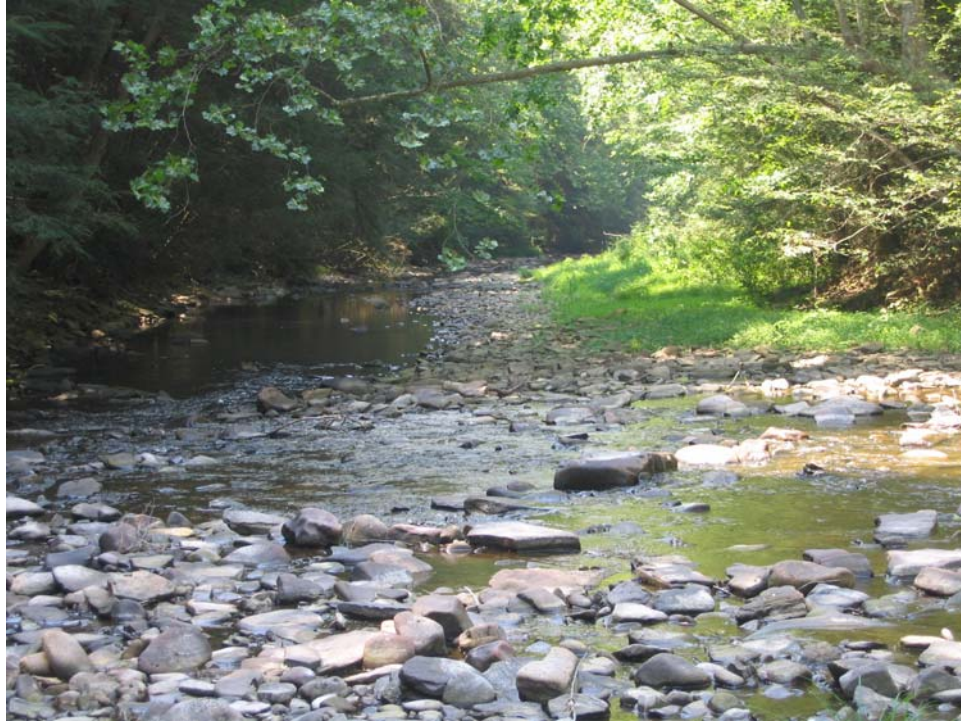


# Comparing Macroinvertebrates from Three Habitats at the Savage River of Western Maryland.



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## **ABSTRACT**

Macroinvertebrates are excellent biological indicators of water quality. The purpose of our study was to compare the macroinvertebrates living in three Savage River habitats (riffles, undercut banks, and stagnant water) of western Maryland. We hypothesized that there would be a significant difference in the average biotic index values for macroinvertebrates found in the three habitats. The group performed simple chemical tests and collected macroinvertebrates using kick-nets and buckets. Later, each habitat's health was evaluated using the Hilsenhoff biotic index. We found that the riffles had an excellent water quality, the undercut banks had a good water quality, and the stagnant water had a poor water quality. We expected these results because the riffles had many sensitive macroinvertebrates, low nutrient levels, and high dissolved oxygen. The stagnant water had many tolerant macroinvertebrates, higher phosphate levels, and lower dissolved oxygen. This biological indicator shows that macroinvertebrates are important to streams and the environment.

## INTRODUCTION

Limnology is the study of lakes and streams. Organisms called macroinvertebrates that live in lakes streams are good indicators of water quality. Many qualities of a good stream are necessary for macroinvertebrates to survive. A Good stream needs specific qualities: suitable dissolved oxygen levels, steady current, and nutrients including nitrate and phosphate. Dissolved oxygen is an essential factor in a healthy stream because it helps macroinvertebrates breathe. A cool temperature helps maintain a high oxygen level (Allan, 2005). Nutrients are necessary for the survival and growth of aquatic plants and macroinvertebrates feed on the plants. A healthy stream must also have a tolerable pH level (around neutral), a gravel bottom, regular and healthy water flow, little to no pollution, and riffles for feeding areas (Allan, 2005).

Macroinvertebrates indicate excellent, good, fair, or poor water quality. Stoneflies and mayflies can indicate excellent water quality; and leeches, midges and blackflies indicate poor water quality. Many macroinvertebrates cannot survive in poor water quality. Macroinvertebrates are good indicators of water quality because they have different physical and chemical preferences in which they can survive.

The spreading of pollutants can end up killing many organisms living in the water. However, pollutants are not just trash or gas from cars; pollution is anything that is introduced to an environment that is not native to it. One of these things is allochthonous input, leaves and branches that fall into the water (Molles, 2005).

Macroinvertebrates are organisms that have no backbone and are visible to the naked eye. Macroinvertebrates live their lives mostly in the water. All macroinvertebrates start their lives in the water. The life cycles of macroinvertebrates vary. Some macroinvertebrates start as eggs, morph into nymphs and transform into adults. Other macroinvertebrates start as eggs, change

into larvae, then pupa, and finally morph into adults (Dodds, 2002). Nymphs and larva live in water, and most adults fly or live on the land.

Macroinvertebrates can be classified into different feeding groups: shredders, collectors, grazers, and predators. Shredders are macroinvertebrates that shred leaves. For example, a crane fly sometimes shreds and eats leaves. Bacteria feed on the leftovers from the leaves (National Park Service, 2006). Collectors gather small sediments and particles with several types of filters and fan-like structures, for example, the black fly. Grazers, like the gilled snail, feed on algae which grow on the surface of rocks and logs in water. Predators, like the hellgrammites, are a more vicious organism; they feed on other macroinvertebrates (National Park Service, 2006).

Each macroinvertebrate has its own pollution tolerance. Some types of pollution are acids (which are measured by pH), nitrates, and phosphates. The classes of macroinvertebrates are low pollution tolerant, somewhat pollution tolerant, and high pollution tolerant (Primbas, 2005). Some macroinvertebrates that are low pollution tolerant are caddisflies, water pennies, stoneflies, and mayflies. Somewhat pollution tolerant macroinvertebrates are dragonflies, crane flies, and damselflies. Some high pollution tolerant macroinvertebrates are blackflies, aquatic worms, and midges (Primbas, 2005).

Biotic index values of macroinvertebrates can be used to determine the water quality. Hillsenhoff's biotic index scale ranges from one to ten. This scale is based on macroinvertebrate pollution tolerance, tolerance to nutrients, and dissolved oxygen requirements. When the average biotic index values ranges from 1 to 3.75 the water quality is considered excellent. Average biotic index values from 3.76 to 5 infer good water quality and values from 5.1 to 6.5 infer fair water quality, and 6.6 to 10.9 infer poor water quality. (Faulds, Murray, & Neville, n.d.)

Each macroinvertebrate has a different body characteristics and its own food preference. These body characteristics are important to the survival of the macroinvertebrates. The water penny has suckers, and it lives on the rocks. When the water flows over the rock, it does not carry the water penny with it. The water penny consumes the algae off the rocks. The blackfly uses its filters to absorb the nutrients and food molecules in the stagnant water. (Faulds, Murray, & Neville, n.d).

The anatomy of a stream includes habitats such as riffles, undercut banks, and stagnant pools. Riffles are fast moving white water with a rocky bottom that is not too deep (Allan, 1995). This habitat has a high dissolved oxygen level due to the fast current. When pollutants enter the stream, the riffles wash them into a habitat, called undercut banks. Undercut banks are slow moving deep waters that flow under the edge of the stream bank. (Allan, 1995). This habitat has an overhang of vegetation. When vegetation falls into the stream, it is washed downstream into stagnant pools where it stays and decomposes. Stagnant water is still. High levels of nutrients are found in stagnant pools. When too many nutrients such as nitrates and phosphates enter the water, eutrophication occurs.

Excess nutrients cause an overgrowth of plants and algae. When the plants and algae die the decaying matter rots in the water which decreases the amount of dissolved oxygen available to the macroinvertebrates in the water. The rotting material can also cause the water to be polluted (Allan, 1995).

Macroinvertebrates have different preferred habitats based on the water quality they need to survive. Many macroinvertebrates prefer or need a high dissolved oxygen level. Dissolved oxygen is the amount of oxygen present in the water and is measured in parts per million (Allan, 1995). Macroinvertebrates, such as mayflies, stoneflies, caddisflies and riffle beetles, need high

dissolved oxygen levels. These macroinvertebrates are found mainly in riffles, but also in undercut banks. Many macroinvertebrates also prefer to live in riffles because the temperature is cold and the current is fast, which increases the dissolved oxygen in the water (Molles, 2005). The warmer the temperature the less dissolved oxygen the water will be able to hold.

Macroinvertebrates such as leeches and aquatic worms are very tolerant to pollution and they do not need high dissolved oxygen levels. These macroinvertebrates can be found in stagnant pools. Many macroinvertebrates can not survive in stagnant pools because there is an excessive amount of nutrients and plants causing eutrophication. Nutrients such as nitrates and phosphates help plants grow, reproduce, survive, and stay healthy (Virginia D.E.Q, 2003). Plants are important to macroinvertebrates because they are the main food source. Nutrient levels depend on temperature, amount of rain, and runoff.

The purpose of our study is to compare the different types of macroinvertebrates in the three different habitats of the Savage River: riffles, undercut banks and stagnant pools. Each habitat has different currents, substrates (like algae, rocks, tree branches and leaves), pH, temperature, dissolved oxygen levels, and nutrients. The null hypothesis is that there is no significant difference in the average Biotic Index Value based on macroinvertebrates in the three habitats. The alternative hypothesis is that there will be a significant difference in the average Biotic Index Value based on macroinvertebrates in the three habitats.

## METHODS

We performed our tests at the Savage River in Western Maryland, an angler stream with a camping site for many civilians. The plans for our study were similar to a previous study done by Metzling, L., Chessman, B., Hardwick, R., and Wong, V. 2003. We picked the Savage River because it had all three habitats in the same area. Fishing is often done in this area from this, we could infer that the quality of water was good.

On July 4, 2007 we arrived at the Savage River at 10:05 am to perform our chemical tests. We split up into five different groups; each group was assigned a chemical test to perform at each habitat. We measured the pH in each habitat by placing a meter into a cup of water then recording the values. We placed the alcohol thermometers into the water for two minutes to get the temperature. To test nitrates and phosphates, we used a LaMotte test kit. The water was compared to the color sheet to indicate nitrate and phosphate levels.

On July 9, 2007, we revisited the Savage River at 10:30 am to collect macroinvertebrates. We collected samples for three riffles, three undercut banks, and three stagnant pools. We took three different samples for each nine habitat; each sample was labeled with the habitat type and number. The first group members started downstream, so they would not disturb any other organisms upstream. One person held the kick net, while the others kicked the rocks to remove macroinvertebrates from underneath the rocks. After stirring the rocks with our feet for 60 seconds, we removed the net from the water and released the macroinvertebrates into the plastic bucket. After that the macroinvertebrates were transferred into the site labeled jars. Later, we preserved our macroinvertebrates using half a bottle of 91% isopropyl alcohol. They were preserved so that they would not decompose before we were able to get all of our identification methods completed.

On July 11, 2007 and July 16, 2007, we divided into our field groups to begin identification methods. We placed a strainer over a pitcher in the sink. The alcohol from the plastic jar was poured into the pitcher, and the macroinvertebrates were captured by the strainer. Using brushes, we removed the organisms from the strainer to a plastic bowl. We wore gloves when picking through the samples, and we used petri dishes to hold and sort the macroinvertebrates. Dissecting scopes were used to identify small characteristics. If we still were not able to identify our macroinvertebrates by looking at them through the dissecting scope, we used Leaf Pack Identification cards and dichotomous keys. Identification maps were labeled with pictures and names and used to categorize macroinvertebrates by order.

We decided to use pie graphs to show the ratio of species in all three habitats. We used a stacked bar graph to show the percentage of macroinvertebrate species in each of the pollution tolerance levels: most sensitive, somewhat sensitive and tolerant classes.

We used Hilsenhoff's biotic index values, which account for macroinvertebrates pollution tolerance levels, tolerance to nutrients, and dissolved oxygen requirements. To find the average biotic index for macroinvertebrates of a particular habitat, we multiplied the assigned Hilsenhoff biotic index value by the number of counted macroinvertebrates of each order. We then added all the values at each habitat and divided them by the total number of macroinvertebrates found at each habitat. We used the bar graph to compare the average biotic index values at each habitat.

A t-test is a statistical test used to compare averages, to show significance between sets of data. We used a one tailed t-test to determine if there was a difference in the average biotic index values between the stagnant pools and the undercut banks, the stagnant pools and the riffles. We used a one tailed t-test because we expected the average biotic index values of the stagnant pools

would be higher than the average biotic index values of the riffles and the undercut banks. We used a two tailed t-test to determine if there was a difference between the average biotic index values in the undercut banks and the riffles. A two tailed t-test was used because we were not sure whether the average biotic index values would be higher or lower in riffles or undercut banks.

## RESULTS

As seen in Table 1 (below), the pH values for all three habitats were all in the same range of about 7.5. The temperature values were all in the same range; they were only higher or lower than one another by 0.1°C or 0.2°C. The nitrate levels of the three habitats were all around the same value of, which was 2.0 to 2.5 parts per million. The phosphates level of the stagnant pool was three parts per million higher than the riffle and the undercut bank. The dissolved oxygen level in the riffle habitat had a higher dissolved oxygen level than the stagnant pool and the undercut bank.

<b>Test</b>	<b>Riffles</b>	<b>Stagnant Pools</b>	<b>Undercut Banks</b>
<b>pH</b>	7.6	7.6	7.4
<b>Temperature</b>	19.5°C	19.4°C	19.6°C
<b>Nitrates</b>	2.5 ppm	2.5 ppm	2.0 ppm
<b>Phosphorus</b>	1 ppm	4 ppm	1 ppm
<b>Dissolved Oxygen</b>	11.8 ppm	9.4 ppm	10.6 ppm

Table.1 chemical test results for the water quality at the three habitats of the Savage River

As seen in Figure 1 we found mostly caddisflies, water pennies and stoneflies (which are highly sensitive to pollution) at the riffle habitat. We found one of each of the following macroinvertebrates: dragonflies, fishflies, water boatmen, blackflies and water striders. Dragonflies, fish flies, water boatmen and water striders are macroinvertebrates that fall under the somewhat sensitive category. The only pollution tolerant macroinvertebrate that we found in the riffle habitat was the blackfly.

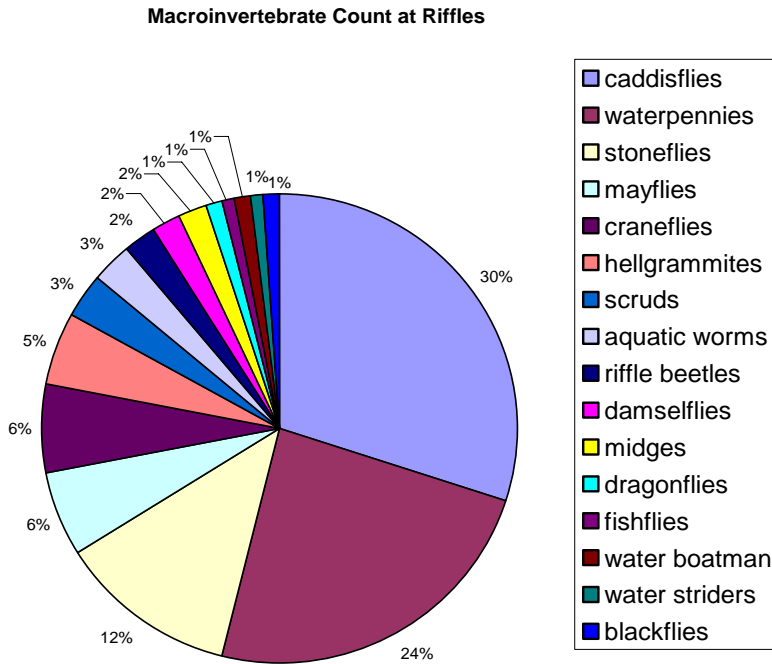


Figure 1- This pie graph shows the percentage for each type of macroinvertebrate found in riffle.

As seen in Figure 2 we found more caddisflies and mayflies than any other macroinvertebrate at the undercut bank habitat. We also found a fairly large percentage of water pennies. Caddisflies, mayflies and water pennies are macroinvertebrates that fall under the most sensitive category. In addition fifteen percent of the macroinvertebrates found in the undercut bank habitat were aquatic worms which are pollution tolerant.

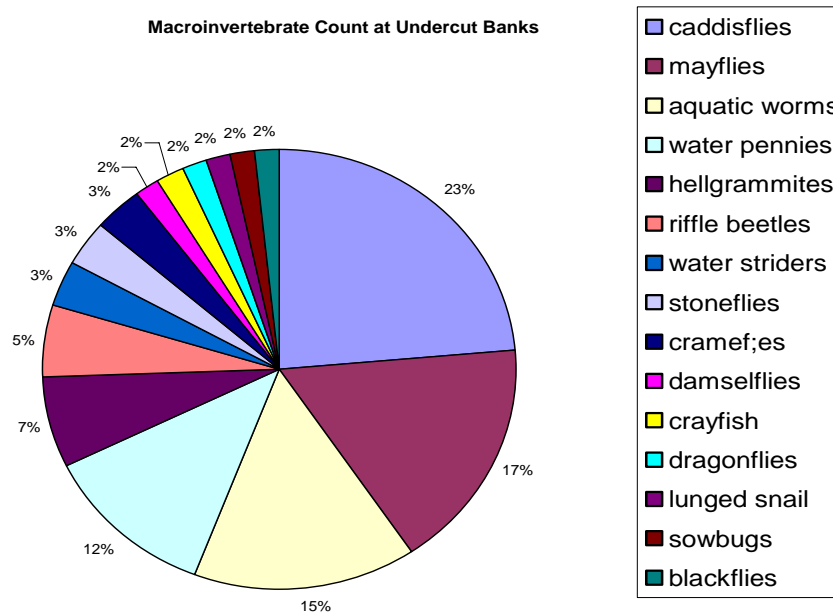


Figure 2- This pie graph shows the percentage of each type of macroinvertebrate found in the undercut bank.

As seen in Figure 3 the most common macroinvertebrates that we found in the stagnant pool were aquatic worms and midges. The least common macroinvertebrates that we found were lunged snails, dragonflies and stoneflies. Aquatic worms, lunged snails, and midges are pollution tolerant. Dragonflies are somewhat sensitive and stoneflies are highly sensitive to pollution.

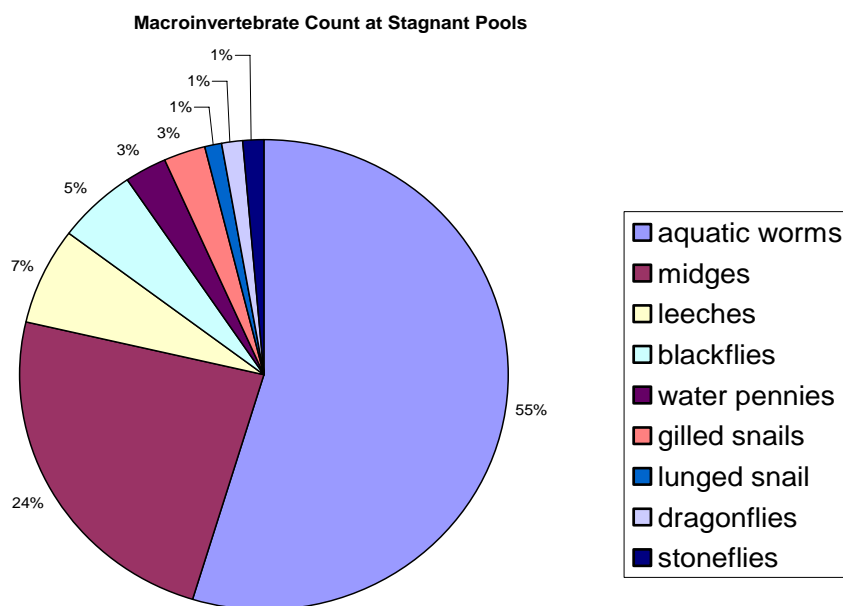


Figure 3- This pie graph shows the percentage for each type of macroinvertebrate found at stagnant pool.

As shown in figure 4, all three of the sensitive taxa were found at all three different habitats. The majority of the macroinvertebrates found at the riffle habitat were highly sensitive to pollution. A few macroinvertebrates that were somewhat sensitive and very few that were pollution tolerant were also found at the riffle habitat. More pollution tolerant than somewhat sensitive macroinvertebrates were found at the undercut bank habitat. The stagnant pool had the most pollution tolerant macroinvertebrates, a few highly sensitive and hardly any somewhat sensitive macroinvertebrates. Overall we found out that sensitive macroinvertebrates had the highest percent at the riffle and undercut bank habitat, and pollution tolerant has the highest percent at the stagnant pool.

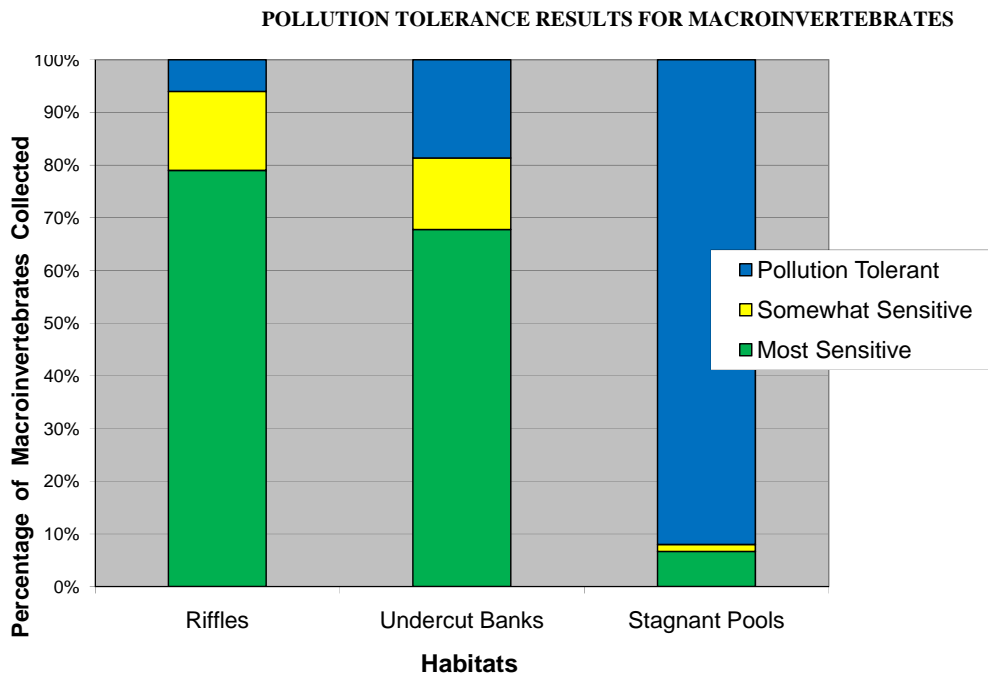


Figure 4. This figure shows the macroinvertebrates classified by sensitivity to pollution.

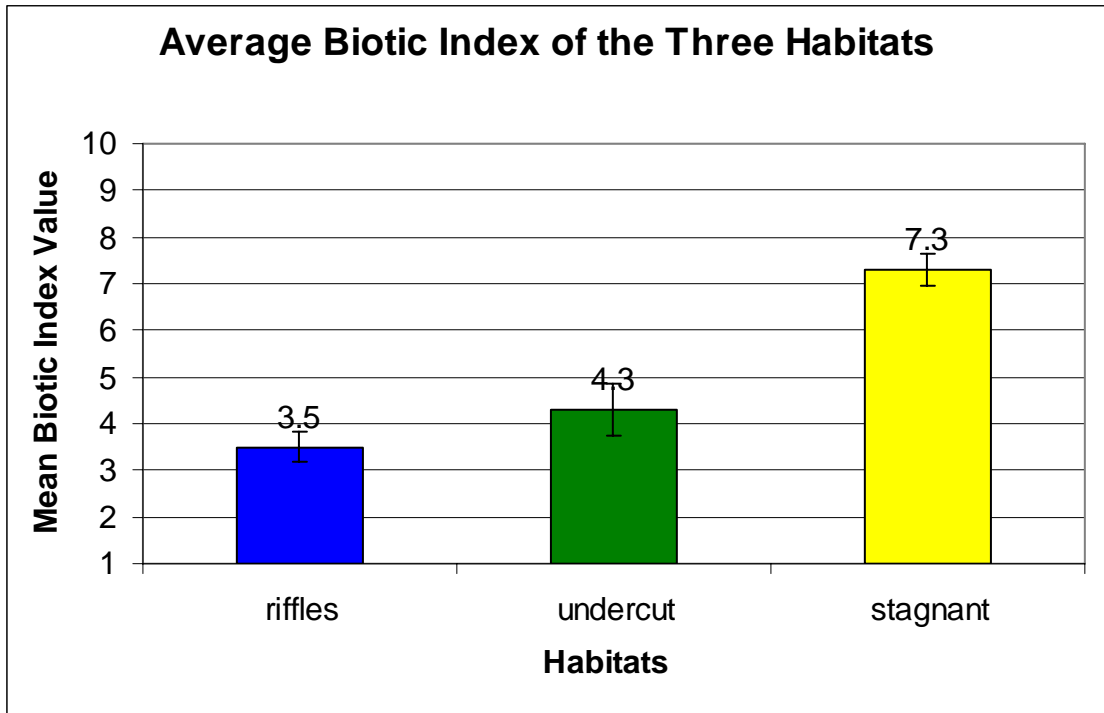


Figure 5. This bar graph shows the average biotic index values for the macroinvertebrates found in the riffle, undercut bank, and stagnant pool habitat.

The stagnant pool had the highest average biotic index value of 7.3. The riffle and undercut bank habitats had much lower biotic index values. The biotic index value for the riffle habitat was 3.5, and the biotic index value for the undercut bank habitat was 4.3. The error bar shows the range where there could be errors in the data. Our confidence interval was 95%. We are 95% confident that our mean biotic index values would fall within the error bars.

Based on the biotic index scale shown in figure 6 the riffle habitat of the Savage River has an excellent water quality; however, the undercut bank habitat of the same river has a good water quality, the stagnant pool habitat at the Savage River only has fair water quality.

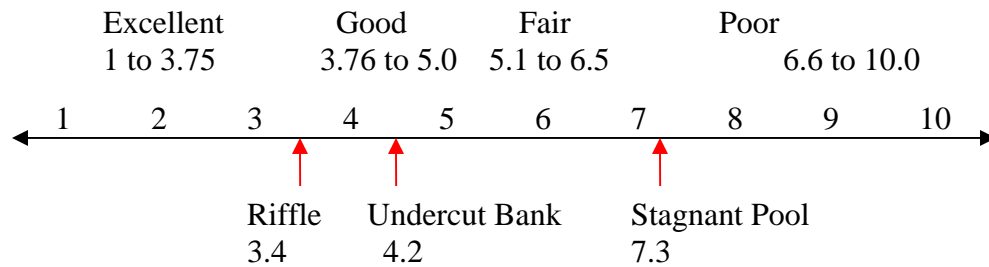


Figure 6. The biotic index values for the three habitats.

A t- test was used to compare macroinvertebrate average biotic index values for each habitat. The p- value shows the probability that the average biotic index values of the two habitats are the same. When we compared the average biotic index values of the riffle habitat and stagnant pool habitat we got a one-tailed p-value of  $2.36 \times 10^{-36}$  which is less than 5 percent. The 5% is stating the probability that the two habitats are the same. There is a 95% confidence level that the averages are significantly different. When we compared the stagnant pool and the undercut bank habitat, we received a one-tailed p-value of  $0.299 \times 10^{-17}$  which is less than 5 percent. There is a 95% confidence level that the averages are significantly different. When we compared the riffle habitat and the undercut bank habitat, we received a two tailed p-value of 0.009942, which is less than 5 percent. There is a 95% confidence level that the averages are significantly different.

## DISCUSSION AND CONCLUSION

Our null hypothesis is that there is no significant difference in average biotic index value for macroinvertebrates of the three different habitats. Our alternative hypothesis is that there is a significant difference in average biotic index value for macroinvertebrates of the three different habitats. The group rejected our null hypothesis because we found significantly different biotic index values for each of the three habitats. The alternative hypothesis was accepted because all three biotic index values for riffles, stagnant pools, and undercut banks, were significantly different based on the t-test.

The average biotic index value of 3.5 indicates water quality for the riffles was excellent. The average biotic index value of 7.3 indicates water quality for the stagnant pools was poor. The water qualities for these two habitats are on opposite ends of the Hilsenhoff spectrum. The biotic index values were significantly different because the macroinvertebrates have different tolerances to pollution and nutrient levels, and different dissolved oxygen needs. The pollution tolerance graph (Figure 4) shows that the riffles contained a lot of sensitive macroinvertebrates while the stagnant pools contained a lot of pollution tolerant macroinvertebrates.

In the figures one, two and three the group found many differences in the macroinvertebrate species found in each of the habitats. For example in the riffles, we found caddisflies, stoneflies, crane flies, mayflies and water pennies because they all have characteristics like suckers and gills that allow them to live in rough water. The suckers help the caddisflies and the water pennies to cling onto rocks while rough water runs overtop of them and can move around on the rocks and eat the algae off. These macroinvertebrates also need more dissolved oxygen to live which the riffles give them. The undercut banks, had caddisflies, mayflies, aquatic worms, water pennies, and hellgrammites. Some of the characteristics that

macroinvertebrates need to live in undercut banks are gills and shredders. Gills help the macroinvertebrates to breathe in the water. In the stagnant water, we found aquatic worms, midges, leeches, and blackflies. Some characteristics that macroinvertebrates have to live in stagnant water are filters, unique ways of obtaining oxygen, and tolerance to high nutrient levels. The filters absorb the detritus, which is broken down leaf material. Leeches and aquatic worms absorb dissolved oxygen through their skin. The lunged snails can get to the surface of the water and trap pockets of the air. These macroinvertebrates could have show up in the stagnant water habitat because they may have needed a certain amount of nutrients. Blackflies, for example, need nitrates and phosphates. The stagnant pools do not have much oxygen or as many rocks to attach to, so animals like the water penny would not be found here.

All of the chemical and temperature tests did not come out as expected but some did. The pH levels were about the same at each habitat. We expected that the stagnant pools would have more of an acidic pH while the undercut and riffles would have more of a neutral pH. The temperature and the nitrates surprised the group with similar results this is because the habitats are all in the same stream. Phosphate was highest in stagnant water because it had the most dead plants in the stagnant pools which the group expected. The dissolved oxygen came out exactly the way the group expected with the riffle having the most. This is because the white water was pulling in air and the algae on the rocks were under going photosynthesis and releasing dissolved oxygen (River Watch, 2001). The dissolved oxygen level was second in the undercut banks because the habitat has smooth and steady movement of water with nearby plants. The dissolved oxygen level was lowest in the stagnant pool because it has little to no water movement with many dead plants floating around. This supports our hypothesis because it states that the stagnant water has more pollution tolerant macroinvertebrates that need less dissolved oxygen and the

riffles have more sensitive macroinvertebrates which needs more dissolved oxygen. We conclude from this that the water quality in the stagnant is not as good as the riffles.

The purpose of our study was to compare macroinvertebrates found at three Savage River habitats: riffles, undercut and stagnant pool. The comparison of the macroinvertebrates helped us to determine the water quality of each habitat. Our group found mostly macroinvertebrates with a higher biotic index value in the stagnant pools, mostly macroinvertebrates with a lower biotic index value in the riffles, and a mix of macroinvertebrates with high and low biotic index values in the undercut banks. The biotic index scale ranges from one to ten; 1 to 3.75 indicates an excellent water quality; 3.76 to 5 is a good water quality; 5.1 to 6.5 is a fair water quality; and 6.6 to 10 is a poor water quality. The water quality affects where the macroinvertebrates live in the stream. If the macroinvertebrates have trouble surviving in their habitats, then there might be less prey for the fish, which could cut the supply of food for humans.

One limitation that our group had was time. If the group had more time, we would have had more habitats to test and to compare. Another limitation could be people earlier disturbing the area, by fishing in the stream. One more limitation that we had was that the dissolved oxygen meter broke on our first day on the site. So, we had to take the dissolved oxygen test five days later, when we were also collecting macroinvertebrates. The dissolved oxygen content may have changed between Wednesday and Monday because on Wednesday, the sun was barely shining and the temperature was cool but on Monday, it was hot and sunny. Photosynthesis is also important to this matter because it is one way for dissolved oxygen to enter the water. However, photosynthesis needs sunlight in order to complete its process. Since it was barely any sunlight on Wednesday, the dissolved oxygen level may have been lower. The heat on Monday may have raised the dissolved oxygen levels. The way we kicked the rocks could have also been a

limitation to our study. If we kicked longer and at the same amount of times, we could have retrieved more of a variety of macroinvertebrates to study. When we went out into in the field, every group kicked for sixty seconds, but some groups could have been kicking faster and more times than other groups. Even though our groups went in order of collecting macroinvertebrates, the habitats were very close and there were still other groups standing in the water. People were falling in the water and it may have disturbed the macroinvertebrates, which may have caused some to migrate into an unfamiliar habitat.

We can suggest some improvements to the study. One improvement would be to visit the Savage River on one day to collect macroinvertebrates and to do chemical testing. Perhaps if we would have gone to the site on one day, our group could see if chemical testing affected the macroinvertebrates. Another improvement for our group would be to visit sites with less human disturbances. If we would have visited a site with less human disturbances, we may have found more macroinvertebrates. We would also suggest back-up equipment in case equipment breaks. If we had another dissolved oxygen meter, chemical testing could have been performed all on the same day. Our group also could have had a specific number of times that we kicked the rocks in each group, instead of just kicking for sixty seconds. We could have also used more than one site. If we had gone to a undercut banks site that was separate from the stagnant water and the riffles, then when our group went to do chemical testing and to collect macroinvertebrates, we might not have caused some macroinvertebrates to move into a different habitat. Another improvement for our group would be to have one group in the water at a time, so that nobody's data is affected. One last improvement would be more testing days. If we did testing for more than two days we could have tested multiple habitats in the water.

Even though the results of our study were very clear to us, we have some future possible research questions. Are some parts of the Savage River more polluted than others? How do the macroinvertebrate populations of the Savage River change over the years? Do daily weather changes affect the macroinvertebrates that can be collected in a river? Would the number and types of macroinvertebrates found in other parts of a river (plunge pools and rapids) differ significantly from the data that was collected in riffles, undercut banks, and stagnant pools? How does photosynthesis increase or decrease the chemical test results in riffles, undercut banks, and stagnant water? Would the macroinvertebrates collected be different in different seasons? For example would the results be the same during the winter or the fall? How would macroinvertebrate abundance differ at another river or site (perhaps a river known to be severely polluted)? We feel that these questions would expand upon our research and provide interesting future studies. Clearly, the study of macroinvertebrates and water quality is helpful to scientists and other community members.

## REFERENCES

- Allan, D.A. (1995). *Stream Ecology*. Netherlands: Kluwer Academic Publishers.
- Clapham, W.B., & Kocher, R.C. *Benthic Macroinvertebrates Index*. Northeast Ohio Rivers Project. <http://rock.geo.csuohio.edu/norp/norp.htm>. Accessed 9 July 2007.
- Dodds, W.D. (2002). *Freshwater Ecology*. San Diego: Academic Press
- Faulds, A.F., Murray, C.M., Neville, K.N. Leaf Pack Experiments Stream Ecology Kit
- Fore, L.S. (1998). "Field Guide to Freshwater Invertebrates."  
<http://www.seanet.com/~leska/online/Guide.html>. Settle, WA. Accessed 9 July 2007.
- Fried, S.F., Mackie, B.M., Nothwehr, E.N. (2003). Nitrate and Phosphate levels positively affect the growth of algae species found in Perry Pond: Biology Department, Grinnell College
- Metzling, L., Chessman, B., Hardwick, R., and Wong, V. (2003) Cooperative Research Centre for Freshwater Ecology, 39-51.
- Molles, M.M. (2005). *Ecology Concepts and Applications*. New York: Margaret J. Kemp.
- National Park Service. (2006). "Stream Ecology". <http://nps.gov/> Accessed 19 June 2007
- Nutrients (Nitrates and Phosphates). (2003). Virginia department of Environmental quality
- Primbas, Angela. (2005). *Save Our Stream*. <http://www.saveourstream.org/> Accessed 30 July 2007.
- River Watch. (1999-2001). Beyond Books Institute of Alberta.  
<http://www.riverwatch.ab.ca/index.cfm> Accessed 19 June 2007.
- Walsh, C.W. (2006). Biological indicators of stream health using macroinvertebrate assemblage composition: a comparison of sensitivity to an urban gradient. *Marine and Freshwater Research*, 37-47.