Post Restoration Evaluation of a Natural Stream Channel Design Project on Big Bear Creek

Presented to the faculty of Lycoming College in partial fulfillment
of the requirements for Departmental Honors in
Biology

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April 24, 2008

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Introduction

Human and natural disasters have vast impacts on streams and rivers. However, human impacts can be much more destructive than natural catastrophes. The lack of riparian buffers near streams allow for excess runoff containing high levels of phosphorus, nitrates, and sediments to be dumped into the stream. Mining for fossil fuels can cause sources of acidity and toxic metals to precipitate out into the stream lowering the pH to levels where aquatic organism can not survive. Both mining and acid precipitation have had heavy impacts on the northeastern United States streams also lowering pH levels. In the Northeast several hundred lakes and streams are threatened by acid deposition (Miller and Spoolman, 2008). Dams have been placed on streams to control flooding, but also cause build-up of sediments, fish migration blockage, and the change in the streams fluvial processes are all consequences of the barrier. More than 40% of the world’s 237 largest rivers have been impacted by dams or canals (Miller and Spoolman, 2008). Human impacts coupled with natural disasters often lead to the devastation of streams and rivers. Studies have shown that fluvial aggradation and degradation in the eastern United States were caused by human induced base-level changes from processes including milldam construction, deforestation due to logging, and agricultural practices all of which influenced increases in sediment supply (Walter and Merritts, 2008). There are immense efforts going on to repair individual streams, thus restoring the watersheds as a whole. Recently there has been a large discussion in the literature about finding the “silverbullet” to restoring streams to their “natural (pre-colonial) state”(Bernhardt *et al.*, 2005). One relatively new process is Natural Stream Channel Design (www.keystonestreamteam.org) which is used to re-channelize the stream and help control bank erosion. Natural stream channel stability is achieved by allowing the river to develop a stable dimension, pattern, and profile such that, over time, channel features are maintained and the stream system neither aggrades nor degrades (Rosgen, 1996).

Natural stream channel design has grown into multibillion-dollar stream restoration industry. Centuries of human influences can mask historically distinctive river forms in and among regions around the world (Montgomery, 2008), making it difficult to determine the “naturalness” of a stream. Early fluvial geomorphological studies conducted in 1950’s by Luna Leopold, M. Gordon Wolman, and their colleagues contributed to the standard model of how the interaction of hydraulics and sediment transport contour river and stream channels. These studies have been elaborated upon and provide the basis for “Natural Channel Design”, which is used in several restoration projects across the United States, including Big Bear Creek (Montgomery, 2008).

Big Bear Creek is a third to fourth order stream nestled in a 17 mi^2 watershed that is 80% forested. It is a tributary of the Loyalsock Creek located in Lycoming County, Pennsylvania. The creek has suffered several devastating events including a removal of a 100-year-old dam and several hurricanes. In the 1800’s a woolen company dammed the creek to secure water for its operations. For the next 100 years, sediments collected behind the dam. In 1991, the Dunwoody Club approached the PA DEP to remove the dam in stages to control sediment flow into the stream. In the process of receiving permits to remove the dam it was discovered that the state had no recorded of it and it was considered a hazard and had to be removed promptly. The Club was giving 48 hours to remove the dam, thus the large amount of sediment flow into the stream.

In 1972 hurricane Agnes caused sever damage to the stream. As a result of Agnes the channel was straightened at the bottom of the watershed to clear gravel and debris from the channel and pass flow under a State Route 87 highway bridge (DRN, 2000). In 1975, flooding from tropical storm Eloise caused destruction of the riparian vegetation along the majority of the stream. Gravel bars and logjams formed with the strength of the water and the channel was forced against the mountainside causing erosion and several bank slides which ultimately landed in the stream. Sediment supply from bank erosion prior to restoration was approximately 2, 124 yard^3/year. Roughly 1,101 yard^3 originated from four slide areas (USFWS 2002). Between the hurricanes and the dam removal, substrate released was flushed down the stream and filled in pools, created mid-channel bars, transverse bars, and in some instances, channel avulsions (USFWS 2002). The newly distributed sediment and substrate caused the stream to become wider and shallower. At the same time this occurred, the Dunwoody Club members noted significant bank erosion and loss of fish population size (especially trout).

In 1993, the Club began taking step to restore the stream. Water chemistry data and flow conditions had been recorded along with the insulation of 14 experimental log structures in 1996. The log vanes maintained stream velocity and increased sediment transport by concentrating flow; they also prevented erosion by protecting the channel sides (DRN, 2000).

In 1997, the United States Fish and Wildlife Services determined that Big Bear Creek was an excellent candidate for a natural stream channel design project. The overall project treated 3.5 miles of the stream and included more than 200 instream structures, making it the second largest demonstration project of its kind in the eastern United States at that time (USFWS 1). The project started in 1999 and took over 3 years to complete, with yearly fine-tunes, repairs and removals of some structures. Several types of structures were placed in the stream including, J-hook rock vanes, rock cross vanes, and log cross vanes. All are used to correct channel avulsions.

The structures are unique because they “roll” the water in the desired direction based on the fact that water will pass over the structure at a 90 degree angle, rather than “push” the water, like many traditional structures attempt to do (Kratzer, 2000). Focusing the water flow into the center of the channel aids in sediment up take, which will then be carried downstream and it dredges the channel back to original depth. The structures create a slack water area near the banks where the sediment load is caused to fall out of suspension and deposit along the shore where it can build up the banks and keep the channel open (Smith, 2001). These structures are effective at all flow levels. The series of structures maintain slope and stability through riffle/pool patterns. The sequence of riffles and pools creates optimal trout habitat in the pools and fine macro-invertebrate habitat in the riffles (Rosgen, 1994).

Since 1999 a total of three independent study projects and seven Honors projects by students from Lycoming College have utilized the Big Bear Creek site (see Appendix A for history/summary of projects). The main objective of this current research is a five year follow up assessment of the entire stream. The original purpose of the restoration project was to stabilize the stream channel, reduce bank erosion and improve fish populations (especially trout). To assess the progress of these goals, this project includes 5 focus areas: habitat structure assessment, water chemistry data, benthic macro-invertebrate community data, fish community population data and a food preference study by Slimy Sculpins (*Cottus cognatus*). These 5 major focus areas will be used to make an overall assessment of the stream and determine if the stream has rebounded successively from the previous construction.

Methods and Materials

The Big Bear Creek study area is owned by the Dunwoody Club and over the last 8 years 16 different sampling sites have been monitored. In this study three representative sites #s, 2, 11, and 16, (representing the upper, middle, and lower sections of the 3.5 mile study) have consistently been sampled since 1999. Site 2 is located just down from the Dunwoody Club. This site is 200m long and includes 2 J-hooks, 3 cross vanes, and 1 pool forming structures. The majority of the site consists of a riffle area. Site 11 is also known as the Red Bridge site, due to the bridge that was constructed over the stream. Facing upstream from the bridge is one of the original log cross vanes constructed in 1996. This site is 200m long and includes 4 cross vanes. The majority of the site consists of a riffle area. Site 16 is also known as Finkler's Furnace. This Site is 200m long and includes 3 J-hooks and 1 cross vane. The majority of the site consists of a run area.

A habitat assessment using EPA's Rapid Bioassessment Habitat Assessment Protocol (Plafken *et al.* 1989) was conducted on all 3 study sites. This assessment relies on the researcher's interpretation of twelve habitat parameters and assigns a score from 0-20 for each parameter (Kratzer, 2000). In addition, an erosion assessment form was also completed. Erosion assessment scores the potential for bank erosion using several parameters such as bank height, bank angle, density of roots, and particle size.

Macrohabitat data were collected by walking the length of the stream to determine the number and percentage of pool, riffle, and run communities. Macrohabitats are important niches to the benthic aquatic insects that inhabit them. These insects make up the base of the food chain for the higher trophic level organisms. Adequate macrohabitats can be a biological indicator of stream health due to the organism that live in each of the environments (Smith and Smith, 2001). Percentage macrohabitat types before restoration in 1999 was compared to after the 1st phase of restoration (in 2002) and after the final phase in 2007. Pool, riffle, and run percentages were compiled via pie graphs. Each site was also surveyed to determine length and width of riffle, run and pools within the individual site.

An overall survey of the Rosgen style Natural Stream Channel Design structures was conducted in the Fall of 2007 and Spring of 2008. Since the “as built” survey was completed in 2004, U.S Fish and Wildlife has gone back in each year 2005, 2006 and fall 2007 to fine-tune, repair and remove some structures. During this survey the 3.5 mile stretch of stream was walked and each structure was photographed, measured, given a status report, pool depth and GPS navigation points were taken. This up-dated data was compared to the original “as built” survey of the stream and determined which structures were still in place and functioning. These data will not only document whether the Rosgen boulder structures were a success in maintaining and restoring the stream, but provides documentation of fish population and health.

Water samples were collected using grab samples in 500-mL containers at the 3 study sites on the stream and analyzed within a twenty-four hour period. Several parameters of water chemistry were analyzed in the lab. These included nitrate nitrogen (ppm), nitrite nitrogen (ppm), total phosphate (ppm), ortho phosphate (ppm), pH, alkalinity (ppm). The nitrate, nitrite, and phosphorus tests were run using HACH 5000 spectrophotometers and using Low Range (LR) assessments. The pH and alkalinity were analyzed using an Oakion 510 series pH meter and titration with 0.02N sulfuric acid. A pH reading is taken at the beginning and then titrated with 0.02N sulfuric acid to a pH level near 4.5. The level of the titration is then multiplied by ten to calculate alkalinity values. Field analyses of temperature (˚C) and dissolved oxygen were analyzed using a YSI 55 DO meter. Conductivity (µS) was analyzed using an OAKTON CON 410 Series meter. Water samples were processed to determine the water quality and possible effects on fish and other aquatic life, giving an overall look at the value of the stream. Due to previous studies on Big Bear Creek alkalinity levels are shown to be low, thus the U.S Fish and Wildlife organization started a new project of using calcium bicarbonate lime to buffer against the acid deposition influences on the stream. The lime is expected to raise alkalinity levels.

To collect the macro-invertebrates two methods were used. A Surber sample and a kick sample. A Surber sample grid is placed in a riffle area of the stream, and then all macro-invertebrates in the square foot grid are collected in the net. With the Suber sample method several other tools are needed. A stiff brush, trowel, bucket, wide mouth jar (for samples collected), 70% ethanol (preservation of sample), forceps, and a sieve with number 30 screen. Once the organisms are collected, they are sieved and then placed in the jar. A kick sample is taken with two individuals, one holding the kick net and the other kicking the stream gravel. This kicking action will cause the organisms to come free and then the current will sweep them into the net. The organisms then should be placed in a collection jar. Due to the larger sample area, kick samples tend to have larger amounts of organisms. Both kick and Surber had the standard 500 µ mesh netting (Rabeni, 1999). Benthic macro-invertebrates where collected throughout the months of September-November 2007 and March 2008. Macro-invertebrate population density and diversity was assessed using the Rapid Bioassessment protocol II (Plafkin et al, 1989). Samples of macro-invertebrates were collected at Site 2, Site 11, and Site 16. Each sample was sorted through collecting and identifying the macroinvertebrates to genus level (Merrit and Cummings, 1988). These data were compared to previous data on Big Bear Creek from 1999-2006. Once identified to genus each taxa was assigned a feeding category, such as scrapers, shredders, predators and collectors. Information on changes in macro-invertebrate community, help determine overall stream health.

Fish population survey data were collected at the 3 study sites September through October 2007 utilizing two Smith-Root model 1500 backpack electro-shockers. Two 200m passes with the electro-shockers were done at each of the sites. For each of the sites the fish were measured (cm), weighed (gm) and identified. Population densities were determined using "Micro-Fish" software, 1998. The dominate species being Brown Trout (*Salmo trutta*), Brook Trout *(Salvelinus fontinalis)*, and Slimy Sculpins (*Cottus cognatus*). Data were used to calculate young-of-the-year trout populations, biomass, and length/weight-frequency graphs. Population data was compared with past studies (1999-2006) to determine whether density fluctuations were positive or negative.

A Kruskal-Wallis statistical test was used to determine significant differences between years for macroinvertebrate densities as well as fish densities. This is a useful test when you have more than two data groups (in this case years), and you wish to test for difference between all of the groups at the same time (Glase *et al.*, 1979) (Steel and Torrie, 1960).

A sub-sample of 20-40 Slimy Sculpins (*Cottus cognatus*) were collected during electro-fishing at the three previously mentioned sites and preserved in 10% formalin to examine the stomach contents. Data collected from the dissections was used for a food preference study on this species. Microscope analysis and visual identification of food types (macro-invertebrates, detritus, other) was used to determine stomach content. It could also determine behavioral elements of the sculpins and provide information about the macro-invertebrate populations.

Results/Discussion

EPA Habitat Assessments and Erosion Assessments (following Plafkin *et al.*, 1989) improved since pre-restoration. Tables 1 compares the habitat assessments scores of the 3 sites pre-restoration (1999) and post-restoration (2007). The largest total percentage increase in habitat score was site 16 which increased 7%. Site 11 increased by 3% and site 2 increased by 1%. However the major habitat parameter which increased at all sites the most was condition of the banks (parameter # 9). This was one of the main goals of the restoration project. Before restoration high amounts of erosion washed away sediment from the mountainside bank. Sediment supply for bank erosion before restoration (prior to 1999) was estimated at 2, 124 yard^3/year (USFWS, 2002). Since the construction of the Rosgen-style fluvial geomorphological structures have reduced the stress on banks, thus reducing mass wasting and bank erosion. Estimated reduction in annual sediment production by Big Bear Creek is 2, 124 yard^3/year (USFWS, 2002). Although the sites did not differ greatly in habitat quality, one habitat parameter remained low across all 3 sites which was instream cover for fish (parameter #1). Instream cover for fish remained a low parameter throughout the entire stream. The lack of cover could possibly have direct affects on trout populations. The introduction of woody debris such as root wads influences both physical and biological features of forested stream ecosystems and is generally recognized as a structural element that provides crucial habitat for stream salmonids (Warren and Kraft, 2003). In another study focusing on Brook Trout response to wood removal from a stream resulted in population decrease. A decrease in habitat, showed decrease in trout abundance following wood removal, thus displaying the direct correlation between habitat and population (Warren and Kraft, 2003). A possible solution could be adding more instream fish habitat to Big Bear Creek to encourage populations of trout to reproduce and mature.

Table 2 summarizes the erosion assessment scores. Erosion assessment resulted in site 2 and 16 having low potential for erosion. These sites had low bank heights, high/moderate root densities, and boulder/large cobble bank substrate. Site 11 had moderate potential for erosion on the left bank facing upstream. The left bank had a high bank height, low root density, and sand/clay bank substrate, thus increasing potential for erosion during high flow events.

Macrohabitats (riffle, runs, pools) provide important environmental niches for macroinvertebrates and fish that inhabit the stream. As seen in Figure 1, before restoration the majority of the stream was 51% run and 42% riffle. In addition 6% of all Runs had subsurface flow providing little habitat for macroinvertebrates or fish. When compared to after the 1st phase (2002) of restoration the percentage of run macrohabitat decreased and riffle area increased to 62%. By 2007-2008 the restoration effort and natural flow patterns resulted in the stream divided up equally with 32% each in riffle and run and pool macrohabitat having the highest percentage of 36%. While the entire stream is divided equally between riffle, run and pool macrohabitats, individual sites can vary differently. As seen in Figure 2, the majority of the 3 main sites (2, 11, 16) consisted of riffle but with varying degrees of pool and run macrohabitats. Although the riffle areas were larger (ranging from 51% to 70%), an established succession between the riffles, pools, runs did occur at the sites. The sequence of riffles and pools creates optimal trout habitat in the pools and excellent macro-invertebrate habitat in the riffles (Rosgen, 1994).

When the initial phase of restoration was complete and an “as built survey” was done (2002), there were 123 Rosgen-style structures in place. During the fall with low flow condition 122 structures were photographed, given a GPS location and status report (see Appendix B). Table 3 compares the type of habitat structure from the first survey (2002) until now. When compared to the original structure map 123 structures were present. The recent survey shows 53 cross vanes, 51 j-hooks, 9 bank stabilizers, and 9 woody habitat elements.

Appendix C summarizes the raw water chemistry data. Water chemistry data collected and analyzed in 2007 was compared with historical data to determine any changes in water quality (see Figures 3-6). As seen in Figure 3, pH has relatively stayed the same over several years. Alkalinity data has continued to remains low (< 10ppm) as shown in Figure 4. Alkalinity is an expression of buffering capacity which is the waters capability to neutralize acid. This is important to help maintain stream pH which, in turn makes the stream more suitable for aquatic life. For protection of aquatic organisms the buffering capacity should be at least 20 parts per million (ppm) (Clesceri *et al.* 1998). Levels range between 6 and 10 ppm during summer and fall months. Seasonal fluctuations in alkalinity have been recorded as shown on Figure 5. This is most likely due to acid deposition of spring snow melt and precipitation. The excess acidity of the runoff water caused the drop in pH. Any pH values lower than 6.5 might inhibit the ability of Brook Trout to reproduce and values lower than 5.0 could inhibit Brown Trout reproduction (Peterson *et al.,* 1982). Brook Trout tolerate pH values from 4.1-9.5 but do very poorly in streams with a pH of less than 5.0 due to associate decreases in blood pH and the ability of blood to transport oxygen (Lovich and Lovich, 1996). pH levels could be stressing the Brook Trout populations, therefore resulting in the decreased population. Alkalinity levels ranged between 1 and 2 ppm during the spring months. Spring is also the time at which trout are most sensitive to low pH since the fall-spawned eggs are hatching (Peterson et al. 1982).Due to the low alkalinity levels on Big Bear Creek the U.S Fish and Wildlife organization started a new project using calcium bicarbonate lime to buffer against the acid precipitation influences on the creek. The bicarbonate lime was dispersed onto the road in hopes that excess runoff would carry it into the stream raising alkalinity levels. The bicarbonate lime is capable of remediating acidic streams because it dissolves in acidic water and is widely distributed by flowing water in high gradient headwater streams (LeFevre and Sharpe, 2002). One study in southwestern Pennsylvania used limestone sand to treat an acidic stream. After one year of monitoring water quality, macroinvertebrates, and fish, they concluded that the limestone sand treatment was only partially successful (LeFevre and Sharpe, 2002). Although Big Bear is not highly acidified and the addition of bicarbonate lime is simply to help buffer, not treat, outlooks of this current project are promising. However, it is important to continue to monitor the bicarbonate lime project to determine if alkalinity levels have increased.

Conductivity is the water's capacity to conduct an electric current due to the dissolved ion concentrations. Conductivity levels (see Figure 6) ranged between 4. 95 and 22µs/cm when compared with years 1999 and 2002 data. Greater than 100µs/cm is recommended (Clesceri *et al.* 1998), to support good mixed fisheries populations. Nitrate levels remained low during the sampling months and across comparisons with years 1999 and 2002 data. Nitrate levels ranged between <0.2 and 1.8ppm. Values below 3 ppm are recommended to keep eutrophication of lakes and streams to a minimal (Clesceria *et al.* 1998). Phosphate is one of the nutrients which is least abundant in aquatic ecosystems. Total Phosphorous levels ranged between <0.2 and 1 ppm when compared with years 1999 and 2002 data. Values below 3 ppm are recommended to decrease the risk of eutrphication (Clesceria *et al*. 1998).

Conductivity, nitrate, and total phosphorous levels remain low. Conductivity reached a maximum of 22.2 µs/cm in 2007. The conductivity of rivers in the United States generally ranges from 50 to 1500 µs /cm (EPA).These data are significantly lower than the general ranges. Nitrate and total phosphorous levels remain below 2ppm. Both nitrogen and phosphorous enrichment can lead to eutrophication. Essential to monitoring of pH, alkalinity and other water chemistry parameters is needed to help keep the stream healthy not only for native trout species but other aquatic organisms as well.

Appendix D contains the classification summary of macroinvertebrates for all sites. As shown in Figure 7, macroinvertebrate densities have increased 10 fold since pre-restoration. From July 1999 through June 2003 recorded densities were less than 200 organisms/ meter^2. November 2007 and March 2008 data shows densities ranging from 200 to 1600 organisms/meter^2. Kruskal-Wallis statistical test determined a significant difference at $\alpha = 0.05$, in macroinvertebrate density (Org/m^2) occurred between the mean of (32.3 ± 16.95 Org/m^2) for 1999 data compared to (658.3 ± 463.05 Org/m^2) for 2007/2008 data. This indicates that macroinvertebrate density has responded significantly pre and post construction. This is a similar response noted by (Matthaei *et al.,* 1996), who also recorded a 3-6 fold increase after a habitat restoration project that utilized a mixture of rock and wood structures. Total taxa and total EPT taxa data have been compared from years 1999 and 2002 as shown in Figures 8 and 9. These data show that both total taxa and EPT taxa increased in 2002 (ranging from 11 to 23 taxa) and decreased in 2008 (ranging from 9 to 18 taxa).

Macro-invertebrates are important part to any aquatic environment. Most of these macro-invertebrates prefer a riffle-dominated area where flow permits much organic material to pass by and where dissolved oxygen levels are highest (Holmes, 2004). As seen in Figure 7, Macroinvertebrate densities have increased over time since 1999. With the restoration producing a more stable system, this allows the macroinvertebrates to colonize more easily (Smith, 2001). Increased macroinvertebrates densities will provide more food for trout, thus possibly having a direct affect on trout populations. Figures 8 and 9, show decrease in total taxa and EPT taxa during 2008. Reasons for the high numbers in 2002 is that sampling occurred in the summer, while 1999 and 2008 sampling occurred in the month of March. Although macroinvertebrate densities are higher, there has been a shift to fewer taxa and fewer EPT taxa. Even though there are fewer taxa, there is no indication of weakened macroinvertebrate populations.

Invertebrate feeding groups include predators, shredders, collecting gatherers, scrapers, and filtering collectors. All 3 sites were compared with pre-restoration and the year 2002 data as shown in Figure 10. Pre-restoration and 2002 data show that collecting gatherers were the dominant feeding group. Ephemeroptera make up the majority of the collecting gathering macroinvertebrates. 2008 data shows a shift in feeding groups from collecting gatherers being the dominant group to scrapers and filtering collectors. Trichoptera and Coleoptera make up the majority of these groups. Changes in habitat from construction caused different amounts of course particulate organic matter (CPOM) and fine particulate organic matter (FPOM) to enter the stream. The change in food source caused the shift in taxa. These data support the shift in total taxa and EPT taxa as mentioned above. This shift in taxa also supports the Sculpin stomach content analysis study (see below).

Fish data were compared across the sites and with historical data to determine any changes in population density. Appendix E shows the “Micro-Fish” Software analysis of density. As shown in Figure 11, during the Fall 2007 sampling at each site, Slimy Sculpins (*Cottus cognatus*) are the dominant fish species in Big Bear Creek. Brown Trout (*Salmo trutta*) is the dominant Salmonid species. At all sites Slimy Sculpin densities were nearly four times the densities of Brown Trout and Brook Trout combined. One study suggests that Slimy Sculpin population sizes may be regulated more by availability of space and shelter than by invertebrate pray availability (Zimmerman and Vondracek, 2007). Similarly with the restoration producing a more stable system for macroinvertebrates, it has also produced more suitable habitat for Slimy Sculpin, thus the increase in population. Trout young-of-the year (YOY) populations resulted in

Brown Trout having the majority of young fish across the 3 sample sites shown in Figure 12. Fish were considered YOY if they were < 10 cm total length. Brown Trout YOY ranged from 3 to 23 individuals per section of creek. Brook Trout YOY ranged from 3 to 6 individuals per section of creek. These numbers suggest that Brown Trout spawning is more successful than Brook Trout. Figures 13 and 14, are length-frequency graphs which reveal that the majority of the trout population is less than 25cm long. Since the majority of the trout population is less than 25cm long, the bulk of weight is less than 125gm, with the largest fish weighing 300+gm. Biomass of the trout population ranged from 60 to 1300gm as shown in Figure 15. The greater part of the biomass fell into the length categories ranging from 8 to 16cm. This compliments the length and weight-frequency graphs mentioned above. In Figure 16, Trout population estimates using 95% confidence interval reveals that Brown Trout are out numbering the Brook Trout. As shown in Table 4, fish density/hectare data ranged from 110 to 256 brown trout and 76 to 107 brook trout. Averages were compared with 2002 data and show increases. Although overall fish density has increased over the years, there was no significant difference between the years as determined by the Kruskal-Wallis statistical test ($\alpha = 0.05$). Even though the 2002 study did not sample the exact same sites as this study, similar reaches of stream were sampled. Brown Trout/ha increased 56%, Brook Trout/ha increased 94% and total trout/ha increased 64%. Total fishes/ 200m were compared between 1999 and 2002 data (see Figure 17). These data show that at site 2 in 2007 the number of fish decreased and increased at site 11 and 16. During Fall of 2007, construction occurred at site 2, and data shows a significant decrease in both Brown Trout and Brook Trout. Recent research suggests that Brook Trout sensitivity to small changes in habitat quality makes them potentially susceptible to global and regional changes including acid deposition from precipitation (Lovich and Lovich, 1996). Brown Trout may have a competitive advantage over Brook Trout in disturbed habitats (Zimmerman and Vondracek, 2007). This might possibly be due to their larger size and more aggressive nature. It is important to note that Longnose Dace (*Rhinichthys cataractae*) and Blacknose Dace (*Rhinichthys atratulus*) were recorded having small populations in the stream prior to restoration. Figure 17, shows at site 16, Longnose Dace was present in 1999, since then these species have not been collected during electroshocking. These species are considered intolerant and it is possible with the decline of habitat during construction and low population numbers to begin with caused the extirpation from the stream. Plunges in pH and alkalinity could have also affected the species making the stream unsuitable for survival. Electroshocking population estimates were compared over the 3 sites for multiple years as displayed in Figure 18. While population estimates are above that of year 1999, populations have decreased since then from 2001-2002. Brown Trout population has increased and brook trout population is shown to have decreased. It is expected that trout populations will increase over time because trout prefer the slower and deeper water of pools with cobble substrates that were shown to be produced by the restoration structures (Hayes and Jowett, 1994). Monitoring of fish populations should continue as the macroinvertebrates populations and habitat improves.

Slimy Sculpin stomach analysis resulted in 91 fish being dissected for stomach analysis. As displayed in Figure 19, the majority of identifiable content revealed Trichoptera being the dominate food source. The second largest group was unidentifiable. These fish were usually 1” or less and were most likely feeding on midges or algae. Sculpin stomach contents from 1999 shows that Trichoptera was also the major food source.

Sculpins are small, bottom dwelling fishes with a large mouth, prominent eyes, and very large pectoral fins (Cushing and Allan, 2001). These large pectoral fins grip the substrate to allow the fish to dart swiftly from rock to rock in fast moving current. Sculpins forage for macroinvertebrates in various habitats including rocky-cobble streams to sedimentary bottoms. The major food source was Trichoptera, followed by unidentifiably midges and algae parts. In one study focusing on the Black Sculpin diet, Diptera, Ephemeroptera, Trichoptera, Coleoptera, and Plecoptera comprised 98.8% of the total number of food items. *Hydropsyche, Cheumatopsyche, and Glossosoma* were the most common Trichopterans eaten (Earl, 2005). *Hydropsyche* and *Cheumatopsyche* are the two most abundant Trichopterans in Big Bear Creek, thus the large percentage eaten. Prey preference is a direct correlation with prey frequency and location. Trichopteran larvae can often be found on the undersides of stones, giving its prime location to where the Sculpin forage a larger percentage will be eaten due to the convenience for the fish. There is no indication of Sculpin predation on trout eggs, thus the hypothesis of declining trout populations due to Sculpin predation can be ruled out. Specific studies involving Sculpin and trout eggs revealed no eggs or their remnants in the stomach content, but did find invertebrate consumption (Clary, 1972). This study complements the finding in Big Bear Creek. In turn many biologist consider Trout-Sculpin ecosystems desirable, believing that the Sculpins constitute a major source of trout food, although the Sculpin constitute is but a very small part of the Trout diets (Clary, 1972).

Conclusion

In completing this study, the need for further monitoring in several areas is documented. Continued monitoring of water quality to assess the bicarbonate lime project and monitoring of trout populations to determine if Brook Trout populations will recover is needed. The Rosgen-style structures have provided sufficient habitat for trout populations, but supplemental habitat additions such as root wads or other woody materials add to fish habitat improvements on Big

Bear Creek. To date the restoration has stabilized the banks and restored macrohabitats of riffles, runs, and pools. Macroinvertebrate (fish food) densities have increased significantly. There appears to be a shift in fish populations (although densities are not significant at this time) to include higher densities of Sculpins and Brown Trout. Big Bear Creek should continue to serve as a model for stream restoration in Northcentral Pennsylvania.

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Table 1: Habitat Assessment Scores, Comparison of Pre and Post Restoration

Site 2	**1999***	**2007**
Instream Cover	18	12
Epifaunal Substrate	20	11
Embeddedness	20	20
Velocity/Depth Regimes	14	14
Channel Alteration	20	18
Sediment Deposition	20	20
Frequency of Riffles	19	18
Channel Flow Status	7	17
Condition of Banks	2	16
Bank Vegetative Protection	19	15
Grazing or Other Disruptive Pressures	20	20
Riparian Vegetative Zone Width	20	20
Total	**199/240=83%**	**210/240=84%**

Site 11	**1999**	**2007**
Instream Cover	20	10
Epifaunal Substrate	17	15
Embeddedness	18	18
Velocity/Depth Regimes	20	18
Channel Alteration	14	18
Sediment Deposition	17	19
Frequency of Riffles	18	18
Channel Flow Status	13	18
Condition of Banks	10	16
Bank Vegetative Protection	11	12
Grazing or Other Disruptive Pressures	15	20
Riparian Vegetative Zone Width	14	18
Total	**187/240=80%**	**200/240=83%**

Site 16	**1999**	**2007**
Instream Cover	17	10
Epifaunal Substrate	20	16
Embeddedness	19	19
Velocity/Depth Regimes	9	16
Channel Alteration	20	18
Sediment Deposition	10	19
Frequency of Riffles	20	18
Channel Flow Status	7	14
Condition of Banks	7	16
Bank Vegetative Protection	17	17
Grazing or Other Disruptive Pressures	20	20
Riparian Vegetative Zone Width	20	20
Total	**186/240=78%**	**203/240=85%**

* from Kratzer, Honors Project 2000

Table 2: Erosion Assessment-Spring 2008

Facing Upstream	Site 2	Bank Height	Bank Angle	Density of Roots	Particle Size	Stream Width (ft)	Length of Site (ft)
	Right Bank	Low	Low	Moderate	Low	10-25	501-1000
	Left Bank	Low	Low	Moderate	Low	10-25	501-1000

Facing Upstream	Site 11	Bank Height	Bank Angle	Density of Roots	Particle Size	Stream Width (ft)	Length of Site (ft)
	Right Bank	Moderate	Moderate	High	Moderate	10-25	501-1000
	Left Bank	Moderate	High	Moderate	Low	10-25	501-1000

Facing Upstream	Site 16	Bank Height	Bank Angle	Density of Roots	Particle Size	Stream Width (ft)	Length of Site (ft)
	Right Bank	Low	Low	Low	Low	10-25	501-1000
	Left Bank	Low	Moderate	Moderate	Low	10-25	501-1000

Table 3: Habitat Structure comparison from first survey (2002) until present

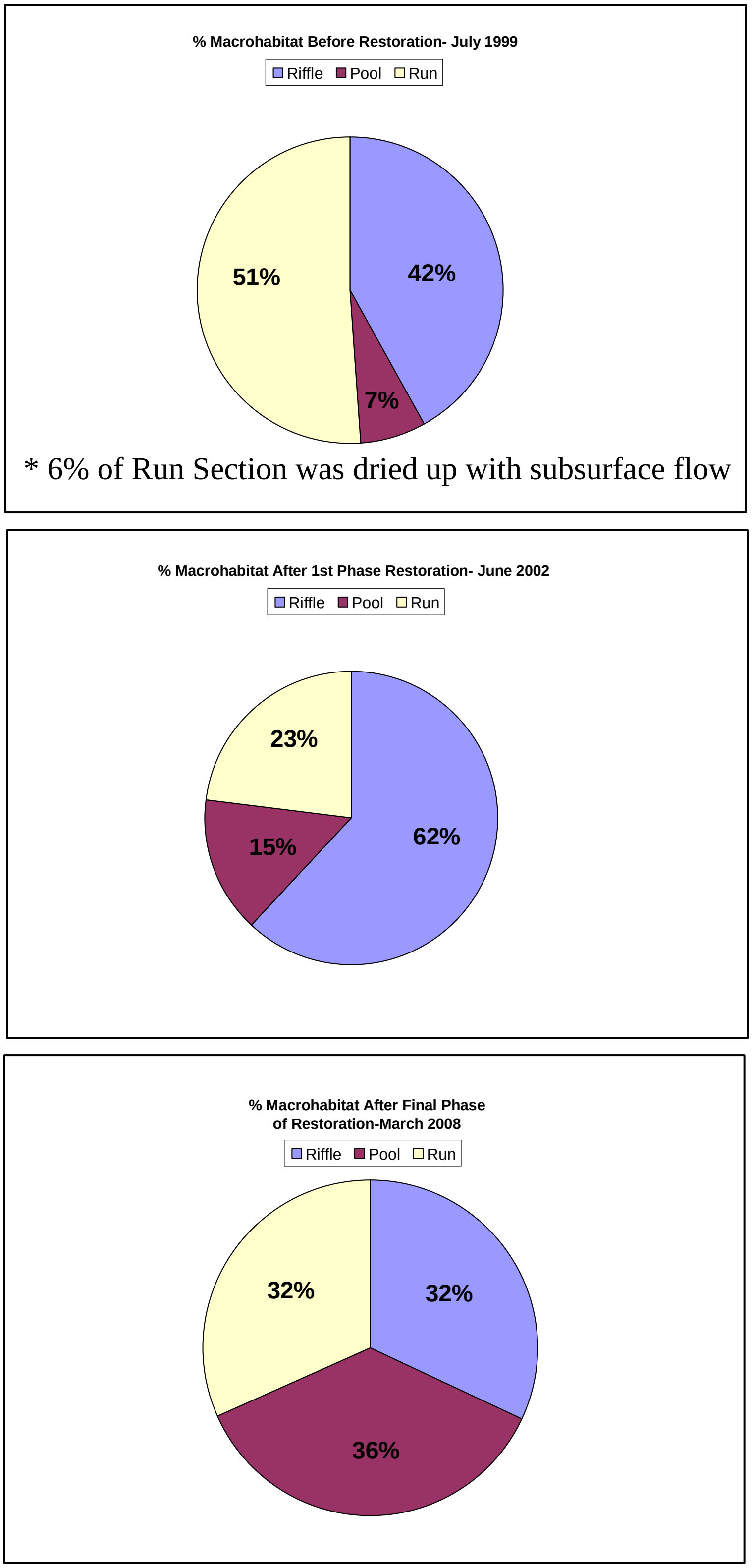
	2002	**2007-2008**
Cross Vane	**63**	**53**
J-Hock	**46**	**51**
Bank Stabilizers	**14**	**9**
Other (woody habitat/deflectors)	**0**	**9**

Table 4: Fish Density/hectare—Fall 2007

	Brown Trout	Brook Trout	Total Trout	Sculpins	Total Fishes
Site 2	110	76	186	686	805
Site 11	560	50	610	3630	4000
Site 16	256	107	363	1779	2200
Mean	309	78	386	2032	2335
2002 Mean	173	73	246		
% increase	56	94	64		

* 2002 data from Patten (2005)

Figure 1: Macrohabitat Percentage for entire stream, comparison of Pre and Post Restoration



% Macrohabitat Before Restoration- July 1999

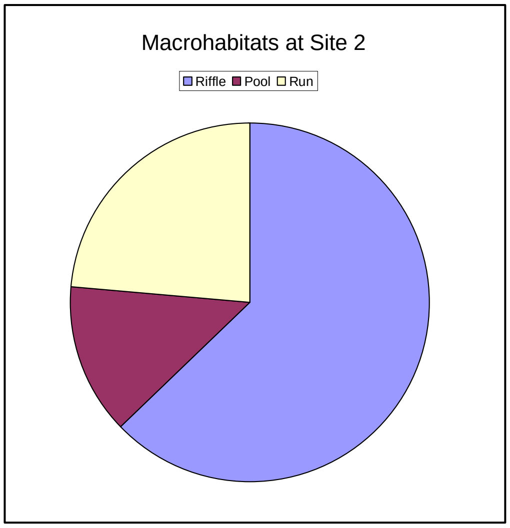
* 6% of Run Section was dried up with subsurface flow

% Macrohabitat After 1st Phase Restoration- June 2002

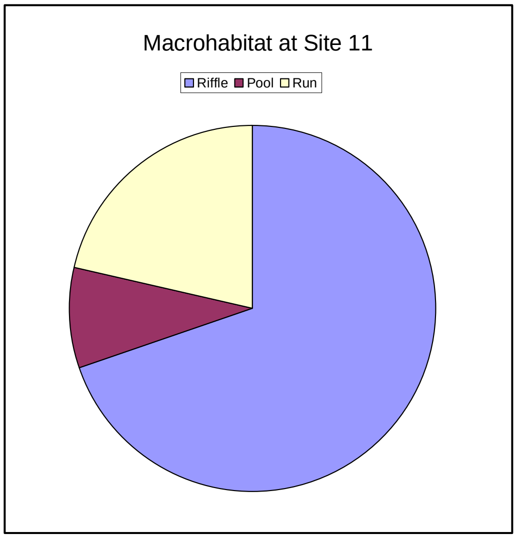
% Macrohabitat After Final Phase of Restoration-March 2008

- 1999 data from Kratzer, Honors Project
- 2002 data from Holmes, Honors Project

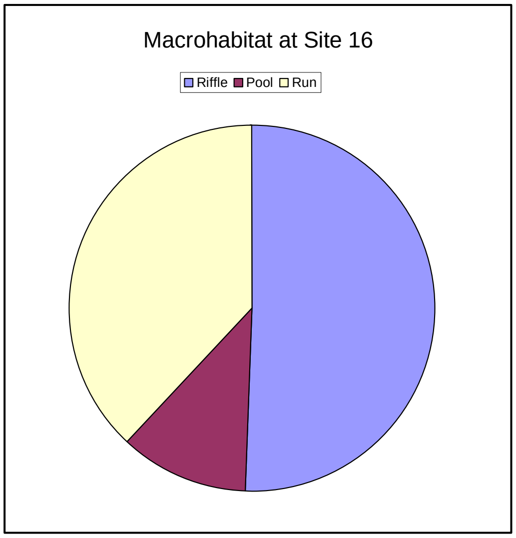
Figure 2: Length (m) of Macrohabitats at the 3 main sampling locations-Spring 2008



Riffle (m)	16.3 ± 15.37
Pool (m)	3.5 ± 2.17
Run (m)	6.16 ± 3.04



Riffle (m)	35.5 ± 31.82
Pool (m)	4.63 ± 0.25
Run (m)	10.83 ± 3.40



Riffle (m)	28.5 ± 14.85
Pool (m)	6.38 ± 3.15
Run (m)	21.5 ± 23.19

Figure 3: pH values over time at Big Bear Creek

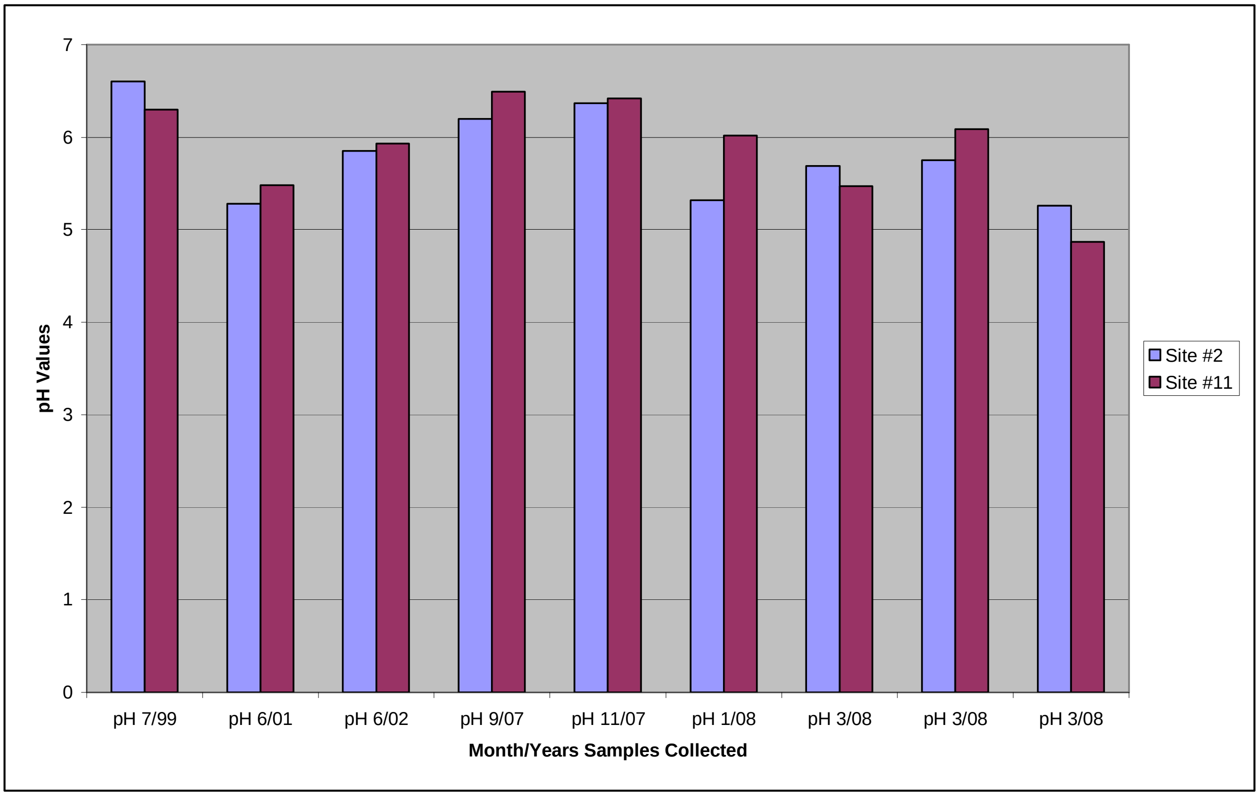


Figure 4: Alkalinity over time at Big Bear Creek

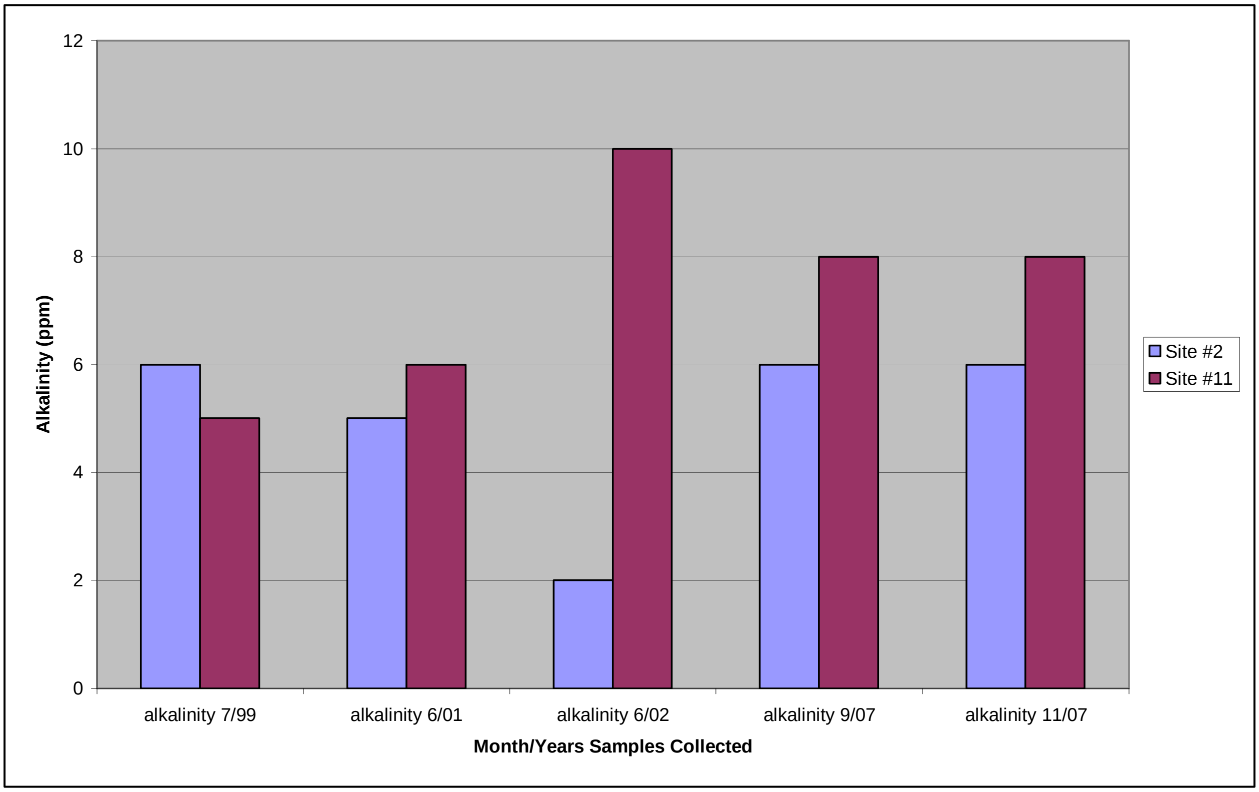


Figure 5: Alkalinity Seasonal Effect

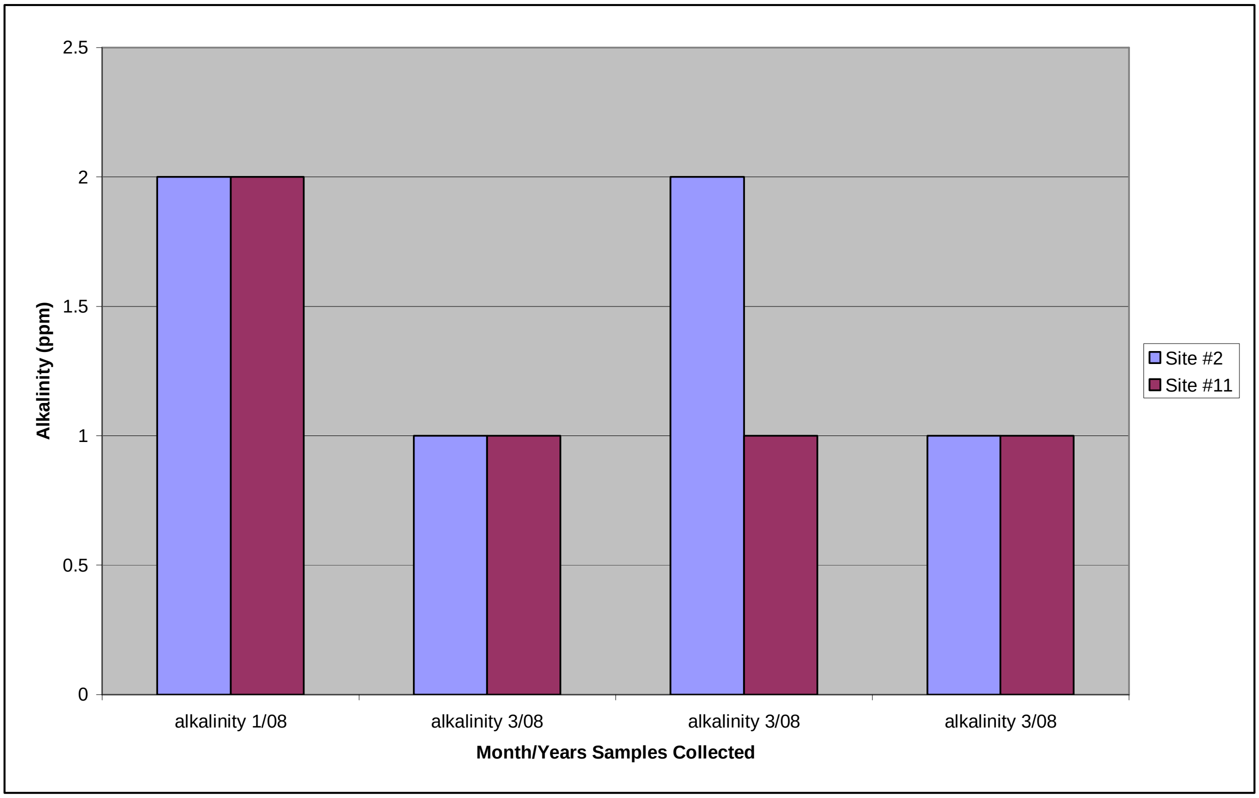
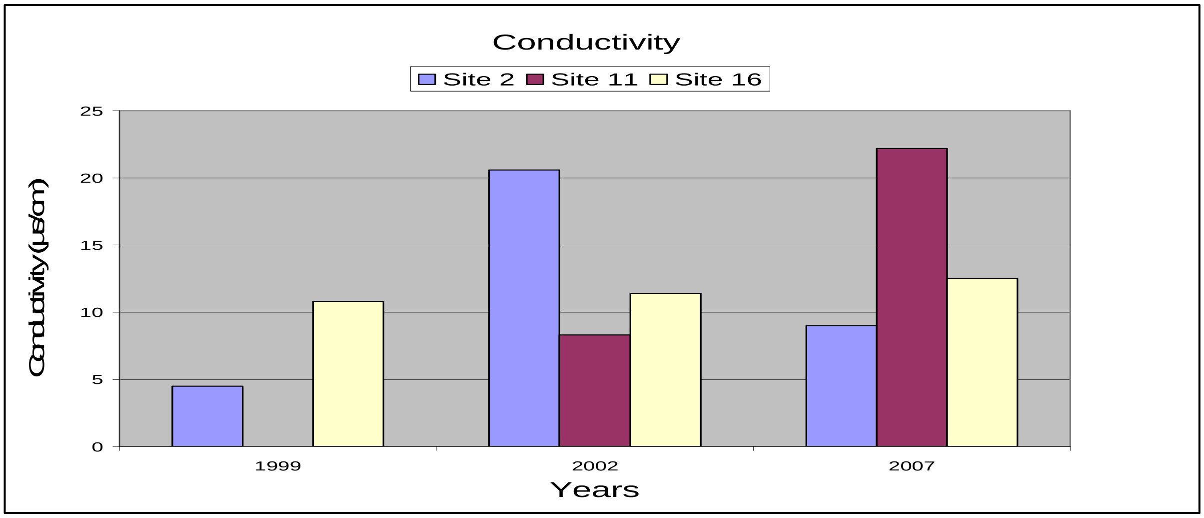
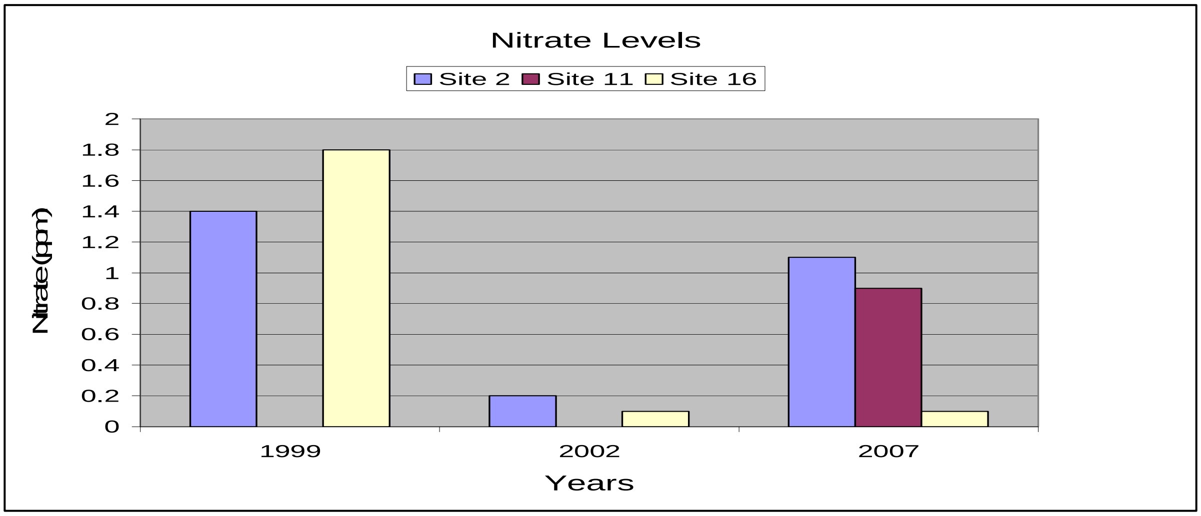


Figure 6: Water Chemistry Data for various parameters over time





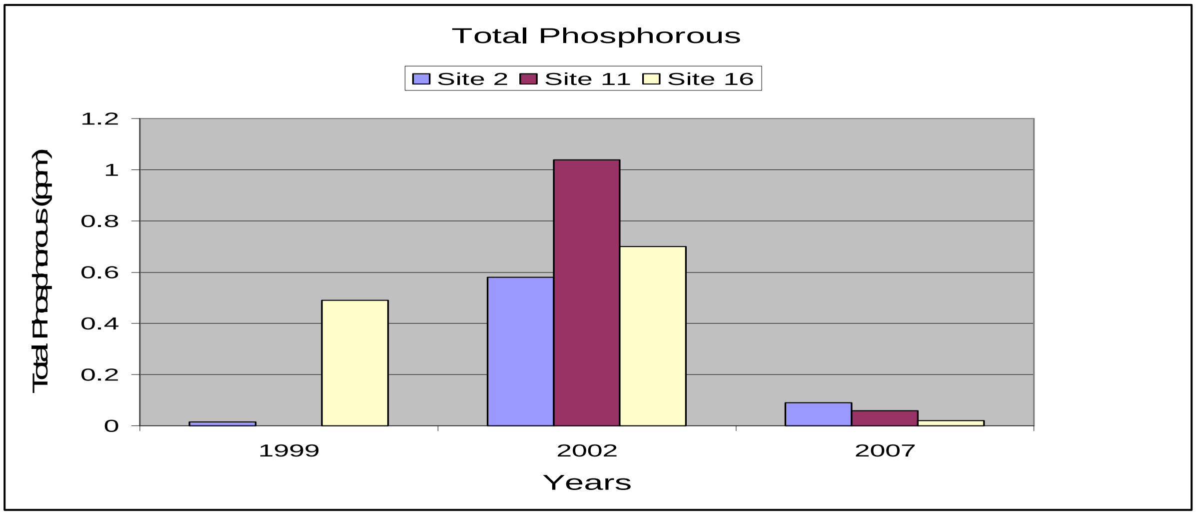


Figure 7: Macroinvertebrate Densities over time at Big Bear Creek

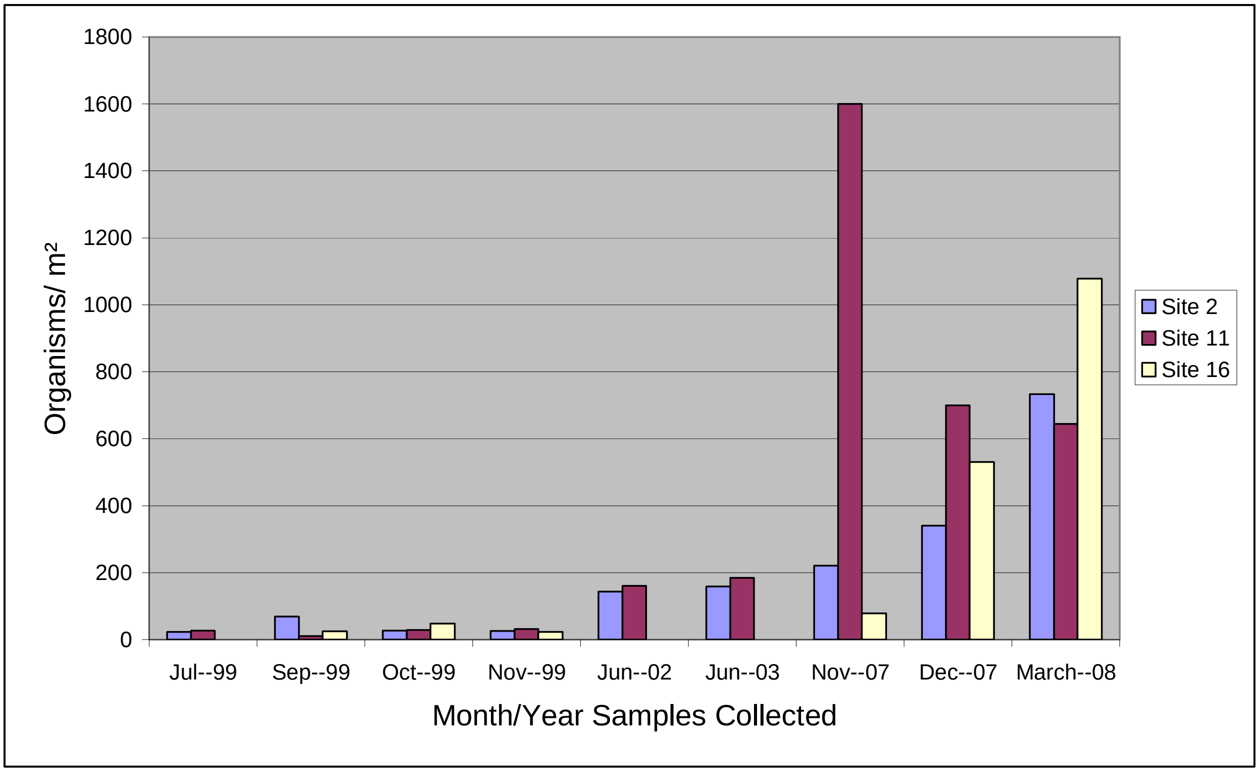


Figure 8: Total Macroinvertebrate Taxa

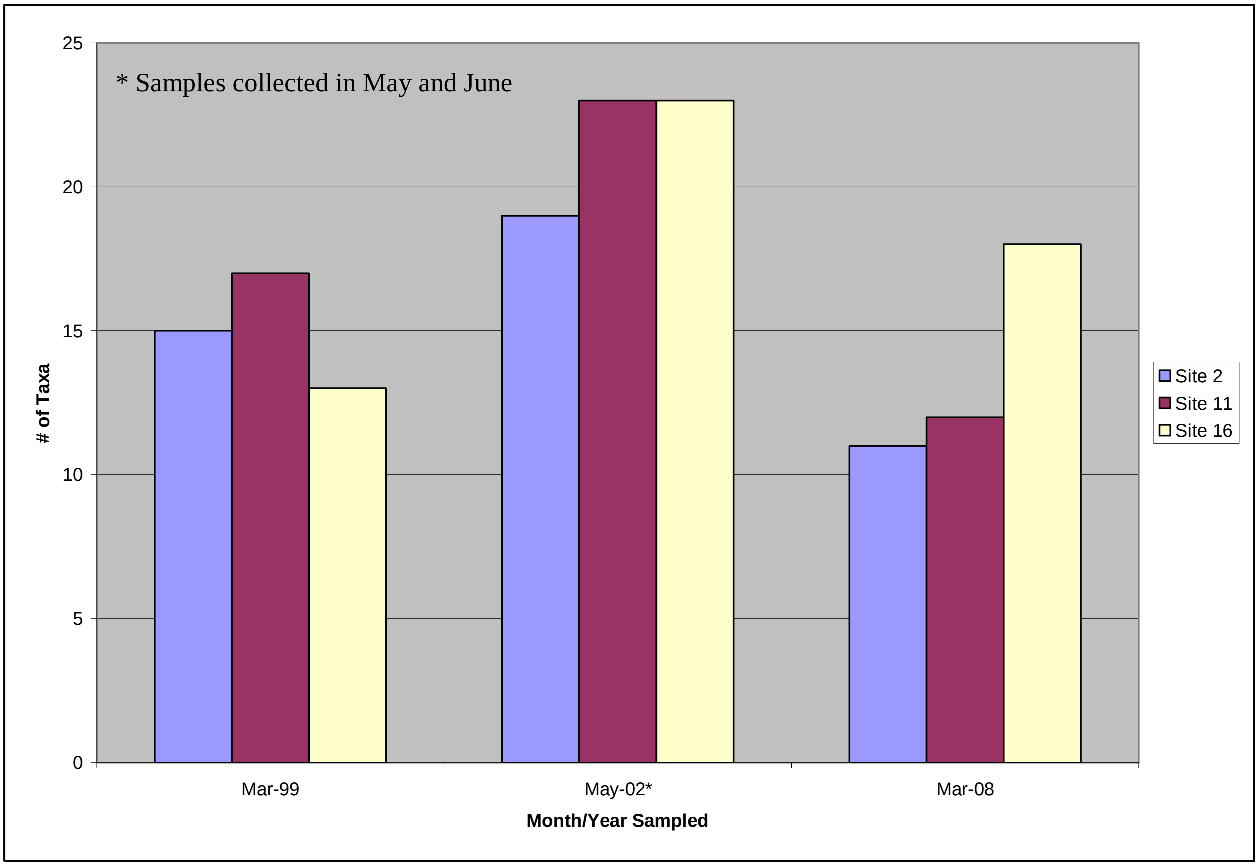


Figure 9: Total EPT Taxa

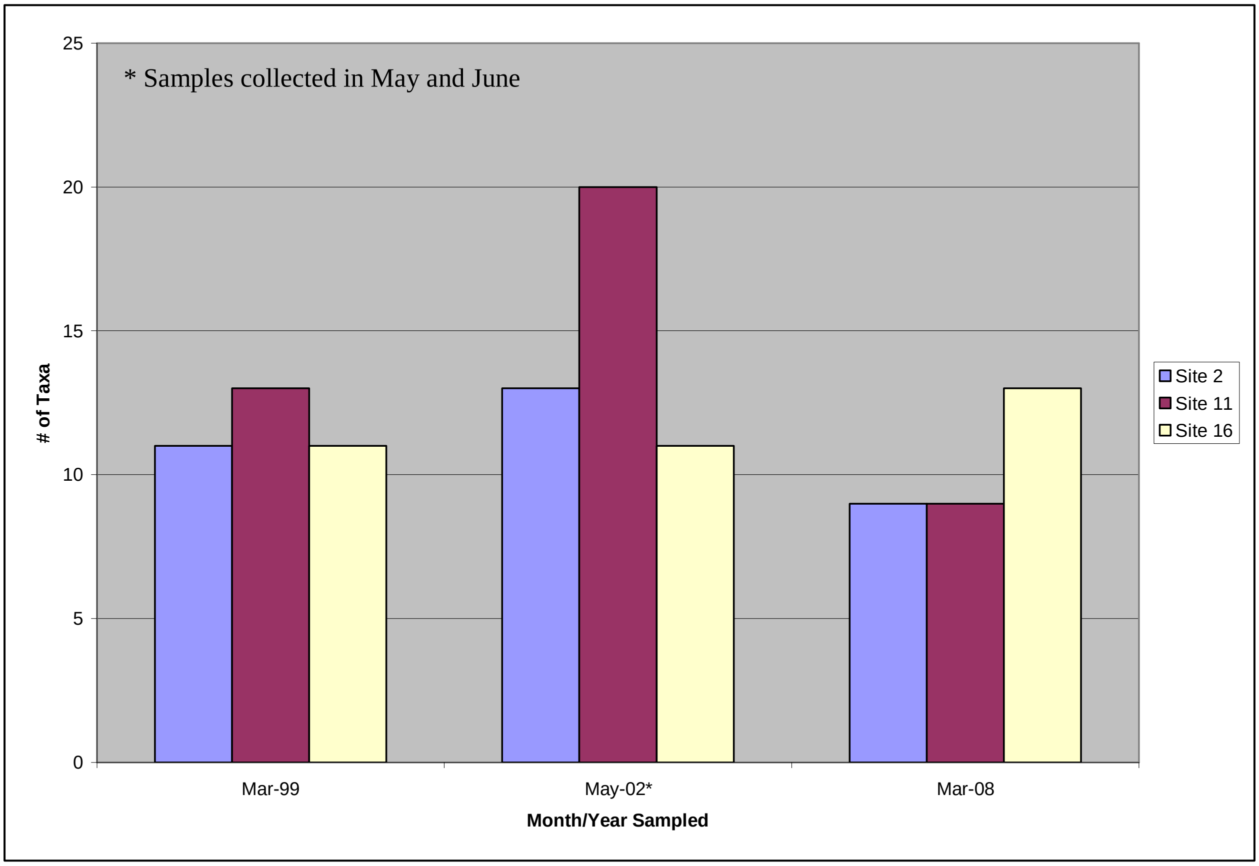
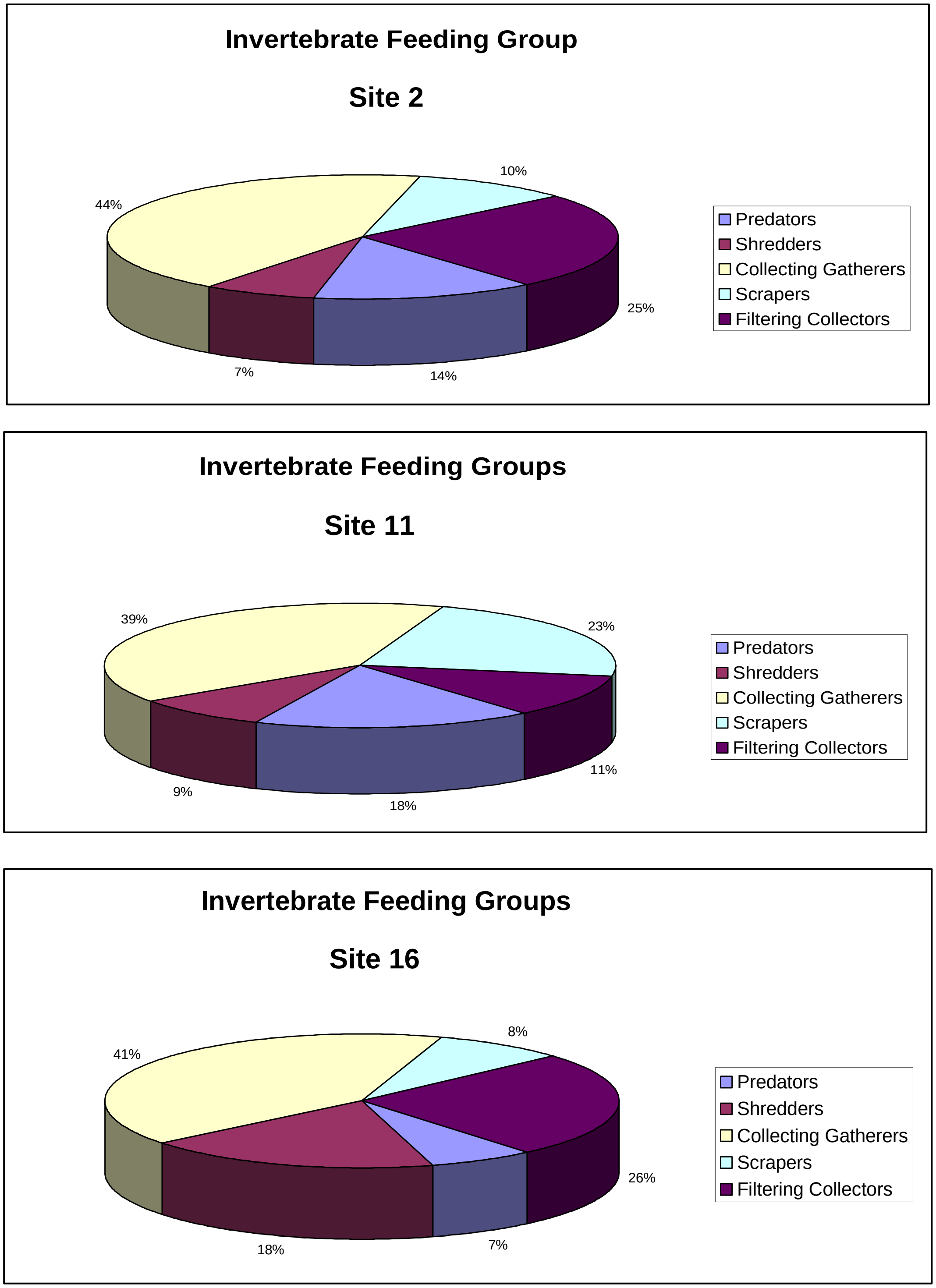
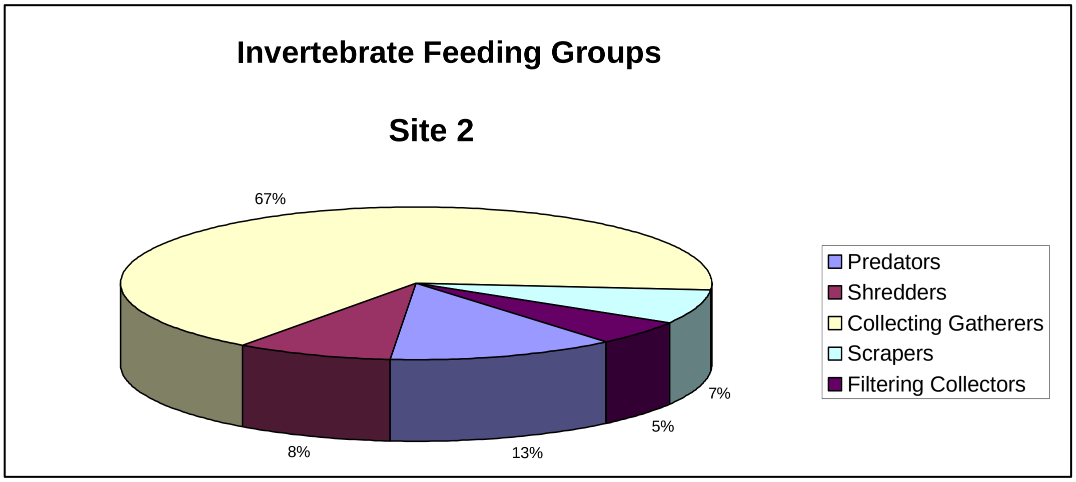


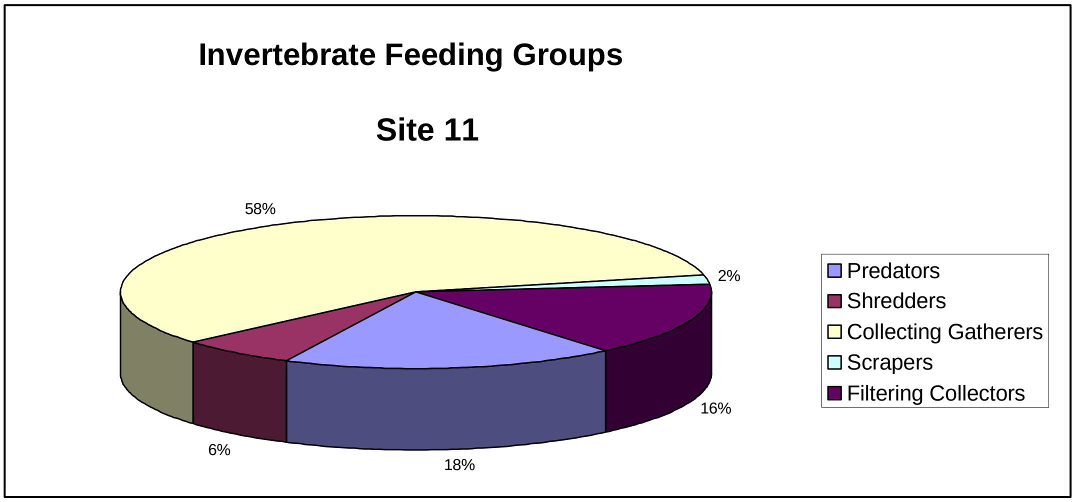
Figure 10: Invertebrate Feeding Groups

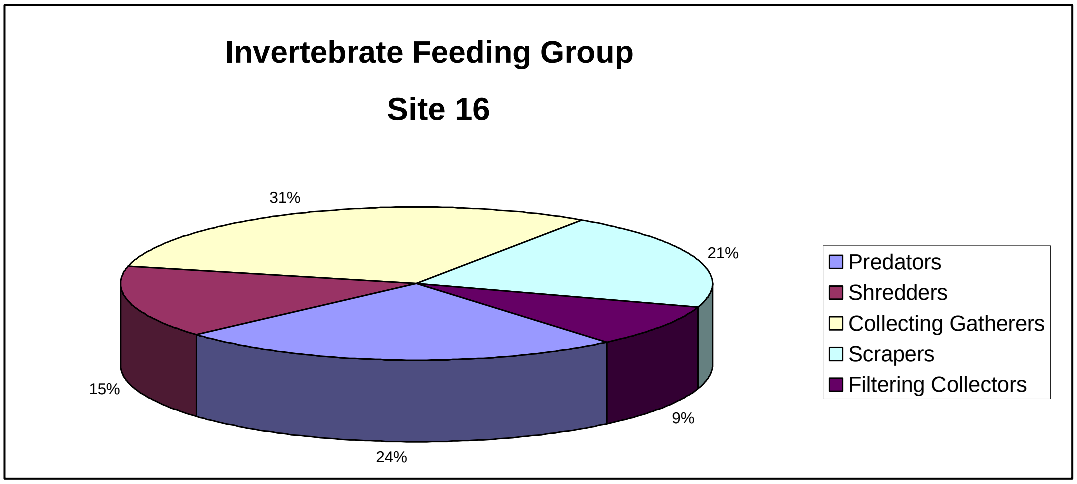
Percentages of the Invertebrate Feeding Groups at the various study sites before construction. Data from Kratzer, 2000.



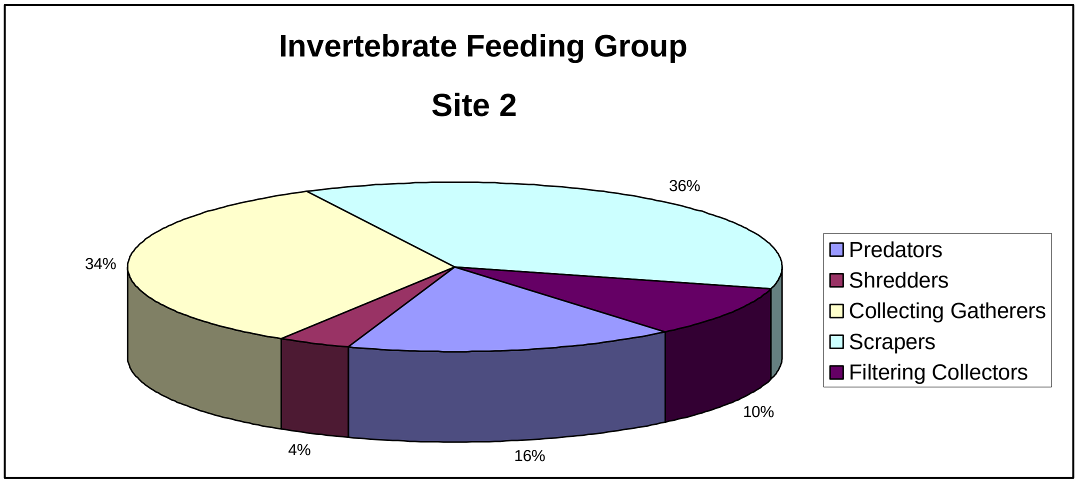
Percentages of the Invertebrate Feeding Groups at the various study sites in 2002. Data from Holmes, 2004

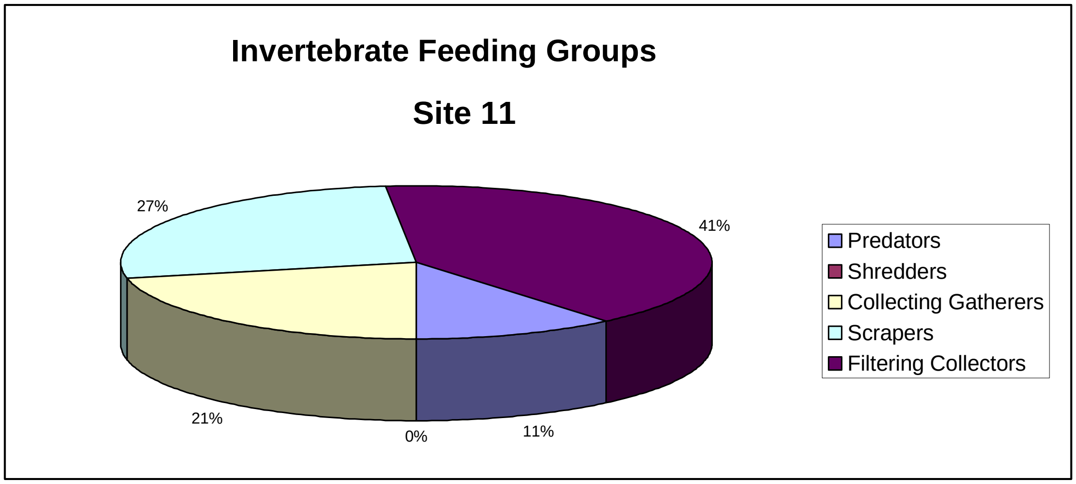






Percentages of the Invertebrate Feeding Groups at the various study sites in 2007.





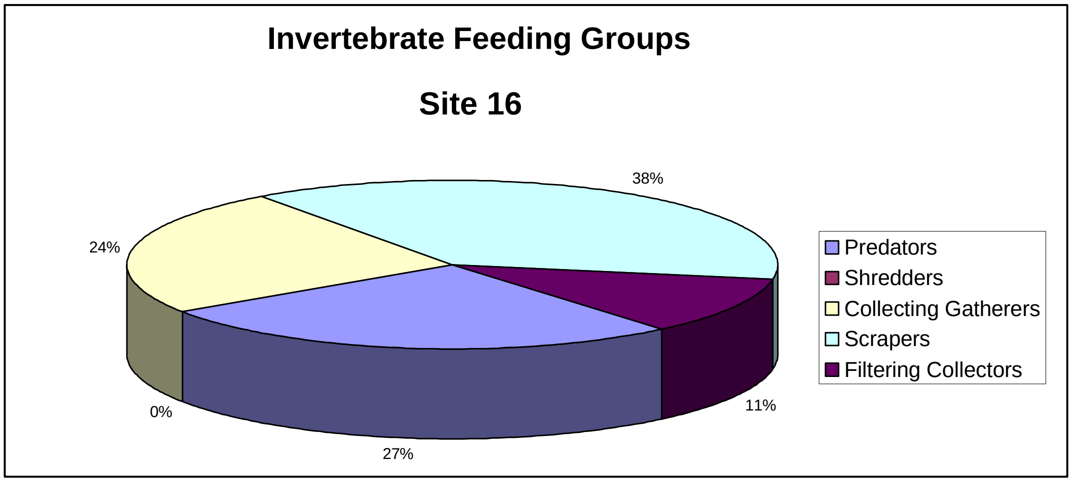
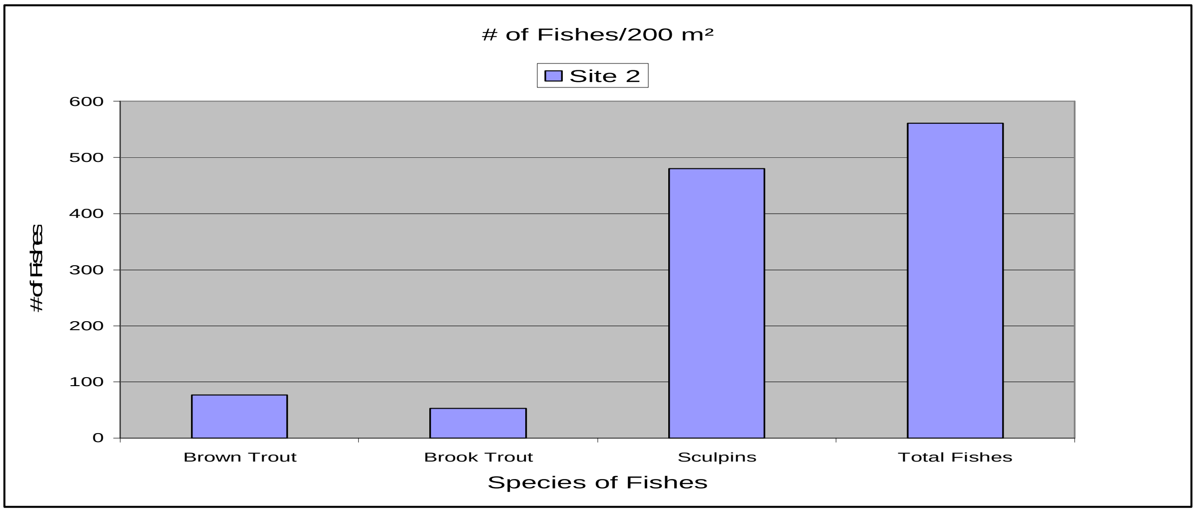
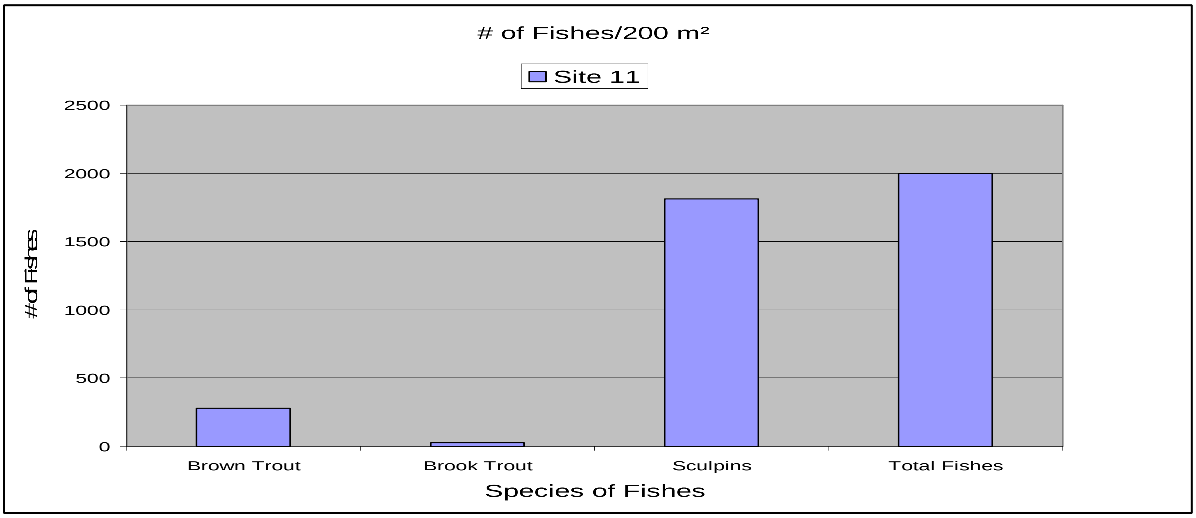


Figure 11: Number of Fishes/200m² at the various study sites- Fall 2007





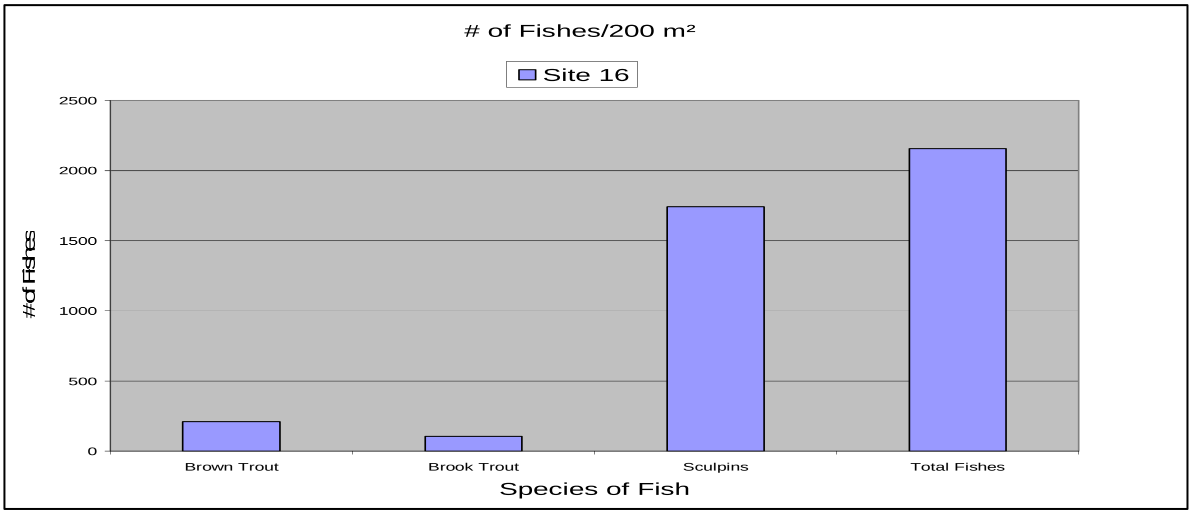


Figure 12: Trout Young-of-the-Year Population Estimates- Fall 2007

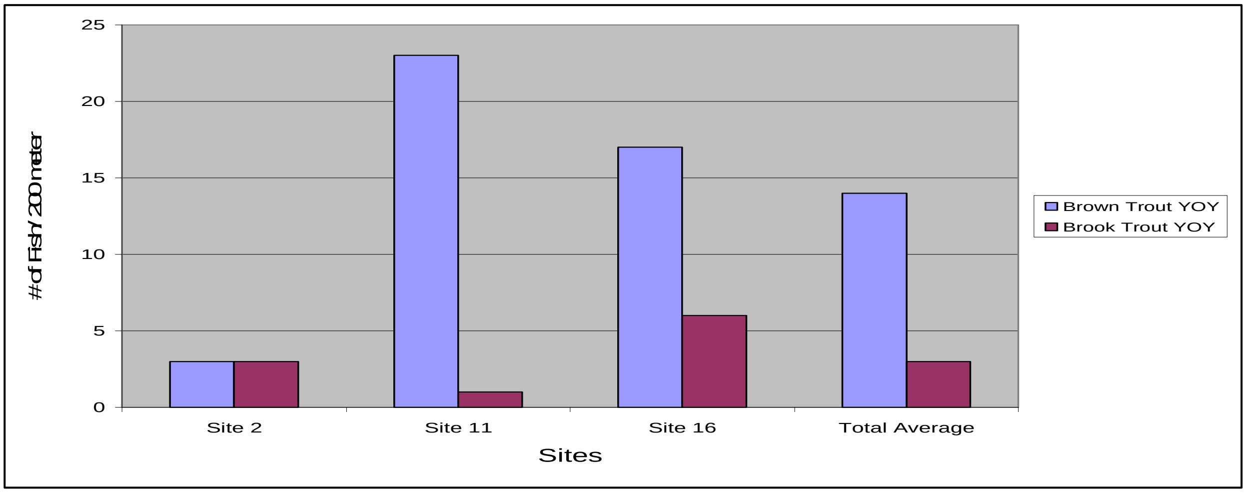


Figure 13: Length-Frequency of Trout Populations- Fall 2007

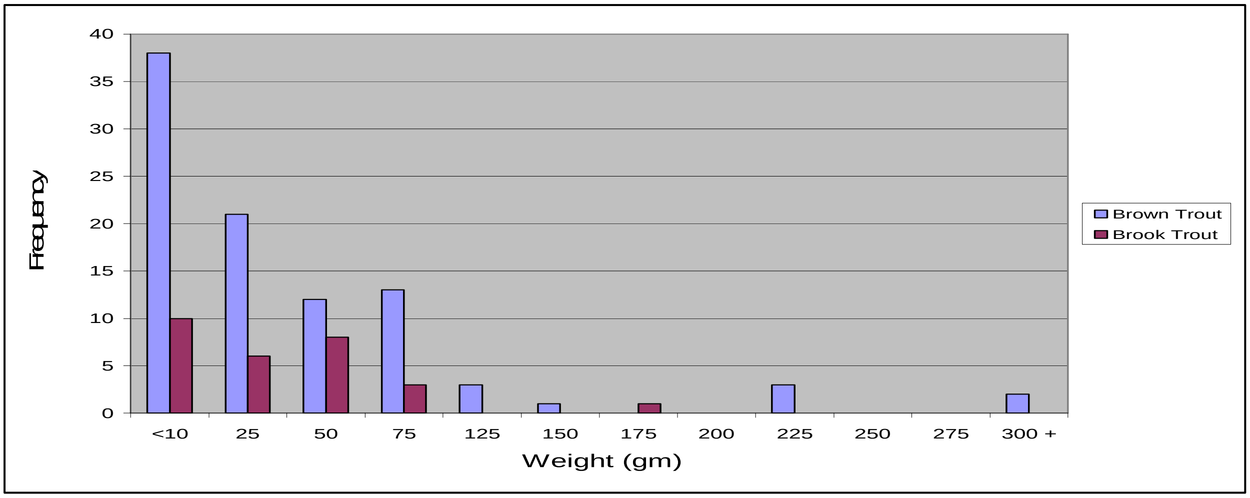


Figure 14: Weight-Frequency of Trout Populations- Fall 2007

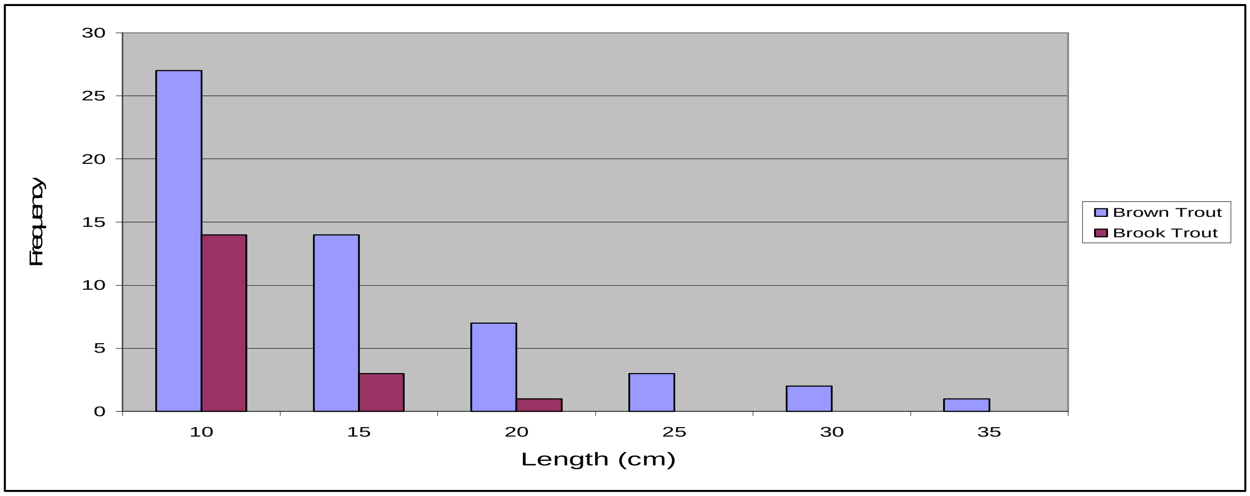


Figure 15: Biomass of Trout Population at Big Bear Creek- Fall 2007

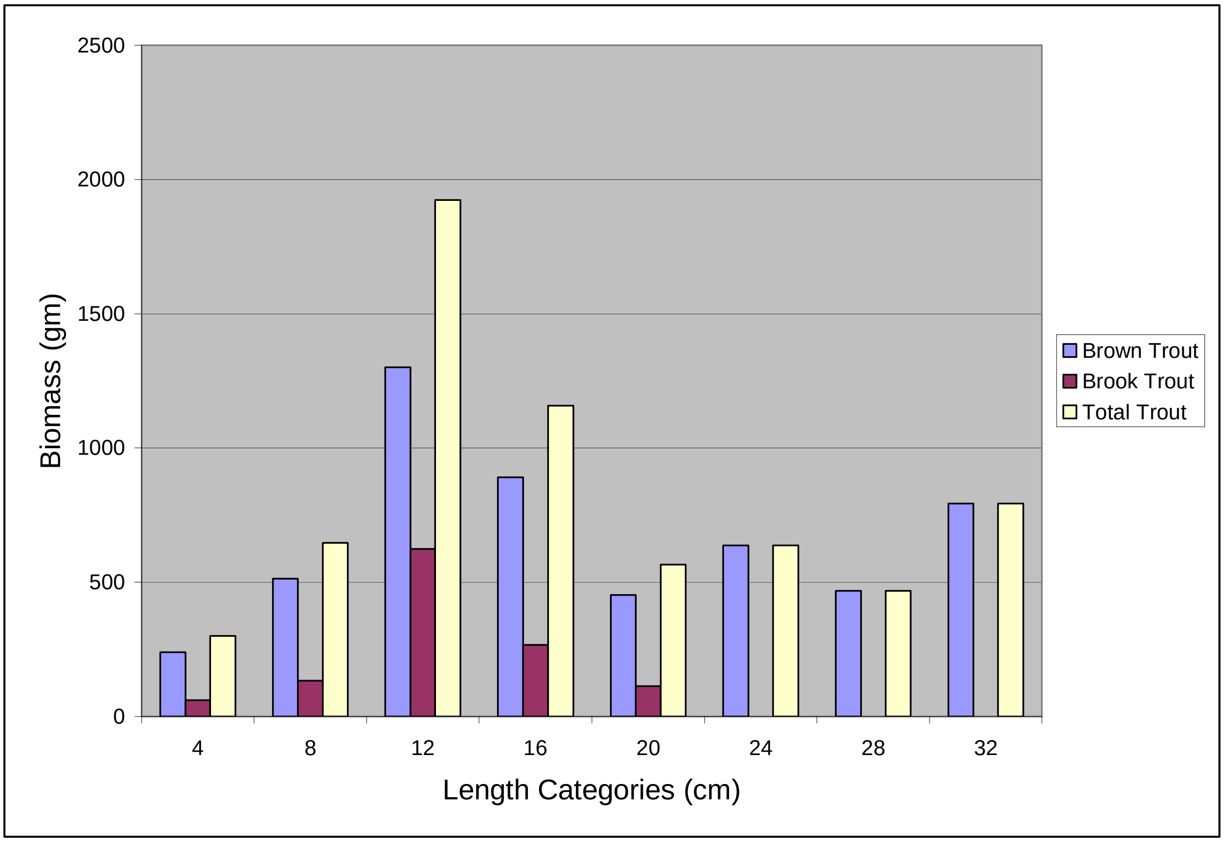


Figure 16: Trout Population Estimates with 95% Confidence Interval

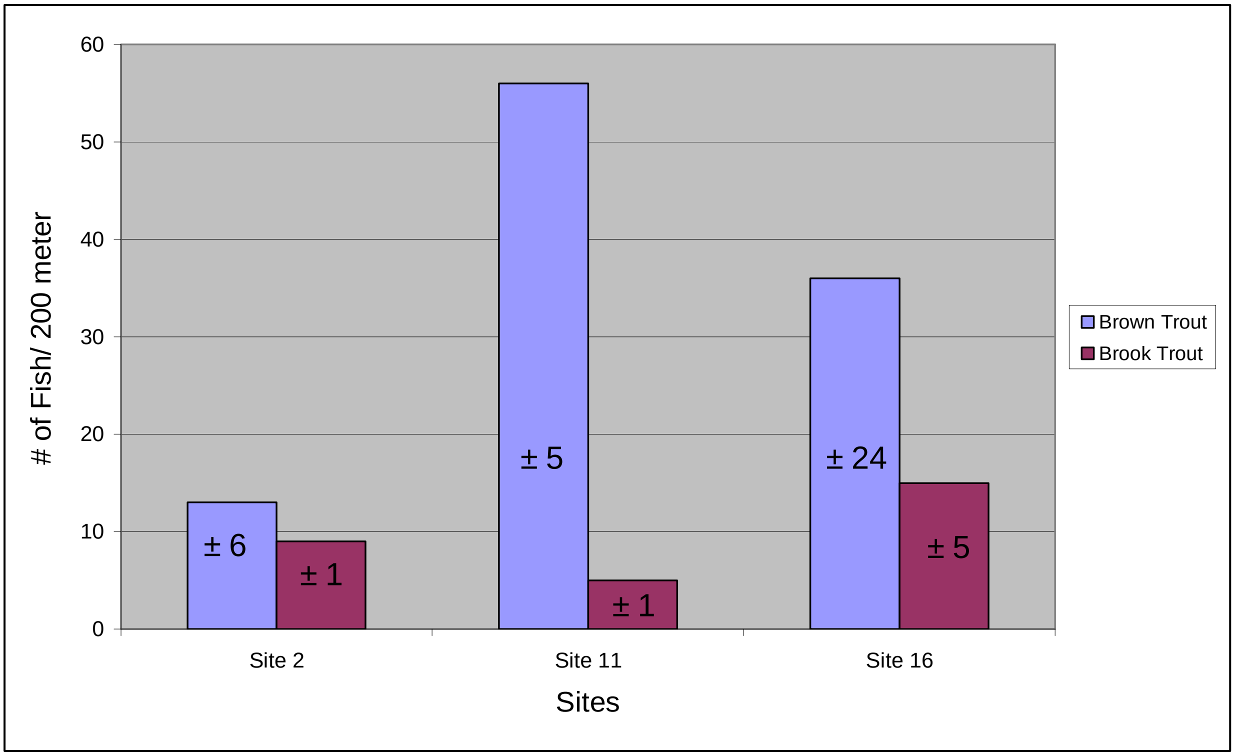
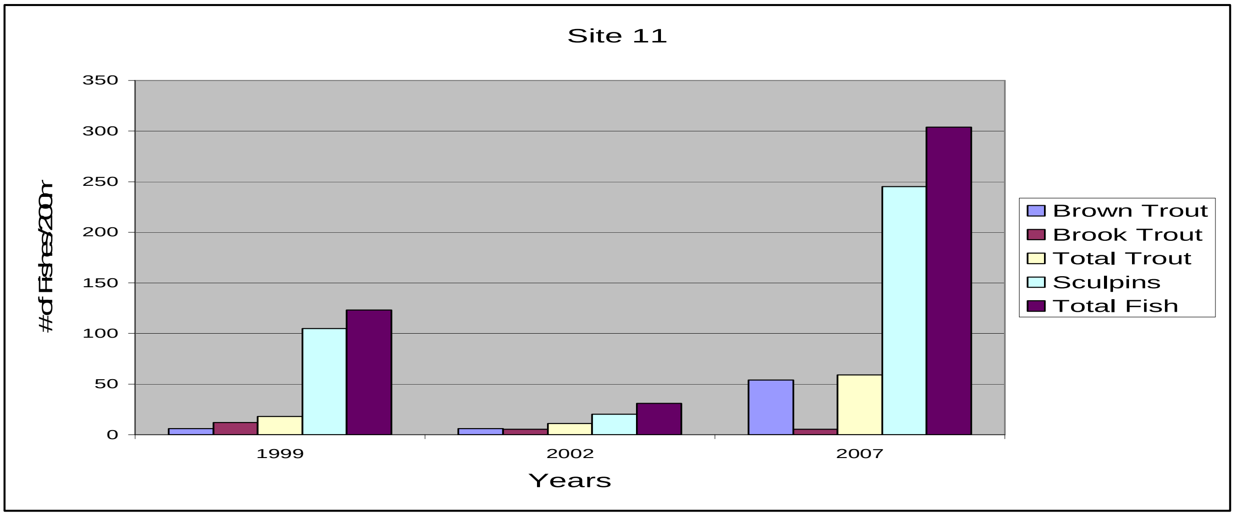


Figure 17: Total Fishes over time at Big Bear Creek

* Repaired structures during Fall 2007→ disturbed stream bed for majority of site.



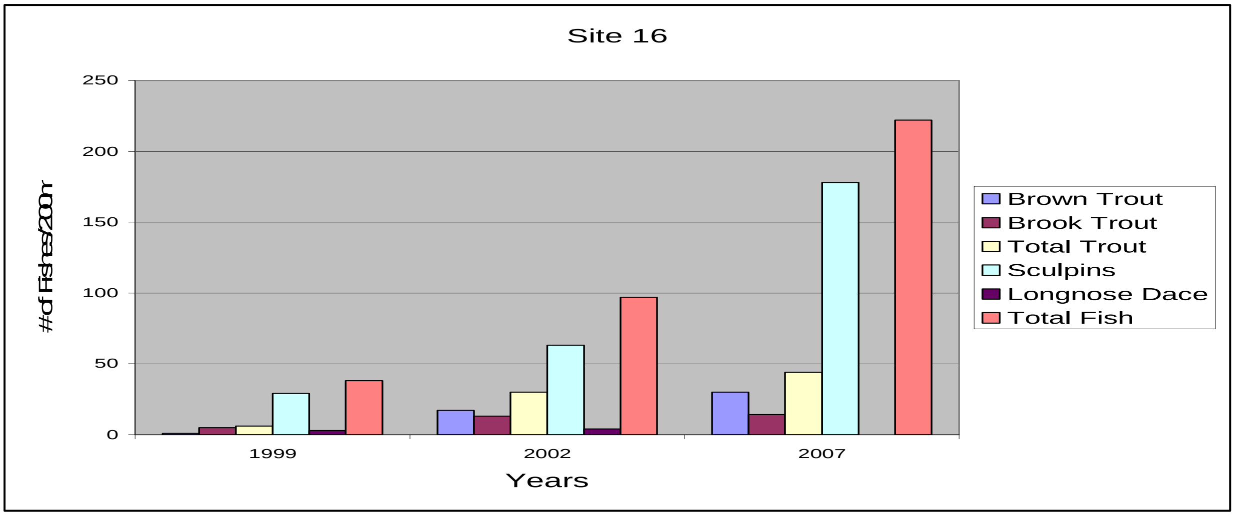
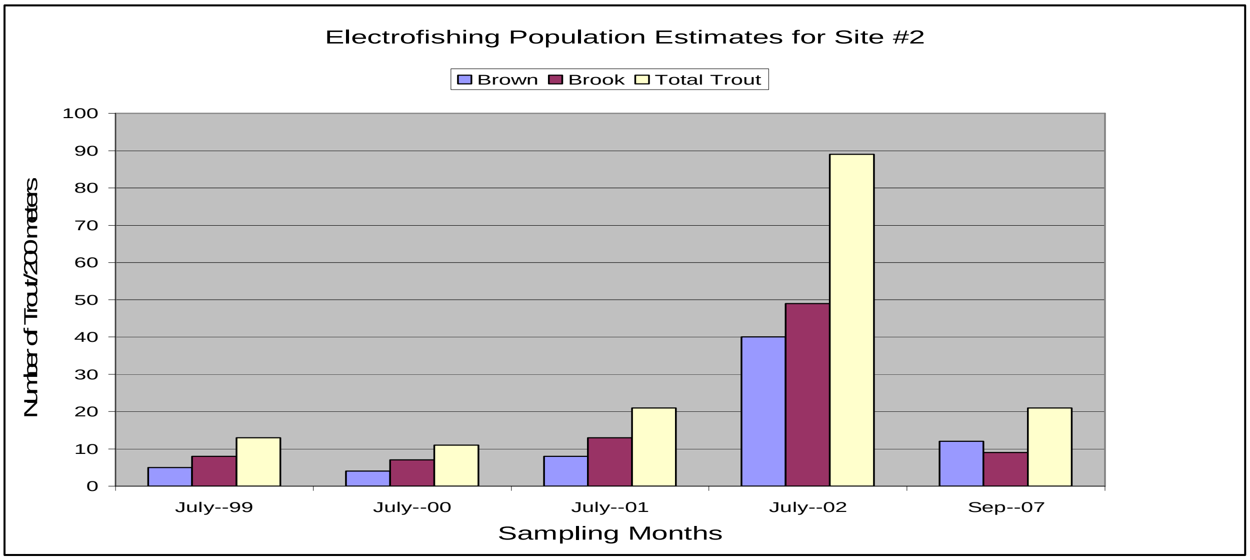
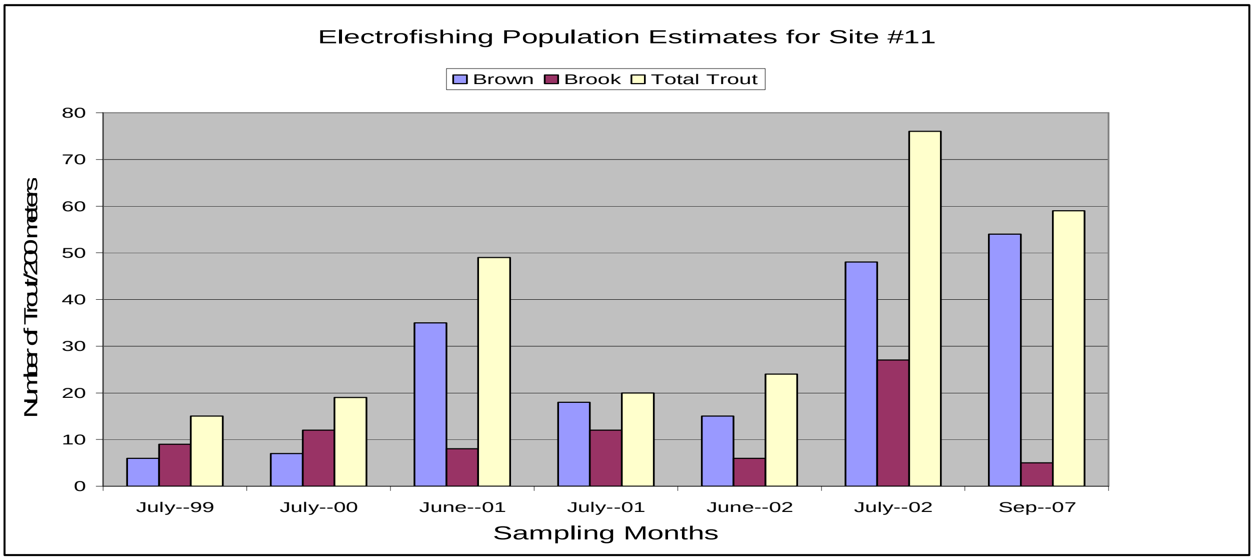


Figure 18: Electroshocking Population Estimates at Study Sites over time





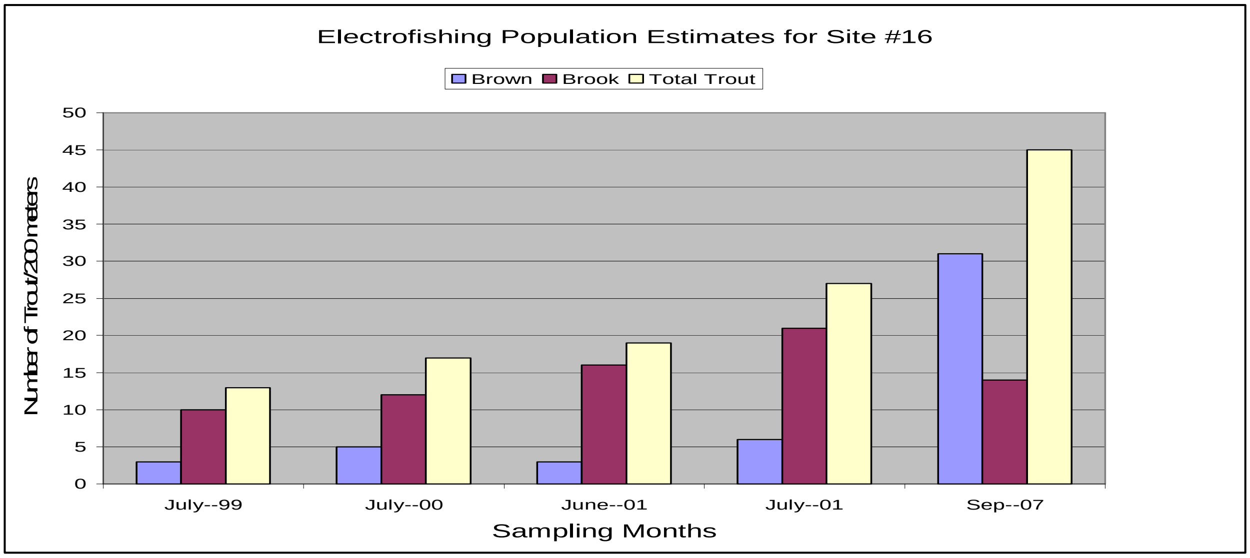
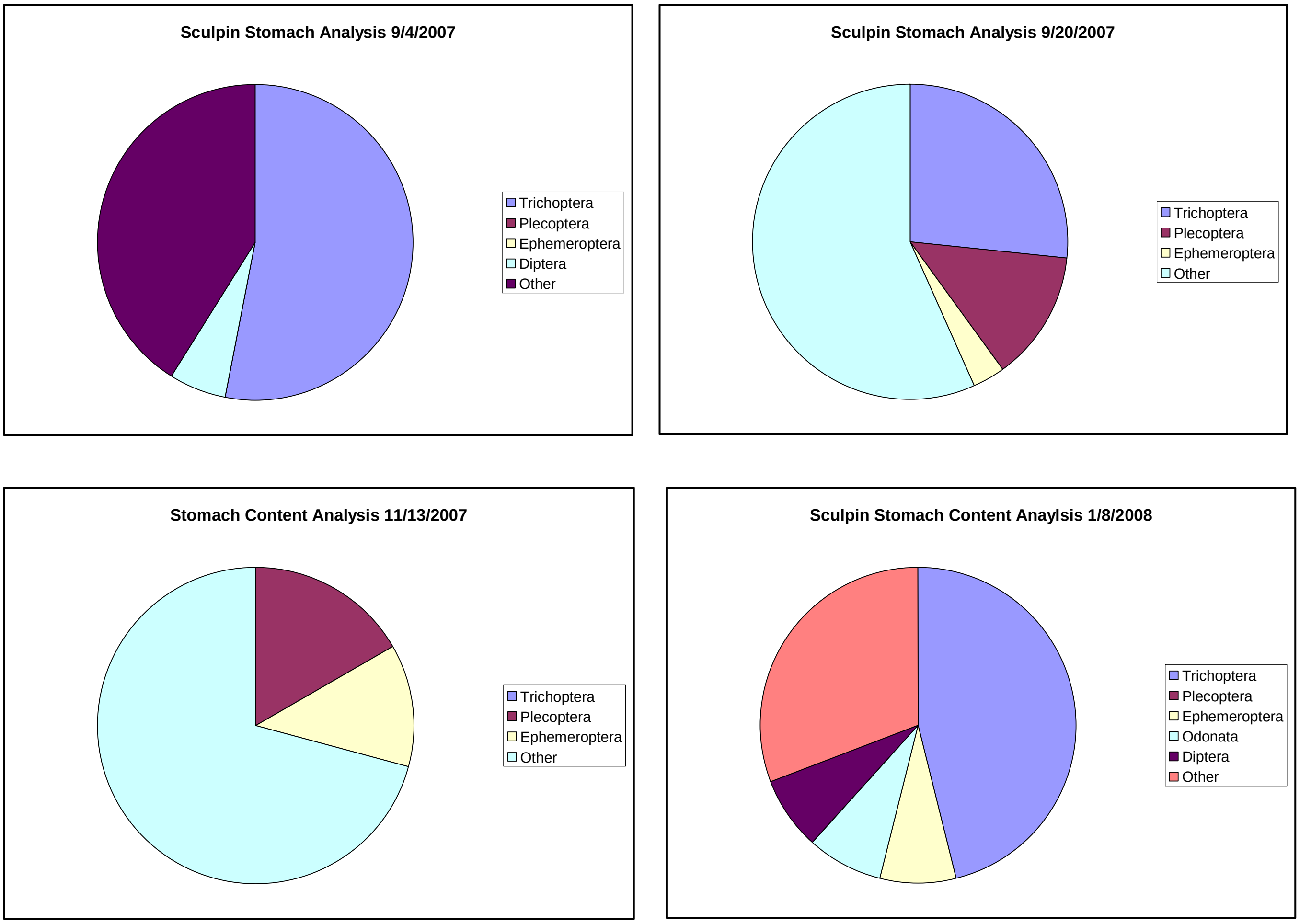


Figure 19: Slimy Sculpin Stomach Content Analysis- Fall 2007



Number of Identifiable/Unidentifiable Organisms in Stomach Content

9/4/2007			**9/20/2007**	
Trichoptera	9		Trichoptera	8
Plecoptera	0		Plecoptera	4
Ephemeroptera	0		Ephemeroptera	1
Diptera	1		Other	17
Other	7			
11/13/2007			**1/8/2008**	
Trichoptera	0		Trichoptera	6
Plecoptera	4		Plecoptera	0
Ephemeroptera	3		Ephemeroptera	1
Other	17		Odonata	1
			Diptera	1
			Other	4

Appendix A: Lycoming College history& summary of projects

History of Lycoming College projects on Big Bear Creek

Dr. Mel Zimmerman's first visit to Big Bear Creek occurred in October of 1982. He was mostly sampling the headwaters above the Dunwoody Club but one of his sampling locations was the Red Bridge (site #11 of this study). pH of the site was 6.3 with 1.5ppm alkalinity. Nitrate nitrogen was 3.8ppm with .002ppm Nitrite nitrogen. Brook and Brown Trout population densities at site #11 were 9 and 14 per 200m respectively. The next phase of involvement was in 1999 prior to the stream restoration project. Since 1999 a total of three independent study projects and seven Honors projects have utilized the site.

Two independent study and four Honors projects looked at water quality and food prospects for macroinvertebrates in the creek:

1) In summer and early fall of 1999, prior to restoration, **Brian Schlee** completed a study titled "Using periphyton communities for determining Water Quality of Big Bear Creek". Periphyton are attached algae living on rock substrates and provide food for scraper feeding macroinvertebrates (esp. caddis flies). This study was followed up by;
2) **Khalique Ghani** in 2000 (after restoration was started) completed a follow up study of the periphyton production. At sites 2 and 11 (as described in this thesis) periphyton production of the pool areas caused change in macroinvertebrate grazers from <30/m2 to over 100/m2

Another aspect of macroinvertebrate food is leaf material accumulating in the stream from the riparian forest (we call this coarse particulate organic mater or CPOM). Once in the stream, leaves of different species of trees are colonized (conditioned) by aquatic fungi and provide an important food source for macroinvertebrates. During the summer and fall seasons of 1999, 2000, 2001, and 2002 the following Honors projects were completed:

3) **Andrew Klinger**, 2000 – "Effects and Relationships of Stream Hydrology, TDS, and passive CPOM Retention on the Detrital Communities of three North Central PA Streams (Big Bear, Mill Creek, and Black Hole Creek).
4) **Emily Strickler**, 2001 – "Leaf Processing in Streams and Determination of Fungal Biomass via a Chemical Index" – used Mill Creek and Big Bear Creek.
5) **Christina Panko**, 2002 – "The Comparison of Leaf Processing Rates in Streams, Percent Organic Content and Fungal Biomass in Summer vs. Fall/Early Winter" worked on Big Bear Creek.
6) **Anthony Sowers**, 2003 – "The Determination of Leaf Processing and Fungal Biomass via a Chemical Index" worked on Big Bear Creek and Mill Creek.

Overall sugar maple leaves provided a higher fungal biomass and supported shedders more than River Birch, Sycamore, and Red Oak (listed in descending order).

To date a total of one independent study and three Honors projects have monitored the macroinvertebrate and fish populations pre and post restoration since 1999. These projects were:

7) **Jud Kratzer** - Honors – 2000 “Effects of Trout Habital Restoration and Cessation of stocking on Big Bear Creek”.
8) **Christopher Fuller** – Fall/Winter 2000 – 2001 Independent Study – “Monitoring the Effects of Trout Habital Restoration on Big Bear Creek”.
9) **Geoff Smith** - Honors – 2001 “Colonization of Benthic Macroinvertebrates following Construction of Fluvial Geomorphology Structures”.
10) **Nathan Holmes** – Honors 2004 – “The Effects of Rosgen Style Trout Habitat Restoration on Trout Populations and Microhabitat selection on Big Bear Creek”.

In addition to these studies, A Pennsylvania State University Graduate Student, **Kirk A. Patten -**2005, completed a project “Brook Trout and Brown Trout Habitat Use in Two Pennsylvania Streams”

In addition to these papers, Lycoming College interns appeared in a 35 minute video entitled “Successful Construction Practices Applied to Natural Stream Channel Design Projects in the Mid-Atlantic Highlands” produced by Mr. Bill Worobec and filmed by Clark Media and released in 2004. The film highlights lessons learned from design, construction, and monitoring of the Big Bear Creek Project. The video has a lot of educational potential for watershed groups considering projects of this type.

Drs. Mel Zimmerman and Peter Petokas of the Lycoming College Clean Water Institute (www.lycoming.edu/biologydept/cwi/) are also co-directors of the Statewide Keystone Stream Team (www.keystonestreamteam.org). The web site includes a set of guidelines for Natural Stream Channel Design Projects in Pennsylvania as well as a database of projects completed in Pennsylvania (including Big Bear Creek).

Appendix B: Big Bear Creek as Built Survey September-November 2007

CV-Cross Vane
JH-J-Hook
Combo-Combination Rock & Log

site location	Site #	GPS Coordinates	Bank-full Width (m)	Depth (cm)	Structure Type	Structure Condition	Notes
Below Lodge	1	41°22.235/76°44.435	8.1	20	Log CV	Good	Continuous Run
Club House	2	41°22.232/76°44.513	9	35	Rock CV	Good	Double Pool
Below Club House	3	41°22.243/76°44.543	9.5	70	Rock CV	Good	Deep Pool
Upper Pond	4	41°22.253/76°44.546	10	35	Rock CV	Good	Double CV
Lower Pond	5	41°22.250/76°44.572	7.5	90	Rock CV	Good	Deep Pool
Upper Walking Bridge	6	41°22.260/76°44.591	7	50	Rock CV	Good	
Lower Walking Bridge	7	41°22.301/76°44.608	8.5	50	Rock CV	Good	
	8		7	20	Rock JH	Fair	
	9		6	10	Log CV	Fair	Right Bank Support
	10	41°22.326/76°44.633	8	40	Rock CV	Good	
Tag #11 Stover's Reach	11	41°22.330/76°44.633	8	15	Rock CV	Good	
	12	41°22.342/76°44.669	9	20	Rock CV	Good	Fish on tree
Tag #13	13	41°22.357/76°44.671	9	50	Rock CV	Good	
	14	41°22.347/76°44.769	6	50	Rock CV	Good	Long Riffle, Deep Pool
Tag #15	15	41°22.373/76°44.746	6	60	Combo CV	Good	Log on Left Bank Side
	15A	41°22.383/76°44.743	7.5	55	Combo CV	Good	
	16	41°22.369/76°44.766			Rock JH	Poor	Non-functional
	17	41°22.422/76°44.798	7.5	60	Log CV	Good	Log on Right Bank Side
Tag #18	18	41°22.411/76°44.766	7.5	45	Rock Structures	Good	2 Parallel Structures
	18A	41°22.430/76°44.822	6.5	45	Combo CV	Good	
Tag #19	19	41°22.426/76°44.800	6	>100	L-Structure	Good	
	19A	41°22.425/76°44.822	6.5	50	Log CV	Good	
Tag #21	21	41°22.429/76°44.821	3	20	Rock JH		
	22A	41°22.423/76°44.823	3	20	Log JH	New	Modified Log JH
	22	41°22.437/76°44.854	11.5	60	Combo CV	New	Right Bank Support/Log on Left Bank
	23	41°22.461/76°44.854	6	20			Bank Support
Tag #24	24	41°22.479/76°44.846	11.5	56	Rock CV	New	Left Bank Structural Support/Right Bank non-functional
Tag #25	25	41°22.471/76°44.865			Rock JH		Non-functional
	26	41°22.471/76°44.911	6.5	28	Rock JH	Good	
	27	41°22.501/76°44.893	8	>100	Log CV	Good	
	28	41°22.533/76°44.915	6	30	Rock JH	Good	
Above 1/2 Mile Marker	29	41°22.524/76°44.927	6.5	45	Rock JH	New	
1/2 Mile Marker	30	41°22.524/76°44.944	10	32	Rock CV	Poor	Low water levels
	39	41°22.551/76°44.975	6.5	55	Combo CV	New	Log on Left Bank Side/ Rock on Right Bank Side/ Recently Constructed
	40	41°22.562/76°44.939	11	20	Log CV	New	Recently Constructed

site location	Site #	GPS Coordinates	Bank-full Width (m)	Depth (cm)	Structure Type	Structure Condition	Notes
	40A	41°22.564/76°44.941			?		Stright Across Boulder Struture
	41	41°22.621/76°44.949	5.5	45	Rock JH	Good	
	42	41°22.619/76°44.951	7	52	Rock CV	Fair	Left Bank Structure Poor
	43	41°22.646/76°44.969					1/2 JH Structure
	44	15 m above 45	9	38	Rock CV	Good	
	46	41°22.696/76°44.967			Rock JH	Fair	
	47	41°22.695/76°44.970			Rock JH	Poor	
	48	41°22.716/76°44.998			Rock JH	Poor	
	49	41°22.709/76°45.005			Rock JH	Poor	
	50	41°22.709/76°45.005	7	50	Rock JH	Poor	Fish #8 on tree
	51	41°22.709/76°45.039	7.5	47	Rock CV	Good	
	52	41°22.705/76°45.077	10.5	85	Rock CV	Good	
	53	41°22.694/76°45.066				Poor	Structure only on Right Bank/ Pool Below
	54	41°22.786/76°45.126	8.75	30	Rock JH	Poor	
	55	41°22.795/76°45.157	10	75		Good	
	56	41°22.803/76°45.160			Rock JH	Fair	
	57	41°22.815/76°45.248	8.1	35	Rock CV	Good	
Above Red Bridge	58	41°22.793/76°45.342	7	23	Log CV	Good	
Below Red Bridge	59	41°22.796/76°45.363	10.75	48	Rock CV	Good	
Tag #61	61		8	60	Rock CV	Good	
	62		10	20	Rock CV	Good	
Tag #63	63		8	15	Rock JH	Good	
Tag #64	64		8	25	Rock CV	Good	
	64A		6	25	Rock JH	Good	
Tag #65	65		9	25	Rock JH	Good	
	67	41°22.807/76°45.537	8	20	Rock JH	Fair	
	68	41°22.811/76°45.521	7	20	Rock JH	Fair	
	69	41°22.837/76°45.561	7	25	Rock JH	Fair	
	70	41°22.841/76°45.633	5	25	Rock JH	Fair	
	71	41°22.864/76°45.642	8	25	Rock CV	Fair	
Tag #72 Finkler's Furnace	72	41°22.848/76°45.682	6	50	Rock JH	Good	Established Pool
Tag #74	74	41°22.873/76°45.742	7	20	Rock JH	Fair	
Tag #75	75	41°22.877/76°45.744	8	30	Rock CV	Good	
Tag #76	76	41°22.907/76°45.797	8	50	Rock JH	Fair	
	78	41°22.927/76°45.791	7	40	Rock JH	Poor	
	79	41°22.935/76°45.803	9	35	Rock JH	Good	
	80	41°22.917/76°45.885	8	50	Rock JH	Good	Established Pool
Tag #81	81	41°22.911/76°45.935	12	20	Rock JH	Fair	No Pool/Fish on tree
Tag #82	82	41°22.906/76°45.956	12	20	Rock JH	Fair	No Pool
	82A	41°22.918/76°45.976	9	25	Rock JH	Good	
	83	41°22.934/76°46.003	12	30	Rock JH	Good	

site location	Site #	GPS Coordinates	Bank-full Width (m)	Depth (cm)	Structure Type	Structure Condition	Notes
Tag #84	84	41°22.937/76°46.025	8	25	Rock JH	Good	
Tag #85	85	41°22.938/76°46.061	7.5	35	Rock JH	Good	
	86	41°22.935/76°46.068	9	20	Rock CV	Good	
	87	41°22.919/76°46.095	7	20	Rock JH	Fair	
Tag #88	88	41°22.914/76°46.108	6	25	Rock JH	Good	
Tag #89	89	41°22.905/76°46.122	6	35	Rock JH	Good	
	90	41°22.921/76°46.145	7.5	25	Rock JH	Good	
Above Shingle Run Trib/Tag #91	91	41°22.925/76°46.161	3	15	Rock JH	Good	
Tag #93	93	41°22.953/76°46.210	10	15	?	Poor	Left Bank Support
Tag #94	94	41°22.950/76°46.229	8	29	Rock CV	Fair	
1 3/4 Mile Marker/Tag #95	95						Structure Missing
Tag #96	96	41°22.948/76°46.289	7	25		Fair	Left Bank Support
	96A	41°22.931/76°46.314	9	30	Rock JH	Poor	Log on Right Bank Side--Non-functional
Tag #97	97	41°22.917/76°46.329	7	30	Rock CV	Fair	
	99	41°22.911/76°46.335	7.5	25	Rock JH	Fair	Structure on Right Bank Side
	100	41°22.914/76°46.387	6	40	Rock JH	Fair	
Tag #101	101	41°22.913/76°46.417	9	43	Rock CV	Fair	
	102	41°22.915/76°46.435	9	30	Rock JH	Good	Structure on Left Bank Side
	103	41°22.917/76°46.496	7.5	75	Rock JH	Good	Stucture on Left Bank Side
	104	41°22.943/76°46.513	11	27	Rock CV	Fair	
Tag #105	105	41°22.973/76°46.364	9.8	15	Rock CV	Fair	2nd Structure above Grouse Club Bridge
Above Grouse Club Bridge	105A		9.5	16	Rock JH	Poor	
Below 87 Bridge	115	41°23.250/76°47.738	11	20	Rock CV	Good	
	116	41°23.267/76°47.769	12	28	Rock CV	Poor	
	117	41°23.287/76°47.800	15	20		Poor	
	118	41°23.313/76°47.812	13.5	37	Rock CV	Fair	
	119	41°23.351/76°47.805	12.1	55	Rock CV	Good	Deep Pool/ Strong Channel
	120	41°23.351/76°47.839	15.7	17	Rock CV	Fair	few leaks behind anchor rock
	121	41°23.356/76°47.837	17.25	37	Rock JH	Good	Log Structure replaced w/stone/ Log on Right Bank--non-functional
	122	41°23.417/76°47.868	6	27	Rock CV	Good	
	123	41°23.425/76°47.876	19	18	Rock JH	Poor	Non-functional
	123A	41°23.430/76°47.907					Bank Support on Right Bank
	124	41°23.459/76°47.949	11.8	27	Rock JH	Poor	Bank Erosion/Stream Split-Left Bank
	125	41°23.469/76°47.973					Log CV removed
	126	41°23.477/76°47.985					Log on Left Bank--non-functional
	127	41°23.475/76°48.005	10	40	Rock CV	Good	

Appendix C: 2007-2008 Raw Water Chemistry Data

Water Chemistry Collected 9/11/07		
	Site #2	**Site #11**
pH (Field)	6.6	6.05
pH (Lab)	6.2	6.49
Conductivity (µs/cm)	15.74	18.1
Alkalinity (ppm)	6	8
Orthophosphate (ppm)	0.11	0.18
Phosphorous (ppm)	0.08	0.16
Nitrate (ppm)	1.2	0.8
Nitrite (ppm)	0.0035	0.0013
Temp (℃)	11.2	12.4

Water Chemistry Collected 11/13/07		
	Site #2	**Site #11**
pH (Field)		
pH (Lab)	6.37	6.42
Conductivity (µs/cm)	19.25	17.7
Alkalinity (ppm)	6	8
Orthophosphate (ppm)	0.11	0.14
Phosphorous (ppm)	0.07	0.06
Nitrate (ppm)	1.1	1.1
Nitrite (ppm)	0.005	0.009
TDS (ppm)	10.2	8.9

Water Chemistry Collected 1/8/08			
	Site # 2	**Red Bridge**	**Finkler's Furnace**
pH (Field)	6.25	6.11	6.14
pH (Lab)	5.32	6.02	5.6
Conductivity (µs/cm)	9	22.2	12.53
Alkalinity (ppm)	2	2	2
Orthophosphate (ppm)	0.13	0.15	0.12
Phosphorous (ppm)	0.09	0.06	0.02
Nitrate (ppm)	1.1	0.9	0.1
Nitrite (ppm)	0.01	0.009	0.008
DO (ppm)	14.8	10.12	11.32

Water Chemistry Collected 3/3/08			
	Site # 2	**Red Bridge**	**Finkler's Furnace**
pH (Field)	5.88	5.89	5.89
pH (Lab)	5.69	5.47	5.8
Conductivity (µs/cm)	14.21	16.08	16.3
Alkalinity (ppm)	1	1	2
Orthophosphate (ppm)	0.07	0.17	0.2
Phosphorous (ppm)	0.03	0.15	0.17
Nitrate (ppm)	0.9	1.2	1.1
Nitrite (ppm)	0.002	0.002	0.01
Temp (℃)	4.1	4.1	4.1
DO (ppm)	13.35	10.4	12.6
TDS (ppm)	7.28	8.05	8.08

Water Chemistry Collected 3/11/08			
	Site # 2	**Red Bridge**	**Finkler's Furnace**
pH (Field)	5.84	5.93	6.05
pH (Lab)	5.75	6.09	5.99
Conductivity (µs/cm)	12.05	13.08	13.03
Alkalinity (ppm)	2	1	5
Orthophosphate (ppm)	0.08	0.04	0.11
Phosphorous (ppm)	0.23	0.16	0.17
Nitrate (ppm)	1.1	1	0.9
Nitrite (ppm)	0.003	0.004	0.004
Temp (℃)	5.1	4.9	4.9
DO (ppm)	11.4	11.63	11.64
TDS (ppm)	6.11	6.61	6.5

Water Chemistry Collected 3/30/08			
	Site # 2	**Red Bridge**	**Finkler's Furnace**
pH (Field)	6.3	6.8	6.9
pH (Lab)	5.26	4.87	5.74
Conductivity (µs/cm)	14.2	26	15.9
Alkalinity (ppm)	1	1	2
Orthophosphate (ppm)	0.07	0.09	0.11
Phosphorous (ppm)	0.25	0.2	0.23
Nitrate (ppm)	1.2	0.7	1
Nitrite (ppm)	0.008	0.006	0.007
Temp (℃)	4	4.5	4.7
DO (ppm)	11.6	11.2	11.7
TDS (ppm)	6.58	12.1	7.5

Appendix D: Raw Marcoinvertebrate Data

		Site 2	Site 2	Site 2	Site 11	Site 11	Site 11	Site 16	Site 16
		11/20/2007	1/8/2008	3/20/2008	11/20/2007	1/8/2008	3/20/2008	1/8/2008	3/20/2008
Annelida									
Oligocheata									9
Plecoptera									
Capniidae	SH								
Allocapnia	SH	3							3
Paracapnia	SH								
Chloroperlidae	P								
Haploperla	P	1		4					2
Suwallia	P								
Sweltsa	P								
Leuctridae	SH								
Leuctra	SH						3		3
Peltoperlidae	SH								
Peltoperla	SH								1
Tallaperla	SH								
Perlidae	P								
Acroneuria	P	12			12	2		8	
Neoperla	P			4			3		4
Perlodidae	P								
Isogenoides	P		6		3	6		1	
Isoperla	P	6			2				
Pteronarcidae	SH								
Pteronarcys	SH			1			1		
Taeniopterygidae	SH								
Taeniopteryx	SH								
Ephemeroptera									
Baetidae	CG								
Acentrella	CG		4			3		3	
Baetis	CG			8	16		14		32

Caenidae	CG								
Caenis	CG							1	
Ephemerellidae	CG								
Attenella	CG		2						
Drunella	SC	3		5	12		14		8
Ephemerella	CG	25			9			1	
Eurylophella	CG						9		
Ephemeridae	CG								
Ephemera	CG				1	6		2	
Heptageniidae	SC								
Cinygmula	SC	22	6				1		6
Epeorus	CG	2		57	54	19	50	17	56
Heptagenia	SC								
Stenacron	CG	1							
Stenonema	SC								
Isonychiidae	FC								
Isonychia	FC	1			1			1	
Leptophlebiidae	CG								
Paraleptophlebia	CG			5					1
Tricorythidae	CG								
Tricorythodes	CG				6				
Odonata									
Aeshnidae	P								
Boyeria	P					1			
Gomphidae	P								
Gomphus	P	5				2			
Lanthus	P	1							
Cordulidae	P								
Somatochlora	P							1	
Megaloptera									
Corydalidae	P								
Corydalus	P					1			

Trichoptera									
Brachycentridae	FC								
Brachycentrus	FC	3	3		20	8		2	
Glossosomatidae	SC								
Glossosoma	SC								
Helicopsychidae	SC								
Helicopsyche	SC	2							
Hydropsychidae	FC								
Cheumatopsyche	FC			1	24		6		22
Hydropsyche	FC	8			24	4		2	
Lepidostomatidae	SH								
Lepidostoma	SH					3			
Leptoceridae	CG								
Ceraclea	CG		1						
Setodes	CG								
Limnephilidae	SH								
Apatania	SC					1			
Odontoceridae	SH								
Psilotreata	SC								
Philopotamiidae	FC								
Chimarra	FC								1
Dolophilodes	FC	5			13				
Phryganeidae	SH								
Polycentropidae	FC								
Neureclipsis	FC	2							
Polycentropus	FC								
Rhyacophilidae	P								
Rhyacophila	P	1		4	2				1
Uenoidae	SC								
Neophylax	SC			1					
Coleoptera									
Elmidae	SC								

Optioservus	SC	44	1		1	1			
Stenelmis	SC						4		
Diptera									
Athericidae	P	5	1						
Ceratopogonidae	P					10		2	1
Chironomidae	CG	37				8		4	5
Empididae	P	1			3				
Muscidae	P				1				
Simuliidae	FC								
Prosimulium	FC			41			84		27
Simulium	FC				1	2			
Tipulidae	SH						2		
Antocha	CG								1
Tipula	SH	4							
TOTAL		**194**	**24**	**131**	**205**	**77**	**191**	**45**	**183**

Appendix E: Micro-Fish Software Fisheries Data- Fall 2007

Site # 2

	Brown Trout	Brook Trout	Sculpins	Total Fishes
Total Catch	12	9	49	72
Population Estimate	13	9	81	95
Chi2	0.496	0.047	0.096	0.083
Pop. Est. Standard Error	2.550	0.369	32.468	16.570
Lower Confidence Interval	12	9	49	72
Upper Confidence Interval	18.555	9.850	145.611	127.988
Capture Probability	0.667	0.9	0.368	0.503
Capture Probability Standard Err.	0.226	0.117	0.186	0.125
Lower Confidence Interval	0.173	0.631	-0.001	0.256
Upper Confidence Interval	1.160	1.169	0.738	0.751
% of Population Estimate	85.47	18.88	159.53	69.28
Actual lower Confidence Interval	7.445	8.150	16.389	62.092
# of fish/200m²	77	53	480	561

Red Bridge (site #11)

	Brown Trout	Brook Trout	Sculpins	Total Fishes
Total Catch	54	5	245	304
Population Estimate	56	5	363	400
Chi2	0.085	0.145	0.017	0.013
Pop. Est. Standard Error	2.391	0.529	48.509	32.982
Lower Confidence Interval	54	5	267.438	335.025
Upper Confidence Interval	60.791	6.469	458.562	464.975
Capture Probability	0.794	0.833	0.429	0.509
Capture Probability Standard Err.	0.075	0.216	0.076	0.060
Lower Confidence Interval	0.644	0.234	0.280	0.391
Upper Confidence Interval	0.944	1.433	0.579	0.627
% of Population Estimate	17.11	58.76	52.65	32.49
Actual lower Confidence Interval	51.209	3.531		
# of fish/200m²	280	25	1,815	2,000

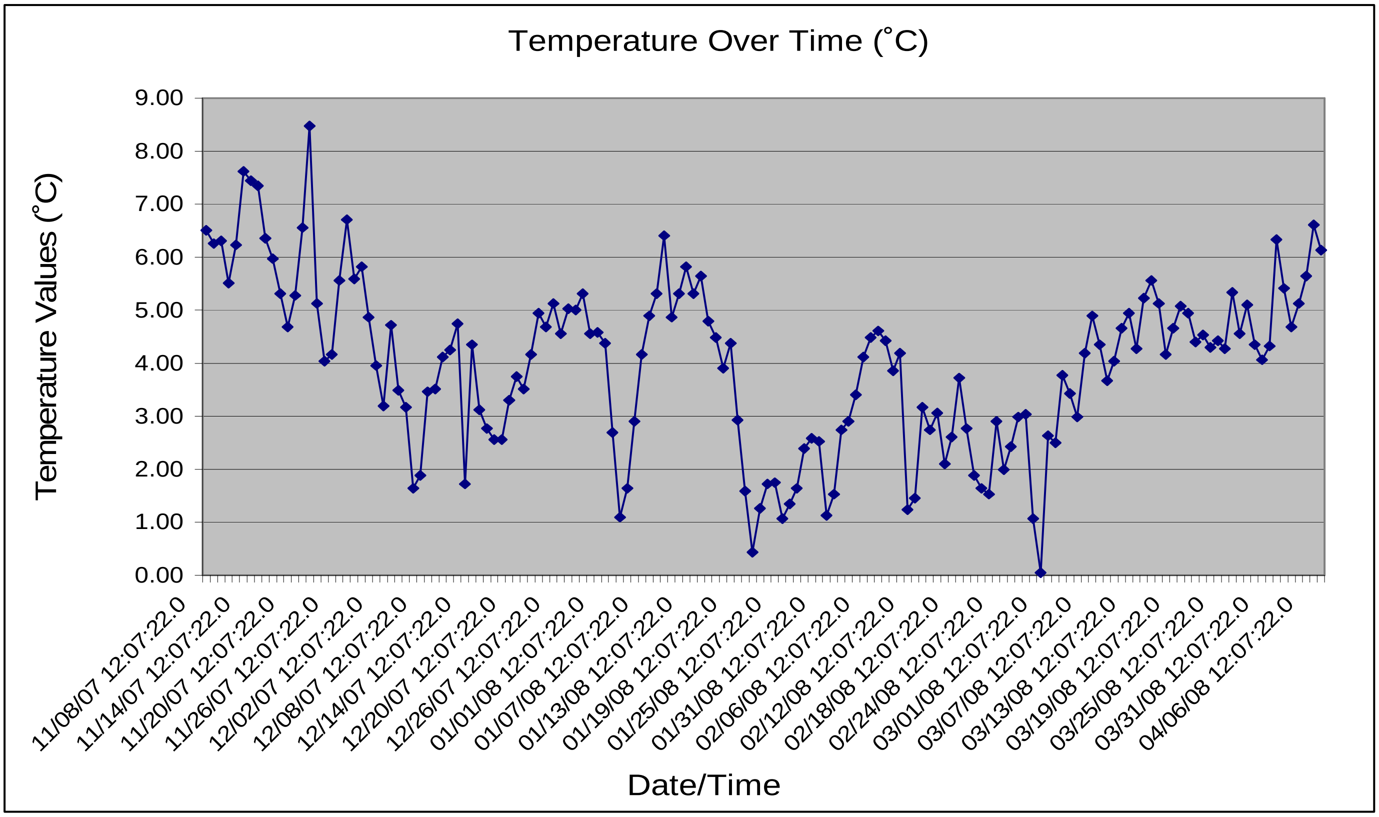
Finkler’s Furnace (site # 16)

	Brown Trout	Brook Trout	Sculpins	Total Fishes
Total Catch	30	14	178	223
Population Estimate	36	15	249	308
Chi2	0.128	0.262	0.023	0.025
Pop. Est. Standard Error	10.025	2.262	33.030	35.046
Lower Confidence Interval	31	14	183.930	283.960
Upper Confidence Interval	60.280	19.852	314.070	377.040
Capture Probability	0.517	0.7	0.465	0.473
Capture Probability Standard Err.	0.186	0.193	0.084	0.074
Lower Confidence Interval	0.140	0.287	0.299	0.327
Upper Confidence Interval	0.893	1.113	0.631	0.620
% of Population Estimate	101.4	64.69	52.26	44.83
Actual lower Confidence Interval	19.720	10.148		
# of fish/200m²	210	105	1,743	2,156

Appendix F: Raw Temperature Data

Date/Time	Temp
11/08/07 12:07:22.0	6.51
11/09/07 12:07:22.0	6.26
11/10/07 12:07:22.0	6.31
11/11/07 12:07:22.0	5.51
11/12/07 12:07:22.0	6.23
11/13/07 12:07:22.0	7.62
11/14/07 12:07:22.0	7.44
11/15/07 12:07:22.0	7.34
11/16/07 12:07:22.0	6.36
11/17/07 12:07:22.0	5.98
11/18/07 12:07:22.0	5.31
11/19/07 12:07:22.0	4.69
11/20/07 12:07:22.0	5.28
11/21/07 12:07:22.0	6.56
11/22/07 12:07:22.0	8.47
11/23/07 12:07:22.0	5.13
11/24/07 12:07:22.0	4.04
11/25/07 12:07:22.0	4.17
11/26/07 12:07:22.0	5.57
11/27/07 12:07:22.0	6.71
11/28/07 12:07:22.0	5.59
11/29/07 12:07:22.0	5.82
11/30/07 12:07:22.0	4.87
12/01/07 12:07:22.0	3.96
12/02/07 12:07:22.0	3.20
12/03/07 12:07:22.0	4.71
12/04/07 12:07:22.0	3.49
12/05/07 12:07:22.0	3.17
12/06/07 12:07:22.0	1.64
12/07/07 12:07:22.0	1.89
12/08/07 12:07:22.0	3.46
12/09/07 12:07:22.0	3.51
12/10/07 12:07:22.0	4.12
12/11/07 12:07:22.0	4.25
12/12/07 12:07:22.0	4.74
12/13/07 12:07:22.0	1.72
12/14/07 12:07:22.0	4.35
12/15/07 12:07:22.0	3.12
12/16/07 12:07:22.0	2.77
12/17/07 12:07:22.0	2.56
12/18/07 12:07:22.0	2.56
12/19/07 12:07:22.0	3.30
12/20/07 12:07:22.0	3.75
12/21/07 12:07:22.0	3.51
12/22/07 12:07:22.0	4.17
12/23/07 12:07:22.0	4.95
12/24/07 12:07:22.0	4.69
12/25/07 12:07:22.0	5.13
12/26/07 12:07:22.0	4.56
12/27/07 12:07:22.0	5.02
12/28/07 12:07:22.0	5.00
12/29/07 12:07:22.0	5.31
12/30/07 12:07:22.0	4.56
12/31/07 12:07:22.0	4.58
01/01/08 12:07:22.0	4.38
01/02/08 12:07:22.0	2.69
01/03/08 12:07:22.0	1.10
01/04/08 12:07:22.0	1.64
01/05/08 12:07:22.0	2.90
01/06/08 12:07:22.0	4.17
01/07/08 12:07:22.0	4.90
01/08/08 12:07:22.0	5.31
01/09/08 12:07:22.0	6.41
01/10/08 12:07:22.0	4.87
01/11/08 12:07:22.0	5.31
01/12/08 12:07:22.0	5.82
01/13/08 12:07:22.0	5.31
01/14/08 12:07:22.0	5.64
01/15/08 12:07:22.0	4.79
01/16/08 12:07:22.0	4.48
01/17/08 12:07:22.0	3.91
01/18/08 12:07:22.0	4.38
01/19/08 12:07:22.0	2.93
01/20/08 12:07:22.0	1.59
01/21/08 12:07:22.0	0.44
01/22/08 12:07:22.0	1.26

01/23/08 12:07:22.0	1.72
01/24/08 12:07:22.0	1.75
01/25/08 12:07:22.0	1.07
01/26/08 12:07:22.0	1.34
01/27/08 06:07:22.0	1.64
01/28/08 12:07:22.0	2.40
01/29/08 12:07:22.0	2.58
01/30/08 12:07:22.0	2.53
01/31/08 12:07:22.0	1.13
02/01/08 12:07:22.0	1.53
02/02/08 12:07:22.0	2.74
02/03/08 12:07:22.0	2.90
02/04/08 12:07:22.0	3.41
02/05/08 12:07:22.0	4.12
02/06/08 12:07:22.0	4.48
02/07/08 12:07:22.0	4.61
02/08/08 12:07:22.0	4.43
02/09/08 12:07:22.0	3.85
02/10/08 12:07:22.0	4.19
02/11/08 12:07:22.0	1.24
02/12/08 12:07:22.0	1.45
02/13/08 12:07:22.0	3.17
02/14/08 12:07:22.0	2.74
02/15/08 12:07:22.0	3.06
02/16/08 12:07:22.0	2.10
02/17/08 12:07:22.0	2.61
02/18/08 12:07:22.0	3.72
02/19/08 12:07:22.0	2.77
02/20/08 12:07:22.0	1.89
02/21/08 12:07:22.0	1.64
02/22/08 12:07:22.0	1.53
02/23/08 12:07:22.0	2.90
02/24/08 12:07:22.0	1.99
02/25/08 12:07:22.0	2.42
02/26/08 12:07:22.0	2.98
02/27/08 12:07:22.0	3.04
02/28/08 12:07:22.0	1.07
02/29/08 12:07:22.0	0.05
03/01/08 12:07:22.0	2.64
03/02/08 12:07:22.0	2.50
03/03/08 12:07:22.0	3.78
03/04/08 12:07:22.0	3.43
03/05/08 12:07:22.0	2.98
03/06/08 12:07:22.0	4.19
03/07/08 12:07:22.0	4.90
03/08/08 12:07:22.0	4.35
03/09/08 12:07:22.0	3.67
03/10/08 12:07:22.0	4.04
03/11/08 12:07:22.0	4.66
03/12/08 12:07:22.0	4.95
03/13/08 12:07:22.0	4.27
03/14/08 12:07:22.0	5.23
03/15/08 12:07:22.0	5.57
03/16/08 12:07:22.0	5.13
03/17/08 12:07:22.0	4.17
03/18/08 12:07:22.0	4.66
03/19/08 12:07:22.0	5.08
03/20/08 12:07:22.0	4.95
03/21/08 12:07:22.0	4.40
03/22/08 12:07:22.0	4.53
03/23/08 12:07:22.0	4.30
03/24/08 12:07:22.0	4.43
03/25/08 12:07:22.0	4.27
03/26/08 12:07:22.0	5.33
03/27/08 12:07:22.0	4.56
03/28/08 12:07:22.0	5.10
03/29/08 12:07:22.0	4.35
03/30/08 12:07:22.0	4.06
03/31/08 12:07:22.0	4.32
04/01/08 12:07:22.0	6.33
04/02/08 12:07:22.0	5.41
04/03/08 12:07:22.0	4.69
04/04/08 12:07:22.0	5.13
04/05/08 12:07:22.0	5.64
04/06/08 12:07:22.0	6.61
04/07/08 12:07:22.0	6.13



# of Days in Stream	152
Maximum Temperature (˚C)	8.47
Minimum Temperature (˚C)	0.05
Average Temperature (˚C)	4.01