” in the stream and what effects are they having on the rest of the ecosystem?

Located in Dutchess County and spanning the towns of Hyde Park, Clinton, Pleasant Valley, and the City of Poughkeepsie, New York, the19.5 square mile Fall Kill watershed contains many soil types, a variety of vegetation, and diverse land use. Stream conditions and pollution are a strong indicator of what is going on in the rest of the watershed and consequence of land use class and intensity (Bean et al. 2006). Studying the areas of high water pollution in the 38 mile long stream provides a basis for local clean-up and stream health improvement initiatives (Bean et al. 2006). This study aimed to increase general knowledge about the state of urban streams, which is especially useful for city and land managers looking to current ecological research for guidance in municipal planning and management.

Previous findings in the scientific community have shown that benthic macroinvertebrates are reliable indicators of water quality and that *Ephemeroptera*, *Plecoptera*, and *Trichoptera* (EPT) are the most sensitive to poor water quality (Lenat 1988). Further research on indicators of water quality has shown that

EPT richness is more relevant to water quality than other biological indices (Thiébaut et al. 2006). The use of benthic macroinvertebrates as indicators of water quality in the Fall Kill has been previously justified in the 2006 Watershed Management Plan.

Riparian zones are the areas of land that border the water. Research has found a potential relationship between riparian vegetation and water quality. It is suggested that leaf litter (fallen leaves) in urban watersheds is important to the dissolved organic carbon and nutrient release and transformations in urban streams (Duan et al. 2014). In a study done on four tropical Australian streams, riparian zones of varying vegetation had moderate effects on the amount of NO_x in the streams, though not enough of an impact to meet water quality regulations in the region (Connolly et al. 2015). Previously, discussions of the riparian zone along the Fall Kill have largely focused on their shrinking size in residential and urban areas and the suggested course of action is to maintain the healthy riparian zones that are creating an appropriate buffer for the stream (Bean et al. 2006).

The effects of land use on water quality is not a new issue. In 2008, a study of streams in Baltimore, Maryland found that the concentration of nitrate-N was second highest in urban streams, second only to agricultural streams (Kaushal et al. 2008). Though it was determined that further research should be done, it was suggested that urban land use can affect the nitrogen retention of nearby streams. A study of streams and various types of surrounding land use (urban, pasture, managed native forest, non-managed native forest) in the Patagonia region showed that urban land use created the most significant changes in the streams studied, including changes in conductivity, nutrients, and habitat conditions (Miserendino et al. 2011). On a more local level, research at the Cary Institute of Ecosystem Studies shows that the use of road salt in urban areas leads to elevated levels of chloride in streams (Findlay and Kelly 2011). Of further concern, the levels of chloride that go up due to this practice in winter seasons do not go back down during the summer when road salt is not being applied. For a stream like the Fall Kill, elevated nitrate levels are often thought to be a result of numerous septic systems in the residential parts of the watershed, but nothing has proved this to be true in the Fall Kill.

In 2006, the Fall Kill Management Plan was produced by the Fall Kill Watershed Committee. The data in this plan show high levels of chloride throughout the stream, plus areas of high nitrate concentrations (Bean et al. 2006). Benthic macroinvertebrates were studied, as well as fish populations. While this was a comprehensive report, it is now outdated and there is need for current data answering specific and applicable questions. In 2017, the concentration of chloride, nitrate, and the conductivity of the Fall Kill was measured and compared to the amount of impervious cover like roads, parking lots, and rooftops (Grosskopf 2017). This research suggests a positive correlation between amount of impervious cover and chloride concentration. Though some aspects of this study are similar, this project will examine the causes and effects of stream pollution from multiple perspectives, with the goal of achieving a broader understanding of the factors that contribute to the Fall Kill's pollution.

The pollutants this study focuses on are chloride and nitrate. This decision is in part due to their known connection to human activity, as well as the ease of measuring their concentrations. The ease of measurement is important for the collaboration with the Mid-Hudson Young Environmental Scientist Aquatic Ecology program (MH-YES). Organized and run by Drs. Rhea Esposito and Alan Berkowitz, MH-YES is a six-week summer program through the Cary Institute of Ecosystem Studies and Marist College in which high school seniors, undergraduate college students, high school science teachers, and scientists form "teams" to ask environmental science questions and do research to answer these questions, culminating in a poster presentation. The high school students had the agency to ask and answer their own questions about the Fall Kill, but they were interested in learning about the macroinvertebrates in the stream and helped with counting the samples collected during this project. They designed their own study to answer questions about soil salt retention in the Fall Kill watershed and its effects on plant growth. Further, the time constraint of the twelve-week Research Experiences for Undergraduates program at the Cary Institute contributed to the approach taken in this research. Finally, the test sites that were used in the 2006 Management Plan and/or the 2017 research done by Sydney Grosskopf were used in this research. These sites are publicly accessible, and they occur at appropriate distances throughout the stream to ensure a comprehensive study of the Fall Kill.

It is crucial to understand the meaning of pollution "hot spots" in this study. "Hot spots" refers to areas with high concentrations of pollution, relative to the rest of the stream. In this research, a concentration of 0.6 milligrams/Liter or higher of nitrate and 100 milligrams/Liter or higher of chloride in 2018 designates a hot spot. This term does not necessarily indicate a high water temperature and should not be interpreted as an indicator of stream temperature, unless specified. This term was used in the Fall Kill Management Plan and was coined in the paper Biogeochemical Hot Spots and Hot Moments at the Interface of Terrestrial and Aquatic Ecosystems (McClain et al. 2003, Bean et al. 2006). This research aimed to answer three specific questions. First, will indicator macroinvertebrates have a higher relative abundance at non-hot spots? I hypothesized that, yes, sensitive macroinvertebrates will be more abundant in testing sites that are not hot spots. An alternative hypothesis was that no, relative abundance of indicator macroinvertebrates will not change in accordance with the pollutant concentrations. Second, do pollution levels affect leaf litter decay? I hypothesized that, yes, high levels of pollution at hot spots will lead to less leaf litter decay. An alternative hypothesis was that hot spots and non-hot spots will not have significantly different levels of leaf decay. Finally, is there a higher area of impervious cover within a radius of a half mile of known hot spots compared to non-hot spots? I hypothesized that, yes, the amount of impervious area within a one-mile radius of the test site is related to the levels of pollution found at that site. An alternative hypothesis is that the occurrence of hot spots is due to other factors and types of land use. Answering these questions will increase public knowledge of the causes of urban stream pollution and the effects it has on the ecosystem.

METHODS AND MATERIALS

First, we took water samples from the seventeen sites by lowering a bucket into the stream off the downstream side of the bridge or road (Table 1). The bucket was rinsed with stream water once, then the two collection bottles were rinsed with the stream water from that site twice before being filled and stored in a cooler until we returned to the lab. Upon return, the samples from each site were tested for their chloride levels with a Fisher XL25 pH/Ion meter. These values were plugged into the standard curve equation $y=-0.0417x+7.0572$ ($r^2=0.99973$) and the estimated chloride concentration per sample was recorded in mg/L. Later, using a Satlantic SUNA V2 nitrate sensor, nitrate was measured and recorded in mg/L then converted using the standard curve equation $y=0.7854x+0.21$ ($r^2=0.99771$) to mg/L. After reviewing pollutant concentrations and considering site accessibility, five sites were chosen to conduct further experiments. These sites were Quaker, Haviland, 159 Roosevelt, Cream, and Verazzano. The two identified as hot spots based on their pollution levels were 159 Roosevelt and Verazzano.

For the leaf mass loss experiment, twenty-five bags of about eight by ten inches were constructed from coated window screen with approximately 18x14 spaces in one square inch of mesh. Labeled tags were placed in each bag and five bags were designated for each site, their number recorded. The mass of groups of five leaves was recorded in grams and the five leaves were placed in one of the bags, their mass recorded with the bag number and destination site. Once the twenty-five bags each had five leaves in them, four small holes, approximately a centimeter in diameter, were cut into the bags to allow macroinvertebrates to enter the bags and contribute to the breaking down process as they would in nature. Finally, these bags were zip-tied onto a piece of chain.

Next, twenty-five bags of gravel were constructed using plastic netting with openings of about one by one-half centimeters. After rinsing the gravel, approximately 200 cm^3 were measured into each bag and it was zip-tied closed. Five bags were designated for each site and zip-tied onto the same chain as the leaf bags in an alternating pattern, so no rock bags were next to each other and no leaf bags were next to each other.

The pieces of chain were then nailed to the bottom of the stream, one at each of the five sites. Similar methods have been used by others to study the dispersal of macroinvertebrates colonizing salmon flesh in Alaskan streams and to measure the effects of methane seepage on biodiversity on the Cascadian margin off Oregon (Monaghan and Milner 2008, Levin et al. 2017). This previous use of this method as well as the time constraints of the experiment went into the decision to use this method.

The bags were placed in the stream at the Verazzano and Cream sites on July 2nd and at the Quaker, Haviland, and 159 Roosevelt sites on July 3rd. The rock bags were removed from all sites on July 19th and the leaf bags were removed from all sites on July 24th.

On the day the rock bags were removed from the stream, they were taken back to the lab and immediately processed. A 3.35mm sieve was stacked on top of a 0.5 mm sieve and the rock bags were rinsed off and emptied into the top sieve so it would catch the rocks and the one under it would catch all of the macroinvertebrates. Once the rocks were separated they were set aside and a squirt bottle and paint brush were used to get the macroinvertebrates out of the 0.5mm sieve and into the plastic tub labeled with the site and a number, one through five, for sample identification purposes, which was then refrigerated. Two samples, Haviland 1 and Haviland 2, were counted the next day while organisms were still alive. The rest of the samples were then preserved in 50% ethyl alcohol. When samples were to be counted, the contents of the container were filtered through a 505 micrometer sieve to remove the ethyl alcohol. On July 25th, 26th, 27th, 30th, and 31st, a total of two samples from each site were chosen at random to be counted. Cream 1, Verazzano 4, Roosevelt 2, and Quaker 5 were counted with the help of those in the MH-YES program. Eventually, it was determined that subsampling was necessary to finish data collection in a timely manner. One eighth of Cream 2 was counted and when a third sample from each site was counted on August 6th and 7th, half of Haviland 3 and Quaker 2 were counted, and one eighth of Cream 5 was counted. To subsample the contents of each sample, it was emptied onto the 0.5mm sieve in a wash tub full of water. Contents of the sample were manipulated to float around in the water until they appeared evenly distributed over the area of the sieve. The sieve was then quickly lifted from the water and a portion of it was removed from the sieve to be counted. The individuals were identified to their order using the key to aquatic insects and collembola in Freshwater Macroinvertebrates of Northeastern North America (Barbara L. Peckarsky et al. 1990). Simple math was done to calculate the percentage of Ephemeroptera, Plecopteran, and Trichopteran out of the total number of individuals for each sample. Finally, using RStudio, we created a boxplot to visually represent the relative abundance of EPT at each site and we ran an ANOVA to determine the statistical significance. Finally, we ran a Bonferroni post hoc to determine which site contrasts were responsible for overall differences.

When the leaf bags were retrieved from the stream, they were immediately brought back to the lab for processing. First, each bag was rinsed of the accumulated sand, mud, and invertebrates. Next, the bags were cut open and the remains of the leaves were placed in aluminum containers with their identifying number tag. The containers were covered in aluminum foil with holes poked through it and placed in the drying oven at 60°C for approximately 40 hours. The containers were removed from the drying oven and the mass of the five leaves from each sample was measured on the same balance as before and recorded for comparison to the original mass. The mass loss was calculated to determine if the leaves with greater mass loss and therefore a greater release of organic carbon are in the areas with lower nitrate levels, as suggested by a 2005 study in Japanese streams that found an inverse relationship between levels of nitrate and dissolved organic carbon (Konohira and Yoshioka 2005). Similar tests have been done by simulating stream conditions in the lab, but this experiment takes a more observational approach (Duan et al. 2014). The percentage of mass loss was calculated for each sample and a box plot was created using RStudio for a visual representation of these data. Then we ran an ANOVA to determine the statistical significance of any differences and a Bonferroni post hoc to identify where these differences occurred.

In order to account for leaf mass loss from handling and transition, we made an additional five leaf bags, took the mass of the leaves and labeled the bag. Then we placed the bags in the stream at the Cream test site for one hour. They were removed, and the leaves were dried in the same manner as the leaves used in the experiment. The mass of the leaves was recorded again and the mass loss was calculated to determine mass loss from the handling of the leaves so that the mass loss after three weeks in the stream can be corrected for this error. The percentages of leaf mass loss used in the statistical analyses of these data were not corrected with this value.

To address our question about the relationship between pollution levels and impervious cover, we used ArcGIS and downloaded the National Land Cover Data raster file with the impervious cover percentages per cell. We drew half mile buffers around the GPS points for each of the seventeen test sites. Next, we went to the Toolbox, Data Management toolbox, Raster toolset, and used the raster "Clip" tool to get the total number of cells for each of the buffers and the total number of cells for each percentage of impervious cover (0% to 100%, excluding the percentages not represented within the buffer) for each buffer. The percentage value was multiplied by the number of cells in the buffer that had that percentage and divided by 100. Then, these new values were added to get a weighted sum for the buffers. Finally, the weighted sum was divided by the total number of cells in the buffer and multiplied by 100 to calculate the percentage of impervious cover within a half mile radius of each site. We then ran a linear regression with these data compared to the chloride concentrations of each site to determine if there was any correlation.

RESULTS

We ran an ANOVA for the relative abundance of EPT per site data and found that there is a significant difference between the sites (ANOVA, df=4, p=0.0172, Figure 1). We then ran a pairwise t-test to determine where the difference was occurring, and the only significant difference was between Quaker and 159 Roosevelt at p=0.015.

An ANOVA was used to analyze the leaf mass loss data. There was a significant difference in the percentage of mass lost between the sites (ANOVA, df=4, p<0.0001, Figure 2). The pairwise t-test determined that 159 Roosevelt and Haviland were significantly different from Cream, Quaker, and Verazzano with p values of less than 0.05.

An average of 0.12 grams of leaf mass was lost in handling and transportation.

A linear regression was run to determine a relationship between the total number of macroinvertebrates counted at each site (approximate values used due to correction for subsampling) and the percentage of leaf mass loss. A significant positive relationship was found (linear regression, df=23, p=0.0012, Figure 3).

To analyze the impervious cover data, we ran a linear regression and found no statistically significant relationship between percentage of impervious cover within a half mile radius and chloride concentrations at each site (linear regression, df=15, p=0.2237, Figure 4).

DISCUSSION

The key findings of this study are that relative abundance of EPT and leaf mass loss are not dependent on a site's hot spot classification, but there is a positive relationship between total invertebrates at a site and leaf mass loss. There is no relationship between impervious cover within a half mile radius and chloride concentrations at each site.

These results suggest that the nitrate and chloride levels in the Fall Kill Creek are still hospitable to macroinvertebrates and they are not currently causing large changes in community composition or leaf decay. One potential problem with this study is that many of the people who assisted with counting macroinvertebrates had never done so before. Though they received help throughout their work, it is possible that identities of individual macroinvertebrates were mistaken. Therefore, future repetitions of this study should be done by people with ability to identify macroinvertebrates to their order and samples should be saved for multiple people to count and compare numbers. Further, we would suggest subsampling from the beginning, as our initial counting process was strenuous and subject to exhaustion error.

The results of the leaf mass loss experiment suggest that the chloride levels in the Fall Kill Creek are not high enough to hinder macroinvertebrates and microbes from breaking down leaves and that the nitrate levels are neither acting as fertilizer and assisting in decay or causing some inhibition of microbes. Therefore, pollution levels are not impacting the leaf decay process enough to cause concern. One variable not well accounted for in this study is the sand and invertebrates that accumulated on leaves and did not come off when samples were initially rinsed. These would, of course, affect the final mass measurement of the leaves. Future repetitions of this study should account for this variable by more carefully cleaning off leaves after their removal from the stream.

Though the leaf mass loss was not related to hot spot classification, there was a positive correlation between mass loss and total number of macroinvertebrates at the test sites. This relationship is not surprising and further suggests that the pollution levels in the Fall Kill do not have a measurable impact on the function of the ecosystem.

It was surprising to find that the percentage of impervious cover within a half mile radius of each test site was not related to the chloride levels at that site. One would assume, based on previous research that there would have been a positive correlation, due to the application of road salt on impervious surfaces during winter months (Grosskopf 2017). A partial explanation of these results is that it is only the area within a half mile radius upstream of the site that would impact the water chemistry of a test site. This test would be more accurate and should be performed and compared to the results of this study.

Based on our findings, it is clear that there are other factors causing pollution hot spots and impacting the abundance of EPT and rates of leaf decay. Simply put, there are other pollutants or environmental factors affecting the Fall Kill Creek and the urban stream ecosystem, such as riparian tree cover or stream velocity. It is good that the two pollutants studied are not necessarily detrimental to the function of the ecosystem, but human actions should still be monitored to prevent pollution levels from increasing any more. The biggest question that remains is the hot spot classification of the 159 Roosevelt site. The pollution levels could be related to the site being a tributary of the Fall Kill and the narrowest of our test sites.

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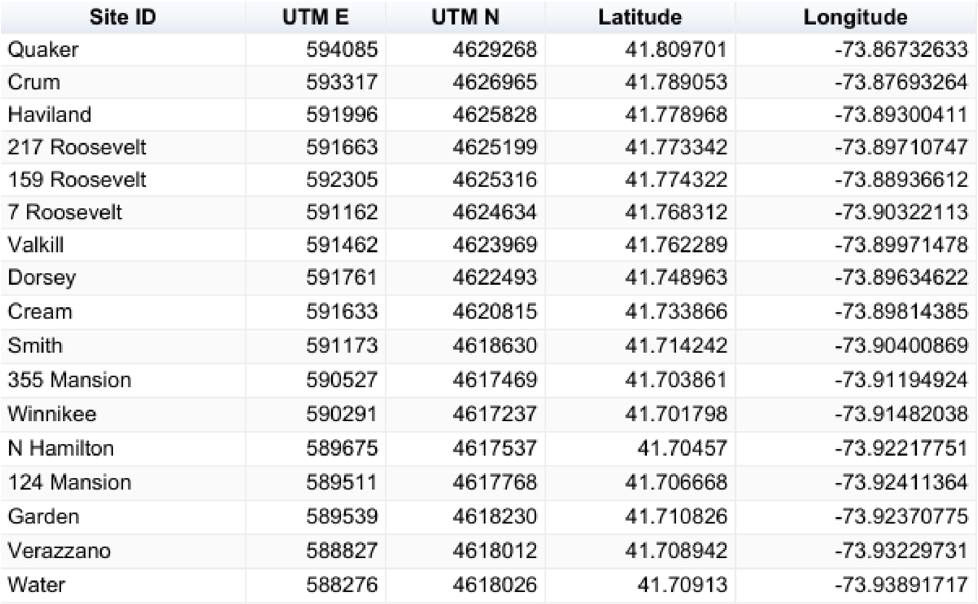
APPENDIX

TABLE 1. Site name as referred to throughout research and reporting and location in UTM (zone 18T) Easting and Northing and latitude and longitude.



Site ID	UTM E	UTM N	Latitude	Longitude
Quaker	594085	4629268	41.809701	-73.86732633
Crum	593317	4626965	41.789053	-73.87693264
Haviland	591996	4625828	41.778968	-73.89300411
217 Roosevelt	591663	4625199	41.773342	-73.89710747
159 Roosevelt	592305	4625316	41.774322	-73.88936612
7 Roosevelt	591162	4624634	41.768312	-73.90322113
Valkill	591462	4623969	41.762289	-73.89971478
Dorsey	591761	4622493	41.748963	-73.89634622
Cream	591633	4620815	41.733866	-73.89814385
Smith	591173	4618630	41.714242	-73.90400869
355 Mansion	590527	4617469	41.703861	-73.91194924
Winnikee	590291	4617237	41.701798	-73.91482038
N Hamilton	589675	4617537	41.70457	-73.92217751
124 Mansion	589511	4617768	41.706668	-73.92411364
Garden	589539	4618230	41.710826	-73.92370775
Verazzano	588827	4618012	41.708942	-73.93229731
Water	588276	4618026	41.70913	-73.93891717

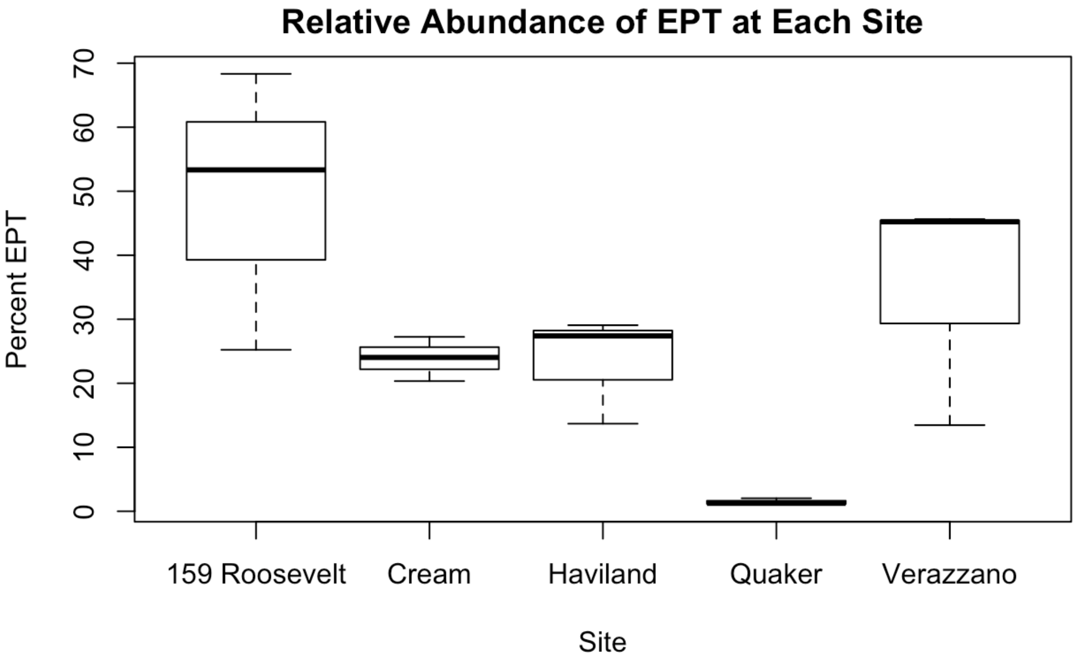


FIGURE 1. Relative abundance of EPT at each site (ANOVA, df=4, p=0.0172).

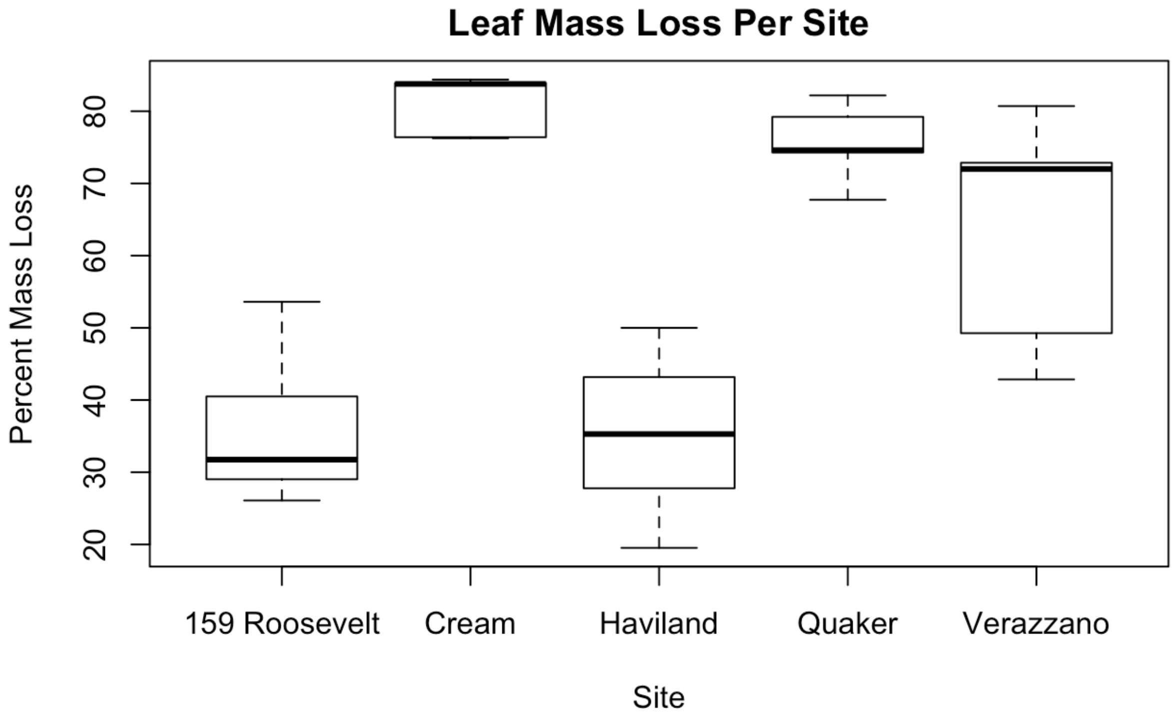


FIGURE 2. Percentage of leaf mass loss at each test site (ANOVA, df=4, p<0.0001).

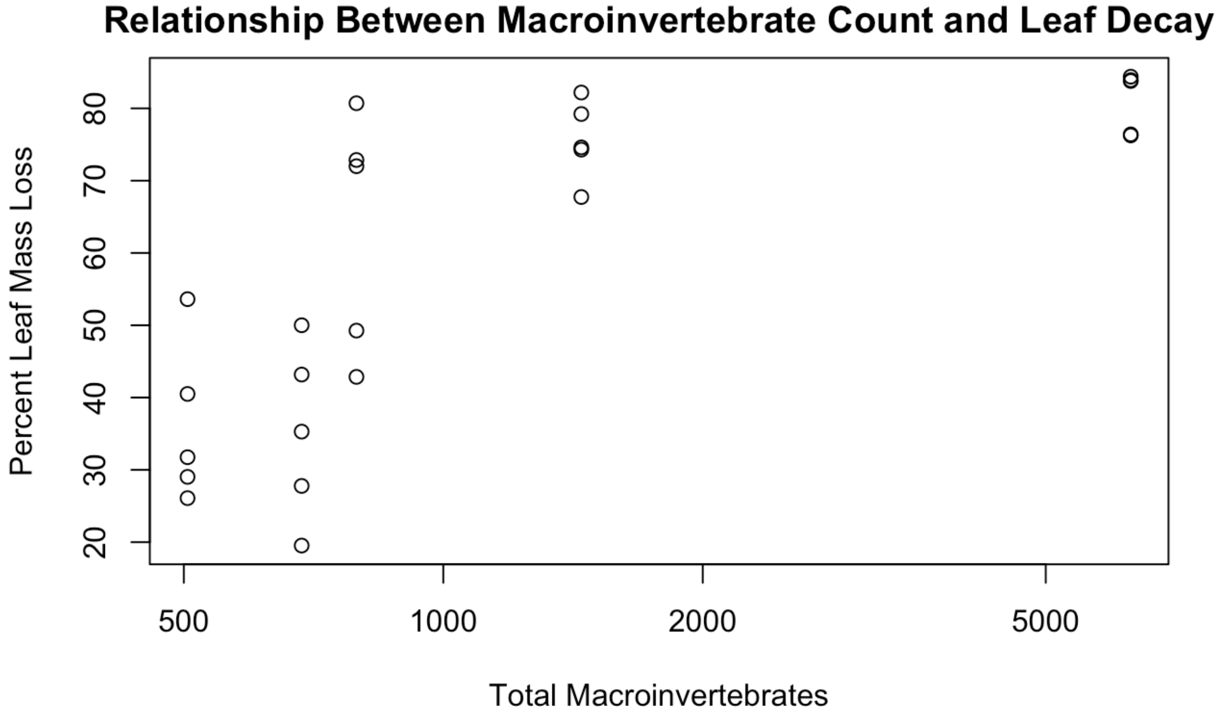


FIGURE 3. The relationship between the total number of macroinvertebrates counted and the percentage of leaf mass loss (linear regression, df=23, p=0.0012).

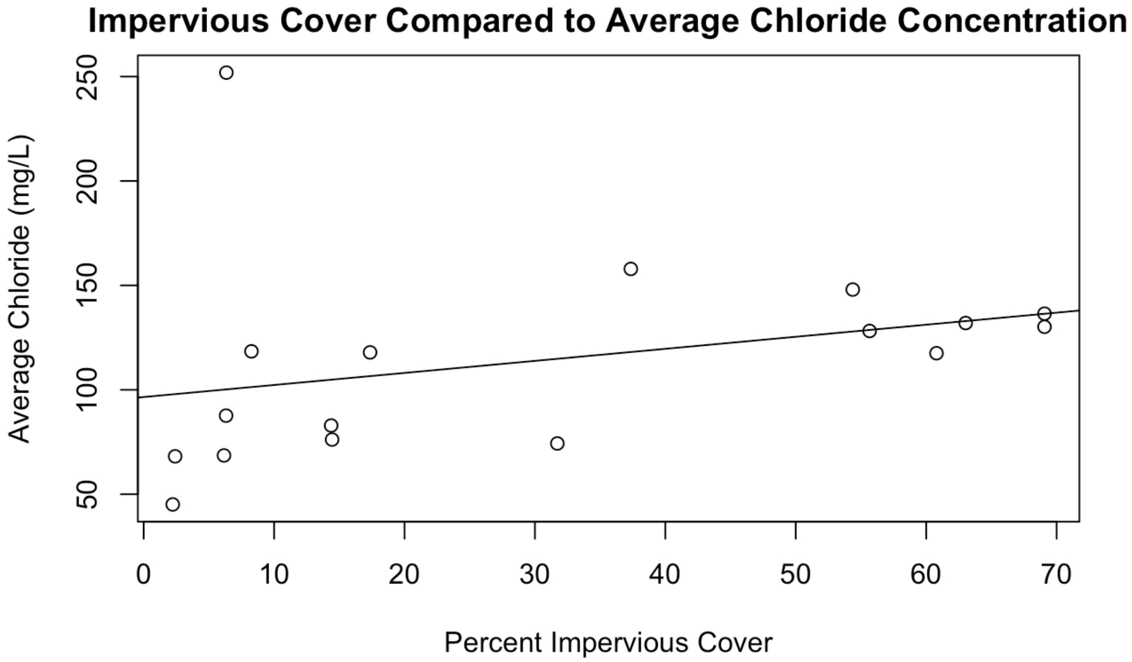


FIGURE 4. Relationship between percentage of impervious cover within a half mile radius and the average chloride at the site (linear regression, df=15, p=0.2237).