COMMUNITY RESPONSE TO HABITAT RESTORATION IN SICKLE AND BEAR CREEKS, WITH EMPHASIS ON MOTTLED SCULPIN IN SICKLE CREEK

A thesis submitted in partial fulfillment of
the requirements for the degree of
Master of Science

By

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To

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June, 2008

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This thesis is accepted in partial fulfillment of the requirements for the degree of Master of Science in Biology.

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Graduate Committee Member _____________________________ Date ____________

"There is… …a conspicuous shortage of large-scale corrections for problems that have large scale causes." -- Wendell Berry

This work is dedicated to my lovely wife, Sue.
Without her inspiration, tolerance, and gentle "directional assistance",
none of this would have been possible.

ACKNOWLEDGMENTS

I would like to thank the members of my graduate committee for their friendship, support, and guidance. Neil, Jodee, and Steph, profound and heartfelt thanks to all of you for help with ideas, revisions, encouragement, and motivation. Dr. Eric Snyder, my major advisor and good friend; I cannot say where I would be without you. Thank you for teaching me perseverance, patience, and helping fuel my thirst for knowledge. Funding was provided by the Little River Band of Ottawa Indians, through grants from the EPA, Forest Service, and Fish and Wildlife Service, along with other partners. Thanks also to the Natural Resource Department of the Little River Band; the numerous seasonal technicians and volunteers who assisted us, and in particular, Marty Holtgren, whose insight and direction were critical to my successful completion of this project. I thank Kris Nault, my fellow grad student for two summers of this project, for helping me improve it immensely, and allowing me access to the habitat data he collected. April Wright, Nichol DeMol, and Nick Gressick, thanks for your work on the project. Thanks to Jason Nelson, the bug wizard. Thanks to my wife Sue, who let me go "play" in the woods up north for three summers. I would like to thank my parents for raising me right and true, and for introducing me to my Lord and Savior, Jesus, the greatest "Fisherman" I know. Last, and certainly not least, I thank Dr. Carol "Griff" Griffin for introducing me to Eric and helping me find an advisor for my M.S. Griff, without your help, I would likely still be in an oak tree somewhere just outside Boston.

ABSTRACT

COMMUNITY RESPONSE TO HABITAT RESTORATION
IN SICKLE AND BEAR CREEKS,
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by Jason DeBoer

Habitat restoration is employed by biologists and managers to improve the natural functionality and value of aquatic resources. Systems suffer impairment from many sources, including excessive fine sediment, which negatively affects substrate composition, channel morphology, aquatic invertebrate habitat, and fish reproduction and recruitment. Primary objectives included monitoring the biophysical response to sediment abatement in the Big Manistee River watershed. Secondary objectives included (1) placing the biophysical response to the restoration in the context of a much larger watershed plan, (2) quantifying seasonal mottled sculpin movement and habitat use in Sickle Creek for 1-year, and (3) determining habitat variables which may predict mottled sculpin distribution in Sickle Creek. Many sampling techniques were used to quantify metrics related to sediment, macroinvertebrates, and fish. Passive Integrated Transponder (PIT) tags were used to determine mottled sculpin seasonal movements. Efforts were often successful in (1) preventing input of sediment, and (2) flushing accumulated sediment from study reaches. Where a positive response in substrate was observed, there was (1) an increase in macroinvertebrate abundance (avg. 218-330 individuals/m^2 in Sickle Creek (1st order tributary), and 514-975 individuals/m^2 in Bear

Creek (4th-order tributary)), (2) increased abundance of sensitive taxa (*Baetidae*), and (3) appearance of additional sensitive taxa (*Ueonidae,* seven others) from the Ephemeroptera, Plecoptera, and Trichoptera orders. The fish community showed a positive response, based on community metrics including richness, diversity, evenness, and similarity. Pronounced changes in Sickle Creek included the virtual disappearance of creek chub (*Semotilus atromaculatus*), brook stickleback (*Culaea inconstans*), and northern redbelly dace (*Phoxinus eos*), and increased abundance of key taxa (Chinook salmon, *O. tshawytscha*). Many taxa exhibited upstream longitudinal distribution shifts, especially mottled sculpin (*Cottus bairdi*). Mottled sculpin seasonal movements were larger than previous estimates (up to 839m, mean 107 ± 26m); distribution was linked to depth of fine sediment and percent medium and large wood. Bear Creek exhibited subtle changes, though we did observe increased CPUE for recreationally important fish taxa including rainbow and brown trout (*Oncorhynchus mykiss* and *Salmo trutta*). In conclusion, Sickle Creek responded more rapidly to restoration than Bear Creek, although in both, positive and statistically significant changes were observed.

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PREFACE

Loss and alteration of aquatic habitats are principal factors in declining native fish abundance and overall loss of biodiversity (Allan and Flecker 1993). Of principal interest in the Big Manistee River watershed is sediment loading (mainly sand), originally resultant from the logging era, as the whole watershed, rich in White Pine (*Pinus strobus*), was logged near the end of the 19th century (Blackburn and Ricards Jr. 1970, Kazmierski et al. 2004). Traditional logging procedures negatively impact many streams by increasing both fine and coarse sediment input, simplifying habitat, interrupting input of organic matter (including woody debris), and changing stream hydrology (Salo and Cundy 1987, Meehan 1991, Murphy 1995). In our study streams, the denuding of upland vegetation as a result of intense and improper logging practices caused intensive erosion and resulted in heavy sedimentation. These sediments are now exacerbated by failing stream banks and poorly designed road-stream crossings (MRWI 2003).

Despite the fact millions of dollars are spent annually on watershed and habitat restoration, thorough monitoring of biological response to restoration is infrequent and inadequate (Reeves and Roelofs 1982, Reeves et al. 1991a,b). A recent survey (Moerke and Lamberti 2004) indicated the costs of 10 restoration projects in Indiana conducted between 1995 and 2000 at $32,000 to $400,000, or $100 to $875 per meter of stream restored. However, biological monitoring was conducted before restoration in only 30% of the streams, and after restoration in only 50% of the streams. In only three of 10 cases was monitoring conducted both before and after restoration. In a few cases, monitoring was intensive and involved characterizing fishes, benthic macroinvertebrates, water quality, stream habitat, and success of riparian plantings (Moerke and Lamberti 2003), though most monitoring efforts were limited to measuring riparian vegetation, water quality, and/or single-time fish surveys.

In 2003, the US Environmental Protection Agency awarded a National Watershed Initiative grant to the Little River Band of Ottawa Indians in the amount of $600,000. This grant was for the improvement of water quality throughout the watershed, as well as for monitoring. A Tribal Wildlife Grant from the US Fish and Wildlife Service complemented this, allowing the Tribe, in collaboration with Grand Valley State University (GVSU), to continue extensively monitoring the restoration efforts and their effectiveness in providing suitable riparian and in-stream habitat. GVSU performed this ongoing monitoring from the spring of 2004 through the summer of 2008. In total, the Tribe obtained over $1 million from various federal, state, and local partners to perform and monitor habitat restoration and improvement in the Big Manistee River Watershed. These efforts included five road-stream crossing improvements, four streambank stabilizations, three access site improvements, and a lake sturgeon (*Acipenser fulvescens*) spawning site reclamation plan.

Native American Importance

The Little River Band of Ottawa Indians utilizes a wide variety of resources which the surrounding riparian land and water bodies provide (Anderson and Moratto, 1996). There are various seasonal fisheries which include walleye (*Sander vitreus*), steelhead (*Oncorhynchus mykiss*), smallmouth and largemouth bass (*Micropterus dolomieui* and *M. salmoides*), northern pike (*Esox lucius*), sucker (*Catostomus* spp.) and Chinook and Coho salmon (*O. tshawytscha* and *O. kisutch*) runs. The river and riparian area are also home to several species which are culturally significant to tribal members, including the bald eagle (*Haliaeetus leucocephalus*), wood turtle (*Clemmys insculpta*) and lake sturgeon.

**this preface shall serve as a contextual introduction for all proceeding chapters.*

STUDY SITE

Manistee Watershed

This study took place on three tributaries of the Big Manistee River, located east of Manistee, MI (Figure 1). The two streams detailed in this document are Sickle Creek (1st order) and Bear Creek (4th order). The watershed is composed of outwash plains and

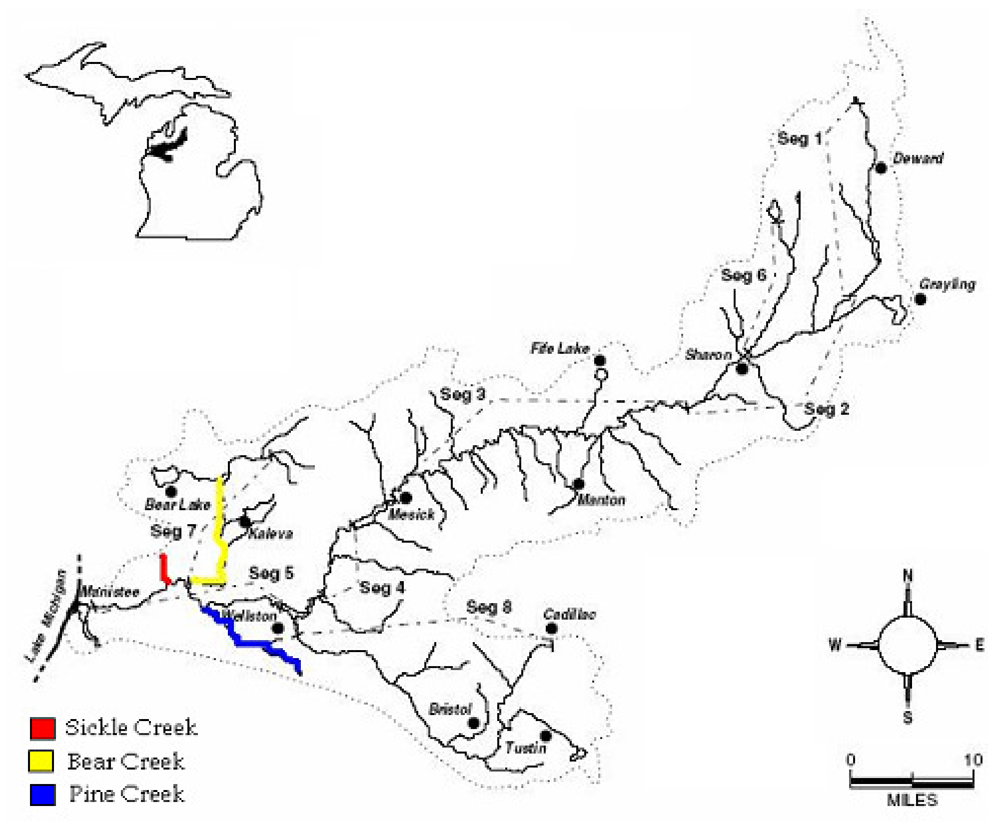

Figure 1. Big Manistee River watershed. Image courtesy of Kurt Thompson, AWRI, Muskegon, MI.

recessional moraines which contain extensive deposits of sand and gravel with the predominant soils being deep sands of the Kalkaska, Rubicon, and Grayling series (Blackburn and Ricards Jr. 1970, Rozich 1998). The pervious nature of these soils allows abundant, beneficial groundwater flow to many streams in this region. However, the friable nature of these soils make them highly erodible, especially in this area with its history of anthropogenic disturbances, such as logging (Blackburn and Ricards Jr. 1970, Kazmierski et al. 2004).

Sickle Creek

Sickle Creek is a 1st-order tributary of the Big Manistee River, located east of Manistee, Michigan (Figure 2). Sickle Creek has a relatively undisturbed riparian zone (forest/wetlands) at the confluence with the Big Manistee River, while the mid-reaches are dominated by rangeland and some agriculture, and the spring-fed headwaters by

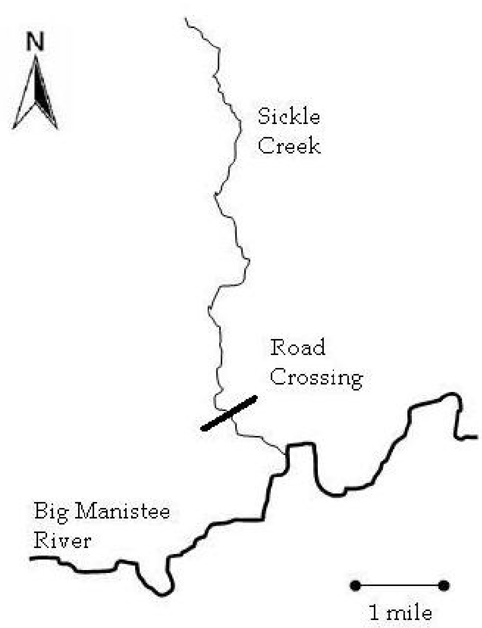

Figure 2. Sickle Creek, with the road stream crossing and the confluence with the Big Manistee River, Manistee County, MI.

agriculture. Analysis of the watershed showed it to be dominated by deciduous forest (~27%), with smaller, nearly equal components of wooded wetland, herbaceous vegetation, and row crops (~15-20% each). The perched and undersized culverts at this crossing were replaced in October 2005 with an open-bottom concrete-span bridge. The installation of the new bridge also raised the level of the road at the crossing, and runoff from the road is now diverted into adjacent lowland areas, whereas before restoration, sediment-laden runoff was allowed to enter the stream directly.

Bear Creek

Bear Creek is the more developed of the two study streams, though the lower portion of it, from Coates Highway (Spirit of the Woods site; rkm 10.5) to its mouth is designated as Wild and Scenic under the Federal Michigan Scenic Rivers Act of 1991 (PL 102-249, Figure 3). Bear Creek drains an area of approximately 529.7 km^2 with 24 km of

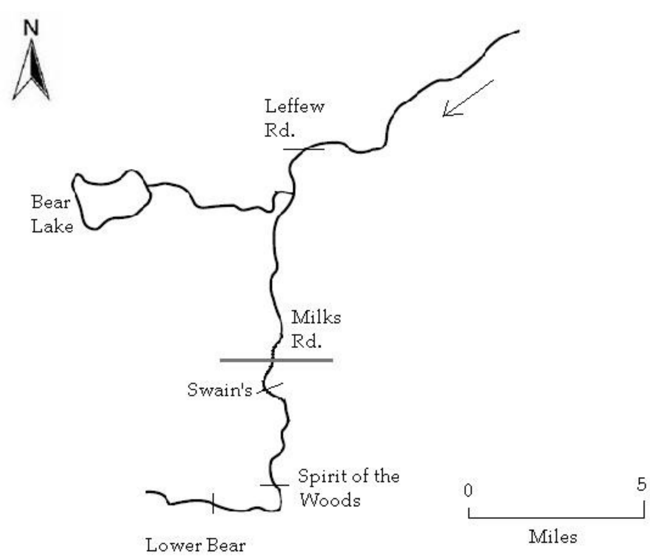

Figure 3. Bear Creek, with study sites and Bear Lake (for reference, near Kaleva, MI). Arrow indicates stream flow direction.

designated Blue Ribbon Trout Stream in its upper reaches. The majority of its bank at many of the sites is well-developed with residential properties, with varying degrees of riparian buffer in place. Five separate locations, including road-stream crossings and bank stabilizations, are being investigated on Bear Creek. They are, from headwaters to mouth: Leffew Road (a reference/control site, added spring 2006), Milks Road (culvert replaced with bridge/bank stabilization), Swain's Property (bank stabilization), Spirit of the Woods (longitudinal reference site), and Lower Bear (longitudinal reference site). Longitudinal reference sites were included to provide a watershed-scale view, placing the entire restoration project in a holistic framework. At Milks Road, two partially submerged culverts which did not accommodate the width of the stream were replaced in December 2005 with an open bottom wooden bridge. In the fall of 2006, a large eroding bank upstream from the bridge was stabilized. The gravel road approaches and top of the bridge were paved in spring 2007. Swain's Property was the location of two additional large eroding banks, which were stabilized in summer 2005. The original design called for Spirit of the Woods and Lower Bear to provide longitudinal perspective on the upstream restoration work, and to place the long-term recovery trajectory in proper perspective. Leffew Road was added as a true reference site in spring 2006, as it is upstream from all restoration efforts, though only two years of data are available for consideration, as opposed to the four years for the other sites.

Timeline

Electrofishing was scheduled to be performed twice annually at all sites during 2004 and 2005, though high water in the spring of 2004 precluded this. For logistical reasons, only Sickle Creek was sampled twice in 2006 and 2007; Bear and Pine Creek sites were sampled once annually, in the spring or early summer. This reduction in electrofishing was intentional, with the extra time being devoted to additional measurements and quantification of the habitat, as well as the fact no clear seasonal signal was obtained in the first 2 years of sampling, given the sample dates were close together.

Table 1. Timeline for research activities.

	Spring 2004	**Fall 2004**	**Spring 2005**	**Fall 2005**	**Spring 2006**	**Fall 2006**	**Spring 2007**	**Fall 2007**	**Spring 2008**
Electrofishing	X	X	X	X	X	*	X	*	X
Sediment Collection	X		X		X		X		X
Channel Morphology	X	X	X	X	X	X	X	X	X
Macroinvertebrates	X	X	X	X	X	X	X	X	X
Organic Matter (OM)	X	X	X	X	X	X	X	X	X
Fish Habitat Metrics							X		
Sculpin Movement							X	X	X

*Sickle Creek only

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CHAPTER I – Sediment

ABSTRACT

Fine sediment negatively alters substrate composition and channel morphology, impacts fish reproduction and recruitment, and degrades habitat for aquatic invertebrates. The objective of this study was to monitor the response of the biological community and physical habitat to sediment abatement techniques employed in the Big Manistee River watershed. To monitor the response of the sediment and substrate to restoration, several metrics were measured from 2004-2007, with most restoration practices taking place in 2005. A strong positive response was recorded in Sickle Creek, a 1^{st}-order tributary. Percent coarse sediment (from core samples) increased from 30% to 68% (by weight, relative to pre-restoration), with ultrafine particulate matter (UFPM; 63µm-0.63µm) decreasing ~21%. Surficial sediment improved, especially downstream, where percent of pebbles (>5mm) increased from 2% to 24%. Depth of fine sediment decreased an average of 34% at 5 of 6 transects. In Bear Creek, a 4^{th}-order tributary, a positive response was observed, though the trends were less pronounced. At an improved road-stream crossing (Milk's Road), there was a 64.5% decrease in UFPM (average up and downstream), whereas an 81.7% decrease was observed downstream only, and data suggest an increase in surficial gravel. At a stream-bank stabilization site (Swain's Property), fine sediment (core samples) decreased from 17% to 5%, and data suggest an increase in surficial gravel. Overall, it appears the sediment abatement techniques utilized in these streams were successful in (1) reducing/preventing the input of additional fine sediment into the streams, and (2) allowing accumulated sediment to be flushed from study reaches.

INTRODUCTION

Fine sediment negatively alters substrate composition and channel morphology, impacts fish reproduction and recruitment, and degrades habitat for aquatic invertebrates (VanDusen et al. 2005, Wood and Armitage 1997). Sedimentation impacts the substrate by altering its surface conditions (Graham 1990) and the volume of fine sediment within the hyporheic zone (Richards and Bacon 1994). In extreme cases, fine sediments smother the entire riverbed, changing channel morphology (Nuttall 1972, Wright and Berrie 1987, Doeg and Koehn 1994), and killing aquatic flora (Edwards 1969, Brookes 1986). In the case of the Big Manistee and its tributary streams, the cumulative effects of sediment loading and loss of large woody debris (LWD) has led to a decline in the river's ability to maintain its fish population. Populations of native fish (lake sturgeon (*Acipenser fulvescens*), burbot (*Lota lota*), and walleye (*Stizostedion vitreum*)), not currently bolstered by hatchery stocks, require improved conditions (spawning locations, nursery and juvenile habitat) to assure continued sustainability. Work by Kock et al. (2006) suggests an abundance of fine sediment may be an important early life-stage mortality factor for sturgeon in rivers like the Big Manistee where they may spawn over fine-sediment substrates. High levels of fine sediment suspension, driven by higher discharge, have also been found detrimental to walleye larvae survival (Mion et al. 1998).

The objective of this study was to thoroughly monitor the response of the biological community and physical habitat to sediment abatement techniques in three streams streams: Bear (4th order), Pine (2nd order), and Sickle (1st order) Creeks, tributaries of the big Manistee River below Tippy Dam. Included in this thesis are the results and discussion from two of the three systems—Bear and Sickle Creeks. Results from Pine Creek have been summarized by K. Nault (MS thesis, GVSU, *in progress*).

HYPOTHESES

A-priori hypotheses were as follows:

1. Sediment characteristics (i.e. the physical habitat) will respond most quickly, followed some time later by macroinvertebrates, and fish. In addition, because sediment is predicted to respond first, the amount of change from pre- to post-restoration should be greatest, relative to the biological response which follows. The mechanism driving this change would be a normalization of the flow regime in which newly-installed open-bottom bridges allow for unrestricted sediment-flushing flood pulses, where before they were slowed or stopped by constrictive culverts. Additionally, streambank stabilization should reduce sediment input from eroding banks, reducing the time necessary for the stream to flush excess fine sediment downstream.
2. The return to a more natural flood pulse should have the most significant and rapid impact on standing stocks of the finest sediment size fractions, namely ultra-fine particulate matter (UFPM) and ultra-fine sands.
3. Channel morphology and dominant substratum should also respond quickly, as more fine sands, which dominate several of the locations, are transported downstream. Down-cutting should predominate in the study reaches, leading to exposure of coarser sand and gravel underneath.

METHODS

Sediment Cores

Six habitat evaluation transects (Figure 1.1) were established at Sickle Creek: three up- and three downstream (at 5m, 100m and 200m). Milks Road has one transect

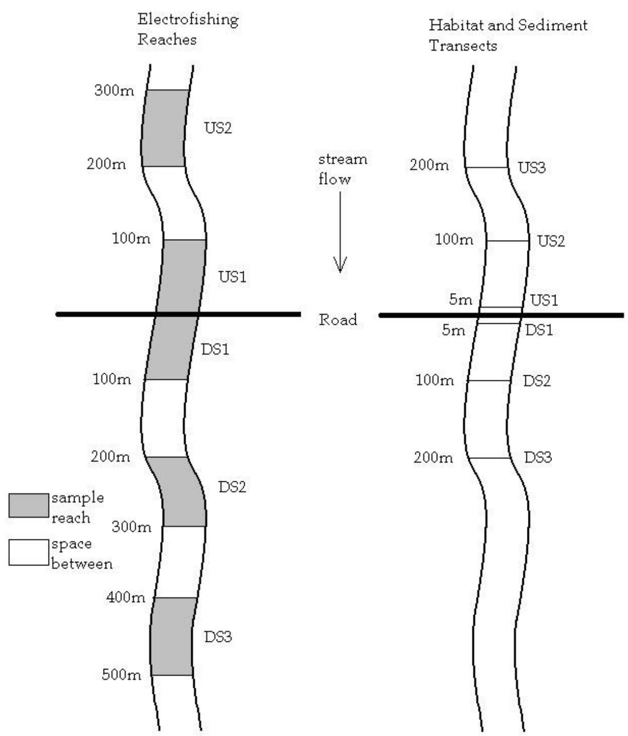

Figure 1.1. Example of transect and reach sampling design, shown for Sickle Creek, Manistee County, MI. US and DS refer to upstream and downstream, respectively. Figure is not drawn to scale.

downstream and three upstream (at 50m down, and 50m, 100m and 200m up [Photo 1, Appendix A]), and Swain Property has four transects (at a baseline, and 50m, 100m, and 200m downstream [Photo 2, Appendix A]). Two sites were established at Leffew Road (in spring 2006, 50m up- and downstream), Spirit of the Woods (at the bridge for Coates Highway, and 100m downstream), and Lower Bear (at a baseline, and 100m upstream). Where permitted by landowners, all transects were located with permanent benchmarks made of capped rebar or pipe. At each transect, three sediment core samples were taken (once annually, typically in the spring) by hand using an 8" PVC pipe to a depth of ~10cm. Transects were divided into equal thirds, and one core sample was taken at a random distance across each third. Each sample was preserved in a Ziploc bag and frozen until processing. In the lab, samples were thawed and then separated by particle size using 8 brass Tyler sieves (16mm to 63µm) and 10L of water run through twice. The separated samples were placed in an oven at 80° C until dry, and each fraction was then quantified by weight and volume. A sub-sample of the residual rinse-water containing ultra-fine particulate matter (UFPM) from processing was collected and frozen for analysis. This sub-sample of UFPM was thawed, shaken, and another 100mL sub-sample was run through 0.63µm pre-weighed filter paper with vacuum assistance, dried and weighed again to determine UFPM accumulation on the filter paper. This accumulated UFPM mass was extrapolated back to its fraction of the total sediment core.

Channel Morphology

At the same transects, fine sediment depth, and water depth and velocity were measured at a minimum of 10 evenly-spaced locations across the transect, perpendicular to the direction of flow. Depth was measured using a steel sediment probe pushed into the substrate; every effort was made to exert consistent pressure on the probe for each sample. These measurements were taken once annually in 2004 and 2005 (in the fall) and twice annually in 2006 and 2007 (once in spring and once in fall). The profile was measured relative to permanent benchmarks using a surveyor's level (Siteline Ltd., Model 20X, Quinn et al. 1997, Bunn et al. 1998). Velocity data were collected using a Marsh-McBirney Flo-Mate and Marsh rod (Hach/Marsh-McBirney, Frederick, MD).

Pebble Count

In order to evaluate the longitudinal surficial sediment at each study site, a modified Wolman pebble count was performed twice annually (spring and fall). The full extent of the reach, from uppermost transect to lowermost was walked, with a random scoop (approximately 0.25 kg) of sediment being sampled at even longitudinal intervals so as to get 50 or 100 samples (depending on stream width) in each upstream or downstream reach. This scoop was taken at a randomly generated percent (from 0 to 100%, in 10% increments) along an imaginary line perpendicular to stream flow. The contents of the scoop were visually identified as being sand, silt, clay, gravel, pebble or other. When pebbles were located, the largest pebble in the scoop was measured for median diameter, and percent embeddedness (0, 25, 50, 75, 100%) was evaluated.

STATISTICS

The initial design called for use of MANOVA in a BACI (before-after, control-impacted) design. Unfortunately, experimental effects were felt at upstream transects in proximity to the restoration sites, and at other experimental sites longitudinally downstream from restoration sites, confounding the BACI analysis. Therefore, 1-way ANOVA was also used, with the following variables for both analyses: (dependent) percent of each sediment size fraction (gravel [16mm - 4mm], very coarse/coarse sand [4mm - 500µm], medium/fine sand [500µm - 125µm], very fine sand [125µm - 63µm], UFPM [63µm – 0.63µm]), and fine sediment depth (mean for each transect); (independent) upstream versus downstream, pre-restoration versus post-restoration, and individual transect. The mean size fraction of the three cores from each transect was considered a replicate, and average sediment depth at each transect was considered a replicate (means were used to facilitate ease of analysis, (*sensu* Yoccoz 1991, McBride et al. 1993, Johnson 1999, McBride 2002), although we acknowledge the potential problems with pseudoreplication (Hurlbert 1984)). The disadvantage of the 1-way ANOVA is by simply comparing pre- to post-restoration communities, we may lack the capacity to truly know if the observed changes are due to natural variability or effects of the restoration. All analyses were performed using SPSS 14.0 (SPSS, Chicago, IL). As the use of null-hypothesis statistical testing is entrenched in the minds of environmental researchers, it would be difficult to disseminate our findings without its use. However, too stringent an application (i.e. too small a *p*-value) might preclude effective conservation of precious resources. To that end, statistical significance was set at a *p*-value of 0.1. By increasing the level of significance, we increase the chances of making a

Type I error, decreasing the chances of making a Type II error, essentially increasing statistical power.

RESULTS

Sickle Creek

Springtime cross sectional profile comparisons (Figure 1.2) reveal post-restoration down-cutting at 5 of 6 transects. US2 was the only transect which aggraded from 2004 to 2007, though at all transects, there was annual variability. The highest degree of down-cutting was at DS1, the transect directly downstream from the new bridge. Of particular note at DS1 is how the channel narrowed considerably and aggraded ~15cm from 2004 to 2006, and incised ~40cm from 2006 to 2007, while maintaining the more narrow channel shape. US3 and DS1 were the only two transects in which the channel width measurably decreased, whereas DS2 was the only transect in which the width increased.

Following culvert replacement on Sickle Creek, both the substrate composition and surficial sediment changed dramatically. Overall, the amount of fine sediment decreased and coarse sediment increased for both up and downstream transects (Figure 1.3). Ultra-fine particulate matter (UFPM) upstream of the bridge decreased following culvert replacement, while downstream from the bridge, UFPM showed an initial increase following construction, and then a slow decrease in subsequent years (Figure 1.4). Significant increases in very coarse/coarse sands were seen upstream and downstream, while medium fine sand decreased significantly upstream, and very fine sand decreased significantly downstream (Table 1.1).

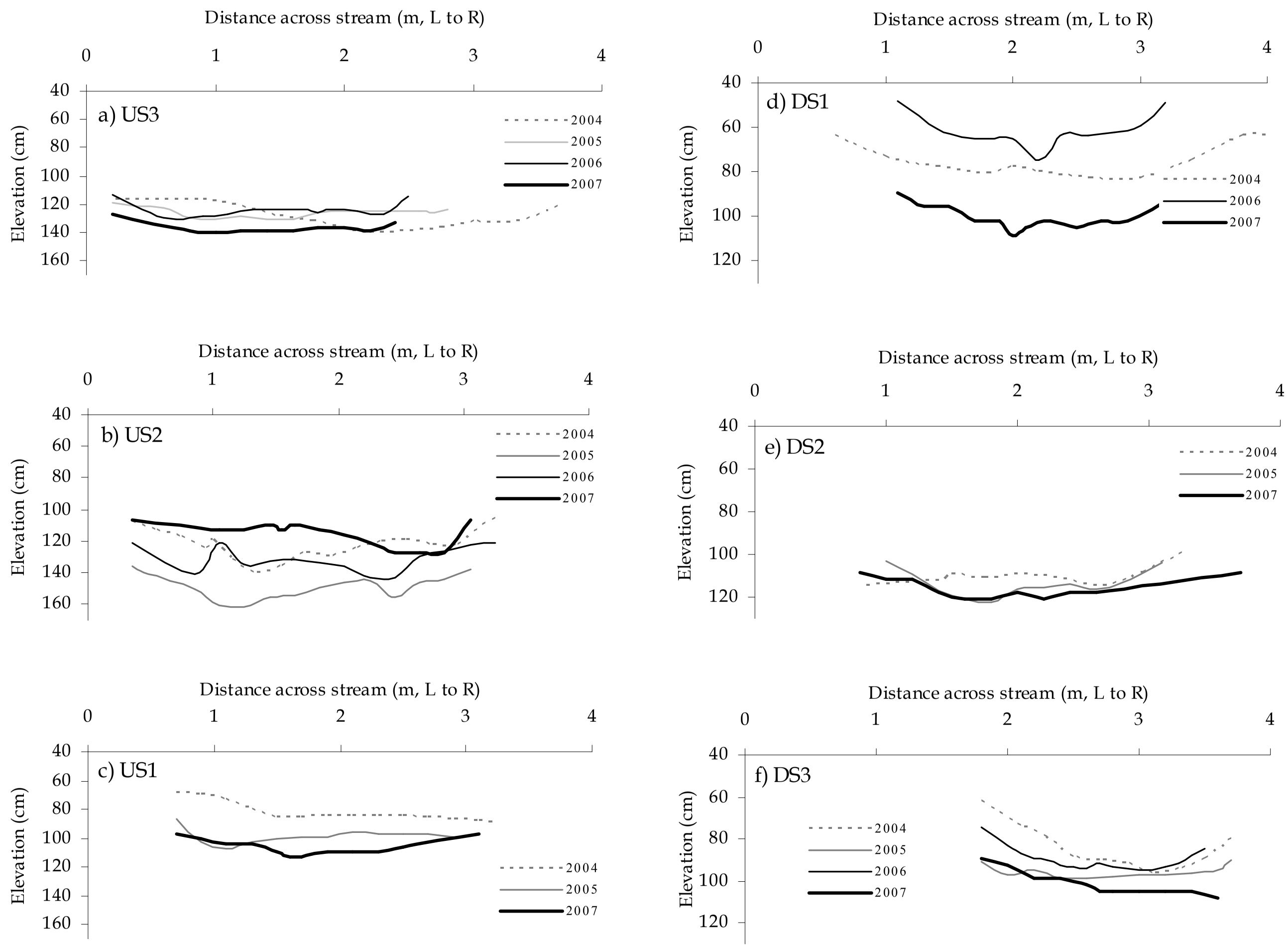

Figure 1.2. Cross-sectional profile of substrate at 6 transects on Sickle Creek, Manistee County, MI.

*note: all elevations are relative to the left bench, determined while looking upstream

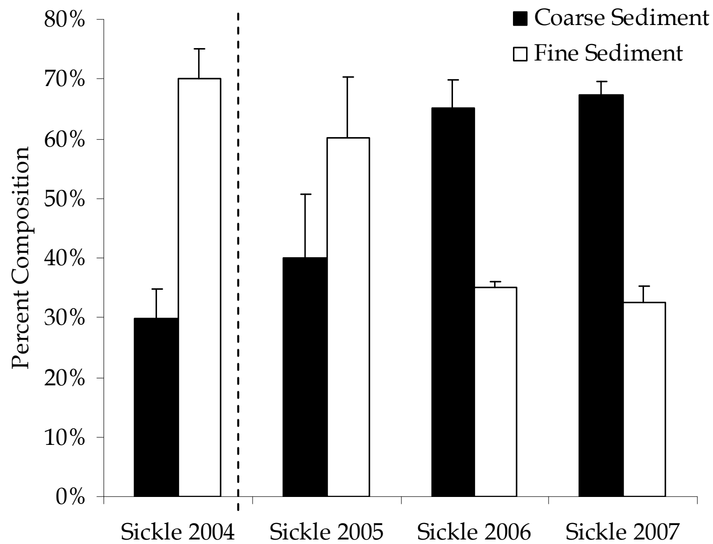

Figure 1.3. Amount of coarse (16mm-500µm) and fine sediments (500µm-63µm) from cores sampled at Sickle Creek (Manistee County, MI), from 2004 through 2007. Habitat restoration took place between 2004 and 2005. Bars indicate average (n=18 cores per season) plus standard error.

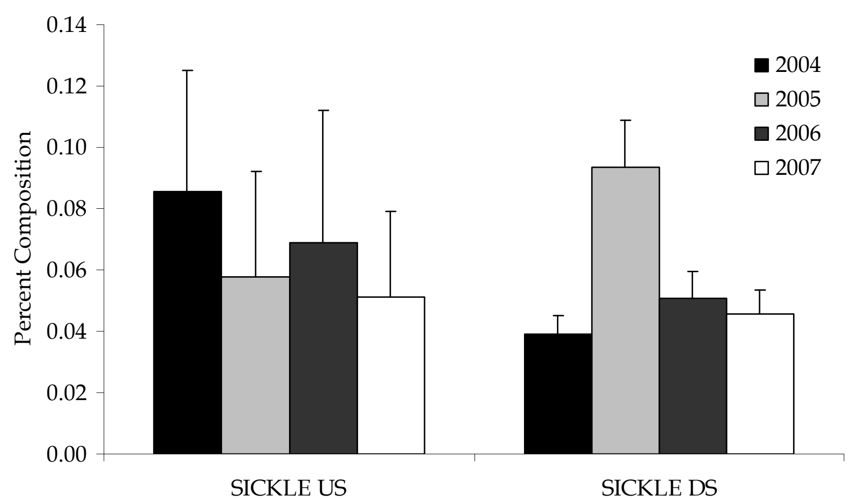

Figure 1.4. Amount of ultra fine particulate matter (UFPM: 63µm-0.63µm) from cores sampled at Sickle Creek (Manistee County, MI), from 2004 through 2007. Habitat restoration took place between 2004 and 2005. Bars indicate average (n=9 cores per season) plus standard error.

Table 1.1. Average percent change and *p*-values (1-way ANOVA) from pre- to post-restoration in five sediment classes for upstream (US) and downstream (DS) sediment cores at Sickle Creek, Manistee Co., MI. Bold values indicate statistical significance.

		% Change		*p*- value	
Sediment Class	Size Range	US	DS	US	DS
Gravel	16mm-4mm	43%	-47%	0.999	0.211
Very Coarse/Coarse Sand	4mm-500μm	209%	165%	**0.001**	**0.066**
Medium/Fine Sand	500μm-125μm	-60%	-47%	**0.004**	0.266
Very Fine Sand	125μm-63μm	-19%	-44%	0.467	**0.080**
Ultrafine Particulate Matter	63μm-0.63μm	-16%	-27%	0.636	0.302

Surficial sediment composition also improved following restoration. An interesting, nearly sinusoidal seasonal pattern in Wolman pebble count data was evident (Figure 1.5). The overall trend indicated an increase in the number of pebbles observed, including a marked seasonal variability with spring being more divergent than fall.

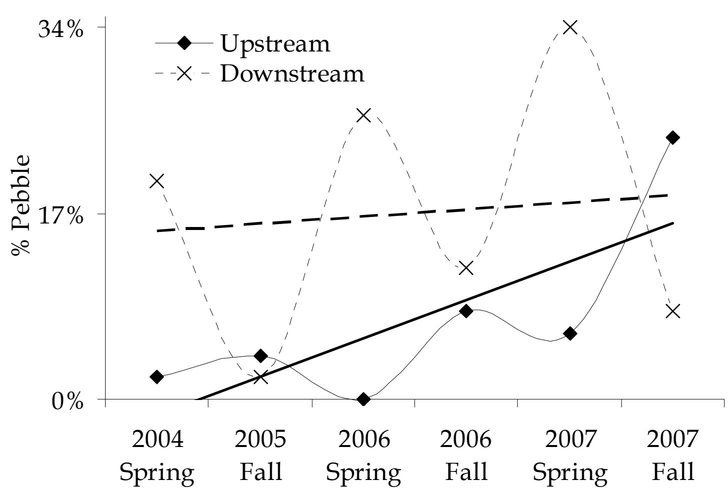

Figure 1.5. Percent of surficial sediment (from modified Wohlman pebble count) comprised of pebbles for upstream and downstream reaches on Sickle Creek, Manistee Co., MI. Habitat restoration took place between spring 2004 and fall 2005. Straight lines represent best-fit regression of the means.

Upstream of the road crossing, the number of pebbles observed in the spring was lower than in the fall, while the opposite was true downstream.

Overall, both up- and downstream transects showed decreases in fine sediment depth (Figure 1.6); depth of fine sediment decreased an average of 34% in 5 of 6 transects. Fall measurements of fine sediment depth were, on average, nearly twice as great as spring measurements, and were consistently more than 50% larger downstream than upstream, in both spring and fall.

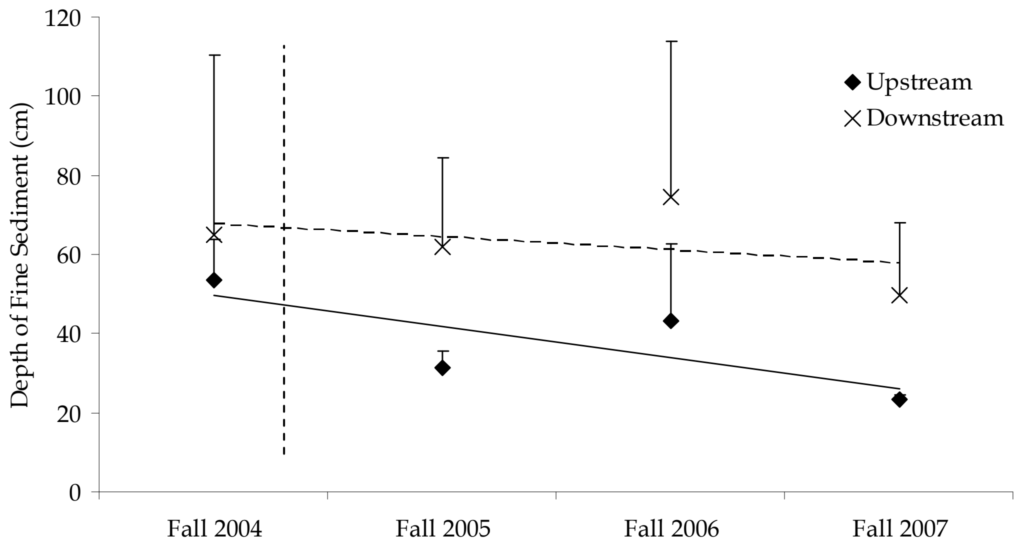

Figure 1.6. Mean fine sediment depth for upstream and downstream reaches (n=≥10 measurements per transect, n=3 transects per reach) at Sickle Creek, Manistee Co., MI. Habitat restoration took place between fall 2004 and fall 2005. Error bars indicate 1 standard error and straight lines represent best-fit regression of the means.

Bear Creek

<u>Milks Road</u>

Springtime cross sectional profile comparisons reveal aggradation at US3 and US2, and downcutting at US1 and DS1 (Figure 1.8). Similar to Sickle Creek, the downcutting at Milks Road appears to have taken place at the two transects nearest the road-stream crossing, where the channel incised as much as 27cm from 2004 to 2007. Channel width does not appear to have changed measurably at any transects at Milks Road, except US3, where the channel widened ~2.5m from 2004 to 2007.

Following culvert replacement at Milks Road, an overall decrease in fine sediment both up- and downstream of the new bridge (Figure 1.7) was observed. Though these differences were not significant, there was a trend indicating an overall post-restoration decrease in fine sediment and an increase in coarse sediment at the site. UFPM decreased significantly post-restoration (p= 0.001) at all transects on Milks Road, by an average of 64.5%. The largest decline, 81.7%, took place at DS1, the only transect below the bridge. In contrast, at the downstream transect at Spirit of the Woods, one of the only proposed control site transects where we have the same 4-year data set, an overall decrease in gravel, an increase in very coarse/coarse sand (VCCS), and a general increase in fine sediments, including UFPM were observed.

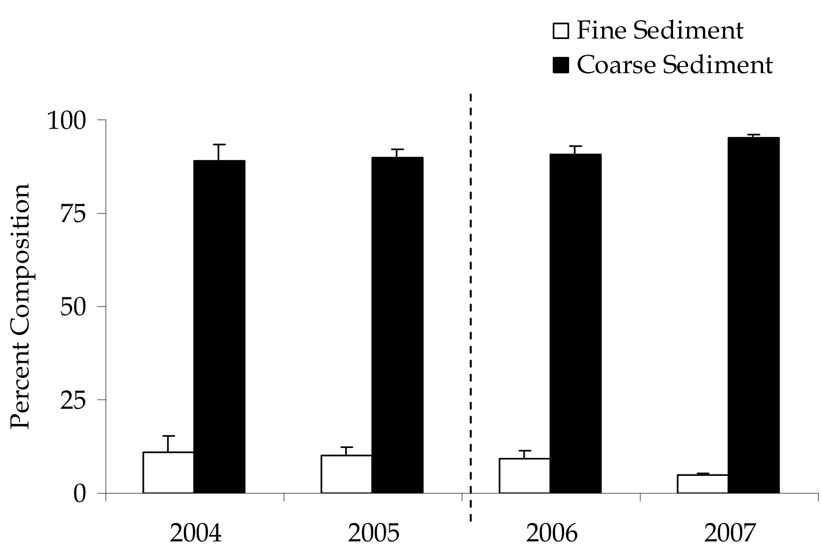

Figure 1.7. Amount of coarse and fine sediments from cores sampled at Milks Road on Bear Creek (Kaleva, MI) from 2004 through 2007. Habitat restoration took place between 2005 and 2006. Bars indicate average (n=12 cores per season) plus standard error.

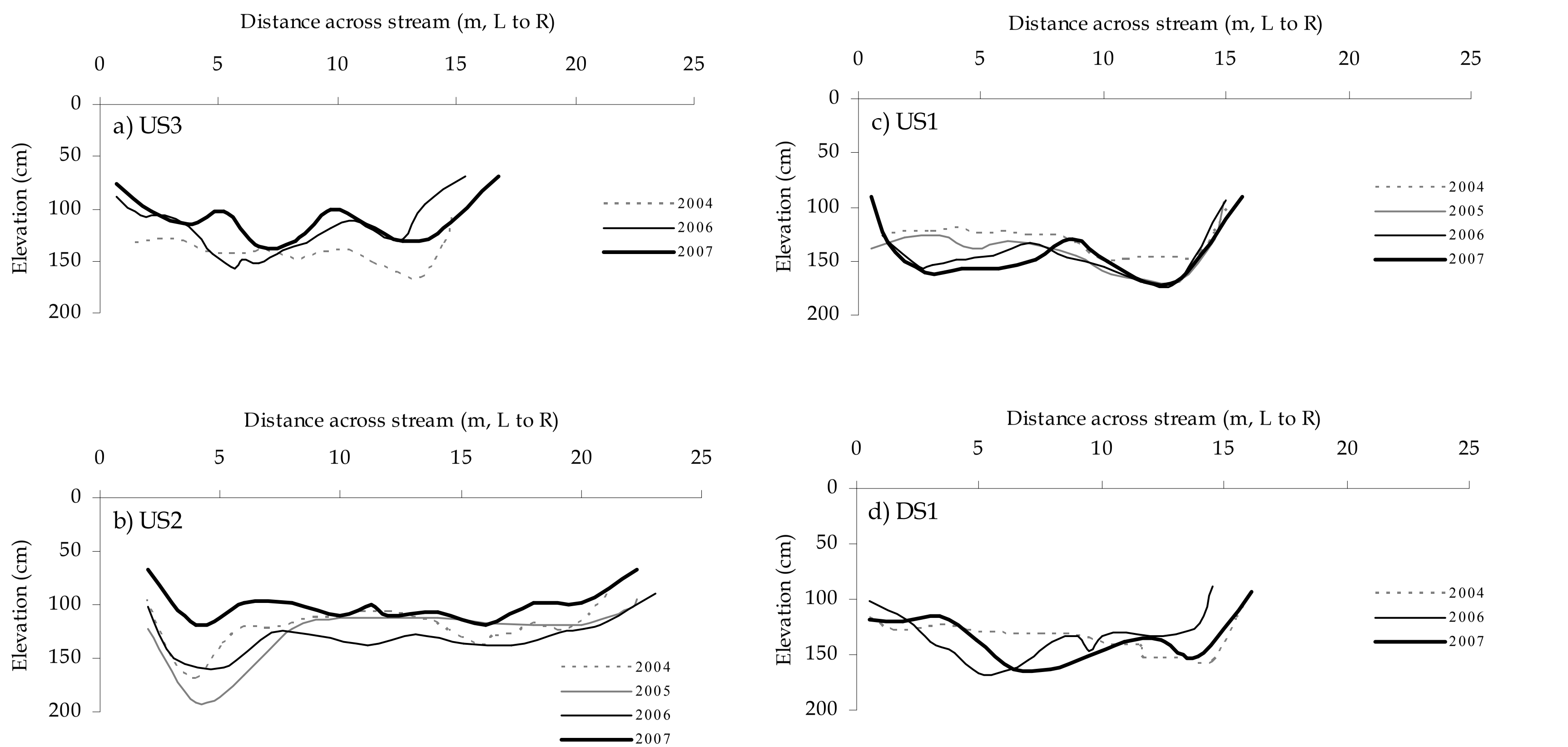

Figure 1.8. Cross-sectional profile of substrate at 4 transects at Milks Road on Bear Creek, Kaleva, MI.

*note: all elevations are relative to the left bench, determined while looking upstream

Surficial sediment, measured by pebble count, showed gradual post-restoration improvement at the Milks Road site, though there is substantial seasonal and yearly variability (Figure 1.9). Depth of fine sediment at Milks Road increased pre- to post-restoration (1-way ANOVA, p= 0.09), especially at US3 and US1 (Table 1.2), as did 5 of 6 transects at our control sites. There was also a significant linear relationship present at Milks Road between water velocity and fine sediment depth (r^2=0.60, p= 0.005, Figure 1.10); as velocity increased, fine sediment depth decreased.

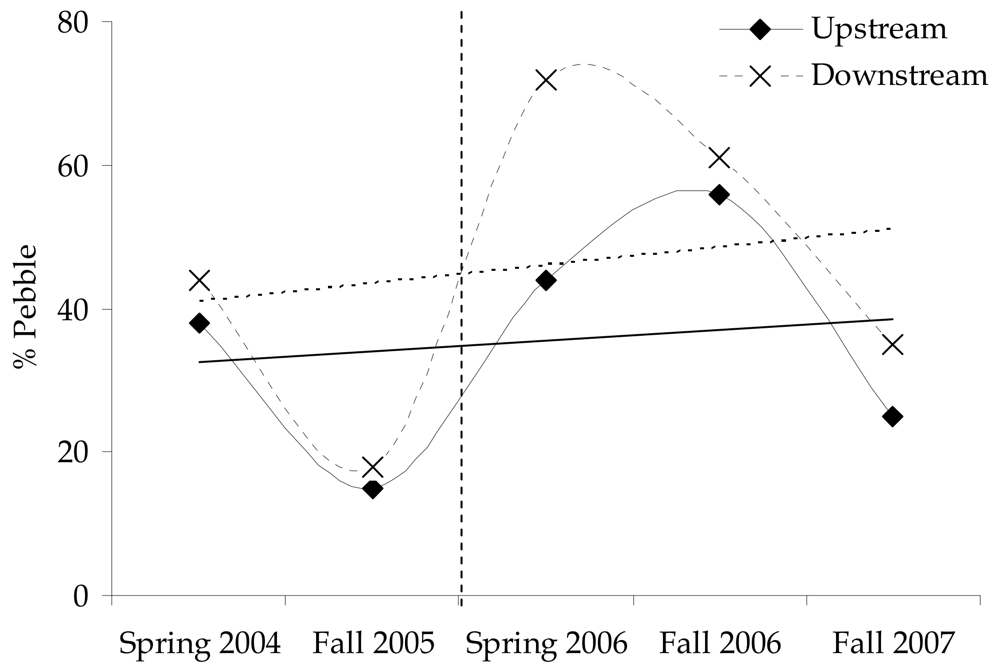

Figure 1.9. Percent of surficial sediment (from modified Wohlman pebble count) comprised of pebbles for upstream and downstream reaches at Milks Road on Bear Creek, Kaleva, MI. Habitat restoration took place between fall 2005 and spring 2006.

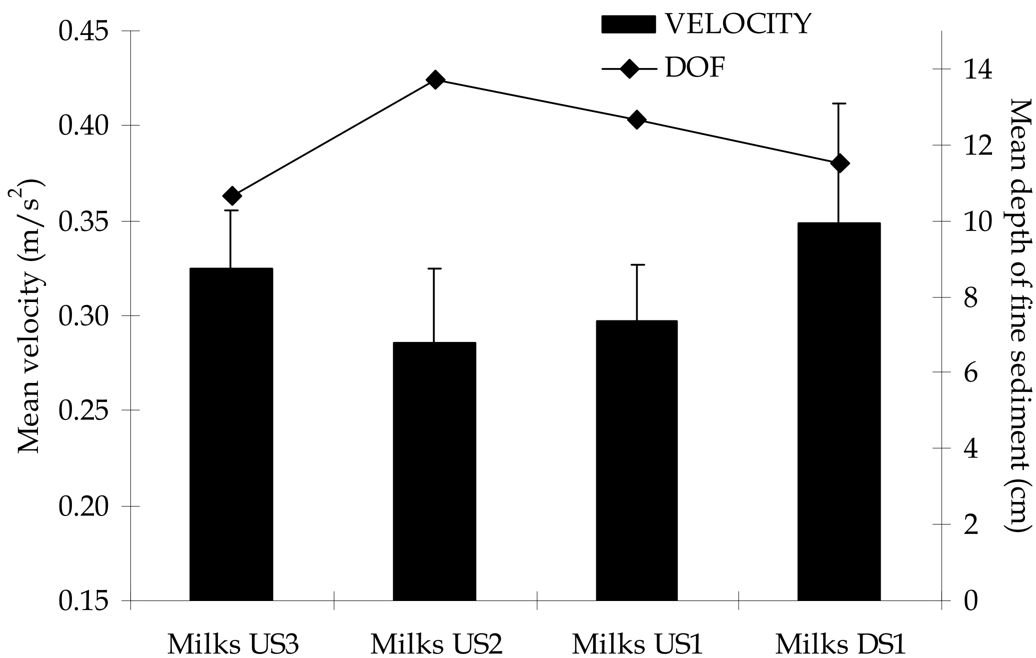

Figure 1.10. Mean water velocity (plus standard error) and mean depth of fine sediment (DOF) by reach at Milks Road on Bear Creek, Kaleva, MI. Data from all sample seasons have been pooled.

Table 1.2. Depth of fine sediment measurements (cm) for Milks Road on Bear Creek (Kaleva, MI) by season. Data is presented for each transect, with mean pre- and post-restoration measurements and 1 standard error (SE), and percent change from pre- to post-restoration. Habitat restoration took place between fall 2005 and spring 2006.

Transect	Fall 2004	Fall 2005	Fall 2006	Fall 2007	mean pre	mean post	Percent Change	*p* -value
US3	3.6	7.3	9.6	13.2	5.5	11.4	108%	0.15
US2	6.8	15.9	5.9	20.2	11.3	13.1	15%	0.86
US1	0.9	12.7	13.4	16.4	6.8	14.9	118%	0.32
DS1	3.9	15.2	7.0	22.2	9.5	14.6	53%	0.65
						Overall	*+83%*	*0.09*

Swain's Property

Due to the location of the restoration efforts at Swain's, there is no true up- and downstream designation, therefore, whole-site metrics were evaluated. Springtime cross sectional profile comparisons reveal downcutting at all four transects at Swain's, most notably at MidSwain and Swain 3, where the channel incised as much as 45cm from 2004 to 2007 (Figure 1.12). As was the case with most transects at Milks Road, channel width at Swain's does not appear to have changed measurably.

Following streambank stabilization at Swain's, a moderate increase in coarse sediment, and a corresponding decrease in finer sediment classes (40%) was observed (when pre and post measurements were averaged), though none of these trends were significant (Figure 1.11). At Swain's, no general trends were apparent for UFPM, as two transects had decreased UFPM, and two had increased UFPM. Although 2007

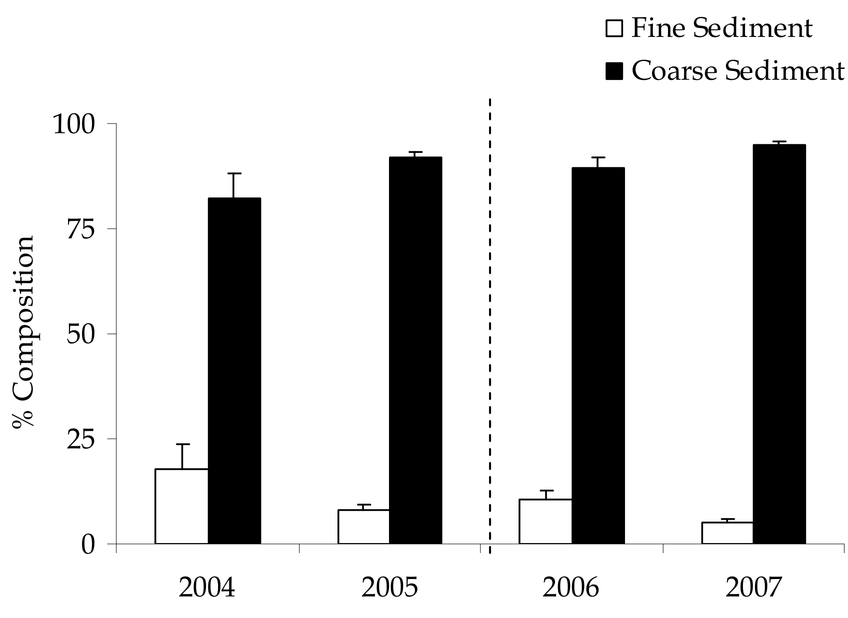

Figure 1.11. Amount of coarse and fine sediments from cores sampled at Swain's Property on Bear Creek (Kaleva, MI), from 2004 through 2007. Habitat restoration took place between 2005 and 2006. Bars indicate average (n=12 cores per season) plus standard error.

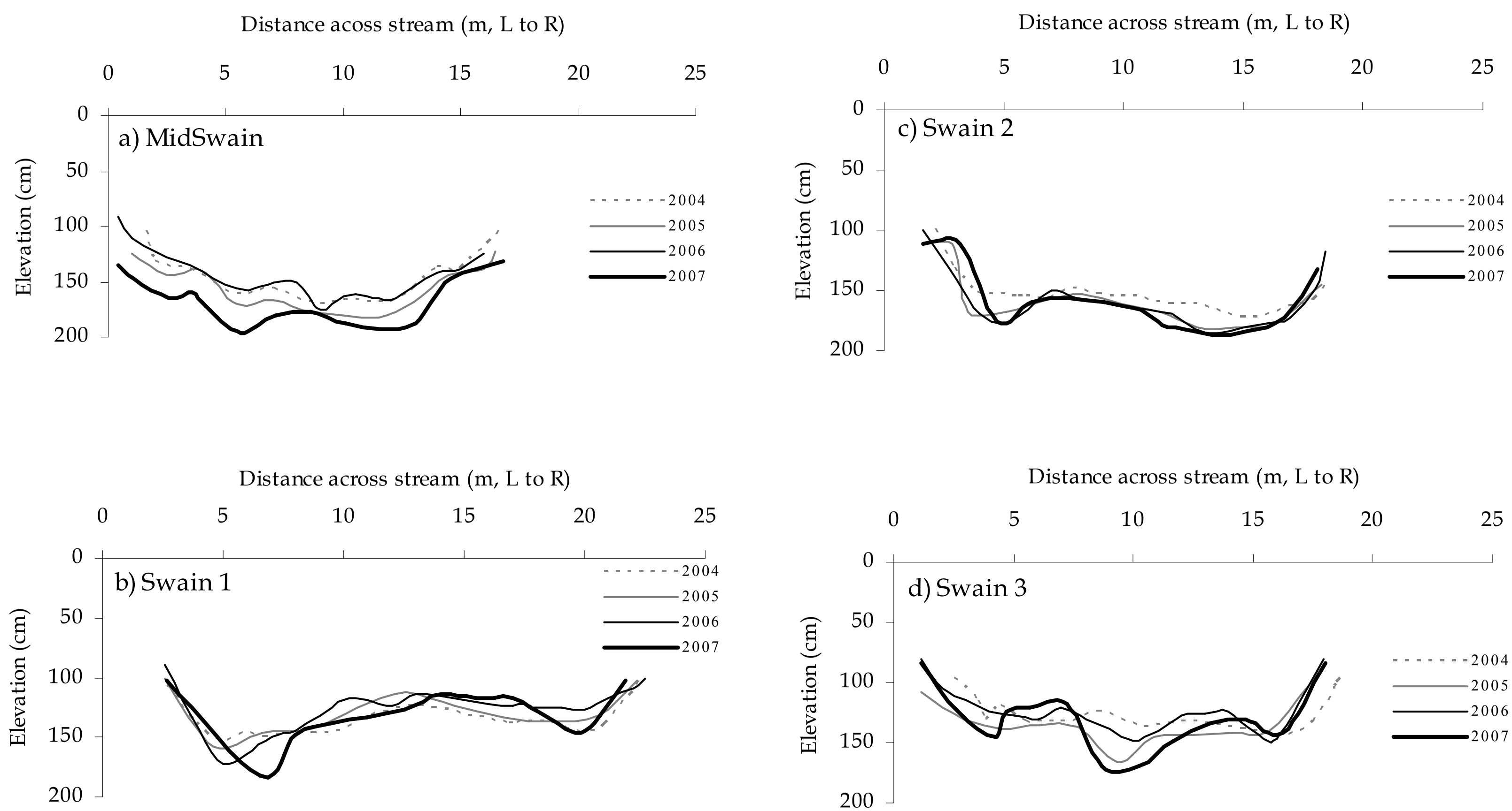

Figure 1.12. Cross-sectional profile of substrate at 4 transects at Swain's Property on Bear Creek, Kaleva, MI.

*note: all elevations are relative to the left bench, determined while looking upstream

measurements indicated decreases from preceding years, there were no significant differences pre- to post restoration. There was, however, an apparent relationship between water velocity and UFPM (r^2=0.89, p= 0.04, Figure 1.13); at sites with lower water velocity, the amount of UFPM collected was higher than at those sites with higher water velocity. At the downstream transect at Spirit of the Woods, one of the only proposed control site transects with the same 4-year data set, a decrease in gravel, an

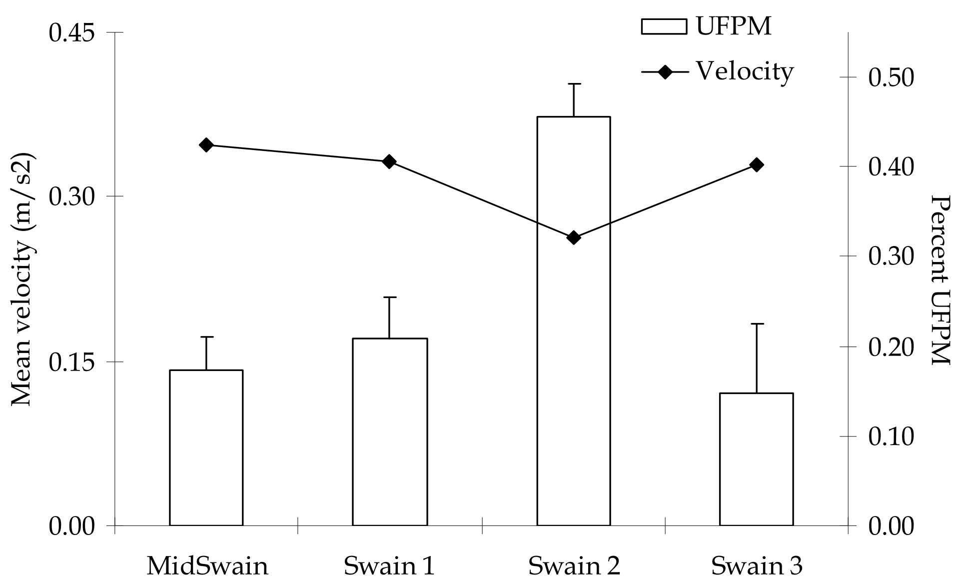

Figure 1.13. Mean water velocity (plus standard error) and mean percent UFPM by reach at Swain's Property on Bear Creek, Kaleva, MI.

increase in VCCS, and a general increase in fine sediments, including UFPM was observed. Surficial sediment parameters improved at Swain's (Figure 1.14), though there was substantial seasonal variability. Depth of fine sediment measurements for 2 of 4 transects at Swain's showed increasing trends over time (1-way ANOVA, p= 0.71, Table 1.3), as did 5 of 6 transects at control sites.

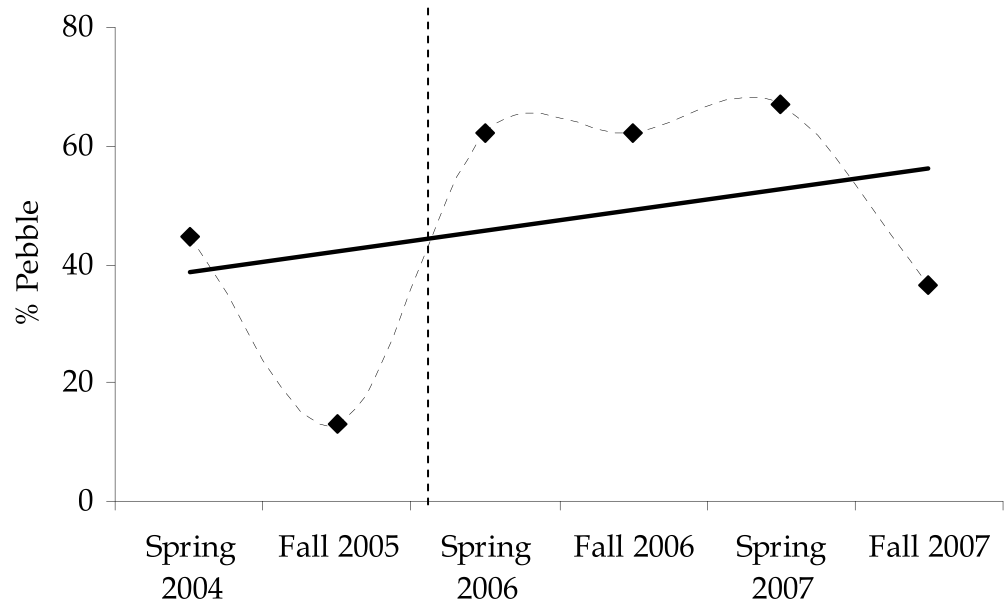

Figure 1.14. Percent of surficial sediment (from modified Wohlman pebble count) comprised of pebbles at Swain's Property on Bear Creek, Kaleva, MI. Habitat restoration took place between fall 2005 and spring 2006.

Table 1.3. Depth of fine sediment measurements (cm) for Swain's Property on Bear Creek (Kaleva, MI) by season. Data is presented for each transect, with mean pre- and post-restoration measurements and 1 standard error (SE), and percent change from pre- to post-restoration. Habitat restoration took place between fall 2005 and spring 2006.

Transect	Fall 2004	Fall 2005	Fall 2006	Fall 2007	mean pre	mean post		Percent Change	p-value
Mid Swain	12.9	8.8	12.1	13.2	10.8	12.6		17%	0.49
Swain 1	18.4	10.7	11.9	13.9	14.5	12.9		-11%	0.72
Swain 2	9.8	8.9	12.6	17.0	9.3	14.8		58%	0.14
Swain 3	50.4	11.6	41.2	28.4	31.0	34.8		12%	0.87
							Overall	*+7%*	*0.71*

DISCUSSION

The River Continuum Concept (Vannote et al. 1980) seeks to explain variability along the longitudinal gradient of a stream by stating "…the structural and functional characteristics of stream communities are adapted to conform to the most probable position or mean state of the physical system." According to the authors, this means rivers and streams are controlled by physical factors which predictably influence variables such as water chemistry, nutrient sources and sinks, and functional processes, all of which in turn selects for specific ecological communities. This suggests by improving the physical condition of the sediment in our streams, the macroinvertebrate communities and fish communities would respond in kind. This discussion includes analyses of both non-significant and significant responses to restoration. Many authors have noted in ecological studies, the conventional use of null-hypothesis significance testing can result in Type II errors; namely failing to reject a null hypothesis (*sensu* Yoccoz 1991, McBride et al. 1993, Johnson 1999, McBride 2002); a conclusion based in part on the fact natural ecosystems are inherently variable.

The use of 0.1 vs. 0.05 as a significance cut-off is the alternative selected in this research project to accommodate this natural, inherent variability and yet provide for traditional null-hypothesis testing.

Sickle Creek

Upstream of the new bridge, the large quantity of impounded fine sediment was released and flushed downstream by the return of a natural flow regime. Though there was considerable seasonal variability, downcutting was predominant at 5 of 6 transects measured. We also saw a dramatic decrease in medium, fine, and very fine sands

(<250μm), and UFPM, both upstream and downstream. Very coarse and coarse sediments showed substantial increases both upstream and downstream. Overall amounts of gravel decreased in 2005, likely due to the construction process of removing the old culvert and installing the new bridge, then rebounded in subsequent years, actually eclipsing pre-restoration levels upstream. Of course, as mentioned with this type of restoration activity, there is often a negative effect felt immediately downstream, due to construction practices, and the release of impounded sediment. This can be seen when looking at several parameters for DS1, including composition and cross sectional profile. Depending on several factors (natural flow regime of the system, time of year in which the restoration takes place, metric in question [sediment, macroinvertebrates, fish]), these negative effects may only last a few weeks, or could last up to a full season or more. Over time, however, the typical long-term effect was positive. These coarser sediment classes became more dominant as finer sediments were flushed downstream, and eventually out of the creek. Measured fine sediment depth also decreased significantly both upstream and downstream. Evidence suggests spates of fine sand, more than a foot deep, now accumulate at the confluence with the Big Manistee River, and are seasonally transported out of Sickle Creek (personal observation). This confluence is now shallow and clear, whereas prior to restoration, the water was slower, deeper, and silty (personal observation). These finer sediments now being transported through and removed from Sickle Creek are known to be detrimental to both macroinvertebrates (Richards and Bacon 1994, Angradi 1999) and fish (Reiser and White 1988, Platts et al. 1989, Suttle et al. 2004). Fine sediments can impact macroinvertebrates in several ways, including the alteration of substrate composition, and decreased suitability of the substrate for several taxa (Erman and Ligon 1988, Richards and Bacon

1994), and increasing drift due to sediment deposition or substrate instability (Rosenberg and Wiens 1978, Culp et al. 1983). Fish can be negatively affected by fine surficial sediment, as well as suspended fine sediment (Bisson and Bilby 1982, Barrett et al. 1992, Korstrom and Birtwell 2006). We anticipate finer sediments will continue flushing out of the system, allowing coarser sands and eventually gravel to become exposed. While this may have a short-term negative effect on the mainstem of the Big Manistee, we feel a beneficial equilibrium will eventually be established.

The increase in quantity and size of surficial pebbles through time indicate this process has already begun, though with some interesting seasonal fluctuations. Our hypothesis is the opposing sinusoidal patterns seen (Figure 1.5) are the result of several factors. The downstream pattern (fewer pebbles in fall than in spring) is due to vehicle traffic disturbing the road surface, sediment-laden runoff from the dirt road from summer rain events, and base-flow accumulation of fine sediments throughout the summer. In winter, snow covers the road much of the season and vehicle traffic is reduced, reducing or preventing sediment transport from the road to the stream. We propose the upstream pattern (fewer pebbles in spring than in fall) is due to upstream sources of sediment input which have not been addressed. The two sections appear to be reaching some sort of new dynamic equilibrium state, perhaps a result of return to natural flow regime. These increases in coarser surface sediment may allow for colonization by sediment-intolerant macroinvertebrates (Angradi 1999) and increased recruitment of fish (Reiser and White 1988, Magee, McMahon, and Thurow 1996).

The overall decrease in depth of fine sediment is likely another positive response to the restoration. The discrepancy observed between fall and spring measurements is partially attributable to the fact Sickle Creek is a groundwater-fed stream with low base-flow, and requires springtime snowmelt and storms to create sufficient discharge to transport fine sediments. The consistent difference between upstream and downstream measurements is probably due to the gravel road itself contributing sediment, likely from vehicle traffic and rain-derived runoff (Lane and Sheridan 2002, Sheridan et al. 2006).

Bear Creek

The increases in coarse sediments and decreases in fine sediments in the core samples, observed at both habitat-improvement sites, suggest the restoration efforts had a positive effect in reducing the amount of fine sediment being washed into the stream, as well as improving the downstream transport of fine sediments by allowing more natural flushing flows. These trends were opposite what was observed at Spirit of the Woods for the same time frame, suggesting the observed changes can likely be attributed to the restoration efforts. In addition, surficial sediment condition appeared to improve at both the Milks and Swain's sites following restoration. When the improving surficial condition is coupled with sediment profile improvements, it appears the restoration efforts had the intended effect of reducing fine sediment inputs into the stream. In spite of this, when focusing on the increase in fine sediment depth seen at most of the transects at Milks and Swain's, the effects seems to be confounded. However, the accumulation of fine sediment seen at the experimental sites appeared to be present throughout the entire creek, as 5 of 6 transects at our three reference sites (Leffew Road, Spirit of the Woods, and Lower Bear) also showed increasing depth of fines measurements over this time, suggesting overriding environmental factors or large-scale influences at work throughout the watershed. It is also possible re-opening the channel at Milks Road has rearranged flow patterns in the stream, causing different sediment deposition patterns to be exhibited post-restoration. As a result, the overall reach may be losing fine sediment, though where it is present in the stream, the depth is increasing. Ongoing analyses of sediment transport dynamics by the Tribe may better elucidate these patterns.

As fine sediment negatively alters substrate composition and channel morphology, impacts fish reproduction and recruitment, and precludes aquatic invertebrates (Wood and Armitage 1997, VanDusen et al. 2005), any sort of reduction in fine-sediment bed-load is beneficial to the biota in a stream (Alexander and Hansen, 1983). These finer sediments now being transported are known to be detrimental to both macroinvertebrates (Richards and Bacon 1994, Angradi 1999) and fish (Reiser and White 1988, Platts et al. 1989, Suttle et al. 2004), as noted above in the discussion of Sickle Creek. With the restoration of natural flushing flows, the finer sediments are expected to continue flushing out of the system, allowing coarser sands and eventually gravel to become exposed. Of course, this conclusion assumes upstream sources of sediment are not the primary contributors at these sites.

The decrease in UFPM observed at Milks Road and not at Swain's is likely due, at least in part, to the difference in restoration activities at the two sites, as well as the nature of the two sites themselves; Milks Road was a road-stream crossing improvement while Swain's was a streambank stabilization. Milks Road itself likely contributed fine sediment and UFPM from the roadbed to the stream; a source not present at the Swain site, as the latter was several hundred meters from the nearest road. Therefore the paving of Milks Road near the stream crossing likely contributed to the reduction in fines at this site (Mar et al. 1982, Reid and Dunne 1984, Clinton and Vose 2003). The new bridge at Milks Road replaced two undersized and seasonally submerged culverts which did not accommodate the width of the stream. Culverts impede flushing flows and typically act as barriers to sediment passage, often forcing impoundment of sediments upstream, while allowing fine sediments to accumulate downstream as a result of a decrease in the intensity of the flood pulse (Wellman et al. 2000). The installation of a bridge at this site allowed flushing flows to remove the accumulated UFPM, and paving the approach reduced the amount of UFPM input into the stream. This combination of factors may explain why a reduction in UFPM was seen at Milks Road and not at Swain's.

Due to the proximity of Swain's Property to Milks Road (<1200m downstream), it was difficult to distinguish differences in trends at the two sites. In addition, effects observed at the upstream site (Milks) may confound effects at the downstream site. We also feel a drought during the summer of 2007 allowed more fine sediment to accumulate than in normal years, potentially affecting fall 2007 values, disrupting patterns recorded in previous years when precipitation levels were more normative.

Classic stream sediment transport models incorporate two main components, suspended load and bed load, and also integrate many variables, such as source areas of sediment, transient flows, variable particle sizes, non-uniformity of channel geometry and flow, and dynamic or adjusting channels (Beschta 1987). Ideally, these variables would have been measured and quantified both pre- and post-restoration in order to determine how the habitat improvements have changed the sediment transport characteristics of these streams, but this was beyond the scope of the project. It is assumed the road-crossing improvements restored a more natural flow regime, in addition to reducing point-source inputs of additional fine sediments. What is not known, is exactly how much (or how little) impact the restoration efforts have had on improving sediment transport. Ongoing research at the Tribe is seeking to better quantify these important variables.

While it may be safe to conclude we have improved sediment transport, it would be important to quantify our assumptions through time. New dynamic equilibriums for transport in these streams may not be reached for several years, depending on a suite of environmental factors including flooding, base flow, winter severity, annual precipitation, and others. Redistribution of accumulated sediments continuously change in-stream flow characteristics, as do riparian landowner actions. To evaluate current sediment transport, it would be necessary to determine the size-fraction at several longitudinal points along of the streambed in question, quantify base flow and seasonal peak flow, measure suspended load during base and peak flow, and monitor stream channel erosion and deposition.

To conclude, it is important to revisit the *a-priori* hypotheses stated earlier, and evaluate the ecological response of the study streams. The hypothesis of a rapid response in sediment characteristics was supported in Sickle Creek, the smaller of the two streams. Dramatic and significant changes in sediment composition, surficial sediment, and depth of fine sediment were observed. While changes were also observed at the study sites on Bear Creek, the pre-restoration condition of those sites was far better than in Sickle Creek, so a lesser response in Bear Creek is not necessarily unexpected. While positive changes were observed in sediment composition, overall the response was mixed, suggesting larger environmental factors at work. The hypothesis of a significant and rapid impact on the finest sediment size fractions was supported in both systems, with significant decreases of UFPM at Sickle Creek and at Milks Road on

Bear Creek, the two road-crossing improvement sites. This is logical, as the road crossing improvements were put in place to restore a natural flow regime capable of removing impounded stocks of fine sediments. The hypothesis concerning channel morphology was also well supported, again, at the two road-crossing improvement sites, Sickle Creek and Milks Road. Channel incision was predominant from 2004 to 2007, with changes from 25-45cm observed.

When all of this is considered, I conclude the restoration practices were successful in (i) restoring natural flood pulses and flow regimes within the reaches formerly constrained by undersized culverts, (ii) reducing the deposition of new sediment into the streams, and (iii) allowing natural flow regimes to transport accumulated sediments.

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CHAPTER II – Macroinvertebrate Community

ABSTRACT

Fine sediment suspension and deposition negatively affects the benthic macroinvertebrate community, mainly by altering and homogenizing the substrate. The objective of this study was to monitor the response of the macroinvertebrate community to sediment abatement techniques employed in the Big Manistee river watershed. To quantify this response to restoration, quantitative and qualitative samples were collected in the spring and fall, from 2004 to 2007, with most restoration practices taking place in 2005. We saw a strong positive response in Sickle Creek, a 1st-order tributary, including an increase in overall abundance (from 218 to 330 individuals/m^2 in the spring; 52 to 162 individuals/m^2 in the fall), and also abundance of critical and sensitive taxa, including *Heptageniidae*. In Bear Creek, a 4th-order tributary, there was an overall positive response, though the trends were less pronounced than in Sickle Creek. Overall, it appears the restoration techniques utilized were successful in (1) increasing the abundance of macroinvertebrates at these sites, and (2) allowing for colonization by more sensitive taxa.

INTRODUCTION

Fine sediment negatively alters substrate composition and channel morphology, and degrades habitat for aquatic invertebrates (VanDusen et al. 2005, Wood and Armitage 1997). For example, Richards and Bacon (1994) suggested 150μm sediments had significant negative effects on both abundance and richness of macroinvertebrates, while Angradi (1999) found macroinvertebrate density, biomass, and richness were all negatively correlated to an increase in fine sediments (<2mm). Fine sediment suspension and deposition affects benthic macroinvertebrates in several ways, including the alteration of substrate composition and changing the suitability of the substrate for several taxa (Erman and Ligon 1988, Richards and Bacon 1994), increasing drift due to sediment deposition or substrate instability (Rosenberg and Wiens 1978, Culp et al. 1983), and filling of pore spaces used as refugia by insects, and smothering vegetation used for food and habitat.

The objective of this study was to thoroughly monitor the response of the biological community and physical habitat to sediment abatement techniques in three streams: Bear (4th order), Pine (2nd order), and Sickle (1st order) Creeks, tributaries of the Big Manistee River below Tippy Dam. Included in this thesis are the results and discussion from two of the three systems—Bear and Sickle Creeks. Results from Pine Creek have been summarized by K. Nault (MS thesis, GVSU, *in progress*).

HYPOTHESES

A-priori hypotheses were as follows:

1. Reduction of fine sands and UFPM will shift the make-up of the macroinvertebrate community away from psammophilic species to those species more suited for higher-quality substrate, as well as increasing the overall abundance of insects. Specifically, taxa such as those in the EPT families are expected to increase in diversity and abundance where a corresponding decrease in fine sediments is observed.

METHODS

Six habitat evaluation transects were established on Sickle Creek: three up- and three downstream (at 5m, 100m and 200m) (Figure 1.4, Chapter I). Milks Road had one transect downstream and three upstream of the road-crossing (at 50m down, and 50m, 100m and 200m up [Photo 1, Appendix A]), and Swain Property had four transects (at a baseline, and 50m, 100m, and 200m downstream [Photo 2, Appendix A]). Two sites were established at Leffew Road (in spring 2006, 50m up- and downstream of the bridge), Spirit of the Woods (at the bridge for Coates Highway, and 100m downstream), Lower Bear (at a baseline, and 100m upstream). At these transects, the macroinvertebrate community was sampled quantitatively, using three Surber samplers ($0.09m^2$, 234µm mesh). Rocks within the sample area were picked up, scrubbed by hand to dislodge macroinvertebrates and organic matter (for 1 minute). The area was then agitated using a small metal spike to a depth of approximately 10 cm (for 1 additional minute). Organic matter and macroinvertebrates were preserved in 70% ETOH for further processing and identification. In addition, a qualitative kick sample was taken using a D-frame net to sample additional habitat types not suited to sampling with a Surber net. These samples were taken twice annually: once in spring and once in fall. In the lab all macroinvertebrates were identified to family and counted, with Ephemeroptera, Plecoptera, and Trichoptera (EPT) identified to genus. Water quality data were collected using a YSI multimeter and sonde (YSI Incorporated, Yellow Springs, OH).

STATISTICS

The initial design called for use of MANOVA in a BACI (before-after, control-impacted) design. Unfortunately, experimental effects were felt at upstream transects in proximity to the restoration sites, and also at other experimental sites longitudinally downstream from restoration sites, confounding the BACI analysis. Therefore, 1-way ANOVA was also used, with the following variables for both analyses: (dependent) abundance (number of macroinvertebrates per m^2), taxa richness, percent EPT (Ephemeroptera / Plecoptera / Trichoptera), EPT abundance, EPT richness, and abundance and richness for Ephemeroptera, Plecoptera, and Trichoptera; (independent) upstream versus downstream, pre-restoration versus post-restoration, and individual transect. Each Surber sample was considered as a replicate. The disadvantage of the 1-way ANOVA is by simply comparing pre- to post-restoration communities, we may lack the capacity to truly know if the observed changes are due to natural variability or effects of the restoration. All analyses were performed using SPSS 14.0 (SPSS, Chicago, IL). As the use of null-hypothesis statistical testing is entrenched in the minds of environmental researchers, it would be difficult to disseminate our findings without its use. However, too stringent an application (i.e. too small a *p*-value) might preclude effective conservation of precious resources. To that end, statistical significance was set at a *p*-value of 0.1. By increasing the level of significance, we increase the chances of making a Type I error, decreasing the chances of making a Type II error, essentially increasing statistical power.

RESULTS

Sickle Creek

Spring

Overall mean spring macroinvertebrate abundance tended to increase pre to post-restoration, from 218 ± 51.3 (mean ± 1 S.E.) to 330 ± 48.9 individuals per m^2, though the difference was not significant (1-way ANOVA, $p = 0.12$) (Figure 2.1). EPT abundance and richness did not change significantly post-restoration (Table 3a, Appendix C). Total taxa richness (whole site, 1-way ANOVA, $p=0.001$) and mean taxa richness (sample

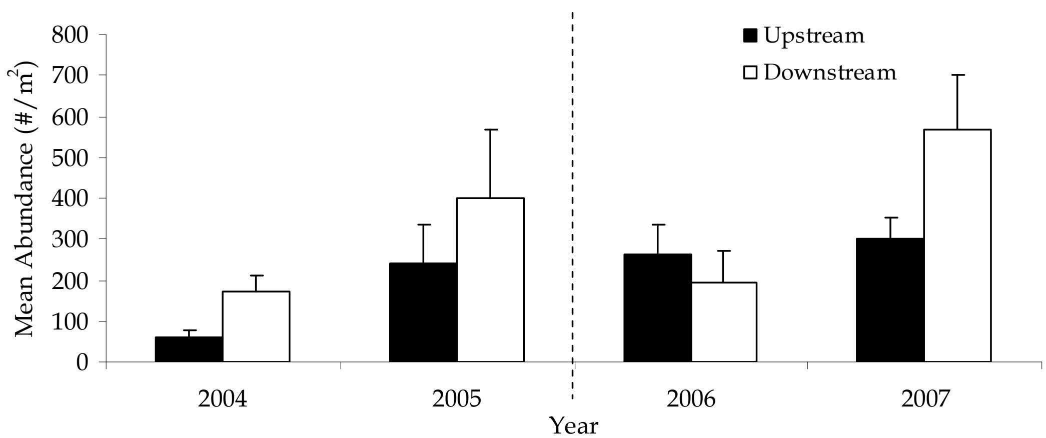

Figure 2.1. Mean spring macroinvertebrate abundance (#/m^2) for Sickle Creek, Manistee Co., MI. Dashed vertical line signifies time of habitat restoration.

mean, 1-way ANOVA, $p < 0.0005$) both increased post-restoration (Table 2.1). Total taxa richness refers to all taxa collected from all samples pooled together at a site (3 surbers from each transect, multiple transects per site), and mean taxa richness refers to the average taxa richness for each individual surber sample. We also observed other community differences, like the addition/loss of several taxa (Table 1, Appendix C); for example, *Heptageniidae*, found post- restoration only, are known to prefer gravel or

Table 2.1. Average values for spring macroinvertebrate community metrics on Sickle Creek, Manistee Co., MI.

Reach		Simpson's Dominance	Shannon's Diversity	Total Richness	Mean Richness
US	Pre-Restoration	0.36	1.56	16.5	6.2
US	Post-Restoration	0.25	1.86	26.0	10.4
DS	Pre-Restoration	0.33	1.67	16.5	8.6
DS	Post-Restoration	0.26	1.85	27.0	10.9

cobble substrate (Voshell 2002). In total, 30 taxa were discovered only post-restoration (considered "added" taxa), while 4 taxa were found only pre-restoration (considered "lost" taxa). Jaccard's Index of Community Similarity (C_J; hereafter referred to as Jaccard's Index) (Table 2.2) indicated 2004 and 2005 communities were most similar, both up- and downstream, whereas 2005 and 2006 communities were least similar,

Table 2.2. Spring Jaccard's Index values for Sickle Creek, Manistee Co., MI.

Upstream		Downstream	
Comparison	Jaccard's Index	Comparison	Jaccard's Index
2004:2005	0.667	2004:2005	0.600
2005:2006	0.429	2005:2006	0.423
2006:2007	0.529	2006:2007	0.459
2004:2007	0.500	2004:2007	0.536

again, both up- and downstream. Because of disparity in the spring sampling dates between years, a regression of sampling date against macroinvertebrate abundance was conducted; results revealed a significant negative linear relationship (r^2=0.57, p= 0.051) in which abundance was lower when samples were collected later in the season. Use of the BACI analysis (Table 3b, Appendix C) indicated EPT richness and Ephemeroptera richness were the only metrics to change significantly in response to the habitat restoration (have a significant interaction term; terminology used throughout); both metrics increased upstream and decreased downstream, post-restoration (p= 0.059 and 0.044, respectively).

Fall

Overall mean fall macroinvertebrate abundance increased 210.5% pre- to post-restoration, from 52 ± 9.4 (mean ± 1 S.E.) to 162 ± 26.4 individuals per m^2 (1-way ANOVA, p= 0.02) (Figure 2.2). EPT richness and abundance both increased (Table 6a,

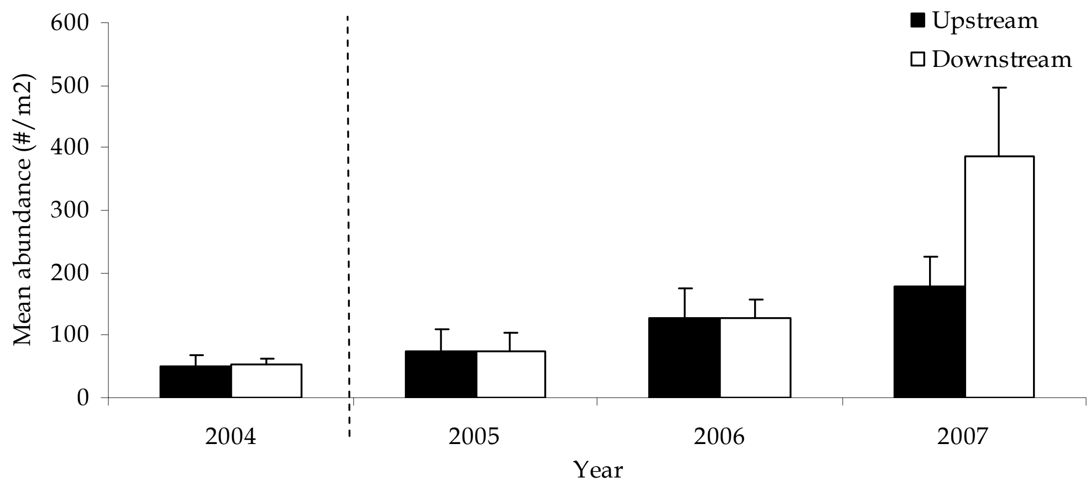

Figure 2.2. Mean fall macroinvertebrate abundance (#/m^2) for Sickle Creek, Manistee Co., MI. Dashed vertical line signifies habitat restoration.

Appendix C) post-restoration (1-way ANOVA, p= 0.023 and 0.001, respectively). Total taxa richness (whole site, 1-way ANOVA, p= 0.051) and mean taxa richness (sample mean, 1-way ANOVA, p< 0.0005) both increased post-restoration (Table 2.3). As in spring, there were community differences observed in the fall, with the addition/loss of several taxa (Table 4, Appendix C) including, as in spring, the addition of *Heptageniidae*, found post- restoration only and known to prefer gravel or cobble substrate (Voshell 2002). In total, 23 taxa were added, and 2 were lost.

Table 2.3. Average values for fall macroinvertebrate community metrics on Sickle Creek, Manistee Co., MI.

Reach		Simpson's Dominance	Shannon's Diversity	Total Richness	Mean Richness
US	Pre-Restoration	0.61	0.88	13.00	2.40
US	Post-Restoration	0.18	2.06	22.00	7.34
DS	Pre-Restoration	0.42	1.29	16.00	3.60
DS	Post-Restoration	0.17	2.16	26.67	8.63

Jaccard's Index (Table 2.4) indicates 2006 and 2007 communities were the most similar, both up- and downstream, whereas 2004 and 2007 communities were the least similar,

Table 2.4. Fall Jaccard's Index values for Sickle Creek, Manistee Co., MI.

Upstream		Downstream	
Comparison	Jaccard's Index	Comparison	Jaccard's Index
2004:2005	0.500	2004:2005	0.480
2005:2006	0.577	2005:2006	0.581
2006:2007	0.594	2006:2007	0.667
2004:2007	0.481	2004:2007	0.455

again, both up- and downstream. Use of the BACI analysis (Table 6b, Appendix C) indicates none of the metrics used changed significantly in response to the habitat restoration.

Bear Creek

Milks Road – Spring

Overall mean spring macroinvertebrate abundance increased 110.4% pre to post-restoration, from 476 ± 72.7 (mean ± 1 S.E.) to 1003 ± 211.6 individuals per m^2 (1-way ANOVA, p= 0.023) (Figure 2.3). Percent EPT decreased (1-way ANOVA, p= 0.001), while neither EPT abundance nor richness changed significantly (Table 9a, Appendix C. In addition, neither total taxa richness (whole site) nor mean taxa richness (sample

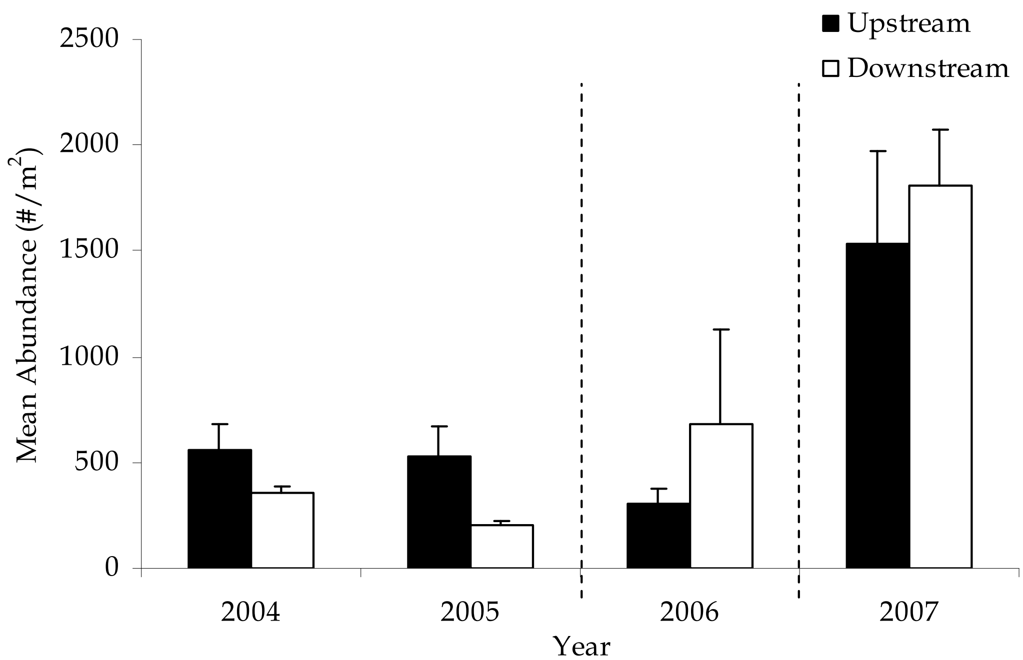

Figure 2.3. Mean spring macroinvertebrate abundance (#/m^2) for Milks Road on Bear Creek, Kaleva, MI. Left dashed vertical line signifies culvert removal, right dashed vertical line signifies upstream bank stabilization.

mean) changed significantly post-restoration (Table 2.5). We also observed other community differences, such as the addition/loss of several taxa including eight families of Plecoptera and Trichoptera not found pre-restoration (Table 7, Appendix C).

Table 2.5. Average values for spring macroinvertebrate community metrics at Milks Road on Bear Creek, Kaleva, MI.

Reach		Simpson's Dominance	Shannon's Diversity	Total Richness	Mean Richness
US	Pre-Restoration	0.20	1.96	23.0	12.0
US	Post-Restoration	0.22	1.92	26.0	12.2
DS	Pre-Restoration	0.22	1.94	17.0	10.7
DS	Post-Restoration	0.18	2.02	22.0	14.0

Jaccard's Index (Table 2.6) indicates 2004 and 2005 communities were the most similar, both up- and downstream, whereas 2004 and 2007 communities were the least

Table 2.6. Spring Jaccard's Index values for Milks Road on Bear Creek, Kaleva, MI.

Upstream		Downstream	
Comparison	Jaccard's Index	Comparison	Jaccard's Index
2004 : 2005	0.800	2004 : 2005	0.619
2005 : 2006	0.517	2005 : 2006	0.550
2006 : 2007	0.529	2006 : 2007	0.571
2004 : 2007	0.514	2004 : 2007	0.469

similar, again, both up- and downstream. BACI analysis (Table 9b, Appendix C) indicated Plecoptera richness was the only metric to change significantly in response to the habitat restoration, increasing both up- and downstream post-restoration (p= 0.078), though having only one downstream transect provided poor replication.

Milks Road - Fall

Overall mean fall macroinvertebrate abundance increased 298.6% pre- to post-restoration, from 892 ± 350.7 (mean ± 1 S.E.) to 3556 ± 499.9 individuals per m^2 (1-way ANOVA, p= 0.004) (Figure 2.4). EPT abundance and richness increased post-restoration

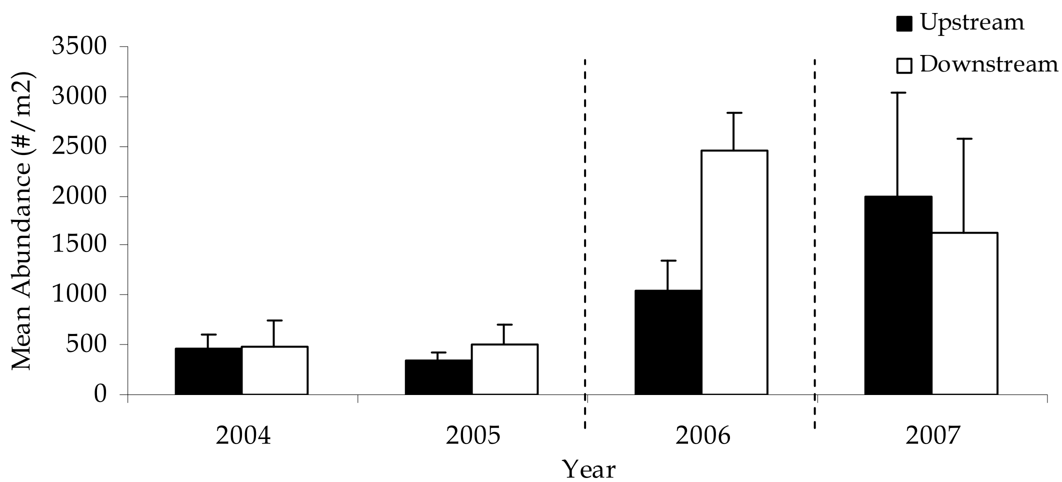

Figure 2.4. Mean fall macroinvertebrate abundance (#/m^2) for Milks Road on Bear Creek, Kaleva, MI. Left dashed vertical line signifies culvert removal, right dashed vertical line signifies upstream bank stabilization.

(1-way ANOVA, p= 0.037 and 0.001, respectively), while percent EPT did not change significantly (Table 12a, Appendix C). Mean taxa richness (sample mean, 1-way ANOVA, p< 0.0005) increased, while total taxa richness (whole site) did not change significantly post-restoration (Table 2.7). We also observed other community differences, such as the addition of several taxa (no taxa were lost when the whole reach was considered), including 7 families from Ephemeroptera, Plecoptera, and Trichoptera (Table 10, Appendix C).

Table 2.7. Average values for fall macroinvertebrate community metrics at Milks Road on Bear Creek, Kaleva, MI.

Reach		Simpson's Dominance	Shannon's Diversity	Total Richness	Mean Richness
US	Pre-Restoration	0.26	1.84	22.5	10.9
US	Post-Restoration	0.21	1.96	29.5	14.6
DS	Pre-Restoration	0.27	1.76	17.0	11.5
DS	Post-Restoration	0.21	1.92	22.0	18.2

Jaccard's Index values (Table 2.8) indicate 2004 and 2005 communities were the most similar, both up- and downstream, whereas 2004 and 2007 communities were the least similar, again, both up-and downstream.

Table 2.8. Fall Jaccard's Index values for Milks Road on Bear Creek, Kaleva, MI.

Upstream		Downstream	
Comparison	Jaccard's Index	Comparison	Jaccard's Index
2004 : 2005	0.800	2004 : 2005	0.619
2005 : 2006	0.517	2005 : 2006	0.550
2006 : 2007	0.513	2006 : 2007	0.517
2004 : 2007	0.500	2004 : 2007	0.469

Use of the BACI analysis (Table 12b, Appendix C) indicates none of the metrics used changed significantly in response to the habitat restoration, though having only one downstream transect provided poor replication.

<u>Swain's Property - Spring</u>

Due to the location of the restoration efforts at Swain's, there was no true up- and downstream designation, therefore, whole-site metrics were evaluated, including a modified design using the three upstream Milks Road transects as controls for the BACI analysis, with all 4 Swain's transects as experimental, or downstream, sites.

Overall mean spring macroinvertebrate abundance increased 71.3% pre to post-restoration, from 553 ± 70.5 (mean ± 1 S.E.) to 948 ± 203.9 individuals per m^2 (1-way ANOVA, p= 0.074), though there was a pronounced decline in 2007 (Figure 2.5).

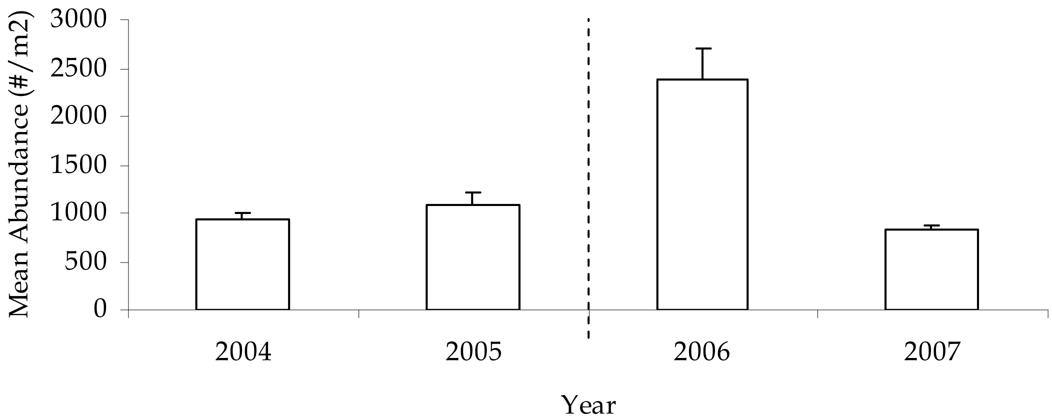

Figure 2.5. Mean spring macroinvertebrate abundance (#/m^2) for Swain's Property on Bear Creek, Kaleva, MI. Dashed vertical line signifies bank stabilization.

Percent EPT tended to increase post-restoration (1-way ANOVA, p= 0.149), though neither EPT abundance nor EPT richness changed significantly post-restoration (Table 15a, Appendix C). Neither total taxa richness (whole site) nor mean taxa richness (sample mean) changed significantly post-restoration (Table 2.9). We also observed other community differences, like the addition/loss of several taxa (Table 13, Appendix C), including the addition of four post-restoration EPT families, and the loss of seven

Table 2.9. Average values for spring macroinvertebrate community metrics at Swain's Property on Bear Creek, Kaleva, MI.

	Simpson's Dominance	Shannon's Diversity	Total Richness	Mean Richness
Pre-Restoration	0.19	2.02	18.8	10.8
Post-Restoration	0.25	1.82	20.5	10.7

other EPT families. Jaccard's Index values (Table 2.10) indicate 2004 and 2005 communities were the most similar, followed closely by 2006 and 2007 communities, whereas 2004 and 2007 communities were the least similar.

Table 2.10. Spring Jaccard's Index values for Swain's Property on Bear Creek, Kaleva, MI.

Swain's	
Comparison	Jaccard's Index
2004 : 2005	0.655
2005 : 2006	0.548
2006 : 2007	0.647
2004 : 2007	0.474

Use of the modified BACI analysis (with Milks US as the upstream transects; Table 15b, Appendix C) indicates Ephemeroptera and Plecoptera richness, and Plecoptera abundance were the only metrics to change significantly in response to the habitat restoration. Ephemeroptera richness decreased in the "control reach", while staying the same in the "impacted reach"; Plecoptera richness and abundance increased in the "control reach", while increasing (though not as much) in the "impacted reach" as well.

Swain's Property - Fall

Overall mean fall macroinvertebrate abundance did not change significantly pre to post-restoration, from 1086 ± 182.1 (mean ± 1 S.E.) to 1203 ± 249.2 individuals per m^2, though there was a pronounced decline in 2007, similar to spring values (Figure 2.6). EPT richness declined slightly from pre- to post-restoration (1-way ANOVA, p= 0.031)

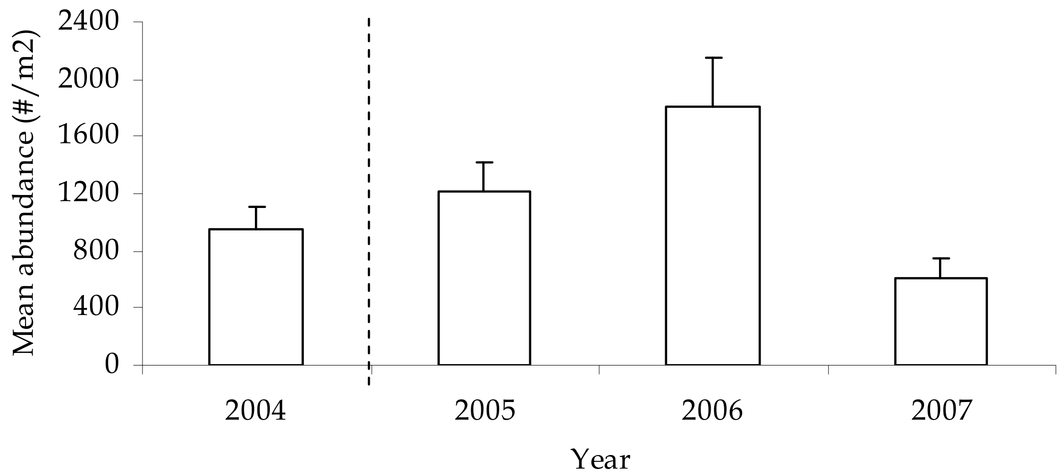

Figure 2.6. Mean fall macroinvertebrate abundance (#/m^2) for Swain's Property on Bear Creek, Kaleva, MI. Dashed vertical line signifies bank stabilization.

(Table 18a, Appendix C), though neither percent EPT nor EPT abundance changed significantly. Neither total taxa richness (whole site) nor mean taxa richness (sample mean) changed significantly post-restoration (Table 2.11). We also observed other community differences, like the addition/loss of several taxa, including the addition of five EPT families post-restoration, and the loss of five other EPT families

Table 2.11. Average values for fall macroinvertebrate community metrics at Swain's Property on Bear Creek, Kaleva, MI.

	Simpson's Dominance	Shannon's Diversity	Total Richness	Mean Richness
Pre-Restoration	0.17	2.11	35.0	14.7
Post-Restoration	0.20	2.03	29.7	15.9

(Table 16, Appendix C). Jaccard's Index values indicate 2005 and 2006 communities were the most similar, whereas 2004 and 2007 communities were the least similar (Table 2.12).

Table 2.12. Fall Jaccard's Index values for Swain's Property on Bear Creek, Kaleva, MI.

Swain's Comparison	Jaccard's Index
2004 : 2005	0.622
2005 : 2006	0.697
2006 : 2007	0.641
2004 : 2007	0.478

Use of the modified BACI analysis (with Milks US as the upstream transects, Table 18b, Appendix C) indicates EPT richness, Ephemeroptera richness, and Plecoptera richness were the only metrics to change significantly in response to the habitat restoration. EPT richness increased slightly in the "control" reach, while decreasing in the "impacted" reach; Ephemeroptera richness stayed the same in the "control" reach, while decreasing in the "impacted" reach; Plecoptera richness increased in the "control" reach, while staying the same in the "impacted" reach.

DISCUSSION

The River Continuum Concept (Vannote et al. 1980) seeks to explain variability along the longitudinal gradient of a stream by stating "…the structural and functional characteristics of stream communities are adapted to conform to the most probable position or mean state of the physical system." According to the authors, this implies rivers and streams are controlled by physical factors which change habitat and nutrient sources and conditions, in turn selecting for specific macroinvertebrate communities, all of which are predictable. It follows by improving the condition, and thereby function, of the substrate in our streams, the macroinvertebrate communities would respond in kind. In the course of this discussion, we will sometimes focus on observed trends as opposed to arbitrary statistical significance values, given the sometimes profound difference between ecologically substantive results and statistically significant results (*sensu* Yoccoz 1991, McBride et al. 1993, Johnson 1999, McBride 2002). The use of 0.1 vs. 0.05 as a significance cut-off is the alternative selected in this research project to accommodate this natural, inherent variability and yet provide for traditional null-hypothesis testing.

Sickle Creek

The springtime macroinvertebrate community showed direct responses to the changing sediment composition in the stream. Other studies have shown releases of impounded sediment can have negative effects on downstream macroinvertebrate communities (Thomson et al. 2005), which may explain the decrease in abundance observed in 2006; impounded sediment and construction spoils may have degraded the downstream reach in the short-term. Additionally, culverts themselves can impede upstream macroinvertebrate movement and colonization (Vaughan 2002, Resh 2004, Blakely 2006), hence the macroinvertebrate community may also have been subject to habitat constraints as a result of the old culverts on Sickle Creek. While the observed increase in abundance is important, it is crucial to note we also observed a community shift towards more sensitive taxa. For example, *Heptageniidae*, found post- restoration only, are known to prefer gravel or cobble substrate. *Hydropsychidae*, also found post-restoration only, are often used as an indicator species of good-quality water (Stuijfzand 1999). No increases in psammophilic taxa (i.e. *Chironomidae*) were observed, which would have had minimal beneficial effects for fish, nor would they have been indicative of a positive response. We also observed a significant increase in both total taxa richness and individual sample taxa richness. Of particular note is the increase in both abundance and richness of EPT taxa. In addition, diversity index measurements indicate a positive response to restoration. Increases in biodiversity of aquatic insects have been shown to be beneficial to ecosystems; for example, by accelerating the processing rate of leaf litter (Mikola and Setälä 1998, Jonsson and Malmqvist 2000). Increased biodiversity has also been shown to increase resistance to invasion (Tilman 1997). Spring surveys also showed several individual taxa exhibited dramatic changes. For example, downstream *Chironomidae* (spp.) density decreased, while upstream *Baetidae* (spp.) density increased. This decrease in fine sediment-tolerant organisms, coupled with an increase in fine sediment-intolerant organisms, suggests Sickle Creek is becoming a less-degraded system. We also saw some interesting trends in Jaccard's community similarity indices, indicating changes were occurring between 2005 and 2006, corresponding with restoration activities, with communities becoming more stable as time progressed post-restoration.

The autumn survey abundance numbers are of particular interest because they show very similar positive trends to the restoration, including strong increases in abundance and richness metrics. However, unlike the spring samples, abundance measurements were nearly identical between upstream and downstream reaches, until 2007. There are many possible interpretations including the possibility of a correlation between seasonal sediment data and macroinvertebrate abundance. Unfortunately, correlation analysis indicated no substantial relationships (r^2=0.16, 0.27), leading us to conclude patterns in sediment did not explain the up- downstream similarity in abundance, at least in the fall.

The strong increase in abundance following restoration, coupled with the community shifts towards more sensitive guilds suggests a positive response to restoration. Fine sediment suspension and deposition affects benthic macroinvertebrates in several ways, including the alteration of substrate composition and changing the suitability of the substrate for several taxa (Erman and Ligon 1988, Richards and Bacon 1994), and increasing drift due to sediment deposition or substrate instability (Rosenberg and Wiens 1978, Culp et al. 1983). Removing culverts which were prohibitive to flushing flows allows the stream to transport fine sediments further downstream and eventually out of the system. The disparity observed in pre-restoration spring sampling date (June 3, 2004; April 30, 2005 – 35 days) caused us to attempt to schedule subsequent spring collections (May 19, 2006; May 17, 2007) directly between the two previous collections, as we wanted to try to capture emergent and resident insect communities at the same stage every year.

In order to place the restoration of Sickle Creek in a larger ecological context, we compared some of our community metrics with those from other studies in similar systems. The highest density we sampled in Sickle Creek was 1180 individuals/m^2 (DS1, spring 2007). These numbers are quite low compared to other upper mid-west streams of similar size. For example, Augusta Creek, a 1st-order stream in southern Michigan, had 14000 to 34000 individuals/m^2 (Cummins and Klug 1979). Gould Creek, a 1st-order stream in Minnesota, had 9000 to 91000 individuals/m^2 (Schlosser and Ebel 1989), and Shane Creek, a 1st-order stream in northern Michigan, had 1799 to 48042 individuals/m^2 (Yamamuro and Lamberti 2007). Compared to Sickle Creek, these three streams, though similar geographically, possessed definitively higher quality substrate than does Sickle Creek, likely predisposing them for higher densities of macroinvertebrates. When compared to other sand-dominated streams, however, Sickle Creek compares slightly more favorably. Five un-named 1st-order streams near the campus of GVSU in southern Michigan had measured maximum densities of 1122, 1766, 2100, 2277, and 5711 individuals/m^2 (Snyder et al. 2008). It should be noted, however, these are extremely flashy systems severely degraded by stormwater inputs; they may have sandy substrates, but they also drain from very fine-textured (clay loam) watersheds with low baseflows, which is very different from Sickle Creek. Big Hurricane Branch, a 2nd-order stream in North Carolina, had an approximate maximum density of 900 individuals/m^2 following recovery from clear-cutting of the watershed (Gurtz and Wallace 1984). Seven Mile Creek, a 2nd-order stream in southern Michigan, had measured mean densities from 448.7 to 938.6 individuals/m^2 (Breen 2008). It is evident Sickle Creek is still a sediment-degraded stream, and has room to improve in terms of attaining macroinvertebrate densities comparable to other regional streams, especially those with higher quality substrate.

In terms of taxa richness, Sickle Creek appears to be quite diverse in its community assemblage, and fares better in cross-stream comparisons. Post-restoration values were observed as high as 20 separate taxa in a single Surber sample, and averaged 10.7 taxa. This compares very favorably to the five degraded GVSU ravine streams where highest richness sampled was 8 taxa, with an average of 5.1 (Snyder et al. 2008).

Bear Creek

The substantial and significant increase in springtime macroinvertebrate abundance at Milks Road is indeed encouraging, and likely indicative of a positive response to the restoration efforts. Of particular note is the fact the largest increase (+300%) was observed downstream of the new bridge. It is also important to note the largest increase in abundance took place between 2006 and 2007, following the bank stabilization and road paving, as fine sediments from vehicle traffic and rain-derived runoff from roads can be particularly detrimental to stream communities (Lane and Sheridan 2002, Sheridan et al. 2006). While the observed increase in abundance is important, it is again crucial to note we also observed a community shift towards more sensitive taxa; increases in burrowing taxa likely would have been neither beneficial to the fish community, nor indicative of a positive response. For example, *Perlidae* and *Tainiopterygidae*, found post-restoration only, are often used as indicators of good-quality water and well-oxygenated streams (Voshell 2002). In addition, *Hydroptilidae* caddisflies, also found post-restoration only, prefer coarse substrate on which to spin cases (Voshell 2002). As in Sickle Creek, we saw a post-restoration increase in abundance of EPT taxa at Milks Road, further suggesting a positive response of these sensitive taxa to restoration. This response is a bit confounded by the post-restoration decline in percent EPT and EPT richness, though these metrics may improve in time, as the stream substrate continues to improve and the community continues to change. We also observed a non-significant increase in both total taxa richness and individual sample taxa richness and, as noted above, given this improvement continues, there should be improvement in ecosystem functional metrics such as leaf litter processing and decomposition rates (Mikola and Setälä 1998, Jonsson and Malmqvist 2000), as well as enhanced nutrient spiraling, and resistence to invasion by exotic species (Tilman 1997). The community comparison indices indicate strong similarity pre-restoration, and also suggest the stream is still in flux, and has not yet attained a new dynamic equilibrium.

We also saw a substantial and significant increase in springtime macroinvertebrate abundance at Swain's Property, though not of the magnitude observed at Milks Road. Due to the proximity of the two sites, it is highly probable in-stream sediment transport and flow dynamic conditions with the new bridge at Milks Road impacted the sediment characteristics at Swain's, and as result, the macroinvertebrate community as well. It is possible the increase in abundance observed in 2006 was a response to the bank stabilization at Swain's, and the much lower abundance observed in 2007 was due to changing sediment characteristics, possibly transported sediment, due to upstream restoration practices. When all metrics studied at Swain's are considered, it is reasonable to conclude the macroinvertebrate community is still undergoing changes. When upstream and downstream sites are considered together, we observed mixed responses in all EPT metrics, and also in diversity, dominance, and richness metrics. It is possible some of the inconsistency in EPT response is actually indicative of greater responses in other taxa, as opposed to a lack of response by EPT taxa. Community similarity comparison suggests the macroinvertebrate community has continued to shift for nearly the entire duration of the study.

In order to place the restoration of Bear Creek in a larger ecological context, we compared some of our community metrics with those from other studies in similar systems. The highest densities we sampled at our sites on Bear Creek were 10528 individuals/m^2 at Milks Road (US2, fall 2007), and 4132 individuals/m^2 at Swain's (Swain 3, spring 2006). These sites compare favorably when considering other streams of similar substrate composition, such as Ottawa Creek, a 3^{rd}-order stream in southern Michigan, which had an average density of 9733 individuals/m^2 (Snyder et al. 2008). However, when we consider taxa richness, Bear Creek also compares more favorably, as did Sickle Creek. Milks Road and Swain's had maximum post-restoration richness values from 10 to 19 taxa per transect, and 11 to 21 taxa per transect, respectively, and average richness values of 12.7 and 12.3 taxa, respectively. Ottawa Creek had a maximum taxa richness of 10 taxa, and an average taxa richness of 6.7 (Snyder et al. 2008).

In conclusion, the overall increase at our sites in spring and autumn macroinvertebrate abundance, richness, and diversity is definitely encouraging. It appears our hypotheses are supported; we have observed increases in abundance and richness, and at several sites, notably the abundance and richness of the more sensitive EPT taxa. Stabilizing erosive banks and paving road approaches near streams helps decrease inputs of damaging fine sediments, and removing culverts which were constraining the natural flood pulse allows the stream to transport standing stocks of fine sediments further downstream and eventually out of the system. I feel it is necessary to continue monitoring the macroinvertebrate communities at these sites, in order to evaluate their context in a long-term plan which might better evaluate the long-term ecological response to restoration documented herein.

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CHAPTER III – Fish Community

ABSTRACT

Degraded systems can suffer impairment from a variety of pollutants, such as chemicals, runoff, thermal effluent, and sediment. In the case of the Big Manistee River and its tributaries, the cumulative effects of sediment loading and loss of large woody debris has led to a decline in the river's ability to maintain fish populations, both native and introduced. To quantify the response of the fish community to restoration, both single (Bear Creek) and triple pass (Sickle Creek) electrofishing was conducted in the spring and summer, from 2004-2007, with most restoration practices taking place in 2005. Pronounced changes were observed in Sickle Creek, a 1st-order tributary, including community composition changes like the loss of more robust taxa such as creek chub (*Semotilus atromaculatus*), brook stickleback (*Culaea inconstans*) and burbot (*Lota lota*), increased abundance of key recreational taxa, such as Chinook salmon (*Oncorhynchus tshawytscha*) and brook trout (*Salvelinus fontinalis*), and longitudinal distribution shifts of mottled sculpin (*Cottus bairdi*). Bear Creek, a 4th-order tributary, exhibited more subdued changes, though increased catch per unit effort for recreationally important taxa such as brown and rainbow trout (*Salmo trutta* and *O. mykiss*) was observed.

INTRODUCTION

In the case of the Big Manistee River and its tributary streams, the cumulative effects of sediment loading and loss of large woody debris has led to a decline in the river's ability to maintain its fish population (MRWI 2003). Populations of native fish (lake sturgeon (*Acipenser fulvescens*), burbot (*Lota lota*), and walleye (*Stizostedion vitreum*)), not currently bolstered by hatchery stocks, require improved conditions (spawning locations, nursery and juvenile habitat) to assure continued sustainability. Work by Kock et al. (2006) suggests sediment cover may be an important early life-stage mortality factor for sturgeon in rivers like the Big Manistee where they may spawn over fine-grained substrates. High levels of suspended fine sediment, carried by high discharge, have also been found detrimental to walleye larvae survival (Mion et al. 1998).

In addition to native fish, the Big Manistee also supports a bountiful fishery for stocked non-native rainbow and brown trout (*Oncorhynchus mykiss* and *Salmo trutta*), as well as Chinook and Coho salmon (*O. tshawytscha* and *O. kisutch)* (Rozich 1998). The fishery in the Big Manistee below Tippy Dam generates an estimated $2.5 million dollars each year from sportfishing expenditures, focused almost exclusively on trout and salmon, and the Manistee River below Tippy Dam is one of the most heavily utilized and economically valuable fisheries in the state of Michigan (Tonello 2004). The detrimental effects of surficial fine sediments on salmon and trout egg survival is well known (Reiser and White 1988, Platts et al. 1989, Suttle et al. 2004), though many people fail to consider the negative impacts of suspended fine sediments on recruitment and survival of trout and salmon fry (Bisson and Bilby 1982, Barrett et al. 1992, Korstrom and Birtwell 2006).

In this study, we analyzed the fish community response to fine sediment abatement techniques, specifically described in Chapter I, in a first-order and fourth-order stream, Sickle Creek and Bear Creek, respectively—both tributaries to the Lower Big Manistee River.

HYPOTHESES

A-priori hypotheses were as follows:

1. The fish community would respond to the changing substrate, as well as the anticipated shift in the insect community.

2. With the removal of fish migration barriers (e.g. perched culverts), I expected the longitudinal distribution of fish to change.

3. With the anticipated reduction of sand, I expected different fish species to dominate where we see a rapid and significant change in sediment characteristics. I anticipate more environmentally tolerant species, such as creek chub, will be replaced by more obligate cool-water species such as sculpin and brook trout, species more suited to cool streams with higher quality substrate.

4. I also anticipate higher community densities (more fish) in response to better available habitat.

METHODS

Five electrofishing reaches were established at the Sickle Creek site: two up- and three downstream (100m each, with 100m between each, in accordance with the USEPA Rapid Bioassesment Protocol (RBP) of 40x mean stream width (Flotemersch and Cormier 2001)) (Figure 4.3a, Chapter IV). Multi-pass technique (in 2004, 2006, and 2007) or 1-pass (in 2005) was used, with blocker nets placed across the stream for multi-pass sampling. A Smith-Root backpack (Model 15-C [2004-2006], Model LR-24 [2007]) unit with pulsed DC current was used. On Bear Creek, 400m reaches (USEPA RBP) were established as follows: at Leffew Road, 1 downstream of the bridge; at Milks Road, 1 up- and 1 downstream of the bridge (Photo 1, Appendix A); at Swain Property, 2 reaches with 100m in between (Photo 2, Appendix A); at Spirit of the Woods, 2 reaches with 100m in between ending at the bridge; at Lower Bear, 2 sites with 100m in between, ending at the upstream habitat transect. Electrofishing on Bear Creek was single-pass, performed with a Smith-Root tote barge (Model SR-6, 5.0 GPP electrofisher). The upstream reach at Milks Road was shifted further upstream in spring 2006 to alleviate conflict with a landowner. All fish collected were identified to species, measured for length and weight, and released. CPUE was calculated as the number of fish captured per minute of effort. Water quality (temperature, dissolved oxygen, specific conductivity, turbidity, pH) and discharge data were also collected during each electrofishing session using a YSI multimeter (YSI Incorporated, Yellow Springs, OH), and discharge data were collected using a Marsh-McBirney Flo-Mate and Marsh rod (Hach/Marsh-McBirney, Frederick, MD).

STATISTICS

The initial design called for use of MANOVA in a BACI (before-after, control-impacted) design. Unfortunately, experimental effects were felt at upstream transects in proximity to the restoration sites, and also at other experimental sites longitudinally downstream from restoration sites, confounding the BACI analysis. Therefore, 1-way ANOVA was also used, with the following variables for both analyses: CPUE for individual species, species richness, Simpson's Dominance Index, and Shannon's Diversity Index (community metrics were calculated for each reach) were used as the dependent variables, and pre-restoration/post-restoration and upstream/downstream were used as independent variables. The disadvantage of the 1-way ANOVA is by simply comparing pre- to post-restoration communities, we may lack the capacity to truly know if the observed changes are due to natural variability or effects of the restoration. All analyses were performed using SPSS 14.0 (SPSS, Chicago, IL). As the use of null-hypothesis statistical testing is entrenched in the minds of environmental researchers, it would be difficult to disseminate our findings without its use. However, too stringent an application (i.e. too small a *p*-value) might preclude effective conservation of precious resources. To that end, statistical significance was set at a *p*-value of 0.1. By increasing the level of significance, we increase the chances of making a Type I error, decreasing the chances of making a Type II error, essentially increasing statistical power.

RESULTS

Sickle Creek

The fish community changed dramatically in Sickle Creek following culvert replacement, as did the distribution of some species relative to the road crossing. Jaccard's Index of community similarity (C_J; hereafter referred to as Jaccard's Index) indicated fish communities in spring 2004 and 2007 were only 45.7% similar, and fall 2004 and 2007 were 49.8% similar. While the dominant species (mottled sculpin, *Cottus bairdi*) has not changed, many of the other species initially sampled have diminished significantly or disappeared altogether; several species (creek chub *Semotilus atromaculatus*, brook stickleback *Culaea inconstans*, northern redbelly dace *Phoxinus eos*, burbot *Lota lota*) are either rarely found or are now absent from Sickle Creek (Table 1, Appendix D). Distribution of fish relative to the road crossing has also changed post-restoration (Figure 3.1), with the percentage change (calculated as: (final-initial)/initial) of total fish captured in each reach as follows: US2: +33.3%, US1: +173.9%, DS1: -45.2%, DS2: -28.2%, DS3: -6.1%.

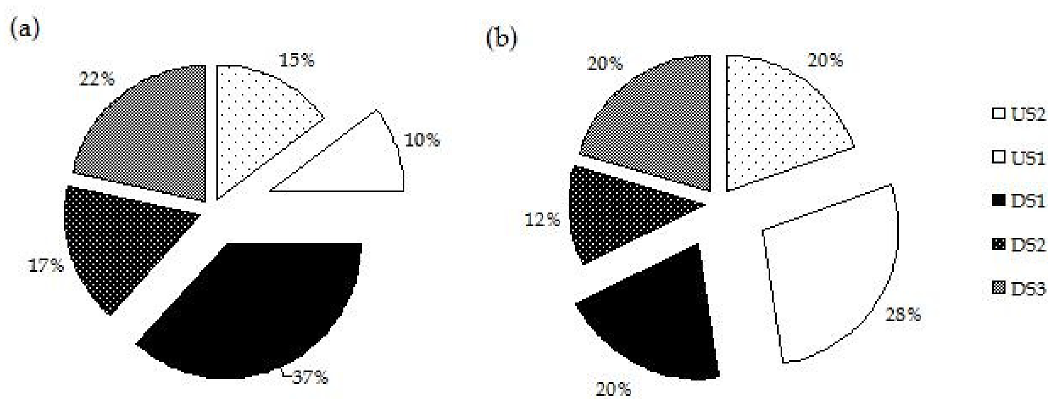

Figure 3.1. Percentage of all fish captured pre-restoration (a) versus post-restoration (b) by reach on Sickle Creek, Manistee Co., MI.

Overall CPUE (pooled for all species) decreased significantly post-restoration (p= 0.067), from 4.1 ± 2.8 fish/minute (mean ± 1 S.E.) to 2.8 ± 1.1, though much of the pre-restoration catch (mean 13.6% of total pre-restoration catch) was made up of those species now absent from the creek. The CPUE of some taxa such as Chinook salmon is significantly higher post-restoration (p= 0.029). For example, Chinook CPUE (mean spring post-restoration) increased to 1.97 from a mean pre-restoration level of 0.59 (Figure 3.2). A general decrease in species diversity (Shannon's Diversity Index), and an increase in dominance (Simpson's Dominance Index), was observed from pre- to post-

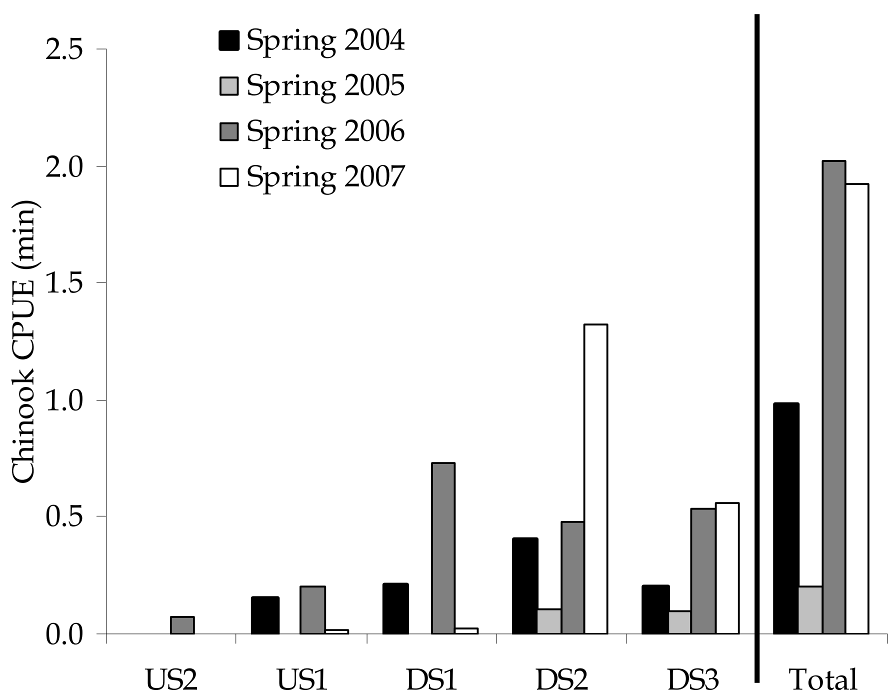

Figure 3.2. Chinook salmon catch per unit effort (CPUE (per minute)) for all electrofishing reaches, and the total for all reaches, by year, on Sickle Creek, Manistee Co., MI. Habitat restoration took place between spring 2005 and spring 2006.

restoration (Table 2a, b, Appendix D). The fish community in this stream appears to be dominated numerically by mottled sculpin, and Simpson's dominance values for the system correspond strongly to the percent relative abundance of mottled sculpin, with regression of these points showing strong correlation (r^2= 0.71, p= 0.005). Population estimates for mottled sculpin (Figure 3.3) show a strong positive response following restoration. Mottled sculpin have also dramatically shifted their distribution post-

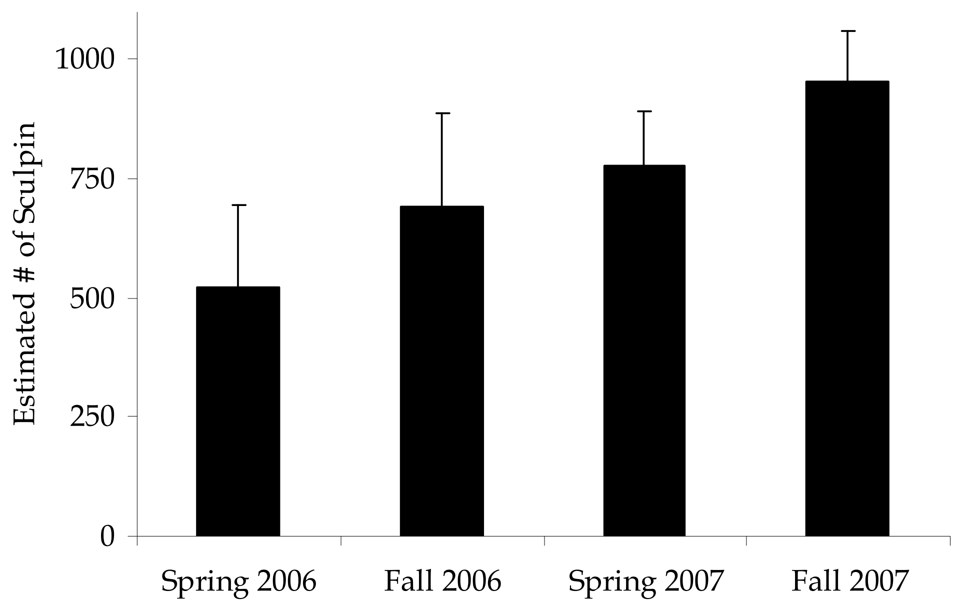

Figure 3.3. Post-restoration population estimates for mottled sculpin, pooled for all five electrofishing reaches, with 95% confidence interval. Data is for Sickle Creek, Manistee Co., MI.

restoration, with the majority now inhabiting the reach upstream from the crossing, whereas before, more were typically found downstream of the culvert (Figure 3.4).

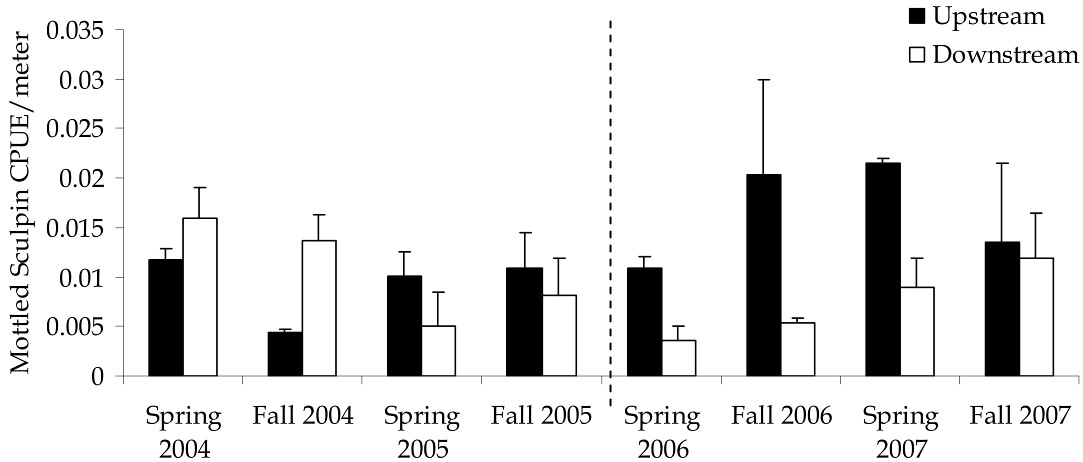

Figure 3.4. Mean mottled sculpin CPUE (minute) per meter sampled, for upstream (n=2) and downstream (n=3) reaches by season, on Sickle Creek, Manistee Co., MI. Vertical dashed line represents habitat restoration.

Use of the BACI analysis (Table 3, Appendix D) indicates overall CPUE, sculpin CPUE, and burbot CPUE were the only metrics to change significantly in response to the habitat restoration; CPUE was nearly identical post-restoration, whereas pre-restoration, DS CPUE was nearly 3x higher than US; sculpin CPUE nearly doubled upstream post-restoration, and decreased slightly downstream post-restoration; burbot CPUE did not change upstream, but decreased downstream post-restoration.

Bear Creek

Milks Road

There were several fish community changes following culvert replacement at Milks Road (Table 4, Appendix D), including increases in relative abundance of rainbow trout, mottled sculpin, and brown trout, and decreases in relative abundance of white suckers, burbot, and creek chub. Total CPUE (all species pooled) increased significantly following restoration, as did CPUE's for brown trout, rainbow trout, and johnny darters (*Etheostoma nigrum*, Table 3.1). Shannon's Diversity Index values at Milks Road were consistently higher downstream of the road-crossing, though there were no statistically significant differences pre to post restoration, nor were there any other apparent trends (Table 5, Appendix D). Simpson's Dominance Index values at Milks Road were consistently lower downstream, though there were no significant differences

Table 3.1. Mean pre- and post-restoration (and standard error), percent change, and *p*-value for CPUE (minute) for all species, brown trout, rainbow trout, and johnny darters at Milks Road (pooled between reaches) on Bear Creek, Kaleva, MI.

	Pre		Post			
Variable	Mean	SE	Mean	SE	% Change	*p* -value
All Species	5.06	0.88	9.71	1.77	92%	0.031
Brown Trout	0.17	0.02	0.40	0.07	132%	0.007
Rainbow Trout	1.13	0.32	2.50	0.50	121%	0.040
Johnny Darter	0.27	0.08	1.02	0.26	277%	0.011

pre- to post-restoration, in addition to species richness significantly higher post-restoration for both up- and downstream reaches (Table 5, Appendix D).

Use of the BACI analysis indicated johnny darter CPUE was the only metric to change significantly in response to the habitat restoration, increasing 5x upstream and 3x downstream post-restoration.

Swain's Property

There were several fish community changes following streambank stabilization at Swain's Property (Table 7, Appendix D), including increases in relative abundance of rainbow trout and brown trout, and decreases in relative abundance of blacknose dace

(*Rhinichthys atratulus*), white suckers (*Catostomus commersonii*), burbot, johnny darters, and creek chub. At Swain's Property, overall CPUE increased slightly (though non-significantly); only rainbow trout CPUE increased significantly pre- to post restoration, though there was a nearly significant increase in brown trout CPUE, while blacknose dace showed a significant decrease (Table 3.2). Shannon's Diversity Index values at Swain's were slightly higher, on average, following restoration, and the difference was significant for the upstream reach (Table 8, Appendix D).

Table 3.2. Mean pre- and post-restoration (and standard error), percent change, and *p*-value for CPUE (minute) for all species, brown trout, rainbow trout, and johnny darters at Swain's Property (pooled between reaches) on Bear Creek, Kaleva, MI.

	Pre		Post			
Variable	Mean	SE	Mean	SE	% Change	*p*-value
All Species	6.21	1.16	7.65	1.16	23%	0.426
Brown Trout	0.13	0.07	0.40	0.12	210%	0.104
Rainbow Trout	0.86	0.31	2.85	0.51	233%	0.020
Blacknose Dace	2.71	0.81	1.35	0.28	-50%	0.100

Use of the BACI analysis (Table 9, Appendix D) indicated none of the metrics changed significantly in response to the habitat restoration.

<u>Longitudinal Profile</u>

In order to get a better understanding of the fish communities in Bear Creek, a longitudinal comparison was performed, using Jaccard's Index. When the 2007 data was examined (Table 3.3), Leffew and Lower Bear were the least similar, while Milks/Swain and Spirit of the Woods were the most similar. Species richness and diversity were highest in the mid- to lower reaches of the stream (Table 3.4).

Table 3.3. Longitudinal comparison of community similarity using 2007 electrofishing data from Bear Creek, Kaleva, MI.

Comparison Sites	Jaccard's Index (C_J)
Leffew : Milks/Swain	0.480
Leffew : S of W	0.545
Leffew : L Bear	0.450
Milks/Swain : S of W	0.621
Milks/Swain : L Bear	0.500
S of W : L Bear	0.500

Table 3.4. Longitudinal comparison of species richness and diversity from upstream to downstream, using 2007 electrofishing data from Bear Creek, Kaleva, MI.

Site	Species Richness	Shannon's Diversity Index
Leffew	12	1.98
Milks/Swain	25	1.90
S of W	22	2.44
L Bear	17	2.32

DISCUSSION

The River Continuum Concept (Vannote et al. 1980) seeks to explain variability along the longitudinal gradient of a stream by stating "…the structural and functional characteristics of stream communities are adapted to conform to the most probable position or mean state of the physical system." According to the authors, this means rivers and streams are controlled by physical factors which change chemistry, nutrient sources, and physical processes, in turn selecting for specific fish communities, all of which are predictable. This would lead us to suggest by improving the condition, and thereby function, of the sediment in our streams, the fish communities would respond in kind. In the course of this discussion, we will often be focusing on observed trends as opposed to true statistical significance, given the sometimes profound difference between ecologically substantive results and statistically significant results (*sensu* Yoccoz 1991, McBride et al. 1993, Johnson 1999, McBride 2002). Our use of 0.1 as a significance cut-off will also facilitate adhering to the convention of null-hypothesis significance testing, while still achieving more plasticity in the rigid interpretation of such statistical tests.

Sickle Creek

The fish community showed direct response to the changing sediment composition in the stream, in contrast to the findings of similar studies, where no direct responses were observed (Wellman et al. 2000). Prior to restoration, the five most abundant fish in Sickle Creek were mottled sculpin, Chinook salmon, rainbow trout, burbot and the American brook lamprey (*Lampetra appendix*), with creek chub and stickleback also present in large numbers. Following restoration, mottled sculpin increased dramatically, both numerically and in dominance. Our population estimates for mottled sculpin show a strong post restoration increase in the number of individuals in the stream, though it is difficult to determine the origin of these additional individuals. They may have arrived as the result of increased recruitment success, immigration from upstream, or immigration from the mainstem of the Big Manistee. It is likely the population has increased in response to several interconnected changes in the stream: reconnection to more suitable upstream habitat (see Chapter IV), decrease in overall fine sediment depth, increased macroinvertebrate density (see Chapter II), and decreased competition from other species. We believe many of these observed changes are linked to the dramatic change in substrate and channel profile (see Chapter I). The downstream reaches, especially near the confluence with the Big Manistee, are much shallower and have higher velocities post-restoration, possibly due to modification of the stream channel as a result of mass-transport of sand through the stream. This is allowing coarser substrate to dominate upstream, while at the same time possibly precluding species more suited to slower, deeper, or slightly warmer water. I speculate decreases in fine sediment may increase groundwater percolation, possibly lowering stream temperatures, though perhaps minimally. In addition to lower diversity (Shannon's index), overall species richness has declined as well, suggesting a more specialized community, better suited to cool, clear, shallow water (*sensu* Schlosser 1982). Specifically, the taxa which have been lost are not limited to cold, clear water, having higher tolerances for warmer and more turbid conditions. For example, creek chub are more adept at foraging at higher temperatures than are several of their trout cohorts (Taniguchi et al. 1998). The significant increase in CPUE for Chinook salmon (parr) suggests increased use of this stream for rearing habitat; anecdotal evidence also suggests Coho salmon still spawn in this stream (personal observation, October 2007), and salmon carcass counts have increased upstream from the bridge post-restoration (M. Holtgren, personal communication), suggesting the reach may be relatively more important as spawning habitat.

The fish community also appears to have responded directly to the removal of the culverts themselves, in addition to the improved substrate condition. Pre-restoration, 75% of the fish captured were downstream of the bridge, while post-restoration, only 52% were captured downstream. The fact we sampled 600m downstream and only 400m upstream further indicates a major shift in community distribution. In particular, DS1 and US1 showed the most dramatic changes.

We have documented a large redistribution of fish following restoration, followed by a steady decline in the rate of redistribution as the upstream reaches approached saturation. The fish now have unimpeded access to over 1 km of stream habitat, roughly half of which was unavailable pre-restoration. Other studies have shown swift and dramatic response to habitat reconnection (Iversen et al. 1993, Bryant et al. 1999, Glen 2002, Poulakis et al. 2002, Raposa 2002), likely the result of the removal of density-dependent constraints like habitat availability and access to forage. Rapid colonization of reconnected habitat is a predictable response, especially if the new habitat is of higher quality, can support more organisms, or if it provides better foraging opportunities or relief from predation. Dingle (1996) suggests long-distance movement may cease when patches with suitable resources are encountered.

In order to place the restoration of Sickle Creek in a larger ecological context, we compared some of our community metrics with those from other studies in similar systems. Species richness in the first four sampling seasons post-restoration in Sickle

Creek ranged from 10 to 13, which compares favorably to other small streams: Seven Mile Creek, a 2nd-order creek in southern Michigan had 10 species (Breen et al. 2009), Martis Creek, a 1st-order creek in California had 12 species (Moyle and Vondracek 1985), and the average richness of several 1st-order streams in coastal South Carolina was 12.7 (Paller 1995).

Bear Creek

The fish community at our sites on Bear Creek also showed a positive response to restoration, though considerably less dramatic than what was observed at Sickle Creek. At Milks Road, an increase in overall CPUE, as well as CPUE for rainbow trout, brown trout, and johnny darters is encouraging, as was the post-restoration increase in rainbow trout CPUE at Swain's. Rainbow and brown trout are important species, both to recreational and tribal anglers, hence the observed post-restoration increase in their abundance is important. It is possible the increased abundance was related to increased forage, as we observed post-restoration increases in the abundance of macroinvertebrates at these sites as well (see Chapter II). Conversations with landowners, several of whom are anglers, suggest they were happy to allow the restoration to take place on or near their property, and were happy to hear about a positive fish community response to restoration. In addition, studies have shown positive economic benefits for landowners permitting streambank stabilization activities on their property (Williams et al. 2004) as a result of increased property value, and increased recreational benefits.

The magnitude of differences seen in pre- to post-restoration species richness for these sites is possibly the product of different shocking crews, with longer shocking times post-restoration. Sampling effort (distance or time) affects the proportion of the assemblage which is sampled at any point along a stream, hence the amount of the assemblage sampled is likely to increase with a corresponding increase in effort (*sensu* Paller 1995, Cam et al. 2002). It is also possible the shifting of the upstream Milks Road site resulted in different catch data.

From up to downstream, the fish communities were least similar at Leffew and Lower Bear—as predicted given these two sites were the most spatially separated. Higher species richness and diversity in the mid- to lower reaches is also not unexpected, and is predicted by the RCC (Vannote et al. 1980, Schlosser 1982).

In order to place the restoration of Bear Creek in a larger ecological context, we compared some of our community metrics with those from other studies in similar systems. Species richness at the two sites in the first two summers following restoration ranged from 15 to 21, with a total richness of 26 species when all reaches were pooled. The average richness of several 4th-order streams in coastal South Carolina was 22 species (Paller 1995). Snodgrass and Meffe (1998) collected a maximum of 26 species in 3rd-order streams in South Carolina, where one would predict comparatively higher richness given the southern climate.

In conclusion, it appears the habitat restoration has had the desired effects on Sickle Creek; reduction of fine-sediment inputs and improvement of in-stream sediment transport has improved the substrate quality, benefited the macroinvertebrate community, and the fish community appears to have responded with the loss of sediment-tolerant taxa and an increase in sediment-intolerant taxa. Many of our initial hypotheses were supported – we observed (1) shifts in distribution due to culvert removal; (2) community changes, including the loss of sediment-tolerant species; (3)

increases in abundance of several taxa. The results in Bear Creek are perhaps not as dramatic, which is not unexpected given the larger size of the system relative to Sickle Creek. In addition, substrate quality was much higher to begin with in Bear Creek. However, the minor improvements in the substrate and the macroinvertebrate community may certainly be linked to the improvements observed in the fish communities. We predicted the larger system would take more time to respond simply because the scope of the restoration projects was much smaller when placed in the context of the size of the watershed. Therefore, it is likely the response trajectory of the fish community in Bear Creek is still largely in flux and thus, like the macroinvertebrate community, more time is needed to establish a new dynamic equilibrium.

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Chapter IV – Sculpin Movement and Habitat Use

ABSTRACT

Man-made barriers, such as dams and improperly designed culverts, are often highly restrictive to fish passage. As part of a much larger watershed-scale habitat restoration and monitoring project, undersized and perched culverts were replaced with an open bottom bridge on Sickle Creek, a 1st-order tributary of the Big Manistee River. Following comparison of the fish community pre- to post-restoration, we observed a significant portion (29%) of the mottled sculpin (*Cottus bairdi*) population redistributed upstream of the new bridge, potentially moving substantial distances. We hypothesize barrier removal resulted in rapid density-dependent upstream migration and dispersal. To better understand the redistribution, an extensive habitat analysis was performed including stream substrate evaluation and macroinvertebrate sampling. To analyze post-restoration movement and habitat use, 95 mottled sculpin were collected by single-pass electrofishing, and were measured, weighed, and injected with a Passive Integrated Transponder (PIT) tag. Fifty-two mottled sculpin were relocated a total of 116 times over a one-year period. Although most fish moved less than 25m between relocations, a subset of the population exhibited substantial movement (up to 839m). These results suggest fish response to restoration via reconnection is an important mechanism aiding in fish community recovery, and also suggest previous research may have underestimated potential mottled sculpin movement.

INTRODUCTION

When compared to other types of road-stream crossings, culverts can act as barriers to juvenile and small-bodied fish movement, even at low flow. The degree to which a crossing acts as a barrier is related to alteration of flow through the crossing. Crossings which substantially increase the flow (culverts) are much more restrictive to fish movement than are those which allow more natural flow (open-box). Culvert crossings have the highest mean velocities and lowest fish passage, whereas open-box crossings have the lowest mean velocities and highest fish passage (Warren and Pardew 1998). For certain species, culverts may allow migratory activity only during certain years, thereby negatively affecting localized populations (Toepfer et al. 1999). For example, Stockard and Harris (2005) found low flow through a perched box-culvert prohibited salmonid passage in certain years. Conversely, in the case of non-perched culverts, low flow might actually allow for the movement of weaker-swimming species (i.e., darters and sculpin). Weak-swimming species, like mottled sculpin (*Cottus bairdi*), are generally more abundant downstream of culverts, sometimes more than twice as abundant (Cahoon et al. 2005), generally a result of net downward movement of fish which cannot move back upstream. This may be attributed to several factors, including higher flows associated with culverts, perched culverts acting as barriers to migration, and reportedly minimal longitudinal movement of mottled sculpin.

Mottled sculpin are numerically dominant in many streams, and provide an important food-web link for many larger stream fishes, including centrarchids and salmonids (Stewart et al. 1981, McNeely et al. 1990). They are considered a weak-swimming species (Behlke et al. 1991) and can therefore be negatively impacted by poorly-designed road-stream crossings.

Sickle Creek is a 1st-order tributary of the Big Manistee River, which is in turn a tributary to Lake Michigan. The perched and undersized culverts at this crossing were replaced in October 2005, as part of a much larger watershed-scale habitat restoration and 5-year pre- and post-restoration monitoring study performed in partnership with the Little River Band of Ottawa Indians and Grand Valley State University.

In the first sampling season following restoration on Sickle Creek (spring 2006), we observed a 31% increase in mottled sculpin distribution upstream from the bridge, relative to pre-restoration data. The impetus for the movement study presented herein was the dramatic change in mottled sculpin distribution, likely in response to the restoration efforts, and the magnitude of movement deemed necessary to facilitate such dispersal. Petty and Grossman (1996, 2004) found mottled sculpin movement and habitat selection to be size-dependant; larger fish moved less than smaller fish, and selected more beneficial habitat patches. The objectives of this study were to: (1) quantify mottled sculpin dispersal and seasonal movements in a newly reconnected system, and (2) determine possible explanations for mottled sculpin population re-distribution following culvert replacement and the resultant habitat reconnection.

HYPOTHESES

A-priori hypotheses were as follows:

1. Redistribution is density-dependent. Therefore it follows the number of sculpin moving should maximize immediately following reconnection and then decline as preferred habitat is colonized. Similarly, it follows as preferred habitat is colonized the distances moved by individual fish should increase in the search for open and/or preferred habitat.
2. Sculpin will prefer areas of habitat with more undercuts and large logs, assuming competition for preferred space does occur among sculpin.

METHODS

Telemetry Study

The following sampling design conformed to electrofishing reaches established pre-restoration (Figure 4.1a). The study reach (Figure 4.1b) was 800m long, with five

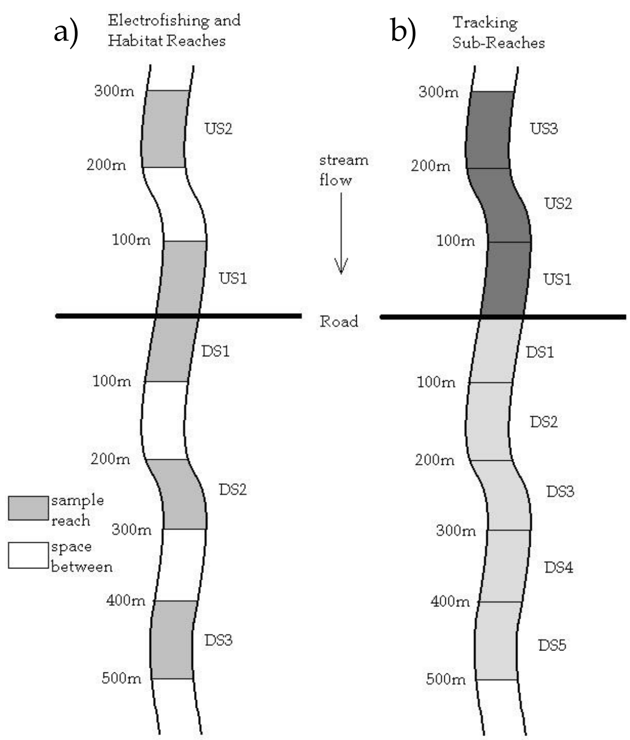

Figure 4.1. Electrofishing and habitat analysis reaches (a), and PIT tagging and tracking sub-reaches (b) from Sickle Creek, Manistee Co., MI.

100m "sub-reaches" downstream of the road stream crossing, and three upstream. Extra sub-reaches were studied downstream because it was anticipated the pre-restoration effects of the culvert would extend further downstream than upstream. An additional 50-100m upstream and downstream of the original study reach was searched to expand the area sampled post-restoration. Mottled sculpin were collected in April 2007 by single-pass electrofishing each 100m sub-reach with a Smith-Root backpack (Model 15-C). To test the possibility of size-dependant movement in this system, individual fish weight, total length, and head width were measured. Individual fish were selected for tagging based on size, as larger individuals were easier to handle and accommodated Passive Integrated Transponder (PIT) tags more successfully (Breen et al. 2009). The goal was to have equal numbers of individuals from upstream and downstream reaches, but an unsatisfactory number of adequately sized mottled sculpin were captured upstream of the bridge, resulting in 45 fish tagged upstream, and 50 tagged downstream. All mottled sculpin were injected with a 12.0 x 2.1mm PIT tag (Model TX-1411-SST, Biomark, Boise, Idaho) by using a 12-gauge hypodermic needle according to the protocol used by Ruetz et al. (2006) and released immediately at a known and recorded point in the sub-reach from which they were initially captured. Tagged individuals were searched for every 2-4 weeks from May - August 2007, and again with single-search events in October 2007 and January, March, and May 2008. Searches were performed using a 30.5cm waterproof multi-directional antenna with 2.4m pole and belt system (Biomark, Boise, Idaho). When located, tagged individuals were identified using the PIT code, location habitat type was identified (as undercut, log, or debris), and GPS coordinates were taken using a handheld unit (Garmin GPS III), with typical accuracy measurements ranging from 6 to 15m. GPS points were differentially corrected post-collection using an internet-based provider (www.ngs.noaa.gov/CORS) to sub-meter accuracy and precision (August et al. 1994). During one sampling event (August 15, 2007), the study reaches were mapped using a Trimble GPS data logger (Trimble Navigation Solutions, Sunnyvale, CA). Water temperature was measured at the bridge using a YSI multimeter (YSI Incorporated, Yellow Springs, OH) during each relocation attempt.

Habitat Analysis

As part of a different project (K. Nault M.S.), detailed habitat analysis was performed in 5 of the 8 100m sampling sub-reaches (Figure 4.3a) in June – August 2007, according to the protocol laid out in Simonson et al. (1994). The five habitat sampling reaches were selected to correspond to the five electrofishing reaches from the larger restoration and monitoring project, and were used to approximate available habitat for sculpin in this study. Habitat variables were measured using 13 evenly spaced transects per 100m sampling sub-reach. Surficial substrate type was visually estimated to the nearest 5% using the following variables: sand, silt, clay, fine gravel, coarse gravel, very small woody debris (<2″ diameter), small woody debris (2-4″), medium woody debris (4-6″), large woody debris (>6″), and vegetation. Fine sediment depth was measured with a steel probe pushed into the sediment. Bank stability was visually estimated and scored on the following scale: 1 - <25% of bank is bare soil; 2 – 25-50% of bank is bare soil; 3 – 50-75% of bank is bare soil; 4 – 75-100% of bank is bare soil. Additional metrics measured included channel width and depth, water velocity (measured using a Marsh-McBirney Flo-Mate and Marsh rod; Hach/Marsh-McBirney, Frederick, MD), amount of overhead fish cover (in the form of tag-alder clumps or large woody debris), number and depth of undercut banks, and the water depth at each undercut bank. In addition to habitat data, quantitative macroinvertebrate samples were collected using Surber nets (0.09 m^2, 234 μm mesh) in spring and fall of 2004-2007 (see Chapter II). Macroinvertebrate abundance data are re-presented here as it was proposed macroinvertebrate availability may affect sculpin foraging, and therefore their distribution. Single- and multi-pass backpack electrofishing were also performed as part of the annual restoration monitoring, and first-pass mottled sculpin CPUE data for those surveys are presented here, as are mottled sculpin population estimates (techniques described in Chapter III).

ArcMap (Version 9.2, ESRI, 2006) was used for analysis of the GPS data. Base maps were produced using digital orthophotographs, and road and hydrology shapefiles downloaded from the State of Michigan Spatial Data Library. Differentially-corrected GPS points were entered into ArcMap in X-Y format, and then distances were measured between points on the stream using the Measure tool. All distances moved were measured along the stream channel and recorded as positive distances, with direction (upstream, downstream – US/DS) noted.

STATISTICS

For analysis of mottled sculpin length, head width, and weight measurements, normality of size data was confirmed using residual plots. Individual sub-reaches were used as the experimental unit for our analysis. One-way ANOVAs were used to test for size differences related to initial capture sub-reach and to movement distance and direction, to test differences in 17 habitat variables among sub-reaches, and to test for differences between the percent of mottled sculpin captured upstream versus downstream, pre- versus post restoration. All statistical analyses were performed using SPSS 14.0 (SPSS, Chicago, IL).

RESULTS

Following culvert removal and bridge installation, comparison of the fish community in Sickle Creek revealed a dramatic distribution shift in the mottled sculpin population. Pre-restoration, 31% of mottled sculpin, on average, were captured upstream of the culvert, while post-restoration, 58% of sculpin, on average, were captured upstream. This difference was significant (1-way ANOVA, p-value: 0.02). Measures of mottled sculpin CPUE per meter sampled indicate higher use of upstream reaches following culvert removal (Chapter III, Figure 3.4), especially in the first three seasons post-restoration. In addition, population estimates calculated for mottled sculpin show a strong increase post-restoration (Chapter III, Figure 3.3).

Of the 95 mottled sculpin initially tagged (50 DS, 45 US), seven dropped tags were located, leaving 88 tagged individuals for relocation (47 DS, 41 US). Fifty-two sculpin (59.1%) were relocated a total of 116 times, as some were relocated more than once. Twenty-six individuals were relocated a total of 62 times upstream of the bridge, while 26 were relocated a total of 54 times downstream of the bridge (Table 4.1).

Table 4.1. Number and density of PIT-tagged mottled sculpin and relocations in up- and downstream sections for all sampling events post-restoration in Sickle Creek, Manistee Co., MI.

	Upstream (350m)		Downstream (600m)	
	#	#/m	#	#/m
Fish	26	0.074	26	0.043
Relocations	62	0.177	54	0.090

Mottled sculpin initially captured upstream and those initially captured downstream moved similar linear distances on average (US: 110 ± 73.7m, DS: 106 ± 59.8m), though there was high variability in these measurements (Table 4.2). The maximum linear

Table 4.2. Number of fish relocated (n), total number of relocations (N), and mean and std. error for linear movement distance based on initial capture reach for PIT-tagged mottled sculpin, post-restoration, in Sickle Creek, Manistee Co., MI.

Initial Capture Reach	n	N	Mean Distance Moved (m)	Standard Error
US3	7	18	25.1	10.9
US2	9	32	169.1	96.4
US1	7	12	135.3	73.7
DS1	6	9	118.5	35.3
DS2	4	7	26.0	15.2
DS3	4	11	179.0	147.5
DS4	8	16	27.1	8.3
DS5	7	11	177.3	92.6
Total	52	116	107.2	26.0

distance moved in Sickle Creek was 839m (Figure 4.2). In comparison, the maximum movement distance noted in Breen et al. (2009) was 511m. Breen et al. noted 16% of

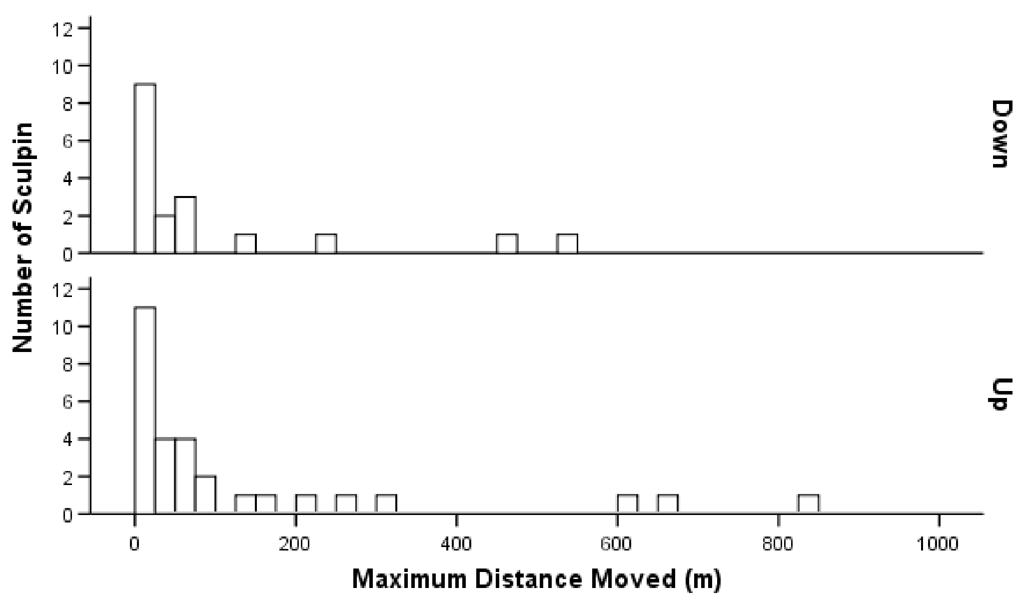

Figure 4.2. Maximum linear distance moved by PIT-tagged mottled sculpin. A total of five fish did not move (<1 m) from their original positions. Data is post-restoration from Sickle Creek, Manistee Co., MI.

tagged mottled sculpin moved >100m, whereas in our study, 23% of tagged mottled sculpin moved >100m.

There were no significant differences in any of our size variables (length, weight, head width) between fish which were relocated and those which were not. However, fish for which we did not detect movement (moved < 1m) tended to have higher mean weight and length (12.1 g, 92.2mm) than those fish which moved >1 m upstream (9.8 g, 86.7mm), and those which moved >1m downstream (8.9 g, 85.9mm) though the relationships were not significant.

Individuals initially captured upstream showed 91% reach fidelity (stayed upstream), while those initially captured downstream showed 76% reach fidelity. Of the 116 total relocations, 66.4% were in the woody debris habitat type, 25.9% were in undercut banks, and 7.8% were under logs, contrary to my hypotheses. Examining only the 62 upstream relocations, 74.2% were in woody debris habitat, 17.7% in undercut banks, and 8.1% under logs. Examining only the 54 downstream relocations, 57.4% were in woody debris habitat, 35.2% were in undercut banks, and 7.4% were under logs.

Six habitat variables significantly differed among sub-reaches (Table 4.3). When we compared sub-reaches, analysis indicated significantly lower channel width and greater channel depth in DS3, and significantly higher velocity in DS3 and US1. Analysis also indicated significantly higher percent clay and lower bank stability in US3, and significantly lower depth-of-fines in US3, US1, and DS1. Percent medium wood and large wood did not significantly differ among sub-reaches, though distinct patterns are obvious; higher amounts of both medium and large wood were found in upstream sub-reaches, with little or no medium and large wood found in some downstream reaches.

Table 4.3. Six habitat variables which were significantly different among sub-reaches (ANOVA), for data collected post-restoration in Sickle Creek, Manistee Co., MI (see footnote for additional detail).

Reach	Channel Width (m)	Channel Depth (cm)	Velocity (m/sec)	Percent Clay	DOF (cm)	Bank Erosivity	Percent Med Wood	Percent Lg Wood
US3	2.27	11.49	0.181	**9.103**	34.9	**2.0**	1.6	4.2
US1	2.17	10.97	**0.234**	1.667	27.6	1.3	0.9	1.9
DS1	2.39	9.79	0.184	0	27.5	1.3	0.6	1.2
DS3	**1.59**	**14.24**	**0.250**	0	**46.2**	1.0	0.3	0.0
DS5	2.30	10.96	0.183	0	**62.6**	1.0	0.0	0.0
p -value	0.004	0.009	0.006	0.016	<0.001	<0.001	0.296	0.286

Average channel width (n=13 per sub-reach), depth (n=13: means of n=4 measurements at n=13 transects per sub reach), velocity (n=13: means of n=4 measurements at n=13 transects per sub reach), percent clay in bottom composition (n=13 transects), Depth of Fines (DOF - n=13: means of n=4 measurements at n=13 transects per sub reach), Bank Erosivity (mean of left and right bank evaluation at n=13 transects per sub-reach; Riparian Bank Condition Scale: 1 - <25% of bank is bare soil; 2 – 25-50% of bank is bare soil; 3 – 50-75% of bank is bare soil; 4 – 75-100% of bank is bare soil). Post-hoc analysis was done using a Tukey's analysis. Values which are statistically different among sub-reaches are shown in **bold,** and are different from other non-bold values within a column. Percent medium and large wood were included as they show definite decreasing trends in both variables from upstream to downstream.

Overall mean spring macroinvertebrate abundance tended to increase pre to post-restoration, from 218 ± 51.3 (mean ± 1 S.E.) to 330 ± 48.9 individuals per m^2, though the difference was not significant (1-way ANOVA, p= 0.12; Chapter II). Abundance of EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa increased post-restoration (1-way ANOVA, p= 0.047; Chapter II). Community evaluation also showed a post-restoration decrease in psammophilic taxa, like *Chironimidae*, and an increase in sediment-intolerant taxa like *Heptageniidae*. Overall mean fall macroinvertebrate abundance increased 210.5% pre- to post-restoration, from 52 ± 9.4 (mean ± 1 S.E.) to 162 ± 26.4 individuals per m^2 (1-way ANOVA, p= 0.02; Chapter II). In addition, fall EPT richness and abundance both increased post-restoration (1-way ANOVA, p= 0.023 and 0.001, respectively; Chapter II). As in spring, fall community evaluation showed a post-restoration decrease in psammophilic taxa, like *Chironimidae*, and an increase in sediment-intolerant taxa like *Heptageniidae*.

DISCUSSION

In beginning this study, we saw a unique opportunity to evaluate the post-restoration redistribution of a species with reportedly limited movement. Our relocation rate of 59.1% is comparable to rates from other PIT tag studies (76%, Breen et al. 2009; 55%, Cookingham and Ruetz 2007). Other researchers postulate most fish marked (by either conventional tags, fin clips, or PIT tags) are never recaptured (Fausch and Young 1995), often due to insufficient study reach length (Gowan 1994). Limited detection distance of small PIT tags can make relocation of tagged fish difficult, especially when they inhabit complex habitat. Cucherousset et al. (2005) suggested a detection distance of 17-30 cm, though our experience suggests a slightly shorter distance, perhaps due to complex woody habitat. Additional dropped tags may have become lost in the stream sediment or flushed into the Big Manistee River. The high relocation rate observed in this study was potentially due to the small size of the stream and the longitudinal distance sampled.

Several studies detected substantially lower maximum movement than what was found in this study (~ 4m on average/median 26m, up to ~200m; McCleave 1964, Brown and Downhower 1982, Petty and Grossman 2004, Schmetterling and Adams 2004, Natsumeda 2007). In contrast to those findings, Breen et al. (2009) documented much more extensive movement in a 2nd-order Michigan stream. Sixteen percent of their 94 tagged mottled sculpin moved >100m, with a maximum displacement of 511m. These different findings may be due, at least in part, to the shorter duration of many studies; Petty and Grossman (2004) only report tracking movement for 45 days, whereas our results (and Breen et al. 2009) encompass nearly a year, and therefore captures longer inter-seasonal movement, both up and downstream (Table 4.2, Figure 4.4). Other authors have noted reports of limited fish movement are perhaps unjustified because many study reaches were not long enough to capture the actual home range of most fish (Gowan 1994). In fact, more extensive mark-recapture surveys (Skalski and Gilliam 2000), and surveys using telemetry (Young 1994; Breen et al. 2009) provide strong evidence of longer estimates of stream fish movement.

We found no significant correlation of movement to any sculpin size variable, though we did have a non-significant trend in our length and weight data similar to what Petty and Grossman (2004) found. They showed movement was size-dependant in their system, where small fish moved more than larger fish, and were able to measure the movement of smaller sculpin (min. total length ≤ 48mm) than could be done in this study (PIT technology precludes use of smaller fishes). The smallest fish used in our study was 64 mm, while Breen et al. (2009) used 55mm. Cookingham and Ruetz (2007) also used 55 mm in a study of round gobies (*Neogobius melanostomus*), which are morphologically similar to sculpin. It is also possible the sculpin population in Sickle Creek is still in flux following restoration, and density dependent intraspecific competition is currently minimal.

Mottled sculpin distribution shifted following restoration; reconnection to upstream habitat and forage previously cut off by the perched culvert may account for this phenomenon. Overall, our tagged sculpin appeared to select woody debris habitat more than 2-to-1 over other habitat types, though upstream, woody debris was preferred more than 4-to-1. Analysis indicated more preferred habitat available upstream, in the form of small, medium, and large wood. In addition, regressing the number of relocations in each sub-reach against the sum percentage of small, medium, and large wood combined for each sub-reach yields a significant relationship ($r^2 = 0.917$,

$p = 0.01$). Upon removal of the old culverts, mottled sculpin were able to access and utilize this newly available cover. Barrett (1989) indicated mottled sculpin spent considerable time underneath cobble resting and waiting to ambush prey. Mottled sculpin in Sickle Creek are likely using woody debris as overhead cover because the creek is nearly devoid of cobble, and it has been shown stream fish often gravitate to areas with higher relative amounts of woody debris (Angermeier and Karr 1984, Roni and Quinn 2001).

It is also possible the shift in mottled sculpin distribution may have been related to higher forage availability upstream. It is evident the macroinvertebrate community also shifted its springtime distribution in the first year post-restoration (higher abundance upstream), likely due to the spate of sediment produced by construction and released from impoundment by the removal of the undersized culverts. Abundance then shifted back to a distribution similar to those in pre-restoration years (higher abundance downstream), though total abundance was greater both up- and downstream post-restoration. While we are pleased to see a strong positive response in autumn abundance, it does not help explain the mottled sculpin redistribution. Other studies have also shown releases of impounded sediment can have negative effects on downstream macroinvertebrate communities (Thomson et al. 2005). The sandy (though improving – Chapter I) substrate of Sickle Creek likely precludes effective colonization and high abundances of preferred macroinvertebrates. Petty and Grossman (1996) found adult mottled sculpin were able to identify patches of high invertebrate density and selected microhabitats which maximized their access to food. These same researchers (2004) also concluded mottled sculpin in a rocky Appalachian stream exhibited restricted movement likely due to readily available refuge and foraging opportunities. Sickle Creek likely contains substantially less favorable cover; this patchy nature suggests small yet significant variations in forage and habitat may have significant impacts on mottled sculpin distribution and movement. Naslund et al. (1993) noted fish employ a full range of movement behavior to take advantage of spatially separated resources, suggesting fish who live in systems with fragmented or diminished resources may have to move greater distances to take advantage of those resources.

We propose there was a large redistribution following restoration, followed by a steady decline as the upstream reach approached saturation, with a new movement baseline slightly higher than pre-restoration. The fish now have unimpeded access to over 1 km of stream habitat, roughly half of which was unavailable pre-restoration. Other studies have shown swift and dramatic response to habitat reconnection (Iversen et al. 1993, Bryant et al. 1999, Glen 2002, Poulakis et al. 2002, Raposa 2002), likely the result of the removal of density-dependent constraints like habitat and forage pressure. Rapid colonization of reconnected habitat would be predicted, especially if the new habitat is of higher quality, can support more organisms, or if it provides better foraging opportunities or relief from predation. Dingle (1996) suggests long-distance movement may cease when patches with suitable resources are encountered.

Our population estimates (Chapter III, Figure 3.3) show a strong post-restoration increase in the number of mottled sculpin in the study sub-reaches (from 521 individuals to 955), though it is difficult to determine the origin of these additional individuals. They may have arrived as the result of increased recruitment success, immigration from the mainstem of the Big Manistee, or something else we failed to consider. It is likely the population has increased in response to several interconnected changes in the stream: reconnection to more suitable upstream habitat, decrease in overall fine sediment depth

(Chapter I), increased macroinvertebrate abundance (Chapter II), and reduced competition with other fish species due to a post-restoration decline in those species (Chapter III).

The use of PIT tags for monitoring small benthic fish is an emerging trend in research. Recently, several authors have used this method for tracking mottled sculpin (Breen et al. 2009, Ruetz et al. 2006), slimy sculpin (Cucherousset 2005, Keeler et al. 2006, 2007), and round gobies (Cookingham and Ruetz 2007) in both lentic and lotic habitats. When the findings of our study are pooled with these studies using the same technology in similar systems, we postulate mottled sculpin movements may have been underestimated by previous researchers for various reasons. These findings might be confounded by the differences in methodologies used, as well as the highly variable nature of the habitats and streams in which mottled sculpin are found.

Our results suggest fish response to restoration via reconnection is an important mechanism aiding in fish community recovery. The culverts presented a barrier to upstream fish passage and to downstream sediment transport, and the new bridge appears to have alleviated both of those concerns. We presume if small fish like sculpin can now move upstream under the road crossing, larger, more energetic fish like trout and salmon can also access the upper stream reach as well. Habitat improvement efforts of any kind are questionable and often misdirected without first having some idea of whether or not they are effective. Post-restoration monitoring is an essential component in determining both good and bad restoration practices. Monitoring can also be an important educational and informational tool, allowing communication regarding successful ventures to granting agencies, fellow scientists, and the general public as well.

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APPENDICES

Appendix A

Aerial Photos, Before and After Photographs of Study Sites

Photo 1. Aerial photograph of Milks Road area, with habitat transects and electrofishing reaches superimposed. Bear Creek, Kaleva, MI.

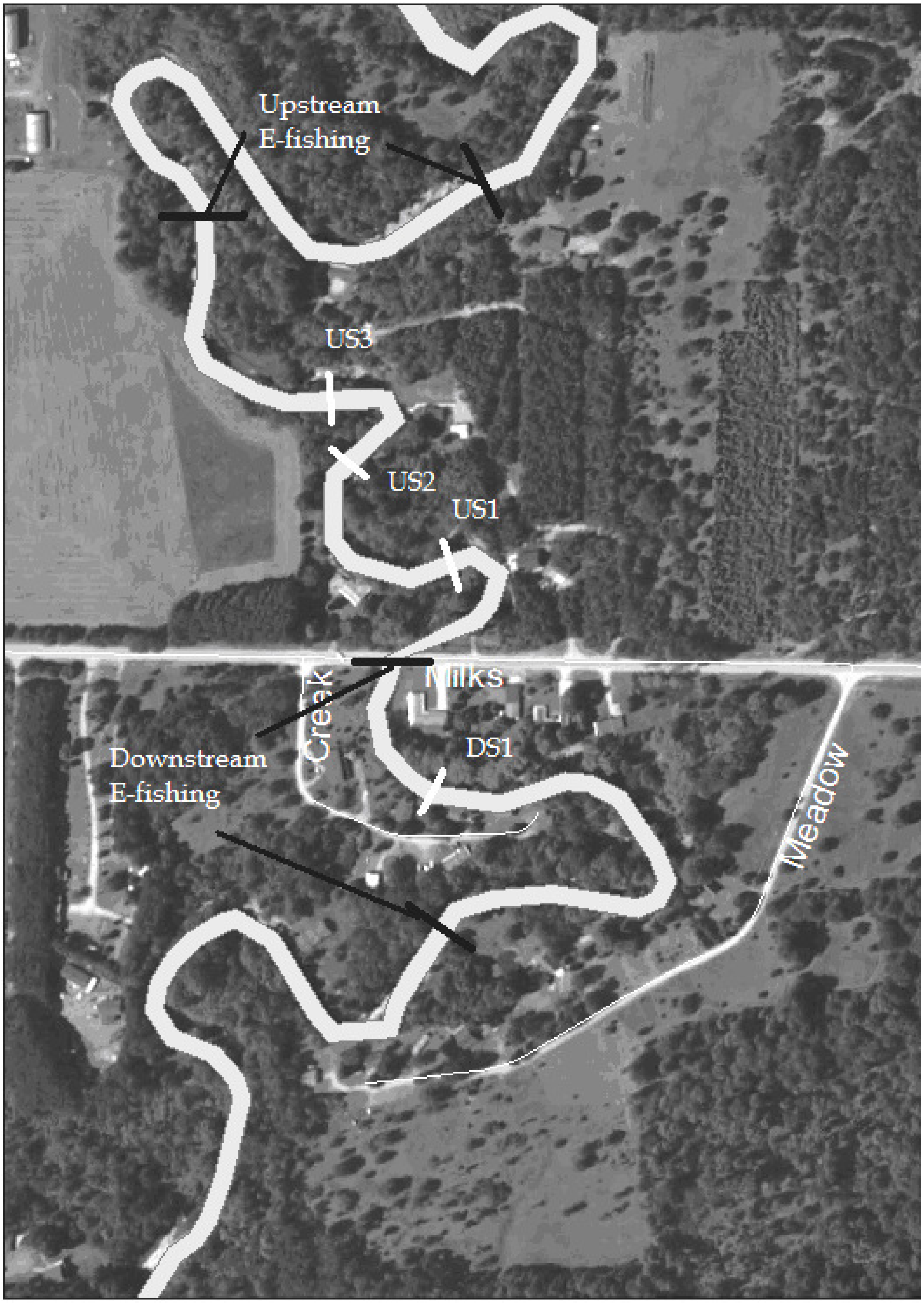

Photo 2. Aerial photograph of Swain's Property area, with habitat transects and electrofishing reaches superimposed. Bear Creek, Kaleva, MI.

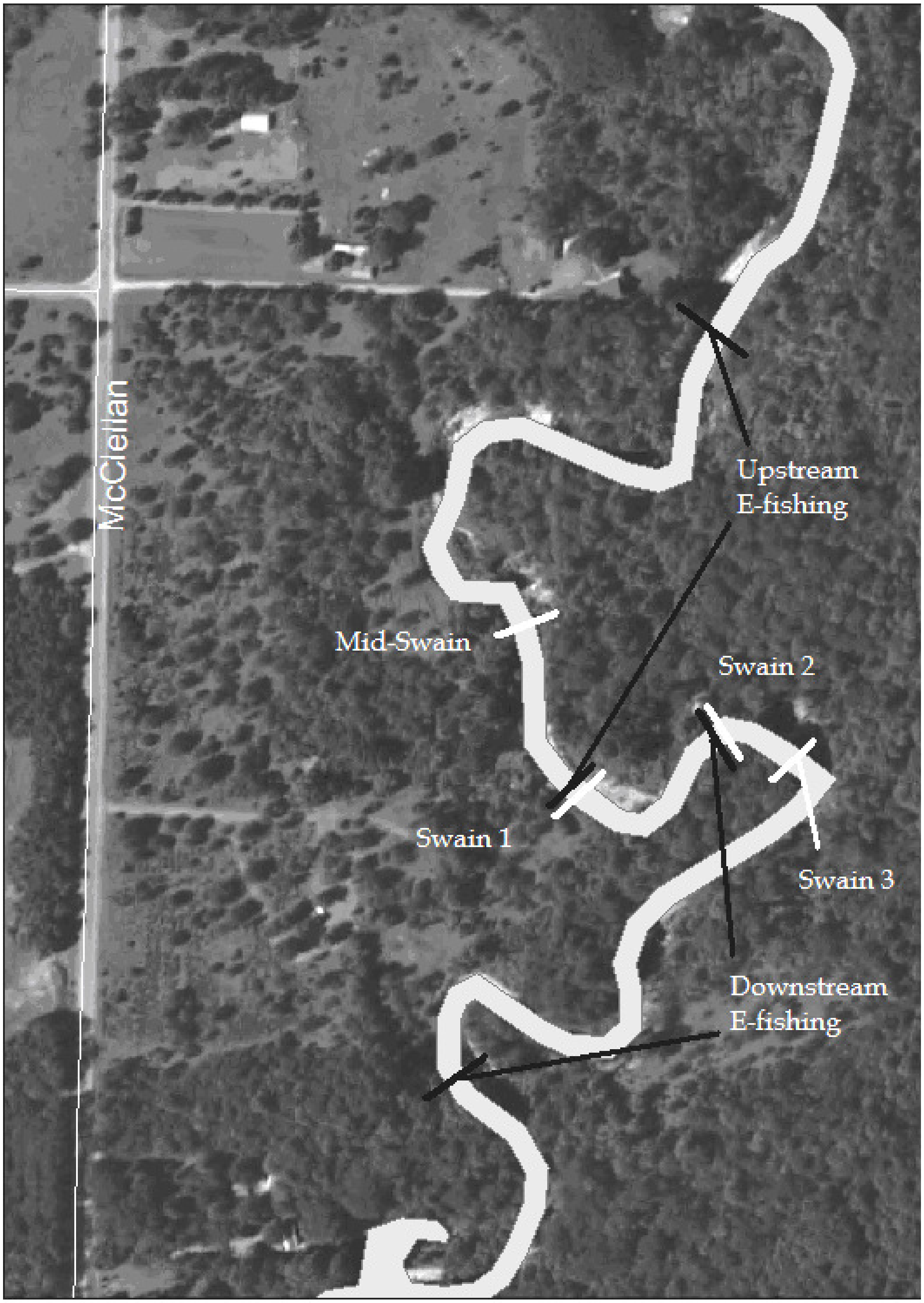

Photo 3. Sickle Creek prior to restoration.

Photo 4. Sickle Creek immediately following restoration.

Photo 5. Sickle Creek in summer 2007, nearly 2 years post-restoration.

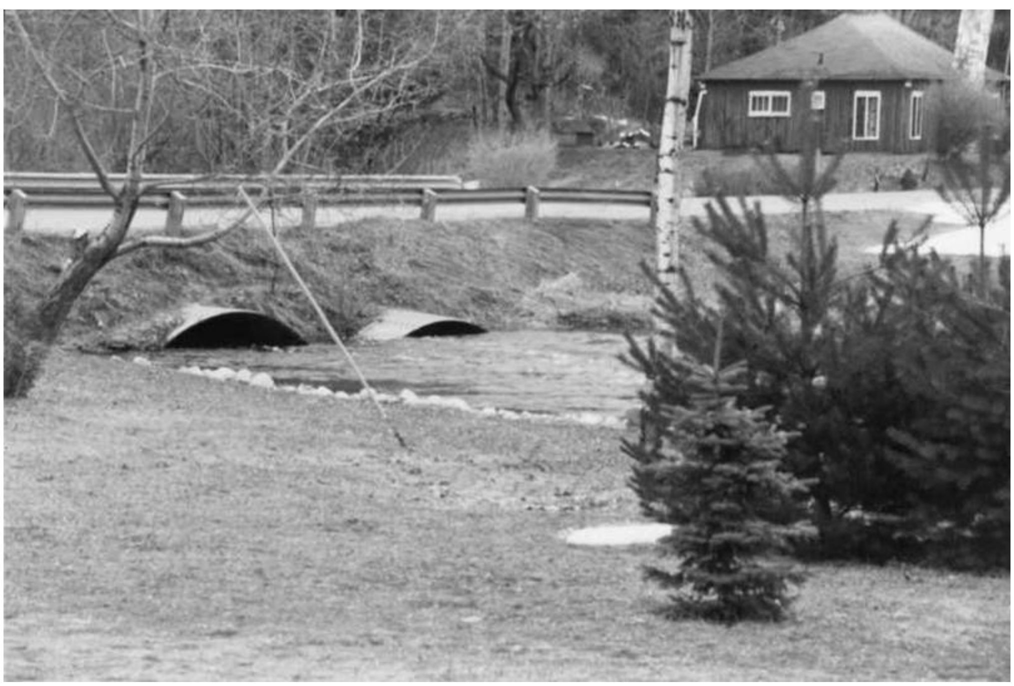

Photo 6. Milks Road crossing (from downstream) prior to restoration.

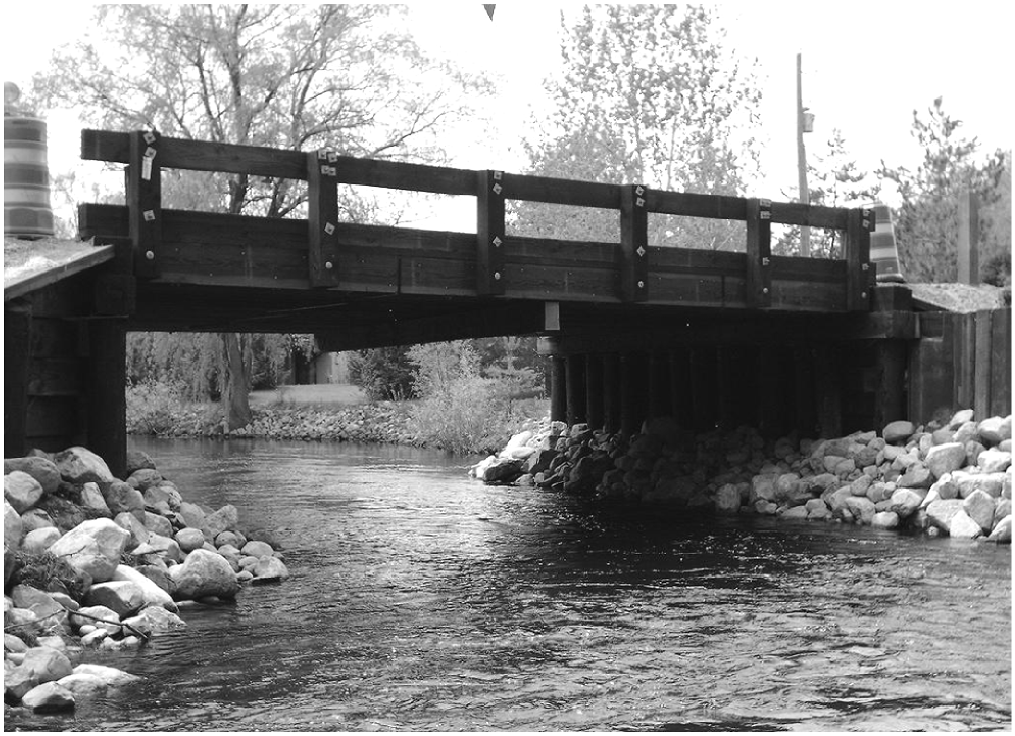

Photo 7. Milks Road crossing (from upstream) immediately following restoration.

Photo 8. Upstream bank at Swain's Property prior to restoration.

Photo 9. Upstream bank at Swain's Property immediately following restoration.

Photo 10. Upstream bank at Swain's in Summer 2007, nearly 2 years post-restoration.

Appendix B

Summary of Sediment Data for Study Sites

Table 1. Sediment core summary data by transect for Sickle Creek, Manistee Co., MI.

			Size Class				
Transect	Pre/Post	Metric	% Gravel 16-4mm	% Very Coarse/ Coarse Sand 4mm-500µm	% Medium/ Fine Sand 500-125µm	% Very Fine Sand 125-63µm	% Ultra Fine Particulate Matter 63-0.63µm
US3	Pre	Mean	13.91	21.47	59.71	4.69	0.22
		N	1	1	1	1	1
		Std. Dev.	.	.	.	.	.
	Post	Mean	10.88	51.88	35.25	1.93	0.09
		N	3	3	3	3	3
		Std. Dev.	9.382	8.197	16.177	1.277	0.017
US2	Pre	Mean	0	2.84	96.08	1	0.08
		N	1	1	1	1	1
		Std. Dev.	.	.	.	.	.
	Post	Mean	0.56	61.40	36.87	1.11	0.08
		N	3	3	3	3	3
		Std. Dev.	0.635	13.660	13.346	0.890	0.051
US1	Pre	Mean	0.09	36.31	62.68	0.47	0.45
		N	1	1	1	1	1
		Std. Dev.	.	.	.	.	.
	Post	Mean	2.58	54.75	41.22	1.12	0.34
		N	3	3	3	3	3
		Std. Dev.	3.564	9.902	12.619	0.487	0.280
DS1	Pre	Mean	37.74	19.48	40.88	1.75	0.15
		N	1	1	1	1	1
		Std. Dev.	.	.	.	.	.
	Post	Mean	7.58	43.94	47.33	1.00	0.17
		N	3	3	3	3	3
		Std. Dev.	8.807	17.097	19.387	0.316	0.118
DS2	Pre	Mean	0.44	14.56	83.29	1.6	0.11
		N	1	1	1	1	1
		Std. Dev.	.	.	.	.	.
	Post	Mean	1.39	55.52	41.91	0.97	0.23
		N	3	3	3	3	3
		Std. Dev.	1.234	31.977	31.490	0.386	0.252
DS3	Pre	Mean	0.14	32.2	65.91	1.63	0.13
		N	1	1	1	1	1
		Std. Dev.	.	.	.	.	.
	Post	Mean	0.21	47.26	50.82	1.45	0.25
		N	3	3	3	3	3
		Std. Dev.	0.192	20.089	19.121	0.576	0.174

Table 2. Mean depth of autumn fine sediment measurements (cm) by transect and year for Sickle Creek (Manistee Co., MI), with 1 SE for post, and percent change pre- to post-restoration.

Transect	2004	2005	2006	2007	mean pre	mean post	SE post	% change
US3	47.9	29.1	51.4	24.8	47.9	35.1	8.3	**-27%**
US2	65.5	36.3	57.2	22.7	65.5	38.7	10.0	**-41%**
US1	47.3	28.5	21.3	22.2	47.3	24.0	2.3	**-49%**
DS1	26.3	64.3	60.4	61.5	26.3	62.1	1.1	136%
DS2	53.1	38.7	44.2	28.4	53.1	37.1	4.6	**-30%**
DS3	115.0	83.1	118.8	59.1	115.0	87.0	17.4	**-24%**
							average	*-6%*

Table 3. Sediment core summary data by transect for Milks Road on Bear Creek, Kaleva, MI.

			Size Class				
Transect	Pre/Post	Metric	% Gravel 16-4mm	% Very Coarse/ Coarse Sand 4mm-500µm	% Medium/ Fine Sand 500-125µm	% Very Fine Sand 125-63µm	% Ultra Fine Particulate Matter 63-0.63µm
Milks US3	Pre	Mean	82.31	12.34	5.13	0.10	0.13
		N	2	2	2	2	2
		Std. Dev.	12.082	7.893	4.231	0.009	0.052
	Post	Mean	71.38	21.60	6.92	0.07	0.04
		N	2	2	2	2	2
		Std. Dev.	2.430	1.770	4.128	0.033	0.023
Milks US2	Pre	Mean	76.20	11.99	11.05	0.54	0.22
		N	2	2	2	2	2
		Std. Dev.	4.373	0.802	4.759	0.387	0.029
	Post	Mean	69.13	21.65	8.96	0.18	0.11
		N	2	2	2	2	2
		Std. Dev.	4.546	1.967	6.252	0.156	0.062
Milks US1	Pre	Mean	53.93	31.57	14.06	0.28	0.16
		N	2	2	2	2	2
		Std. Dev.	10.328	0.859	11.005	0.134	0.048
	Post	Mean	69.13	26.15	4.35	0.33	0.07
		N	2	2	2	2	2
		Std. Dev.	25.346	24.321	1.427	0.362	0.013
Milks DS1	Pre	Mean	68.61	21.42	9.57	0.15	0.24
		N	2	2	2	2	2
		Std. Dev.	1.493	3.618	4.877	0.131	0.103
	Post	Mean	80.22	16.31	3.39	0.07	0.04
		N	2	2	2	2	2
		Std. Dev.	7.443	9.534	2.034	0.033	0.000

Table 4. Sediment core summary data by transect for Swain's Property on Bear Creek, Kaleva, MI.

Transect	Pre/Post	Metric	Size Class % Gravel 16-4mm	% Very Coarse/ Coarse Sand 4mm-500µm	% Medium/ Fine Sand 500-125µm	% Very Fine Sand 125-63µm	% Ultra Fine Particulate Matter 63-0.63µm
MidSwain	Pre	Mean	56.48	27.69	15.37	0.28	0.19
		N	2	2	2	2	2
		Std. Dev.	0.315	6.235	5.732	0.197	0.009
	Post	Mean	63.80	24.63	11.32	0.18	0.10
		N	2	2	2	2	2
		Std. Dev.	7.791	2.705	4.922	0.069	0.052
Swain 1	Pre	Mean	77.41	13.61	8.61	0.20	0.17
		N	2	2	2	2	2
		Std. Dev.	2.683	5.293	2.491	0.121	0.003
	Post	Mean	58.79	32.40	8.63	0.10	0.13
		N	2	2	2	2	2
		Std. Dev.	3.164	9.637	6.337	0.015	0.061
Swain 2	Pre	Mean	43.20	35.49	20.74	0.36	0.22
		N	2	2	2	2	2
		Std. Dev.	17.128	0.911	17.727	0.325	0.014
	Post	Mean	75.82	18.69	4.92	0.11	0.53
		N	2	2	2	2	2
		Std. Dev.	4.268	5.801	0.873	0.011	0.554
Swain 3	Pre	Mean	88.54	5.73	5.53	0.08	0.12
		N	2	2	2	2	2
		Std. Dev.	0.192	0.576	0.835	0.006	0.062
	Post	Mean	80.61	14.24	4.99	0.08	0.12
		N	2	2	2	2	2
		Std. Dev.	1.117	3.139	1.872	0.045	0.042

Table 5. Sediment core raw data for Sickle Creek, Manistee Co., MI.

					DRY WEIGHT (g)						
Year	Transect	16mm	8mm	4mm	1mm	500µm	250µm	125µm	63µm	UFPM	Total
2004	SICKLEUS3 CORE1	200.56	506.79	225.41	132.41	912.03	514.6	120.49	30.97	2	2645.3
2004	SICKLEUS3 CORE2	78.79	31.25	18.78	24	663.86	1686.26	200.21	24.02	8	2735.2
2004	SICKLEUS3 CORE3	61.78	12.54	4.14	9.44	18.82	288.38	2085.36	329.32	8	2817.8
	Sickle US3 core total	341.13	550.58	248.33	165.85	1594.71	2489.24	2406.06	384.31	18	8198.2
	percentage	4.161%	6.716%	3.029%	2.023%	19.452%	30.363%	29.349%	4.688%	0.220%	
2004	SICKLEUS2 CORE1	0	0	0	4.52	251.92	4386.84	365.32	22.28	0	5030.9
2004	SICKLEUS2 CORE2	0	0.14	0.06	3.16	43.94	2721.56	189.32	36.48	4	2998.7
2004	SICKLEUS2 CORE3	0.02	0	0.04	2.32	50.66	3906.32	506.24	66.84	6	4538.4
	Sickle US2 core total	0.02	0.14	0.1	10	346.52	11014.72	1060.88	125.6	10	12568.0
	percentage	0.000%	0.001%	0.001%	0.080%	2.757%	87.641%	8.441%	0.999%	0.080%	
2004	SICKLEUS1 CORE1	1.26	0.08	0.8	30.22	359.7	1984.24	157.8	9.5	21	2564.6
2004	SICKLEUS1 CORE2	0	0.28	5.48	111.44	1882.8	2365.16	301.64	15.88	6	4688.7
2004	SICKLEUS1 CORE3	0	0.28	1.4	28.24	1565.04	1618.16	438.12	26.56	22	3699.8
	Sickle US1 core total	1.26	0.64	7.68	169.9	3807.54	5967.56	897.56	51.94	49	10953.1
	percentage	0.012%	0.006%	0.070%	1.551%	34.762%	54.483%	8.195%	0.474%	0.447%	
	sickle us avg	1.391%	2.241%	1.033%	1.218%	18.990%	57.496%	15.328%	2.054%	0.249%	
2004	SICKLEDS1 CORE1	53.86	159.76	66.92	34.42	86.2	1154.34	664.5	107.16	6	2333.2
2004	SICKLEDS1 CORE2	1140.42	738.65	384.02	212.12	254.69	756.54	68.74	17.7	4	3576.9
2004	SICKLEDS1 CORE3	423.53	191.26	76.91	21.99	1060.42	635.36	224.58	24.83	3	2661.9
	Sickle DS1 core total	1617.81	1089.67	527.85	268.53	1401.31	2546.24	957.82	149.69	13	8571.9
	percentage	18.873%	12.712%	6.158%	3.133%	16.348%	29.704%	11.174%	1.746%	0.152%	
2004	SICKLEDS2 CORE1	0	0	0.18	6.8	146.88	2138.32	262.72	20.84	2	2577.7
2004	SICKLEDS2 CORE2	0	0	0.74	34.32	712.96	1120.16	151.62	7.38	2	2029.2
2004	SICKLEDS2 CORE3	21.58	4.2	4.76	17.86	121.52	1752.52	526.24	86.34	4	2539.0
	Sickle DS2 core total	21.58	4.2	5.68	58.98	981.36	5011	940.58	114.56	8	7145.9
	percentage	0.302%	0.059%	0.079%	0.825%	13.733%	70.124%	13.162%	1.603%	0.112%	
2004	SICKLEDS3 CORE1	0.68	4.32	5.28	148.8	3088.4	1248.28	120.96	20.88	4	4641.6
2004	SICKLEDS3 CORE2	0.4	1.52	1.92	9.68	142.76	3082.44	575.6	85.56	4	3903.9
2004	SICKLEDS3 CORE3	0	0	0.86	5.66	167.6	1958.78	305.84	73.88	6	2518.6
	Sickle DS3 core total	1.08	5.84	8.06	164.14	3398.76	6289.5	1002.4	180.32	14	11064.1
	percentage	0.010%	0.053%	0.073%	1.484%	30.719%	56.846%	9.060%	1.630%	0.127%	
	sickle ds avg	6.395%	4.275%	2.103%	1.814%	20.267%	52.225%	11.132%	1.660%	0.130%	
	sickle avg	3.893%	3.258%	1.568%	1.516%	19.628%	54.860%	13.230%	1.857%	0.189%	

2005	SICKLEUS3 CORE1	0.28	1.42	0.86	39.55	1572.4	921.86	79.23	11.03	4	2630.6
2005	SICKLEUS3 CORE2	2.64	0.74	0.04	10.12	1336.6	1015.68	253.2	19.12	2	2640.1
2005	SICKLEUS3 CORE3	2.8	8.48	1.52	6.92	9.24	112.32	1391.72	208.8	1	1742.8
	Sickle US3 core total	5.72	10.64	2.42	56.59	2918.24	2049.86	1724.15	238.95	7	7013.6
	percentage	0.082%	0.152%	0.035%	0.807%	41.608%	29.227%	24.583%	3.407%	0.100%	
2005	SICKLEUS2 CORE1	7.17	2.84	1.62	2.43	2215.75	407.81	69.03	9.24	3	2718.9
2005	SICKLEUS2 CORE2	0.8	0.76	0.54	4.9	428.42	2323.48	212.22	41.18	2	3014.3
2005	SICKLEUS2 CORE3	2.9	1.98	2.36	10.76	1085.84	746.38	114.24	9.5	2	1976.0
	Sickle US2 core total	10.87	5.58	4.52	18.09	3730.01	3477.67	395.49	59.92	7	7709.2
	percentage	0.141%	0.072%	0.059%	0.235%	48.384%	45.111%	5.130%	0.777%	0.100%	
2005	SICKLEUS1 CORE1	0.23	2.34	3.43	49.26	1593.49	488.29	120.79	14.29	4	2276.1
2005	SICKLEUS1 CORE2	4.28	0.59	2.23	47.8	1616.28	376.29	70.41	5.57	2	2125.5
2005	SICKLEUS1 CORE3	1.66	0.24	0.51	16.85	557.45	1453.42	212.68	30.35	32	2305.2
	Sickle US1 core total	6.17	3.17	6.17	113.91	3767.22	2318	403.88	50.21	38	6706.7
	percentage	0.092%	0.047%	0.092%	1.698%	56.171%	34.562%	6.022%	0.749%	0.542%	
	sickle us avg	0.105%	0.090%	0.062%	0.913%	48.721%	36.300%	11.912%	1.644%	0.247%	
2005	SICKLEDS1 CORE1	2.29	8.75	4.01	46.87	781.76	1211.54	170.66	43.04	6	2274.9
2005	SICKLEDS1 CORE2	0	9.5	36.94	78.12	328.96	1301.04	146.02	7.2	6	1913.8
2005	SICKLEDS1 CORE3	0	13.52	11.14	40.82	578.26	1596.2	247.76	37.7	8	2533.4
	Sickle DS1 core total	2.29	31.77	52.09	165.81	1688.98	4108.78	564.44	87.94	20	6722.1
	percentage	0.034%	0.473%	0.775%	2.467%	25.126%	61.123%	8.397%	1.308%	0.285%	
2005	SICKLEDS2 CORE1	75.94	1.9	1.2	1.86	28.3	2171.68	171.38	40.76	10	2503.0
2005	SICKLEDS2 CORE2	0	0.28	0.76	22.28	953	1191.34	76.26	14.24	10	2268.2
2005	SICKLEDS2 CORE3	0	1.9	1.24	33.34	282.3	1811.3	126.14	44.8	16	2317.0
	Sickle DS2 core total	75.94	4.08	3.2	57.48	1263.6	5174.32	373.78	99.8	36	7088.2
	percentage	1.071%	0.058%	0.045%	0.811%	17.827%	72.999%	5.273%	1.408%	0.513%	
2005	SICKLEDS3 CORE1	9	2.73	1.62	4.21	16.52	1665.36	244.89	82.67	24	2051.0
2005	SICKLEDS3 CORE2	5.94	0.72	0.52	1.02	16.84	1542.04	145.48	26.48	2	1741.0
2005	SICKLEDS3 CORE3	0.31	2.51	1.75	10.94	1362.59	560.79	89.51	13.07	2	2043.5
	Sickle DS3 core total	15.25	5.96	3.89	16.17	1395.95	3768.19	479.88	122.22	28	5835.5
	percentage	0.261%	0.102%	0.067%	0.277%	23.922%	64.573%	8.223%	2.094%	0.399%	
	sickle ds avg	0.456%	0.211%	0.296%	1.185%	22.291%	66.232%	7.298%	1.604%	0.399%	
	sickle avg	0.280%	0.151%	0.179%	1.049%	35.506%	51.266%	9.605%	1.624%	0.323%	

2006	SICKLEUS3 CORE1	149.2	247.6	147.1	178.3	936	531.7	147.3	31.1	x	2368.3
2006	SICKLEUS3 CORE2	98.7	91.2	33.1	62.2	1396.1	661	86.5	31	1	2460.8
2006	SICKLEUS3 CORE3	120.7	43.2	26	24.9	1201.2	367.7	69	13.6	4	1870.3
	Sickle US3 core total	368.6	382	206.2	265.4	3533.3	1560.4	302.8	75.7	5	6699.4
	percentage	5.502%	5.702%	3.078%	3.962%	52.741%	23.292%	4.520%	1.130%	0.075%	
2006	SICKLEUS2 CORE1	0	0.2	0.4	3.1	2296	209.2	33.7	7	3	2552.6
2006	SICKLEUS2 CORE2	0.7	1	1.4	23.8	2160.3	388.4	53.5	7.8	2	2638.9
2006	SICKLEUS2 CORE3	1.7	1.9	1.6	30	1361.7	1000.1	140.4	19.1	3	2559.5
	Sickle US2 core total	2.4	3.1	3.4	56.9	5818	1597.7	227.6	33.9	8	7751.0
	percentage	0.031%	0.040%	0.044%	0.734%	75.061%	20.613%	2.936%	0.437%	0.119%	
2006	SICKLEUS1 CORE1	0	14.4	18.8	52.6	719.2	1627.1	239.8	39.8	26	2737.7
2006	SICKLEUS1 CORE2	0	9.3	4.6	43.3	1691.5	540.2	79.9	9.8	x	2378.6
2006	SICKLEUS1 CORE3	4.1	4.4	6.3	182.1	559	1403.5	136.2	20.8	5	2321.4
	Sickle US1 core total	4.1	28.1	29.7	278	2969.7	3570.8	455.9	70.4	31	7437.7
	percentage	0.055%	0.378%	0.399%	3.738%	39.928%	48.009%	6.130%	0.947%	0.463%	
	sickle us avg	1.863%	2.040%	1.174%	2.811%	55.910%	30.638%	4.529%	0.838%	0.219%	
2006	SICKLEDS1 CORE1	0	0	1.6	229.5	2216.1	200.4	44.2	18.7	5	2715.5
2006	SICKLEDS1 CORE2	21.5	49.2	126.6	177.1	1681	470.3	60.4	10	6	2602.1
2006	SICKLEDS1 CORE3	39.3	31	25.4	37.2	414.5	1662.6	156.5	23.4	x	2389.9
	Sickle DS1 core total	60.8	80.2	153.6	443.8	4311.6	2333.3	261.1	52.1	11	7707.5
	percentage	0.789%	1.041%	1.993%	5.758%	55.940%	30.273%	3.388%	0.676%	0.164%	
2006	SICKLEDS2 CORE1	6.3	1.6	4	46	1639.9	846.7	117.3	38.2	6	2706.0
2006	SICKLEDS2 CORE2	1.5	1	5.8	144.5	2120.5	398.1	37.4	7.6	3	2719.4
2006	SICKLEDS2 CORE3	0	0	1.2	82.6	1882.9	383.7	56.5	8.2	1	2416.1
	Sickle DS2 core total	7.8	2.6	11	273.1	5643.3	1628.5	211.2	54	10	7841.5
	percentage	0.099%	0.033%	0.140%	3.483%	71.967%	20.768%	2.693%	0.689%	0.149%	
2006	SICKLEDS3 CORE1	0	1	1.5	25.7	1877.2	351.8	46.6	8	3	2314.8
2006	SICKLEDS3 CORE2	0.4	0.9	0.05	1.4	1543.3	376.7	149.1	26.1	2	2100.0
2006	SICKLEDS3 CORE3	0	1.5	0.2	1.8	477	1749.9	216.4	54.6	14	2515.4
	Sickle DS3 core total	0.4	3.4	1.75	28.9	3897.5	2478.4	412.1	88.7	19	6930.2
	percentage	0.006%	0.049%	0.025%	0.417%	56.240%	35.763%	5.946%	1.280%	0.284%	
	sickle ds avg	0.298%	0.374%	0.719%	3.219%	61.382%	28.934%	4.009%	0.882%	0.199%	
	sickle avg	1.080%	1.207%	0.947%	3.015%	58.646%	29.786%	4.269%	0.860%	0.209%	

Note: 'x' indicates no data

2007	SICKLEUS3 CORE1	337.8	353.2	141.8	165.2	2601.4	1330	224.8	43.6	26	5223.8
2007	SICKLEUS3 CORE2	400.6	732.4	597.4	400.6	1777.8	771.8	373.2	82	1	5136.8
2007	SICKLEUS3 CORE3	54.6	14	5.8	43.4	3257.2	530	290.8	59.2	5	4260.0
	Sickle US3 core total	793	1099.6	745	609.2	7636.4	2631.8	888.8	184.8	32	
	percentage	5.424%	7.521%	5.096%	4.167%	52.230%	18.001%	6.079%	1.264%	0.219%	
2007	SICKLEUS2 CORE1	7	8.8	6.2	103.6	4141.2	490	198	40.2	2	4997.0
2007	SICKLEUS2 CORE2	0	0	3.2	115.2	3453.4	1041.8	235.6	41.6	2	4892.8
2007	SICKLEUS2 CORE3	11.2	60	86.2	158	523.2	2309.8	956.2	219.6	3	4327.2
	Sickle US2 core total	18.2	68.8	95.6	376.8	8117.8	3841.6	1389.8	301.4	7	
	percentage	0.128%	0.484%	0.672%	2.650%	57.099%	27.021%	9.776%	2.120%	0.049%	
2007	SICKLEUS1 CORE1	8.4	3.2	5.8	112.8	3651.2	804	127.2	19.2	3	4734.8
2007	SICKLEUS1 CORE2	17.9	17.7	20	28.4	1566.5	1525.3	602.8	180.7	1	3960.3
2007	SICKLEUS1 CORE3	0	11	10.2	106.2	4424	348	147.6	24.8	3	5074.8
	Sickle US1 core total	26.3	31.9	36	247.4	9641.7	2677.3	877.6	224.7	7	
	percentage	0.191%	0.232%	0.261%	1.797%	70.020%	19.443%	6.373%	1.632%	0.051%	
	sickle us avg	1.914%	2.745%	2.010%	2.871%	59.783%	21.488%	7.409%	1.672%	0.106%	
2007	SICKLEDS1 CORE1	3.8	2.8	4.6	146.8	4319.6	418.8	121.2	18.4	5	5041.0
2007	SICKLEDS1 CORE2	28	42.1	66.1	102.4	1233.6	2922.1	370	42.5	6	4812.8
2007	SICKLEDS1 CORE3	1288.4	803.8	550.8	402	520.8	1939.8	366.2	97.8	4	5973.6
	Sickle DS1 core total	1320.2	848.7	621.5	651.2	6074	5280.7	857.4	158.7	15	
	percentage	8.341%	5.362%	3.927%	4.114%	38.376%	33.364%	5.417%	1.003%	0.095%	
2007	SICKLEDS2 CORE1	0	9	55.8	354.6	3438	970.8	224.2	28.6	6	5087.0
2007	SICKLEDS2 CORE2	36.4	69.4	131.6	376.4	2821.2	1371.6	210.2	47.6	2	5066.4
2007	SICKLEDS2 CORE3	38.3	33.6	31.8	129.3	3725.8	631.3	183.7	44.5	1	4819.3
	Sickle DS2 core total	74.7	112	219.2	860.3	9985	2973.7	618.1	120.7	9	
	percentage	0.499%	0.748%	1.464%	5.746%	66.688%	19.861%	4.128%	0.806%	0.060%	
2007	SICKLEDS3 CORE1	1.9	0.3	0.4	3.2	235.2	3694.1	681.1	112.5	3	4731.7
2007	SICKLEDS3 CORE2	8	0	3	92.2	4337	467.6	76.2	8.2	2	4994.2
2007	SICKLEDS3 CORE3	0.5	1.1	1.7	17	4092.8	418.8	131	20.7	12	4695.6
	Sickle DS3 core total	10.4	1.4	5.1	112.4	8665	4580.5	888.3	141.4	17	
	percentage	0.072%	0.010%	0.035%	0.779%	60.084%	31.762%	6.160%	0.980%	0.118%	
	sickle ds avg	2.971%	2.040%	1.809%	3.547%	55.049%	28.329%	5.235%	0.930%	0.091%	
	sickle avg	2.443%	2.393%	1.909%	3.209%	57.416%	24.909%	6.322%	1.301%	0.099%	

Table 6. Sediment core raw data for experimental sites on Bear Creek, Kaleva, MI.

		DRY WEIGHT (g)									
Year	Transect	16mm	8mm	4mm	1mm	500µm	250µm	125µm	63µm	UFPM	Total
2004	MILKS US3 CORE1	1844.49	360.15	70.09	31.04	19.59	39.04	7.71	1.08	2	2375.19
2004	MILKS US3 CORE2	800.52	235.04	111.68	43.21	12.35	13.95	1.46	0.28	3	1221.49
2004	MILKS US3 CORE3	556.08	271.39	212.58	172.95	52.85	35.93	6.8	3.14	3	1314.72
	MILKS US3 core total	3201.1	866.6	394.4	247.2	84.8	88.9	16.0	4.5	8.0	4911.4
	percentage	65.177%	17.644%	8.029%	5.033%	1.726%	1.810%	0.325%	0.092%	0.163%	
2004	MILKS US2 CORE1	350.77	226.4	241.99	258.24	174.11	211.78	62.43	10.8	4	1540.52
2004	MILKS US2 CORE2	633.03	277.47	219.21	201.43	79.95	124.59	41.14	4.81	5	1586.63
2004	MILKS US2 CORE3	2275.45	640.67	234.02	70.48	23.23	44.7	9.63	1.39	4	3303.57
	MILKS US2 core total	3259.3	1144.5	695.2	530.2	277.3	381.1	113.2	17.0	13.0	6430.72
	percentage	50.683%	17.798%	10.811%	8.244%	4.312%	5.926%	1.760%	0.264%	0.202%	
2004	MILKS US1 CORE1	0.3	0.52	0.48	6.36	1813.9	1249.24	169.06	22.26	8	3270.12
2004	MILKS US1 CORE2	682.09	276.35	169.16	160.09	80.19	82.49	18.8	1.35	3	1473.52
2004	MILKS US1 CORE3	1552.18	529.58	209.11	168.97	41.18	49.11	33.29	3.98	3	2590.4
	MILKS US1 core total	2234.6	806.5	378.8	335.4	1935.3	1380.8	221.2	27.6	14.0	7334.04
	percentage	30.468%	10.996%	5.164%	4.573%	26.388%	18.828%	3.015%	0.376%	0.191%	
	milks us avg	48.776%	15.479%	8.001%	5.950%	10.809%	8.855%	1.700%	0.244%	0.185%	
2004	MILKS DS1 CORE1	351.24	295.28	222.8	212.17	72.52	210.36	61.68	4.37	3	1433.42
2004	MILKS DS1 CORE2	354.48	303.55	237.34	222.16	200.64	211.01	34.15	3.06	5	1571.39
2004	MILKS DS1 CORE3	522.51	363.31	201.35	83.39	5.53	13.48	19.08	2.9	5	1216.55
	MILKS DS1 core total	1228.2	962.1	661.5	517.7	278.7	434.9	114.9	10.3	13.0	4221.36
	percentage	29.096%	22.792%	15.670%	12.264%	6.602%	10.301%	2.722%	0.245%	0.308%	
	milks avg	38.936%	19.136%	11.836%	9.107%	8.705%	9.578%	2.211%	0.244%	0.247%	
2004	MIDSWAIN CORE1	73.49	480.06	450.88	425.2	443.07	623.03	120.94	17.58	6	2640.25
2004	MIDSWAIN CORE2	1313.72	627.5	315.5	188.89	471.29	280.74	29.96	2.34	4	3233.94
2004	MIDSWAIN CORE3	523.74	761.03	469.13	402.69	127.49	532.14	130.58	16.9	6	2969.7
	MIDSWAIN core total	1911.0	1868.6	1235.5	1016.8	1041.9	1435.9	281.5	36.8	16.0	8843.89
	percentage	21.608%	21.129%	13.970%	11.497%	11.780%	16.236%	3.183%	0.416%	0.181%	
2004	SWAIN1 CORE1	935.65	577.92	264.39	145.02	40.39	321.2	92.79	15.92	4	2397.28
2004	SWAIN1 CORE2	406.05	988.35	409.63	248.99	119.51	284.99	30.98	3.72	3	2495.22
2004	SWAIN1 CORE3	1732.54	689.77	280.78	153.82	74.33	69.65	22.05	3.34	6	3032.28
	SWAIN1 core total	3074.2	2256.0	954.8	547.8	234.2	675.8	145.8	23.0	13.0	7924.78
	percentage	38.793%	28.468%	12.048%	6.913%	2.956%	8.528%	1.840%	0.290%	0.164%	
2004	SWAIN2 CORE1	24.26	62.3	67.24	17.52	1096.62	1868.3	66.6	4.22	2	3209.06
2004	SWAIN2 CORE2	154.68	726.06	554.77	487.47	638.53	419.81	33.7	3.61	7	3025.63
2004	SWAIN2 CORE3	82.48	425.67	605.42	553.38	236.13	316.16	187.97	43.16	9	2459.37
	SWAIN2 core total	261.4	1214.0	1227.4	1058.4	1971.3	2604.3	288.3	51.0	18.0	8694.06
	percentage	3.007%	13.964%	14.118%	12.173%	22.674%	29.955%	3.316%	0.586%	0.207%	
2004	SWAIN3 CORE1	1858.01	360.23	108.94	43.65	7.97	13.1	6.7	0.88	1	2400.48
2004	SWAIN3 CORE2	1918.38	488.65	171.78	74.97	40.37	79.52	10.89	0.95	2	2787.51
2004	SWAIN3 CORE3	917.14	562.58	256.4	129.21	103.9	305.86	43.64	3.86	3	2325.59
	SWAIN3 core total	4693.5	1411.5	537.1	247.8	152.2	398.5	61.2	5.7	6.0	7513.58
	percentage	62.467%	18.785%	7.149%	3.298%	2.026%	5.303%	0.815%	0.076%	0.080%	
	swain avg	31.469%	20.587%	11.821%	8.470%	9.859%	15.006%	2.288%	0.342%	0.158%	

2005	MILKS US3 CORE1	2196.18	770.29	298.13	147.05	147.34	337.76	16.73	1.78	2	3917.26
2005	MILKS US3 CORE2	1915.49	639.67	390.76	372.49	295.46	206.17	12.59	1.61	3	3837.24
2005	MILKS US3 CORE3	859.93	703.85	447.16	353.61	681.58	263.45	68.2	8.35	5	3391.13
	MILKS US3 core total	4971.6	2113.8	1136.1	873.2	1124.4	807.4	97.5	11.7	10.0	11145.63
	percentage	44.606%	18.965%	10.193%	7.834%	10.088%	7.244%	0.875%	0.105%	0.090%	
2005	MILKS US2 CORE1	2462.2	617.1	295.69	190.95	135.95	1278.63	148.67	96.98	24	5250.17
2005	MILKS US2 CORE2	1866.54	573.94	376.14	267.15	210.54	110.71	11.76	1.75	3	3421.53
2005	MILKS US2 CORE3	1270.4	994.69	553.52	359.77	243.4	215.91	11	1.31	3	3653
	MILKS US2 core total	5599.1	2185.7	1225.4	817.9	589.9	1605.3	171.4	100.0	30.0	12324.7
	percentage	45.430%	17.735%	9.942%	6.636%	4.786%	13.025%	1.391%	0.812%	0.243%	
2005	MILKS US1 CORE1	1139.28	742.99	249.88	95.71	73.6	152.53	10.64	0.73	2	2467.36
2005	MILKS US1 CORE2	1536.67	788.36	430.13	218.47	47.27	35.26	4.89	0.85	3	3064.9
2005	MILKS US1 CORE3	13.07	41.74	33.64	71.85	2107.59	200.32	106.63	13.58	5	2593.42
	MILKS US1 core total	2689.0	1573.1	713.7	386.0	2228.5	388.1	122.2	15.2	10.0	8125.68
	percentage	33.093%	19.359%	8.783%	4.751%	27.425%	4.776%	1.503%	0.187%	0.123%	
	milks us avg	41.043%	18.686%	9.639%	6.407%	14.100%	8.348%	1.256%	0.368%	0.152%	
2005	MILKS DS1 CORE1	1517.45	784.25	321.99	181.28	65.68	127.51	12.32	0.93	2	3013.41
2005	MILKS DS1 CORE2	687.31	436.9	228.82	277.92	1237.22	344.41	31.04	2.05	7	3252.67
2005	MILKS DS1 CORE3	1557.76	719.67	638.1	505.76	104.63	68.46	22.25	2.99	7	3626.62
	MILKS DS1 core total	3762.5	1940.8	1188.9	965.0	1407.5	540.4	65.6	6.0	16.0	9892.7
	percentage	38.033%	19.619%	12.018%	9.754%	14.228%	5.462%	0.663%	0.060%	0.162%	
	milks avg	39.538%	19.153%	10.829%	8.081%	14.164%	6.905%	0.960%	0.214%	0.157%	
2005	MIDSWAIN CORE1	28.84	472.09	491.09	606.92	714.59	526.98	44.01	8.42	7	2899.94
2005	MIDSWAIN CORE2	1458.04	846.15	469.99	278.89	355.02	350.02	18.64	2.58	7	3786.33
2005	MIDSWAIN CORE3	987.37	659.03	398.83	220.7	1139.09	200.14	28.8	3.3	6	3643.26
	MIDSWAIN core total	2474.3	1977.3	1359.9	1106.5	2208.7	1077.1	91.5	14.3	20.0	10329.53
	percentage	23.953%	19.142%	13.165%	10.712%	21.382%	10.428%	0.885%	0.138%	0.194%	
2005	SWAIN1 CORE1	1631.58	1093.48	488.41	235.02	38.56	80.89	13.05	1.12	3	3585.11
2005	SWAIN1 CORE2	521.78	1140.25	722.91	518.72	813.34	375.15	80.84	8.13	10	4191.12
2005	SWAIN1 CORE3	1656.3	900.18	401.14	223.85	136.79	177.72	47.94	4.22	6	3554.14
	SWAIN1 core total	3809.7	3133.9	1612.5	977.6	988.7	633.8	141.8	13.5	19.0	11330.37
	percentage	33.623%	27.659%	14.231%	8.628%	8.726%	5.593%	1.252%	0.119%	0.168%	
2005	SWAIN2 CORE1	1227.82	593.09	373.45	161.35	901.03	261.3	29.04	2.98	4	3554.06
2005	SWAIN2 CORE2	350.09	1039.15	580.86	558.86	799.49	215.64	36.72	4.83	11	3596.64
2005	SWAIN2 CORE3	394.15	671.73	621.4	889.38	512.86	284.47	40.39	5.59	9	3428.97
	SWAIN2 core total	1972.1	2304.0	1575.7	1609.6	2213.4	761.4	106.2	13.4	24.0	10579.67
	percentage	18.640%	21.777%	14.894%	15.214%	20.921%	7.197%	1.003%	0.127%	0.227%	
2005	SWAIN3 CORE1	2393.73	695.41	246.46	122.12	72.74	121.27	21.51	2.8	6	3682.04
2005	SWAIN3 CORE2	2606.54	478.94	186.38	102.39	44.92	107.33	15.3	2.76	9	3553.56
2005	SWAIN3 CORE3	1815.22	746.32	388.26	218.13	101.33	234.95	31.8	3.56	3	3542.57
	SWAIN3 core total	6815.5	1920.7	821.1	442.6	219.0	463.6	68.6	9.1	18.0	10778.17
	percentage	63.234%	17.820%	7.618%	4.107%	2.032%	4.301%	0.637%	0.085%	0.167%	
	swain avg	34.863%	21.600%	12.477%	9.665%	13.265%	6.880%	0.944%	0.117%	0.189%	

2006	MILKS US3 CORE1	1141.7	618.6	380.2	195.4	98.1	291.2	60.4	5.5	2	2793.1
2006	MILKS US3 CORE2	1485.2	363.6	211.0	132.2	553.7	124.6	7.4	0.9	3.0	2881.6
2006	MILKS US3 CORE3	935.9	714.1	495.0	334.3	539.9	338.3	74.5	2.1	0.0	3434.1
	MILKS US3 core total	3562.8	1696.3	1086.2	661.9	1191.7	754.1	142.3	8.5	5	9108.8
	percentage	39.114%	18.623%	11.925%	7.267%	13.083%	8.279%	1.562%	0.093%	0.055%	
2006	MILKS US2 CORE1	48.3	167.7	404.9	592.4	483.4	623.3	104.1	16.0	7.0	2447.1
2006	MILKS US2 CORE2	1309.3	847.8	458.2	251.0	43.2	101.9	48.4	5.6	4.0	3069.4
2006	MILKS US2 CORE3	1198.2	585.1	238.9	118.5	127.9	175.6	13.8	1.5	1.0	2460.5
	MILKS US2 core total	2555.8	1600.6	1102	961.9	654.5	900.8	166.3	23.1	12	7977
	percentage	32.040%	20.065%	13.815%	12.058%	8.205%	11.292%	2.085%	0.290%	0.150%	
2006	MILKS US1 CORE1	1328.5	701.2	385.7	220.1	42.7	119.2	42.1	1.1	3.0	2843.6
2006	MILKS US1 CORE2	2327.0	399.7	194.8	133.3	18.3	15.9	4.4	0.4	0.0	3093.8
2006	MILKS US1 CORE3	1221.2	568.5	475.0	288.9	78.6	87.7	22.7	50.0	2.0	2794.6
	MILKS US1 core total	4876.7	1669.4	1055.5	642.3	139.6	222.8	69.2	51.5	5	8732
	percentage	55.849%	19.118%	12.088%	7.356%	1.599%	2.552%	0.792%	0.590%	0.057%	
	milks us avg	42.334%	19.269%	12.609%	8.894%	7.629%	7.374%	1.480%	0.324%	0.088%	
2006	MILKS DS1 CORE1	1455.9	749.7	216.8	106.8	111.8	154.5	18.5	1.6	1.0	2816.6
2006	MILKS DS1 CORE2	2296.1	474.8	183.9	102.6	21.2	15.0	4.9	0.1	2.0	3100.6
2006	MILKS DS1 CORE3	908.9	668.5	385.1	338.9	140.0	148.7	72.7	5.9		2668.7
	MILKS DS1 core total	4660.9	1893	785.8	548.3	273	318.2	96.1	7.6	3	8585.9
	percentage	54.286%	22.048%	9.152%	6.386%	3.180%	3.706%	1.119%	0.089%	0.035%	
	milks avg	45.322%	19.963%	11.745%	8.267%	6.517%	6.457%	1.390%	0.265%	0.074%	
2006	MIDSWAIN CORE1	239.3	792.1	789.4	468.5	797.9	499.6	52.6	12.0	6.0	3657.4
2006	MIDSWAIN CORE2	170.6	680.9	514.4	343.8	329.3	417.6	37.2	3.3	4.0	2501.1
2006	MIDSWAIN CORE3	985.3	624.4	429.9	228.4	211.9	274.0	45.5	5.5	2.0	2806.9
	MIDSWAIN core total	1395.2	2097.4	1733.7	1040.7	1339.1	1191.2	135.3	20.8	12	8965.4
	percentage	15.562%	23.394%	19.338%	11.608%	14.936%	13.287%	1.509%	0.232%	0.134%	
2006	SWAIN1 CORE1	45.2	14.3	4.4	45.7	1458.5	627.1	13.4	1.0	4.0	2213.6
2006	SWAIN1 CORE2	664.4	1055.7	564.8	448	265.2	424.8	78.9	7.9	11	3520.7
2006	SWAIN1 CORE3	2613.2	314.7	60.9	18.1	2.1	1.6	0.8	0.4		3011.8
	SWAIN1 core total	3322.8	1384.7	630.1	511.8	1725.8	1053.5	93.1	9.3	15	8746.1
	percentage	37.992%	15.832%	7.204%	5.852%	19.732%	12.045%	1.064%	0.106%	0.172%	
2006	SWAIN2 CORE1	341.0	883.4	475.9	321.6	204.4	196.3	40.2	2.4	6.0	2471.2
2006	SWAIN2 CORE2	446.6	859.4	465.9	316.3	101.8	115.2	35.8	2.5	55.0	2398.5
2006	SWAIN2 CORE3	1629.7	561.2	248.4	132.8	16.9	12.1	15.7	3.7	8.0	2628.5
	SWAIN2 core total	2417.3	2304	1190.2	770.7	323.1	323.6	91.7	8.6	69	7498.2
	percentage	32.238%	30.727%	15.873%	10.278%	4.309%	4.316%	1.223%	0.115%	0.920%	
2006	SWAIN3 CORE1	1565.6	922.2	382.7	268.5	162.4	158.2	34.9	7.3	5.0	3506.8
2006	SWAIN3 CORE2	2477.5	513.6	255.5	222.5	147.5	129.6	19.5	2.3	9.0	3777.0
2006	SWAIN3 CORE3	1590.9	888.2	144.1	412.3	77.2	309.3	26.9	2.7	2.0	3453.6
	SWAIN3 core total	5634	2324	782.3	903.3	387.1	597.1	81.3	12.3	16	10737.4
	percentage	52.471%	21.644%	7.286%	8.413%	3.605%	5.561%	0.757%	0.115%	0.149%	
	swain avg	34.566%	22.899%	12.425%	9.038%	10.646%	8.802%	1.138%	0.142%	0.344%	

2007	MILKS US3 CORE1	2962.6	1248.2	674.7	379.4	514.1	394	52.9	4.1	2	6232
2007	MILKS US3 CORE2	2733.3	1098.7	637.7	493.6	643.2	102.6	17.3	3.2	2.0	5731.6
2007	MILKS US3 CORE3	2131.3	1053.5	649.5	561.7	1531.6	149.2	6.3	1.2	0.0	6084.3
	MILKS US3 core total	7827.2	3400.4	1961.9	1434.7	2688.9	645.8	76.5	8.5	4	18047.9
	percentage	43.369%	18.841%	10.871%	7.949%	14.899%	3.578%	0.424%	0.047%	0.022%	
2007	MILKS US2 CORE1	2620.1	1261.3	672.3	549.3	550.1	150.4	30.2	3.7	8.0	5845.4
2007	MILKS US2 CORE2	2447.9	1208.2	937.0	712.0	292.3	224.0	39.7	4.8	2.0	5867.9
2007	MILKS US2 CORE3	1032.1	1762.9	922.9	848.8	1145.2	325.8	36.5	4.0	1.0	6079.2
	MILKS US2 core total	6100.1	4232.4	2532.2	2110.1	1987.6	700.2	106.4	12.5	11	17792.5
	percentage	34.285%	23.788%	14.232%	11.859%	11.171%	3.935%	0.598%	0.070%	0.062%	
2007	MILKS US1 CORE1	422.1	714.1	401.9	212.5	2457.3	325.1	29.5	5.4	3.0	4570.9
2007	MILKS US1 CORE2	705.8	779.7	439.1	1371.7	2419.3	371.5	52.1	4.7	0.0	6143.9
2007	MILKS US1 CORE3	3164.6	1028.8	564.5	362.3	135.6	70.0	12.6	2.4	9.0	5349.8
	MILKS US1 core total	4292.5	2522.6	1405.5	1946.5	5012.2	766.6	94.2	12.5	12	16064.6
	percentage	26.720%	15.703%	8.749%	12.117%	31.200%	4.772%	0.586%	0.078%	0.075%	
	milks us avg	34.791%	19.444%	11.284%	10.642%	19.090%	4.095%	0.536%	0.065%	0.053%	
2007	MILKS DS1 CORE1	2500.3	1301.5	731.4	629.0	556.8	148.1	14.9	1.5	1.0	5884.5
2007	MILKS DS1 CORE2	1378.3	1205.3	774.6	795.5	1713.3	130.5	20.6	4.2	2.0	6024.3
2007	MILKS DS1 CORE3	3387.0	1194.9	484.7	256.1	33.7	15.8	6.9	1.6	3.0	5383.7
	MILKS DS1 core total	7265.6	3701.7	1990.7	1680.6	2303.8	294.4	42.4	7.3	6	17292.5
	percentage	42.016%	21.406%	11.512%	9.719%	13.323%	1.702%	0.245%	0.042%	0.035%	
	milks avg	36.597%	19.934%	11.341%	10.411%	17.648%	3.497%	0.463%	0.059%	0.048%	
2007	MIDSWAIN CORE1	623.9	1202.7	1142.7	944.2	1309.3	400.0	125.1	17.4	5.0	5770.3
2007	MIDSWAIN CORE2	2799.0	1147.1	616.8	321.8	580.2	253.1	52.8	4.3	4.0	5779.1
2007	MIDSWAIN CORE3	1786.2	2194.4	1009.8	523.9	425.0	563.9	20.7	2.6	2.0	6528.5
	MIDSWAIN core total	5209.1	4544.2	2769.3	1789.9	2314.5	1217	198.6	24.3	11	18077.9
	percentage	28.815%	25.137%	15.319%	9.901%	12.803%	6.732%	1.099%	0.134%	0.061%	
2007	SWAIN1 CORE1	1022.7	1291.7	1033.8	427.6	2324.4	116.4	24.4	2.7	4.0	6247.7
2007	SWAIN1 CORE2	806.8	1044.5	1484.4	1055.6	1784.9	172.2	32.1	3.2	11	6394.7
2007	SWAIN1 CORE3	952.6	1853.6	998.2	891.9	787.8	371.8	52.3	9.9	1.0	5919.1
	SWAIN1 core total	2782.1	4189.8	3516.4	2375.1	4897.1	660.4	108.8	15.8	16	18561.5
	percentage	14.989%	22.573%	18.945%	12.796%	26.383%	3.558%	0.586%	0.085%	0.086%	
2007	SWAIN2 CORE1	916.5	1715.9	1134.5	968.3	421.0	387.2	21.9	2.5	8.0	5575.8
2007	SWAIN2 CORE2	2528.5	1445.4	819.0	636.1	111.4	93.4	89.4	12.2	7.0	5742.4
2007	SWAIN2 CORE3	1494.4	1779.5	927.0	719.1	1139.1	146.5	16.2	2.8	9.0	6233.6
	SWAIN2 core total	4939.4	4940.8	2880.5	2323.5	1671.5	627.1	127.5	17.5	24	17551.8
	percentage	28.142%	28.150%	16.411%	13.238%	9.523%	3.573%	0.726%	0.100%	0.137%	
2007	SWAIN3 CORE1	2162.3	1339.2	926.8	715.4	473.0	186.2	23.5	3.6	4.0	5834.0
2007	SWAIN3 CORE2	3741.4	1111.2	338.9	98.2	14.5	13.3	3.5	1.5	9.0	5331.5
2007	SWAIN3 CORE3	1322.8	1337.2	1122.6	877.4	584.7	354.1	35.6	3.4	2.0	5639.8
	SWAIN3 core total	7226.5	3787.6	2388.3	1691	1072.2	553.6	62.6	8.5	15	16805.3
	percentage	43.001%	22.538%	14.212%	10.062%	6.380%	3.294%	0.373%	0.051%	0.089%	
	swain avg	28.737%	24.599%	16.222%	11.499%	13.772%	4.289%	0.696%	0.092%	0.093%	

Table 7. Sediment core raw data for longitudinal sites on Bear Creek, Kaleva, MI.

		DRY WEIGHT (g)									
Year	Transect	16mm	8mm	4mm	1mm	500µm	250µm	125µm	63µm	UFPM	Total
2004	S of W DS CORE1	1514.18	639.65	434.18	265.02	31.1	50.68	296.46	77.7	14	3322.97
2004	S of W DS CORE2	1685.5	493.53	240.59	118.68	32.13	64.54	21.83	1.76	1	2659.56
2004	S of W DS CORE3	1760.39	709.09	345.17	166.33	13.2	26.86	24.16	2.85	3	3051.05
	S of W DS core total	4960.1	1842.3	1019.9	550.0	76.4	142.1	342.5	82.3	18.0	9033.58
	percentage	54.907%	20.394%	11.291%	6.089%	0.846%	1.573%	3.791%	0.911%	0.199%	
2004	L BEAR DS CORE1	531.56	110.83	53.44	53.12	156.78	1170.68	249.59	92.96	14	2432.96
2004	L BEAR DS CORE2	9.31	3.44	1.9	32.74	1257.38	940.66	63.81	3.39	5	2317.63
2004	L BEAR DS CORE3	5.36	0.72	0.64	5.32	11.02	2170.44	832.14	101.72	8	3135.36
	L BEAR DS core total	546.2	115.0	56.0	91.2	1425.2	4281.8	1145.5	198.1	27.0	7885.95
	percentage	6.927%	1.458%	0.710%	1.156%	18.072%	54.296%	14.526%	2.512%	0.342%	
2005	S of W DS CORE1	1069.57	487.82	376.72	121.89	8.92	27.83	26.47	2.07	3	2124.29
2005	S of W DS CORE2	1311.33	535.75	330.5	156.64	87.81	133.66	22.79	1.86	2	2582.34
2005	S of W DS CORE3	792.65	953.61	614.45	345.77	225.56	309.97	42.94	3.14	2	3290.09
	S of W DS core total	3173.6	1977.2	1321.7	624.3	322.3	471.5	92.2	7.1	7.0	7996.72
	percentage	39.686%	24.725%	16.528%	7.807%	4.030%	5.896%	1.153%	0.088%	0.088%	
2005	L BEAR DS CORE1	1.19	0.27	0.72	39.76	2005.85	585.41	162.64	25.05	10	2830.89
2005	L BEAR DS CORE2	0	0	0.5	21.46	1705.44	327.58	24.56	0.28	4	2083.82
2005	L BEAR DS CORE3	3.06	0.52	0.2	3.42	1878.2	550.58	94.02	11.36	6	2547.36
	L BEAR DS core total	4.3	0.8	1.4	64.6	5589.5	1463.6	281.2	36.7	20.0	7462.07
	percentage	0.057%	0.011%	0.019%	0.866%	74.905%	19.613%	3.769%	0.492%	0.268%	

2006	S of W US CORE1	2375.6	446.0	246.7	142.1	88.1	108.2	21.9	2.8	4.0	3435.4
2006	S of W US CORE2	1620.7	445.3	339.0	207.2	71.5	102.3	20.3	2.4	3.0	2811.7
2006	S of W US CORE3	391.7	674.9	553.3	344.4	132.6	322.7	85.3	8.4	1.0	2514.3
	S of W US core total	4388	1566.2	1139	693.7	292.2	533.2	127.5	13.6	8	8761.4
	percentage	50.083%	17.876%	13.000%	7.918%	3.335%	6.086%	1.455%	0.155%	0.091%	
2006	S of W DS CORE1	1319.8	528.6	324.4	235.4	39.2	131.7	90.0	24.8		2693.9
2006	S of W DS CORE2	1196.4	694.5	332.1	160.3	117.5	234.1	54.1	4.6		2793.6
2006	S of W DS CORE3	504.2	829.1	437.5	211.7	144.8	480.3	127.8	13.8	4.0	2753.2
	S of W DS core total	3020.4	2052.2	1094	607.4	301.5	846.1	271.9	43.2	4	8240.7
	percentage	36.652%	24.903%	13.276%	7.371%	3.659%	10.267%	3.299%	0.524%	0.049%	
	s of w avg	43.368%	21.390%	13.138%	7.644%	3.497%	8.177%	2.377%	0.340%	0.070%	
2006	L BEAR US CORE1	20.3	9.9	3.1	7.9	16.8	1736.7	349.2	77.4		2221.3
2006	L BEAR US CORE2	0.0	0.5	1.3	44.4	224.9	1701.3	45.3	0.8	1.0	2019.5
2006	L BEAR US CORE3	11.8	5.6	2.5	5.5	523.0	243.4	95.3	23.5	33.0	943.6
	L BEAR US core total	32.1	16	6.9	57.8	764.7	3681.4	489.8	101.7	34	5184.4
	percentage	0.619%	0.309%	0.133%	1.115%	14.750%	71.009%	9.448%	1.962%	0.656%	
2006	L BEAR DS CORE1	0.0	3.3	2.5	60.2	466.2	1413.2	40.7	2.1	1.0	1989.2
2006	L BEAR DS CORE2	0.0	0.3	0.9	25.4	578.9	1713.1	67.3	3.1	3.0	2392.0
2006	L BEAR DS CORE3	416.4	129.1	48.3	45.2	354.8	667.9	122.8	43.6	48.0	1876.1
	L BEAR DS core total	416.4	132.7	51.7	130.8	1399.9	3794.2	230.8	48.8	52	6257.3
	percentage	6.655%	2.121%	0.826%	2.090%	22.372%	60.636%	3.688%	0.780%	0.831%	
	l bear avg	3.637%	1.215%	0.480%	1.603%	18.561%	65.823%	6.568%	1.371%	0.743%	
2006	LEFFEW US CORE1	1376.2	510.7	198.1	67.0	45.2	157.7	16.6	0.5		2372.01
2006	LEFFEW US CORE2	1889.5	126.0	48.1	25.0	25.0	57.6	5.9	0.2		2177.3
2006	LEFFEW US CORE3	1557.6	376.3	237.0	142.1	46.8	178.6	64.9	5.4	9.0	2617.7
	LEFFEW US core total	4823.3	1013.01	483.2	234.1	117	393.9	87.4	6.1	9	7167.01
	percentage	67.299%	14.134%	6.742%	3.266%	1.632%	5.496%	1.219%	0.085%	0.126%	
2006	LEFFEW DS CORE1	55.9	113.0	61.9	29.7	45.3	1510.0	68.9	5.2	5.0	1894.9
2006	LEFFEW DS CORE2	474.9	485.5	274.7	131.6	84.8	667.4	111.7	5.0	4.0	2239.6
2006	LEFFEW DS CORE3	948.3	96.1	56.2	34.2	13.7	27.3	6.2	5.0	15.0	1202.0
	LEFFEW DS core total	1479.1	694.6	392.8	195.5	143.8	2204.7	186.8	15.2	24	5336.5
	percentage	27.717%	13.016%	7.361%	3.663%	2.695%	41.314%	3.500%	0.285%	0.450%	
	leffew avg	47.508%	13.575%	7.051%	3.465%	2.164%	23.405%	2.360%	0.185%	0.288%	

2007	S of W US CORE1	2686.8	1338.4	741.7	379.1	109.7	204.3	18.1	3.2	4.0	5485.3
2007	S of W US CORE2	3058.0	995.3	621.4	558.1	380.8	245.2	34.1	4.2	3.0	5900.1
2007	S of W US CORE3	3276.0	1044.5	443.4	251.9	303.1	364.4	52.6	2.6	1.0	5739.5
	S of W US core total	9020.8	3378.2	1806.5	1189.1	793.6	813.9	104.8	10	8	17124.9
	percentage	52.677%	19.727%	10.549%	6.944%	4.634%	4.753%	0.612%	0.058%	0.047%	
2007	S of W DS CORE1	3031.1	1162.8	727.0	336.9	364.8	140.0	19.1	2.1	6.0	5789.8
2007	S of W DS CORE2	2669.8	1200.1	972.5	534.9	667.9	149.1	26.0	2.8	9.0	6232.1
2007	S of W DS CORE3	1711.2	1454.6	1038.9	647.5	1359.7	290.2	74.1	8.6	4.0	6588.8
	S of W DS core total	7412.1	3817.5	2738.4	1519.3	2392.4	579.3	119.2	13.5	19	18610.7
	percentage	39.827%	20.512%	14.714%	8.164%	12.855%	3.113%	0.640%	0.073%	0.102%	
	s of w avg	46.252%	20.120%	12.632%	7.554%	8.745%	3.933%	0.626%	0.065%	0.074%	
2007	L BEAR US CORE1	0.6	2.4	15.4	51.8	3925.4	336.8	35.6	2.8	2.0	4372.8
2007	L BEAR US CORE2	0	0.4	3	66	4912.4	121.2	32.4	2.2	1	5138.6
2007	L BEAR US CORE3	0.0	0.0	1.8	49.0	4893.4	191.4	19.4	1.4	3.0	5159.4
	L BEAR US core total	0.6	2.8	20.2	166.8	13731.2	649.4	87.4	6.4	6	14670.8
	percentage	0.004%	0.019%	0.138%	1.137%	93.595%	4.426%	0.596%	0.044%	0.041%	
2007	L BEAR DS CORE1	6.4	5.2	16.8	101.0	4356.6	480.8	65.0	5.6	1.0	5038.4
2007	L BEAR DS CORE2	1.4	4.8	0.8	32.6	4555.6	322.8	103.8	16.8	3.0	5041.6
2007	L BEAR DS CORE3	0.0	0.0	1.4	38.4	4638.4	362.4	35.0	2.6	28.0	5106.2
	L BEAR DS core total	7.8	10	19	172	13550.6	1166	203.8	25	32	15186.2
	percentage	0.051%	0.066%	0.125%	1.133%	89.230%	7.678%	1.342%	0.165%	0.211%	
	l bear avg	0.028%	0.042%	0.131%	1.135%	91.413%	6.052%	0.969%	0.104%	0.126%	
2007	LEFFEW US CORE1	2250.0	735.4	562.3	344.3	1803.9	85.0	27.7	2.2	5.0	5815.8
2007	LEFFEW US CORE2	4466.1	282.1	48.0	8.1	2.1	1.8	2.2	1.2	26.0	4837.6
2007	LEFFEW US CORE3	2164.4	605.6	309.3	159.2	2474.6	75.8	16.0	1.2	9.0	5815.1
	LEFFEW US core total	8880.5	1623.1	919.6	511.6	4280.6	162.6	45.9	4.6	40	16468.5
	percentage	53.924%	9.856%	5.584%	3.107%	25.993%	0.987%	0.279%	0.028%	0.243%	
2007	LEFFEW DS CORE1	1390.0	1454.6	655.4	439.4	1675.0	140.9	33.6	2.0	5.0	5795.9
2007	LEFFEW DS CORE2	130.7	196.5	115.5	80.0	2491.4	596.1	146.3	8.6	4.0	3769.1
2007	LEFFEW DS CORE3	3417.1	933.2	484.4	332.9	284.3	158.0	23.0	1.7	15.0	5649.6
	LEFFEW DS core total	4937.8	2584.3	1255.3	852.3	4450.7	895	202.9	12.3	24	15214.6
	percentage	32.454%	16.986%	8.251%	5.602%	29.253%	5.883%	1.334%	0.081%	0.158%	
	leffew avg	43.189%	13.421%	6.917%	4.354%	27.623%	3.435%	0.806%	0.054%	0.200%	

Appendix C

Summary of Macroinvertebrate Data for Study Sites

Table 1. Sickle Creek (Manistee Co., MI) pre- and post-restoration macroinvertebrate community from Surber samples taken in spring.

Taxa	Before	After
Coleoptera (Beetles)		
Elmidae	X	X
Curculionidae		X
Dytiscidae		X
Diptera (True Flies)		
Ceratopogonidae		X
Chironomidae	X	X
Dixidae		X
Dolichopodidae		X
Empididae	X	X
Ephyridae		X
Simuliidae	X	X
Tabanidae	X	X
Tipulidae	X	X
Ephemeroptera (Mayflies)		
Baetidae	X	X
Ephemeridae		X
Ephemerellidae	X	X
Heptageniidae		X
Plecoptera (Stoneflies)		
Capniidae		X
Leuctridae		X
Nemouridae	X	X
Perlodidae	X	X
Tainopterygidae	X	
Trichoptera (Caddisflies)		
Brachycentridae	X	X
Glossosomatidae	X	
Hydropsychidae		X
Lepidostomatidae		X
Limnephilidae		X
Philopotamidae	X	
Ueonidae		X
Hemiptera		
Aphidae		X
Homoptera		X
Notonectidae		X
Odonata		
Cordulegastridae		X
Miscellaneous		
Amphipoda		X
Annelida/Oligochaeta		X
Carabidae	X	
Embiidina		X
Hydrachnida/Hydracarina		X
Hymenoptera		X
Ichneumonidae		X
Isopoda		X
Isotomidae		X
Lepidoptera		X
Membracidae		X
Thysanoptera		X
Vespidae		X

Table 2. Sickle Creek (Manistee Co., MI) spring macroinvertebrate summary data by transect, pre to post restoration, for spring samples.

Transect			Days After January 1st	Abundance (#/m^2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
US3	Pre	Mean	136.5	249.3	6.0	20.0	22.0	2.8	7.3	0.7	2.0	0.5	12.7	1.7
		std error	7.8	147.1	1.2	10.0	7.4	0.8	3.5	0.2	0.9	0.2	4.3	0.4
	Post	Mean	133.5	311.3	10.7	32.7	91.3	4.8	48.0	1.7	9.3	1.5	34.0	1.7
		std error	2.0	65.7	0.9	5.3	13.4	0.9	11.6	0.2	3.2	0.6	10.9	0.6
US2	Pre	Mean	136.5	56.7	5.7	28.7	20.7	2.2	8.0	0.8	3.3	0.7	9.3	0.7
		std error	7.8	12.7	1.0	13.4	9.7	0.9	2.7	0.3	1.6	0.3	6.7	0.4
	Post	Mean	133.5	208.7	8.3	13.1	31.3	3.3	11.3	1.0	7.3	0.7	12.7	1.7
		std error	2.0	80.4	1.4	5.1	14.6	1.1	5.7	0.3	4.2	0.3	6.7	0.6
US1	Pre	Mean	136.5	143.3	6.8	25.9	31.3	3.3	12.7	1.2	8.7	0.8	10.0	1.3
		std error	7.8	54.0	1.3	12.0	18.9	1.0	8.0	0.4	5.6	0.3	5.4	0.4
	Post	Mean	133.5	320.7	12.3	24.3	73.3	5.0	30.0	1.3	22.7	1.5	20.7	2.2
		std error	2.0	87.7	1.7	6.1	21.8	0.9	12.3	0.4	7.0	0.3	7.5	0.5
DS1	Pre	Mean	136.5	494.0	8.5	28.3	70.7	3.7	47.3	1.2	12.0	1.2	11.3	1.3
		std error	7.8	242.1	0.9	11.2	19.6	0.9	13.6	0.3	3.6	0.3	3.9	0.4
	Post	Mean	133.5	694.7	13.8	24.3	180.7	5.5	87.3	1.8	42.7	1.7	50.7	2.0
		std error	2.0	193.8	2.3	4.2	52.8	1.3	27.8	0.3	14.2	0.6	18.3	0.6
DS2	Pre	Mean	136.5	252.0	8.3	25.0	62.0	4.3	25.3	1.8	10.0	1.0	26.7	1.5
		std error	7.8	45.5	0.8	5.0	18.4	0.6	8.0	0.3	3.1	0.3	9.7	0.4
	Post	Mean	133.5	338.7	11.3	14.6	60.0	4.0	16.0	1.0	26.0	1.5	18.0	1.5
		std error	2.0	66.2	1.5	4.9	24.4	0.9	9.5	0.4	13.6	0.2	8.4	0.6
DS3	Pre	Mean	136.5	114.0	9.0	43.1	52.7	4.3	14.0	1.3	18.7	1.3	20.0	1.7
		std error	7.8	33.5	1.3	8.6	17.6	0.9	4.5	0.3	6.5	0.3	8.6	0.3
	Post	Mean	133.5	108.0	7.7	10.6	8.7	1.3	4.0	0.5	0.7	0.2	4.0	0.7
		std error	2.0	24.8	1.6	6.5	3.3	0.4	2.5	0.2	0.7	0.2	2.5	0.3

Table 3. 1-way ANOVA (a) and MANOVA (BACI) (b) analysis of macroinvertebrate community data for Sickle Creek (Manistee Co., MI), for spring samples. Bold numbers indicate statistical significance. BACI *p*-value is for interaction term (Pre_Post x Up_Down).

a)

		Days After January 1st	Abundance (#/m^2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
Pre	Mean	136.5	218.2	7.4	28.5	43.2	3.4	19.1	1.2	9.1	0.9	15.0	1.4
	Std. Error	3.0	51.3	0.5	4.1	6.9	0.3	3.7	0.1	1.8	0.1	2.8	0.2
Post	Mean	133.5	330.3	10.7	20.0	74.2	4.0	32.8	1.2	18.1	1.2	23.3	1.6
	Std. Error	0.8	48.9	0.7	2.4	13.7	0.4	7.2	0.1	4.1	0.2	4.7	0.2
p-value (1-way ANOVA)		0.329	0.118	**0.000**	**0.078**	**0.047**	0.322	**0.095**	0.775	**0.048**	0.247	0.128	0.365

b)

			Days After January 1st	Abundance (#/m^2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
Pre	US	Mean	136.5	149.8	6.2	24.9	24.7	2.8	9.3	0.9	4.7	0.7	10.7	1.2
		Std. Error	4.2	52.8	0.6	6.5	7.1	0.5	2.9	0.2	2.0	0.2	3.0	0.2
	DS	Mean	136.5	286.7	8.6	32.1	61.8	4.1	28.9	1.4	13.6	1.2	19.3	1.5
		Std. Error	4.2	86.7	0.6	5.1	10.2	0.4	6.1	0.2	2.7	0.2	4.5	0.2
Post	US	Mean	133.5	280.2	10.4	23.4	65.3	4.4	29.8	1.3	13.1	1.2	22.4	1.8
		Std. Error	1.1	44.3	0.8	3.6	11.0	0.6	6.7	0.2	3.2	0.2	5.1	0.3
	DS	Mean	133.5	380.4	10.9	16.5	83.1	3.6	35.8	1.1	23.1	1.1	24.2	1.4
		Std. Error	1.1	87.2	1.2	3.2	25.3	0.7	12.8	0.2	7.4	0.3	7.9	0.3
p-value (BACI)			1.000	0.795	0.251	0.142	0.525	**0.059**	0.400	**0.044**	0.899	0.155	0.529	0.193

Table 4. Sickle Creek (Manistee Co., MI) pre- and post-restoration macroinvertebrate community from Surber samples taken in fall.

Taxa	Before	After
Coleoptera (Beetles)		
Elmidae	X	X
Circulonidae		X
Dytiscidae	X	X
Lampyridae	X	
Diptera (True Flies)		
Ceratopogonidae	X	X
Chironomidae	X	X
Dixidae		X
Empididae		X
Muscidae		X
Sciomyridae		X
Simuliidae	X	X
Stratiomyidae		X
Tabanidae	X	X
Tipulidae	X	X
Ephemeroptera (Mayflies)		
Baetidae	X	X
Ephemeridae		X
Ephemerellidae	X	X
Heptageniidae		X
Leptophlebiidae		X
Plecoptera (Stoneflies)		
Capniidae	X	X
Nemouridae	X	X
Perlodidae	X	X
Tainopterygidae	X	X
Trichoptera (Caddisflies)		
Brachycentridae	X	X
Glossosomatidae		X
Hydropsychidae	X	X
Lepidostomatidae		X
Limnephilidae	X	X
Phryganeidae		X
Polycentropodidae		X
Psychomiidae		X
Ueonidae		X
Hemiptera		
Aphidae		X
Cicadellidae		X
Delphacidae		X
Veliidae		X
Odonata		
Cordulegastridae		X
Miscellaneous		
Amphipoda		X
Annelida/Oligochaeta	X	
Gastropoda		X
Hydrachnida/Hydracarina		X
Isopoda	X	X

Table 5. Sickle Creek (Manistee Co., MI) macroinvertebrate summary data by transect, pre to post restoration, for fall samples.

Transect			Days After January 1st	Abundance (#/m^2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
US3	Pre	Mean	296.0	60.0	3.3	14.1	6.7	1.7	0.0	0.0	4.0	1.0	2.7	0.7
		std error	0.0	38.0	1.5	10.0	3.5	0.9	0.0	0.0	2.3	0.6	1.3	0.3
	Post	Mean	297.3	133.3	7.8	26.3	59.1	3.4	11.1	0.7	27.1	1.2	20.9	1.6
		std error	2.7	49.8	1.7	7.6	28.7	1.2	6.7	0.3	14.6	0.4	8.9	0.6
US2	Pre	Mean	296.0	58.7	1.7	4.8	1.3	0.3	0.0	0.0	0.0	0.0	1.3	0.3
		std error	0.0	43.2	0.7	4.8	1.3	0.3	0.0	0.0	0.0	0.0	1.3	0.3
	Post	Mean	297.3	166.2	8.7	25.8	39.1	3.7	6.7	0.8	19.6	1.4	12.9	1.4
		std error	2.7	48.5	1.6	6.3	15.3	1.1	3.3	0.3	8.0	0.5	5.2	0.4
US1	Pre	Mean	296.0	34.7	3.0	14.3	4.0	1.0	0.0	0.0	0.0	0.0	4.0	1.0
		std error	0.0	8.7	1.0	14.3	4.0	1.0	0.0	0.0	0.0	0.0	4.0	1.0
	Post	Mean	297.3	83.6	6.8	39.2	36.0	3.2	4.9	0.7	7.6	1.0	23.6	1.6
		std error	2.7	28.4	1.3	4.1	15.5	0.8	2.0	0.2	2.9	0.4	11.9	0.4
DS1	Pre	Mean	296.0	49.3	4.0	15.0	6.7	1.3	0.0	0.0	6.7	1.3	0.0	0.0
		std error	0.0	8.7	1.0	7.6	3.5	0.7	0.0	0.0	3.5	0.7	0.0	0.0
	Post	Mean	297.3	176.0	9.2	41.0	84.4	4.6	14.2	1.2	48.0	1.4	22.2	1.9
		std error	2.7	68.7	1.8	7.7	45.0	1.2	7.3	0.4	35.2	0.4	9.4	0.6
DS2	Pre	Mean	296.0	50.7	3.3	9.4	5.3	0.7	0.0	0.0	5.3	0.7	0.0	0.0
		std error	0.0	4.8	0.3	5.8	3.5	0.3	0.0	0.0	3.5	0.3	0.0	0.0
	Post	Mean	297.3	141.8	9.1	34.2	64.4	4.4	7.6	1.0	17.3	1.6	39.6	1.9
		std error	2.7	49.2	1.4	8.2	36.1	1.1	3.7	0.2	6.1	0.4	28.0	0.6
DS3	Pre	Mean	296.0	60.0	4.7	16.9	14.7	2.3	4.0	1.0	2.7	0.7	8.0	0.7
		std error	0.0	28.4	1.9	8.9	7.4	1.2	2.3	0.6	1.3	0.3	4.6	0.3
	Post	Mean	297.3	272.0	9.0	37.7	92.9	4.2	11.6	1.4	32.4	1.1	48.9	1.7
		std error	2.7	111.8	1.3	9.2	51.5	0.9	4.1	0.3	20.9	0.3	27.8	0.4

Table 6. 1-way ANOVA (a) and MANOVA (BACI) (b) analysis of macroinvertebrate community data for Sickle Creek (Manistee Co., MI), for fall samples. Bold numbers indicate statistical significance. BACI *p*-value is for interaction term (Pre_Post x Up_Down).

a)

		Days After January 1st	Abundance (#/m^2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
Pre	Mean	296.0	52.2	3.3	12.4	6.4	1.2	0.7	0.2	3.1	0.6	2.7	0.4
	Std. Error	0.0	9.4	0.5	3.3	1.8	0.3	0.5	0.1	1.0	0.2	1.1	0.2
Post	Mean	297.3	162.1	8.4	34.0	62.7	3.9	9.3	1.0	25.3	1.3	28.0	1.7
	Std. Error	1.0	26.4	0.6	3.0	13.8	0.4	1.9	0.1	7.3	0.2	7.1	0.2
p-value (1-way ANOVA)		0.465	**0.020**	**0.000**	**0.000**	**0.023**	**0.001**	**0.013**	**0.001**	**0.085**	**0.029**	**0.045**	**0.001**

b)

			Days After January 1st	Abundance (#/m^2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
Pre	US	Mean	296.0	51.1	2.7	11.0	4.0	1.0	0.0	0.0	1.3	0.3	2.7	0.7
		Std. Error	0.0	17.3	0.6	5.4	1.8	0.4	0.0	0.0	0.9	0.2	1.3	0.3
	DS	Mean	296.0	53.3	4.0	13.8	8.9	1.4	1.3	0.3	4.9	0.9	2.7	0.2
		Std. Error	0.0	8.8	0.6	3.9	3.0	0.5	0.9	0.2	1.6	0.3	1.9	0.1
Post	US	Mean	297.3	127.7	7.7	30.4	44.7	3.4	7.6	0.7	18.1	1.2	19.1	1.5
		Std. Error	1.5	25.0	0.9	3.6	11.7	0.6	2.5	0.2	5.6	0.3	5.1	0.3
	DS	Mean	297.3	196.6	9.1	37.6	80.6	4.4	11.1	1.2	32.6	1.4	36.9	1.8
		Std. Error	1.5	46.2	0.8	4.7	24.9	0.6	3.0	0.2	13.5	0.2	13.2	0.3
p-value (BACI)			1	0.473	0.987	0.688	0.522	0.732	0.746	0.668	0.670	0.512	0.475	0.302

Table 7. Milks Road on Bear Creek (Kaleva, MI) pre- and post-restoration macroinvertebrate community from Surber samples taken in spring.

Taxa	Before	After
Coleoptera		
Elmidae	X	X
Limnichidae		X
Salpingidae		X
Diptera		
Athericeridae	X	X
Ceratopogonidae		X
Chironomidae	X	X
Empididae	X	X
Simuliidae	X	X
Tabanidae	X	X
Tipulidae	X	X
Ephemeroptera		
Baetidae	X	X
Caeniidae	X	
Ephemerellidae	X	X
Heptageniidae	X	X
Leptophlebiidae	X	
Plecoptera		
Nemouridae		X
Perlidae		X
Perlodidae	X	X
Pteranarcyidae	X	X
Tainopterygidae		X
Trichoptera		
Brachycentridae	X	X
Glossosomatidae	X	X
Helicopsychidae	X	X
Hydropsychidae	X	X
Hydroptilidae		X
Lepidostomatidae		X
Leptoceridae		X
Limnephilidae	X	
Philopotamidae	X	
Polycentropodidae		X
Psychomiidae	X	X
Uenoidae		X
Hemiptera		
Alterodidae		X
Fulgoroidea		X
Odonata		
Gomphidae	X	X
Miscellaneous		
Amphipoda	X	X
Annelida	X	X
Annelida/Oligochaeta		X
Bivalvia		X
Gastropoda	X	
Hirudinea		X
Hydrachnida	X	X
Hymenoptera - Formicidae		X
Isopoda	X	X
Megaloptera - Corydalidae		X

Table 8. Milks Road on Bear Creek (Kaleva, MI) macroinvertebrate summary data by transect, pre- to post restoration, for spring samples.

Transect			Days After January 1st	Abundance (#/m2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
Milks US3	Pre	Mean	147.0	340.7	11.7	38.4	132.0	5.7	93.3	3.0	0.7	0.2	38.0	2.5
		std error	12.1	33.6	1.3	4.3	18.7	0.7	13.2	0.4	0.7	0.2	8.1	0.4
	Post	Mean	136.0	484.0	10.3	19.6	148.7	3.2	123.3	1.8	4.0	0.5	21.3	0.8
		std error	0.9	236.1	1.3	6.8	117.1	0.7	99.6	0.4	2.7	0.3	18.2	0.3
Milks US2	Pre	Mean	147.0	688.7	11.8	48.1	354.7	5.5	214.7	2.8	0.0	0.0	140.0	2.7
		std error	12.1	169.3	1.4	8.7	115.7	1.0	69.4	0.3	0.0	0.0	54.4	0.7
	Post	Mean	136.0	1093.3	13.8	27.3	407.3	5.5	325.3	2.2	8.0	0.7	88.8	2.7
		std error	0.9	362.1	1.3	8.1	194.4	1.1	163.3	0.5	5.8	0.3	27.6	0.7
Milks US1	Pre	Mean	147.0	594.0	12.5	47.4	286.7	5.2	183.3	2.5	0.7	0.2	102.7	2.5
		std error	12.1	207.7	1.3	6.1	121.7	0.6	74.6	0.3	0.7	0.2	47.2	0.3
	Post	Mean	136.0	1187.3	12.5	28.6	434.7	5.0	366.0	2.3	18.0	1.2	50.7	1.5
		std error	0.9	667.6	1.7	6.5	262.3	1.2	223.0	0.2	12.7	0.7	27.8	0.6
Milks DS	Pre	Mean	147.0	283.3	10.7	39.6	101.3	4.5	66.0	2.5	0.0	0.0	35.3	2.0
		std error	12.1	36.8	1.3	10.4	17.5	0.8	12.2	0.3	0.0	0.0	12.8	0.5
	Post	Mean	136.0	1247.3	14.0	28.0	421.3	6.2	330.7	2.3	18.0	1.8	72.7	2.0
		std error	0.9	342.3	2.1	5.6	149.7	1.2	129.2	0.4	9.8	0.6	19.4	0.4

Table 9. 1-way ANOVA (a) and MANOVA (BACI) (b) analysis of macroinvertebrate community data for Milk's Road on Bear Creek (Kaleva, MI), for spring samples. Bold numbers indicate statistical significance. BACI *p*-value is for interaction term (Pre_Post x Up_Down).

a)

		Days After January 1st	Abundance (#/m2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
Pre	Mean	147.0	476.7	11.7	43.4	218.7	5.2	139.3	2.7	0.3	0.1	79.0	2.4
	Std. Error	5.6	72.7	0.6	3.7	45.3	0.4	27.3	0.2	0.2	0.1	19.5	0.2
Post	Mean	136.0	1003.0	12.7	25.9	353.0	5.0	286.3	2.2	12.0	1.0	57.0	1.8
	Std. Error	0.4	211.6	0.8	3.3	91.5	0.6	77.4	0.2	4.2	0.3	12.1	0.3
p-value (1-way ANOVA)		**0.057**	**0.023**	0.336	**0.001**	0.195	0.712	**0.080**	**0.035**	**0.008**	**0.001**	0.348	**0.076**

b)

			Days After January 1st	Abundance (#/m2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
Pre	US	Mean	147.0	541.1	12.0	44.6	257.8	5.4	163.8	2.8	0.4	0.1	93.6	2.6
		Std. Error	6.5	91.8	0.7	3.7	57.5	0.4	34.5	0.2	0.3	0.1	24.9	0.3
	DS	Mean	147.0	283.3	10.7	39.6	101.3	4.5	66.0	2.5	0.0	0.0	35.3	2.0
		Std. Error	12.1	36.8	1.3	10.4	17.5	0.8	12.2	0.3	0.0	0.0	12.8	0.5
Post	US	Mean	136.0	921.6	12.2	25.2	330.2	4.6	271.6	2.1	10.0	0.8	48.7	1.7
		Std. Error	0.5	260.3	0.9	4.0	113.0	0.6	95.5	0.2	4.7	0.3	14.4	0.3
	DS	Mean	136.0	1247.3	14.0	28.0	421.3	6.2	330.7	2.3	18.0	1.8	72.7	2.0
		Std. Error	0.9	342.3	2.1	5.6	149.7	1.2	129.2	0.4	9.8	0.6	19.4	0.4
p-value (BACI)			0.993	0.311	0.235	0.582	0.345	0.132	0.470	0.498	0.434	**0.078**	0.139	0.358

Table 10. Milks Road on Bear Creek (Kaleva, MI) pre- and post-restoration macroinvertebrate community from Surber samples taken in fall.

Taxa	Before	After
Coleoptera		
Elmidae	X	X
Limnichidae		X
Salpingidae		X
Diptera		
Athericeridae	X	X
Ceratopogonidae		X
Chironomidae	X	X
Dolichopodidae		X
Empididae	X	X
Simuliidae	X	X
Tabanidae	X	X
Tipulidae	X	X
Ephemeroptera		
Baetidae	X	X
Caeniidae	X	X
Ephemerellidae	X	X
Heptageniidae	X	X
Isonychidae		X
Leptophlebiidae		X
Plecoptera		
Capniidae		X
Nemouridae		X
Perlidae		X
Perlodidae	X	X
Pteranarcyidae	X	X
Taineopterygidae	X	X
Trichoptera		
Brachycentridae	X	X
Glossosomatidae	X	X
Helicopsychidae	X	X
Hydropsychidae	X	X
Leptoceridae		X
Limnephilidae	X	X
Psychomiidae	X	X
Uenoidae		X
Odonata		
Gomphidae	X	X
Miscellaneous		
Amphipoda	X	X
Annelida/Oligochaeta	X	X
Gastropoda	X	X
Hydrachnida	X	X
Isopoda	X	X
Megaloptera - Corydalidae		X
Turbellaria		X

Table 11. Milks Road on Bear Creek (Kaleva, MI) macroinvertebrate summary data by transect, pre to post restoration, for fall samples.

Transect			Days After January 1st	Abundance (#/m2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
Milks DS	Pre	Mean	302.0	489.3	11.5	30.1	151.3	5.5	38.0	2.0	24.7	1.5	88.7	2.0
		std error	5.8	150.3	1.0	6.9	72.5	0.5	14.0	0.4	5.7	0.2	64.8	0.5
	Post	Mean	330.0	2034.0	18.2	30.3	729.3	7.3	330.7	2.5	108.0	2.3	290.7	2.5
		std error	17.0	498.8	1.1	10.3	425.7	0.6	184.9	0.2	41.9	0.2	254.7	0.4
Milks US1	Pre	Mean	302.0	512.0	10.7	26.1	117.3	4.3	55.3	2.0	14.0	1.2	48.0	1.2
		std error	5.8	134.7	1.3	9.5	46.3	1.0	21.9	0.5	4.1	0.2	26.7	0.5
	Post	Mean	330.0	1232.0	17.7	25.2	313.3	7.7	129.3	3.0	138.7	3.0	45.3	1.7
		std error	17.0	228.7	0.6	3.0	71.0	0.3	28.2	0.3	48.3	0.4	17.0	0.2
Milks US2	Pre	Mean	302.0	537.3	11.8	22.8	142.0	4.7	29.3	1.8	17.6	1.4	98.0	1.7
		std error	5.8	181.2	1.0	3.2	68.1	0.6	6.7	0.3	3.0	0.2	69.9	0.4
	Post	Mean	330.0	2875.3	17.3	32.3	1342.7	6.8	720.0	2.5	134.7	2.7	488.0	1.7
		std error	17.0	1568.8	2.2	7.1	952.1	1.2	506.3	0.6	48.2	0.5	427.6	0.5
Milks US3	Pre	Mean	302.0	293.3	10.3	31.0	72.7	4.7	36.7	1.2	20.0	1.5	16.0	2.0
		std error	5.8	76.8	1.0	5.2	9.5	0.6	8.0	0.2	2.9	0.2	5.0	0.5
	Post	Mean	330.0	966.0	13.5	28.5	392.0	5.3	155.3	1.5	44.0	2.0	192.7	1.8
		std error	17.0	432.7	1.9	5.7	265.8	0.8	94.1	0.2	16.7	0.7	158.3	0.4

Table 12. 1-way ANOVA (a) and MANOVA (BACI) (b) analysis of macroinvertebrate community data for Milk's Road on Bear Creek (Kaleva, MI), for fall samples. Bold numbers indicate statistical significance. BACI *p*-value is for interaction term (Pre_Post x Up_Down).

a)

		Days After January 1st	Abundance (#/m2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
Pre	Mean	302.0	458.0	11.1	27.5	120.8	4.8	39.8	1.8	19.1	1.4	62.7	1.7
	std error	2.7	68.7	0.5	3.2	26.5	0.3	6.8	0.2	2.1	0.1	24.1	0.2
Post	Mean	330.0	1776.8	16.7	29.1	694.3	6.8	333.8	2.4	106.3	2.5	254.2	1.9
	std error	7.9	429.5	0.8	3.3	265.3	0.4	136.9	0.2	20.6	0.2	126.4	0.2
p-value (1-way ANOVA)		**0.002**	**0.004**	**0.000**	0.737	**0.037**	**0.001**	**0.037**	**0.025**	**0.000**	**0.000**	0.143	0.504

b)

			Days After January 1st	Abundance (#/m2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
Pre	US	Mean	302.0	447.6	10.9	26.6	110.7	4.6	40.4	1.7	17.2	1.4	54.0	1.6
		std error	3.2	79.3	0.6	3.6	26.9	0.4	8.0	0.2	2.0	0.1	24.9	0.3
	DS	Mean	302.0	489.3	11.5	30.1	151.3	5.5	38.0	2.0	24.7	1.5	88.7	2.0
		std error	5.8	150.3	1.0	6.9	72.5	0.5	14.0	0.4	5.7	0.2	64.8	0.5
Post	US	Mean	330.0	1691.1	16.2	28.6	682.7	6.6	334.9	2.3	105.8	2.6	242.0	1.7
		std error	9.2	553.8	1.0	3.1	330.4	0.5	174.5	0.3	24.4	0.3	149.7	0.2
	DS	Mean	330.0	2034.0	18.2	30.3	729.3	7.3	330.7	2.5	108.0	2.3	290.7	2.5
		std error	17.0	498.8	1.1	10.3	425.7	0.6	184.9	0.2	41.9	0.2	254.7	0.4
p-value (BACI)			0.970	0.810	0.552	0.828	0.982	0.883	0.998	0.842	0.916	0.545	0.978	0.664

Table 13. Swain's Property on Bear Creek (Kaleva, MI) pre- and post-restoration macroinvertebrate community from Surber samples taken in spring.

Taxa	Before	After
Coleoptera		
Elmidae	X	X
Hydrophilidae	X	X
Diptera		
Athericeridae	X	X
Ceratopogonidae	X	
Chironomidae	X	X
Empididae	X	X
Muscidae		X
Simuliidae	X	X
Tabanidae	X	
Tipulidae	X	X
Ephemeroptera		
Baetidae	X	X
Baetiscidae		X
Caeniidae	X	
Ephemerellidae	X	X
Heptageniidae	X	X
Plecoptera		
Tainopterygidae	X	X
Nemouridae	X	
Perlidae	X	X
Perlodidae	X	X
Trichoptera		
Brachycentridae	X	
Glossosomatidae	X	X
Helicopsychidae	X	X
Hydropsychidae	X	X
Hydroptilidae	X	X
Leptoceridae		X
Limnephilidae	X	
Philopotamidae	X	
Polycentropodidae		X
Psychomiidae	X	
Ryacophilidae	X	
Uenoidae		X
Hemiptera		
Corixidae	X	
Fulgoroidae		X
Odonata		
Gomphidae	X	X
Miscellaneous		
Amphipoda	X	X
Annelida	X	X
Gastropoda	X	X
Hydracarina	X	X
Isopoda	X	X
Isotomidae		X

Table 14. Swain's Property macroinvertebrate summary data on Bear Creek (Kaleva, MI) by transect, pre- to post-restoration, for spring samples.

Transect			Days After January 1st	Abundance (#/m2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
MidSwain	Pre	Mean	147.5	416.3	10.0	37.5	183.3	3.3	132.0	2.0	0.0	0.0	51.3	1.3
		Std. Error	11.9	155.0	1.7	9.7	118.2	0.5	82.4	0.3	0.0	0.0	36.5	0.3
	Post	Mean	133.0	502.0	9.0	34.4	121.3	3.7	112.0	2.2	0.7	0.2	8.7	1.3
		Std. Error	1.3	341.4	1.2	10.5	53.7	0.6	51.3	0.3	0.7	0.2	2.4	0.2
Swain 1	Pre	Mean	147.5	666.0	10.8	33.4	232.7	4.7	166.0	2.3	0.0	0.0	66.7	2.3
		Std. Error	11.9	140.1	1.7	6.4	62.3	0.7	34.7	0.3	0.0	0.0	34.7	0.4
	Post	Mean	133.0	1215.3	14.5	36.6	346.7	5.7	278.0	2.3	3.3	0.7	65.3	2.7
		Std. Error	1.3	419.4	1.5	8.4	120.1	0.9	77.5	0.3	1.9	0.3	45.9	0.7
Swain 2	Pre	Mean	147.5	570.0	12.3	49.2	298.7	6.0	190.7	2.7	1.3	0.3	106.7	3.0
		Std. Error	11.9	113.9	1.7	5.5	73.9	1.2	44.7	0.4	0.8	0.2	52.2	0.7
	Post	Mean	133.0	784.3	11.7	26.2	210.0	3.5	194.0	2.7	1.3	0.2	14.7	0.7
		Std. Error	1.3	171.6	1.1	4.1	63.7	0.3	54.9	0.2	1.3	0.2	8.1	0.2
Swain 3	Pre	Mean	147.5	560.7	11.5	37.7	172.0	4.8	146.7	2.5	2.0	0.5	23.3	1.8
		Std. Error	11.9	168.5	1.6	9.6	56.0	1.0	49.1	0.5	2.0	0.5	10.3	0.3
	Post	Mean	133.0	1290.0	13.8	29.3	277.3	4.7	244.7	2.5	0.7	0.2	32.0	2.0
		Std. Error	1.3	600.3	1.5	5.3	110.3	0.8	97.4	0.2	0.7	0.2	14.4	0.6

Table 15. 1-way ANOVA (a) and MANOVA (BACI) (b) analysis of macroinvertebrate community data for Swain's Property on Bear Creek (Kaleva, MI) for spring samples. Bold numbers indicate statistical significance. BACI *p*-value is for interaction term (Pre_Post x Up_Down), with US Milks Road serving as the upstream component.

a)

		Days After January 1st	Abundance (#/m2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
Pre	Mean	147.5	553.3	11.2	39.5	221.7	4.7	158.8	2.4	0.8	0.2	62.0	2.1
	Std. Error	5.5	70.5	0.8	3.9	39.3	0.5	26.4	0.2	0.5	0.1	18.2	0.3
Post	Mean	133.0	947.9	12.3	31.6	238.8	4.4	207.2	2.4	1.5	0.3	30.2	1.7
	Std. Error	0.6	203.9	0.8	3.6	46.1	0.4	36.3	0.1	0.6	0.1	12.3	0.3
p-value (1-way ANOVA)		**0.012**	**0.074**	0.331	0.149	0.778	0.581	0.287	0.858	0.424	0.636	0.154	0.223

b)

			Days After January 1st	Abundance (#/m2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
Pre	US	Mean	147.0	541.1	12.0	44.6	257.8	5.4	163.8	2.8	0.4	0.1	93.6	2.6
		Std. Error	6.5	91.8	0.7	3.7	57.5	0.4	34.5	0.2	0.3	0.1	24.9	0.3
	DS	Mean	147.5	553.7	11.2	39.5	221.7	4.7	158.8	2.4	0.8	0.2	62.0	2.1
		Std. Error	5.5	70.4	0.8	3.9	39.3	0.5	26.4	0.2	0.5	0.1	18.2	0.3
Post	US	Mean	136.0	921.6	12.2	25.2	330.2	4.6	271.6	2.1	10.0	0.8	48.7	1.7
		Std. Error	0.5	260.3	0.9	4.0	113.0	0.6	95.5	0.2	4.7	0.3	14.4	0.3
	DS	Mean	133.0	947.9	12.3	31.6	238.8	4.4	207.2	2.4	1.5	0.3	30.2	1.7
		Std. Error	0.6	203.9	0.8	3.6	46.1	0.4	36.3	0.1	0.6	0.1	12.3	0.3
p-value (BACI)			0.684	0.968	0.592	0.138	0.672	0.559	0.561	**0.055**	**0.035**	**0.078**	0.714	0.453

Table 16. Swain's Property on Bear Creek (Kaleva, MI) pre- and post-restoration macroinvertebrate community from Surber samples taken in fall.

Taxa	Before	After
Coleoptera		
Elmidae	X	X
Hydrophilidae		X
Isonychidae	X	
Sialidae	X	
Diptera		
Athericeridae	X	X
Ceratopogonidae	X	
Chironomidae	X	X
Empididae	X	X
Simuliidae	X	X
Tabanidae	X	X
Tipulidae	X	X
Ephemeroptera		
Baetidae	X	X
Baetiscidae	X	
Ephemerellidae	X	X
Heptageniidae	X	X
Leptophlebiidae	X	X
Tricorythidae	X	
Plecoptera		
Capniidae	X	X
Leutridae		
Nemouridae		X
Perlidae	X	X
Perlodidae	X	X
Pteranarcyidae	X	
Tainopterygidae	X	X
Trichoptera		
Apataniidae		X
Brachycentridae	X	X
Glossosomatidae	X	X
Helicopsychidae	X	X
Hydropsychidae	X	X
Lepidostomatidae		X
Leptoceridae		X
Limnephilidae	X	X
Philopotamidae	X	
Polycentropodidae	X	X
Psychomiidae	X	X
Ryacophilidae	X	
Uenoidae		X
Odonata		
Gomphidae	X	X
Miscellaneous		
Amphipoda	X	X
Annelida	X	X
Bivalvia		X
Decopoda		X
Gastropoda	X	X
Hydracarina	X	X
Isopoda	X	X
Megaloptera - Corydalidae	X	X
Turbellaria		X

Table 17. Swain's Property macroinvertebrate summary data on Bear Creek (Kaleva, MI) by transect, pre- to post-restoration, for fall samples.

Transect			Days After January 1st	Abundance (#/m2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
MidSwain	Pre	Mean	296.0	1125.3	16.0	41.0	506.7	9.3	238.7	5.7	96.0	1.0	172.0	2.7
		std error	0.0	418.3	1.7	5.5	224.5	1.8	108.9	0.9	26.6	0.0	134.2	1.2
	Post	Mean	322.3	747.6	14.9	28.8	228.0	5.6	126.7	1.9	40.0	1.3	61.3	2.3
		std error	11.7	126.9	0.8	4.2	49.6	0.4	29.9	0.3	16.8	0.3	29.1	0.5
Swain 1	Pre	Mean	296.0	1069.3	15.7	42.9	521.3	8.3	194.7	2.0	80.0	2.7	246.7	3.7
		std error	0.0	330.9	2.4	10.0	249.3	2.2	106.3	1.0	18.0	1.2	128.8	0.9
	Post	Mean	322.3	1443.1	15.0	34.8	597.3	6.2	241.8	1.8	37.8	1.6	317.8	2.9
		std error	11.7	342.9	1.1	7.1	208.1	0.6	97.9	0.3	21.4	0.2	183.4	0.4
Swain 2	Pre	Mean	296.0	576.0	11.3	35.8	218.7	6.0	77.3	2.7	13.3	1.0	128.0	2.3
		std error	0.0	127.5	0.3	7.1	73.1	0.6	21.8	0.7	4.8	0.0	56.0	0.9
	Post	Mean	322.3	1419.1	16.6	35.4	552.9	6.7	333.8	2.0	164.9	1.9	54.2	2.8
		std error	11.7	360.1	0.8	4.2	178.3	0.6	104.9	0.3	71.2	0.4	11.8	0.4
Swain 3	Pre	Mean	296.0	1048.0	15.7	41.6	457.3	8.7	178.7	2.7	52.0	2.0	226.7	4.0
		std error	0.0	132.3	0.9	8.7	154.4	0.3	44.2	0.3	10.6	0.0	111.1	0.6
	Post	Mean	322.3	1224.0	17.0	38.7	468.4	7.8	246.7	2.2	88.9	2.1	132.9	3.4
		std error	11.7	242.1	1.2	4.2	108.7	0.7	55.6	0.3	28.8	0.4	65.6	0.4

Table 18. 1-way ANOVA (a) and MANOVA (BACI) (b) analysis of macroinvertebrate community data for Swain's Property on Bear Creek (Kaleva, MI) for fall samples. Bold numbers indicate statistical significance. BACI *p*-value is for interaction term (Pre_Post x Up_Down), with US Milks Road serving as the upstream component.

a)

		Days After January 1st	Abundance (#/m2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
Pre	Mean	296.0	954.7	14.7	40.3	426.0	8.1	172.3	3.3	60.3	1.7	193.3	3.2
	std error	0.0	137.4	0.9	3.5	88.3	0.7	38.5	0.5	11.9	0.3	49.7	0.4
Post	Mean	322.3	1208.4	15.9	34.4	461.7	6.6	237.2	2.0	82.9	1.7	141.6	2.9
	std error	5.6	143.6	0.5	2.5	75.4	0.3	39.5	0.1	21.3	0.2	50.5	0.2
p-value (1-way ANOVA)		**0.010**	0.338	0.232	0.224	0.801	**0.031**	0.374	**0.002**	0.554	0.868	0.578	0.496

b)

			Days After January 1st	Abundance (#/m2)	Taxa Richness	% EPT	EPT Abundance	EPT Richness	Ephemeroptera Abundance	Ephemeroptera Richness	Plecoptera Abundance	Plecoptera Richness	Trichoptera Abundance	Trichoptera Richness
Pre	US	Mean	289.0	517.8	11.1	31.5	146.2	5.3	43.6	2.0	15.1	1.1	87.6	2.2
		Std. Error	0.0	135.1	0.7	6.5	49.3	0.5	14.9	0.4	2.8	0.2	46.8	0.3
	DS	Mean	296.0	954.7	14.7	40.3	426.0	8.1	172.3	3.3	60.3	1.7	193.3	3.2
		Std. Error	0.0	137.4	0.9	3.5	88.3	0.7	38.5	0.5	11.9	0.3	49.7	0.4
Post	US	Mean	325.0	1253.2	14.4	26.3	480.1	5.7	235.7	2.0	76.3	2.2	168.1	1.5
		Std. Error	6.2	386.3	0.9	2.3	225.3	0.5	118.5	0.2	18.1	0.2	101.0	0.2
	DS	Mean	322.3	1208.4	15.9	34.4	461.7	6.6	237.2	2.0	82.9	1.7	141.6	2.9
		Std. Error	5.6	143.6	0.5	2.5	75.4	0.3	39.5	0.1	21.3	0.2	50.5	0.2
p-value (BACI)			0.512	0.468	0.260	0.920	0.432	**0.094**	0.521	**0.027**	0.457	**0.058**	0.482	0.477

Appendix D

Summary of Fish Data for Study Sites

Table 1. Relative abundance (RA) of fish (calculated as % CPUE/min) for all years combined, and for pre- vs. post-restoration in Sickle Creek, Manistee Co., MI. Negative values in italics indicate a decrease in that species RA from pre- to post-restoration.

Species	Mean Relative Abundance	Pre-Restoration	Post-Restoration	Difference	% change
MOS	72.12	61.53	76.31	14.78	24
CHS	6.43	2.89	7.83	4.94	170
RBT	5.78	4.34	6.34	2.01	46
BUT	3.52	11	0.57	*-10.43*	*-94*
ABL	3.18	1.69	3.77	2.09	123
COS	1.93	4.9	0.76	*-4.14*	*-84*
CRC	1.86	5.94	0.25	*-5.69*	*-95*
BKT	1.36	0.8	1.59	0.78	97
JOD	0.93	1.69	0.63	*-1.05*	*-62*
BNT	0.8	1.12	0.67	*-0.46*	*-40*
BRS	0.66	2.33	0	*-2.33*	*-100*
SEL	0.59	0	0.82	0.82	100
NRD	0.32	1.04	0.03	*-1.01*	*-96*
BND	0.2	0.16	0.22	0.06	38
CEM	0.14	0.32	0.06	*-0.26*	*-80*
BLG	0.05	0	0.06	0.06	100
BNM	0.02	0.08	0	*-0.08*	*-100*
FSD	0.02	0	0.03	0.03	100
NOP	0.02	0.08	0	*-0.08*	*-100*
LMB	0.02	0	0.03	0.03	100
WHS	0.02	0.08	0	*-0.08*	*-100*

Fish abbreviations: MOS – mottled sculpin; CHS – Chinook salmon; RBT – rainbow trout; BUT – burbot; ABL – American brook lamprey; COS – Coho salmon; CRC – creek chub; BKT – brook trout; JOD – johnny darter; BNT – brown trout; BRS – brook stickleback; SEL – sea lamprey; NRD – northern redbelly dace; BND – blacknose dace; CEM – central mudminnow; BLG – bluegill; BNM – bluntnose minnow; FSD – finescale dace; NOP – northern pike; LMB – largemouth bass; WHS – white sucker.

Table 2. CPUE (pooled for all species, # fish per minute) and community metrics by season for upstream and downstream reaches at Sickle Creek, Manistee Co., MI. Upstream and downstream *p*-values indicate 1-way ANOVA significance (in bold) between pre- and post-restoration, which took place between fall 2005 and spring 2006. Data is for spring (a) and summer (b) samples.

a)

Spring Samples	Upstream				Downstream				*p*-value	
Metric	2004	2005	2006	2007	2004	2005	2006	2007	Upstream	Downstream
CPUE	2.67	2.29	1.99	3.35	7.34	2.97	2.52	3.03	0.712	0.146
Shannon Diversity Index (H)	0.42	0.39	0.84	0.18	1.43	1.16	1.47	0.74	0.256	0.407
Simpson's Dominance Index (D)	0.69	0.76	0.64	0.93	0.37	0.43	0.30	0.61	0.598	0.582
Richness	4.5	2.0	7.0	4.0	10.7	6.7	8.3	5.7	0.146	0.386

b)

Summer Samples	Upstream				Downstream				*p*-value	
Metric	2004	2005	2006	2007	2004	2005	2006	2007	Upstream	Downstream
CPUE	1.06	2.49	3.65	2.43	7.51	3.80	2.36	3.25	0.212	**0.033**
Shannon Diversity Index (H)	1.05	0.39	0.63	0.20	1.34	1.13	1.33	0.81	0.364	0.287
Simpson's Dominance Index (D)	0.51	0.75	0.73	0.92	0.35	0.44	0.40	0.62	0.234	0.528
Richness	6.0	2.0	7.5	4.5	8.7	5.7	8.7	7.7	0.253	0.397

Table 3. BACI analysis of spring and fall electrofishing samples on Sickle Creek, Manistee Co., MI. BACI *p*-value is for interaction term (Pre_Post x Up_Down).

			CPUE	Chinook CPUE	Sculpin CPUE	Burbot CPUE	Mean Richness	Shannon's Diversity	Simpson's Dominance
Pre	US	Mean	2.1	0.0	1.8	0.0	3.6	0.562	0.676
		Std. Error	0.276	0.000	0.273	0.000	0.8	0.144	0.073
	DS	Mean	5.4	0.2	3.1	0.8	7.9	1.264	0.399
		Std. Error	0.846	0.035	0.525	0.235	0.8	0.071	0.030
Post	US	Mean	2.9	0.2	3.4	0.0	5.8	0.512	0.806
		Std. Error	0.417	0.090	0.586	0.003	0.6	0.101	0.050
	DS	Mean	2.8	0.4	2.3	0.0	7.6	1.086	0.481
		Std. Error	0.332	0.109	0.464	0.010	0.6	0.143	0.069
p-value (BACI)			**0.008**	0.776	**0.026**	**0.008**	0.105	0.602	0.684

Table 4. Relative abundance (RA) of fish (calculated as % CPUE/min) for all years combined, and for pre- vs. post-restoration at Milks Road on Bear Creek, Kaleva, MI. Negative values in italics indicate a decrease in that species RA from pre- to post-restoration.

Species	Mean Relative Abundance	Pre-Restoration	Post-Restoration	Difference	% change
BND	33.03	33.39	32.85	*-0.55*	-2
RBT	23.92	22	24.92	2.92	13
JOD	8.85	5.34	10.69	5.35	100
WHS	7.5	9.07	6.68	*-2.39*	-26
CHS	7.1	7.12	7.09	*-0.03*	0
MOS	6.85	8.48	6	*-2.48*	-29
BNT	3.96	3.44	4.23	0.79	23
CRC	3.36	4.92	2.55	*-2.37*	-48
COS	1.12	1.07	1.15	0.08	8
BLG	0.86	0	1.31	1.31	100
BUT	0.86	2.08	0.22	*-1.86*	-90
CMM	0.65	1.42	0.25	*-1.17*	-83
SEL	0.45	0	0.68	0.68	100
BKT	0.41	0.77	0.22	*-0.55*	-72
ABL	0.37	0.89	0.09	*-0.8*	-90
GOR	0.12	0	0.19	0.19	100
YEP	0.1	0	0.16	0.16	100
SHR	0.1	0	0.16	0.16	100
NRD	0.08	0	0.12	0.12	100
GRS	0.06	0	0.09	0.09	100
BNS	0.04	0	0.06	0.06	100
PUS	0.04	0	0.06	0.06	100
BNM	0.02	0	0.03	0.03	100
LND	0.02	0	0.03	0.03	100
STS	0.02	0	0.03	0.03	100
HYB	0.02	0	0.03	0.03	100
RAD	0.02	0	0.03	0.03	100
STB	0.02	0	0.03	0.03	100
CMS	0.02	0	0.03	0.03	100
GOS	0.02	0	0.03	0.03	100

Fish abbreviations: BND – blacknose dace; RBT – rainbow trout; JOD – johnny darter; WHS – white sucker; CHS – Chinook salmon; MOS – mottled sculpin; ; BNT – brown trout; CRC – creek chub; COS – Coho salmon; BLG – bluegill; BUT – burbot; CMM – central mudminnow; SEL – sea lamprey; BKT – brook trout; ABL – American brook lamprey; GOR – golden redhorse sucker; YEP – yellow perch; SHR – shorthead redhorse sucker; NRD – northern redbelly dace; GRS – green sunfish; BNS – blacknose shiner; PUS – pumpkinseed sunfish; BNM – bluntnose minnow; LND – longnose dace; STS – spottail shiner; HYB – hybrid sunfish; RAD – rainbow darter; STB – stickleback; CMS – common shiner; GOS – golden shiner.

Table 5. CPUE (pooled for all species, # fish per minute) and community metrics by season for upstream and downstream reaches at Milks Road, Kaleva, MI. Upstream and downstream *p*-values indicate significance (in bold) between pre- and post-restoration, which took place between fall 2005 and spring 2006.

	Upstream					Downstream					*p*-value	
Metric	Fall 2004	Spring 2005	Fall 2005	Spring 2006	Spring 2007	Fall 2004	Spring 2005	Fall 2005	Spring 2006	Spring 2007	Upstream	Downstream
CPUE (min)	4.21	4.94	8.74	12.82	12.38	2.11	4.77	5.59	4.94	8.23	**0.031**	0.276
Shannon Diversity Index (H)	1.69	1.76	1.89	2.01	1.80	2.00	1.83	2.03	2.32	1.91	0.334	0.418
Simpson's Dominance Index (D)	0.26	0.25	0.20	0.18	0.22	0.15	0.21	0.18	0.13	0.22	0.285	0.909
Richness	10	12	13	18	15	10	13	13	21	18	**0.056**	**0.022**

Table 6. BACI analysis of electrofishing data for Milks Road on Bear Creek, Kaleva, MI. BACI *p*-value is for interaction term (Pre_Post x Up_Down).

			CPUE	Blacknose Dace CPUE	Brown Trout CPUE	Chinook CPUE	Johnny Darter CPUE	Rainbow Trout CPUE	White Sucker CPUE	Shannon's Diversity	Simpson's Dominance
Pre	US	Mean	6.0	2.3	0.2	0.3	0.3	1.2	0.6	1.783	0.234
		Std. Error	1.405	0.284	0.039	0.195	0.160	0.572	0.172	0.059	0.020
	DS	Mean	4.2	1.1	0.2	0.4	0.2	1.0	0.3	1.954	0.182
		Std. Error	1.050	0.467	0.021	0.281	0.045	0.406	0.016	0.064	0.018
Post	US	Mean	12.6	2.8	0.5	0.8	1.5	2.9	1.0	1.906	0.205
		Std. Error	0.220	2.095	0.131	0.157	0.126	0.433	0.007	0.105	0.021
	DS	Mean	6.8	1.6	0.3	0.6	0.6	2.1	0.3	2.116	0.176
		Std. Error	1.410	0.204	0.056	0.198	0.085	1.026	0.021	0.204	0.041
p-value (BACI)			0.163	0.996	0.331	0.580	**0.027**	0.660	0.234	0.852	0.641

Table 7. Relative abundance (RA) of fish (calculated as % CPUE/min) for all years combined, and for pre- vs. post-restoration at Swain's Property on Bear Creek, Kaleva, MI. Negative values in italics indicate a decrease in that species RA from pre- to post-restoration.

Species	Mean Relative Abundance	Pre-Restoration	Post-Restoration	Difference	% change
RBT	32.49	13.89	38.59	24.7	178
BND	24.37	44.09	17.89	*-26.2*	*-59*
CHS	12.42	11.6	12.68	1.09	9
WHS	7.71	9.41	7.15	*-2.26*	*-24*
JOD	5.22	6.56	4.78	*-1.79*	*-27*
BNT	5.09	2.19	6.04	**3.85**	176
MOS	3.3	3.28	3.31	0.02	1
CRC	2.87	5.36	2.05	*-3.31*	*-62*
COS	1.27	1.53	1.19	*-0.35*	*-23*
BLG	0.84	0	1.11	1.11	100
SEL	0.84	0	1.11	1.11	100
BUT	0.78	0.88	0.75	*-0.12*	*-14*
CNS	0.62	0	0.83	0.83	100
CMM	0.35	0.88	0.18	*-0.7*	*-79*
YEP	0.32	0	0.43	*0.43*	*100*
GOR	0.22	0	0.29	0.29	100
BKT	0.19	0.33	0.14	*-0.18*	*-56*
LND	0.19	0	0.25	0.25	100
NBL	0.16	0	0.22	0.22	100
NRD	0.14	0	0.18	0.18	100
PUS	0.11	0	0.14	0.14	100
SHR	0.11	0	0.14	0.14	100
GOS	0.11	0	0.14	0.14	100
GRR	0.08	0	0.11	0.11	100
MIS	0.08	0	0.11	0.11	100
GRS	0.05	0	0.07	0.07	100
NEP	0.03	0	0.04	0.04	100
RAD	0.03	0	0.04	0.04	100
LMB	0.03	0	0.04	0.04	100

Fish abbreviations: RBT – rainbow trout; BND – blacknose dace; CHS – Chinook salmon; WHS – white sucker; JOD – johnny darter; BNT – brown trout; MOS – mottled sculpin; CRC – creek chub; COS – Coho salmon; BLG – bluegill; SEL – sea lamprey; BUT – burbot; CNS – common shiner; CMM – central mudminnow; YEP – yellow perch; GOR – golden redhorse sucker; BKT – brook trout; LND – longnose dace; NBL – American brook lamprey; NRD – northern redbelly dace; PUS – pumpkinseed sunfish; SHR – shorthead redhorse sucker; GOS – golden shiner; GRR – greater river redhorse sucker; MIS – mimic shiner; GRS – green sunfish; NEP – northern pike; RAD – rainbow darter; LMB – largemouth bass.

Table 8. CPUE (pooled for all species, # fish per minute) and community metrics by season for upstream and downstream reaches at Swain's Property on Bear Creek, Kaleva, MI. Upstream and downstream *p*-values indicate significance (in bold) between pre- and post-restoration, which took place between fall 2005 and spring 2006.

	Upstream					Downstream					*p*-value	
Metric	Fall 2004	Spring 2005	Fall 2005	Spring 2006	Spring 2007	Fall 2004	Spring 2005	Fall 2005	Spring 2006	Spring 2007	Upstream	Downstream
CPUE (min)	6.89	6.18	6.54	4.91	8.83	8.69	3.10	4.96	12.39	8.27	0.890	0.501
Shannon Diversity Index (H)	1.55	1.77	1.89	2.11	1.95	1.59	1.87	1.71	2.15	1.67	**0.071**	0.648
Simpson's Dominance Index (D)	0.32	0.23	0.22	0.17	0.20	0.31	0.19	0.24	0.18	0.29	0.134	0.840
Richness	10	11	12	17	17	11	11	10	20	18	0.114	0.294

Table 9. BACI analysis of electrofishing data for Swain's Property on Bear Creek, Kaleva, MI. BACI *p*-value is for interaction term (Pre_Post x Up_Down).

			CPUE	Blacknose Dace CPUE	Brown Trout CPUE	Chinook CPUE	Johnny Darter CPUE	Rainbow Trout CPUE	White Sucker CPUE	Shannon's Diversity	Simpson's Dominance
Pre	US	Mean	6.5	2.9	0.2	1.0	0.4	0.7	0.6	1.658	0.276
		Std. Error	0.355	0.830	0.158	0.971	0.141	0.120	0.122	0.112	0.047
	DS	Mean	5.9	2.6	0.1	0.5	0.5	1.0	0.6	1.730	0.246
		Std. Error	2.794	1.794	0.051	0.426	0.126	0.741	0.077	0.145	0.061
Post	US	Mean	6.8	1.1	0.4	0.7	0.3	2.3	0.6	1.984	0.195
		Std. Error	1.136	0.565	0.228	0.404	0.048	0.483	0.155	0.067	0.013
	DS	Mean	8.5	1.6	0.4	1.0	0.4	3.4	0.5	1.844	0.239
		Std. Error	2.149	0.130	0.119	0.429	0.019	0.868	0.160	0.155	0.030
p-value (BACI)			0.545	0.653	0.890	0.493	0.786	0.555	0.956	0.442	0.338

Appendix E

Mottled Sculpin Movement Study Summary Data

Table 1. Summary of biometric and tracking data for mottled sculpin movement study conducted on Sickle Creek, Manistee Co., MI.

PIT #	Length (mm)	Weight (g)	Head Width (mm)	Cap. Loc.	# recaps	max dist moved	1st Reloc. Reach	2nd Reloc. Reach	3rd Reloc. Reach	4th Reloc. Reach	5th Reloc. Reach	6th Reloc. Reach	7th Reloc. Reach	8th Reloc. Reach	9th Reloc. Reach	10th Reloc. Reach
3ECB46	83	7.1	16	DS1	1	237	DS3									
485E9B	95	10.7	22	DS4	1	21									DS5	
4568A7	86	9.3	18	DS4	1	23						DS5				
45FF90	76	6.9	16	US2	1	460	DS3									
46E3B7	96	10.9	17	US1	2	533	DS3				DS3					
433B27	91	10.5	18	US3	1	7	US3									
456E42	85	10.1	18	US3	4	38	US3	US3			US3	US3				
45ADDD	71	5.5	14	DS4	2	50	DS4				DS4					
4601C7	85	10.4	17	US3	3	65				US3	US3					US3
4647D4	96	12.1	18	DS1	2	7			DS1						DS1	
4698C7	85	7.3	13	DS5	3	24			DS5	DS5	DS5					
46C362	85	8.4	19	US2	2	54	US2	US2								
46E3C4	100	15	20	US1	3	31		US1		US1					US1	
480E67	70	5.1	15	DS4	6	24		DS4		DS4	DS4		DS4		DS4	DS4
48AC86	90	8.4	20	DS4	1	14	DS4									
48B5D2	84	7	14	DS3	3	26	DS3	DS3								DS4
513CE0	69	4.4	12	DS3	2	6	DS3									DS3
434B78	65	4.8	12	DS3	1	93	DS2									
457FCC	83	7.7	16	DS5	1	315		DS1								
4587D3	107	15.6	23	DS5	1	211	DS3									
460C1E	90	11.5	20	DS3	2	617	DS3	US3								
460DEA	70	4.8	15	DS5	1	660		US2								
46E298	100	10.7	21	DS1	3	143	US1	US2							DS1	
48121E	101	14.5	18	US1	1	253			+US3							
4863AC	113	15.4	20	DS4	2	73		DS3				DS2				
48AB81	87	9.8	20	US3	1	61				+US3						
485C06	101	13.9	21	US2	1	33									US3	
48ADE1	85	11.1	15	US1	4	17	US1	US2	US1							US1
46081C	85	8.8	16	US3	2	3									US3	US3
514A4F	74	6.9	15	DS5	2	23	DS4	DS4								
434079	110	16.3	21	DS1	4	27				DS1			DS1		DS1	DS1
3ECD51	66	4.2	12	DS5	2	3	DS5					DS5				
3FD197	81	7.7	16	US2	5	67	US2	US2			US2		US2			US2
459A38	70	4.8	15	DS2	1	13	DS2									
4601D4	100	11.5	19	DS2	1	15	DS2									
4610F0	90	11.1	16	US1	2	19	US1									US1
46939C	64	3.6	12	DS5	2	5					DS5				DS5	
46C77A	75	6.4	15	DS4	1	12		DS4								
48914C	94	11.8	19	US2	1	31	US2									
489E2C	108	16.7	25	DS2	1	71	DS2									
48AA8C	86	8.8	16	US2	5	38		US2	US2	US2	US2				US2	
485914	91	11.3	15	US1	1	81										US2
458326	64	2.3	13	DS1	1	138								US2		
48ABF7	97	13.8	17	US1	1	13								US1		
486642	87	11.3	17	US3	1	2								US3		
46EA21	76	6.4	15	US2	4	839			US1			US1		-DS5		+US3
4607E0	93	10.3	19	DS1	3	159								US2	US2	US2
513815	118	19	24	DS2	2	0	DS2	DS2								
4652B9	106	19	24	US3	1	0		US3								
48475E	80	6.5	15	US2	4	0	US2		US2	US2	US2		US2		US2	US2
485C84	77	5.7	14	DS4	2	0	DS4	DS4					DS4			
48646D	80	10.1	20	US2	2	0	US2			US2						