1-1-2008

# Artificial Riffles As A Stream Remediation Technique

Bethany S. Harrington
*Eastern Illinois University*

# THESIS MAINTENANCE AND REPRODUCTION CERTIFICATE

TO: Graduate Degree Candidates (who have written formal theses)

SUBJECT: Permission to Reproduce Theses

The University Library is receiving a number of request from other institutions asking permission to reproduce dissertations for inclusion in their library holdings. Although no copyright laws are involved, we feel that professional courtesy demands that permission be obtained from the author before we allow these to be copied.

PLEASE SIGN ONE OF THE FOLLOWING STATEMENTS:

Booth Library of Eastern Illinois University has my permission to lend my thesis to a reputable college or university for the purpose of copying it for inclusion in that institution's library or research holdings.

Bobby S. Han 8-1-08

Author's Signature Date

I respectfully request Booth Library of Eastern Illinois University **NOT** allow my thesis to be reproduced because:

Author's Signature Date

**This form must be submitted in duplicate.**

Artificial Riffles as a Stream Remediation Technique

(TITLE)

BY

Bethany S. Harrington

**THESIS**

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Science in Biological Sciences

IN THE GRADUATE SCHOOL, EASTERN ILLINOIS UNIVERSITY
CHARLESTON, ILLINOIS

2008
YEAR

I HEREBY RECOMMEND THAT THIS THESIS BE ACCEPTED AS FULFILLING THIS PART OF THE GRADUATE DEGREE CITED ABOVE

18 August 2008
DATE

Dr. Robert Fischer
THESIS DIRECTOR

18 August 2008
DATE

Andrew S. Methven
DEPARTMENT/SCHOOL HEAD

# ACKNOWLEDGEMENTS

I'd like to first thank my advisor, Dr. Bud Fischer, who seemed to believe in me from the beginning and somehow kept that belief even after four years. This project was a great learning experience as a biologist and person and I feel Bud was an integral part of that experience. I'd also like to give a heartfelt thanks to my committee members, Dr. Chuck Pederson and Dr. Scott Meiners, who tirelessly answered my questions and whose positive outlook always made me laugh (at least most of the time).

I'd also like to acknowledge my EIU peers and Kaskaskia friends who contributed their time throughout the field sampling process. Special thanks go to Mike Harrington, Dr. Dan Shoup, Jeanine Tolemy, Terri Thomsen, INHS Kaskaskia technicians, and the EIU Freshwater Aquatics Research Team for countless field and lab hours. Finally, all of my appreciation goes to my family and close friends, who have shown me support and patience through this very long journey.

## TABLE OF CONTENTS


Abstract ..........................i

Acknowledgements ..........................ii

List of Tables ..........................v

List of Figures ..........................vi

Introduction ..........................1

Materials and Methods ..........................5

- -Study Sites ..........................5
- -Physical Habitat Assessment ..........................6
- -Fish Community Assessment ..........................7
- -Benthic Invertebrate Assessment ..........................8
- -Analytical Methods ..........................9

Results ..........................11

- -Physical Habitat Assessment ..........................11
- -Fish Community Assessment ..........................13
- -Benthic Invertebrate Assessment ..........................15

Discussion ..........................16

- -Physical Habitat ..........................17
- -Fish Communities ..........................18
- -Benthic Invertebrates ..........................21
- -Overall Conclusions ..........................23

References ..........................27

Appendix - Data ..........................54

## LIST OF TABLES

**Table** **Page**

1 SHAP categories used in the Modified SHAP method to qualitatively assess individual riffle characteristics............................................34

2 MBI Scores and Interpretive Water Quality Association (Resh et al. 1996).............................................................................35

3 Individual SHAP assessments for riffles on Ashmore, Hurricane, and Sugar Creeks.................................................................36

4 Total number of fish collected in natural and artificial riffles on study sites combining spring and fall sampling periods. Note fall samples were not collected from Hurricane Creek due to drought conditions.......................................................................37

5 Relative abundance of invertebrates collected from artificial and natural riffles in both Sugar and Ashmore Creeks. Sampling was conducted three times during the months of July-September 2005........................38

6 MBI Ratings for riffles on Sugar and Ashmore Creeks. Sampling was conducted during the months of July-September 2005.....................39

7 Relative abundances of invertebrates in each tolerance rating as classified by Voshell 2002. Sampling was conducted during the months of July-September 2005.........................................................40

## LIST OF FIGURES

**Figure** **Page**

1 Location of the three study site riffles sampled for fish and invertebrates located on Sugar Creek, Hurricane Creek, and Ashmore Creek..................41

2 Mean stream depth (m) for natural and artificial riffles on Ashmore, Hurricane, and Sugar Creeks.........................................................42

3 Mean current velocities ($s^{-1}$) for Hurricane, and Sugar Creeks. Due to drought conditions, Ashmore Creek had an average current velocity of 0 and was not included in the figure............................43

4 Mean species richness on combined fish community samples for each study stream. Species richness did not differ significantly between natural and artificial riffles within streams. Hurricane Creek was not sampled in the fall of 2005 due to drought conditions.........................................44

5 Mean Shannon-Weiner Diversity of combined fish community samples for each study stream. Diversity did not differ significantly between natural and artificial riffles within streams. Hurricane Creek was not sampled in the fall of 2005 due drought.........................................................45

6 Mean Index of Biotic Integrity Scores of combined fish community samples for each study stream. IBI did not differ significantly between natural and artificial riffles within streams. Hurricane Creek was not sampled in the fall of 2005 due to drought.........................................46

7 MDS ordination of fish assemblages in artificial and natural riffles of Ashmore, Hurricane, and Sugar Creeks. A significant relationship existed among creeks (r=0.823; p<0.001). Hurricane Creek was not sampled in the fall of 2005 due to drought conditions............................................47

8 MDS of fish assemblages in natural and artificial riffles in Sugar Creek........................................................................48

9 Abundances of fish identified in the BVSTEP routine of combined fish samples for each stream. Hurricane Creek was not sampled in the fall of 2005 due to drought conditions.........................................49

10 Mean Shannon Weiner Diversity of benthic invertebrate community samples for each study stream..................................................50

11 Relative abundance of invertebrate taxa identified in each stream that are tolerant to organic and inorganic pollution (Voshell 2002)..................51

12 Relative abundance of invertebrate taxa identified in each stream that are intolerant to organic and inorganic pollution (Voshell 2002)...............52

13 MDS ordination of invertebrate assemblages for artificial and natural riffles of each study stream. A significant difference was found between Ashmore and Sugar Creek assemblages (r=0.695; p=0.001)...............53

# INTRODUCTION

The potential for ecosystem adaptation is directly influenced by human culture and requirements (Ebersole et al. 1997). Increasing land development and demand for resources have long been primary causes of international debate regarding freshwater habitat degradation and endangerment of stream biota (Federal Interagency Stream Restoration Working Group 199, Rosenfeld 2003). Traditionally, water bodies were viewed as agents of transportation and production and were not valued for their ecological importance (Harper et al. 1998, Ebrahimnezhad and Harper 1997, Tompkins and Kondolf, unpublished data).

Large expanses of riparian area in the Midwestern United States were cleared and rivers were diverted, straightened, or deepened for flood control and agricultural drainage purposes in the late 19th and early 20th centuries (Barbour et al. 1999, Frothingham et al. 2002, Landwehr and Rhoads 2003, Urban and Rhoades 2003). Straightening, also referred to as channelization, causes loss of woody debris and gravel deposits (Brooker 1985, Frothingham et al. 2001, Harrison et al. 2004, Landwehr and Rhoads 2003, Magilligan 1985) while decreasing soil infiltration, increasing overland flow, and increasing erosion (Poff et al. 1997). In Illinois, channelization has greatly affected headwater streams (Landwehr and Rhoads 2003) with nearly all of first-order streams and half of the total length of second-order streams straightened for agricultural purposes (Frothingham et al. 2002). Specifically, channelization in East-Central Illinois is on a catastrophic scale, with more streams being altered than can be corrected by natural processes (Frothingham et al. 2002).

In recent years, reduced water quality has made people aware of the need for additional habitat (Bond and Lake 2003, Gregory 1895, Kondolf 1995, Lake 2001, Peterson et al. 1990, Rinaldi and Johnson 1997, Tompkins and Kondolf, unpublished data) and restoration of natural flow regimes with the assumption that an ecological response would follow (Bond and Lake 2003). Restoration is termed as the attempt to return components of an ecosystem to their original, undisturbed state (Ebersole et al. 1997, Kondolf and Micheli 1995, Lake 2001, Moerke and Lamberti 2003, Roni at al 2002, Sheilds et al. 2003). Restoration management consists of several steps beginning with identification of anthropogenic pressures, reducing or relieving these constraints, understanding the ability of a specific ecosystem to adjust to restoration and continued monitoring of biotic response (Ebersole et al. 1997). The National Research Council recommended in 1992 that 400,000 stream and river miles in the United States be restored by the year 2012; therefore restoration methods, adequacy of monitoring programs, and scale of current efforts need to be evaluated (Moerke and Lamberti 2003).

Habitat managers commonly employ both passive and active tactics for stream restoration. Passive techniques allow water bodies to recover naturally as a result of hydraulic forces, whereas active techniques apply physical measures to initiate recovery (Harrison, et al. 2004, Lake 2001). Active remediation techniques include the placement of large woody debris (D'Aoust and Millar 2000, Fausch et al. 1995, Hilderbrand et al. 1998, Roni et al. 2002), flow deflectors (Carline and Klosiewski 1985, Harrison et al. 2004, Laasonen et al. 1998, Pretty et al. 2003), bank stabilization methods including vegetative plantings (Moerke and Lamberti 2003, Roni et al. 2002), and artificial riffles (Carline and Klosiewski 1985, Edwards et al. 1984, Ebrahimnezhad and Harper 1997,

Fuselier and Edds 1995, Harper et al. 1998, Harrison et al. 2004, Pretty et al. 2003) to restore stream reaches. Of these techniques, large woody debris (Fausch et al. 1995) and flow deflectors are among the most commonly used and yield qualitative biological responses a majority of the time (Carline and Klosiewski 1985, Hilderbrand et al. 1998). Specifically, rock deflectors in two Ohio streams enhanced fish diversity and biomass as compared to control sections (Carline and Klosiewski 1985).

Most research has focused on physical aspects of restored streams as opposed to biological responses to restoration (Bond and Lake 2003, Roni et al. 2002). A study by Smokorwoski et al. (1998) demonstrated that 98% of restoration projects reached their physical habitat goals while only 5% accomplished their biological restoration goals (quoted in Bond and Lake 2003). Biological responses are considered the "ultimate measure of restoration effectiveness" as opposed to studies of physical restoration responses (i.e. replacement of course cobble, depletion of fine sediment in streams, current velocity, depth, and substratum particle size;(Roni et al. 2002). Thus, biological communities serve as an important management tool in examining whole ecosystem health and the response of interest due to their sensitivity to the combined effects of environmental stressors (Barbour et al. 1999).

Historically, intensified agriculture has reduced biological diversity (Ebrahimnezhad and Harper 1997, Frothingham et al. 2002, Pretty et al. 2003), abundance, and biomass (Barbour et al. 1999, Carline and Klosiewski 1985, Negishi et al. 2002). Loss of habitat heterogeneity in streams (Frothingham et al. 2002, Pretty et al. 2003) has resulted in the loss of foraging inputs, spawning habitat, and cover for biota (Ebrahimnezhad and Harper 1997, Pretty et al. 2003). In Britain, channelization resulting

from agriculture negatively affected fish abundance in lowland rivers by homogenizing habitat (Pretty et al. 2003). A variety of substrata and habitat complexity has been shown to be necessary to fulfill the requirements of fish and invertebrate life stages (Pretty et al. 2003). In a study by Moerke and Lamberti (2003), gravel, boulders, and large woody debris were added to two streambeds in Indiana to enhance spawning conditions, decrease erosion, and provide habitat. In one of two streams, enhancements did increase fish richness, diversity, and biomass. Although much work is being done to improve habitat, there are a limited number of research projects that have conducted post stream restoration sampling to quantitatively analyze restoration effectiveness (Carline and Klosiewski 1985, Edwards et al. 1984, Fuselier and Edds 1995, Kondolf and Micheli 1995, Roni et al. 2002). Of these, only handfuls have examined artificial riffles as a restoration technique, though research has identified riffles as an adequate restoration method to increase habitat heterogeneity and encourage biological community perseverance (Negishi et al. 2002).

My project sought to answer the question of how physical structures, specifically artificial riffles, perform in first through third-order streams with respect to biological assemblages in East-Central Illinois. Our main objective was to determine whether fish and invertebrate assemblages differ between natural and artificial riffles to assess restoration effectiveness. Collection of fish assemblages allowed for the investigation of a range of trophic levels (Barbour et al. 1999, Karr 1981) and gave the opportunity to study mobile communities affected by both upstream and downstream processes (Frothingham et al. 2002, Sovell et al. 2000). Benthic invertebrates are commonly used as a bioassessment tool of water quality and overall habitat health due to their limited

mobility (Barbour et al. 1999, Sovell et al. 2000). Information gained from the comparison of fish and invertebrate communities between artificial and natural riffles will allow for the evaluation of artificial riffles as a stream remediation technique and assess their economic feasibility in Midwestern streams.

For the overall evaluation of the above feasibility objectives, I considered one popular definition of restoration success encompassing three primary goals of ecological success, learning success, and stakeholder success. Within these goals are evaluation criteria that take into account cost-effectiveness, self-sustainability, ecosystem health, ecosystem resiliency, and long-term effects (Palmer et al. 2005).

## MATERIALS AND METHODS

**Study Sites:**

From 2000 through 2003, the Illinois Department of Agriculture installed 30 artificial riffles on eight streams to slow flood waters and increase stability in low gradient channels. Of these, three study streams (Downes et al. 2006) in East-Central Illinois were selected based on ease of access, stream order, and presence of both artificial and natural riffles. Each study site consisted of two randomly chosen artificial riffles and one natural riffle occurring within 100 meters downstream (Ebrahimnezhad and Harper 1997, Harrison et al. 2004), a distance considered suitable for hydraulic and biological independence from other riffles (Harrison et al. 2004). Study sites were located on Sugar Creek (third-order) in McLean County, Hurricane Creek (second-order) in Coles County, and Ashmore Creek (first-order) in Clark County (Figure 1). All streams were surrounded by land converted for row crop agriculture. Artificial riffles were constructed of small boulders, course cobble, and gravel occupying an average area

per riffle of 240$m^2$ in Sugar Creek, 47$m^2$ in Hurricane Creek, and 30$m^2$ in Ashmore Creek.

**Physical Habitat Assessment:**

The quality of physical habitat in the study area can be a potential limiting factor in the lifecycle of biological communities and can affect the structure and function of aquatic life (Barbour et al. 1999). Physical and environmental characteristics of each site including mean stream depth, mean stream width, and current velocity were quantified for each riffle (Ebrahimnezhad and Harper 1997, Pretty et al. 2003). These measurements were chosen based on measurements used in the common Instream Flow Incremental Methodology (IFIM) model to describe the effects of changing flows on fishes (Poff et al. 1997).

Both quantitative and qualitative assessments were used to analyze the stream physical habitat. The quantitative assessment used to describe and compare substrate was based on The Illinois Environmental Protection Agency's Eleven Transect Method (Illinois Environmental Protection Agency 1994). The Eleven Transect Method was modified to better suit the purpose of comparing individual riffles and not stream reaches. Thus, my modified transect method used three transects per riffle; an upstream, mid, and downstream transect to yield a total of nine transects per stream. Wetted width, depth, and substrate type (boulders, cobble, gravel, or sand) were recorded at one or two-foot intervals (based on stream width) along transects running perpendicular to the flow (Illinois Environmental Protection Agency 1994).

In addition, The Stream Habitat Assessment Procedure (SHAP) was used to qualitatively evaluate instream habitat (Illinois Environmental Protection Agency 1994)

at each site. SHAP is an efficient and cost effective way to determine stream quality and make comparisons among similar water bodies. SHAP allows fisheries professionals to assess stream quality based on 15 metrics that are subjectively assessed and assigned to one of four habitat quality categories. Similar to the Eleven Transect Method, the SHAP was modified for the purpose of this study since individual riffles, and not whole reaches, were assessed. Categories that pertained to whole reach characteristics (e.g. pool quality) were not evaluated as part of the individual riffle assessments (Table1). Data from both the modified Eleven Transect Method and SHAP were used to compare habitat quality between artificial and natural riffles within streams and then the habitat information was related to biota present at each site.

Mean depth and velocity were plotted for each study stream. Differences in depth, velocity, and modified SHAP scores were tested using a one-way analysis of variance (ANOVA). Bonferonni *post hoc* tests were conducted to examine where differences in physical parameters lie (i.e. stream, riffle type, or individual riffle). Statistical analyses were performed using SPSS software (SPSS 12.0 SPSS Inc., Chicago, IL). Significance was determined at the 0.05 level.

**Fish Community Assessment:**

Fish communities on the artificial and natural riffles were sampled by electroshocking procedures as defined by Environmental Protection Agency protocols. Two fish assemblage samples were taken on each stream between March 2005-June 2005 and two samples from Sugar and Ashmore Creeks between September 2005-November 2005. Hurricane Creek was not sampled in the fall of 2005 due to a lack of flowing water over the riffles resulting from drought conditions. During fish sampling, the reach was

blocked upstream and downstream with 1/8″ bar double-leaded seines preventing fish from entering or exiting the sampling reach. Fish were sampled using a nine-meter electric seine (Angermeier and Smogor 1991) powered by a single phase, 110V AC, 3000 W AC generator. Due to the local drought and reduced water depths, fall samples were taken using a Smith-Root model LR 24 volt battery powered backpack shocker as suggested in Reynolds (1983). Fish captured in block nets were included in the sample (Bayley et al. 1989).

Fish greater than 140 mm were recorded in the field and released. All other fish were preserved in 20% formalin and returned to the lab for later identification. Fish were retained in formalin for at least two weeks to ensure proper fixing before being rinsed and placed in 70% ethanol for long-term storage. Collections were identified to species by two examiners and total number of individuals recorded. A quality check of proper identification was conducted by a fisheries professional as suggested in Environmental Protection Agency protocols and voucher specimens retained at Eastern Illinois University.

**Benthic Macroinvertebrate Community Assessment**

Benthic invertebrate communities on the artificial and natural riffles were sampled from Sugar Creek and Ashmore Creek during the summer of 2005 using standard stream sampling techniques as defined by the Environmental Protection Agency (Barbour et al. 1999). Hurricane Creek was not sampled due to excessive drought causing intermittent conditions. Two replicate sites (upstream and downstream) were collected from each riffle by kick sampling a ½ m area (Ebrahimnezhad and Harper 1997) until all organisms were thought to be dislodged. Samples were preserved with

95% ethanol in the field and replaced with 70% ethanol upon returning to the lab. The sampling was repeated three times during the months of June-September when discharges were thought to be stable as suggested in Harrison et al. (2004).

Samples were thoroughly rinsed in a 500 μm mesh sieve to remove fine sediment. Large organic material, such as leaves, twigs, and rocks not removed in the field were rinsed, inspected for organisms and discarded. Subsampling procedures, as described in Resh et al. (1996), were employed to identify organisms to the lowest taxonomic level possible (Ebrahimnezhad and Harper 1997, Van Sickle et al. 2005). Substrate passing through the sieve was spread evenly along the bottom of a metal grid divided into four, $in^2$ sections. A random number table was used to choose a section of the grid to pick until all organisms were thought to be removed and identified. This procedure was repeated until a minimum of 300 individuals (Lorenz et al. 2004, Van Sickle et al. 2005) was picked from each sample and stored in 70% ethanol. Organisms in each sample were identified and tallied using a dissecting microscope and appropriate keys. In samples having less than 300 individuals, all organisms were removed, counted, and identified to family where possible. A quality check for proper identification was completed by a professional and voucher specimens were preserved at Eastern Illinois University.

**Analytical Methods**

The study design facilitated a replicated, paired comparison of restored riffles to natural riffles. A combination of aggregate and ordination analyses was used to examine the overall fish and invertebrate assemblage response variables using fish and invertebrate taxon richness, assemblage diversity, total fish abundance, and Index of Biotic Integrity (IBI) (Karr et al. 1981) or Macroinvertebrate Biotic Index (MBI) (Kerans

and Karr 1994), as appropriate. Species richness (total number of species present) for the fish assemblage and Shannon-Weiner Diversity (H') for both fish and invertebrate assemblages were calculated similar to Harrison et al. (2004).

The IBI is a composite index based on twelve separate metrics in five categories (species richness and composition, indicator species, trophic function, reproductive function and condition, and abundance) to evaluate fish assemblages. Each individual metric is given a score of one, three, or five allowing for total IBI scores ranging from 12 (worst) to 60 (best). These IBI scores correspond to qualitative assessments of water quality with higher scores indicating better quality sites. IBI scores used in this study were calculated using IBI-AIBI 2.01 software developed by the Illinois Environmental Protection Agency (Bicker et al. 1998).

The MBI, based on the tolerance/intolerance of various macroinvertebrate taxa, was calculated. Each taxon is assigned a score (Resh et al. 1996) between 0 (highly intolerant) and 10 (highly tolerant) and the MBI score was calculated as a weighted average by the following equation:

$$MBI = 1/N \Sigma n_i t_i$$

where N = total number of individuals, $n_i$ = number of individuals of *i*th taxon and $t_i$ = tolerance value of the *i*th taxon. MBI scores correspond to qualitative assessments of water quality, with lower scores indicating better quality sites (Table 2).

Aggregate statistical analyses were performed using SPSS software (SPSS 12.0 SPSS Inc., Chicago, IL) with the significance determined at the 0.05 level. A paired T-Test was used to compare sampling effort for the fish community assessment and an Analysis of Similarity used to determine time and spatial differences during the

invertebrate community assessment. Differences in species richness, diversity, IBI, and MBI scores were tested using a one-way analysis of variance (ANOVA) with the aggregate analysis being examined as the independent variable. Bonferonni *post hoc* tests were conducted to examine where differences in assemblages lie (i.e. stream, riffle type, or individual riffle). Significance was determined at the 0.05 level.

To detect influential species and further explore their relationship with water quality, similarities among fish and invertebrate assemblages were examined using a Bray-Curtis similarity matrix calculated from root-transformed data for combined sampling periods. Ordination was used to examine whole-community composition shifts and displayed using Multidimensional Scaling (MDS). Relationships among streams and riffles were calculated using an Analysis of Similarity (ANOSIM) producing an R statistic to compare average differences among pairs within groups to average differences seen between groups. A BVSTEP routine generated a list of influential taxa that supported the same pattern as the whole. All multivariate analyses were performed using Primer 6.3.1 (Clark and Warwick 2001).

## RESULTS

### Physical Habitat Assessment:

Natural and artificial riffles in study streams had observable geomorphologic and hydrologic differences. Natural riffles were composed of mainly sand and fine gravel in Sugar Creek, medium cobble in Hurricane Creek, and fine gravel in Ashmore Creek. All artificial riffles were composed of small to medium cobble located between boulders. Artificial substrate was 80 times (232 mm) larger on average than natural substrate in all streams. The most dramatic results of all streams were seen in Sugar Creek which was

significantly deeper than other study streams (d.f.=2; f=57.456; p=.000) with the first artificial riffle having the greatest average depth overall at 0.22 meters (Figure 2). When comparing individual depth measurements among Sugar Creek riffles, the first artificial riffle differed significantly from both the natural riffle (d.f.=8; f=20.364; p=.000) and the second artificial riffle (d.f.=8; f=20.364; p=.001) of the same stream.

Hydrologic differences among riffles occurred over the six-month study period (Figure 3). Mean velocity for all riffles in Sugar Creek was significantly greater than the other streams (d.f=2; f=50.782; Ashmore Creek p=.000; Hurricane Creek p=.001). Hurricane and Sugar Creeks had velocities that were quantifiable. Artificial riffles in Sugar Creek gauged approximately $1cm/1s^{-1}$ more than the natural riffle for a period of four months. The current velocity of the first artificial riffle in Sugar Creek (closest to the natural riffle) was approximately 0.76 $cm/s^{-1}$ greater than the second artificial riffle (furthest from the natural riffle). Current velocity in Hurricane Creek's artificial riffles was greater than the natural riffle although this parameter was only measurable for a one-month period.

The modified SHAP survey was used in conjunction with a modified Eleven Transect Method to evaluate physical parameters. Individual riffle SHAP assessments ranked from good to excellent for each riffle surveyed (Table 3). Overall, SHAP scores among all three streams did not differ but artificial riffles in Sugar and Ashmore Creeks had higher scores than natural riffles. Individual metrics indicated all natural riffles had a moderate accumulation of sand and gravel affecting approximately 30% of the riffle. Individual metrics also indicated that riffles in Hurricane Creek ranked highest in bank stability with approximately 70% of stream bank surfaces covered by vegetation and

periphyton. Observations of the stream reach showed each stream as extremely shallow with only 6-12% of instream cover such as submerged logs, undercut banks, and other stable habitat present.

In summary, observable differences in substrate size, depth, and current velocity were seen among streams and between riffles within streams. Artificial substrate was larger and more homogeneous than natural substrate. SHAP scores revealed streams were affected by moderate deposition, were shallow, and did not have a substantial amount of stable habitat.

**Fish Community Assessment:**

The thirty samples taken during the study periods of March-June 2005 and September-November 2005 yielded a total sample size of 6124 individual fish representing 38 species. Over 5000 individual fish were collected from riffles on Sugar Creek while the remaining fish were collected from Hurricane and Ashmore Creeks. The Sand Shiner (*Notropis stramineus*) was the most frequently caught species (41%), followed by the Red Shiner (*Cyprinella lutrensis*) (17%) and the Bluntnose Minnow (*Pimephales notatus*) (10%). Overall fish abundance in natural riffles was approximately double that of rehabilitated riffles in Sugar and Hurricane Creeks (Table 4).

A paired t-test of sampling effort revealed a significant difference in effort among streams (Sugar Creek and Ashmore Creek: d.f.=1; t=-1.325; p=.000; Sugar and Hurricane Creeks: d.f.=1; t=-2.593; p=0.25) but not among riffles within streams. Therefore, to obtain a larger sample size, artificial riffle samples were first lumped by site and then combined by season. This variation among shocking times limited the number of

comparisons that could be made; therefore, only within stream comparisons of species richness, diversity, and IBI scores were made.

Species richness, diversity, and IBI scores did not differ between natural and artificial riffles within streams (Figures 4-6). Artificial riffles in Sugar and Hurricane Creeks had greater species richness and diversity as compared to the natural riffles. Species diversity ranged from 0.97 in artificial riffles of Ashmore Creek to the highest score of 2.24 in the artificial riffles of Sugar Creek. IBI scores categorized all sites as fair to moderate quality but scores did not differ between artificial and natural riffles within streams. IBI scores were greatest in Sugar Creek and lowest in Ashmore Creek with natural riffles scoring highest among all streams.

Since no differences were seen among the aggregate scores of natural and artificial riffles in species richness, diversity and IBI scores within streams, a Bray-Curtis similarity index was used to examine similarity among riffle types with respect to fish assemblages using square-root transformed data to down-weight the influence of abundant taxa. When fish assemblages were ordinated using MDS, differences were found in fish assemblages between first (Ashmore Creek), second (Hurricane Creek), and third-order (Sugar Creek) streams ($r=0.823$; $p<0.001$) (Figure 7). MDS showed no differences between natural and artificial riffles within streams, however. Sugar Creek had an ecological relationship between the first sampled (closest to the natural) and the second artificial riffle (farthest from the natural), with the first artificial being the most distinct compared to the natural riffle (Figure 8).

The BVSTEP routine isolated relative abundances of a subset of orangethroat darters (*Etheostoma spectabile*), sand shiners (*Notropis stramineus)*, red shiners

(*Cyprinella lutrensis*), creek chubs (*Semotilus atromaculatus*), central stonerollers (*Campostoma anomalum*) and blacknose dace (*Rhinichthys atratulus*) that supported the same pattern as the whole fish assemblage (BEST correlation statistic =0.951). Each stream was found to support a relatively distinct fish assemblage based on the relative abundance of the above influential taxa (Figure 9). Sand shiners were most abundant in Ashmore Creek (first-order); common stonerollers were most abundant in Hurricane Creek (second-order); and sand and red shiners were most abundant in Sugar Creek (third-order). Sand shiners and red shiners were the most abundant species while common stonerollers and orangethroat darters were present in all three streams. Interestingly, two species not commonly identified in Sugar or Hurricane Creeks, the blacknose dace and creek chub, characterized Ashmore Creek.

**Benthic Invertebrate Assessment:**

The summer of 2005 yielded 8880 subsampled invertebrates representing 21 classes and families from Sugar and Ashmore Creeks. The greatest relative abundant taxa in Sugar Creek were Chironomidae and Hydropsychidae whereas Oligochaeta dominated in Ashmore Creek (Table 5). Hydropsychidae, Baetidae, and Chironomidae were the most prolific taxa in the natural riffle while Hydropsychidae, Simuliidae, and Chironomidae were the most abundant families in artificial riffles of Sugar Creek. Oligochaeta was greatest in relative abundance followed by Chironomidae in all Ashmore Creek riffles.

Since no significant chronological or spatial differences were found within streams, upstream and downstream samples taken on each riffle were lumped for the remaining statistical analyses. Though riffles were statistically similar, the natural riffle

of Sugar Creek was characterized by a higher diversity than artificial riffles while the opposite trend was observed in Ashmore Creek (Figure 10). MBI scores for Sugar Creek indicated "fair" water quality while ratings for Ashmore Creek indicated "very poor" water quality (Table 6). It is interesting to compare the tolerance level of each taxa to organic and inorganic pollution as defined by Voshell (2002); Ashmore Creek hosted the greatest number of species tolerant to pollution while Sugar Creek had less tolerant species (Table 7) (Figures 11 and 12).

There were no differences among natural and artificial riffles with respect to diversity or MBI scores. ANOSIM found differences between streams (r=0.695; p=0.001) but not among riffles within streams (Figure 13). A BVSTEP routine isolated relative abundances of a subset of invertebrates that supported the observed pattern. In Sugar Creek, Baetidae, Hydropsychidae, Simuliidae, and Chironomidae families drove the community pattern (BEST correlation statistic=0.985) while Chironomidae and Oligochaeta were responsible for the pattern observed in Ashmore Creek (BEST correlation statistic=0.965). Chironomidae and Oligochaeta are known to have a high tolerance of pollution and are characteristic of poor water quality.

## DISCUSSION

For centuries, streams and rivers have had continuing modifications (Tompkins, M.R. and Kondolf, G.M., unpublished data) that promoted the production of goods and services needed to sustain growing human populations (Palmer et al. 2005). Methods to re-establish self-sustaining ecosystems have been introduced to secure ecological resources for future human populations (Palmer et al. 2005). Of the restoration methods

employed, many have not been assessed and no standard definition of success has been established (Palmer et al. 2005).

One popular definition of overall restoration achievement encompasses three primary goals: ecological success, learning success, and stakeholder success (Palmer et al. 2005). Within these goals are several criteria including cost-effectiveness, self-sustainability, ecosystem health, ecosystem resiliency, and long-term effects (Palmer et al. 2005). For this study, I considered these criteria when evaluating the performance of artificial riffles as a restoration technique and assessing the feasibility of this type of restoration in central Illinois streams.

**Physical Habitat**

The modified Eleven Transect method, SHAP survey, and current velocity data illustrate geomorphologic and hydrologic differences between natural and artificial riffles within streams. Although artificial riffles create additional habitat and cover, the modified Eleven Transect method revealed artificial substrate was approximately 80 times larger (232mm) than natural substrate creating variations in deposition amount, water depth, and current velocity between artificial and natural riffles. In an artificial riffle study by Harrison et al. (2004), riffles in low-gradient streams were compromised by sedimentation and silt deposition. The SHAP survey indicated that although most habitat parameters ranked fair to good, study streams had more deposition than pristine Midwest streams (30%), contained only 6-12% instream cover such as submerged logs and undercut banks, and were naturally composed of predominantly sand or silt. These qualitative observations indicate deposition is depleting study streams of natural submerged habitat including large woody debris. This observation could indicate that

overall project feasibility is dependent upon the influx of deposition that should be taken into account when choosing restoration sites.

Depth and current velocity data demonstrate the overall strength of artificial riffle habitat restoration, principally in the third-order stream. Both first and second-order streams were extremely shallow throughout the study and did not produce quantifiable velocities during July and August which may indicate the need to monitor flow rates when evaluating streams for rehabilitation. Ebrahimnezhad and Harper (1997) found artificial structures most adapt at preventing excessive deposition, and therefore aiding in biota recovery, occurred at depths $<25$ cm and velocities $> 40$ cm/s$^{-1}$. Structures at these depths and velocities are more likely to resist being completely covered by sediment. Although study streams in this project did not meet the current velocity requirement, Sugar Creek, the third-order stream had the greatest velocity and most closely followed this restoration recommendation; again indicating the need for pre-installation monitoring of flow rates when choosing sites for restoration.

**Fish Communities**

Despite physical differences, species richness, diversity, IBI, and similarity index analyses for fish communities did not reveal a difference between natural and artificial riffles within study streams. Artificial riffles of Sugar Creek and the natural riffle of Ashmore Creek were characterized by higher diversity, which is commonly indicative of optimal habitat heterogeneity (Katano et al. 1998). Differences in absolute abundance did occur, however, indicating that although species were dispersed equally among riffles, a greater number of individuals preferred the natural riffle in Sugar and Hurricane Creeks and the artificial riffles in Ashmore Creek.

It is important to consider that reduced water quality may prevent an increase in species richness and diversity and may be the limiting factor rather than the lack of habitat (Pretty et al. 2003). IBI scores indicated poor water quality in the low order stream; possibly caused by isolated pools, low current velocity, or intermittent conditions created by artificial substrate. Artificial riffles of Hurricane and Sugar Creeks had greater diversity scores than Ashmore Creek, suggesting artificial riffles may be more suitable for larger order streams. Overall, aggregate data suggests that artificial riffles mimic natural riffles; however, IBI scores indicate the need for further examination of the fish assemblage using an ordination.

MDS ordinations revealed a relatively distinct fish assemblage among streams but not among riffles within streams. This supports the conclusion that artificial and natural riffles function similarly despite physical differences. Although no statistical differences existed, an ecological trend was found between fish assemblages in the artificial riffles of Sugar Creek with the first artificial riffle being the most distinct as compared to both the second artificial and natural riffle. Similar results were found in a study by Ebrahimnezhad and Harper (1997) in which only two of three artificial riffles examined were geomorphologically similar to the natural riffle with the third artificial riffle found to be most like the run sites. Differences between artificial riffles in Sugar Creek may be best explained by examining qualitative assessments of artificial riffle construction.

The first artificial riffle had greater average substrate size, current velocity, and depth then the second artificial and natural riffles. The first artificial riffle was also most distinct in fish richness and diversity as compared to the second artificial and natural riffles. The second artificial riffle was shorter in overall length and presented a more

gradual grade change between upstream and downstream reaches thus creating cover and habitat more similar to the natural riffle. Moerke and Lamberti (2003) suggested that habitat structure in two Indiana study streams played a major role in fish community response and colonization. The stream with restoration most similar to natural conditions had the fastest colonization of fish species whereas the dramatic restoration of the second study stream led to low fish densities and an altered community structure (Moerke and Lamberti 2003). Schaefer (2001) found the same in a study quantifying the rate of cyprinid movement where fish movements across riffles decreased as current velocity increased. These studies demonstrate the importance of considering spatial scale when determining an appropriate restoration scheme. Spatial scale and variation are directly responsible for the physical stream characteristics that determine aquatic community composition (Frothingham et al. 2002). Patch dynamics and habitat fragmentation studies suggest that restoration scale is a key factor in the success or failure of the chosen restoration method (Bond and Lake 2003).

In recent years, hydraulic engineering has witnessed a shift toward soft river engineering that focuses on the biological recovery as much as the hydraulic recovery of channelized streams (Walker et al. 2004). This type of construction considers the importance of natural fluvial processes and spatial scale of restoration while also meeting the original engineering goals of flood control (Walker et al. 2004, Harrison et al. 2004). An appropriate improvement to artificial riffle construction may be to decrease gradient and use variety of natural and artificial substrates instead of homogeneous quarried rock. This may encourage colonization and provide fish spawning habitat at a suitable scale (Fuselier and Edds 1995).

Fish community results suggest the type of restoration method used in study streams is at an appropriate scale. However, when combined with physical assessment results, a more reasonable conclusion would be that artificial riffle placement is most beneficial to streams with a constant flow throughout dry months. It has been shown by Schaefer (2001) that fish species show a decreased movement over riffles at a shallow depth due to increased predation and risk of being stranded. Harrison et al. (2004) suggests that whole stream, natural rehabilitation methods may be best suited for small streams as compared to localized artificial substrate patches. Alternate restoration strategies such as increased bank vegetation (Harrison et al. 2004) or increased sinuosity may need to be explored for smaller order streams.

**Benthic Invertebrate Communities**

Relative abundance data show the most prolific taxa in Sugar Creek were collector-filterers (*Hydropsychidae*) and collector-gatherers (*Chironomidae*) whereas scavengers (*Oligochaeta*) dominated in Ashmore Creek. Both natural and artificial riffles of first-order and third-order study sites supported high relative abundances of Chironomids and Oligochaetes, two families generally found in the sediment of slower moving waters (Ebrahimnezhad and Harper 1997). As expected based on physical assessments, the greatest relative abundance of taxa characteristic of fast flowing waters (Elmidae, Simuliidae, and Hydropsychidae; (Ebrahimnezhad and Harper 1997) were found in Sugar Creek's artificial riffles. Hydrologic data show these artificial riffles having the greatest current velocity of all riffles, gauging approximately 1cm/s$^{-1}$ more than their natural riffle counterpart and 2.5 cm/s$^{-1}$ more than artificial riffles of other study streams.

Although diversity differs between streams, no difference is observed between natural and artificial riffles within streams. MBI ratings indicate “very poor” water quality in Ashmore Creek and “fair” water quality in Sugar Creek. These findings support information gained from observing the tolerance levels of abundant species in each stream. The taxa most tolerant of inorganic and organic pollution were found in Ashmore Creek (Chironomidae and Oligochaeta) while the most facultative species were found in Sugar Creek (Baetidae and Hydropsychidae). Intermittent streams with isolated pools may produce conditions where few species can thrive. Various invertebrate studies have demonstrated that a slow recovery rate is correlated with rehabilitation isolation and that the success of habitat improvements depends on if water quality can adequately support a diverse biological community (Pretty et al. 2003). Furthermore, organisms not accustomed to escaping intermittent conditions may not participate in habitat shifts, allowing them to find refuge during drought (Bond and Lake 2003). If artificial riffles in this study promote isolated, toxic conditions resulting in reduced water quality, effectiveness and therefore feasibility may be compromised.

The BVSTEP routine supported the above conclusions that study streams with reduced water quality support invertebrates capable of tolerating organic and inorganic pollution. This analysis revealed the majority of invertebrates driving patterns observed in Sugar Creek were indicative of large, stable substrate and moderate organic or nutrient pollution including Baetidae and Hydropsychidae. The subset shown in Ashmore Creek, Oligochaeta and Chironomidae, specified the presence of organic pollution and low dissolved oxygen characteristic of slow moving sections of streams with sand or gravel substrate (Ebrahimnezhad and Harper 1997) that may be derived from intermittence. The

BVSTEP identified a substantial amount of collectors in artificial riffles of both streams indicating that a habitat distinctive to the stream is being created within the new riffles. Collectors are a functional group characterized by their dominant food of decomposed, fine particular organic matter (FPOM) (Merritt and Cummins 1996). Sugar Creek artificial riffles also had a pronounced number of scrapers consuming periphyton, including attached algae and associated vegetation (Merritt and Cummins 1996). Collectors and scrapers indicate that organic matter and periphyton are getting caught in crevices created by large substrate and thus producing a unique and diverse habitat not often observed in riffles of low-gradient streams.

**Overall Conclusions**

Overall, both fish and invertebrate assessments of study streams indicate artificial riffles mimic natural riffles and encourage a self-sustaining ecosystem. As Fuselier and Edds (1995) found in a artificial riffle study, biological data show artificial riffles in the Midwest as an appropriate mitigation technique to overcome habitat disturbances caused by channelization. I believe, however, that restoration should also encompass a wide range of goals including water quality improvement, habitat enhancement, ecosystem resiliency, increased positive long-term outcomes, and cost effectiveness to determine if the overall restoration was successful. These criteria are based on the three primary goals of restoration achievement including ecological success, learning success, and stakeholder success.

Artificial riffles on all study streams provided value through deposition resiliency when current velocity was present. The third-order stream exhibited the greatest velocity during the 2005 drought and the most positive ecological results (i.e. richness, diversity,

IBI, and MBI). Restoration measures in first and second-order streams caused isolation of pools without measurable velocities occurring for part of the study. This marginalization of habitat does not aid in resiliency to overcome natural disturbances such as drought and may cause long-term negative effects to biota.

Economic practicality of the physical, biological, chemical, and anthropogenic need of restoration must also be considered when determining overall feasibility (Harrison et al. 2004). The Sugar Creek project cost $30,000; the Hurricane Creek project cost $10,150; and the Ashmore Creek project cost $6,052 (Illinois Department of Agriculture unpublished data). When prioritizing projects, those with a high probability of success, fast response time, and low variability should be considered first depending upon the overall project goals (Roni et al. 2002). Although expensive, the high probability of success and low variability demonstrated in the third-order stream makes it the most cost effective followed by Ashmore and then Hurricane Creek.

Pretty et al. (2003) stated that high failure rates of artificial riffles in North America might indicate their limited functionality. Restoration can only be effective if connectivity is maintained allowing existing populations to disperse and colonize rehabilitated reaches (Pretty et al. 2003, Bond and Lake 2003). Taxa mobility, reproductive capabilities influenced by water quality, availability of food resources, and the distance to suitable colonists influence the success of restoration structures (Moerke and Lamberti 2003). It has been shown that without current velocity and connectivity between stream sections, artificial riffles act as soft barriers shielding source populations (Bond and Lake 2003).

Stream classification, stream type, and drainage patterns must be considered when determining a restoration scheme and function as a guide to restoration methods employed (Palmer et al. 2005). Extreme habitat change such as channelization in small streams may exceed the evolutionary capabilities of the present biota causing extirpation in the reach or reducing connectivity creating more marginal habitats. One suggestion to determine which restoration method is appropriate is to make judgments based on individual aquatic systems taking into account the variable flow regime, duration of impairment, land use history, and specific restoration goals for each system (Palmer et al. 2005). Since a majority of artificial riffle research has been centered in high gradient, fast flowing rivers (Pretty et al. 2003), agencies should avoid generalized habitat targets and focus on individual watershed conditions including grade and current velocity (Roni et al. 2000, Pretty et al. 2003). Modification of streams can yield almost entirely positive results if the individual ecosystem's potential for natural recovery is identified and combined with the correct amount of modification on an individual stream basis. Focus should rest on connecting, networking, and avoiding fragmentation of aquatic habitats where practical (Roni et al. 2000).

The ultimate goal of overall restoration is to return streams to the widely regarded model of The River Continuum Concept (RCC). This guide identifies the longitudinal continuum of biotic and abiotic patterns from high gradient headwater streams to low gradient rivers (Vannote et al. 1980, Frothingham et al. 2002). Managers should acknowledge where their system falls within this model and then use this as a guide to the type of restoration required for a specific stream.

As with most projects, continued monitoring of the sites is recommended. Aquatic ecosystems often take years to recover from disturbances including the installation of restoration measures. In studies such as the Kissimmee River project in Florida, fish took 12-20 years and invertebrates 10-12 years to re-establish and recover from disturbance (Lake 2001). Ecosystems may also be under some unforeseen stress causing increased variability in results (Lake 2001). As many have suggested, long term monitoring at the terminus of the project should be considered and budgeted for to increase our understanding of the viability of restoration techniques in Midwestern streams.

## REFERENCES


Angermeier PL, Smogor RA. 1991. An Electric Seine for Collecting Fish in Streams. North American Journal of Fisheries Management 11:52-257.

Barbour MT, Gerritsen J, Snyder BD, Stribling JB. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Bayley PB, Larimore RW, Dowling DC. 1989. Electric Seine as a Fish-Sampling Gear in Streams. Transactions of the American Fisheries Society 118:447-453.

Bickers CA, Kelly MH, Levesque JM, Hite RL. 1988. IBI-AIBI Version 2.01: a BASIC program for computing the Index of Biotic Integrity with the IBM-PC. IEPA/WPC/89-007. Illinois Environmental Protection Agency. Springfield, Illinois.

Bond NR, Lake PS. 2003. Local Habitat Restoration in Streams: Constraints on the Effectiveness of Restoration for Stream Biota. Ecological Management & Restoration 4(3):193-198.

Carline R F, and Klosiewski SP. 1985. Responses of Fish Populations to Mitigation Structures in Two Small Channelized Streams in Ohio. North American Journal of Fisheries Management 5(1):1-11.

Clarke KR, and Warwick RM. 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation, 2nd edition. PRIMER-E Ltd, Plymouth U.K.

Downes B., Lake PS, Glaister A, Bond, NR. Effects of Sand Sedimentation on the Macroinvertebrate Fauna of Lowland Streams: Are the Effects Consistent? Freshwater Biology 51:144-160.

Downs PW, and Kondolf GM 2002. Post-Project Appraisals in Adaptive Management of River Channel Restoration. Environmental Management 20(4):477-496.

Ebersole JL, Liss WJ, and Frissell CA. 1997. Restoration of Stream Habitats in the Western United States: Restoration as Reexpression of Habitat Capacity. Environmental Management 21(1):1-14.

Ebrahimnezhad M, and Harper DM. 1997. The Biological Effectiveness of Artificial Riffles in River Rehabilitation. Aquatic Conservation: Marine and Freshwater Ecosystems 7:187-197.

Edwards CJ, Griswold BL, Tubb RA, Weber EC, Woods LC. 1984. Mitigating Effects of Artificial Riffles and Pools on the Fauna of a Channelized Warmwater Stream. North American Journal of Fisheries Management 4:194-203.

Fausch KD, Gowan C, Richmond AD, Riley SC. 1995. The Role of Dispersal in Trout Population Response to Habitat Formed by Large Woody Debris in Colorado Mountain Streams. Bulletin Francais De La Peche Et De La Pisciculture 337-339:179-190.

Federal Interagency Stream Restoration Working Group. 1998. Stream Corridor Restoration: Principles, Processes, and Practices: General Technical Report No. 3-1- 3-28.

Frothingham KM, Rhoads BL, Herricks EE. 2002. A Multiscale Conceptual Framework for Integrated Ecogeomorphological Research to Support Stream Naturalization in the Agricultural Midwest 29(1):16-33.

Fuselier L, Edds D. 1995. An Artificial Riffle as Restored Habitat for the Threatened Neosho Madtom. North American Journal of Fisheries Management 15:499-503.

Gregory K.J. 1985. The Impact of River Channelization. The Geographical Journal 151(1):53-54.

Harper D, Ebrahimnezhad M, Climent I Cot F. 1998. Artificial Riffles in River Rehabilitation: Setting the Goals and Measuring the Successes. Aquatic Conservation: Marine and Freshwater Ecosystems 8(1):5-16.

Harrison SSC, Pretty JL, Shepherd D, Hildrew AG, Smith C, and Hey RD 2004. The Effect of Instream Rehabilitation Structures on Macroinvertebrates in Lowland Rivers. Journal of Applied Ecology 41:1140-1154.

Hilderbrand RH, Lemly AD, Dollorr CA, Harpster KL. 1998. Design Considerations for Large Woody Debris Placement in Stream Enhancement Projects. North American Journal of Fisheries Management 18:161-167.

Illinois Environmental Protection Agency. 1994. Appendix 1, Quality Assurance and Field Sampling Procedures, in Quality Assurance Project Plan: Integrated Water Monitoring Program Document. Bureau of Water, Springfield, Illinois.

Kerans BL, Karr JR. 1994. A Benthic Index of Biotic Integrity (B-IBI) for the Rivers of the Tennessee Valley. Ecological Applications 4:768-785.

Karr JR. 1981. Assessment of Biotic Integrity Using Fish Communities. Fisheries 6(6):21-27.

Katano O, Toi J, Maekawa K, Iguchi K. 1998. Colonization of an Artificial Stream by Fishes and Aquatic Macro-invertebrates. Ecological Research 13:83-96.

Kondolf, GM. 1995. Five Elements for Effective Evaluation of Stream Restoration. Restoration Ecology 3(2):133-136.

Kondolf GM, Micheli ER 1995. Evaluating Stream Restoration Projects. Environmental Management 19(1):1-15.

Laasonen P, Muotka T, Kivijarvi I. 1998. Recovery of Macroinvertebrate Communities from Stream Habitat Restoration. Aquatic Conservation: Marine and Freshwater Ecosystems 8:101-113.

Lake PS. 2001. On the Maturing of Restoration: Linking Ecological Research and Restoration. Ecological Management and Restoration 2(2):110-198.

Landwehr K, Rhoads BL. 2003. Depositional Response of a Headwater Stream to Channelization, East-Central Illinois, USA. River Research and Applications 19:77-100.

Lorenz A, Kirchner L, Hering D. 2004. 'Electronic Subsampling' of Macrobenthic Samples: How Many Individuals are Needed for a Valid Assessment Result? Hydrobiologia 516:299-312.

Magilligan, FJ. 1985. Historical Floodplain Sedimentation in the Galena River Basin, Wisconsin and Illinois. Annals of the Association of American Geographers 75(4):583-594.

Merritt RW, Cummins KW. 1996. Trophic Relations of Macroinvertebrates. In: Hauer RF, Lamberti GA, editors. Methods in Stream Ecology. Elsevier Science, San Diego, California. p 453-474.

Moerke AH, Lamberti GA. 2003. Responses in Fish Community Structure to Restoration of Two Indiana Streams. North American Journal of Fisheries Management 23:748-759.

Negishi JN, Inoue M, Nunokawa M. 2002. Effects of Channelisation on Stream Habitat in Relation to Spate and Flow Refugia for Macroinvertebrates in Northern Japan. Freshwater Biology 47:1515-1529.

NRC (National Research Council) 1992. Restoration of Aquatic Ecosystems. National Academy Press, Washington, D.C.

Ormerod SJ, Marshall EJP, Kerby G, Rushton SP. 2003. Meeting the Ecological Challenges of Agricultural Change: Editors' Introduction. Journal of Applied Ecology 40:939-946.

Palmer MA, Bernhardt ES, Allan JD, Lake PS, Alexander G, Brooks S, Carr J, Clayton S, Dahm C., Follstad SJ, Galat DL, Loss SG, Goodwin P, Hart DD, Hassett B, Jenkinson R, Kondolf GM, Lave R, Meyer JL, O'Donnell TK, Pagano L, Sudduth E. 2005. Standards for Ecologically Successful River Restoration. Journal of Applied Ecology 42:208-217.

Poff NL, Allan JD, Bain MB, Karr LL, Prestergaard BD, Richter B., Sparks RE, Stromberg JC. 1997. The Natural Flow Regime: A Paradigm for River Conservation and Restoration. Bioscience 47(11):769-784.

Pretty JL, Harrison SC, Shepherd DJ, Smith C, Hildrew AG, Hey RD 2003. River Rehabilitation and Fish Populations: Assessing the Benefit of Instream Structures. Journal of Applied Ecology 40:251-265.

Resh VH, Myers MJ, Hannaford MJ. 1996. Macroinvertebrates as Biotic

Indicators of Environmental Quality. In: Hauer RF, Lamberti GA, editors. Methods in Stream Ecology. Elsevier Science, San Diego, California. p 647-667.

Reynolds JB. 1983. Electrofishing. In: Nielson, LA and Johnson DL, editors. Fisheries Techniques. American Fisheries Society, Bethesda, Maryland. p 147-163.

Rinaldi M, Johnson PA. 1997. Characterization of Stream Meanders for Stream Restoration. Journal of Hydraulic Engineering: 567-570.

Roni P. Beechie TJ, Bilby RE, Leonetti BE, Pollock MM, Pess GR. 2002. A Review of Stream Restoration Techniques and a Hierarchical Strategy for Prioritizing Restoration in Pacific Northwest Watersheds. North American Journal of Fisheries Management 22:1-20.

Rosenfeld J. 2003. Assessing the Habitat Requirements of Stream Fishes: An Overview and Evaluation of Different Approaches. Transactions of the American Fisheries Society 132:953-968.

Schaefer J. 2001. Riffles as Barriers to Fish Movement. Freshwater Biology 46:379-388.

Shields DF Jr, Copeland RR, Klingeman PC, Doyle MW, Simon A. 2003. Design for Stream Restoration. Journal of Hydraulic Engineering: 575-584.

Sovell LA, Vondracek B, Frost JA, Mumford KG. 2000. Impacts of Rotational Grazing and Riparian Buffers on Physicochemical and Biological Characteristics of Southeastern Minnesota, USA, Streams. Environmental Management 26 (6):629-641.

Urban MA, Rhoades BL. 2003. Catastrophic Human-Induced Change in Stream-Channel Planform and Geometry in an Agricultural Watershed, Illinois, USA. Annals of the Association of American Geographers 93(4):783-796.

U.S. Environmental Protection Agency (USEPA). Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish Second Edition 8.1- 8.

Vannote RL, Minshall GW, Cummins KW, Sedell JR, Cushing CE. 1980. The River Continuum Concept. Canadian Journal of Fisheries and Aquatic Science 37:130-137.

Van Sickle J, Hawkins CP, Larsen DP, Herlihy AT. 2005. A Null Model for the Expected Macroinvertebrate Assemblage in Streams. Journal of the North American Benthological Society 24(1):178-191.

Voshell J Reese Jr. 2002. A Guide to Common Freshwater Invertebrates of North America. The McDonald & Woodward Publishing Company Blacksburg, Virginia.

Walker DR, Millar RG, Newbury RW. 2004. Energy Profiles Across Constructed Riffles. Journal of Hydraulic Engineering 130(3):199-207.

Table 1. SHAP categories used for individual riffle assessment.

| SHAP CATEGORY |
| --- |
| Bottom Substrate |
| Deposition |
| Substrate Stability |
| Canopy Cover |
| Bank Vegetative Protection/Stability |
| Top of Bank Land Use |
| Flow-related Refugia |
| Width/Depth Ratio |

Table 2. MBI Scores and Interpretive Water Quality Association for each score (Resh et al. 1996).

| MBI | WATER QUALITY |
|---|---|
| 0.00-3.75 | Excellent |
| 3.76-4.25 | Very Good |
| 4.26-5.00 | Good |
| 5.01-5.75 | Fair |
| 5.76-6.50 | Fairly poor |
| 6.51-7.25 | Poor |
| 7.26-10.00 | Very Poor |

Table 3. Individual SHAP assessments for riffles on Ashmore, Hurricane, and Sugar Creeks based on modified SHAP ratings (<62 Excellent, 20-62 Good, <20 Fair).

| | **ASHMORE CREEK** | | | **HURRICANE CREEK** | | | **SUGAR CREEK** | | |
|---|---|---|---|---|---|---|---|---|---|
| | Natural Riffle | Artificial Riffle 1 | Artificial Riffle 2 | Natural Riffle | Artificial Riffle 1 | Artificial Riffle 2 | Natural Riffle | Artificial Riffle 1 | Artificial Riffle 2 |
| **SCORE** | 41 | 60 | 60 | 71 | 72 | 68 | 53 | 69 | 67 |
| **RATING** | Good | Good | Good | Excellent | Excellent | Excellent | Good | Excellent | Excellent |

Table 4. Total number of fish collected in natural and artificial riffles on study sites combining spring and fall sampling periods. Note fall samples were not collected from Hurricane Creek due to drought.

| | Natural Riffle **(NR)** | Artificial Riffle 1 **(AR1)** | Artificial Riffle 2 **(AR2)** |
|---|---|---|---|
| *Sugar Creek* | 2966 | 709 | 1724 |
| *Hurricane Creek* | 164 | 128 | 60 |
| *Ashmore Creek* | 54 | 131 | 188 |

Table 5. Relative abundance of invertebrate taxa collected from artificial and natural riffles in both Sugar and Ashmore Creeks. Sampling was conducted summer of 2005.

| | Sugar NR | Sugar AR 1 | Sugar AR 2 | Ashmore NR | Ashmore AR 1 | Ashmore AR 2 |
|---|---|---|---|---|---|---|
| ELMIDAE | 0% | 0% | 0% | 1% | 2% | 1% |
| SIMULIIDAE | 1% | 13% | 10% | 0% | 0% | 0% |
| CHIRONOMIDAE | 49% | 40% | 12% | 25% | 36% | 16% |
| TIPULIDAE | 0% | 0% | 0% | 2% | 0% | 1% |
| TABANIDAE | 0% | 0% | 0% | 1% | 0% | 0% |
| BAETIDAE | 33% | 6% | 4% | 1% | 2% | 1% |
| CAENIDAE | 0% | 0% | 0% | 1% | 2% | 1% |
| HEPTAGENIIDAE | 0% | 0% | 0% | 1% | 2% | 1% |
| HYDROPSYCHIDAE | 15% | 30% | 70% | 1% | 4% | 1% |
| HYDROPTILIDAE | 0% | 1% | 0% | 0% | 0% | 0% |
| SALDIDAE | 0% | 0% | 0% | 3% | 2% | 1% |
| PHYSIDAE | 0% | 0% | 0% | 1% | 0% | 0% |
| OLIGOCHAETA | 1% | 0% | 0% | 63% | 49% | 74% |
| TURBELLARIA | 0% | 9% | 3% | 0% | 0% | 0% |

Table 6. MBI Ratings for riffles on Sugar and Ashmore Creeks. Sampling was conducted during the summer of 2005.

| CREEK | RATING | WATER QUALITY |
|---|---|---|
| Sugar Natural | 5.01-5.75 | Fair |
| Sugar Artificial | 5.01-5.75 | Fair |
| Ashmore Natural | 7.26-10.00 | Very Poor |
| Ashmore Artificial | 7.26-10.00 | Very Poor |

Table 7. Relative abundance of invertebrates in each tolerance rating as classified by Voshell 2002. Sampling was conducted during the summer of 2005.

| TOLERANCE RATING | SUGAR Natural Riffle % | SUGAR Artificial Riffle 1 % | SUGAR Artificial Riffle 2 % | ASHMORE Natural Riffle % | ASHMORE Artificial Riffle 1 % | ASHMORE Artificial Riffle 2 % |
|---|---|---|---|---|---|---|
| Very Tolerant | 1 | 0 | 0 | 63 | 49 | 74 |
| Somewhat Tolerant | 0 | 9 | 3 | 2 | 2 | 2 |
| Facultative | 99 | 91 | 97 | 31 | 47 | 22 |
| Sensitive | 0 | 0 | 0 | 0 | 0 | 0 |

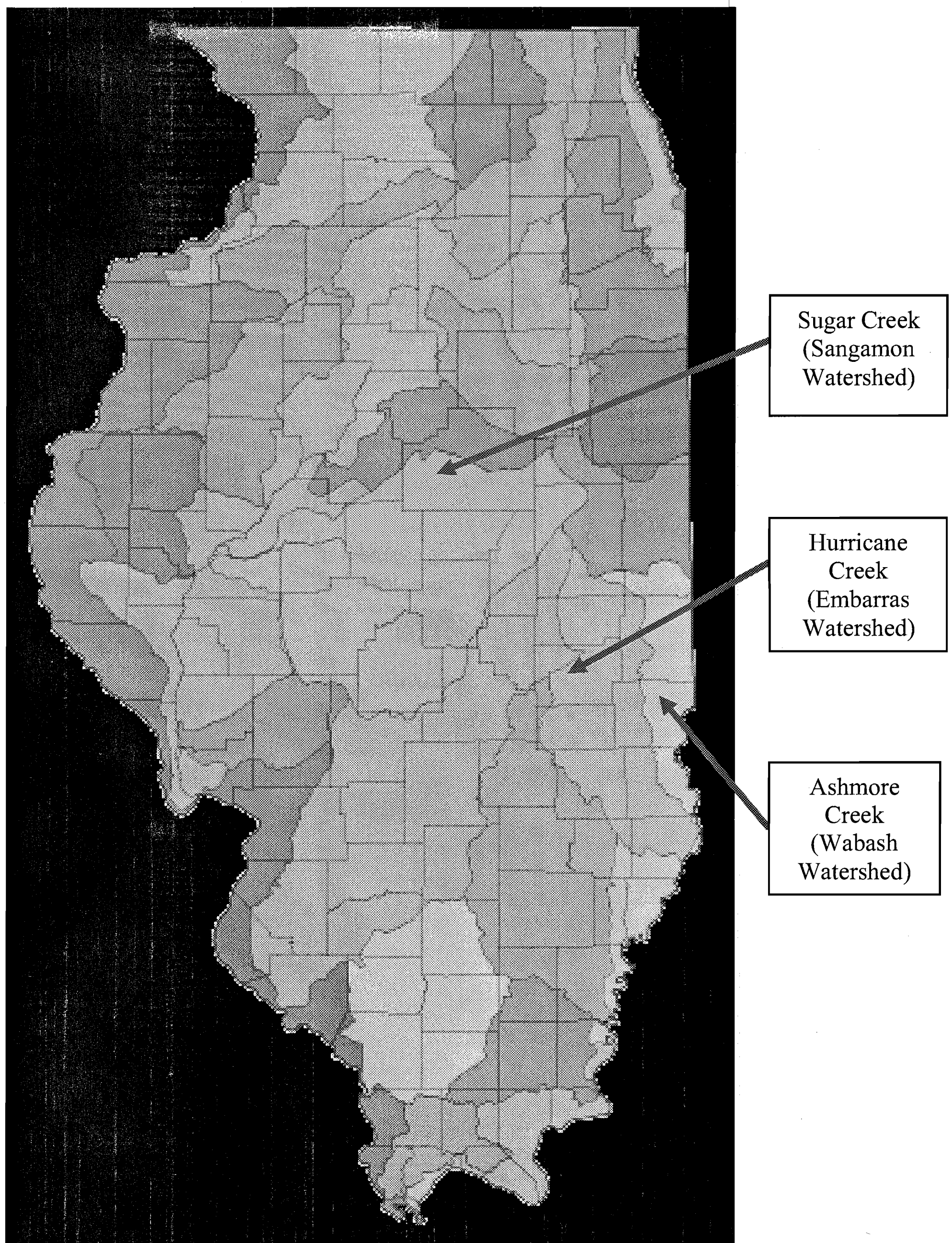



Figure 1. Location of three study riffles sampled for fish and invertebrates located on Sugar Creek, Hurricane Creek, and Ashmore Creek.

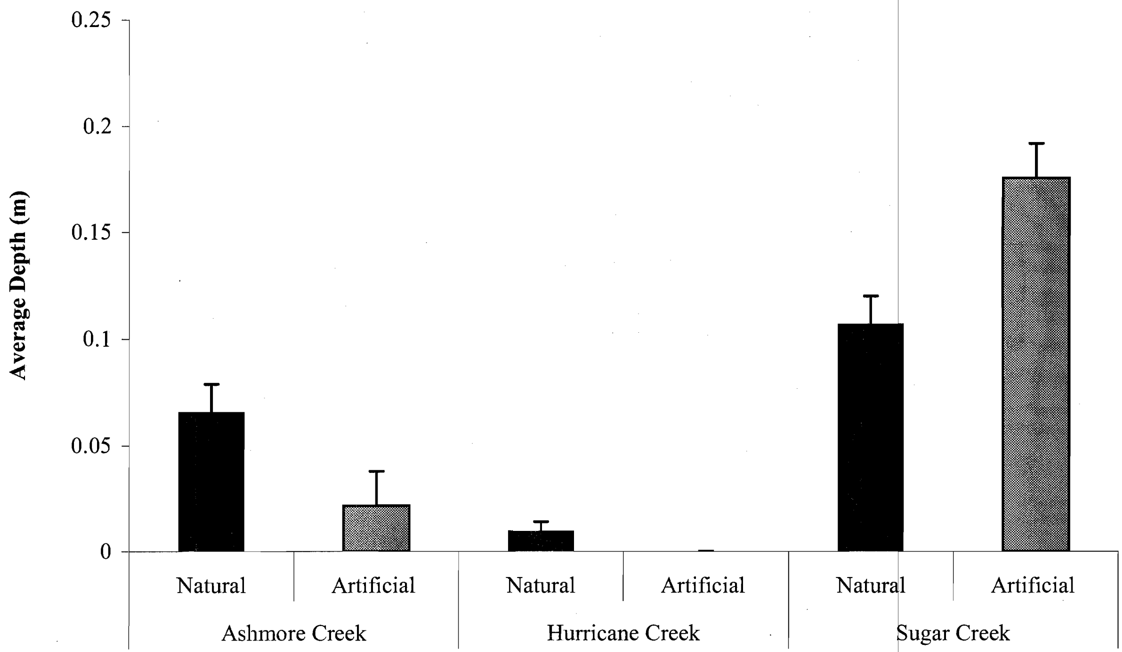



Figure 2. Mean stream depth (m) of natural and artificial riffles on Ashmore, Hurricane, and Sugar Creeks. The bars shown represent standard error.

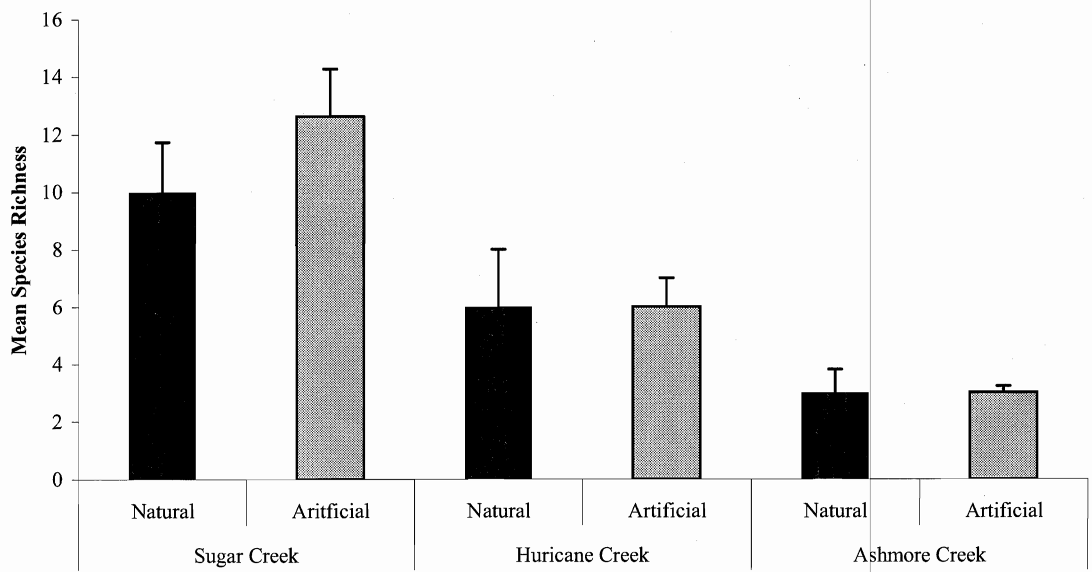



Figure 4. Mean species richness of combined fish community samples on Ashmore, Hurricane, and Sugar Creeks. The bars shown represent standard error.

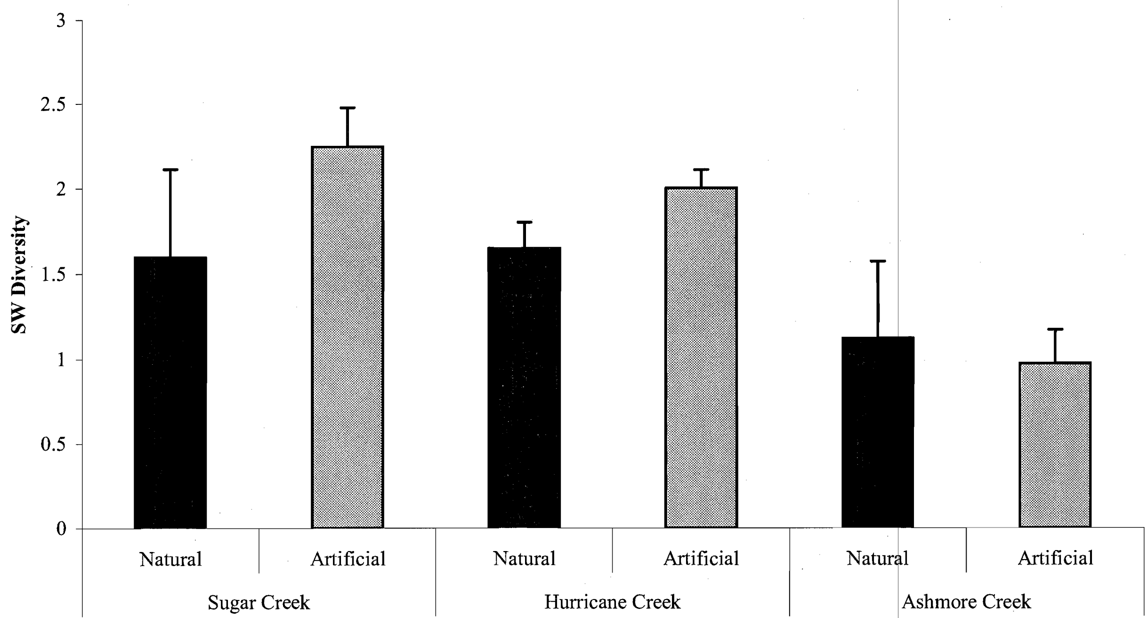



Figure 5. Mean Shannon Weiner Diversity of combined fish community samples on Ashmore, Hurricane, and Sugar Creeks. The bars shown represent standard error.

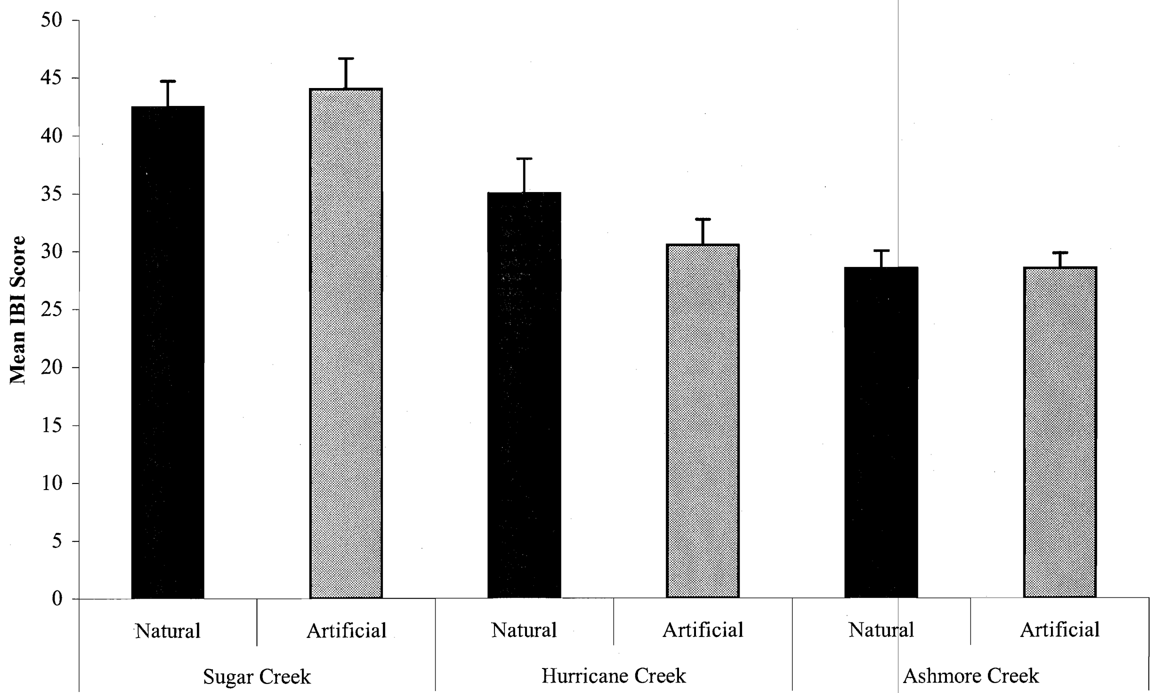



Figure 6. Mean Index of Biotic Integrity Scores of combined fish community samples on Ashmore, Hurricane, and Sugar Creeks. The bars shown represent standard error.

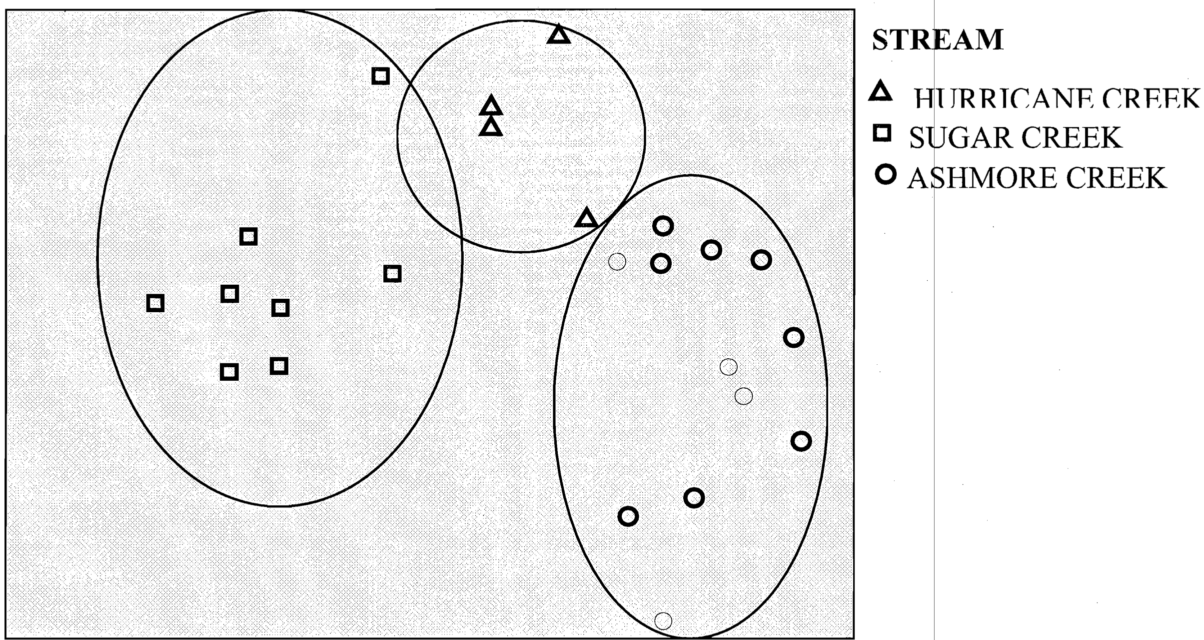
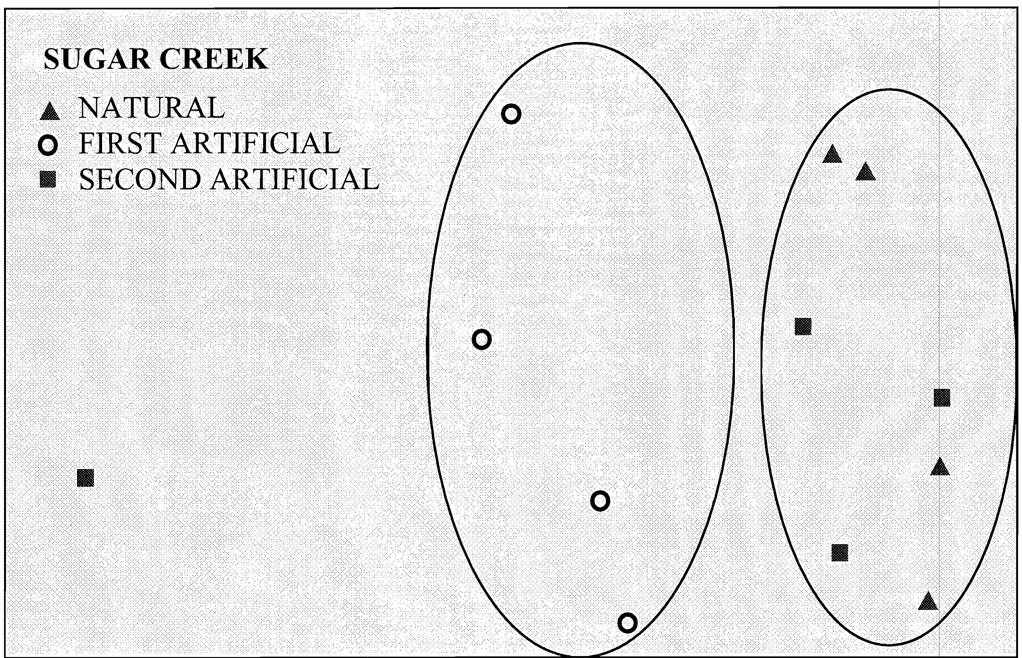



Figure 7. MDS ordination of fish assemblages in artificial and natural riffles of Ashmore, Hurricane, and Sugar Creeks.




P<0.1

Figure 8. MDS ordination of fish assemblages in natural and artificial riffles in Sugar Creek.

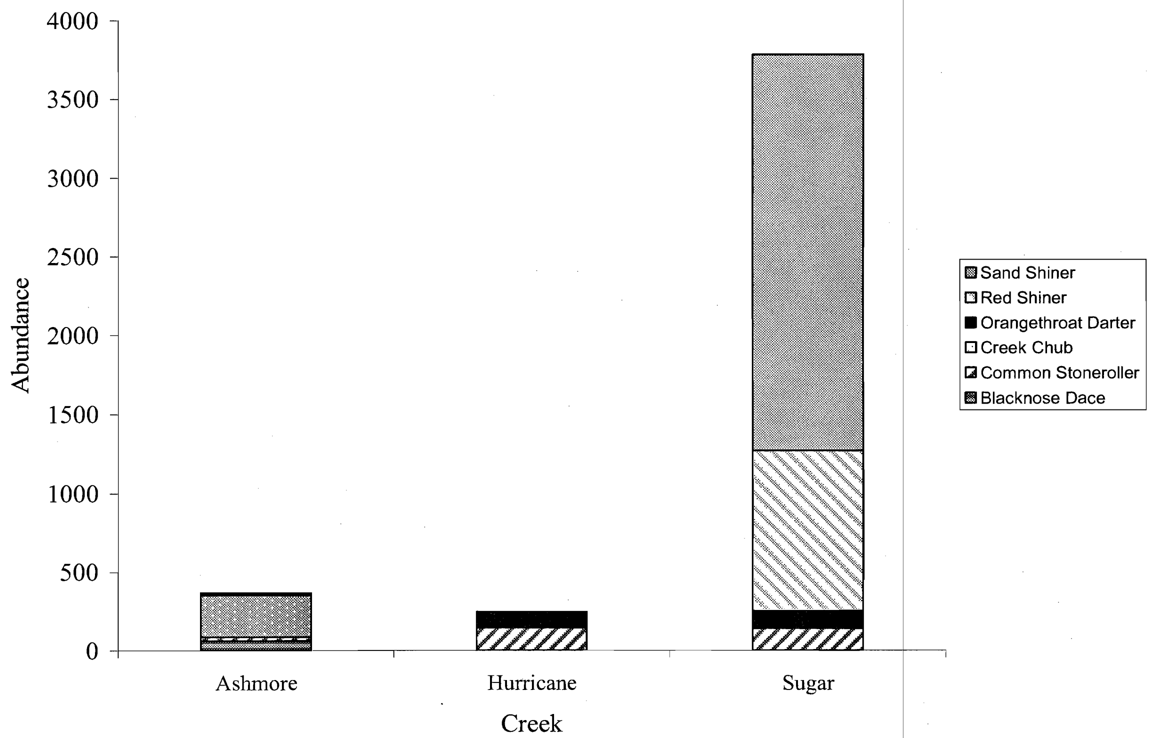



Figure 9. Abundances of fish identified in the BVSTEP routine of combined fish samples for each study stream.

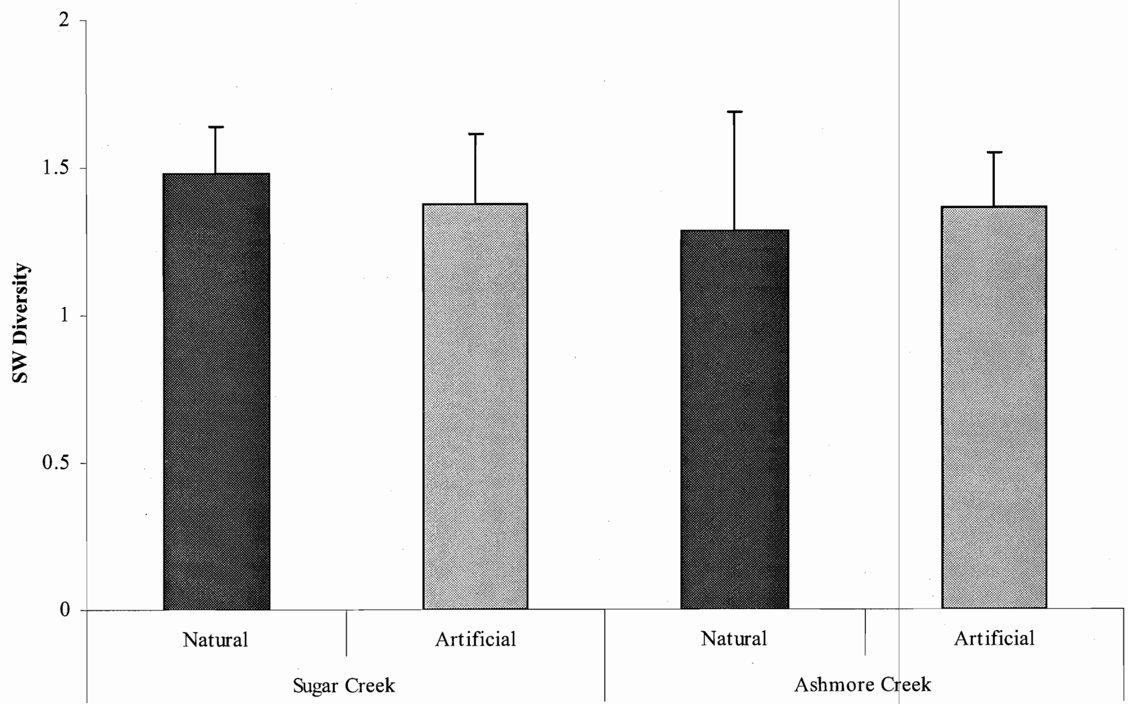



Figure 10. Mean Shannon Weiner Diversity of benthic invertebrate community samples on Ashmore, Hurricane, and Sugar Creeks. The bars shown represent standard error.

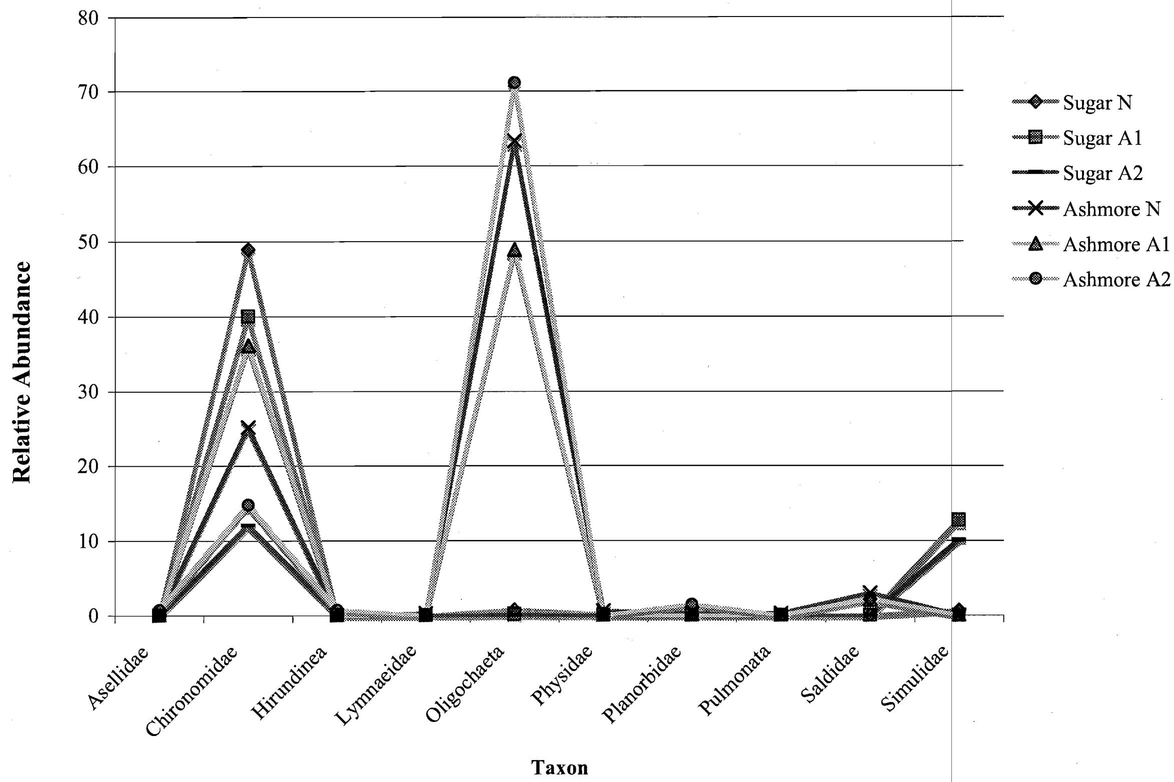



Figure 11. Relative abundance of tolerant invertebrate taxa as classified by Voshell 2002.

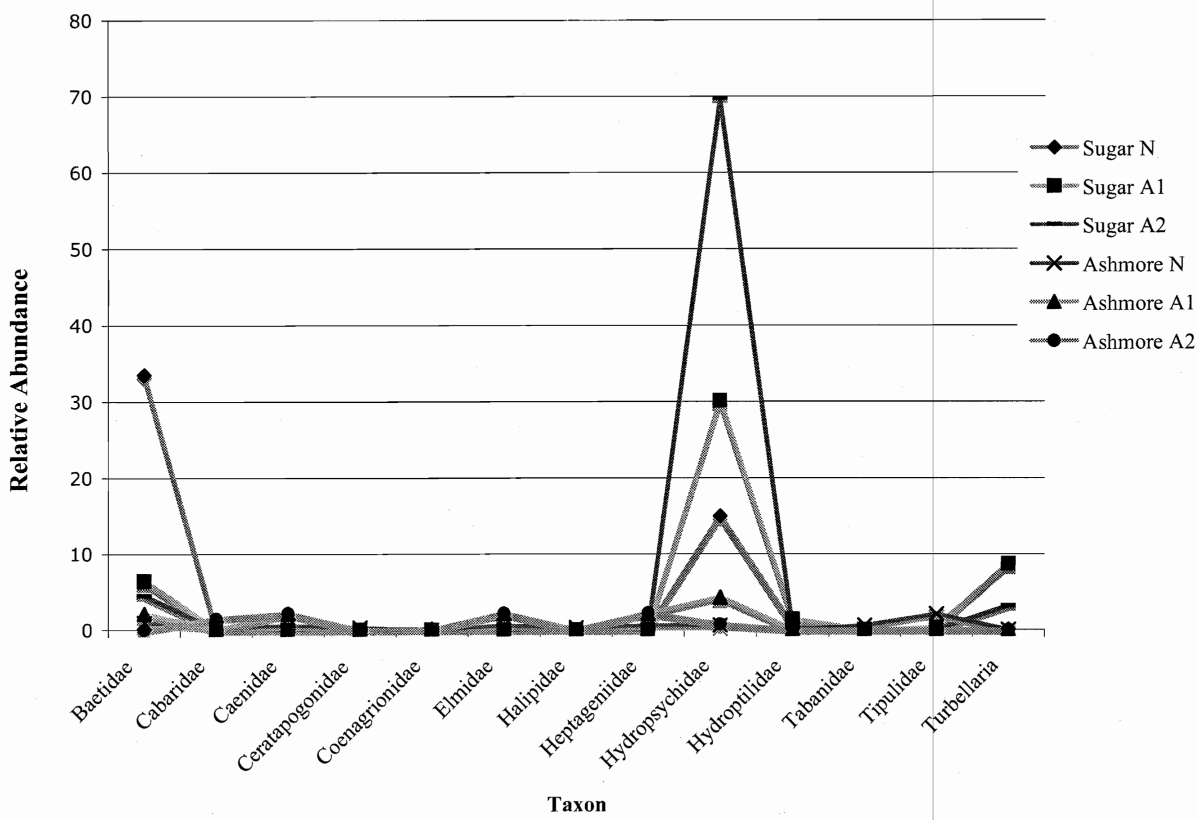



Figure 11. Relative abundance of intolerant invertebrate taxa as classified by Voshell 2002.

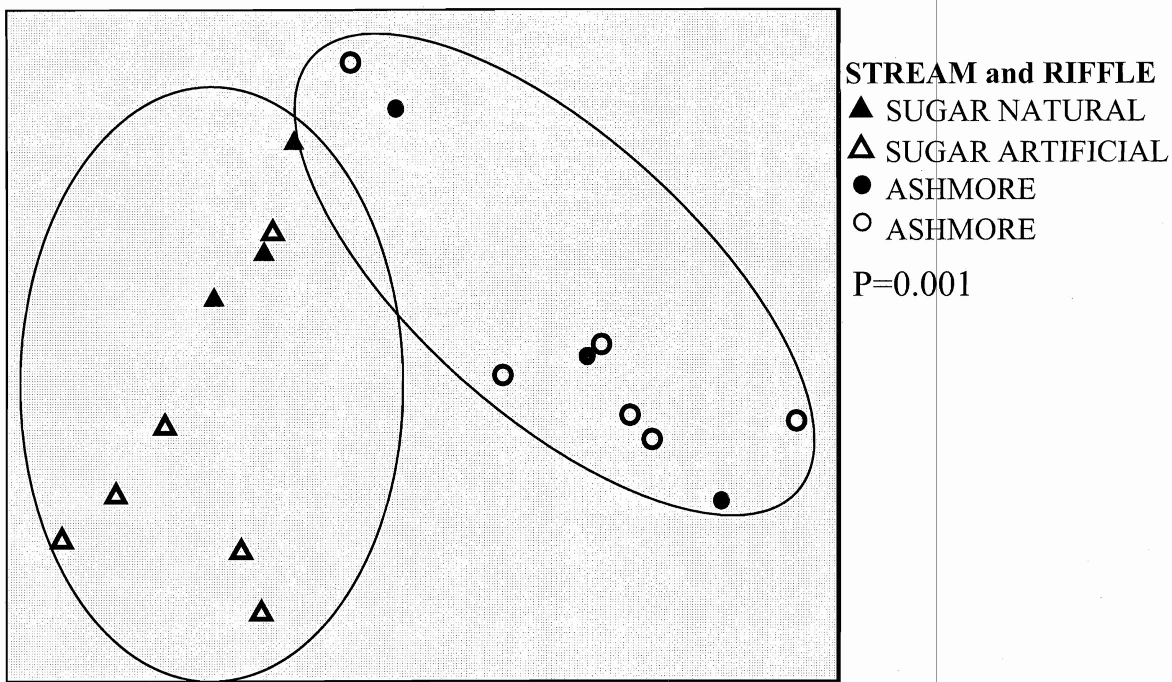



Figure 13. MDS ordination of invertebrate assemblages in artificial and natural riffles of study streams.

## APPENDIX A- DATA

### TRANSECT DATA

| Creek Name | Riffle | Date | Riffle Length (m) | Transect Length (m) | Distance From Initial Point (ft) | Depth (m) | Substrate Code |
|---|---|---|---|---|---|---|---|
| Sugar | Nat | 6/22/2005 | 21.6 | 19.2 | 0 | 0.07 | 1 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.2 | 5 | 0.4 | 4.1 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.2 | 10 | 0.22 | 3.1 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.2 | 15 | 0.065 | 3.2 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.2 | 20 | 0.03 | 3.1 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.2 | 25 | 0 | 1 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.2 | 30 | 0 | 1 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.2 | 35 | 0.01 | 1 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.2 | 40 | 0.06 | 2 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.2 | 45 | 0.105 | 3.1 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.2 | 50 | 0.08 | 3.1 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.2 | 55 | 0.075 | 3.1 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.2 | 60 | 0.08 | 3.2 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.2 | 63 | 0.05 | 3.1 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.8 | 0 | 0.1 | 3.1 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.8 | 5 | 0.19 | 3.1 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.8 | 10 | 0.11 | 3.2 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.8 | 15 | 0.115 | 3.2 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.8 | 20 | 0.08 | 3.3 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.8 | 25 | 0.075 | 3.2 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.8 | 30 | 0.06 | 3.2 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.8 | 35 | 0.08 | 3.3 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.8 | 40 | 0.135 | 3.2 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.8 | 45 | 0.07 | 3.2 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.8 | 50 | 0.015 | 3.2 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.8 | 55 | 0 | 4.1 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.8 | 60 | 0.09 | 3.1 |
| Sugar | Nat | 6/22/2005 | 21.6 | 19.8 | 65 | 0.145 | 3.2 |
| Sugar | Nat | 6/22/2005 | 21.6 | 20.5 | 0 | 0.11 | 3.1 |
| Sugar | Nat | 6/22/2005 | 21.6 | 20.5 | 5 | 0.26 | 3.1 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sugar | Nat | 6/22/2005 | 21.6 | 20.5 | 60 | 0.23 | 3.2 |
| | | | | | **Distance** | | |
| | | | **Riffle** | **Transect** | **From** | | |
| **Creek** | | | **Length** | **Length** | **Initial** | **Depth** | **Substrate** |
| **Name** | **Riffle** | **Date** | **(m)** | **(m)** | **Point (ft)** | **(m)** | **Code** |
| Sugar | Nat | 6/22/2005 | 21.6 | 20.5 | 65 | 0.09 | 3.2 |
| Sugar | Nat | 6/22/2005 | 21.6 | 20.5 | 67 | 0.02 | 3.1 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 0 | 0 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 5 | 0.02 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 10 | 0.22 | 4.2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 15 | 0.06 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 20 | 0.15 | 4.2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 25 | 0.225 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 30 | 0.37 | 3.2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 35 | 0.12 | 3.1 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 40 | 0.05 | 3.1 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 45 | 0.33 | 4.2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 50 | 0.52 | 4.2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 55 | 0.6 | 2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 60 | 0.45 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 65 | 0.38 | 2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 70 | 0.56 | 3.1 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 75 | 0.68 | 3.1 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 80 | 0.81 | 4.1 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 85 | 0.58 | 3.1 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 27.5 | 90 | 0.15 | 3.2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 28.66 | 0 | 0.03 | 3.2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 28.66 | 5 | 0 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 28.66 | 10 | 0 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 28.66 | 15 | 0 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 28.66 | 20 | 0.32 | 2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 28.66 | 25 | 0.15 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 28.66 | 30 | 0.03 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 28.66 | 35 | 0.2 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 28.66 | 40 | 0.13 | 4.2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 28.66 | 45 | 0.14 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 28.66 | 50 | 0.125 | 4.2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 28.66 | 55 | 0.06 | 4.2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 28.66 | 60 | 0.03 | 5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sugar | Art 1 | 6/22/2005 | 8.1 | 26.53 | 10 | 0.08 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 26.53 | 15 | 0.23 | 1 |
| **Creek Name** | **Riffle** | **Date** | **Riffle Length (m)** | **Transect Length (m)** | **Distance From Initial Point (ft)** | **Depth (m)** | **Substrate Code** |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 26.53 | 20 | 0.21 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 26.53 | 25 | 0.3 | 2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 26.53 | 30 | 0.36 | 4.2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 26.53 | 35 | 0.34 | 1 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 26.53 | 40 | 0.2 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 26.53 | 45 | 0.01 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 26.53 | 50 | 0.16 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 26.53 | 55 | 0.11 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 26.53 | 60 | 0.34 | 2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 26.53 | 65 | 0.47 | 2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 26.53 | 70 | 0.465 | 2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 26.53 | 75 | 0.45 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 26.53 | 80 | 0.27 | 4.2 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 26.53 | 85 | 0.34 | 5 |
| Sugar | Art 1 | 6/22/2005 | 8.1 | 26.53 | 87 | 0.08 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.8 | 0 | 0 | 1 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.8 | 5 | 0.03 | 1 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.8 | 10 | 0.15 | 1 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.8 | 15 | 0.12 | 2 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.8 | 20 | 0.16 | 2 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.8 | 25 | 0.25 | 3.1 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.8 | 30 | 0.24 | 3.2 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.8 | 35 | 0.26 | 2 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.8 | 40 | 0.34 | 2 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.8 | 45 | 0.15 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.8 | 50 | 0.25 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.8 | 55 | 0.28 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.8 | 60 | 0.2 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.8 | 65 | 0.24 | 4.1 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.8 | 70 | 0.11 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.8 | 75 | 0.04 | 4.2 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 21.5 | 0 | 0.1 | 4.2 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 21.5 | 5 | 0.18 | 2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sugar | Art 2 | 6/22/2005 | 11.4 | 21.5 | 55 | 0.02 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 21.5 | 60 | 0.01 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 21.5 | 65 | 0 | 5 |
| **Creek Name** | **Riffle** | **Date** | **Riffle Length (m)** | **Transect Length (m)** | **Distance From Initial Point (ft)** | **Depth (m)** | **Substrate Code** |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 21.5 | 70 | 0.075 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.56 | 0 | 0.1 | 2 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.56 | 5 | 0.1 | 3.1 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.56 | 10 | 0.1 | 3.2 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.56 | 15 | 0.08 | 4.1 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.56 | 20 | 0.16 | 4.2 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.56 | 25 | 0.02 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.56 | 30 | 0 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.56 | 35 | 0 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.56 | 40 | 0.32 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.56 | 45 | 0.11 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.56 | 50 | 0.08 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.56 | 55 | 0.05 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.56 | 60 | 0.125 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.56 | 65 | 0.02 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.56 | 70 | 0 | 5 |
| Sugar | Art 2 | 6/22/2005 | 11.4 | 22.56 | 74 | 0.05 | 4.1 |
| shemor | Nat | 7/16/2005 | 7.4 | 2.3 | 1 | 0.11 | 4.2 |
| shemor | Nat | 7/16/2005 | 7.4 | 2.3 | 2 | 0.13 | 3.2 |
| shemor | Nat | 7/16/2005 | 7.4 | 2.3 | 3 | 0.105 | 4.2 |
| shemor | Nat | 7/16/2005 | 7.4 | 2.3 | 4 | 0.11 | 2 |
| shemor | Nat | 7/16/2005 | 7.4 | 2.3 | 5 | 0.06 | 2 |
| shemor | Nat | 7/16/2005 | 7.4 | 2.3 | 6 | 0.01 | 2 |
| shemor | Nat | 7/16/2005 | 7.4 | 0.65 | 1 | 0.01 | 4.1 |
| shemor | Nat | 7/16/2005 | 7.4 | 2.05 | 1 | 0.09 | 6 |
| shemor | Nat | 7/16/2005 | 7.4 | 2.05 | 2 | 0.0065 | 2 |
| shemor | Nat | 7/16/2005 | 7.4 | 2.05 | 3 | 0.05 | 3.1 |
| shemor | Nat | 7/16/2005 | 7.4 | 2.05 | 4 | 0.06 | 2 |
| shemor | Nat | 7/16/2005 | 7.4 | 2.05 | 5 | 0.05 | 2 |
| shemor | Art 1 | 7/17/2005 | 4.7 | 4.3 | 0 | 0 | 4.1 |
| shemor | Art 1 | 7/17/2005 | 4.7 | 4.3 | 2 | 0 | 3.2 |
| shemor | Art 1 | 7/17/2005 | 4.7 | 4.3 | 4 | 0 | 5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| shemor | Art 1 | 7/17/2005 | 4.7 | 5 | 10 | 0.02 | 5 |
| shemor | Art 1 | 7/17/2005 | 4.7 | 5 | 12 | 0 | 5 |
| shemor | Art 1 | 7/17/2005 | 4.7 | 5 | 14 | 0 | 4.2 |
| shemor | Art 1 | 7/17/2005 | 4.7 | 5 | 16 | | |
| | | | | | **Distance** | | |
| | | | **Riffle** | **Transect** | **From** | | |
| **Creek** | | | **Length** | **Length** | **Initial** | **Depth** | **Substrate** |
| **Name** | **Riffle** | **Date** | **(m)** | **(m)** | **Point (ft)** | **(m)** | **Code** |
| shemor | Art 1 | 7/17/2005 | 4.7 | 5 | 18 | | |
| shemor | Art 1 | 7/17/2005 | 4.7 | 4.1 | 0 | 0 | 5 |
| shemor | Art 1 | 7/17/2005 | 4.7 | 4.1 | 2 | 0 | 5 |
| shemor | Art 1 | 7/17/2005 | 4.7 | 4.1 | 4 | 0.55 | 4.2 |
| shemor | Art 1 | 7/17/2005 | 4.7 | 4.1 | 6 | 0 | 5 |
| shemor | Art 1 | 7/17/2005 | 4.7 | 4.1 | 8 | 0.02 | 4.2 |
| shemor | Art 1 | 7/17/2005 | 4.7 | 4.1 | 10 | 0 | 5 |
| shemor | Art 1 | 7/17/2005 | 4.7 | 4.1 | 12 | 0 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 3.3 | 2 | 0.005 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 3.3 | 4 | 0 | 2 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 3.3 | 6 | 0 | 2 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 3.3 | 8 | 0 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 3.3 | 10 | 0 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 4.7 | 0 | 0.005 | 3.2 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 4.7 | 2 | 0 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 4.7 | 4 | 0 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 4.7 | 6 | 0 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 4.7 | 8 | 0 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 4.7 | 10 | 0 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 4.7 | 12 | 0 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 4.7 | 14 | 0 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 5.3 | 0 | 0 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 5.3 | 2 | 0 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 5.3 | 4 | 0 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 5.3 | 6 | 0 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 5.3 | 8 | 0 | 4.2 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 5.3 | 10 | 0 | 4.2 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 5.3 | 12 | 0 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 5.3 | 14 | 0 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 5.3 | 16 | 0 | 5 |
| shemor | Art 2 | 7/16/2005 | 9.05 | 5.3 | 18 | 0 | 5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 0 | 0 | 3.2 |
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 2 | 0 | 4.2 |
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 4 | 0 | 3.2 |
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 6 | 0 | 3.2 |
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 8 | 0 | 4.1 |
| **Creek Name** | **Riffle** | **Date** | **Riffle Length (m)** | **Transect Length (m)** | **Distance From Initial Point (ft)** | **Depth (m)** | **Substrate Code** |
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 10 | 0 | 3.3 |
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 12 | 0 | 3.3 |
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 14 | 0 | 4.1 |
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 16 | 0 | 4.1 |
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 0 | 0 | 4.2 |
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 2 | 0 | 4.1 |
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 4 | 0 | 4.2 |
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 6 | 0 | 2 |
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 8 | 0 | 4.2 |
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 10 | 0 | 2 |
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 12 | 0 | 2 |
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 14 | 0 | 3.3 |
| Hurrican | Nat | 7/17/2005 | 13.1 | 5.2 | 16 | 0 | 3.2 |
| Hurrican | Art 1 | 7/17/2005 | | 5.9 | 0 | 0 | 5 |
| Hurrican | Art 1 | 7/17/2005 | | 5.9 | 2 | 0 | 5 |
| Hurrican | Art 1 | 7/17/2005 | | 5.9 | 4 | 0 | 5 |
| Hurrican | Art 1 | 7/17/2005 | | 5.9 | 6 | 0 | 5 |
| Hurrican | Art 1 | 7/17/2005 | | 5.9 | 8 | 0 | 5 |
| Hurrican | Art 1 | 7/17/2005 | | 5.9 | 10 | 0 | 1 |
| Hurrican | Art 1 | 7/17/2005 | | 5.9 | 12 | 0 | 5 |
| Hurrican | Art 1 | 7/17/2005 | | 5.9 | 14 | 0 | 4.2 |
| Hurrican | Art 1 | 7/17/2005 | | 5.9 | 16 | 0 | 5 |
| Hurrican | Art 1 | 7/17/2005 | | 5.9 | 18 | 0 | 2 |
| Hurrican | Art 1 | 7/17/2005 | | 5.9 | 20 | 0 | 2 |
| Hurrican | Art 1 | 7/17/2005 | | 5.8 | 0 | 0 | 4.2 |
| Hurrican | Art 1 | 7/17/2005 | | 5.8 | 2 | 0 | 4.2 |
| Hurrican | Art 1 | 7/17/2005 | | 5.8 | 4 | 0 | 5 |
| Hurrican | Art 1 | 7/17/2005 | | 5.8 | 6 | 0 | 5 |
| Hurrican | Art 1 | 7/17/2005 | | 5.8 | 8 | 0 | 2 |
| Hurrican | Art 1 | 7/17/2005 | | 5.8 | 10 | 0 | 1 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Hurrican | Art 1 | 7/17/2005 | | 6.3 | 10 | 0 | 5 |
| Hurrican | Art 1 | 7/17/2005 | | 6.3 | 12 | 0 | 1 |
| Hurrican | Art 1 | 7/17/2005 | | 6.3 | 14 | 0 | 3.2 |
| Hurrican | Art 1 | 7/17/2005 | | 6.3 | 16 | 0 | 2 |
| Hurrican | Art 1 | 7/17/2005 | | 6.3 | 18 | 0 | 5 |
| Hurrican | Art 1 | 7/17/2005 | | 6.3 | 20 | 0 | 5 |
| **Creek Name** | **Riffle** | **Date** | **Riffle Length (m)** | **Transect Length (m)** | **Distance From Initial Point (ft)** | **Depth (m)** | **Substrate Code** |
| Hurrican | Art 2 | 7/17/2005 | | 5.4 | 2 | 0 | 2 |
| Hurrican | Art 2 | 7/17/2005 | | 5.4 | 4 | 0 | 5 |
| Hurrican | Art 2 | 7/17/2005 | | 5.4 | 6 | 0 | 5 |
| Hurrican | Art 2 | 7/17/2005 | | 5.4 | 8 | 0 | 4.2 |
| Hurrican | Art 2 | 7/17/2005 | | 5.4 | 10 | 0 | 1 |
| Hurrican | Art 2 | 7/17/2005 | | 5.4 | 12 | 0 | 5 |
| Hurrican | Art 2 | 7/17/2005 | | 5.4 | 14 | 0 | 1 |
| Hurrican | Art 2 | 7/17/2005 | | 5.4 | 16 | 0 | 5 |
| Hurrican | Art 2 | 7/17/2005 | | 5.4 | 18 | 0 | 2 |
| Hurrican | Art 2 | 7/17/2005 | | 5 | 0 | 0 | 5 |
| Hurrican | Art 2 | 7/17/2005 | | 5 | 2 | 0 | 5 |
| Hurrican | Art 2 | 7/17/2005 | | 5 | 4 | 0 | 5 |
| Hurrican | Art 2 | 7/17/2005 | | 5 | 6 | 0 | 4.2 |
| Hurrican | Art 2 | 7/17/2005 | | 5 | 8 | 0 | 5 |
| Hurrican | Art 2 | 7/17/2005 | | 5 | 10 | 0 | 4.2 |
| Hurrican | Art 2 | 7/17/2005 | | 5 | 12 | 0 | 5 |
| Hurrican | Art 2 | 7/17/2005 | | 5 | 14 | 0 | 5 |
| Hurrican | Art 2 | 7/17/2005 | | 7.4 | 0 | 0 | 5 |
| Hurrican | Art 2 | 7/17/2005 | | 7.4 | 2 | 0 | 5 |
| Hurrican | Art 2 | 7/17/2005 | | 7.4 | 4 | 0 | 4.2 |
| Hurrican | Art 2 | 7/17/2005 | | 7.4 | 6 | 0 | 4.2 |
| Hurrican | Art 2 | 7/17/2005 | | 7.4 | 8 | 0 | 5 |
| Hurrican | Art 2 | 7/17/2005 | | 7.4 | 10 | 0 | 4.2 |
| Hurrican | Art 2 | 7/17/2005 | | 7.4 | 12 | 0 | 5 |
| Hurrican | Art 2 | 7/17/2005 | | 7.4 | 14 | 0 | 5 |
| Hurrican | Art 2 | 7/17/2005 | | 7.4 | 16 | 0 | 2 |
| Hurrican | Art 2 | 7/17/2005 | | 7.4 | 18 | 0 | 3.1 |
| Hurrican | Art 2 | 7/17/2005 | | 7.4 | 20 | 0 | 5 |
| Hurrican | Art 2 | 7/17/2005 | | 7.4 | 22 | 0 | 3.3 |

## VELOCITY DATA

| MONTH | CREEK | RIFFLE | FLOW 1 | FLOW 2 |
|---|---|---|---|---|
| | | | | |
| August | Ashmore | Art 1 | <.001 | <.001 |
| August | Ashmore | Art 2 | <.001 | <.001 |
| August | Ashmore | Nat | <.001 | <.001 |
| August | Sugar | Art 1 | 11.7 | 11.4 |
| August | Sugar | Art 2 | 14.66 | 14.14 |
| August | Sugar | Nat | 4.43 | 4.41 |
| July | Ashmore | Art 1 | <.001 | |
| July | Ashmore | Art 2 | | |
| July | Ashmore | Nat | <.001 | |
| July | Hurricane | Art 1 | <.001 | |
| July | Hurricane | Art 2 | <.001 | |
| July | Hurricane | Nat | <.001 | |
| July | Sugar | Art 1 | 11.68 | 11.96 |
| July | Sugar | Art 2 | 6.57 | 9.96 |
| July | Sugar | Nat | 5 | 4.14 |
| June | Sugar | Art 1 | 11.15 | 10.9 |
| June | Sugar | Art 2 | 9.94 | 7.34 |
| June | Sugar | Nat | 5.6 | 4.9 |
| May | Ashmore | Art 1 | <.001 | <.001 |
| May | Ashmore | Art 2 | <.001 | <.001 |
| May | Ashmore | Nat | <.001 | <.001 |
| May | Hurricane | Art 1 | 1.57 | 3.38 |
| May | Hurricane | Art 2 | 4.55 | 6.49 |
| May | Hurricane | Nat | 2.87 | 3.83 |
| May | Sugar | Art 1 | 7.66 | 10.01 |
| May | Sugar | Art 1 | 7.66 | |
| May | Sugar | Art 2 | 6.41 | 10.21 |
| May | Sugar | Nat | 6.3 | 7.9 |
| May | Sugar | Nat | 6.3 | 7.9 |
| November | Ashmore | Art 1 | | |
| November | Ashmore | Art 1 | | |
| November | Ashmore | Art 1 | 0.57 | |
| November | Ashmore | Art 2 | 2.79 | |
| November | Ashmore | Nat | | |
| November | Ashmore | Nat | 1.48 | |
| November | Sugar | Art 1 | 7.15 | 6.3 |
| November | Sugar | Art 2 | <.001 | <.001 |
| November | Sugar | Nat | 2.88 | 7 |
| October | Sugar | Art 1 | 2.25 | 0 |
| October | Sugar | Art 2 | <.01 | 3.25 |
| October | Sugar | Nat | 5 | 3.45 |
| September | Ashmore | Art 2 | | |
| September | Ashmore | Art 2 | | |
| September | Ashmore | Nat | | |

## SHAP DATA

| | Sug Nat | Sug Art 1 | Sug Art 2 | Hurr Nat | Hurr Art 1 | Hurr Art 2 | Ash Nat | Ash Art 1 | Ash Art 2 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| Bottom Substrate | 11 | 18 | 16 | 15 | 16 | 16 | 4 | 16 | 16 |
| Deposition | 7 | 12 | 12 | 9 | 11 | 11 | 4 | 9 | 9 |
| Substrate Stability | 10 | 15 | 15 | 10 | 13 | 13 | 4 | 9 | 9 |
| Instream Cover | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Pool Substrata | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Characterization | | | | | | | | | |
| Pool Quality | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Pool Variability | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Canopy Cover | 5 | 7 | 7 | 10 | 10 | 10 | 10 | 10 | 10 |
| Bank Vegetative Protection/ | 5 | 5 | 5 | 12 | 12 | 12 | 6 | 6 | 6 |
| Stability | | | | | | | | | |
| TOB land use | 1 | 2 | 2 | 2 | 2 | 2 | 4 | 4 | 4 |
| Flow-related Refugia | 9 | 7 | 8 | 7 | 4 | 4 | 4 | 2 | 2 |
| Channel alteration | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Channel sinuosity | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Wedth/Depth ratio | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 |
| Hydrologic Diversity | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

**FISH DATA**

| TAXA | Hur Nat s1 | Hur Nat s2 | Hur AR1 s1 | Hur AR1 s2 | Hur AR2 s1 | Hur AR2 s2 |
|---|---|---|---|---|---|---|
| bigeye shiner | 0 | 0 | 0 | 0 | 0 | 0 |
| bigmouth shiner | 0 | 0 | 0 | 0 | 0 | 0 |
| black redhorse | 0 | 0 | 0 | 0 | 0 | 0 |
| blackside darter | 0 | 0 | 0 | 0 | 0 | 0 |
| blacknose dace | 0 | 0 | 0 | 0 | 0 | 0 |
| blackstripetopminnov | 0 | 0 | 0 | 0 | 0 | 0 |
| bluntnose minnow | 0 | 0 | 1 | 1 | 1 | 3 |
| bluegill | 0 | 0 | 0 | 0 | 0 | 0 |
| common stoneroller | 15 | 48 | 42 | 7 | 27 | 6 |
| common carp | 0 | 0 | 0 | 0 | 0 | 0 |
| common shiner | 0 | 0 | 0 | 0 | 0 | 0 |
| creek chub | 1 | 3 | 3 | 2 | 0 | 0 |
| fathead minnow | 0 | 0 | 1 | 0 | 0 | 0 |
| green sunfish | 0 | 0 | 0 | 0 | 0 | 0 |
| greenside darter | 0 | 0 | 0 | 0 | 0 | 0 |
| horneyhead chub | 0 | 0 | 0 | 0 | 0 | 0 |
| johnnie darter | 0 | 1 | 0 | 0 | 0 | 1 |
| mimic shiner | 0 | 0 | 0 | 0 | 0 | 0 |
| northern hog sucker | 0 | 1 | 1 | 0 | 0 | 0 |
| orangethroat darters | 45 | 12 | 21 | 5 | 10 | 0 |
| plains minnow | 0 | 0 | 0 | 0 | 0 | 0 |
| red shiner | 0 | 0 | 0 | 0 | 0 | 0 |
| redfin shiner | 0 | 0 | 0 | 0 | 0 | 0 |
| river shiner | 0 | 0 | 0 | 0 | 0 | 0 |
| rainbow darter | 20 | 16 | 12 | 0 | 5 | 0 |
| sand shiner | 0 | 0 | 0 | 0 | 0 | 0 |
| silver redhorse | 0 | 0 | 0 | 0 | 0 | 0 |
| slenderhead darter | 0 | 0 | 0 | 0 | 0 | 0 |
| smallmouth bass | 0 | 0 | 0 | 0 | 0 | 0 |
| spotfin shiner | 0 | 0 | 0 | 0 | 0 | 0 |
| steelcolor shiner | 0 | 0 | 0 | 0 | 0 | 0 |
| stonecat madtom | 0 | 0 | 0 | 0 | 0 | 0 |
| striped shiner | 0 | 0 | 28 | 3 | 3 | 3 |
| suckermouth minnov | 0 | 1 | 0 | 0 | 0 | 0 |
| silverjaw minnow | 0 | 1 | 1 | 0 | 0 | 1 |
| white suckers | 0 | 0 | 0 | 0 | 0 | 0 |
| yellow bullhead | 0 | 0 | 0 | 0 | 0 | 0 |

**FISH DATA**

| TAXA | Sug AR1 s1 | Sug AR1 s2 | Sug AR1 s3 | Sug AR1 s4 | Sug AR2 s1 | Sug AR2 s2 | Sug AR2 s3 | Sug AR2 s4 | Sug Nat s2 | Sug Nat s3 | Sug Nat s4 | Sug Nat s1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| bigeye shiner | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| bigmouth shiner | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 4 | 0 | 0 | 6 |
| black redhorse | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| blackside darter | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| blacknose dace | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| blackstripetopminnow | 0 | 0 | 19 | 15 | 0 | 1 | 36 | 12 | 8 | 189 | 149 | 3 |
| bluntnose minnow | 2 | 7 | 8 | 59 | 0 | 54 | 123 | 143 | 4 | 164 | 47 | 7 |
| bluegill | 0 | 2 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| common stoneroller | 5 | 0 | 6 | 35 | 23 | 3 | 25 | 36 | 0 | 7 | 0 | 0 |
| common carp | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| common shiner | 0 | 0 | 8 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| creek chub | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 5 | 0 | 0 |
| fathead minnow | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| green sunfish | 0 | 2 | 4 | 9 | 0 | 1 | 2 | 1 | 0 | 2 | 1 | 0 |
| greenside darter | 0 | 15 | 7 | 10 | 0 | 1 | 0 | 2 | 1 | 0 | 1 | 0 |
| horneyhead chub | 0 | 8 | 5 | 3 | 2 | 0 | 0 | 1 | 0 | 11 | 0 | 0 |
| johnnie darter | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| mimic shiner | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0 |
| northern hog sucker | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| orangethroat darters | 3 | 1 | 9 | 47 | 0 | 1 | 9 | 23 | 1 | 2 | 8 | 2 |
| plains minnow | 0 | 0 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| red shiner | 16 | 24 | 93 | 35 | 15 | 73 | 0 | 0 | 40 | 530 | 151 | 42 |
| redfin shiner | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| river shiner | 0 | 0 | 3 | 0 | 0 | 0 | 30 | 67 | 0 | 0 | 67 | 0 |
| rainbow darter | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| sand shiner | 41 | 36 | 60 | 7 | 0 | 212 | 514 | 262 | 556 | 391 | 81 | 347 |
| silver redhorse | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| slenderhead darter | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| smallmouth bass | 0 | 0 | 1 | 5 | 0 | 3 | 4 | 6 | 0 | 0 | 0 | 0 |
| spotfin shiner | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 88 | 1 |
| steelcolor shiner | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| stonecat madtom | 0 | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| striped shiner | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| suckermouth minnow | 2 | 0 | 0 | 25 | 1 | 0 | 11 | 5 | 0 | 4 | 10 | 0 |
| silverjaw minnow | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| white suckers | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 |
| yellow bullhead | 0 | 12 | 7 | 11 | 0 | 0 | 4 | 2 | 0 | 11 | 2 | 0 |

**FISH DATA**

| TAXA | Ash AR1 s1 | Ash AR1 s2 | Ash AR1 s3 | Ash AR1 s4 | Ash AR2 s1 | Ash AR2 s2 | Ash AR2 s3 | Ash AR2 s4 | Ash Nat s1 | Ash Nat s3 | Ash Nat s4 | Ash Nat. s2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| bigeye shiner | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| bigmouth shiner | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| black redhorse | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| blackside darter | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| blacknose dace | 0 | 15 | 12 | 14 | 3 | 1 | 1 | 3 | 1 | 10 | 3 | 0 |
| blackstripetopminnow | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| bluntnose minnow | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 |
| bluegill | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| common stoneroller | 3 | 0 | 0 | 1 | 8 | 0 | 2 | 8 | 1 | 0 | 0 | 0 |
| common carp | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| common shiner | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| creek chub | 1 | 79 | 0 | 1 | 1 | 154 | 1 | 1 | 0 | 2 | 1 | 26 |
| fathead minnow | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| green sunfish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| greenside darter | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| horneyhead chub | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| johnnie darter | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| mimic shiner | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| northern hog sucker | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| orangethroat darters | 2 | 2 | 0 | 0 | 2 | 2 | 0 | 0 | 4 | 1 | 2 | 0 |
| plains minnow | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| red shiner | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| redfin shiner | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| river shiner | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| rainbow darter | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| sand shiner | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| silver redhorse | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| slenderhead darter | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| smallmouth bass | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| spotfin shiner | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| steelcolor shiner | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| stonecat madtom | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| striped shiner | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| suckermouth minnow | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| silverjaw minnow | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| white suckers | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| yellow bullhead | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## ELECTROSHOCKING TIME

| Sample | Creek | Riffle | Shocking Time (min) |
|---|---|---|---|
| 1 | Ashmore | artificial 1 | 5.1 |
| 1 | Ashmore | artificial 2 | 8.93 |
| 1 | Ashmore | natural | 3.77 |
| 2 | Ashmore | artificial 1 | 3.38 |
| 2 | Ashmore | artificial 2 | 7.02 |
| 2 | Ashmore | natural | 3.18 |
| 3 | Ashmore | artificial 1 | 6 |
| 3 | Ashmore | artificial 2 | 8 |
| 3 | Ashmore | natural | 6 |
| 4 | Ashmore | artificial 1 | 5.05 |
| 4 | Ashmore | artificial 2 | 4.12 |
| 4 | Ashmore | natural | 3 |
| 1 | Hurricane | artificial 1 | 14.75 |
| 1 | Hurricane | artificial 2 | 10.93 |
| 1 | Hurricane | natural | 12.17 |
| 2 | Hurricane | artificial 1 | 4.25 |
| 2 | Hurricane | artificial 2 | 4.87 |
| 2 | Hurricane | natural | 8.72 |
| 1 | Sugar | artificial 1 | 21.08 |
| 1 | Sugar | artificial 2 | 10.17 |
| 1 | Sugar | natural | 11.5 |
| 2 | Sugar | artificial 1 | 13.12 |
| 2 | Sugar | artificial 2 | 9.4 |
| 2 | Sugar | natural | 7.65 |
| 3 | Sugar | artificial 1 | 28 |
| 3 | Sugar | artificial 2 | 13 |
| 3 | Sugar | natural | 20 |
| 4 | Sugar | artificial 1 | 33.75 |
| 4 | Sugar | artificial 2 | 14.7 |
| 4 | Sugar | natural | 22.3 |

**INVERTEBRATE DATA**

| Taxa | Ash Nat | Ash Nat | Ash Nat | Ash A1 | Ash A2 | Ash A1 | Ash A2 | Ash A1 | Ash A2 |
|---|---|---|---|---|---|---|---|---|---|
| ELMIDAE | 0 | 2 | 0 | 0 | 1 | 1 | 2 | 0 | 0 |
| HALIPLIDAE | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIMULIIDAE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIRONOMIDAE | 46 | 31 | 7 | 4 | 0 | 6 | 14 | 7 | 6 |
| TIPULIDAE | 1 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TABANIDAE | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| BAETIDAE | 0 | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| CAENIDAE | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 2 |
| HEPTAGENIIDAE | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 2 |
| Ephemeroptera Adults | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| HYDROPSYCHIDAE | 1 | 1 | 0 | 0 | 0 | 2 | 1 | 0 | 0 |
| HYDROPTILIDAE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SALDIDAE | 9 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 2 |
| COENAGRIONIDAE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PHYSIDAE | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PLANORBIDAE | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| LYMNAEIDAE | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pulmonata | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| OLIGOCHAETA | 4 | 68 | 139 | 0 | 6 | 9 | 58 | 14 | 32 |
| HIRUNDINEA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| TURBELLARIA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CERATAPOGONIDAE | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CABARIDAE | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| ASELLIDAE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

## INVERTEBRATE DATA

| Taxa | Sug Nat | Sug Nat | Sug Nat | Sug A1 | Sug A2 | Sug A1 | Sug A2 | Sug A1 | Sug A2 |
|---|---|---|---|---|---|---|---|---|---|
| ELMIDAE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| HALIPLIDAE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIMULIIDAE | 12 | 1 | 0 | 426 | 306 | 5 | 7 | 0 | 1 |
| CHIRONOMIDAE | 221 | 392 | 310 | 148 | 122 | 1122 | 130 | 84 | 123 |
| TIPULIDAE | 0 | 0 | 0 | 1 | 0 | 3 | 0 | 5 | 0 |
| TABANIDAE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BAETIDAE | 272 | 290 | 69 | 18 | 8 | 159 | 122 | 40 | 9 |
| CAENIDAE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| HEPTAGENIIDAE | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Ephemeroptera Adults | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| HYDROPSYCHIDAE | 139 | 7 | 136 | 179 | 218 | 293 | 432 | 547 | 1512 |
| HYDROPTILIDAE | 1 | 2 | 6 | 0 | 0 | 46 | 7 | 0 | 0 |
| SALDIDAE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| COENAGRIONIDAE | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 1 |
| PHYSIDAE | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| PLANORBIDAE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| LYMNAEIDAE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pulmonata | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| OLIGOCHAETA | 0 | 11 | 3 | 2 | 1 | 3 | 0 | 1 | 0 |
| HIRUNDINEA | 0 | 0 | 0 | 2 | 2 | 1 | 1 | 0 | 0 |
| TURBELLARIA | 1 | 0 | 0 | 188 | 34 | 45 | 25 | 61 | 39 |
| CERATAPOGONIDAE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CABARIDAE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ASELLIDAE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |