Comparison of macroinvertebrate communities in urban SCM versus peri-urban unmanaged ponds

Introduction

Stormwater Control Measures (SCMs) have become an abundant feature of urban environments due to the growing need for mitigating stormwater runoff. The conversion of natural environments into urban landscapes introduces increasing pressures on ecosystems to regulate and function amidst these rapid changes (Foley et al., 2005). The manifestations of increasing anthropogenic pressures present themselves as increased flooding events near river basins and impaired urban steams. SCM structures such as constructed wetlands and bioretentions aim to restore essential ecosystem services to urbanized areas and minimize the movement of urban pollutants into the surrounding environment. When correctly implemented and maintained, SCMs have been found to effectively capture stormwater effluent and improve downstream water quality (McDonough et al., 2017). However, these devices may also facilitate the accumulation of environmental toxins, decreasing ecosystem health and biodiversity in the immediate area.

In recent years, Wake County North Carolina and surrounding areas have experienced rapid urban growth and development. In response to the current surge in residential and commercial construction, implementation of SCMs has likewise increased to satisfy County stormwater regulations aimed to reduce pollution of nearby waterbodies (Wake County Gov 2020). Environmental health and ecosystem quality are important features of SCMs because water retaining structures act as important habitat for aquatic organisms such as amphibians and aquatic macroinvertebrates. Poor habitat quality may result in an impaired trophic network where pollution tolerant organisms such as mosquitoes (*Culicidae*) and other opportunistic or invasive organisms thrive. By examining and quantifying the presence of indicator species such as macroinvertebrates in aquatic environments, one can determine the quality of an ecosystem. While previous research has investigated the effectiveness of SCMs in providing sufficient ecosystem services through studying changes in surrounding waterbodies, fewer researchers have studied how the ecology and community structure of SCMs compare to natural waterbodies. In a 2015 study, researchers found compositions of macroinvertebrate taxa in SCMs to be similar to that of unmanaged urban ponds (Hassall & Anderson, 2015). Previous research also suggests that biodiversity in urban pond ecosystems is most significantly affected by land usage in the immediately surrounding area (Thornhill et al., 2017). Urbanization imposes both short-term and long-term changes on water quality, which has shown to reduce macroinvertebrate diversity in surrounding waterbodies (Gray, 2004). In addition, data suggests that past land usage has a significant impact on macroinvertebrate biodiversity in urban ponds due to long lasting landscape effects caused by urbanization.

The aim of this study was to investigate the macroinvertebrate compositions of urban water retaining SCMs as well as peri-urban unmanaged ponds in the Wake County area to evaluate the difference in environmental quality and biodiversity between these two groups. I investigated the taxa present at each pond site, paired with water quality testing and environmental observations, such as pond size and vegetation, to determine which factors associated with urbanization impact macroinvertebrate biodiversity. I predict that the results of this study will support the findings of previous research by depicting reduced diversity and increased abundance of pollution tolerant taxa in urban SCM ponds as a result of anthropogenic stressors from surrounding land usage.

Methods

Study Area and Site Selection

Stormwater control measure ponds and constructed wetlands sampled were provided by environmental servicing company, Dragonfly Pond Works. Five SCM ponds located in residential communities were selected in Cary and Morrisville, an urban area which has undergone rapid development in recent years. Five unmanaged ponds and wetlands were selected in peri-urban areas with minimal to no surrounding impervious surfaces. Due to State park closures during the spring of 2020, two out of the five unmanaged pond sites became inaccessible during the sampling period resulting in incomplete data for those sites.

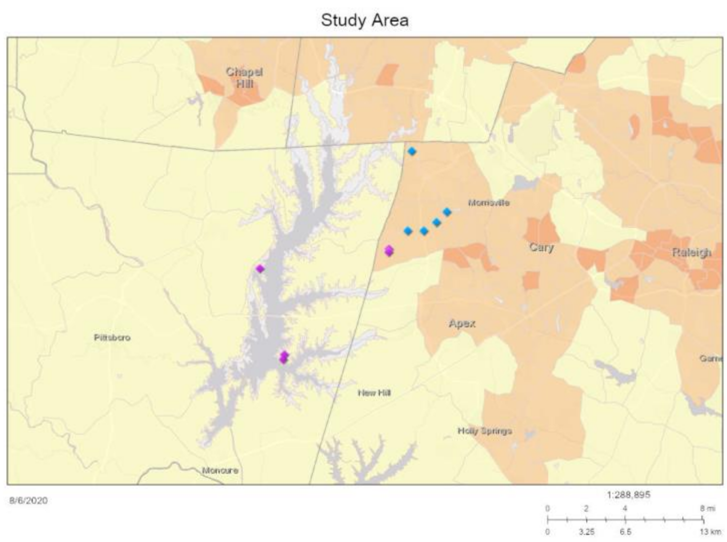

Figure 1: Map of study area depicting urban SCM ponds in blue diamonds and peri-urban unmanaged ponds in purple diamonds

Macroinvertebrate Sampling

Sampling was conducted monthly over a three-month period from March to May. Sampling consisted of a four-minute netting interval using an aquatic D-net to scoop across vegetation and bottom substrate. Organisms were sifted out of substrate and other debris and retained in plastic trays containing pond water as they were identified to taxonomic family and recorded. Organisms were returned to the pond at the end of each sampling event.

Environmental and Landscape Variables

All ponds surveyed remained submerged throughout the sampling period. Pond size and depth varied between sites to site around a mean area of 760 square meters. Aquatic vegetation composition also varied between sites with higher amounts of aquatic vegetation present in SCM sites because of management practices performed by Dragonfly Pond Works. Amount of vegetation was objectively quantified on a scale from 1-5, with 1 representing little to no vegetation and 5 representing abundant vegetation throughout the pond. Chemical indicator tests were used to measure the levels of nitrates, phosphates, ammonia, and pH level at each site. Water temperature and total dissolved solids (TDS) were measured using a meter.

Statistical Methods

The Shannon-Weaver diversity index was used to calculate the diversity and evenness of macroinvertebrate families sampled.

$$H=\sum[(pi)\times ln(pi)]$$

For analysis, taxa were sorted by ecological role; predator, collector, and shredder. Biotic indexes were also calculated for each site using the Hilsenhoff Biotic Index Pollution tolerance values from the HBI were assigned to macroinvertebrates at the taxonomic family level (Hilsenhoff, 1982).

$$BI=\sum (n_i \times a_i) / N$$

T-tests with a 95% confidence interval were conducted to determine statistical differences between taxa diversity, richness, and evenness in the SCM ponds and unmanaged ponds. T-tests were also used to measure differences between TDS, pH, and phosphate values in SCM verses unmanaged ponds. Linear regressions and ANOVA were used to examine relationships between landscape factors, such as pond size, and taxa composition. Statistical methods were completed using Microsoft Excel and JMP programs.

Results

Taxa Richness and Diversity

A total of 1,652 macroinvertebrates comprising 32 different taxa were sampled over the course of the study. Significant differences were observed between the taxa sampled from the two pond types, with SCM ponds containing greater predator taxa overall (see figure 2). Very few shredder species were sampled during the study. Shannon-Weaver diversity, and evenness were found to be significantly higher in peri-urban, unmanaged ponds compared to urban SCM ponds (df=5.618, p=0.023; df=5.946, p=0.038; see figures 3 and 4), while there was no significant difference in taxa richness between the two pond types (df=2.344, p=0.733; see figure 5).

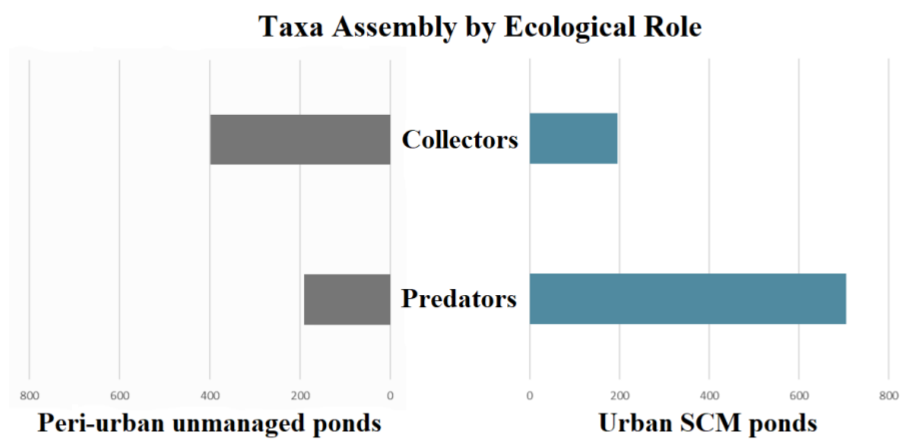

Figure 2: Taxa assembly by ecological role in peri-urban unmanaged ponds versus urban SCM ponds

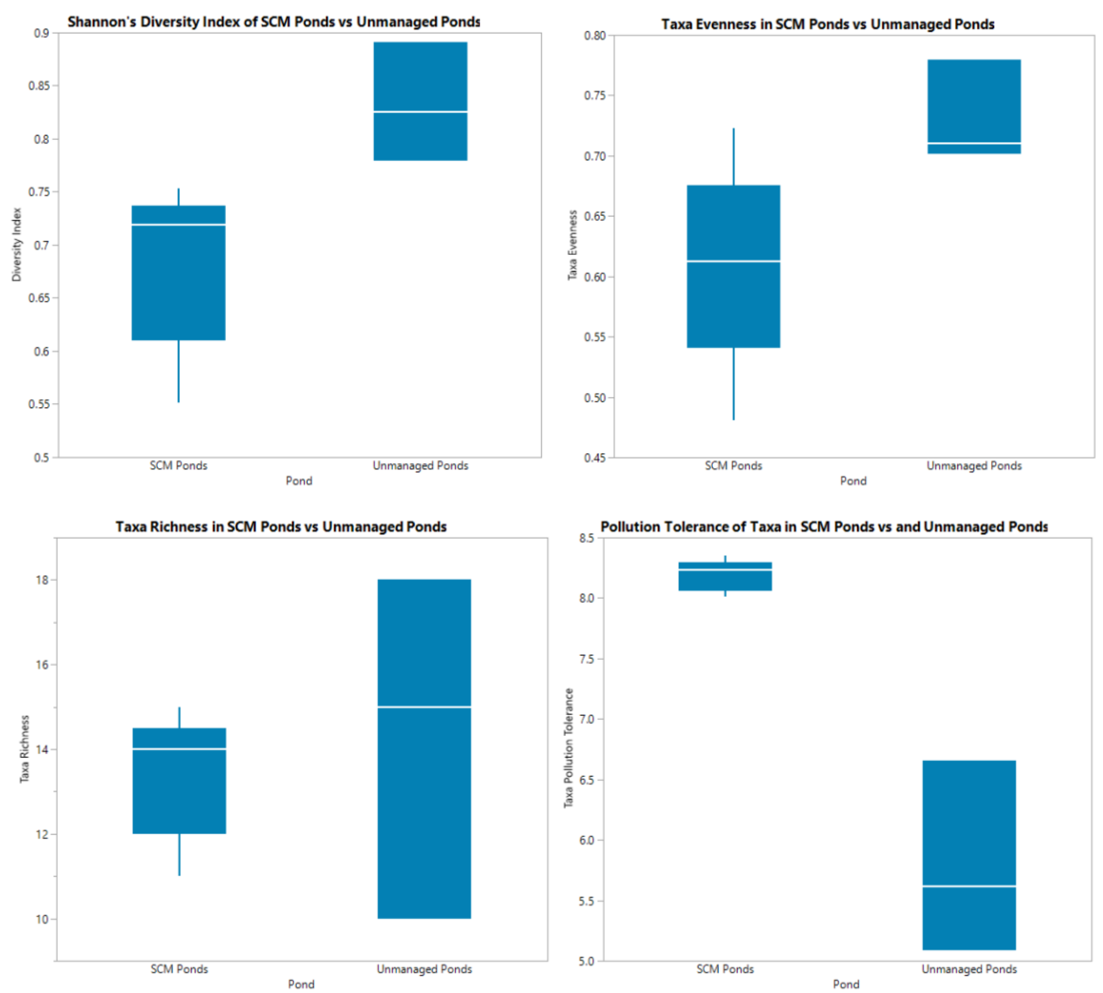

Figure 3-6: Shannon-Weaver diversity index of urban SCM ponds versus peri-urban unmanaged ponds; Taxa evenness of urban SCM ponds versus peri-urban unmanaged ponds; Taxa richness in urban SCM ponds versus peri-urban unmanaged ponds; and pollution tolerance of taxa in urban SCM versus peri-urban unmanaged ponds based on Hilsenhoff family tolerance values

Biotic Index

Peri-urban unmanaged ponds were found to have significantly lower total biotic index values compared to urban SCM ponds (df=2.065, p=0.0333; see figure 6). In total, pollution sensitive taxa were sampled at a higher abundance in unmanaged ponds versus SCM ponds.

Environmental Factors

Pond surface area showed no relationship with taxa diversity, evenness, or pollution tolerance, and no significant difference was found between pond size of the two pond types. Mean pond area of SCM ponds was 759.77 m^2, and mean area of unmanaged ponds was 761.48 m^2. Urban SCM ponds contained significantly more aquatic vegetation compared to unmanaged ponds (df=5.69, p=0.0015; see figure 7). Vegetation showed a weak negative relationship with taxa diversity (H'=0.878-0.04466*X, p=0.04). Levels of total dissolved solids were significantly higher in urban SCM ponds compared to the peri-urban unmanaged ponds (df=14.113, p=0.0014; see figure 8). Water quality measures of ammonia, phosphates, nitrates, and pH were found to be insignificant between the two pond types.

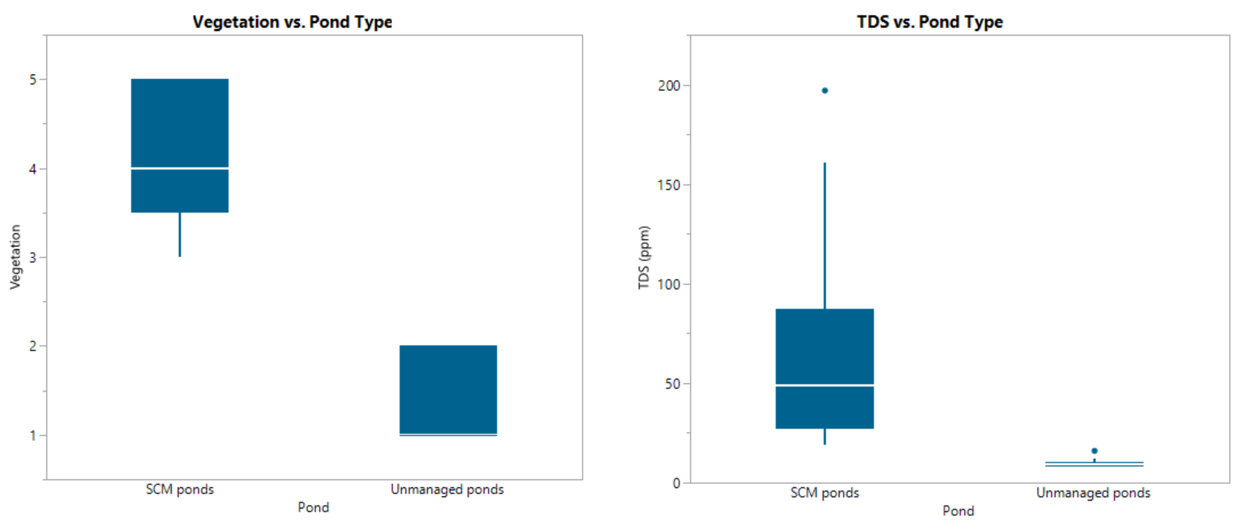

Figure 7 & 8: Abundance of aquatic vegetation in urban SCM versus peri-urban unmanaged ponds, and total dissolved solids in urban SCM versus peri-urban unmanaged ponds

Discussion

While urban SCM ponds support a similar richness of macroinvertebrate taxa to peri-urban unmanaged ponds, the diversity and trophic structure of macroinvertebrate communities differed between the two pond types. Besides total dissolved solids, no significant differences in the water chemistry measures were found between the two pond types. Despite the similarities in water chemistry, taxa diversity was found to be significantly higher in peri-urban unmanaged ponds surrounded by natural habitat. This result supports the findings of previous research in which the diversity of macroinvertebrate communities is significantly lowered by the impacts of urbanization (Gray, 2004). It is likely that differences in other water quality factors commonly impacted by urbanization such as dissolved oxygen, sedimentation, salinity, conductivity, and concentrations of metals may be important variables impacting the diversity of the SCM ponds. For instance, researchers have found species richness and diversity of macroinvertebrates to be negatively correlated with the specific conductivity of the water (Johnson et al., 2013). Although specific conductivity was not measured, higher levels of total dissolved solids was measured in the urban SCM ponds which may be indicative of higher conductivity.

Predatory taxa were found to be more abundant in the urban SCM ponds compared to the peri-urban ponds which contained a higher proportion of collector taxa. Very few shredder organisms were sampled, likely because shredders are represented by pollution sensitive organisms. In a previous study investigating the effects of non-point-source pollutants, researchers found that specific conductivity and dissolved nutrients in streams were strongly associated with macroinvertebrate community structure and secondary production (Johnson et al., 2013). The deposition of dissolved solids and nutrients into water bodies is influenced by the amount of nearby impervious surfaces, resulting in urban areas having higher pollution accumulation compared to non-urban areas. Previous research has shown a positive relationship between the abundance of impervious surfaces and the trophic position of macroinvertebrate communities in constructed wetlands (Mackintosh et al., 2015). This finding can be explained by the dynamic stability hypothesis which asserts that environments subject to frequent and unpredictable change are expected to have simplified food webs (Vander Zanden et al., 1999). This is a possible explanation for the inverted food web, paired with low diversity observed in the urban SCM ponds, which are frequently disturbed by human actions.

Analysis of the biotic index shows that urban SCM ponds harbor a higher proportion of pollution tolerant taxa compared to peri-urban unmanaged ponds. This trend suggests that the water quality of the unmanaged ponds is superior to that of the SCM ponds. This difference in taxa assemblage and ecological roles imply that certain taxa can thrive at a higher rate in the SCM ponds than other taxa. Certain opportunistic organisms appear to be better adapted to the changing environment of the urban SCM ponds, resulting in their higher abundance. The biotic indexes of the ponds were calculated using Hilsenhoff's family-based pollution tolerance levels which introduces biases due to the differences in pollution tolerance at species levels (McGauley et al., 2018). Although the HBI provides a relatively simple methodology for evaluating water quality of benthic environments, values should be interpreted as generalizations instead of exact measures.

Aquatic vegetation abundance was significantly higher in the urban SCM ponds due to the pond maintenance practices implemented by Dragonfly Pond Works, who manage the ponds on a regular basis. Unmanaged peri-urban ponds featured low amounts of aquatic vegetation, and higher amounts of organic matter debris along the bottom substate. Although analysis on the effect of aquatic vegetation abundance on macroinvertebrate diversity depicted a significant negative relationship, this is likely a result of the overall higher vegetation and lower diversity observed in the urban SCM ponds. Aquatic vegetation provides habitat and cover for macroinvertebrates, and some species such as Odonates utilize vegetation for depositing their eggs and emerging from their larval forms. Previous research has demonstrated that macroinvertebrate abundance and diversity is enhanced in aquatic environments with substantial amounts of submerged aquatic vegetation (Engel, 1988; Thorp et al., 1997). This suggests that while the planting of aquatic vegetation in SCM ponds is likely beneficial for macroinvertebrate communities, the influence of vegetation is this study was inconclusive. The effect of submerged aquatic vegetation density and diversity on macroinvertebrate communities in SCM ponds is a relatively unexplored area of research that could inform management practices in the future.

Conclusion

The findings of this study corroborate those of past research on the effects of human actions on macroinvertebrate communities and environmental quality of water bodies. These findings add to the body of knowledge on stormwater control measures and their contributions to ecology. Although the urban SCM ponds were found to contain a lower diversity of macroinvertebrate taxa, the trophic assembly depicted an inverted food web in which predatory taxa were more abundant than collector taxa. This pattern in trophic structure among the urban SCM ponds may be a desirable feature in urban and suburban environments because higher predator abundance might result in lower populations of less desirable pest species such as mosquitos and midge flies. Further research on urban SCM ponds is needed to better understand the interactions and tradeoffs between trophic structure and taxa diversity of macroinvertebrates. Since SCM ponds are important landscape features for both ecology and human wellbeing, management practices should aim to maximize benefits to both.

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