2015

Recovery Potential Of The Mussel Communities In The Lower Section Of Big Walnut Creek

Jared B. Ellenbogen
Otterbein University, jared.ellenbogen@otterbein.edu

Recovery Potential of the Mussel Communities in the Lower Section of Big Walnut Creek

By

Jared B Ellenbogen

Department of Biology and Earth Science

Otterbein University

Westerville, Ohio 43081

16 April 2015

Submitted in partial fulfillment of the requirements

For graduation with Honors

Michael A. Hoggarth, Ph.D.	__________________________
Project Advisor	Advisor’s Signature
Kevin Svitana, Ph.D.	__________________________
Second Reader	Second Reader’s Signature
Jonathan DeCoster, Ph.D.	__________________________
Honors Representative	Honors Rep’s Signature

Acknowledgments

First, I would like to thank my research advisor, Dr. Michael Hoggarth, for his extensive help and guidance with this project. I would also like to thank Donna Rhodeback for help with the acquisition of materials, and Dr. Kevin Svitana for serving as the second reader for this thesis project. Finally, I would like to thank both the Otterbein Student Research Fund, and the Otterbein Biology and Earth Sciences Department for funding this study.

Abstract

Since the enactment of the 1977 Clean Water Act, biologists have created numerous multimetric assessment tools to evaluate the biological integrity of water resources, using biological criteria. The integrity of Big Walnut Creek, Ohio, has been in flux since the 1955 construction of Hoover Dam, and while current water quality is high, mussel communities in the creek have yet to recover to historical levels. This study sought to determine the cause of the decline in the mussels in the lower section of the creek below the dam. Historical creek data, including a fish-based index of biotic integrity (f-IBI), invertebrate community index (ICI), qualitative habitat evaluation index (QHEI) and modified index of well-being (MIWB), were compared to a recent mussel-IBI for the creek. These data were compared to urbanization data (i.e. percent plant cover) describing land use in 1 km^2 sample regions around each biometric data collection site. Data were analyzed using linear region and student t-tests to understand any correlative relationships with the status of mussel communities. Mussel-IBI data were compared to percent land developed (r^2=0.225, p>0.01), percent plant cover (r^2=0.1 p>0.01), road density (r^2=0.007, p>0.01), census tract data as a measure of population density (r^2=0.003, p>0.01), riparian zone width (r^2=0.107, p>0.01) and creek width (r^2=0.001, p>0.01). Ohio EPA biometric data were compared to percent plant cover data: f-IBI (r^2=0.185, p>0.01), MIWB (r^2=0.004, p>0.01), ICI (r^2=0.028, p>0.01) and QHEI (r^2=0.265, p>0.01). No significant correlations were found between urbanization and integrity, suggesting that land use does not directly affect the lower section of Big Walnut Creek. Therefore, it is possible (pending future research) that the mussel communities could recover in time, similar to the fish and invertebrate communities in the creek.

Table of Contents

List of tables

List of Figures

Introduction

The 1977 Clean Water Act called for the assessment of the biological integrity of natural and artificial water resources, for the purpose of monitoring water quality and environmental health. Since this law was enacted, biologists have been working to substantiate biological methods of water quality assessment. Prior to the demands of the Clean Water Act, most water quality assessments were performed using only chemical and physical criteria (Karr 1991). Additionally, most efforts to monitor water resource quality focused solely on the impacts of degraded water resources to human health (Karr 1991), rather than the impacts on overall environmental health. Karr (1991) was one of the first to present an assessment using biological criteria when he proposed the Index of Biotic Integrity (IBI), a multi-metric tool that uses a combination of habitat-specific metrics to determine the overall health of a waterway. Metrics are considered to be any significant measurable characteristic of a water resource that is sensitive to human degradation (i.e. Shannon-Weiner diversity index or species richness). Karr developed his IBI using freshwater fish metrics to determine the health of a waterway; however, subsequent studies have validated the usefulness of the IBI in many other habitat types, with many other indicator species (Kerrans and Karr 1994; Hill *et al*. 2000; Llanso *et al*. 2002; Kane 2004; Lacouture *et al.* 2006; Weigel and Dimick 2011; Lunde and Resh 2012).

The Index of Biotic Integrity has come to be an extremely useful tool that is regularly used to assess the health of many different waterways. Furthermore, once an IBI is used to designate the status of a waterway, its findings may be used to inform policy; if a waterway is found to be impaired, policy makers may enact new legislation to better protect it. Karr and Kerans (1994) developed a benthic IBI for use in assessing rivers in the Tennessee Valley. However, they used invertebrate data to develop their IBI, rather than fish metrics as seen in

Karr's (1991) earlier IBI. Later studies have successfully created IBIs able to evaluate the biological integrity of many different aquatic habitat types, including rivers in mountainous regions (Hill *et al*. 2000), large nonwadeable rivers (Weigel and Dimick 2011), estuaries (Llanso *et al*. 2002; Lacouture *et al.* 2006), and freshwater wetlands (Lunde and Resh 2012). Additionally, biologists have created IBIs using various types of metrics; Karr (1991) used freshwater fish metrics to develop his IBI, but researchers have since created IBIs using invertebrate data (Kerans and Karr 1994), macroinvertebrate data (Weigel and Dimick 2011; Lunde and Resh 2012), periphyton data (Hill *et al*. 2000), phytoplankton data (Lacouture *et al.* 2006) and more. Numerous ecological studies have managed to demonstrate the usefulness of the Index of Biotic Integrity as a means to effectively use biological criteria to evaluate the health of waterways.

In addition to the Index of Biotic Integrity, other multi-metric bioassessment tools have been created to meet the goals of the Clean Water Act concerned with monitoring the biological integrity of water resources. These include the Invertebrate Community Index (ICI) (Deshon 1995), the Modified Index of Well Being (OEPA 1987), and the Qualitative Habitat Evaluation Index (QHEI) (Rankin 1995). The ICI and MIWB are relatively similar to the IBI in composition and use, as they base waterway assessments on animal community characteristics; however, the QHEI assesses the characteristics of the physical habitat. Because of the requirements of the Clean Water Act that necessitate the inclusion of biological criteria in methods of water quality assessment (Karr 1991), there are now many established methods to assess the biological integrity of water resources using primarily biological criteria.

Though these multi-metric bioassessment tools are good assessment tools for identifying the health of a waterway, they are often unable to independently identify the cause of any observed degradation. Many studies have been conducted to identify the various causes of water quality decline, and ultimately each waterway is affected by a unique set of environment-specific conditions. However, it is well established that human activity significantly impacts water quality, and that various types of anthropogenic land use can be damaging to waterways. Previous studies have demonstrated the significantly negative effects on water quality of activities such as mining, transportation and highway construction, hydromodification (both dam creation and channelization) intensive agriculture and urban development (Allan 2004; Hoscic and Wu 2006; Broussard and Turner 2009). These activities all have damaging environmental consequences, brought about by either habitat degradation (pollution) or habitat destruction (physical damage to the environment). Intensive agriculture is known to increase the occurrence of non-point source pollution in streams, and cause increased rates of sedimentation, nutrient loading, and pesticide occurrence in waterways. Urbanization often leads to high rates of impermeable surfaces around a waterway, causing high rates of runoff of polluted water. Hydromodification alters the physical habitat and may interfere with the movement of species through a waterway. Any activities that destroy or reduce the riparian zone of a waterway may lead to warmer water temperatures and destabilized banks (Box and Mossa 1999). These represent just a small selection of the many environmental problems caused by human activity

Because of the significant effects of human activity on environmental integrity, and water quality, it is critical that water resources be carefully monitored. Bioassessment tools are often used to determine the integrity of a water resource, and many of these tools depend on the assessment of an indicator species found in the aquatic habit being assessed. These species yield a great deal of information about their environment, as the health of an indicator species reflects the quality of its environment, the integrity of is habitat, and the integrity of the trophic structure of the community. If human activity interferes with these (for example, displacing one of two species that engage in a significant symbiotic relationship) a species may face significant consequences, as severe as (local) extinction. So, as the consequences of human activity on water resources can be significant to animals, studying the responses of animal populations to degradation and changes in water resources can be very meaningful.

The use of mussel community characteristics to evaluate biological integrity has been verified by multiple studies (Kerans and Karr 1994; Llanso *et al*. 2002). Freshwater mussels (*Bivalvia: Unionidae)* are very sensitive to environmental degradation, and consequently represent the most rapidly declining group of freshwater organisms (Vaughn and Taylor 1999). Mussels are long-lived, immobile suspension feeders (Vaughn *et al.* 2008); these life-history characteristics make mussels highly sensitive to changes at both the watershed level and the microhabitat level. Additionally, the larvae (glochidia) of freshwater mussels are obligate parasites that depend on specific fish host species (Vaughn and Taylor 1999). Because of their unique biology, mussels are sensitive to a variety of environmental changes, including increased sedimentation, changing water velocity, changing water temperature, changes in availability of fish host species, and more (Strayer 1999; Vaughn and Taylor 1999; Box *et al* 2002; Box and Mossa 1999). Excessive sedimentation can clog the gills of mussels, interfering with respiration, and it can also interfere with filter feeding. Altered water velocity could displace mussels from mussel beds (Carrington 2002), and changes in water temperature – in either direction – can interfere with physiological behaviors of mussels such as feeding and reproduction (Vaughn *et al.* 2008). Additionally, any circumstances that prevent a larval host fish species from living in an area will prevent that species of mussels from inhabiting it as well (Vaughn and Taylor 2000). Mussels are very sensitive to changing environmental conditions, and environmental degradation; therefore, they are a good candidate for use as an indicator organism to determine overall environmental health.

Big Walnut Creek (Fig. 1), in central Ohio, runs from its head in Morrow County, through Delaware and Franklin counties, to its convergence with the Scioto River near the division between Franklin and Pickaway counties. Approximately midway along its route, the creek flows into Hoover Reservoir, just northeast of Westerville. Hoover Reservoir was created as a water supply source for the city of Columbus in 1955, and it has become an incredibly important water resource for the continually developing city, now holding 2,818 acres of water (ODNR 2012). Just below the impoundment begins the lower Big Walnut Creek watershed (Fig. 2), encompassing the lower 37.6 miles the creek as it flows south through Franklin County to its mouth at the Scioto River. Along this stretch of the creek, it is met by its three main tributaries: Rocky Fork Creek, Alum Creek, and Blacklick Creek (Friends of Big Walnut Creek 2006). The lower section of Big Walnut Creek flows through a mix of urban, suburban, and rural settings; the last ten miles of the lower creek flow through rural, agricultural land, while the preceding 27.6 miles flow through the suburbs of Gahanna, Whitehall, Reynoldsburg, Obetz and Groveport, in addition to the city of Columbus.

The lower Big Walnut Creek watershed (Fig. 3) is highly developed, and it has been for many years. As of 1994, 14.8% of the Lower Big Walnut Creek watershed was developed/urbanized, 56.7% was devoted to agriculture, 22.9% was forested, 1.9% was open water, 0.9% was wetlands, and the remaining 2.9% was barren (Friends of Big Walnut Creek 2006). This corresponds to over seventy percent of the watershed being used for human activity twenty years ago. Meanwhile, a 2012 MORPC (Mid-Ohio Regional Planning Commission) publication for the entire (upper and lower) Big Walnut Creek watershed states that 35% of the land in the total watershed is agricultural, 52.6% is developed (with 42.2% of that developed land being residential), and the remaining land is devoted to open spaces, parks, and undeveloped land. The Lower Big Walnut Creek Watershed is far more populous than the Upper Big Walnut Creek watershed. The US Census Bureau estimated that in 2000, 222,260 lived in the lower watershed, and MORPC projected that to grow to 320, 652 by 2030. Consequently, the 99,419 houses found in the lower watershed in 2000 were projected to grow to 143,350 by 2030 (Friends of Big Walnut Creek 2006). The Lower Big Walnut Creek watershed occurs almost entirely in Franklin County, which includes the city of Columbus; the county had a 2013 population of 1,212,263 people. Meanwhile, the Upper Big Walnut Creek Watershed occurs in Morrow and Delaware counties, which had 2013 populations of 35,033 and 184,979 people respectively (US Census Bureau 2014). Additionally, Franklin County had an estimated 535,094 housing units in 2013, while Morrow County had only 14,040, and Delaware 42,374 (US Census Bureau 2014). The number of people living in the Lower Big Walnut Creek watershed exceeds the number of people living in Morrow and Delaware counties together, and the upper watershed does not even include the entirety of either county. Therefore, the majority of the development reported by MORPC (2012) likely exists in the lower watershed, and therefore the consequences of that development are extremely important for the integrity of the lower section of Big Walnut Creek.

Since the lower Big Walnut Creek watershed is significantly developed, concern has arisen in recent years over the integrity of the creek and its larger watershed. The population of Franklin County (including most of the Big Walnut Creek watershed) is continually growing, and therefore new land is being developed constantly. As it is established that anthropogenic land use negatively impacts water quality, and that urbanization and agriculture (the two biggest uses of land in Franklin County) are among the most harmful human land uses to waterways (note that though they are among the most ecologically harmful uses of land, they are not the absolute most harmful), it seems imperative to monitor the status of the creek, to ensure that it is not being significantly harmed by development and urbanization.

It is known that the integrity of the creek has been historically compromised. Part of this is attributed to hypolimnetic release of water from Hoover Reservoir, as well as runoff into the creek from suburban areas leading to elevated nutrients, high bacterial counts, and contaminated sediment at sites within the creek (MORPC 2012). Additionally, there have been numerous recorded spills of various harmful materials into the creek (OEPA 2003). This has historically damaged fish, macroinvertebrate and mussel communities, however the former two have currently recovered to almost meet Exceptional Warm Water Habitat designation (OEPA 2000, MORPC 2012). Meanwhile, the mussel community within the creek has yet to recover entirely (Hoggarth and Grumney 2013), and as mussels are known to serve as an indicator species for overall creek health, it is important to determine why mussel communities are still suffering in the creek (Fig. 4).

Towards the completion of this goal, Hoggarth and Grumney (2013) began to assess the state of the lower section of Big Walnut Creek, studying the distribution and abundance of mussels in the creek. They sampled mussel communities at twenty-one sites in the lower portion of the creek below Hoover Dam, using timed visual searches, quadrat sampling, and transect lines (Hoggarth and Grumney 2013). They calculated a mussel IBI for these sites, and compared their data to the Shannon-Wiener Diversity Index (H'), the Jaccard Coefficient of Similarity, and Ohio EPA (OEPA) data for the stream from 2000 (in the form of fish IBI and ICI data). Hoggarth and Grumney (2013) found that the mussel community in the upper third of the lower watershed had the highest diversity and m-IBI scores, the middle third had the lowest diversity and m-IBI scores, and the lower third had intermediate diversity and m-IBI scores (Fig. 4). The purpose of the current study therefore was to examine watershed metrics that could be used to understand recovery of some communities (fish and macroinvertebrates) and the potential for recovery of other communities (mussels). The first objective of this study was to compare Hoggarth and Grumney's mussel-IBI data to historical Ohio EPA biometric data, to determine if there is any agreement between the data sets. This would indicate whether the status of the creek has changed significantly in the period of time between the calculations of the biometric scoring systems for the creek. The mussels in Big Walnut Creek had not been extensively studied before; however, the creek is known to be near mussel rich waterways, and therefore likely should support a diverse mussel community (Hoggarth and Grumney 2013). As mentioned before, the creek has experienced periods of historical degradation, and while fish and invertebrate communities in the lower section of the creek have rebounded, the mussels have not. So, the second objective of this study was to determine why the mussel communities have yet to recover, by attempting to identify potential causes of water quality decline. This was accomplished by studying land use in the area, and attempting to correlate it with changes seen in water quality. The ultimate aim of understanding why mussel communities have yet to rebound is to determine their potential for recovery; determining exactly what is harming mussel communities will allow for appropriate management techniques within the watershed to promote their recovery, if feasible. So, the overall purpose of this study was to determine if the integrity of the lower section of the creek had changed significantly in recent years, if so to determine why, and finally to use that information to assess the potential for mussel communities to recover from historical degradation.

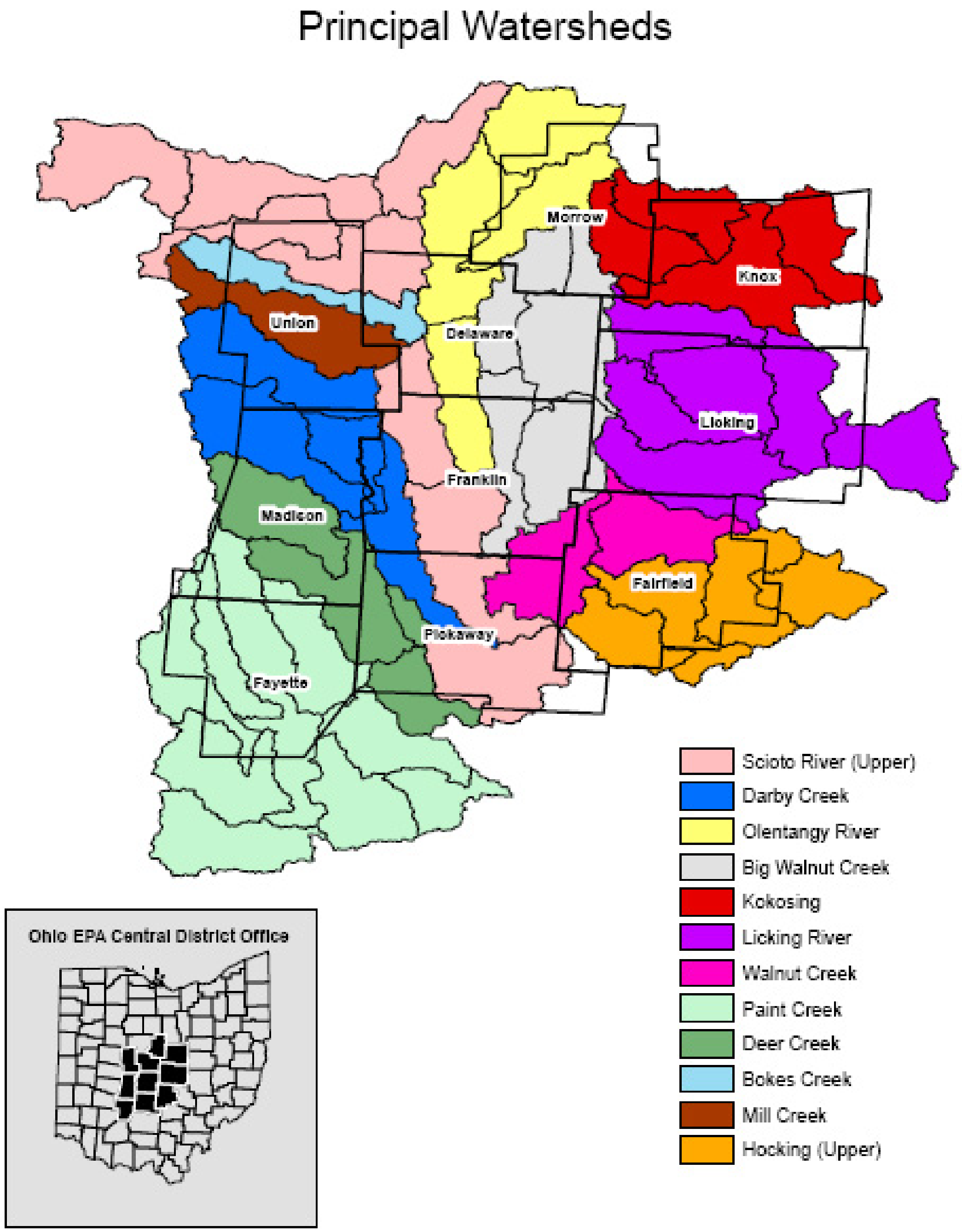

Figure 1. Map of Ohio Watersheds. The lower Big Walnut Creek watershed consists of the portion of the watershed located in Franklin County as well as a small area of land in Pickaway County (OEPA 2015).

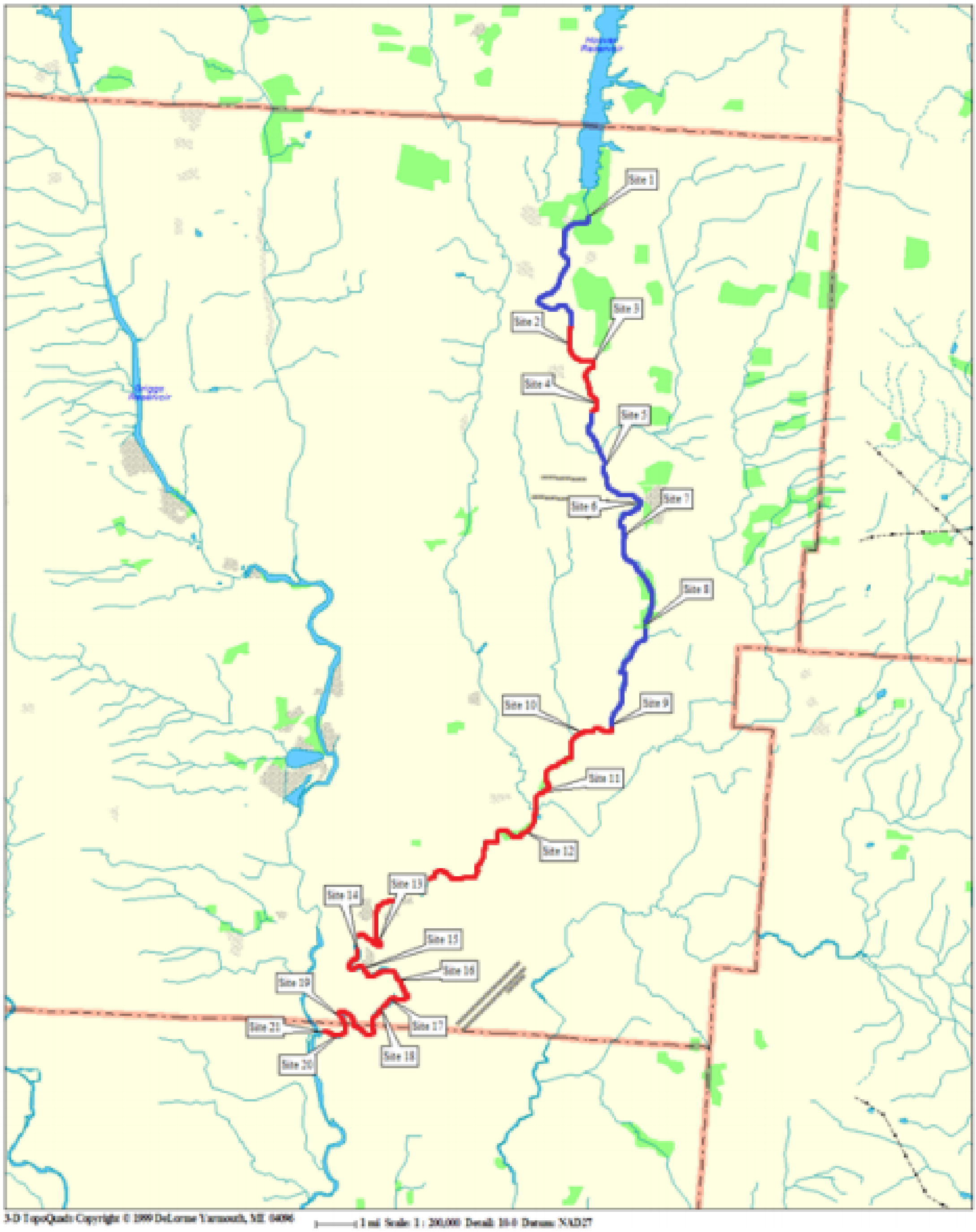

Figure 2. Lower Big Walnut Creek watershed site map from Hoggarth and Grumney (2013).

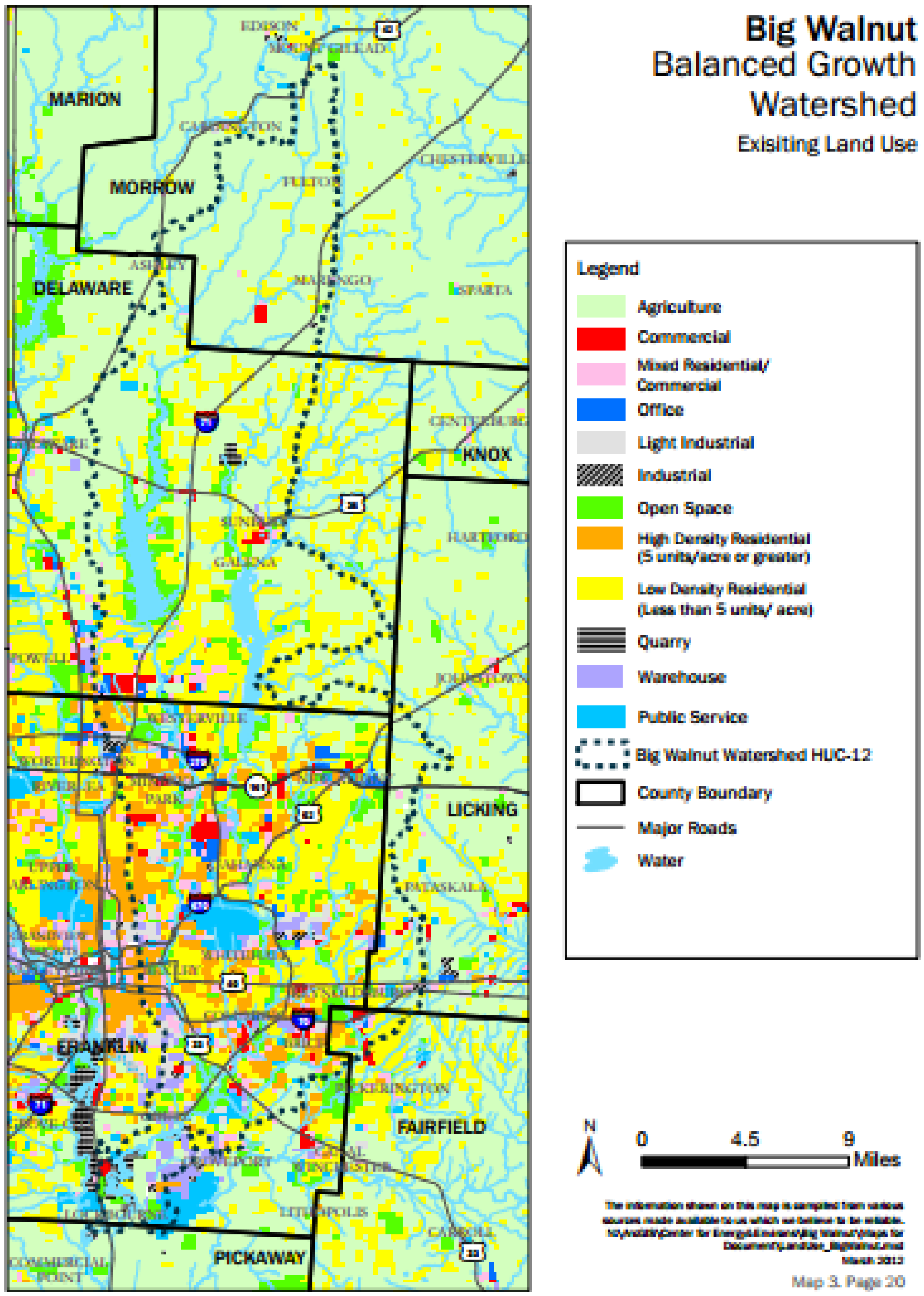

Figure 3: 2012 land use in the Big Walnut Creek Watershed. Hoover Reservoir is the large lake that begins just south of Galena and continues northeast of Westerville (MORPC 2012).

Materials and Methods

Comparison of recent and historical data for the Lower Big Walnut Creek

This study began with a comparison of the mussel-IBI (m-IBI) data collected by Hoggarth and Grumney (2013) to historical creek data. This was performed to determine if the status of the waterway changed significantly in the time period between the collections of the data sets. Data obtained from Hoggarth and Grumney (2013), measured at twenty-one sites located in the lower section of Big Walnut Creek, included: site location (longitude and latitude), m-IBI score (Table 4, Table 6), water temperature (˚C), dissolved oxygen (mg/L), pH, conductivity (uS/cm), turbidity (NTU units), H' total, percent mussels extant, and Jaccard percent similarity (Table 5).

Most historical data for the creek came from the Ohio Environmental Protection Agency's (OEPA) *Biological and Water Quality Study of the Big Walnut Creek Basin 2000* report (Table 7); a limited amount of data were taken from the OEPA's 2005 Total Maximum Daily Loads for the Big Walnut Creek Watershed report. These reports included data from twelve sites across lower Big Walnut Creek including fish-based IBI scores, (f-IBI), ICI, MIWB, and QHEI. For eight of these sites, data were available describing average water temperature (˚C), dissolved oxygen (mg/L), and dissolved nutrients found in the water, such as total phosphorus, calcium, and nitrogen. Furthermore, the 2000 OEPA report contained more specific chemical data for four of these sites, describing both nutrients and pollutants found in the water.

m-IBI data were compared to the OEPA f-IBI, ICI, QHEI and MIWB data, using linear regression. All linear regression for this project was performed in Microsoft Excel, and consisted of calculating both r^2 and p-values. Additionally, linear regression was used to compare the biometric data score to the location in the creek at which it was measured (to look for any linear trends in the biometric tool scores). Mean IBI scores were calculated for both m-IBI and f-IBI, and the two values were compared with a student-t test. Finally, the OEPA biometric data sets were compared to each other, using linear regression, to determine any correlations.

Assessment of the disparity between m-IBI and OEPA findings: causes of water quality decline

Once the disagreement between m-IBI and historical creek data was proven significant, analysis was done to determine possible historical causes of degradation in the creek. This was accomplished by analysis of available documents detailing water quality history for the creek, which were obtained from the OEPA and the Ohio Department of Natural Resources (ODNR). Land use, and temporal changes in it, was studied using satellite imagery acquired from Google Earth for the current and past states of the creek.

Riparian Analysis

The first characteristic of the creek studied as a variable for comparison with m-IBI data was the width of the riparian zone surrounding the creek (Table 1). Measurements were made, in meters, using visual estimation of Google Earth satellite images and the ruler tool on Google Earth. First, riparian zone width was measured at every rive mile in the lower section of the creek, starting from Hoover Dam and continuing until the convergence of the creek with the Scioto River (yielding a total of 38 measurements). The right and left riparian zones were measured separately, and their widths were summed. These data were then compared to position within the creek, using linear regression, to look for any linear trends in riparian width.

Next, riparian zones were measured for the twenty-one m-IBI sites, using the above methodology. These data were compared to both position in the creek and m-IBI scores, using linear regression. Similarly, riparian zone width was measured for the OEPA biometric sites, and compared to index score using linear regression. A historical study of the riparian zone was also performed, using historical satellite imagery from Google Earth. The riparian zone was measured at the twenty-one m-IBI sites for 1994 and 2002 (the earliest available date, and the date nearest the collection of the OEPA data); present day riparian width data was already measured. The three data sets were analyzed to determine if the width of the riparian zone had changed significantly over time, using both linear regression and student-t tests.

In addition to comparison with m-IBI data, the present day riparian width data were compared to the other data collected by Hoggarth and Grumney, including: conductivity, water temperature, pH, dissolved oxygen, turbidity, H' total, percent mussels extant, and Jaccard percent similarity. Finally, the width of the actual creek was measured (Table 1), in meters, for comparison with m-IBI data. This was performed based on the conclusion of Strayer (1993), that stream size appears to be a significant predictive factor for mussel species richness.

Scoring System Data

Next, land use in the lower Big Walnut Creek watershed was analyzed, to determine its effects on water quality. This was accomplished using Google Earth, which provided present and historical satellite imagery of the creek region, the ruler measuring tool, and the polygon area-measuring tool (this feature was available only in Google Earth Pro). To begin this part of the study, a 1 km x 1 km box was drawn centered around each m-IBI site (the box was drawn with the satellite image zoomed to street view); each box would serve as a sample region in which land use metrics could be studied and compared to m-IBI scores. Multiple metrics were studied within each sample region, including percent plant cover, percent land developed, road density, and general number of residential buildings. These data sets were all gathered using the polygon tool on Google Earth Pro to draw a polygon over the desired feature of the landscape wherever it was determined to be present within the sample region. The number of residential buildings was not a measure of area, and therefore buildings were visually identified and counted without this tool. Google Earth Pro provides the area of any polygon drawn, and thus the sum total of all polygons drawn in a sample region representing a land use metric were summed and divided by sample region area.

To study percent plant cover, polygons were drawn over all forested lands, and over all large regions of green space; large open parks covered in grass, with few buildings or roads, were considered to be covered by vegetation whereas small or very small green spaces, such as individual lawns and parking lot medians, were unable to be included for practicalities sake (and because they are not large enough to provide significant naturally functioning habitat). This metric was studied at the full scale, and also at a one-fourth scale sample region, to determine if the results would be affected by sample region size. Percent land developed included residential lands, roads, commercially developed lands, and heavily farmed fields that lacked vegetation altogether (and had been clearly plowed). Road density included all paved roads and long driveways when possible; dirt roads and paths were not included. Finally, estimated numbers of residential buildings were counted by visually identifying the number of distinct housing units within each sample site. Data were not readily available for housing population, so multiple family homes were counted as one residential building, and therefore the validity of this data is likely less than that of the other metrics collected.

All of the land use data (Table 2) were compared to m-IBI scores with linear regression. Additionally, percent plant cover was determined, using the same methodology, for the OEPA biometric score sites (Table 3) using 2002 satellite imagery, to compare to the f-IBI, ICI, QHEI and MIWB data. Finally, because it is often expected that the effects of land use can affect a creek downstream of the anthropogenic activity, a "downstream assessment" was performed, where the percent plant cover and percent land developed data were compared to the m-IBI score corresponding to one site downstream of where the activity was occurring. Principal component analysis was performed, in addition to linear regression, to analyze the scoring system data; however, since it failed to show anything significant (no correlations were found between m-IBI score and combinations of land use data sets), its results were not included in this report.

Census tract analysis

2010 census tract data (US Census Bureau, 2014) were obtained from the US Census Bureau. Census tracts were defined as containing a population of under two thousand people, two thousand to three thousand people, three thousand to four thousand people, four thousand to five thousand people, five thousand to six thousand people, or above six thousand. Each population size category was given a number, one corresponding to the least populated category (under two thousand), and six corresponding to the most populous category (over six thousand). Census tract population categories were identified for the area surrounding each of the m-IBI sites, and that was compared to m-IBI scores with linear regression.

Chemical Water Quality Analysis

This study concluded with a brief analysis of the chemical water quality of lower Big Walnut Creek. As stated, a variety of chemical data were available from the Hoggarth and Grumney (2013) paper (Table 5), the OEPA papers (Table 7), and from the USGS (2014) (Table 8), which had limited data detailing a variety of chemical sampling parameters dating back to the 1950s. Unfortunately, the USGS did not provide enough data points for many parameters to be able to compare with other data sources; sufficient data was only available to compare creek pH, water temperature and dissolved nitrogen (measured as nitrate + nitrite).

First, historical pH data were available from the USGS to study the average water pH with student t-tests. The USGS also provided enough data on water temperature to do a historical analysis. 95% confidence intervals were calculated for the 1960s, 1970s, 1990s, 2000s and 2010s, and compared to each other see if water temperature changed significantly; data was no provided for the 1980s.. No other chemical parameters were studied due to the limited amount of historical and modern data for the creek.

In addition to looking at physical and chemical parameters of the waterway, the last component of this study included an assessment of potentially harmful pollutants found in the lower Big Walnut Creek watershed. The OEPA 2000 creek report contains a detailed list of various chemical pollutants found in the creek, as well as a list of significant instances of point pollution – chemical spills – in the creek that occurred in 2000. A brief literature review was conducted to determine if any chemicals were present in the water that could have damaged water quality, and ultimately mussel communities (OEPA 2000, 2003; Bringolf *et al.* 2007; Auspsurger *et al.* 2009).

<u>Fieldwork</u>

Fieldwork was attempted to determine if large populations of dead mussels were present in the lower section of the creek, to determine if a distinct historical die-off could be identified. However, the desired mussel patch – first found by Hoggarth while preparing his m-IBI survey in 2013 – could not be located, and thus this part of the project could not be completed.

Results

Comparison of recent and historical data for the Lower Big Walnut Creek

All biometric data sets were compared to position within the creek (measured as river mile) using linear regression, to look for any notable trends in the biometric scores (i.e. if one index found a significant decline or increase in scores moving downstream of Hoover Dam towards the Scioto River). Comparisons included river mile/position and m-IBI (r^2= 0.042, p=0.414), MIWB (r^2= 0.0118, p=0.781), f-IBI (r^2= 0.206, p=0.220), QHEI (r^2= 0.0085, p=0.813), and ICI (r^2= 0.206, p=0.161). All r-squared values were relatively small, and p-values were insignificant, meaning that no significant correlations were found. Thus, no such directional trends were present for any of the biometric indices calculated for the lower section of Big Walnut Creek.

Next, the mussel IBI data collected by Hoggarth and Grumney (2013) were compared to the 2000 OEPA biometric indices (Fig. 5), to look for any significant correlations; these comparisons included m-IBI with f-IBI (r^2= 0.015, p=0.933), ICI (r^2=0.032, p=0.179), QHEI (r^2=0.5723, p=0.049) and MIWB (r^2=0.0028, p=0.0910). The m-IBI data were only found to be significantly correlated with the QHEI data, and this was found to be a negative, or inverse, correlation (further addressed in the discussion).

Mean m-IBI and f-IBI scores were compared using a student t-test to determine if Hoggarth and Grumney (2013) calculated a significantly different IBI from what the OEPA found in 2000. The mean m-IBI score was 47.78 with a standard deviation of 6.18, while the mean f-IBI score was 27.53 with standard deviation of 6.46. Thus, the mean IBI score determined in 2013 by Hoggarth and Grumney was significantly higher than what the OEPA determined it to be in 2000 (albeit they used different indicator species in their respective assessments).

Additionally, the OEPA biometric data sets were compared to each other using linear regression (Fig. 6), to determine their level of agreement. The comparisons included: f-IBI and ICI (r^2=0.6143, p=0.012), f-IBI and QHEI (r^2=0.1405, p=0.320), f-IBI and MIWB (r^2=0.6303, p=0.011), ICI and QHEI (r^2=0.016, p=0.919), ICI and MIWB (r^2=0.3328, p=0.102), and QHEI and MIWB (r^2=0.3364, p=0.104). The two comparisons that resulted in significant correlative relationships - f-IBI and ICI as well as f-IBI and MIWB- were positive or direct relationships.

Finally, both the OEPA and Hoggarth and Grumney provided data regarding dissolved oxygen (mg/L) and water temperature (C), both of which were compared using student t-tests. The mean water temperature found by Hoggarth and Grumney (17.94 C +/- 3.27 C) was not found to be significantly different from what the OEPA found (22.47 C +/- 1.45 C). Likewise, the value for dissolved oxygen (7.63 mg/L +/- 0.75 mg/L) was not found to be significantly different from what the OEPA found (7.66 mg/L +/- 1.13 mg/L). So, although the mean IBI score for the creek was found to have changed – improved - significantly in the time period between the calculations of the two IBIs, neither the mean water temperature or dissolved oxygen concentration seemed to change significantly.

Assessment of the disparity between m-IBI and OEPA findings: causes of water quality decline

Riparian Analysis

Riparian zone width was measured at each river mile and compared to position (Fig. 8) within the creek (r^2=0.0037, p=0.717) to determine if the width of riparian corridor changed in a linear fashion moving downstream (which could potentially explain changes seen in water quality moving downstream, if such trends in water quality were found). Indicated by the extremely low r-squared value, and high p-value, no such relationship was determined to be present. Riparian zone width was also measured at the m-IBI sites, and compared to both m-IBI site number (r^2=0.0017, p=0.859) (Fig. 9), and the actual IBI scores (r^2=0.1069, p=0.185) (Fig. 10). This was intended to see if the width of the riparian corridor could explain changes in water quality (m-IBI score). Furthermore, riparian zone width was compared to the OEPA biometric data (Fig. 7), including f-IBI (r^2=0.0597, p=0.526), ICI (r^2=0.1475, p=0.244), QHEI (r^2=0.2708, p=0.151) and MIWB (r^2=0.0067, p=0.834). The relatively low r-squared values suggest that no significant relationship between m-IBI (nor any other biometric index) and riparian corridor width existed, meaning that the size of the riparian corridor could not be directly implicated in the quality of the water in the lower section of Big Walnut Creek.

Next, a historical assessment of the width of the riparian zone (Fig. 11) was conducted, to determine if the width had changed significantly over time (thus suggesting if temporal differences in it could be implicated in temporal changes seen in the water quality of the creek). This assessment was conducted looking at present day (2014) satellite imagery, 2002 satellite imagery (the date nearest the collection of the OEPA data) and 1994 satellite imagery (the earliest available satellite imagery). Mean riparian widths with standard deviations were calculated and compared for 2014, 2002 and 1994 data using student t-tests. The mean riparian zone widths were found to be: 198.76 m +/- 206.42 m (2014), 200.59 m +/- 204.82 m (2002) and 192.96 m +/- 205.57 m (1994). None of these were found to be significantly different from each other, meaning that the width of the riparian zone was generally constant between 1994 and 2014. Additionally, linear regression was performed comparing the three sets of historical riparian width data to the m-IBI data, and both r^2 and p values were calculated: 2014 (r^2= 0.0017, p= 0.859), 2002 (r^2=0.0017, p=0.88) and 1994 (r^2=0.0021, p=0.844).

Present day riparian zone width for the m-IBI sites was also compared to data collected by Hoggarth and Grumney (Fig. 13) including conductivity (r^2=0.0354 p=0.414), water temperature (r^2=0.2433, p=0.023), pH (r^2=0.0016, p=0.862), dissolved oxygen (r^2=0.2191, p=0.032), turbidity (r^2=0.0914, p=0.183), H' total (r^2=0.0121, p=0.635), percent mussels extant (r^2=0.05360, p=0.313) and Jaccard percent similarity (r^2=0.0644, p=0.267). This was done to analyze whether any of the data collected in 2013 correlated with the riparian width data, however no significant correlations were determined. Two relationships were determined to be significant: riparian width and dissolved oxygen (a direct relationship), and riparian width and temperature (an inverse relationship). For both relationships, the correlation is weak (r^2 is around 0.2 for both variables) however the p-value (>0.05) suggests that both relationships are significant. This is not surprising, as the status of the riparian corridor surrounding a waterway is very influential on the health of the creek. Although the exact reason why these correlations exists may not be clear, there are many possible reasons; for example, the riparian corridor may provide shade for the creek, keeping the water temperature lower, and oxygen is more soluble in colder water. So, this relationship is not unexpected, and only serves to reinforce the importance of the riparian zone in maintaining the integrity of a water resource.

Lastly, the creek width was also compared to m-IBI data (r^2=0.0006, p=0.923) (Fig. 12), to determine whether the actual width of the creek could directly affect the quality of the water in it. The extremely low r-squared value did not indicate such a relationship.

Scoring System Data

To begin to determine possible causes for significant differences in the quality of the water in Big Walnut Creek, m-IBI data were compared to a variety of land-use metrics measured for the land surrounding the creek (Fig. 14). Land use metrics were all studied in a 1 km x 1 km sampling region around each m-IBI site, including percent plant cover (r^2=0.1307, p= 0.14), percent land developed (r^2=0.2253, p=0.047), number of residential buildings (r^2=0.0779, p=0.262), and road density (r^2=0.0069, p= 0.744). Additionally, percent plant cover was studied in a sample region one-fourth of the size of the original sampling area (r^2=0.0232, p=0.547). The study of percent plant cover in a smaller sample region did not appear to make any difference, suggesting that studying the land-use metrics at a smaller scale would not yield any correlations not found in the current study. None of the measured land-use metrics appeared to correlate with the m-IBI scores, meaning that none of the studied land-use metrics determined the quality of water in the creek. The one exception to this is the percent of land developed; although only a weak correlation was determined, the p-value suggests that it is significant. However, the weak correlation found is a direct relationship, meaning that increasing development parallels improving m-IBI scores. This is unexpected, as it would seem that increasing development surrounding the creek should lead to increased impairment, not increased integrity. The primary uses of land surrounding the lower creek are detrimental to water quality, and as the development is not particularly sustainable, it should not be benefitting water quality. The exact mechanism behind this relationship is thus unclear, and more work would need to be done to determine if it is meaningful; perhaps because it is such a weak correlation (r^2 is low, and p is just barely significant), it might be discredited by future work.

Furthermore, percent plant cover was determined for the OEPA sites (Fig. 15) using 2002 satellite imagery, and compared to f-IBI (r^2=0.1845, p=0.228), ICI (r^2=0.0276, p=0.646), QHEI (r^2=0.2645, p=0.192) and MIWB (r^2=0.0044, p=0.876). No significant correlations were found, and therefore just as the land-use metrics studied did not appear to correlate with m-IBI, the one studied land-use metric did not appear to correlate with the OEPA biometric indices.

Finally, as it was suggested that anthropogenic land use could affect water quality downstream of the land itself, a downstream correlation was attempted (Fig. 16), where land use metrics were compared to the m-IBI score for the next site downstream of the site at which the land use metric was studied. The land use metrics observed included percent land developed (r^2=0.0003, p=0.946) and percent plant cover (r^2=0.005, p=0.787). The low r-squared values suggested that the land-use metrics studied did not affect water quality directly downstream.

Census Tract Analysis

Census tract population category data were compared to m-IBI (Fig. 17) via regression (r^2=0.0032, p=0.823) to determine if relative population density in the larger area surrounding the creek affected water quality. Again, nothing was found as the r-squared value was very low, and did not suggest a significant correlation between the two variables.

Chemical Water Quality Analysis

Average water pH was analyzed using student t-tests; mean water pH and standard deviations were calculated for the 1950s (7.77 +/- 0.26), the 1960s (7.68 +/-0.05), the 1970s (7.95 +/- 0.39), [no data were given for the 1980s] the 1990s (8.08 +/- 0.48) and the 2000s (7.48 +/- 0.22). Mean pH did not appear to change significantly between 1950 and 2000.

Next, average water temperature was calculated to determine if it changed significantly over time. Mean water temperature and standard deviation were calculated for the 1960s (19.5 C +/- 1.41 C), the 1970s (18.32 C +/- 2.53 C), [no data were given for the 1980s] the 1990s (20.81 C +/- 2.59 C), 2002 (22.66 C +/- 1 C) and 2012 (17.94 C +/- 1.43 C). Like pH, water temperature appeared to remain constant (statistically) over the past fifty years within the creek.

Pollution in Big Walnut Creek

As mentioned, many chemicals have been spilled into the creek resulting from a variety of methods of land use, and this has introduced a wide variety of harmful pollutants into the water, including heavy metals, oil, jet fuel, gasoline, sewage, and a variety of chemicals such as acetone and pyrene. The OEPA provides the concentrations or volumes of pollutants in the creek as known for measurements taken in 2000, however more recent data is not available. The presence of potentially harmful pollutants in the creek was quantified in 2000, however the persistence, mobility and toxicity of these pollutants was not studied. Furthermore, the lower section of Big Walnut Creek is met with multiple tributaries, and in particular, the middle section of the lower watershed is met by its two principal tributaries, Alum Creek and Blacklick creek. It is possible that the tributaries of Big Walnut Creek could be acting as point sources of pollution for the lower watershed. Pollution in the creek seems to be a likely problem, so the implications of this will be addressed further in the discussion.

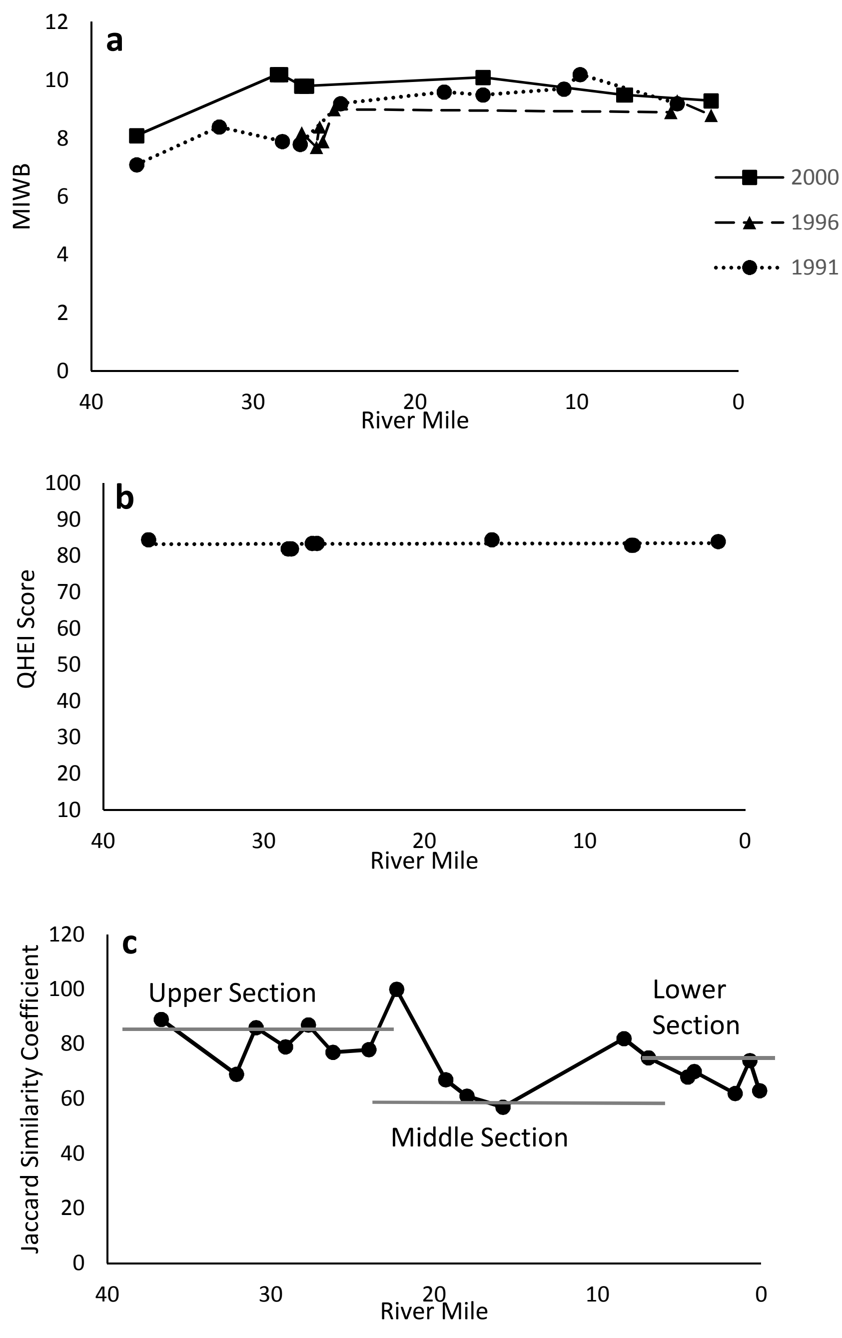

Figure 4. Current and historical status of the lower watershed of Big Walnut Creek. (a) MIWB data from the OEPA for 1991, 1996 and 2000, reflecting an increase in the status of the creek over time. (b) QHEI data from OEPA for 2000, suggesting high integrity of physical habitat surrounding creek. (c) Jaccard similarity coefficient from Hoggarth and Grumney (2013) displaying the trend determined in mussel communities in the creek, with the upper third of the lower watershed having the healthiest mussel communities, the middle third having the most damaged, and the lower third having mussel communities of an intermediate status.

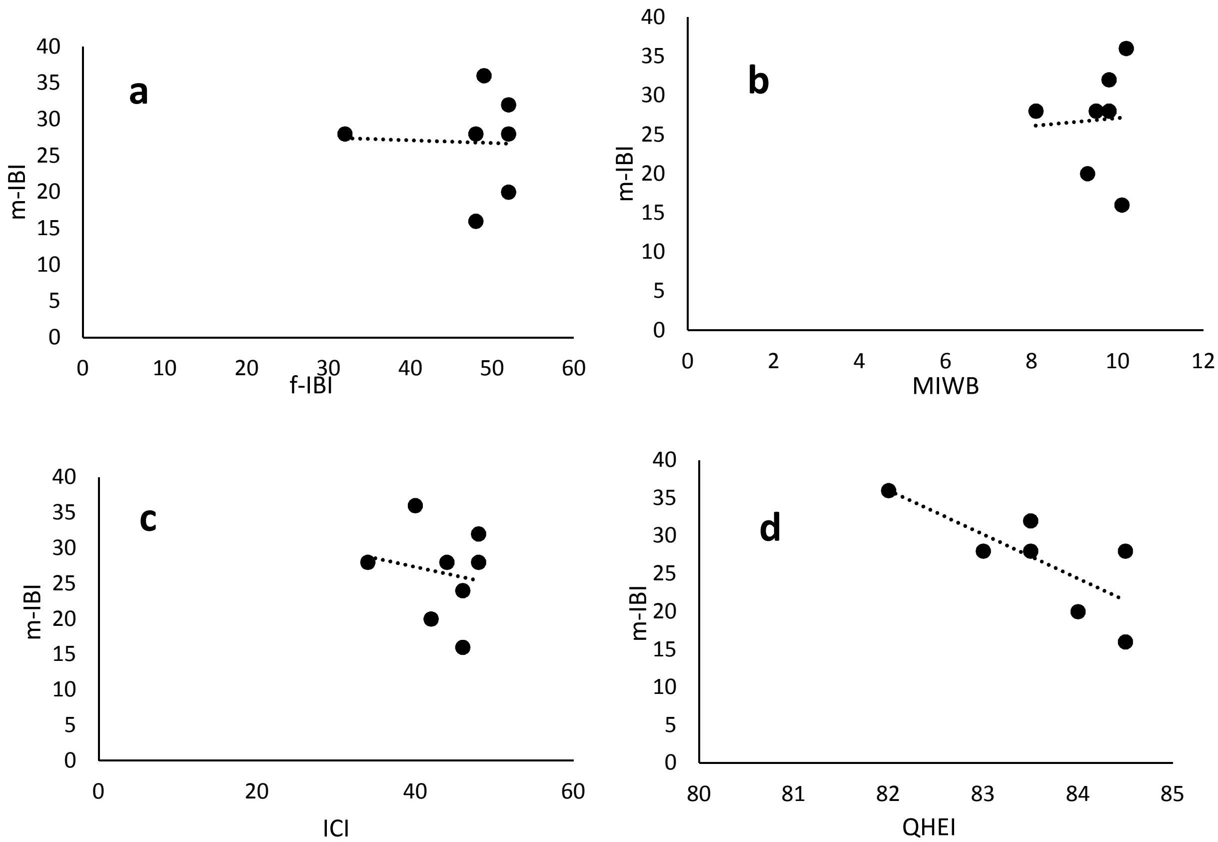

Figure 5. Comparison of m-IBI scores to OEPA biometric data sets, including (a) f-IBI (r^2=0.0015, p=0.933), (b) MIWB (r^2=0.0028, p=0.910), (c) ICI (r^2=0.032, p=0.179), and (d) QHEI (r^2=0.5723, p=0.049)

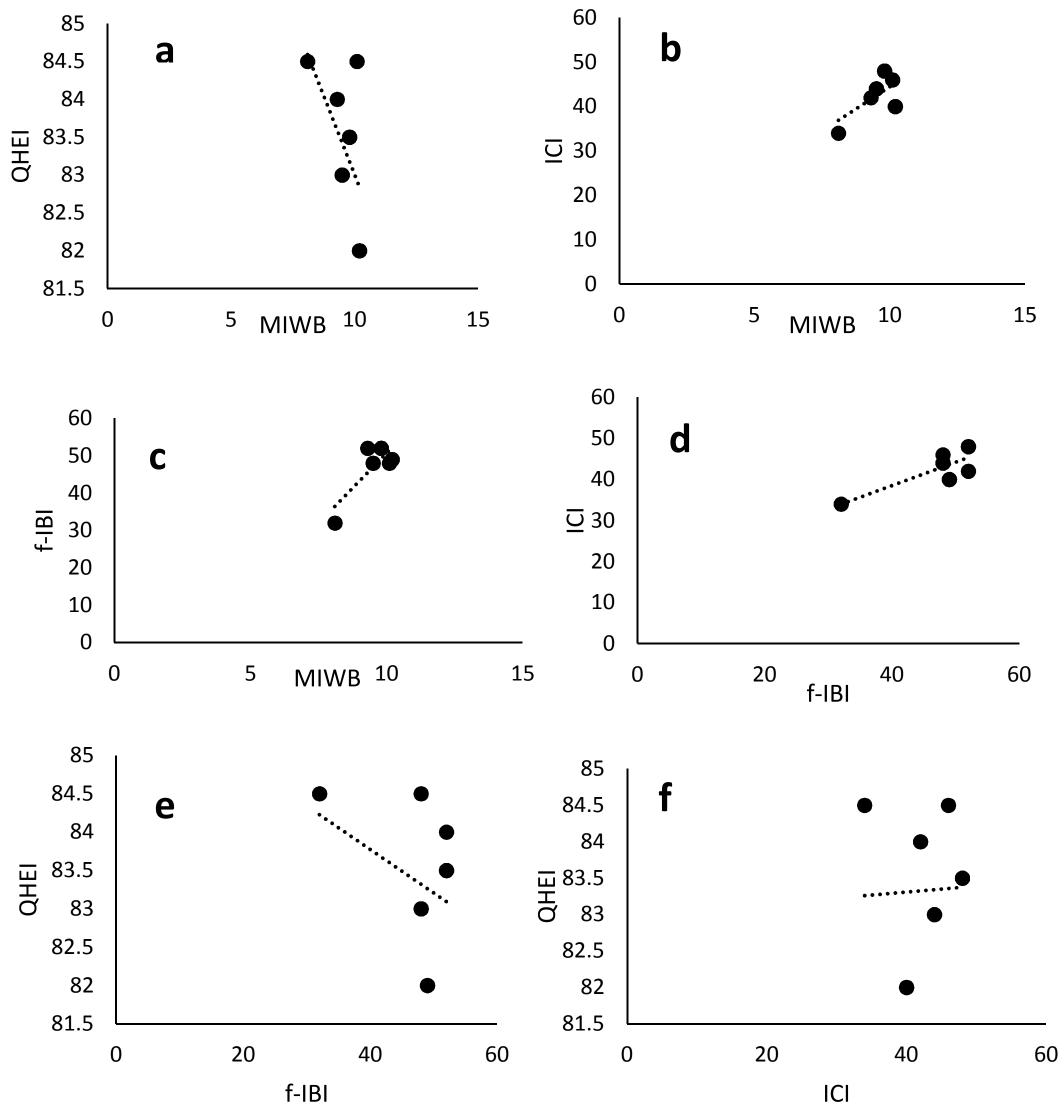

Figure 6. Comparisons of all OEPA biometric data sets to each other. Comparisons included (a) MIWB and QHEI (r^2=0.3364, p=0.104), (b) MIWB and ICI (r^2=0.3328, p=0.102), (c) MIWB and f-IBI (r^2=0.6303, p=0.011), (d) f-IBI and ICI (r^2=0.6143, p=0.012), (e) f-IBI and QHEI (r^2=0.1405, p=0.320), and (f) ICI and QHEI (r^2=0.0016, p=0.919).

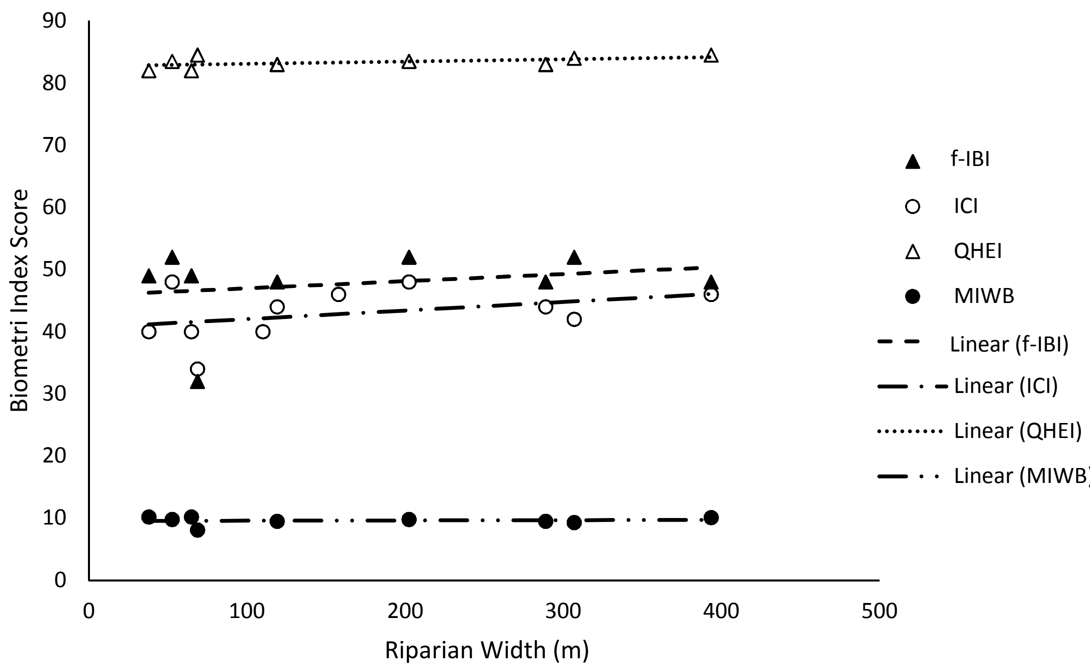

Figure 7. Comparison of all OEPA biometric data sets to riparian width for Big Walnut Creek. Comparisons included riparian width and f-IBI (r^2=0.0597, p=0.526), ICI (r^2=0.1475, p=0.244), QHEI (r^2=0.2708, p=0.151), and MIWB (r^2=0.0067, p=0.834).

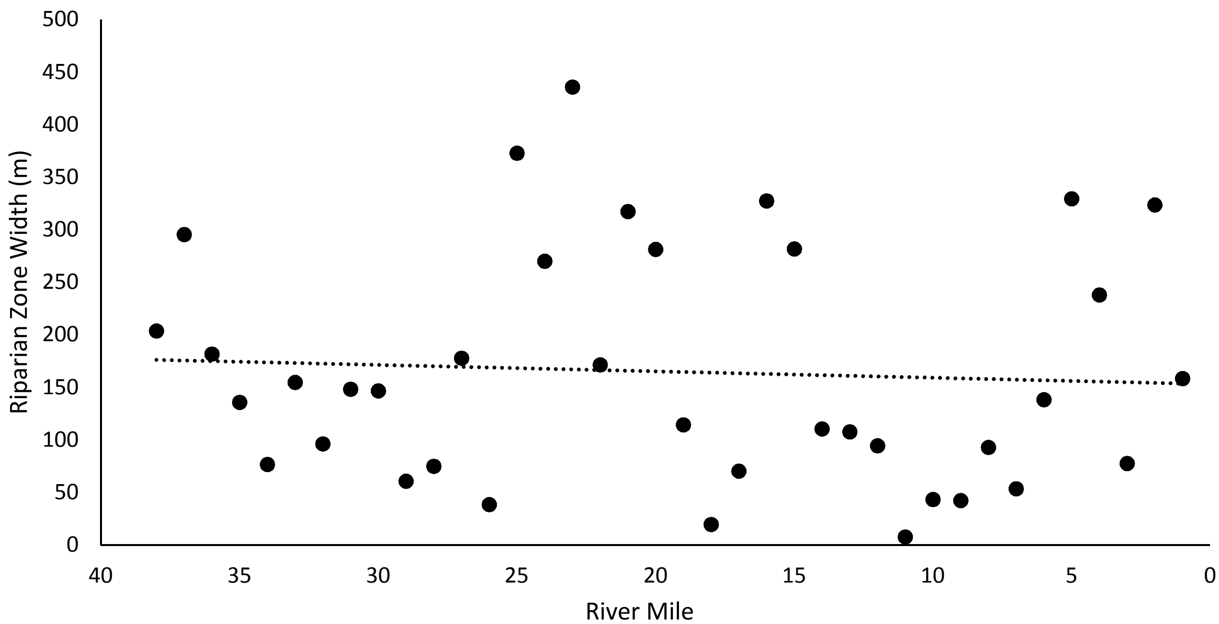

Figure 8. Comparison of riparian zone width, measured at every river mile downstream of Hoover Reservoir, with river mile (r^2=0.0037, p=0.717).

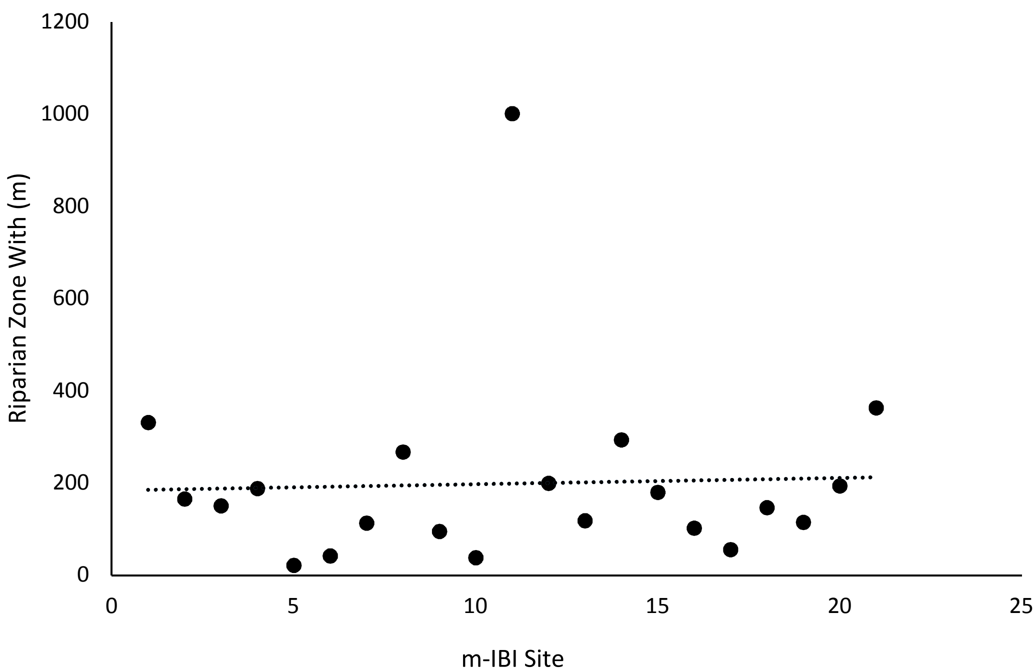

Figure 9. Comparison of riparian zone width to m-IBI site number (r^2=0.0017, p=0.859).

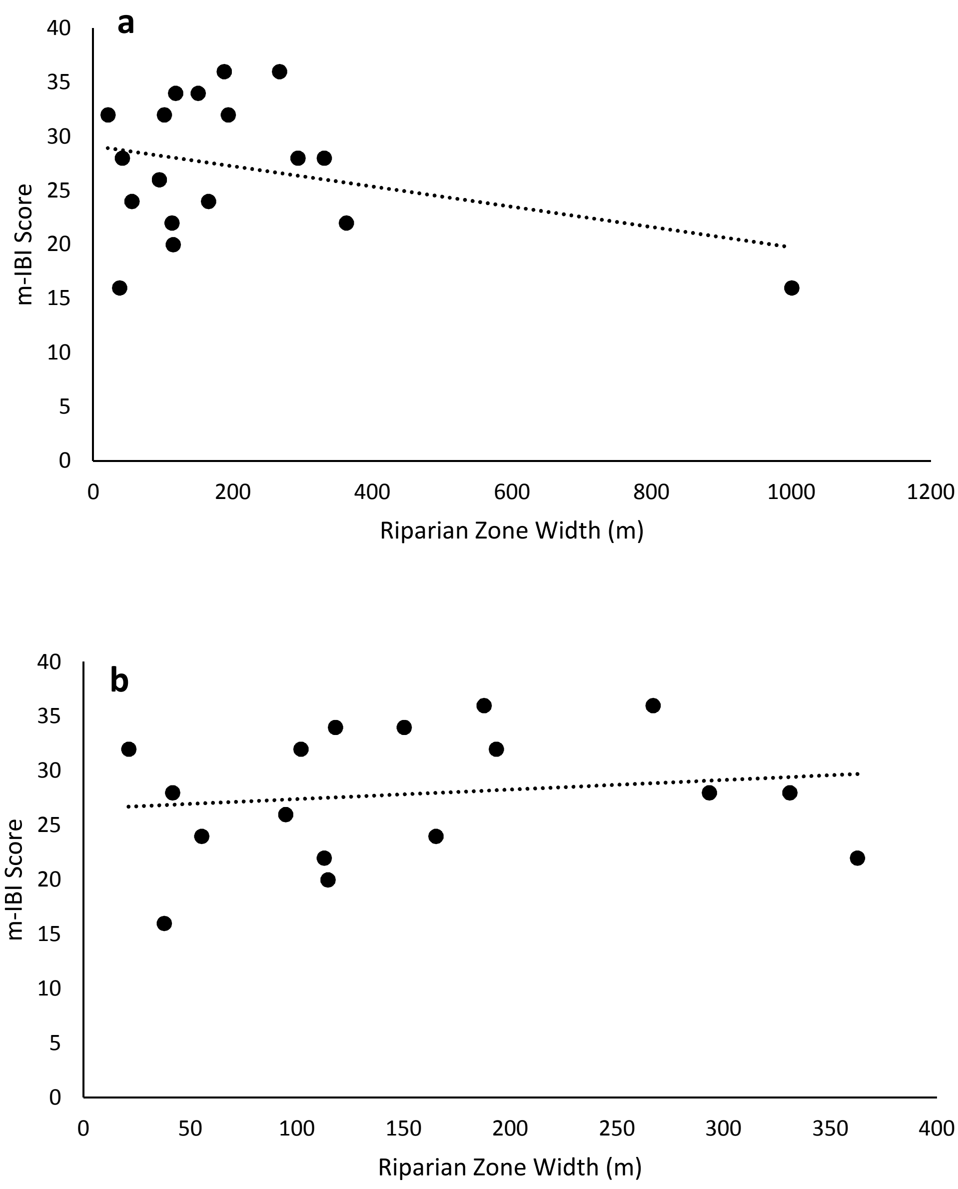

Figure 10. Comparison of riparian zone width and m-IBI score; (a) includes data for riparian zone widths measured at all m-IBI sites (r^2=0.1069, p=0.185) while (b) does not include a possible outlier. (r^2=0.0239, p=0.554).

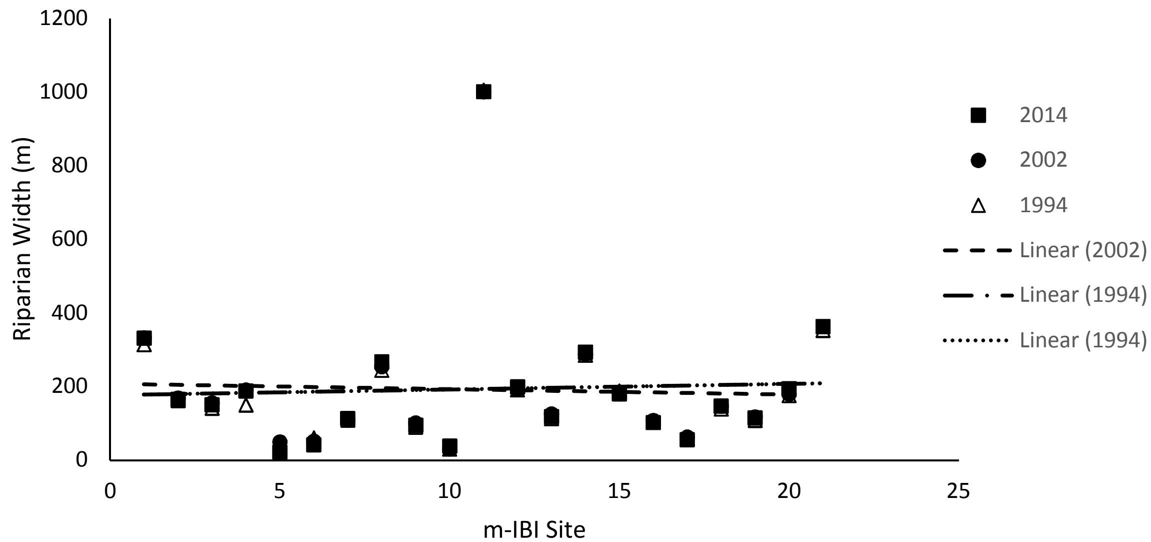

Figure 11. Historical analysis of the width of the riparian zone surrounding Big Walnut Creek, measured in 2014, 2002 and 1994. Riparian width measured in three different years was compared to m-IBI site number, to determine the presence of any trends in the riparian width moving downstream of Hoover Reservoir. Comparisons included riparian width and m-IBI site number in 2014 (r^2=0.0017, p=0.859), 2002 (r^2=0.0017, p=0.88) and 1994 (r^2=0.0021, p=0.844).

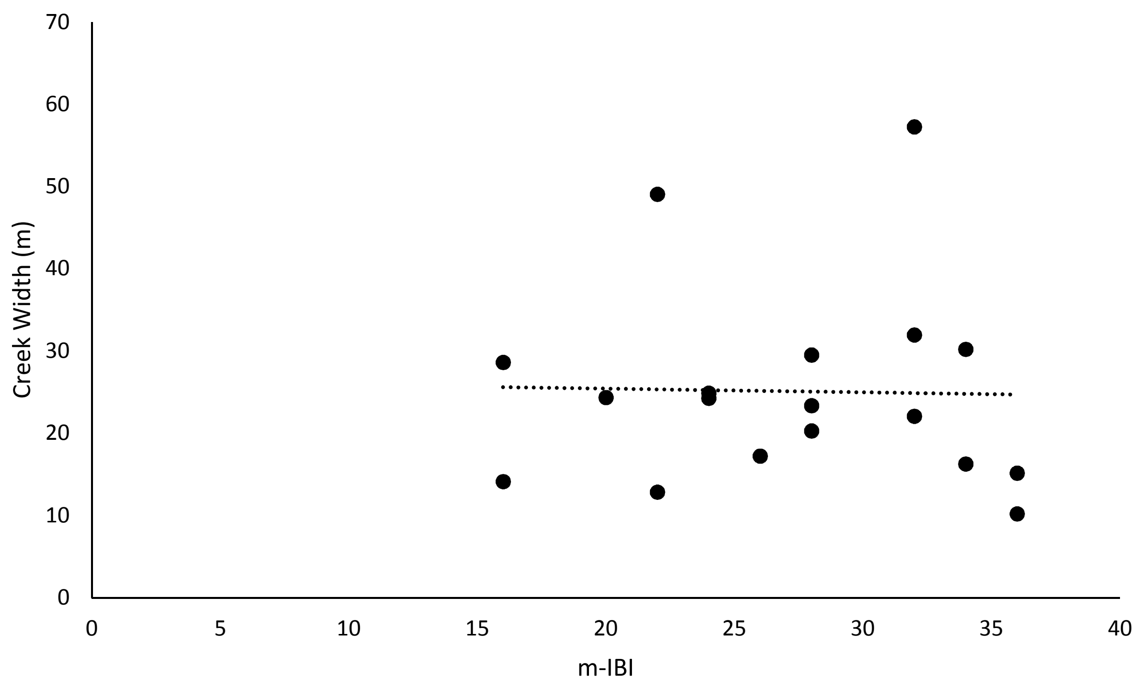

Figure 12. Comparison of creek width (m) to m-IBI score (creek width was measured at m-IBI sites) (r^2=0.0006, p=0.923).

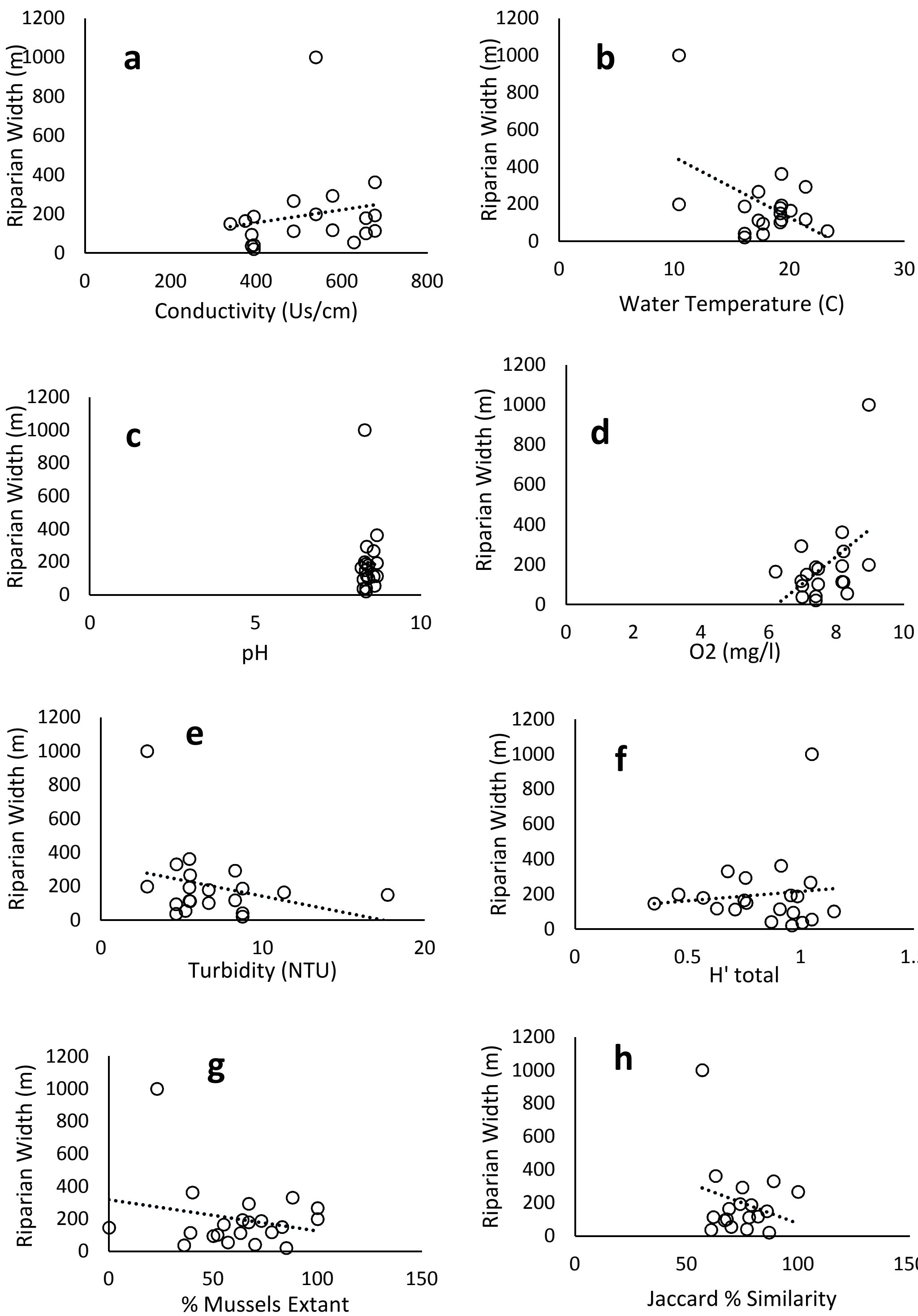

Figure 13. Comparison of riparian width data to Big Walnut Creek data collected by Hoggarth and Grumney (2013). Comparisons included riparian width and (a) conductivity (r^2=0.0354, p=0.414), (b) water temperature (r^2=0.2433, p=0.023),(c) pH (r^2=0.0016, p=0.862), (d) oxygen (r^2=0.2191, p=0.032), (e) turbidity (r^2=0.0914, p=0.183), (f) H' total (r^2=0.0121, p=0.635), (g) percent mussels extant (r^2=0.0536, p=0.313) and (h) Jaccard percent similarity (r^2=0.0644, p=0.267).

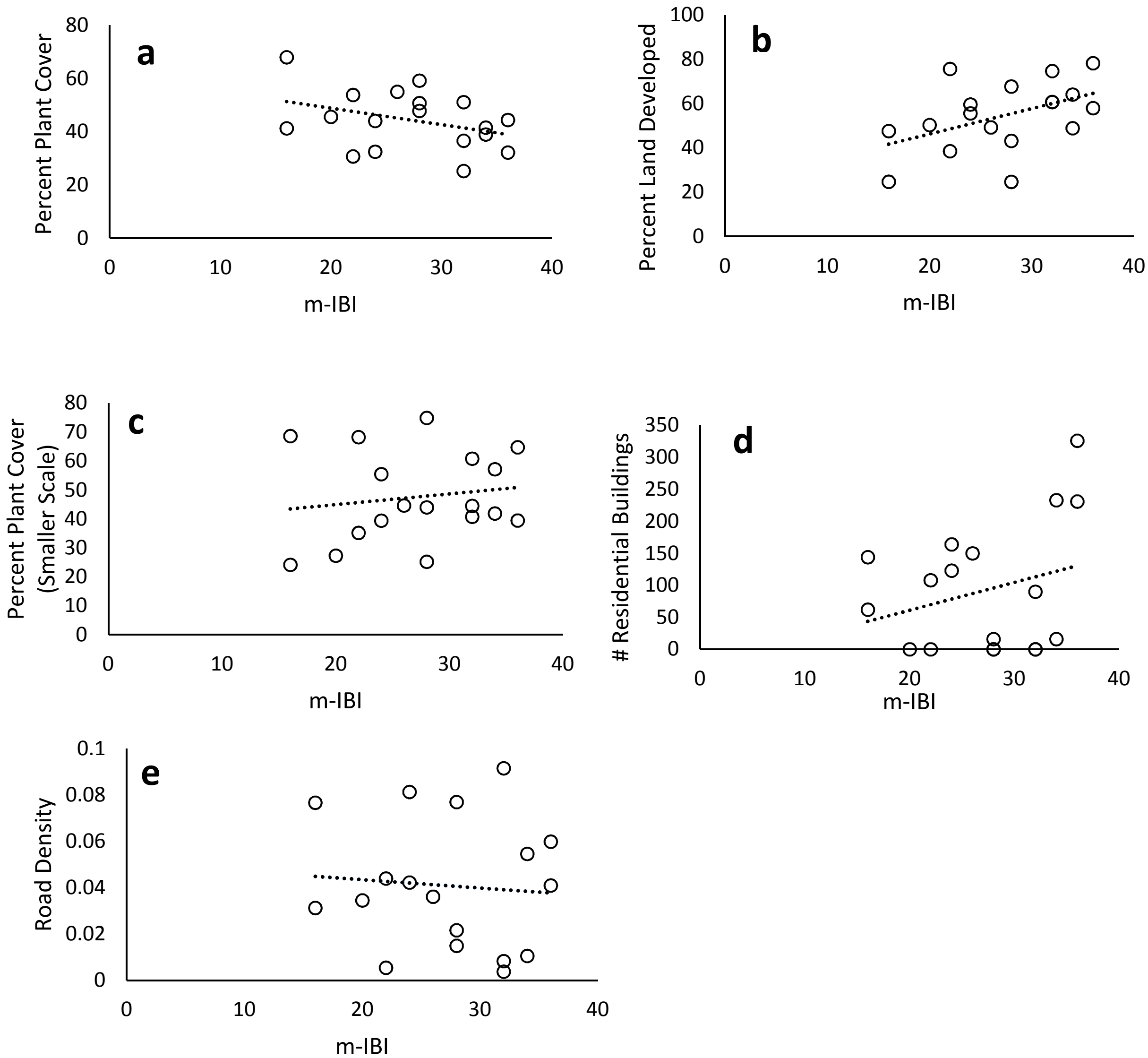

Figure 14. Comparisons of scoring system data to m-IBI data, including (a) percent plant cover (r^2=0.1307,p=0.140), (b) percent land developed (r^2=0.2253, p=0.047), (c) percent plant cover at a one-fourth scale (r^2=0.0232, p-0.547), (d) number of residential buildings (r^2=0.0779, p=0.262), and (e) road density (r^2=0.009, p=0.744).

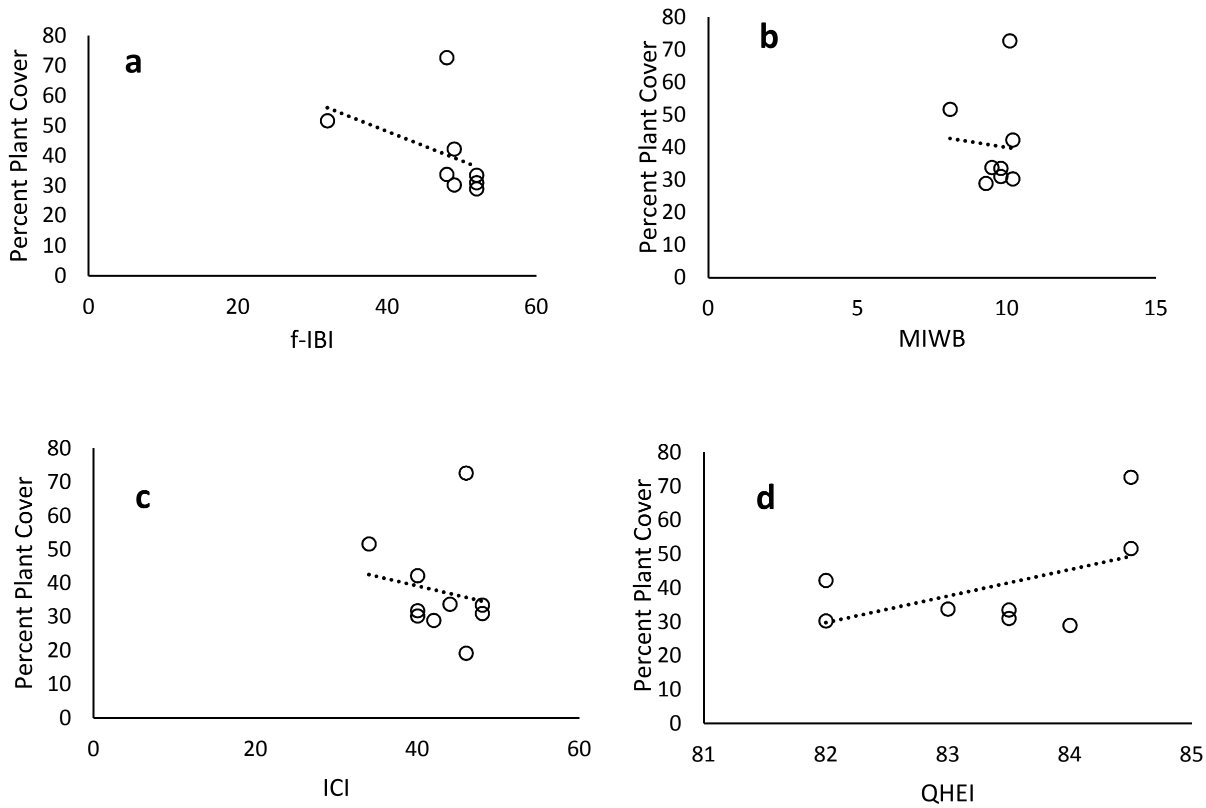

Figure 15. Comparisons of percent plant cover to OEPA biometric data, including percent plant cover and (a) f-IBI (r^2=0.1845,p=0.228), (b) MIWB (r^2=0.0044, p=0.876), (c) ICI (r^2=0.0276, p-0.646), and (d) QHEI (r^2=0.2645, p=0.192)

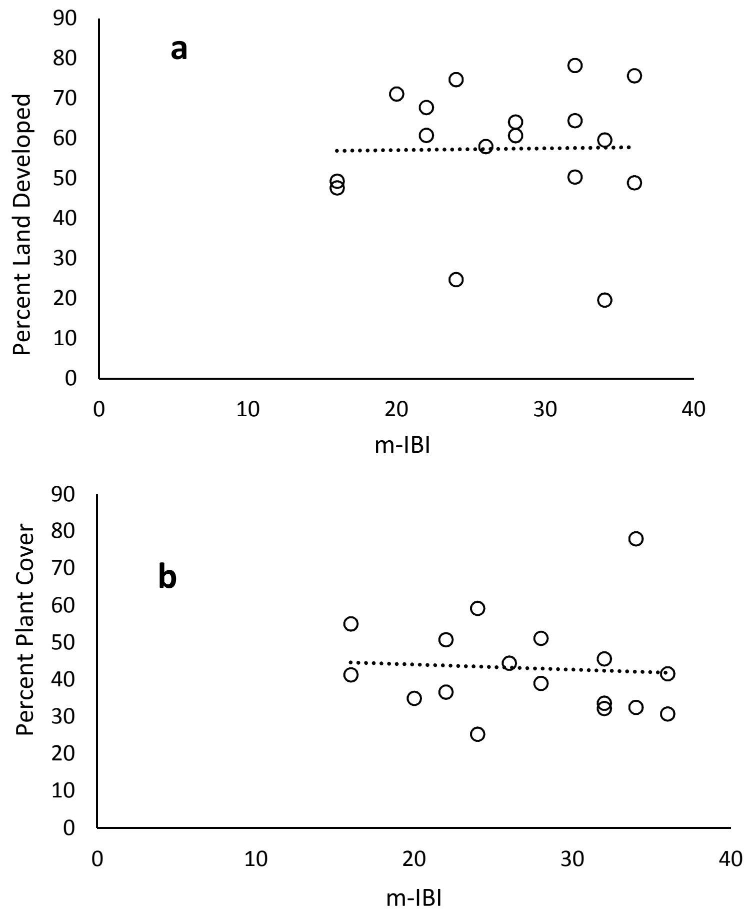

Figure 16. Attempted correlation between land use data and downstream m-IBI score, for both (a) percent land developed (r^2=0.0003, p=0.946) and (b) percent plant cover (r^2=0.005, p=0.787)

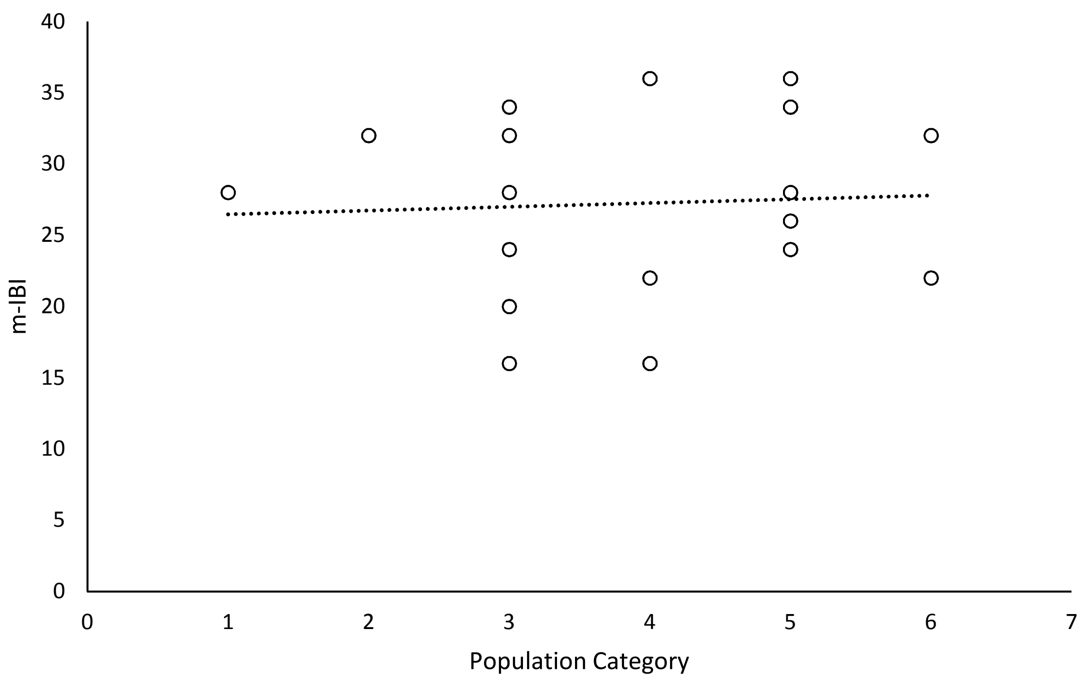

Figure 17. Comparison of census tract data (as a means of measuring population density) to m-IBI. Census tract population sizes were ordered on a numbered scale, and those numbers (representing the census tract in which each m-IBI site fell) were compared to m-IBI data (r^2=0.0032, p=0.823).

Discussion

Interpretation of Results – Differences between creek assessments

This project yielded significant findings regarding the status of the lower section of Big Walnut Creek. Note that conclusions supported by the data are exclusively applicable to the lower section of Big Walnut Creek, and may not apply to other water resources. First, the creek assessment performed by Hoggarth and Grumney in 2013 yielded significantly different information than the OEPA assessment in 2000, based mainly on comparison of m-IBI data with OEPA biometric indices (f-IBI, MIWB, QHEI & ICI). The results of the 2013 bioassessment suggested a significant increase in the health of the waterway in the thirteen years between the two studies, seen in the significant increase in mean IBI score between 2000 and 2013. Although the IBIs calculated in the two assessments were based on very different indicator species (fish versus mussels) IBIs are intended to assess an entire habitat (and not simply the indicator species in that habitat), thus the fish and mussel data can be compared. So, the first important finding of this study was the substantial improvement in the water quality found in the lower section of Big Walnut Creek.

Next, no linear trends in water quality were found moving downstream of Hoover Reservoir (from comparisons of biometric indices with river mile), and this might rule out the possibility of activity at a certain site damaging the creek and all sites downstream of it (i.e. the dam is not significantly affecting the entire lower section of the creek). So, it could be the case that water quality is either dependent on activity occurring locally to the sites at which it is measured, or conversely that the quality of water in the creek depends on larger-scale activities happening at the watershed level, which cannot be reflected in any sort of linear trend within one section of a mid-sized creek.

The m-IBI data did not correlate with any of the OEPA biometric indices, bolstering the difference between the two assessments of the creek. The sole exception to this is the negative correlation between m-IBI and QHEI; however, this correlation is probably negligible. The QHEI scores all fall within such a small range (about three points on the QHEI scale) that any determined correlations with QHEI data may not be reflective of a significant trend (i.e. it is not particularly meaningful that certain m-IBI scores seem to correlate with a QHEI score of 85, while others correlate with a score of 82, as both are exceptionally high QHEI scores).

Some of the OEPA biometric indices did correlate with each other; f-IBI and ICI, as well as f-IBI and MIWB, were found to have significant, direct relationships indicating that they found similar patterns of water quality. No other OEPA biometrics were found to significantly correlate, which again could be attributable to differences in index score range. This was a means of determining that the OEPA data supported their results regarding the quality of the creek, and the positive linear relationships seen did that.

Finally, the brief chemical comparison suggested that neither dissolved oxygen, pH, nor temperature differed significantly between creek assessments. That these three chemical attributes of the creek did not change significantly between the assessments suggests some stability in the environment in the time between assessments. For example, more release of cold water from the dam did not significantly lower water temperature, nor was the riparian zone destroyed entirely so that water temperature rose significantly (which in turn would affect oxygen levels in the water). However, though perhaps some physical stability was seen in the general region surrounding the creek, the substantial increase in mean IBI scores is more meaningful data; there is much more of it, and it is more robust data. Overall, the quality of the water in the lower section of Big Walnut Creek has improved significantly since 2000.

Interpretation of Results – Improvement in water quality, methods of land use, and mussels

As stated above, the quality of the water in the lower section of Big Walnut Creek improved significantly since 2000. After a largely unknown period(s) of historical degradation, the fish and invertebrate communities in the creek are thriving. However, based on the conclusions of Hoggarth and Grumney (2013), the mussels in the creek are currently suffering. Hoggarth and Grumney (2013) found diminished species diversity in the creek, and fewer extant populations of mussels known to have previously been established in the water. In their assessment, they divided the lower section of the creek into three parts (sites 1-7, sites 8-14 and sites 15-21), and they noted that the upper section (sites 1-7) had significantly better mussel communities – considering diversity and m-IBI scores – than the middle (sites 8-14) and lower (sites 15-21) sections. They did not ultimately determine the cause for this pattern, however they put forth a few suggestions. Sites 1-4 are surrounded by dams, and therefore the fish host species that mussel larva depend on may not be able to be transported to those sites. However, sites 1-4 were not seen to be suffering the most, and therefore this would not explain trends in the rest of the creek. Nothing was determined for the middle section, as they did not determine the presence of excess nutrients or obvious pollutants (both of which would be detrimental to mussel communities in the creek). They determined the middle section to have narrow riparian corridors, however this study analyzed the riparian width relative to m-IBI data, and found no correlation. Hoggarth and Grumney (2013) discussed briefly the presence of various development around the creek, as a potential source of damage to the water and mussels in it, and therefore this study looked in depth at land use surrounding the m-IBI sites.

Present day riparian width was measured, and was not found to be significantly related to the m-IBI scores, suggesting that the riparian width (as suggested by Hoggarth and Grumney) is not particularly influential regarding the biometric index score. This was surprising, as it is well established that riparian zones are very important in maintaining high water quality, and there was considerable fluctuation in the widths of the riparian zone moving down the studied section of the creek. Because the riparian zone was (due to limited time) measured using satellite imagery, it is possible that the measurements made could be slightly inaccurate. Measurements were made twice to ensure that similar results were yielded, however it is difficult to determine the functional riparian zone of a waterway without assessing it in person. However, assuming the reliability of the data collected for this assessment, the riparian zone width did not significantly affect the m-IBI scores, and thus something else should be to blame for the decline observed in mussels in the lower section of the creek. This seems reasonable, as it was determined that the width of the riparian zone had not changed significantly at least since 1994, while the water quality had. If water quality improved in recent years, but riparian zone width did not, the two variables are likely not related to each other. There are likely other variables that could be used to assess the quality of the riparian zone (i.e. plant community diversity) however they could not be performed from satellite data used for this project. Future research with different types of imagery - such as GIS, infrared or color based imagery - would be pertinent to validate the results found in this study. Additionally, creek width did not correlate with m-IBI data, suggesting that, like riparian width, it could not explain trends seen in the m-IBI data.

Next, because the mussels in the creek were established by Hoggarth and Grumney (2013) to be suffering, and they suggested land development as a cause of that, land use surrounding the creek was studied. However, no studied metrics were found to correlate with m-IBI data; neither percent plant cover data, road density, nor general number of residential buildings were found to be significantly correlated to the m-IBI data. The percent land developed data was found to be weakly however (just barely) significantly positively correlated to m-IBI score. Again, this is suspicious, and will not be accepted as a truly significant relationship without further data to support it. Similarly, the population density data (the census tract population category data) did not correlate with m-IBI data. So, none of the studied land-use variables correlated with m-IBI data, suggesting that land use did not affect the current mussel communities in the creek. Furthermore, percent plant cover was not found to correlate with any of the OEPA biometric data, suggesting that land use could not explain historical creek data either. Because land use can potentially affect water quality downstream of said activities, the aforementioned "downstream correlation" was attempted, and failed to yield a significant relationship. Again, this cemented the conclusion that land use did, and does, not significantly affect the mussel communities in the lower section of Big Walnut Creek.

Chemical water quality, pollution, and the need for more data

The presented data appears to support the conclusion that land use is not an important factor in determining water quality in the lower section of Big Walnut Creek. This appears contrary to other studies and general ecological principles however, and it is entirely possible that they have a large influence; however that possible influence is not reflected in the mussels in the creek. The minimal chemical water quality analysis performed is not particularly meaningful, due to an extremely limited amount of data. However, the OEPA 2000 report for the Big Walnut Creek watershed includes data regarding pollutants and sediments found in the creek that could be very significant for mussels and other organisms.

First, the OEPA provides list of spills into the creek, and its tributaries, of various materials (reporting the volume of spilled material if known) including waste water, muddy water, ethylene glycol, an unknown "red material", an unknown "black material", jet fuel, heavy metals, grease, hog manure, and more. They next provide information regarding sediments found in the creek, and they indicate the presence of elevated levels of aluminum, arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, nickel and zinc. Other sediments measured in the creek were either not found to be in exceedance of various water quality guidelines, or no established guidelines existed for comparison. Finally, the OEPA presents a list of other (typically not naturally occurring) sediments in the creek that were found to be in excess of either the threshold effect concentration (4-4' DDD, alpha-chlordane, gamma-chlordane, pyrene and other polycyclic aromatic hydrocarbons) or the probable effect concentration (chrysene, pyrene, phenanthrene, and other polycyclic aromatic hydrbocarbons). The OEPA reports the presence of elevated heavy metals and other sediments, however they do not note the (probable) sources of these pollutants. Furthermore, the OEPA identified point sources of pollution along the creek in 2000, and they determined impairment in the water due to high phosphorus levels, the aforementioned excessive sedimentation, and pathogens introduced into the water by recreational use (OEPA, 2003). Finally, as stated earlier, it is feasible that the tributaries of Big Walnut Creek could be point sources of pollution for the lower watershed. The tributaries were not assessed in this study, but an assessment of the entire watershed, and not just the lower section of Big Walnut Creek itself, would be pertinent.

The data above are all historical, and represents the condition of the creek in 2000; meanwhile, no present data describing similar parameters are available. However, many of the aforementioned pollutants or sediments found in the creek in 2000 are known to be environmentally significant, and harmful to mussels. Copper, in elevated levels, is well known to be toxic to many species of freshwater mussels (Augpsurger *et al.*, 2009). 4-4' DDD and chlordane are both pesticides, which may or may not be problematic for mussels. Many historically used pesticides have caused very significant environmental harm (DDT, atrazine, etc), whereas others, like pendimethalin (Bringolf *et al*., 2007), are fairly safe to use. Many of the other pollutants found in the creek are known to be harmful to both environmental and human health – such as PAHs, many of which are carcinogenic – and furthermore, many of the substances spilled in the creek (oil, waste beer, sewage) seem potentially detrimental to mussel health.

Ultimately, though this data does represent the status of the creek fifteen years ago, it demonstrates that at one point in relatively recent history, the creek was significantly contaminated. This data also demonstrates the uncertainty that exists surrounding the quality of the water in the creek, and exactly how that could affect mussel communities in the creek. Clearly, more research is necessary to determine the current chemical water quality of the lower section of Big Walnut Creek. It is imperative to know if any recent industrial, agricultural or domestic activities have led to more recent contaminations of the creek. Pollutants have certainly been in the creek if they are not still, and they could be found either in the actual water, or settled into the sediment at the bottom of the creek. Mussels bury into the sediment, and thus contaminated sediment could represent a significant source of exposure to potentially harmful chemicals. So, it seems reasonable to suggest that, while an analysis of the chemical water quality needs to be performed, that it should primarily focus on analysis of the sediment in the creek. The presence of any pollutants persisting in the sediment could potentially explain the impairment seen in mussel communities (as opposed to recovered invertebrates and fish, which may not burrow), and the feasibility of cleaning up such pollutants would suggest the recovery potential of the mussel communities in the creek.

Final Suggestions

The findings of this study clearly demonstrate that the quality of the water found in the lower section of Big Walnut Creek has improved significantly in the past fifteen years, and that is promising news regarding the status of the creek as a whole. However, it was determined in 2013 that the mussels were still faring poorly in the creek, and this study suggests that anthropocentric land use is not to blame for that. Clearly, more research is imperative to better understand why the mussels in the creek seem to be suffering, so that proper resource management techniques can be applied and enforced. Historical chemical water quality data for the creek suggests that a next step towards the ultimate goal of helping the mussels to recover seems to be an assessment of the chemical water quality of the creek, and such an assessment should focus on analysis of the sediment in the creek. Such an assessment might look at the presence and storage of pollutants in sediment, the release of stored pollutants by sediment, and more. Ideally, this sediment analysis would be both spatial and temporal, to better understand trends seen in mussel (and other animals) communities within the creek; however, the limited existence of historical chemical water quality data would likely limit this to a spatial analysis. Hopefully, this will provide new insight as to the status of the mussels in the creek, ultimately leading to a full recovery of the mussel communities.

References

1. Allan JD. 2004. Landscapes and riverscapes: The influence of land use on stream ecosystems. Annu Rev Ecol Syst. 35(1):257-84.

2. Augspurger F, Dwyer J, Ingersoll C, Kane C. 2009. Advances and opportunities in assessing contaminant sensitivity of freshwater mussel (Unionidae) early life stages. Environmental Toxicology and Chemistry 26(10):2025-2028.

3. Box JB, Mossa J. 1999. Sediment, land use, and freshwater mussels: prospects and problems. J N Am Benthol Soc. 18(1):99-117.

4. Box JB, Dorazio RM, Liddell WD. 2002. Relationships between streambed substrate characteristics and freshwater mussels (Bivalvia: Unionidae) in coastal plain streams. J N Am Benthol Soc. 21(2):253-60.

5. Bringolf RB, Coper GW, Eads CB, Lazaro PR. 2007. Acute and chronic toxicity of technical-grade pesticides to glochidia and juveniles of freshwater mussels (Unionidae). Environmental Toxicology and Chemistry 26(10):2086-2093.

6. Broussard W, Turner RE. 2009. A century of changing land-use and water-quality relationships in the continental US. Front Ecol Environ. 7(6):302-07

7. Carrington E. 2002. The ecomechanics of mussel attachment: from molecules to ecosystems. Integr Comp Biol. 42(4):846-52.

8. Deshon JE. 1995. Development and application of the Invertebrate Community Index (ICI). In: Biological assessment and criteria: Tools for water resource planning and decision making. Davis WS, Simon TP, editors. Boca Raton (FL): Lewis Publishers. p. 217-244

9. Friends of Big Walnut Creek. 2006 Dec. Lower Big Walnut Creek watershed Watershed Action Plan and Inventory. Gahanna (OH). Available from: www.friendsofbigwalnutcreek.com/action_plan.htm.

10. Hill BH, Herlihy AT, Kaufmann PR, Stevenson RJ, McCormick FH, Johnson CB. 2000. Use of periphyton assemblage data as an Index of Biotic Integrity. J N Am Benthol Soc. 19(1):50-67.

11. Hoggarth M, Grumney M. 2013 May. A report on a mussel survey of Big Walnut Creek from Hoover Dam to its mouth, Franklin and Pickaway counties, Ohio. Westerville (OH).

12. Hoscic I, Wu J. 2006. Land use and watershed health in the United States. Land Econ. 82(2):214-239.

13. Kane D. 2004. The development of a Planktonic Index of Biotic Integrity for Lake Erie. [dissertation]. The Ohio State University.

14. Karr JR. 1991. Biological integrity: A long-neglected aspect of water resource management. Ecol Appl. 1(1):66-84.

15. Kerans BL, Karr JR. 1994. A Benthic Index of Biotic Integrity (B-IBI) for rivers of the Tennessee valley. Ecol Appl. 4(4):768-85.

16. Lacouture RV, Johnson JM, Buchanan C, Marshall HG. 2006. Phytoplankton Index of Biotic Integrity for Chesapeake Bay and its tidal tributaries. Estuaries Coasts. 29(4):598-616.

17. Llansó RJ, Scott LC, Hyland JL, Dauer DM, Russell DE, Kutz FW. 2002. An estuarine benthic Index of Biotic Integrity for the mid-Atlantic region of the United States II index development. Estuaries. 25(6, Part A):1231-42.

18. Lunde KB, Resh VH. 2012. Development and validation of a macroinvertebrate Index of Biotic Integrity (IBI) for assessing urban impacts to northern California freshwater wetlands. Environ Monit Assess. 184(6):3653-74.

19. Map of Ohio Watershed [Internet]: Ohio Environmental Protection Agency (OEPA); c2015 [cited 2015 1/13]. Available from: http://www.epa.state.oh.us/cdo/dsw.aspx .

20. Mid-Ohio Regional Planning Commission (MORPC). 2012. Big Walnut Watershed Planning Partnership Balanced Growth Plan. Columbus (OH).

21. Ohio Department of Natural Resources (ODNR). Hoover Reservoir [Internet]. Columbus (OH): ODNR. 2012; 2014 Nov 11. Available from http://wildlife.ohiodnr.gov/hooverreservoir#tabr2

22. Polycylic Aromatic Hydrocarbons (PAHs) [Internet]: CDC; cJuly 1, 2013 [cited 2015 1/28]. Available from:http://www.atsdr.cdc.gov/csem/csem.asp?csem=13 .

23. State of Ohio Environmental Protection Agency (OEPA). 1987 Oct. Biological criteria for the protection of aquatic life: Volume II: User's manual for biological field assessment of Ohio surface waters. Columbus (OH)

24. State of Ohio Environmental Protection Agency (OEPA). 2003 Nov. Biological and Water Quality Study of the Big Walnut Creek Basin 2000. Columbus (OH). DSW/EAS 2003-11-10.

25. State of Ohio Environmental Protection Agency (OEPA) Division of Surface Water. 2005 Aug. Total maximum daily loads for the Big Walnut Creek watershed. Columbus (OH).

26. Rankin ET. 1995. Habitat indices in water resource assessments. In: Biological assessment and criteria: Tools for water resource planning and decision making. Davis WS, Simon TP, editors. Boca Raton (FL): Lewis Publishers. p. 181-208

27. Strayer DL. 1993. Macrohabitats of freshwater mussels (Bivalvia:Unionacea) in streams of the Northern Atlantic Slope. J N Am Benthol Soc. 12(3):236-46

28. Strayer DL. 1999. Use of flow refuges by unionid mussels in rivers. J N Am Benthol Soc. 18(4):468-76.

29. United States Census Bureau. 2010 Census – Total Population Map [Internet]. 2014. United States Census Bureau. [cited 2014 Nov 17]. Available from: https://maps.google.com/gallery/details?id=z4f-ZuCLmiKg.ktn2BlCStgbc

30. United States Census Bureau. C2014. State and County Quick Facts [Internet]. Washington, DC: United States Census Bureau. [cited 2014/11/10]. Available from: http://quickfacts.census.gov/qfd/states/39000.html

31. United States Geological Survey (USGS). 2014. Water Quality Samples for Ohio [Internet]. USGS. [cited 2014 Oct 6]. Available from: http://nwis.waterdata.usgs.gov/oh/nwis/qw

32. Vaughn CC, Taylor CM. 1999. Impoundments and the decline of freshwater mussels: A case study of an extinction gradient. Conserv Biol. 13(4):912-20.

33. Vaughn CC, Taylor CM. 2000. Macroecology of a host-parasite relationship. Ecography 23(1):11-20.

34. Vaughn CC, Nichols SJ, Spooner DE. 2008. Community and food web ecology of freshwater mussels. J N Am Benthol Soc. 27(2):409-23.

35.Weigel BM, Dimick JJ. 2011. Development, validation, and application of a Macroinvertebrate-based Index of Biotic Integrity for nonwadeable rivers of Wisconsin. J N Am Benthol Soc. 30(3):665-79.

Appendix I: Data

Table 1: Riparian width and creek width data.

Site	Longitude	Latitude	m-IBI[a]	Creek Width (m)	2013 Riparian Width (m)[b]	2002 Riparian Width (m)[b]	1994 Riparian Width (m)[b]
1	-82.8804	40.09761	28	30.15	331.01	332.08	313.62
2	-82.8907	40.05103	24	28.16	165.14	168.32	161.84
3	-82.88	40.04409	34	18.27	150.23	155.22	140.96
4	-82.8777	40.02956	36	18.84	187.67	190.27	149.55
5	-82.8746	40.00666	32	59.87	21.130	49.100	36.440
6	-82.8578	39.99351	28	30.78	41.670	50.870	60.400
7	-82.864	39.98153	22	23.42	112.75	108.31	108.70
8	-82.8545	39.94918	36	18.78	266.92	253.63	243.98
9	-82.8704	39.91287	26	14.80	94.680	100.70	89.400
10	-82.8832	39.91002	16	27.32	37.740	30.170	30.000
11	-82.905	39.88787	16	15.42	1000.9	1000.5	1004.9
12	-82.9124	39.87335	--	47.80	199.16	192.01	190.91
13	-82.9805	39.83399	34	35.03	118.01	125.13	112.35
14	-82.9927	39.83138	28	23.28	293.30	287.35	284.70
15	-82.99	39.82356	--	23.71	179.53	179.99	187.62
16	-82.9702	39.81912	32	28.43	101.84	107.41	104.59
17	-82.9694	39.81207	24	24.52	55.310	62.500	58.430
18	-82.978	39.8095	--	23.01	146.30	146.41	138.39
19	-82.9965	39.80068	20	18.09	114.49	117.03	107.92
20	-83.0041	39.80012	32	19.58	193.43	178.66	175.23
21	-83.0078	39.79959	22	36.76	362.72	376.67	352.32

[a] Data taken from Hoggarth and Grumney (2013)

[b] Widths were measured on Google Earth (and represent the actual values determined from the satellite imagery)

Table 2. Scoring system data for Hoggarth and Grumney 2013 m-IBI sites

Site	Longitude	Latitude	Percent Plant Cover[a]	Percent of Land Developed[a]	Road Density[a]	Number of Residential Buildings[a]	Census Tract Population[b]
1	-82.8804	40.09761	59.24	24.72	0.0149	16	5
2	-82.8907	40.05103	32.53	59.62	0.0813	164	5
3	-82.88	40.04409	41.60	48.92	0.0546	233	5
4	-82.8777	40.02956	32.23	78.24	0.0599	231	5
5	-82.8746	40.00666	51.16	60.71	0.0915	90	2
6	-82.8578	39.99351	50.79	67.74	0.0770	0	1
7	-82.864	39.98153	30.76	75.67	0.0440	108	4
8	-82.8545	39.94918	44.46	57.99	0.0410	326	4
9	-82.8704	39.91287	55.05	49.31	0.0361	150	5
10	-82.8832	39.91002	41.31	47.64	0.0767	144	4
11	-82.905	39.88787	68.02	24.75	0.0313	62	3
12	-82.9124	39.87335	78.00	19.60	0.0041	8	3
13	-82.9805	39.83399	39.01	64.11	0.0106	16	3
14	-82.9927	39.83138	47.87	43.20	0.0216	0	3
15	-82.99	39.82356	33.67	64.45	0.0144	0	3
16	-82.9702	39.81912	25.30	74.72	0.0038	0	3
17	-82.9694	39.81207	44.11	55.63	0.0422	123	6
18	-82.978	39.8095	34.97	71.11	0.0173	39	6
19	-82.9965	39.80068	45.63	50.35	0.0345	0	5
20	-83.0041	39.80012	36.66	60.77	0.0083	0	5
21	-83.0078	39.79959	53.85	38.56	0.0055	0	5

[a] All urbanization metrics are proportions or numerical counts of the metrics within a 1 km^2 sample region around each m-IBI site.

[b] Census Tract Population Categories
1 – Less than or equal to 2000
2 – Greater than 2000, but less than or equal to 3000
3 - Greater than 3000, but less than or equal to 4000
4 - Greater than 4000, but less than or equal to 5000
5 - Greater than 5000, but less than or equal to 6000
6 – Greater than 6000

Table 3. 2000 scoring system data for OEPA biometric index sites

OEPA Site	Stream River Mile	Longitude	Latitude	Percent Plant Cover
1	37.2	-82.883889	40.103056	51.68
2	34.9	-82.8925	40.079167	31.87
3	28.5	-82.8775	40.015278	30.30
4	28.3	82.876111	40.012222	42.26
5	27.0	-82.865833	39.996389	33.54
6	26.7	-82.860556	39.994722	31.04
7	15.8	-82.915556	39.882778	72.73
8	7.10	-82.992222	39.832778	33.81
9	7.00	-82.993333	39.831944	--[a]
10	3.70	-82.975	39.811111	--[a]
11	3.60	-82.975556	39.810278	19.26
12	1.70	-82.994722	39.807222	28.99

[a] Measurements were not made for sites 9 and 10 due to their respective short distances from sites 8 and 11.

Appendix II: Data from "A report on a mussel survey of Big Walnut Creek from Hoover Dam to its mouth, Franklin and Pickaway counties, Ohio"(Hoggarth and Grumney, 2013)

Table 4. m-IBI sites and m-IBI scores from 2013 Hoggarth and Grumney Big Walnut Creek report.

Site	Latitude	Longitude	m-IBI Score	m-IBI Value
1	40.09761	-82.8804	28	Fair
2	40.05103	-82.8907	24	Fair
3	40.04409	-82.88	34	Good
4	40.02956	-82.8777	36	Good
5	40.00666	-82.8746	32	Good
6	39.99351	-82.8578	28	Fair
7	39.98153	-82.864	22	Fair
8	39.94918	-82.8545	36	Good
9	39.91287	-82.8704	26	Fair
10	39.91002	-82.8832	16	Poor
11	39.88787	-82.905	16	Poor
12	39.87335	-82.9124	--	----
13	39.83399	-82.9805	34	Good
14	39.83138	-82.9927	28	Fair
15	39.82356	-82.99	--	----
16	39.81912	-82.9702	32	Good
17	39.81207	-82.9694	24	Fair
18	39.8095	-82.978	--	----
19	39.88068	-82.9965	20	Fair
20	39.80012	-83.0041	32	Good
21	39.79959	-83.0078	22	Fair

Table 5. m-IBI site data from 2013 Hoggarth and Grumney Big Walnut Creek report.[a]

Site	Water Temp ˚C	pH	O_2 mg/l	Turbidity NTU	Jaccard % Similarity	Percent Extant	H' Total	Conductivity Us/cm
1	----	----	----	4.66	89	88	0.6761	----
2	20.1	8.20	6.20	11.30	69	55	0.7495	374
3	19.2	8.33	7.12	17.70	86	83	0.7593	339
4	16.1	8.34	7.39	8.74	79	73	0.9849	394
5	16.1	8.34	7.39	8.74	87	85	0.9608	394
6	16.1	8.34	7.39	8.74	77	70	0.869	394
7	17.3	8.57	8.21	5.50	78	63	0.7088	487
8	17.3	8.57	8.21	5.50	100	100	1.0428	487
9	17.7	8.26	6.99	4.64	67	50	0.9666	389
10	17.7	8.26	6.99	4.64	61	36	1.0066	389
11	10.4	8.30	8.96	2.85	57	23	1.0488	539
12	10.4	8.30	8.96	2.85	--	100	0.4582	539
13	21.4	8.36	6.96	8.28	82	78	0.6282	578
14	21.4	8.36	6.96	8.28	75	67	0.7549	578
15	19.2	8.41	7.46	6.65	--	67	0.5676	656
16	19.2	8.41	7.46	6.65	68	52	1.1468	656
17	23.3	8.60	8.32	5.22	70	57	1.0487	628
18	----	----	----	----	--	0	0.3510	----
19	19.3	8.67	8.17	5.46	62	39	0.9071	677
20	19.3	8.67	8.17	5.46	74	64	0.9554	677
21	19.3	8.67	8.17	5.46	63	40	0.9125	677

[a] Timing of measurements and methods of analysis can be found in Hoggarth and Grumney (2013)

Table 6. Example Mussel-IBI calculation template for 2013 Hoggarth and Grumney Big Walnut Creek report.

Site Number: Location & Date Sampled

Metric	Value	5	3	1	Score
Distribution & Abundance					
1 # of state listed species					
2 % state listed species					
3 # of federal listed species					
Subtotal					
Reproductive Potential					
4 % extant species					
5 % extant individuals					
6 ratio of mean to median age					
Subtotal					
Community Structure					
7 Shannon-Weiner Index					
8 % invasive bivalves					
9 % burying species					
10 total # of extant individuals					
Subtotal					
Total Score					

Appendix III: Historical Creek Data

Table 7. Data from the OEPA's Biological and Water Quality Study of the Big Walnut Creek Basin 2000

Stream River Mile	Latitude	Longitude	f-IBI	MIWB	ICI	QHEI	Water Temp ˚C	O_2 mg/l	pH
37.2	40.103056	-82.883889	32	8.1	34	84.5	20.5	9.4	--
34.9	40.079164	-82.8925	--	--	40	--	20.8	9.0	7.77
28.5	40.015278	-82.8775	49	10.2	40	82.0	--	--	--
28.3	40.012222	-82.876111	49	10.2	40	82.0	22.0	7.3	--
27.0	39.996389	-82.865833	52	9.8	48	83.5	22.5	8.0	7.59
26.7	39.994722	-82.860556	52	9.8	48	83.5	--	--	--
15.8	39.882778	-82.915556	48	10.1	46	84.5	23.5	8.0	7.20
7.10	39.832778	-82.992222	48	9.5	44	83.0	24.0	6.6	--
7.00	39.831944	-82.993333	48	9.5	44	83.0	--	--	--
3.70	39.811111	-82.975	--	--	--	--	24.0	6.5	--
3.60	39.810278	-82.975556	--	--	46	--	--	--	--
1.70	39.807222	-82.994722	52	9.3	42	84.0	24.0	6.5	7.40

Table 8. United States Geological Survey (USGS) historical creek data with averages and standard deviations by decade.

	1950s	1960s	1970s	1980s	1990s
Water Temp (˚C)	--	16.1643	12.859	--	13.3
STDEV	--	7.479	7.582	--	7.734
O_2 (mg/l)	--	--	10.643	--	--
STDEV	--	--	2.3165	--	--
pH	7.771	7.675	7.948	--	8.075
STDEV	0.262	0.05	0.387	--	0.483