Spring 2022

Logging Impacts on Aquatic Ecosystem Quality in Michaux State Forest, Pennsylvania

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Abstract

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Keywords

Michaux State Forest, freshwater invertebrates, water quality, coarse woody debris

Disciplines

Environmental Indicators and Impact Assessment | Environmental Studies | Water Resource Management

Comments

Written for ES 400: Environmental Studies Senior Seminar

Logging Impacts on Aquatic Ecosystem Quality in Michaux State Forest, Pennsylvania

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ES 400 Senior Seminar

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May 24, 2022

Honor Code

I affirm that I have upheld the highest principles of honesty and integrity in my academic work and have not witnessed a violation of the Honor Code. Sara Baran, Tim Bell, Erick Seager

Abstract

Logging can affect freshwater streams around logging sites, even years after the logging has occurred. In this study, we looked into how sustainable logging in Michaux State Forest (in Adams County, Pennsylvania) has affected two streams within the state park: Mountain Creek and Birch Run. Six sites were selected along each stream, with three upstream and three downstream from the logging area. We hypothesized that the water quality would be lower at the stream sites downstream from the logged areas as compared to the upstream sites. At each site, water samples were collected, including pH, water temperature, and turbidity, as were freshwater macroinvertebrates. Turbidity was low, indicating good stream quality at all sites, but pH was also low, indicating poor stream quality. Coarse woody debris (CWD) was examined at each site, as it can impact stream quality by creating extra particulate matter, but counts of CWD were low. Diversity of freshwater macroinvertebrates was relatively high, with most of the collected taxa showing good water quality, though a few indicated poor water quality. The Hilsenhoff Index and the EPT Index, both based on the presence or absence of specific macroinvertebrate taxa, indicated good water quality for all locations. This study determined that future research should be conducted on logging impacts on stream quality in Michaux State Forest, as there were several indicators that the stream waters could be low quality, even if the majority of the indicators showed good water quality.

Introduction

Logging, even sustainable logging, can cause long-lasting damages to the environment (Zimmerman & Kormos, 2012). Logging can affect the temperature, flow, primary production, amount of organic matter, and macroinvertebrate communities in streams (Stone & Wallace, 2002). Macroinvertebrates in particular provide insight into the health of aquatic ecosystems. Not only do they serve as grazers, breaking down organic material, and a food source to fish, but they are also indicators of the presence of pollutants in stream water, as different species vary greatly in their tolerance to different environmental changes (Hussain & Pandit, 2012). These sensitivities include an array of factors, such as water pH, temperature, and stream geomorphology (Hussain & Pandit, 2012).

It's difficult to predict how macroinvertebrates will react to logging. In a meta-analysis by Nislow and Lowe (2006), some studies resulted in decreased macroinvertebrate abundance due to the increased sedimentation and embeddedness in the streams. Others, however, found that logging resulted in increased macroinvertebrate biomass due to the greater light levels and nutrient availability in the streams. Most studies suggest that logging and the increase of organic and inorganic material negatively affect macroinvertebrate feeding habits, life cycles, dispersal, prevalence of eggs, and overall species richness in freshwater streams (Rajakallio et al., 2021).

One study found that there was still a drastic decrease in macroinvertebrate counts in streams that were by regenerated forest areas, or forests that did controlled burns to increase the speed of regeneration. This decrease was still seen 15 years after the initial logging (Davies et al., 2005). To combat this, Entrekin et al. (2009) recommends either replanting trees or not cutting trees near streams. They more strongly recommend not cutting by streams, because while the replanting of trees can help with stream biomass restoration, it can also take years for the effects to be seen.

The purpose of our study was to determine how logging, even sustainable logging, might interfere with the goals of conservation in state forests. We specifically focused on two streams in Michaux State Forest. Michaux State Forest is part of the Cumberland, Adams, and Franklin counties in south central Pennsylvania. The forest is composed of a wide variety of species of trees, including pine, maple, and oak species. It is at the northern point of the Blue Ridge Mountains (Pennsylvania Department of Conservation and Natural Resources, 2022). Michaux would be considered a level V protected area under the IUCN's definitions. It is used for many recreational activities such as camping, biking, hiking, and hunting/shooting. It is also used for logging, timber sales and protecting the quality of local water resources. These water quality protections are of specific interest, as they can be contradictory to the goals of sustainable logging and sales because of how logging can harm water quality (Pennsylvania Department of Conservation and Natural Resources, 2022).

The logging sites in this study were subjected to "shelterwood" and "removal/clearcut" logging. Shelterwood logging is defined by DCNR as "a partial cutting and removal of overstory trees." This method allows more sunlight to reach the forest floor, allowing seedlings to grow and flourish. Once enough seedlings have grown, a removal harvest will occur. A removal harvest is the logging of almost every overstory tree in an area. This method also allows for seedling growth and forest regeneration, but the retaining of some overstory trees can prevent erosion (DCNR). These processes are considered "sustainable" because they specifically allow for the regrowth of the logged areas after the process has been completed.

We used freshwater macroinvertebrate counts, water quality data, and downed woody debris data to assess how logging in this park is impacting streams. We hypothesized that the water quality would be lower at the stream sites downstream from the logged areas as compared to the upstream sites. Macroinvertebrates in freshwater streams vary greatly in their sensitivity to changes in their environment. For example, Ephemeroptera, or mayfly larvae, are an important prey animal for both vertebrates and macroinvertebrates in freshwater systems, and they are highly sensitive to changes in their environment, so their presences indicated high water quality (Cardoso et al., 2018). The order Diptera, on the other hand, is often an indicator of poor water quality.

We were also interested in how the abundance of woody debris affects the freshwater macroinvertebrates. Coarse woody debris can shape stream morphology; the deposits and retention of organic matter; create backwaters, eddies, and other new formats to the stream; and provide habitat for organisms of a variety of sizes (Roberts et al., 2021). This debris could benefit the freshwater macroinvertebrates if their habitat is somewhat restored by the coarse woody debris, but they could also be harmed by the changes to their natural habitat.

Methods

We selected our focal sites using the "Hunting in PA" website (Pennsylvania Department of Conservation and Natural Resources) and based off of the year logged and how close they were to a stream (Figure 1). The logged area around Birch Run stream was logged in 2007, and the logged area around Mountain Creek was logged between 2011-2018 according to the "Hunting in PA" website (Pennsylvania Department of Conservation and Natural Resources). During our visits, however, there were signs along the ATV trail saying logging was occurring in

2020, which is likely more accurate due to sightings of more recently felled trees. We created maps of the locations of selected sites using ArcMap version 10.8.1 (Figure 1). All research was conducted under research permit SFRA-2201.

We measured eight water quality parameters: pH, nitrates, dissolved oxygen, dissolved solids, temperature, depth, flow, and turbidity. For nitrate measurements, samples were taken of the stream water at each site, and we ran the final tests in the lab a few hours later with a LaMotte nitrate test kit. We measured water temperature and dissolved solids with a HM Digital COM 100 meter, air temperature with a thermometer, and pH with EMD Chemicals pH sampling strips. Turbidity, a measurement of how clear the water is based on the amount of sediments floating in the water, was measured with a turbidity tube (Utah State University Extension, 2016).

We also measured stream characteristics. We measured tree cover with a densiometer and recorded as "complete coverage, partial coverage, or none." Sediment type was determined through observation and noting the majority of the sediment in the stream. We also measured water flow, which is the volume of water that moves over a set point in a certain amount of time. Water flow is affected by water from the watershed entering the stream, but also by weather, seasonal changes, and withdrawal for industrial uses. It also impacts the types of organisms that can live within the streams (United States Environmental Protection Agency, 2012a). The collection of macroinvertebrates required a strong enough flow so that specimens could be swept into the sampler. Water flow was measured and calculated by guidelines by the United States Environmental Protection Agency. The stream flow equation is as follows:

$$Flow = \frac{A * L * C}{T}$$

where *A* stands for the mean cross-sectional area of the stream (where stream width multiplied by average water depth), *L* stands for the length of the stream measured (for this study, length was 20 feet), *T* stands for the time recorded of the float, and *C* stands for the correction factor, which allows for the correction that water on the surface of the stream moves faster than the water at the bottom, as the water at the bottom faces resistance from gravel, cobble, or any sediment at the bottom of the stream. This helps give a more accurate measure of the overall velocity (2012a). For this study, we used a correction factor of 0.8, which is the correction factor used by the EPA for rocky-bottomed streams.

To ensure accurate times, we selected a relatively straight portion of stream at each data collection site to measure water flow. We used a transect tape in order to measure a 6.1 meter stretch that was marked off every 1.5 meters using colored flags. We floated an orange down the stretch of stream, timing from its release at the beginning of the stretch to its recapture at the end (2012a).

We captured macroinvertebrates in a surber sampler by disturbing the stream bed in a 30 by 30-centimeter square for one minute. The specimens were then immediately preserved in jars of 91% ethanol for later identification in the lab. We identified the macroinvertebrates using a dissecting scope, and identification at the order level, and where possible, the family level, was determined through two taxonomic keys (NRM Education, 2011; University of Wisconsin, 2012). We performed chi-square tests on the macroinvertebrates taken from both streams using the statistical software R. In order to determine the water quality, we calculated the Hilsenhoff biotic index and EBT biotic index. The Hilsenhoff formula accounts for all taxa found:

$$\text{HBI} = \frac{\Sigma(n_i + a_i)}{N}$$

where *n* equals the number of individuals collected of taxa *i*, *a* is the pollution tolerance value of taxa *i*, and *N* is the total number of individuals collected. The EPT biotic index accounts for three indicator taxa, which are *Ephemeroptera*, *Plecoptera*, and *Trichoptera*. The equation for this biotic index is as follows:

$$\text{EPT} = \frac{e + p + t}{n}$$

Where *e* represents the total number of *Ephemeroptera* collected, *p* represents the total number of *Plecoptera* collected, *t* represents the total number of *Trichoptera* collected, and *n* represents the total number of individuals across all taxa collected.

Coarse woody debris (CWD) is defined by the USDA Forest Service as, "Dead pieces of wood including downed, dead tree and shrub boles, large limbs, and other woody pieces that are severed from their original source of growth or are leaning more than 45 degrees from vertical. For decay classes 1-4, CWD transect diameter must be > 3.0 inches (7.6cm), for decay class 5 the transect diameter must be > 5.0 inches (12.7 cm)" (2007). For the purposes of collecting only relevant data, only CWD that we located in the water were included in data collection. We examined each piece that could potentially be CWD to determine if they were connected to a larger, live body. The amount of coarse woody debris was counted at each site as well as the circumference and length of each piece.

Results

We collected the first round of data along Mountain Creek on Sunday, March 20, 2022. Data collection occurred the day after a thunderstorm, so this affected results, especially dissolved solids measurements (Appendix 1). The dissolved solid counts ranged from 58-59.4 ppm, with an average of 58.9 ppm (Figure 2). We collected the second round of data from the

Birch Run sites on Saturday, March 26, 2022 (Appendix 1). The dissolved solid counts ranged from 15.9-16.9 ppm with an average of 16.45 ppm (Figure 2). At both sites the turbidity was always greater than 60cm, which was converted to 8 NTU (Utah State University Extension 2016). There were essentially no nitrates found in the streams. Every sampling site had a pH of 4.5. At Mountain Creek, flow rate ranged from 0.3-0.6 m^3/sec ($p = 0.3$) (Appendix 1), and at Birch Run flow rate ranged from 0.6-2.1 m^3/sec ($p = 0.3$) (Appendix 1). There was not a significant difference between the upstream and downstream sites in either stream (Appendix 1).

In terms of macroinvertebrates, the streams seemed to be relatively healthy both upstream and downstream from the logging sites. Upstream from the logging site in Mountain Creek, we found eight Ephemeroptera nymphs, one Simuliidae larva, and one Plecoptera nymph with a Hilsenhoff Biotic Index of 4.0 and EPT Biotic Index of 75%. Downstream, we found seven Ephemeroptera nymphs, five Simuliidae larvae, and three Elmidae adults (Figure 3), a Hilsenhoff Index of 4.667 and an EPT Index of 46.667%. Upstream in Birch Run, we found two Plecoptera nymphs, one Trichoptera larva, four Ephemeroptera nymphs, and one Elmidae larva with a Hilsenhoff Index was 3.125 and the EPT Index was 87.5%. Downstream, we found four Diptera larvae, four Plecoptera nymphs, five Trichoptera larvae, and one Ephemeroptera nymph (Figure 4) with a Hilsenhoff Index of 3.357 and an EPT Index of 71.429%. There was no significant difference between the upstream and downstream macroinvertebrates found in either Mountain Creek, ($df = 4$, $N = 27$, $X^2 = 7.29$, $p = 0.121$) or Birch Run, ($df = 4$, $N = 22$, $X^2 = 9.18$, $p = 0.057$).

At Mountain Creek, we found three total pieces of CWD downstream and one piece upstream (Figure 5). The downstream debris had an average in-water length of 3.5 meters, with an average circumference of 39.8 cm. We found the upstream piece had an in-water length of

1.01 m, with a circumference of 49.5 cm. At Birch Run two pieces of CWD were found, both of which were found upstream. Of these pieces, one was unmeasurable due to the fact that it was partially sedimented into the ground and could not be accurately measured without removing it entirely. The other piece had an in-water length of 1.5 meters, with a circumference of 84 cm (Appendix 2). Despite also searching for debris in classes 1-4, all of the debris encountered that qualified for measurements ended up falling into class 5 at the upstream and downstream of both the Mountain Creek and Birch Run sites. Importantly, we found a significant number of downed materials hanging over the water that could not be counted as CWD. We did not run any significance tests for CWD due to the low sample size.

Discussion

Our results did not support our proposed hypothesis that the aquatic ecosystem quality would be lower downstream than it would be upstream. We instead found that water quality was relatively high regardless of location. However, our results yielded important and sometimes contradictory data regarding the overall stream quality at Michaux State Forest. Some of these results indicate degradation of aquatic ecosystem quality, while others indicate higher levels of ecosystem quality. Low quality indicators included the unexpectedly low pH levels and macroinvertebrate taxa that can show ecosystem degradation. High quality indicators included dissolved solid levels and macroinvertebrate taxa that show high ecosystem quality due to their low pollution tolerance levels.

Water Quality Parameters

The average amount of nitrates in surface waters at all locations at Michaux State Forests were less than 1 mg/L, indicating good water quality (United States Environmental Protection

Agency, 2012b). We anticipated that total dissolved solids counts would be higher around the Birch Run sites, as that site is more maintained and the sampling sites were very close to the Birch Run Road. Birch Run Road is a paved road that goes over the stream. Dissolved solid counts are higher after a rainstorm due to the runoff caused by the rain (United States Environmental Protection Agency, 2012c). However, the Mountain Creek sites had higher dissolved solids not only because of the recent rain, but also because an ATV trail made of gravel goes over and around the sites. The ATV trail was also used frequently while we were out doing data collection, so this moderate use of the trail could be kicking more sediments into the stream. At both sites, however, total dissolved solids were still in a healthy range, as they fell within the recommended range of 50-250 mg/L (LEO EnviroSci Inquiry, 2011).

Flow rate was calculated for every sampling location (Appendix 3). However, for an accurate analysis of water flow rate, the data should be compared to stream flow rate data over time, and there does not seem to be any openly published data on historic stream flow rate in Michaux State Forest. All of the turbidity measurements collected were greater than 60cm. Using the conversion table provided by the Utah State University Extension, this would convert to 8 NTU. This is an acceptable range for freshwater streams and is good for local wildlife (Utah State University Extension 2016).

Of the water quality measures examined, the only indication of low water quality was the pH, which was low at all sites. pH should range from 6.5-9 in freshwater streams. Low pH can decrease the overall biodiversity of the streams in Michaux State Forest (United States Environmental Protection Agency, 2022). The official Michaux State Forest website mentions that there is natural gas drilling that occurs within the state forest, along with spraying for gypsy moths (Pennsylvania Department of Conservation and Natural Resources, 2022). Acid mine drainage is another possible reason for low pH levels. Pennsylvania is historically one of the largest U.S. states for coal production, and the runoff from the coal mines is still affecting streams today (Lenahan, 2022). While it's not known if these activities occurred near the sampling locations, these are a few possible occurrences that, if anything runs off into the streams, could lower the pH.

Macroinvertebrates

The macroinvertebrate analysis suggested good water quality at each of the streams. While there were some differences between the upstream and downstream samples taken that could indicate lower stream quality downstream, our sample sizes were not large enough to reach any conclusions. In Mountain Creek, high counts of *Ephemeroptera* both upstream and downstream indicate low levels of pollutants. The high number of *Simuliidae* larvae could indicate some degradation of the stream, as they are capable of tolerating water pollutants to some extent (Docile et al., 2015). A similar instance of higher counts of Diptera larvae is seen in the taxa collected downstream from the Birch Run logging site, but they were collected alongside a great number of *Plecoptera* and *Trichopter*a, which are indicators of good water quality. In fact, the large EPT ratio found in both the downstream and upstream data in Birch Run relative to Mountain Creek could indicate increased management of the surrounding area, which was anecdotally noted during our visits to these sites. Overall, the calculated biotic indices suggest that the sustainable logging practices laid out by the Pennsylvania DCNR State Forest Resource Management Plan, which requires a variety of logging regulations and restrictions to be obeyed within state forests (2016), are helping to maintain stream ecosystem health. Buffer management, in particular, is responsible for protecting water quality from logging activity within state forests (Pennsylvania Department of Conservation and Natural Resources, 2016).

Studies on the impact of logging on benthic macroinvertebrates are contradictory, suggesting that logging impacts are context-specific and depend on habitat type and management practices. For example, in a case study carried out in Borneo, Indonesia, macroinvertebrate species richness, evenness, and diversity, as well as the EPT ratio were all significantly lower in streams after logging activity has occurred (Derleth, 2003). On the other hand, there are some studies which have found that logging has actually increased benthic macroinvertebrate indices. For example, the case study by Nislow and Lowe (2006) in New Hampshire, U.S., found that increased light penetration and nutrient availability leads to increased autotroph growth, which, in turn, increases primary macroinvertebrate consumers and their predators. They concluded that logging impacts on macroinvertebrate communities varies by region, which seems to be plausible, based on contradictory results of different studies (Nislow & Lowe, 2006).

The idea that the macroinvertebrate communities of different streams react variably to logging was tested in a study by Medhurst et al. (2010), in which they observed several streams in the eastern Washington Cascade region, each with differing conditions. In this study, it was concluded that each biogeographical region's headwaters had different responses to logging, with some responding negatively, while others responded positively, and others yet showing minimal to no response at all in some parameters (Medhurst et al., 2020). The heightened levels of management that land and streams in Michaux State Forest receive may be buffering communities at this location from the adverse impacts of logging.

CWD Discussion

CWD has been shown to provide positive increases in ecosystem respiration rates, as well as gross primary production (Roberts et al., 2021). Alongside helping to shape rivers and streams, CWD is also vital to these ecosystems because it deposits organic matter into streams by decomposition and can be used as habitats by algae and more (Roberts et al., 2021). Previous research suggests that CWD is positively and significantly correlated with taxon richness indices, but is not significantly correlated with the total abundance of macroinvertebrates or Shannon diversity indexes (Arnaiz et al., 2011). The collected results do not seem to indicate that logging has any significant impact on the presence or absence of CWD. However, it is important to note that these results were only a snapshot occurring after logging took place and only include CWD that were present in the streams themselves; it did not include any of the downed trees and sticks outside of the stream. It is important to note that Arnaiz et al. (2011) followed different definitions of CWD than we did. Although they still only measured in-stream CWD, it is possible that if we had followed methods similar to theirs that we may have had more data to process.

Limitations

The water sampling tests for dissolved oxygen and nitrates had to be cut from the final results due to invalid results. The dissolved oxygen test kits, as well as the nitrate test kits, were found to have expired chemicals that were providing results that were seemingly either far too high or far too low.

Further, limited sample sizes could have impacted macroinvertebrate findings. More samples could be taken for more accurate biotic index calculations. More specific identification than order and family could be used for more accurate pollution tolerance, as well. Some species of Diptera, for example, are much more sensitive to pollutants, while others are more tolerant (Lock et al., 2014).

It should be noted that the data collected from Mountain Creek occurred the day after a rainstorm, which affects the nitrate, dissolved solids, and macroinvertebrate counts.

Macroinvertebrate abundance, richness, and diversity have all been shown to decrease after periods of rain, due to increased stream flow rates (Theodoropoulos et al., 2017). Flow increases of even moderate proportions were shown to have drastic impacts on benthic macroinvertebrate communities.

Conclusions and Future Recommendations

According to the Pennsylvania Department of Conservation and Natural Resources page on Michaux State Forest, the Bureau of Forestry manages Pennsylvania's state forests for "their long-term health and productivity while conserving native wild plants. These forests are managed as 'working forests' and provide a suite of uses and values to Pennsylvania citizens, while maintaining the forest's wild character" (2022). These forests are also managed for "pure water, recreation, scenic beauty, plant and animal habitat, sustainable timber and natural gas, and many other uses and values" (Pennsylvania Department of Conservation and Natural Resources, 2022). This study has found conflicting results about the well-being of the state forest's streams, which could conflict with the DCNR and Bureau of Forestry's management of the state forest. Most of the results, such as low turbidity and a wide variety of freshwater macroinvertebrates with low tolerance to pollution, indicated good quality streams. However, there were also several concerning results about the stream quality, such as the low pH and several species indicative of poor water quality. Given our low sample size, however, further monitoring of these streams is recommended. Taking samples from the same streams in different seasons will yield more comprehensive results and give a more holistic indication of the impacts of logging. We recommend that Michaux uses a before-and-after study design to best compare the stream quality over time. Based on our limited results, we suggest that Michaux State Forest continue their management efforts to reduce the impacts of logging, as they seem to be buffering the park's streams' negative impacts.

Author Contributions

All three authors worked on all aspects of the paper. Sara worked on the water quality parameters, Tim worked on the coarse woody debris data, and Erick worked with the freshwater macroinvertebrate data.

Acknowledgements

Thanks to Tom Stahl and John Schwartzer from the PA Department of Conservation and Natural Resources in Michaux State Forest for your guidance on this project.

Thank you to Dr. Peter Fong from the biology department at Gettysburg College for providing us information and equipment for benthic macroinvertebrate collection.

Thanks to the environmental studies department at Gettysburg College for your help and support with this project, especially Dr. Monica Ogra and Dr. Rud Platt.

Thanks to Lisa Rynkiewicz from the Gettysburg College environmental studies department for getting us gas money refunds and ordering new testing kits.

And a special thanks to Dr. Natasha Gownaris, as she was so supportive throughout this whole project!

Works Cited

Arnaiz, O. L., Wilson, A. L., Watts, R. J., & Stevens, M. M. (2011). Influence of riparian condition on aquatic macroinvertebrate communities in an agricultural catchment in south-eastern australia. Ecological Research, 26(1), 123-131. http://dx.doi.org/10.1007/s11284-010-0767-2

Cardoso, M., Calvão, L., de Assis Montag, L., Godoy, B., and Juen, L. (2018). Reducing the deleterious effects of logging on Ephemeroptera communities through reduced impact management. *Hydrobiologia 823*(1): 191-203.

Davies, P., Cook, L., McIntosh, P., and Munks, S. (2005). Changes in stream biota along a gradient of logging disturbance, 15 years after logging at Ben Nevis, Tasmania. *Forest Ecology and Management 219*(2-3), 132-148.

DCNR. Description of Timber Harvests. https://maps.dcnr.pa.gov/bof/huntmap/pdfs/TimberHarvestDesc.pdf

Derleth, P. (2003). *Benthic macroinvertebrates and logging activities: a case study in a lowland tropical forest in East Kalimantan (Borneo, Indonesia)* (Publication No. 2836) [Doctoral dissertation, University of Lausanne]. ResearchGate.

Docile, T. N., Figueiró, R., Gil-Azevedo, L. H., Nessimian, J. L. (2015). Water pollution and distribution of the black fly (Diptera: Simuliidae) in the Atlantic Forest, Brazil. *Revista de biologia tropical*, *63*(3), 683-693.

Entrekin, S., Tank, J., Rosi-Marshall, E., Hoellein, T., Lamberti, G. (2009). Response of secondary production by macroinvertebrates to large wood addition in three Michigan streams. *Freshwater Biology 54*(8), 1741-1758.

Hussain, Q. A. and Pandit, A. K. (2012). Macroinvertebrates in streams: A review of some ecological factors. *International Journal of Fisheries and Aquaculture 4*(7), 114-123.

IUCN. Category V: Protected Landscape/Seascape. https://www.iucn.org/theme/protected-areas/about/protected-areas-categories/category-v-protected-landscapeseascape Accessed 3 May 2022.

Lenahan, G. (2022). Acid mine drainage facilities - reversing hundreds of years of pollution to bring Pennsylvania's streams and rivers back to life. https://www.dep.pa.gov/OurCommonWealth/Pages/Article.aspx?post=92 Accessed 24 May 2022.

Leo EnviroSci Inquiry. (2011). Total Dissolved Solids. https://ei.lehigh.edu/envirosci/watershed/wq/wqbackground/tdsbg.html Accessed 3 May 2022.

Lock, K., Adriaens, T., Goethals, P. (2014). Effect of water quality on blackflies (Diptera: Simuliidae) in Flanders (Belgium). *Limnologica 44*, 58-65.

Medhurst, R. B., Wipfli, M. S., Binckley, C., Polivka, K., Salter, R. B. (2010). Headwater streams and forest management: Does ecoregional context influence logging effects on benthic communities? *Hydrobiologia 641*, 71-83.

Nislow, K., and Lowe, W. (2006). Influences of logging history and riparian forest characteristics on macroinvertebrates and brook trout (*Salvelinus fontinalis*) in headwater streams (New Hampshire, USA.) *Freshwater Biology 51*(2): 388-397.

NRM Education. (2011). Aquatic macroinvertebrate identification key. *Government of South Australia*.

Pennsylvania Department of Conservation and Natural Resources. *Hunting in PA.* https://maps.dcnr.pa.gov/bof/huntmap/index.html Accessed 7 April 2022.

Pennsylvania Department of Conservation and Natural Resources. (2022). *Michaux State Forest.* https://www.dcnr.pa.gov/StateForests/FindAForest/Michaux/pages/default.aspx Accessed 12 April 2022.

Rajakallio, M., Jyväsjärvi, J., Muokotka, T., and Aroviita, J. (2021). Blue consequences of the green bioeconomy: clear-cutting intensifies the harmful impacts of land drainage on stream invertebrate diversity. *Journal of Applied Ecology 58*(7): 1523-1532.

Roberts, B., Griffiths, N., Houser, J., and Mulholland. (2021). Response of stream metabolism to coarse woody debris additions along a catchment disturbance gradient. *Ecosystems*. https://doi.org/10.1007/s10021-021-00687-9

Stone, M. and Wallace, J.B. (2002). Long-term recovery of a mountain stream from clear-cut logging: the effects of forest succession on benthic invertebrate community structure. *Freshwater Biology 39*(1): 151-169.

Theodoropoulos, C., Vourka, A., Stamou, A., Rutschmann, P., and Skoulikidis, N. (2017). Response of freshwater macroinvertebrates to rainfall-induced high flows: A hydroecological approach. *Ecological Indicators 73*: 432-442.

United States Environmental Protection Agency. 2012. 5.1 Stream flow. https://archive.epa.gov/water/archive/web/html/vms51.html Accessed 7 April 2022.

United States Environmental Protection Agency. 2012. 5.7 Nitrates. https://archive.epa.gov/water/archive/web/html/vms57.html#:~:text=Nitrates%20are%20essential%20plant%20nutrients,that%20live%20in%20the%20stream Accessed 6 April 2022.

United States Environmental Protection Agency. 2012. 5.8 Total Solids. https://archive.epa.gov/water/archive/web/html/vms58.html#:~:text=Total%20solids%20are%20dissolved%20solids,(0.002%20cm)%20in%20size Accessed 7 April 2022.

United States Environmental Protection Agency. 2022. pH. https://www.epa.gov/caddisvol2/ph#:~:text=It%20is%20one%20of%20the,range%20of%206.5%20to%209 Accessed 6 April 2022.

USDA. 2004. 2.0 Phase 3 Field Guide – Down Woody Materials. 2004 https://www.nrs.fs.fed.us/fia/topics/dwm/documents/dwm-field-manual-2004.pdf

USDA. 2007. Down Woody Materials. https://www.nrs.fs.fed.us/fia/topics/dwm/glossary/ Accessed 30 March 2022.

Utah State University Extension. 2016. Turbidity Tube Conversion Chart. https://extension.usu.edu/utahwaterwatch/monitoring/field-instructions/turbidity/turbiditytube/turbiditytubeconversionchart Accessed 7 April 2022.

University of Wisconsin. 2012. Key to Macroinvertebrate Life in the River. *Wisconsin Department of Natural Resources*.

Zimmerman, B. and Kormos, C. (2012). Prospects for Sustainable Logging in Tropical Forests. *BioScience 62*(5): 479-487.

Appendix

Appendix 1. A summary of most of the data collected around Mountain Creek and Birch Run. Included are air and water temperatures, stream depth, pH, tree cover, stream bed sediment composition, dissolved solids (DS), and nitrates. Nitrates were cut from future analysis due to faulty chemicals.

Site	Air Temp (C)	Water Temp (C)	Water Depth (in)	pH	Amount of Tree Cover	Sediment type	DS	Nitrates (ppm)
Mountain Creek								
DS 1	6	8.7	7.5	4.5	Partial	Rock/sand	58	0
DS 2	6	8.7	7	4.5	Partial	Sand/rock	59	0
DS 3	6	8.7	4	4.5	Partial	Sand/rock	59.4	0
US 1	6	9.1	8.5	4.5	Partial	Rock/sand	59.0	0.44
US 2	6	9.2	3	4.5	None	Rock/sand	59.1	0
US 3	7	9.3	5	4.5	Partial	Sand/rock	59.2	0
						Average:	58.95	
Birch Run								
DS 1	4	7.6	20	4.5	None	Rocky/Sandy	15.9	0
DS 2	5	7.9	13	4.5	None	Rocky/Sandy	16.4	0
DS 3	5	7.9	17.5	4.5	Partial	Rocky	16.3	0
US 1	5	7.5	12	4.5	Full	Rocky	16.9	0
US 2	6	7.9	13	4.5	Full	Rocky	16.6	0
US 3	7	7.6	28	4.5	Full	Rocky	16.6	0
						Average:	16.45	

Appendix 2. A summary of Coarse Woody Debris (CWD) found within Mountain Creek and Birch Run. Measurements were included where possible, but there was often no CWD on site or it was unmeasurable due to being submerged in stream sediment.

Site	CWD Amount	Length 1 (m)	Circumference 1 (cm)	Length 2 (m)	Circumference 2 (cm)
Mountain Creek					
DS 1	2	6.65	49	1.3	38
DS 2	1	2.55	32.5		
DS 3	0				
US 1	1	1.01	49.5		
US 2	0				
US 3	0				
Birch Run					
DS 1	0				
DS 2	0				
DS 3	0				
US 1	1	Unmeasurable			
US 2	1	1.5	84		
US 3	0				

Appendix 3. A summary of the parameters calculated for the Mountain Creek and Birch Run flow rates. Average area calculations included the stream width multiplied by average water depth.

Water Flow Calculations	Time (sec)	Average Area	Flow Rate (m^3/sec)
Mountain Creek			
DS 1	12.4	1.1	0.4
DS 2	20.7	1.6	0.4
DS 3	8.5	1.0	0.6
US 1	20.2	1.3	0.3
US 2	11.2	0.8	0.4
US 3	11.3	1.2	0.5
Birch Run			
DS 1	22.4	4.7	1.0
DS 2	11.1	1.4	0.6
DS 3	15.0	2.2	0.7
US 1	10.8	1.5	0.7
US 2	16.3	1.9	0.6
US 3	17.9	7.7	2.1

Figures

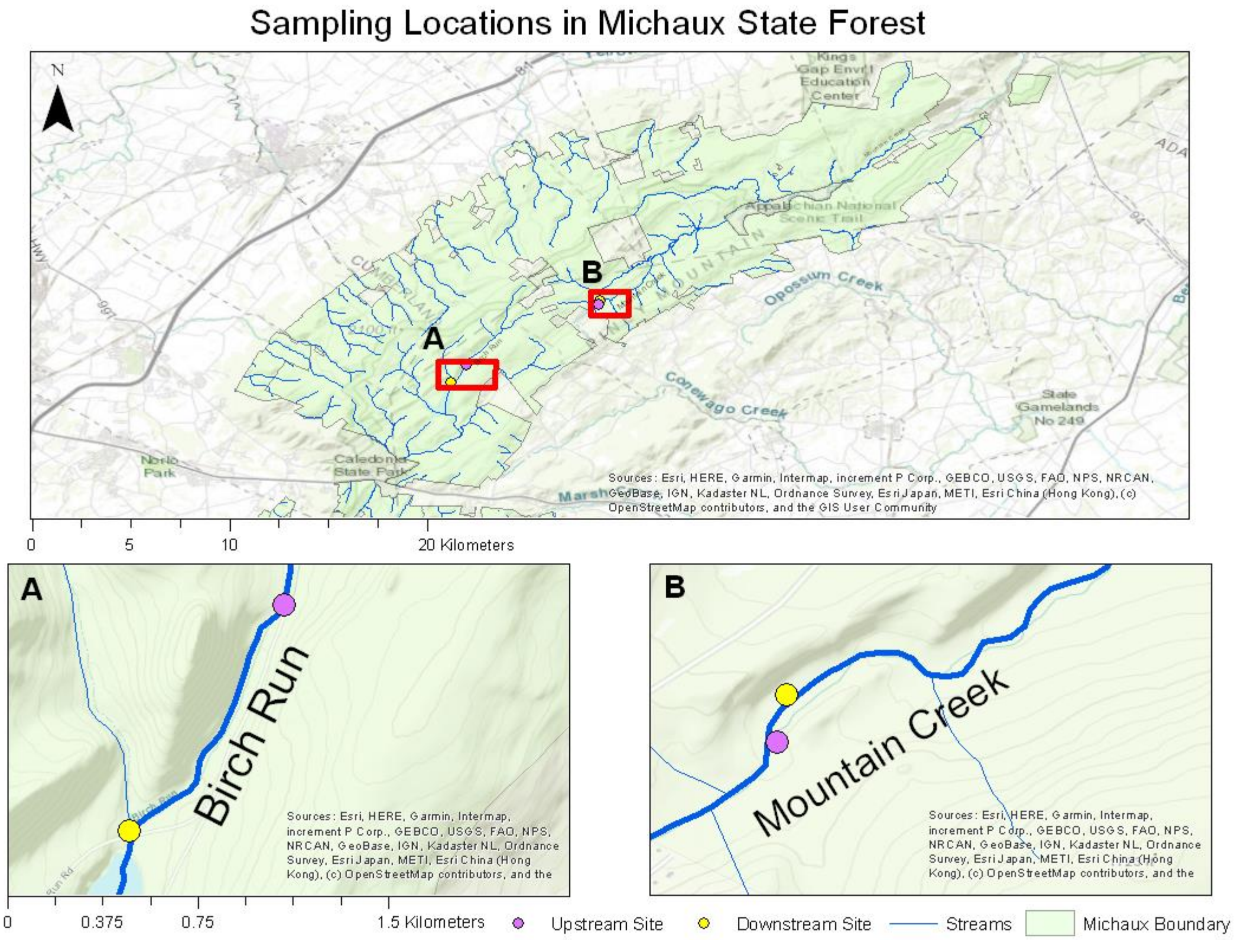

Figure 1. A map of the Mountain Creek and Birch Run sites with reference to Caledonia State Park and the upper portion of Michaux State Forest. The upstream (purple) point of Birch Run is at 39.95872N, -77.43709W, while the downstream (yellow) point is at 39.95073N, -77.44426W. The upstream (yellow) point of Mountain Creek is at 39.98631N, -77.37686W, while the downstream (purple) point is at 39.9878N, -77.37659W. The designated sites included are general areas and do not include all three sites that samples were taken from.

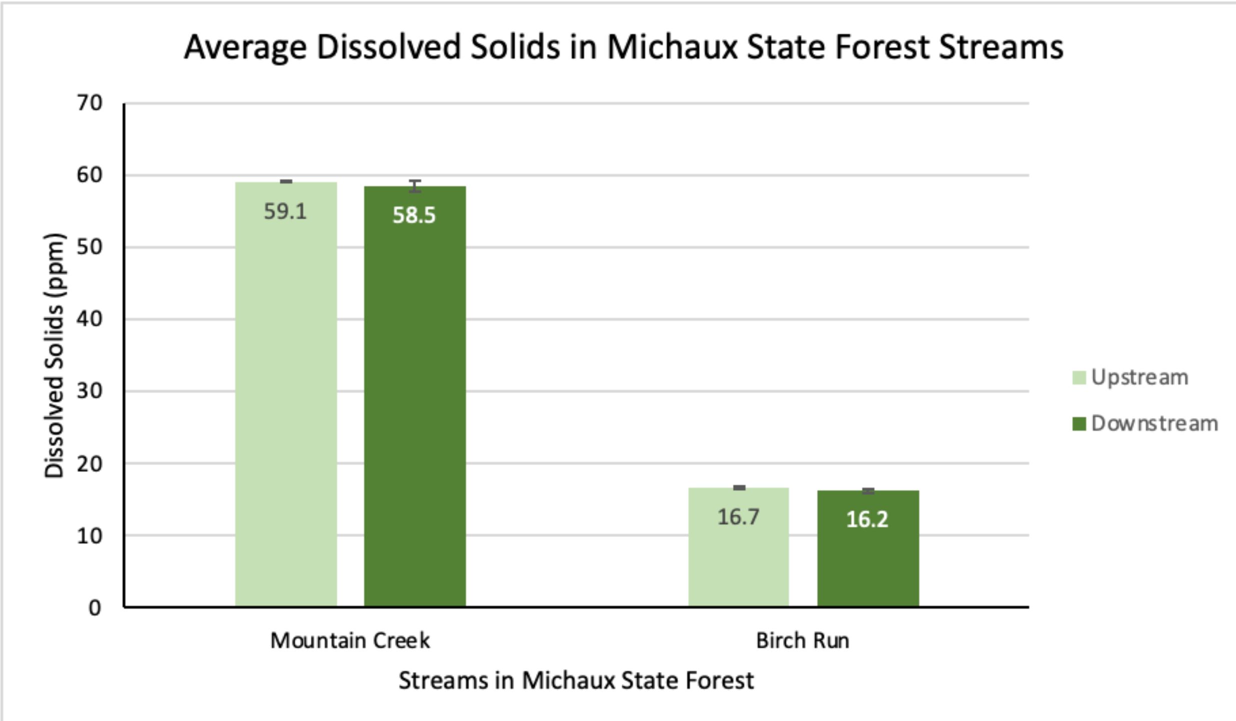

Figure 2. Averaged dissolved solids values collected upstream and downstream at both Mountain Creek and Birch Run. T-tests were run on these data, with neither being significant (both results were $p = 0.3$).

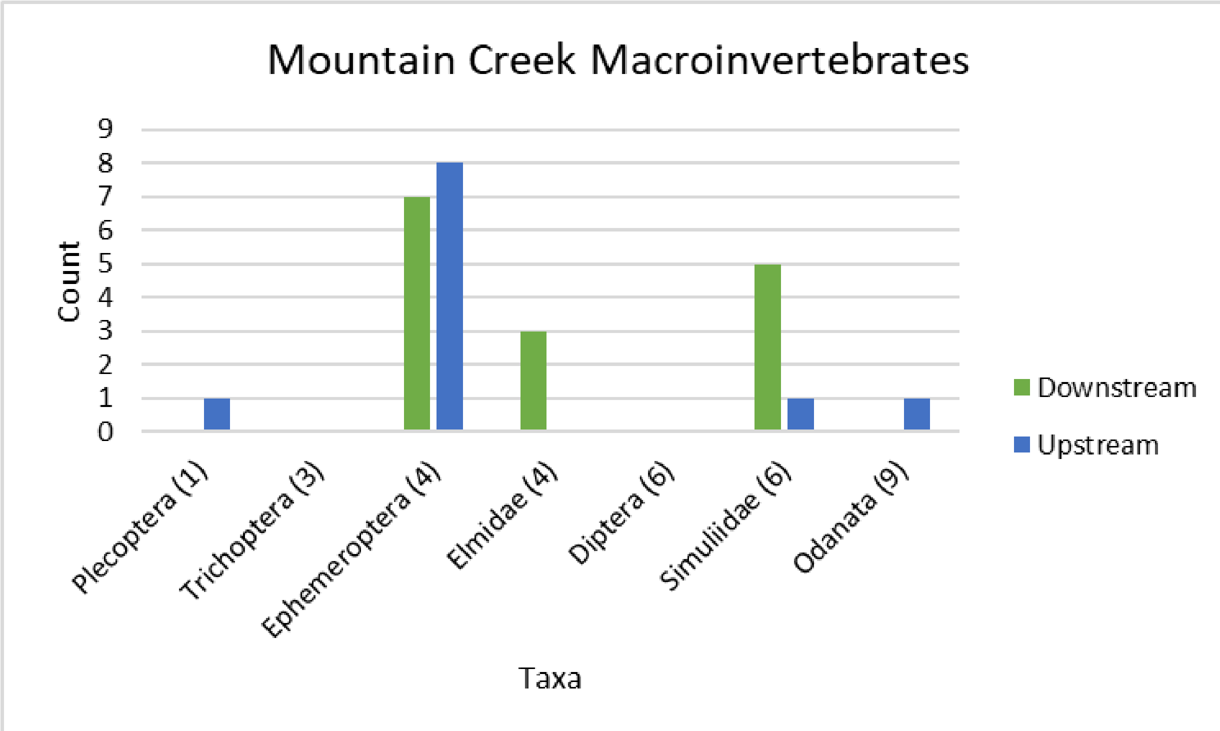

Figure 3. Counts of macroinvertebrates found at the Mountain Creek sites. Taxa are organized from least tolerant to most tolerant of pollution, with the tolerance level used in calculations included in parenthesis next to the taxonomic name. Significance could not be tested due to low sample size.

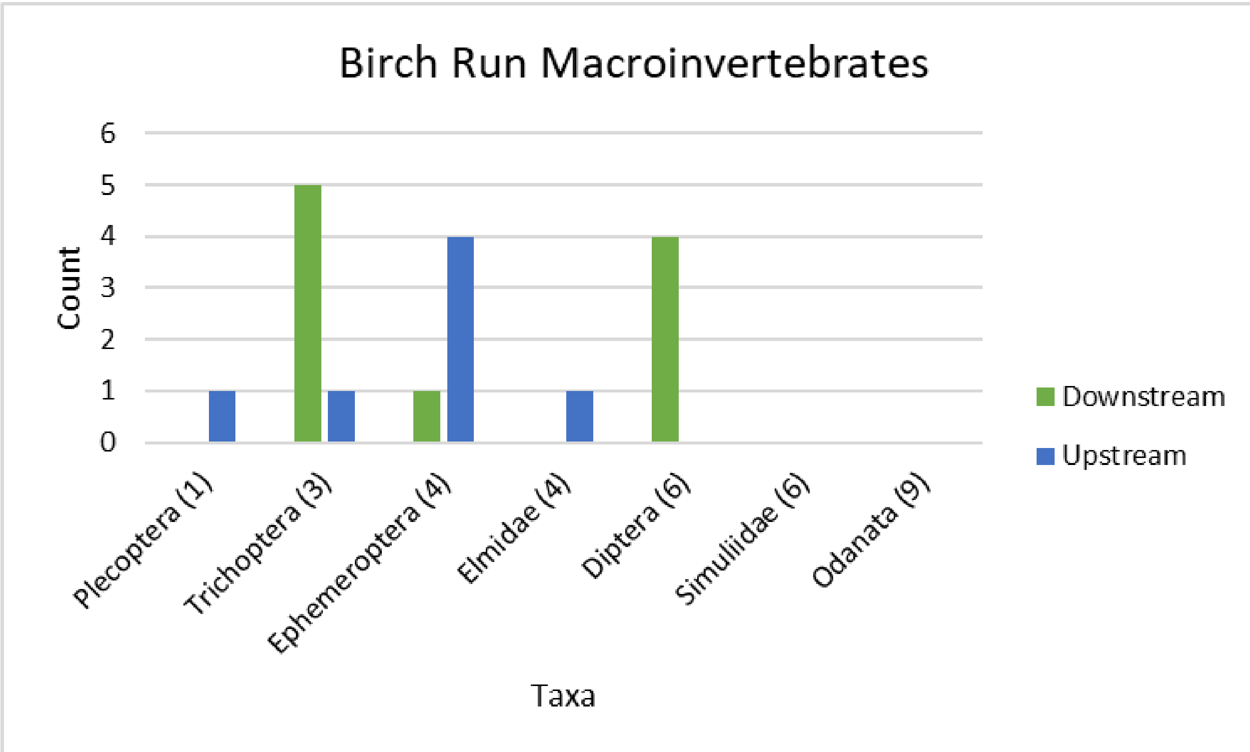

Figure 4. Counts of macroinvertebrates found at Birch Run. Taxa are organized from least tolerant to most tolerant of pollution, with the tolerance level used in calculations included in parenthesis next to the taxonomic name. Significance could not be tested due to low sample size.

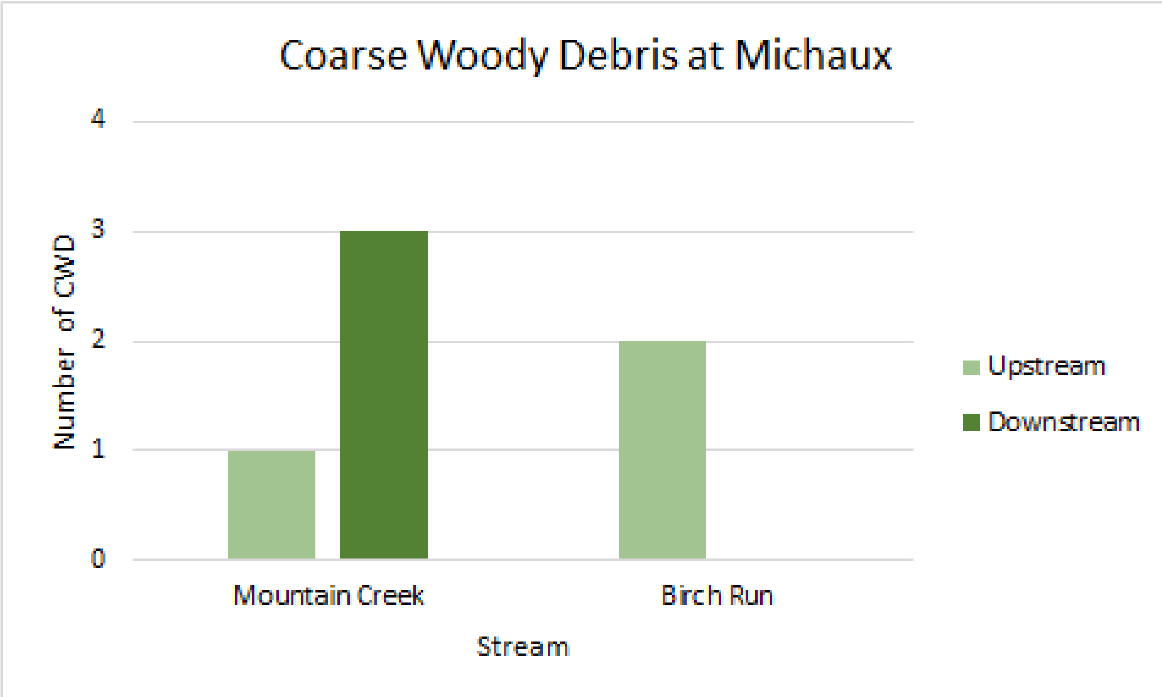

Figure 5. Number of pieces of coarse woody debris (CWD) found at both Mountain Creek and Birch Run. No significance testing could be performed due to the low sample size.