State of Ohio
Environmental Protection Agency

Wetland Ecology Group
Division of Surface Water

AN ECOLOGICAL AND FUNCTIONAL ASSESSMENT OF URBAN WETLANDS IN CENTRAL OHIO

VOLUME 3: A COMPARISON OF THE AMPHIBIAN COMMUNITIES OF URBAN AND REFERENCE WETLANDS, USING LEVEL 1, 2 AND 3 ASSESEMENT TOOLS

Ohio EPA Technical Report WET/2008-1






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Appropriate Citation:

Micacchion, M. and B. Gara. 2008. An ecological and functional assessment of urban wetlands in central Ohio. Volume 3: Comparisons of the Amphibian Communities of Urban and Reference Wetlands Using Level 1, 2 and 3 Assessment Tools. Ohio EPA Technical Report WET/2008-1. Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, Ohio.

This entire document can be downloaded from the web site of the Ohio EPA, Division of Surface Water:

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ACKNOWLEDGMENTS

This study was funded under Wetland Program Development Grant CD965763-01 from U.S. EPA Region 5. Thanks to Sue Elston, Catherine Garra, Lula Spruill and Rachel Nailer (U.S. EPA) for their technical and fiscal assistance. Special thanks to Kim Vogel, Chelsea Korfel, Leah Adams, John Reinier and Phil Renner, Ohio EPA wetland interns in 2006, 2007 and 2008, for their able assistance in field work, data entry and analysis. We appreciate the cooperation of John Watts, Columbus Metro Parks, Elayna Grody, Columbus Recreation and Parks, Greg Schneider, ODNR, Division of Natural Areas and Preserves, Tony Collins, Gahanna Parks and Recreation, Dave Orndorf, Michael Keller and the other private landowners for granting access to their properties to conduct this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract

Fourteen wetlands, exhibiting amphibian breeding habitat characteristics, inside the Interstate 270 outerbelt, around the city of Columbus, in Franklin County, central Ohio were monitored using Level 1, 2 and 3 assessment tools. In order to find 14 wetlands that met the criteria as potential amphibian breeding habitat, 200 randomly selected wetlands were inspected. The Level 1 tool used was the Landscape Development Intensity Index (LDI), the Ohio Rapid Assessment Method for Wetlands Version 5.0 (ORAM) was used for Level 2 assessments and both the Amphibian Index of Biotic Integrity (AmphIBI) and the Vegetation Index of Biotic Integrity (VIBI) were used in the Level 3 monitoring. Additionally, five central Ohio wetlands, considered to be of "reference" condition for amphibian breeding communities were picked selectively and also monitored. Monitoring results were compared between the urban and reference amphibian wetlands as well as with results from our large set of natural wetlands, individual mitigation and mitigation bank wetlands. Of the 14 urban wetlands monitored for amphibians three were of poor quality, nine were of fair quality and two were of good quality. All five of the reference wetlands had excellent quality amphibian communities. The most common species at urban sites were leopard frog, *Rana pipiens*, smallmouth salamander, *Ambystoma texanum*, spring peeper, *Pseudacris crucifer*, western chorus frog, *P. triseriata* and green frog, *R. clamitans melanota*, respectively. Wood frog, *R. sylvatica*, Jefferson salamander, *A. jeffersonianum*, spring peeper, green frog and smallmouth salamander, respectively were the most common species at the reference wetlands. Urban wetlands had a range of from zero to six species while reference wetlands had between five and nine species. Only two urban wetlands had sensitive amphibian species present, each had one, the Jefferson salamander. All reference wetlands had at least three sensitive species represented in their amphibian communities. Reference wetlands had significantly higher AmphIBI, VIBI and ORAM scores than urban amphibian wetlands. Urban amphibian wetlands compare most strongly with Category 1 natural forest and shrub wetlands and natural emergent wetlands. They are significantly different than Category 2 and 3 natural forest and shrub wetlands and individual mitigation and mitigation bank wetlands. Strong correlations exist between wetlands' AmphIBI , VIBI, and ORAM scores and some LDI scores. The largest factor restricting higher quality amphibian communities from occupying urban wetlands is the high intensity of surrounding land uses. Urban wetlands with the ability to support breeding amphibian communities are scarce; those with the ability to support amphibian communities of good quality are extreme rarities. Amphibian communities of excellent quality are not compatible with historical and current urban development patterns.

INTRODUCTION

The State of Ohio has been developing wetland assessment methods since 1996 with the goal of incorporating statewide wetland monitoring into its existing rotating basin surface water monitoring program. Strategies for designing an effective monitoring program are described in what is known as the "three-tier framework" for wetland monitoring and assessment (U.S. EPA 2006). Wetland monitoring and assessment programs in the U.S. are designed to report on the ambient condition of wetland resources, evaluate restoration success, and report on the success of management activities. The "three-tier framework" is a strategy for designing effective monitoring programs. This approach breaks assessment procedures into a hierarchy of three levels that vary in the degree of effort and scale, ranging from broad, landscape assessments using readily available data (known as Level 1 methods), to rapid field methods (Level 2), to intensive biological and physico-chemical measures (Level 3) (Brooks 2004, Fennessy et al. 2004, 2007). The objective of this project was focus on amphibian utilization of urban wetlands using Level 1, Level 2 and Level 3 assessment data.

The general effects of urbanization on aquatic resources, especially streams, are relatively well known. Urbanization can increase the frequency and intensity of floods, reduce stream base flow during dry periods, eliminate riparian buffers, and cause bank erosion and channel widening (Poff et al. 1997). These changes are reflected in shifts in fish and invertebrate communities to tolerant, generalist, often low diversity assemblages. Wetlands can provide ecological services (functions and values) that can ameliorate these effects by capture and storing storm water, desynchronizing peak flows, and storing or converting pollutants (Mitsch and Gosselink 2000). In contrast, wetlands can also be degraded ecologically in the same manner as streams by storm water, nutrient enrichment, sedimentation, altered hydrologic cycles and loss of upland buffers as well as other landscape development effects.

In this study we take a critical look at how the urban environment affects wetlands by focusing on amphibian communities and urban wetlands having the characteristics to support amphibian breeding. Additionally, we compare the results to data from five central Ohio non-urban "reference" wetlands and our large reference set of natural and mitigation wetlands from across Ohio. Our Level 1 tool for evaluating the wetlands is the Landscape Development Intensity Index (Brown and Vivas 2003), for Level 2 assessments we use the Ohio Rapid Assessment Method for Wetlands, Version 5.0 (Mack 2001) and our Level 3 assessments utilize the Amphibian Index of Biotic Integrity (Micacchion 2004, Mack and Micacchion 2006) and the Vegetation Index of Biotic Integrity (Mack 2004, Mack and Micacchion 2006).

Wetlands are known to provide outstanding habitat for the group known as pond-breeding amphibians. Originally, prior to European settlement, Ohio was 95% forested (Lafferty 1979) and these forested areas were rich with ephemeral forested and shrub wetlands that provided breeding habitat for a range of amphibians adapted to the forested landscape. With urbanization the trend is to eliminate forest in favor of earlier successional stages as well as with completely artificial land uses including buildings, pavement and concrete. In this study we investigate how these changes affect urban amphibian populations and what is the potential for urban wetlands to support amphibian communities.

REGULATORY BACKGROUND

Wetland Water Quality Standards

The State of Ohio adopted Wetland Water Quality Standards and a Wetland Antidegradation Rule on May 1, 1998. The rules categorize wetlands based on their quality and functionality and impose differing levels of protection based on the wetland's category (OAC rules 3745-1-50 through 3745-1-54). The regulations specify three wetland categories: Category 1, Category 2, and Category 3 wetlands. These categories correspond to wetlands of low, medium and high quality and/or function. In addition, there is an implied fourth category described in the definition of Category 2 wetlands, i.e. wetlands that are degraded but restorable (modified Category 2). These potentially restorable wetlands are Category 2 wetlands and receive the same level of regulatory protection as other Category 2 wetlands.

Category 1 Wetlands

Ohio Administrative Code Rule 3745-1-54(C)(1) defines Category 1 wetlands as wetlands which "...support minimal wildlife habitat, and minimal hydrological and recreational functions," and as wetlands which "...do not provide critical habitat for threatened or endangered species or contain rare, threatened or endangered species." Category 1 wetlands are often hydrologically isolated, have low species diversity, no significant habitat or wildlife use, little or no upland buffers, limited potential to achieve beneficial wetland functions, and/or have a predominance of non-native species. Category 1 wetlands are defined as "limited quality waters" in OAC Rule 3745-1-05(A). They are considered to be a resource that has been so degraded or with such limited potential for restoration, or of such low functionality, that no social or economic justification and lower standards for avoidance, minimization, and mitigation are applied. Category 1 wetlands would include wetlands in "poor" ecological condition.

Degraded but Restorable (modified) Category 2 Wetlands

Ohio Administrative Code Rule 3745-1-54(C) states that wetlands that are assigned to Category 2 constitute the broad middle category that "...support moderate wildlife habitat, or hydrological or recreational functions," but also include "...wetlands which are degraded but have a reasonable potential for reestablishing lost wetland functions" creating an implied fourth category of wetlands (modified Category 2 wetlands). Modified Category 2 wetlands include wetlands in "fair" ecological condition.

Category 2 Wetlands

Ohio Administrative Code Rule 3745-1-54(C)(2) defines Category 2 wetlands as wetlands which "...support moderate wildlife habitat, or hydrological or recreational functions," and as wetlands which are "...dominated by native species but generally without the presence of, or habitat for, rare, threatened or endangered species..." Category 2 wetlands constitute the broad middle category of "good" quality wetlands. In comparison to Ohio EPA's stream designations, they are equivalent to "warmwater habitat" streams, and thus can be considered a functioning, diverse, healthy water resource that has ecological integrity and human value. Some Category 2 wetlands are relatively lacking in human disturbance and can be considered to be naturally of moderate quality; others may have been Category 3 wetlands in the past, but have been disturbed "down to" Category 2 status. Category 2 wetlands would include wetlands in "good" ecological condition.

Category 3 Wetlands

Wetlands that are assigned to Category 3 have "...superior habitat, or superior hydrological or recreational functions." They are typified by high levels of diversity, a high proportion of native species, and/or high functional values. Category 3 wetlands include wetlands which contain or provide habitat for threatened or endangered species, are high quality mature forested wetlands, vernal pools, bogs, fens, or which are scarce regionally and/or statewide. Category 3 would include wetlands of "very good" or "excellent" condition.

Wetland Tiered Aquatic Life Uses

The State of Ohio has proposed draft rules which would revise OAC Rules 3745-1-50 to -54 and include an expansion of the OAC Rule 3745-1-53 with Wetland Tiered Aquatic Life Uses (WTALUs) (Tables 1, 2, 3 and 4). The WTALUs generally correspond to the antidegradation categories with the exception that a wetland can be degraded but still exhibit a residual function or value at moderate or high levels such that it is Categorized as Category 2 or 3 but has a lower WTALU use designation. Narrative WTALU categories were first proposed in Mack (2001) and have been subsequently updated (Mack 2004b; Micacchion 2004; Mack and Micacchion 2006) and are summarized in Table 1. In addition to the tiered uses, special uses (values or ecological services) provided by wetlands can be assigned (Table 2). The WTALUs were developed by partitioning the 95th percentile of wetland IBI scores for that TALU category into sextiles and combining the sextiles into the 4 aquatic life use categories proposed as numeric biological criteria for Ohio wetlands: limited quality wetland habitat (LQWLH) (poor condition) (1st and 2nd sextiles), restorable wetland habitat (RWLH) (fair condition) (3rd and 4th sextiles), wetland habitat (good condition) (5th sextile), and superior wetland habitat (SWLH) (excellent condition) (6th sextile). Numeric TALUs (biological criteria) for Ohio wetlands were developed based on AmphIBI and VIBI scores, ecoregion, landscape position, and plant community (Tables 3and 4). In the context of this study, the WTALUs were used as true wetland condition categories for evaluating the results of the Level 1, 2, and 3 assessments.

METHODS

Assessment Approach

Recent approaches to wetland assessment have advocated a multi-level approach which incorporates assessments based on landscape (remote sensing) data (level 1), on-site, but "rapid" methods using checklists of observable stressors and other observable wetlands features (level 2), and intensive methods where quantitative floral, faunal, and/or biogeochemical data is collected (level 3) (USEPA 2006; Brooks 2004; Fennessy et al. 2004, 2007a). In this study we collected all three types of data: 1) remote sensing data on the types of land uses surrounding wetlands was used to develop Landscape Development Intensity Index (LDI) (Brown and Vivas, 2003) scores at differing radii 2) rapid assessment data obtained from a site visit and recorded on a background information form, a wetland determination form, and scores from the Ohio Rapid Assessment of Wetlands v. 5.0 (Mack 2001) 3) quantitative ecological data on vegetation and amphibian assemblages and chemical water quality. We assessed "wetlands" as defined by ORAM scoring boundary rules (most often the same boundary criteria as the U.S. Army Corps of Engineers' 1987 Wetland Delineation Manual (Corps 1987)) instead of a fixed area around a point.

Study Region and Site Selection

Our 2006 study of urban wetland condition (Mack and Micacchion 2007) drew from a set of randomly selected wetlands in central Ohio. For this study, we added sites from the list of 2006 random selections. All of the urban wetland study sites were located in Franklin County, Ohio. Franklin County is located near the eastern boundary of the Eastern Corn Belt Plains ecoregion (Woods et al. 1998), characterized by rolling till plains with local end moraines. Soils are rich, relatively well drained loams. Most of the original mesic forests have been converted to agriculture. Much of Franklin County is developed and includes the City of Columbus and its surrounding suburbs. However outlying areas of the county are still predominately agricultural. The sample for this study was generally the boundary of the Interstate 270 outerbelt to exclude wetlands not located in urbanized locations. All wetlands mapped as palustrine emergent (PEM), palustrine forest (PFO), and palustrine scrub-shrub (PFO) by the National Wetland Inventory and significant pixel agglomerations of the Ohio Wetland Inventory that were not mapped by the NWI (predominately woods on hydric soils) were numbered (total = 649). Areas mapped as PUBs were excluded. A simple random sample of 100 wetlands was obtained using the random sample feature of Minitab v. 12.0 for our 2006 study (Mack and Micacchion 2007). Recent (2006) aerial photography was inspected to determine whether a wetland could still be found near that location (e.g. the site was not developed or the wetland obviously destroyed).

For this study an additional 100 of the randomly selected sites were inspected. We focused on wetlands that could be considered to be amphibian habitat. In order to assign that designation a wetland needed to have a number of predetermined characteristics. Those features were: 1). a significant component of the wetland dominated by a tree or shrub canopy; 2). depressional wetland primarily dependent on either precipitation, surface water runoff, ground water inputs, or any combination of two or three of these hydrology sources; 3). inundation throughout the amphibian breeding season; 4.) absence of predatory fish. By examination of aerial photos of the randomly selected sites and follow-up field verifications an additional eight urban amphibian sites were added to the six that were selected and monitored in the 2006. Two additional sites from the 2006 random selections that were not monitored for amphibians when those wetlands were otherwise assessed in 2006 were monitored for amphibians in 2008. The 2008 monitoring results showed that our earlier determinations that these two wetlands did not meet our criteria for inclusion in the study were confirmed and their results do not appear in the data analysis.

We also selectively chose five reference wetlands in the central Ohio area to study in 2008. All wetlands monitored were either in Franklin County or immediately adjacent counties. Three of these sites we had monitored before and had documented them to be of outstanding quality. The other two were monitored in some form by others in the past and were also known to be habitat for excellent amphibian communities. We monitored these sites to demonstrate the reasonable potential for central Ohio wetlands to provide viable amphibian community habitat as well as to provide a comparison with results from the same monitoring year for the results from the urban amphibian wetlands sampled.

Sampling methods – Level 1 Remote Sensing Assessment

For each of the 39 wetlands included in this study (34 urban random picks (2006 & 2008 selections) and five reference sites) a digital wetland boundary was created. ArcGIS ArcInfo editing tools were used to digitize the boundary with 1-foot resolution orthophotography generated by the Ohio Statewide Imagery Program in 2006 and 2007 serving as the visual reference. 100, 250, 500, 750 and 1000 meter buffers were created for each wetland with the interior portion of the polygon, representing the jurisdictional area, being subtracted from the shape. The buffer zones were then compared to the United States Geological Survey's "National Land Cover Dataset" created using both 1992 and 2004 LANDSAT imagery. The total area for each land use category was determined for each wetland buffer and multiplied by a landscape development intensity (LDI) coefficient derived from work done in Florida (Table 5; Brown and Vivas, 2003). The resulting LDI scores for the 14 urban and five reference wetlands using both 1992 and 2004 LANDSAT imagery and the Florida coefficients are listed in Table 6.

Sampling methods – Level 2 Rapid Assessment

The ORAM assessment was performed at each wetland point in accordance with the *Ohio Rapid Assessment Method for Wetlands v. 5.0, User's Manual and Scoring Forms,* Ohio EPA Technical Report WET/2001-1. A Background Field Data form was also completed at each site.

Sampling methods - Level 3 Assessment

Amphibians. Funnel-ended activity traps were used for sampling the amphibians present in wetlands. Sample methods followed the amphibian IBI protocols in Micacchion (2004). Funnel traps were constructed of aluminum window screen cylinders with fiberglass window screen funnels at each end. Traps were 46 cm (18") in length, 20 cm (8") in diameter and each funnel end had 4.5 cm (1.75") openings. The funnel traps were similar in shape to commercially available minnow traps but with a smaller mesh-size. Ten funnel traps were placed evenly around the perimeter of each wetland and the trap location marked with flagging tape and numbered sequentially. Traps were set at the same locations throughout the sample period. Most of the 14 urban wetlands were sampled three times between March and July.

Traps were unbaited and left in the wetlands for 24 hours in order to ensure unbiased sampling for species with diurnal and nocturnal activity patterns. Upon retrieval, the traps were emptied by everting a funnel end and shaking the contents into a white collection and sorting pan. Individuals that could be readily identified in the field (typically adult amphibians) were counted and released. The remaining amphibians were transferred to wide-mouth one liter plastic bottles and preserved with 95% ethanol. Laboratory identification of the preserved samples was carried out using the keys in Pfingsten and Downs (1989), Petranka (1998) and Walker (1946).

Vegetation. A plot-based vegetation sampling method was used to sample wetland plant communities (Peet et al., 1998). Sampling was performed in accordance with *Field Manual for the Vegetation Index of Biotic Integrity v. 1.4* (Mack 2007). At most sites, a "standard" 20 m x 50 m plot was established (0.1 ha). The location of the plot was qualitatively selected by the investigator based on site characteristics and rules for plot location (Mack 2007). Presence and areal cover was recorded for herb and shrub stratums; stem density and basal area was recorded for all woody species >1m. Percent cover was estimated using cover classes of Peet et al. (1998) (solitary/few, 0-1%, 1-2.5%, 2.5-5%, 5-10%, 10-25%, 25-50%, 50-75%, 75-90%, 90-95%, 95-99%). All woody stems >1 m tall were counted and placed into diameter classes (0-1 cm, 1- 2.5 cm, 2.5-5 cm, 5-10 cm, 10-15 cm, 20-25 cm, 25-30 cm, 30-35 cm, 35-40 cm) except that trees with diameters >40 cm were individually measured. The midpoints of the cover and diameter classes were used in all analyses. Other data collected included standing biomass (g/m^2 from eight $0.1m^2$ clip plots) and various physical variables (e.g. % open water, depth to saturated soils, amount of coarse woody debris, etc.). A soil pit was dug in the center of every plot and soil color, texture, and depth to saturation were recorded. A grab sample of water was also collected either at the time of the amphibian or vegetation sampling and analyzed for standard inorganic parameters at Ohio EPA's laboratory.

Data analysis

Minitab v. 12.0 was employed for the analyses of all data. Descriptive statistics, box and whisker plots, ANOVA, and regression analysis were used to evaluate the data.

RESULTS AND DISCUSSION

Assessment of Condition of Urban Wetlands – Amphibians

All reference wetlands had sufficient water depths to be trapped during all three passes. Some urban sites did not have sufficient water present during the second and third trapping runs and were only trapped one or two times. Of the 14 urban wetlands eight were trapped three times, four were trapped two times and two were trapped once. The Venice Club wetland was trapped once and was the only site that yielded no amphibians. However, four intact spotted salamander egg masses were observed attached to under water woody debris during the first trapping run and in all other ways it appeared to be good amphibian breeding habitat. Further investigations of the pool characteristics, including the vegetation survey, lead us to believe that the wetland's hydrologic regime had been recently altered. We suspected that its shortened hydoperiod was due to the wetland being drained by a connection to an adjacent buried storm sewer or through loss of ground water input due to draw down or restriction from surrounding development.

Amphibian Index of Biotic Integrity (AmphIBI), Vegetation Index of Biotic Integrity (VIBI) and Ohio Rapid Assessment Method for Wetlands Version 5.0 (ORAM) scores for the sites where amphibian monitoring occurred are presented in Table 7. AmphIBI scores for the urban wetlands were lower than any of the scores for the reference sites. Figure 2 shows a graph of AmphIBI scores versus ORAM scores for the 14 urban and five reference wetlands and shows a regression line exhibiting a strong relationship between the two sets of scores (df =

18, F = 52.02, R^2 = 75.4%, p < 0.001) . This relationship demonstrates that amphibian communities do an excellent job of reflecting ecological conditions, not only within the wetland, but also of the wetland buffers, the other surrounding land uses and their degree of connectivity.

AmphIBI scores for the urban sites ranged from 0 to 26 with a mean of 13.57 and a standard deviation of 6.57. AmphIBI scores for the reference sites ranged from 30 to 50 with a mean of 42.20 and a standard deviation of 8.41. Keller High, the reference site that scored the lowest on the AmphIBI, 30, had its surrounding woodlot and parts of its wetland border selectively cut in 2006 leaving large openings in the forest canopy reflected in its 2008 ORAM score of 57.5 (Category 2). This site had been previously monitored by us in 1997 (Micacchion 2004). Results from the 1997 sampling resulted in an AmphIBI score of 50. This wetland is definitely showing negative impacts in the amphibian assemblage from the recent logging and its consideration as a reference wetland in its current condition is questionable. Mean AmphIBI scores for urban versus reference sites are significantly different than each other (df = 18, F = 60.80, p < 0.001) (Figure 3).

The composition of the amphibian communities of the urban wetlands were much different than those of the reference wetlands (Table 8). The most common species in urban wetlands were leopard frog, *Rana pipiens* (58.14%), smallmouth salamander, *Ambystoma texanum* (14.58%), spring peeper, *Pseudacris crucifer* (11.34%), western chorus frog, *Pseudacris triseriata* (8.18%) and green frog, *Rana clamitans melanota* (7.08%). These five species accounted for 99.32% of the individuals trapped in the urban wetlands during the study. Four of the urban wetlands had smallmouth salamanders as the only amphibian species present. The other three species collected at urban sites in order of abundance were Jefferson salamander, *Ambystoma jeffersonianum,* gray treefrog, *Hyla versicolor* and bullfrog, *Rana catesbeiana*. One sensitive species, the Jefferson salamander was present at two of the urban sites. One of these sites was situated within a slightly over 8 hectare (20 acre) forested parcel and the other was connected to a much larger amount of forested habitat, both rarities in an urban setting. These two wetlands also had the highest AmphIBI scores of all urban sites, 20 and 26, respectively. All other amphibian species encountered at the urban sites were either tolerant or facultative species. A total of eight amphibian species were sampled at the urban sites. One urban wetland had six species, no other urban site had more than three species and five of the wetlands had a single species.

From a wetland tiered aquatic life use prospective, of the 14 urban wetlands monitored, three (21.4%) would be designated Limited Quality Wetland Habitat (poor condition), nine (64.3%) would be designated as Restorable Wetland Habitat (fair condition) and two (14.3%) would be designated as Wetland Habitat (good condition). These results show that on average the attainable condition for urban wetlands that have the characteristics needed to support amphibian breeding is to provide amphibian habitat of fair quality. In contrast, all five (100%) of the reference wetlands would be designated as Superior Wetland Habitat (excellent condition) and provide outstanding amphibian habitat, even Keller High, which along with much of its surrounding woodlot had recently been selectively logged.

The species with the greatest relative abundances at the reference sites (Table 9) were wood frog, *Rana sylvatica* (77.11%), Jefferson salamander (7.63%), spring peeper (3.92%), green frog (3.32%), leopard frog (2.67%), smallmouth salamander (2.45%) and eastern red-spotted newt, *Notophthalmus viridescens* (1.58%). Spotted salamanders, *Ambystoma maculatum*, tiger salamanders, *Ambystoma tigrinum* and gray treefrogs were also collected for a total of 10 species at the reference sites. Four-toed salamander, *Hemidactylium scutatum* females, brooding eggs, were observed at three of the reference sites, however this species did not show up in the activity trap samples and therefore was not counted. We believe the fact that four -toed salamander larvae reside in extremely shallow water at the edges of pools and are relatively sessile keeps them from appearing in the activity traps. Excluding four-toed salamanders, which are a sensitive species, reference sites had a range of from five to nine species, of which from three to five were sensitive species.

In Figure 3 the AmphIBI scores from the 14 urban wetlands are compared to those from 106 natural wetlands, 10 individual wetland mitigation projects and 35 mitigation bank wetlands we have previously monitored. The mean AmphIBI scores are significantly different ($p < 0.001$) between urban wetlands, Category 2 and 3 natural forested and shrub wetlands, individual wetland mitigation projects and wetland mitigation banks. However, the means for the 14 urban wetlands are not significantly different than the mean AmphIBI scores for Category 1 natural forested and shrub wetlands and natural emergent wetlands. This illustrates that the reasonably attainable condition for urban wetlands is poor to fair quality amphibian communities.

Comparisons of LDI scores based on 2004 LANDSTAT imagery and AmphIBI scores show direct correlations. Correlations were strongest at the 1000 meter radius (R^2=54.4%) and decreased with narrower radii: 750 meters (R^2=52.9%); 500 meters (R^2=50.2%); 250 meters (R^2=43.6%): and 100 meters (R^2=40.8%) (Figures 4 through 8). These results indicate that amphibian communities are influenced by affects on a large scale but also that changes in the areas immediately adjacent to the wetlands greatly influence the composition of the amphibian community (Semlitsch 2000). Porej et al. 2004 found that amphibians are influenced by activities that occur within one kilometer of a site and this study further substantiates those findings.

The strongest correlations compared to VIBI scores, reported below, were found using LDI scores based on 1992 LANDSTAT data while strongest correlations compared to AmphIBI scores were found using LDI scores based on 2004 LANDSTAT data. This indicates that while both communities are affected by changes in the landscapes surrounding the wetlands they occupy the amphibian community responds more rapidly to those changes. This difference should be expected given that amphibians only spend a portion of their life cycle in the wetlands and are dependent on the adjacent upland habitats for the remainder of the time (Semlitsch 1998). Therefore, amphibians experience the changes in the landscape outside the wetlands almost immediately. Conversely, the plants are full-time residents of the wetlands and their local conditions do not change instantaneously, unless the surrounding disturbances are extremely severe, but instead generally take more time to be felt.

Assessment of Condition of Urban Wetlands – Vegetation

A total of seven new urban wetland sites (random picks) and five reference sites located near the Central Ohio study area were monitored during the 2008 growing season using the Vegetation Index of Biotic Integrity (VIBI) protocols (Mack, 2007). The additional vegetation survey results for these new sites have been included with the original 2006 site data and used for analysis in this study (Table 10).

Of the new urban wetlands monitored, one site was determined to be a Limited Quality Wetland Habitat ("poor"), five were Restorable Wetland Habitat ("fair"), and one was Superior Wetland Habitat ("excellent") based on the VIBI analysis. None of the wetlands studied during the 2008 growing season fell into the Wetland Habitat ("good") category. For the entire study (2006 and 2008), which includes a total of 34 urban wetlands, 73.5% were considered to be "poor" (14.7%) or "fair" (58.8%) condition, and 26.5% were in "good" (11.8%) or "excellent" (14.7%) condition based on the results from the Level 3 vegetation sampling. Comparisons of VIBI scores with AmphIBI scores for the 14 urban amphibian and five reference wetlands shows strong correlation (df = 17. F = 25.28, R^2 = 61.2%, $p < 0.001$) (Figure 9).

Comparing the VIBI results for all urban wetlands with the antidegradation categories determined using the Ohio Rapid Assessment Method (ORAM), shows a clear relationship between the two field-based techniques that is statistically significant (df = 33, F = 18.46, $p < 0.001$; (Figure 10)). This supports findings documented in our 2006 urban wetland study (Mack and Micacchion, 2007). Performing a regression analysis on the VIBI scores and raw ORAM scores for these urban wetlands also illustrates this relationship (df = 33, F = 56.13, R^2 = 63.7%, $p < 0.001$) (Figure 11).

The mean VIBI score for the 34 urban wetlands included in the overall study was 37.4 which is significantly different than the mean score of 72.2 for the five reference wetlands monitored in 2008 (df = 38, F = 19.37 $p < 0.001$; Figure 12). Likewise, the mean ORAM scores between the urban (45.2) and reference sites (75.6) also differed significantly (df = 38, F = 24.26, $p < 0.001$ (Figure 13)). One of the most obvious differences between the urban wetlands versus those in reference condition was the integrity of the buffer surrounding the jurisdictional boundary. This information is documented as part of the ORAM analysis, and is also determined using a GIS analysis of Land Cover data. Reference sites generally had a significant forested buffer and a low overall intensity of surrounding land use. Three of these reference sites (Gahanna Woods, Slate Run and Orndorf) were protected either as a publically-owned park (Gahanna Woods and Slate Run) or with a restrictive conservation easement (Orndorf). The remaining two reference sites (Fisher and Keller High) are privately owned and have been selectively logged in the past few years (Keller High in 2006 and Fisher in 2008 after the amphibian monitoring was completed). It is anticipated that these two wetlands will recover, as most of the surrounding buffer has remained intact. In contrast, a large majority of the urban sites had a limited area of forest or other natural habitat providing protection from the surrounding land use, which was generally much more intensive than for the reference sites.

The LDI score generated for each urban wetland was then compared to ORAM and VIBI scores. The relationship between the LDI values and both ORAM and VIBI scores were found to be statistically significant (Figures 14 and 15). Comparing the LDI scores between the urban and reference sites in this study illustrates the difference in surrounding land uses. There was a significant difference between the mean LDI values for the urban (2.86) and reference (1.33) sites (df = 38, F = 6.85, p= 0.013 (Figure 16).

Conclusions

Amphibians, as their name suggests, are dependent on not only the quality of the wetlands they use for breeding but also on the condition of the adjacent upland habitats where most of these species spend the majority of their lives. The upland habitats healthy amphibian communities rely on occur not only immediately adjacent to the wetland borders but can extend as far as one kilometer or perhaps more depending on the species. This study shows that the intensity of land uses in the areas surrounding urban wetlands is not compatible with the maintenance of high quality amphibian assemblages even if within wetland habitat features are of high quality. Therefore, if we are to maintain amphibian biodiversity within our urban corridors careful planning is required. The best amphibian habitat in areas of impending development should be identified. Then, prior to any planned development, the wetland pools and an appropriate amount of adjacent upland habitat, of suitable quality, should be set aside and preserved as green space. This approach would provide a balance between the need for more development and retaining the landscape elements that support the important ecological services that make a place desirable for working and living.

While there appears to be a direct correlation between overall urban wetland condition and the intensity of surrounding land use, it is worth noting that more than 85% of the wetlands included in our larger urban study were functioning at a “fair” or better level. These urban wetlands are providing at least some degree of ecological services and potentially play a significant role in the overall water quality of the watershed in which they are located even though their amphibian habitat abilities are greatly compromised. Results from this study suggest that expanding the natural buffer associated with degraded urban wetlands would likely result in a recovery to a higher level of ecological condition over time. Future studies of urban wetlands should focus on temporal changes to the condition of these systems as it relates to both increasing and decreasing levels of surrounding land use intensity.

This study also points out the relative scarcity of wetlands providing any type of amphibian breeding habitat in the urban setting. To find 14 wetlands that met our amphibian monitoring criteria required carefully examining 200 randomly selected wetlands. Of those 14 (7%) only two (1%) were of good quality, and all others were fair (4.5%) to poor (1.5%) quality. Clearly a good quality amphibian wetland in the urban setting should be a valued commodity as it likely exhibits the highest attainable condition and is an extremely rare resource. Based on our study results, current urban development patterns are not compatible with maintaining excellent quality amphibian habitat.

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Table 1. General Wetland Aquatic Life Use Designations.

code	designation	definition
SWLH	Superior Wetland Habitat	Wetlands that are capable of supporting and maintaining a high quality community with species composition, diversity, and functional organization comparable to the vegetation IBI score of at least 83% (five-sixths) of the 95th percentile for the appropriate wetland type and region.
WLH	Wetland Habitat	Wetlands that are capable of supporting and maintaining a balanced, integrated, adaptive community having a species composition, diversity, and functional organization comparable to the vegetation IBI score of at least 66% (two-thirds) of the 95th percentile for the appropriate wetland type and region.
RWLH	Restorable Wetland Habitat	Wetlands which are degraded but have a reasonable potential for regaining the capability of supporting and maintaining a balanced, integrated, adaptive community of vascular plants having a species composition, diversity, and functional organization comparable to the vegetation IBI score of at least 33% (one-third) of the 95th percentile distribution for the appropriate wetland type and region.
LQWLH	Limited Quality Wetland Habitat	Wetlands which are seriously degraded and which do not have a reasonable potential for regaining the capability of supporting and maintaining a balanced, integrated, adaptive community having a species composition, diversity, and functional organization comparable to the vegetation IBI score of less 33% (one-third) of the 95th percentile for the appropriate wetland type and region.

Table 2. Special wetland use designations.

subscript	special uses	description
A	recreation	wetlands with known recreational uses including hunting, fishing, bird watching, etc. that are publicly available
B	education	wetlands with known educational uses, e.g. nature centers, schools, etc.
C	fish reproduction habitat	wetlands that provide important reproductive habitat for fish
D	bird habitat	wetlands that provide important breeding and non-breeding habitat for birds
E	T or E habitat	wetlands that provide habitat for federal or state endangered or threatened species
F	flood storage	wetlands located in landscape positions such that they have flood retention functions
G	water quality improvement	wetlands located in landscape positions such that they can perform water quality improvement functions for streams, lakes, or other wetlands

Table 3. Wetland Tiered Aquatic Life Uses (WTALUs) for specific plant communities and landscape positions. LQWLH = limited quality wetland habitat, RWLH = restorable wetland habitat, WLH = wetland habitat, SWLH = superior wetland habitat.

HGM class	HGM subclass	plant community	ecoregions	LQWLH (Cat 1)	RWLH (mod Cat 2)	WLH (Cat 2)	SWLH (Cat 3)
Depression	all	Swamp forest, Marsh, Shrub swamp	EOLP all other regions	0 - 30 0 - 24	31 - 60 25 - 50	61 - 75 51 - 62	76 - 100 63 - 100
	all	Wet Meadow (incl. prairies and sedge/grass dominated communities that are not slopes)	all regions	0 - 29	30 - 59	60 - 75	76 - 100
Impound-ment	all	Swamp forest, Marsh, Shrub Swamp	EOLP all other regions	0 - 26 0 - 24	27 - 52 25 - 47	53 - 66 48 - 63	67 - 100 64 - 100
		Wet Meadow (incl. prairies and sedge/grass dominated communities that are not slopes)	all regions	0 - 29	30 - 59	60 - 75	76 - 100
Riverine	Headwater	Swamp forest, Marsh, Shrub swamp	EOLP all other regions	0 - 27 0 - 23	28 - 56 24 - 47	57 - 69 47 - 59	70 - 100 60 - 100
	Mainstem	Swamp forest, Marsh, Shrub swamp	EOLP all other regions	0 - 29 0 - 20	30 - 56 21 - 41	57 - 73 42 - 52	74 - 100 53 - 100
	Headwater or Mainstem	Wet Meadow (incl. prairies and sedge/grass dominated communities that are not slopes)	all regions	0 - 29	30 - 59	60 - 75	76 - 100
Slope	all	Wet meadow (fen), tall shrub fen, forest seep	all regions	0 - 29	30 - 59	60 - 75	76 - 100
Coastal	various	Swamp forest, Marsh, Shrub swamp	all regions	0 - 24	25 - 49	50 - 61	62 - 100
Bog	weakly ombrotrophic	Tamarack-hardwood bog, Tall shrub bog	all regions	0 - 32	33 - 65	66 - 82	83 - 100
	moderately to strongly ombrotrophic	Tamarack forest Leatherleaf bog Sphagnum bog	all regions	0 - 23	24 - 47	48 - 59	60 - 100

Table 4. Wetland Tiered Aquatic Life Uses (WTALUs) based on Amphibian Index of Biotic Integrity (AmphIBI) scores. LQWLH = limited quality wetland habitat, RWLH = restorable wetland habitat, WLH = wetland habitat, SWLH = superior wetland habitat.

HGM class	HGM subclass	plant community	ecoregions	LQWLH (Cat 1)	RWLH (mod Cat 2)	WLH (Cat 2)	SWLH (Cat 3)
Depression	all	Swamp forest, Shrub swamp	all regions	0-9	10-19	20-29	30-50

Table 5. Landscape Development Intensity (LDI) coefficients assigned to 1992 National Land Cover Dataset (NLCD) land use categories for Ohio.

Land Use Code	Land Use Category	Landscape Development Intensity (LDI) Coefficient
11	Open Water	1.00
21	Low Intensity Residential	7.47
22	High Intensity Residential	7.55
23	Commercial/Industrial/Transportation	9.42
31	Bare Rock/Sand/Clay	8.32
32	Quarries/Strip Mines/Gravel Pits	8.32
33	Transitional	8.32
41	Deciduous Forest	1.00
42	Evergreen Forest	1.00
43	Mixed Forest	1.00
71	Grassland/Herbaceous	3.41
81	Pasture	3.74
82	Row Crops	4.54
85	Urban/Recreational Grasses	6.92
91	Woody Wetlands	1.00
92	Emergent Wetlands	1.00

Table 6. LDI Scores by Site - Vivas and Brown 2003 Coefficients and 1992 & 2004 LandSat Data.

Site Name	LDI92 100M	LDI92 250M	LDI92 500M	LDI92 750M	LDI92 1000M	LDI04 100M	LDI04 250M	LDI04 500M	LDI04 750M	LDI04 1000M
Airport Plaza	4.223	5.199	6.755	7.405	7.455	4.294	5.070	6.812	7.035	7.355
Asherton	1.000	1.637	2.699	3.825	4.005	6.394	6.468	5.885	5.946	6.199
Eastland	4.138	4.686	5.849	6.491	6.454	2.895	3.830	5.503	6.471	6.594
Easton	3.065	3.840	4.341	4.385	4.487	6.641	7.471	7.243	7.074	6.749
Hill	2.815	4.111	4.341	4.363	4.267	3.157	4.657	4.837	4.986	4.976
ISG	2.282	3.368	4.861	5.462	6.198	2.148	3.013	4.478	5.843	6.205
Old Dominion	2.684	4.346	5.016	5.473	5.724	1.510	3.074	4.596	5.316	6.123
Sawmill	3.114	4.341	5.634	6.300	6.611	6.156	7.242	7.954	7.934	7.818
Somerset	5.337	5.097	4.962	4.075	4.147	4.166	5.171	6.619	6.750	6.478
Spangler	4.967	5.539	5.696	5.538	5.390	4.602	4.924	4.634	4.955	5.015
Towne Center	3.965	3.394	3.197	3.783	4.062	7.047	7.169	6.494	5.527	5.535
Venice Club	3.462	3.466	3.571	3.601	3.894	5.319	5.610	5.721	5.619	5.557
Watkins	4.494	4.057	3.964	4.243	4.286	2.297	2.736	3.362	3.856	3.953
Woodmark	3.332	6.137	6.155	6.373	6.227	2.989	6.225	7.193	7.119	6.914
Fisher	1.289	2.367	3.545	3.761	3.664	1.084	2.178	3.277	3.674	3.750
Gahanna Woods	1.000	1.613	2.582	3.012	3.254	1.000	1.463	3.727	4.951	5.345
Keller High	2.357	3.064	3.507	3.463	3.582	2.370	2.785	3.089	3.215	3.450
Orndorf	1.000	1.181	1.652	1.649	1.856	1.342	1.415	1.855	1.908	1.949
Slate Run	1.000	1.239	1.415	1.888	2.327	1.000	1.069	1.235	1.684	2.207

Table 7. Sites with ORAM, VIBI, AmphIBI Scores and AmphIBI Tiered Aquatic Life Uses (TALUS).

Site Name	Type	Year	ORAM Score	VIBI Score	AmphIBI Score	AmphIBI TALUs
Airport Plaza	Urban	2006	35	39	3	LWH
Asherton	Urban	2008	71	63	16	RWH
Eastland	Urban	2008	37.5	42	13	RWH
Easton	Urban	2006	47	25	16	RWH
Hill	Urban	2006	64	50	26	WLH
ISG	Urban	2006	32	none	9	LWH
Old Dominion	Urban	2008	46.5	26	16	RWH
Sawmill	Urban	2008	40	47	16	RWH
Somerset	Urban	2006	40	43	16	RWH
Spangler	Urban	2008	34.5	16	10	RWH
Towne Center	Urban	2006	30	29	13	RWH
Venice Club	Urban	2008	40	41	0	LWH
Watkins	Urban	2008	35	26	16	RWH
Woodmark	Urban	2008	58	47	20	WLH
Fisher	Reference	2008	82	87	50	SWLH
Gahanna Woods	Reference	2008	82.5	87	37	SWLH
Keller High	Reference	2008	57.5	46	30	SWLH
Orndorf	Reference	2008	80	71	47	SWLH
Slate Run	Reference	2008	76	71	47	SWLH

Table 8. Relative Abundances and Numbers of Amphibian Species at Central Ohio Urban Wetlands.

Site Name	Ambystoma jeffersonianum	Ambystoma texanum	Hyla versicolor	Pseudacris crucifer	Pseudacris triseriata	Rana catesbeiana	Rana clamitans	Rana pipiens	# of species
Airport Plaza					100.00%				1
Asherton		100.00%							1
Eastland							4.02%	95.98%	2
Easton		100.00%							1
Hill	50.00%			25.00%		25.00%			3
ISG		10.23%		51.16%	38.60%				3
Old Dominion		85.00%					12.50%	2.50%	3
Sawmill		100.00%							1
Somerset		100.00%							1
Spangler				29.69%			7.81%	62.50%	3
Towne Center		57.14%					42.85%		2
Venice Club									0
Watkins		7.72%	1.10%	1.10%	4.04%		17.28%	68.75%	6
Woodmark	14.29%	57.14%					28.57%		3
Relative Abund. All Sites	0.34%	14.58%	0.26%	11.34%	8.18%	0.09%	7.08%	58.14%	8
Sites Present	2	9	1	4	3	1	6	4	

Table 9. Relative Abundances and Numbers of Amphibian Species at Central Ohio Reference Wetlands.

Site Name	Ambystoma jeffersonianum	Ambystoma maculatum	Ambystoma texanum	Ambystoma tigrinum	Hyla versicolor	Notophthalmus viridescens	Pseudacris crucifer	Rana clamitans	Rana pipiens	Rana sylvatica	Number of species
Fisher	1.87%	0.04%	0.04%			1.96%	0.30%	0.30%	0.04%	95.44%	8
Gahanna Woods	23.08%	0.81%	8.50%			2.43%	37.65%		27.53%		6
Keller High	8.02%	0.94%	4.72%	2.36%	5.19%	2.83%	11.32%	50.94%	13.68%		9
Orndorf	14.04%	2.44%	1.00%					0.57%		81.95%	5
Slate Run	38.79%	0.61%	30.90%	5.45%			12.12%	1.82%		10.30%	7
Relative Abund. All Sites	7.63%	0.63%	2.45%	0.38%	0.30%	1.58%	3.92%	3.32%	2.67%	77.11%	10
Sites Present	5	5	5	2	1	3	4	4	3	3	

Table 10. Comparison of wetland condition class as determined by ORAM (antidegradation category), and Vegetation IBI (Wetland Tiered Aquatic Life Uses).

Wetland Number	Year Monitored	Urban Study or Reference Wetland	site name	HGM	plant community	LDI	ORAM	VIBI	antidegradation category	WTALU	ORAM to VIBI
	2008	reference	Keller High	depression	shrub swamp	2.357	57.5	46	Category 2	RWLH	over by 1
-	2008	reference	Orndorf	depression	shrub swamp	1.000	80	74	Category 3	SWLH	same
-	2008	reference	Fisher	depression	shrub swamp	1.289	82	87	Category 3	SWLH	same
-	2008	reference	Slate Run	depression	shrub swamp	1.000	76	67+	Category 3	SWLH	same
-	2008	reference	Gahanna Woods	depression	shrub swamp	1.000	82.5	87+	Category 3	SWLH	same
460	2008	Urban	Sawmill	depression	swamp forest	3.114	52	47	Category 2	RWLH	over by 1
195	2008	Urban	Spangler Rd.	depression	swamp forest	4.957	34.5	16	Mod Cat 2	LQWLH	over by 1
222	2008	Urban	Eastland Mall	depression	marsh	4.138	37.5	42	Mod Cat 2	RWLH	same
144	2008	Urban	Old Dominion	depression	swamp forest	2.684	46.5	26	Category 2	RWLH	over by 1
294	2008	urban	Woodmark	depression	swamp forest	3.332	58	47	Category 2	RWLH	over by 1
258	2008	urban	Asherton	depression	swamp forest	1.000	71	63	Category 3	SWLH	same
002	2008	urban	Venice Club	depression	swamp forest	3.462	40	41	Mod Cat 2	RWLH	same
019M	2006	Urban	Ridenour Rd.	slope	fen	1.399	71	80	Category 3	SWLH	same
019O	2006	Urban	Ridenour Rd.	impound	swamp forest	1.352	47	53	Category 2	WLH	same
44	2006	Urban	Airport Plaza	depression	swamp forest	4.223	35	39	mod Cat 2	RWLH	same
76	2006	Urban	Big Walnut	mainstem	swamp forest	1.050	43	26	mod Cat 2	RWLH	same
82	2006	Urban	ATV	mainstem	swamp forest	1.340	63	58	Category 2	SWLH	under by 1
142A	2006	Urban	Watkins Rd (S)	depression	swamp forest	4.494	35	26	mod Cat 2	RWLH	same
142B	2006	Urban	Watkins Rd (N)	depression	swamp forest	4.494	35	34	mod Cat 2	RWLH	same
147/150	2006	Urban	ISG	depression	swamp forest	2.282	54	60	Category 2	WLH	same
201	2006	Urban	Three Creeks	mainstem	swamp forest	1.396	59	43	Category 2	WLH	same
204A	2006	Urban	Alum Creek A	mainstem	swamp forest	2.612	41	27	mod Cat 2	RWLH	same
204B	2006	Urban	Alum Creek B	mainstem	wet meadow	2.653	46	43	Category 2	WLH	same
242A	2006	Urban	Sunbury Rd	mainstem	marsh	3.190	60	53	Category 2	SWLH	under by 1
242C	2006	Urban	Sunbury Rd	mainstem	marsh	3.089	31	32	mod Cat 2	RWLH	same
268	2006	Urban	Towne Centre	depression	swamp forest	3.965	30	29	Category 1	RWLH	under by 1
274	2006	Urban	Somerset	depression	swamp forest	5.337	40	43	mod Cat 2	RWLH	same
281	2006	Urban	Bridgeview	headwater	swamp forest	2.964	36	27	mod Cat 2	RWLH	same
286	2006	Urban	Hills	depression	swamp forest	2.815	64	50	Category 2	RWLH	over by 1
308	2006	Urban	Easton	depression	swamp forest	3.065	47	25	Category 2	RWLH	over by 1
351	2006	Urban	Worthing HS	mainstem	swamp forest	3.174	43	29	mod Cat 2	RWLH	same
352	2006	Urban	Worthing Park	mainstem	swamp forest	4.400	39	19	mod Cat 2	LQWLH	over by 1
354	2006	Urban	Antrim Park	mainstem	swamp forest	1.269	46	20	Category 2	LQWLH	over by 2
358	2006	Urban	Graceland	mainstem	swamp forest	2.116	36	23	mod Cat 2	RWLH	same
409	2006	Urban	Wilson Rd	depression	marsh	4.511	29	23	Category 1	LQWLH	same
464A	2006	Urban	Quarry Seep	slope	forest seep	1.387	69	47	Category 3	RWLH	over by 2
464B	2006	Urban	Quarry Fringe	fringing	swamp forest	1.310	74	67	Category 3	SWLH	same
492	2006	Urban	Bolton Field	depression	swamp forest	3.470	21	10	Category 1	LQWLH	same
529	2006	Urban	Cherry Bottom	mainstem	swamp forest	1.151	35	24	mod Cat 2	RWLH	same
										under by 2	**0.0%**
										under by 1	**7.7%**
										same cat.	**66.7%**
										over by 1	**20.5%**
										over by 2	**5.1%**

[+]conducted prior to 2006/2008 Urban Wetland Study

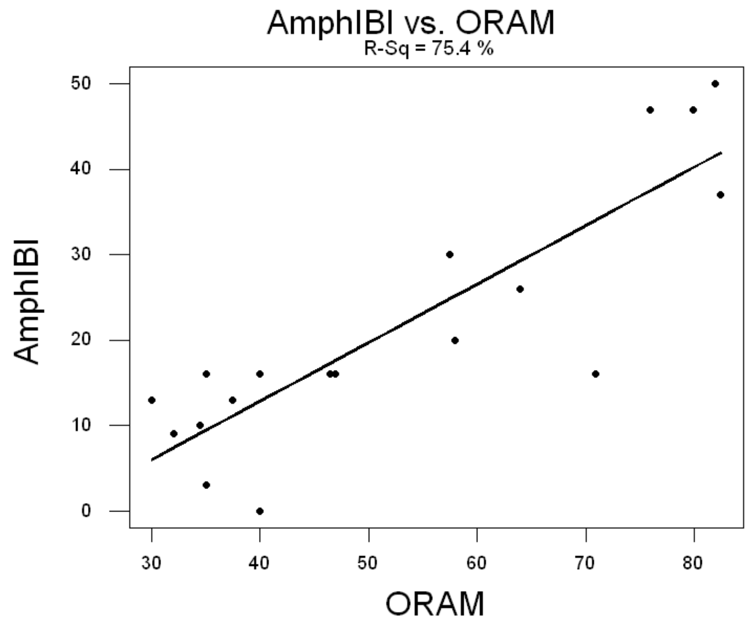

Figure 1. Fitted line regression plot of AmphIBI versus ORAM scores of urban and reference wetlands (df = 18, F = 52.02, $p < 0.001$, R2 = 75.4%).

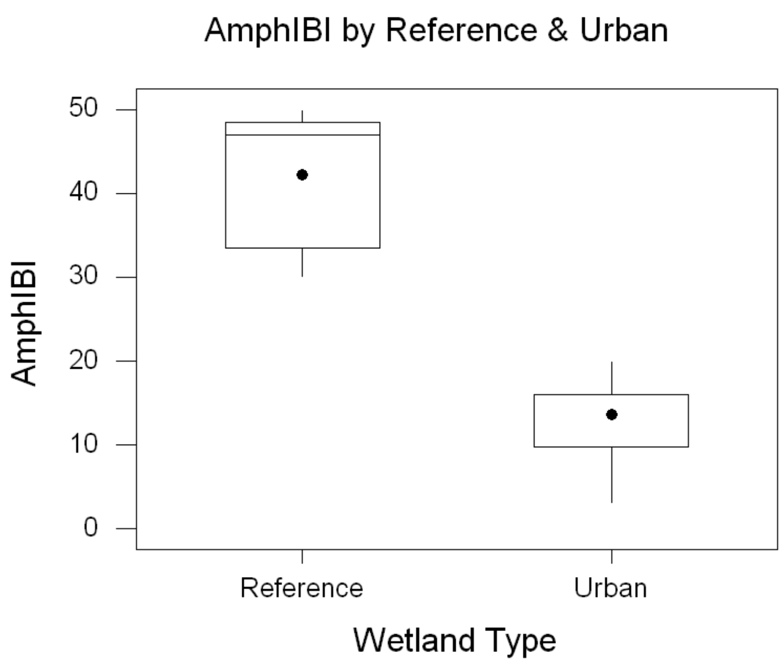

Figure 2. Box and whiskers plot of AmphIBI scores by wetland types (df = 18, F =60.80, $p < 0.001$). Reference and urban wetlands mean AmphIBI scores significantly different.

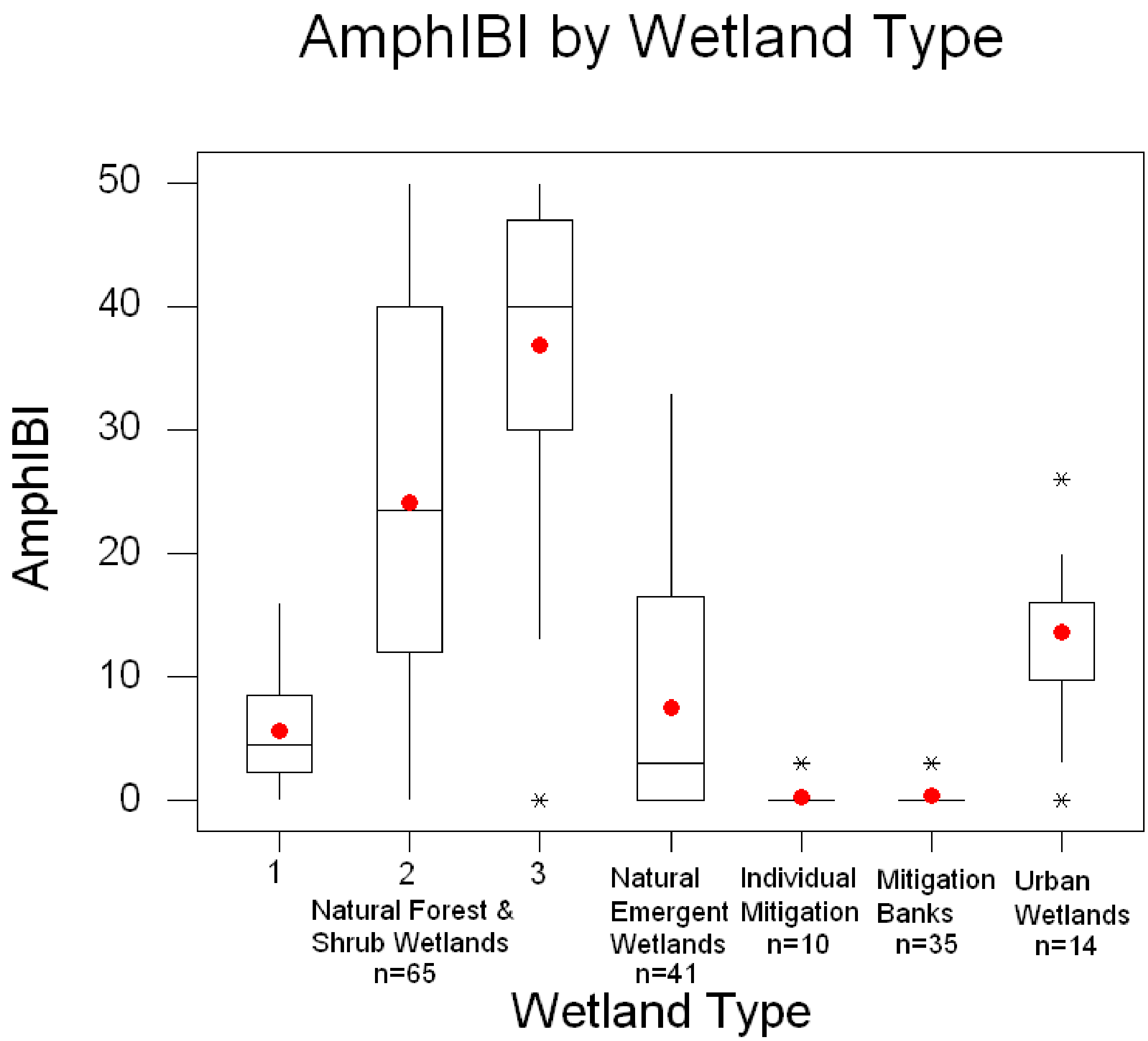

Figure 3. Box and whiskers plots of AmphIBI scores by wetland types (df = 164, F = 53.41, p < 0.001). Urban wetlands significantly different than Category 2 and 3 natural forest and shrub wetlands and individual mitigation and mitigation bank wetlands, not significantly different than Category 1 natural forest and shrub wetlands and natural emergent wetlands.

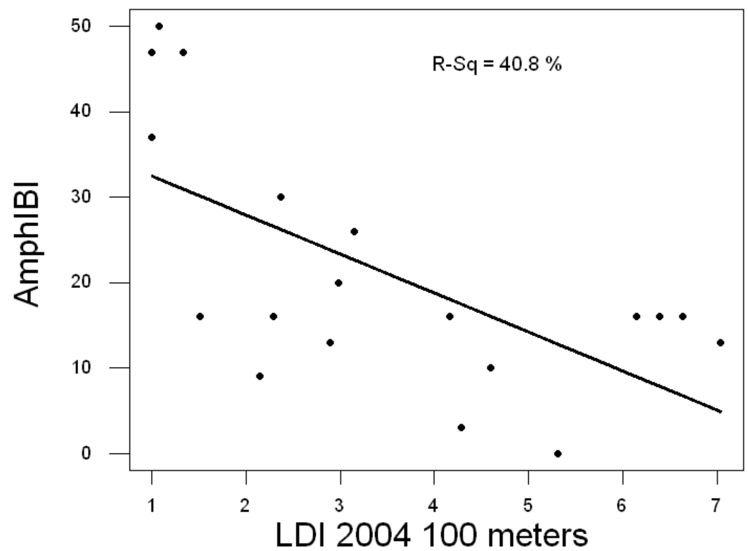

Figure 4. Fitted line regression plot of AmphIBI versus 2004 LDI at 100 meter radius (df = 18, F = 11.69, $p = 0.003$, $R^2 = 40.8\%$).

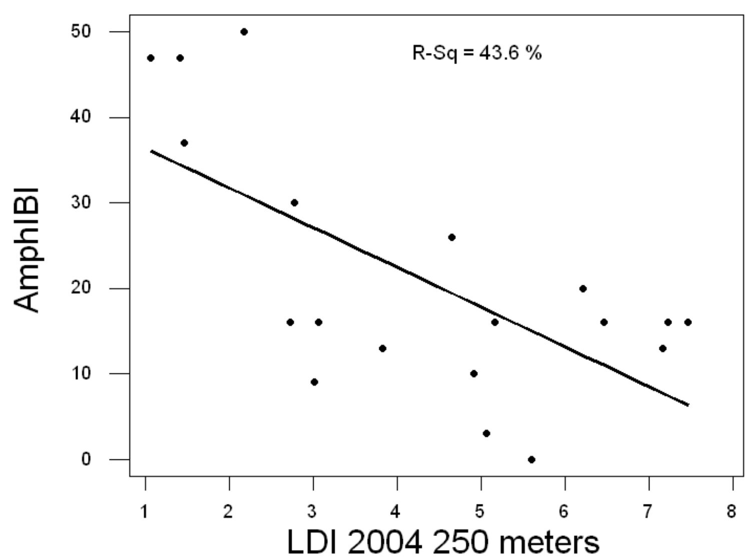

Figure 5. Fitted line regression plot of AmphIBI versus 2004 LDI at 250 meter radius (df = 18, F = 13.16, $p = 0.002$, $R^2 = 43.6\%$).

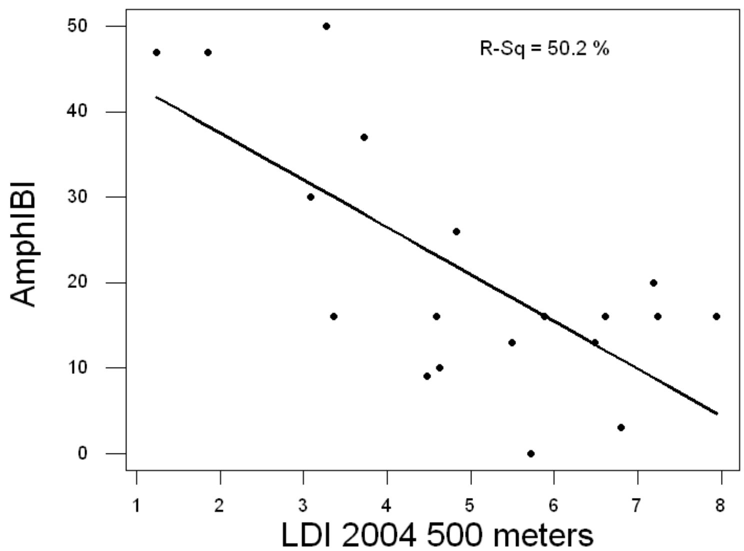

Figure 6. Fitted line regression plot of AmphIBI versus 2004 LDI at 500 meter radius (df = 18, F = 17.14, $p = 0.001$, $R^2 = 50.2\%$).

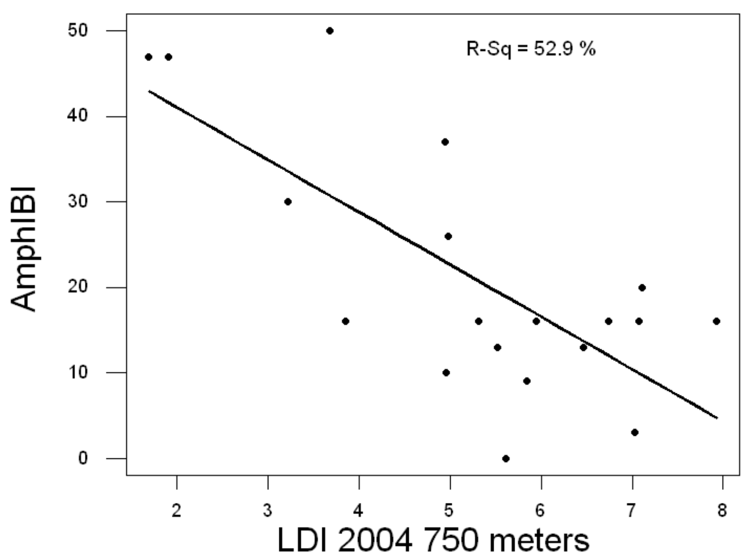

Figure 7. Fitted line regression plot of AmphIBI versus 2004 LDI at 750 meter radius (df = 18, F = 19.06, $p < 0.001$, $R^2 = 52.9\%$).

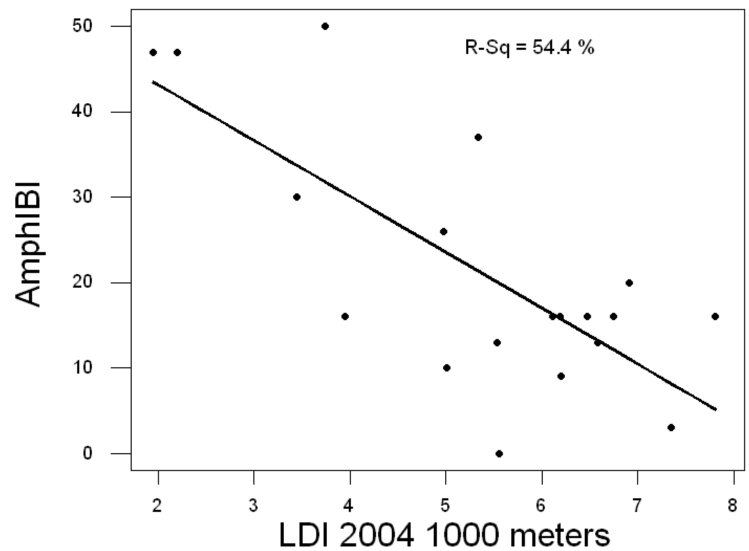

Figure 8. Fitted line regression plot of AmphIBI versus 2004 LDI at 1000 meter radius (df = 18, F = 20.27, $p < 0.001$, $R^2 = 54.4\%$).

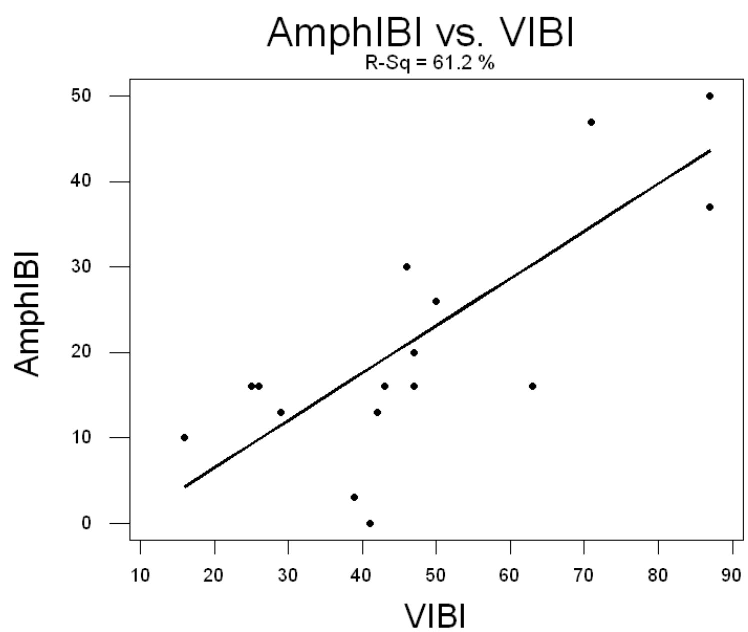

Figure 9. Fitted line regression plot of AmphIBI versus VIBI (df = 17, F = 25.28, $p < 0.0001$, $R^2 = 61.2\%$).

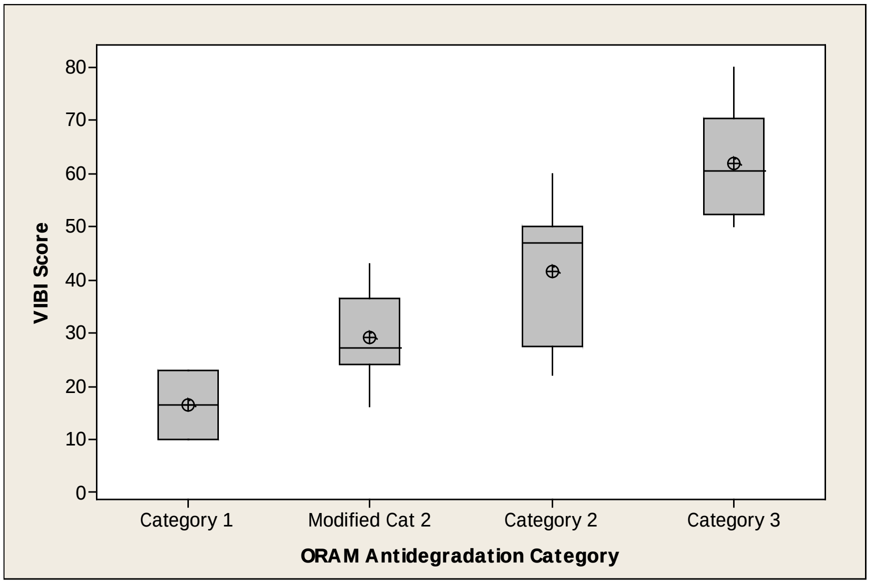

Figure 10. Box and whisker plots of VIBI scores by ORAM antidegradation Category (df = 33, F = 18.46, $p < 0.001$).

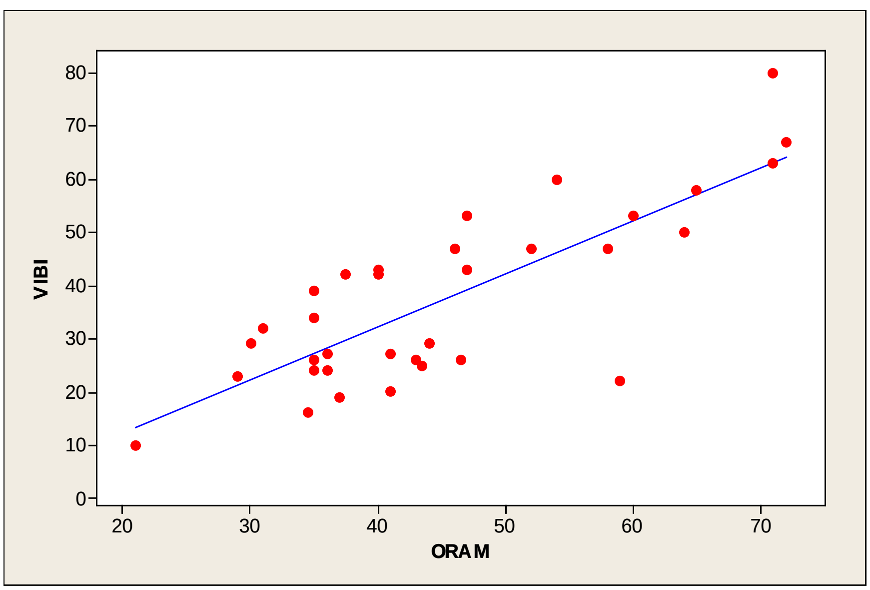

Figure 11. Scatter plot of VIBI scores and ORAM scores (df = 33, F = 56.13, R^2 = 63.7%, $p < 0.001$).

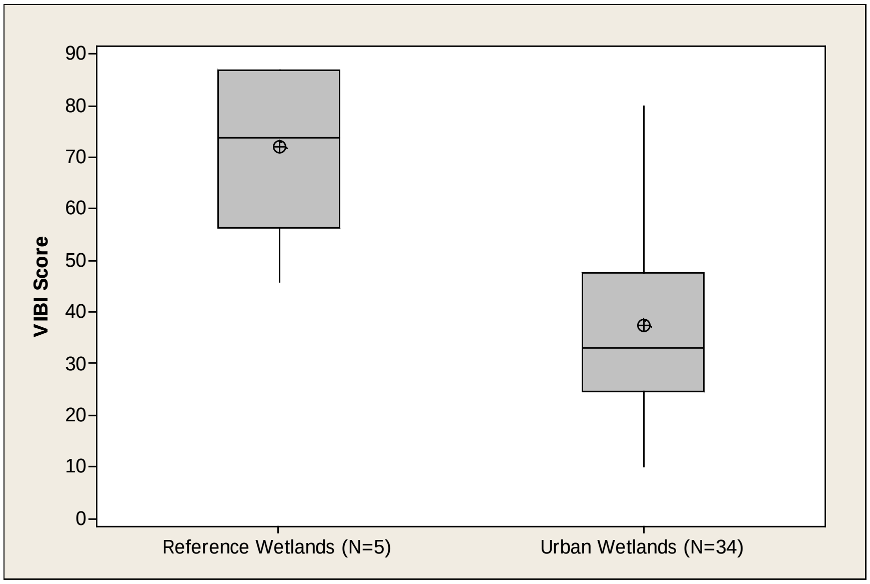

Figure 12. Box and whisker plots of VIBI scores by Wetland Type (Urban Vs. Reference; df = 38, F = 19.37, p < 0.001).

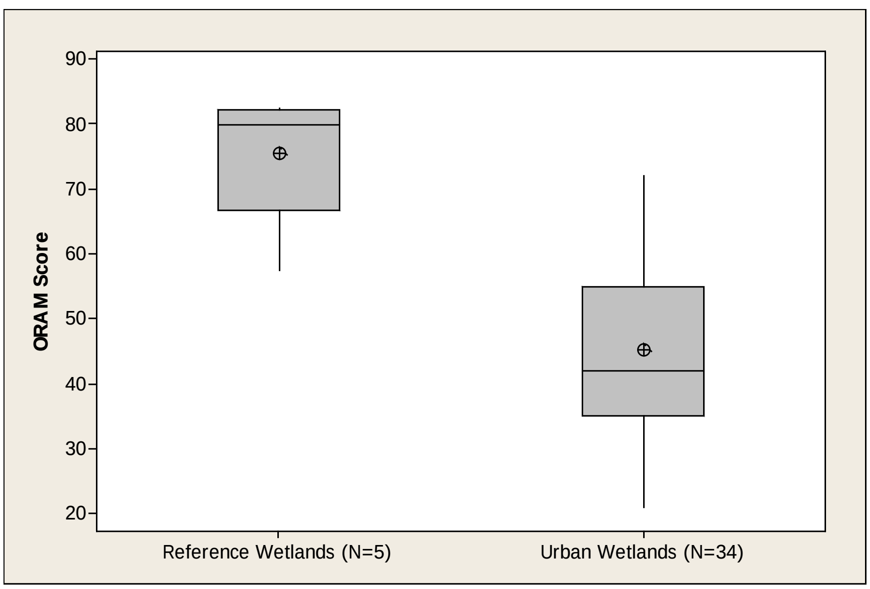

Figure 13**.** Box and whisker plots of ORAM scores by Wetland Type (Urban Vs. Reference; df = 38, F = 24.26, p < 0.001).

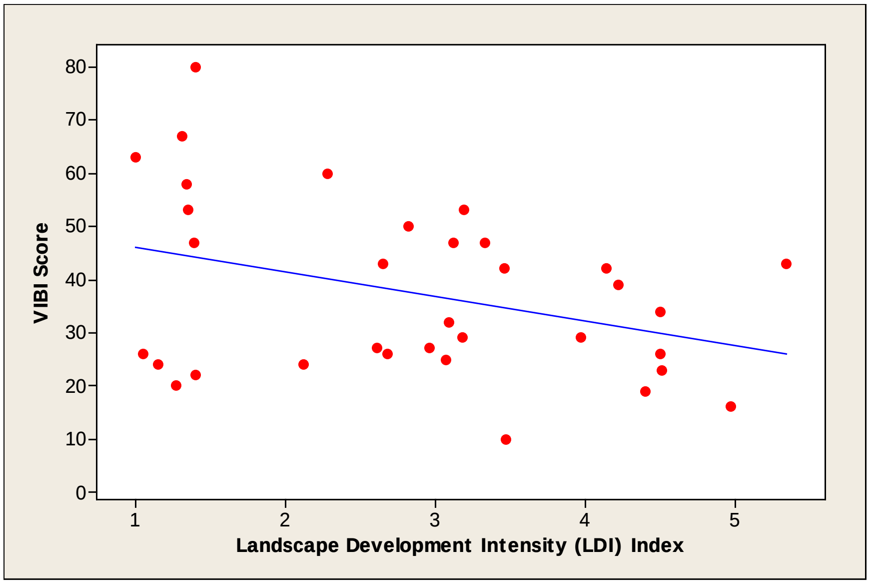

Figure 14. Scatter plot of VIBI scores and LDI scores (df = 33, F = 4.78, R^2 = 13.0%, p= 0.036).

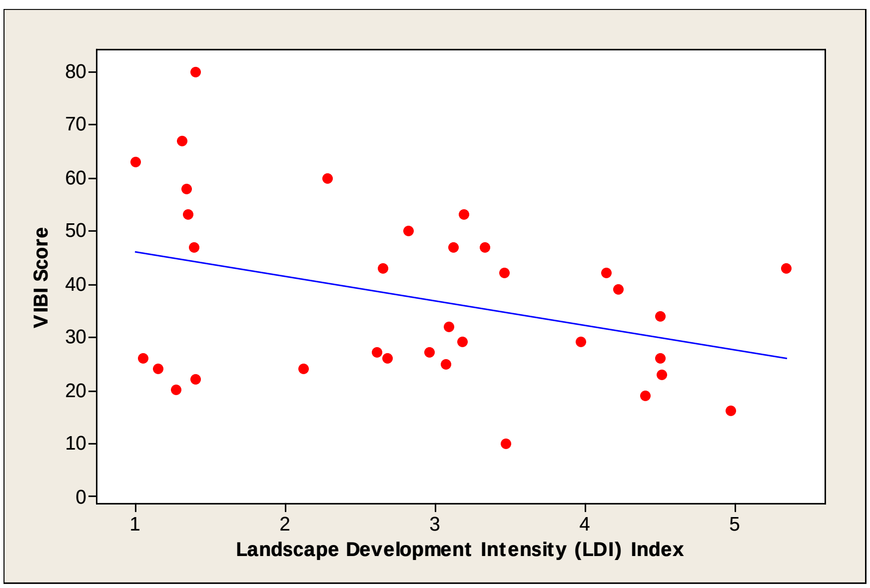

Figure 15. Scatterplot of ORAM scores and LDI scores (df = 33, F = 14.73, R^2 = 31.5%, p= 0.001).

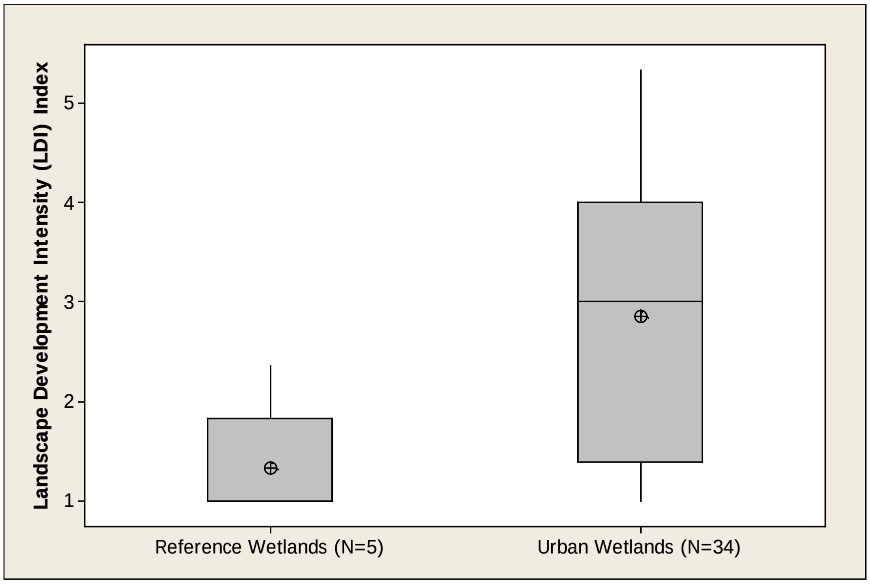

Figure 16. Box and whisker plots of LDI scores by Wetland Type (Urban Vs. Reference; df = 38, F = 6.85, p= 0.013).