5-2017

Land Use Effects on Benthic Macroinvertebrate Communities in Conesus, Hemlock, Canadice, and Honeoye Lakes

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By

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A thesis submitted to the Department of Environmental Science and Biology of the State University of New York College at Brockport in partial fulfillment of the requirements for the degree of Master of Science

May 2017

Abstract

Conesus, Hemlock, Canadice and Honeoye lakes are among the smallest Finger Lakes, but they are important for drinking water, recreation and homes along their shorelines. Farms and forests are the major land uses in their watersheds. Hemlock and Canadice lakes are both within a state forest, which provides a buffer along the shoreline. Conesus and Honeoye lakes are unprotected. While the chemical water quality of these lakes is relatively well understood, the benthic macroinvertebrate communities in these lakes have not been studied. This study established baseline macroinvertebrate community data for all four lakes and determined the presence or absence of eight potential invasive species (*Bithynia tentaculata, Cipangopaludina chinensis malleata*, *Viviparus georgianus, Dreissena polymorpha, Dreissena rostriformis bugensis, Corbicula fluminea, Echinogammarus ischnus,* and *Hemimysis anomala*). Five of the eight species (*B. tentaculata, C. c. malleata, V. georgianus, D. polymorpha,* and *D. r. bugensis)* were found in at least one lake. All five of these species were found in Honeoye. All species but *B. tentaculata* were found in Conesus. Only Dreissenid mussels were found in Hemlock and Canadice. This study also explored whether having a near-shore forest buffer improves water quality in lakes and whether relationships exist between individual sub-watershed land use and biotic indicators of water quality and, as determined by biotic indices using benthic macroinvertebrates. While significant differences were found in the overall benthic community compositions between the lakes, biotic indices were similar between lakes and did not follow the expected water quality patterns. In addition, no correlations were found between sub-watershed land use and biotic indices of water quality. This suggests that near-shore buffers in Hemlock and Canadice Lakes have no effect on biotic indicators of water quality and only whole-watershed management might positively influence water quality.

Acknowledgements

This project was far too large for me to tackle by myself, and I want to thank everyone who made it possible. I'd like to thank Dr. James Haynes, my advisor, for making sure everything actually happened and that it happened in a relatively timely and smooth fashion, and for taking me in when I needed an advisor. Dr. Clay Williams and Dr. James Zollweg were both integral parts of my committee and helped enormously when technology, whether R or ArcGIS, got the better of me. Hillary Mosher, Lisa Kleckner, and the Finger Lakes Institute made this project possible with their funding and occasional help and guidance in the field. Anthony Marsocci was an excellent field crew chief and occasional gear designer when we needed to get creative to make everything work in our boat setup. My many other field and lab assistants made all of this work actually feasible within a reasonable time frame. Evelyn Shepard has been a tremendous emotional support whenever things got exceptionally chaotic or frustrating during this process. Finally, I'd like to thank my parents for their constant, unwavering support, including in the field.

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Introduction

Anthropogenic changes in land use can have significant negative effects on aquatic ecosystems. Urban and agricultural land use in watersheds have been linked to degradation in water chemistry (Ortolani 2014; Wang *et al*. 2014), in riparian plant communities (Gomes *et al*. 2014), in fish communities (Lammert and Allan, 1999; Lenat and Crawford, 1994), in aquatic macroinvertebrate communities (Stenroth *et al*. 2015; Lammert and Allan, 1999; Lenat and Crawford, 1994), and on terrestrial consumers of aquatic fauna (Stenroth *et al*. 2015). In addition, increases in anthropogenic pollution from urban and agricultural land use have been linked to increases in invasive species in affected watersheds (Ortolani 2014). While purely forested land cover is correlated to healthier water quality in streams and small rivers, the ability of forests to buffer pollutants from anthropogenic land use has not been shown and may be dependent on the location of the forest in the watershed (Wang *et al*. 2014). In some ponds, for example, catchment-scale land use was the only significant spatial-scale influence on the chemical water quality and narrow buffer zones around the pond having little effect (Novikmec *et al*. 2015) The relationship between mixed land use watersheds with and without riparian buffers and water quality needs to be further explored to better understand the full effects of anthropogenic land use on aquatic systems and if negative effects can be mitigated.

Biological Assessment

Benthic macroinvertebrate communities are frequently used to asses water quality conditions in aquatic systems due to their intermediate status in the food chain, high diversity, and species-specific tolerances to disturbances (NYDEC 2014). Anthropogenic stresses, such as shoreline development, have been shown to decrease biodiversity, thereby homogenizing aquatic communities (Gutierrez-Canovas *et al*. 2013; McGoff *et al.* 2013). Assessing the biological integrity of aquatic ecosystems is possible using indices such as the Biological Assessment Profile (BAP, NYDEC 2014).

A BAP is a collection of individual metrics that provide various interpretations of the biological health of a system that are standardized and combined to create an easily comparable measure of a system's overall health (NYDEC 2014). A typical BAP uses measures such as species richness, species diversity, dominance, EPT richness, Hilsenhoff's biotic index, percent model affinity, non-chironomidae and oligochaeta richness, and the nutrient biotic index for phosphorus as its individual metrics.

Study Site

The Finger Lakes (Figure 1-2) are a collection of eleven lakes in Western New York that provide major ecological and economic benefit to the surrounding region, including recreation, agriculture, and potable water supplies (Watershed

Assessment Associates 2014). The four westernmost Finger Lakes (Conesus, Hemlock, Canadice, and Honeoye) have a range of uses. Hemlock and Canadice are located within the Hemlock-Canadice State Forest (Halfman and O'Neill 2009) and are primarily water supplies for the City of Rochester. To maintain their water quality they also are protected by various use restrictions. Due to their small size, somewhat remote location, and stringent regulation, these two lakes are essentially unstudied and have little historical data for comparison to their current environmental and ecological state. Conversely, Conesus and Honeoye are open to a variety of uses; their shorelines have been heavily developed for private interests ranging from housing to large-scale agriculture. Conesus has been heavily impacted by agriculture in its watershed; nutrient-rich runoff has caused eutrophication and general water quality degradation (Somarelli *et al.* 2005). Honeoye is also highly impacted by its surrounding community. The combination of its small size, shallow depth, and nitrogen-limitation has subjected it to extreme water quality degradation (Halfman and O'Neill 2009). While there are ongoing long-term water quality studies occurring in both of these lakes, their overall ecological health is poorly understood.

While the benthic macroinvertebrate communities of Conesus, Hemlock, Canadice, and Honeoye are unstudied, the other seven Finger Lakes have been studied previously and can be used to help predict what may be found in the target lakes. Six of the seven eastern lakes are primarily dominated by amphipods (Skaneateles is primarily dominated by Ephemeroptera), while Diptera, Gastropoda and Pelecypoda are dominant groups in all seven lakes (Watershed Assessment

Associates 2014). In comparison to the other previously studied lakes, Seneca Lake has the most degraded conditions across all measured metrics (e.g. Shannon diversity, mayfly and caddisfly richness, percent tolerant individuals, and percent non-insects; Watershed Assessment Associates 2014).

One of the primary biotic concerns in the Finger Lakes is the growing presence of various invasive species. According to the USGS (2014) Nonindigenous Aquatic Species database for the state of New York, there appear to be eight primary invasive species in the Finger Lakes region that may be present in the four targeted lakes: *Bithynia tentaculata* (faucet snail), *Cipangopaludina chinensis malleata* (Chinese Mystery Snail), *Viviparus georgianus* (Banded Mystery Snail), *Dreissena polymorpha* (zebra mussel), *Dreissena rostriformis bugensis* (quagga mussel), *Corbicula fluminea (*Asian clam), *Echinogammarus ischnus* (euryhaline amphipod), and *Hemimysis anomala* (bloody red shrimp). It has been documented that these species have detrimental effects on the population health of some native species (Ilarri *et al*. 2014; Sandland *et al*. 2014; Halpin *et al*. 2013; Kang *et al.* 2007; Haynes *et al.* 2005). *D. polymorpha* and *E. ischnus* are the most widespread in the region (Watershed Assessment Associates 2014).

Invasive Species Descriptions

D. polymorpha (Table 1) was introduced to the Great Lakes from the Ponto-Caspian region in the late 1980s, establishing itself as a dominant and nuisance species. Its rapid spread incapacitated water treatment plants, causing millions of dollars in damage, repair, and control efforts every year. These mussels can quickly out-compete native mollusks and crustaceans due to their rapid reproduction, high rates of nutrient uptake, and capability to colonize any hard surface, including other shellfish (Burdick 2005). When *D. polymorpha* becomes the dominant shellfish in a lake, it can cause major shifts in community composition by changing the structure of the lake bottom and reorganizing the flow of nutrients in the water (Souza et al. 2014). This systemic restructuring creates opportunities for other invasive macroinvertebrates. For instance, *E. ischnus* uses the space between Dreissenid mussels for shelter (Kang *et al.* 2007). Watershed Assessment Associates (2014) recently confirmed the presence of zebra mussels in the eastern Finger Lakes for the first time, but their abundance in the western four lakes is still in question. Sightings in Conesus, Honeoye, and Hemlock have been reported, but none yet in Canadice.

D. r. bugensis (Table 1), another mussel from the Ponto-Caspian region and similar to *D. polymorpha*, filters large amounts of water and can cause massive changes in nutrient flow and community structure after becoming established (Aldridge *et al*. 2014; Souza *et al*. 2014). Some organizations view *D. r. bugensis* as potentially more problematic than *D. polymorpha* because it has started to spread more quickly and out-competes its relative in areas where they both occur (Aldridge *et al.* 2014; Haynes *et al*. 2005). It has been recorded in five of the seven eastern

Finger Lakes, but has not yet been reported in the four lakes in my study (Watershed Assessment Associates 2014)

E. ischnus (Table 1) was introduced into the Great Lakes from the Ponto-Caspian region in the early 1990s and has been recorded in each of the seven eastern Finger Lakes (Watershed Assessment Associates 2014). *E. ischnus* does not appear to be able to establish itself or out-compete native species except in areas where *Dreissena* populations have restructured lake substrates. Under these conditions, *E. ischnus* has been able to establish healthy populations and displace native amphipods (Kang et al. 2007). It has been recorded in all seven eastern Finger Lakes but not in the four western Finger Lakes.

C. fluminea (Table 1) is one of the most common invasive bivalves in the world (Illari *et al*. 2014). It has demonstrated the ability to influence both benthic communities in bodies of water where it is established, likely through change in benthic structure provided by its hard, ridged shell, as well as by affecting how suspended matter is moved from the water column to the benthos (Illari *et a*l. 2014; Souza *et al*. 2014). It has been recorded in four of the seven eastern Finger Lakes (Watershed Assessment Associates 2014) but not in the four western Finger Lakes.

B. tentaculata (Table 1), originally from Europe, is a long-established (late 1800s) invasive snail in the Great Lakes region. It is potentially most damaging because it is an intermediate host for trematodes, such as *Cyathocotyle bushiensis*, *Sphaeridiotrema globulus*, and *S. pseudoglobulus* that cause high mortality rates in native waterfowl (Sandland 2014). It has only been recorded in two of the eastern Finger Lakes and has been recorded a number of times in the City of Rochester and nearby waterways (USGS 2014), but has not been reported in the four western Finger Lakes.

C. chinesis malleata (Table 1) is an invasive snail from Asia that has become established in over half of the United States since it was initially observed in a San Francisco food market in the 1890s (Harried *et al.* 2014; Chaine *et al*. 2012). While *C. c. malleata* is widespread and tends to occur at relatively high population densities, very little is known about its overall effects on other populations and the overall ecosystem once it becomes established (Harried *et al*. 2014; Chaine *et al*. 2012). It has been recorded in two of the eastern Finger Lakes (Watershed Assessment Associates 2014), but none of the four western Finger Lakes.

V. georgianus (Table 1) is a snail native to the Mississippi River system that, since the 1960s, has expanded out of its historical range into much of the eastern and upper mid-western United States (Bury *et al.* 2007). Despite its range and long-time status as an invasive species, very little is known about its effects on the systems to which it is introduced. *V. georgianus* has been found in Lake Ontario and Lake Erie, as well as along the Erie Canal, but has not been previously reported from any of the Finger Lakes (USGS 2014).

H. anomala (Table 1) is a recently introduced mysid in the Great Lakes region that also comes from the Ponto-Caspian region; its effects in the Great Lakes and other aquatic systems are still unknown, but its introduction has been linked to decreases in native cladoceran and copepod abundances in European water bodies (Halpin *et al.* 2013). Notably, it is a near-shore predator, unlike the major native, pelagic invertebrate zooplankton predators off shore, potentially increasing predation pressure in previously unexploited regions of lakes (Halpin *et al.* 2013). In the Finger Lakes, it has only been recorded in Seneca Lake (Watershed Assessment Associates 2014); however, it is wide-spread throughout the northeastern United States, is well established in Lake Ontario and Lake Erie, and has the potential to be in the western Finger Lakes (USGS 2014).

Study Objectives and Hypotheses

The goals of this study were to complete a comprehensive macroinvertebrate survey of Conesus, Hemlock, Canadice, and Honeoye lakes and to use biotic assessments (i.e., the BAP) of water quality and link it with changes in watershed land use and water quality among and within the Western Finger Lakes. The overall community composition of each lake was compared with the hypothesis that Canadice and Hemlock would be similar to each other and different from Conesus and Honeoye due to differences in management, and Conesus and Honeoye would be different due to Honeoye's unique water chemistry. As a comparison of the effects of lake-wide watershed management, the BAP scores of each lakes' samples were compared with the hypothesis that the protected lakes would have higher scores than the unprotected lakes. Finally, the sample sites were compared to each other based on individual sub-watershed land use/land cover composition, with the hypothesis that samples from sub-watersheds with higher percentages of natural land use would have correspondingly higher BAP scores than samples from sub-watersheds with lower percentages of natural land use.

Methods

Geographical Data Collection

Every sub-watershed around the four target lakes was delineated using StreamStats (USGS 2012) and the eight largest accessible sub-watersheds, as calculated in ArcMap 10.2.2, were chosen as the sample locations (one of the original eight largest sub-watersheds for Hemlock lake was inaccessible due to boating restrictions and was not sampled, Figures 3-6). The land use/land cover for each sub-watershed was determined using 2011 National Land Cover Data (Homer *et al*. 2015).

Macroinvertebrate Sampling Methods

During July and August 2015, 64 samples were collected: 4 lakes * 8 sub-watersheds/ lake * 2 samples/sub-watershed (one in the littoral zone, typically 2-3m deep, and one just beyond the submerged aquatic vegetation zone, typically 3-5m deep). Benthic samples were taken using a modified dome suction sampler that covered an area of 0.165 m^2 (Haynes *et al*. 2005). The dome was placed on the surface of the lake bed by SCUBA divers, and an air lift system was run for approximately 30 seconds to collect the sample. Each sample was filtered through a 595 µm sieve and the contents were placed into a labeled container of 10% buffered formalin. Samples were transported to the laboratory and within 24 hours were transferred into fresh containers of 80% ethanol and stored until processed.

In the lab each sample was washed through a 595 µm sieve again to remove fine particulate matter then evenly distributed over a white, gridded sorting tray. Cells of the tray were randomly selected and sorted until a minimum of 100 organisms were collected and at least 10% of a sample had been processed (NYDEC 2014). Using current taxonomic keys (e.g., Merritt *et al.* 2010, Peckarsky 1990), macroinvertebrates were identified to the lowest practical taxon (typically genus or species, but some taxa like worms or leeches were left at the class level Oligochaeta and Hirundea, respectively).

The New York State Department of Environmental Conservation BAP for ponar samples from soft sediments was used to assess the water quality experienced by sampled organisms collected by this project's equivalent sampling method in soft sediments in the four lakes. The BAP index score was calculated by determining species richness (total number of different taxa identified), Hilsenhoff biotic index (a water quality index calculated using values indicating the overall tolerance of taxa found), dominance-3 (the combined percentage of the sample made up by the three dominant taxa), percent model affinity (a measure indicating how well a community fits to an ideal community composition model for a given habitat), and species diversity (a measure of richness and evenness of taxa found), all normalized on a 0-10 scale (with 0-2.5 meaning severely impacted, 2.5-5 moderately impacted, 5-7.5 slightly impacted, and 7.5-10 non-impacted), and averaging the scores of each component for a sample (NYDEC 2014).

Analysis

All statistical analyses were done in R. Differences in land use/land cover percentages between the lakes was determined using a permutational multiple analysis of variance (MANOVA) through R's vegan package (Anderson 2001; Oksanen *et al*. 2016). A reshuffled pairwise comparison based on Euclidian distance was used as a post-hoc analysis to explore differences between the lakes in the MANOVA. To determine which land cover/land use classes were responsible for any differences between the lakes, a principal component analysis was run on the untransformed land use/land cover percentages to determine which class types accounted for the variance in sites.

A two-way analysis of variance (ANOVA) with lakes and sample depth as factors was used to determine a difference or interaction between the factors in the BAP scores, and a post-hoc Tukey's test was used to determine which, if any, lakes were different from each other. Pearson's correlation was used to determine whether a relationship existed between the land use/land cover of each sub-watershed (using the principal component score) and BAP score of each sample.

The overall communities in each lake were compared to determine if there were any biological differences that the stream-oriented BAP did not assess. A two-way permutational MANOVA, through R's vegan package, was used to compare the percent abundance of each species across lakes and site depth (Anderson 2001; Oksanen *et al*. 2016). A reshuffled pairwise comparison based on Euclidian distance was used as a post-hoc analysis to explore differences between the lakes in the MANOVA. To determine which organisms were responsible for any differences between the lakes, first the number of taxa were reduced using a principal component analysis on the untransformed percent abundance data, showing which taxa were primarily responsible for the variance in samples.

Results

Macroinvertebrate Survey Results

<u>Invasive Species Occurrences</u>

Only five of the eight invasive species that occur in the Finger Lake's region were found in the four lakes studied here (Table 1). Both species of Dreissenid mussels were found in all lakes surveyed. *D. polymorpha* was found in five of eight Conesus sites (9.26% ± 9.10% [SD] of total organisms sampled when found), seven of eight Hemlock sites (33.34% ± 26.38%), four of eight Canadice sites (14.02% ± 18.39%), and all eight Honeoye sites (14.62% ± 13.61%). *D. r. bugensis* was found in four of eight Conesus sites (7.46% ± 6.57% of organisms where sampled), five of eight Hemlock sites (17.54% ± 15.62%), three of eight Canadice sites (14.82% ± 11.78%, and four of eight Honeoye sites (22.77% ± 13.42%). One unidentifiable juvenile *Dreissena* was found at an additional Conesus site.

V. georgianus and *C. c. malleata* were found in both Conesus and Honeoye. *V. georgianus* was found in two of eight Conesus sites (1.30% ± 0.004% of organisms sampled) and in four of eight Honeoye sites (2.80% ± 1.71%). *C. c. malleata* was found at one of eight sites in both Conesus and Honeoye (1.82% and 0.90% of organisms sampled, respectively). *B. tentaculata* was found only in Honeoye, at two of eight sites (2.98% ± 1.55% of organisms where sampled). *C. fluminea*, *E. ischnus*, and *H. anomala* were not sampled in any of the four lakes.

General Community Occurrences

Including the invasive species, 44 unique invertebrate taxa were found in the four lakes (Table 2). Twenty-six taxa were found in Conesus, two unique: *Promentus* sp. (Gastropoda: Planorbidae) and *Enallagma* sp. (Odonata: Coenagrionidae). Thirty taxa, the most in any lake, were found in Hemlock, four unique: *Ferrissia* sp. (Gastropoda: Ancylidae), *Brachycerus* sp. (Ephemeroptera: Ephemeridae), *Ephemera* sp. (Ephemeroptera: Ephemeridae), and *Hexagenia* sp. (Ephemeroptera: Ephemeridae). Twenty-six taxa were found in Canadice lake, seven unique: *Epitheca* sp. (Odonata: Corduliidae), a non-*Epitheca* juvenile (Odonata: Corduliidae), *Macromia* sp. (Odonata: Macromiidae), *Nectopsyche* sp. (Trichoptera: Leptoceridae), *Orthotricha* sp. (Trichoptera: Hydroptillidae), *Oxyethira* sp. (Trichoptera: Hydroptillidae), and *Polycentropus* sp. (Trichoptera: Polycentropodidae). Twenty-one taxa were found in Honeoye lake, two unique: the previously mentioned invasive *B. tentacula* and *Acentria* sp. (Lepidoptera: Crambidae).

Macroinvertebrate Community Comparison

The permutational MANOVA found no significant difference in macroinvertebrate composition between the sample depths (p=0.1829) and no interaction between lake and depth (p=0.4636). However, a significant difference was found between lakes (p=0.0004). The post-hoc analysis showed that the Hemlock's macroinvertebrate community was significantly different than those of all other lakes (p≤0.025) and Conesus and Honeoye's communities were significantly different (p=0.0062). The results suggested a difference between the communities in Canadice and Conesus (p=0.0708). There was no difference found in the communities of Honeoye and Canadice (p=0.4334).

Three principal components were retained from the percent abundance data (Figures 7-9). The first principal component was defined by a positive relationship between Oligochaetea and Chironomidae (Diptera). The second principal component was defined by an inverse relationship between *D. polymorpha* and the native *Pisidium* spp. (Bivalvia: Sphaeriidae). The third principal components was defined by a positive relationship between *Caecidota* spp. (Isopoda: Asellidae) and *Gammarus* spp. (Amphipoda: Gammaridae).

Land Use/Land Cover and Biological Assessment Profile Analysis

The permutational MANOVA showed a difference between the four lakes ($p<0.001$), and the pairwise comparison showed that Conesus was significantly different from the other three lakes ($p \leq 0.0098$ for all), which were all statistically similar ($p \geq 0.12$ for all). One principal component was retained from the land use/land cover data, showing a positive relationship between Hay Pasture and Cultivated Crop, and an inverse relationship between those two and Deciduous Forest.

The average BAP score for all four lakes fell in the moderately impacted range, the second lowest score range (Figure 10). The ANOVA found no significant difference in BAP scores among lakes ($p=0.748$) or between depths ($p=0.346$), and no significant interaction was found between the two factors ($p=0.335$). The regression analysis also found no significant relation between land use/land cover PCA score and BAP score (Figure 11, $r^2=0.001$, $p=0.855$).

Discussion

Neither of the proposed hypotheses for this study were confirmed. The expected differences in the macroinvertebrate communities were between the protected lakes, Hemlock and Canadice, and the unprotected lakes, Conesus and Honeoye, and a difference between Conesus and Honeoye because of their differing water chemistry. While there were differences between the lakes, the differences, particularly the difference between Canadice and Hemlock, the lack of a distinct difference between Conesus and Canadice, and the complete lack of difference between Canadice and Honeoye, did not reflect the known differences in management and water chemistry between the lakes. A difference was expected in the biological assessment between the protected lakes, Hemlock and Canadice, and the unprotected lakes, Conesus and Honeoye. However, there was no difference found between any of the lakes, which likely has major implications for future lake watershed management.

Macroinvertebrate Survey

The most notable discoveries from the general macroinvertebrate survey were the complete absence of three expected invasive species from all four lakes, and the absence of three invasive snails from Hemlock and Canadice lakes. These absences are unquestionably good signs for the four lakes because one or more factors have prevented the spread of these organisms and allow the stakeholders who manage the lakes to continue implementing measures to prevent the future spread of new invasive species. Although the causes of their absences are unknown they could be due to simple geographic isolation from current affected bodies of water or current management practices used to prevent the introduction of new invasive species, such as monitoring and cleaning stations for boats near launches and, in Canadice and Hemlock's cases, restrictions on what is allowed in the water at all (i.e., no large motorboats or swimming allowed in the lakes). Since the cause of prevention is unknown, no specific recommendations for better management can be given at this time. Additionally, while the absence of a number of potential invasive species is a heartening positive, it is important to note that the banded mystery snail was found for the first time in the Finger Lakes in Conesus and Honeoye lakes, showing that whatever factors may be currently preventing the spread of species from the other Finger Lakes has not necessarily stopped the spread of all species from other bodies of water in the general region.

Community Comparison

Having a significant difference between the lake communities but not in the BAP inferred water quality index immediately suggests that the metrics used were not the best fit for these macroinvertebrate communities. However, looking more closely at the organisms driving the differences among the lakes and the overall compositions of the lakes, this may not actually be the case. Based on the principal component analysis, the primary difference between Hemlock and the other three lakes is that the samples taken from Hemlock Lake contained a greater number of *D. polymorpha* and fewer number of *Pisidium* clams. However, the when the macroinvertebrate communities were analyzed, the two bivalves were similar indicators of water quality in the metrics calculated (e.g. both were highly dominant species, both were indicators of mid-to-poor water quality for HBI). The difference between Honeoye and Conesus was caused by Honeoye's lack of oligochaetes and chironomids, which by itself would suggest a better water quality for Honeoye, but the Honeoye samples tended to have a higher number of mollusks and crustaceans, which are generally indicators of poor water quality like oligochaetes and chironomids. This all suggests that while there were differences in the overall communities, the biological assessment methods used were not affected by these differences and the BAP results not reflecting the community results is reasonable.

Land Use/Land Cover and Biological Assessment Profile

The difference in land use/land cover between Conesus and Honeoye and the lack of difference between Honeoye, Hemlock, and Canadice show that differences in land use do not inherently change the composition of benthic invertebrate communities. If overall land use combined with implemented buffer zones did have an effect on water quality, then the observed differences in land cover suggest that there should have been a difference in BAP between Conesus and all three other lakes, and also between Honeoye and the two protected lakes.

The absence of a difference in biotic water quality indicators among the four lakes suggests that nearshore watershed management does not actually make a difference on a lake-wide scale. In addition, the lack of correlation between individual sub-watersheds and BAP scores from corresponding samples suggests that individual sub-watershed management has no effect on nearshore water quality. Both of these findings agree with the previous research on watershed management in ponds, which showed that only whole-watershed management had an effect on water quality (Novikmec *et al.* 2015). Additionally, recent research has shown that intensity of the land use intensity is a better indicator of environmental impact than just percent and location of anthropogenic land uses (Julian *et al.* 2017). Although no land use intensity data was available for this study, this relationship could explain the lack of difference in biotic indicators between the lakes, especially given the history of work with best management practices on Conesus farms (Bosch *et al.* 2009, Makarewicz *et al.* 2009).

Management Recommendations

Due to the unclear reasons behind these lakes' lack of many prevalent invasive species, it is difficult to recommend many new future measures. However, continuing all current measures in place, like the Watercraft Stewards program and providing wash stations at the public launches, should be continued. Implementing regular invertebrate surveys (such as on an annual or biennial basis) would allow stakeholders to keep track of any changes in current invasive populations or of any introductions of new invasive species. Additionally, educating stakeholders about the various invasive species, including how to recognize these species and how to best respond to them, could help with tracking current invasive species and detecting new species if they reach these lakes.

Future water quality improvement protections that are enacted need to be implemented on a whole-lake, whole-watershed scale, especially in Hemlock and Canadice lakes where the current shoreline protections seem to be ineffective based off of biotic indicators. Taking actions like protecting the entirety of inlet streams or getting farms within the watershed to implement best management practices could help improve the water quality and make the lakes more habitable to less tolerant invertebrate species.

Conclusions and Recommendations for Future Studies

Since this is the first study to look at the effects of forested buffers on lakes, there are a number of avenues for potential future studies. This study showed that limited watershed management did not have an effect on biotic indicators of water quality, but that does not mean that chemical water quality follows the same patterns, and a follow-up study should be done to understand what, if any, effects this limited management has on the lake water itself. Also, since no correlation was found between individual watershed land use and biotic indicators of water quality and no difference was caused by limited, near-shore management, a study should be undertaken to determine both what scale of land use analysis reflects biotic water quality in lakes, and what type and degree of management would affect biotic water quality. Finally, with the data from this study serving as a baseline, regular, continued macroinvertebrate surveys could create an excellent long-term data set, especially if management methods change over time and those changes eventually get reflected by a changing macroinvertebrate community in these lakes.

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Table 1: List of invasive species found in all 11 Finger Lakes. Presence is indicated by an "X"

	Conesus	Hemlock	Canadice	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Viviparus georgianus  Picture: Amy Benson, USGS	X			X							
Cipangopaludina sp.  Picture: Amy Benson, USGS	X			X	X	X					
Bithinya tentaculata  Picture: Amy Benson, USGS				X			X				

Corbicula fluminea  Picture: Noel M. Burkhead, USGS						X			X		X
Dreissena bugensis  Picture: USGS	X	X	X	X	X	X	X	X		X	
Dreissena polymorpha  Picture: USGS	X	X	X	X	X	X	X	X	X	X	X
Echinogammarus ischnus  Picture: Colin van Overdijk					X	X	X	X	X	X	X
Hemimysis sp.  Picture: National Oceanic and Atmospheric Administration							X				

Table 2: List of species found in the survey, which lakes they were found in, and percent composition by lake in samples where the species were found (mean ± 1 SD).

	Conesus	Hemlock	Canadice	Honeoye
Oligichaeta	32.49 ± 18.15	26.37 ± 22.68	23.30 ± 19.24	18.64 ± 19.20
Hirundea	4.21 ± 2.72	1.53 ± 0.23	5.51 ± 11.13	5.12 ± 9.42
Bivalvia Dreissenidae *D. polymorpha*	9.26 ± 9.10	33.34 ± 26.38	14.02 ± 18.39	14.62 ± 13.61
Bivalvia Dreissenidae *D. r. bugensis*	7.46 ± 6.57	17.54 ± 15.62	14.82 ± 11.78	22.77 ± 13.42
Bivalvia Sphaeriidae *Pisidium*	15.23 ± 17.72	3.95 ± 5.74	22.99 ± 9.14	28.15 ± 25.70
Bivalvia Sphaeriidae *Sphaerium*		0.72		6.26 ± 4.61
Gastropoda Viviparidae *V. georgianus*	1.30 ± .004			2.80 ± 1.71
Gastropoda Viviparidae *C. c. malleta*	1.82			0.90
Gastropoda Bithyniidae *B. tentacula*				2.98 ± 1.55
Gastropoda Ancylidae *Ferrissia*		1.16		
Gastropoda Valvatidae *Valvata*	3.85 ± 2.58	1.29 ± 0.458	9.00 ± 9.14	10.06 ± 8.94
Gastropoda Viviparidae *Campeloma*	2.53 ± 3.16	2.11		1.75 ± 1.56
Gastropoda Hydrobiidae *Gillia*	3.57	1.01	1.01	4.83 ± 2.59
Gastropoda Hydrobiidae *Amnicola*	1.02	1.69		
Gastropoda Planorbidae *Helisoma*	1.59	1.51 ± 0.76	2.98 ± 2.57	2.14 ± 2.25
Gastropoda Planorbidae *Gyraulus*	2.04	1.18 ± 0.26		
Gastropoda Planorbidae *Promenetus*	1.03			
Gastropoda Physidae *Physa*	1.21 ± 0.54	1.05	3.43 ± 2.53	1.51 ± 0.89
Amphipoda Gammaridae *Gammarus*	17.41 ± 17.09	8.58 ± 10.20	7.50 ± 9.77	16.79 ± 24.03
Amphipoda Hyalellidae *Hyalella*	5.60 ± 2.42	9.71 ± 13.16	6.61 ± 6.35	22.21 ± 12.37
Isopoda Asellidae *Caecidota*	14.96 ± 24.16	6.71 ± 6.70	23.68 ± 25.09	11.90 ± 9.87
Decapoda Cambaridae *spp.*	1.02	0.98	1.01	
Ephemeroptera Caenidae *Caenis*	5.05	2.11	1.37 ± 0.65	
Ephemeroptera Caenidae *Brachycerus*		2.27		
Ephemeroptera Ephemeridae *Ephemera*		1.77 ± 0.70		
Ephemeroptera Ephemeridae *Hexagenia*		1.34 ± 0.50		
Odonata Gomphidae *Dromogomphus*		1.05	1.72 ± 0.90	
Odonata Coenagrionidae *Enallagma*	1.01			
Odonata Corduliidae *Epitheca*			2.47 ± 2.05	
Odonata Corduliidae juvenile			0.98	
Odonata Macromiidae *Macromia*			0.98	
Megaloptera Sialidae *Sialis*		2.23 ± 1.43	3.82 ± 2.58	1.94 ± 0.81
Trichoptera Leptoceridae *Oecetis*	2.99	2.00	2.62 ± 2.83	2.02 ± 0.03
Trichoptera Leptoceridae *Nectopsyche*			1.52 ± 0.71	
Trichoptera Hydroptilidae *Orthotricha*			1.02	
Trichoptera Hydroptilidae *Oxyethira*			1.00	
Trichoptera Dipseudopsidae *Phylocentropus*		2.57 ± 1.21	1.84 ± 0.51	
Trichoptera Polycentropodidae			1.01	
Lepidoptera Crambidae *Acentria*				0.96
Coleoptera Elmidae *Dubiraphia*	1.82	2.74		
Diptera Ceratopogonidae *Sphaeromias*	1.66 ± 0.23	0.98		
Diptera Ceratopogonidae *Bezzia*	0.79		1.49	
Diptera Pelecorhynchidae *Glutops*	1.03	1.69		
Diptera Chironomidae	17.39 ± 11.99	21.31 ± 16.61	16.90 ± 12.01	12.17 ± 14.70

Figure 1: Map of New York with Finger Lakes region outlined.

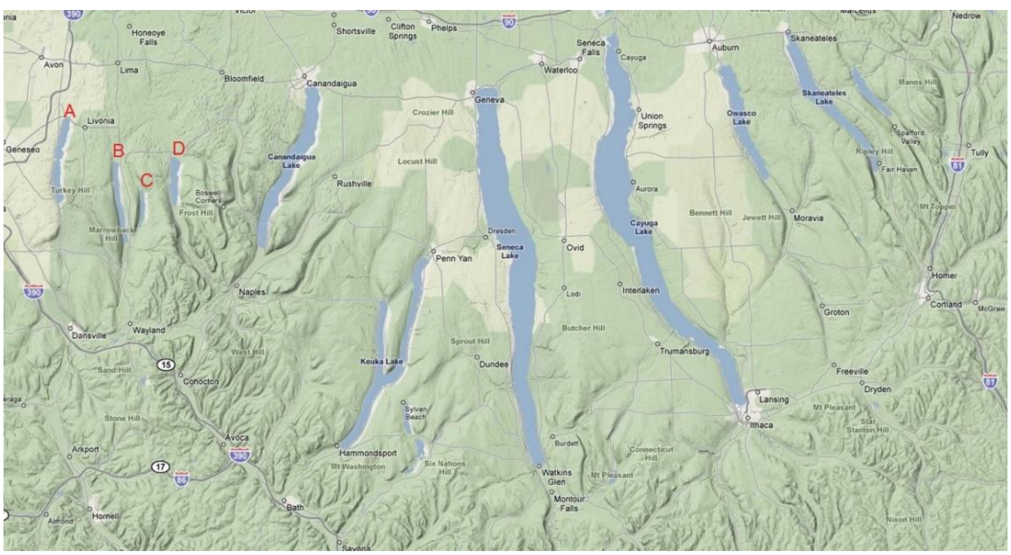

Figure 2: Map of the Finger Lakes region with the target lakes labeled (Conesus-A, Hemlock-B, Canadice-C, and Honeoye-D)

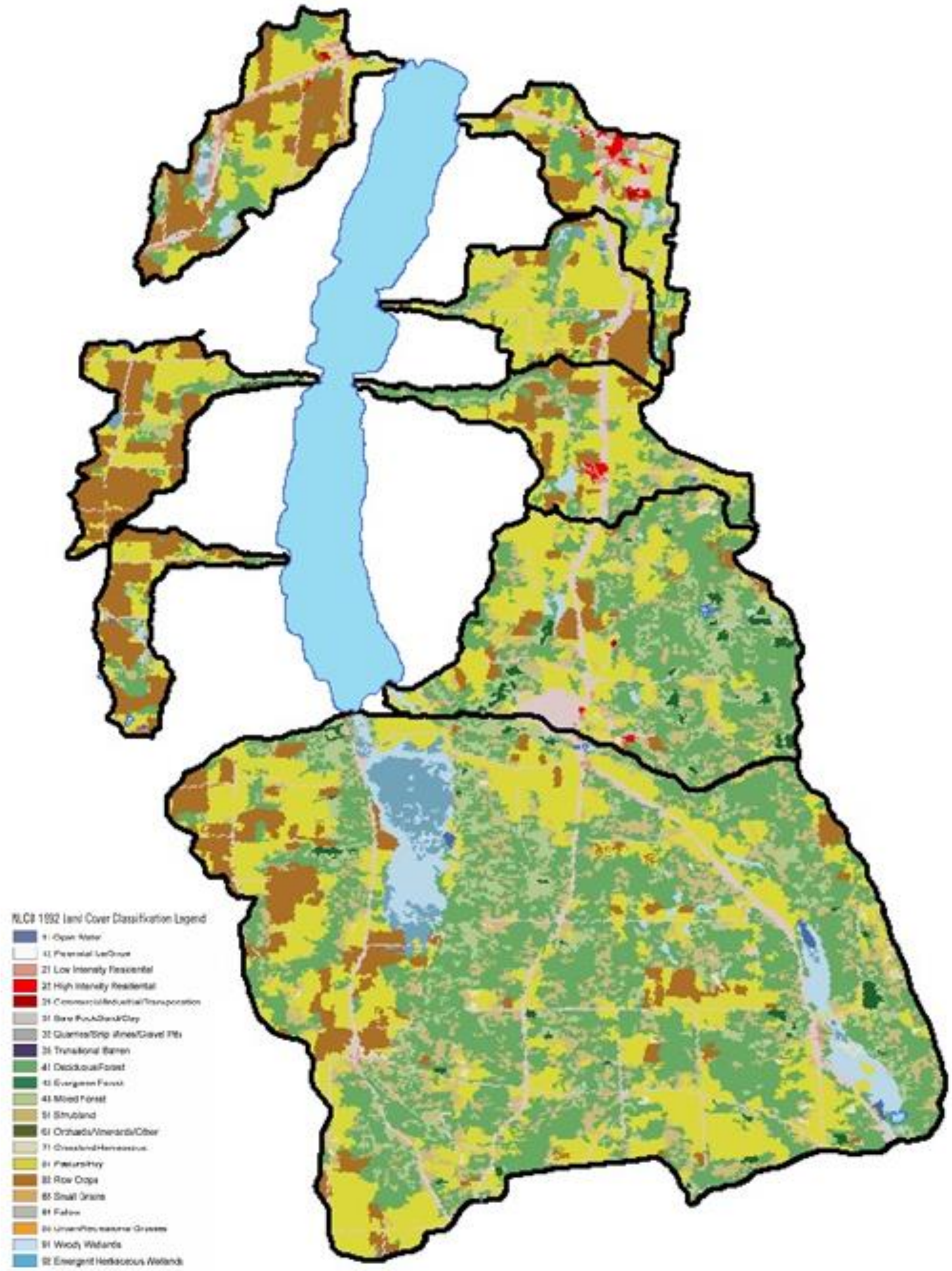

Figure 3: Land Use/Land Cover map of sub-watersheds sampled in Conesus Lake

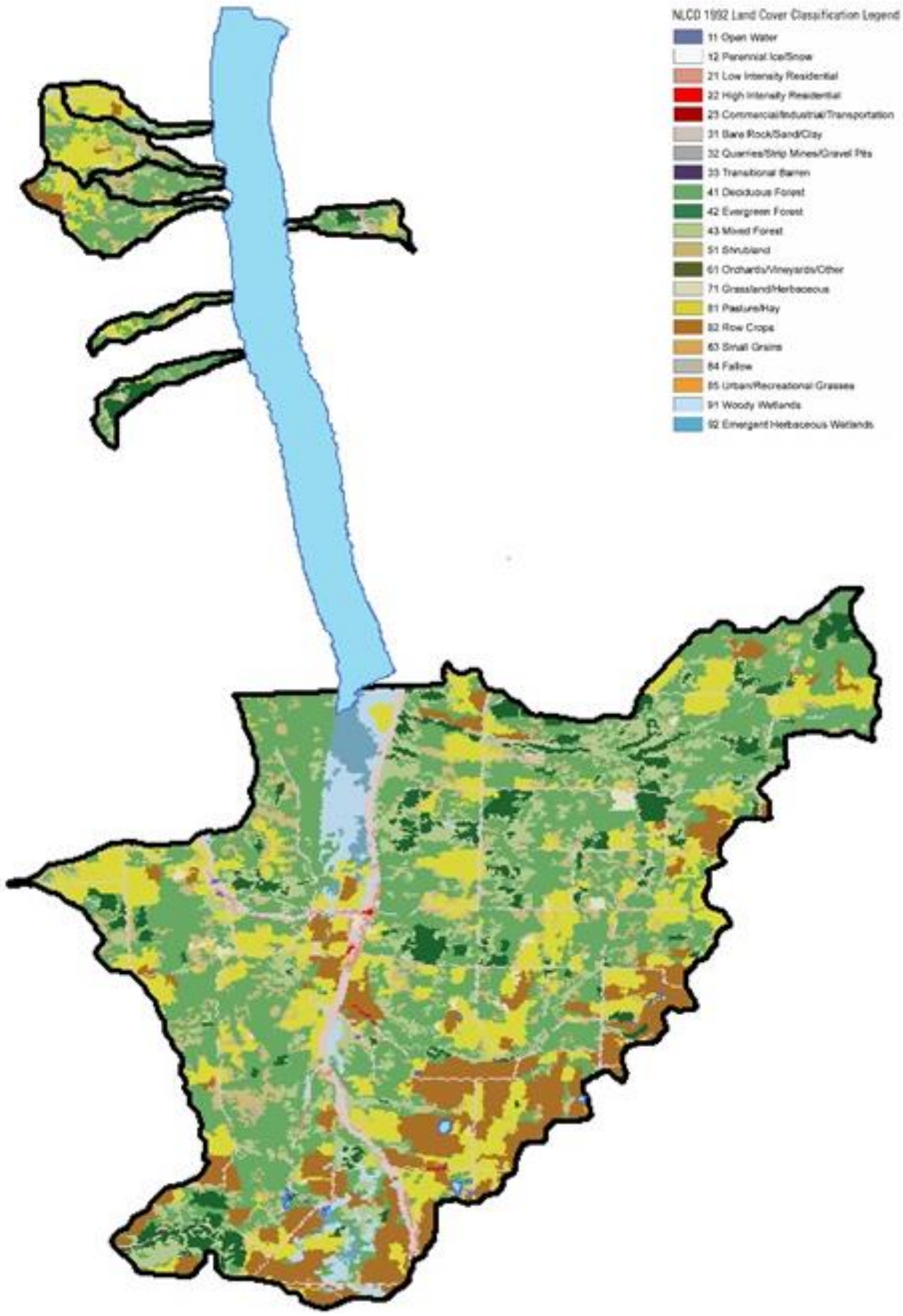

Figure 4: Land Use/Land Cover map of sub-watersheds sampled in Hemlock Lake

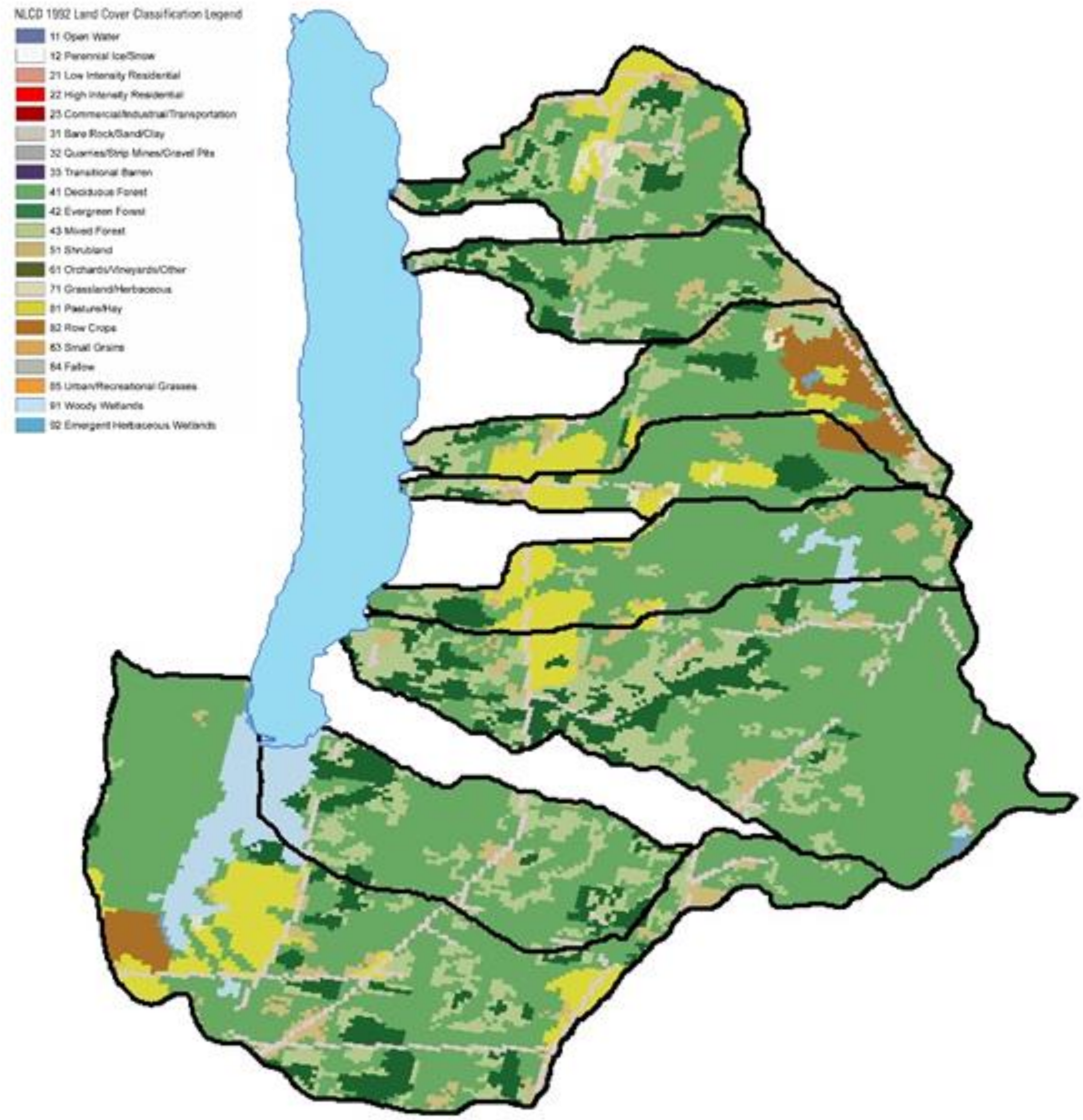

Figure 5: Land Use/Land Cover map of sub-watersheds sampled in Canadice Lake

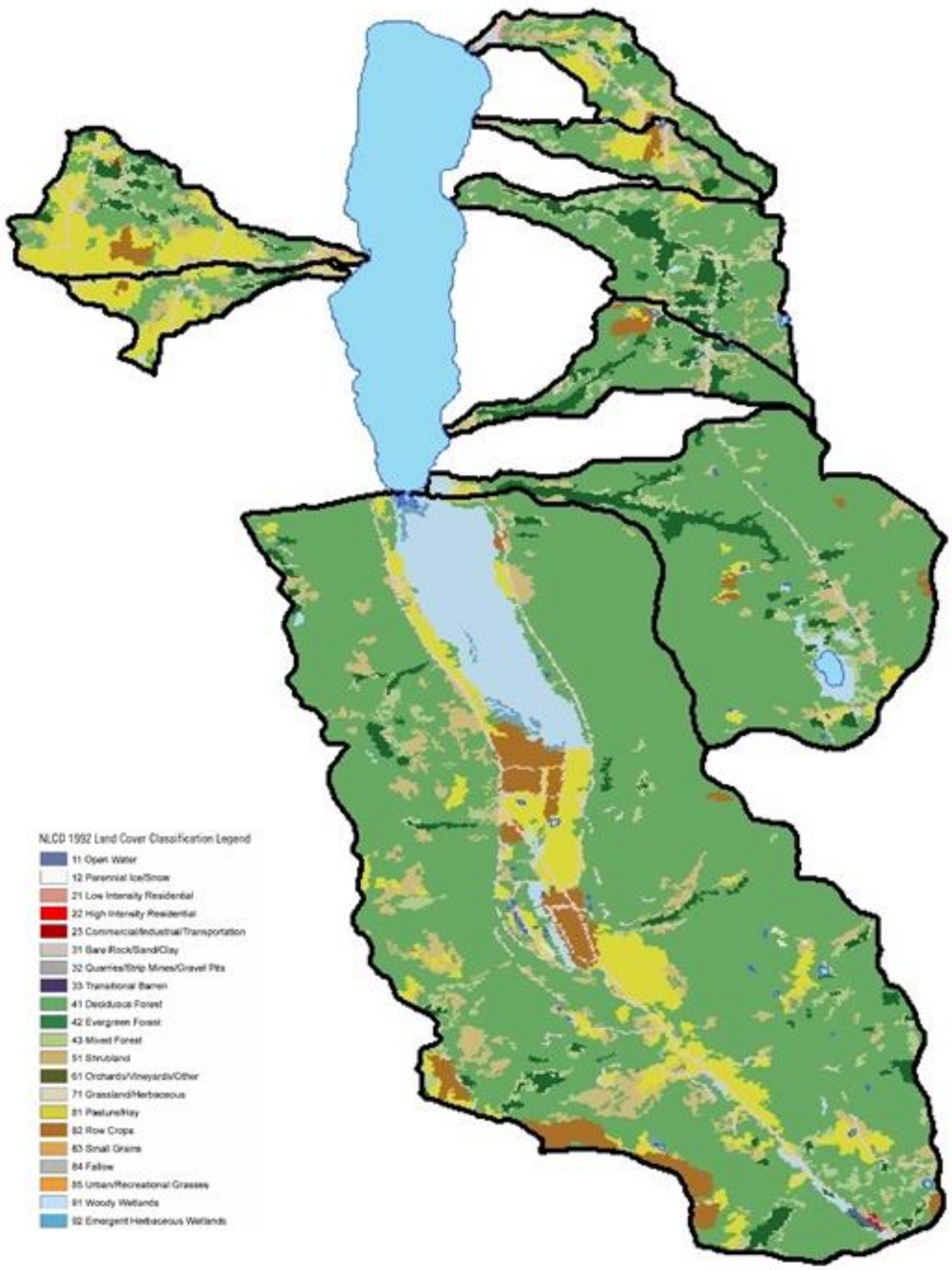

Figure 6: Land Use/Land Cover map of sub-watersheds sampled in Honeoye Lake

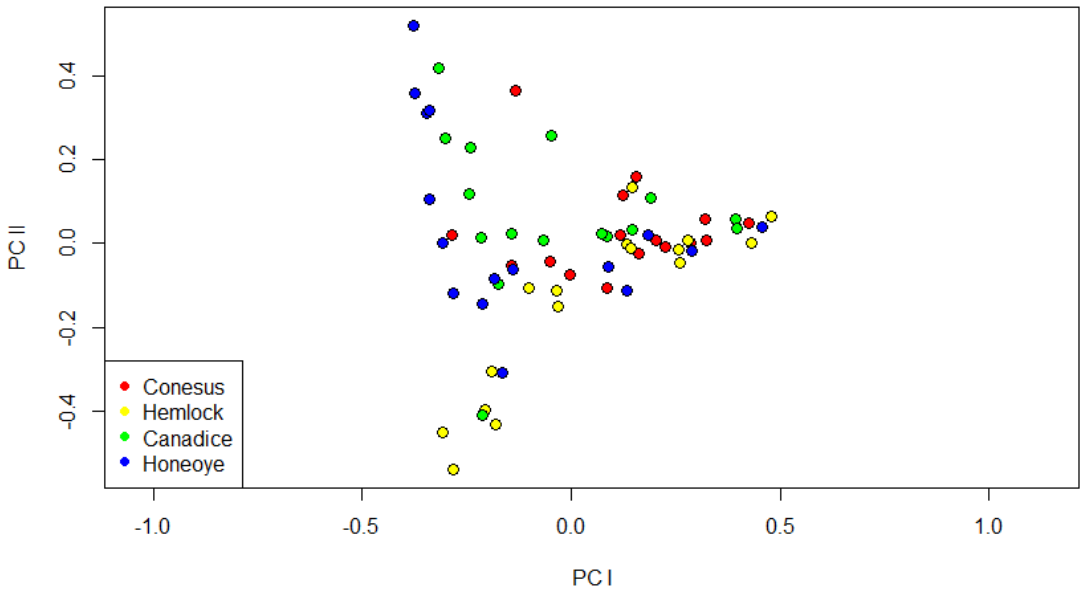

Figure 7: Plot of principal component scores for each sample from principal components I and II retained from the macroinvertebrate community comparison. Higher values for PC I indicate a higher abundance of Oligochaeta and Chironomidae. Higher values for PC II indicate a greater abundance of *Pisidium* sp. and lower values indicate a greater abundance of *D. polymorpha*.

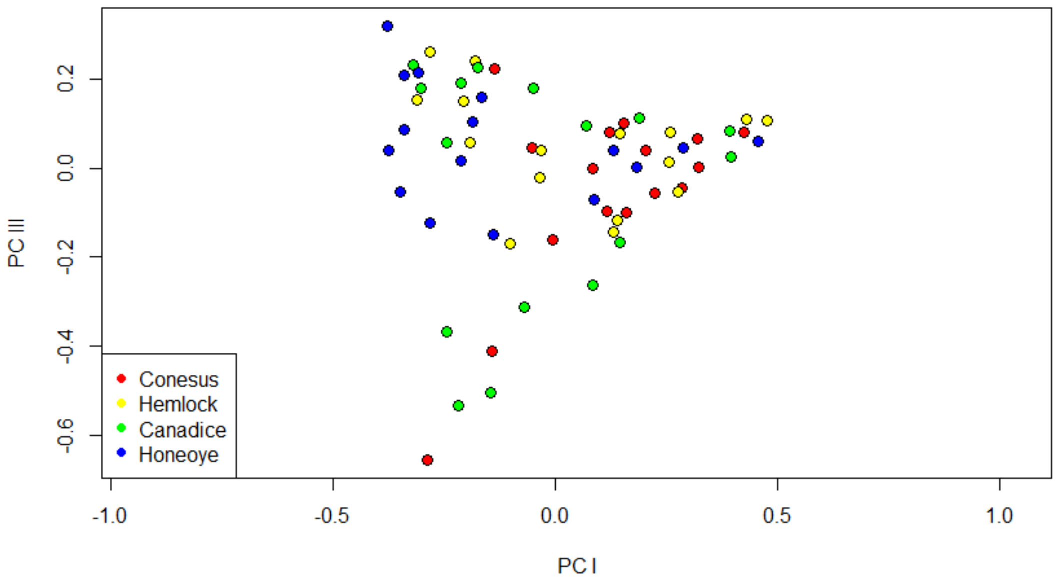

Figure 8: Plot of principal component scores for each sample from principal components I and III retained from the macroinvertebrate community comparison. Higher values for PC I indicate a higher abundance of Oligochaeta and Chironomidae. Lower values for PC III indicate a higher abundance of *Caecidota* sp. and *Gammarus* sp.

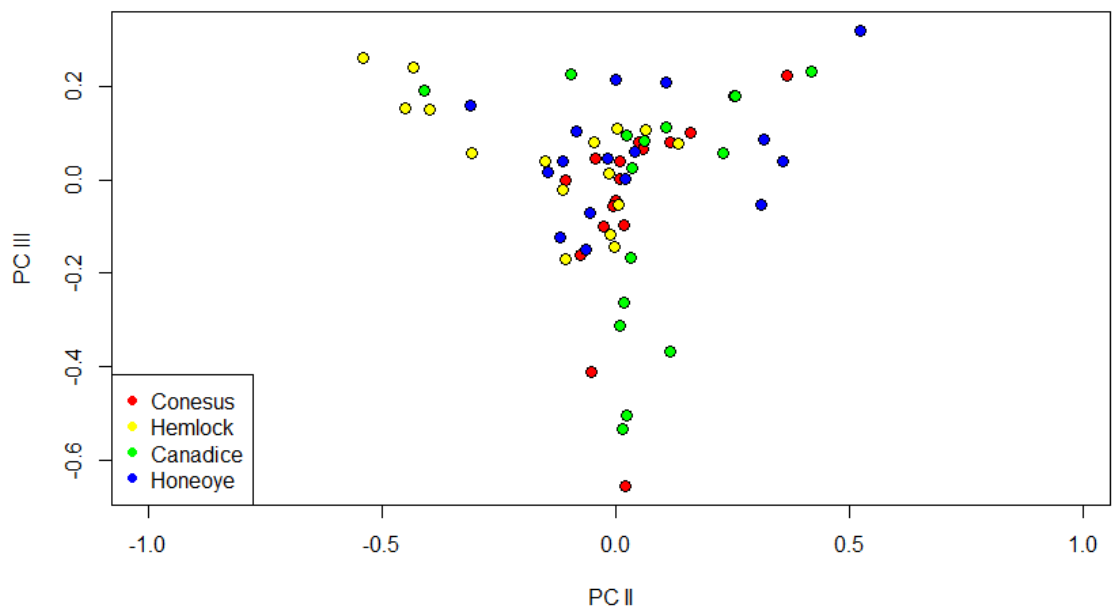

Figure 9: Plot of principal component scores for each sample from principal components II and III retained from the macroinvertebrate community comparison. Higher values for PC II indicate a greater abundance of *Pisidium* sp. and lower values indicate a greater abundance of *D. polymorpha*. Lower values for PC III indicate a higher abundance of *Caecidota* sp. and *Gammarus* sp.

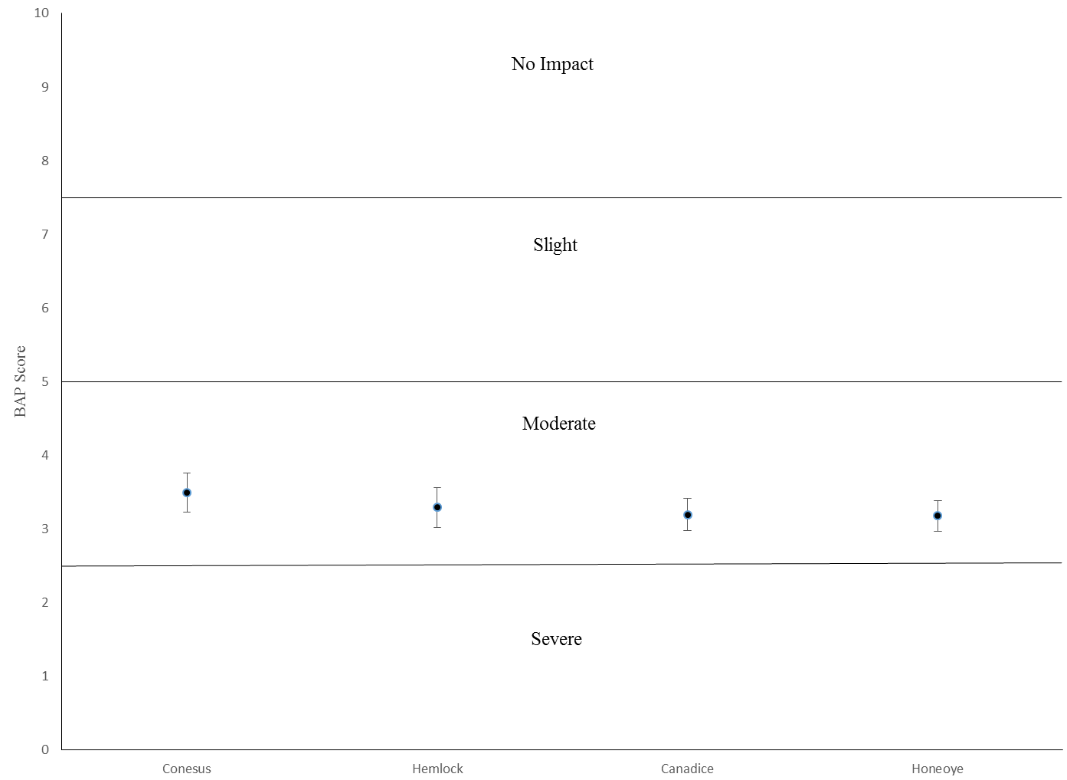

Figure 10: Mean Biological Assessment Profile scores for each of the studied lakes.

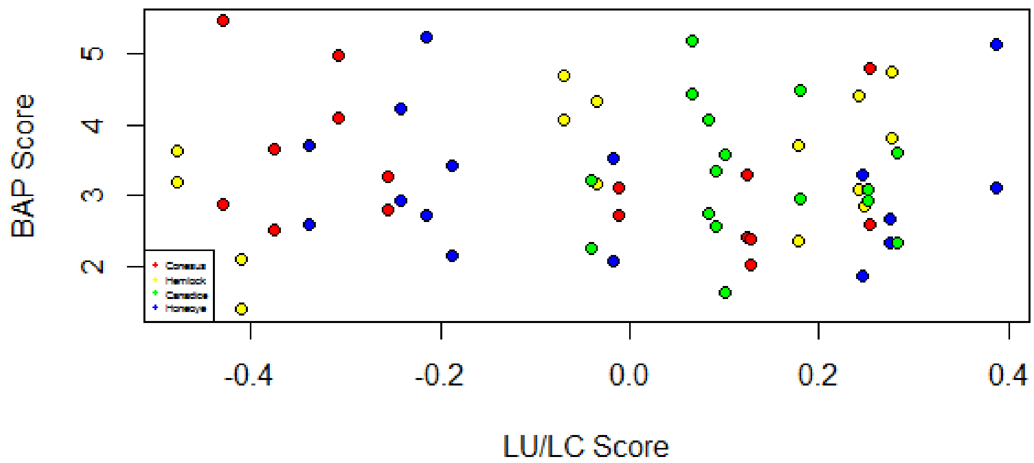

Figure 11: Land Use/Land Cover principal component score (higher values indicate higher percentage of Deciduous Forest cover, lower values indicate higher percentages of Cultivated Crop and Hay Pasture cover) plotted against the BAP score for each sample.