Abstract

Aquatic macroinvertebrates are a group of organisms that play an essential role in stream ecosystems by cycling organic matter and serving as a primary food source for many fish species. Climate change-

Introduction

Climate Change

Anthropogenic climate change is affecting every organism and ecosystem on Earth. Increased carbon dioxide and other greenhouse gas emissions are resulting in an increasing average global temperature, which in turn produces rising sea levels, increased precipitation, melting ice caps, and even loss of habitats, biodiversity, and resources. New York State, which has a humid continental climate, has been affected with the average annual temperature increasing by 1.3°C across the state and 2.4°C increase in winter since 1970 (New York State Department of Environmental Conservation [DEC], 2015). This increase is higher than the 2°C cap the United Nations Framework Conference on Climate Change (UNFCCC) has set in an effort to slow and prevent further global warming. Increased air temperatures have led to increased precipitation, as warmer air can hold more moisture. The northeastern United States has also seen an increase in heavy precipitation events of about 70% (DEC, 2015). Shorter intense precipitation increases the possibility of flooding as the absorption rate is exceeded leading to more runoff. This can lead to higher water temperatures and an increase in available nutrients.

Various global climate models have predicted different air temperatures for the rest of the 21^{st} century, based on different emissions scenarios and years. The Fourth National Climate Assessment predicts a low emissions and high emissions scenario for mid-century (2036-2065) and late-century (2071-2100). For the Northeast United States, air temperature mid-century will rise 3.98°F and 5.09°F under the low and high emissions scenarios respectively. For the late-century, air temperatures will rise 5.27°F and 9.11°F under each scenario respectively (USGCRP, 2017). The Union of Concerned Scientists predicts that in the Northeast summer air temperatures will increase by 3°–7°F and winter air temperatures will increase by 5°–8°F. However, under the high emissions scenario, air temperatures will rise 8°–12°F in the winter and 6°–14° in the summer (Frumhoff et. al, 2007).

Freshwater Systems

Freshwater systems globally will be drastically affected by climate change, especially those near urban areas, where runoff is increased. According to the CAC, “lakes, streams, inland wetlands, and associated aquatic species will be highly vulnerable to changes in timing, supply, and intensity of rainfall and snowmelt, groundwater recharge, and duration of ice cover... [Increasing] water temperatures will negatively affect brook trout and other native coldwater fish” (Rosenzweig et al., 2011). As they are so greatly affected by changing temperatures, these ecosystems can also act as indicators for wider-spread climate change effects (Woodward et al., 2010). Freshwater ecosystems provide many services, including recreation locations, aesthetic generally occupy different microhabitats along the stream (headwaters, midreaches, river outlet) based on resource availability, a phenomenon called the River Continuum Concept (RCC) (Vannote et al., 1980). Aquatic macroinvertebrates, in conjunction with microbes, are communities' resiliency (Marshall & Wallace, 2002). That being said, temperature is a main influencing factor on the life cycles and metabolisms of aquatic insects (Sweeney et al., 1992, 1995). Long-term studies on macroinvertebrate population dynamics in Western Europe, the Mediterranean, and Sweden have shown that rising stream temperatures may have an impact on aquatic insect communities, with cold-adapted macroinvertebrate species being disproportionately affected (Burgmer et al., 2007; Hering et al., 2009; Kroll et al., 2017). In the future, these insect communities could experience a loss in biodiversity, i.e. a loss in resiliency to other environmental fluctuations, and consequently, would be susceptible to population decline (Burgmer et al., 2007). Cuffney et al. artificially lowered the population of an aquatic macroinvertebrate community at the headwaters of a North Carolina stream and found marked increase in the amount of CPOM and decrease in the amount of FPOM in the system, essentially loading the stream with unprocessed organic matter. Aquatic macroinvertebrate population decline, and subsequent nutrient loading in the aquatic system, could lead to eutrophication of standing water bodies downstream. Additionally, macroinvertebrate population decline would create a trophic gap between primary producers (terrestrial and aquatic plants, algae) and fish species, leading to a decline in fish populations.

Previous studies investigating the impacts of increasing stream temperature on aquatic organisms have focused on the summer months, when maximum stream temn ma BT 50 0.2 (pe)1m, wid energetically costly and may have long term consequences for these species, including decreased survivorship and reproductive success (Weber et al., 2013). There has been little to no research conducted on the impacts of winter stream temperature increase on aquatic macroinvertebrate communities. Although global climate models (GCMs) can predict shifts in environmental parameters and how they affect individual species, “our understanding of climate change impacts diminishes as projections are scaled up... to ecosystem function and services” (Climate Action Plan Interim Report, 2010). The goal of this study is to assess the impacts of climate-driven temperature change in winter on aquatic macroinvertebrate communities in New York State, and how potential shifts in macroinvertebrate community structure will impact stream ecosystem function.

Methods

Study Areas

Kayaderosseras

For our study, we focused on two main regions for obtaining macroinvertebrates, the first being the Kayaderosseras and the associated Hudson River Watershed. According to a study conducted in 1964 on the geology and hydrology of this region, “the quality of the water in ...Kayaderosseras Creek ...is satisfactory for public supply and most industrial purposes” (Mack et al., 1964). Previously serving as the primary hunting place for Mohawk Native Americans, the Kayaderosseras watershed is now a quickly developing area. From 2001 to 2010 this area experienced a 15.2% net increase of developed area and a 16.18% net increase in impervious surface area (C-Cap, 2018). Transitioning to an urbanized area resulted in overexploitation of

impervious surface area (C-Cap, 2018). According to the New York Department of Environmental Conservation (DEC), the water quality in Greenwich was not impacted by pollution, as observed through a study of macroinvertebrates. Samples were taken from this region in 1984, 1986, 1987, 1993, and 1999, and it was noted that no change was observed from previous years to 1992. However, declined water quality was observed in the Battenkill in surrounding sections, such as in Center Falls and Clarks Mill. This was attributed to a nonpoint pollution source (Department of Environmental Conservation, 2002).

Popular recreation on the Battenkill includes camping, canoeing, kayaking and fly-fishing. We hope to be able to project climate change effects in this area to determine the impacts upon not only the environment, but the public as well. It is likely that these such activities will be hindered with increased water temperature, eutrophication, and overall depleted water quality in the region.

Temperature Data

Using historical climate data from the closest station at Albany, the average temperature for January 15th to March 15th from 2001 to 2017 was calculated. This average air temperature was 26.7°F (National Oceanic and Atmospheric Administration [NOAA], 2017).

Air temperature and water temperature data from 1998 and 1999 from July to October for the Kayaderosseras and the Battenkill were obtained from a stream temperature database, which is part of the Spatial Hydro-Ecological Decision System (SHEDS) (Letcher et al., 2015). Regression equations showing the relationship between air temperature and water temperature were calculated from the data at the DEC Battenkill Station 36 and the DEC Kayaderosseras Station 74. The average water temperature at the Battenkill was 18.76°C with a standard deviation of 2.08. The average water temperature at the Kayaderosseras was 18.75°C with a standard deviation of 3. Therefore because the average water temperature for both rivers was very similar, only the Kayaderosseras equation ($y = 0.7075x + 4.8812$) was used to calculate the baseline water temperature used in the experiment. The R^2 value for the equation was 0.82, indicating that water temperature can be predicted from an air temperature input with 82% confidence. The average air temperature from the historical Albany climate data was converted to Celsius and input into the Kayaderosseras equation to get 2.79°C or 37°F. 37°F was used as the baseline water temperature for the time of collecting aquatic macroinvertebrates for the experiment.

Macroinvertebrate Collection

We selected 4 total sites for sampling - one at each of the headwaters of the Kayaderosseras (Glowegee Creek) and the Battenkill (White Creek), and one on each of the mainstems. The DEC conducts biomonitoring to determine the health and water quality of the

Figure 1. Lab setup

Samples selected for preservation were passed through a sieve to remove excess water. Once at the lowest water levels possible, 3L jars were filled with quantities of 95% ethanol necessary to achieve an 85% ethanol concentration for preservation of organisms.

At the end of a two week period, experimental samples were transferred to collection jars

Shannon’s Diversity Index

Shannon’s diversity index (Figure 2) was chosen to calculate biodiversity for each sample. This diversity index accounts for species richness, or the total number of species in the sample, and equitability, or evenness of total number of individuals spread among each species (Tramer, 1969). As macroinvertebrates were only identified to the family level, the index accounts for family richness and equitability.

Figure 2. Shannon’s diveristy index equation

Results

Diversity

Biodiversity at the Kayaderosseras headwaters site decreased from 2.4 in the historical sample to 1.7 in the present sample, with a slight decrease from the present sample to 1.6 in the experimental sample (Figure 4, Appendix B). At the mainstem of the Kayaderosseras, biodiversity greatly decreased from 4.3 in the historical sample to 2.4 in both the present and experimental samples (Figure 4, Appendix B).

At the Battenkill headwaters site, biodiversity increased from 1.88 in the historical sample to 2.15 i

Figure 6: Family composition of Kayaderosseras samples. (a): Headwaters Historical, (b): Headwaters Present, (c): Headwaters Experimental, (d): Mainstem Historical, (e): Mainstem Present, (f): Mainstem Experimental. Families are color coded by Order. Blue: Trichoptera (caddisflies), Red: Plecoptera (stoneflies), Green: Ephemeroptera

Figure 7: Family composition of Battenkill samples. (a): Headwaters Historical, (b): Headwaters Present, (c): Headwaters Experimental, (d): Mainstem Historical, (e): Mainstem Present, (f): Mainstem Experimental. Families are color coded by Order. Blue: Trichoptera (caddisflies), Red: Plecoptera (stoneflies), Green: Ephemeroptera (mayflies), Orange: Diptera (true flies), Purple: Coleoptera (beetles), Teal: Megaloptera (alderflies, dobsonflies and fishflies).

Discussion

Diversity Index

Our study found substantial differences in Shannon's diversity index values between historical and present and historical and experimental samples in the Kayaderosseras. At the headwaters site, diversity greatly decreased from historical to present and experimental. At the mainstem site, diversity decreased slight from historical to present and experimental. On average, the Kayaderosseras mainstem site had higher diversity than the headwaters site. This finding is consistent with the RCC's assertion that macroinvertebrate biodiversity increases downstream as more functional feeding groups are present (Vannote et al., 1980). Despite the fact that winter macroinvertebrate composition can be slightly different to summer composition (especially if eggs or larvae are diapausing and therefore more difficult to sample), our Kayaderosseras index values still showed a significant drop after removing the winter and early spring-emergent families from the present and experimental samples (Houghton & Shoup, 2014; Chadd, 2010). The Battenkill sites had minimal differences in index values across historical, present, and experimental values. Our finding that macroinvertebrate diversity remained relatively constant across present and experimental samples for both sites indicates that these communities are resilient to short term temperature increase. However, the substantial difference in diversity between historical and present and historical and experimental samples for both Kayaderosseras sites suggests that another factor is negatively impacting macroinvertebrate communities in this river system.

Community Composition: Kayaderosseras

At the Kayaderosseras headwaters site, a significant difference in community

(Thorp & Covich, 2010). The majority of larvae emerge in summer months (Thorp & Covich, 2010). *Isonychiidae*, previously part of the *Oligoneuriidae* family, are identified by the setae on their forearms (Thorp & Covich, 2001). A study by S

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Trichoptera

With over 1,400 species in North America alone, caddisflies are a diverse order and their presence in streams and lakes is known to indicate good water quality (Rogowski & Stewart, 2016; Thorp & Covich, 2010). However within the order, various species have various tolerances to different pollutants and different levels of pollution (Thorp & Covich, 2010). Studies have shown that Trichoptera morality increases when exposed to warmer temperatures (Rogowski & Stewart, 2016). *Hydropsychidae*, easily identifiable by their branched filamentous gills on the ventral side of their abdomen, are net-spinning caddisflies. With about 150 species in North America, there is a wide variety in tolerance levels of pollution (Thorp & Covich, 2010). However, their overall sensitivity to organic pollution and eutrophication has warranted the creation of a *Hydropsychidae* Index, which has been used in a few studies (Ratia et al., 2011).

Headwaters

Hydropsychidae are the primary family behind the significant difference in community composition between the historical sample and both the present and experimental samples. As the significant difference is not between the present and experimental samples, it is likely this caddisfly family is more affected by other pollutants, rather than temperature. The absence of *Simuliidae* in the historical sample, its appearance in the present sample, and its absence again in the experimental sample is a significant difference in community composition at the Battenkill headwaters. We hypothesize the *Simuliidae* in our samples are likely those that emerge in colder temperatures in winter, because they disappear in the experimental sample. The absence of *Simuliidae* in the historical sample could indicate that the *Simuliidae* found at this site are mostly winter emergent.

Mainstem

Simuliidae are also the primary family behind the significant difference in community composition at the mainstem of the Battenkill. As with those found at the headwaters site, we hypothesize the *Simuliidae* at the mainstem are likely those adapted to colder temperatures and emerge in colder seasons.

Impacts on Stream Ecosystem

Aquatic macroinvertebrates are a group of organisms essential to stream ecosystems because they cycle organic matter and serve as a primary food source for many fish species (Sweeney et al., 1992; Marshall & Wallace, 2002). Our research indicates that further increases in winter stream temperature may disproportionately affect cool-adapted, winter/early spring emergent organisms belonging to the families *Taeniopterygidae*, *Nemouridae*, and *Simuliidae*. A loss of these families may have a negative impact on organic matter cycling in stream ecosystems. This is particularly relevant for the two stonefly families *Taeniopterygidae* and *Nemouridae*, since they belong to the shredder functional feeding group (Webster, 1996). Although there is redundancy in functional feeding groups along the RCC, shredders typically only occupy the headwaters of a river, and they perform the first step in breaking down organic matter so that other functional feeding groups can access it (Vannote et al.,1980). Consequently, a loss of these shredding aquatic insects may have a rippling impact on the entire organic matter processing chain, particularly during the winter, when these organisms are consuming increased levels of organic matter in preparation for emergence (Sweeney et al., 1986; Tyufekchieva et al., 2013). The loss of *Simuliidae* may also have a negative impact on organic matter cycling, though this impact may not be as pronounced since the family belongs to the filter feeder/gatherer functional feeding group, which is more widespread throughout the river continuum, and has greater redundancy than the shredder functional feeding group (Vannote et al., 1980).

In addition to negatively impacting organic matter cycling, a loss of *Taeniopterygidae*, *Nemouridae*, and *Simuliidae* may also negatively impact fish populations. These winter and early spring-was so low. Since climate change is expected increase winter temperature fluctuations, future studies should also investigate the impact of stream temperature fluxuations on aquatic macroinvertebrate communities. Additionally, there is considerable variation in temperature tolerances of species within any given family, so identifying insects to the species level would improve the accuracy of this study. The comparison of present to historical family composition data was limited by the fact the historical data was collected in summer months, while our present data was collected in the winter. Future studies could also collect macroinvertebrate samples in the summer so that this comparison is more accurate, and to look at summer climate change effects on aquatic macroinvertebrate communities and stream ecosystems

References

Hering, D., Schmidt-Kloiber, A., Murphy, J., Lucke, S., Zamora-Munoz, C., Lopez-Rodriguez, M., Huber, T. & Graf, W. (2009). Potential impact of climate change on aquatic insects: A sensitivity analysis for European caddisflies (Trichoptera) based on distribution patterns and ecological preferences. *Aquatic Science*, *74,* 3-14.

Horn, H. S. (1966). Measurement of "Overlap" in Comparative Ecological Studies. *The American Naturalist, 100* (914), 419-424.

Houghton, D., & Shoup, L. (2014). Seasonal changes in the critical thermal maxima of four species of aquatic insects (Ephemeroptera, Trichoptera). *Environmental Entomology, 43.*

Hughes, G. & Roberts, J. (1970). A Study of the Effect of Temperature Changes on the Respiratory Pumps of the Rainbow Trout. *The Journal of Experimental Biology, 52,* 177-192.

Hurst, T. (2007). Causes and consequences of winter mortality in fishes. *Journal of Fish Biology, 71,* 315-345.

Kroll, S.A., Ringler, N.H., de la Cruz Can Costa, M. & De las Heras Ibanez, J. (2017). Macroinvertebrates on the front lines: projected community response to temperature and precipitation changes in Mediterranean streams. *Journal of Freshwater Ecology*.

Lessard, J. & Hayes, D. (2003). Effects of Elevated Water Temperature on Fish and Macroinvertebrate Communities Below Small Dams. *River Research and Applications,* (in press).

Letcher, B. L., Walker, J. D., Coombs, J., Hocking, D., Kanno, Y., Childress, E., ... Rosm., Hat q : Qq 0.24 0

Letcher, B. L., Walker, J. D., Coombs, J., Hocking, D., Kanno, Y., Childress, E., ... Rosner, A. (2015). *Stream Temperature Database, NY_DEC_Kayaderosseras Creek_74*. Retrieved from http://db.ecosheds.org/viewer.

Liu, J., et al. (2015) Towards Threshold-Based Management of Freshwater Ecosystems in the Context of Climate Change. *Ecological Monitoring, 318*, 265-274.

Mack, Frederick, K., Pauszek, F & Crippen, J. (1964). *Geology and hydrology of the west Milton area, Saratoga County, New York*. No. 1747. US Govt. Print.

Marshall, E. & Wallace, J. (2002). Invertebrate food webs along a stream resource gradient. *Freshwater Biology, 47*, 129-141.

Merritt, R.W., & Cummins, K. W. (Eds.). (1984). *An Introduction to the Aquatic Insects of North America*

National Oceanic and Atmospheric Administration, Office for Coastal Management. (2018). *New York's Washington County 2001 to 2010*.Coastal Change Analysis Program (C-CAP) Regional Land Cover. Charleston, SC: NOAA Office for Coastal Management. Retrieved from www.coast.noaa.gov/ccapftp.

New York State Climate Action Council. (2010). *Climate Action Plan Interim Report*.

New York State Department of Environmental Conservation. (n.d.a) *Biomonitoring.* Retrieved from https://www.dec.ny.gov/chemical/23847.html.

New York State Department of Environmental Conservation. (n.d.b). *Trout.* Retrieved from https://www.dec.ny.gov/animals/7016.html.

New York State Department of Environmental Conservation. (2002). *30 Year Trends in Water Quality of Rivers and Streams in New York State - Basin 11 - Upper Hudson.* Retrieved from https://www.dec.ny.gov/docs/water_pdf/sbu30yrintro.pdf

New York State Department of Environmental Conservation. (2014). *Climate Projections in the Hudson River Estuary*. Retrieved from https://www.dec.ny.gov/docs/remediation_hudson_pdf/cphv.pdf

Ratia, H., Vuori, K., & Oikari, A. (2011). Caddis larvae (Trichoptera, Hydropsychidae) indicate delaying recovery of a watercourse polluted by pulp and paper industry. *Ecological Indicators, 15.*

Rogowski, D. L., & Stewart, K. R. (2016). Effects of increased temperature on a Trichoptera (Hydropsychidae) from premontane forest streams in Southern Costa Rica.

Assessment for Effective Climate Change Adaptation. Technical Report. New York State Energy Research and Development Authority (NYSERDA), Albany, New York. Retrieved from www.nyserda.ny.gov.

Sweeney, B. W. (1978). Bioenergetic and Developmental Response of a Mayfly to Thermal Variation. *Limnology and Oceanography*. *23 (3)*. 461-477.

Sweeney, B.W., Jackson, J.K., Newbold, J.D. & Funk, D.H. (1991). Climate change and the life histories and biogeography of aquatic insects in eastern North America. In Firth, P., Fisher, S.G. (eds) *Global Climate Change and Freshwater Ecosystems,* New York, New York, Springer.

USGCRP, 2017: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 470 pp., doi: 10.7930/J0J964J6.

Appendix A

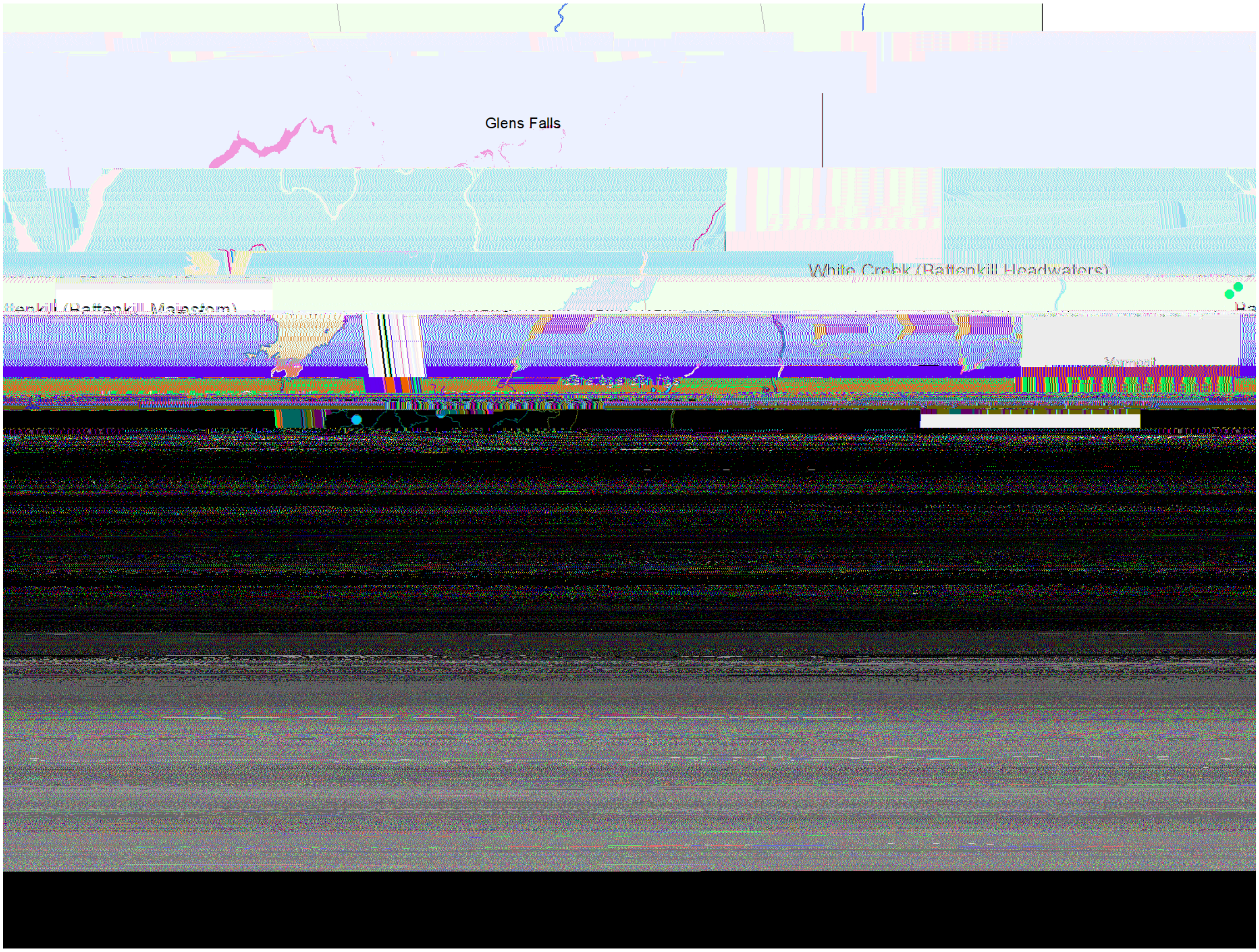

Figure 1A. Locations of Aquatic Macroinvertebrate Sampling

Appendix C

Table 1C. Morisita's modified index of similarity for families and sites with biologically significant differences in community composition across all three samples

Site	Samples (Order)	Morisita's Index
Kayaderosseras Mainstem	Present/Experimental (Plecoptera)	0.263
Kayaderosseras Mainstem	Historical/Experimental (Plecoptera)	0.519
Battenkill Headwaters	Present/Experimental (Diptera)	0.399
Battenkill Headwaters	Historical/Present (Diptera)	0.157
Battenkill Mainstem	Present/Experimental (Diptera)	0.247