Developing a Monitoring Protocol for the Monkey River Watershed, Belize, Central America

Sean Elliott Collins
sean_e_collins@hotmail.com

Follow this and additional works at: http://mds.marshall.edu/etd
Part of the Marine Biology Commons

Recommended Citation

This Thesis is brought to you for free and open access by Marshall Digital Scholar. It has been accepted for inclusion in Theses, Dissertations and Capstones by an authorized administrator of Marshall Digital Scholar. For more information, please contact zhangj@marshall.edu.
DEVELOPING A MONITORING PROTOCOL FOR THE MONKEY RIVER
WATERSHED, BELIZE, CENTRAL AMERICA

A Thesis submitted to
the Graduate College of
Marshall University

In partial fulfillment of
the requirements for the degree of
Master of Science

Biological Sciences: Watershed Resource Sciences

by
Sean Elliott Collins

Approved by

Dr. Thomas G. Jones, Ph.D., Committee Chairperson
Dr. Frank S. Gilliam, Ph.D., Committee Member
Dr. John J. Enz, Ph.D., Committee Member

Marshall University
December 2009
Acknowledgements

This thesis was funded in part by the Marshall University Graduate College through their summer thesis research grant. Dr. Tom Jones used part of his start-up monies for further funding. Other institutions played key roles in the completion of the project. The Belize Foundation for Research and Environmental Education was my home in the jungle for the many weeks of field sampling. To all of you at BFREE, many thanks! Jacob and Kelly, Judy and Dan, Tom, Marcelino, Conti, Satranino, Carolina, Salana and Maria… you all were wonderful during my time in Belize. You became like family to me. To Ya’axche Conservation Trust, thanks for your help getting all the necessary permits in order and for help brainstorming on this project. Thanks also to Toledo Institute for Development and Environment for collaboration and sharing of unpublished reports.

I could not have completed this project without the help of Manuel Zuniga from Medina Bank, Belize. Thank you for spending many hours and days with me in the bush. I certainly learned a lot from you, and I hope that you learned something from me, as well. I appreciate not only your hard work in the field but also your company during some rather demanding times.

I would also like to express thanks to my lab mates during my time as a graduate student at Marshall. Brian Bridgewater, Tyler Hern, Nathan Hoxie, Paul Hughes, Brad Musser, Casey Swecker, and Emily Vargo all played the role of peer to me during this time. To Matt Kinsey and Sean Reese, my experience at MU would not have been the same without you both. I cannot thank you two enough for everything.

To my committee go many thanks for time well-spent in offices learning from you all. I would like to thank Dr. Gilliam for all his help with the final analyses and composition of this thesis. I would also like to thank Dr. John Enz for his help in Belize, especially with macroinvertebrate identification. I just hope that I was not too bothersome during these last few months. I also have to say a special word of thanks to my advisor, Tom Jones. You have given me so many tools for my future. I hope that I can learn to put them all to good use.

I would also like to thank my family. My parents and my brother and sister-in-law are incredibly supportive. Last but certainly not least, I have to thank my fiancéé. Kelly, you are my better half. This experience was trying for both of us in many ways. I know, though, that what we have ahead of us can only be amazing.
# Table of Contents

**Title Page** ........................................................................................................... *i*

**Acknowledgements** .......................................................................................... *ii*

**Table of Contents** ............................................................................................... *iii*

**List of Figures** .................................................................................................... *iv*

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

**List of Symbols** .................................................................................................. *v*

**Abstract** ............................................................................................................... *vi*

**Chapter I – Introduction** ..................................................................................... 1

**Chapter II – Land Cover Classification** ............................................................... 5

**Chapter III – Stream Characteristics** ................................................................. 18

**Chapter IV – Discussion and Conclusion** ........................................................... 37

**Appendix A – GIS Images** .................................................................................. 41

**Appendix B – Benthic Macroinvertebrates** ......................................................... 182

**Literature Cited** .................................................................................................. 186

**Curriculum Vitae** ............................................................................................... 193
List of Figures

Figure 2.1. False color composite (bands 4, 5, 3) of Belize from Landsat ETM+ taken in 2004 .... 11

Figure 2.2. Supervised classification of Belize, Central America. This only depicts continental Belize as the barrier islands were removed from analysis ........................................ 12

Figure 2.3. Supervised classification of Monkey River watershed. Behind the clipped image is the false color composite (2004 Landsat ETM+ 4, 5, 3) of the surrounding area. This composite shows the effects of cloud cover (pink) on classification within Monkey River watershed ....... 13

Figure 2.4. Comparison between land cover of continental Belize and Monkey River watershed in southern Belize. Barrier islands and sea were removed from calculations ....................... 14

Figure 2.5. Initial dendrogram created using all six land cover types where class 1 = water, 2 = urban, 3 = savannah, 4 = banana agriculture, 5 = citrus agriculture, and 6 = broadleaf forest. Low distance between classes 2 and 4 and between classes 3 and 5 led to the combination of agriculture land cover types into one broad group ........................................ 15

Figure 2.6. Final dendrogram created using combined agriculture land cover type where 1 = water, 2 = urban, 3 = savannah, 5 = agriculture, and 6 = broadleaf forest. Combination of agriculture types lead to more distance between classes. This resulted in more accurate classification ............. 16

Figure 3.1. Political boundaries of Belize showing Monkey River watershed outlined in blue...... 29

Figure 3.2. Map showing study sites within the Monkey River watershed. Sites sampled are indicated in blue. Sites not sampled are indicated in red ................................................. 30

Figure 3.3. US EPA rapid bioassessment protocol worksheet for wadeable streams ........ 31

Figure 3.4. Explanation of inverse distance weighting (IDW) process. A. Map of B08 site showing arbitrary sample locations. Each location received a categorical substrate score. B. Map of B08 site showing interpolated substrate raster created from IDW of collected scores .......................................................... 33

Figure 3.5. Expected local stress intensity score map (Esselman and Buck 2007). Overall scores were a combination of thermal alteration, habitat alteration, flow alteration, contaminants, nutrient loading, and sedimentation scores ............................................. 34

Figure 3.6. Principle components analysis of log_{10} transformed mean values for each variable from each site ................................................................. 35
List of Tables

Table 2.1. Comparison between land cover of continental Belize and Monkey River watershed in southern Belize. Barrier islands and sea were removed from calculations ................................ 17

Table 3.1. Comparison of categorical scores from B04 site. If-then logic was applied to test for correlations between categorical scores of various categories ........................................ 36

Table 3.2 Comparison of categorical scores from B07 site. If-then logic was applied to test for correlations between categorical scores of various categories ........................................ 36

List of Symbols

BERDS – Biodiversity and Environmental Resource Data System of Belize
ELSI – Expected Local Stress Intensity
EPA – Environmental Protection Agency
ESRI – Environmental Systems Research Institute
FWPCA – Federal Water Pollution Control Act
GDP – Gross domestic product
GIS – Geographic information system
Landsat ETM+ – Landsat Enhanced Thermal Mapping Plus
LCC – Land cover classification
MMMC – Maya Mountain Marine Corridor
MSS – Multispectral scanner system
PCA – Principle components analysis
RBP – Rapid biomonitoring protocol
WVSOS – West Virginia Save Our Streams
Abstract

Developing a monitoring protocol for the Monkey River watershed, Belize, Central America

SEAN E. COLLINS. Dept. of Biological Science, Marshall University, One John Marshall Drive, Huntington, West Virginia 25755.

The study of tropical aquatic systems has been limited. Research in developing countries can be challenging due to inadequate resources and cultural variety. Generally, efforts are concentrated on developing and maintaining economic stability rather than ecological sustainability. The aim of this project was to preliminarily develop and utilize a rapid bioassessment protocol (RBP) for the Monkey River watershed in Belize by determining which metrics best described overall stream health. Like biomonitoring protocols already established for temperate systems, a regional tropical aquatic watershed monitoring program should provide information including stream and watershed health. These protocols score systems on a variety of parameters including water chemistry, land use, stream physiognomy, and biological components. Since an understanding of tropical aquatic environments cannot be gained through studying temperate systems, this project was necessary. Human impacts are an important factor in aquatic systems. Changes in land use practices in a watershed can drastically alter stream processes. The RPB used measures of basic water chemistry and stream morphometrics. The protocol included categorical assessment of biological attributes of each reach. Land cover was determined using satellite imagery and ground truth data. Results from human impact assessment, land cover determination, and the RBP were compared to show trends in the aquatic ecosystem of the Monkey River basin. Few factors measured using the RBP showed significant trends with regard to human impact. Temperature, pH, fish, and algae all showed trends with increasing human impacts. PCA showed that pH, specific conductivity, depth, and riparian zone width were important in determining differences among sites. Future studies including continuous monitoring of land use and stream ecosystems may show evidence of how land affects streams in Belize.

Keywords: biomonitoring, land cover classification, tropical stream ecology, Monkey River
CHAPTER I – INTRODUCTION

Development and utilization of watershed bioassessment protocols requires an intimate knowledge of broad scale components of biological communities and stream ecosystems. To develop an effective conservation plan, biological composition, physical structure, chemical processes, and land use must be understood and applied to the ecosystem as a whole. Biological assessment of aquatic systems has become inseparable from monitoring protocols associated with stream health. Physiognomy is also linked to overall stream condition. The study of the chemical constituents of a system can relate much information pertaining to that system. One step towards understanding of these processes is to sample multiple stream sites with variable characteristics. By measuring these characteristics and comparing them to developed standards, the creation of a rapid bioassessment protocol (RBP) for that area can begin. The benefits of RBPs are many and include cost-effectiveness, quick turn-around of results, environmentally benign procedures, and the ability to visit several sites in a single field season (Barbour et al. 1999).

The history of RBPs in the United States can be traced to the move toward cleaner water in the 1970s. Amendments to the Federal Water Pollution Control Act (FWPCA) led the US Environmental Protection Agency (EPA) to set standards for discharges into the waterways of the United States. EPA guidelines limited point source and non-point source pollution (McCall 2007). By the mid-1980s the need for cost- and time-effective monitoring protocols was realized, and the development of RBPs began (Barbour et al. 1999). Protocols from states that already monitored their streams were compiled and eventually monitoring programs of three levels (of varying intensity) were created (Barbour et al. 1999).
In West Virginia, the Save Our Streams (WVSOS) protocol is used for volunteer bioassessment. There are three WVSOS protocol levels. Level one WVSOS protocol consists of basic water quality analysis (usually including pH, temperature, and dissolved oxygen), standard physical characterization (including substrate embeddedness, sediment deposition, bank stability, riparian zone, and substrate composition using a Wolman pebble count), benthic macroinvertebrate collection using a kick net, and macroinvertebrate identification (sorting and family level identification). Advanced level WVSOS protocols include the same basic principles, but the rigor with which each task is performed is intensified. Water chemistry monitoring may include pH, temperature, dissolved oxygen, nutrients, and metals. Physical characterization includes all of the criteria above with the addition of riffle frequency, attachment sites, velocity and depth patterns, channel alteration and flow status, and vegetative protection on banks. Benthic macroinvertebrates are collected and identified to family or genus level (US EPA 1997). Level three WVSOS surveys are based on EPA’s rapid bioassessment procedures.


Global rates of tropical deforestation have reached nearly 20 million hectares per year (Bruijnzeel 1996). The change from forest to agricultural or pastoral lands can lead to net loss of carbon and nitrogen from soils (Murty 2001). Achard et al. (2002) note that the rate of tropical
deforestation is 23% lower than generally accepted. These rates are rising especially rapidly in
countries with high population and debt (Rudel and Roper 1996). Although Belize has the lowest
population density in Central America, its GDP is the lowest (Background Note: Belize 2009).
Since nitrogen and phosphorus are the limiting nutrients in most tropical systems (Downing et al.
1999), changes from tropical forest to agricultural field must be monitored because these changes
can lead to eutrophication in these systems.

Neotropical freshwater ecosystems are not well studied. In his review, Dudgeon (2000)
wrote that the biggest constraint to conservation in these areas is a current lack of information.
Unfortunately, the solution to a lack of knowledge about tropical aquatic systems is not as simple
as drawing direct correlations to what is known about temperate systems (Lewis 1987). Little is
known about the relationship in the tropics between land use and stream condition (Ometo et al.
2000). Many authors note the inadequate sampling of tropical systems and the paucity of peer-
reviewed literature on the subject (Griffith 1976, Dudgeon 2000, Boulton et al. 2008).

It is known that tropical systems have a higher annual irradiance, more intense rainfall,
warmer water, and usually distinct wet- and dry-seasons (Lewis 1987, Boulton et al. 2008).
Unlike temperate systems, daily mean air temperatures vary by as little as 5 degrees in the
tropics (Lewis 2008) which causes less variation in water temperature. Warmer water
temperatures may lead to less oxygen content available for metabolism (Lewis 2008). Tropical
benthic macroinvertebrates are not well known; identification below family level is difficult for
non-specialists (Jacobsen et al. 2008). Nutrient loads (phosphorus and nitrogen) in tropical
systems can maintain sufficient biomass of autotrophs and may not be significantly different than
nutrient loads in temperate systems (Lewis 2008). These factors make the study of tropical
systems difficult but very important.
The Maya Mountain Marine Corridor (MMMC) is a one million acre corridor that connects the Maya Mountains to the Caribbean Sea. The Monkey River makes up one of six major watersheds within the MMMC (Esselman et al. 2006). The Belize Center for Environmental Studies (1990) and Programme for Belize (1995) list this as an area with high potential for the preservation of biodiversity. Some of the current impacts on the Monkey River watershed include commercial banana, mango and citrus cultivation, timber harvesting, and aquaculture. Several villages and settlements also use the Monkey River watershed for irrigation of subsistence agriculture (crops and livestock), for subsistence fisheries, and for drinking and cooking.

Many RBPs have been developed for temperate aquatic systems, but these cannot be used as a guide with which to measure tropical systems (Lewis 1987). Conservation in any area can be impeded by a lack of knowledge (Dudgeon 2000). Since relatively little is known about tropical aquatic ecology in general, and the MMMC specifically, this is an area that could greatly benefit from studies that lead to RBP creation. Developing an RPB for the Monkey River watershed would allow scientists and volunteers to actively protect this area of ecological importance.

This thesis does not intend to lead to the immediate creation of a rapid biomonitoring protocol for southern Belize. The specific questions of this study are: (1) What metrics best describe the overall health/quality of streams in the Monkey River watershed? and (2) How does directly neighboring and upstream landscape cover types affect heterogeneity of streams in that watershed? By answering these questions, one more step can be made toward understanding some of the processes that influence aquatic system health in the Maya Mountains of Belize. I hypothesized that chemical parameters (pH and dissolved oxygen), physical characteristics (substrate composition and depth/flow regimes), and benthic macroinvertebrate diversity will
give the most complete picture of stream condition. I also think that increasing human impacts in surrounding landscapes will lead to decreasing heterogeneity within the stream.

CHAPTER II – LAND COVER CLASSIFICATION

Introduction

Remote sensing refers to the group of techniques for collecting information about an object and the object’s surroundings from a distance and without ever physically contacting the object (Lo, 1986). Remote sensing can also be described as the measurement of reflected, emitted, or backscattered electromagnetic radiation from the Earth’s surface using instruments stationed at a distance from the site of interest (Roughgarden et al. 1991, Wickland 1991). Remotely sensed data can be used to a variety of ends, but very commonly these data are used in the creation of a geographic information system (GIS) that can be easily used to display or interpret the information contained within. A GIS can be any computer-based system for the input, storage, analysis, and display of spatial information (Haines-Young et al. 1993). Remote sensing coupled with GIS is an important tool that can be used to address environmental concerns associated with the growing human population on Earth including sustainability, disease outbreak, and overall environmental health (Barrett and Curtis 1976, Pope et al. 1994).

Remotely sensed data are collected from sophisticated sensor units that act in many fashions. Scanner systems collect electromagnetic radiation in a variety of wavelengths and frequencies (Lo 1986). A multispectral scanner system (MSS) is one that has been modified such that it collects information in multiple spectral bands simultaneously. This multi-band approach has led to the development of a kind of analysis that identifies and interprets spectral signatures. Spectral signatures are developed for unique features, and these signatures can be used to
differentiate between features (Lo 1986). Data collected from MSS can be used to separate land cover or feature types such as water, soil, and many types of vegetation.

Land cover is an important variable that plays a role in the relationship between human and physical environments (Foody 2002). Land cover has been called the single most important variable of global change affecting ecological systems (Vitousek 1994). Land cover classification (LCC) uses multivariate statistics to transform multispectral imagery into rasters containing thematic categories. LCC has been performed at every scale from local to continental based upon analysis of spectral signatures of various feature types (Nemani and Running 1997). There are two pathways by which LCC can be achieved, and these are supervised or unsupervised classification. Unsupervised classification defines feature types simply based on spectral similarity. The benefit of unsupervised classification is that it can be performed without ever visiting the area of interest. A downfall to this type of classification is that ground truth data are lacking, and the resulting image may not be accurate. Supervised classification defines feature types based on their spectral similarity to predefined classes. Supervised classification requires information about the area in the form of ground truth data before the classification is begun. Ground truth data are used to create spectral signatures for feature types of interest. Another benefit to supervised classification is the production of a dendrogram to quickly assess the accuracy of the signature file. Dendrograms provide a clear, succinct summary of various features of a mean similarity matrix (Van Sickle 1997). For both classification methods, software calculates statistics for a set of raster datasets (i.e. multiple bands from a multispectral image). LCC does have limitations including inaccurate classification of imagery containing cloud cover. Spectral signatures for some classes may remain very similar depending on which bands are chosen for analysis.
The goal of this project was to define various land cover classes for the Monkey River watershed in the Toledo District in Belize, Central America based on multispectral and ground truth data. A secondary goal was to determine overall percent composition of those classes nationwide and within the Monkey River watershed. Classes chosen were water, urban, pine savannah, agriculture (banana and citrus), and broadleaf forest.

Methods

Study Area

The Monkey River watershed is a 1275 km$^2$ basin in the Toledo District of southeastern Belize, Central America. It is bordered to the west by the Maya Mountains and drains into the Caribbean Sea to the east. This watershed is part of the Maya Mountain Marine Corridor (MMMC). The Monkey River basin represents the 4$^{th}$-largest in Belize and the 2$^{nd}$-largest in the Maya Mountains. The watershed is named for the Monkey River, and it contains 3 branches (Bladen, Swasey and Trio). When the Monkey River enters the sea it is a 6$^{th}$ order stream. The headwaters of the Monkey River flow from undisturbed, and in some cases, virgin tropical broadleaf forest. These headwaters are also protected by 3 contiguous national reserves. In the coastal plains region the rivers travel through anthropogenically influenced landscape types including subsistence agriculture, commercial citrus and banana plantations and gravel mining. Large portions of the coastal plains region remain undeveloped (Heyman and Kjerfve 1999).

The Monkey River watershed receives $>3000$ mm of precipitation annually; rainfall events are most common during the distinct wet season with little or no rain falling in the dry season. The wet season occurs from July to October; during this time river discharges account for $\sim84\%$ of the annual total (Heyman and Kjerfve 1999). The dry season is characterized by stable base-flow conditions in the rivers.
The geologies of the headwaters of the Monkey River are composed of two distinct groupings. The first, the Santa Rosa Group, is dominantly composed of sedimentary rock of various metamorphic stages with some granite intrusions (Bateson and Hall 1977). This group makes up roughly 80% of the total area of the Maya Mountains. Headwaters of the Swasey and Trio Rivers drain these geologies. The second group consists of lavas and associated volcanic sediments which adjoin areas of Cretaceous karstic limestone (Bateson and Hall 1977). This group, the Bladen Volcanic Group, is uncharacteristic in the Maya Mountains and may confer differences in sites located in the headwaters of the Bladen River.

Satellite Imagery

I obtained remotely sensed raster data (Landsat ETM+) from 2004 through the Biodiversity and Environmental Resource Data System of Belize (BERDS 2009). These data were imported into ArcMap 9.2 (ESRI 2006). I used bands 4, 5 and 3, (0.76 - 0.90 μm, 1.55 - 1.75 μm, 0.61 - 0.69 μm, respectively) to create a false color composite image of the study area (Fig. 2.1). This composite was used to differentiate between vegetation to classify land cover types within the watershed. Band 4 (near-infrared) showed high reflectance in healthy vegetation. Band 5 (mid-infrared) was used to assess moisture content of vegetation. This band also contains agricultural information because of differences in soil moisture. Band 3 (red) was used to distinguish between vegetation types based on chlorophyll absorption. In this 4, 5, 3 band combination, inland lakes and streams were more easily identified.

Land Cover Classification

A supervised classification was performed using the multivariate package in ArcMap 9.2. First, I created a training site signature file. This file used ground truth data from several locations in Belize sampled between April and May 2009 to describe 6 types of land cover
(water, urban, banana agriculture, citrus agriculture, savannah, and broadleaf forest). From this signature file, multivariate statistics within ArcMap 9.2 determined average pixel values for each land cover type. I created a class dendrogram to visually interpret differences between classes. Classes that are very close together must be combined or a new signature file can be created to produce more specific results. Based on the dendrogram analysis, I reduced the total number of classes to 5, combining both agriculture types. I performed maximum likelihood classification on the raster dataset using the signature file.

**Results and Discussion**

Supervised classification was performed for Belize (Fig. 2.2). Land cover was classified as water, urban areas, pine savannah, agriculture, or broadleaf forest. Extraction of the classified raster for Belize led to the creation of the Monkey River watershed classified image (Fig. 2.3). Percent cover for each class was also determined both for continental Belize and for the Monkey River watershed (Table 2.1, Fig. 2.4).

The false color composite (band 4, 5, 3) can be used to easily distinguish vegetation from other feature types such as urban areas or water. Multiple vegetation types become more difficult to separate, especially similar vegetation types as found in banana and citrus plantations. Broadleaf forest separates from pine savannah and agriculture much more easily than the latter two separate from each other. Broadleaf forest makes up a majority of land cover both in Belize in general and in the Monkey River watershed specifically (Table 2.1, Fig. 2.4). Interpretation of the initial class dendrogram (Fig. 2.5) which contained both agriculture types separately led to the combination of citrus and banana agriculture types into one class. Class groupings with distance separations < 2 were combined. Urban areas were close to banana farms because of similar spectral signatures. This is probably because urban areas have mostly dirt or
gravel paving and thatch roof buildings. Citrus plantations were similar to savannahs because of sparse tree cover and lowland shrubs. After banana plantations and citrus plantations were combined for the overall LCC, the resulting dendrogram showed a much more distinct separation (Fig. 2.6). Differentiating between agriculture types was not possible with this level of classification.

For both the continental classification and the extracted Monkey River watershed, cloud cover resulted in some misleading classification. For example, within the Monkey River watershed the Bladen Nature Reserve comprises >100,000 acres in the southwest headwaters of the watershed. This reserve is pristine, undisturbed broadleaf forest. The raster shows some urban, savannah, and agriculture land cover types within this region of the watershed. These areas were misclassified because of cloud cover in the original MSS data. Cloud cover could be used as a potential classification type. Any areas classified as cloud could be removed from further analysis. This may alleviate errors due to misclassification of feature types.

Classification errors often lead to the assumption that derived land cover maps are of insufficient quality for many applications (Foody 2002). Derived maps have often been judged against reference data sets showing disagreements between the two (Smedes 1975, Congalton 1991). Foody (2002) states that of all items depicted on maps, land cover changes most rapidly. Even with the most recent multispectral data and with no classification errors, land cover classification may be unreliable simply because of the rapid rate of change. To strengthen land cover classification maps, classification accuracy assessment is a widely accepted component of these investigations (Congalton 1994, Merchant et al. 1994, Cohen and Justice 1999, Cihlar 2000, Justice et al. 2000). Classification accuracy assessment was not available for this project because of the lack of data available from the Forestry Department of Belize.
Figure 2.1. False color composite (bands 4, 5, 3) of Belize from Landsat ETM+ taken in 2004.
Figure 2.2. Supervised classification of Belize, Central America. This only depicts continental Belize as the barrier islands were removed from analysis.
Figure 2.3. Supervised classification of Monkey River watershed. Behind the clipped image is the false color composite (2004 Landsat ETM+ 4, 5, 3) of the surrounding area. This composite shows the effects of cloud cover (pink) on classification within Monkey River watershed.
Figure 2.4. Comparison between land cover of continental Belize and Monkey River watershed in southern Belize. Barrier islands and sea were removed from calculations.
Figure 2.5. Initial dendrogram created using all six land cover types where class 1 = water, 2 = urban, 3 = savannah, 4 = banana agriculture, 5 = citrus agriculture, and 6 = broadleaf forest. Low distance between classes 2 and 4 and between classes 3 and 5 led to the combination of agriculture land cover types into one broad group.
Figure 2.6. Final dendrogram created using combined agriculture land cover type where 1 = water, 2 = urban, 3 = savannah, 5 = agriculture, and 6 = broadleaf forest. Combination of agriculture types lead to more distance between classes. This resulted in more accurate classification.
Table 2.1. Comparison between land cover of continental Belize and Monkey River watershed in southern Belize. Barrier islands and sea were removed from calculations.

<table>
<thead>
<tr>
<th>Land Cover</th>
<th>Belize (%)</th>
<th>Monkey River (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>1.8</td>
<td>1.4</td>
</tr>
<tr>
<td>Urban</td>
<td>7.5</td>
<td>3.3</td>
</tr>
<tr>
<td>Savannah</td>
<td>9.9</td>
<td>7.1</td>
</tr>
<tr>
<td>Agriculture</td>
<td>16.5</td>
<td>18.5</td>
</tr>
<tr>
<td>Forest</td>
<td>64.4</td>
<td>69.7</td>
</tr>
</tbody>
</table>
CHAPTER III – STREAM CHARACTERISTICS

Introduction

Neotropical freshwater ecosystems are not well studied. In his review, Dudgeon (2000) concluded that the biggest constraint to conservation is a current lack of information. Unfortunately, the solution to this is not as simple as drawing direct correlations to what is known about temperate systems (Lewis 1987). Many authors note the inadequate sampling of tropical systems and the paucity of peer-reviewed literature on the subject (Griffith 1976, Dudgeon 2000). Little is known about the relationship in the tropics between land use and stream condition (Ometo et al. 2000). Human impacts on aquatic systems can be severe. Water chemistry can be greatly affected by land use (Peierls et al. 1991, Hunsaker and Levine 1995, Puckett 1995, Howarth et al. 1996, Allan et al. 1997). Land use also affects biotic components of rivers (Allan and Flecker 1993, Richards et al. 1996). Allan (2004) notes streams are influenced by surrounding land use at multiple scales. Burcher et al. (2007) describe the potential for upstream land cover to greatly influence hydrodynamic processes downstream as part of what they called the land cover cascade. Studies within specific areas in the tropics could lead to a broader understanding of processes in tropical ecology. The Maya Mountain Marine Corridor (MMMC) is a region in southern Belize recognized for its high conservation value and potential for preservation of biodiversity and critical habitats (BCES 1990, Heyman et al. 1995, Programme for Belize 1995).

The goal of this project was to characterize several sites within the Monkey River watershed on the basis of chemical, physical, and biological components. These sites were compared to one another, and site scores were compared to human impact. Human impacts were Expected Local Stress Intensity (ELSI) scores derived from Esselman and Buck (2007).
Methods

Study area

The Monkey River watershed is a 1275 km² basin in southeastern Belize (Fig. 3.1). It is bordered to the west by the Maya Mountains and drains into the Caribbean Sea to the east. This watershed is part of the Maya Mountain Marine Corridor (MMMC). The watershed is named for the Monkey River and contains its 3 branches (Bladen, Swasey and Trio). When the Monkey River enters the sea it is a 6th order stream. The headwaters of the Monkey River flow from undisturbed, and in some cases, virgin tropical broadleaf forest. These headwaters are also protected by 3 contiguous national reserves. In the coastal plains region the rivers travel through anthropogenically influenced landscape types including subsistence agriculture, commercial banana plantations and gravel mining. Large portions of the coastal plains region remain undeveloped (Heyman and Kjerfve 1999).

The Monkey River watershed receives >3000 mm of precipitation annually; rainfall events are most common during the distinct wet season with little or no rain falling in the dry season. The wet season occurs from July to October; during this time river discharges account for ~84% of the annual total (Heyman and Kjerfve 1999). The dry season is characterized by stable base-flow conditions in the rivers.

A random sample of 30 sites was selected from >4th order streams (Fig. 3.2). To do this, four major rivers (Bladen, Monkey, Swasey, and Trio) that make up the watershed were identified. Each major river was measured to determine its proportional length with regard to total stream length within the watershed. Each river was subdivided into 1 km segments. Each segment was numbered, and a random number generator was used to select a proportional number of sites from each major river. Due to remoteness of upper river reaches, sites > 10 km
from the nearest road were not included at the time of site selection. Sites were visited once between April and May 2009 during base-flow conditions.

Sampling methods

Sampling of chemical and physical characteristics was adapted from Esselman et al. (2006). Basic water chemistry including temperature, pH, dissolved oxygen and specific conductivity was determined once per sample site using a Hach SensIon 156 portable multiparameter meter. Water chemistry data were taken at the top of each study site at the beginning of each sampling event. Each sample reach was approximately 200 m long. Along the left descending bank of each reach at 11 points spaced about 20 m apart, physical measurements were recorded. These included wetted perimeter width, bankful width, canopy cover, canopy height, and approximate width of riparian zone. All these data were measured using a Nikon laser range finder. Greatest possible riparian zone width was 18 m due to inability to accurately measure greater distances. At 45 arbitrarily selected points along the sample reach, several physical criteria were recorded. Substrate particle type was recorded by size (Wentworth 1922) and depth was determined using a meter stick. This value was estimated for depths >1 m. Stream velocity (m/s) was calculated at 60% depth using a Marsh-McBirney FloMate.

At each arbitrary point several categorical scores were given for several metrics. These scores were assessed using a snorkel mask and looking in four directions (upstream, downstream, left, and right) at each point. Fish abundance was scored using an ordinal metric where 0 = no fish, 1 = one individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals. Each arbitrary point received a fish abundance score. Field identification of fishes was also performed where possible to gather community composition information. All species present could not be identified and accounted for at any site. For these reasons, these generated
data represent the common species within the assemblage. Backpack electrofishing was not used because of gear limitations, and it is not a low-cost technique. At each point, snails were also scored using the same metric as above (0 = no snails, 1 = one individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20). Algae and macrophyte abundances were also recorded by visual survey depending on percent coverage (0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage). These metrics were chosen to represent the biological components of the river.

Benthic macroinvertebrates were collected with the MACS protocol (Lenat 1988) using a 0.25 m² kick net at 8 sites per reach. Kicks were performed at different habitat types based on proportion of that habitat type within the reach. All specimens were preserved in approximately 70% alcohol. Benthic macroinvertebrates were identified to family level using Merrit and Cummins (1997). Several metric scores were determined for each sample reach including total taxa, EPT taxa, biotic abundance, percent EPT, percent dominant, percent tolerant, percent chironomidae, and percent hydropsychidae.

The US EPA rapid bioassessment protocol (RBP) for wadeable streams was used to give individual categorical scores and a composite score for each site (Barbour et al. 1999). Categories included epifaunal substrate cover, pool substrate, pool variability, sediment deposition, channel flow status, channel alteration, channel sinuosity, bank stability, bank vegetation, and riparian zone width. Scores from 1-20 were given for each category and all categories were summed for a final score (Fig. 3.3).

GIS Analysis

For each site images were created with ArcMap 9.2 (ESRI 2006) using inverse distance weighting (IDW) for each recorded characteristic. IDW is a technique that interpolates a surface
based on known points. Any unknown points on the raster are calculated using values from the 16 nearest neighbor values (Fig. 3.4). Algae, depth, fish, macrophytes, snails, substrate, and velocity measurements were used to create these IDWs. A mask was created for each reach using wetted perimeter width from each of the 11 points taken on the left descending bank. The mask was used to clip each IDW to show only those interpolated values within the sample reach. IDWs from two randomly selected sites were compared to show trends (i.e. depth versus velocity, fish abundance versus substrate, etc.). Boolean logic was applied to show correlations between categorical variables at each of these sites. Any areas where scores overlapped between the two compared rasters received a 1 where areas that did not have overlapping scores received a 0. All areas with a 1 were considered a match. Percentage of matching data for each comparison was calculated to show strength of correlation between compared data types.

Statistical Analysis

Mean values (μ) for all data recorded for each site were calculated. Standard deviation (σ) was also calculated for each variable. Spatial heterogeneity was measured by determining coefficient of variation (c_v). Changes in mean could be seen by calculating c_v. Means were calculated for all data that fell into each human impact score category for each variable (i.e. all substrate scores that fell into 0 impact scores). Sites were given human impact scores based on expected local stress intensity (ELSI) scores (Fig 3.5). Mean and c_v were tested against ELSI human impact scores using regression analysis. In this way, patterns in stream composition and heterogeneity were tested against human impact. Significance was determined at p < 0.1 because of the low number of dependent variable (ELSI score) categories.

Principle components analysis (PCA) was performed on log_{10} transformed mean values to show any correlations within sampled data (ter Braak 1987). This analysis attempts to reduce
the degree of duplication or correlation in a dataset by finding highly correlated combinations of factors. Each combination is called a component. These components are represented in the two axes of the PCA output. Any sites which are grouped closely together are similar, whereas sites which are far apart are relatively dissimilar. Factors are represented by lines in the PCA ordination. The line length is a measure of importance of the value. The line direction also can be used to draw conclusions based on where sites are relative to the line. PCA was performed using μ for all measured variables at each site including temperature, pH, specific conductivity, depth, bankful width, wetted perimeter width, velocity, macrophyte abundance, algae abundance, riparian zone width, snail abundance, fish abundance, substrate, RBP score, and canopy height. A log(10) transformation was used because of the large range of values especially with regard to water chemistry data. Follow up t-tests were used to determine statistically significant differences between variables based on analysis of PCA.

Backward stepwise linear regression (Analytical Software 2000) was also used for model selection. This technique uses all collected data to draw correlations. All data are tested against a dependent variable. In the first round, any data that do not show a significant trend are removed. The second round starts without data that have been removed. Again, data that are not significant are removed. This continues until only significant data remain. In this case, ELSI score was the dependent variable. Independent variables were algae abundance, bank stability, bank vegetation, bankful width, channel alteration, channel flow, channel sinuosity, canopy height, distance from the mouth, depth, epifaunal substrate, fish, macrophyte abundance, number of Ephemeroptera, Plecoptera, and Tricoptera (EPT) taxa, total taxa, percent Chironomidae, percent EPT, percent Hydropsychidae, percent dominant taxa, percent tolerant taxa, overall macroinvertebrate score,
pool substrate, pool variability, RBP score, riparian zone, sediment deposition, snail abundance, specific conductivity, temperature, pH, substrate, velocity, and wetted perimeter width.

**Results**

**GIS Analysis**

Inverse distance weighting was performed for all data at each site (see Appendix A). Boolean logic was applied to test if any correlations existed between measured and categorical data. Reclassified images were compared using “equal to” tool in ArcMap. Any areas of the two compared rasters that had the same categorical scores were said to be a “match.” Areas that had unequal categorical scores were “no match.” At B04 site, when algae score was compared against snail score or fish score, there was less than 1% matched data (Table 3.1). When macrophyte score was compared to snail score there, was only 0.68% match; when macrophyte score was compared with fish score, there was a > 90% correlation (Table 3.1). For B07 site, algae scores were compared against snails scores showing less than 1% correlation between categorical scores (Table 3.2). Macrophyte scores were compared against fish scores with less than 2% correlation between scores (Table 3.2). Algae scores were compared against fish scores with a 43.69% correlation (Table 3.2). Macrophyte scores were compared against snail scores showing greater than 90% correlation between scores and categories (Table 3.2). Please see Appendix A for all figures.

**Statistical Analysis**

Linear regression analysis of mean values for all measured variables tested against ELSI scores showed some trends in the data. Water chemistry data had variable fit to linear trend lines. There were no significant trends in specific conductivity or dissolved oxygen. Both showed $r^2 < 0.2$ and $p > 0.4$ with values appearing to decrease as human impact increased. Temperature
increased \( (r^2 = 0.66, p = 0.09) \) and pH decreased \( (r^2 = 0.65, p = 0.09) \) as human impact increased. There were also negative trends in fish abundance \( (r^2 = 0.68, p = 0.08) \) and algae \( (r^2 = 0.80, p = 0.04) \). RBP scores showed a weak trend toward decreasing scores as human impact increased \( (r^2 = 0.50, p = 0.18) \). Benthic macroinvertebrates from each site were identified to family level, and sites were scored using the WVSOS index (see Appendix B). These data were also used for regression analysis. Using a quadratic trend line \( (r^2 = 0.83) \), WVSOS scores showed a bi-modal best fit with lowest scores at sites where human impact scores were 2. Using Pearson product-moment critical values table, this value was significant at \( p = 0.1 \) (3 d.f.). Means for other measured and categorical data showed either no linear trend or very weak downward trends as human impact scores increased. For these data \( r^2 \leq 0.50 \) and \( p > 0.2 \).

Coefficient of variation was also plotted against human impact scores to show trends in variation versus impact. No variables had statistically significant relationships. Linear regression of variation in algae, snails, and depth versus ELSI score showed weak trends \( (r^2 = 0.08, 0.32, \) and \( 0.35 \) respectively) with algae and depth seeming to decrease and snails seeming to increase as impact scores increased. Variation in velocity showed a linear fit against impact \( (r^2 = 0.60) \) decreasing as ELSI score increased. Variation in substrate and fish score showed bi-modal fit \( (r^2 = 0.56 \) and \( 0.59, \) respectively) increasing toward ELSI scores of 2 and 3 and decreasing at either end. Variation in macrophyte score had the best fit \( (r^2 = 0.71) \) decreasing as impact increased, although it was also not statistically significant.

Specific conductivity and pH were important in describing spatial heterogeneity at all sampled sites based on principle components analysis (PCA). Riparian zone width, fish score, snail score, RBP score, and canopy height were other important factors in determining
similarities and differences between sites. Groups of sample reaches (Swasey group and Bladen group) were also apparent based on PCA (Fig. 3.4).

**Discussion**

Two sites were randomly chosen to compare categorical scores between categories (i.e. macrophyte versus fish, algae versus snails) and to demonstrate the application of “equal to” tool. I showed that by using “equal to” in the ArcMap toolbox categorical scores could be compared between rasters that were created for a site. Comparisons using this tool for rasters at B07 site showed very weak correlation among some categories (algae versus snails, macrophyte versus fish) but very strong relationships between others (macrophyte versus snails). These relationships reflect the variability of scores at B07 site. At B04 site, highly “matched” data were only found in the macrophyte versus fish comparison. All other comparisons at B04 site showed > 99% “no match” data. This suggests that while categorical scores can be compared using this tool, they must be compared on a site-by-site basis. The benefit of this method is that the data are spatially explicit. Fish could be related to algae at a particular place, and other influencing factors at that location could be further studied. This would allow researchers to study relationships between herbivory of algae by fish at a local scale while understanding spatial relationships between these factors.

Linear regression analysis of mean versus ELSI score showed that some categories had significant trends when compared to human impact score. Water temperature increased and pH decreased as ELSI score increased. Water chemistry is known to be affected by human impacts (Peierls *et al.* 1991, Hunsaker and Levine 1995, Puckett 1995, Howarth *et al.* 1996, Allan *et al.* 1997), however some argue that resource management is too focused on water chemistry (Karr 1995). It is also known that biotic factors are influenced by anthropogenic impacts (Allan and
In this study, fish and algae abundance both decreased as impact increased. Karr and Chu (2000) conclude that biotic indicators may be more valuable because they can integrate many physiochemical factors over long periods of time. These trends show that human actions influence both stream chemistry and biotic composition.

Linear regression analysis of $c_v$ against human impact scores showed that there were no statistically significant trends between ELSI score and variation in any measured variable. Variation in some categories seemed to have well-fit trend lines (velocity, depth, and substrate), but no $p$-values were < 0.1. In other categories, there were no apparent trends. Although it is known that human disturbances can affect both water chemistry (Peierls et al. 1991, Hunsaker and Levine 1995, Puckett 1995, Howarth et al. 1996, Allan et al. 1997) and biology within a stream (Allan and Flecker 1993, Richards et al. 1996), this study does not support that overall variation within a stream is positively or negatively influenced by impact.

Depth was one of the most important factors determining similarities and differences among sites (Fig 3.3). Even in relatively pristine watersheds, stream diversions can result in decreased flow velocity and water depth, reducing habitat availability (Brasher 2003). Although water temperature was not one of the most important factors from PCA for mean site data, some sites seemed to separate from one another based on this variable. Sites on Swasey Branch (S01, S02, S03, S07) clustered opposite to a group of sites from Bladen Branch (B01, B02, B03, B04) with regard to temperature and algae. Temperature data were not significantly different between Swasey and Bladen sites ($p = 0.49$), but algae scores were with higher algae scores at Bladen sites ($p = 0.09$). There were significantly higher ELSI scores at the Swasey sites ($p < 0.01$). It is known that stream temperature is affected by modified riparian vegetation and channel morphology (Poole and Berman 2001). Riparian vegetation and canopy height were not
significantly different at the Swasey or Bladen sites ($p = 0.35, 0.69$). There were no significant differences between Swasey or Bladen sites with regard to channel flow, sinuosity, or alteration. The increase in temperature could be the result of other influences.

The analysis using backward stepwise linear regression showed that channel sinuosity, percent tolerant taxa (macroinvertebrates), and riparian zone width produced the best model:

$$Impact = 4.41 + 0.15(channel\ sinuosity) - 0.01(percent\ tolerant\ taxa) - 0.65(riparian\ zone)$$

The overall $r^2 = 0.91$ for this model. This is a very good fit for the data. Channel sinuosity may be affected by site distance to the mouth of the river, however ELSI scores were not related to distance. The analysis of macroinvertebrate communities is still an important step in determining overall stream health. Riparian zone width also plays an important role in the final model.

It is not completely supported by this work, but it is known that human actions disrupt vital processes that maintain rivers and their associated biota and frequently lead to habitat that is degraded and less heterogeneous (Allan 2004). There were significant trends in temperature, pH, algae, and fish when plotted against ELSI scores. These were also some of the factors that were most important in describing variation based on PCA. However, there were no significant trends in variation in stream properties versus human impact.
Figure 3.1. Political boundaries of Belize showing Monkey River watershed outlined in blue.
Figure 3.2. Map showing study sites within the Monkey River watershed. Sites sampled are indicated in blue. Sites not sampled are indicated in red.
<table>
<thead>
<tr>
<th>Habitat Parameter</th>
<th>Optimal</th>
<th>Suboptimal</th>
<th>Marginal</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Epifaunal Substrate/Available Cover</td>
<td>Greater than 70% of substrate favorable for epifaunal colonization and fish cover; mix of unconsolidated, submerged logs, undercut banks, cobbles or other stable habitat and at stage to allow full colonization potential (i.e., logs/nests that are not new fall and not transients).</td>
<td>40-70% mix of stable habitat: well-suited for full colonization potential, adequate habitat for maintenance of populations: presence of additional substrate (in the form of newfall), but not yet prepared for colonization (may rate at high end of scale).</td>
<td>20-40% mix of stable habitat: habitat availability less than desirable; substrate frequently disturbed or removed.</td>
<td>Less than 20% stable habitat: lack of habitat is obvious; substrate unstable or lacking.</td>
</tr>
<tr>
<td>SCORE</td>
<td>20 19 18 17 16</td>
<td>15 14 13 12 11</td>
<td>10 9 8 7 6</td>
<td>5 4 3 2 1 0</td>
</tr>
<tr>
<td>2. Embeddedness</td>
<td>Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment. Layering of cobbles provides diversity of niche space.</td>
<td>Gravel, cobble, and boulder particles are 25-50% surrounded by fine sediment.</td>
<td>Gravel, cobble, and boulder particles are 50-75% surrounded by fine sediment.</td>
<td>Gravel, cobble, and boulder particles are more than 75% surrounded by fine sediment.</td>
</tr>
<tr>
<td>SCORE</td>
<td>20 19 18 17 16</td>
<td>15 14 13 12 11</td>
<td>10 9 8 7 6</td>
<td>5 4 3 2 1 0</td>
</tr>
<tr>
<td>3. Velocity/Depth Regime</td>
<td>All four velocity/depth regimes present (slow-deep, slow-shallow, fast-deep, fast-shallow). (Slow is &lt; 0.3 m/s, deep is &gt; 0.5 m)</td>
<td>Only 3 of the 4 regimes present (if fast-shallow is missing, score lower than if missing other regimes).</td>
<td>Only 2 of the 4 habitat regimes present (if fast-shallow or slow-shallow are missing, score low).</td>
<td>Dominated by 1 velocity/depth regime (actually slow-deep).</td>
</tr>
<tr>
<td>SCORE</td>
<td>20 19 18 17 16</td>
<td>15 14 13 12 11</td>
<td>10 9 8 7 6</td>
<td>5 4 3 2 1 0</td>
</tr>
<tr>
<td>4. Sediment Deposition</td>
<td>Little or no enlargement of islands or point bars and less than 5% of the bottom affected by sediment deposition.</td>
<td>Some new increase in bar formation, mostly from gravel, sand or finesediment; 5-30% of the bottom affected; slight deposition in pools.</td>
<td>Moderate deposition of new gravel, sand or finesediment on old and new bars; 30-50% of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.</td>
<td>Heavy deposits of fine material, increased bar development, more than 50% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.</td>
</tr>
<tr>
<td>SCORE</td>
<td>20 19 18 17 16</td>
<td>15 14 13 12 11</td>
<td>10 9 8 7 6</td>
<td>5 4 3 2 1 0</td>
</tr>
<tr>
<td>5. Channel Flow Status</td>
<td>Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.</td>
<td>Water fills &gt;75% of the available channel, or &gt;25% of channel substrate is exposed.</td>
<td>Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.</td>
<td>Very little water in channel and mostly present as standing pools.</td>
</tr>
<tr>
<td>SCORE</td>
<td>20 19 18 17 16</td>
<td>15 14 13 12 11</td>
<td>10 9 8 7 6</td>
<td>5 4 3 2 1 0</td>
</tr>
</tbody>
</table>

Figure 3.3. US EPA rapid bioassessment protocol worksheet for wadeable streams.
<table>
<thead>
<tr>
<th>Habitat Parameter</th>
<th>Optimal</th>
<th>Suboptimal</th>
<th>Marginal</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. Channel Alteration</td>
<td>Channelization or dredging absent or minimal; stream with normal pattern.</td>
<td>Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging (greater than past 20%) may be present, but recent channelization is not present.</td>
<td>Channelization may be extensive; embankments or housing structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.</td>
<td>Banks cleared with gabions or concrete; over 80% of the stream reach channelized and disrupted. Invasive habitat greatly degraded or removed entirely.</td>
</tr>
<tr>
<td>SCORE</td>
<td>20 19 18 17 16</td>
<td>15 14 13 12 11</td>
<td>10 9 8 7 6</td>
<td>5 4 3 2 1 0</td>
</tr>
<tr>
<td>7. Frequency of Riffles (or bends)</td>
<td>Occurrence of riffles relatively frequent; ratio of distance between riffles divided by width of the stream divided by 2 to 5; variety of habitats is key. In streams where riffles are continuous, placement of boulders or other large, natural obstruction is important.</td>
<td>Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 to 15.</td>
<td>Occasional riffle or bend; bottoms contain some habitat, distance between riffles divided by the width of the stream is between 25 to 50.</td>
<td>Generally flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is a ratio of &gt;25.</td>
</tr>
<tr>
<td>SCORE</td>
<td>20 19 18 17 16</td>
<td>15 14 13 12 11</td>
<td>10 9 8 7 6</td>
<td>5 4 3 2 1 0</td>
</tr>
<tr>
<td>8. Bank Stability (score each bank)</td>
<td>Banks: stable evidence of erosion or bank failure absent or minimal; little potential for future problems. &lt;5% of bank affected.</td>
<td>Moderately stable; occasional small areas of erosion mostly bared over; 5-30% of bank as reaching areas of erosion.</td>
<td>Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.</td>
<td>Very eroded; many eroded areas; very frequent along straight sections and bends; obvious bank sloughing; 50-100% of bank has bank erosion or erosion.</td>
</tr>
<tr>
<td>Left Bank</td>
<td>10 9 8 7 6 5 4 3 2 1 0</td>
<td>10 9 8 7 6 5 4 3 2 1 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Bank</td>
<td>10 9 8 7 6 5 4 3 2 1 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Vegetative Protection (score each bank)</td>
<td>More than 90% of the streambank surface and immediate riparian zone covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetation absent or minimal or not evident; almost all plants allowed to grow naturally.</td>
<td>50-90% of the streambank surface covered by native vegetation, but one class of plants is not well represented; disruption evident but not affecting full growth potential to any great extent; more than one-half of the potential plant stable height remaining.</td>
<td>50-70% of the streambank surface covered by vegetation; disruption obvious; patches of bare soil or clumped vegetation common; less than one-half of the potential plant stable height remaining.</td>
<td>Less than 50% of the streambank surface covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stable height.</td>
</tr>
<tr>
<td>Left Bank</td>
<td>10 9 8 7 6 5 4 3 2 1 0</td>
<td>10 9 8 7 6 5 4 3 2 1 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Bank</td>
<td>10 9 8 7 6 5 4 3 2 1 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Riparian Vegetative Zone Width (score each bank riparian zone)</td>
<td>Width of riparian zone &gt;15 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, drains, or crops) have not impacted zone minimally.</td>
<td>Width of riparian zone 12-15 meters; human activities have impacted zone only minimally.</td>
<td>Width of riparian zone 6-12 meters; human activities have impacted zone a great deal.</td>
<td>Width of riparian zone &lt;6 meters; little or no riparian vegetation due to human activities.</td>
</tr>
<tr>
<td>Left Bank</td>
<td>10 9 8 7 6 5 4 3 2 1 0</td>
<td>10 9 8 7 6 5 4 3 2 1 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Bank</td>
<td>10 9 8 7 6 5 4 3 2 1 0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.3 (cont.). US EPA rapid bioassessment protocol worksheet for wadeable streams.
Figure 3.4. Explanation of inverse distance weighting (IDW) process. A. Map of B08 site showing arbitrary sample locations. Each location received a categorical substrate score. B. Map of B08 site showing interpolated substrate raster created from IDW of collected scores.
Figure 3.5. Expected local stress intensity score map (Esselman and Buck 2007). Overall scores were a combination of thermal alteration, habitat alteration, flow alteration, contaminants, nutrient loading, and sedimentation scores.
Figure 3.6. Principle components analysis of $\log_{10}$ transformed mean values for each variable from each site.
Table 3.1. Comparison of categorical scores from B04 site. If-then logic was applied to test for correlations between categorical scores and various categories.

<table>
<thead>
<tr>
<th>Category</th>
<th>No Match</th>
<th>Match</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algae/Snails</td>
<td>99.76</td>
<td>0.24</td>
</tr>
<tr>
<td>Macro/Fish</td>
<td>3.55</td>
<td>96.45</td>
</tr>
<tr>
<td>Algae/Fish</td>
<td>99.97</td>
<td>0.03</td>
</tr>
<tr>
<td>Macro/Snails</td>
<td>99.32</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Table 3.2. Comparison of categorical scores from B07 site. If-then logic was applied to test for correlations between categorical scores and various categories.

<table>
<thead>
<tr>
<th>Category</th>
<th>No Match</th>
<th>Match</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algae/Snails</td>
<td>99.87</td>
<td>0.13</td>
</tr>
<tr>
<td>Macro/Fish</td>
<td>98.65</td>
<td>1.35</td>
</tr>
<tr>
<td>Algae/Fish</td>
<td>56.31</td>
<td>43.69</td>
</tr>
<tr>
<td>Macro/Snails</td>
<td>5.15</td>
<td>94.85</td>
</tr>
</tbody>
</table>
CHAPTER IV – DISCUSSION AND CONCLUSION

Systems can be studied remotely with data logging instruments. These instruments can collect data from afar and transmit data directly to researchers. I used remotely sensed data from Landsat ETM+ to describe landscape features for the country of Belize. I narrowed our study area to the Monkey River basin in the Toledo district in the southern part of the country. By looking at these data and the processed results, I gained a better understanding of the make up of the country and the watershed. The Monkey River watershed is very similar in land cover type and percent composition to the rest of the country of Belize. The Monkey River watershed has slightly higher forest cover and slightly lower urban area cover than the rest of the country. Aquatics can also be studied in the field. Data collection can take place within the stream. I applied these concepts for this project, as well. Important features within the watershed were revealed, and significant trends with regard to current human impacts were identified. The major components of the model created using backward stepwise linear regression were channel sinuosity, percent tolerant taxa, and riparian zone width. These factors indicate that streams need to be studied on different levels. The landscape surrounding a stream and the organisms within it play important roles in determining overall health. I also looked toward correlations between categorical scores by comparing rasters using digital image processing. This thesis examined stream ecology on a landscape scale with remotely sensed and satellite imagery as well as on a much smaller scale with water chemistry and stream morphometrics. Through this study, I gained better idea of the overall condition of the Monkey River watershed.

Streams are uniquely tied to the surrounding landscapes. Changes in landscape or land use can lead to drastic changes in overall stream processes (Allan 2004, Burcher et al. 2007). Water chemistry can be influenced by surrounding land cover change at a variety of scales and in

Biological components can also be changed due to changes in land use within a watershed (Allan and Flecker 1993, Richards et al. 1996). The land cover for the Monkey River basin is very similar to that of the rest of Belize. In Chapter II, I see that overall percent cover for each identified type (water, urban, agriculture, savannah, and forest) in the Monkey River watershed was comparable to the percent cover for each of those types in the country as a whole (Table 2.1). Although the land cover for the whole watershed seems to be similar to the rest of the country, portions of the watershed are at higher risk from human impacts. Some sections of the watershed appear to have more overall areas of potential human impacts from commercial citrus and banana cultivation.

Sections of the Monkey River watershed that are already altered by heavy anthropogenic impacts may be at greater risk in the future if these practices continue. On the Swasey Branch, there appeared to be a higher percentage of agricultural land cover when compared to the Bladen Branch (Fig. 2.3). This high amount of land within the Swasey Branch sub-watershed that is impacted by commercial agriculture may lead to an unhealthy stream condition from both a chemical and biological standpoint. This could be the result of eutrophication, a decrease in dissolved oxygen, or an increase in turbidity. There were also significantly higher ELSI human impact scores at the Swasey Branch sites compared to Bladen Branch sites ($p < 0.01$). These factors may be caused by anthropogenic changes in the landscape and may play a role in the overall stream health.

Research within the streams that make up the Monkey River showed that only some parameters were significantly influenced by human impacts based on the ELSI scoring system.
Temperature and pH were the only two measured water chemistry variables that showed a significant trend with regard to human impact scores. Temperature increased and pH decreased as human impact increased (see Chapter III). These differences may be explained by decreases in riparian vegetation that is usually associated with human disturbances (Poole and Berman 2001). Water chemistry is not the only factor influenced by human impacts. Biological components of stream ecosystems are also affected by human impacts (Allan and Flecker 1993, Richards et al. 1996). Karr (1995) argues that more concern needs to be placed on monitoring stream biology. Biological monitoring is valuable because biotic indicators integrate physiochemical factors over broad temporal scales (Karr and Chu 2000). In this study, fish and algae significantly decreased as human impacts increased. This study supports that some biological criteria are influenced by human impacts. Human actions also disrupt vital processes that maintain rivers and their associated biota, and these actions also frequently lead to habitat that is degraded and less heterogeneous (Allan 2004). The original hypothesis that variation within streams would be negatively influenced by human impacts was not supported by this project. There were no significant trends in variation (measured as a coefficient of variation) with regard to ELSI score.

One important digital image processing tool was developed and utilized for rasters created for this project. Using this process, I was able to show where our categorical scores for algae or macrophytes matched categorical scores for fish or snails. Our comparison process was tested at two randomly selected sites. The outcome gave us an idea of whether or not there were relationships or correlations in plant and animal abundance at a given site. Although some site comparisons showed high levels of matched data, others did not. The highest level of matched data came from a comparison of score from macrophytes to scores from fish from B04 site on
the Bladen Branch (Fig. 3.2). The lowest match also came from this site (algae vs. fish). It would appear that this comparison technique must be used on a site-by-site and category-by-category basis. This processing tool would only be applicable where there are highly matched categorical scores at a given site. Where applicable, however, it could be shown by using this tool that fewer parameters need to be measured to derive an accurate picture of plant or animal abundance.

An important study for the future may be to track changes in land cover and land use practices over time. This process could easily be accomplished by obtaining a series of remotely sensed data from multiple years both from the past and from future recordings. Additional series of ground truth data from the area would also be necessary to create accurate depictions of land use in the future. Another way to improve future studies would be to obtain remotely sensed data with higher spatial resolution. This would allow for a more accurate classification of land cover types. It is known that changes in land use practices from grasslands to agricultural or pastoral lands can change many processes within a stream (Murty 2001). By monitoring both the landscape changes and the aquatic system at the same time, a better understanding of this connection could be constructed. Continuous monitoring at sample stations on each branch, along with additional monitoring of changes in land use practices, will ultimately lead to a better understanding of the processes and relationships between land use and aquatic ecosystems within this watershed.
Figure 1. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B01 site on the Bladen Branch of the Monkey River.
Figure 2. Inverse distance weighting (IDW) image of variation in depth at B01 site on the Bladen Branch of the Monkey River.
Figure 3. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B01 site on the Bladen Branch of the Monkey River.
Figure 4. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B01 site on the Bladen Branch of the Monkey River.
Figure 5. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B01 site on the Bladen Branch of the Monkey River.
Figure 6. Inverse distance weighting (IDW) image of variation in substrate type at B01 site on the Bladen Branch of the Monkey River.
Figure 7. Inverse distance weighting (IDW) image of variation in velocity at B01 site on the Bladen Branch of the Monkey River.
Figure 8. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B02 site on the Bladen Branch of the Monkey River.
Figure 9. Inverse distance weighting (IDW) image of variation in depth at B02 site on the Bladen Branch of the Monkey River.
Figure 10. Inverse distance weighting (IDW) image of variation in fish abundance where $0 = \text{no fish}$, $1 = \text{1 individual}$, $2 = \text{<10 individuals}$, $3 = \text{10-20 individuals}$ and $4 = \text{>20 individuals}$ at B02 site on the Bladen Branch of the Monkey River.
Figure 11. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B02 site on the Bladen Branch of the Monkey River.
Figure 12. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B02 site on the Bladen Branch of the Monkey River.
Figure 13. Inverse distance weighting (IDW) image of variation in substrate type at B02 site on the Bladen Branch of the Monkey River.
Figure 14. Inverse distance weighting (IDW) image of variation in velocity at B02 site on the Bladen Branch of the Monkey River.
Figure 15. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B03 site on the Bladen Branch of the Monkey River.
Figure 16. Inverse distance weighting (IDW) image of variation in depth at B03 site on the Bladen Branch of the Monkey River.
Figure 17. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B03 site on the Bladen Branch of the Monkey River.
Figure 18. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B03 site on the Bladen Branch of the Monkey River.
Figure 19. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B03 site on the Bladen Branch of the Monkey River.
Figure 20. Inverse distance weighting (IDW) image of variation in substrate type at B03 site on the Bladen Branch of the Monkey River.
Figure 21. Inverse distance weighting (IDW) image of variation in velocity at B03 site on the Bladen Branch of the Monkey River.
Figure 22. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B04 site on the Bladen Branch of the Monkey River.
Figure 23. Inverse distance weighting (IDW) image of variation in depth at B04 site on the Bladen Branch of the Monkey River.
Figure 24. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B04 site on the Bladen Branch of the Monkey River.
Figure 25. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B04 site on the Bladen Branch of the Monkey River.
Figure 26. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B04 site on the Bladen Branch of the Monkey River.
Figure 27. Inverse distance weighting (IDW) image of variation in substrate type at B04 site on the Bladen Branch of the Monkey River.
Figure 28. Inverse distance weighting (IDW) image of variation in velocity at B04 site on the Bladen Branch of the Monkey River.
Figure 29. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B05 site on the Bladen Branch of the Monkey River.
Figure 30. Inverse distance weighting (IDW) image of variation in depth at B05 site on the Bladen Branch of the Monkey River.
Figure 31. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B05 site on the Bladen Branch of the Monkey River.
Figure 32. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B05 site on the Bladen Branch of the Monkey River.
Figure 33. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B05 site on the Bladen Branch of the Monkey River.
Figure 34. Inverse distance weighting (IDW) image of variation in substrate type at B05 site on the Bladen Branch of the Monkey River.
Figure 35. Inverse distance weighting (IDW) image of variation in velocity at B05 site on the Bladen Branch of the Monkey River.
Figure 36. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B06 site on the Bladen Branch of the Monkey River.
Figure 37. Inverse distance weighting (IDW) image of variation in depth at B06 site on the Bladen Branch of the Monkey River.
Figure 38. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B06 site on the Bladen Branch of the Monkey River.
Figure 39. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B06 site on the Bladen Branch of the Monkey River.
Figure 40. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B06 site on the Bladen Branch of the Monkey River.
Figure 41. Inverse distance weighting (IDW) image of variation in substrate type at B06 site on the Bladen Branch of the Monkey River.
Figure 42. Inverse distance weighting (IDW) image of variation in velocity at B06 site on the Bladen Branch of the Monkey River.
Figure 43. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B07 site on the Bladen Branch of the Monkey River.
Figure 44. Inverse distance weighting (IDW) image of variation in depth at B07 site on the Bladen Branch of the Monkey River.
Figure 45. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B07 site on the Bladen Branch of the Monkey River.
Figure 46. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B07 site on the Bladen Branch of the Monkey River.
Figure 47. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B07 site on the Bladen Branch of the Monkey River.
Figure 48. Inverse distance weighting (IDW) image of variation in substrate type at B07 site on the Bladen Branch of the Monkey River.
Figure 49. Inverse distance weighting (IDW) image of variation in velocity at B07 site on the Bladen Branch of the Monkey River.
Figure 50. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B08 site on the Bladen Branch of the Monkey River.
Figure 51. Inverse distance weighting (IDW) image of variation in depth at B08 site on the Bladen Branch of the Monkey River.
Figure 52. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B08 site on the Bladen Branch of the Monkey River.
Figure 53. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B08 site on the Bladen Branch of the Monkey River.
Figure 54. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B08 site on the Bladen Branch of the Monkey River.
Figure 55. Inverse distance weighting (IDW) image of variation in substrate type at B08 site on the Bladen Branch of the Monkey River.
Figure 56. Inverse distance weighting (IDW) image of variation in velocity at B08 site on the Bladen Branch of the Monkey River.
Figure 67. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B09 site on the Bladen Branch of the Monkey River.
Figure 58. Inverse distance weighting (IDW) image of variation in depth at B09 site on the Bladen Branch of the Monkey River.
Figure 59. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B09 site on the Bladen Branch of the Monkey River.
Figure 60. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B09 site on the Bladen Branch of the Monkey River.
Figure 61. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B09 site on the Bladen Branch of the Monkey River.
Figure 62. Inverse distance weighting (IDW) image of variation in substrate type at B09 site on the Bladen Branch of the Monkey River.
Figure 63. Inverse distance weighting (IDW) image of variation in velocity at B09 site on the Bladen Branch of the Monkey River.
Figure 64. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B10 site on the Bladen Branch of the Monkey River.
Figure 65. Inverse distance weighting (IDW) image of variation in depth at B10 site on the Bladen Branch of the Monkey River.
Figure 66. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B10 site on the Bladen Branch of the Monkey River.
Figure 67. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at B10 site on the Bladen Branch of the Monkey River.
Figure 68. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at B10 site on the Bladen Branch of the Monkey River.
Figure 69. Inverse distance weighting (IDW) image of variation in substrate type at B10 site on the Bladen Branch of the Monkey River.
Figure 70. Inverse distance weighting (IDW) image of variation in velocity at B10 site on the Bladen Branch of the Monkey River.
Figure 71. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at M01 site on the Monkey River.
Figure 72. Inverse distance weighting (IDW) image of variation in depth at M01 site on the Monkey River.
Figure 73. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at M01 site on the Monkey River.
Figure 74. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at M01 site on the Monkey River.
Figure 75. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at M01 site on the Monkey River.
Figure 76. Inverse distance weighting (IDW) image of variation in substrate type at M01 site on the Monkey River.
Figure 77. Inverse distance weighting (IDW) image of variation in velocity at M01 site on the Monkey River.
Figure 78. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at M02 site on the Monkey River.
Figure 79. Inverse distance weighting (IDW) image of variation in depth at M02 site on the Monkey River.
Figure 80. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at M02 site on the Monkey River.
Figure 81. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at M02 site on the Monkey River.
Figure 8.2 Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at M02 site on the Monkey River.
Figure 83. Inverse distance weighting (IDW) image of variation in substrate type at M02 site on the Monkey River.
Figure 84. Inverse distance weighting (IDW) image of variation in velocity at M02 site on the Monkey River.
Figure 85. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at S01 site on the Swasey Branch of the Monkey River.
Figure 86. Inverse distance weighting (IDW) image of variation in depth at S01 site on the Swasey Branch of the Monkey River.
Figure 87. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at S01 site on the Swasey Branch of the Monkey River.
Figure 88. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at S01 site on the Swasey Branch of the Monkey River.
Figure 89. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at S01 site on the Swasey Branch of the Monkey River.
Figure 90. Inverse distance weighting (IDW) image of variation in substrate type at S01 site on the Swasey Branch of the Monkey River.
Figure 91. Inverse distance weighting (IDW) image of variation in velocity at S01 site on the Swasey Branch of the Monkey River.
Figure 92. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at S02 site on the Swasey Branch of the Monkey River.
Figure 93. Inverse distance weighting (IDW) image of variation in depth at S02 site on the Swasey Branch of the Monkey River.
Figure 94. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at S02 site on the Swasey Branch of the Monkey River.
Figure 95. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at S02 site on the Swasey Branch of the Monkey River.
Figure 96. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at S02 site on the Swasey Branch of the Monkey River.
Figure 97. Inverse distance weighting (IDW) image of variation in substrate type at S02 site on the Swasey Branch of the Monkey River.
Figure 98. Inverse distance weighting (IDW) image of variation in velocity at S02 site on the Swasey Branch of the Monkey River.
Figure 99. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at S03 site on the Swasey Branch of the Monkey River.
Figure 100. Inverse distance weighting (IDW) image of variation in depth at S03 site on the Swasey Branch of the Monkey River.
Figure 101. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at S03 site on the Swasey Branch of the Monkey River.
Figure 102. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at S03 site on the Swasey Branch of the Monkey River.
Figure 103. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at S03 site on the Swasey Branch of the Monkey River.
Figure 104. Inverse distance weighting (IDW) image of variation in substrate type at S03 site on the Swasey Branch of the Monkey River.
Figure 105. Inverse distance weighting (IDW) image of variation in velocity at S03 site on the Swasey Branch of the Monkey River.
Figure 106. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at S06 site on the Swasey Branch of the Monkey River.
Figure 107. Inverse distance weighting (IDW) image of variation in depth at S06 site on the Swasey Branch of the Monkey River.
Figure 108. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at S06 site on the Swasey Branch of the Monkey River.
Figure 109. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at S06 site on the Swasey Branch of the Monkey River.
Figure 110. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at S06 site on the Swasey Branch of the Monkey River.
Figure 111. Inverse distance weighting (IDW) image of variation in substrate type at S06 site on the Swasey Branch of the Monkey River.
Figure 112. Inverse distance weighting (IDW) image of variation in velocity at S06 site on the Swasey Branch of the Monkey River.
Figure 113. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at S07 site on the Swasey Branch of the Monkey River.
Figure 114. Inverse distance weighting (IDW) image of variation in depth at S07 site on the Swasey Branch of the Monkey River.
Figure 115. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at S07 site on the Swasey Branch of the Monkey River.
Figure 116. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at S07 site on the Swasey Branch of the Monkey River.
Figure 117. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at S07 site on the Swasey Branch of the Monkey River.
Figure 118. Inverse distance weighting (IDW) image of variation in substrate type at S07 site on the Swasey Branch of the Monkey River.
Figure 119. Inverse distance weighting (IDW) image of variation in velocity at S07 site on the Swasey Branch of the Monkey River.
Figure 120. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at T01 site on the Trio Branch of the Monkey River.
Figure 121. Inverse distance weighting (IDW) image of variation in depth at T01 site on the Trio Branch of the Monkey River.
Figure 122. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at T01 site on the Trio Branch of the Monkey River.
Figure 123. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at T01 site on the Trio Branch of the Monkey River.
Figure 124. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at T01 site on the Trio Branch of the Monkey River.
Figure 125. Inverse distance weighting (IDW) image of variation in substrate type at T01 site on the Trio Branch of the Monkey River.
Figure 126. Inverse distance weighting (IDW) image of variation in velocity at T01 site on the Trio Branch of the Monkey River.
Figure 127. Inverse distance weighting (IDW) image of variation in algae cover where 0 = no algae, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at T05 site on the Trio Branch of the Monkey River.
Figure 128. Inverse distance weighting (IDW) image of variation in depth at T05 site on the Trio Branch of the Monkey River.
Figure 129. Inverse distance weighting (IDW) image of variation in fish abundance where 0 = no fish, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at T05 site on the Trio Branch of the Monkey River.
Figure 130. Inverse distance weighting (IDW) image of variation in macrophyte cover where 0 = no macrophytes, 1 = <10% coverage, 2 = 10-20% coverage, 3 = 20-50% coverage and 4 = >50% coverage at T05 site on the Trio Branch of the Monkey River.
Figure 131. Inverse distance weighting (IDW) image of variation in snail abundance where 0 = no snails, 1 = 1 individual, 2 = <10 individuals, 3 = 10-20 individuals and 4 = >20 individuals at T05 site on the Trio Branch of the Monkey River.
Figure 132. Inverse distance weighting (IDW) image of variation in substrate type at T05 site on the Trio Branch of the Monkey River.
Figure 133. Inverse distance weighting (IDW) image of variation in velocity at T05 site on the Trio Branch of the Monkey River.
Figure 134. “Equal to” raster analysis comparing categorical scores for algae and snails at B04 site. There was < 1% matched data for this comparison.
Figure 135. “Equal to” raster analysis comparing categorical scores for macrophyte and fish at B04 site. There 96.45% matched data for this comparison.
Figure 136. “Equal to” raster analysis comparing categorical scores for algae and fish at B04 site. There was < 1% matched data for this comparison.
Figure 137. “Equal to” raster analysis comparing categorical scores for macrophyte and snails at B04 site. There was < 1% matched data for this comparison.
Figure 138. “Equal to” raster analysis comparing categorical scores for algae and snails at B07 site. There was < 1% matched data for this comparison.
Figure 139. “Equal to” raster analysis comparing categorical scores for macrophyte and fish at B07 site. There was only 1.35% matched data for this comparison.
Figure 140. “Equal to” raster analysis comparing categorical scores for algae and fish at B07 site. There was 43.69% matched data for this comparison.
Figure 141. “Equal to” raster analysis comparing categorical scores for macrophytes and snails at B07 site. There was 94.85% matched data for this comparison.
### APPENDIX B – BENTHIC MACROINVERTEBRATES

Table 1. List of all macroinvertebrates collected by site in the Bladen Branch of the Monkey River including total taxa, total specimens, and stream index score as calculated by WVSOS family level index.

| Order       | Family              | B01 | B02 | B03 | B04 | B05 | B06 | B07 | B08 | B09 | B10 |
|-------------|---------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Amphipoda   | Gammaridae          | 1   |     |     |     |     |     |     |     |     |     |     |
| Coleoptera  | Elmidae             | 5   | 2   | 3   | 1   | 1   | 12  | 4   | 16  |     |     |     |
| Coleoptera  | Psephenidae         |     |     |     | 2   | 6   |     |     |     |     |     |     |
| Diptera     | Ceratopogonidae     | 3   |     |     |     |     |     |     |     |     |     |     |
| Diptera     | Chironomidae        | 39  | 3   | 6   | 3   | 1   | 8   |     | 8   |     |     |     |
| Diptera     | Ephydridae          |     |     |     |     |     |     |     |     | 2   | 1   |     |
| Diptera     | Simuliidae          |     |     |     |     |     |     |     |     |     | 2   |     |
| Diptera     | Tipulidae           |     | 5   | 3   |     |     |     |     |     | 3   | 7   |     |
| Ephemeroptera| Baetidae           | 7   | 14  | 3   | 4   | 9   | 2   | 6   |     |     |     |     |
| Ephemeroptera| Euthyplociida     |     |     |     |     |     |     |     |     |     | 3   |     |
| Ephemeroptera| Leptophyphidae   | 18  | 5   | 3   | 2   |     |     |     |     |     |     |     |
| Ephemeroptera| Leptophlebiidae | 73  | 17  | 4   | 27  |     |     |     |     |     |     |     |
| Hemiptera   | Naucoridae          | 1   | 2   | 1   |     | 2   | 5   | 3   |     |     |     |     |
| Megaloptera | Corydalidae         |     |     |     | 5   | 1   |     |     |     |     |     | 2   |
| Odonata     | Coenagrionidae      |     |     |     |     |     |     |     |     | 2   | 2   |     |
| Odonata     | Gomphidae           | 1   | 1   |     |     |     |     |     |     |     | 1   |     |
| Odonata     | Libellulidae        |     |     |     |     |     |     |     |     |     |     | 1   |
| Plecoptera  | Taeniopterygidae    |     |     |     |     |     |     |     |     | 2   | 2   | 5   |
| Trichoptera | Brachycentridae     |     |     |     | 5   | 1   | 1   | 1   |     |     |     |     |
| Trichoptera | Hydropsychidae      | 1   | 3   | 16  | 9   |     |     |     |     |     |     | 2   |
| Trichoptera | Philopotamidae      | 1   |     |     | 105 | 4   |     |     |     |     |     |     |

| Total Taxa  | 1     | 8   | 8   | 8   | 1   | 2   | 10  | 10  | 11  | 16  |     |     |
| Total Specimens | 1   | 76  | 34  | 34  | 3   | 2   | 211 | 53  | 30  | 91  |     |     |
| Stream Index Score | 27.3 | 42.5 | 67.3 | 60.1 | 5.52 | 30.7 | 75.4 | 66  | 66.5 | 73.9 |     |     |
Table 2. List of all macroinvertebrates collected by site in the Monkey River including total taxa, total specimens, and stream index score as calculated by WVSOS family level index.

<table>
<thead>
<tr>
<th>Order</th>
<th>Family</th>
<th>M01</th>
<th>M02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amphipoda</td>
<td>Gammaridae</td>
<td>29</td>
<td>17</td>
</tr>
<tr>
<td>Diptera</td>
<td>Ceratopogonidae</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Diptera</td>
<td>Chironomidae</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total Taxa</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Total Specimens</td>
<td>29</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Stream Index Score</td>
<td>29.3</td>
<td>31.1</td>
</tr>
</tbody>
</table>
Table 3. List of all macroinvertebrates collected by site in the Swasey Branch of the Monkey River including total taxa, total specimens, and stream index score as calculated by WVSOS family level index.

<table>
<thead>
<tr>
<th>Order</th>
<th>Family</th>
<th>S01</th>
<th>S02</th>
<th>S03</th>
<th>S06</th>
<th>S07</th>
<th>S08</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coleoptera</td>
<td>Elmidae</td>
<td>1</td>
<td>5</td>
<td>6</td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coleoptera</td>
<td>Psephenidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Diptera</td>
<td>Chironomidae</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diptera</td>
<td>Simuliidae</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ephemeroptera</td>
<td>Baetidae</td>
<td>1</td>
<td>9</td>
<td>4</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ephemeroptera</td>
<td>Caenidae</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Ephemeroptera</td>
<td>Heptageniidae</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ephemeroptera</td>
<td>Leptophlebiidae</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ephemeroptera</td>
<td>Caenidae</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemiptera</td>
<td>Naucoridae</td>
<td></td>
<td>2</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lepidoptera</td>
<td>Crambidae</td>
<td></td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Megaloptera</td>
<td>Corydalidae</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odonata</td>
<td>Hydropsychidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odonata</td>
<td>Coenagrionidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odonata</td>
<td>Gomphidae</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odonata</td>
<td>Libellulidae</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plecoptera</td>
<td>Taeniopterygidae</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trichoptera</td>
<td>Brachycentridae</td>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trichoptera</td>
<td>Hydropsyridae</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trichoptera</td>
<td>Leptoceridae</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trichoptera</td>
<td>Philopotamidae</td>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Total Taxa</th>
<th>Total Specimens</th>
<th>Stream Index Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>29</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>34</td>
<td>63.4</td>
</tr>
<tr>
<td></td>
<td>60.1</td>
<td>31.7</td>
<td>30.7</td>
</tr>
<tr>
<td></td>
<td>69</td>
<td>68.1</td>
<td>63.4</td>
</tr>
</tbody>
</table>
Table 4. List of all macroinvertebrates collected by site in the Trio Branch of the Monkey River including total taxa, total specimens, and stream index score as calculated by WVSOS family level index.

<table>
<thead>
<tr>
<th>Order</th>
<th>Family</th>
<th>T01</th>
<th>T05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amphipoda</td>
<td>Gammaridae</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Coleoptera</td>
<td>Elmidae</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Diptera</td>
<td>Chironomidae</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Diptera</td>
<td>Ephydridae</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Ephemeroptera</td>
<td>Baetidae</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Ephemeroptera</td>
<td>Leptophlebiidae</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Megaloptera</td>
<td>Corydalidae</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Odonata</td>
<td>Coenagrionidae</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Odonata</td>
<td>Libellulidae</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Trichoptera</td>
<td>Hydropsychidae</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Trichoptera</td>
<td>Philopotamidae</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Total Taxa</td>
<td></td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Total Specimens</td>
<td></td>
<td>1</td>
<td>72</td>
</tr>
<tr>
<td>Stream Index Score</td>
<td></td>
<td>5.52</td>
<td>64.2</td>
</tr>
</tbody>
</table>
LITERATURE CITED


SEAN E. COLLINS

Curriculum Vitae

99 Cedar Drive, W. Portsmouth, OH 45663
Tel: 740.464.8746
Email: collins84@marshall.edu

EDUCATION

Master of Science: Biological Sciences
  Area of Emphasis: Watershed Science Resources
  GPA: 3.95
  Marshall University, Huntington, WV. December 2009
  Advisor: Thomas G. Jones, Ph.D.
  Thesis: Developing a monitoring protocol for the Monkey River watershed
  (Belize, Central America)

Bachelor of Science: Major, Biological Sciences
  Minors: Chemistry, Spanish, Anthropology
  GPA: 3.77
  Marshall University, Huntington, WV. May 2007
  Advisor: Thomas K. Pauley, Ph.D.
  Undergraduate Project: Larval success of spotted salamander (Ambystoma
  maculatum) based on water quality

Summer Programme for Continuing Education
  Exeter College, Oxford University, Oxford, England. Summer 2005

Summer Program for Junior Scholars
  Miami University, Oxford, OH. Summer 2002

Graduate Record Examination
  Verbal – 550
  Quantitative – 710
  Analytical Writing – 4.0

AFFILIATIONS

  Society of Yeager Scholars
  Alpha Chi Sigma, Professional Chemistry Fraternity – Historian
  Marshall University Whitewater Club – Vice Pres., Secretary/Treasurer
  American Fisheries Society, Marshall University Subchapter – President
GRANTS and AWARDS

Summer Thesis Research Grant, Marshall University Graduate Program – 2008

GRADUATE RESEARCH EXPERIENCE: Contact info – Dr. Tom Jones
(jonest@marhall.edu – 304.389.5832)

- **White River, AR Mussel Survey** (August 2009 – present)
  - SCUBA sampling for unionid mussels
  - SCUBA habitat assessment, substrate mapping

- **Allegheny River, PA Mussel Survey** (August-October 2009)
  - SCUBA sampling for unionid mussels
  - SCUBA habitat assessment, substrate mapping

- **Kanawha River, WV Bioassessment** (March-September 2009)
  - Bathymetric and substrate mapping with GIS components
  - Hester-Dendy multiplate sampling for macroinvertebrates
  - Night-time electrofishing
  - Larval fish sampling (quatrefoil light traps)
  - Sediment accumulation (Booner tubes)

- **Monkey River watershed, Belize – RPB Development** (May 2008-May 2009)
  - Bathymetric mapping
  - Stream velocity mapping
  - Substrate mapping (Wolman pebble count)
  - Aquatic community surveys
  - GIS applications – Inverse Distance Weighting

- **Monongahela River, PA Mussel Survey** (August 2008)
  - SCUBA sampling for unionid mussels
  - SCUBA habitat assessment, substrate mapping

- **Susquehanna River, MD Trawling/Diving** (August 2008)
  - Benthic trawling for darters and other fishes
  - SCUBA sampling for unionid mussels
  - SCUBA habitat assessment, substrate mapping
  - SCUBA surber sampling

- **Raisin River, MI Mussel Survey** (July 2008)
  - SCUBA/Hookah sampling for unionid mussels
  - SCUBA/Hookah habitat assessment, substrate mapping
• **Little Coal River Survey** (June 2008)
  - Bathymetric mapping
  - Substrate mapping (copper pole)
  - Stream velocity mapping
  - Collected macroinvertebrate samples using kick net

• **Ohio River Run** (July-August 2007)
  - Collected benthic fishes using a modified Missouri trawl
  - Collected crayfishes using snorkel survey techniques
  - Collected river turbidity and bottom contour using SonTek River Surveyor
  - Performed SCUBA mussel surveys using dive transects

**UNDERGRADUATE RESEARCH EXPERIENCE**: Contact info – Mr. Zac Loughman (zloughman@westliberty.edu – 304.231.7033); Dr. Thomas K. Pauley (pauley@marshall.edu – 304.696.2376)

• **Flushing Escarpment Crayfish Surveys** (May-July 2006)
  Ohio DNR Funding  
  Technician
  - Collected crayfish using standardized astacological collection methods
  - Identified specimens in the lab and in the field to species level
  - Completion of 38 variable field data sheet and Jarr Label
  - Utilized crayfish field preservation techniques
  - Use GPS datum for site location
  - Surveyed 48 sites within the flushing escarpment using the above methods

• **Marshall County Herpetological Survey** (May-July 2006)
  WVDNR Funding  
  Technician
  - Collected reptiles and amphibians using haphazard search, frog surveys (NAAMP Methods), turtle trapping
  - Measured each herp taxa using specific morphometrics for each order
  - Sampled 110+ sites using the above methods
  - Generated and maintained a database on all data collected during the study
  - Gathered important conservation datum on species of special concern
  - Gathered specific natural history data on all snakes captured during study

• **Crayfish surveys along Ohio River floodplain, West Virginia** (May-July 2006)
  WVDNR funding  
  Technician
  - Collected crayfish using standardized astacological collection methods
  - Identified specimens in the lab and in the field to species level
  - Completion of 38 variable field data sheet and Jarr Label
  - Utilized crayfish field preservation techniques
  - Use GPS datum for site location
  - Curated collection in laboratory
  - Surveyed 61 sites using the above methods
• **West Virginia Northern Panhandle Crayfish Survey** (May-July 2006)  
  WVDNR funding  
  Technician  
  – Collected crayfish using standardized astacological collection methods  
  – Identified specimens in the lab and in the field to species level  
  – Completion of 38 variable field data sheet and Jarr Label  
  – Utilized crayfish field preservation techniques  
  – Use GPS datum for site location  
  – Surveyed 38 sites using the above methods

• **Spotted Salamander Larval Success Study** (February-May 2006)  
  – Designed original research project  
  – Collected water quality data (pH, temp., dissolved oxygen, etc.)  
  – Collected data on egg masses and larval salamanders  
  – Performed statistical analysis of data

**WORK EXPERIENCE**

April – December 2007  
Marshall University Research Corp.  
Huntington, WV  

• **Laboratory Technician**  
  • Learned basic bacteriology techniques.  
  • Performed Live/Dead assays and other bactericidal assays.

May – July 2006  
Schrader Environmental Education and Research Center  
Wheeling, WV  

• **Fieldwork Internship**  
  • Learned herpetology fieldwork techniques  
  • Learned astacology fieldwork techniques

May – July 2006  
Schrader Environmental Education and Research Center  
Wheeling, WV  

• **Environmental Educator**  
  • Performed offsite public demonstrations with live animals  
  • Teaching aid for advanced classes on herpetology for the public  
  • Teaching aid for advanced classes on odonates for the public

**TEACHING EXPERIENCE**  
Contact info – Mrs. Susan Weinstein (weinstei@marshall.edu – 304.696.2428)  
Introduction to Biology Lab (for non-majors) – August-December 2007; Marshall Univ.  
RELEVANT COURSEWORK


FIELDWORK SKILLS

*Large River Ecology*: Trawling, SCUBA surveys, snorkel surveys, electrofishing, gill netting, larval fish sampling, Hester-Dendy multiplates.

*Herpetology*: Drift fences, cover boards, funnel traps, call surveys, hoop traps, dip netting, road search, eye shine location, snorkeling, photography in the field.

*Astacology*: Crayfish field collecting (dip netting, seine netting, burrow excavations), crayfish field preservation techniques.
REFERENCES

Dr. Tom Jones
Graduate Advisor, Professor
Dept. of Integrated Science and Technology
Marshall University
Huntington, WV 25755
(304)-696-6305
jonest@marshall.edu

Dr. Thomas K. Pauley
Undergraduate Advisor, Professor of Herpetology
Dept. of Biological Sciences
Marshall University
Huntington, WV 25755
(304)-696-2376
pauley@marshall.edu

Dr. Hongwei Yu
Research Advisor
Dept. of Biochemistry and Microbiology
Marshall University
Marshall University Research Corp.
Huntington, WV 25755
yuh@marshall.edu

Dr. William Price
Dept. of Chemistry
Marshall University
(304)-696-3156
pricew@marshall.edu

Dr. Frank Gilliam
Dept. of Biological Sciences
Marshall University
Huntington, WV 25755
(304)-696-3636
gilliam@marshall.edu

Zachary Loughman, M.S.
Research/Fieldwork Advisor, Schrader Center
Dept. of Biological Sciences
West Liberty State College
PO Box 295
West Liberty, WV 26074
(304)-231-7033
zloughman@westliberty.edu