Spatial and Temporal Changes of Nutrients and Organisms in Lake Outflow Streams

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Abstract

Few studies have investigated the effects of time and space on water chemistry in lake outflow streams. I expected nutrient levels to increase as I traveled farther downstream due to the fact that streams generally contain higher nutrient levels than lakes. Lake organisms should also decrease downstream because they are not adapted for life in running waters. I also predicted a higher level of nutrients to be found in the outflow stream while spring turnover was occurring in the lake compared to when the lake was stratified during the summer since turnover causes nutrients settled on the bottom of the lake to become dispersed. The null hypothesis is that no changes in soluble reactive phosphorus concentrations, ammonium concentrations, phytoplankton densities, or zooplankton densities will be found downstream of a lake outflow. The second null hypothesis is that no differences in these variables will exist when the lake is undergoing turnover compared to when it is stratified. Ten sites on two lake-stream systems were sampled on three days throughout the summer and pH, conductivity, DO, zooplankton densities, SRP concentrations, and ammonium concentrations were determined. Statistically significant increases were found in conductivity (R^2=0.432; p=0.000078) and ammonium (R^2=0.257; p=0.0042) when compared to distance downstream in Tenderfoot Creek. Temporal changes were seen in pH from the first to second sampling day (t= -10.069; df=9; p=0.0000034), and heavy rainfall caused an increase in conductivity and a decrease in SRP in TC on the last day of sampling. Overall, stream water tends to contain the same physical, chemical, and biological characteristics of lake water until an outside source, event, or physical feature can alter its make-up.

Introduction

Ecosystems are a way of classifying distinct environments and their correlating biota (flora & fauna). Lakes and streams are two independent ecosystems with their own physical, chemical, and biological characteristics. However, in places where these bodies of water are connected (an outflow stream/lake outflow), transitional zones appear that contain features of both lakes and streams (Cole, 1975). A transitional zone such as this is termed an “ecotone” (Samways and Stewart, 1997).

One of the most notable transitional changes has been found in zooplankton densities. Zooplankton flow out of lakes at different rates due to water velocity and zooplankton densities. However, persistence in the streams is controlled by temperature, turbidity, nutrients, predation, vegetation, and water movement (Hynes, 1970; Cole, 1975). Walks and Cyr (2004) conducted a study that found that zooplankton decreased dramatically within 50 m downstream of a source lake and were practically eliminated 1 km downstream. Similarly, Armitage and Capper (1976) found that the greatest decline in density appeared within the first 1.4 km downstream, especially in the first 400 m, although the reduction did not occur at a constant rate. These reductions are due to the fact that zooplankton flowing out of the lake are adapted to live in lentic waters while the stream environment consists of lotic water. Also, Campbell (2002) observed that rain events can flush zooplankton out of lakes at an increased rate, causing plankton densities to be higher much farther downstream than usual.

Source lakes greatly influence the amount and variety of certain stream organisms in an outflow because the lake provides extra plankton, algae, and nutrients as food sources (Hynes, 1970; McCreadie and Robertson, 1998). For example, passive filter-feeders such as blackfly larvae (Diptera: Simuliidae) and caddisfly larvae (Trichoptera) can be found in increased quantities in lake outlets, although their numbers soon return to normal a short distance downstream. Eriksson (2001) reported that a steady increase of filter-feeders in an outlet stream occurred, most notably in the region 20-350 m downstream of the lake. Likewise, Harding (1997) found that both the density of zooplankton and of *Aoteapsyche raruraru* (a species of caddisfly larvae) had decreased by a distance 250 m downstream of a source lake. Phytoplankton and epilithic algae concentrations were also measured but showed no significant reductions over this distance, suggesting that the zooplankton were the preferred food source of the larvae.

Nutrients found naturally in freshwater are also used by many plants and animals as a food source. Microbes, phytoplankton, macrophytes, and riparian vegetation are able to assimilate ammonium, soluble phosphate ions, and some organic phosphorous compounds from the lake (Allan, 1995). Zooplankton then utilize these nutrients by consuming these organisms. Phosphorous and nitrogen are the two main nutrients that limit productivity/algae growth in freshwaters, although phosphorous usually has more of a limiting effect than nitrogen (Wetzel, 2001). The main sources of phosphorous are the decay and mineralization of animal and plant carcasses (Cole, 1975) and unweathered rocks and soil (Schlesinger, 1997). Various physical-chemical factors such as precipitation and sorption onto sediments affect concentrations of phosphorous, and sorption may help regulate stream concentrations of dissolved phosphorous. Nitrogen enters lakes and streams through runoff, atmospheric diffusion, acid rain, animal waste, anthropogenic inputs, and decomposing plants and animals. In streams, ammonium regeneration is fueled by decomposition and excretion (Allan, 1995).

Nutrient cycling is affected by season, location, rainfall, local geology, human influence, and animals (Allan, 1995). For example, in the spring, lakes undergo turnover which causes the nutrients at the bottom of the lake to be mixed throughout the rest of the lake. By summer, the lake stratifies and the additional nutrients have either been flushed out of the lake or have settled back down to the bottom of the lake (Wetzel, 2001). While nutrient cycling in lakes and streams has been studied a great deal, little research has been conducted to observe the changes in nutrients that occur in lake outflows. In lakes, primary production occurs in the water column while in streams it occurs in the benthos (Wetzel, 2001; Allan, 1995). Therefore, phytoplankton densities in lake outflows should decrease as one travels farther downstream. Also, since higher levels of phosphorous and nitrogen tend to be found in streams compared to lakes (Allan, 1995), one would expect nutrient levels to increase as one travels farther downstream. This is due to the fact that the volume of an outflow stream is much less than the volume of the source lake; thus, incoming nutrients in a stream would become more concentrated than in a lake. Higher levels of nutrients would also be expected to be found in the outflow stream while spring turnover was occurring in the lake compared to when the lake was stratified during the summer since turnover causes nutrients settled on the bottom of the lake to become dispersed. Studying these changes will allow us to better understand the affects man can have on an environment by creating, destroying, or altering lake outflows or their water chemistry, such as by building dams or introducing various chemicals (fertilizers, detergents, etc.) into the surrounding environment/water (Allan, 1995).

The purpose of this study is to determine the rate of transitional changes of water nutrients and organisms in lake outflow streams by examining spatial and temporal transformations. The null hypothesis is that no changes in soluble reactive phosphorus concentrations, ammonium concentrations, phytoplankton densities, or zooplankton densities will be found downstream of a lake outflow. The second null hypothesis is that no differences in these variables will exist when the lake is undergoing turnover compared to when it is stratified.

Materials and Methods

Sampling Sites

Experimentation was conducted at the University of Notre Dame Environmental Research Center (UNDERC) in the Upper Peninsula of Michigan. Two different lakes and their outflowing streams were studied. Tenderfoot Lake is located at 46^{o}13'10" N 89^{o}31'38" W at an elevation of 503 m (DigitalGlobe and Tele Atlas). The lake's surface area is 194.24 ha and its deepest point is around 9.1 m (UNDERC, 1997). Tenderfoot Creek flows north out of Tenderfoot Lake and is the only outflow stream. It is slow-moving and 40 m wide, on average (Digital Globe and Tele Atlas). Plum Lake is located at 46^{o}13'17'' N 89^{o}30'15" W at an elevation of 505 m (DigitalGlobe and Tele Atlas). The lake's surface area is 91.43 ha and its deepest point is around 7.3 m (UNDERC, 1997). Plum Creek flows northeast out of Plum Lake and is the only outflow stream. It is slow-moving and about 1-3 m wide (Digital Globe and Tele Atlas). Ten sites were established along each lake-stream system. At Tenderfoot, one was in the epilimnion of the lake, one was right at the mouth of the outflow (0 m), and the last eight were at 50, 100, 150, 200, 250, 300, 3500, and 4000 m downstream of the mouth (Appendices 1 and 2). Tenderfoot Creek is slow-moving and relatively wide; the site 3500 m downstream is in the midst of the first riffle in the creek. At Plum, one site was in the epilimnion of the lake, one was at the mouth of the outflow (0 m), and the last eight were at 25, 50, 100, 150, 200, 250, 300, and 500 m downstream of the mouth (Appendix 3). Plum Creek is a narrow, slow-moving creek with no true riffles.

Field Methods

Plankton and water chemistry samples from each site were collected in plastic bottles three different days throughout the summer (June 2, June 22, and July 13). Sixty milliliter water chemistry samples were filtered in the field using a syringe and 25 mm Whatman GF/F filters. At each site, conductivity and temperature were measured using an HI 9033 Multi-range Conductivity meter. In addition, pH was determined using an HI 98127 pHep meter and dissolved oxygen (DO) was recorded using a 55/50 FT YSI 55 Dissolved Oxygen meter; weather was noted by using simple observation.

Plankton Processing

Plankton water samples were treated with Lugol's iodine to preserve and stain the specimens. Phytoplankton and zooplankton densities were determined using a gridded petri dish and light microscope. Zooplankton were also identified to order.

Nutrient Processing

Water chemistry samples were frozen until after the third collection day. Soluble reactive phosphorus (SRP) concentrations were determined using a spectrophotometer set at 885 nm by following the procedure outlined by Tank (2003), and ammonium levels were determined using a spectrophotometer set at 630 nm by following the procedure outlined by Bouma (2003). For each procedure, reagents were made to dye the samples. For SRP, standards were made that contained concentrations similar to those expected in the samples. For ammonium, standards with concentrations higher than expected in the samples were created so that a good standard curve could be obtained. The absorbances from the standards were later utilized to create standard curve graphs (Figures 1 and 2). The equation of the regression line of each curve was used to calculate sample concentrations based off of their absorbance values.

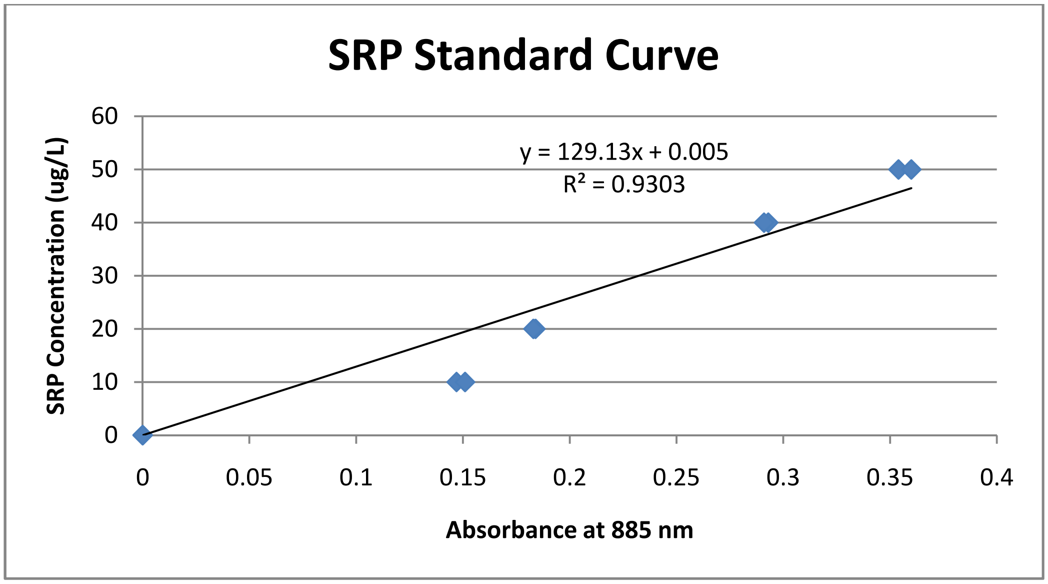

Figure 1. SRP standard curve. The equation of the regression line (y=129.1x + 0.005) was used to determine SRP concentrations of water samples based off of their absorbance readings.

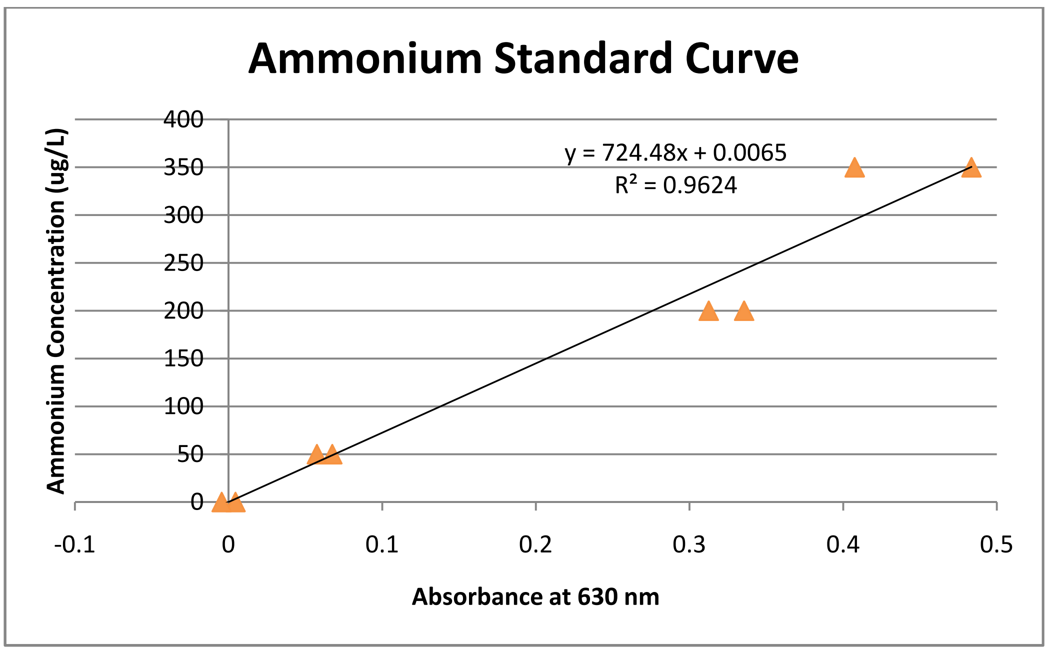

Figure 2. Ammonium standard curve. The equation of the regression line (y=724.4x + 0.006) was used to determine ammonium concentrations of water samples based off of their absorbance readings.

Hydrolabs

A second facet of experimentation utilized two hydrolabs to examine diel cycles in a lake and its outflowing stream to note spatial differences between the two locations. One hydrolab was placed in Tenderfoot Lake and the second was placed in Tenderfoot Creek 4000 m downstream of its mouth. These instruments collected data on the depth, pH, specific conductivity, percent dissolved oxygen, temperature, turbidity, chlorophyll, and redox potential. The hydrolabs collected data four times a day in 6 hour intervals starting at 5:36 am for fifteen consecutive days (July 2-July 16).

Results

Spatial Changes

Least squares linear regressions were run in Systat 12 to analyze the data and note statistically significant spatial changes that occurred as one moved farther downstream. Lake samples were set as being -25 m downstream for graphs and statistics. No statistically significant results were found for Plum Creek (PC); however, Tenderfoot Creek (TC) showed a statistically significant increase in conductivity when compared to distance downstream (R^2=0.432; p=0.000078) and a statistically significant increase in ammonium concentrations when compared to distance downstream (R^2=0.257; p=0.0042). The average conductivity in the lake was 125.8 uS/cm and the average conductivity at 4000 m was 164.4 uS/cm. The average ammonium concentration in the lake was 8.6 ug/L and the average ammonium concentration at 4000 m was 16.3 ug/L. These results, as displayed in Figure 3 (conductivity) and Figure 4 (ammonium), do not contain values for the region between 300 and 3500 m, so statistical analyses may be slightly inaccurate due to the fact that no middle values are present.

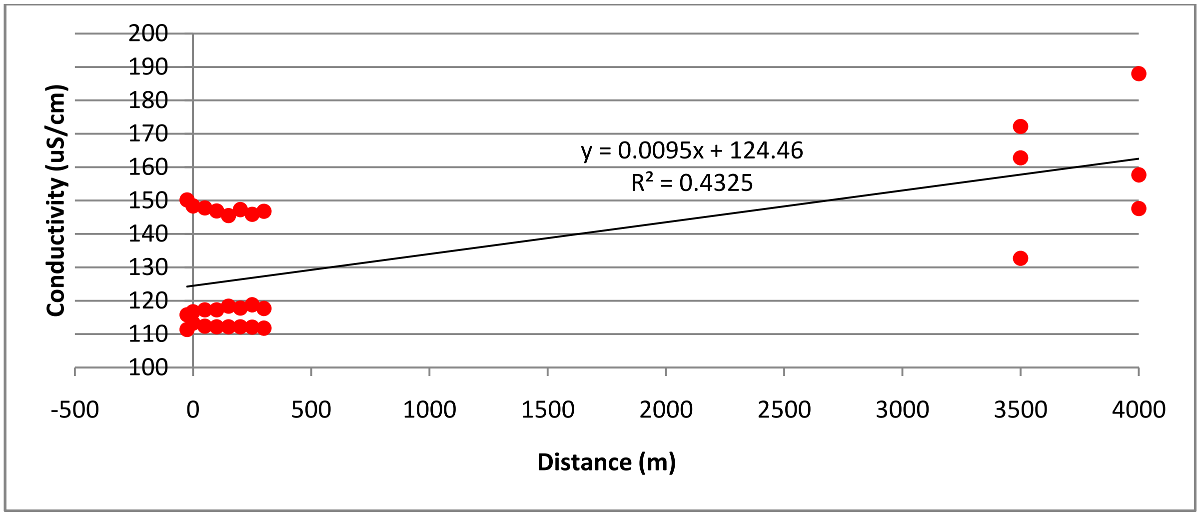

Figure 3. Downstream changes in conductivity in Tenderfoot Creek. A statistically significant increase in conductivity was found as one moved farther downstream in TC. The lake values are set at -25 m.

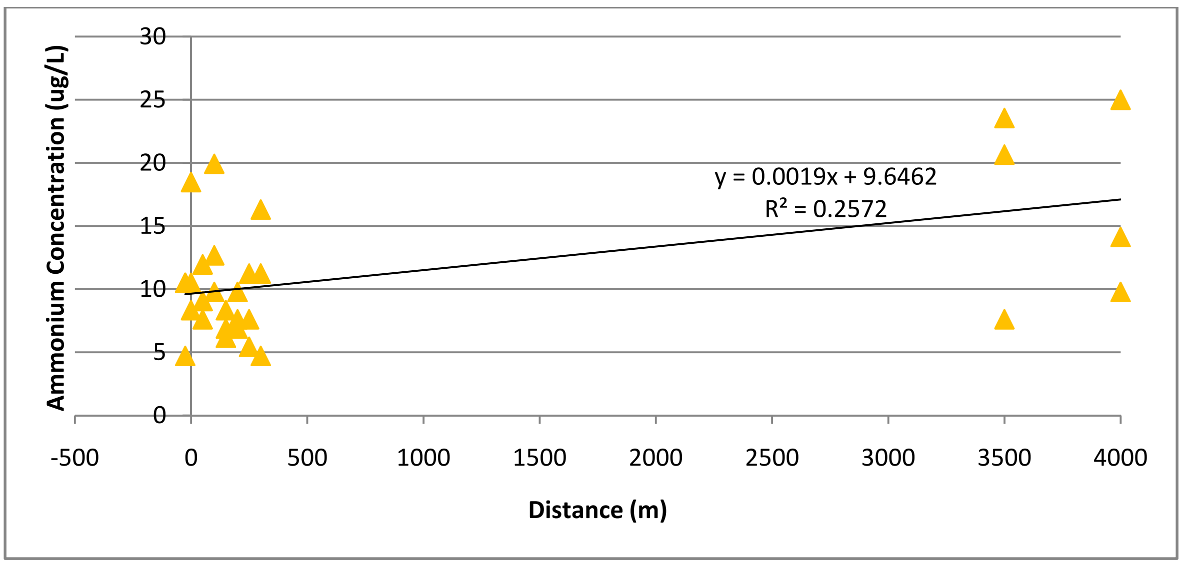

Figure 4. Downstream changes in ammonium in Tenderfoot Creek. A statistically significant increase in ammonium was found as one moved farther downstream in TC. The lake values are set at -25 m.

Plankton

No visible trends are apparent in PC zooplankton densities (Figure 5), but TC densities show a slight trend of an initial increase then decrease of zooplankton (Figure 6). The average density in PC was 38.3 zooplankton/L, and the average density in TC was 117.8 zooplankton/L.

Regression analyses were performed and no statistically significant spatial differences in average zooplankton densities were found in either creek. For TC, a linear regression was only carried out on the first 8 sites (lake to 300 m) and excluded the last 2 sites (3500 and 4000 m) since Armitage and Capper (1976) had previously found that zooplankton densities decreased the most within 400 m downstream and Walks and Cyr (2004) found that zooplankton were practically eliminated 1 km downstream. Also, densities at 3500 and 4000 m were relatively low and had high standard deviations, which would have affected the regression. Phytoplankton densities were also counted, but this data was later determined to be untrustworthy due inexperience in identifying benthic and pelagic algae species. Accurate phytoplankton densities would have excluded suspended benthic algae since I am examining the transitional changes from the lake to the stream.

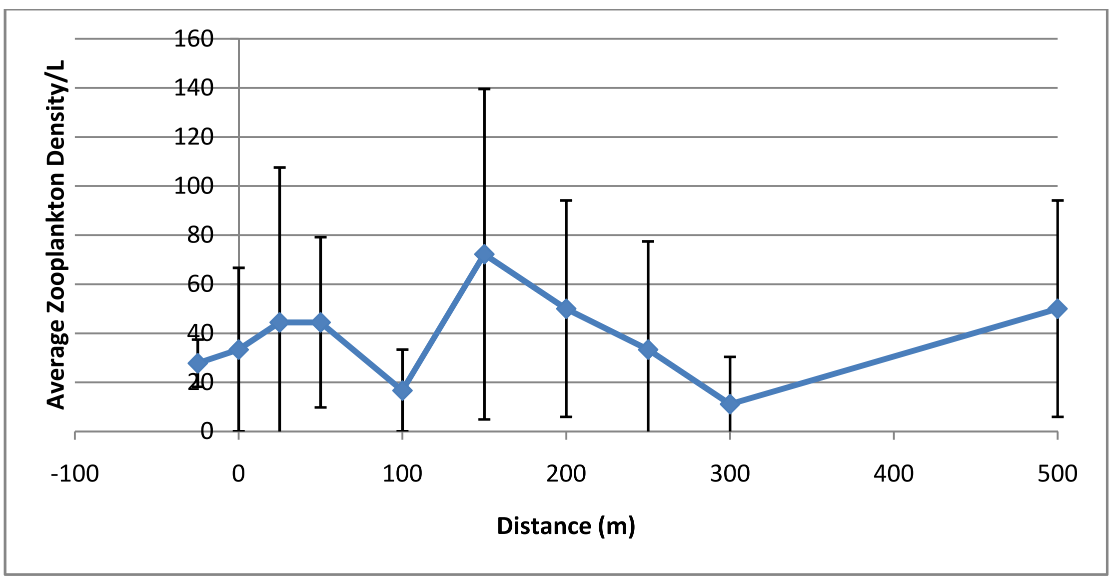

Figure 5. Plum creek average zooplankton densities. No visible or statistically significant trends were found in average zooplankton densities in PC. The lake sample is set at -25 m and error bars represent standard deviation.

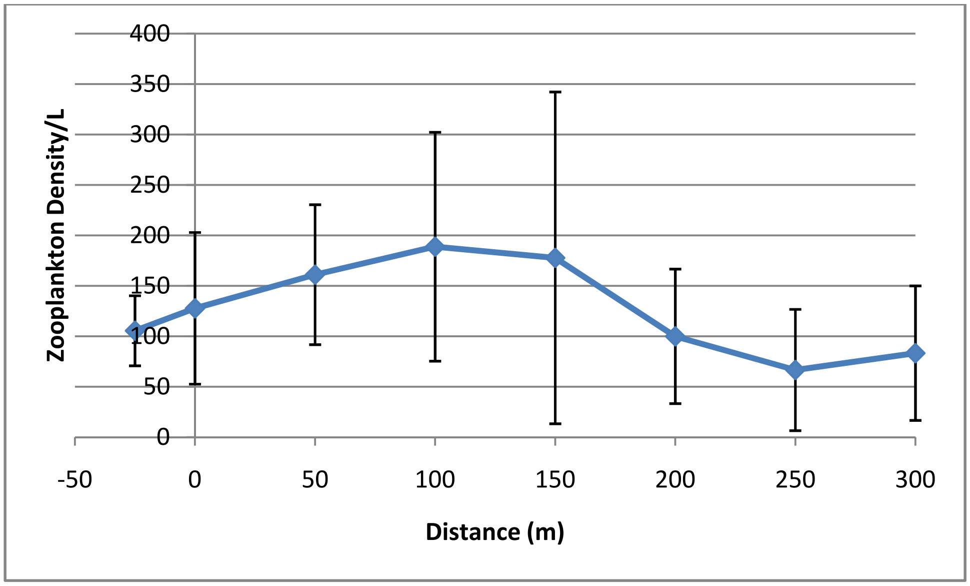

Figure 6. Tenderfoot creek average zooplankton densities. No statistically significant trends were found in average zooplankton densities in TC, however, there appears to be a slight trend where zooplankton increase and then decrease as one moves farther downstream. Sites 3500 and 4000 m downstream are not represented on this graph since they were not used in statistical analyses and since the greatest changes in zooplankton have been found to appear around the first 400 m downstream (Armitage and Capper, 1976). The lake sample is set at -25 m and error bars represent standard deviation.

Temporal Changes

Temporal changes were analyzed using paired t-tests that compared data collected on 6/2 and data collected on 6/22. These dates were selected because the spring turnover was occurring in the lakes on 6/2 and by 6/22 the lakes were stratified. Data collected on 7/13 was excluded in statistical analyses because a heavy rainstorm about 40 hours prior to data collection influenced several factors such as conductivity and SRP. No statistically significant results were found in PC. However, in TC, a statistically significant increase in pH from 6/2 to 6/22 was found (t= -10.069; df=9; p=0.0000034) (Figure 7). The pH range on 6/2 was between 6.8 and 7.3 with an average of 7.0 while the range on 6/22 was 7.3-7.9 with an average of 7.6.

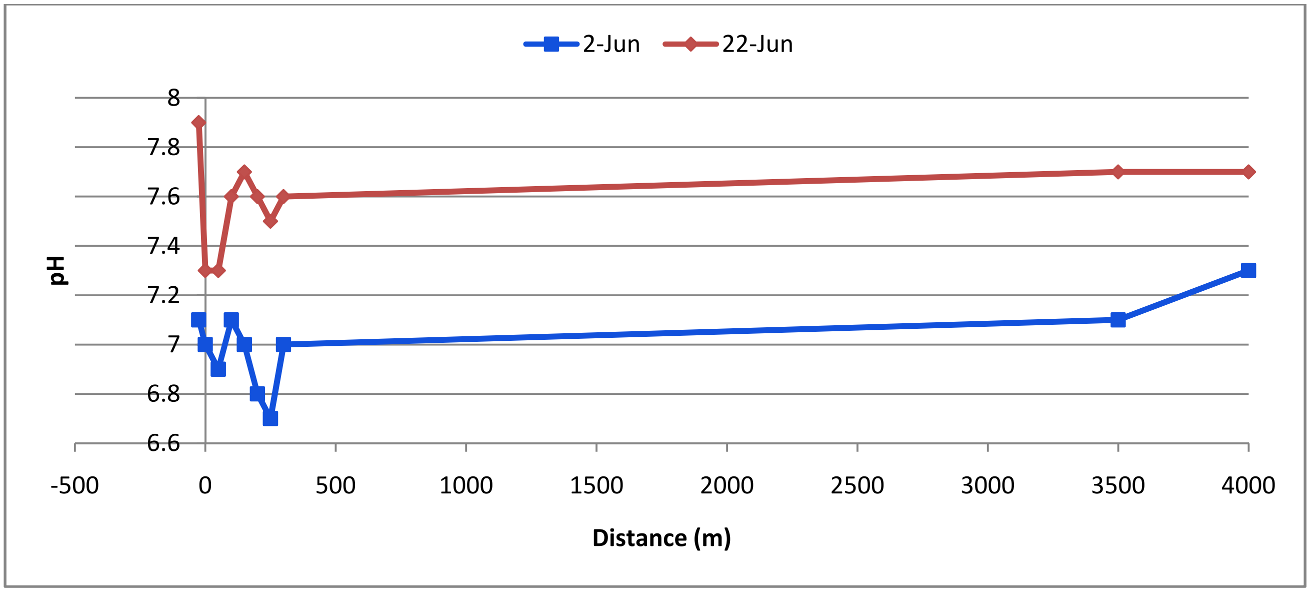

Figure 7. Temporal changes of pH in Tenderfoot Creek. A statistically significant increase in pH occurred in TC from June 2 to June 22. On June 2, pH ranged from 6.7 to 7.3 while on June 22 pH ranged from 7.3 to 7.9. The lake sample is set at -25 m.

No notable visual trends were seen in SRP and ammonium when the lakes was undergoing turnover versus when they were stratified (Figures 8 and 9). However, SRP was much lower and conductivity was much higher in both creeks on the last day of sampling (7/13), presumably due to the heavy rain (Figures 8 and 10). SRP ranged from 5.2-27.1 ug/L in TC and 2.8-19.0 ug/L in PC on the first two days of sampling. However, on the last day of sampling, SRP ranged from 1.0-3.1 ug/L in TC and from 0.7-3.7 ug/L in PC. The average conductivity for TC on the first two days of sampling was 123.9 uS/cm while the average on the last day of sampling was 150.0 ug/L. In PC, the average conductivity on the first two days of sampling was 63.2 uS/cm while the average on the final day of sampling was 82.8 uS/cm.

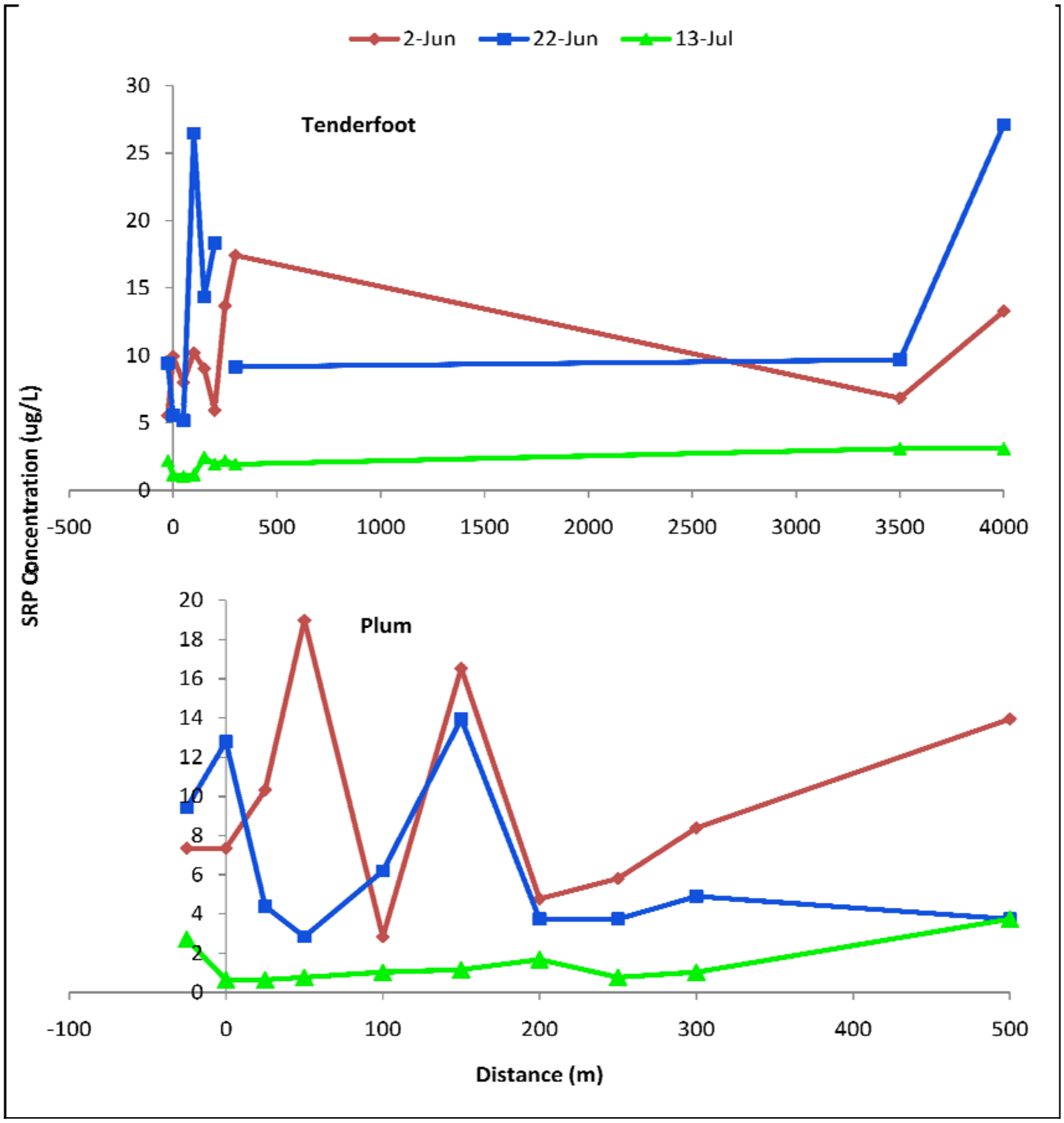

Figure 8. SRP concentrations of Tenderfoot and Plum Creeks on three days during the summer. Samples collected on 6/2, 6/22, and 7/13 show no visual trends or temporal changes in SRP concentrations due to lake turnover and stratification. However, low values for both creeks on 7/13 can be seen due to heavy rain activity. The lake sample is set at -25 m.

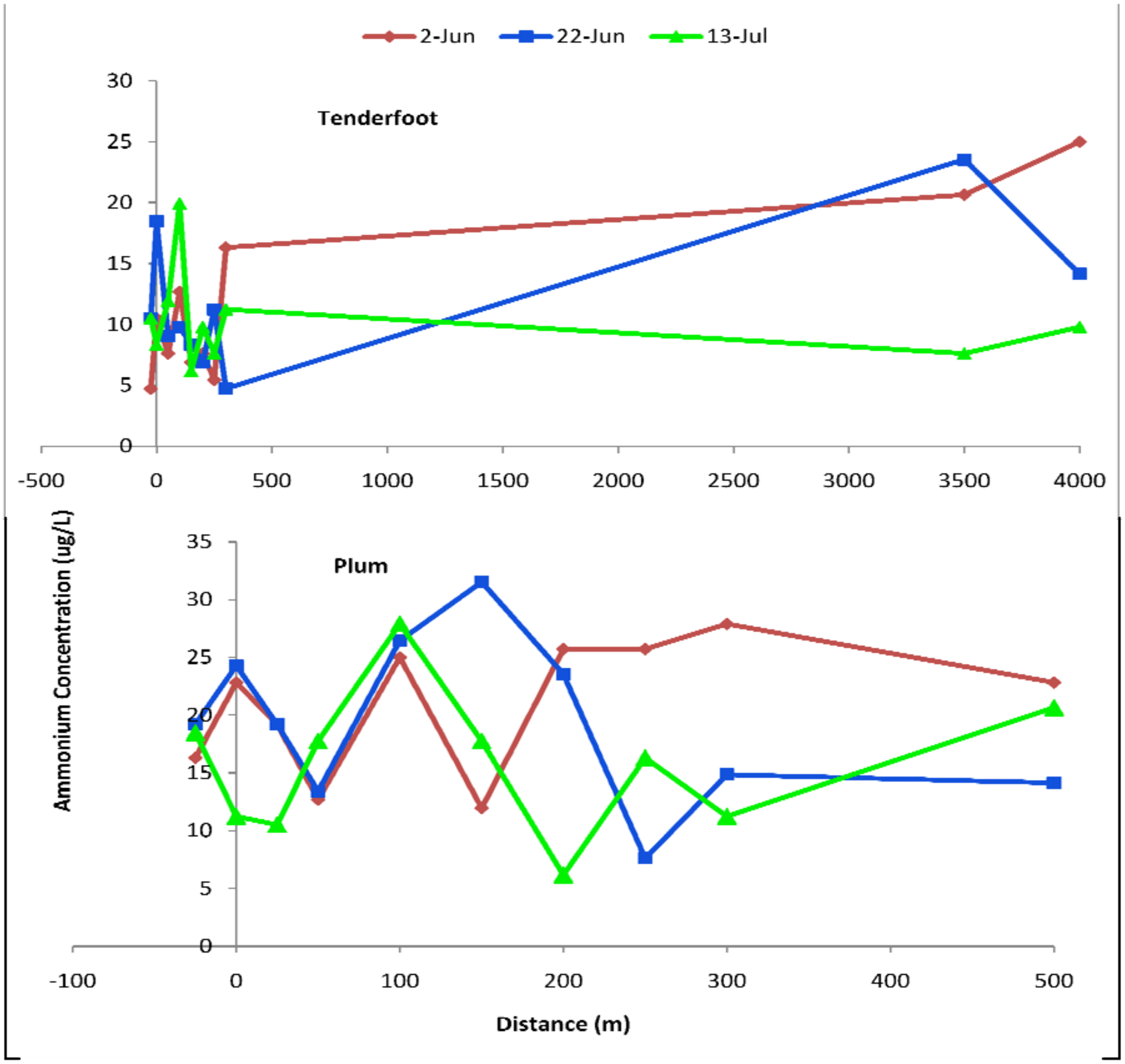

Figure 9. Ammonium concentrations of Tenderfoot and Plum Creeks on three days during the summer. Samples collected on 6/2, 6/22, and 7/13 show no temporal changes in ammonium concentrations. The lake sample is set at -25 m.

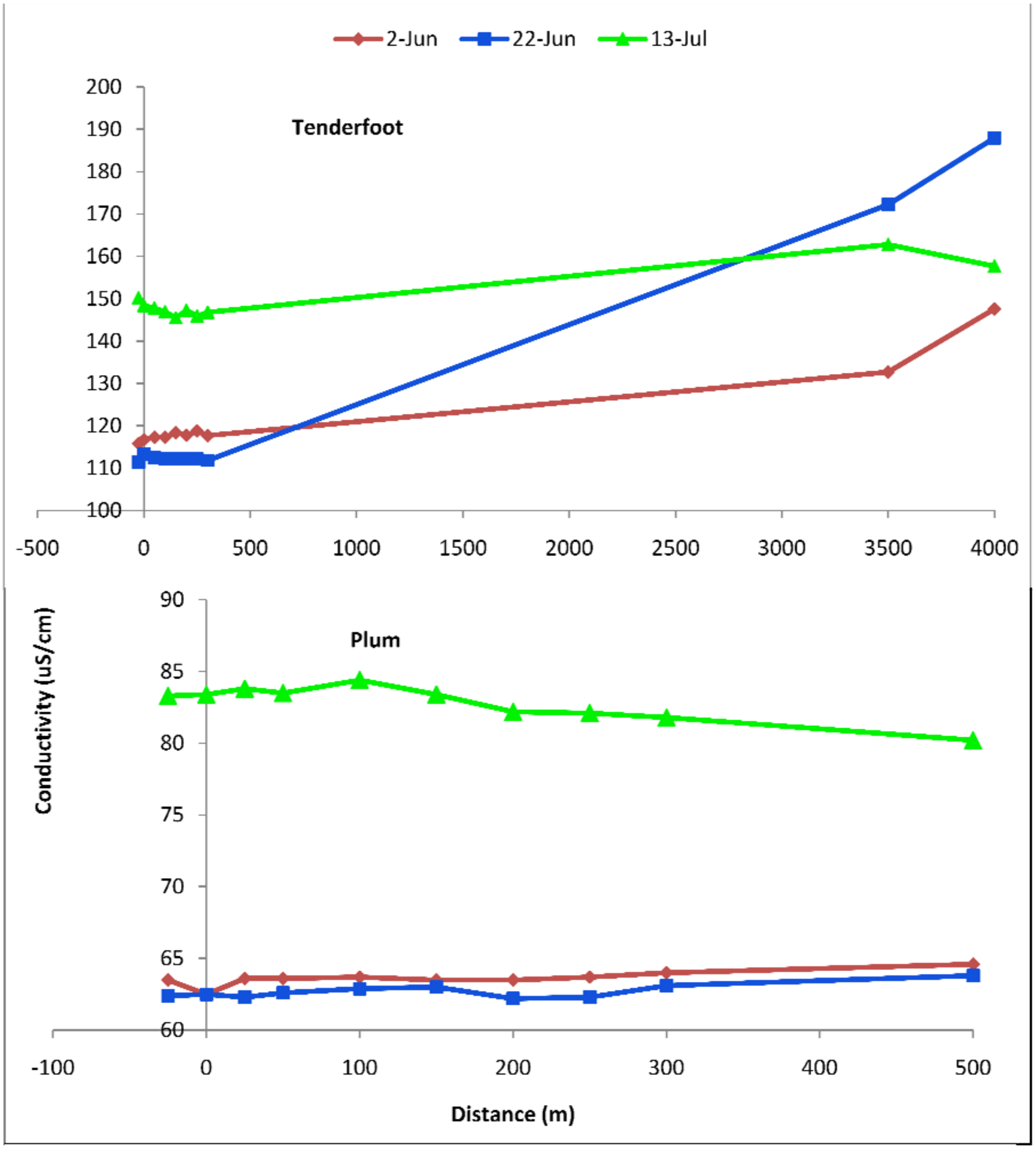

Figure 10. Conductivity in Tenderfoot and Plum Creeks on three days during the summer. Data collected on 6/2, 6/22, and 7/13 show no temporal changes in conductivity due to lake turnover and stratification. However, high values for both creeks on 7/13 can be seen due to heavy rain activity. The lake sample is set at -25 m.

Diel Cycles

Data from the lake hydrolab could not be retrieved due to instrument malfunctions, thus comparisons cannot be made between the lake and creek. However, data from the creek hydrolab revealed that specific conductivity, DO%, temperature, and pH diel cycles were present (Figure 11). Specific conductivity was generally highest in the morning (between 5:36 and 11:36 am), and DO%, temperature, and pH were all highest at 5:36 pm.

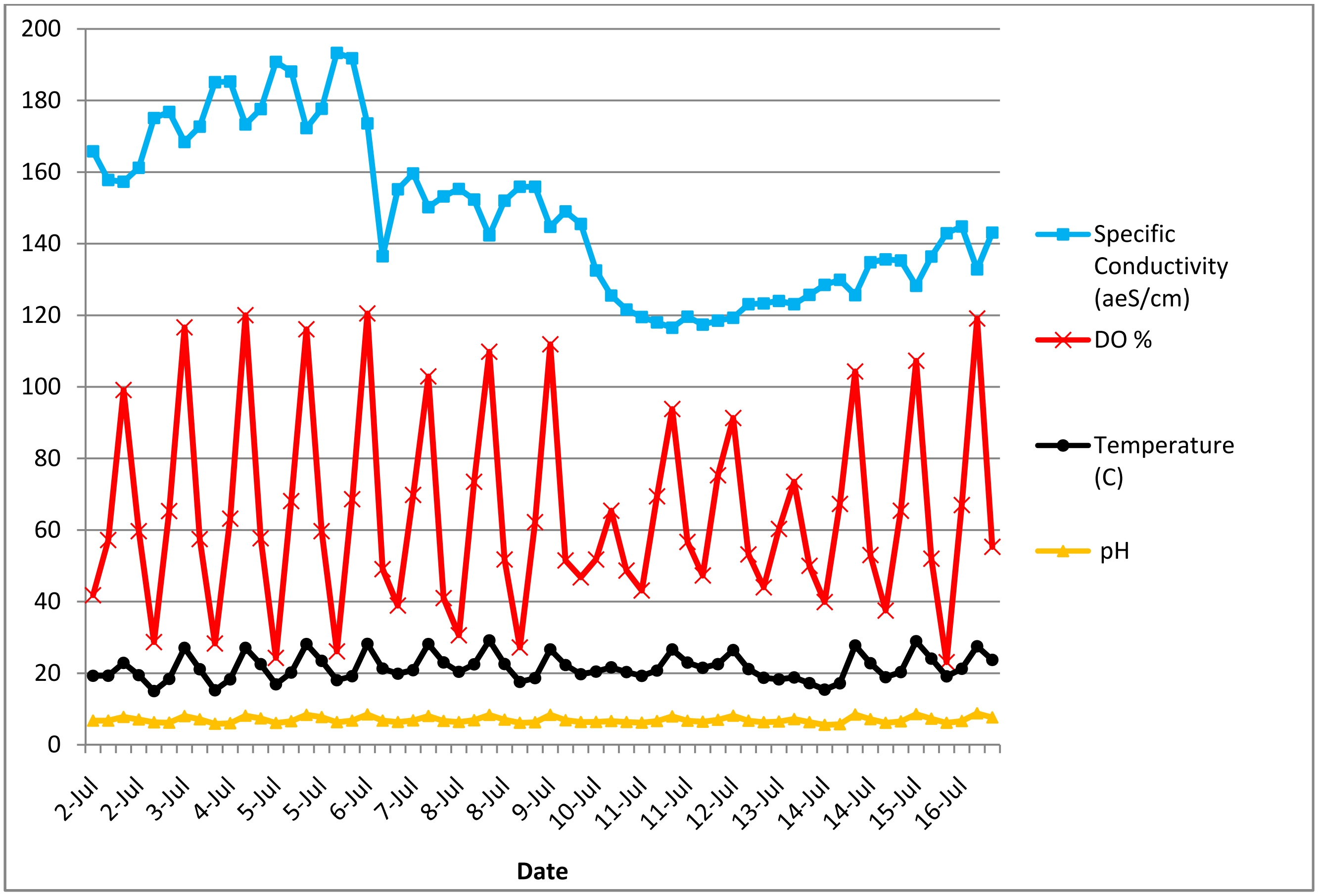

Figure 11. Diel cycles in Tenderfoot Creek. Diel cycles of specific conductivity, DO%, temperature, and pH were found in TC. Data was collected by a hydrolab four times a day (5:36 am, 11:36 am, 5:36 pm, and 11:36 pm) for 15 consecutive days. First data point on graph represents July 2, 5:36 am.

Discussion

Several diel cycles could be seen in TC from the hydrolab data. The temperature was the highest at 5:36 pm since the sun had caused the water temperature to increase throughout the day. The DO% was also highest at this time due to small autotroph and macrophyte productivity that had been occurring during the day when the sun was out (Allan, 1995). pH was also highest at 5:36 pm. This trend is due to high levels of productivity during the day which caused low levels of CO_2. pH is interdependent with CO_2 concentrations, so as CO_2 decreased, pH increases (Parker et al., 2005). Although diel cycles were generally present in specific conductivity, large variations occurred between days. High ion concentrations in surface runoff from rain may have been a factor, although the large shifts in conductivity did not coincide with the days that rain occurred (AccuWeather, Inc., 2008). Also, since data was not collected from multiple points in the creek, it is not clear whether these large shifts in conductivity were experienced throughout the creek or if just a small region was affected. Thus, the location of the hydrolab may have influenced these results.

The diel cycle of conductivity may have slightly influenced the results of my main study. However, sampling began between 10 am and 2 pm each sampling day, and TC was always sampled before PC, so the results should not have been affected very much. Also, the temporal changes in pH that were noted may be due more to changes during the day rather than changes throughout the summer since sampling occurred about 3 hours apart on the first 2 sampling days. Taking these cycles into consideration is an important factor in determining sampling regimes that are dependent on a certain temperature, DO%, pH, and/or conductivity.

No changes in zooplankton densities were found due to a small sample size and large standard deviations. If more samples had been collected, a statistically significant result may have been found since previous studies (Walks and Cyr, 2004; Armitage and Capper, 1976) have shown a decrease in similar ranges downstream of lake outflows. However, notable changes may not have been seen due to the fact that both streams are slow-moving and are more suitable for lentic zooplankton to live in compared to streams with high current velocities (Wetzel, 2001).

The only statistically significant temporal change that was found was an increase in pH in TC from 6/2 to 6/22, suggesting that the pH is lower during spring turnover compared to summer stratification. Low pH values are characteristic of water rich in dissolved organic matter (DOM). The decomposed material found at the bottom of the lake would be high in DOM, which would circulate through the lake during turnover and would thus have caused the pH to be lower on 6/2 than on 6/22 (Wetzel, 2001). In addition, a study by Maberly (1996) found that during stratification, the weather caused periods of high and low pH due to high pressure, low rainfall, low wind velocity, and various other factors. Thus, it is also possible that the second sampling day merely occurred during a period of high pH and that if sampling had occurred on a different day during summer stratification the pH would have been lower.

A statistically significant increase in conductivity versus distance was found in TC. However, due to the sampling regime, no data was collected between 300 and 3500 m, so it is not clear whether a gradual change in conductivity exists between these two points or whether a sudden increase occurs somewhere between these sites. The source of the increase may be a stream or groundwater input that contains high ion concentrations. Also, since a high increase is first noted at 3500 m, which is in the midst of a ripple, another reason for the increase may be due to higher flow rates. The high water velocity found in the ripple would increase the rate of mechanical and chemical weathering of rocks and substrate and, thus, would increase ion and mineral concentrations (Schlesinger, 1997). Since PC does not contain any ripples, this fact would explain why no significant spatial changes in conductivity were found there. Another observation noted that the conductivity greatly increased after a heavy rain event. This increase is most likely due to an increase in surface runoff containing sediment and soil high in ions and minerals (Schlesinger, 1997). A brief survey of conductivity in TC was performed after experimentation to reveal whether or not a gradual increase in conductivity occurred between 300 and 3500 m. However, data was again collected about 40 hours after a heavy rain storm, so conductivity levels were relatively high. Interestingly, no increase in conductivity occurred at 3500 m, which had been the case on all sampling days, even the last one. If this increase had occurred during the survey, then the increase in conductivity could have been attributed to the riffle. One difference between the last sampling day and the survey day, however, was that a number of beaver dams on TC had been cleared. This factor combined with the recent rain caused water levels and flow rates to be much higher than on previous days. Thus, the effects of a stream or groundwater input may have been imperceptible on the survey day due to additional lake water and surface runoff.

A statistically significant increase in ammonium concentrations versus distance downstream was found in TC, while no other statistically significant results were found concerning spatial or temporal differences in water nutrients. As previously mentioned, these statistics may be somewhat inaccurate due to the fact that no values between 300 and 3500 m were present. However, if phosphorus is the limiting nutrient in the creek, which is normally the case (Allan, 1995), then this may explain why SRP never increased while ammonium did. More nitrogen was entering the stream from various outside sources than was needed by the organisms, and, thus, ammonium concentrations slowly built-up downstream. However, SRP was not able to increase due to constant uptake by organisms. Another factor regulating SRP and ammonium concentrations is sorption onto sediments, although SRP is more strongly affected than ammonium (Allan, 1995). Hence, the SRP concentrations in TC may be partially controlled by sorption while ammonium is able to avoid sorption more easily. No temporal changes were seen in SRP or ammonium, which suggests that spring turnover in the lakes did not cause higher level of nutrients in the streams when compared to stream nutrients during summer stratification. Low SRP levels were obtained the last day of sampling after the rainstorm. Robson, et al. (1993) found that the water chemistry of high flow rain events influences stream chemistry. Since rain water is much more dilute that stream water (Allan, 1995), heavy rainstorms would tend to decrease chemical concentrations, which is what was observed in this study.

With the exception of ammonium in TC, no statistically significant temporal or spatial differences were found in Tenderfoot or Plum; thus, I fail to reject the null hypotheses. These results suggest that stream water is merely a continuation of lake water and that this water retains its chemical and biological characteristics until an outside source (e.g. groundwater, a spring, etc.), event (e.g. heavy rain), or physical feature (e.g. a ripple) alters its make-up. Thus, people need to keep in mind that whatever they put into lakes will not only affect the lake ecosystem but will also alter the lake outflow stream for a variable distance downstream, depending on where outside inputs come into play.

Future experimentation should include more streams and replicate samples at each site. In addition, sample sites that are farther apart (possibly about every ½ km) should be used so that greater changes can be seen in water nutrients. Creeks without stream or groundwater inputs could also be compared to those with inputs to note the difference between the two. In addition, hydrolabs could be used to compare lakes and their outflowing streams during spring turnover and summer stratification to determine any temporal differences.

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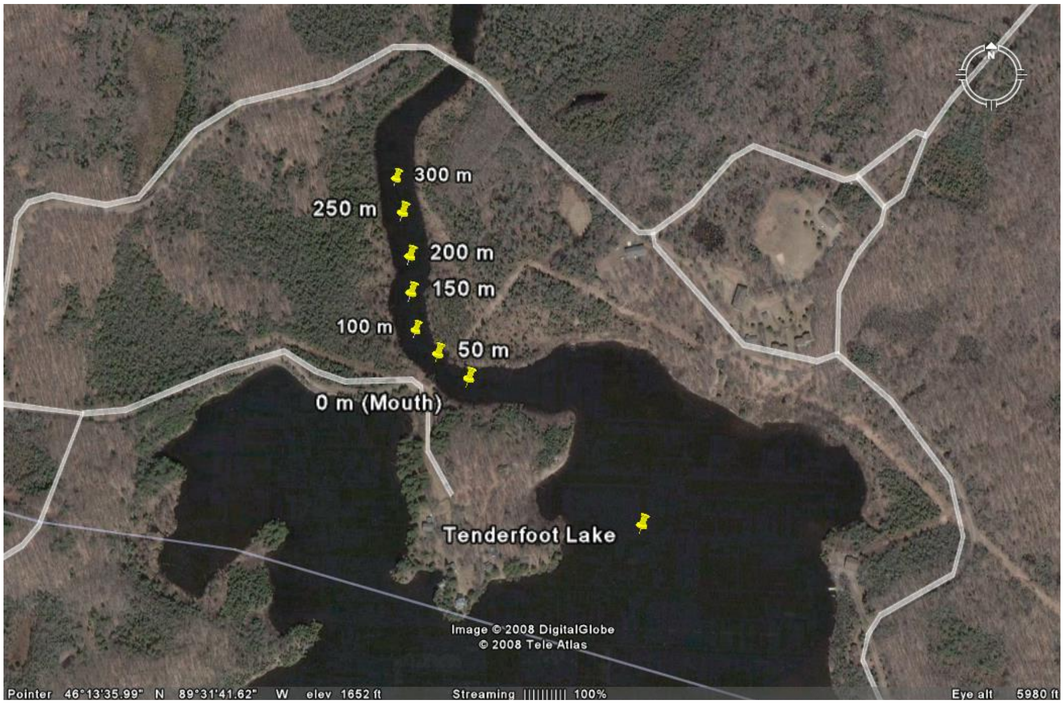
Appendix

Appendix 1. Map of sites on Tenderfoot Lake and Creek. Ten sites were used for experimentation on Tenderfoot. The first site was in the epilimnion of the lake and the last 9 sites were at 0 (the mouth), 50, 100, 150, 200, 250, 300, 3500, and 4000 m downstream. TC is slow-moving and relatively wide and contains a riffle around 3500 m downstream.



Appendix 2. Map of first eight sites on Tenderfoot. The first 8 sites in Tenderfoot are relatively close together compared to the last 2 sites (3500 and 4000 m) and are found in the lake and at 0, 50, 100, 150, 200, 250, and 300 m downstream of the mouth.

Appendix 3. Map of sites on Plum Lake and Creek. Ten sites were used for experimentation on Plum. The first site was in the epilimnion of the lake and the last 9 sites were at 0 (the mouth), 25, 50, 100, 150, 200, 250, 300, and 500 m downstream. Plum Creek is a narrow, slow-moving creek with no true riffles.