5-2014

# Examining the Effects of pH and Macrophyte Diversity on Benthic Macroinvertebrate Assemblages in Adirondack Lakes

Jacob A. Gaskill

Examining the Effects of pH and Macrophyte Diversity on Benthic Macroinvertebrate Assemblages in Adirondack Lakes

by

Jacob A. Gaskill
Candidate for Bachelor of Science
Environmental Science
With Honors

May, 2014

**APPROVED**

Thesis Project Advisor: ______________________________
Dr. Kimberly Schulz

Second Reader: ______________________________
Dr. Neil Ringler

Honors Director: ______________________________
William M. Shields, Ph.D.

Date: ______________________________

## Abstract:

Acidification in ecosystems, such as water bodies of the northeastern United States, causes significant changes in their biological communities. Changes in lower trophic levels significantly affect the structure and function of higher trophic levels. Benthic macroinvertebrates are useful when examining the effects of acidification because different species are tolerant or sensitive to particular conditions and can act as indicators of water quality. Macrophyte diversity is another explanatory variable influencing macroinvertebrates. Many studies have examined macroinvertebrate assemblages in streams related to water quality, but macroinvertebrates in lakes are less well studied.

We compared the benthic macroinvertebrate assemblages in four Adirondack lakes with differing pH. We predicted that as pH decreased, the abundance and diversity of the macroinvertebrates would decline. To test this, we measured pH and collected 40 benthic samples from four Adirondack lakes using a PONAR samler. Macroinvertebrates were sorted, identified to the lowest possible taxon (generally family or genus) and tallied. Macrophytes were identified and diversity was estimated with the Shannon Diversity Index.

Benthic macroinvertebrate richness decreased with lower pH ($p = 0.03$) and increased with greater macrophyte diversity ($p = 0.02$). However, total macroinvertebrate abundance was not statistically correlated with pH ($p = 0.08$) or macrophyte diversity ($p = 0.07$). Diversity is often considered a strong indicator of ecosystem health, thus our results suggest that further reduction of acidification may restore diversity of lower trophic levels in Adirondack lakes and improve their ecological conditions.

## Table of Contents

## Figures:



## Table:



## Appendix:



## Acknowledgments:

This study would not have been possible without the help of several individuals. I would like to thank Dr. Neil Ringler for agreeing to review this report and providing very valuable insight. I would also like to thank Dr. Kimberly Schulz for her instruction and support, as well being available to answer my questions and sign my many forms. Finally, I would like to thank Andrew Brainard. As main collaborator on the project, his guidance and direction cannot be overstated. As a friend , his advice and insight was invaluable. The assistance of these three individuals has sparked my enthusiasm in the scientific process and I am incredibly thankful for their contributions to my education.

## Introduction:

Acidification in ecosystems causes significant changes, especially to species that inhabit those ecosystems. Its effects are especially felt in the Northeastern United States (Geller and Schultze, 2009). The southwestern region of the Adirondack Park is one of the most affected areas in the country (Driscoll et al., 1991), because this area receives high amounts of rainfall, and the granite and gneiss bedrock has little cation exchange capacity with which to neutralize acids (Cumming et al., 1991). However, the percentage of acidified lakes in this region is dropping. Since the implementation of the Acid Rain Program, a 1990 amendment to the Clean Air Act that reduced sulfate emissions, and the Nitrogen Budget Program, a 2003 cap and trade program designed to regulate NOx emissions, Waller et al. (2012) found that the percentage of severely acidified lakes in their study sample dropped from 15.2% to 8.3%. Furthermore, Driscoll et al. (1998) showed that sulfate concentrations have decreased since 1983 in both precipitation and lake water. This coincides with a reduction in sulfate emissions in the Midwest, largely attributed to the 1990 amendment to the Clean Air Act. Many believe that these pieces of legislation have been some of the most successful environmental policies in the United States, and they are widely thought to have decreased acid deposition.

Despite reductions, acid deposition in the Adirondack Park is still occurring and causes a range of pH values in different bodies of water. Baldigo et al. (2009) conducted a comprehensive study of Western Adirondack streams, finding that while there has been some recovery, many streams and lake outlets are still acidified. Their study compared present water quality and benthic macroinvertebrate communities with similar data collected in 1980. Macroinvertebrates are useful when examining the effects of acidification because of the high diversity that they exhibit. Different species are able to survive different conditions, and therefore can act as indicators to water quality. Furthermore, as stressors (such as pH or changing habitat) increase and the environment becomes less habitable, diversity decreases (Rapport and Whitford, 1999). Many believe that an ecosystem's health is directly related to the biodiversity it supports (relative to the ecosystem if it were undisturbed). Thus, it is possible to assess the health of similar ecosystems based on biodiversity. A decrease in benthic macroinvertebrate diversity also has a great potential to affect higher taxonomic levels negatively. Shifting macroinvertebrate regimes have a great potential to affect fish by altering the availability and concentrations of energy and nutrients, especially amino acids (Forster, 2011). This would make it more costly for some species to meet nutritional requirements and might ultimately open the door for other species to flourish (Lento et al., 2008).

Many studies (for example, Baldigo et al., 2009) examine stream acidification in the Adirondack Park. Much attention is given to the effects of acid deposition on streams, because they are more prone to acidification than lakes. Streams receive water from shallow soils with little buffering capacity and have few in-stream processes with which to buffer acid (US Geologic Survey, 2009). Consequently, much less work has been put into studying the effects of acid deposition in lakes, where cations are typically present in slightly higher concentrations than streams and thus are able to buffer acid inputs more effectively. This is significant because management for both water bodies should not be the same if the effects of acidification on each are different. Both are very prevalent throughout the Adirondack Park, making management implications widespread. This study attempts to bridge the gap in the current understanding of acidification in Adirondack waters by examining lake benthic macroinvertebrates.

**Objective and Hypotheses:**

This study investigates how environmental disturbances like changes in pH and macrophyte diversity affect the abundance and taxa richness of benthic macroinvertebrates in four Adirondack Lakes. We predict that benthic macroinvertebrate abundance and richness will be greater in lakes with higher pH values and a greater diversity of macrophytes.

## Methods:

Four Adirondack lakes were sampled for this study: Cranberry Lake, Lake Flower, Long Lake, and Raquette Lake. Lakes were selected using two main criteria: the availability of a boat launch for public access and the existence of public use data required for a second study on non-native macrophytes that was being conducted at the same time. Sites were selected by measuring the total length of shoreline around each lake and dividing it by ten (since ten sites were sampled in each lake). This was the distance between each site. The first site was always placed at the boat launch and then subsequent sites were marked off around the lake. Theoretically, this is a sound method for making sure that the whole lake was evenly sampled. In practice, some sites were not able to be sampled because of unnavigable physical features. A handheld GPS unit was used to record the coordinates of the location of each sample site. At each site, pH was measured using a YSI 6600 Sonde. The pH for each lake was calculated by averaging the measured pH at each site. The lakes we sampled were relatively small, so averaging the measured pH values at each site is an appropriate way to accurately reflect the dominant ph of each lake.

At each site, four benthic samples were collected using a petite PONAR (15.5 cm x 15.5 cm). Samples were taken from between a one and three meter depth. This was done to maximize the number of benthic macroinvertebrates collected. On calm days, samples were collected from different sides of the boat to ensure an even sampling of the site. This was not necessary when the boat was drifting. Within 24 hours of collection, a 70-80% ethanol solution was added to the samples to preserve the benthic macroinvertebrates. A 70-80% ethanol, Rose Bengal ($C_{20}H_2Cl_4I_4Na_2O_5$) solution was added to each sample to preserve and to dye all of the organic matter in the samples a bright pink. This facilitated the sorting process and increased its accuracy as well.

Dyed samples were run through a 0.50 millimeter sieve and rinsed. These rinsed samples were sorted through using forceps. All benthic macroinvertebrates were removed and placed in a vial with 70-80% ethanol solution. Any remains (shells, cases) were also removed and taken note of, but were not used in analysis.

For macroinvertebrate identification, we used the key by Peckarsky et al., (1990). Sorted samples were examined using a stereo microscope (though occasionally a dissecting microscope was also used for smaller organisms). Organisms were identified to the furthest possible taxon, typically family or genus. The exceptions to this were Oligochaeta, Amphipoda, and Chironomidae which were just identified to order (or in the case of chironomid, Family). This was done because these three taxa are known for their tolerance to environmental stressors and were very difficult to identify to any finer taxonomic resolution.  All identified organisms were counted and returned to the 70-80% ethanol solution. This allowed for the creation of a list of taxa present, and abundance of each taxon in each sample.

**Analysis:**

Total abundance was calculated for each lake by summing up the abundances of all benthic macroinvertebrates present in each site (for a total of ten sites). This number was averaged (divided by ten) to find the relative abundance per site. Taxon richness was calculated by averaging the number of taxa present in the four samples of each site. This was done for each site (for a total of ten values). The taxon richness of each lake was the average of these ten sites. The pH of each lake was found by averaging the measured pH values of each site (ten total values). Macrophyte diversity was measured using the Shannon Diversity Index, which takes into account the abundance and evenness of species present in the community. A high Shannon Diversity Index value is representative of a diverse community with an even species distribution.

## Results:

Benthic macroinvertebrate richness increased with pH ($p = 0.034$) and macrophyte diversity ($p = 0.015$) (Figure 1). However, total macroinvertebrate abundance was not statistically correlated with pH ($p = 0.077$) or macrophyte diversity ($p = 0.071$) (Figure 2).

Both Ephemeroptera and Trichoptera increased in percent composition of benthic macroinvertebrates per lake as pH increased (Figure 3). Otherwise, there were few other noticeable trends in percent composition of different macroinvertebrate orders with pH (Table 1).

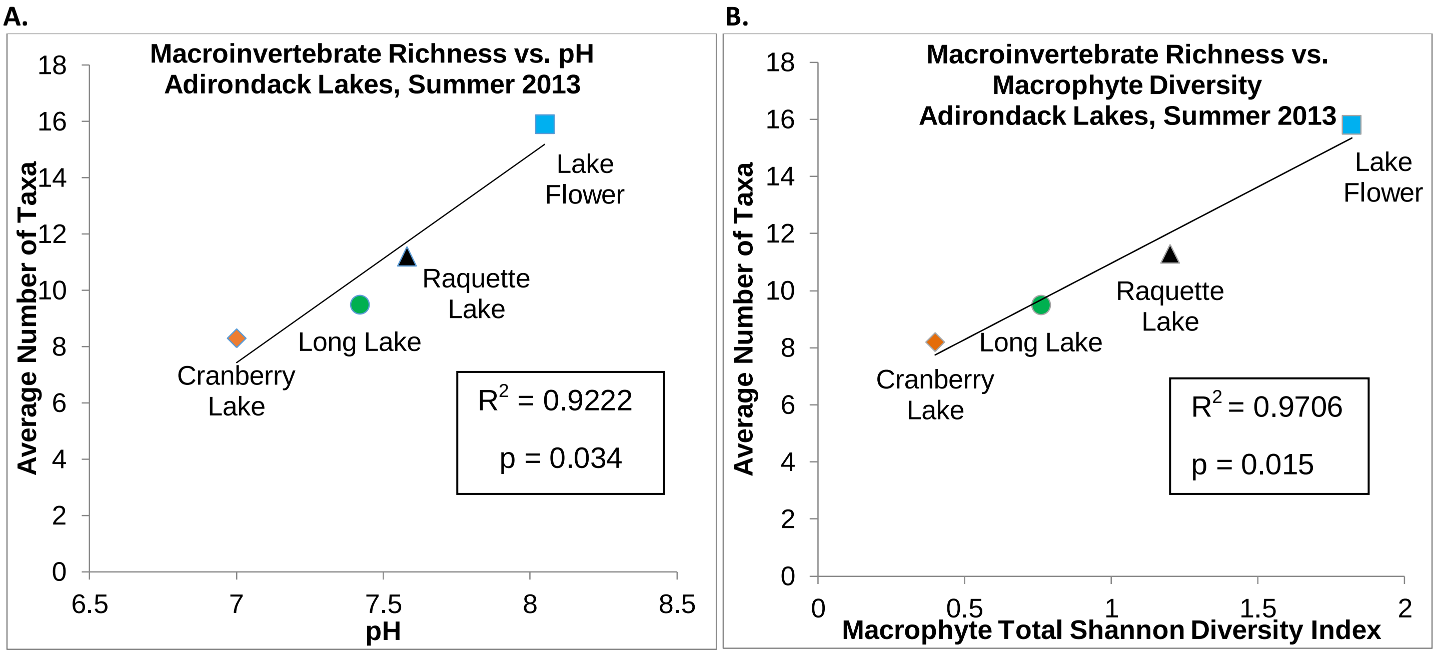


**Figure 1: A.** Benthic macroinvertebrate richness increases as pH increases ($p = 0.034$). **B.** Benthic macroinvertebrate richness increases as macrophyte diversity increases ($p = 0.015$).

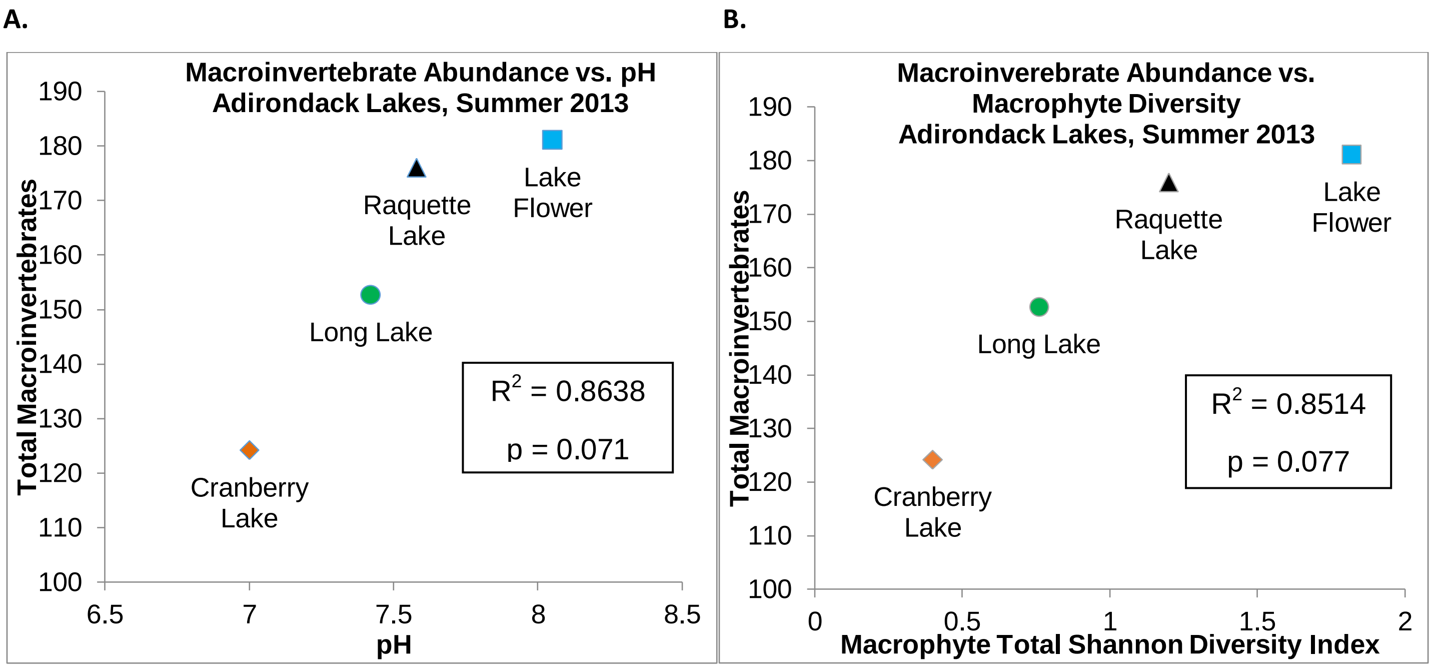


**Figure 2: A.** There are no significant correlations between benthic macroinverebrate abundance and pH (p = 0.071) **B.** or macrophyte diversity (p = 0.077).

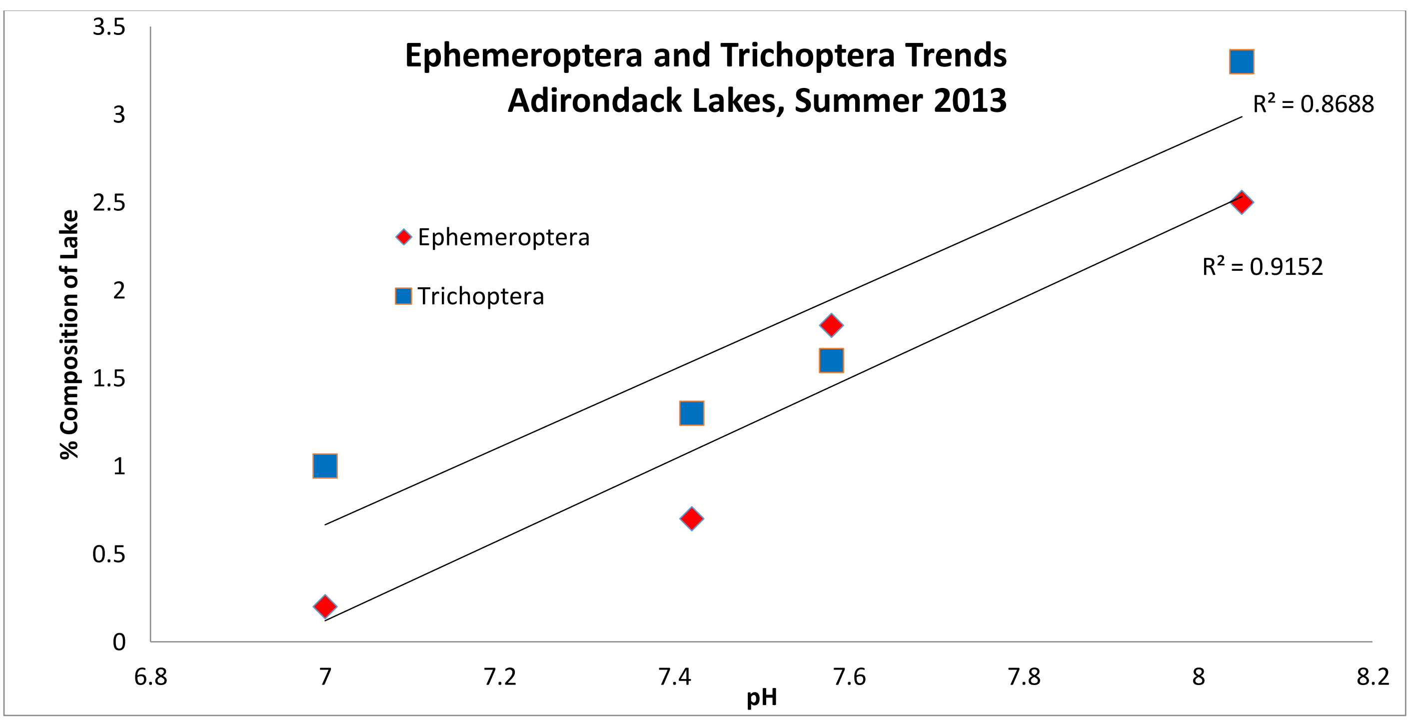


**Figure 3:** Both Ephemeroptera and Trichoptera increased as pH increased. Many Ephemeroptera species are very intolerant of acidic condition and are used as an indicator species for water quality.

**Table 1:** Percent composition of each taxon in each lake. Here, taxa are displayed as orders or classes (as denoted by "C"). For a percent composition table with finer identification, please refer to the Appendix. Also shown are the average pH values of each lake.

| | **Cranberry Lake (pH = 7.00)** | **Long Lake (pH = 7.42)** | **Raquette Lake (pH = 7.58)** | **Lake Flower (pH = 8.05)** |
|---|---|---|---|---|
| **Ephemeroptera** | 0.2 | 0.7 | 1.8 | 2.5 |
| **Odonata** | 0.1 | 0.1 | 0.1 | 0.1 |
| **Plecoptera** | 0.1 | 0.0 | 0.0 | 0.0 |
| **Trichoptera** | 1.0 | 1.3 | 1.6 | 3.3 |
| **Coleoptera** | 0.4 | 0.1 | 0.1 | 0.1 |
| **Megaloptera** | 0.4 | 1.3 | 0.3 | 0.3 |
| **Diptera** | 44.4 | 54.7 | 26.9 | 38.1 |
| **Amphipoda** | 15.3 | 3.1 | 22.0 | 3.9 |
| **Isopoda** | 9.4 | 3.6 | 2.7 | 13.3 |
| **Gastropoda (C)** | 3.0 | 2.9 | 2.3 | 5.9 |
| **Bivalvia (C)** | 3.4 | 6.4 | 4.0 | 3.2 |
| **Oligochaeta (C)** | 22.3 | 25.1 | 31.0 | 33.3 |

## Discussion:

Hypothesis 1 was supported. Benthic macroinvertebrate richness is significantly correlated with both pH ($p = 0.034$) and macrophyte diversity ($p = 0.015$). Both of these variables partially explain the change in taxon richness between lakes.

Hypothesis 2 must be rejected. We found no significant correlation between the decrease in benthic macroinvertebrate abundance with pH ($p = 0.071$) or macrophyte diversity (0.077), indicating that these two variables do not explain changes in abundance between lakes. Macroinvertebrate abundance levels off at higher pH than macrophyte richness, so there is not a linear relationship between these variables.

Our results indicate that certain environmental stressors (in particular pH and degrading habitat) may directly affect the richness of lower trophic levels (Figure 1). However, pH and macrophyte diversity do not have a statistically significant effect on the abundance of benthic macroinvertebrates (Figure 2). There are several probable explanations for this. As the number of taxa decrease, it appears that the percent composition of a few specific taxa increases, most notably Diptera (comprised mostly of chironomids), Isopoda, and to a limited extent, Amphipoda (Table 1). This suggests that more tolerant species are able to replace sensitive ones, causing a shift in the benthic macroinvertebrate assemblages in the lake. The tolerant taxa not affected by the pH or macrophyte changes increased in number, and so replaced individuals from taxa that were negatively affected by low pH or macrophyte diversity. Even if a particular species is able to survive at a decreased pH, individuals may be less successful procuring enough energy to thrive and reproduce at the rate experienced in less stressful conditions. This creates an opportunity for other taxa not affected by the increasing stressors to flourish. So, overall numbers of macroinvertebrates may not change even though the taxonomic diversity changes.

**Effects on Higher Trophic Levels:**

Many species of fish feed on benthic macroinvertebrates at one point in their life history and may favor specific taxa due to their nutritional and energetic value. As these are replaced by increased abundances of other taxa, fish must shift their diets or starve. This makes it harder (and sometimes impossible) for the fish to acquire the nutrients they require. This phenomenon has been well documented and has significant reverberations throughout the ecosystem (McNickle, Rennie, and Sprules, 2006; Schaeffer, Diana, and Haas, 2000).

For example, McNickle, Rennie, and Sprules (2006) observed significant changes in abundance of Diporeia (a genus in the Order Amphipoda) following the introduction of the zebra mussel in Lake Huron. A study sponsored by the Cooperative Institute for Limnology and Ecosystem Research observed similar trends in Lake Michigan, Erie, Huron, and Ontario. *Diporeia* abundance has declined dramatically in deeper zones as zebra mussel and later quagga mussel populations have increased. McNickle, Rennie, and Sprules (2006) believe that this will reduce whitefish populations in the lake unless the whitefish are able to switch their diets to other food sources. If this switch is not made, whitefish diets are predicted to contain only 57-84% of their former energy content (McNickle, Rennie, and Sprules, 2006). Schaeffer, Diana, and Haas (2000) used an energetic model to explain declines in Yellow Perch in Saginaw Bay (Lake Huron). They found yellow perch to be food limited as a result of subsistence feeding on small Chironomid larvae. Formerly, yellow perch used to feed on *Hexagenia* larvae, but these were extricated from the bay by 1965. Since then, yellow perch growth rates and lifespan have declined and mortality has increased (Schaeffer, Diana, and Haas, 2000). Yellow perch are fished commercially in the Great Lakes region, especially in Lake Erie, and were valued at over $4.8 million in 2007 (Moy and Kinnunen, n.d.). In our study, we observed Ephemeroptera reductions (mainly consisted of *Hexagenia*) in conjunction with decreased pH (Figure 3). This, combined with the fact that the percent composition of Diptera in our study lakes (which was mostly made up of chironomids) consisted of anywhere from 26.9-

54.7% makes the negative effects of changes in benthic macroinvertebrates on fish in Saginaw Bay a very real possibility in acidic Adirondack lakes (Table 1).

**Disturbances:**

While any changes in the Adirondacks will be much smaller than those in the Great Lakes, it is important that environmental stressors be minimized in order to preserve greater diversity at low trophic levels, as it has been found that stressors such as low pH decrease diversity in Adirondack ecosystems. Smith et al. (1989) found that benthic macroinvertebrate assemblages immediately downstream of beaver dams were much different than assemblages upstream of the same dams. They concluded that disturbances due to the dam changed benthic macroinvertebrate structure and function and suggested several causes of the changes including high concentrations of trace metals and low dissolved oxygen. They also observed decreases in Ephemeroptera and increases in larval densities of Trichoptera and Chironomid (Smith et al., 1989). These observations remain largely consistent with what we observed in our analysis of Adirondack lakes, except that instead of studying beaver dams, we found that reductions in pH and macrophyte diversity are correlated with decreased benthic macroinvertebrate richness. This means that two ways to maintain benthic macroinvertebrate richness will be to prevent pH from dropping too low (a larger sample of lakes will need to be conducted to pinpoint this number, but the four lakes sampled in this study suggest a significant drop in richness between a pH of 7.00 and 8.05) and to maintain productivity and habitat structure in Adirondack lakes, as indicated by macrophyte diversity. As observed by Smith et al. (1998), we saw an increased sensitivity of Ephemeroptera to even slight environmental stressors. Unlike Smith et al. (1998), we saw the opposite trend in Trichoptera species, observing declines as disturbances increased (Figure 3). However, Trichoptera drift increased within an hour of reaching a pH of 5.9 (Robertson-Bryan 2004). This finding is consistent with the findings of our study.

The range of pH values we measured in our study is relatively small. Cranberry Lake was the lowest pH lake we sampled, but average pH of the lake was 7.00. Lake Flower was the highest pH lake we sampled and it had a pH of 8.05 (Table 1). Many species would probably be able to withstand these changes in pH because they are relatively small and organisms must continually survive some amount of environmental change. This is exemplified by the percent composition changes found in each of the four lakes we studied (Table 1). Many taxa do not show any dramatic changes, notable trends with changes in pH, or make up such a small percentage of total abundance that it is difficult to observe any relevant changes to percent composition. Courtney and Clements (1998) conducted an experiment to see how benthic macroinvertebrates in streams responded to changes in pH. They had three treatment trials with pH values of 4.0, 5.5, and 6.5 and one control trial with pH of 7.4 and found that only the lowest pH trial showed any significant change in benthic macroinvertebrate diversity or abundance. They also cited a study by Johnson et al., (1993) that found the pH value at which half of the tested species died was between 2.45 and 5.38, much lower than even the lowest pH measurement in Cranberry Lake. Since our most acidic lake was between the two highest pH values in the study by Courtney and Clements (1998), we could expect not to observe any dramatic shifts in macroinvertebrate communities. However, even disturbances that do not extirpate a particular taxon might cause it to suffer. This makes it possible for other taxa to increase, ultimately creating the potential for minor shifts in benthic macroinvertebrate assemblages.  This seemed to be the case with two exceptions. We observed a direct increase in percent composition of mayflies (Ephemeroptera) and caddisflies (Trichoptera) as pH increased (Figure 3). This is partially consistent with prevailing literature. Mayflies are widely accepted to be one of the most sensitive orders to acidification, consisting of many important indicator species. Simpson, Bode, and Colquhoun (1985), Courtney and Clements (1998), and Smith et al. (1989) all observed  significant declines in Ephemeroptera abundance as pH declined, though Courtney and Clements (1998) found that declines of other genera occurred at a finer level than Order.

It is also important to note that several other factors might describe the patterns observed in our study. The four lakes we studied are small in comparison to the Great Lakes (United States) where much of the existing research in lentic ecosystems is centered. Furthermore, the shape and size of the lakes in our study sample vary. Lake Flower is shallow, small, and ovate while Cranberry Lake is much larger, deeper, and is oddly shaped, containing several dendritic arms. Substrate size and detritus content also plays a very large role in determining benthic macroinvertebrate composition (Parker, 1989). Since it is virtually impossible to find a set of lakes identical in all aspects except pH, manipulation experiments are a useful way of isolating specific variables. This type of experimentation could provide a greater level of confidence to degree of influence pH and macrophyte diversity have on determining benthic macroinvertebrate assemblages. However, the oversimplification associated with manipulation experiments detracts from the complex relationships in natural ecosystems. This is why it is important to use both the observations and analyses from sampling natural ecosystems in conjunction with experimentation that eliminates the uncontrollable variation found in natural ecosystems. Future experimentation concerning this topic should continue to focus on determining the degree of influence different variables (pH, macrophyte diversity, lake size, substrate) have on determining benthic macroinvertebrate assemblages in the Adirondacks.

**Continuity with Streams:**

The effects of acidification on streams in the Adirondacks have been well studied. Simpson, Bode, and Colquhoun (1985) examined two Adirondack streams, one with a moderate pH (5.8-7.32) and the other with a lower pH (4.4-5.0). They found that the site with the moderate pH had a higher diversity of benthic macroinvertebrates than the site with the lower pH. They also found that species regimes change with pH. This is in agreement with our study. They observed an increase in Chironomidae abundance during September sampling. Our sampling was done late in the year (between late August and early October), but since we have no samples from earlier in the year with which to compare, any connections drawn between our study and theirs is speculative. Between 2003 and 2005, the Western Adirondack Stream Survey (WAAS) (Baldigo et al., 2009) sampled benthic macroinvertebrates in 36 streams in the Oswegatchie and Black River basins. The WAAS Project is unique because it compared results to the results of a similar survey conducted in the early 1980s (Baldigo et al., 2009). They found that macroinvertebrates were moderately to severely affected in 52% of assessed streams (US Geologic Survey, 2009). Both the WAAS Project and the study done by Simpson, Bode, and Colquhourn (1985) support the findings of our study: increased acidification is strongly correlated with a decline in the number of benthic macroinvertebrates that are able to survive. The biggest difference we found is the degree of sensitivity. We believe that macroinvertebrates in the lakes we sampled were more sensitive to small changes in pH and might have a higher threshold than those in streams. However, several other factors might contribute to this instead. Increasing our sample size of lakes will help to provide some insight to this hypothesis.

Often, Adirondack streams are more acidic than lakes since streams continually receive water from shallow soils with little buffering capacity. Furthermore, there are few in-stream processes with which to buffer acid deposition while lakes tend to have a greater concentration of cations. Lakes are also generally composed of more homogeneous water. In streams, discharge and water chemistry is almost completely dependent on upstream occurrences. This means that benthic macroinvertebrates living in streams have to face a wider range of disturbances that occur at a greater frequency than benthic macroinvertebrates in lakes. It is very possible then that benthic macroinvertebrates in lakes are more vulnerable to handling disturbances than those in streams since disturbances are not as common in lakes. The fact that many stream studies have found the threshold for declines in benthic macroinvertebrate diversity to be a much lower pH value for macroinvertebrates in streams further supports this hypothesis.

**Importance for Management:**

Ultimately, this means that management of lakes and streams in the Adirondacks should be similar and should focus on mitigating acidification and preventing dramatic changes in the diversity of macrophytes. Acidification of many Adirondack water bodies has slowly decreased since the legislation of the 1970's was passed, but many more water bodies are still affected (Baldigo et al., 2009). Acid deposition is particularly difficult to manage since pollutants originate from out of state and several of the other factors are out of human control (bedrock composition, wind patterns, precipitation trends). Current education programs exist that inform boaters about the dangers of invasive species and provide information about how to take precautions to stop their spread. This will be important to continue since many of the invasive macrophytes of concern in the Adirondacks are commonly known to reduce diversity of different water bodies. Finally, many lakes are heavily trafficked by boats traveling from sometimes great distances. This poses a unique issue for managers trying to stop the spread of invasive macrophytes that is not present in many streams, as boat traffic on small streams is much lower than that on lakes). Ultimately, it is important that managers know that while benthic macroinvertebrates in streams and lakes both experience declines in diversity due to increased acidification, the macroinvertebrates in lakes probably are more sensitive to these changes. This will enable them to create and implement appropriate regulations with the goal of maintaining the health and productivity of Adirondack systems.

**Potential Sources of Error:**

There were several sources of error in this study. Samples were collected between late August and early October. This late into the season, cold might have become a factor in the mortality of some benthic macroinvertebrates. Furthermore, sampling over such a wide time frame allows for some error in benthic macroinvertebrate assemblages due to the emergence of some species. Finally, a few samples were lost or mislabeled (one sample from Cranberry Lake, one sample from Raquette Lake, and two samples from Long Lake). This would affect the abundance of benthic macroinvertebrates found in each lake, but the effects of this are expected to be marginal since our sample size was so large.

**Continuation of Study:**

We plan to continue this study by examining three more lakes (Lake Placid, Arbutus Pond, and Fourth Lake).Samples have already been procured from these lakes but have not yet been prepared and analyzed. These lakes will strengthen our data set by increasing our sample size and will extend the high end range for pH values to 8.11 (Fourth Lake).

## Conclusion:

Our study indicates that benthic macroinvertebrate taxon richness in Adirondack lakes is affected by pH and macrophyte diversity. Conversely, abundance did not share a significant relationship with either pH or macrophyte diversity. It appears that as sensitive taxa (namely Trichoptera and Ephemeroptera) declined, more tolerant taxa increased in number to take their place. This has a potential to cause disruptions up the food chain as some species of fish might not be able to acquire sufficient nutrients or energy from these alternative prey. When compared to the results of similar analyses of streams, the results of our study remain consistent. The most notable difference is that benthic macroinvertebrates in lakes appear to be more sensitive to disturbances, experiencing significant changes in richness over a 7.00 to 8.05 range in pH values. In streams, the literature reports significant changes at much lower pH values. Ultimately, our study attempts to learn more about the effects of acidification on Adirondack lakes, in which benthic macroinvertebrates are largely unstudied, especially compared to the vast amount of work put into understanding more about Adirondack streams. It is important for managers to know the similarities and differences of acidification in lakes and streams so that they can implement regulations accordingly.

## Works Cited:


Baldigo, Barry P., Gregory B. Lawrence, Robert W. Bode, Howard A. Simonin, Karen, M. Roy, and Alexander J. Smith. “Impacts of Acidification on Macroinvertebrate Communities in Streams of the Western Adirondack Mountains, New York, USA.” *Ecological Indictors* 9 (2009): 226-9.

Courtney, L.A., and W. H. Clements. "Effects of acidic pH on benthic macroinvertebrate communities in stream microcosms." *Hydrobiologia* 379 (1998): 135-145.

Cumming, B.F., J. P. Smol, J.C. Kingston, D.F. Charles, H. J.B. Birks, K.E. Camburn, S.Ss. Dixit, A. J. Uutala, and A. R. Selle. “How Much Acidification Has Occurred in Adirondack Region Lakes (New York, USA) since Preindustrial Times?” *Canadian Journal of Fisheries and Aquatic Sciences* 49 (1992): 128-41.

Driscoll, C. T., K. M. Postek, D. Mateti, K. Sequeira, J. D. Aber, W. J. Krester, M. J. Mitchell, and D. J. Raynal. “The Response of Lake Water in the Adirondack Region of New York to Changes in Acidic Deposition.” *Environmental Science and Policy* 1 (1998): 185-98.

Driscoll, C. T., Newton, R. M., Gubala, C. P., Baker, J. P., Christensen, S. W., 1991. Adirondack Mountains. In: Charles, D.F. (Ed.), Acidic Deposition and Aquatic Ecosystems: Regional Case Studies. Springer-Verlag, New York, pp. 133e202

Foster, I.P. "Food Acquisition and Digestion: Dietary Requirements of Fish Under Culture Conditions." *Encyclopedia of Fish Physiology* (2011): 1617-622. *Science Direct*. Web. 25 Apr. 2014.

Geller, W., and M. Schultze. "Acidification." *Reference Module in Earth Systems and Environmental Sciences Encyclopedia of Inland Waters* (2009): 1-12. *Science Direct*. Web. 25 Apr. 2014.

Johnson, R.R., T. Wiederholm and D.M. Rosenberg, 1993. Freshwater biomonitoring using individual organisms, populations, and species assemblages of benthic macroinvertebrates. In D.M. Rosenberg and V.H. Resh (eds), Freshwater Biomonitoring and Benthic Macroinvertebrates. Chapman and Hall, Inc., New York: 40-158.

Lento, Jennifer, Peter J. Dillon, Keith M. Somers, and Ron A. Reid. “Changes in Littoral Benthic Macroinvertebrate Communities in Relation to Water Chemistry in 17 Precambial Shield Lakes.” *Canadian Journal of Fisheries and Aquatic Sciences* 65 (2008): 906-18.

McNickle, G.G., M.D. Rennie, W.G. Sprules. "Changes in benthic invertebrate communities of South Bay, Lake Huron following invasion by zebra mussels (Dreissena polymorpha), and potential effects on lake whitefish (Coregonus clupeaformis) diet and growth. *Journal of Great Lakes Research* 32 (2006): 180-193.

Moy, Phil, and Ron Kinnunen. *Great Lakes Commercial Fisheries*. National Oceanic and Atmospheric Administration, n.d. Web. 9 Apr. 2014. <http://fshn.ifas.ufl.edu/seafood/sst/33rdann/ppt/day2/12_moy_phil.pdf>.

Parker, Michael S. "Effect of Substrate Composition in Detritus Accumulation and Macroinvertebrate Distribution in a Southern Nevada Desert Stream." *The Southwestern Naturalist* 34.2 (1989): 181-187. *JSTOR*. Web. 25 Apr. 2014.

Peckarsky, Barbara L., Pierre R. Fraissinet, Marjory A. Penton, and Don J. Conklin, Jr. *Freshwater Macroinvertebrates of Northeastern North America*. Ithaca: Comstock Pub. Associates, 1990. Print.

Rapport, David J., and Walter G. Whitford. "How Ecosystems Respond to Stress." *BioScience* 49.3 (1999): 193. Print.

Robertson-Bryan Inc. *Technical Memorandum: PH Requirements of Freshwater Aquatic Life*. Tech. Elk Grove: Robertson-Bryan, 2004. Web. http://www.swrcb.ca.gov/rwqcb5/water_issues/basin_plans/ph_turbidity/ph_turbidity_04phreq.pdf

Schaeffer, J.S., J.S. Diana, R.C. Haas "Effects of long-term changes in the benthic community on yellow perch in Saginaw Bay, Lake Huron." *Journal of Great Lakes Research* 26 (2000): 340-351.

Simpson K.W., R. W. Bode, and J.R. Colquhoun. "The macroinvertebrate fauna of an acid-stressed headwater stream system in the Adirondack Mountains, New York." *Freshwater Biology*15 (1985): 673-681.

Smith, M. E., C.T. Driscoll, B.J. Wyskowski, C.M. Brooks, and C.C. Cosentini. "Modification of stream ecosystem structure and function by beaver (Castor canadensis) in Adirondack Mountains, New York." Canadian Journal of Zoology. 69 (1991):55-61.

The Cooperative Institute for Limnology and Ecosystems Research (CILER). *Trends in Benthic Macroinvertebrate Populations in Lake Michigan*. Ann Arbor: CILER, n.d. Print.

USA. US Department of the Interior. US Geological Survey. *Acid Rain Effects on Adirondack Streams - Results from the 2003-05 Western Adirondack Stream Survey (the WAAS Project)*. By Gregory B. Lawrence, Karen M. Roy, Barry B. Baldigo, Howard A. Simonin, Sophia I. Passy, Robert W. Bode, and Susan B. Capone. N.p.: US Geologic Survey, 2009. Print.

Waller, Kristen, Charles Driscoll, Jason Lynch, Dani Newcomb, and Karen Roy. "Long-term Recovery of Lakes in the Adirondack Region of New York to Decreases in Acidic Deposition." *Atmospheric Environment* 46 (2012): 56-64.

## Appendix:

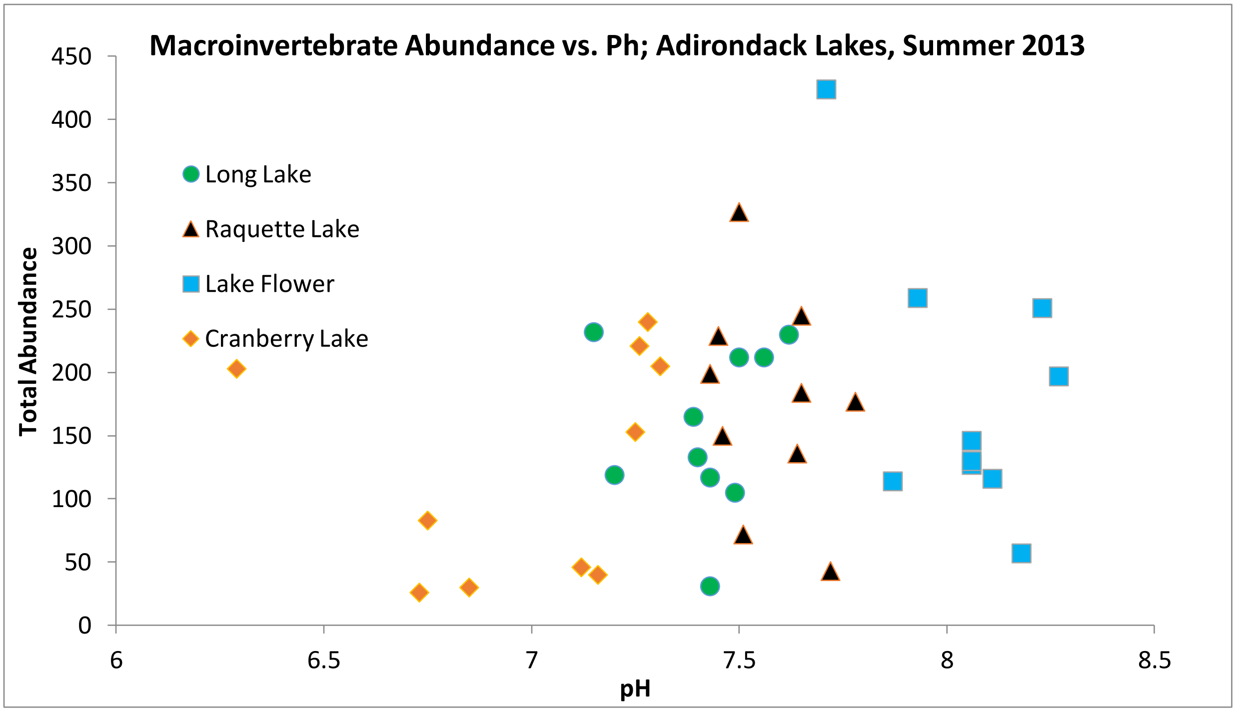


**Figure 1:** The total number of benthic macroinvertebrates found at each of the ten sample sites within each lake. pH was measured at each site and averaged for all four lakes, but the pH of each site is depicted here.

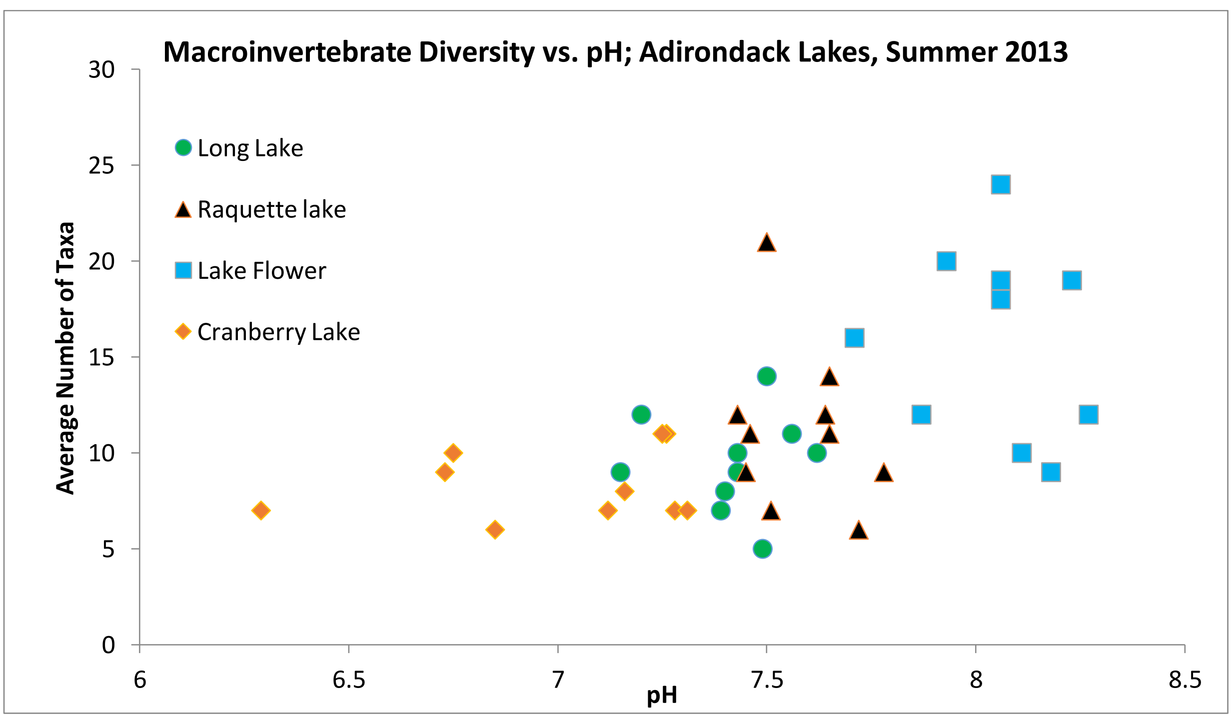

**Figure 2:** The average number of taxon found at each of the ten sample sites within each lake. pH was measured at each site and averaged for all four lakes, but the pH of each site is depicted here.

**Table 1:** Percent composition of each taxon in each lake. Here, taxa are displayed to the family level, with a few exceptions. Many organisms were identified as far as genus, but are displayed to the family level here because the degree of confidence in correct identification is much higher for family than Genus.
"O" indicates that this taxon is identified to the Order level.
"C" indicates that this taxon is identified to the Class level.
"U" indicates that members of the family Unionidae were found in this lake.

| | **Cranberry Lake** | **Long Lake** | **Raquette Lake** | **Lake Flower** |
|---|---|---|---|---|
| **Ephemeroptera Ephemeridae** | 0.08 | 0.64 | 1.42 | 1.04 |
| **Ephemeroptera Ephemerellidae** | 0.00 | 0.00 | 0.42 | 1.43 |
| **Ephemeroptera Polymitarcyidae** | 0.00 | 0.06 | 0.00 | 0.00 |
| **Ephemeroptera (unidentified)** | 0.08 | 0.00 | 0.00 | 0.00 |
| **Odonata Anisoptera** | 0.08 | 0.00 | 0.58 | 0.05 |
| **Odonata Zygoptera** | 0.00 | 0.00 | 0.00 | 0.44 |
| **Odonata (unidentified)** | 0.00 | 0.00 | 0.00 | 0.33 |
| **Plecoptera (unidentified)** | 0.08 | 0.00 | 0.00 | 0.00 |
| **Trichoptera Brachycentridae** | 0.00 | 0.13 | 0.11 | 0.00 |
| **Trichoptera Glossosomatidae** | 0.08 | 0.00 | 0.00 | 0.00 |
| **Trichoptera Hydroptilidae** | 0.00 | 0.00 | 0.00 | 0.27 |
| **Trichoptera Lepidostomatidae** | 0.00 | 0.06 | 0.00 | 0.00 |
| **Trichoptera Leptoceridae** | 0.08 | 0.06 | 0.68 | 1.32 |
| **Trichoptera Limnephillidae** | 0.00 | 0.19 | 0.00 | 0.00 |
| **Trichoptera Odontoceridae** | 0.00 | 0.19 | 0.00 | 0.00 |
| **Trichoptera Philopotamidae** | 0.08 | 0.13 | 0.00 | 0.00 |
| **Trichoptera Phryganeidae** | 0.08 | 0.00 | 0.16 | 0.22 |
| **Trichoptera Polycentropidae** | 0.24 | 0.13 | 0.37 | 0.82 |
| **Trichoptera Psychomyiidae** | 0.00 | 0.00 | 0.11 | 0.49 |
| **Trichoptera Sericostomatidae** | 0.00 | 0.19 | 0.11 | 0.00 |
| **Trichoptera (unidentified)** | 0.40 | 0.00 | 0.11 | 0.11 |
| **Coleoptera Dytiscidae** | 0.24 | 0.00 | 0.00 | 0.00 |
| **Coleoptera Elmidae** | 0.00 | 0.00 | 0.05 | 0.00 |
| **Coleoptera Hydrophilidae** | 0.00 | 0.00 | 0.00 | 0.05 |
| **Coleoptera Psephenidae** | 0.00 | 0.06 | 0.00 | 0.00 |
| **Coleoptera (unidentified)** | 0.16 | 0.00 | 0.00 | 0.00 |
| **Megaloptera Sialidae** | 0.40 | 1.34 | 0.32 | 0.33 |
| **Diptera Chaoloeridae** | 0.96 | 11.47 | 0.26 | 2.14 |
| **Diptera Chironomidae** | 43.11 | 43.28 | 26.61 | 35.91 |
| **Diptera Culicidae** | 0.32 | 0.00 | 0.00 | 0.00 |
| **Amphipoda (O)** | 15.30 | 3.06 | 21.97 | 3.79 |
| **Isopoda Asellidae** | 9.38 | 3.57 | 2.74 | 13.34 |
| **Gastropoda (C)** | 3.04 | 2.87 | 2.32 | 5.93 |
| **Bivalvia (C)** | 3.45 | 6.37 | 3.48 | 3.12 (U) |
| **Oligochaeta (O)** | 22.28 | 25.11 | 30.93 | 33.28 |