The Impacts of Climate Change in Winter on Aquatic Macroinvertebrates

Skidmore College
Environmental Science Capstone 2018
Ben Curell, Angelea McPartlin, and Maurah Steinmetz

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-induced stream temperature increase may have a greater impact on aquatic organisms during the winter, since this is generally a period of greater susceptibility to temperature changes, particularly for cold-adapted organisms. This study investigates the impact of winter stream temperature increase on aquatic macroinvertebrate communities. Macroinvertebrate samples were collected from headwaters and mainstem sites at the Kayaderosseras and Battenkill rivers in February and March 2018. Experimental samples underwent a two-week temperature trial simulating winter stream temperatures in a late-century high emissions scenario. Overall diversity and family composition were compared across historical, present, and experimental samples at each site, using Shannon's diversity index and Morisita's modified index of similarity. Our findings indicate that organisms belonging to the families *Taeniopterygidae*, *Nemouridae*, and *Simuliidae* will be disproportionately impacted, likely because these families contain many cold-adapted, winter and early spring-emergent species. The loss of these families may have a negative impact on organic matter cycling and reduce the amount of food available to fish species in the winter.

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 21st 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 beauty, climate regulation and carbon storage, drinking water sources, waste disposal, nutrient cycling, and industrial uses (Liu et al., 2015). Only 3% of Earth's water is freshwater, and yet provides habitats for about 6% of all species (Woodward et al., 2010). Furthermore, less than 1% of the total freshwater is surface water found in rivers, streams, and lakes (United States Geological Survey, 2016).

Role of Aquatic Macroinvertebrate in Freshwater Ecosystems

Aquatic macroinvertebrates serve an integral role in stream ecosystem function. A macroinvertebrate community is composed of several functional groups: grazers, shredders, filter-feeders, gatherers, and predators (Wallace & Webster, 1996). These functional groups 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 responsible for processing organic matter in the stream system, primarily in the form of leaf detritus (Marshall & Wallace, 2002). Shredders, which typically dominate the headwater macroinvertebrate community, convert leaf detritus from coarse particulate organic matter (CPOM) in sedimentary storage to fine particulate organic matter (FPOM), which is carried downstream and further processed by filter-feeders and microbes (Wallace and Webster, 1996; Covich et al.,1999). Additionally, grazers convert algae and macrophyte biomass into FPOM, which is sent downstream for further processing.

Aquatic macroinvertebrates are also vitally important to stream ecosystem function because they serve as a trophic link between the detrital and algal food base and fish (Brittain, 1982; Sweeney et al., 1992). Aquatic insects represent a significant portion of the diets of running-water fish (Wallace & Webster, 1996; Grey et al., 1997). *Salvelinus fontinalis* (Brook trout) and *Salmo Trutta* (Brown trout), two economically-significant game fish species in New York State, rely heavily on aquatic macroinvertebrates as a food source, particularly as juveniles (DEC, n.d.a).

Since each functional group contains a broad range of macroinvertebrate taxa, it is difficult to categorize any one macroinvertebrate as a keystone species (Wallace & Webster, 1996). The redundancy of functional roles in the processing of stream organic matter makes the aquatic macroinvertebrate community somewhat resilient to ecological change. Additionally, studies have shown that macroinvertebrates can switch between functional groups based on resource availability and their location along the stream continua, further adding to the 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 temperature occurs (Hughes & Roberts, 1970; Lessard & Hayes, 2003; Chadwick & McCormick, 2017). More recently, studies have looked at the impact of winter stream temperature increase on cold-adapted fish species (Hurst, 2007; Weber et al., 2013). Cold-adapted fish typically operate on a lowered metabolism during the winter, and an increase in stream temperature during this timeframe causes their metabolism to increase. This temperature-driven metabolic increase is 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 resources such as water, trees and soils, and many other harmful effects. The construction of roads not only increased the movement of humans into the area, but also introduced materials into the environment that affected the chemical composition of soils and water (Taff & DeCoste, n.d.). Increased impervious surfaces, such as pavement and roads, increases runoff. Increased runoff results in increased eutrophication, sedimentation and salinity of the water. All together, these anthropogenic components and climate change are contributing to increased temperatures observed in the Kayaderosseras.

In terms of locality, the Kayaderosseras is popular for flat-water paddling, and fly-fishing. While little has been done in terms of studying the impact on macroinvertebrates, there has been a notable impact upon trout populations. Fishing specifically contributes greatly to the activity of the area - approximately 7,000 individuals of various trout (rainbow and brown included) are stocked yearly to enhance recreational fishing. With an open season year round, fishing is central to the recreation held at Kayaderosseras. Trout are a cold water fish that are sensitive to water temperature changes (Dunning et al., 2015). The impact of climate change upon water temperature alone is enough to greatly impact activity in this region. The addition of eutrophication, depleted water quality, and decline of the environment as a whole do more to threaten life in the Kayaderosseras.

Battenkill

Our second area of study is the Battenkill River. Stretching 59 miles long, the Battenkill courses from East Dorset, Vermont to the Hudson River (Battenkill Alliance, 2003). The associated watershed covers 407 square miles. The town of Greenwich, the focus area of the Battenkill for our study, is found in Washington County. From 2001 to 3020, Washington County experienced a 2.29% net increase in developed area and a 3.35% net increase in 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 state's rivers (DEC, n.d.b). These sites were selected because they were locations where historical macroinvertebrate data was available from the DEC (Appendix A).

Sampling was conducted at the two Kayaderosseras sites on Sunday, February 4th, 2018. We first went to the Kayaderosseras Headwaters site at Glowegee Creek, where we selected an area with cobble substrate and riffles. At each selected stretch, we conducted 9, 20-second D-frame kick net samples to gather our experimental sample that we would be keeping in the lab. In between each kick, nets were cleared of organisms into collection buckets to ensure that all captured organisms were contained (Environmental Protection Agency, 2012). At the completion of 9 kicks, the contents of the bucket were transferred to a covered bucket for transport. Nine additional 20-second kicks were conducted using the same methods to gather our present sample for the location. Upon completion of this collection, excess water was drained from the sample, and captured organisms and remaining water were transferred to 3L jars for transport. This same protocol was followed for sampling at the mainstem site of the Kayaderosseras.

Sampling was conducted at the two Battenkill sites on Saturday, March 3rd, 2018. A stretch of stream of comparable width to the headwaters and mainstem of the Kayaderosseras was selected, with similar cobbly substrate and riffles. The same protocol was followed.

Temperature Experiment

Upon returning to the lab, experimental samples were immediately transferred to 5 gal aquaria. Leaf litter and rocks collected from the sites were introduced to the aquaria for shelter and food sources. Aerator stones were used to aerate the environment. Screens were laid over each tank in order to collect any insects that may have emerged during our experiment. Overhead lamps provided a 12 hour light/dark cycle. The aquaria were set in a large tub filled with water 43-44°F. While 37°F was the baseline temperature, 43-44°F was the lowest temperature the chiller would allow. A submersible pump was used to keep the water circulating and ensuring even temperature distribution (Figure 1). The macroinvertebrates were allowed to acclimate for three days before the temperature was raised to 49°F.

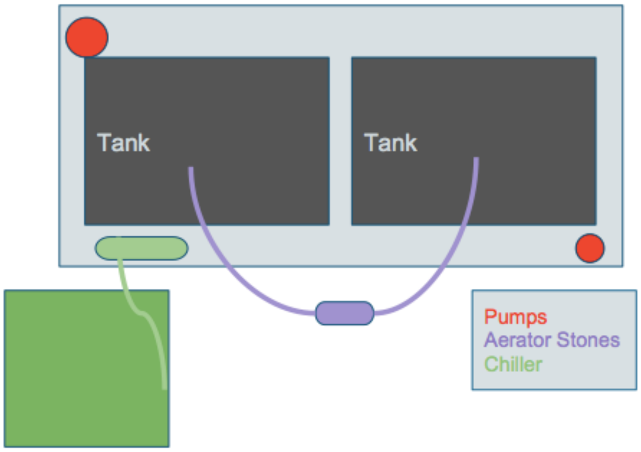

Figure 1. Lab setup

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 for preservation. Water was drained and sieved through into a bucket while organisms and sediment were put into a 3L jar and combined with 95% ethanol to achieve an 85% concentration.

We selected specimen for identification by pouring the contents of preserved jars onto a flat sheet pan with a 10-by-10 inch grid in the center (Hayslip & Gretchen, 2007). We began in a particular square, collecting all of the individuals within that square before moving on to the next square. This process was continued until around 100 individuals were collected from each sample. The second and third editions of *An Introduction to the Aquatic Insects of North America* were used to identify insects to the family level (Merritt & Cummins, 1984, 1995).

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.

$$\text{Shannon Index (H)} = - \sum_{i=1}^{s} p_i \ln p_i$$

Figure 2. Shannon's diveristy index equation

Morisita's Index of Similarity

A modified version of Morisita's index of similarity (Figure 4) was used to identify significant differences in insect community composition. Morisita's index ranges from 0 to 1, with 0 being no biologically significant overlap between samples and 1 being complete biologically significant overlap between samples (Horn, 1966). Anything below 0.6 is a biologically significant lack of overlap, thus indicating a significant difference in samples, or community composition.

$$C_H = \frac{2\sum_{i=1}^{S} x_i y_i}{\left(\frac{\sum_{i=1}^{S} x_i^2}{X^2} + \frac{\sum_{i=1}^{S} y_i^2}{Y^2}\right) XY}$$

Figure 3. The modified equation of Morisita's index of simmilarity

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 in the present sample, before decreasing slightly to 2.13 in the experimental sample (Figure 5, Appendix B). At the mainstem of the Battenkill, biodiversity increased slightly from 1.95 in the historical sample to 1.97 in the present sample, before increasing again to 2.14 in the experimental sample (Figure 5, Appendix B).

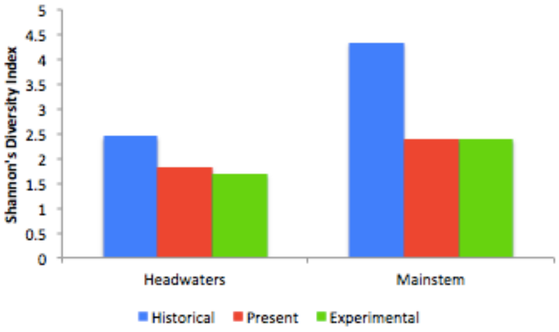

Figure 4. Shannon's diversity index for the Kayaderosseras

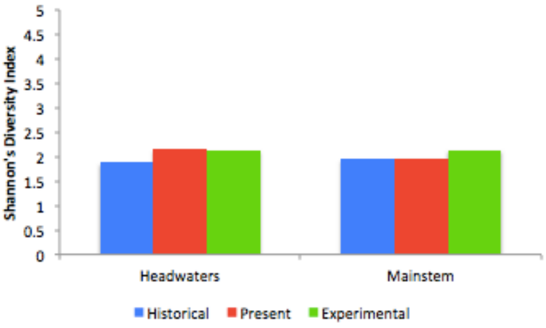

Figure 5. Shannon's diversity index for the Battenkill

Family Composition

A modified version of Morisita's index of similarity was used to identify significant changes in community composition across historical, present, and experimental samples for each site. Comparisons were made on the order level. For the Kayaderosseras headwaters site, there were no significant differences in family composition between present and experimental samples (Figures 6b, 6c). However, there was a significant difference between historical and present and historical and experimental samples for the orders Ephemeroptera and Diptera (Figures 6a, 6b, 6c, Appendix C). For Ephemeroptera, the difference across samples was mainly due to changes in the abundance of *Heptageniidae* and *Isonychiidae.* For Diptera, the difference across samples was mainly due to changes in abundance of *Chironomidae.* For the Kayaderosseras mainstem site, the order Plecoptera was significantly different across historical, present and experimental samples (Figures 6d, 6e, 6f, Appendix C). This was mainly due to changes in the abundance of *Taeniopterygidae* and *Nemouridae*.

For the Battenkill headwaters site, the order Diptera was significantly different across historical, present and experimental samples (Figures 7a, 7b, 7c, Appendix C). This was mainly due to changes in the abundance of *Simuliidae.* For the Battenkill mainstem site, the order Diptera was also significantly different across historical, present and experimental samples (Figures 7d, 7e, 7f, Appendix C). This was also mainly due to changes in the abundance of *Simuliidae.*

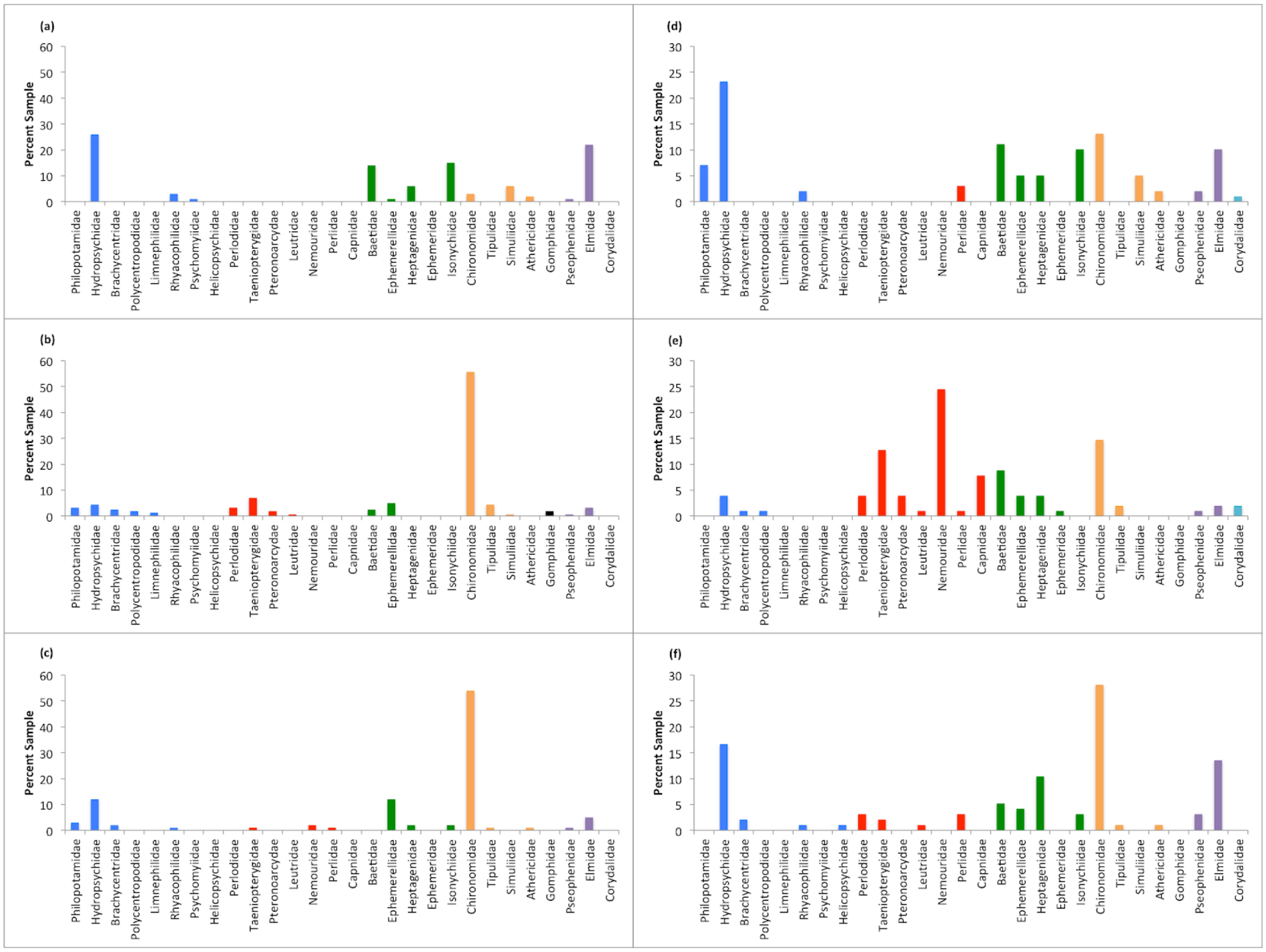

Figure 6: Family composition of Kayaderosseras samples. (a): Headwaters Historical, (b): Headwaters Present, (c): Headwaters Experimental, (d): Mainstem Historical, (e): Mainstem Present, (f): Mainstem Experimental. Families are color coded by Order. Blue: Trichoptera (caddisflies), Red: Plecoptera (stoneflies), Green: Ephemeroptera (mayflies), Orange: Diptera (true flies), Black: Odonata (dragonflies and damselflies), Purple: Coleoptera (beetles), Teal: Megaloptera (alderflies, dobsonflies and fishflies).

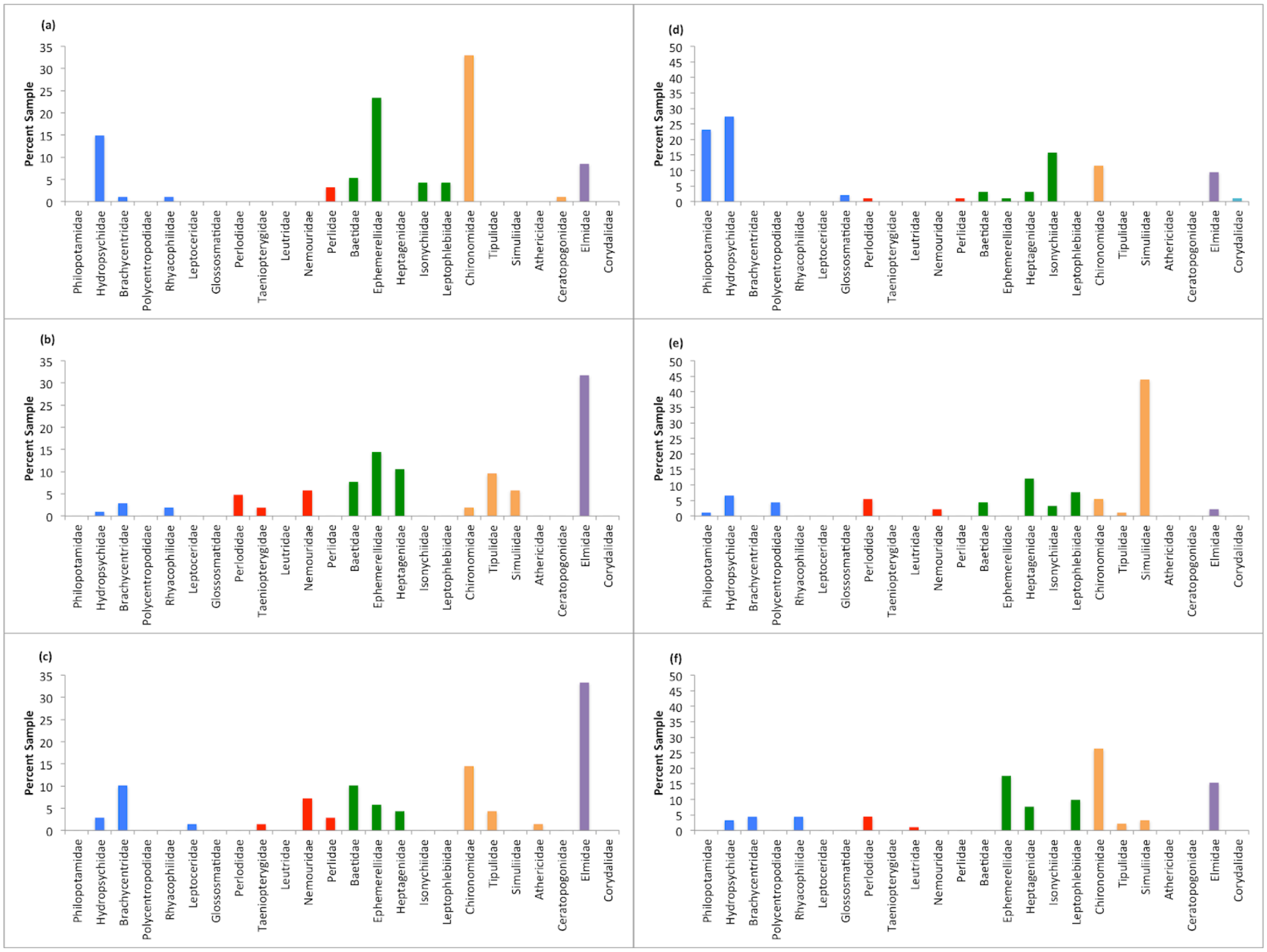

Figure 7: Family composition of Battenkill samples. (a): Headwaters Historical, (b): Headwaters Present, (c): Headwaters Experimental, (d): Mainstem Historical, (e): Mainstem Present, (f): Mainstem Experimental. Families are color coded by Order. Blue: Trichoptera (caddisflies), Red: Plecoptera (stoneflies), 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 composition between the historical sample and both present and experimental samples was found, due to an increase in *Chironomidae* and the presence or absence of the mayfly families *Heptageniidae* and *Isonychiidae*. At the mainstem site the stonefly families *Taeniopterygidae* and *Nemouridae* were the primary families behind the significant difference in community composition across all three samples.

Chironomidae

Chironomidae are found on all continents, including Antarctica in freshwater ecosystems and are beginning to emerge along coastlines in some marine ecosystems (Ferrington, 2007). They are extremely versatile, as they can often be found in abundance to signal good water quality as well as the presence of a pollutant in the environment (Epler, 2001). With over 2000 species in North America alone, *Chironomidae* are some of the most tolerant aquatic macroinvertebrates to different temperatures (Thorp & Covich, 2010; Merritt et al., 2008). They are easily identifiable by their pair of anterior prolegs and their standard accepted body plan of a larva (Merritt et al., 2008).

Ephemeroptera

Often a vital food source for fish, mayflies have a diverse range of tolerance for dissolved oxygen levels and water temperatures (Thorp & Covich, 2010). Larvae are all entirely aquatic and are usually collectors or scrapers (Merritt et al., 2008; Thorp & Covich, 2010). *Heptageniidae* are known for their flattened heads and often lack a median caudal filament

(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 Sweeney found a species of *Isonychiidae* found in New York to be very sensitive to changes in water temperature over short and long periods of time (1978).

Headwaters

At the headwaters, there was a significant difference in community composition due to the increase of *Chironomidae*, the disappearance of *Isonychiidae*, and the appearance of *Heptageniidae* in the present and experimental samples. We hypothesize that the increased presence is due to the survivorship of Chironomidae; this family was able survive the changes in conditions since 2001 that other families did not and established themselves as a predominant family in this environment. The two mayfly families were both present in the historical samples and decreased in number of individuals in the present and experimental samples. We hypothesize that these families were probably affected by some other pollutant, possibly in addition to an increase in temperature.

Plecoptera

Known for their preference for cold running water, stoneflies are very important primary and secondary consumers and prey in freshwater aquatic ecosystems. With over 3,500 species identified globally, 660 species are currently found in North America (Thorp & Covich, 2010). Currently believed to be the most diverse family is Perlidae, with 82 of 1,049 species found in North America. Nemouridae follows in diversity, with 71 of 633 species found in North America

(Fochetti & Tierno de Figueroa, 2008). As this order spans the globe and has been studied in various continents, Plecoptera are globally recognized for their environmental sensitivity and are known for their general intolerance of pollution and lack of dissolved oxygen (DeWalt et. al, 2012; Thorp & Covich, 2010). It is thought that stoneflies might be one of the most endangered orders of insect, due to the combination of increasing pollution and their restricted habitat range, based on a preference for cooler water temperatures and running water (Fochetti & Tierno de Figueroa, 2008). Other studies have shown that Plecoptera are not well adapted to high temperatures and lower dissolved oxygen levels. A study by Li et. al, which looked at historic continental drift and subsequent climates in terms of presence of Plecoptera found that biodiversity of stonefly species decreased in the past due to climate change (2015).

Nemouridae are known as spring stoneflies, as they begin to emerge in early spring (Glime, 2017; Thorp & Covich, 2010). The family is generally tolerant of cooler temperatures, with growth recorded while the average water temperature was only 0.6°C, slightly warmer than the 0.2°C recorded at the time of our sampling (Glime, 2017). Most species are univoltine, with one generation per year, with their eggs diapausing during warmer months (Thorp & Covich, 2010). *Taeniopterygidae*, or winter stoneflies due to their winter and early spring emergence period, are similarly adapted to colder temperatures (Glime, 2017). As such, larvae are thought to spend the summer diapausing (Thorp & Covich, 2010).

Mainstem

The most significant change in community composition at the mainstem was the lack of Plecoptera historically, as the present sample had a sizable increase, especially in *Nemouridae* and *Taeniopterygidae*. As these families are spring and winter stoneflies respectively, we hypothesize that the increase in their numbers from the historical to present sample and subsequent decrease to the experimental sample is because of their overall intolerance to warmer temperatures. The historical samples were collected early to mid-September at the end of summer, while our samples were collected mid February and early March in the middle of winter. Other studies have hypothesized the lack of a warmer temperature intolerant aquatic macroinvertebrates in summer samples was also due to an egg diapause or other way to evade hot summer temperatures (Houghton & Shoup, 2014).

Community Composition: Battenkill

At the headwaters site of the Battenkill, primarily the caddisfly family *Hydropsychidae* was responsible for a significant change in community composition between the historical sample and both the present and experimental samples. At both the headwaters site and the mainstem site, *Simuliidae* numbers caused a significant change in community composition across all three samples.

Simuliidae

Simuliidae filter suspended particulate organic matter from water and act as a food source themselves for other invertebrates and fishes in the ecosystem.

Some species are winter emergent while some emerge in warmer temperatures, with larvae hatching based on "temperature, oxygen tension, and perhaps photoperiod" (Merritt et al., 2008). Likewise, each species is are better adapted to specific temperatures (Merritt et al., 2008). They are also considered a strong indicator for water quality (Ciadamidaro, 2016).

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-emergent aquatic insects, particularly *Taeniopterygidae* and *Nemouridae,* may represent a significant portion of the aquatic insect biomass during winter months as they are undergoing rapid body growth in preparation to emerge (Sweeney et al., 1986; Tyufekchieva et al., 2013). When winter stream temperature increase causes fish metabolisms to increase, these winter and early spring-emergent stoneflies will likely become a more significant food source. Our findings suggest that an increase in experimental water temperature caused *Taeniopterygidae* and *Nemouridae* to die prematurely instead of emerge, since there was no evidence of emergence in the aquaria throughout the experiment (exoskeletons clinging to the side walls, floating in the water). If these stoneflies are unable to reach adulthood and reproduce due to increased stream temperature, local fish populations would lose a significant seasonal food source not just for one winter, but for many. This would have a negative impact on recreational fishing in the Kayaderosseras and Battenkill.

Future Studies

This study was a preliminary look at how increased winter stream temperature in may affect aquatic macroinvertebrate communities, and subsequently stream ecosystems. Further research needs to be done to confirm our finding that *Taeniopterygidae*, *Nemouridae*, and *Simuliidae* may be disproportionately impacted, especially since the sampling size of this study 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.

Acknowledgements

We would like to thank everyone that helped us throughout this study, especially our advisor, Professor Karen Kellogg. Thank you to Professor Anne Ernst, who dedicated many hours to helping us learn how to identify aquatic macroinvertebrates. We would also like to thank Professor AJ Schneller, Mr. Brian Duffy, Dr. AJ Smith, Dr. Daniel Hocking, Mr. Mike Bingham and Ms. Alyson Bingham, the Environmental Studies and Sciences Program, and the Student Opportunity Fund.

References

Brittain, J.E. (1982). Biology of mayflies. *Annual Review Entomology*, *27,* 119-147.

Burgmer T., Hillebrand H. & Pfenninger M. (2007). Effects of climate driven temperature changes on the diversity of freshwater macroinvertebrates. *Oecologia*, *151,* 93-103.

Chadwick, J. & McCormick, S. (2017). Upper thermal limits of growth in brook trout and their relationship to stress physiology. *The Journal of Experimental Biology, 21,* 3976-3987.

Ciadamidaro, S., Mancini, L., & Rivosecchi, L. (2016). Black flies (diptera, simuliidae) as ecological indicators of stream ecosystem health in an urbanizing area (Rome, Italy). *Annali Dell'Istituto Superiore Di Sanità*, *52*, 269. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/27364403.

Covich, A.P., Palmer, M.A. & Crowl, T.A. (2009). The role of benthic invertebrate species in freshwater ecosystems-zoobenthic species influence energy flows and nutrient cycling. *Bioscience*, *49,* 119-127.

Cuffney, T., Wallace, J. & Lugthart, G. (1990). Experimental evidence quantifying the role of benthic invertebrates in organic matter dynamics in headwater streams. *Freshwater Biology*, *23,* 281-299.

DeWalt, R. E., Cao, Y., Tweddale, T., Grubbs, S. A., Hinz, L., Pessino, M., & Robinson, J. L. (2012). Ohio USA stoneflies (Insecta, Plecoptera): Species richness estimation, distribution of functional niche traits, drainage affiliations, and relationships to other states. *ZooKeys, 178.*

Dunning, J., Gordon, Z. & Wu, A. (2015). Impacts of Urbanization and Thermal Loading within the Kayaderosseras Creek Watershed. *Skidmore College.*

Environmental Protection Agency. (2012). “Chapter 7: Benthic Macroinvertebrate Protocols.” *EPA*, Environmental Protection Agency. Retrieved from archive.epa.gov/water/archive/web/html/ch07b.html.

Ferrington, L. (2007). Global diversity of non-biting midges (Chironomidae; Insecta-Diptera) in freshwater. *Hydrobiologia, 595.*

Firth, P. & Fisher, S.G. (1991). *Climate Change and Freshwater Ecosystems*, pp. 143-176. New York, NY: Springer Verlag.

Fochetti, R., & Tierno de Figueroa, J. M. (2008). Global diversity of stoneflies (Plecoptera; Insecta) in freshwater. *Hydrobiologia, 595.*

Frumhoff, P. C., McCarthy, J. J., Melillo, J. M., Moser, S. C., & Wuebbles, D. J. (2007). *Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions.* Synthesis report of the Northeast Climate Impacts Assessment (NECIA). Cambridge, MA: Union of Concerned Scientists (UCS).

Glime, J. (2017). *Bryophyte ecology volume 2: Biological interaction.* Michigan Technological University and the International Association of Bryologists. Retrieved from http://digitalcommons.mtu.edu/bryophyte-ecology2/.

Grey, E., Boltz, J., Kellogg, K. & Stauffer, J. (1997). Food resource partitioning by nine sympatric darter species. *Transactions of the American Fisheries Society*, *126,* 822- 840.

Hayslip, R., & Gretchen, B. (2007). Methods for the collection and analysis of benthic macroinvertebrate assemblages in wadeable streams of the Pacific Northwest. *Pacific Northwest Aquatic Monitoring Partnership*, Cook, Washington. Retrieved from https://www.pnamp.org/sites/default/files/2007_0531PNAMP_macroinvert_protocol_final.pdf

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., ... Rosner, A. (2015). *Stream Temperature Database, NY_DEC_Battenkil_36.* Retrieved from http://db.ecosheds.org/viewer.

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* (2nd ed.). Dubuque, IA: Kendall/Hunt Publishing Company.

Merritt, R.W., & Cummins, K. W. (Eds.). (1995). *An Introduction to the Aquatic Insects of North America* (3rd ed.). Dubuque, IA: Kendall/Hunt Publishing Company.

Merritt, R. W., Cummins, K. W., & Berg, M. B. (Eds.). (2008). *An Introduction to the Aquatic Insects of North America* (4th ed.). Dubuque, IA: Kendall/Hunt Publishing Company.

National Oceanic and Atmospheric Administration, National Centers for Environmental Information. (2017). *Albany Local Climate Data Publication.* Retrieved from https://www.ncdc.noaa.gov/IPS/lcd/lcd.html?_page=1&state=NY&stationID=14735&_target2=Next+%3E.

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

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. *Tropical Ecology, 57 (1),* 57-68.

Rosenzweig, C., W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, & P. Grabhorn (Eds.). (2011). *Responding to Climate Change in New York State: The ClimAID Integrated*

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.

Taff, Canor, and Jon DeCoste. (n.d.) "History of the Kayaderosseras Watershed: An Environmental Approach."

Thorp, J. H., & Covich, A. P. (Eds.). (2001). *Ecology and Classification of North American Freshwater Invertebrates* (1st ed.). London, UK: Academic Press.

Thorp, J. H., & Covich, A. P. (Eds.). (2010). *Ecology and Classification of North American Freshwater Invertebrates* (3rd ed.). London, UK: Academic Press.

Tramer, E. J. (1969). Bird Species Diversity: Components of Shannon's Formula. *Ecology, 50 (5),* 927-929.

Tyofekchieva, V., Kalcheva, H., Vidinova, Y., Yaneva, I., Stoyanova, T. & Ljubomirov, T. (2013). Distribution and Ecology of Taeniopterygidae (Insecta: Plecoptera) in Bulgaria. *Acta Zoologica, 65,* 89-100.

United States Geological Survey. (2016, Dec 2). *The World's Water*. Retrieved from https://water.usgs.gov/edu/earthwherewater.html.

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.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R. & Cushing, C.E. (1980). The river continuum concept. *Canadian journal of Fisheries and Aquatic Sciences, 37,* 130-137.

Wallace, J. & Webster, J. (1996). The role of macroinvertebrates in stream ecosystem function. *Annual Review Entomology, 41,* 115-139.

Weber, C., Nilsson, C., Lind, L., Alfredsen, K. & Polve, L. (2013). Winter Disturbances and Riverine Fish in Temperate and Cold Regions. *Bioscience, 63,* 199-210.

Woodward, G., D. Perkins, & Brown, L. (2010). Climate Change and Freshwater Ecosystems: Impacts Across Multiple Levels of Organization. *Philosophical Transactions of the Royal Society, 365*, 2093-2106.

Appendix A

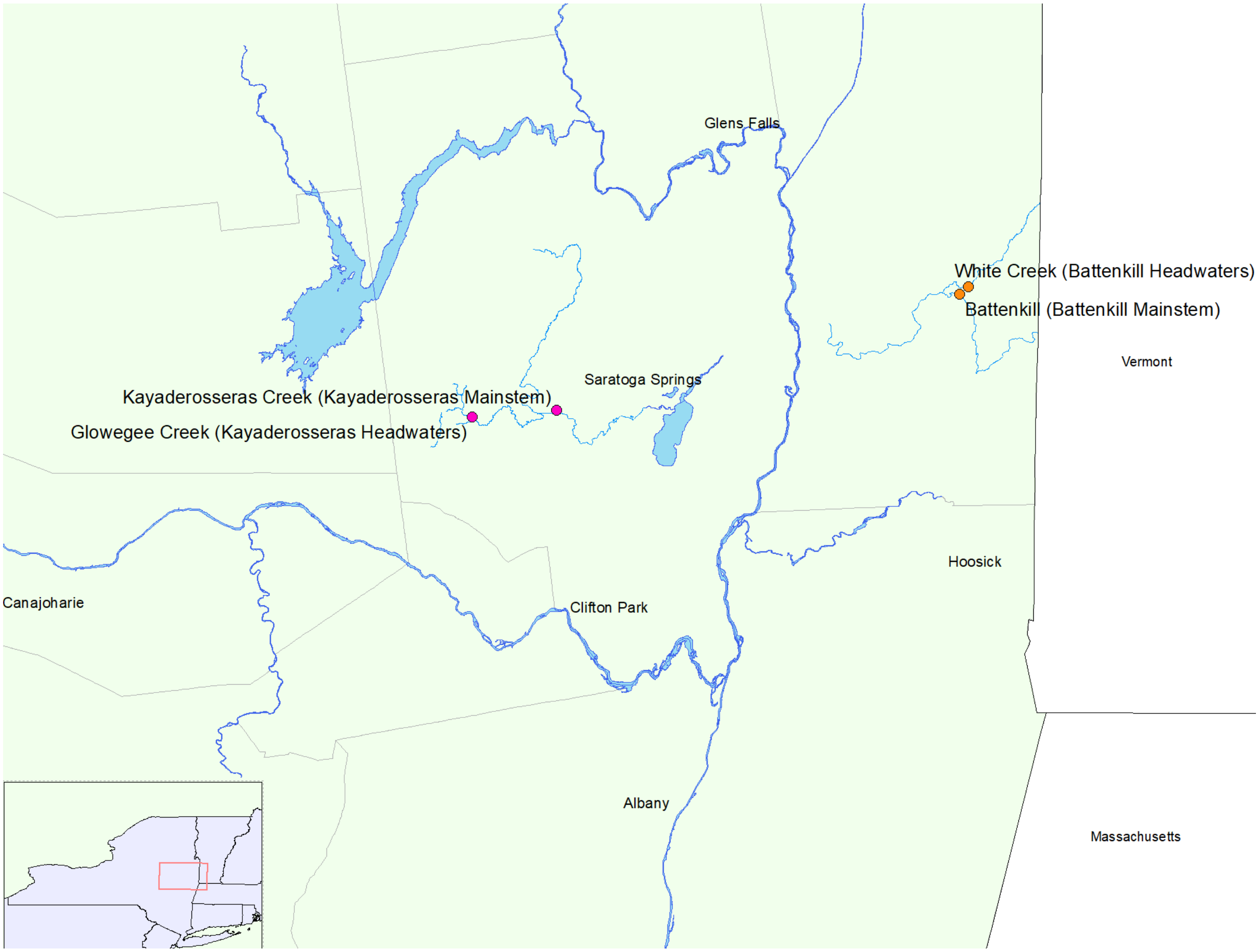

Figure 1A. Locations of Aquatic Macroinvertebrate Sampling

Appendix B

Table B1. Shannon's Diversity Index for the Kayaderosseras Sites

	Headwaters	Mainstem
Historical	2.45	4.34
Present	1.83	2.4
Experimental	1.69	2.4

Table B2. Shannon's Diversity Index for the Battenkill Sites

	Headwaters	Mainstem
Historical	1.88	1.95
Present	2.15	1.97
Experimental	2.13	2.14

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
Battenkill Mainstem	Historical/Present (Diptera)	0.123

Table 2C. Morisita's modified index of similarity for families and sites with biologically significant differences in community composition between only the historical sample and the present and experimental samples

Site	**Samples (Order)**	**Morisita's Index**
Kayaderosseras Headwaters	Historical/Present (Ephemeroptera)	0.324
Kayaderosseras Headwaters	Historical/Present (Diptera)	0.373
Battenkill Headwaters	Historical/Present (Trichoptera)	0.34