ROLE OF BEAVER IMPOUNDMENTS IN THE STRUCTURE AND FUNCTION OF SOUTHERN GEORGIA STREAMS

By

CODY RICK McNEELY

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Cody Rick McNeely

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The North American beaver (*Castor canadensis*) is one of the few extant mammals able to modify its surrounding landscape dramatically, often complicating its relationship with humans. However, the vast majority of research has been limited to north temperate regions, with almost no data regarding southern beaver populations. The focal point of this study was to understand the impact beaver impoundments on stream systems of warm temperate regions.

Two sites in Thomasville, Georgia (Gatling Branch and Unnamed Creek) were selected for this study based on location, morphology, hydrology and active beaver populations. Sampling was conducted from November 2006 through April 2007, with April capturing the effects of extensive anthropogenic construction activities. For each system, two 100-m stretches, upstream and downstream of the beaver pond, and the pond proper were sampled. Measurements and/or samples included chemical / physical parameters (temperature, dissolved oxygen, specific conductivity and total suspended solids), macroinvertebrate communities and benthic organic matter storage. Statistical comparisons were made between compartments (upstream, downstream and pond), sampling periods and compartments relative to sampling period.

During the pre-anthropogenic disturbance period, few parameters were longitudinally or temporally significant when compared between sampling compartment and sampling dates.

However, effects resulting from beaver activity included changes in organic matter (OM) storage, dissolved oxygen (DO) and invertebrate abundance. Mean upstream OM storage at Unnamed Creek was 6,600 g/m^2, while storage within the pond proper increased to 56,000 g/m^2, almost an order of magnitude greater. Longitudinal DO at Gatling Branch decreased from 7.6 mg/L upstream to 3.2 mg/L within impounded areas, and was attributed to increased OM loading. Responding to changes in DO, invertebrate abundance at Gatling Branch decreased from 94,000 invertebrates/m^2 upstream to 24,000 invertebrates/m^2 within the backwater / pond.

Longitudinal and temporal effects attributed to human construction activities adjacent to and immediately downstream of the beaver pond at Gatling Branch included intense changes in water temperature, dissolved oxygen, suspended solids (turbidity) and invertebrate abundance. During April, mean water temperature increased from 16^{o}C in undisturbed sections of the stream to over 22^{o}C within backwater / pond and downstream segments. During the same sampling period, mean DO decreased from 6.8 mg/L upstream to 3.9 mg/L within the pond, while mean turbidity increased from 4.6 NTU upstream to 14.7 NTU within and downstream of the beaver pond. In response to these chemical / physical changes, invertebrate abundance during April decreased from 162,000 individuals/m^2 upstream to 28,000 individuals/m^2 within the backwater / pond area.

During this study, the effects of beaver impoundments were limited to invertebrate abundance, dissolved oxygen and OM storage. Conversely, anthropogenic disturbances appear to have much greater effect on stream systems, with dramatic changes in temperature, dissolved oxygen, turbidity and invertebrate communities. Finally, the OM and carbon sequestration potential of these beaver impoundments was tremendous and may offer an overlooked component to counter global climate change.

CHAPTER 1
INTRODUCTION

The late nineteenth and early twentieth centuries witnessed the decline of the North American beaver from most waterways. Intense human pressure caused the demise of beaver and left many streams without nature's wetland engineers for almost a century. Among the most heavily influenced beaver populations were those of the southeastern United States, with complete extirpation from some regions by the early twentieth century. An aggressive conservation program has helped North American beaver populations recover. Extensive migration to southeastern waterways and establishment of healthy populations are prime evidence of successful conservation efforts (Everett and Schaefer 2006).

As semi-aquatic rodents native to North America and Europe, beaver are the only living members of the family Castoridae, which contains the single genus Castor. Beavers inhabit riparian zones of streams as well as the channel. Families typically consist of around eight members with adults weighing up to 25 kg. The health and productivity of aquatic ecosystems depend in part on the influence of beaver. Functioning as a keystone species by creating wetland habitat (McHale *et al*., 2004), beaver are best known for construction of dams in streams and lodges in the ponds that form. Construction of lodges is common in temperate regions, with bank dwelling more prevalent in warm southern regions. Beaver dams are created both as protection against predators and to provide food access during winter. During dam and lodge construction, beaver selectively remove riparian tress, creating gaps in canopy cover. This facilitates macrophyte colonization and proliferation in beaver ponds, resulting in altered nutrient cycling and aquatic food webs (Ray *et al*., 2001).

Nutrient sequestration is often considered the most valuable function of a beaver pond. In addition, beaver ponds accumulate vast quantities of inorganic and organic matter. However, bacteria that produce cellulase can utilize cellulose in organic matter for energy, creating the base of the microbial loop. Additional environmental benefits derived from beaver impoundments include flood control, increased biodiversity and sequestration of organic carbon. Next to humans, no other extant animal does more to shape its landscape than beaver (Morgan 1986).

This study was conducted because few data or studies on beaver exist for warm temperate regions. The focal point of this study was to understand how warm-temperate beaver impoundments in southern Georgia affect organic matter storage, water quality and macroinvertebrate communities. Investigation of organic matter included quantifying storage capacity and the potential role of beaver ponds in global carbon cycling. Change in water quality was assessed by temperature, specific conductivity, dissolved oxygen and turbidity. The structure and function of macroinvertebrate assemblages included identifying and assigning individuals to feeding guilds. Previous studies investigating effects of beaver impoundments have been confined to regions that experience distinct seasonality. This study focused on beaver impoundments in a region experiencing long growing seasons and moderate winters.

CHAPTER 2
MATERIALS AND METHODS

Site Description

Two sites in southern Georgia were selected for this study, Gatling Branch and Unnamed Creek, based on geographical location, morphology, hydrologic regimes and accessibility. In addition, both sites had an active beaver population prior to the study that provided impoundment maintenance and presumed long-term sustainability.

Gatling Branch

Gatling Branch is a low gradient, second-order stream (Strahler method) located in Thomas County, Georgia (30^{o} 51’ 11.3’’ N, 83^{o} 54’ 00.6’’ W). Headwaters of the two first order streams originate from seepage wetlands and flow south to their confluence north of Georgia state road 122 (Figure 2-1). USGS (U.S. Geological Survey) classified the flow regime of Gatling Branch (HUC 3110103) as intermittent, and it has mean bankfull width and mean water depth of 4.7 m and 9.8 cm, respectively. However, mean water depth within the reach of stream influenced by beaver activity increased to 46.4 cm (Figure. 2-3). The substrate of the stream channel is predominantly sand with increasing organic content approaching the beaver pond from upstream. Upstream of the beaver pond, the channel is fully canopied, and the riparian zone is dominated by water oak (*Quercus nigra*), sweetgum (*Liquidambar styraciflua*) and willow (*Salix caroliniana*). The canopy downstream is sparse and dominated by tulip poplar (*Liriodendron tulipifera*). The beaver pond has an approximate surface area of 80 m^2 and is located 1.5 kilometers south of Georgia state road 122. In addition, this site has an extensive backwater area, extending approximately 250 m upstream of the pond proper. Constructed primarily from wood and mud, the dam stood an impressive 1.5 m high. Water discharge occurred predominantly at the base of the dam with surface overflow only during high water.

Unnamed Creek

Unnamed Creek is a low gradient, second-order stream (Strahler method) located in Thomasville, Georgia (30^o 52' 32.1'' N, 83^o 56' 30.7'' W). The principal headwater originates from a seepage wetland, while a secondary headwater originates from channelized overland flow. Both stream channels flow north to a confluence south of US 84 bypass (Figure 2-2). USGS classified the flow regime of Unnamed Creek (HUC 3120002) as intermittent. Mean bankfull width and mean water depth are 2.1 m and 28 cm, respectively. However, mean water depth within the reach of stream influenced by beaver activity increased to 55.5 cm (Figure. 2-4). The substrate of the stream channel is predominantly sand and clay with increasing organic content approaching the beaver pond from upstream. The stream channel is fully canopied with a riparian zone dominated by water oak (*Quercus nigra*), sweetgum (*Liquidambar styraciflua*), red maple (*Acer rubrum*) and longleaf pine (*Pinus palustris*). The beaver pond has an approximate surface area of 2,900 m^2 and is located 0.16 kilometers north of US 35. Constructed primarily from wood, the dam stands at a height of 0.65 m. Water discharge occurred predominantly as surface overflow with almost no discharge from the base of the dam.

Field Methods

For each stream, two 100-m stretches, upstream and downstream of the beaver pond and the beaver pond proper were sampled. Sampling was conducted at Gatling Branch and Unnamed Creek three times from November 2006 through April 2007 (3 and 4 November 2006, 13 and 14 January 2007 and 6 and 7 April 2007). Benthic organic matter was sampled once at the beginning of the study. Fieldwork required two days per site, 13 and 14 October 2006 for Gatling Branch and 20 and 21 October 2006 for Unnamed Creek.

Organic Matter and Sedimentation

Benthic organic matter (BOM) samples were collected using a clear PVC coring device 1-m long and 3.8 cm in diameter. BOM cores were collected at a transect interval of 0, 10, 25, 50, 75 and 100 m upstream and downstream of the beaver pond. Eleven additional cores at Gatling Branch and five at Unnamed Creek were collected within the pond and backwater areas at 25-m intervals. Three BOM cores were collected at each location; left bank, center channel / pond and right bank. Samples consisted of all material down to the sand or clay substrate. Collection began at the 100-m downstream transect and proceeded upstream to avoid contamination between segments.

Macroinvertebrate Communities

Macroinvertebrate samples were collected via the same PVC coring device used in BOM sampling. Macroinvertebrates from Unnamed Creek were collected at a transect interval of 0, 10, 50, and 100 m upstream and downstream of the beaver pond. Three additional samples were collected within the pond at randomly selected locations. Because of the extensive backwater area at Gatling Branch, macroinvertebrates were collected at a transect interval of 10, 50, and 100 m upstream of the beaver pond and 0, 10, 50 and 100 m downstream of the impoundment. Macroinvertebrates were not collected at the 0-m upstream transect. However, two samples were collected from within the backwater area 10 m upstream from the pond (BWUSP) and 10 m downstream from the upstream 0-m transect (BWDSE). Three additional samples were collected within the pond at randomly selected locations. Only one macroinvertebrate sample was collected at each transect and consisted of all material to a depth of 15 cm. Samples were placed into one-liter plastic containers and preserved in situ with 70% ethanol containing 0.2 mg/l of Rose Bengal stain. Collection began at the 100-m downstream transect and proceeded upstream to avoid sampling interference between segments.

Physical – Chemical Parameters

Physical / chemical parameters (temperature, dissolved oxygen and specific conductivity) were measured in situ using a YSI 585 field probe. Total suspended solids (turbidity) was measured in the laboratory by analyzing a 25-ml water sample using a LaMotte 2020 Turbidimeter, and results were reported in nephelometric turbidity units (NTU's). Measurements from Unnamed Creek were taken at 0, 10, 50, and 100 m upstream and downstream of the beaver pond. Three additional measurements were taken within the pond at randomly selected locations. Because of the extensive backwater area at Gatling Branch, measurements were taken at 10, 50, and 100 m upstream of the beaver pond and 0, 10, 50 and 100 m downstream of the impoundment. Physical / chemical parameters were not taken at the 0-m upstream transect. However, two measurements were taken from within the backwater area 10 m upstream from the pond (BWUSP) and 10 m downstream from the upstream 0-m transect (BWDSE). Three additional measurements were taken within the pond at randomly selected locations. Measurements and sample collection began at the 100-m downstream transect and proceeded upstream to avoid sampling interference between segments.

Laboratory Methods

Loss on Ignition (LOI) Analysis

BOM cores were divided longitudinally into 10-cm segments and homogenized using a standard mortar and pistil. One sub-sample of 5 cm^3 was taken from each homogenized segment and dried at 60 °C for 48 hrs. Upon removal, a dry weight was obtained using an analytical balance measuring to three decimals. Each sample was then combusted in a muffle furnace at 550 °C for 5 hrs. Samples were allowed to cool in a desiccator for 8 hrs and weighed again to obtain ash free dry weight.

Macroinvertebrates

Samples remained in collection bottles for a minimum of 48 hrs to ensure sufficient staining with Rose Bengal. To aid in sorting macroinvertebrates, samples were washed through 500-µm sieves to collect larger and more developed larva, and through 250-µm sieves to collect smaller and earlier instar stages. The collected macroinvertebrates were placed into 10-ml glass vials and labeled with the transect location. Identification was made to lowest practical taxonomic level to facilitate assignment of individuals to a functional feeding group (Merritt and Cummings 1996). Using a dissecting microscope, taxonomic identification was determined to genus for all specimens belonging to the class Insecta. Individuals in the family Chironomidae were identified to genus after mounting head capsules on slides and using a compound microscope. Identification was to class and/or family for all other macroinvertebrates.

Statistics

For the purpose of statistical comparison, each system was divided into three treatments; upstream, downstream and backwater / pond. Using an ANOVA statistical model in SAS, parameters of organic matter, physical / chemical characteristics and macroinvertebrates were compared among treatments and sampling dates. Three statistical comparisons were made relative to treatment: upstream versus downstream, pond versus downstream and upstream versus pond.

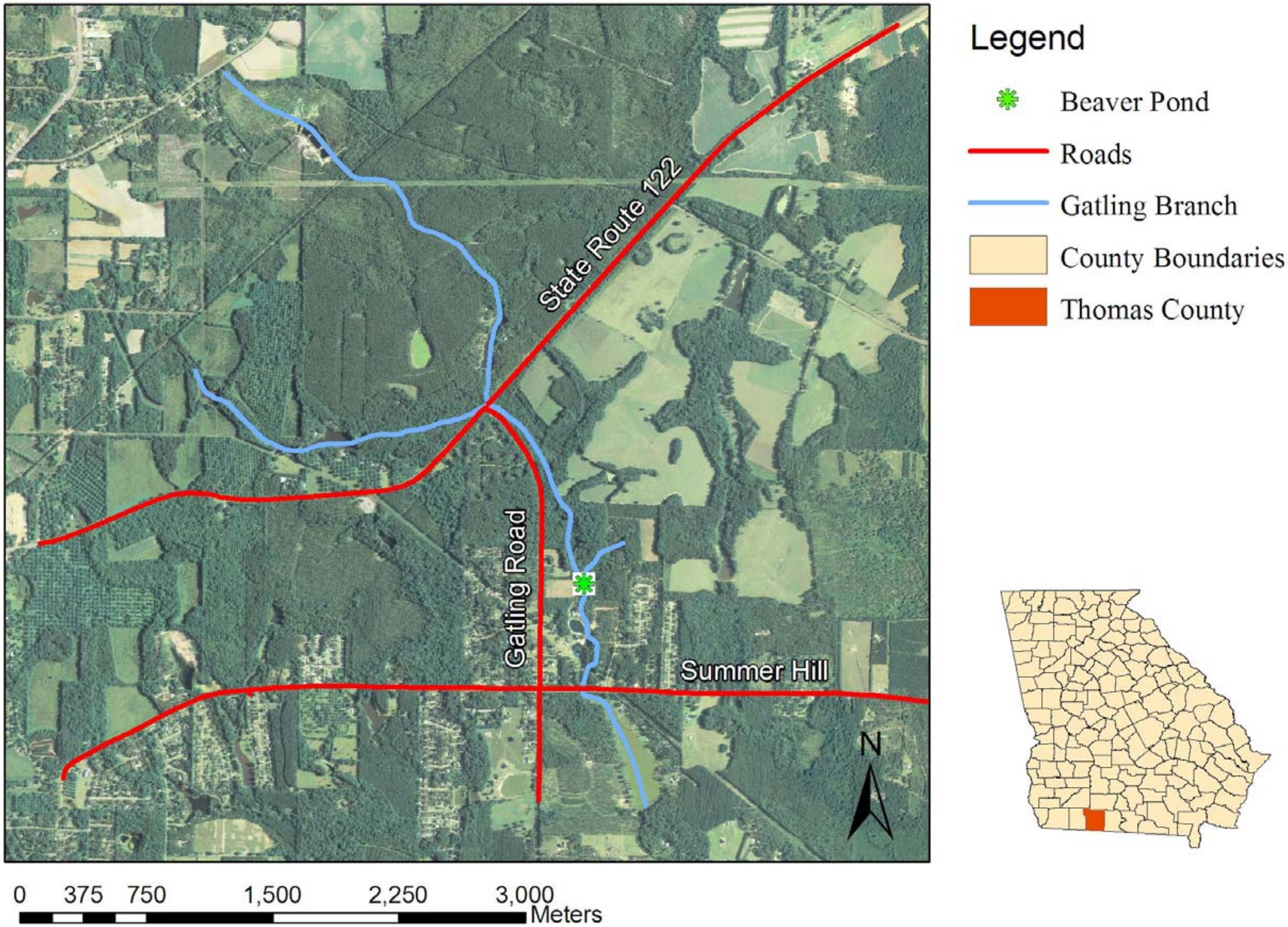

Figure 2-1. Aerial map of Gatling Branch.

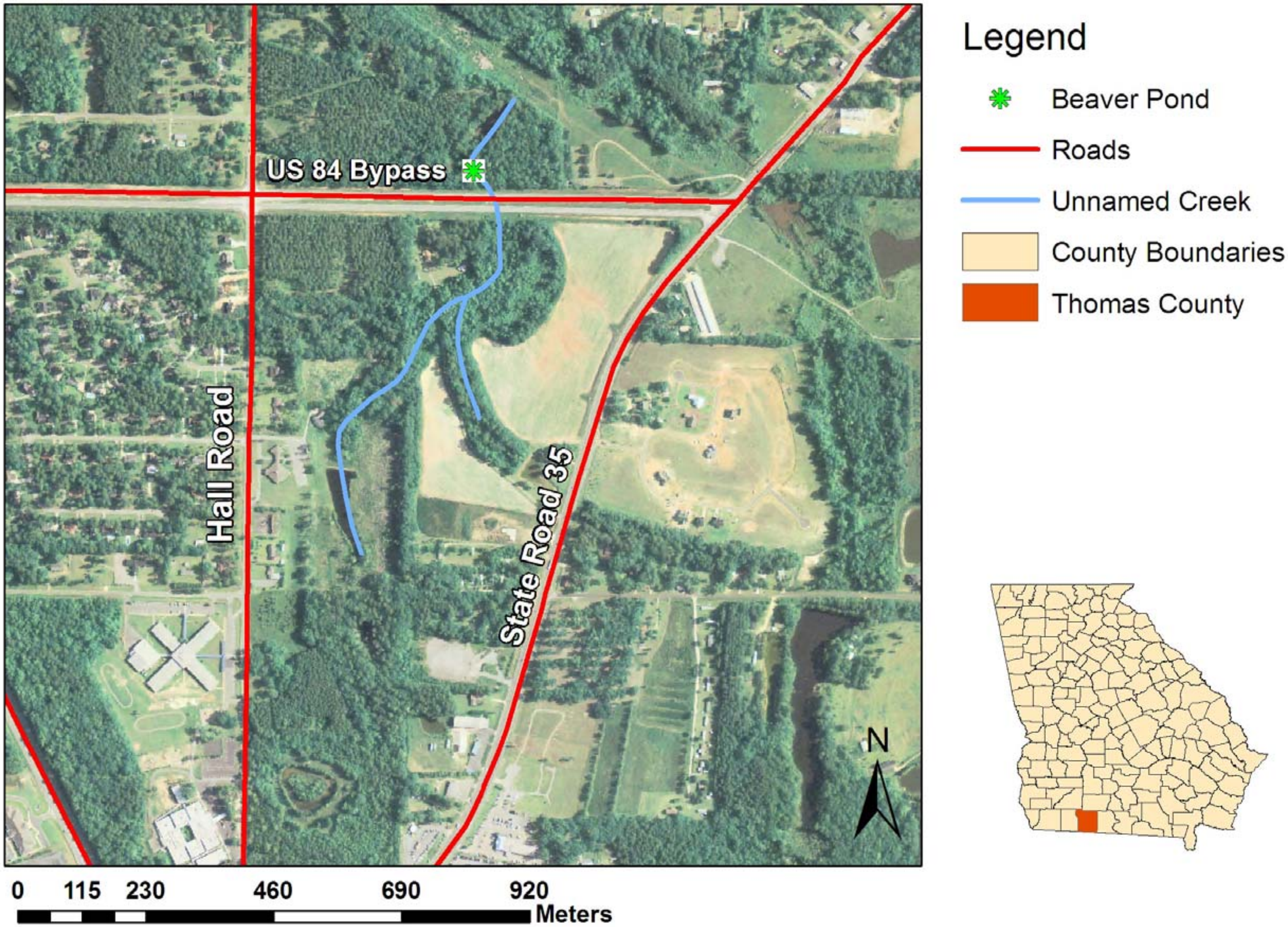

Figure 2-2. Aerial map of Unnamed Creek.

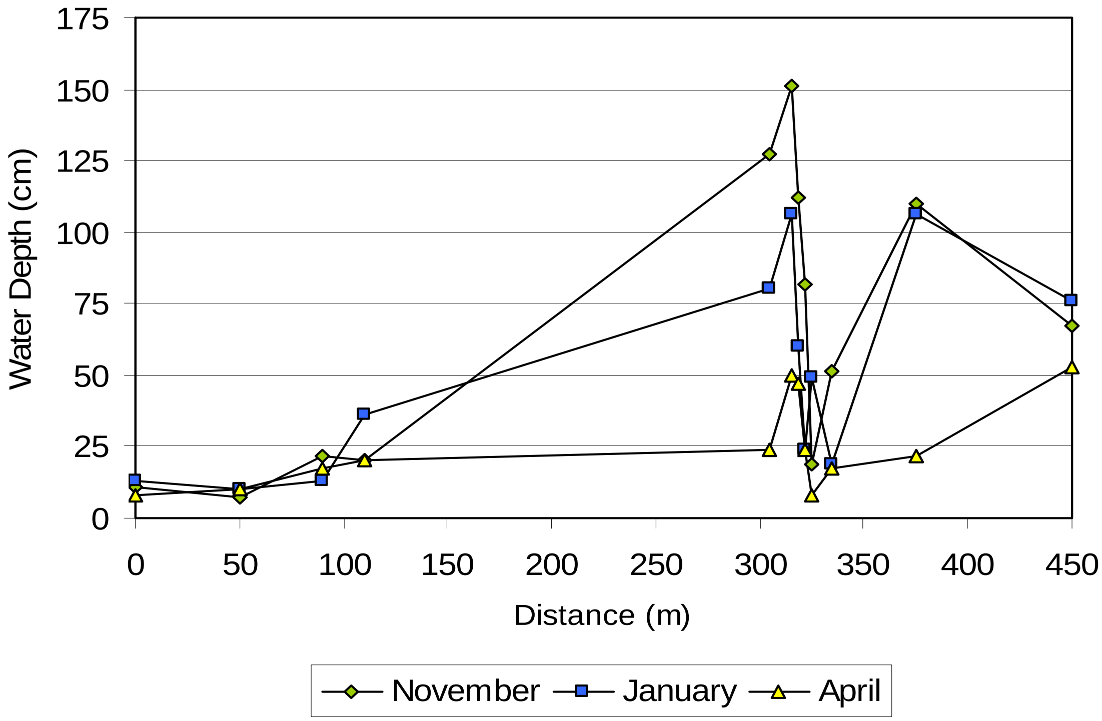

Figure 2-3. Longitudinal profile of water depth at Gatling Branch.

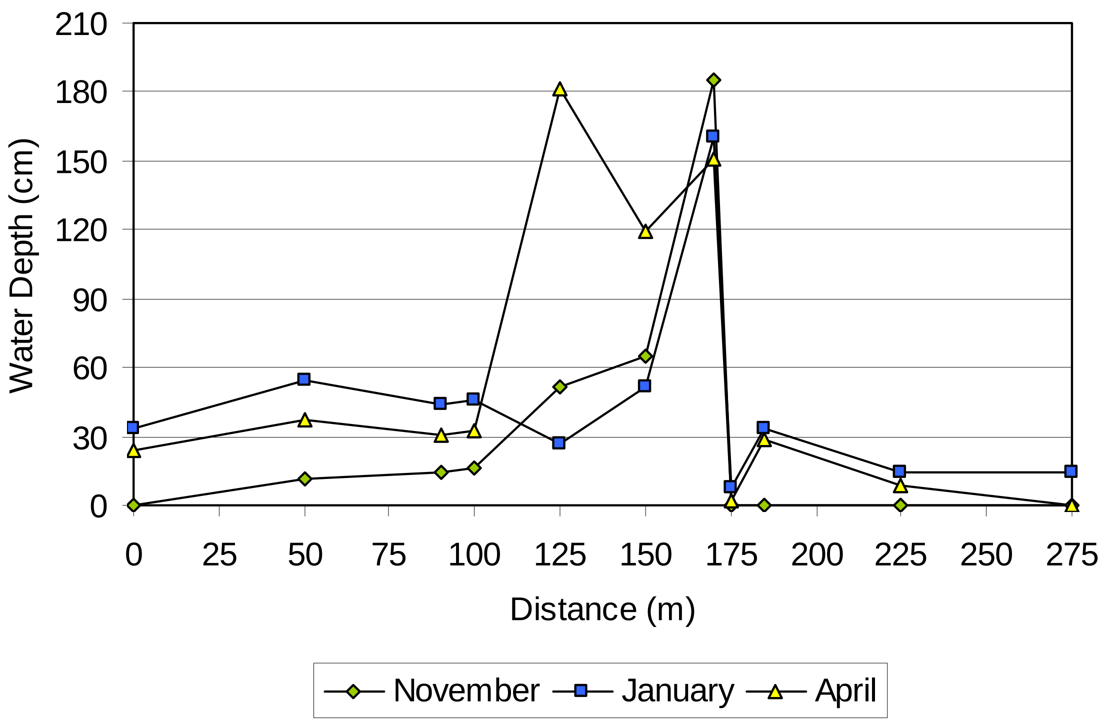

Figure 2-4. Longitudinal profile of water depth at Unnamed Creek

CHAPTER 3
RESULTS AND DISCUSSION

Benthic Organic Matter

Gatling Branch

The study area at Gatling Branch consisted of 350 m of stream channel and three impoundments. The main impoundment (Pond 10) was the largest and most central. A second and slightly smaller impoundment was approximately 250 m upstream (BW225) of the beaver pond. The third and smallest impoundment was located 100 m downstream (DS100) of the beaver pond.

Spatial differences in organic matter (OM) occurred longitudinally throughout the system, with storage greatest at stream / impoundment interface. Correspondingly, OM storage at the main impoundment / stream interface was 57,000 g/m^2 (Pond 10), while storage at the stream interface for the two smaller impoundments was 59,000 (BW225), and 53,000 (DS100) g/m^2 (Figure. 3-1). Mean OM storage was greatest downstream of the beaver pond (38,000 g/m^2), while storage for upstream and backwater / pond were 13,000 and 35,000 g/m^2, respectively. Transects 0 and 10 m upstream (23,000 and 21,000 g/m^2, respectively) heavily influenced mean upstream storage, presumably due to the abrupt decease in velocity and precipitation of OM. Using the 25, 50, 75 and 100-m transects as a baseline for normal stream condition, a much smaller upstream mean of 8,100 g/m^2 was calculated. Using an ANOVA model in SAS, significant longitudinal effects on OM storage were observed between downstream versus upstream and pond versus upstream ($p<0.03$) and ($p<0.02$), respectively, with downstream and pond segments having significantly greater OM storage compared to upstream. The pond was not significantly different from downstream.

The vertical OM profiles for upstream, backwater / pond and downstream exhibited an indirect relationship with depth, with the exception of the interface between stream and impoundments, which exhibited a direct relationship between OM and depth (Figure 3-2). Complex vertical stratification presented difficulties in analyzing core segments. Thus, each core was divided vertically at the midpoint into larger upper and lower sections, and mean OM for each section was calculated. Mean OM storage for the upper and lower profile for upstream and downstream segments were 4,500 and 2,200 g/m^2 and 6,900 and 6,000 g/m^2, respectively. Mean backwater / pond storage was 7,000 and 6,100 g/m^2, respectively. However, mean OM storage for the upper and lower profile at upstream 0 m was 5,600 and 8,000 g/m^2, respectively. Storage profiles for both minor impoundments were 5,300 and 9,300 g/m^2 (BW225) and 9,200 and 11,000 g/m^2 (DS100), respectively. The main impoundment (Pond10) had an upper and lower profile of 2,600 and 8,900 g/m^2, respectively. However, no significant vertical difference in OM was observed for any sampling compartment.

Unnamed Creek

Spatial differences in organic matter (OM) storage occurred longitudinally throughout Unnamed Creek. Storage was greatest at the upstream / pond interface and directly behind the beaver dam, averaging 93,000 and 71,000 g/m^2, respectively (Figure 3-3). Mean OM storage was greatest within the pond proper (56,000 g/m^2), while upstream and downstream storage were 37,000 and 18,000 g/m^2, respectively. Using an ANOVA model, significant longitudinal effects on OM storage were observed between pond versus upstream and pond versus downstream ($p<0.001$), with the pond having significantly greater OM storage compared to upstream and downstream segments. No statistical significance in OM storage was observed between upstream and downstream segments. Transects 0 and 10 m upstream (93,000 and 92,000 g/m^2, respectively) heavily influenced mean upstream storage, presumably due to the abrupt decease in velocity and precipitation of OM. In addition, downstream transects 75 and 100 m reside within a marsh. Calculating baseline stream conditions excluding these transects yielded a much smaller upstream and downstream mean of 6,600 and 12,000 g/m^2, respectively. Using the adjusted upstream mean, OM storage per area within the pond is almost an order of magnitude greater than baseline stream conditions (6,600 and 56,000 g/m^2, respectively).

Vertical OM profiles for upstream and downstream segments at Unnamed Creek exhibited an indirect relationship with depth. The interfaces between stream / pond and directly behind the dam were the exception with vertical profiles exhibiting a direct relationship between OM and depth (Figure 3-4). Unnamed Creek exhibited the same complex vertical stratification as Gatling Branch. Thus, each core was similarly divided vertically at the midpoint into larger upper and lower sections and mean OM calculated for each. Mean upper and lower profiles for upstream and downstream segments were 10,000 and 8,000 g/m^2 and 14,000 and 12,000 g/m^2, respectively. However, mean OM storage for the upper and lower profile at upstream 0 m was 9,000 and 14,000 g/m^2, respectively. The OM profile with pond proper was 11,000 and 13,000 g/m^2, respectively. However, no significant vertical difference in OM was observed for any sampling compartment.

Discussion

Investigation of sediment depth and accumulation rates within beaver ponds at Glacier National Park suggested that sediment volume was strongly correlated with pond area, with rate of sedimentation greater in ponds than upstream (Butler and Malanson 1995). The longitudinal OM profile at Unnamed Creek further supports these finding, with greatly increased OM storage within the pond proper compared to upstream and downstream areas. In contrast, the longitudinal profile at Gatling Branch was unique in that the downstream segment had the greatest storage per area basis. This profile is presumed to be the result of a multi-dam system. The relatively close longitudinal proximity of impoundments presumably prevented OM from returning to baseline conditions, resulting in increasing OM with progression downstream.

Complex vertical profiles were observed for Gatling Branch and Unnamed Creek. Vertical stratification was presumably the result of precipitation events that introduce large quantities of allocthonous sand. When the rain event subsides and/or the stream encounters an impoundment, stream velocity decreases and sand accumulates. Conversely, during periods of low flow, allocthonous OM will accumulate. Thus, it is suggested that oscillation in stage is the cause for vertical stratification. The vertical profile for upstream and downstream segments at Gatling Branch and Unnamed Creek exhibited an indirect relationship between OM and depth, while a direct relationship existed at stream / impoundment interfaces. This direct relationship between OM and depth is presumably caused by the predominantly sand substrate that allows for vertical movement of organic matter and a confining layer of clay that defines the extent of downward movement. Reduced velocity and increased retention time at stream / impoundment interface allows biota to process coarse OM, causing a reduction in particle size (Kaplan *et al.,* 1980, Wetzel 1983). The fine particulate organic matter (FPOM) presumably moves through the sand substrate, creating a vertical OM profile inverted from upstream and downstream segments.

Sequestered organic matter in aquatic systems represents a significant component of the global carbon pool. Photosynthetic and respiratory processes within these systems are important regulators of inorganic carbon (i.e. CO_2 and CH_4) in the atmosphere (Amundson 2001). The storage potential of carbon compounds in wetlands, and specifically beaver ponds, can offer significant contributions to global carbon cycling. Prior to near-extirpation, there was an estimated 12.5 million beaver ponds in North America trapping hundreds of billions cubic meters of organic sediment in streams (Butler 2006). The impoundments at Gatling Branch influenced at least 350 m of stream and sequestered more than 42,800 kg of organic matter. In addition, the single impoundment at Unnamed Creek influenced at least 175 m of stream, sequestering more than 124,000 kg of organic matter. Beaver activity at Gatling Branch and Unnamed Creek had a tremendous influence on the longitudinal and vertical distribution of OM, demonstrating the storage potential of these systems. Serving as large OM (i.e. carbon) sinks, beaver ponds offer an overlooked component to the complicated problem of global climate change.

Physical – Chemical Parameters

Spatial differences in physical and chemical parameters occurred both longitudinally and temporally in Gatling Branch and Unnamed Creek. November 2006 and January 2007 data for Gatling Branch were collected prior to anthropogenic disturbance, while April recorded the effects of extensive construction activities adjacent to pond and downstream transects that began in mid January 2007. For statistical analysis, each system was divided into three compartments: upstream, downstream and backwater / pond.

Gatling Branch

Water temperature in Gatling Branch ranged longitudinally between 14.3 and 14.9 ^{o}C during November, while January and April ranged between 9.1 and 10.9 ^{o}C and 16.9 and 24.9 ^{o}C, respectively (Figure. 3-5). Mean water temperature was 14.7 ^{o}C during November, while January dropped to 10.1 ^{o}C. Water temperature was greatest during April (19.4 ^{o}C). Mean longitudinal temperature was greatest within backwater / pond (15.3 ^{o}C), with upstream and downstream segments averaging 14.1 and 14.7 ^{o}C, respectively. Using an ANOVA model in SAS to analyze and compare longitudinal temperature between sampling compartments yielded no statistical significance for any date. However, statistical significance was observed between longitudinal temperature and sampling period when comparing downstream and pond segments between November and April and January and April ($p<0.005$) and ($p<0.001$), respectively, with downstream and pond temperature significantly greater during April. No temporal significance was observed between November and January.

Dissolved oxygen (DO) ranged longitudinally between 2.3 and 7.3 mg/L during November, with January and April ranging between 8.3 and 9.1 mg/L and 3.6 and 7.0 mg/L, respectively (Figure. 3-6). Mean DO during November was lowest (4.5 mg/L) and January highest (8.8 mg/L). Dissolved oxygen was intermediate during April at 5.4 mg/L. Mean longitudinal DO was greatest upstream and lowest within backwater / pond at 7.6 and 5.2 mg/L, respectively. Dissolved oxygen was intermediate downstream with an average of 5.8 mg/L. Using an ANOVA model to analyze longitudinal DO between sampling compartments yielded statistical significance for downstream versus upstream and pond versus upstream segments ($p<0.001$), with the upstream having significantly greater DO than pond and downstream. No statistical significance in DO was observed in pond versus downstream. In addition, statistical significance was observed between longitudinal DO and sampling period when comparing downstream and pond segments between November and January and April and January ($p<0.001$), with downstream and pond DO significantly greater during January. Comparisons between November and April sampling periods yielded no temporal significance.

Specific conductivity ranged longitudinally between 45 and 58 µm during November. January and April ranged between 40 and 43 µm and 63 and 80 µm, respectively (Figure. 3-7). Mean conductivity during November was intermediate at 54 µm. During January, mean conductivity was lowest (42 µm) and during April highest (70 µm). Mean longitudinal conductivity was the same for backwater / pond and downstream segments at 57 µm, while upstream averaged 52 µm. Using SAS to analyze and evaluate conductivity between sampling compartments yielded statistical significance for downstream versus upstream and pond versus upstream segments, ($p<0.03$) and ($p<0.004$), respectively, with pond and downstream segments having higher conductivity. No statistical significance in conductivity was observed in pond versus downstream. However, statistical significance was observed between longitudinal conductivity and sampling period when comparing downstream segments between November and April and January and April ($p<0.001$), with downstream conductivity greater during April. No significant temporal changes were observed between November and January sampling periods.

Turbidity at Gatling Branch ranged longitudinally between 5.1 and 9.0 NTU during November, while January and April ranged between 5.4 and 7.0 NTU and 4.4 and 16.2 NTU, respectively (Figure. 3-8). Mean turbidity levels during November and January were similar, 6.0 and 6.5 NTU, respectively, and greatest during April at 10.8 NTU. Mean longitudinal turbidity was greatest downstream and lowest upstream at 8.9 and 5.8 NTU, respectively. Turbidity was intermediate within backwater / pond (8.6 NTU). Using an ANOVA model to evaluate longitudinal turbidity between sampling compartments yielded statistical significance for downstream versus upstream and pond versus upstream segments ($p<0.001$), with pond and downstream segments having significantly greater turbidity. No statistical significance in turbidity was observed in pond versus downstream. However, statistical significance was observed between turbidity and sampling period when comparing downstream and pond segments between November and April and January and April ($p<0.001$), with pond and downstream turbidity significantly higher during April. No temporal significance was observed between November and January.

Unnamed Creek

Water temperature in Unnamed Creek ranged longitudinally between 10.4 and 12.9 ^oC during November. January and April ranged between 9.2 and 11.4 ^oC and 11.4 and 15.7 ^oC, respectively (Figure. 3-9). Mean water temperature was greatest during April (13.9 ^oC), with November at 11.1 ^oC and January at 10.4 ^oC. Mean longitudinal temperature upstream and within the pond proper were the same (11.8 ^oC). Mean temperature was greatest downstream (12.2 ^oC). Using an ANOVA model to compare longitudinal temperature between sampling compartments yielded no statistical significance for any date. However, statistical significance was noted between longitudinal temperature and sampling period when comparing downstream and pond segments between January and April and November and April ($p<0.001$), with downstream and pond temperature significantly higher during April.

Dissolved oxygen (DO) ranged longitudinally between 1.5 and 3.8 mg/L during November, with January and April ranging between 5.4 and 7.9 mg/L and 1.1 and 6.5 mg/L, respectively (Figure. 3-10). Mean DO during April was lowest (2.4 mg/L) and highest during January (6.8 mg/L). November was intermediate at 2.5 mg/L. Mean longitudinal DO was greatest upstream and lowest within the pond proper at 4.7 and 3.6 mg/L, respectively. Dissolved oxygen was intermediate downstream (4.4 mg/L). Using an ANOVA model to compare and evaluate longitudinal DO between sampling compartments yielded no statistical significance for any date. However, statistical significance was observed between longitudinal DO and sampling period when comparing the beaver pond between January and April ($p<0.001$), with pond DO significantly greater during the former.

Conductivity ranged longitudinally between 33 and 50 µm during November, while January and April ranged between 45 and 52 µm and 58 and 70 µm, respectively (Figure. 3-11). During November, mean conductivity was lowest (38 µm) and highest during April (65 µm). Conductivity during January was intermediate at 48 µm. Mean longitudinal conductivity upstream and downstream were both 54 µm, while the pond proper averaged 48 µm. Using SAS to compare and analyze longitudinal conductivity between sampling compartments and sampling periods yielded no statistical significance.

Turbidity at Unnamed Creek ranged longitudinally between 2.3 and 4.1 NTU during November, with January and April ranging between 3.1 and 5.3 NTU and 5.0 and 10.1 NTU, respectively (Figure. 3-12). Mean turbidity levels during November and January were similar, 3.0 and 3.9 NTU, respectively. Turbidity was greatest during April at 6.1 NTU. Mean longitudinal turbidity was greatest downstream and lowest within the pond proper at 7.0 and 3.8 NTU, respectively. Turbidity was intermediate upstream, averaging 4.4 NTU. Using an ANOVA model to evaluate longitudinal turbidity between sampling compartments yielded statistical significance for downstream versus pond segments ($p<0.002$), with downstream having greater turbidity. In addition, statistical significance was observed between turbidity and sampling period when comparing downstream segments between January and April ($p<0.001$), with the latter having significantly increased turbidity downstream.

Discussion

According to research by Maxted *et al*. (2005), water temperatures in beaver ponds and downstream fluctuate seasonally, with longitudinal temperatures being stable during winter and elevated during summer. Increased water temperature was attributed to larger surface area of ponds and increased adsorption of solar radiation during summer. Longitudinal variation in water temperature at Unnamed Creek followed this pattern. Upstream and downstream riparian zones created a nearly closed canopy and provided longitudinal stability in temperature during November and January, while the large surface area of the beaver pond and limited canopy protection from the riparian zone allowed for increased sunlight penetration and elevated temperatures during April.

Similar to Unnamed Creek, water temperature during November at Gatling Branch experienced almost no longitudinal variation, likely the result of a well-vegetated riparian zone and the relatively small surface area of impoundments. However, during January, water temperature at Gatlin Branch decreased within pond and downstream segments. This very different pattern was attributed to the beaver population abandoning the impoundment, and the ability of cooler bottom water to mix and discharge through subsequently degraded sections of the dam. During April, pond and downstream temperature at Gatling Branch paralleled the finding of Maxted *et al*. (2005), with temperature being greatest at the dam and decreasing with downstream progression. However, increased temperatures were not the result of beaver activity; rather, the extensive removal of riparian vegetation during construction and resulting increase of solar radiation. Temporal differences in mean water temperature at Gatling Branch and Unnamed Creek between November, January and April are presumed to be the result of seasonal variation, caused by changes in ambient air temperature and length of daylight.

Research conducted in New Zealand suggested that dissolved oxygen (DO) in beaver ponds and downstream fluctuates temporally, with reduced DO during summer. Decreases in DO were attributed to increased organic loading and increased decomposition within the beaver pond (Maxted *et al*., 2005). During November and April, longitudinal DO decreased dramatically within the backwater / pond area at Gatling Branch. Similarly, DO levels at Unnamed Creek greatly decreased within the pond proper during January and April. As suggested by Maxted *et al.* (2005), such longitudinal changes in DO at Gatling Branch and Unnamed Creek are likely the result of increased metabolic processes and rapid consumption of DO within impounded areas. However, removal of riparian vegetation, combined with poor performance of installed silt barriers during construction, presumably caused the decrease in DO observed during April at

Gatling Branch. Analogous to previous months, increased lateral input of fine particulate organic matter (FPOM) from construction resulted in increased decomposition and biological demand for oxygen.

The January sampling period at Gatling Branch yielded very different results, with almost no longitudinal change in dissolved oxygen. During this period, water flowed unimpeded through degraded sections of the beaver dam. This continuous flow prevented depletion of DO within the backwater / pond area, resulting in little longitudinal variation. Temporal differences in mean DO at Gatling Branch and Unnamed Creek between November, January and April are assumed to be the result of seasonal variation in ambient / water temperature and resulting changes in saturation of oxygen into water.

The conductive properties of aquatic environments are principally controlled by watershed geology, soil composition and vegetation. Thus, anion and cation strength (i.e. specific conductivity) is the result of weathered rock, biogeochemical interactions within the soil matrix and the storage potential of adjacent terrestrial landscapes. Longitudinal stability of specific conductivity at Unnamed Creek for all sampling compartments and sampling periods is presumed the result of stability within the watersheds geology, soils, vegetation and storage capacity.

Contrary to Unnamed Creek, conductivity during November and April at Gatling Branch increased within the backwater / pond and downstream segments. The observed increase in conductivity during November is presumed to be the result of warmer water temperatures, increased organic decomposition and production of ions within impounded areas. However, during April, ion storage capacity of the adjacent riparian zone was altered with the near complete removal of riparian vegetation during construction. When combined with the poor performance of silt barriers, the result was increased lateral inputs of ions causing the increase in conductivity observed between transects BWUSP and DS10.

In contrast, January had almost no longitudinal variation in conductivity, presumably resulting from the continual flow of water through degraded sections of the main dam, which prevented accumulation of ions in impounded areas. Temporal differences in conductivity at Gatling Branch and Unnamed Creek between November, January and April are presumed to reflect seasonal changes in temperature, rate of decomposition and ion production within the watershed.

Hillman *et al.* (2004) investigated suspended solids within beaver ponds and found that concentrations of fine particulate organic and inorganic matter were greatest near the impoundment outlet and decreased progressively downstream. In contrast, longitudinal turbidity during November and January sampling periods at Gating Branch and Unnamed Creek was relatively stable, and presumed the result of an extensive riparian zone that provided bank stabilization and reduced lateral input of allocthonous material. However, during November, small increases in turbidity were observed at upstream transect BWDSE and downstream transect DS0, resulting from interactions between moving waters of the upstream and static water of the backwater / pond, and the interface between the main beaver dam and downstream. As found by Hillman *et al.* (2004), turbidity during April at Gatling Branch increased dramatically within and downstream of the impoundment. However, increases in turbidity are presumed to result from construction activities that facilitated increased riparian inputs of particulate material that caused the observed increase in turbidity between transect BWUSP and DS100, and not from beaver activity. In contrast, increased turbidity observed downstream during April at Unnamed Creek was presumed the result of low flow conditions (less than 2 cm in depth) and resulting difficultly in collecting a non-contaminated sampling. Thus, transects DS0, DS10 and DS50 were omitted from the April dataset at Unnamed Creek.

Macroinvertebrates

Spatial differences in macroinvertebrate communities occurred both longitudinally and temporally in Gatling Branch and Unnamed Creek. November 2006 and January 2007 sampling for Gatling Branch were prior to anthropogenic disturbance, while April 2007 recorded the effects of extensive construction activities adjacent to pond and downstream transects that began in mid January 2007. Analyses included changes in abundance, taxonomic richness and feeding guilds, as well as trends within individual invertebrate groups. For statistical analysis, each system was divided into three compartments: upstream, downstream and backwater / pond.

Gatling Branch

Mean abundance was greatest during April and lowest during January at 68,500 and 25,500 invertebrates/m^2, respectively. November was intermediate at 54,000 invertebrates/m^2 (Figure. 3-13). Mean longitudinal abundance was greatest upstream (94,000 invertebrates/m^2), while downstream and backwater / pond segments averaged 30,000 and 23,600 invertebrates/m^2, respectively. Using an ANOVA model to analyze and compare longitudinal abundance between sampling compartments yielded statistical significance for pond versus upstream and downstream versus upstream segments ($p<0.001$), with upstream invertebrate abundance significantly greater than pond and downstream. No significance was observed between pond and downstream segments. However, statistical significance was observed between longitudinal abundance and sampling period when comparing upstream segments between November and January ($p<0.04$), November and April ($p<0.002$) and January and April ($p<0.001$), with upstream abundance during April significantly greater than November and January (162,000, 85,500 and 35,000 invertebrates/m^2, respectively). No significance was observed between pond and downstream segments for any sampling period.

Taxonomic richness was greatest during April, with an average of 4.2 families throughout the system. Richness during November and January displayed close similarities, averaging 3.8 and 3.5 families, respectively (Figure. 3-14). Mean richness was greatest upstream and lowest downstream, 4.5 and 3.5 families, respectively. Richness was intermediate within backwater / pond at 3.8 invertebrate families. No statistical significances between longitudinal taxa richness and sampling compartment were observed. However, statistical significance was observed between richness and sampling period, when comparing upstream segments between January and April ($p<0.002$), with upstream richness significantly greater during April compared to January (5.8 and 3 taxa, respectively). There were no significant differences in taxa richness for any other sampling compartment or period.

Three main feeding guilds were present at Gatling Branch: collector/gatherers, filterer feeders and predators. Although longitudinal variation was observed, collector/gatherers dominated all sampling compartments and dates, accounting for 85 to 97 percent of total individuals. Mean abundances of both collector/gatherers and filter feeders were greatest during April, with 63,500 and 4,300 individuals/m^2, respectively. January had the lowest abundance of collector/gatherers and filterers with 23,000 and 600 individuals/m^2, respectively. November was intermediate at 51,000 and 1,500 individuals/m^2, respectively. Predators followed a different trend with November and January having the greatest abundance, averaging 1,500 and 1,000 individuals/m^2, respectively. April had the lowest abundance at 600 individuals/m^2.

Mean upstream abundance of collector/gatherers was greatest (88,000 individuals/m^2), while downstream and backwater / pond segments were similar with 27,000 and 22,000 individuals/m^2, respectively (Figure. 3-15). Longitudinal abundance of filter feeders was greatest upstream and lowest within the pond / backwater with 4,000 and 950 individuals/m^2, respectively. Abundance of filter feeders was intermediate downstream, averaging 1,500 individuals/m^2 (Figure. 3-16). Upstream and downstream predator abundance averaged of 2,000 and 660 individuals/cm^2, respectively, while average abundance was lowest within the backwater / pond segments at 370 individuals/m^2 (Figure. 3-17). However, using an ANOVA model for statistical analysis, no significance between functional feeding groups and sampling compartment or sampling date was observed.

Unnamed Creek

Mean invertebrate abundance was greatest during November with 23,000 individuals/m^2, while mean abundance for both January and April was 21,000 invertebrates/m^2 (Figure. 3-18). Mean longitudinal abundance was greatest upstream and lowest downstream with 27,900 and 14,800 invertebrates/m^2, respectively. The pond proper was intermediate with 22,400 invertebrates/m^2. Using an ANOVA model to analyze and compare longitudinal abundance between sampling compartments yielded no statistical significance. However, statistical significance was observed between longitudinal abundance and sampling period, when comparing upstream segments between November and January and April and January ($p<0.04$) and ($p<0.001$), respectively, with upstream abundance during November and April significantly greater than January (29,500, 42,000 and 11,900 invertebrates/m^2, respectively). No temporal significance was observed between pond and downstream segments for any sampling period.

Taxonomic richness was greatest during April, averaging 5.5 families throughout the system, while November and January were similar at 3.9 and 4.1 families, respectively (Figure. 3-19). Mean taxa richness was greatest upstream, averaging 4.8 families per transect. Downstream and pond richness were the same, with an average of 4.3 invertebrate families per transect. No statistical significance between longitudinal taxonomic richness and sampling compartment was observed. However, statistical significance was observed between taxonomic richness and sampling period. Comparing upstream segments between January and April yielded significance of ($p<0.002$), with mean upstream richness greater during April compared to January (7.3 and 3 taxa, respectively). Statistical significance in richness was not observed for any other sampling compartment or period.

Three major feeding guilds were present at Unnamed Creek: collector/gatherers, filterer feeders and predators. In contrast to Gatling Branch, collector/gatherers at Unnamed Creek did not dominate all sampling compartments and dates, instead filter feeders accounted for 12 to 44 percent of total invertebrates. Mean abundance of collector/gatherers was greatest during November, with an average of 20,000 individuals/m^2. Abundance during January and April were nearly identical, averaging 14,000 and 12,500 individuals/m^2, respectively. Mean abundances of filter feeders was greatest during April and lowest during November, with 7,000 and 2,400 individuals/m^2, respectively. Abundance of filter feeders was intermediate during January with 5,100 individuals/m^2. Mean abundance of predators during January and April were similar, with 1,200 and 1,350 individuals/m^2, respectively. Predator abundance was lowest during November at 640 individuals/m^2.

Mean upstream and pond abundances of collector/gatherers were similar, averaging 20,000 and 18,500 individuals/m^2, respectively. Longitudinal abundance of collector/gatherers was lowest downstream with 9,100 individuals/m^2 (Figure 3-20). Filter feeder abundance was greatest upstream and lowest within the pond, averaging 6,400 and 3,200 individuals/m^2, respectively. Downstream abundance was intermediate at 4,500 individuals/m^2 (Figure. 3-21). Mean predator abundance was lowest within the pond proper at 670 individuals/m^2, while upstream and downstream averaged 1,300 and 1,100 individuals/m^2, respectively (Figure. 3-22). Using an ANOVA model for statistical analysis, no significance between functional feeding groups and sampling compartment or sampling date was observed.

Discussion

The relative abundance of macroinvertebrates was significantly elevated in Ontario beaver ponds, and was attributed to accumulation of coarse woody debris and trapped sediment within impounded areas (France 1997). However, research finding by Collen and Gibson (2001), suggested that invertebrate abundance within beaver ponds decreased per unit area, when compared to the upstream reach. Similarly, relative abundance of macroinvertebrates within impounded areas at Gatling Branch was dramatically lower for all sampling periods, while no significant longitudinal change in abundance was observed in Unnamed Creek. Upstream and backwater / pond abundance at Gatling Branch averaged 94,000 and 23,600 individuals/m^2, respectively. Longitudinal changes in relative abundance were attributed to decreased DO within impounded areas. Upstream DO at Gatling Branch averaged 7.6 mg/L, while decreasing to 3.2 mg/L within the beaver pond.

France (1997) suggested increased taxonomic richness within beaver ponds that was attributed to accumulation of organic debris and trapped sediment within impounded areas, promoting increased habitat heterogeneity. No significant longitudinal changes in taxonomic richness at Gatling Branch or Unnamed Creek were observed during this study. However, temporal significance was noticed between January and April for both Gatling Branch and Unnamed Creek. Greater upstream richness during April was attributed to longitudinal changes in dissolved oxygen and the ability to capture larger / more developed instar stages of invertebrates.

Margolis *et al.* (2001) studied the effects of beaver impoundments on macroinvertebrate communities of low order Appalachian streams and found that pond and downstream taxonomic composition and functional feeding groups were strongly correlated with water temperature, chemistry and dissolved oxygen. Neither Gatling Branch nor Unnamed Creek exhibited significant longitudinal change in taxa composition or dominate feeding groups, even though longitudinal and temporal changes in temperature and DO were observed. However, analogous to relative abundance, significant reduction in abundance within and downstream of the beaver pond was observed for each feeding group (collector/gatherers, filterers and predators). Correspondingly, longitudinal changes in the abundance of collector/gatherers and filterers were attributed to decreased DO within impounded areas. However, longitudinal change in predator abundance was attributed to the inability for the dominant genus *Probezzia spp*. (lotic) to inhabit the deeper waters of the impounded areas (lentic), presumably causing the dramatic reduction of predators within the beaver ponds (Merritt and Cummings 1996).

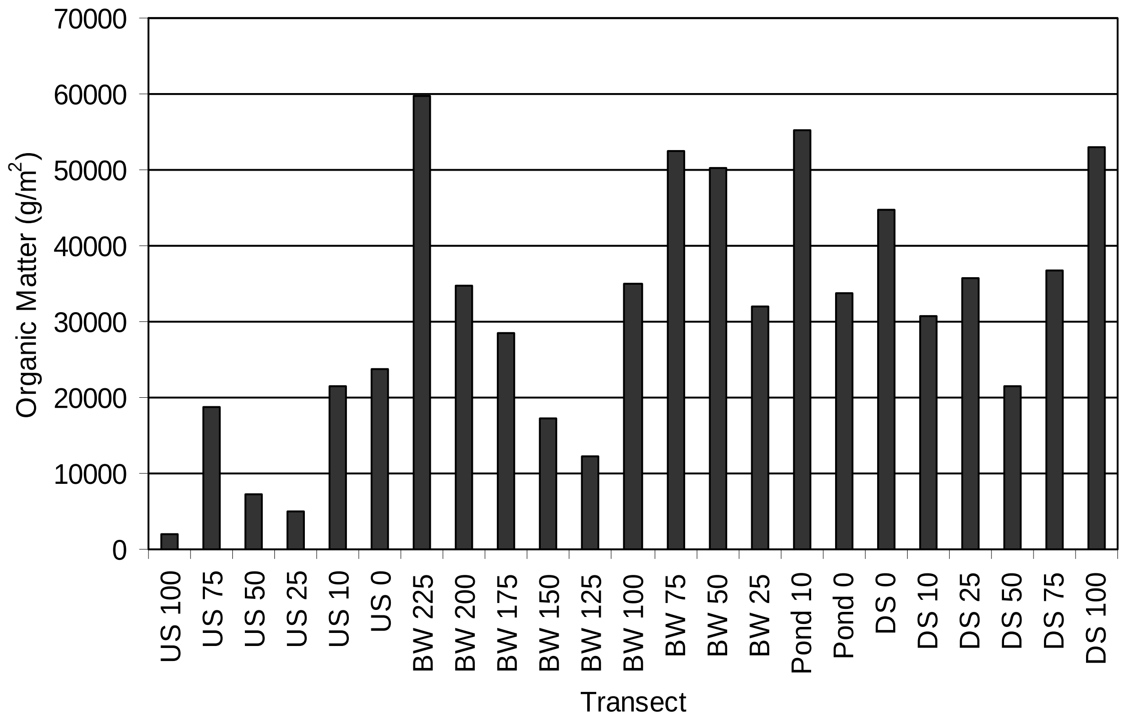

Figure 3-1. Longitudinal distribution of benthic organic matter at Gatling Branch.

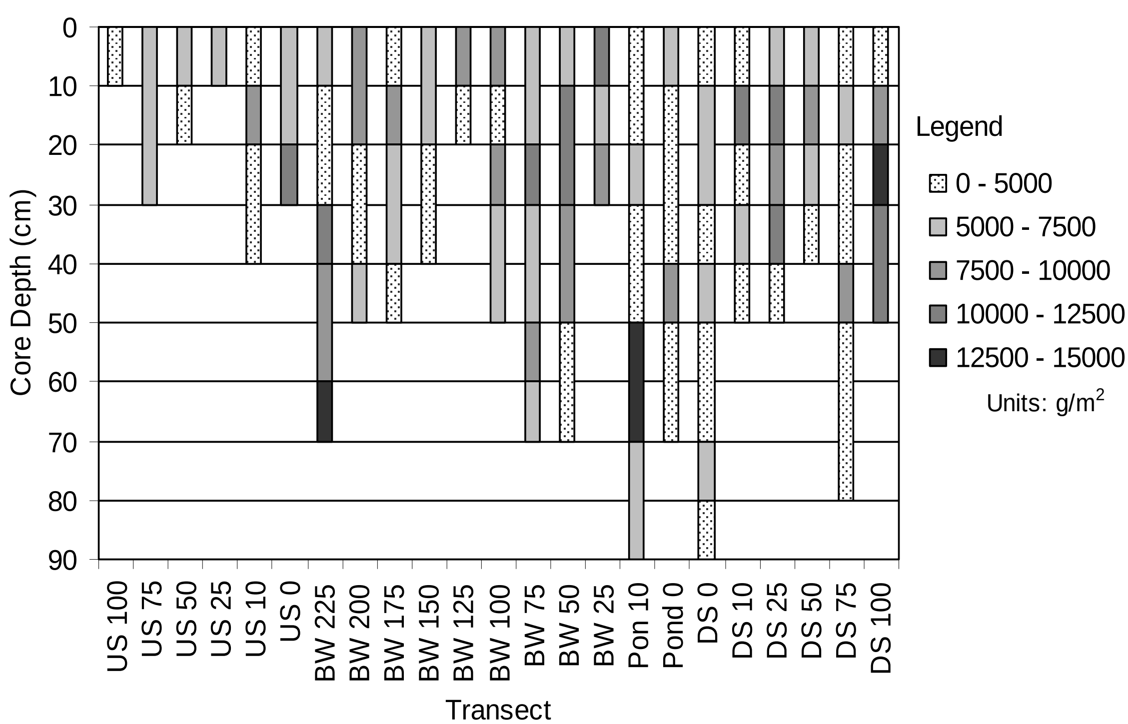

Figure 3-2. Vertical distribution of benthic organic matter at Gatling Branch.

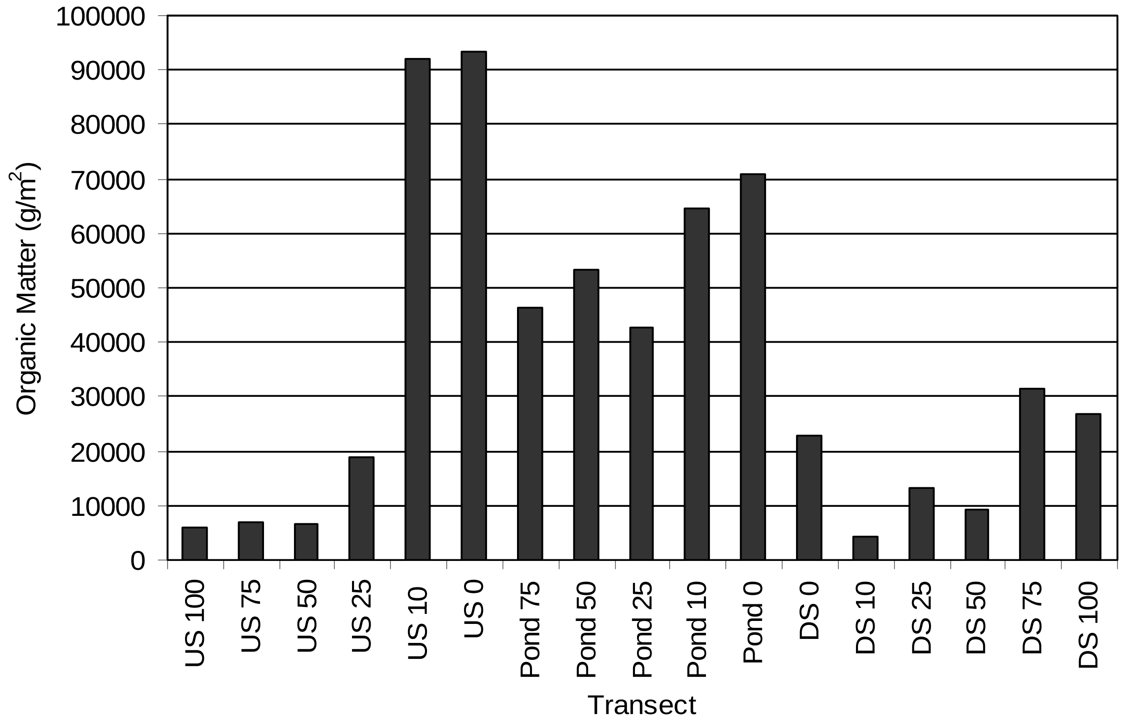

Figure 3-3. Longitudinal distribution of benthic organic matter at Unnamed Creek.

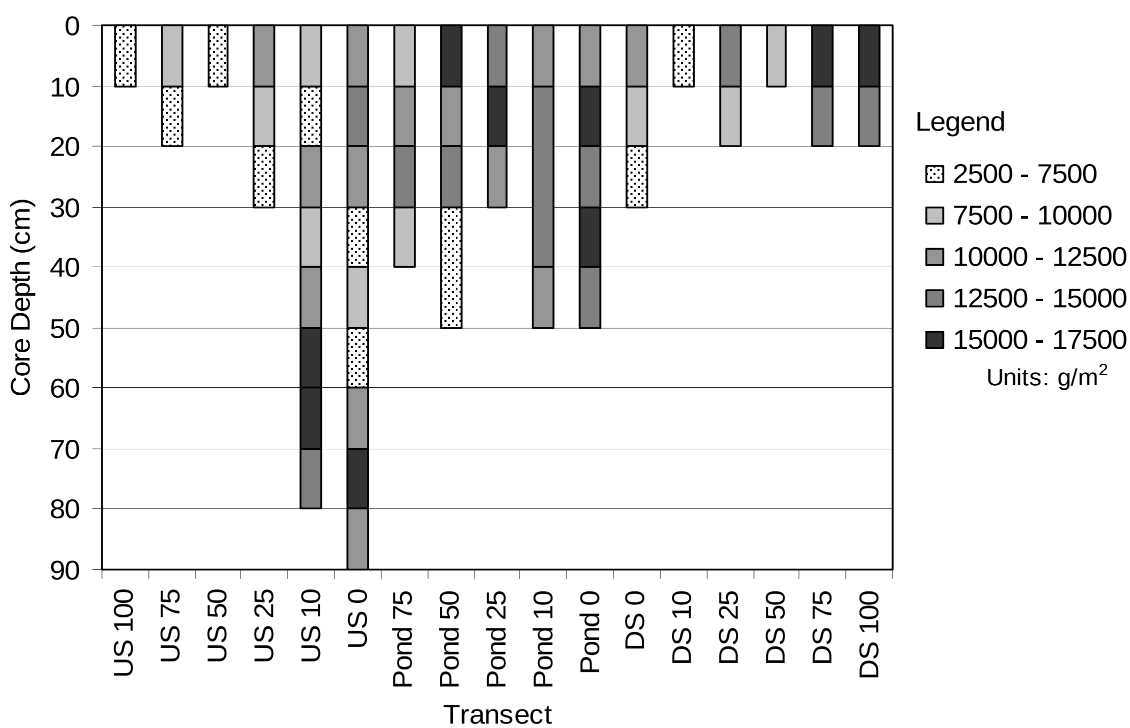

Figure 3-4. Vertical distribution of benthic organic matter at Unnamed Creek.

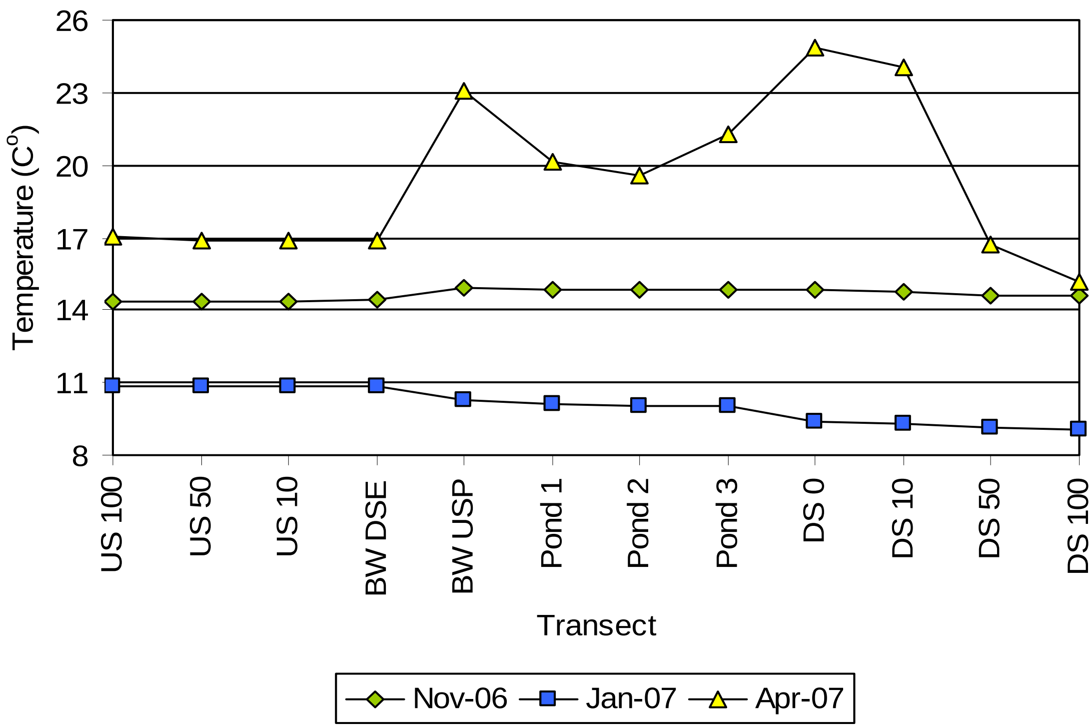

Figure 3-5. Longitudinal temperature profile for Gatling Branch.

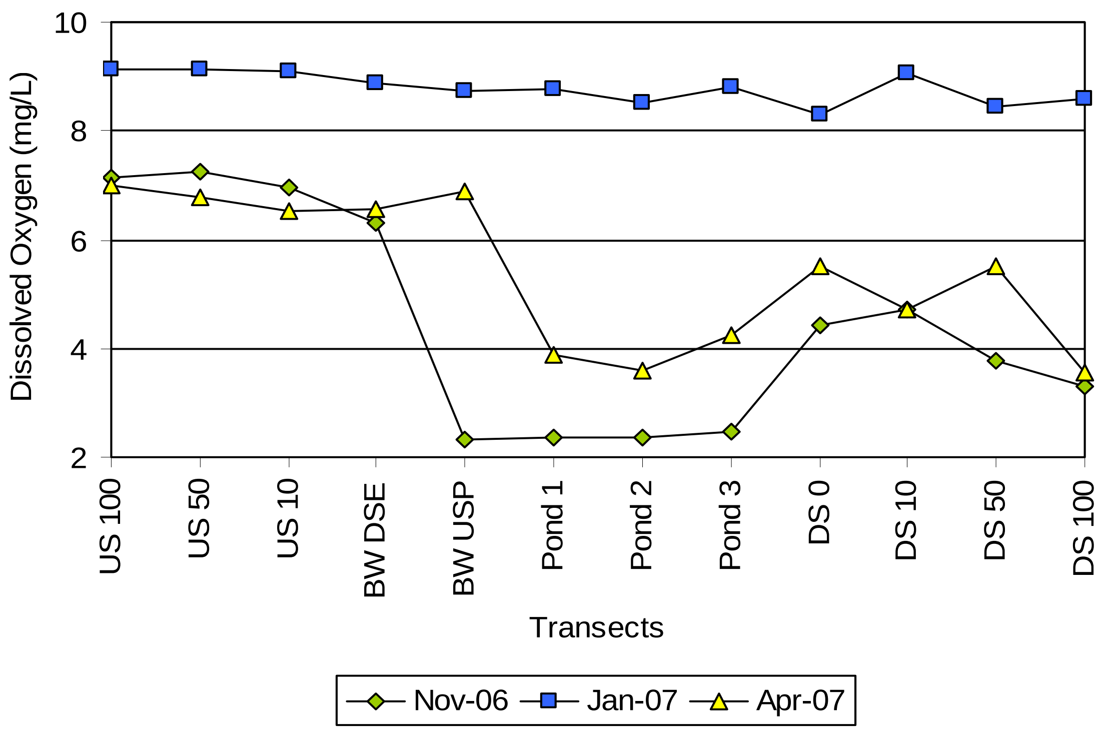

Figure 3-6. Longitudinal dissolved oxygen profile for Gatling Branch.

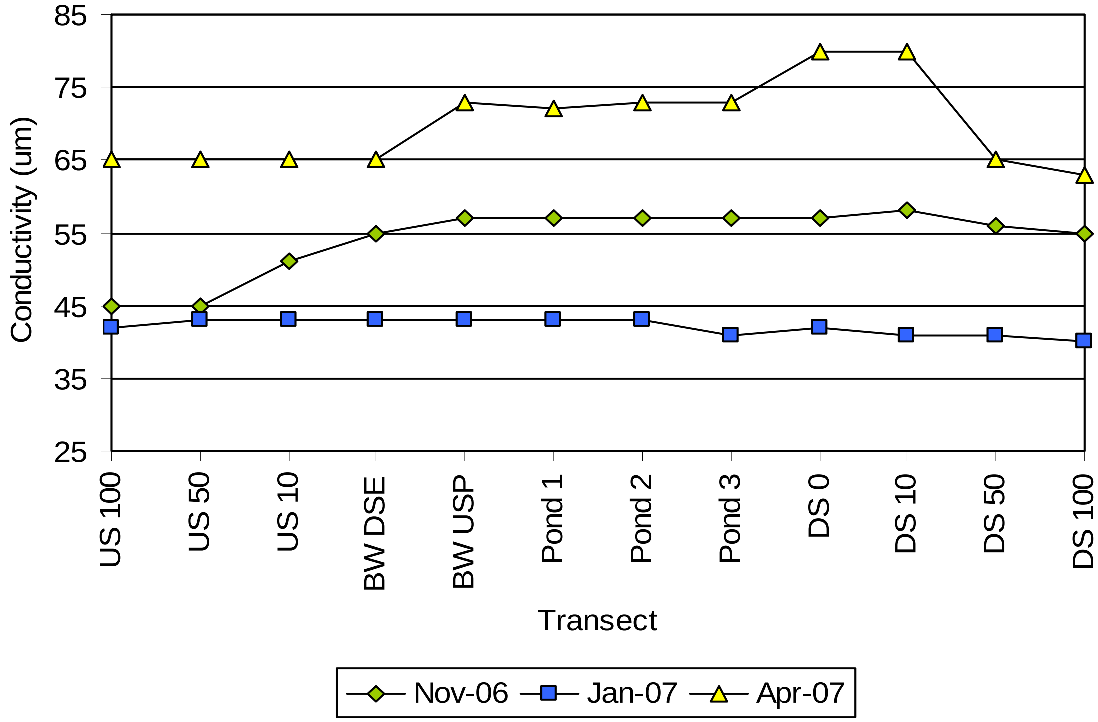

Figure 3-7. Longitudinal specific conductivity profile for Gatling Branch.

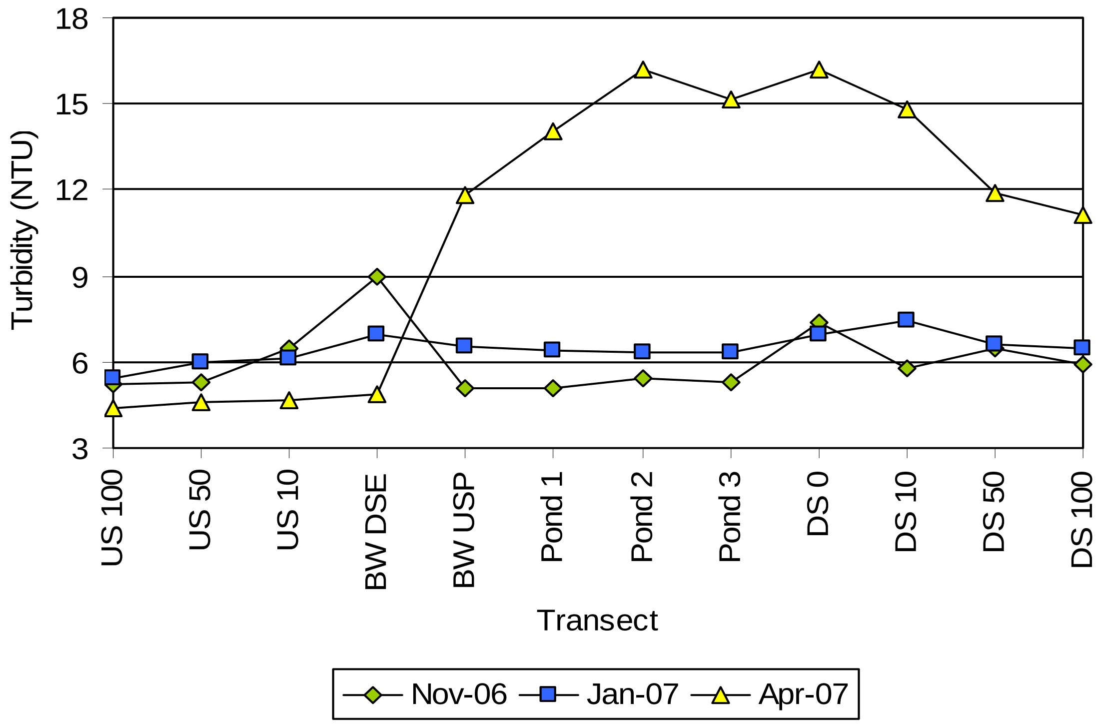

Figure 3-8. Longitudinal turbidity profile for Gatling Branch.

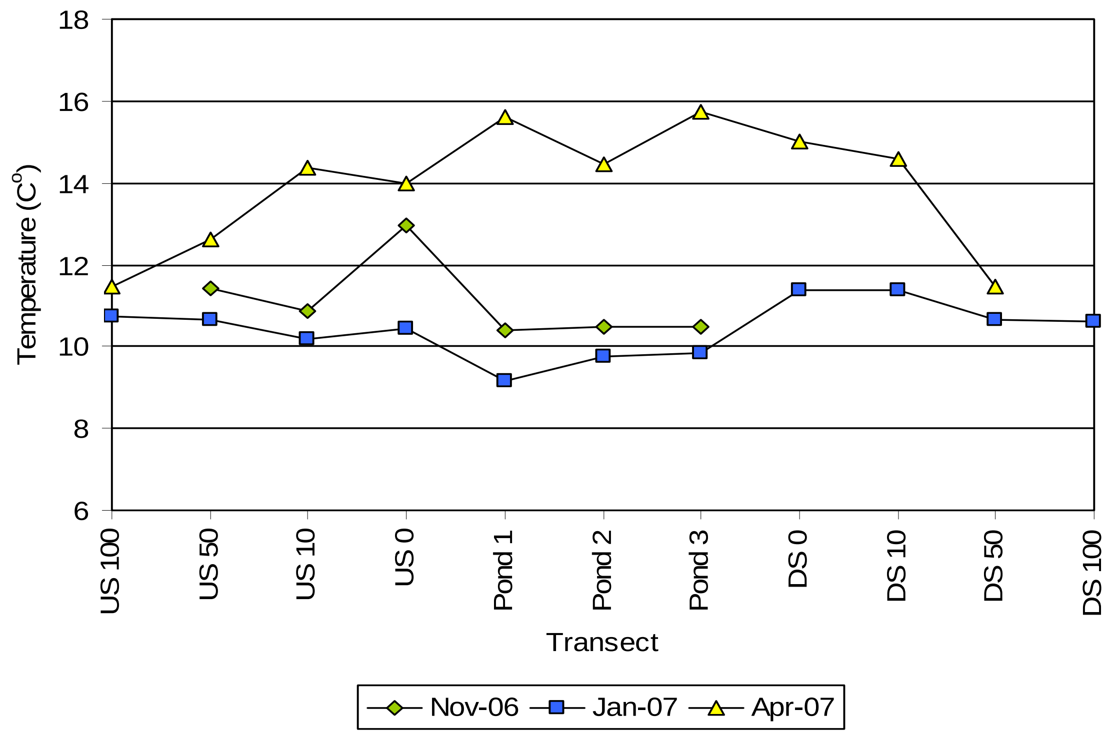

Figure 3-9. Longitudinal temperature profile for Unnamed Creek.

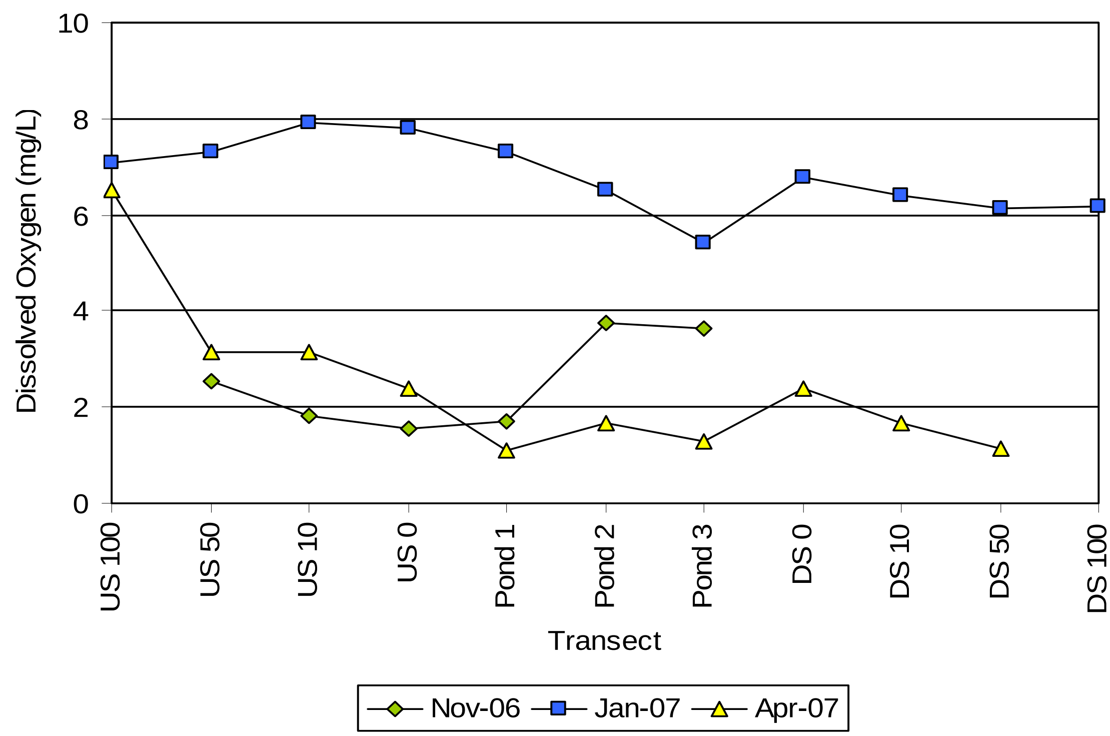

Figure 3-10. Longitudinal dissolved oxygen profile for Unnamed Creek.

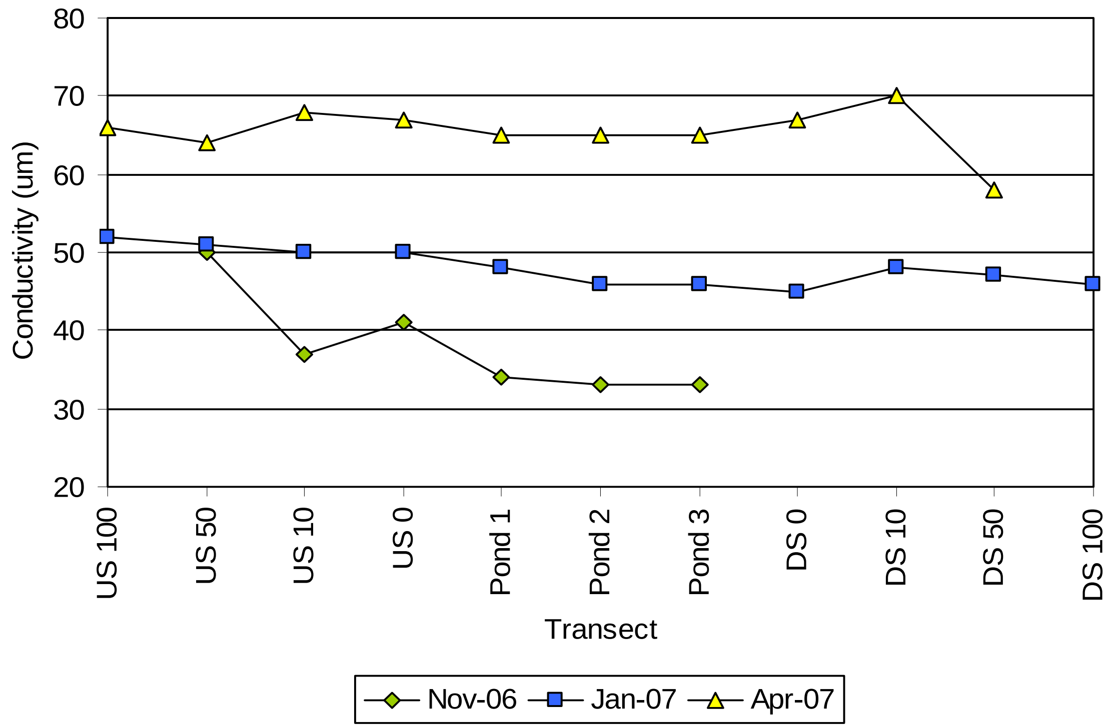

Figure 3-11. Longitudinal specific conductivity profile for Unnamed Creek.

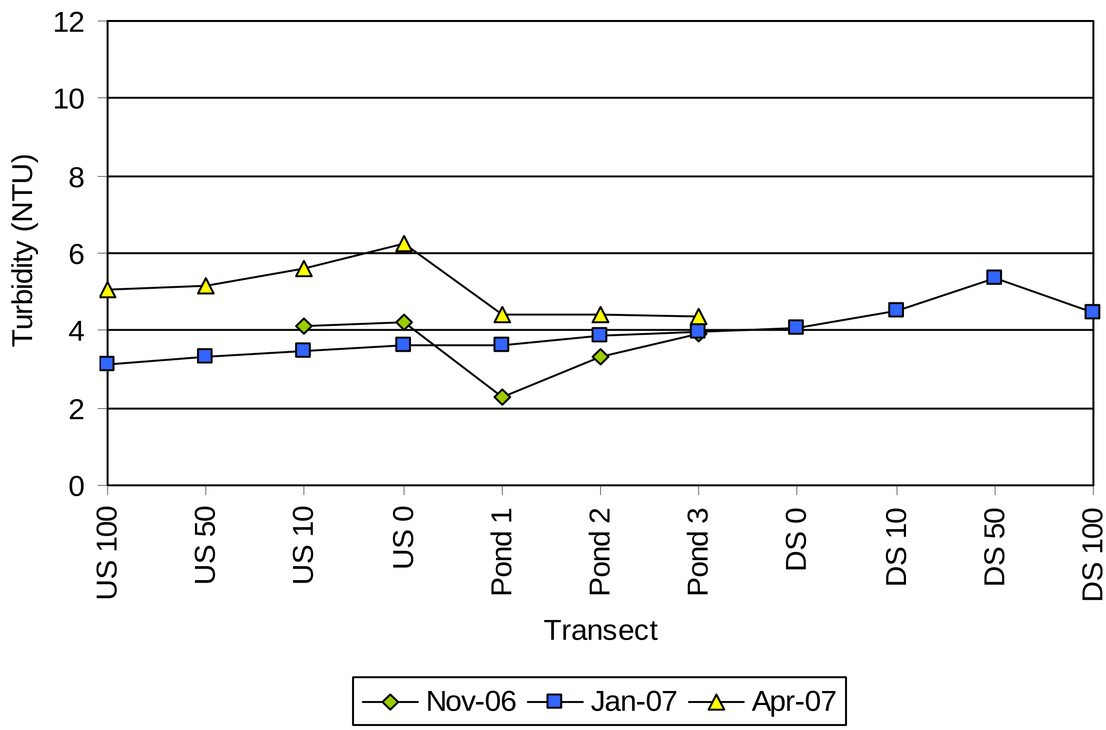

Figure 3-12. Longitudinal turbidity profile for Unnamed Creek.

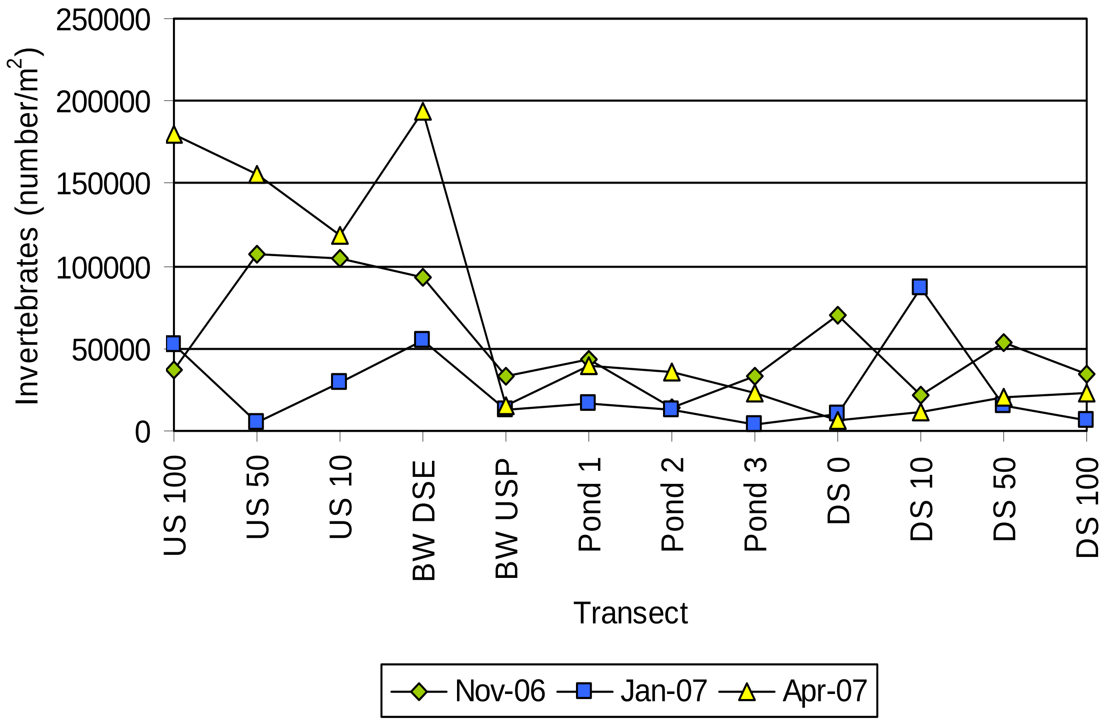

Figure 3-13. Longitudinal invertebrate distribution for Gatling Branch.

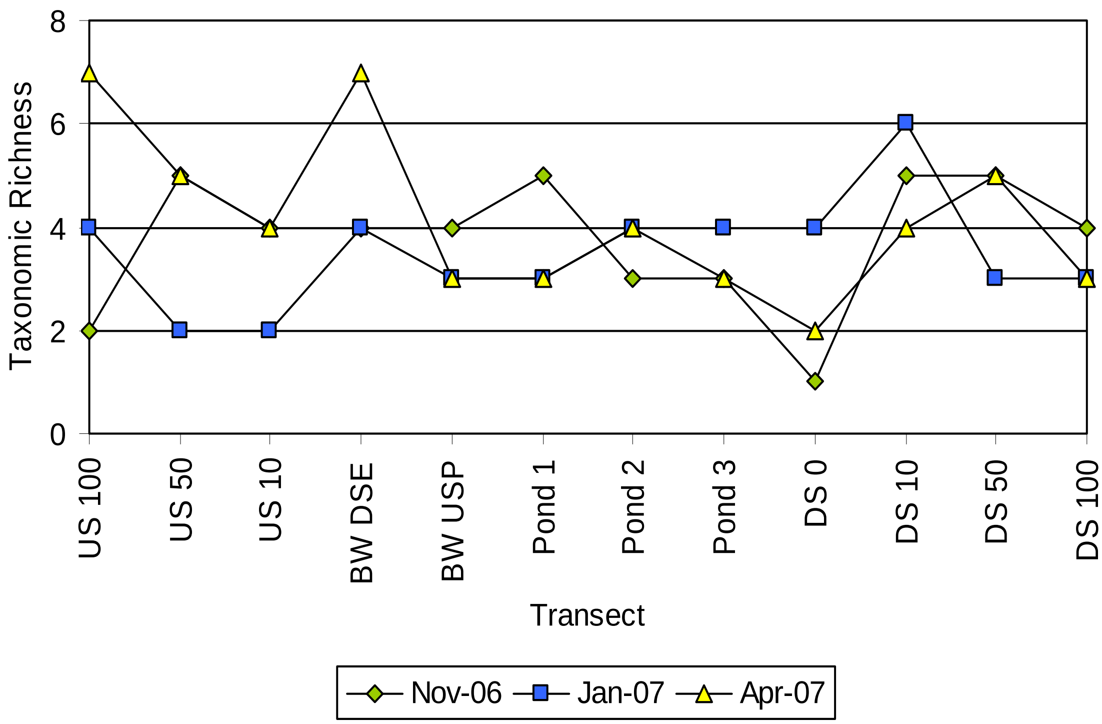

Figure 3-14. Longitudinal taxonomic distribution for Gatling Branch.

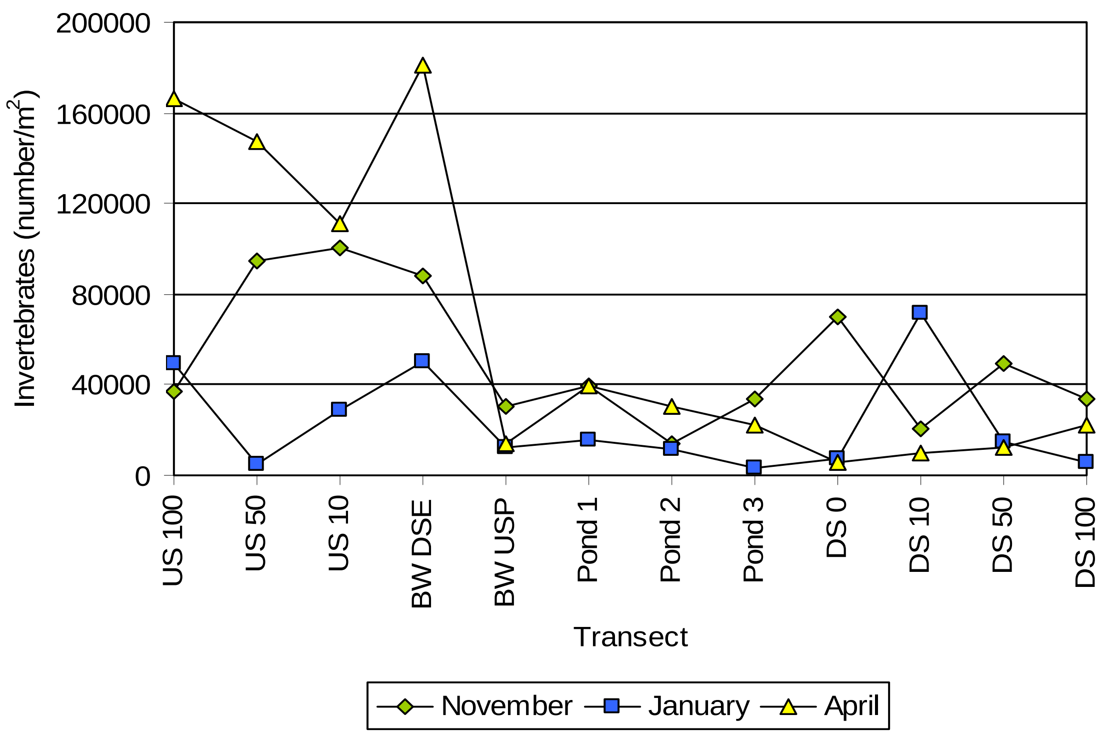

Figure 3-15. Longitudinal distribution of collector/gatherers at Gatling Branch.

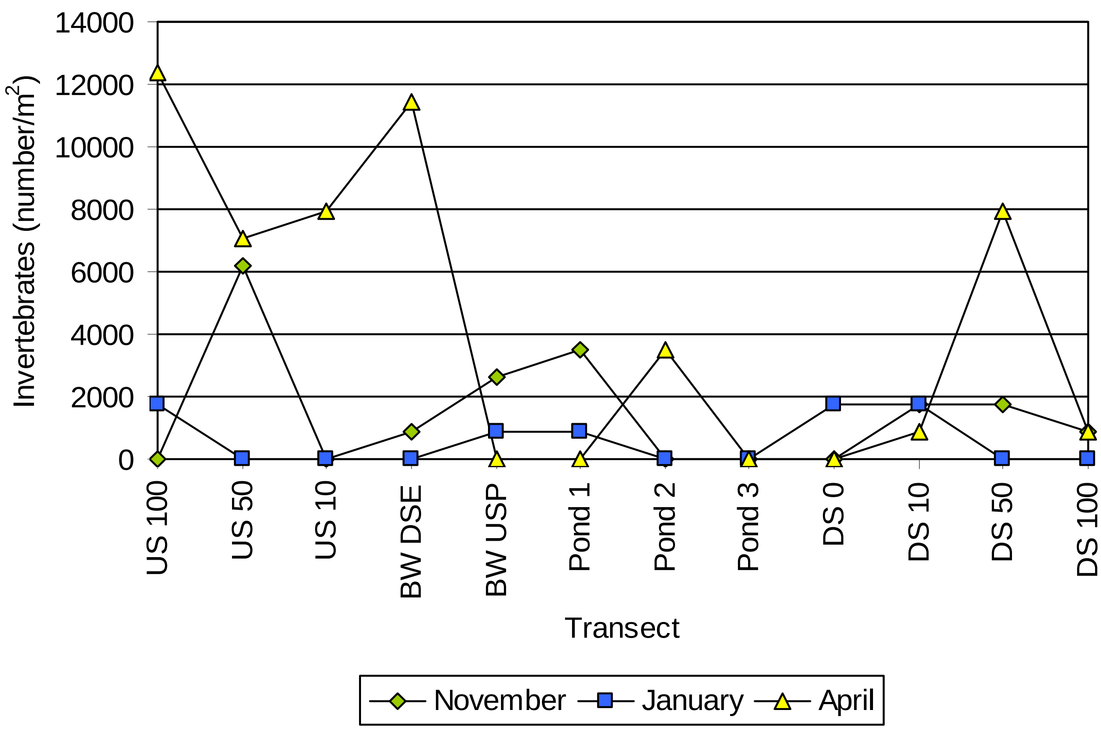

Figure 3-16. Longitudinal distribution of filter feeders at Gatling Branch.

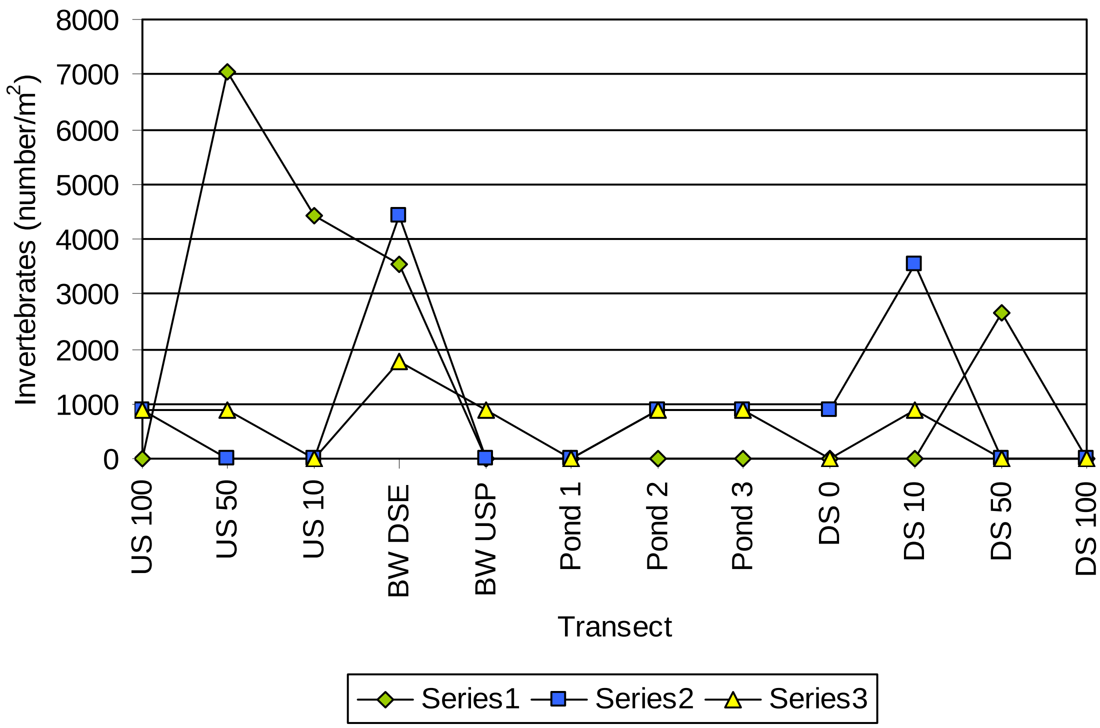

Figure 3-17. Longitudinal distribution of predators at Gatling Branch.

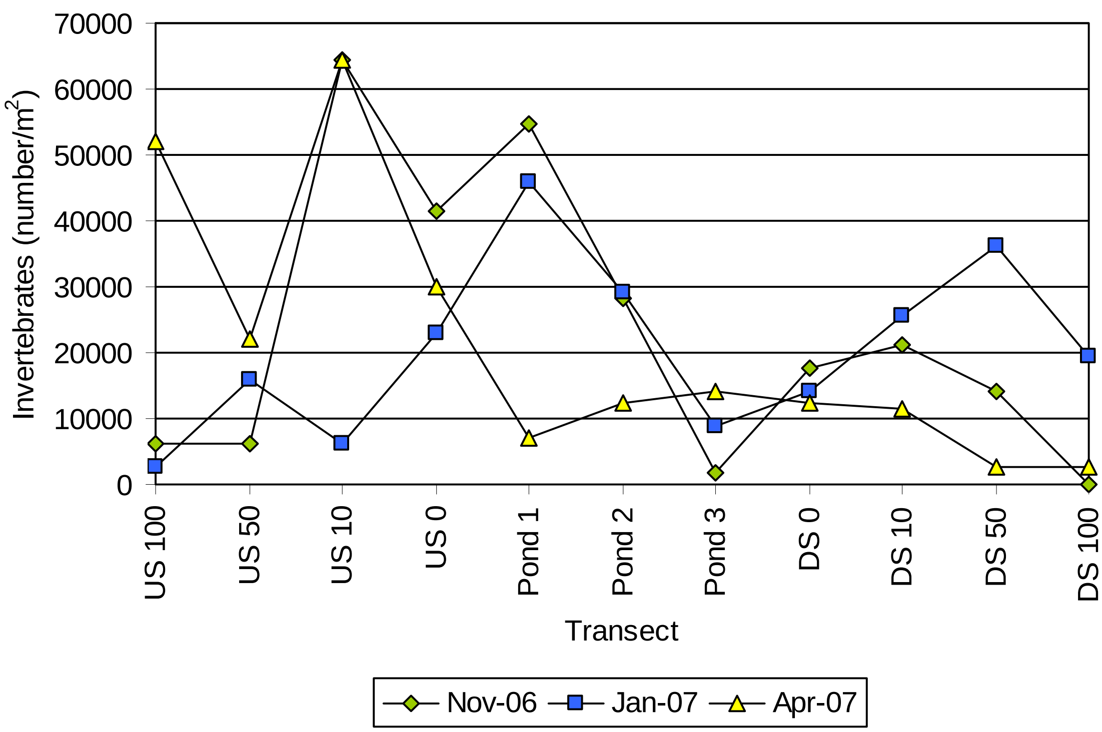

Figure 3-18. Longitudinal invertebrate distribution for Unnamed Creek.

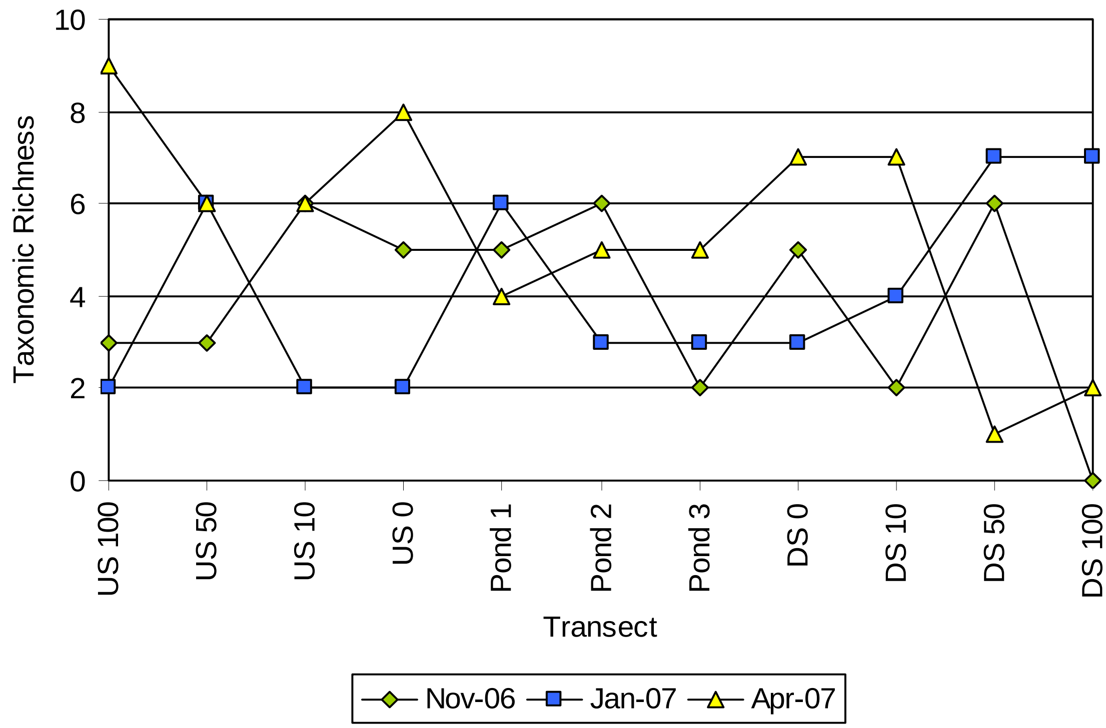

Figure 3-19. Longitudinal taxonomic distribution for Unnamed Creek.

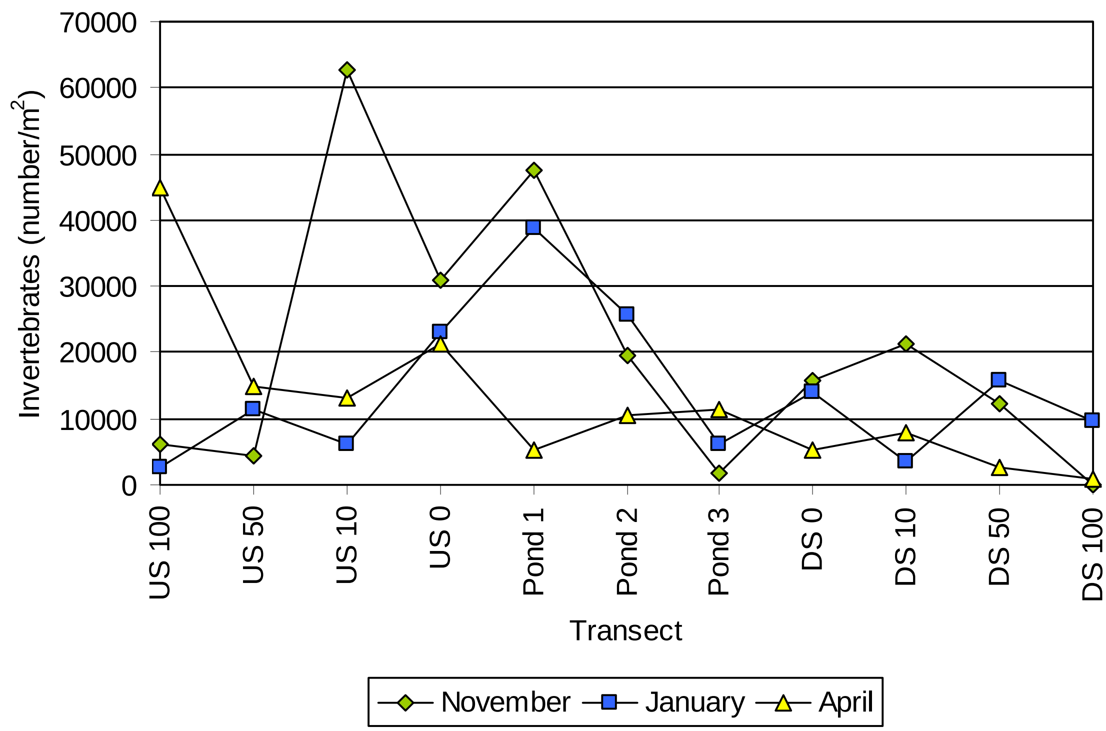

Figure 3-20. Longitudinal distribution of collector/gatherers at Unnamed Creek.

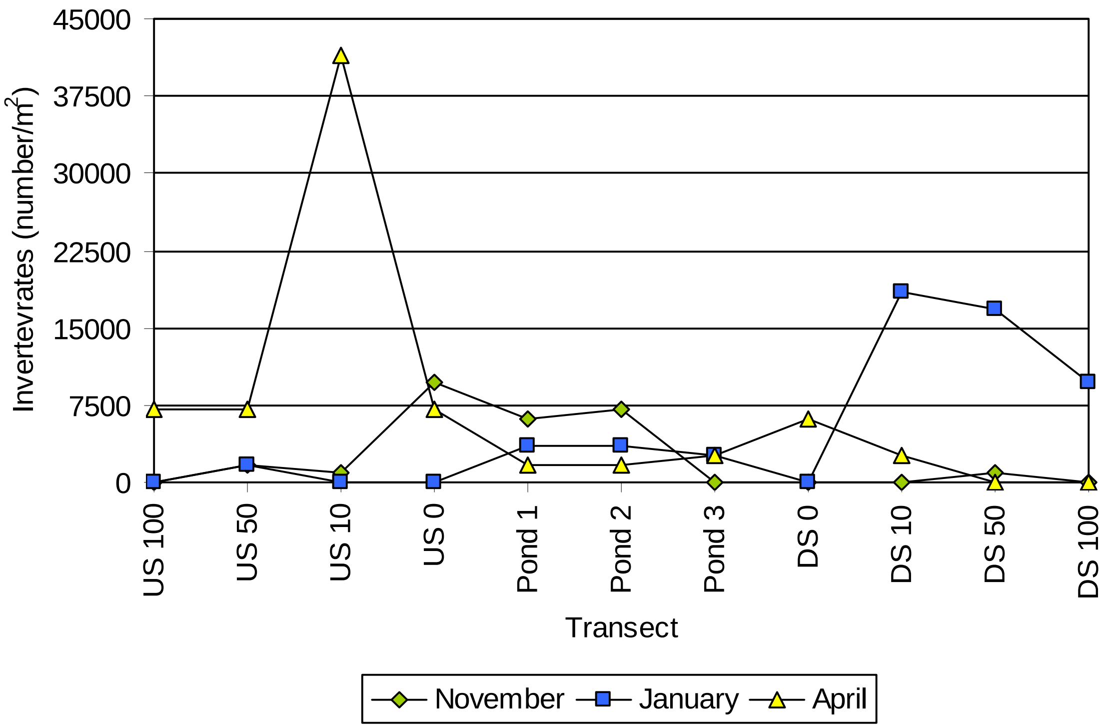

Figure 3-21. Longitudinal distribution of filter feeders at Unnamed Creek.

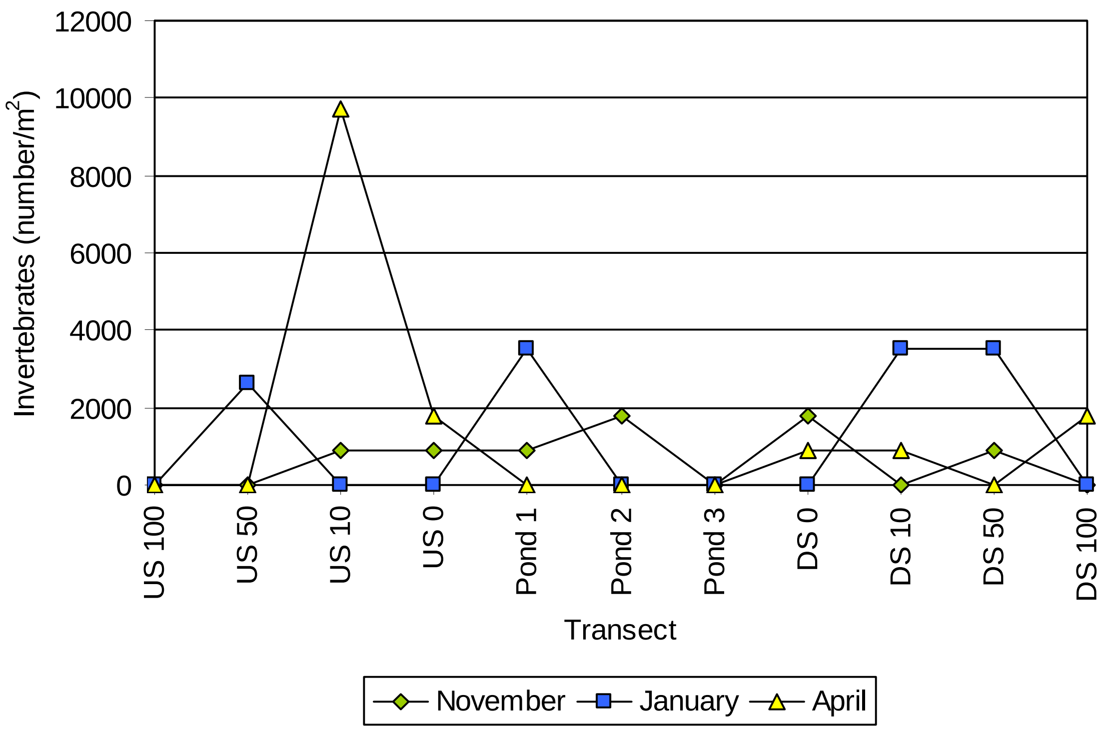

Figure 3-22. Longitudinal distribution of predators at Unnamed Creek.

CHAPTER 4
CONCLUSIONS

The objective of this study was to understand the impact of beaver (Castor canadensis) impoundments on the structure and function of streams in warm temperate, southern Georgia. The ability of beaver to modify its surrounding landscape considerably has created a complicated relationship with humans, often leading to wildlife management plans that prescribe their complete eradication.

Two sites in Thomasville, Georgia were selected for this study (Gatling Branch and Unnamed Creek), with sampling conducted from November 2006 through April 2007. Measurements and/or samples included chemical / physical parameters (temperature, dissolved oxygen, specific conductivity and total suspended solids), macroinvertebrate communities and benthic organic matter storage. Longitudinal and temporal effects attributed to beaver activity included changes in dissolved oxygen (DO), invertebrate abundance and benthic organic matter storage, while effects of construction activities adjacent to pond at Gatling Branch and immediately downstream included profound changes in water temperature, dissolved oxygen and suspended solids (turbidity).

Although Maxted *et al*. (2005) reported increased water temperature within and downstream of beaver ponds, significant longitudinal changes in temperature were not observed in Gatling Branch (pre-disturbance) or Unnamed Creek. However, extensive removal of riparian vegetation along Gatling Branch during human construction activities resulted in increased sunlight penetration and significant elevation in water temperature within and downstream of the beaver pond. Observed temporal variations were attributed to external / seasonal influences and not to beaver activity. As noted by Maxted *et al*. (2005), decreased dissolved oxygen (DO) within and downstream of beaver ponds was observed at Gatling Branch and Unnamed Creek.

Longitudinal decreases in DO were attributed to increased organic matter (OM) loading within impounded areas and increased biological demand for oxygen resulting from decomposition. Changes in DO during November and January were assumed to result from beaver activity, with changes during April attributed to construction activities.

Additional impacts resulting from human construction included significant increases in suspended solids (turbidity) within adjacent stream segments during the April sampling period. This was attributed to removal of riparian vegetation, combined with poor silt barrier performance, facilitating increased lateral inputs of particulate material and the observed turbidity increase between transects BWUSP and DS100. Unlike Hillman *et al*. (2004), turbidity did not increase significantly approaching the impoundment outlet or downstream for any other sampling period at Gatling Branch (pre-disturbance) or Unnamed Creek. With such intense changes in temperature, dissolved oxygen, turbidity and potentially invertebrate communities, lotic systems appear to be far more sensitive to anthropogenic disturbances than impoundment from beavers.

Similar to founding by Collen and Gibson (2001), invertebrate abundance in Gatling Branch and Unnamed Creek was significantly lower (per unit area) within and downstream of impounded areas for all sampling periods. The longitudinal decrease in abundance was attributed to additional stress resulting from reduced DO within beaver impoundments. Although not examined in the current study, Bertolo and Magnan (2006), and Hagglund and Sjoberg (1999) suggested that many fish taxa (brown trout, walleye and lake whitefish) experience reduced abundance within regions of stream affected by beaver. The relationship between an altered food web (i.e. reduced invertebrate abundance) and subsequent reduction in fish abundance within beaver impoundments suggests that beaver have a profound ecological role, ultimately controlling biological structure within its zone of influence.

In addition to localized changes in ecosystem structure and function, sequestration of organic matter (OM) within beaver ponds may have global implications. Sequestered organic matter in aquatic systems (i.e. beaver ponds) represents a significant component of the global carbon pool, helping to regulate emissions of CO_2 and CH_4 into the atmosphere through photosynthetic and respiratory processes (Amundson 2001). Organic carbon storage at Unnamed Creek occurred at a rate 10 times greater within the pond than upstream, further demonstrating the storage potential of beaver impoundments. Although the ultimate fate of stored OM is unknown, this vast carbon storage potential clearly offers an overlooked compartment in the mitigation of climate change.

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BIOGRAPHICAL SKETCH

Cody Rick McNeely was born in 1980 in Hinsdale, Illinois. The younger of two, he grew up in Lemont, Illinois, graduating from Lemont High School in 1998. Cody earned his B.S. in environmental sciences from Benedictine University (BU) in 2003. Upon graduating, he began working for Carnow Conibear and Associates (CCA) in Chicago, Illinois. While employed with CCA, his job responsibilities included discovery and oversight in the removal of hazardous materials. In August 2005, after two years of employment with CCA, Cody decided to pursue his M.S. in interdisciplinary ecology at the University of Florida (UF). Upon completion of his M.S. program in December of 2007, he has plans of returning to Chicago and CCA.