THE GEOMORPHOLOGICAL AND ECOLOGICAL CONDITIONS OF A LOWER MIDWESTERN COLDWATER STREAM SYSTEM

A Thesis

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By

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ABSTRACT

This research has focused on the ecology and geomorphology of a coldwater stream system: Mac-o-chee Creek in Logan County, Ohio, U.S.A. Future conservation and restoration of the stream depends on a better understanding of the physical and biological conditions at present. I conducted a complete geomorphological assessment of the whole system and created a regional curve of bankfull dimensions in the stream across a range of drainage areas. This study provides insight into hydrological processes operating on the entire watershed. Additionally, I assessed habitat and geomorphic impairment in the context of structuring fish and macroinvertebrate assemblages. Fishes and macroinvertebrates were sampled in mesohabitat units of the stream classified as riffle, run, or pool in reaches classified as impaired or recovering. The fish and macroinvertebrates demonstrated slight trends towards more pristine coldwater communities in recovering reaches.

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CHAPTER 1

INTRODUCTION

The landscape of the modern Midwestern United States of America best resembles a mosaic consisting of patches of agriculture, urban areas, and remnant natural areas of forest or prairie. Natural and human disturbances have determined the development and configuration of this mosaic (Hobbs 2002). Land cover on a regional scale alters the structure and function of many landscape elements, including one of our most precious natural resources, freshwater in the form of streams and rivers (Schlosser 1991). Streams in Ohio have been greatly modified by settlement and agriculture in the past 250 years. The removal of wooded riparian corridors, deforestation, drainage, and channelization have contributed to major shifts in flow regime, sediment transport patterns, and biological communities within Ohio streams (Trautman 1981).

As water travels from headwater streams to large rivers, spatial and temporal variation in physical, chemical, and biological processes follow predictable patterns (Vannote, *et al.* 1980). Natural disturbance regimes, including extremes in discharge such as drought and flood, are crucial to nutrient cycling, channel form, instream habitat, and the biological communities of streams (Lepori and Hjerdt 2006; Resh, *et al.* 1988; Schlosser 1991). Agricultural practices, specifically channelization, disrupt these relationships. Straightened channels are constructed to be deeper than unchannelized streams and lose many important aspects of stream function but it may still be possible to identify failing versus stable reaches based on geomorphological principles generally reserved for more natural systems. A straightened channel becomes entrenched and disconnected from the floodplain, and consequently cannot reduce power and sediment load during high flow events (Stanford, *et al.* 1996). Channelization can lead to increased bank erosion, siltation, and a reduction of structural and habitat heterogeneity, which can be detrimental to fish and macroinvertebrate assemblages (Smiley and Dibble 2008; Soar and Thorne 2001). Heterogeneity within a stream occurs at multiple spatial and temporal scales and affects multiple patterns and processes (Palmer and Poff 1997). This thesis addresses geomorphological heterogeneity in channel form and habitat quality in Mac-o-chee Creek.

In the lower Midwestern United States (specifically Ohio, Indiana, Iowa, and Illinois), streams vary substantially in gradient, degree of anthropogenic impact and temperature. Thus, some management strategies are not applicable to all watersheds in a state. For this reason, localized, small-scale studies are needed to provide effective management for unique systems. As the focus of stream management shifts towards restoration and improving stream integrity, further understanding of the structure and function of such systems are needed (Alexander and Allan 2006; Shields, *et al.* 2003). This thesis will address both geomorphological and ecological research to assess the condition of a low gradient coldwater stream system in west central Ohio with the ultimate goal of aiding natural resource managers in decision making.

In Ohio, a number of restoration techniques are currently being implemented and it is not known which methods are most effective. There is a need for information linking channel form with instream habitat and biotic integrity and this information can used to prioritize restoration practices. The Ohio Department of Natural Resources, Division of Wildlife funded this research as part of "A Watershed Approach to Evaluating Stream Enhancement and Restoration in Ohio's Focus Watersheds" (Williams, 2006). This thesis addresses the overall research objective of defining the role of habitat and geomorphological heterogeneity in structuring the physical and biological nature of Mac-o-chee Creek.

Though rivers contain only 0.0001% of the world's total water, they are an integral part of human civilization, land forming processes, and nutrient cycling (Allan 1995). Streams are a vital component of the hydrologic cycle, transporting water that falls as precipitation from land to the oceans. Habitats as diverse as snowmelt-driven high gradient mountain streams and large, slow, meandering rivers provide habitat for aquatic organisms that have evolved to survive in the often harsh conditions of freshwater systems. As anthropogenic change on the landscape scale and global climate change continue to alter natural systems, stream organisms will respond to terrestrial and in-channel changes in nature. As dynamic and variable systems, streams provide ecologists with a valuable and challenging landscape for study.

Several studies have investigated how the ecological function of a stream is determined by the geomorphology (Danehy, *et al.* 1999; Huryn and Wallace 1987; Poff and Allan 1995). Smiley and Dibble (2005) confirmed the existence of a hierarchical relationship between geomorphology, instream habitat, and stream communities. Thus, if we can improve the natural geomorphological processes in a system, ecological integrity may improve.

Every living organism exists within a certain range of tolerable temperatures that is largely related to the taxonomic lineage to which it belongs. Any substantial variance from this range will result in decreased abilities to survive, reproduce, and may eventually prove fatal (Allan 1995). Temperature serves as a cue for many life cycle activities of stream biota including egg laying, hatching, emergence, and mating. Alterations to the natural temperature regime caused by dams, stormwater runoff, or channelization may result in the alteration of these cues (Allan 1995). Depending on the level of groundwater input, in-stream water temperatures can vary with seasonal trends in air temperature or remain quite constant (Winter 2007). Water temperature is an integral ecological character in defining the biological assemblage that will inhabit a stream. As global climate change continues to impact our planet, temperature shifts in streams will alter available habitat for native coldwater fish assemblages (Rahel, *et al.* 1996). Temperature conditions were measured the at three locations in Mac-o-chee Creek in the summer of 2007 (Appendix D).

Coldwater stream systems differ from warmwater streams in that the native biodiversity, abundance, and species richness of stream biota is greatly reduced. Degradation of coldwater streams by channelization and poor land-use practices may lead to alterations in the thermal regime allowing eurythermal fish and macroinvertebrates to colonize streams that were once limited by low temperatures (Lyons, *et al.* 1996). Coldwater fish and macroinvertebrate taxa can provide valuable insight about the health of a stream because their presence decreases with increased impairment (Mundahl and Simon 1998).

Classification and water use designation of coldwater streams varies by state throughout the United States. While the criteria can be related strictly to temperature, such as long term temperature averages or daily maxima, Ohio's guidance is related to the persistence of coldwater assemblages of macrophytes, fish, or macroinvertebrates (OEPA 2008). Because of the paucity of coldwater stream systems in Ohio, the state uses currently bioassesment criteria developed for warmwater streams. These techniques have been demonstrated to be effective at detecting trends but further calibration is necessary (OEPA 2005). See Appendices A and B for examples of Ohio Environmental Protection Agency's bioassesment tools, the Index of Biotic Integrity (IBI) for fish, and Invertebrate Community Index (ICI) for macroinvertebrates. Both tools are multi-metric indices that are part of Ohio's legally codified management plan for streams and rivers (OEPA 1987).

Practical methods to guide restoration and assess the relationship between channel form and biotic communities in lower Midwestern coldwater streams is lacking. As stream restoration practices gain importance and prevalence, there is a need to prioritize funds based on the restoration potential of a stream. The confirmed hierarchical relationship between channel form, instream habitat, and biotic communities indicates that restoration of channelized systems requires extensive alteration of geomorphic condition, not merely changes in instream habitat (Brookes and Sear 1996; Smiley and Dibble 2005; Sullivan, *et al.* 2004). For further discussion of geomorphological principles, see Chapter 2.

In recent decades stream restoration has become an increasingly high priority objective of land management agencies (Fisher and Burroughs 2003). Concurrently, the quantity of research concerning stream restoration has increased dramatically (Shields, *et al.* 2003). Numerous reviews of the state of stream restoration have come to the similar conclusions: we do not know how to efficiently and effectively restore streams on a large scale and there is not enough monitoring of current projects to learn from what has already been completed (Alexander and Allan 2006; Bash and Ryan 2002; Bond and Lake 2003; Ehrenfeld 2000; Hassett 2005; Palmer, *et al.* 2005). The variable time scale of system recovery after restoration, lack of baseline data, and paucity of post-restoration monitoring often precludes researchers and land managers from accurately the assessing the outcomes of restoration.

Channel realignment and “natural channel design” (NCD) are increasingly common methods of restoring stream morphology with the desired objectives of increased habitat heterogeneity, sinuosity and reconnection with the floodplain (Brookes and Sear 1996; Roni, *et al.* 2005). However, it may take many years for improved morphology to lead to improvements in biological integrity following these types of restorations (Moerke and Lamberti 2003; Roni, *et al.* 2005). Additionally, NCD may not be effective at recreating physical equilibrium processes at a scale larger than the restored reach (Simon, *et al.* 2007).

Future stream restoration research will require the collaboration of engineers, hydrologists and ecologists to develop techniques that best harness the innate capability of a stream or river to return to equilibrium conditions (Stanford, *et al.* 1996). Techniques that incorporate a catchment-wide approach to channel evaluation rather than just reach level study have become more widespread and are increasingly using bioassesment and geomorphological tools, such as Rapid Geomorphic Assessments and regional curves, for their restoration planning and decision making (Simon, *et al.* 2007).

CHAPTER 2

THE CREATION OF A REGIONAL CURVE FOR A HEADWATER STREAM SYSTEM IN WESTERN OHIO

Introduction

Freshwater fluvial systems are dynamically varying environments. In order to understand the ecological processes occurring within them, it is crucial to appreciate channel form and the movement of water and sediment within the channel and floodplain. The magnitude, frequency, duration, and timing of bankfull flow events define the flow regime of streams and rivers (Poff, *et al.* 1997). The flow regime, input from groundwater, and anthropogenic influences will collectively determine the physical and ecological integrity of stream systems.

Water quality and biodiversity of aquatic assemblages have suffered large losses since the development of the United States began with European settlers arriving in the 1600's. The Midwest, in particular, has suffered enormous losses in stream ecosystems and structural integrity through stream channelization, wetland destruction, and subsurface drainage (Trautman 1981). Headwater streams comprise the vast majority of impaired channels in agriculturally impacted areas of the Midwest. These small streams are especially valuable for their ability to process nitrogen before it travels to rivers and lakes (Peterson, *et al.* 2001; Urban and Rhoads 2003). State and federal agencies have enacted legislation, beginning with the Clean Water Act of 1972, and more recently including programs such as Total Maximum Daily Loads (TMDLs), that have the goals of the prevention of further losses, restoration of native biodiversity, and improvement of water quality (Davies and Jackson 2006; D'Ambrosio, *et al.* 2008).

Active restoration of stream function by improving stream structure has been occurring at an increasing rate in the Midwest and has been the focus of much research in recent decades (Brookes and Sear 1996; Shields, *et al.* 2003). As aquatic ecosystem management strategies shift toward restoration, effective assessment tools for prioritizing locations within a watershed for alteration or protection are needed (Alexander and Allan 2006). The development of useful tools to aid in assessment and restoration design for headwater streams is an area that requires further research (Shields 2003). Further, tools developed in one region are not easily transferable to others and can even lead to project failure if used incorrectly (Shields, *et al.* 2003; Sullivan, *et al.* 2004).

Regional curves are used as an engineering tool for channel sizing, restoration planning, and management (Ward and Trimble 2004). Powell (2007) recommends using the dimensions from a regional curve as one part of a weight of evidence approach to channel sizing for improvements in agricultural ditches. Regional curves have also been used to assess the impact of urban development on channel form (Doll, *et al.* 2002). As a management tool, regional curves are often used on a large scale, across multiple subwatersheds within an ecoregion, and generally at locations close to USGS stream gage stations. They are rarely calibrated for small, headwater stream systems (Powell, *et al.*

2007) and use of planform approaches such as regional curves have seen criticism (Doyle, *et al.* 2007; Simon, *et al.* 2007). Little is known about the suitability of using planform and channel-forming discharge approaches in unique systems. This paper addresses such a system, namely a modified coldwater headwater stream system in western Ohio.

The objectives of this study were threefold. First, to determine if the planform (dimension, pattern, and profile) of the studied headwater stream is associated with bankfull discharge and regional curve concepts. The second objective was to determine if the bed material (D_{50} and D_{84}) is related to the tractive force on the bed caused by bankfull discharges. The final objective was to determine if a weight of evidence approach can be used to assess dynamic equilibrium.

The terms “stable” and “unstable” are used inconsistently in published literature to describe geomorphic character (Beisel, *et al.* 1998; Hupp 1992; Watzin and McIntosh 1999). Instability can refer to failing or migrating channels, which are aggrading or degrading with high rates of bank erosion. Conversely, the term “stable” is applied to channels that are undergoing shifts in channel form are within the realm of the dynamic nature of geomorphological processes. Often, channel migration and floodplain development are key elements to stream function and are key aspects to passive restoration techniques (Ritter, *et al.* 2007). Bankfull discharge and regional curve concepts are usually associated with stable channel systems that are in dynamic equilibrium. Therefore, application of these concepts in modified incised channels is not well understood and not widely researched. However, in Ohio and other parts of the

Midwest, seeking to obtain data from natural channel systems is sometimes an exercise in futility. Where these systems do exist, they can provide misleading information on how a channelized system might perform if modified to a more natural state.

Channelized streams in low gradient areas that receive increased sediment input from agricultural land uses have been shown not to follow predictable patterns of recovery from channelization (Poff, *et al.* 2006). Such systems are not directly connected to a floodplain and are unable to dispel energy during high flow events or to concentrate energy during low flows, so degraded conditions can persist over many years. Thus, these systems often become out of balance, no longer able to maintain a dynamic equilibrium (Ward, *et al.* 2004). A stream in equilibrium may experience minor shifts in channel pattern caused by bankfull discharge events. On a longer time scale, however, they will not greatly change bankfull dimensions or pattern. A stream that is not in equilibrium will manifest dramatic increases in channel width (over-widening), depth (incision), or pattern change on a relatively short time scale (Ritter, *et al.* 2007).

Methods

Study area

Mac-o-chee Creek, in Logan County, Ohio, is a tributary of the Mad River, which is the largest coldwater river system in the Ohio (Figure 2.1). The watershed drains and area of 53 square kilometers and is located on an end glacial moraine with thick deposits of glacial till overlying layers of sand and gravel outwash. Deep river valleys, a high water table, and many freshwater springs contribute to high base flows year round in the Mad River and the lower reaches of Mac-o-chee Creek (Koltun 1995). The current land use of the watershed is largely agricultural fields planted primarily to row crops (76%) and forested (24%) (Choi and Engel 2007). Much of Mac-o-chee Creek has been channelized. While some reaches have not been modified in more than 100 years, other areas, particularly in the headwaters, continue to be maintained as drainage ditches by private landowners and county engineers.

Site Selection and Stream Survey Methodology

In 2006-2007, 16 study sites in Mac-o-chee Creek were selected to represent a range of fluvial conditions and drainage areas in the watershed. Final site selection was based on accessibility and land owner permission. Geomorphological surveys were conducted according to previously published methods (Harrelson, *et al.* 1994; Ward and Trimble 2004). A single-beam horizontal self-leveling rotary laser and a receiver mounted on a telescoping rod were employed to collect elevation data along study reaches which ranged from 60 to 350 m in length. Longitudinal bedform elevations and water surface profiles were measured at each bed feature (i.e. tops of riffles, maximum depths of pools) along the thalweg with the laser receiver and a measuring tape. Meander patterns were measured by reading the azimuth angle from a compass at each bed feature. Throughout each site, measurements were made of bankfull elevations associated with grade breaks, point bars, depositional benches, and floodplains.

Two to three representative channel cross-section profiles were taken at stable riffles within each site to aid in determining bankfull dimensions. Wolman pebble counts were conducted at riffles to measure bed particle size (Wolman 1954). In conducting the counts, a minimum of 100 measurements were made with a ruler, spread approximately evenly among all riffles within each study site.

Objective 1

Analysis included the use of the Reference Reach Spreadsheet, which is one of the STREAM spreadsheet tools that has been developed by the ODNR to aid in analysis of geomorphological data (Ward and Mecklenburg 2005). Measurements from stream surveys such as meander pattern, longitudinal profile, bed material, and channel cross section dimensions were entered into this Excel-based spreadsheet. Algorithms in the spreadsheet then perform a wide range of calculations that are useful in assessing stream geomorphology. The spreadsheets also make useful plots of pebble size distributions, channel profile variables, channel system cross-sections, bankfull discharge elevations, and the meander pattern. Channel slope was calculated by determining the change in water surface elevation over the length of stream measured. The change in water surface elevation better reflects changes in the valley elevation than the bed elevation surface because of uneven features such as scour pools and log jams (Powell, *et al.* 2007). Sinuosity is calculated as the ratio of stream length divided by valley length. Bankfull discharge at each study site was calculated using Manning's equation.

For construction of the Mac-o-chee Creek regional curve (MCRC), two channel cross sections were chosen from the data collected at each study site. With study sites where three cross sections were recorded in the field, the two that best represented conditions of the site were selected for use in creation of the curve. Mean bankfull width, depth and cross-sectional area of the two cross sections was calculated. Drainage areas were obtained using the Online Watershed Delineation Web-GIS tool developed by Purdue University's Center for Advanced Application of GIS (Choi and Engel 2007). The curve was created by plotting the measured channel dimensions on the y-axis and drainage area on the x-axis on a log-log scale. These data were then fit with a power regression curve. The regression analysis generated a mathematical function relating channel dimensions to any drainage area. These equations were then used to predict channel dimensions based on trends present in the entire watershed.

The STREAMS spreadsheet tools include the USGS empirical regression method for estimating peak discharge for rural ungaged watersheds in Ohio (Sherwood 1994). This method was used to develop relationships between discharge and recurrence interval for each site. The method was calibrated by comparing predicted values with values calculated from an annual peak flow analysis with 32 years of annual data from a nearby USGS gage station (Gage 03266500, Mad River at Zanesfield OH). The estimated recurrence interval for the bankfull discharge at each site was then used to determine if they fell within an expected range. In Ohio, the recurrence interval of the bankfull discharge is usually less than two years (Powell, *et al.* 2006). However, in Ohio ditch systems with low stream power, the recurrence interval is often less than one year (Jayakaran, *et al.* 2005; Powell, *et al.* 2007).

Using the power regression functions for bankfull width and depth, percent difference between observed and expected measurements were calculated for each study site using three different regional curves. The three curves were (1) the regional curve created as part of this study (MCRC); (2) a regional curve created for the Upper Scioto

River (USRC) drainage basin, located East of Mac-o-chee Creek (Witter 2006); and (3) a regional curve for the Eastern United States (EURC, Dunn and Leopold 1978). The percentage difference between the observed and predicted bankfull dimension data were used to determine with regional curve best predicted the observed dimensions.

The spacing of riffles and pools was estimated from the plots for each site that were generated by the Reference Reach Spreadsheet tool. An Assessment was then made of which sites had riffle and pools spacing within the expected range of 5-7 times the bankfull width (Ritter, *et al.* 2007; Ward and Trimble 2004).

Rosgen stream types were determined for each study site by evaluating the following parameters: channel slope, entrenchment ratio (flood-prone width / bankfull width), W/D ratio (bankfull width / bankfull depth), D_{50}, and sinuosity (Rosgen 1996). The stream classification results were used to identify which sites exhibited stable C or E stream types and which sites exhibited unstable F or G stream types.

Objective 2

Channel systems in dynamic equilibrium often have tractive forces, on the channel bed, associated with the bankfull discharges that move the measured median bed particle size (Knighton 1993; Ward and Trimble 2004; Wilcock 2001). The tractive force (kg/m^2) was calculated as the product of the specific weight (1000 kg/m^2), the slope of the water surface as a fraction, and the mean bankfull depth (m). In order to determine if the bed material present at each study site was related to the tractive force caused by bankfull discharge, the D_{50} and D_{84} (as determined by Wolman pebble count), were compared to the mean particle size that can be moved at incipient motion. This mean particle size at incipient motion is then calculated by multiplying the tractive force by a conversion factor. In this case, the conversion factor equals 1 because metric units were used (Ward and Trimble 2004). The mean particle size moved by bankfull discharge should, is less than the D_{50} or greater than the D_{84} particle sizes, aggradation or degradation may occur (Ward and Trimble 2004). The results were used to identify which sites had bed materials in riffles that were within the expected ranges.

Objective 3

The Bank Height Ratio (BHR, maximum depth from the top of the bank divided by the maximum depth associated with the bankfull discharge) of a single cross section at each of the 16 study sites was calculated by dividing the maximum bankfull depth by the height of the banks. BHR's greater than 1.5 suggest a level of entrenchment that might cause instability (personal communication with Andy Ward). These results were evaluated in combination with the results of the first two objectives as part of a weight of evidence approach to assessing the condition of dynamic equilibrium in Mac-o-chee Creek. Powell et al. (2007) suggest that a simple scoring system might be used to obtain a weight of evidence index. For this study, the following scoring system was used: width and depth each assigned 2 if there was less than a 25% difference between the observed and predicted (based on the MCRC) values and a score of 1 if there was a 25-50% difference; score if 2 if the bankfull discharge recurrence interval was less than two years, and a score of 1 if the bankfull discharge recurrence interval was two to three years; a score of 1 if the the site was a Rosgen C or E stream; a score of 1 if the spacing of the riffles and pools were within the expected range; a score of 1 if the size particle at incipient motion associated with the bankfull discharge was between the d_{50} and d_{84} of the bed material; and a score of 1 if the BHR was less than 1. Then possible scores ranged from 0-10.

Results

Objective 1

Table 2.1 includes a summary of bankfull width, depth and area of one representative cross section at each study site. A range of conditions and channel dimensions were present throughout the watershed, and the identification of bankfull features was related to grade breaks in the banks most often. Sample cross-sections at two sites (Figure 2.2) demonstrate the most commonly encountered features of this watershed. Study sites included moderately to severely entrenched channels where the bankfull elevation was not equal to the bank height but was instead indicated by smaller grade breaks within the large channel. The flood prone area, as defined by Rosgen (1996), for many sites was within the larger entrenched channel.

Five of the 16 study sites did not have a pattern of riffles and pools that repeated along a stream length within a range of 5-7 bankfull widths (Table 2.1). Sites 3 and 4 are impacted by their proximity to a state highway and any channel migration is prevented, so the site is not able to recover from channelization. Thus, the site is dominated by run habitat and riffles rarely form. Additionally, Site 10 did not indicate equilibrium conditions because of the large distance between riffle units. This site is quite entrenched and the stream bed is characterized as uniform and flat (Figure 2.2). Finally, sites 15 and

16 possessed profile patterns that also did not indicated equilibrium conditions because of severe impacts from agricultural fields and livestock, respectively. The recurrence interval of the bankfull discharge at each site varied from 0.87 to 1.65 for the headwater sites (drainage < 35 square kilometers) and were within the expected ranges reported in previous studies (Crowder and Knapp 2005; Powell, *et al.* 2007). The sites closer to the mouth of the stream had slightly larger than expected recurrence intervals ranging from 2.00 to 4.26 years. Site 1 is near the confluence with the Mad River and might be influenced by backwater flows from the mainstem.

The regression analysis for MCRC indicate a high correlation between drainage area and bankfull cross-sectional area, width and depth (0.93, 0.95, and 0.73, respectively; Table 2.2). Regional curves have historically been developed on many scales, and here I compare three curves in how they relate to the observed conditions in Mac-o-chee Creek (Table 2.2). MCRC consistently yielded expected channel dimension values that were closest to the observed values. The absolute mean difference in percent deviation among the three curves for bankfull width was smallest for MCRC (10%), larger for the USRC (20%), and largest for EURC (21%). When each curve is ranked (1, 2, or 3) by smallest absolute deviation for each study site, the mean rank is MCRC (1.3), followed by EURC (2.3), and finally USRC (2.4) for bankfull width. For bankfull depths, the trends are similar. Absolute mean difference in percent deviation was slightly lower for USRC (24%) than MCRC (25%), but both were much lower than EURC (74%). The mean rank for all study sites was the same for MCRC and USRC (1.6) and higher for EURC (2.8).

Individual site characteristics accounted for additional deviations from the general trends for the watershed that are represented in MCRC. For example, Site 15, which is an agricultural drainage ditch in the upper reaches of Mac-o-chee Creek (Figure 2.1), was constructed larger than regional conditions (Table 2.1) to provide the depth needed for subsurface tile outlets (Figure 2.4A). Bank failure, the lack of riparian cover, and increased sediment from surrounding row crop agricultural fields has created silty conditions in the stream bed, resulting in low particle sizes at the site (Table 2.5).

In a second example, the bankfull dimensions of Site 13 are much shallower and wider than expected (Table 2.1) because this site is located in an area where the stream channel lies over bedrock and therefore the channel is unable to deepen (Figure 2.4B). Again, these characteristics are evident in the large bed material size at this site (Table 2.5). Finally, at Site 7, the stream shows some recovery from past channelization (Figure 2.4C). The channel has begun to migrate within a narrow floodplain and has a smaller cross-sectional area than regional trends would indicate (Table 2.1). The bed material is dominated by gravel with a bed material size that is roughly average for the whole watershed (Table 2.5).

Table 2.4 includes the pattern (sinuosity), material (D_{50}) and channel dimensions (width depth ratio and entrenchment ratio) that are required for Rosgen stream type classification (Rosgen 1996). The sinuosity of all 16 study sites was very low (1.0 – 1.3) because of channelization throughout the watershed has reduced or eliminated meander patterns. Therefore, the study sites generally do not fit the Rosgen Stream Classification Method in this regard. Also, slope ranges are often lower throughout the watershed than streams used in the development of the Rosgen Stream Classification. Sites 1 - 4 fit the criteria of C4 streams (other than sinuosity) with the important exception that the floodplain for most of these sites is in fact not broad and well defined, but generally limited to the edges of the entrenched channel or to the edge of an agricultural field. Many of the sites fit Rosgen's F4 classification which is characterized as "failing" (Table 2.4). F channels are highly entrenched, low gradient, and are laterally unstable with high bank erosion potential. In Mac-o-chee Creek, if these channels were not so entrenched and confined to their channels, they could potentially be C or E channels. Site 11 is classified as a G channel which is a steep "gully" with step pools.

Objective 2

The threshold particle size was determined to be between the D_{50} and D_{84} bed material sizes for 13 out of the 16 study sites (Table 2.5). For those 13 sites, the result indicates that the field measurements were in agreement with calculations based on the bed slope and bankfull dimensions and that bankfull discharges are moving much of the finer bed material downstream are not creating further downcutting, and the dimensions are not exhibiting large changes. Substantial aggradation of fine particles or degradation of the stream bank is not likely to be occurring at these study sites. One of the exceptions to this condition, site 4, has a threshold particle size that is smaller than the d_{50}. This result is most likely related to aggrading conditions at this site. The channel in this part of the stream is wide and the slope is extremely low. Silt and other fine particles collect during low flow and they are not moved during bankfull or smaller sized flow events. Coarser material was observed 2 to 4 mm below the finer bed materials.

Evaluation of the incipient particle in motion size at site 15 also indicated aggrading conditions. This reach of Mac-o-chee Creek (Figure 2.4A) does not have enough power to flush out silt and sand bed material. Field observations confirmed these trends – the site had very thick layers of silt and larger bed material was not readily observed. Site 16 had a calculated threshold particle size that was substantially larger than the D_{84} bed material size. This site was unusual compared to the other 15 study sites in the system in that it was heavily impacted by livestock and a livestock watering pond created by a dam at the point were the stream originates as a spring. These conditions have lead to a lower gradient at the study site than may exist without those anthropogenic-caused impacts.

Objective 3

Table 2.6 summarizes the bank height ratios for all 16 study sites. These data again indicate the variation among study sites (Range: 1.33 – 7.50; Mean: 2.98) and the generally entrenched nature of Mac-o-chee Creek. The weight of evidence variables from the previous analyses (Table 2.1 and 2.6) are summarized in Table 2.7 and weight of evidence scores are presented in Table 2.8. Site 16 had a low score of 4 and Sites 1, 6, 7, 14, and 15 had scores of 6. All other sites had scores of 7 to 9 out of a possible 10.

Discussion

Bankfull dimensions of Mac-o-chee Creek at the 16 selected study sites were associated with regional curve concepts and were generally consistent throughout the watershed. The profiles and bankfull widths of the 16 study sites appear to be associated with bankfull discharge and most maintained channel unit (riffle and pool) spacings that were consistent with equilibrium concepts (Ward and Trimble 2004). Localized stressors, such as livestock influences at Site 16, resulted in less stable conditions at some sites. The low sinuosity of this stream was associated with anthropogenic effects, namely channelization and straightening. As drainage area increases, bankfull depth changes at a slower rate than width, which accounts for the smaller slope of this trendline (Olson-Rutz K and Marlow 1992) (Figure 2.3). Observation of bankfull features in the field is a subjective measurement and can include a large amount of observer variation, which may account for the lower correlation coefficient for bankfull depths on the MCRC. Comparisons with two other regional curves revealed that the MCRC was the most effective for predicting channel dimensions throughout the watershed. My observed measurements were narrower and deeper than those predicted by the USRC and they were wider and deeper than those predicted by the EURC. The USRC and EURC were constructed using a range of sites, generally selected to represent reference conditions rather than the entirely altered conditions that are present at Mac-o-chee Creek because of channelization. Differences in dimensions predicted by the USRC and the MCRC were small and the performance of both curves was similar for bankfull depth.

The deviations from the USRC might be related to groundwater inputs into Mac-o-chee Creek that are not as commonly found in the Upper Scioto River watershed. An earlier study by Koltun (1995) estimated that 17.2 % of the baseflow of the Mad River just upstream from its confluence with Mac-o-chee Creek is groundwater supplied. Some of the study sites (Sites 1- 10) are at the same groundwater potentiometric surface level as the Mad River. Therefore, these sites may be supported by deep, stable groundwater systems rather than originating primarily from overland surface flows (runoff), (Koltun 1995). The groundwater, which leads to larger than average baseflows, may create a larger bankfull cross-sectional area than is found in nearby watersheds, such as the Upper Scioto, or the Eastern United States as a whole. Channelization, which leads to deeper stream channels than natural conditions, may result in larger amounts of groundwater entering the channels. The specific relationship between higher base flows in Midwestern groundwater-dominated streams and channel geometry has rarely been investigated. This is an area where future research is necessary.

For most sites, the size of particles at incipient motion associated with bankfull discharges were within the d_{50} and d_{84} of the bed material in riffles at each site. The d_{84} was more highly correlated with the size of particles at incipient motion than the d_{50} (R^2 = 0.31, and 0.79, respectively; Figure 2.5). The results are consistent with observations on other streams and modified channels in Ohio (personal communication with Andy Ward). As there was not a broad floodplain at the bankfull elevation at each site, it is speculated that the relationship between measured bed material sizes and the size of particles at incipient motion in this stream system might be due to frequency of bankfull discharges, rather than the ability of a floodplain to dissipate the energy of events larger than the bankfull discharge. Perhaps with more distinct and broader floodplains, the correlation with the d_{50} would be higher.

The weight of evidence analysis suggests that no one factor clearly establishes the equilibrium state of a channel. While more or less weight could have been applied to each of the variables considered, it is clear that Site 16 is the most unstable. Also, several of the sites and in particular Sites 1, 6, 7, 14, and 15 are, at best, in a quasi-state of equilibrium. Changes in hydrology caused by land use changes or climate change might result in downcutting, widening and shifts in the stream pattern. Removal of stabilizing vegetation along the banks might have the same effect. The lack of attachment to a broad floodplain and the low sinuosity of this system make it very prone to shifting out of equilibrium. These same factors appear to be restricting recovery of the system beyond current levels.

The data presented here could aid land managers looking to address failing systems and seeking to restore them to conditions that are closer to an equilibrium state. Rosgen stream type classification was used in this study as a tool to demonstrate stream condition in terms that many practitioners are familiar with (Sullivan, *et al.* 2004). Many of the sites were appear to be on the threshold of failure because of their entrenchment. Some of the other factors considering in this analysis provide more quantifiable information on the geomorphology of the system.

The research presented here is important because it was conducted on an ungaged, modified channel system. Stream gages are most often installed on medium to large rivers (greater than fourth order) and therefore hydrologic events on low order (first to third order) streams are often not recorded. Poff (2006) expresses the need for more effective modeling tools on smaller order streams because of the paucity of gages on these streams. Such models can aid in simulating streamflow trends with changing land use or changing hydrological conditions. Regional curves fulfill this role, in part, by increasing the ability to predict changes in channel form which may occur with shifting land use in the future (Doll, *et al.* 2002) or the how channelization alters stream geometry. In conclusion, these results indicate that within a somewhat degraded stream system, it is possible to observe evidence of the fact that channel form, profiles and processes are driven by bankfull flow events. The regional curve that was obtained compares well with the curves obtained on more natural and/or larger stream systems. Using a weight of evidence, geomorphic approach that assesses profile, pattern, bed material, and dimensions of a stream aided in determining if the stream is in an equilibrium state or on the verge of failure. In a system with both stable and unstable reaches, it is useful to look at the whole stream system to better understand the processes occurring therein.

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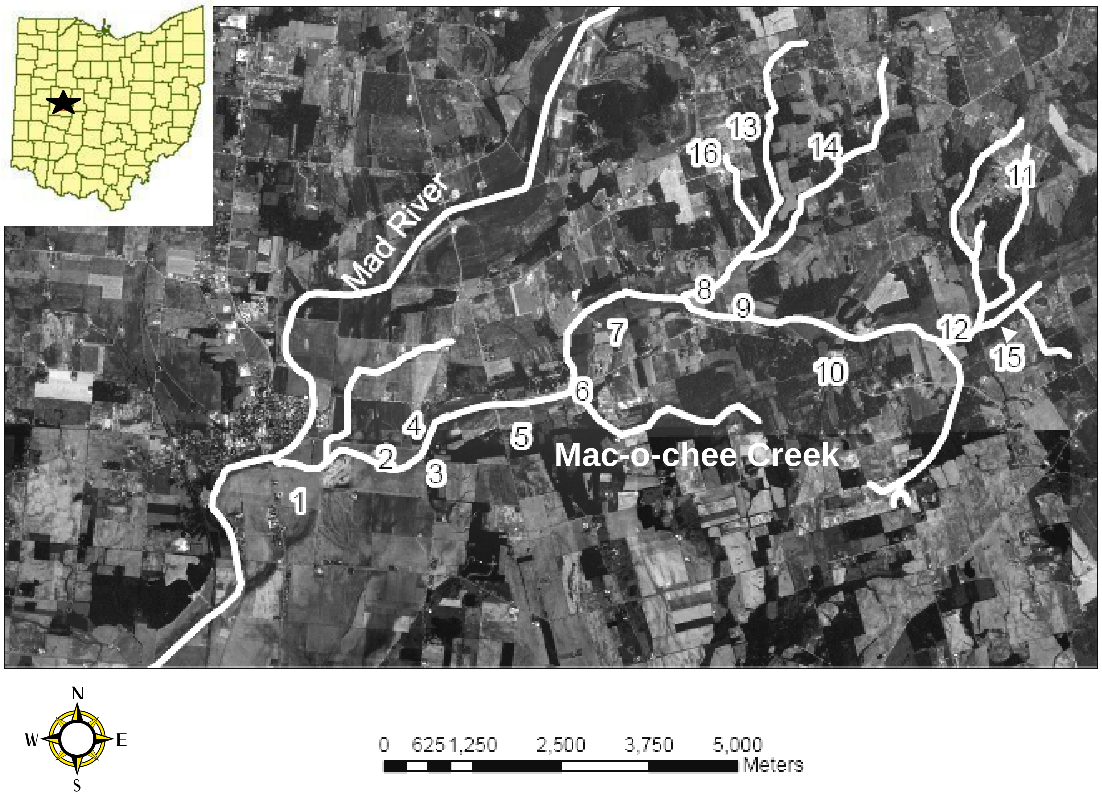

Figure 2.1 Map of study sites within Mac-o-chee Creek in Logan County. Inset shows location within Ohio, U.S.A. Sites numbers increase from mouth to headwaters. Sites 1-16 were used for the creation of the Regional Curve.

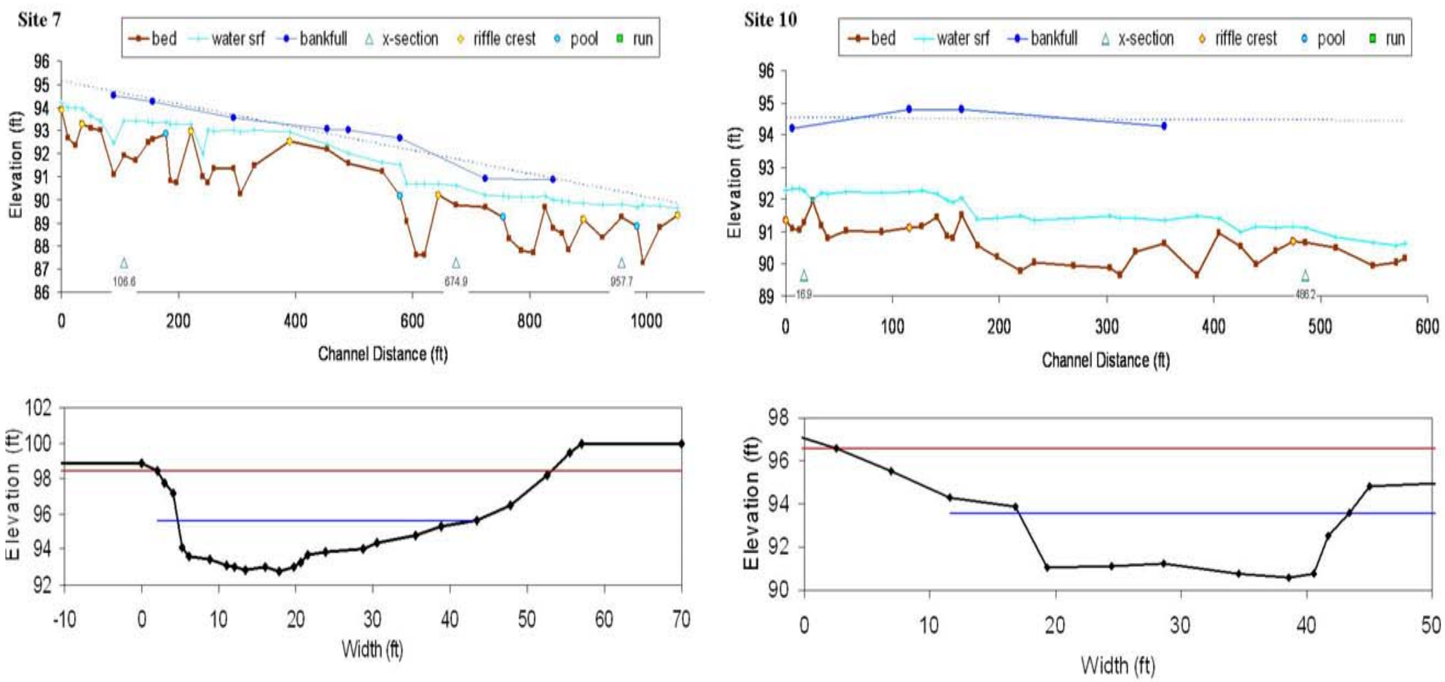

Figure 2.2: Profiles of study Sites 7 & 10 generated by using the STREAMS Reference Reach Spreadsheet. Profiles of study Sites 7 & 10. The top image is the bed profile. The bottom images are cross-sectional profiles.

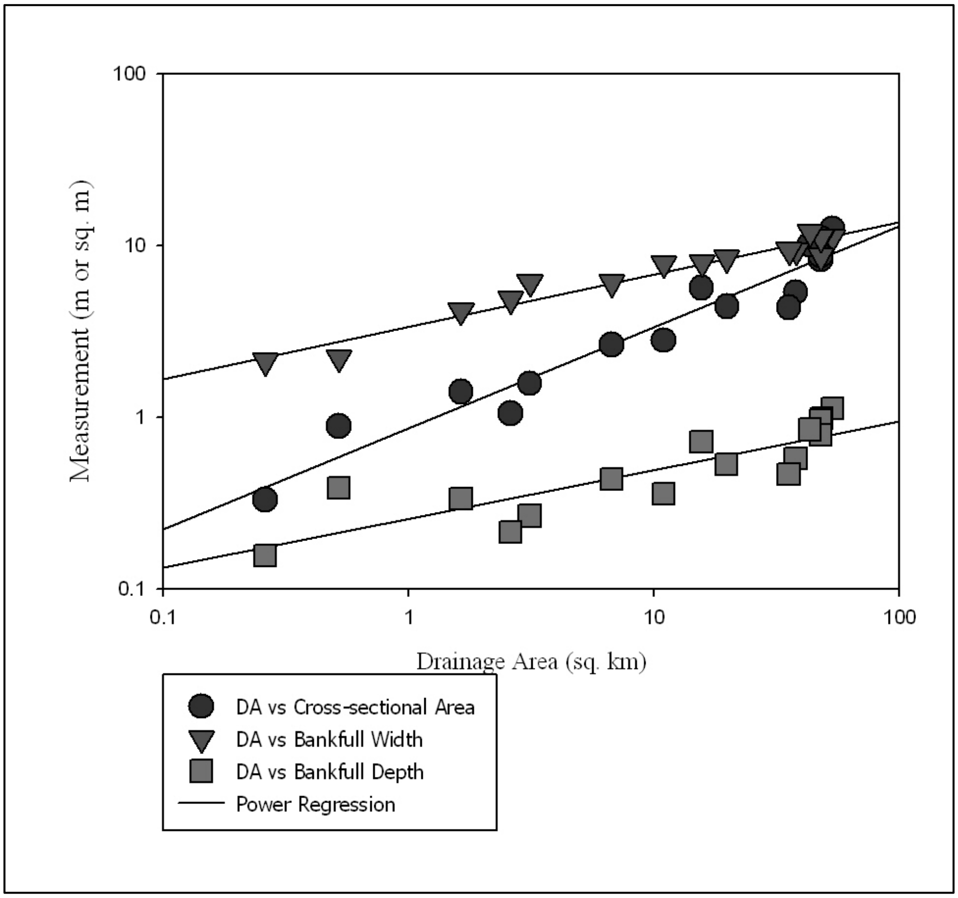

Figure 2.3: Regional curve of the bankfull dimensions of Mac-o-chee Creek. Each data point represents the mean bankfull measurement from two cross sections in a reach.

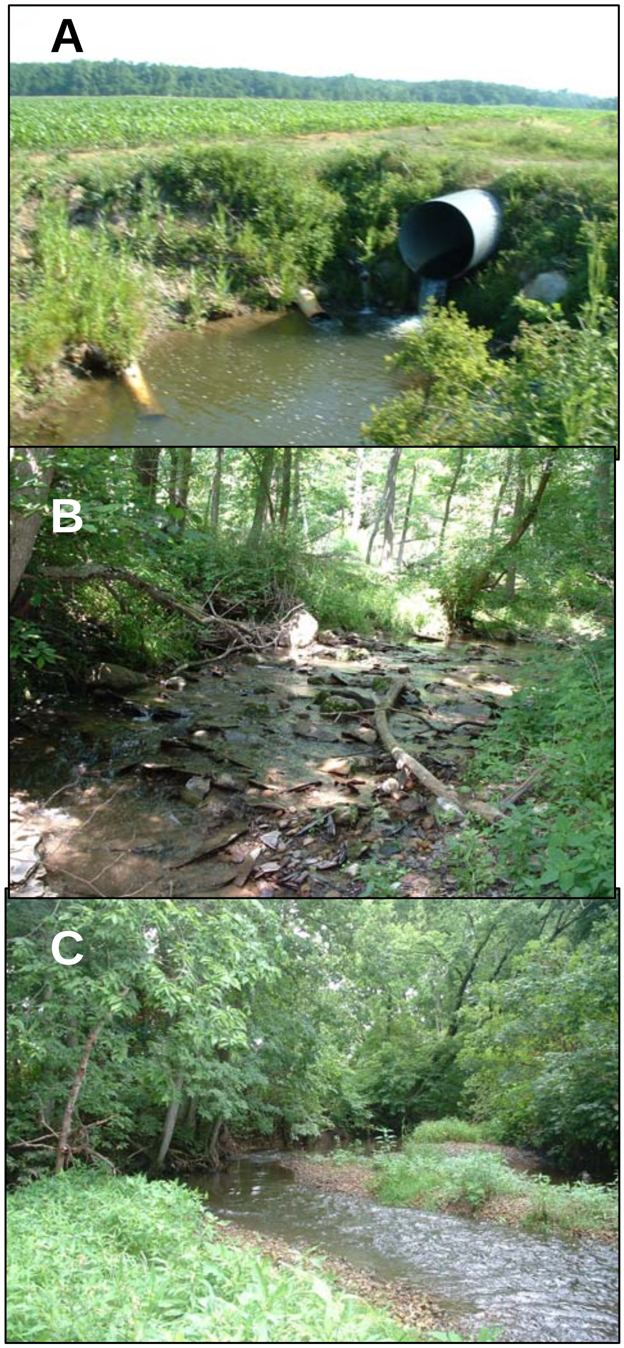

Figure 2.4: Digital photographs from three study reaches in Mac-o-chee Creek. (A) Site 15: drainage area = 1.6 km^2, Many subsurface drainage outlets are visible. (B) Site 13: drainage area = 3.1 km^2, Bedrock control created a channel much wider than predicted by the regional curves. (C) Site 7: drainage area = 35.4 km^2, In channel gravel bars and vegetated banks indicate natural recovery from channelization and channel widths lower than predicted by the regional curves.

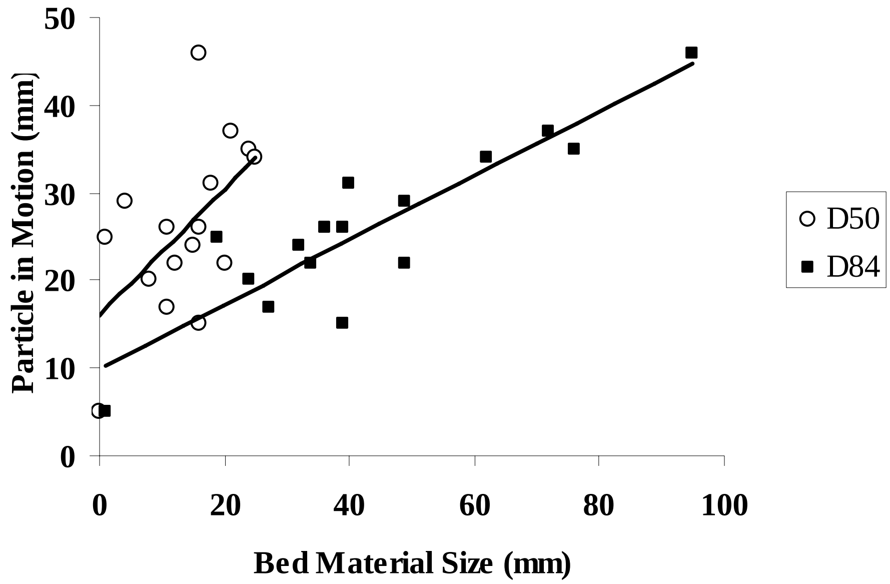

Figure 2.5: Relationships between the particle at incipient motion, the d_{50} and d_{84} of the bed material in riffles. Each point represents one study site.

Site Number	Drainage Area (km^2)	A (sq m)	W (m)	D (m)	Spacing	RI (yr)	Q (cms)
1	53.3	12.6	12.0	1.1	Y	4.26	21.9
2	48.2	8.2	9.0	0.9	Y	2.25	13.3
3	47.6	8.2	9.0	0.9	N	2.06	12.1
4	47.5	8.5	10.9	0.8	N	1.88	10.8
5	43.1	7.5	11.3	0.7	Y	2.09	12.3
6	37.7	6.7	9.4	0.7	Y	2.00	11.7
7	35.4	5.9	11.8	0.5	Y	1.65	9.1
9	19.8	4.3	7.4	0.6	Y	1.39	6.7
10	15.6	5.7	8.0	0.7	N	1.61	8.8
8	10.9	2.6	6.9	0.4	Y	1.09	3.5
12	6.7	0.2	1.1	0.2	Y	0.99	0.3
13	3.1	0.3	2.1	0.2	Y	0.95	0.3
14	2.6	1.5	4.7	0.3	Y	0.94	2.1
15	1.6	1.3	4.8	0.3	N	0.95	1.6
16	0.5	1.3	5.5	0.2	N	0.86	1.5
11	0.3	1.2	3.7	0.3	Y	0.87	1.6

Table 2.1: Cumulative dimension data from 16 selected study sites within Mac-o-chee Creek. A = Bankfull area, W = Bankfull width, D = Bankfull Depth, RI = Recurrence Interval, Q = Discharge. Spacing refers to the adherence of the site to a repeat of riffle-run-pool sequence within a length of stream equal to 5-7 bankfull widths (Yes or No).

	Mac-o-chee Creek Regional Curve	
Parameter	**Power Function Equation**	**R^2**
Bankfull Area (m^2)	$y = 0.86\ DA^{0.59}$	0.93
Bankfull Width (m)	$y = 3.37\ DA^{0.30}$	0.95
Bankfull Depth (m)	$y = 0.26\ DA^{0.28}$	0.73

Table 2.2: Power function regression equations for the Mac-o-chee Creek Regional Curve (MCRC). For each equation, y = individual parameter, DA = Drainage Area (km^2). R^2 = the coefficient of determination for the regression equation.

Site Number	Drainage Area (km^2)	Width MCRC	Width USRC	Width EURC	Depth MCRC	Depth USRC	Depth EURC
1	53.3	0.4	-25.9	-27.7	29.5	30.6	-36.2
2	48.2	-20.3	-38.0	-52.9	15.4	17.1	-61.3
3	47.6	-24.2	-39.9	-57.7	18.9	20.9	-53.8
4	47.5	3.0	-23.0	-23.2	2.5	4.9	-84.8
5	43.1	12.6	-13.6	-9.8	10.7	13.2	-67.2
6	37.7	-7.6	-28.8	-33.5	-26.3	-22.7	-133.6
7	35.4	-5.3	-26.7	-29.8	-54.3	-49.0	-182.1
9	19.8	1.8	-16.2	-14.3	-13.2	-8.0	-94.1
10	15.6	2.9	-13.0	-10.4	21.1	25.1	-31.8
8	10.9	12.0	-0.3	3.4	-41.7	-32.4	-125.7
12	6.7	1.5	-6.0	-3.1	0.0	7.0	-51.9
13	3.1	22.4	30.1	24.9	-33.3	-19.5	-82.1
14	2.6	7.6	11.3	12.0	-61.9	-45.1	-117.7
15	1.6	6.5	15.6	14.9	11.8	22.3	-11.8
16	0.5	-25.3	-1.9	-1.6	43.6	52.5	38.3
11	0.3	-6.6	24.4	19.3	-12.5	6.7	-14.0

Table 2.3: Percent difference between observed and expected values calculated from regression equations for three different regional curves. MCRC: Mac-o-chee Creek; USRC: Upper Scioto River (Witter 2006); EURC: Eastern United States (Dunne and Leopold 1978).

Site Number	Slope (%)	d_{50} (mm)	Sinuosity	W/D	ER	Stream Type
1	0.11	8	1.0	11.4	>2.2	C4
2	0.40	20	1.0	13.6	>2.2	C4
3	0.20	11	1.0	9.8	>2.2	C4
4	0.20	16	1.1	13.9	>2.2	C4
5	0.58	21	1.0	16.8	1.3	F4
6	0.45	18	1.0	13.2	1.4	F4
7	0.50	15	1.1	23.7	1.3	F4
9	0.48	16	1.0	12.6	1.7	E4
10	0.28	12	1.0	11.2	>2.2	E4
8	0.96	24	1.1	18.4	1.6	F4
12	1.90	11	1.1	6.2	1.7	E4
13	1.70	16	1.1	12.8	1.5	F4
14	1.70	25	1.3	14.3	1.5	F4
15	1.50	<1	1.0	17.2	1.2	F6
16	0.18	1	1.0	23.8	1.3	F6
11	1.60	4	1.0	11.1	1.3	G4

Table 2.4: Channel properties relevant to Rosgen stream type classification guidelines.

Site Number	d_{50} (mm)	d_{84} (mm)	Incipient Particle in Motion (mm)	In Range
1	8	24	20	Y
2	20	49	22	Y
3	11	27	17	Y
4	16	39	15	N
5	21	72	37	Y
6	18	40	31	Y
7	15	32	24	Y
9	16	39	26	Y
10	12	34	22	Y
8	24	76	35	Y
12	11	36	26	Y
13	16	95	46	Y
14	25	62	34	Y
15	<1	1	5	N
16	1	19	25	N
11	4	49	29	Y

Table 2.5: Bed materials in Mac-o-chee Creek. d_{50} and d_{84} determined through 100 measurement Wolman pebble count. In Range refers to the adherence of the site of possessing an incipient particle in motion size that is between the d_{50} and d_{84} particle sizes (Yes or No).

Site Number	Max Depth	Bank Height	BHR
1	0.73	2.07	2.85
2	1.14	1.51	1.33
3	1.15	1.71	1.48
4	1.06	1.49	1.41
5	0.95	2.52	2.64
6	0.94	1.92	2.04
7	0.87	1.87	2.16
9	0.81	1.74	2.15
10	0.91	2.07	2.27
8	0.65	1.55	2.39
12	0.45	1.10	2.42
13	0.34	0.77	2.23
14	0.42	1.66	3.93
15	0.50	2.46	4.94
16	0.25	1.87	7.50
11	0.25	1.45	5.86

Table 2.6: Bank Height Ratio (BHR) for all study sites in Mac-o-chee Creek. This ratio is calculated by dividing the full bank height by the maximum bankfull depth in the channel.

Site	Width	Depth	Stream Type	Spacing	RI	Bed Size	BHR
1	0.4	29.5	C4	Y	4.26	Y	2.85
2	-20.3	15.4	C4	Y	2.25	Y	1.33
3	-24.2	18.9	C4	N	2.06	Y	1.48
4	3.0	2.5	C4	N	1.88	N	1.41
5	12.6	10.7	F4	Y	2.09	Y	2.64
6	-7.6	-26.3	F4	Y	2.00	Y	2.04
7	-5.3	-54.3	F4	Y	1.65	Y	2.16
9	1.8	-13.2	E4	Y	1.39	Y	2.15
10	2.9	21.1	E4	N	1.61	Y	2.27
8	12.0	-41.7	F4	Y	1.09	Y	2.39
12	1.5	0.0	E4	Y	0.99	Y	2.42
13	22.4	-33.3	F4	Y	0.95	Y	2.23
14	7.6	-61.9	F4	Y	0.94	Y	3.93
15	6.5	11.8	F6	N	0.95	N	4.94
16	-25.3	43.6	F6	N	0.86	N	7.50
11	-6.6	-12.5	G4	Y	0.87	Y	5.86

Table 2.7: Summary of the weight of evidence variables from Tables 2.1 to 2.6.

Site	Width	Depth	Stream Type	Spacing	RI	Bed Size	BHR	Score
Max	**2**	**2**	**1**	**1**	**2**	**1**	**1**	**10**
1	2	1	1	1	0	1	0	**6**
2	2	2	1	1	1	1	1	9
3	2	2	1	0	1	1	1	8
4	2	2	1	0	2	0	1	8
5	2	2	0	1	1	1	0	7
6	2	1	0	1	1	1	0	**6**
7	2	0	0	1	2	1	0	**6**
9	2	2	1	1	2	1	0	9
10	2	2	1	0	2	1	0	8
8	2	1	0	1	2	1	0	7
12	2	2	1	1	2	1	0	9
13	2	1	0	1	2	1	0	7
14	2	0	0	1	2	1	0	**6**
15	2	2	0	0	2	0	0	**6**
16	1	1	0	0	2	0	0	**4**
11	2	2	0	1	2	1	0	8

Table 2.8: Summary of the weight of evidence scores, based on Table 2.7 and scoring criteria in the text. Bold scores indicate sites that show signs of instability.

CHAPTER 3

THE INFLUENCE OF HABITAT QUALITY ON MACROINVERTEBRATE AND FISH ASSEMBLAGES IN A MIDWESTERN COLDWATER STREAM SYSTEM.

Introduction

Biota in fluvial systems are influenced by physical and chemical parameters as well as by the geographic and geological history of the systems that they inhabit (Allan 1995; Poff 1997; Vannote, *et al.* 1980). The wide ranges in the scales of factors that shape a stream system are hierarchical in nature-from watershed, to reach, to microhabitat scale (Poff 1997). Researchers have tested how these relationships shape the way channel form influences habitat and fish and macroinvertebrate assemblages (Parsons and Thoms 2007; Schlosser 1991; Smiley and Dibble 2005). Studies have confirmed that mesohabitat units (riffles, runs and pools) in a stream are directly impacted by channel form and will support distinct biotic communities (Beisel, *et al.* 1998; Gorman and Karr 1978; Taylor 2000). As habitat changes occur in lotic systems, mesohabitat units can become altered resulting in changes to the aquatic assemblages in response to increasing environmental stressors. The assemblage changes will depend on the natural state of the system and the type of stressors that are occurring (Davies and Jackson 2006). In this paper, the primary type of degradation that is addressed is channelization, which can alter the geomorphology of a stream and lead to lower habitat quality.

Anthropogenic modification of stream channels to accommodate agricultural landuse is widespread in the United States. When European settlers first encountered the fertile, relatively flat lands of the Midwestern United States, many regions contained stream systems that regularly flooded interconnected wetland complexes (Dameron-Hager 2004; Schumm, *et al.* 1984). Early inhabitants converted large areas of these wetland complexes to agricultural fields which have persisted in many areas until today. Wetland drainage and channel straightening caused geomorphic changes in stream systems that were well beyond the rate of change that would have occurred without human influence (Urban and Rhoads 2003). The results of these changes across large areas of the Midwest have included the loss of connectivity to floodplains, channel widening, increased bank erosion, lower sinuosity, and a loss of instream habitat heterogeneity (Stanford, *et al.* 1996). Agricultural impacts in Ohio have been shown to have a variety of impacts on fishes and macroinvertebrates (Yoder and Rankin 1995), making it unclear which aspect of agricultural impairment most affects biota. Sedimentation, non-point source nutrient input, temperature regime alterations, and modification of channel form often occur concurrently and may have additive effects on the ecological integrity of impacted stream systems (D'Ambrosio, *et al.* 2008; Richards, *et al.* 1993).

This study was conducted in a headwater coldwater stream system in central Ohio that has received a coldwater use designation by the Ohio Environmental Protection Agency (OEPA 2005). Coldwater stream systems in the lower Midwest are not common and are often surrounded by and connected to warmwater systems that differ geologically and support different biota. Most research on coldwater streams in the region has focused on streams in the Upper Midwest, such as Wisconsin, Michigan, and Minnesota dominated by trout (Lyons, *et al.* 1996; Mundahl and Simon 1998; Wehrly, *et al.* 2003). Historically salmonid-free, coldwater systems in the lower Midwest (defined here as Ohio, Indiana, and Iowa), are now often stocked with brown trout (*Salmo trutta*), rainbow trout (*Onchorhynchus mykiss*), or brook trout *(Salvelinus frontinalis*), which vary widely in their thermal tolerances (Trautman 1981). Brown trout are best able to survive, but not reproduce, in agricultural coldwater systems of the lower Midwest. High summer water temperatures and limited availability of suitable habitat keeps their populations levels low and requires annual stocking by fisheries managers to maintain a population (Aarestrup, *et al.* 2005). Threats to native fish fauna include global climate change, urban development, and biotic homogenization (Hobbs 2002; Rahel, *et al.* 1996).

It has been demonstrated that increased heterogeneity and quality of instream habitat leads to increases in the abundance and diversity of biota in warmwater streams (Gorman and Karr 1978; Lau, *et al.* 2006; Palmer and Poff 1997; Vadas and Orth 2000). However, in coldwater streams, this assumption may not hold because pristine coldwater streams generally have unique species assemblage attributes including lower diversity, lower species richness, and higher proportions of intolerant species than their warmwater counterparts. As coldwater streams undergo limited to moderate degradation, species richness and diversity of fish tends to increase (Lyons, *et al.* 1996). This pattern has rarely been evaluated in macroinvertebrates or for both taxa within the same system.

The goal of this study was to analyze the impacts of degradation on biota of a coldwater stream ecosystem, specifically channelization and the resulting loss of habitat integrity. My objectives were: (1) to examine how habitat and geomorphic impairment influences the abundance and assemblage structure of benthic macroinvertebrate and fish assemblages; (2) to examine the trophic structure of fish and macroinvertebrate assemblages in mesohabitat units that differ in their degrees of impairment from historic channelization; and (3) for each taxonomic group, test if the impairment gradient was more influential in structuring the assemblages than habitat type. I predicted that geomorphic impairment would strongly influence the assemblages, in that more warmwater and tolerant species would occur in the impaired reaches. I expected wetted width to influence the assemblages as well.

Methods

Study Area

Mac-o-chee Creek drains an area of 53 km^2 (Figure 3.1) and consists of 76 % agricultural (row crop and pasture) and 24 % second growth mixed forest land covers (Choi and Engel 2007) in the watershed. In the past two centuries, the stream has served as a mill power source, an agricultural drainage way, and as a stocked brown trout recreational fishery. In many ways, it is a typical example of the history of stream management in the Midwest (Trautman 1981). The gradient of the system near the mouth, where this study was conducted, is very low (1-3%) as the stream enters a relatively flat valley and its confluence with the Mad River. Most of the lower end of the stream system was channelized about 100 years ago to accommodate agricultural development and the construction of a state highway.

The retreat of the Laurentide ice sheet during the Wisconsin period created vast till and outwash deposits across northern Ohio, Indiana, and Iowa. Glacial melt waters that cut through glacial till layers in end moraines created deep river valleys that are often characterized by abundant groundwater entering surface stream channels (Koltun 1995). The input of groundwater into the region of this study creates high base flows in summer months and consistently cool water temperatures (OEPA 2005). The measured water temperature of Mac-o-chee Creek during summer months in 2007 was, on average, 17°C (unpublished data, see Appendix D) which is much cooler than nearby warmwater streams.

Site Selection and Habitat Data Collection

Six study reaches of approximately 150 m in length were selected for this study. Based on visual assessment and personal knowledge of the system, three reaches were classified *a priori* as “Impaired” and three as “Recovering” (Treatment codes I or R, respectively). The Qualitative Habitat Evaluation Index (QHEI), a multi-metric index that is an effective tool to detect trends in habitat impairment (Lau, *et al.* 2006; Moerke and Lamberti 2003), was calculated for each study site and confirmed the prior classification.

Impaired reaches were located close to a road that has contributed to degraded conditions by preventing channel migration within these reaches. They were distinct in their lack of channel unit development, artificial side channel pools formed by riprap, and lack of canopy cover. The impaired reaches included long runs and a few short riffles.

Pools in the impaired reaches were side channel pools with large pieces of concrete and limestone riprap forming the primary substrate.

Recovering reaches were bordered on both banks by wooded riparian corridors of varying widths. These reaches were characterized by the presence of clear building features within the channel such as active gravel bars, the narrowing of the channel in riffle areas, and the presence of pools formed by scour downstream of large wood, logjams, or tree roots at meander curves. Riffles were fast flowing and abundant in the recovering reaches.

Within each of the six study reaches, mesohabitat units were delineated as riffle, run or pool (mesohabitat unit Codes R, N, or P, respectively) using a visual classification method (Rabeni, *et al.* 2002). A total of 31 mesohabitat units were sampled, constituting six types (IR, RR, IN, RN, IP, RP). All sampling was conducted from July to August 2007.

Two habitat variables, QHEI and canopy cover, were sampled on a reach scale. Canopy cover was measured using a hand held densiometer at three evenly spaced locations within each reach. All other habitat measurements were determined for each mesohabitat unit following delineation. Flow rate (m/s) and water depth (m) were measured at 2-3 locations within each mesohabitat unit along a transect along the thalweg of the stream using a Marsh-McBirney Flowmate and depth rod. Additional measurements included mesohabitat unit length and average wetted-width.

Fish Sampling

Fish were sampled in each mesohabitat unit by electroshocking with a generatorpowered long line electrofisher, with a pulsed DC current, mounted on a small, towable boat (OEPA 1987). Block nets were placed at the upstream and downstream ends of each unit prior to shocking to prevent escape. Each mesohabitat unit was shocked with 2-3 passes, until the majority of fish were removed and no new species were collected. All fish were identified and enumerated on site, and returned to the stream immediately.

Macroinvertebrate Sampling

Macroinvertebrates were sampled in each mesohabitat unit using both a Surber sampler and a D-frame kicknet and the data were later combined for each mesohabitat unit. A timed (5 minute) Surber sample was taken at a single location within each riffle and run. A timed (5 minute) D-frame kicknet sample was taken within each riffle, run and pool, wherein all available habitats within each unit were sampled with the kicknet, in a method similar to the USEPA Rapid Bioassesment Protocol (Barbour, *et al.* 1999). Samples were preserved on site in 95% EtOH.

All samples were identified with dissecting microscopes in the Stream Ecology Laboratory at The Ohio State University. Most arthropod invertebrates were identified to family and some non-insect groups were identified to order. Diptera of the family Chironomidae were eliminated from all data analysis because of the wide variety of trophic and tolerance levels that the family constitutes (Danehy, *et al.* 1999; Mykrä, *et al.* 2007; Rabeni and Wang 2001).

Data Analysis

Extremely rare taxa (comprising less than 0.01% of total abundance, or only present in one mesohabitat unit sample) were removed for both fish and invertebrate taxa. Assemblage metrics that were calculated for both fish and invertebrates included Shannon's evenness, richness, total abundance, and Shannon-Weiner's diversity index using PC-ORD 5.0 for Windows (McCune and Mefford 1999). The fish assemblage metrics included trophic and tolerance metrics after (Lyons*, et al.* 1996) and (OEPA 1987). Fish were assigned to one of five feeding categories: invertivore, herbivore, top carnivore, generalist or filter feeder. Additionally, each fish species was designated as tolerant, intolerant, or undetermined, and the percent individual of each category was calculated for each mesohabitat unit. The percent individuals that are simple lithophils was calculated for each sample as well because these species are sensitive to silt accumulation and substrate quality (Poff and Allan 1995). Temperature preferences play an important role for fish dispersal in coldwater stream systems; therefore the percent coldwater obligate fish at each mesohabitat unit was also calculated with temperature preference data (Lyons*, et al.* 1996).

For the invertebrate dataset, the percent individuals in each trophic category were calculated to serve as measures of energy linkage within the assemblage (Weigel, *et al.* 2003). Each macroinvertebrate taxa was categorized into one of five functional feeding groups: predator, scraper, collector-filterer, shredder, and collector-gatherer (Merritt and Cummins 1984). Average tolerance value per sample and mean pollution tolerance value (MPTV: average tolerance per sample divided by sample richness) metrics were calculated to indicate the assemblage sensitivity to water quality impairments (Bouchard 2004). Two other commonly used assemblage metrics that were calculated included percent Ephemeroptera-Plecoptera-Trichoptera (EPT) individuals and percent Diptera individuals. They are easily calculated and have been shown to accurately reflect water quality (Wang 2007; Weigel, *et al*. 2003). Multivariate analysis of variance (MANOVA) tests were conducted for each assemblage metrics to test if variance the can be explained by the mesohabitat unit, treatment classification, or an interaction term of both factors.

A set of four ordination analyses were used to interpret how aspects of fish or invertebrate abundance and assemblage metrics interact with environmental variables. A detrended canonical correspondence analysis (DCCA) was conducted using CANOCO with the environmental, invertebrate and fish datasets to determine the appropriate ordination technique. The gradient lengths (fish abundance: 1.648, invertebrate abundance: 1.57, fish assemblage metrics: 0.759, invertebrate assemblage metrics: 0.759) suggested that the relationships among the explanatory variables were linear so redundancy analysis (RDA) was selected for ordination (ter Braak, Cajo J.F. and Prentice 1988). RDA is a multivariate indirect gradient analysis technique that incorporates multiple dependent variables at once (ter Braak, Cajo J.F. and Prentice 1988). For each RDA, a Monte Carlo permutation test with 500 permutations was conducted using CANOCO on all canonical axes to determine if the ordination diagram was significantly different than one that could have occurred by chance alone. Nominal variables, in this case Riffle, Run, Pool, Impairment, and Recovery, were coded as dummy variables and are represented in the ordination diagrams by a “X” at the centroid of the sample scores belonging to that class (ter Braak, Cajo J.F. and Smilauer 2002).

Finally, to determine if differences in the assemblage and trophic structure were significantly different by mesohabitat unit or treatment type, MultiResponse Permutation Procedures (MRPP), using a Euclidean distance measure, were performed using PC-ORD. This distance-based classification method evaluates the null hypothesis of no difference among groups (McCune and Grace 2002). For both the fish and invertebrate datasets, abundance and percent trophic composition were tested for classification by mesohabitat type and treatment type.

Results

Habitat Measurements

Single factor ANOVA indicated significant differences between impaired and recovering reaches. The QHEI indicated that impaired sites were significantly lower quality than recovering sites ($P = 0.024$). Canopy cover was higher in recovering sites ($P = 0.001$) where intact wooded areas were present on both banks.

Pools in impaired reaches were confined to lateral part of the channel and the primary substrate in these pools was rip rap, boulders, and other artificial material introduced in to the stream for bank stabilization. Pools in recovering reaches were deeper and longer than impaired reaches. They were and located at rootwads, channel curves, or logjams and stretched across the width of the channel (Table 3.1). Riffles in recovering reaches were generally narrower than in impaired reaches and often bordered in-channel point bars. Though not statistically significant, runs in impaired reaches and recovering reaches were similar in depth and flow but were somewhat longer in impaired reaches.

Fish and Invertebrate Assemblage Characteristics

The fish collection included a total of 9,514 individuals constituting 19 species in seven families. One very rare taxa, the striped shiner, (comprising <0.001% of the total collection or collected and only one mesohabitat unit) was deleted from further analysis. Seven abundant fish species (mottled sculpin, creek chub, blacknose dace, white sucker, rainbow darter, silver shiner, and central stone roller; for scientific names, see Table 3.2) comprised 98% of the total abundance. Mottled sculpin constituted 54% of the total abundance across all samples and were particularly dominant in all riffle mesohabitat units, in which they constituted 92% abundance. I also captured three individuals of a state threatened species, the tonguetied minnow. The greatest numbers of fish were collected in impaired reaches and run mesohabitat units.

The invertebrate collection consisted of 51,554 individuals in 63 taxa after the removal of Chironomidae (Table 3.3). Six abundant taxa, Hydropsychidae, Elmidae, Baetidae, Corixidae, Hydracarina, and Hydroptilidae constituted 83 % of the total abundance. Fourteen very rare taxa and one taxon present at only one sample site (Perlidae) were eliminated from the dataset (Table 3.3). Common and rare taxa, comprising 0.05 - 5% and 0.001 - 0.05%, respectively, were retained for further analysis. The final subset of the data includes 8,285 individuals of 41 taxa.

Assemblage Metrics

This study included a wide array of fish and invertebrate assemblages among mesohabitat units as indicated by the large standard deviations for many of the calculated assemblage metrics (Table 3.4). MANOVA indicated that many of the metrics had significant variance among mesohabitat unit types but were not statistically significant between impaired and recovering reaches. Fish diversity was always highest in pools ($P > 0.001$). Shannon's evenness for fish species varied little among all sample units. Fish species richness was higher in impaired reaches and pool mesohabitat units. Total fish abundance varied widely but was highest in all impaired reaches and run mesohabitat units. Average percent tolerant individuals were higher in all impaired reaches and in pool mesohabitat units. Average percent simple lithophil individuals were lowest in riffle units. They were more abundant in recovering runs and pools than impaired runs and pools.

Invertebrate taxa diversity, richness, and mean total abundances were all higher in impaired reaches. Shannon's evenness for invertebrate taxa varied little across all sample units. Low average tolerance and MPTV values at all sites indicate the assemblages are not impaired by water quality (Bouchard 2004). All tolerance measures were higher in impaired reaches. Both percent EPT individuals and percent diptera individuals were higher overall in recovering reaches but patterns differed by mesohabitat unit among the taxa.

Fish Abundance-Environmental Relations

The fish abundance RDA (Figure 3.2A) identified a significant interaction between fish abundance and environmental variables (Table 3.5). The first two RDA axes accounted for 95.3% of the explained variation. On the first RDA axis, creek chub and white sucker species scores were associated positively with water depth and the centroid of the pool variable (Figure 3.2A). Many of the rare species, such as tonguetied minnow, fantail darters, and green sunfish, were strongly associated with wetted-width. The second RDA axis, which accounted for 13.8% of the explained variation, was strongly associated with pool mesohabitat units. Sensitive and intolerant taxa are more strongly associated with recovering reaches than impaired reaches.

Invertebrate Abundance-Environment Relations

The RDA for invertebrate abundance also identified a significant interaction between species and environmental variables (Table 3.5). The percent variance of the species-environment relation was lower than that of the other three RDA ordinations, but the species-environment correlation was quite high (0.88). Along the first RDA axis, many of the Odonate, Hemiptera, and Mollusk families were positively associated with length and depth (Figure 3.2B). Conversely, many of the Trichoptera and the only Plecoptera family (Leuctridae) were associated with flow and the riffle variable centroid. Sensitive species (in this case, EPT taxa) are more strongly associated with recovering reaches than impaired reaches.

Fish Assemblage Metrics-Environment Relations

The fish assemblage metric RDA did not identify a significant interaction between assemblage metrics and environmental variables (Table 3.5). This analysis was retained to compare to the other three ordinations, and because the percentage of variance of the species-environment relation was very high (97.1% for the first two RDA axes). Along the first RDA axis, intolerance, coldwater preference and percent invertivore individuals were positively associated with flow (Figure 3.2C). In the other direction, percent tolerant individuals, percent generalist individuals, and percent simple lithophil species were associated with depth. Along the second axis, the diversity metrics (diversity, evenness, richness), percent herbivore individuals, percent top carnivore individuals, and total abundance are positively associated with length and width of mesohabitat units. All of the diversity metrics are more strongly associated with impairment than recovery, indicating that the values of theses metrics are higher in impaired reaches.

Invertebrate Assemblage Metrics-Environment Relations

The final RDA was determined to demonstrate a significant interaction among species and environmental variables, although the Monte Carlo Permutation Test P-value for this ordination was higher than for either the fish or invertebrate abundance ordinations (Table 3.5). Along the first RDA axis, percent scrapers and percent predators were positively associated with depth (Figure 3.2D). In the other direction along that axis, percent collector-gatherer individuals, and total abundance were associated with flow. Along the second RDA axis, percent EPT individuals and percent shredder individuals are associated with the run and recovery nominal environmental variables. In the other direction, richness and percent collector-filterer individuals were positively associated with width of mesohabitat units. All of the diversity metrics (diversity, evenness, richness) are more strongly associated with impairment than recovery. Sample scores were well divided between treatment types but not among mesohabitat unit type (Figure 3.2D).

Feeding Guild Structure

Trophic composition for each mesohabitat unit type is graphed for both taxonomic groups (Figure 3.3). When examining fish trophic structure, the differences among mesohabitat unit types are larger than the differences between treatment groups. There are slightly higher percent invertivore individuals in each of the recovering sites, and slightly higher percent generalist individuals in each of the impaired sites.

For invertebrate functional feeding structure, differences are more pronounced between treatment groups (Figure 3.3B). Impaired riffles are dominated by collector-filterer taxa including Sphaeridae and Simuliidae. Comparatively, recovering riffles have higher proportions of shredder, especially Tipulidae, and predator taxa, particularly Leuctridae and Ceratopogonidae. The recovering riffles resemble recovering runs in their composition more than impaired riffles resemble impaired runs. Impaired pools and impaired runs have higher proportions of scraper taxa than recovering pools and runs.

Shredder taxa are more abundant in recovering reaches than in impaired reaches. This trend is pronounced from riffles and runs but only slightly higher for pools. Collector-gatherer taxa are evenly distributed across all sample types. Collector filterer taxa are most abundant in impaired riffles, comprising an average of 43% of those samples and dominated by Simuliidae individuals. Scraper taxa are more abundant at impaired runs and pools than recovering runs and pools but are about equally distributed in riffles of both treatment types. Predator taxa are more abundant at recovering riffles and pools than impaired riffles and pools but about equally present in all run samples.

MultiResponse Permutation Procedures

Five of eight MRPP tests conducted indicated significant differences among groups (Table 3.6). All habitat classification tests were significant ($P<0.001$) but those for treatment classification were not as consistent. For fish abundance and trophic composition, the classifications by treatment were not different from what could be derived from chance alone. Invertebrate abundance among reaches of two states of impairment were not significantly different ($P = 0.06$). For invertebrate functional feeding composition, the MRPP indicated a significant grouping by treatment ($P = 0.03$), which was not as strong as the results for classification by mesohabitat unit.

Discussion

The results of this study indicate that the biota in Mac-o-chee Creek are influenced by degradation, in this case most importantly channelization and its impacts on habitat quality. Macroinvertebrates demonstrate more sensitivity than fish to impairment caused by channelization at this scale of study. Both assemblages exhibit trends consistent with coldwater assemblages in the recovering reaches more so than the degraded reaches. Species abundance, diversity and richness are lower in recovering reaches, which is indicative of a more pristine coldwater stream system (Lyons, *et al.* 1996). This trend, again, is stronger with the macroinvertebrates than the fish.

These results are not consistent with the commonly accepted principle that higher quality habitat will lead to greater species diversity, richness and abundance (Lepori, *et al.* 2005; Smiley and Dibble 2005; Sullivan, *et al.* 2006; Syrkanen and Muotka 2007).

Many multi-metric indices for fish and invertebrates generally award higher integrity scores for assemblages with more species and higher abundance. For this reason, warmwater indices are often inappropriate for detecting trends of degradation in coldwater stream systems (Hughes 2004; Lyons, *et al.* 1996).

Positive correlations between physical (geomorphological or habitat) and ecological assessment scores for stream reaches is cited as confirmation of the effectiveness of these indices (Lammert and Allan 1999; Sullivan, *et al.* 2004; Weigel, *et al.* 2003). This study adds further weight to the idea that ecological integrity is associated with physical structure but integrity and diversity are not necessarily equal surrogates in all systems (Davies and Jackson 2006).

The results indicate that for small-scale studies, designed to identify which areas of a stream are impaired, invertebrate assemblages are more sensitive to small scale variations in habitat quality. Other studies have reached similar conclusions (Berkman, *et al.* 1986; Smiley and Dibble 2005; Williams, *et al.* 2002). Stream restoration is routinely conducted on small, reach-scale patches at great cost per stream mile (Alexander and Allan 2006). Therefore, a better understanding of small scale fluctuations in the distribution of stream biota is important.

Most variation in the fish assemblage is related to habitat classification. Riffle mesohabitat units were dominated by benthic invertivore fish that prefer coldwater and are intolerant. Prior to the channelization, it is likely that riffles were more common than they are today in the system. Pools were dominated by tolerant, eurythermal, generalist fish that have probably colonized Mac-o-chee Creek from the nearby larger Mad River.

Prior to agricultural conversion of the landscape in this region, tolerant pioneering species such as white sucker and creek chub were probably not as abundant in coldwater headwater streams (Trautman 1981). High suspended sediment levels (from altered geomorphology), and warmer temperatures (from increased sunlight related to the clearing of the riparian area) allow these warmwater fish to thrive in streams that may have been clearer and prohibitively cold in the past. In higher gradient streams, such as those of mountain ranges of the Western or Northeastern United States, barriers including waterfalls have prevented warmwater fish from colonizing coldwater stream systems (Lyons, *et al.* 1996). Macroinvertebrates are less inhibited by gradient, and are more likely to have patchy distributions in a watershed. Thus, they are only present where local habitat conditions are suitable (Malmqvist 2002). Limited research has been conducted that focuses on the native macroinvertebrate biodiversity of lower Midwestern coldwater streams. My results suggest that macroinvertebrate responses to habitat degradation are similar to those of fishes. Higher proportions of tolerant individuals, diversity, species richness, and abundance are likely to occur areas that are prohibited from recovering from historic channelization.

The trophic composition of fishes and macroinvertebrates in Mac-o-chee Creek was clearly linked to both mesohabitat classification and habitat quality. Fishes demonstrated less variability between sites of varying quality because of their ability to move among locations in a stream (Williams, *et al.* 2003b). Fish have been found to be less sensitive to local conditions than to regional influences, particularly in agriculturally dominated watersheds (Smiley and Dibble 2008; Zimmerman, *et al.* 2003). For macroinvertebrates, dispersal is often accomplished by adult forms or by nocturnal drift so local assemblages are more sensitive to instream conditions at a reach scale (Beisel, *et al.* 1998; Korsu 2004).

Patterns of functional feeding composition of the macroinvertebrate assemblage may have differed with a finer level of identification but previous studies had shown that family level identification can be nearly as effective for the purposes of identifying gradients of degradation in stream systems (Bailey, *et al.* 2001; Bowman 1997). For families that contain multiple feeding groups (i.e. Tipulidae), some detail was lost in combining those data into one group. This may have lead to a coarsening of the data resolution when classifying the samples in this study (Poff and Allan 1995; Williams, *et al.* 2002).

Higher proportions of macroinvertebrate scrapers in impaired reaches are likely related to higher primary productivity and silty conditions that occur in the lengthy runs that characterize the impaired areas. High proportions of scrapers have been related to agricultural activity in other studies (Delong and Brusven 1998; Moore and Palmer 2005). It should be noted that algal growths and large in-channel macrophyte beds were observed in the impaired reaches, further indicators of high levels of productivity. The lack of canopy cover in those areas allows more sunlight to reach the streambed. Central stonerollers, which are algivorous fish, were not observed in higher numbers at these sites, however.

Increased proportions of shredding taxa in recovering riffles and recovering runs was most likely influenced by the more intact riparian cover at these sites. Large wood and leaves entering the stream provide the desired food source or sites for colonization for these taxa. The recovering reaches were characterized by large trees bordering the stream on both banks. Intact riparian corridors have been shown to have strong impacts on invertebrate communities in watersheds that are primarily agricultural in their land use composition (Delong and Brusven 1998; Moore and Palmer 2005). There was a higher abundance of filterers in the impaired riffles. This difference is largely driven by high abundances of Simuliidae which are relatively tolerant. Riffles in the impaired areas, immediately downstream of long runs with low flows are likely to have more particulate organic matter suspended in the water column. Simuliidae were also present in greater abundances in impaired runs than recovering runs.

This research helps elucidate system response in coldwater stream ecosystems that are part of agricultural watersheds.   These systems are exposed to a complex variety of stressors that can be chemical, physical, or hydrological in nature. Such stressors have changed substantially in the recent past as our ability to conduct agriculture on a large scale has increased (Watzin and McIntosh 1999). Fish and macroinvertebrates respond differently to changes accumulated over time and the assemblages currently present in a stream may reflect factors acting at widely different spatial and time scales (Williams, *et al.* 2003a). As watershed scale approaches to improving water quality increase in importance, assessment and monitoring techniques need to be refined for unique systems such as coldwater streams. Additionally, as climate change increases global temperatures, coldwater stream systems will undergo drastic change but still may not resemble warmwater systems in their response to degradation (Rahel, *et al.* 1996).

Species-poor assemblages are rarely recognized as being of high conservation value, but in agricultural areas, where nutrient input is a common stressor, these assemblages may be increasingly threatened (Watzin and McIntosh 1999). If water quality improvement and stream restoration are to improve in effectiveness, then new management strategies need to be developed for protecting coldwater streams in the lower Midwestern United States.

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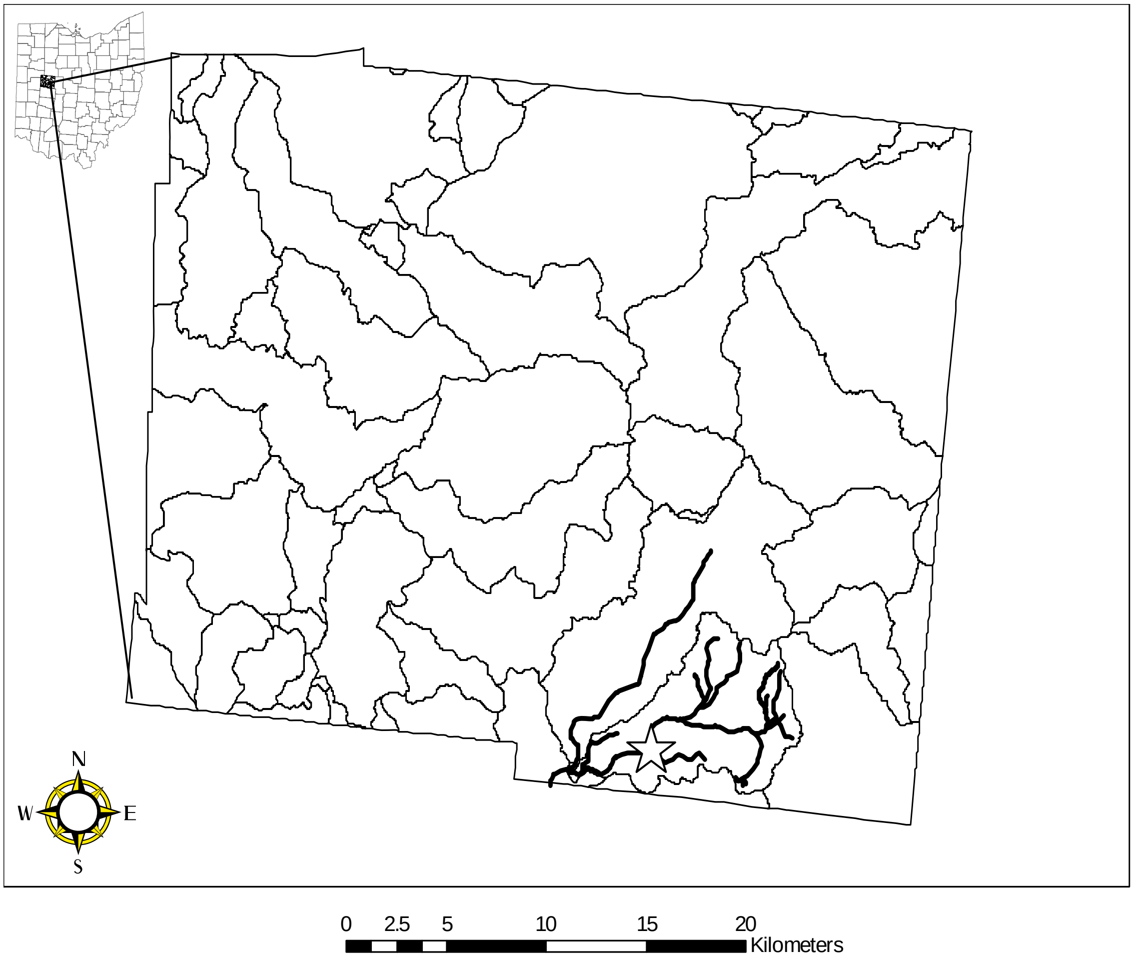


Figure 3.1: Map of the hydrologic boundaries of the watershed of Mac-o-chee Creek within Logan County. Inset identifies location within the state of Ohio. Star indicates center of study area.

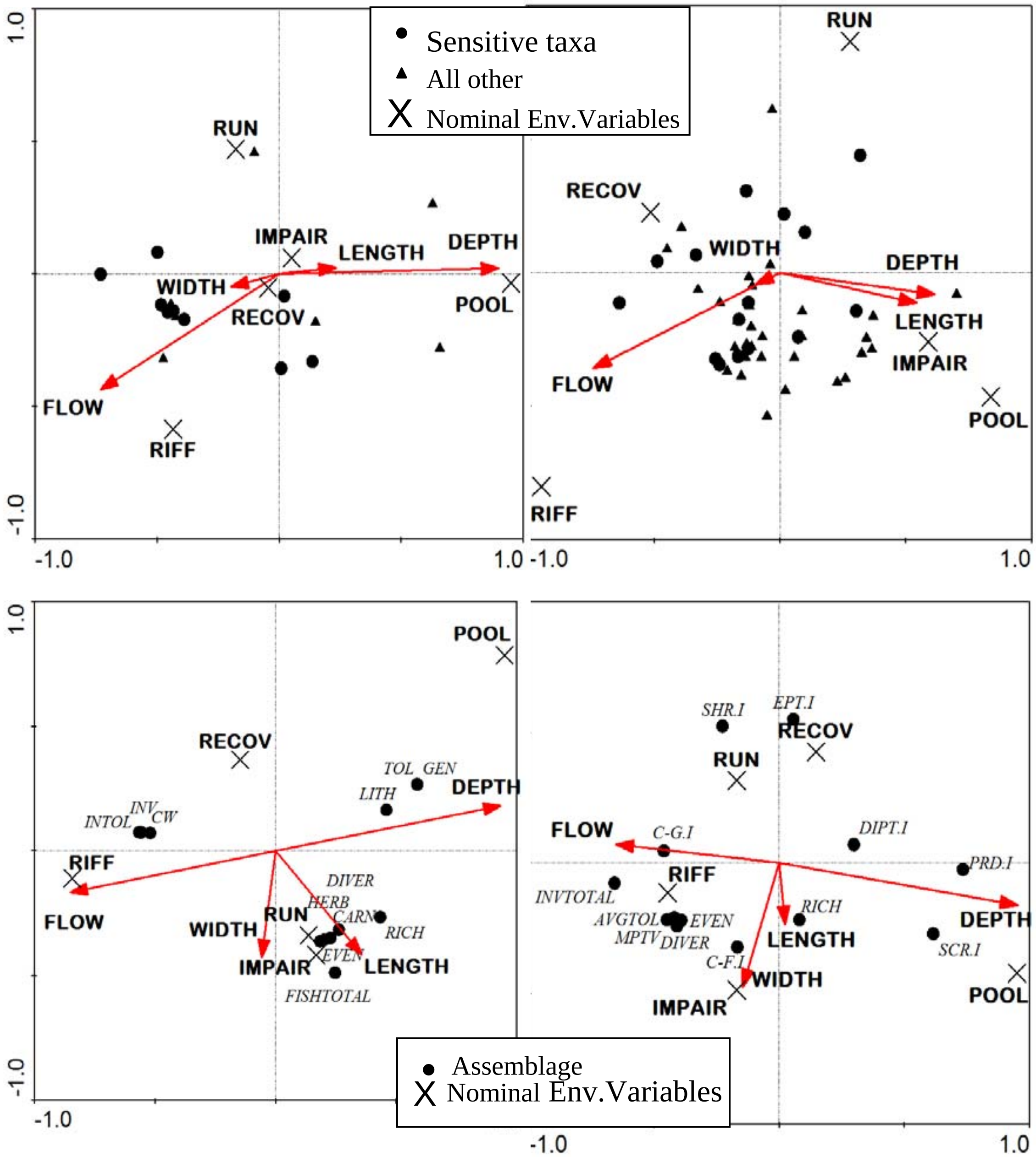
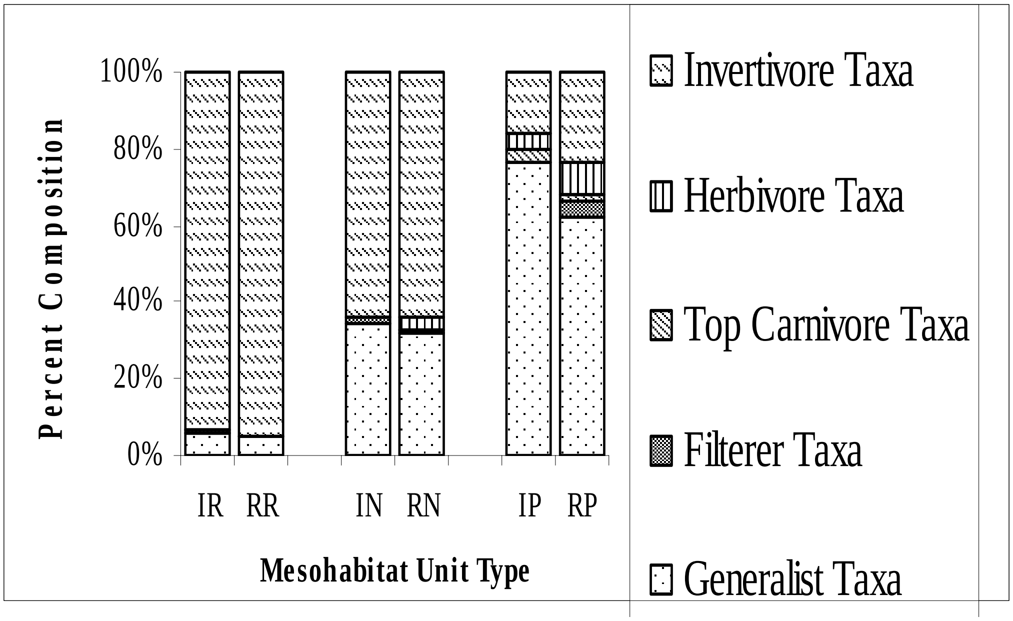


Figure 3.2: Redundancy Analysis (RDA) ordination biplots of environmental variables and fish and invertebrate abundance (A and B); fish and invertebrate assemblage metrics (C and D) as explained by environmental variables. Acronyms are defined in Tables 3.4. Nominal environmental variables are expressed as the centroid of the sample score of that variable.

A Fish Trophic Composition



B Invertebrate Functional Feeding Composition

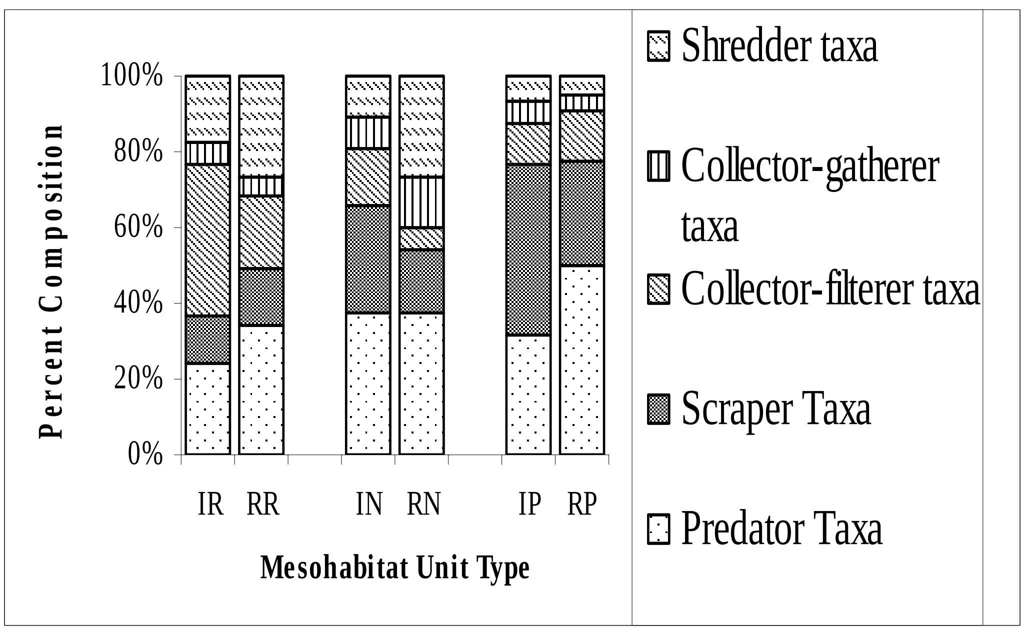


Figure 3.3: Mean trophic composition of fish (A) and invertebrate (B) assemblages. Mesohabitat unit type codes on X-axis refer to the treatment, Impaired or Recovering , (I or R) and the type of mesohabitat unit, riffle, run, or pool (R, N, or P).

Unit Type	Treatment	N	Flow (m/s)	Depth (m)	Width (m)	Length (m)
Riffle						
	Impaired	4	0.71 (0.15)	0.12 (0.05)	7.38 (1.50)	14.23 (4.48)
	Recovering	7	0.57 (0.13)	0.10 (0.03)	7.35 (2.18)	16.76 (7.04)
	All	11	0.62 (0.15)	0.11 (0.03)	7.36 (1.84)	15.74 (6.00)
Run						
	Impaired	7	0.21 (0.07)	0.36 (0.13)	7.55 (1.5)	34.89 (28.1)
	Recovering	6	0.27 (0.12)	0.30 (0.07)	6.62 (1.5)	17.76 (8.7)
	All	13	0.24 (0.10)	0.33 (0.11)	7.12 (1.5)	28.66 (8.7)
Pool						
	Impaired	3	0.11 (0.06)	0.76 (0.28)	6.73 (0.55)	19.45 (3.23)
	Recovering	4	0.09 (0.06)	0.84 (0.30)	6.46 (1.11)	25.10 (9.36)
	All	7	0.10 (0.06)	0.80 (0.27)	6.58 (0.86)	23.22 (7.96)
	All Impaired	14	0.33 (027)	0.38 (0.27)	7.33 (1.29)	26.15 (22.4)
	All Recovering	17	0.34 (0.22)	0.36 (0.33)	6.86 (1.66)	19.43 (8.41)

Table 3.1: Mean value (± standard deviation) of mesohabitat unit measurements.

Family/Species Names	Common Name	Trophic Group	Abundance (% of total)	IR	RR	IN	RN	IP	RP
Catostomidae									
Catostomus commersoni	White sucker	GEN	9.9	+	+	+++	++	+++	+++
Hypentelium nigricans	Nothern hog sucker	INV	0.1	-	+	-	+	+	+
Centrarchidae									
Lepomis cyanellus	Green sunfish	GEN	<0.1	-	-	-	-	+	+
L. macrochirus	Bluegill	INV	<0.1	-	-	+	+	-	+
Micropterus salmoides	Largemouth bass	CARN	0.2	+	-	++	+	+	-
Cottidae									
Cottus bairdi	Mottled sculpin	INV	56.2	+++	+++	+++	+++	++	+++
Cyprinidae									
Campostoma anomalum	Central stoneroller	HERB	1.9	-	-	+	++	++	++
Exoglossum laurae	Tonguetied minnow	INV	<0.1	-	-	-	+	+	+
Luxilus chrysocephalus	Striped shiner	INV	<0.1 (VR)	-	-	-	-	+	-
Notropis photogenis	Silver shiner	INV	1.5	-	-	++	+	++	++
Phoxinus erythrogaster	Southern redbelly dace	HERB	<0.1	-	+	-	+	-	-
Rhinichthys atratulus	Blacknose dace	GEN	7.4	++	++	+++	+++	++	++
Ricardsonius balteatus	Red side dace	INV	0.3	-	-	+	+	+	++
Semotilus atromaculatus	Creek chub	GEN	18.4	+++	+++	++	++	+++	+++
Petromyzontidae									
Lampetra lamottei	American brook lamprey	FILT	1.1	+	+	++	++	+	++
Percidae									
Etheostoma caeruleum	Rainbow darter	INV	2.3	++	++	++	++	++	+
E. flabellare	Barred fantail darter	INV	<0.1	-	+	-	-	-	-
Salmonidae									
Salmo trutta	Brown trout	CARN	0.5	-	-	+	-	++	++

le 3.2: Fish Abundance across 31 mesohabitat units sampled. Acronym indicates names used in RDA ordinations. Very rare (VR) were eliminated from data analysis. Trophic groups are defined as: GEN = Generalist, INV = Invertivore, CARN = Top carnivore, RB = Herbivore, FILT = Filter feeder. Sample unit codes are a combination of treatment (I= Impaired, R = Recovering) and mesohabitat type (R = Riffle, N = Run, P = Pool). "-"Indicates species was not present in any sample units; "+"Indicates total abundance in sample <0.1% of overall fish abundance (<10 fish); "++" Indicates total abundance in sample type between 0.1 and 1.0% of overall fish ndance (11-95 fish); "+++" indicates >1% total fish abundance (>96 fish).

Order/Family	FF Group	Abundance (% of total)	IR	RR	IN	RN	IP	RP
Amphipoda								
Hyalellidae	C-G	0.01	-	-	-	+	-	+
Annelida								
Hirudinea	PRD	0.04	+	+	+	+	-	+
Arachnida								
Hydracarina	PRD	9.13	++	+++	+++	++	++	++
Bivalvia								
Sphaeriidae	C-F	0.33	+	+	++	++	+	+
Coleoptera								
Curculionidae	SHR	0.01 (VR)	-	-	+	-	-	+
Dytiscidae	PRD	0.15	+	-	+	+	+	+
Elmidae	SCR	20.05	+++	+++	+++	+++	++	++
Gyrinidae	PRD	0.10	+	-	+	+	+	+
Haliplidae	SHR	0.04	-	-	+	+	+	+
Hydrophilidae	PRD	0.09	+	+	+	+	+	+
Collembola								
Collembola	C-G	0.11	+	+	+	+	-	-
Decapoda								
Cambaridae	C-G	0.08	+	+	+	+	+	+
Diptera								
Athericidae	PRD	0.01 (VR)	+	+	-	+	+	-
Ceratopogonidae	PRD	0.63	+	++	+	++	+	+
Culicidae	C-F	0.03	-	-	+	-	-	+
Dolichapodidae	PRD	0.01	-	-	+	+	-	+
Empididae	PRD	2.54	++	++	++	++	+	++
Ephydridae	SHR	0.03	+	-	+	+	+	+
Psychodidae	C-G	0.01 (VR)	-	-	+	-	+	+
Sciomyzidae	PRD	<0.01 (VR)	-	-	+	-	-	-
Simuliidae	C-F	2.61	+++	++	++	++	+	+
Tabanidae	PRD	0.12	+	+	+	+	+	+
Tipulidae	SHR	2.22	++	+++	++	++	+	+
Ephemeroptera								
Baetidae	C-G	9.97	+++	+++	+++	++	++	+
Caenidae	C-G	0.09	+	+	+	+	+	+
Ephemerellidae	C-G	0.25	+	+	+	+	+	+
Ephemeridae	C-G	<0.01 (VR)						
Heptageniidae	SCR	0.73	++	++	+	++	+	+
Isonychiidae	C-F	0.04	+	+	-	+	-	+
Leptophlebidae	C-G	<0.01 (VR)						
Tricorythidae	C-G	0.52	+	+	++	+	+	+

Table 3.3: Invertebrate abundance across 31 mesohabitat units sampled. Very rare (VR) taxa were eliminated from data analysis. Functional Feeding groups are PRD = predator, SCR = scraper, C-F = collector filterer, SHR = shredder, C-G = collector gatherer. Sample unit codes are a combination of treatment (I= Impaired, R = Recovering) and unit type (R = Riffle, N = Run, P = Pool). “- “Indicates taxa was not present in any sample units; “+” Indicates total abundance in sample type <0.1% of overall invertebrate abundance (<52 invertebrates); “++” Indicates total abundance in sample type between 0.1 and 1.0% of overall invertebrate abundance (53-515 invertebrates); “+++” Indicates >1% total invertebrates abundance (>516 invertebrates). (continued)

Table 3.3 continued

Order/Family	FF Group	Abundance (% of total)	IR	RR	IN	RN	IP	RP
Gastropoda								
Ancylidae	SCR	<0.01 (VR)	-	-	-	+	+	-
Hydrobiidae	SCR	0.41	+	+	++	+	+	+
Lymnaeidae	SCR	0.03	-	-	+	+	-	-
Physidae	SCR	0.58	+	+	++	+	++	+
Planorbidae	SCR	1.00	+	++	++	++	++	+
Hemiptera								
Belostomatidae	PRD	<0.01 (VR)	-	-	+	-	-	-
Corixidae	C-G	9.39	++	+	+++	++	+++	++
Gerridae	PRD	0.04	+	-	+	-	+	+
Notonectidae	PRD	<0.01 (VR)	+	-	+	-	-	-
Pleidae	PRD	<0.01 (VR)	-	-	+	-	-	-
Veliidae	PRD	0.32	+	+	++	+	+	+
Isopoda								
Asellidae	C-G	0.14	-	+	+	+	+	+
Lepidoptera								
Pyralidae	SHR	0.01 (VR)	+	-	+	-	+	-
Megaloptera								
Corydalidae	PRD	0.05	+	+	+	+	+	+
Sialidae	PRD	0.14	+	+	+	+	+	+
Odonata								
Aeshnidae	PRD	0.03	-	+	+	+	+	+
Calopterygidae	PRD	0.17	+	+	+	+	+	+
Coenagrionidae	PRD	0.02	-	+	+	-	-	-
Gomphidae	PRD	0.07	+	+	+	+	+	+
Plecoptera								
Leuctridae	PRD	0.82	++	++	+	++	+	-
Perlidae	PRD	0.05 (VR)	-	-	-	+	-	-
Trichoptera								
Glossosomatidae	SCR	0.01	+	+	+	-	-	-
Helicopsychidae	SCR	0.43	++	+	++	+	+	+
Hydropsychidae	C-F	27.92	+++	+++	+++	+++	+	+
Hydroptilidae	SCR	7.36	+++	++	+++	+++	++	+
Lepidostomatidae	SHR	<0.01 (VR)	+	-	-	-	-	-
Leptoceridae	PRD	0.17	+	+	+	+	+	+
Limnephilidae	SHR	0.70	++	++	++	++	+	-
Philopotamidae	C-F	0.18	+	++	+	+	+	-
Polycentropodidae	C-F	<0.01 (VR)	-	-	-	+	-	+
Psychomyiidae	C-G	<0.01 (VR)	-	-	-	-	-	+

Acronym	Definition	Mean	SD	Min	Max	P-Value		
						Unit	Treatment	Interaction
Fish Assemblage Metrics								
DIVER	Shannon's Diversity Index	0.9	0.5	0.1	1.7	**	ns	ns
EVEN	Shannon's Evenness	0.4	0.2	0.1	0.8	**	ns	ns
RICH	Taxa Richess	7.0	2.8	2.0	13.0	**	ns	ns
FISHTOTAL	Total abundance of fish	307	158	73	879	ns	**	ns
CW	% Individuals that prefer coldwater	64.6	33.6	5.9	100	**	ns	ns
TOL	% Individuals that are tolerant	31.3	29.3	0	82.1	**	ns	ns
INTOL	% Individuals that are intolerant	65.8	32.2	12.5	100	**	ns	ns
CARN	% Individuals that are top carnivores	0.7	1.4	0	5.4	**	ns	ns
GEN	% Individuals that are generalist feeders	31.2	29.3	0	82.1	**	ns	ns
HERB	% Individuals that are herbivorous	2.2	4.5	0	15.1	**	ns	ns
INV	% Individuals that are insectivorous	64.8	32.9	10.2	100	**	ns	ns
LITH	% Individuals that are simple lithophils	20.7	17.7	0.6	59.0	**	ns	ns
Invertebrate Assemblage Metrics								
DIVER	Shannon's Diversity Index	2.4	0.3	1.7	2.9	**	ns	ns
EVEN	Shannon's Evenness	0.8	0.1	0.6	1.0	**	ns	ns
RICH	Taxa Richess	22.7	5.0	7.0	33.0	*	*	ns
INVTOTAL	Total abundance of invertebrates	267	175	10	689	**	ns	ns
AVGTOL	Average tolerance value of all individuals	1.8	0.5	0.5	3.0	*	ns	ns
MPTV	Mean pollution tolerance value	3.1	0.5	2.0	4.6	ns	ns	ns
C.F.I	% Individuals that filter particles	16.9	15.0	0.9	59.9	**	**	ns
SHR.I	% Individuals that shred CPOM	17.1	13.1	1.6	48.2	**	**	ns
C.G.I	% Individuals that collect particles	7.4	5.4	0	24.4	**	ns	ns
PRD.I	% Individuals that engulf or pierce prey	36.1	13.2	16.9	70.7	ns	ns	ns
SCR.I	% Individuals that scrape particles	22.4	12.6	5.8	54.3	**	**	*
DIPT.I	% Individuals that are Diptera taxa	44.9	19.0	2.9	75.4	**	ns	ns
EPT.I	% Individuals that are EPT taxa	25.3	16.6	1.4	81.3	*	ns	ns

ns = P-value >0.10; * = P-value 0.10 – 0.05; ** = P-value <0.05

Table 3.4: Summary statistics for fish and invertebrates assemblage metrics. Acronyms indicate name used in RDA ordinations. (SD = Standard Deviation). P-values are for Multi-way Analysis of Variance (MANOVA) for mean assemblage metric value by mesohabiat unit type (riffle, run or pool), treatment type (impaired or recovering), and the interaction term of both.

	Fish				Invertebrates			
	Abundance		**Assemblage Metrics**		**Abundance**		**Assemblage Metrics**	
	Axis 1	**Axis 2**	**Axis 1**	**Axis 2**	**Axis 1**	**Axis 2**	**Axis 1**	**Axis 2**
Eigenvalue	0.378	0.064	0.267	0.057	0.306	0.058	0.298	0.064
Percentage of variance of species-environment relation	81.5	13.8	80.1	17	70.8	13.4	73.8	15.8
Species-environment correlation	0.75	0.59	0.57	0.65	0.73	0.64	0.75	0.63
Monte Carlo P-value for all axes	0.004*		0.2056		0.004*		0.0319*	
Monte Carlo F-value for all axes	2.72		1.57		2.40		2.13	

*indicates P-value <0.05

Table 3.5: Summary of results of redundancy analysis (RDA) for macroinvertebrate and fish abundance and assemblage metrics. Monte Carlo tests are based on 500 permutations.

	Fish		Invertebrates	
	Treatment	Habitat	Treatment	Habitat
Abundance	0.235	<0.001*	0.057	<0.001*
Trophic	0.643	<0.001*	0.030*	<0.001*

*indicates P-value <0.05

Table 3.6: Summary of results based on Multiresponse Permutation Procedures (MRPP). In MRPP, the null hypothesis of no difference among groups was tested.

CHAPTER 4

CONCLUSION

One of the most important themes of this thesis is the role of scale in how we measure these physical influences and the biotic assemblages in the stream.

My geomorphological study expands on previous methods for assessing condition of small ungaged streams. Using a weight of evidence approach, I determined that stable and unstable reaches occur in Mac-o-chee Creek. Overall, the condition of the stream is heavily impacted by channelization and is characterized by entrenched channels that have limited access to floodplains. The minimal flood plain that is available within the entrenched channel is enough, however, to observe the fact that the stream is still controlled by bankfull discharges. Channel dimensions were consistent with regional curve concepts. My methods could be applied to other channelized systems and can aid in identifying failing sites in a watershed as well as over all processes.

The results from the ecological study indicate that along a gradient of degradation in Mac-o-chee Creek, more degradation creates a biotic community more indicative of a warmwater stream that a coldwater assemblage. Higher diversity, abundance and species richness were observed in reaches with low habitat quality.

The stream fish and invertebrate assemblages were influenced by the physical structure of the stream. Invertebrates were associated with microhabitat changes in habitat, while fish were less sensitive and able to move between reaches of high and low habitat quality. Mac-o-chee Creek differs from warmwater streams in Ohio in its diversity and assemblage response to degradation. Bioassesment techniques should be calibrated for coldwater streams in the lower Midwest.

The research presented in this thesis should be used, in part, as a starting point to evaluate restoration projects in Mac-o-chee Creek. The ODNR is planning a channel reconstruction project on a portion of the stream. Further research will add to our knowledge of the processes occurring in small lower Midwestern coldwater streams. Further conclusions about how to restore stream ecosystems will require monitoring of completed projects and comparisons to baseline data similar to what I have collected. Reference study sites in pristine streams are difficult to locate in the agriculturally dominated and highly fragmented Midwestern landscape. They would, however, provide interesting comparisons to the relatively modified systems such as Mac-o-chee Creek. Further, Mac-o-chee Creek could potentially serve as a useful model for a restoration endpoint of nearby coldwater streams that are even more degraded. This study shows that ecological integrity of Mac-o-chee Creek is quite high. In the area of a proposed restoration project, temporary declines in biotic integrity may occur shortly after construction, but in all likelihood they will recover eventually. As demonstrated in my ecological study, suitable populations for recolonization of the area to be restored exist both upstream and downstream.

To improve stream quality in the future, enforceable riparian setbacks from both urban and agricultural areas will aid in channel recovery from channelization and the reinstatement of natural flow patterns and physical processes. Mac-o-chee Creek does not have access to a wide floodplain and this may limit its geomorphic potential. As an ecological study, there are of course numerous potentially unmeasured or immeasurable factors at work in shaping the present conditions of Mac-o-chee Creek. I attempted to address many, but this thesis was limited to instream factors. Mac-o-chee Creek and the entire Upper Mad River watershed are unique in their fauna, geology, and history. My research has demonstrated that despite many anthropogenic influences, the stream is dynamic and has maintained a high level of quality to this point. In the future, I hope it is protected and restoration efforts continue.

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APPENDIX A: THE INDEX OF BIOTIC INTEGRITY (IBI)

Fish were evaluated through single pass electroshocking without block nets, a method adequate to evaluate species abundance, richness, and assemblage structure (Simon 1995). All fish were identified and enumerated, then promptly released. Brown trout (*Salmo trutta*) lengths and identifying mouth tags were recorded. Reaches with a drainage area larger than 26 km^2 (10 mi^2) were electroshocked using a tow barge with a gas generator operated at 125 Volts of pulsed DC current. All other reaches were electroshocked using a backpack electroshocker operated at 200-400 Volts of pulsed DC current. An IBI was calculated for each site (OEPA 1989).

The IBI scores for Mac-o-chee Creek (Table 1) show there is not a wide variability among the 11 sites sampled in 2006. All of the sites with drainage areas >4 sq. miles fall within the good to excellent range as determined by the OEPA. These scores are consistent with past OEPA results in the creek. The historical IBI range from 1986 – 2003 OEPA sampling in Mac-o-chee Creek is 36 – 56. The warmwater IBI is effective at detecting trends over time within a coldwater system but may not accurately capture the community assemblage in a coldwater stream (OEPA 2005).

Site Number	1	2	3	4	5	6	7	8	9	10
Number:										
Native Species	11 (3)	8 (1)	7 (1)	8 (1)	6 (1)	8 (1)	8 (1)	8 (3)	8 (3)	7 (3)
Minnow Species	4 (3)	4 (3)	3 (1)	3 (1)	3 (1)	4 (3)	4 (3)	3 (3)	4 (3)	4 (3)
Headwater Species	3 (3)	2 (3)	2 (3)	3 (3)	2 (3)	2 (3)	2 (3)	3 (3)	4 (5)	3 (3)
Sensitive Species	5 (3)	3 (1)	1 (1)	2 (1)	1 (1)	3 (1)	3 (1)	0 (1)	1 (1)	1 (1)
Darter / Sculpin	2 (1)	2 (1)	2 (1)	2 (1)	2 (1)	2 (1)	2 (1)	2 (3)	2 (3)	2 (3)
Lithophilic Species	6 (3)	5 (3)	3 (1)	3 (1)	3 (1)	5 (3)	5 (3)	2 (1)	4 (3)	4 (3)
Percent:										
Tolerant Individuals	0.51 (3)	0.16 (5)	0.28 (5)	0.25 (5)	0.32 (3)	0.32 (3)	0.34 (3)	0.66 (1)	0.34 (3)	0.34 (3)
Omnivore Individuals	0.21 (3)	0.05 (5)	0.02 (5)	0.01 (5)	0.15 (5)	0.02 (5)	0.05 (5)	0.05 (5)	0.04 (5)	0.03 (5)
Pioneering Individuals	0.25 (5)	0.05 (5)	0.06 (5)	0.05 (5)	0.11 (5)	0.11 (5)	0.11 (5)	0.31 (5)	0.11 (5)	0.19 (5)
Insectivore Individuals	0.43 (3)	0.83 (5)	0.71 (5)	0.74 (5)	0.63 (5)	0.64 (5)	0.63 (5)	0.05 (1)	0.65 (5)	0.65 (5)
Individuals w/ DELT Anomalies	0 (5)	0 (5)	0 (5)	0 (5)	0 (5)	0 (5)	0 (5)	0 (5)	0 (5)	0 (5)
Rel. # minus Tolerants	168 (1)	546 (3)	370 (3)	755 (5)	486 (3)	534 (3)	350 (3)	270 (5)	201 (5)	199 (5)
Total IBI Score	**36**	**40**	**36**	**38**	**34**	**38**	**38**	**34**	**46**	**44**

Table A.1: IBI metric raw value (index score) as per OEPA protocol.

APPENDIX B: THE INVERTEBRATE COMMUNITY INDEX (ICI)

The Invertebrate Community Index (ICI) was developed in Ohio conducted at a subset of the sites (Sites 1, 3 and 7 only) were collected using Hester-dendy traps that were deployed in the stream for six weeks. The traps were preserved in the field with 10% formalin. Processing of these traps was completed in compliance with OEPA guidelines in the Groveport OEPA laboratory. All invertebrates were identified according to OEPA protocol and ICI values were calculated (OEPA 1989). The semi-quantitative samples described above served as the quantitative samples for the ICI. Chironomidae individuals were cleared in a 10% KOH solution for 25-35 minutes.

		1	3	7
	Site	**1**	**3**	**7**
	Drainage Area (sq km)	53	47.6	35.4
Total Taxa		56(6)	44(6)	33(4)
Number:	**Mayfly Taxa**	7(6)	6(4)	4(2)
	Caddisfly Taxa	5(6)	7(6)	6(6)
	Dipteran Taxa	38(6)	25(6)	18(4)
	Mayflies	6.4(2)	2.5(2)	3.1(2)
	Caddisflies	7.7(6)	3.0(4)	28.7(6)
Percent:	**Tanytarsini**	30.3(6)	14.9(4)	50.6(6)
	Other Dipt/NI	55.0(2)	79.2(0)	17.5(6)
	Tolerant Organisms	6.1(6)	38.0(0)	0.0(6)
Qualitative EPT		12(6)	16(6)	12(6)
Ecoregion		5	5	5
	ICI Score	**52**	**38**	**48**

Table B.1 Summary of scores for three ICIs at sites 1, 3 and 7 in Mac-o-chee Creek. Metric value (index value) as per OEPA protocol. Total scores for sites 1 and 7 are within the range designated for excellent warmwater habitat designation. Site 3 is slightly outside of this range.

APPENDIX C: QUALITATIVE HABITAT EVALUATION INDEX DATA

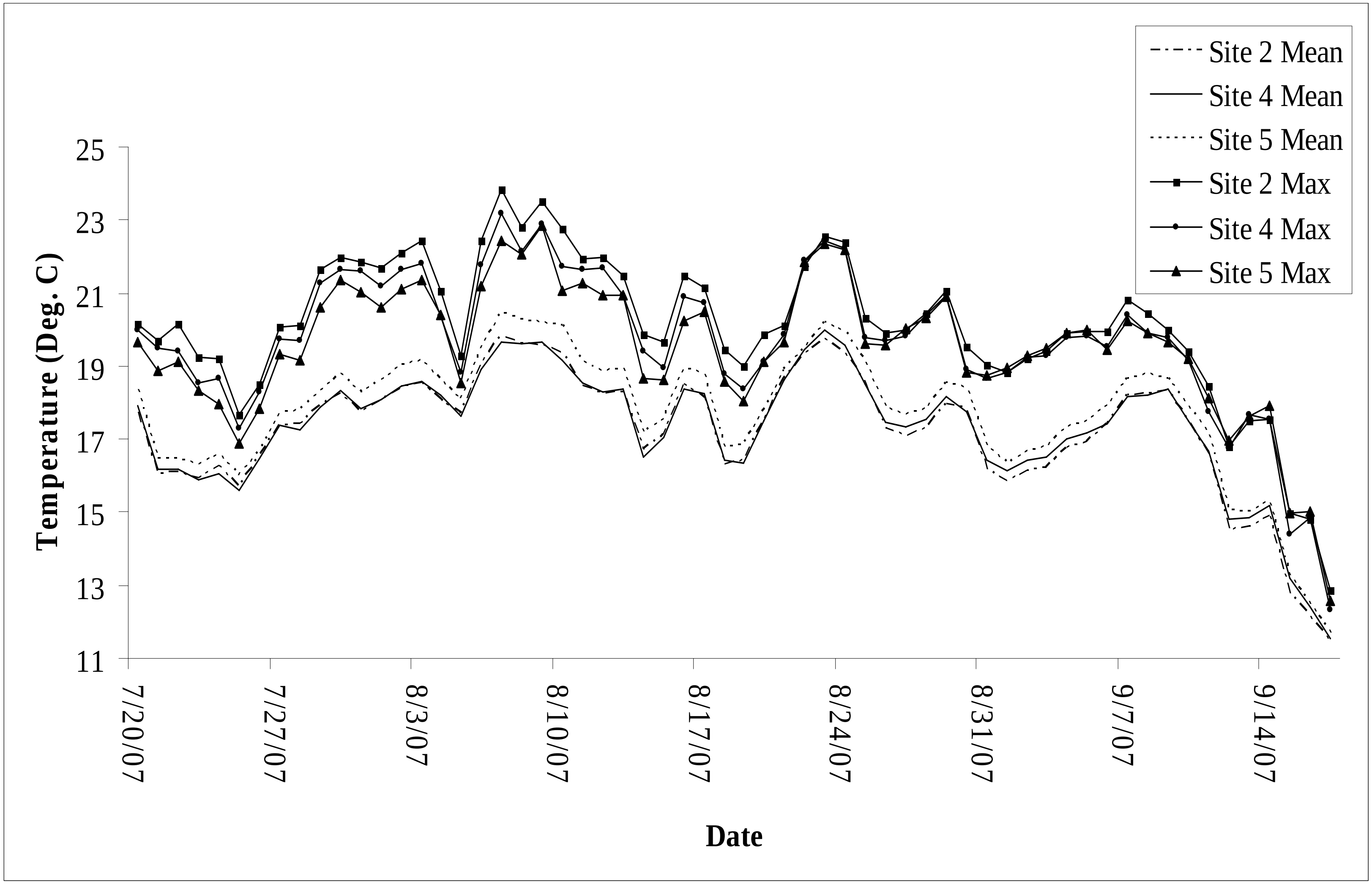
Instream habitat data were collected by two methods at each site. The QHEI (Rankin 1995), which provides a qualitative numeric value for each of six metrics concerning aspects of instream habitat was estimated for each 150 meter reach.

Site	1	2	3	4	5	6	7	8	9	10
Substrate	15.5	16	14.5	15.5	18.5	17	16	14.5	15.5	15.5
Instream Cover	14	12	8	10	15	12	15	12	15	8
Channel Morphology	11	13	9	9	12	10	13	8.5	11.5	10
Bank & Riparian	5	5	5.5	6	6.5	6	4.5	3.5	4.5	7.5
Quality	11	9	3	4	11	5	11	9	7	6
Gradient	14.5	16.5	12.5	14	18	16	18	15	17	11
Total QHEI Score	**71**	**71.5**	**52.5**	**58.5**	**81**	**66**	**77**	**62.5**	**70.5**	**58**

Table C.1: Individual metrics and total values for the Qualitative Habitat Evaluation Index completed at Study sites 1-10 in the summer of 2006

APPENDIX D: TEMPERATURE LOGGER DATA

Temperature in the stream was determined using HOBO Water Temp v2 data loggers. Three loggers were deployed in run habitat with similar flow rate and depth at Sites 2, 3, and 5. The loggers were attached with heavy twine to bricks that were found in the stream. We dug small holes and placed the bricks in such that the top of the brick was flush with the surrounding natural rock substrate. The loggers were suspended just above the substrate, downstream of the brick. All loggers remained in the stream for two months (July 20 – September 17, 2007). The loggers continually recorded water temperature at five minute intervals for this time period.


Site 2 Mean
Site 4 Mean
Site 5 Mean
Site 2 Max
Site 4 Max
Site 5 Max
Temperature (Deg. C)
25
23
21
19
17
15
13
11
7/20/07
7/27/07
8/3/07
8/10/07
8/17/07
8/24/07
8/31/07
9/7/07
9/14/07
Date