EFFECTS OF HUMAN LAND USE ON THE ACTIVITY, DIVERSITY, AND DISTRIBUTION OF NATIVE BATS

Tyler Norman Turner

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Committee:

Karen Root, Advisor

Kevin McCluney

Helen Michaels

ABSTRACT

Karen Root, Advisor

Bats play critical roles in the numerous ecosystems they inhabit as nutrient cyclers, pollinators, and major sources of pest control. In agricultural landscapes, such as those in the Oak Openings, these services can be extremely valuable. Unfortunately, bats face population declines due to threats such as wind farms along migration routes, the lethal fungal disease white-nose syndrome, and habitat degradation and loss due to anthropogenic pressures. The objective of this study was to examine how native bats are using both natural and human dominated landscapes within this region while identifying features within these landscapes that promote bat activity and diversity. To do so I developed a three-part study to observe spatial and temporal trends. First, driving transects were conducted from May through September to analyze activity and diversity in three different landscape types (natural, mosaic, and agricultural landscapes). Second, paired stationary sites were set up overnight to compare core sites within Oak Openings Preserve to edge sites to assess how bats responded to areas of natural landscapes directly facing human pressure. Finally, with the help of citizen science volunteers, walking surveys were conducted through three different parks, as part of an ongoing project of the Root Lab at BGSU, to look at temporal trends in bat populations. Over the course of five months and more than 50 nights, I recorded and identified over 2,200 bat calls. The majority of these calls (95%) were dominated by just three bat species (big brown, silver-haired, and eastern red). I found a significant decrease in activity in agricultural landscapes ($p=0.04$, Pearson's Test), compared to mosaic and natural landscapes. I also found certain landscape features, such as canopy cover and distance to riparian systems, were correlated with bat activity. Within the Oak Openings Park, I found that core natural sites had significantly more activity than edge or savanna sites. There was no difference between interior edges and exterior edges, suggesting human impact has little to do with how bats are using these edges. However, vegetation density and canopy cover were predictors of increased relative foraging activity, increasing our understanding of how the bats are using their environment. This finding suggests that both natural and human dominated landscapes can be managed to promote bat activity and diversity. This is important as there was evidence of long term population declines and declines in total number of observed species in the third study. By properly managing both natural and human dominated landscapes, we can help mitigate both current and future threats that bats may face.

This is dedicated to my parents, Ted Turner and Cheryl Turner, who taught me to love and respect nature in all its forms, to my sisters Kaley and Shelby, who enjoyed the outdoors with me growing up, and to my girlfriend Megan Dunlap, who pushed me to continue my education and supported me while I did so.

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TABLE OF CONTENTS

Page

GENERAL INTRODUCTION………………………………………………………...... 1

References……………………………………………………………………… 4

CHAPTER I. ASSESSING NATIVE BAT ACTIVITY AND DISTRIBUTION ACROSS AN AGRICULTURAL GRADIENT………………………………………... 7

Introduction…………………………………………………………………….. 7

Methods………………………………………………………………………… 11

Acoustic Surveying…………………………………………………….... 11

Environmental and Landscape Variables………………………………... 12

Call Identification………………………………………………………... 13

Statistical Analysis………………………………………………………. 14

Results………………………………………………………………………….. 15

Discussion……………………………………………………………………… 19

Figures………………………………………………………………………….. 24

Tables…………………………………………………………………………… 35

References……………………………………………………………………… 43

CHAPTER II. OBSERVING THE IMPACTS ANTHROPOGENIC PRESSURES ON BATS IN A NATURAL PRESERVE ……………….……………………………….. 50

Introduction…………………………………………………………………….. 50

Methods………………………………………………………………………… 54

Acoustic Surveying…………………………………………………….... 54

Environmental and Landscape Variables………………………………... 55

Call Identification………………………………………………………………... 57

Statistical Analysis……………………………………………………………. 57

Results…………………………………………………………………………….. 58

Discussion……………………………………………………………………….. 61

Figures…………………………………………………………………..………. 65

Tables……………………………………………………………………………… 71

References………………………………………………………………………….. 75

CHAPTER III. USING CITIZEN SCIENCE TO ASSESS TEMPORAL TRENDS IN NATIVE BAT ABUNDANCE AND DIVERSITY ……………….………….....……. 80

Introduction……………………………………………………………………….. 80

Methods…………………………………………………………………………… 84

Acoustic Surveys…..………………………………………………………….... 84

Call Identification………………………………………………………………... 85

Environmental Variables……………………………………………………… 86

Statistical Analysis……………………………………………………………. 86

Results…………………………………………………………………………….. 87

Discussion……………………………………………………………………….. 89

Acknowledgements……………………………………………………………….. 92

Figures…………………………………………………………………………….. 94

Tables……………………………………………………………………………… 103

References………………………………………………………………………….. 105

CHAPTER IV. SUMMARY, MANAGEMENT IMPLICATIONS, AND FUTURE DIRECTIONS…………………………………………………………………………. 110

References……………………………………………………………………………. 114

APPENDIX A. INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE

AGREEMENT…………………………………………………………………………… 117

LIST OF FIGURES

1	Map of the Oak Openings Region and Outline of Study Site……………………	24
2	Study Site Landscape Types and Landcover Based on Martin and Root Landcover Map………………………………………………………………...	25
3	Satellite Examples of Landscape Type Classifications…………………………..	26
4	Map of Roads & Landscape Variable Count Points……………………………...	27
5	Example of Scatterboard Used for Vegetation Density Measurements…..……..	28
6	Oneway ANOVA Results of Average Calls By Landscape Type……………….	29
7	Species Diversity Indexes for Landscape Types…………………………………	30
8	Stacked Bar Graph Showing Species Totals by Month…………………………..	31
9	GPS Coordinates in ArcMap 10.2 for *E. fuscus* and *L. noctivagans*……………..	32
10	GPS Coordinates in ArcMap 10.2 for *L. borealis*………………………………..	33
11	GPS Coordinates in ArcMap 10.2 for WNS affected species …………………...	33
12	GPS Coordinates in ArcMap 10.2 for *N. humeralis* and *L. cinereus* ……………	34
13	Map of the Oak Openings Region and Outline of Study Site……………………	65
14	Overnight study site locations within the Oak Openings Preserve and Landcover Based on Martin and Root Landcover Map…………………………	66
15	Example of Scatterboard Used for Vegetation Density Measurements…..……..	67
16	Stacked Bar Graph Showing Species Totals by Month…………………………..	68
17	Bar and Line Graph Showing Species Call Totals by Time of Night …………...	69
18	Total Activity and Species Totals per Site……………………………………….	70
19	Map of the Oak Openings Region and Outline of Study Sites…..………………	94
20	Landcover Map of Oak Openings Metropark……………………………………	95

21	Landcover Map of Wildwood Metropark………………………………………..	96
22	Landcover Map of Secor Metropark…………..…………………………………	97
23	Species Diversity Indexes for the Three Parks…………………………………...	98
24	Average Abundances per Year for Total Calls and *E. fuscus* …………………...	99
25	Average Abundances per Year for *L. noctivagans, L. borealis, N. humeralis, and L. cinereus* ………………………………………………………………..	100
26	Average Abundances per Year for the thre WNS Affected Species……………..	101
27	Species Totals per Park per Year…………………………………………………	102

LIST OF TABLES

Table		Page
1	Total Calls and Percentage of Total Calls for Each Species by Landscape Type……………………………………………………………………………….	35
2	Oneway ANOVA Standard Errors and p-values for Each Species by Landscape Type and Mean Calls per Landscape………………………………………………..	35
3	Nonparametric Chi-Square Results for Each Landscape Variable per Species and for Total Calls. Chi-square Value, Degrees of Freedom, and p-value Reported……………………………………………………………………....	36
4	Stepwise Regression Model Results for *E. fuscus* ………………………………..	37
5	Stepwise Regression Model Results for *L. noctivagans* ………………..………..	38
6	Stepwise Regression Model Results for *L. borealis*…..…………………………..	39
7	Stepwise Regression Model Results for *N. humeralis* ………………….……..	40
8	Stepwise Regression Model Results for Total Relative Activity ………………...	41
9	Stepwise Regression Model Results for Total Species Diversity………..……..	42
10	Site Information for the Sixteen Overnight Sites Including Landscape Type, Edge Type, Species Detected, and Total Calls Recorded………………………....	71
11	Matrix with Jaccard's Similarity Index Results and Landscape Type……………	72
12	Average Calls Per Landscape Type and Percentage of the Total for Each Species……………………………………………………………………….	73
13	Landscape Variables Compared to Site Type……………………………………..	74
14	Total Number and Percentage of Calls of Each Species for Each Park During the 2017 Study……………………………………………………..……….	103

15 Total Number and Percentage of Total of Each Species for Every Survey Year in Wildwood Metropark………………………………………………………….. 103

16 Total Number and Percentage of Total of Each Species for Every Survey Year in Secor Metropark………………………………………………………….…. 104

17 Total Number and Percentage of Total of Each Species for Every Survey Year in Oak Openings Metropark…………………………………………………..... 104

GENERAL INTRODUCTION

Bats are the second largest and most trophically diverse order of mammals and can be found in all but the most polar ecosystems. Within those ecosystems, bats play numerous critical roles. They are key nutrient cyclers (Duchamp et al, 2010), pollinators (Petchmunee, 2001), and integral parts of the food web (Maas et al., 2016). Being generalist hunters, insectivorous bats are major sources of pest control. These services can be of great value to humans. Consumption of mosquitos by bats can help control mosquito borne viruses such as West Nile and Dengue Fever (Gonsalves et al., 2013). They can also have indirect benefits by consuming crop pests. In the US, the average value of these pesticide services averages $74 an acre, which when totaled across the country equals $22.9 billion per year (Boyles et al., 2011).

Unfortunately, bats face serious global population declines from numerous threats. In Europe and the United States, wind farms along migration routes can pose major threats (Horn et al., 2008). This is, in fact, the leading cause of death for bats in Europe. In the US, the recently emergent and highly lethal fungal disease known as white-nose syndrome (WNS) is responsible for the largest population declines (O'Shea et al., 2016). Caused by the *Pseudogmynascus destructans* fungus, this disease affects bats who overwinter in hibernacula. In response to the virus, bats boost their metabolism, which awakens them from topor, and causes them to starve with no sources of food. Being highly contagious, this disease can lead to 90-100% mortality and the collapse of the colony (Turner et al., 2011). Studies have predicted nation-wide population declines of up to 95% for certain species over the next fifteen years (Frick et al., 2010). In Ohio, mass mortalities of three species (northern long-eared bats, little brown bats, and tri-colored bats) have been confirmed due to this disease (ODNR, 2013). A fourth species (big brown bats) has confirmed mortalities in other states, while a fifth (silver haired bats) has been confirmed as a carrier for the fungus, though no mortality events have occurred. While these threats are serious, they are mostly country specific. The biggest threat to bats worldwide is habitat degradation and loss (O'Shea et al., 2016). In northwest Ohio, the area for this study, most of this pressure comes from agricultural and urban expansion.

The Oak Openings Region is unique study area and considered one of The Nature Conservancy's "200 Last Great Places on Earth" (Groove, 2005). As a result of the same glaciation that shaped the Great Lakes, this region was shaped into a drainage basin with multiple soil types and layers. This resulted in many unique habitat types such as sand barrens, wet prairies, oak savannas, and woodlands (Brewer and Vankat, 2004). Stretching 340 square kilometers from northwest Ohio into southeast Michigan, this region has experienced centuries of human development in the form of agriculture and urban development. While much of the biodiversity prior to 1920 has been lost from habitat destruction and homogenization (Becker et al., 2013), multiple parks and preserves have been established in the area to help protect the remaining rare and endangered species. However, even with fragmentation and habitat loss, this area remains a biodiversity hotspot. Despite being only a fraction of Ohio's total area, the Oak Openings Region contains nearly a third of Ohio's rare plants and animals (Schetter et al., 2013). This biodiversity extends to its native bat species. Eight species have been identified in this region, including one threatened species (*Myotis septentrionalis*) and another being considered for federal listing (*Perimyotis subflavus*).

My study took a three-part, multispecies approach to study the challenges these bat species face in the Oak Openings Region. Surveys were conducted using standardized practices with acoustic monitors (Hayes et al., 2009). Each part has been separated into its own chapter and written as a stand-alone manuscript. In the first part (Chapter I), I used driving transects with Anabat SDII acoustic monitors to survey bats within a 105 square kilometer agricultural mosaic landscape. This allowed me to identify what landscapes bats are using and what features were promoting activity and diversity. In Chapter II, I looked at the differences between natural edges and human influenced edges versus core habitat sites in a natural setting. This was done by setting up stationary overnight monitors within the Oak Openings Preserve at paired sites. Finally, in the last part (Chapter III), I organized citizen science walking surveys to monitor bat activity in three different parks from June-August. This is part of an ongoing dataset within the Root Lab (Sewald, 2012; Janos, 2013; Nordal, 2016; Hollen, 2017) and allows us to look at long term trends in bat activity and diversity within the region. Through these three studies, my result will contribute to the overall understanding of how bats are using the landscapes of northwestern Ohio, and how we may better manage them to help protect these fascinating and valuable creatures.

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CHAPTER I. ASSESSING NATIVE BAT ACTIVITY AND DISTRIBUTION ACROSS AN AGRICULTURAL GRADIENT

Introduction

As one of the most diverse orders of mammals, bats can be found in nearly every ecosystem around the world, making conflicts between humans and bats inevitable. While they do face serious threats such as wind farms along migration routes (Horn et al., 2008) and the lethal fungal disease white-nose syndrome (WNS; Turner et al., 2011), habitat loss from human activities is the leading cause of bat population declines worldwide (O'Shea et al., 2016). Thus, it is critical for us to understand the effects that human activity have on bat activity, diversity, and distribution. This is especially important for human dominated landscapes such as the Oak Openings Region in northwestern Ohio, as landscape structure and composition have been found to have significant effects of both activity and species diversity in bats (Charbonnier et al., 2016).

Northwest Ohio is heavily impacted by agricultural expansion, and both urban and rural development. This presents an opportune intersection between human activity and biodiversity. The Oak Openings is a biodiversity hotspot comprised of a diverse, sometimes rare, ecosystems in a mixed disturbance landscape that stretches for 476 km^2 in northwestern Ohio (Brewer & Vankat, 2004) (Figure 1). Unfortunately, much of this land has suffered varying degrees of anthropogenic pressure since the early 1900's. Much of the area has been cleared for agricultural development, while the major urban center of Toledo and its associated sprawl sits directly in the center of the region. However, the Oak Openings is still home to nearly 1/3 of Ohio's rare plant and animal species (Schetter et al., 2013).

This diversity extends to Ohio's bat species. More than 50% of the species of bats in Ohio can be found in this region (Bellwood, 1998). These eight species are the big brown bat (*Eptesicus fuscus*), silver-haired bat (*Lasionycteris noctivagans*), eastern red bat (*Lasiurus borealis*), hoary bat (*Lasiurus cineresus*), little brown bat (*Myotis lucifugus*), evening bat (*Nycticeius humeralis*), tri-colored bat (*Perimyotis subflavus*), and northern long-eared bat (*Myotis septentrionalis*). This last species is considered as threatened under the US Endangered Species act, while *P. subflavus* is being considered for listing (USFWS, 2018).

While bats show incredible trophic diversity around the world, all eight of these species are considered insectivores (Tuttle, 1988). Insectivorous bats are typically generalist hunters and can adapt to consume different species of insects as they emerge. They will actively forage on mosquitoes and can help decrease the spread of mosquito-borne viruses (Gonsalves et al, 2013). But more than just pests that directly affect humans, bats will consume crop pests that harm agricultural production. This can be very important to farm production, as bats can begin consuming crop pests before typical detection methods can identify the problem (Maslo et al., 2017).

The value of these services is immense to agriculture. Boyles et al. (2011) found the value of bats to agricultural production to be $74 per acre, which is a yearly total of $22.9 billion per year for agriculture across the US. Bats have been known to forage and control crop pests for grapes (Rambaldini & Brigham, 2011), pecans (Braun de Torrez, 2014), corn and cotton (McCraken et al, 2012; Lee & McCracken, 2005), and many other crops of value to humankind. Additionally, Maine and Boyles (2015) found that when bats were excluded from crops those crops had 59% more damage from pest larva and an 8% increase in fungus spread by pests. These animals are not only valuable to our agriculture but can be critical to our global food security going forward (Kunz et al., 2011). Of course, the value and importance of these services will continue to grow as agricultural land use increases with a growing human population. Furthermore, there is some evidence that bats could serve as bio-indicators for a wide range of species in their responses to agricultural development (Park, 2015).

While different bat species may consume the same prey, foraging behavior and the locations in which they forage can be highly variable between species. Behaviors can range from open air hawking, to gleaning, to hovering all at differing vertical heights (Altringham and Kerth, 2016). Furthermore, certain species utilize or show preferences for different habitats. Bats such as the little brown, northern long-eared, eastern red, and tri-colored generally prefer forest habitat and high canopy cover (Kniowski & Gehrt, 2014; Kurta, 1995; White et al., 2015). Other species, such as the evening bat, hoary bat, and silver-haired bat tend to prefer open canopy (White et al., 2015; Whitaker and Mumford, 2009), while the big brown bat is considered a generalist able to adapt to many different landscape and habitat types (Gehrt and Chelsvig 2014). As a result of this variation, a multi-species approach is necessary to fully understand the spatial and temporal dynamics of bat land use.

Along with variations in foraging patterns, species specific behaviors can make traditional survey methods difficult. A common method for studying bats is using mist nets to capture and identify bats. While this does make for more consistent identification, some species are more adept at avoiding mist nets (Hayes et al., 2009), which can skew the results of a multi-species study such as this. Therefore, we used acoustic monitors to survey these animals but eliminate capture bias (Roadhouse et al., 2011). This helps not only eliminate sample bias, but utilizes non-invasive techniques so we both limit damage to the animals and eliminate the risk of spreading pathogens.

Unfortunately, on top of anthropogenic pressures, three species of bats in Ohio have had mass mortalities from WNS: *M. lucifugus, M. septentrionalis,* and *P. subflavus* (ODNR, 2013). Some studies suggest that during the next 15 years we will see species declines as great as 99% for some species (such as the *M. lucifugus*) nationwide (Frick, 2010). Another species, *E. fuscus*, has been documented with this disease in other states (Foley et al., 2011) while two of Ohio's bat species (*L. noctivagans* and *L. borealis*) are known carriers of the fungus that causes the disease (Bernard et al, 2015). Thus, it is imperative to study how these animals utilize the landscapes, in order to mitigate these threats and maximize their chances of success.

While there have been similar studies in Europe (Kalda et al., 2015; Park, 2015; Charbonier et al., 2016), Mexico (Castro-Luna and Galindo-Gonzalez, 2012), and South America (McCracken et al., 2012; Maas et al., 2016), there have been few studies on bats and their abundance in agricultural areas in the United States. Furthermore, much of the research in the US focuses on intact forest habitat (McCracken et al., 2012) or urban environments (Ghert and Chelsvig, 2014). There is a need for research on bats and the effects of human dominated landscapes like agricultural areas and mixed-use land.

Our study examined the relationships among land use and landscape characteristics and native bat activity, diversity, and distribution. Studies have shown that landscape composition is very important for both bat activity and diversity (Arroyo-Rodriguez et al, 2016), so we wanted to look at this composition in an agricultural gradient. We conducted driving transects over a 105 square kilometer area in northwest Ohio. This study area contained a gradient of land uses including predominantly natural landscapes in the east, mostly agricultural in the west, and a mosaic landscape in between consisting of a mix of residential, agricultural, and forests (Figure 2). This study site allowed us to compare those natural areas to places with different levels of human impact. We explored (1) what types of landscapes were being used by native bats in this region, (2) what landscape features promoted bat activity and diversity, and (3) how bat activity and diversity in these homogenous row crop agriculture areas compared to other landscape types. We expected to see that bat activity would be greatest in natural landscapes and would be significantly higher in mosaic landscapes than agricultural. We also expected that there would be species specific responses to different land use and landscape variables. Finally, we expected to find certain variables, such as distance to forest patches and riparian systems would be important predictors for bat activity. Our overall goal was to identify what landscapes these bats were using, how they were distributed, and what landscape features were promoting activity and diversity.

Methods

Acoustic Surveying

A gradient of natural, residential, agricultural mosaic, and row crop agricultural covering approximately 105 square kilometers within the Oak Openings Region was selected as the target area for driving transects. This grid ran from the Oak Openings Metropark on the eastern edge to Delta on the west (Figure 2). Within this grid, 33 roads were chosen for transects, ranging from 1.2km to 9.5km per road. These transects included every road within the selected area, minus the major road bounding the northern length. The roads were fairly evenly distributed through different landscape types: 11 in natural, 10 in mosaic, and 12 in agricultural. Land area was similarly evenly distributed with 33.4 km^2 of agricultural landscape, 34.3 km^2 of natural landscapes, and 37 km^2 of mosaic landscapes. Agriculture consisted of mostly large homogenous row crop farms (e.g. corn, soybean), while natural was mostly natural preserves.

Mosaic landscapes were defined as residential land mixed with small farms, riparian systems, and forest patches (Figure 3).

Transects were randomized each month and any that crossed each other were re-ordered to maintain randomness. Surveys began mid-May as the temperatures became more conducive to bat activity and continued until the end of September when bats began leaving foraging grounds for their overwintering locations. Five transects were randomly selected each survey night, with two backup roads selected in case of road closures. Surveys began 30 minutes after sunset and continued until all five transects had been surveyed. Anabat SD2 monitors (Titley Electronics, Ballina, New South Wales, Australia) were attached to an extendable pole and placed out the driver's side window at 45 degrees. Monitors were connected to a Garmin eTrex handheld GPS unit which recorded GPS location approximately every 3 seconds. Anabat units were turned on at the start of each transect and shut off at the end. Driving speeds were kept consistent at 30 km/h to maintain consistency while minimizing likelihood of recording repeated individuals.

Environmental and Landscape Variables

Temperature (ºC), humidity (%), and barometric pressure (inHg) were measured before the start of each transect with Brunton ADC-Pro handheld weather units. Wind speed (km/h) and direction were taken from NOAA weather center at the Toledo Airport (http://w1.weather.gov/obhistory/KTOL.html) after completion of the surveys. Percent illumination and Moon Phase were recorded from MoonGiant (http://www.moongiant.com/phase/today/). Nights with high winds (< 24 km/h), rain, temperature under 12ºC, and nights within two days of the full moon were excluded as possible sampling nights due to decreased bat activity (Voight et al., 2011).

For environmental measurements, we sampled at points along each road (total of 104 points) at intervals equal to the shortest road segment (1.29 km, Figure 4). These measurement points were distributed nearly evenly across landscape types: agricultural (n = 34), mosaic (n = 36), and natural (n = 34). At each point we measured canopy cover, canopy height, vegetation height, vegetation density, distance to vegetation, minimum distance to tree stands, road width, and minimum distance to riparian system. Tree stands were defined as a patch of trees at least 30 m by 30 m. Canopy cover was measured by taking a picture of the canopy on either side of the road (Fiala et al., 2006) and estimated as a percentage cover with HabitApp (version 1.2). Vegetation density was measured with a 6.5 m cloth scatterboard by counting the number of squares not covered by vegetation and subtracting those from the total number to get the number and percent coverage (Figure 5). Distances were measured via measuring wheel (if < 10 m), measuring tape (< 30 m), Nikon Prostaff 3 laser rangefinder (30-500 m), and Google Earth satellite images and measuring tool (> 500 m). Vegetation height (meters) was measured with measuring tape, while canopy height (meters) was measured via rangefinder. We also recorded the land use type (forest, field, residential, or agriculture) on both sides of the road. If the land use was agricultural, we recorded the dominant crop type.

Call Identification

Calls were recorded with Anabat SDII monitors and autotagged with GPS locations using connected global positioning satellite units (Garmin Ecotrex GPS Unit). Monitors used Anabat Standard omindirectional microphones and were attached to an extendable pole, which extended out of the driver's side window. Division ratio was set at 16 and sensitivity at 8. This device has a detection radius of 30 meters and records all bat call frequencies. Bowling Green State

University's Institutional Animal Care and Use Committee (IACUC) approved all research methods and protocols (Appendix A).

Calls were analyzed in Kaleidoscope Viewer Software (Wildlife Acoustics, 2016) and checked with Bat Call Identification Software (BCID, BCID version 9 2.7c). When identifications disagreed, we made the final decision based on our own knowledge of calls and the call library collected by previous research (Sewald, 2012). Calls were only identified to species if a clean "pass" was recorded. Passes were defined as three or more clear and identifiable calls made by one species in one file (Parsons and Szewcwak, 2009). GPS locations were recorded by time for each call and mapped on ArcMap 10.2 (ESRI, 2011) and provided data on the distribution of each species. The number of calls was treated as a measure of relative activity.

Statistical Analysis

Environmental and landscape variables were averaged (except distance measurements for which we used the minimum rather than the average) across all five months for each of the 104 different data collection points on the transects (Figure 4). To get total call counts and species counts for each point a square buffer of 640 meters by 640 meters buffer was drawn around each variable point and all calls within were identified within that buffer. Spearman's rho correlation analysis was run to test for significant correlations between environmental and landscape variables. Correlations were considered significant if $|r| > 0.6$ and $p < 0.05$. A Kruskal-Wallis analysis was run for all landscape variables to test for significance among total relative activity, individual species activity, and species diversity. To test for spatial auto correlation, a Moran's *I* test was run on the call locations in ArcMap 10.2 for both total relative activity of all species and for individual species.

To look at the landscape types, individual calls were marked as either agricultural, mosaic, or natural based on the landscape in which they were recorded. Pairwise Wilcoxon tests were run to test for significant differences in activity and diversity between landscapes. This was assessed for total calls, and for each individual species.

Finally, a backwards stepwise regression model was run to look at relationships between sets of significant variables and total activity, individual species activity, and species diversity. All tests were performed using JMP Statistical Analysis Software (JMP®, Version 11. SAS Institute Inc., Cary, NC, 1989-2007), except for Moran's *I* test for spatial autocorrelation, which was run in ArcMap 10.2 (ESRI, 2011). All reported significantly significant results met the criteria for Bonferroni correction to account for multiple comparisons.

Results

In total, 653 calls over 35 survey nights were recorded and identified across five months. All eight species of native bats were recorded and identified (Table 1). For 93 calls we were either unable to identify the species or there were not enough calls to be considered a full pass. Out of the identified calls 61% (397 calls) were recorded from *E. fuscus*. *L. noctivagans* was the second most common comprising of 23% of the totals and 147 calls (Figure 9) The only other significant amount of calls came from *L. borealis,* comprising 11% of the total and 71 calls (Figure 10). The three least common species were the three species that have been affected by WNS in Ohio, *P. subflavus, M. lucifugus,* and *M. septentrionalis,* (Figure 11) and were detected in less than 1% of the total calls. The other two species (*N. humeralis, L. cinereus*) were recorded in 25 and 9 calls, respectively (Figure 12).

At a landscape level, as predicted the natural landscape had the highest amount of activity, with 40% of the total calls (262 calls). Mosaic landscapes had 37% (239 calls), while agriculture had the lowest total activity with 23% (152 calls). When we averaged the number of calls associated with each measurement point within that landscape, natural landscapes (mean 13 calls per point) were significantly higher in activity level than the human dominated mosaic (mean 9 calls) and agricultural (mean 6 calls) landscapes. However, we found that mosaic landscapes had significantly higher activity than agricultural areas (Figure 6) Furthermore, all eight species were identified in the mosaic landscape, while only six were found in natural and five were found in agricultural landscapes. Looking at the Shannon Diversity Index, the mosaic landscape scored the highest diversity with 1.159 (Figure 7). Both natural and mosaic landscapes had significantly higher activity than agricultural landscapes with pairwise Wilcoxon tests ($p = 0.04$ in both cases).

Using a Moran's I test, data for total relative activity was not spatially autocorrelated ($z = -0.295$, $p = 0.768$). This was examined for individual species as well. *E. fuscus* ($z = -0.301$, $p = 0.759$), *L. noctivagans* ($z = -0.348$, $p = 0.728$), *L. borealis* ($z = -0.827$, $p = 0.408$), and *N. humeralis* ($z = -0.866$, $p = 0.512$) were all not spatially autocorrelated. The test was not run for *L. cinereus, P. subflavus, M. lucifugus,* or *M. septentrionalis* due to low numbers.

We found wind speed and direction to be positively correlated ($r = 0.612$, $p < 0.001$) and a negative correlation between time and month ($r = 0.600$, $p < 0.001$). Total calls of *E. fuscus* and *L. noctivagans* were positively correlated with total relative activity ($r = 0.876$, $p < 0.001$

and $r = 0.678$, $p < 0.001$, respectively). No other environmental or landscape variables were significantly correlated with each other.

Total bat activity and species activity were counted within the buffer set around each of the 104 sites. Based on our one-way ANOVA, all three landscapes were significantly different from one another (Wilcoxon each pair; Natural vs Agricultural $p < 0.001$, Mosaic vs Agricultural $p = 0.002$, and Mosaic vs Natural $p = 0.003$). Average counts at each point in each landscape type were 13.6 calls for natural landscapes, 9.1 for mosaics, and 6.2 for agricultural, respectively. Activity in natural landscapes was significantly higher compared to both agricultural (Kruskal Wallis; $p = < 0.001$) and mosaics (Kruskal Wallis; $p = 0.002$). Mosaic landscapes also had significantly higher total activity than agricultural (Kruskal Wallis; $p = 0.03$). Results for the species activity differences among landscapes are shown in Table 2. We found significant differences for the four most common species. The number of *E. fuscus* calls was significantly lower in agricultural areas compared to natural and mosaic. The number of *L. noctivagans* and *N. humeralis* calls both were significantly higher in natural landscapes compared to mosaic and agricultural. For *L. borealis,* significant differences were found among all three landscapes, with highest averages in the natural landscape and lowest in agriculture. Calls from *L. cinereus, P. subflavus, M. lucifugus,* and *M. septentrionalis* did not show any significant differences, which might have been a result of the low numbers of calls (less than 5% of total calls).

The landscape values that were found to be significantly positively related to total relative activity were landscape type (Kruskal Wallis; $p < 0.001$), vegetation height (Kruskal Wallis; $p < 0.001$), vegetation density (Kruskal Wallis; $p < 0.001$), and canopy cover (Kruskal Wallis; $p < 0.001$). Distance to tree stands (Kruskal Wallis; $p = 0.008$) was significant but negatively related. Distance to vegetation, distance to riparian systems, and road width were not significantly related to total relative activity. At a species-specific level, we found significant relationships to landscape variables in the four most common species (*E. fuscus, L. noctivagans, L. borealis,* and *N. humeralis*) where total activity was significant, where there were no significant relationships to landscape variables in the four less common species (*L. cinereus, P. subflavus, M. lucifugus,* and *M. septentrionalis*). The only species-specific response that differed from total activity significantly was a positive relationship to distance to riparian systems for *L. borealis* ($p = 0.030$) and a lack of a relationship between *E. fuscus* and distance to tree stands ($p = 0.083$) (Table 3).

Peak activity was observed in July and August, with the most calls (177) in August (Figure 8). Recording month was significantly related to total relative activity (Kruskal Wallis, $p = 0.001$). However, none of the other environmental variables were significantly related to total relative activity, individual species activity, or species diversity.

Finally, using a stepwise regression, we built models for the four most common species (*E. fuscus, L. noctivagans, L. borealis,* and *N. humeralis*) along with total relative activity and total species diversity. The four less common species (*L. cinereus, P. subflavus, M. lucifugus,* and *M. septentrionalis*) were excluded because of small sample sizes ($n < 10$ for *L. cinereus,* $n < 3$ for the rest). The top models, shown in Tables 4 to 9, were built with significant landscape variables. Model 1 included all five variables (landscape type, vegetation density, vegetation height, distance to tree stands, and canopy cover). Model 2 looked at landscape along with density measurements (canopy cover and vegetation density). Model 3 excluded landscape type but kept the other four variables. Model 4 was built with landscape type and tree measurements (canopy cover and distance to tree stands), while Model 5 used landscape types and vegetation measurements (vegetation height and vegetation density). For *E. fuscus,* models 1 and 3 were the strongest (AICc = 538.070, Adjusted $R^2 = 0.289$, $p < 0.001$) (Table 4). Models 1, 2, and 5 were the strongest for *L. noctivagans* (AICc = 420.181, Adjusted $R^2 = 0.348$, $p < 0.001$) (Table 5). All models except model 4 were strong for *L. borealis* (AICc = 303.587, Adjusted $R^2 = 0.199$, $p < 0.001$) (Table 6). Similar to *L. noctivagans,* models 1, 2, and 5 were strongest for *N. humeralis* (AICc = 147.129, Adjusted $R^2 = 0.153$, $p < 0.001$) (Table 7). This was true as well for total relative activity (AICc = 615.039, Adjusted $R^2 = 0.383$, $p < 0.001$) (Table 8) and species totals (AICc = 279.278, Adjusted $R^2 = 0.272$, $p < 0.001$) (Table 9).

Discussion

Through the use of acoustic monitoring, this study looked at the effects of agricultural, natural, and mixed-use mosaic landscapes to determine the influence of human dominated landscapes on bat foraging activity, diversity, and distribution. We took a multispecies approach and looked at the types of landscapes that were being used by native bats in this region, the features that promoted bat activity and diversity, and at changes in activity and diversity in row crop agriculture areas compared to other landscape types. We explored what environmental and landscape variables could explain this activity, diversity, and distribution. We found that landscape type (natural vs mosaic vs agricultural) was closely associated with bat activity and diversity and that there were significant declines in agricultural areas. We also found that vegetation density, canopy cover, distance to tree stands, and vegetation height all had a significant effects on activity and diversity of these bats.

None of the environmental variables measured were significantly related to activity. One explanation for the lack of relationships was that the weather over the sampling period was relatively consistent; there were very few nights when weather was unfavorable for bats (e.g., strong winds, rain, cool). We also specifically selected for nights with suitable weather conditions for bats since favorable conditions had been well established by previous research (Sewald, 2012; Janos, 2013; Nordal, 2016; Hollen, 2017). Thus, we can likely rule out weather as a factor driving activity, diversity, and distribution in this study and focus on landscape type and variables in this study.

This study found that both landscape type and landscape features had significant effects on total relative activity. We also found a number of species specific responses, such as the significant positive relationship between distance to riparian system between *L. borealis* activity, and distance to tree stands was not significantly related to the activity of the generalist species *E. fuscus*. These species specific responses were only found in the four most common species. We did not have many calls of the other four (*L. cinereus, P. subflavus, M. lucifugus,* and *M. septentrionalis,* which may have hampered our ability to detect significant relationships.

Landscape variables had more predictive power for both activity and diversity. As expected, total bat activity was significantly lower in agricultural landscapes when compared to natural. The majority of calls identified in this landscape belonged to *E. fuscus*. This was not surprising since this species is considered a generalist and is highly adaptable (Valdez and O'Shea, 2014). Two other species found in agricultural areas were *L. noctivagans,* a species which prefers open canopy foraging (Tuttle, 1988) and second most common species, and *L. borealis,* which was the third most common species. Three calls identified as *L. cinereus* and one as *N. humeralis* were also discovered in this landscape. The one *N. humeralis* appears to be an outlier since all the other calls were recorded in mosaic or natural landscapes. However, both *L. cinereus* and one as *N. humeralis* are considered to be open canopy foragers (Sewald, 2012), so they might be more adept at using the open agricultural land as foraging habitat.

Mosaic landscapes, even with their high human impact, had much more foraging activity and diversity than the agricultural areas. While total relative activity was highest in natural landscapes, species diversity and total number of species detected were both highest in mosaic landscapes. The only calls identified from *M. septentrionalis* and *P. subflavus* occurred in these human dominated mosaics. This suggests that while it seems bats are avoiding agricultural areas, it is not necessarily human activity that is the driving factor for this avoidance. *Myotis* species are particularly vulnerable to open agricultural areas, as they are typically low flying, forest dwelling gleaners (Safi and Kerth, 2004).

Our stepwise regression models support these findings. For *E. fuscus,* the best models were the ones that included vegetation and both tree variables. However, landscape type did not change the value. This species also had the highest AICc value in all models, indicating the weakest fit. So while landscape characteristics are probably important, these bats are also able to adapt to human dominated landscapes, including homogenous agricultural landscapes. The other notable species is *L. borealis.* For this species, AICc value only increases in model 3 when landscape type was removed, suggesting that landscape type was a strong factor for *L. borealis* activity and that all landscape characteristics were weighted equally. For *L. noctivagans* and *N. humeralis*, as well as species diversity and total relative activity, models 1, 2, and 5 were the strongest. All of these models included landscape type, which was an influential characteristic.

Model 5 used vegetation measurements (vegetation height and vegetation density), while model 2 used density measurements (canopy cover and vegetation density). These models suggest that vegetation density was a very important structural characteristic in general.

These data indicated that while most bat species preferred natural systems, they were able to adapt and use less desirable landscapes even if those landscapes had a high human impact. However, if they are to use these landscapes, high structural diversity is key to fostering bat activity and diversity. Landscape heterogeneity has been recognized as critical for bat activity in numerous studies. For example, Gehrt and Cheslvig (2004) found that bats would use fragmented forest patches within an urban context as long as there was some structural variation in vegetation clutter. Another study by Henderson and Broders (2008) compared bat activity in homogenous fields to heterogeneous forests and found bats chose to forage where they had canopy cover and riparian systems. Fuentes-Montemayor et al. (2013) looked at woodland characteristics at a large scale and found that the flight energy is much more for bats in a homogenous system, therefore structural diversity is necessary for large scale management. We identified vegetation height, vegetation density, canopy cover, and distance to tree stands as the driving factors for increased activity and diversity in this region. Each of these changes from one landscape type to another, and all of these factors are manageable to one degree or another. Maintaining existing preserves and forest patches with different amounts of canopy cover and vegetation densities through active management is critical for improving bat activity and diversity. Thus, we may be able to successfully manage and shape landscapes for the benefit of native bats. This can be especially beneficial to farmers looking to utilize their ecosystem services (Boyles et al., 2010). In addition, this heterogeneity is like to be critical to those bats that are facing severe population declines.

As mentioned, only one individual call was recorded from each *M. septentrionalis* and *P. subflavus*. Furthermore, only two calls were recorded all summer for *M. lucifugus*. Unfortunately, these are the three species which have had mass mortalities in the state of Ohio from white-nose syndrome (ODNR, 2013). Even more alarming is the fact that our most common species (*E. fuscus*) has been affected by this disease in nearby states (Frick et al, 2016), while the second and third most common (*L. noctivagans* and *L. borealis*) have both been identified as asymptomatic carriers of the fungus *P. destructans* responsible for the disease (Hayman, 2013). Protecting favorable habitat for bats may be critical for those that survive the disease to have a chance to recover (Maslo and Fefferman, 2015).

Moving forward, we must keep these landscape features in mind when managing both natural and human dominated landscapes. Understanding the interactions between species and the landscape is critical to proper management. By increasing structural heterogeneity in the landscape, we can help promote bat activity and species diversity. This will help mitigate the numerous threats these species face. Not only should we consider the inherent value of biodiversity, but we can look at the numerous different biological and economic benefits of these creatures. By protecting and providing usable habitat, we can help bats to flourish while in turn maximizing the benefits that these animals provide both to their ecosystems and to humans. Furthermore, since bats may be an indicator of anthropogenic effects on other wildlife species (Park, 2015), by managing landscapes they favor we may increase biodiversity in a suite of other species. Thus, proper management can have a tremendous impact and can include great benefits to humans and the ecosystem as a whole.

Figures

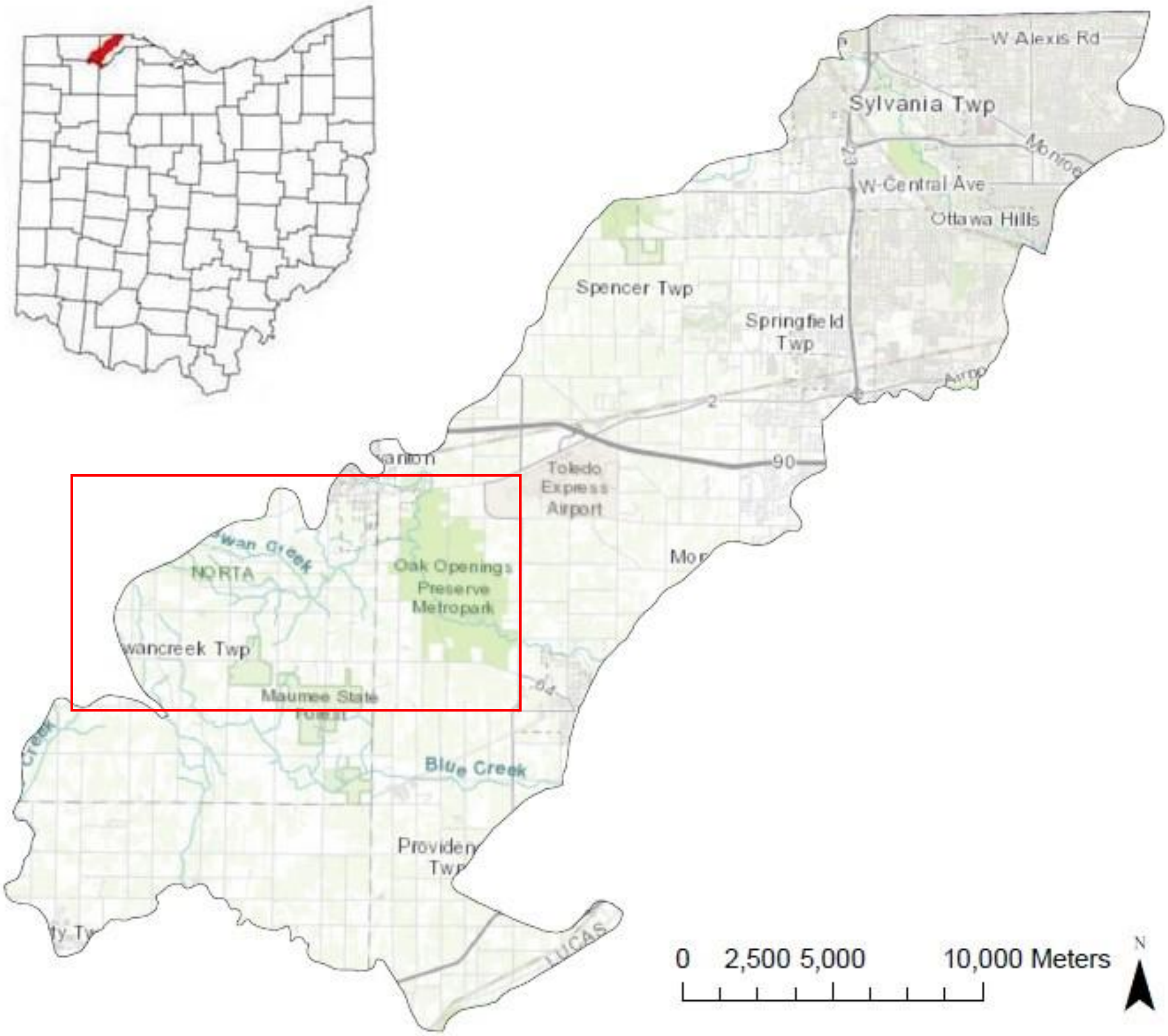

Figure 1: The Oak Openings Region of NW Ohio as defined by Brewer and Venkat (2004). Study area outlined in red. Basemap courtesy of USGS.

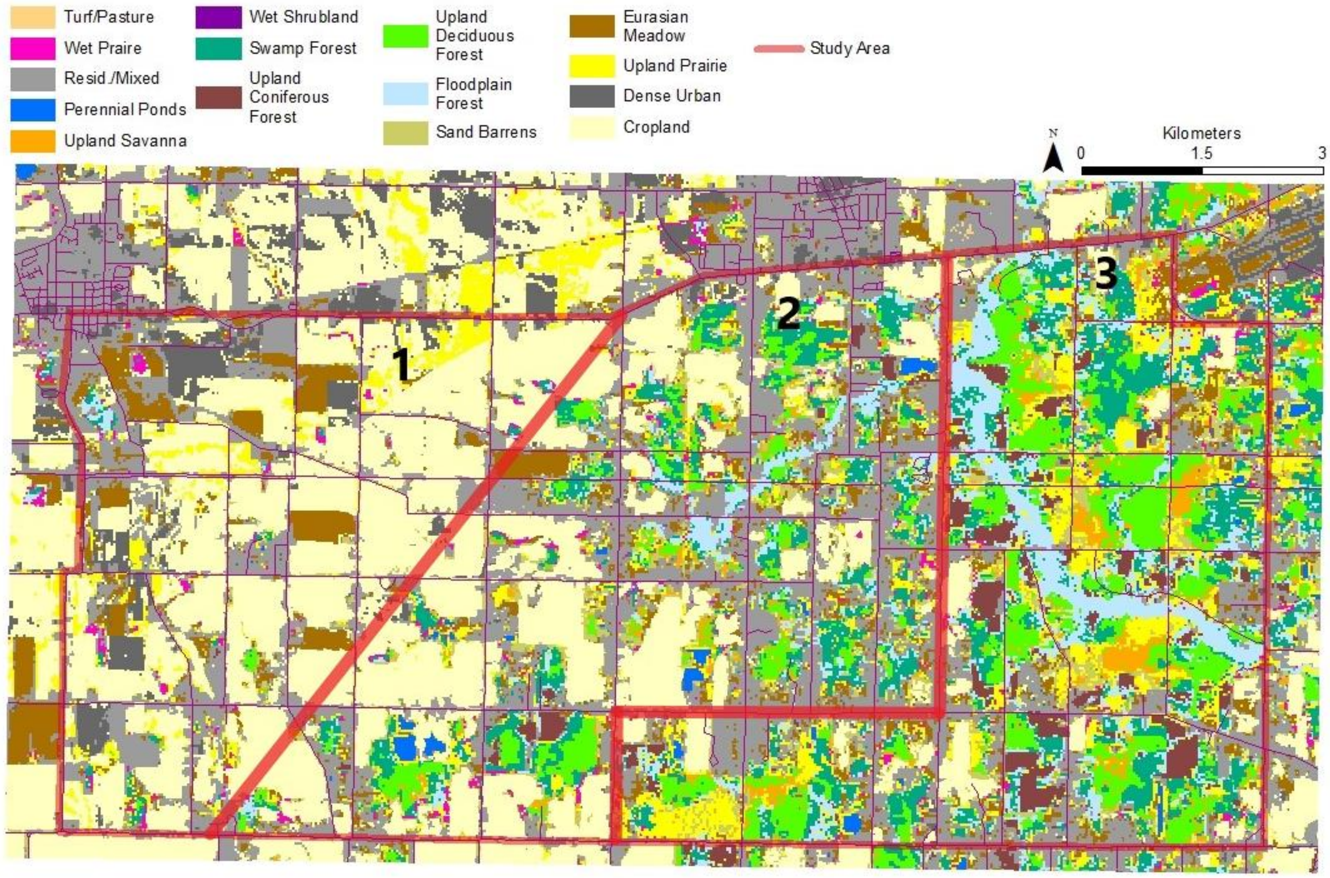

Figure 1: Outline of the study area in northwest Ohio broken down by landscape type. 1) Agricultural Landscape, mostly cropland and meadow, some residential and mixed use. 2) Mosaic Landscape, residential and mixed-use landscape with forest remnants and riparian systems. (3) Natural Landscape, mostly forest, savanna, and riparian habitats. Landcover map based on Martin and Root (2017).

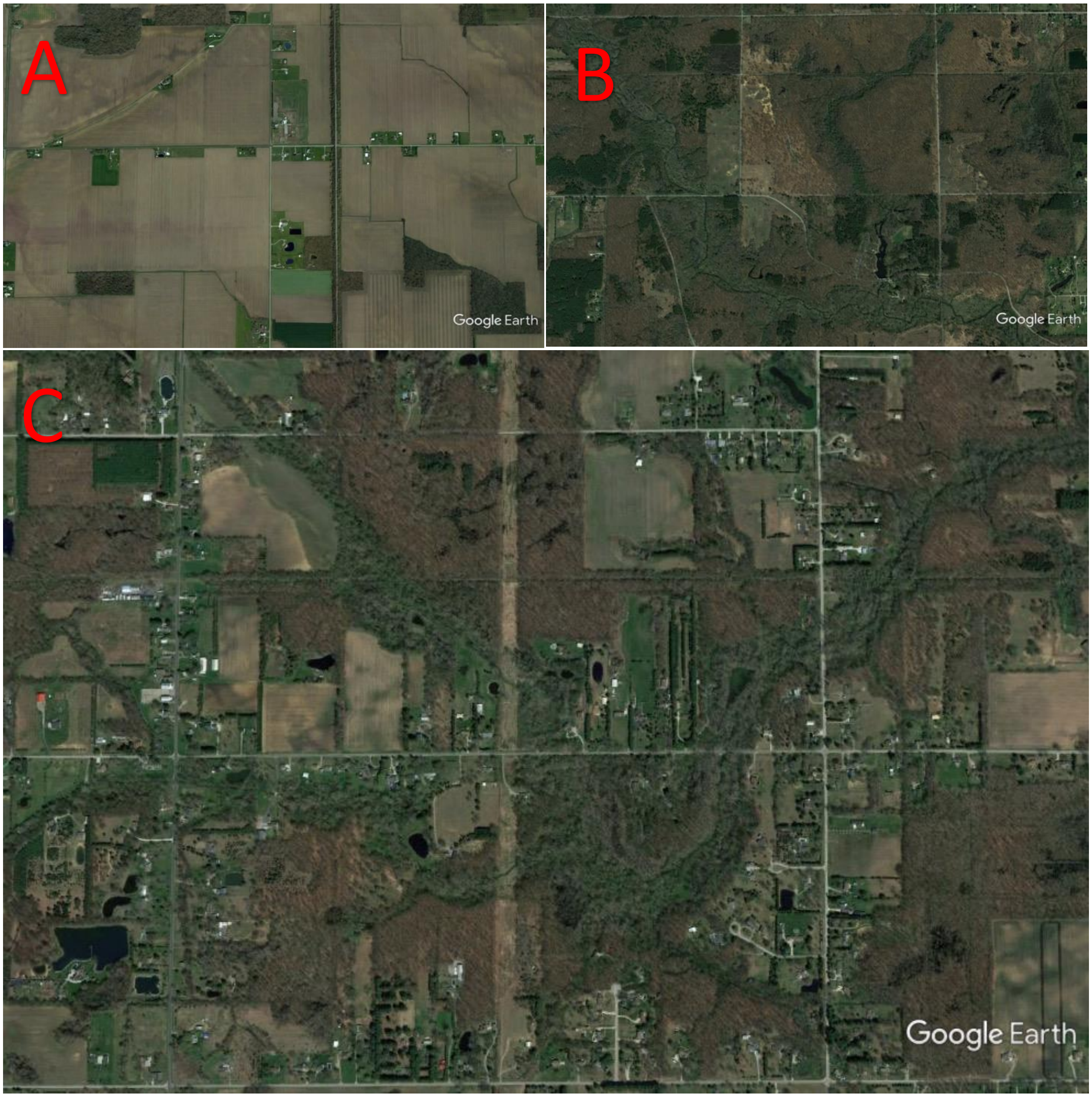

Figure 3: Example of different landscape types in our study area in Northwest Ohio. A: Agricultural land, the majority is homogenous row crop farms with low structural diversity. B: Natural landscape. Forest, savanna, and prairie land, some riparian systems, low farm and residential use. C: Mosaic Landscape. Human impact from residential land and small farms. Heterogenous structure from tree stands, ponds, streams, and vegetation.

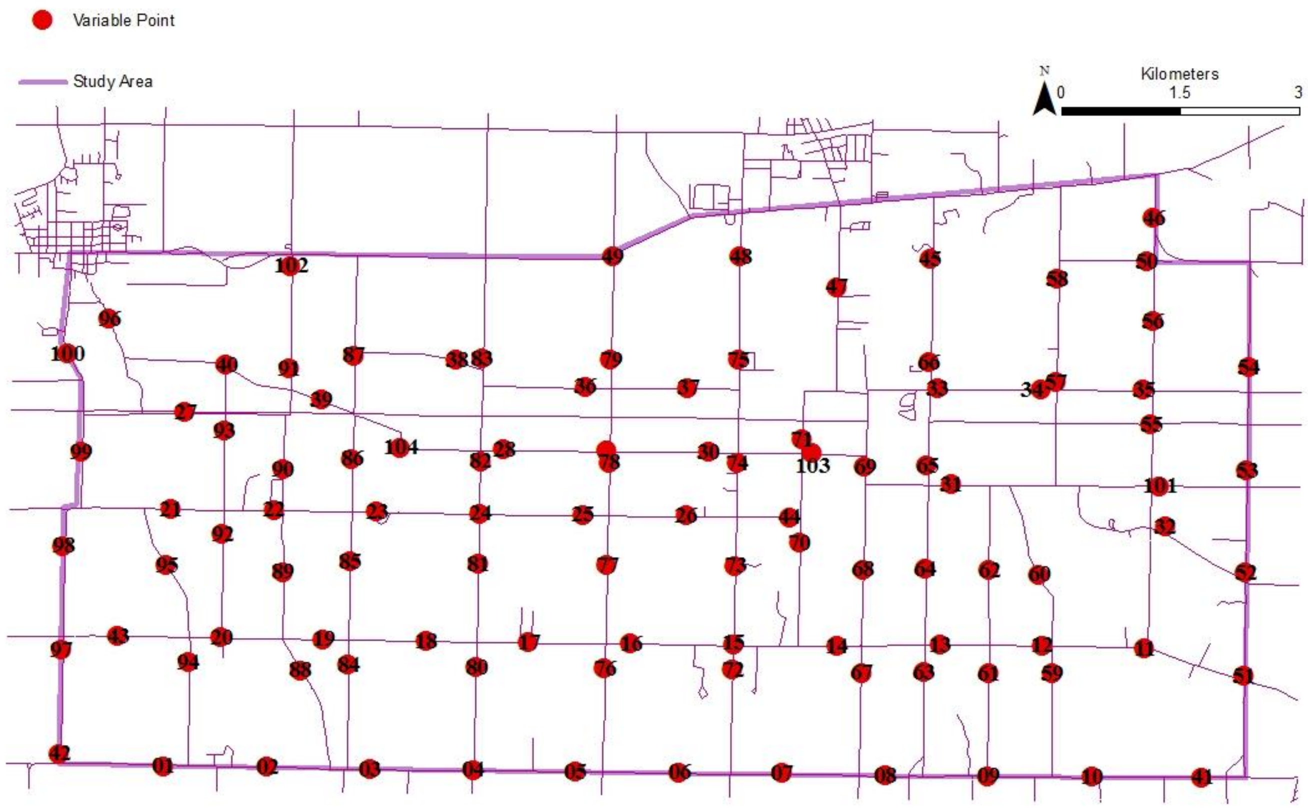

Figure 4: Variable point locations. We chose 104 points spaces out every 1.29 km (equal to the length of the shortest road) on each of the 33 roads. Measurements were taken at each point on either side of the road for all landscape variables. A 1.29 km by 1.29 km square buffer was drawn with each point as the center and bats within that buffer were counted and associated with the variables measured there.

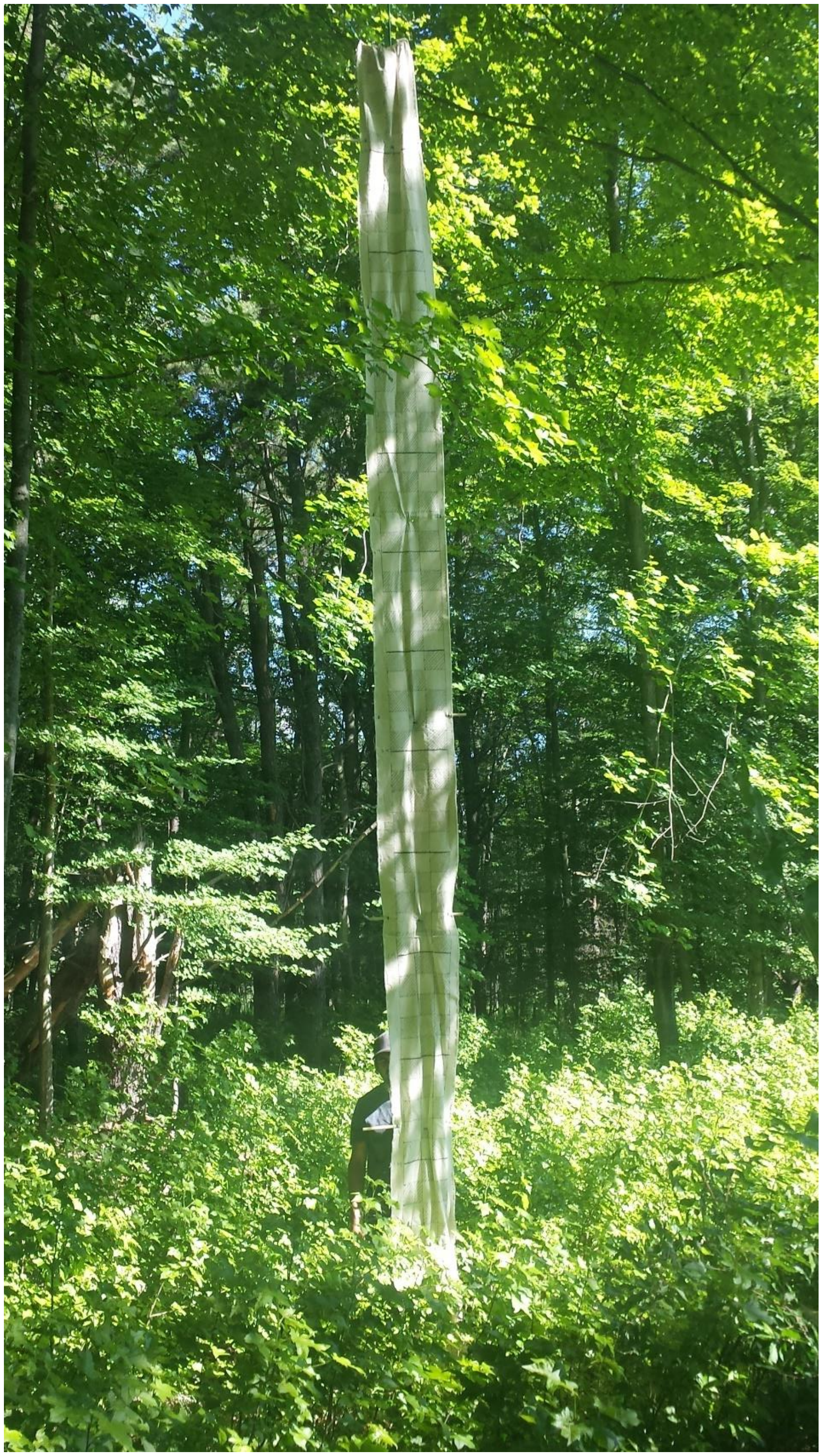

Figure 5: Example of use of a scatterboard to measure vegetation densities at varying heights. Squares unobstructed by vegetation were counted to obtain a density.

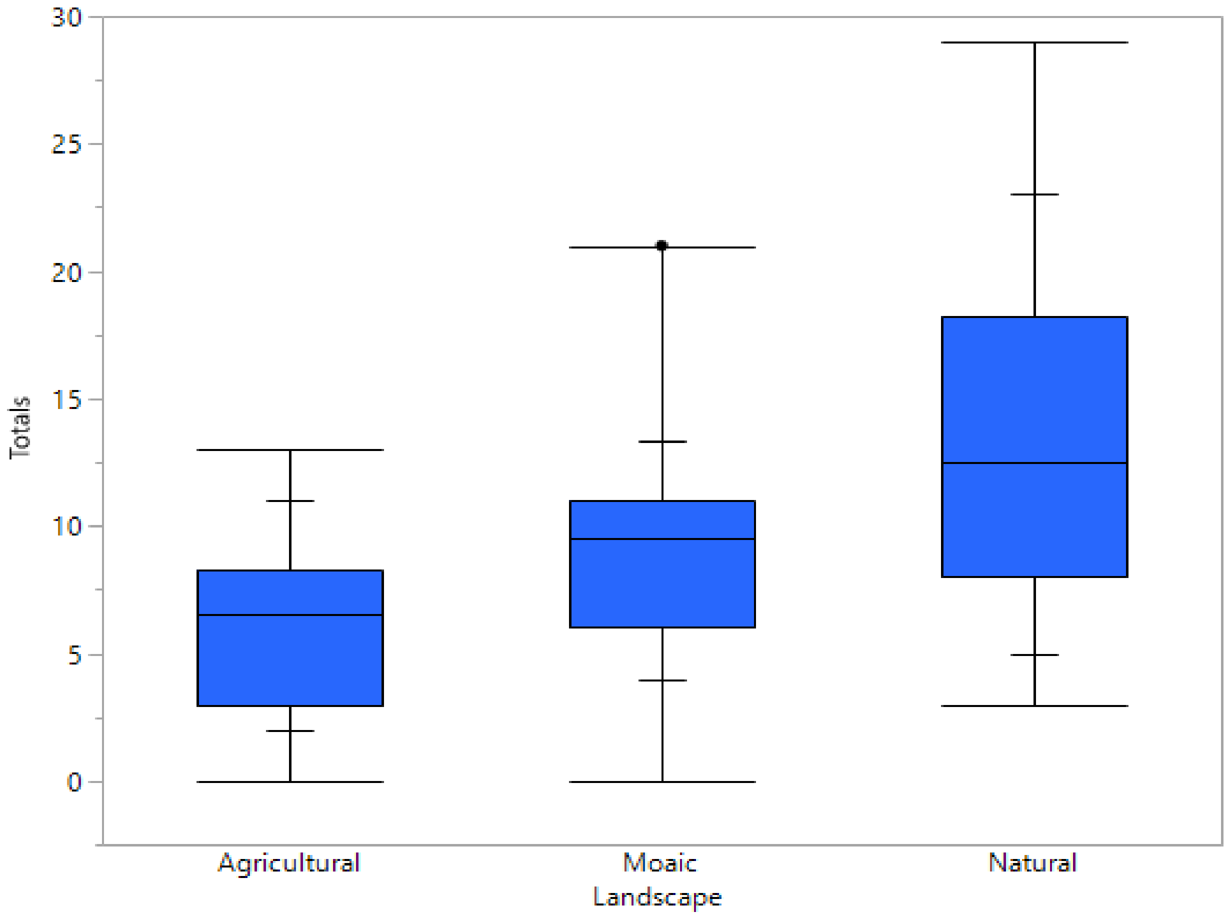

Figure 6: Average call totals for each landscape type based on number of calls associated with a measurement point within that landscape. Landscape type was significantly related to total relative activity (Kruskal Wallis; p < 0.001) and all three landscapes were significantly different from each other versus total relative activity; Natural vs Agricultural, Mosaic vs Agricultural, and Mosaic vs Natural (Wilcoxon each pair; p <0.001, p =0.002, and p = 0.003, respectively). The dot above mosaic landscapes represents an outlier.

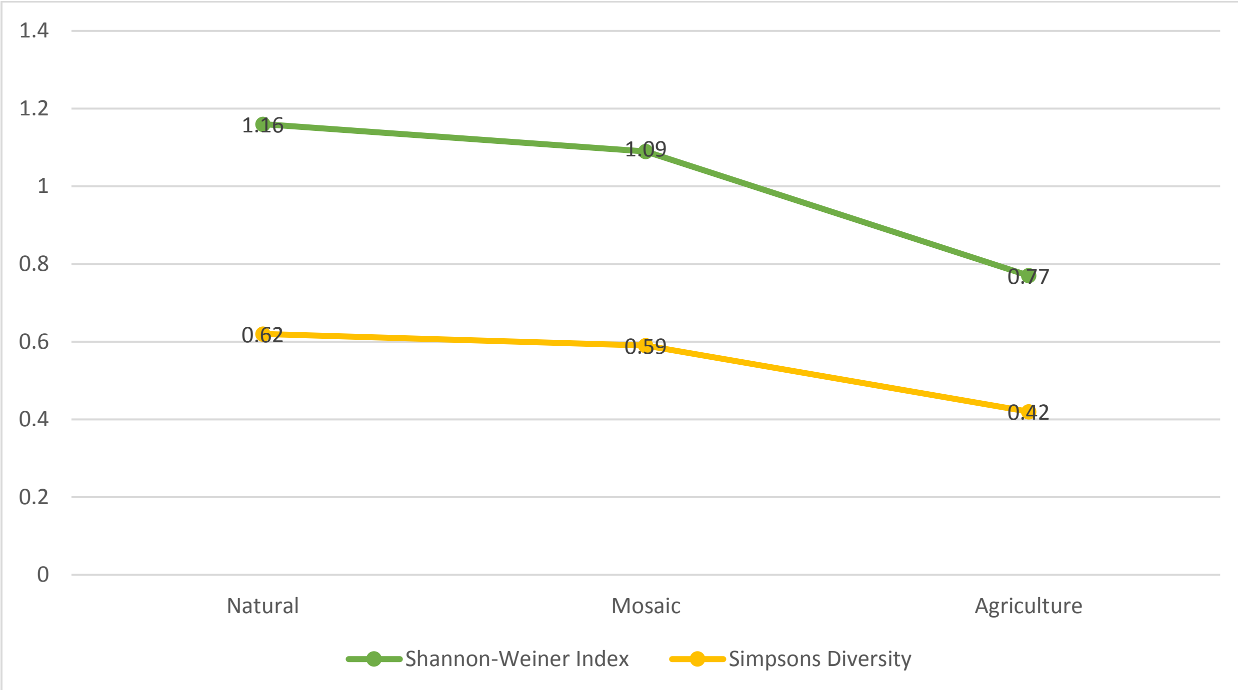

Figure 7: Species diversity indexes (Simpsons and Shannon-Weiner) for all three landscape types. Natural had the highest diversity (0.62 Simpson's, 1.16 Shannon-Weiner). Mosaic had the second highest (0.59, 1.09), while agricultural had the lowest (0.42, 0.77).

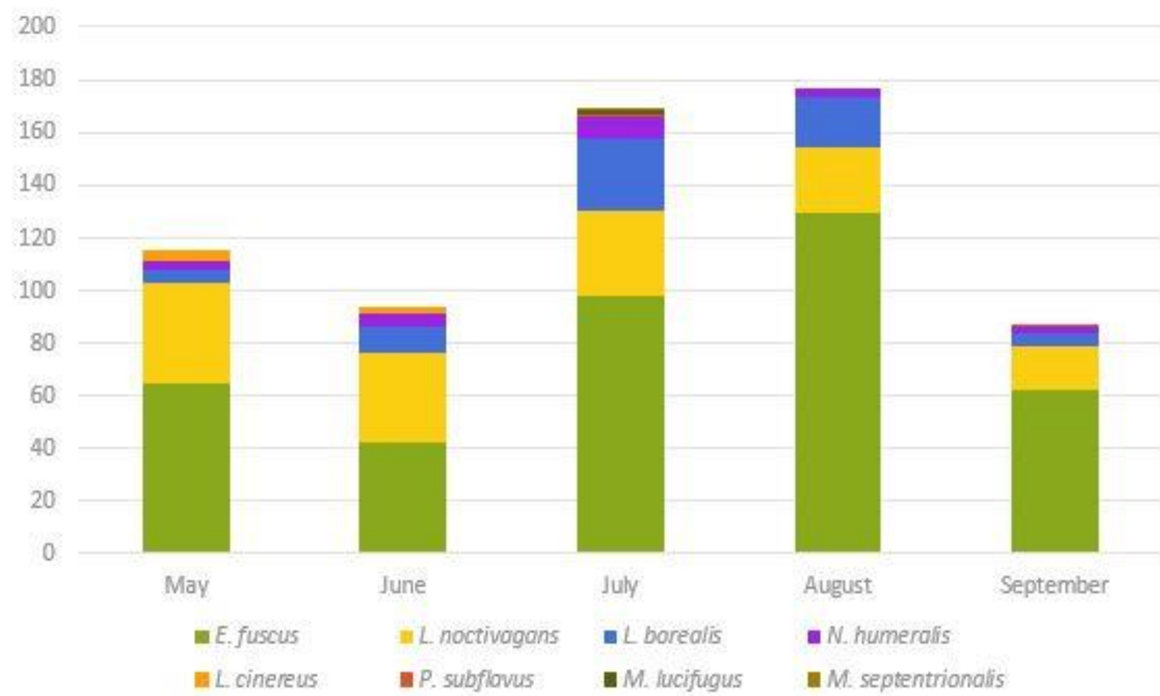

Figure 8: Monthly total calls for each bat species for each month. The top of each bar represents total relative activity for that month, while individual colors correlate to different species. Highest call totals were recorded in July and August, while lowest were in June and September.

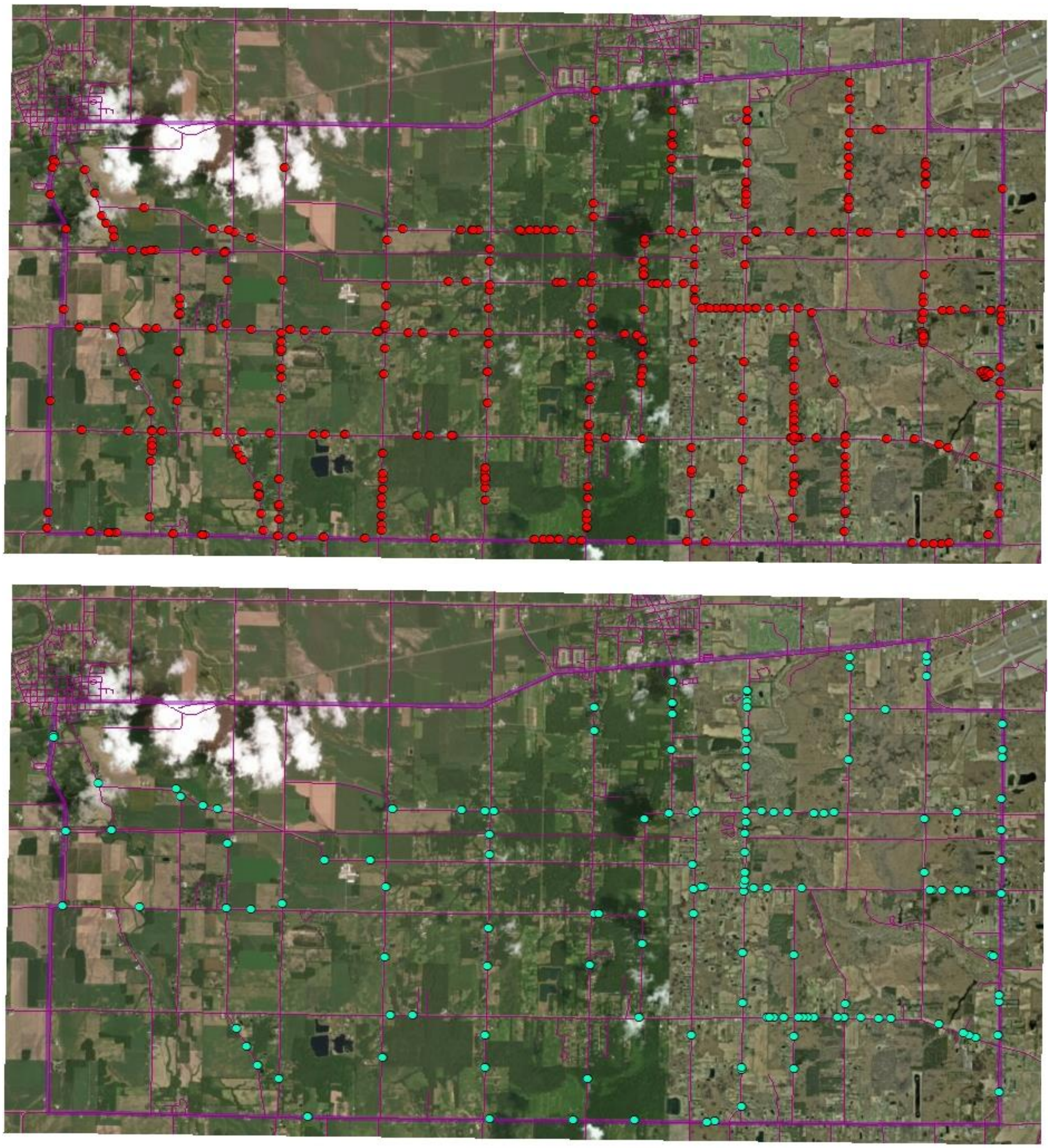

Figure 9: GPS locations of Eptesicus fuscus (top) and Lasionycteris noctivagans (bottom).

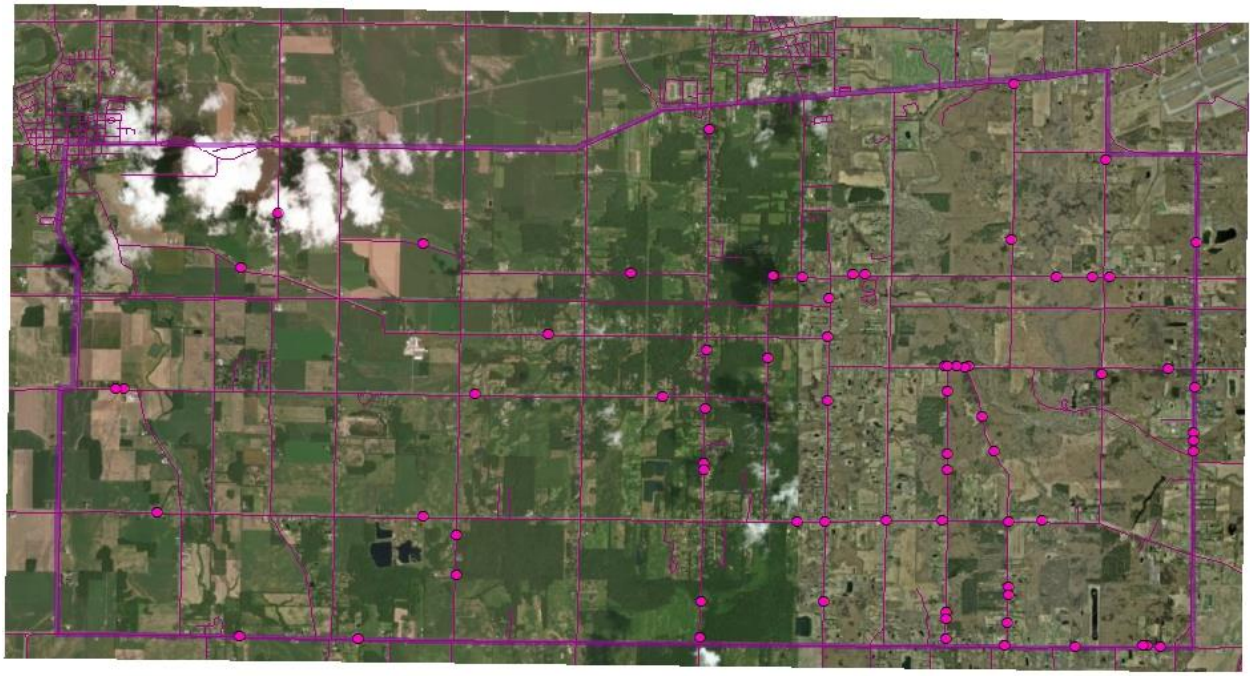

Figure 10: GPS locations for Lasiurus borealis.

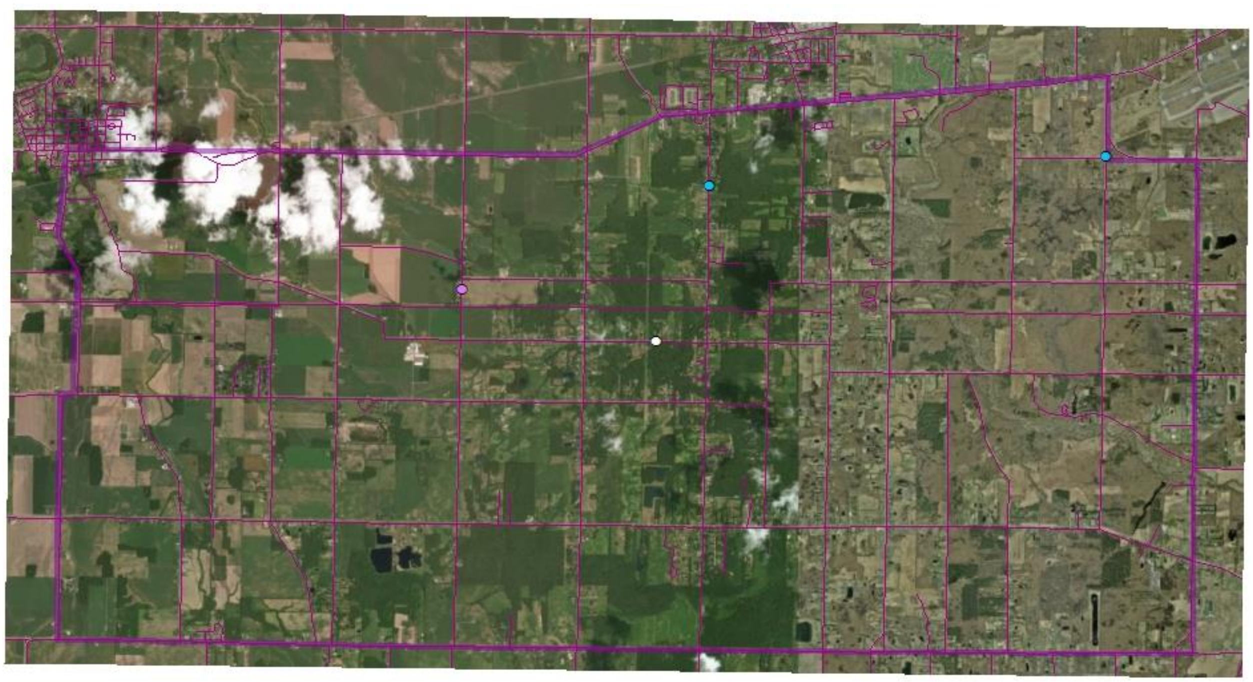

Figure 11: GPS locations of the three species affected by white-nose syndrome in Ohio: Perimyotis subflavus (purple), Myotis lucifugus (blue), and Myotis septentrionalis (white).

Figure 12: GPS locations of Nycticeius humeralis (top) and Lasiurus cinereus (bottom).

Tables

Table 1: Total number of calls recorded in each landscape type. Percentages reflect the percentage of the total number of calls (653).

	Natural		**Mosaic**		**Agricultural**		**Total**	
Species	Calls	% of Total	Calls	% of Total	Calls	% of Total	Calls	%
E. fuscus	148	22.66	135	20.67	114	17.46	397	60.80
L. noctivagans	74	11.33	52	7.96	21	3.22	147	22.51
L. borealis	33	5.05	27	4.13	11	1.68	71	10.87
N. humeralis	13	1.99	8	1.23	4	0.61	25	3.83
L. cinereus	3	0.46	4	0.61	2	0.31	9	1.38
P. subflavus	0	0.00	1	0.15	0	0.00	1	0.15
M. lucifugus	1	0.15	1	0.15	0	0.00	2	0.31
M. septentrionalis	0	0.00	1	0.15	0	0.00	1	0.15
Total	272	41.65	229	35.07	152	23.28	653	100.00

Table 2: Oneway ANOVA Kruskal Wallis Test Results. Standard error and p-values are listed, along with mean for each species and landscape. Significant differences between landscape types in bold.

	Natural - Agricultural		**Mosaic - Natural**		**Mosaic - Agricultural**		**Mean Calls per Landscape**		
Species	S.E.	p-value	S.E.	p-value	S.E.	p-value	Natural	Mosaic	Agricultural
E. fuscus	4.777	**0.006**	4.830	**0.019**	4.846	0.389	7.353	6.361	4.471
L. noctivagans	4.709	**< 0.001**	4.798	**0.001**	4.680	0.160	3.764	1.500	1.088
L. borealis	4.425	**< 0.001**	4.304	**0.001**	4.667	**0.026**	1.588	0.917	0.294
N. humeralis	4.054	**0.003**	4.166	**0.007**	3.535	0.718	0.618	0.250	0.212
L. cinereus	2.531	0.202	2.528	0.254	1.957	0.942	0.176	0.088	0.056
P. subflavus	0.000	1.000	1.404	0.160	1.404	0.148	0.059	0.000	0.000
M. lucifugus	1.404	0.160	4.707	0.536	1.000	0.346	0.059	0.028	0.000
M. septentrionalis	1.000	0.346	0.000	1.000	1.000	0.346	0.028	0.000	0.000
Total	4.778	**< 0.001**	4.844	**0.002**	4.853	**0.003**	13.559	9.139	6.206

Table 3: Results of Kruskal Wallis analysis for landscape variables. Chi Squared, degrees of freedom, and p values are reported for each species and for total relative activity. Significant p values indicated in bold. All significant values were positively correlated except for distance to tree stands.

	E. fuscus	***L. noctivagans***	***L. borealis***	***N. humeralis***	***L. cinereus***	***P. subflavus***	***M. lucifugus***	***M. septentrionalis***	**Total Activity**	**+/-**
Landscape Type										
χ^2	9.064	24.129	22.67	11.657	2.300	4.158	2.082	1.889	26.148	
DF	2	2	2	2	2	2	2	2	2	
p-value	**0.011**	**<0.001**	**<0.001**	**0.003**	0.317	0.125	0.353	0.389	**<0.001**	**+**
Vegetation Height										
χ^2	23.368	13.662	23.837	10.672	3.731	4.544	3.059	1.000	34.129	
DF	3	3	3	3	3	3	3	3	3	
p-value	**<0.001**	**0.003**	**<0.001**	**0.014**	0.292	0.208	0.383	0.801	**<0.001**	**+**
Vegetation Density										
χ^2	19.653	16.938	20.065	10.993	3.921	4.544	4.701	1.537	36.248	
DF	4	4	4	4	4	4	4	4	4	
p-value	**0.001**	**0.001**	**0.001**	0.027	0.417	0.337	0.319	0.820	**<0.001**	**+**
Distance to Vegetation										
χ^2	18.569	10.142	1.993	0.078	0.824	0.831	0.317	0.779	24.807	
DF	17	8	4	2	2	1	1	1	22	
p-value	0.354	0.255	0.737	0.961	0.662	0.362	0.573	0.377	0.306	
Canopy Cover										
χ^2	25.599	20.274	19.290	8.582	6.201	1.799	0.926	4.200	39.843	
DF	3	3	3	3	3	3	3	3	3	
p-value	**<0.001**	**0.001**	**0.001**	0.035	0.102	0.615	0.819	0.241	**<0.001**	**+**
Distance to Tree Stands										
χ^2	25.567	21.572	14.899	13.885	4.899	0.784	0.632	0.207	41.225	
DF	17	8	4	2	2	1	1	1	22	
p-value	0.083	**0.006**	**0.005**	**0.001**	0.086	0.376	0.427	0.649	**0.008**	-
Distance to Riparian										
χ^2	19.724	5.362	10.703	4.697	2.746	2.331	0.019	0.380	18.463	
DF	17	8	4	2	2	1	1	1	22	
p-value	0.289	0.718	0.030	0.096	0.253	0.127	0.892	0.538	0.678	
Road Width										
χ^2	15.076	10.084	3.206	0.109	0.316	1.090	1.725	0.285	19.691	
DF	17	8	4	2	2	1	1	1	22	
p-value	0.590	0.259	0.524	0.947	0.854	0.297	0.189	0.593	0.602	

Table 4: Stepwise regression models for E. fuscus. Akaike information criterion (AICc), Adjuster R^2*, and p-values shown. Lower AICc values show a stronger fit. Variables used are the significant landscape variables. Model descriptions are shown below model number. Best fit model values are in bold.*

E. fuscus	**Variables**	**AICc**	**Adj. R^2**	**p-value**
Model 1 All Variables	Landscape Type Distance to Trees Canopy Cover Vegetation Height Veg. Density	538.07	0.289	<0.001
Model 2 Landscape and Density Measures	Landscape Type Canopy Cover Veg. Density	542.992	0.246	<0.001
Model 3 No Landscape Types Included	Distance to Trees Canopy Cover Vegetation Height Veg. Density	**538.07**	**0.289**	**<0.001**
Model 4 Landscape and Trees	Landscape Type Distance to Trees Canopy Cover	548.769	0.212	<0.001
Model 5 Landscape and Vegetation	Landscape Type Vegetation Height Veg. Density	542.992	0.246	<0.001

Table 5: Stepwise regression models for L. noctivagans. Akaike information criterion (AICc), Adjuster R^2, and p-values shown. Lower AICc values show a stronger fit. Variables used are the significant landscape variables. Model descriptions are shown below model number. Best fit model values are in bold.

L. noctivagans	**Variables**	**AICc**	**Adj. R^2**	**p-value**
Model 1 All Variables	Landscape Type Distance to Trees Canopy Cover Vegetation Height Veg. Density	420.181	0.348	<0.001
Model 2 Landscape and Density Measures	Landscape Type Canopy Cover Veg. Density	**420.181**	**0.348**	**<0.001**
Model 3 No Landscape Types Included	Distance to Trees Canopy Cover Vegetation Height Veg. Density	438.415	0.214	<0.001
Model 4 Landscape and Trees	Landscape Type Distance to Trees Canopy Cover	424.779	0.311	<0.001
Model 5 Landscape and Vegetation	Landscape Type Vegetation Height Veg. Density	**420.181**	**0.348**	**<0.001**

Table 6: Stepwise regression models for L. borealis. Akaike information criterion (AICc), Adjuster R^2, and p-values shown. Lower AICc values show a stronger fit. Variables used are the significant landscape variables. Model descriptions are shown below model number. Best fit model values are in bold.

L. borealis	**Variables**	**AICc**	**Adj. R^2**	**p-value**
Model 1 All Variables	Landscape Type Distance to Trees Canopy Cover Vegetation Height Veg. Density	303.587	0.199	<0.001
Model 2 Landscape and Density Measures	Landscape Type Canopy Cover Veg. Density	**303.587**	**0.199**	**<0.001**
Model 3 No Landscape Types Included	Distance to Trees Canopy Cover Vegetation Height Veg. Density	306.136	0.18	<0.001
Model 4 Landscape and Trees	Landscape Type Distance to Trees Canopy Cover	**303.587**	**0.199**	**<0.001**
Model 5 Landscape and Vegetation	Landscape Type Vegetation Height Veg. Density	**303.587**	**0.199**	**<0.001**

Table 7: Stepwise regression models for N. humeralis. Akaike information criterion (AICc), Adjuster R^2, and p-values shown. Lower AICc values show a stronger fit. Variables used are the significant landscape variables. Model descriptions are shown below model number. Best fit model values are in bold.

N. humeralis	**Variables**	**AICc**	**Adj. R^2**	**p-value**
Model 1 All Variables	Landscape Type Distance to Trees Canopy Cover Vegetation Height Veg. Density	147.129	0.153	<0.001
Model 2 Landscape and Density Measures	Landscape Type Canopy Cover Veg. Density	**147.129**	**0.153**	**<0.001**
Model 3 No Landscape Types Included	Distance to Trees Canopy Cover Vegetation Height Veg. Density	151.13	0.11	0.001
Model 4 Landscape and Trees	Landscape Type Distance to Trees Canopy Cover	150.481	0.116	0.001
Model 5 Landscape and Vegetation	Landscape Type Vegetation Height Veg. Density	**147.129**	**0.153**	**<0.001**

Table 8: Stepwise regression models for total relative activity. Akaike information criterion (AICc), Adjuster R^2, and p-values shown. Lower AICc values show a stronger fit. Variables used are the significant landscape variables. Model descriptions are shown below model number. Best fit model values are in bold.

Total Calls	**Variables**	**AICc**	**Adj. R^2**	**p-value**
Model 1 All Variables	Landscape Type Distance to Trees Canopy Cover Vegetation Height Veg. Density	615.039	0.383	<0.001
Model 2 Landscape and Density Measures	Landscape Type Canopy Cover Veg. Density	**615.039**	**0.383**	**<0.001**
Model 3 No Landscape Types Included	Distance to Trees Canopy Cover Vegetation Height Veg. Density	617.242	0.37	<0.001
Model 4 Landscape and Trees	Landscape Type Distance to Trees Canopy Cover	628.715	0.296	<0.001
Model 5 Landscape and Vegetation	Landscape Type Vegetation Height Veg. Density	**615.039**	**0.383**	**<0.001**

Table 9: Stepwise regression models for species totals. Akaike information criterion (AICc), Adjuster R^2, and p-values shown. Lower AICc values show a stronger fit. Variables used are the significant landscape variables. Model descriptions are shown below model number. Best fit model values are in bold.

Species Diversity	**Variables**	**AICc**	**Adj. R^2**	**p-value**
Model 1 All Variables	Landscape Type Distance to Trees Canopy Cover Vegetation Height Veg. Density	279.278	0.272	<0.001
Model 2 Landscape and Density Measures	Landscape Type Canopy Cover Veg. Density	**279.278**	**0.272**	**<0.001**
Model 3 No Landscape Types Included	Distance to Trees Canopy Cover Vegetation Height Veg. Density	285.167	0.221	<0.001
Model 4 Landscape and Trees	Landscape Type Distance to Trees Canopy Cover	286.009	0.223	<0.001
Model 5 Landscape and Vegetation	Landscape Type Vegetation Height Veg. Density	**279.278**	**0.272**	**<0.001**

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CHAPTER II. OBSERVING THE IMPACTS ANTHROPOGENIC PRESSURES ON BATS IN A NATURAL PRESERVE

Introduction

While we tend to think of preserves as pristine examples of natural areas for the local flora and fauna, in actuality there is usually some form of anthropogenic pressure both on (from pressures of adjacent human land use) and within (from internal trails, roads, and other human uses) these areas. Agriculture, residential land, and even urban centers can encroach on preserves and cause hostile edges along these parks, limiting the amount of core habitat for the animals using these preserves (Wade et al., 2003). Roads and trails can increase fragmentation and edges within protected areas, as well (Wimpey and Marion, 2011). This is especially true in areas such as the Oak Openings Region of northwestern Ohio, where human pressures have been degrading a natural biodiversity hotspot over the past century. Despite these pressures, this region is still home to nearly a third of Ohio's rare flora and fauna and is considered one of the "200 Last Greatest Places on Earth" (Grove, 2005). However, in order for this diversity to continue to flourish, we need to know how these anthropogenic pressures affect local wildlife populations. Not only is there inherent value to protecting biodiversity, but we must also consider the ecological value and even economic value of animals facing these threats.

Bats are an example of one of these valuable wildlife orders facing worldwide declines. They are incredibly important to both the local ecosystem and to humans within them. From nutrient cycling (Duchamp et al, 2010) to pollination (Petchumee, 2004) to pest control (Gonsalves et al., 2013), these animals have an enormous impact on both natural and human dominated landscapes. These pollination services can be worth up to $13 million in certain countries, such as Thailand, where bats are the sole pollinators of the Durian fruit (Petchmunee, 2008). Here in the United States, pesticide services can help numerous agricultural productions such as grapes (Rambaldini & Brigham, 2011), pecans (Braun de Torrez, 2014), and corn (McCracken et al., 2012). The value of these services is estimated to be a staggering $22.9 billion annually (Boyles et al., 2011).

Despite this value, bats face worldwide population declines due to numerous threats, the largest of which is habitat degradation and loss (O'Shea et al., 2016). Driving factors include anthropogenic pressure due to agricultural intensification and residential expansion, which can fragment, degrade, and destroy natural forests. Bats use these forests to forage and roost in, especially during the warmer spring and summer months (Tuttle, 1988), so understanding how to manage these properly can be critical to their viability. Not only does understanding lead to better management for bats but can help improve biodiversity at many levels. As Park (2015) indicates, bats are a likely indicator species for many mammals facing habitat loss due to agricultural expansion and intensification.

This study took a multi-species approach, looking at eight different species of bats in the Oak Openings Region; the big brown bat (*Eptesicus fuscus*), silver-haired bat (*Lasionycteris noctivagans*), eastern red bat (*Lasiurus borealis*), hoary bat (*Lasiurus cineresus*), little brown bat (*Myotis lucifugus*), evening bat (*Nycticeius humeralis*), tri-colored bat (*Perimyotis subflavus*), and northern long-eared bat (*Myotis septentrionalis*). The tri-colored bat is being considered for national listing under the US Endangered Species Act (ESA), while the northern long-eared is considered a threatened species under the ESA (USFWS, 2018).

Bats require forest fragments for foraging, but the characteristics that drive foraging activity can differ (Arroyo-Rodriguez et al, 2016). These bats have shown species specific responses to environmental variables such as shrub density and clutter. Smith and Ghert (2010) found that smaller bat species such as *M. septentrionalis* and *M. lucifugus* respond positively to vegetation density, while larger bats such as *L. noctivagans* showed a negative response. Bats can also respond to urbanization and residential areas, with species such as *L. borealis* and *N. humeralis* responding positively to vegetation within urban systems, while *E. fuscus* showed a more positive response to riparian systems (Li and Wilkins, 2014). Furthermore, while edges generally have negative connotations for wildlife, some species of bats can adapt to and even show preference for edge habitat while foraging (Either & Fahrig, 2011). For certain species, such as *L. borealis* and *M. lucifugus,* edges have a positive influence regardless of forest patch size (Kalda et al., 2015). Thus, it is important to understand what habitats and landscape features are being used by native bats both in terms of total relative activity and of individual species activity.

To categorize these species, we can divide them into two guilds: open canopy foragers and closed canopy foragers. Closed canopy bats are those who research suggests prefer to forage in high canopy cover forests; these included *L. borealis, M. lucifugus, M. septentrionalis,* and *N. humeralis*. Open canopy bats are those that prefer less canopy cover and clutter or prefer to forage in the open; these species are *E. fuscus, P. subflavus, L. cinereus,* and *L. noctivagans*. These categorizations are based on foraging and detection data compiled from published studies (Tuttle, 1988; Gehrt and Chelsvig, 2004; Henderson and Broders, 2008; Kniowski and Gehrt, 2014; Kurta, 1995; Whitaker and Mumford, 2009; Silvis et al., 2014; Bergeson et al., 2015;

White et al., 2016) and previous work done by the Root Lab (Sewald, 2012; Janos, 2013; Nordal, 2016; Hollen, 2017).

The Oak Openings Preserve is a large protected area with a heterogenous mix of numerous landscape types. It is the largest preserve in Ohio's Oak Opening Region (Figure 13). This includes forest types such as deciduous, coniferous, floodplain and swamp forests (Root and Martin, 2017). These forest habitats are bounded on their edges by natural open areas such as upland and wet prairies, upland savanna, Eurasian meadows, and shrubland. As always, there are also anthropogenic pressures on these natural forest and open landscapes. The preserve is bounded by human dominated land such as residential, turf, pasture, and cropland. The variety of habitats and edge types provides an opportunity to better understand how bats respond to these variations and what landscape and environmental features promote diversity and activity.

In this study, we wanted to look at how bat activity and diversity compared between interior and exterior edge sites within a natural preserve, and how those compared to core forest and savanna sites. We also wanted to look at landscape and environmental characteristics at these locations to see if we could identify what was influencing activity. We used acoustic monitors set up at overnight stationary sites to get both a temporal and spatial view of how bats were using these sites. The objectives were to (1) examine how bat activity and diversity changed between interior and exterior edge sites, (2) explore how activity and diversity at these edges sites compared to core habitat, and (3) assess temporal changes over the full course of a foraging period to assess if different bat species were hunting at different times. We predicted that exterior edges would be significantly lower in activity and diversity than interior edges, while core habitats would be significantly higher in both activity and diversity than both types of edge sites due to higher structural diversity in the core sites. We also predicted that there would be species specific responses in both habitat use and foraging times. We expected open canopy foragers (*E. fuscus, P. subflavus, N. humeralis, L. cinereus,* and *L. noctivagans*) to prefer savanna sites and have higher activity at edge sites, while closed canopy foragers (*L. borealis, M. lucifugus* and *M. septentrionalis*) to prefer forest sites.

<u>Methods</u>

Acoustic Surveying

Sixteen stationary sites (divided into eight pairs each month) were chosen for acoustic monitoring based on different landscape types within the boundaries of the Oak Openings Preserve. Six sites were considered core bat habitat (three forest and three oak savanna), while the other ten were chosen to sample different types of edge (Figure 14). Core sites were at least 50 m from any edge in order to differentiate them from edge sites. Forest and savanna sites had all been sampled and classified previously (Sewald, 2012; Janos, 2013; Nordal, 2016; Hollen, 2017) and classifications were confirmed with the current landcover map (Root and Martin, 2017). Of the edge sites, five were along the exterior edges (park edges which bordered agricultural or residential land outside the park), while five were chosen along interior edges (forest edges inside the park that bordered open habitat such as savanna or prairies). Edge sites were chosen by observation, and checked for landcover (Martin and Root, 2017). A 50 m radius buffer was drawn in ArcMap 10.2 and used to identify the composition of the landcover of edge sites. If the landcover bordering the forest site boundaries were prairie, residential, or turf/pasture and was greater than 40% the site's coverage then the site was considered an edge. All sites were at least 100 m from any roads in order to eliminate confounding effects. Sites were also at least 100 m from other sites in order to avoid recording overlapping calls at separate stations. Surveys ran every month from June through September. Each month, sites were randomized and paired based on land type (forest sites were paired with savanna; interior edges paired with exterior edges). One pair was surveyed each night, and all 16 were surveyed within each month.

Anabat SDII (Titley Electronics, Ballina, New South Wales, Australia) monitors were set to record at one randomized set of paired sites within the park each survey night. The location of the monitor was considered the center of each site. Sensitivity was set at 8 and division ratio at 16. Monitors were placed in weatherproof lock boxes attached approximately 0.5 meters off the ground attached to PVC poles, with Anabat omnidirectional microphones at the ends of the poles at approximately 1.5 m pointed downward toward Lexan plates angled at 45 degrees. These units were then attached to trees via bungee cables at the selected GPS coordinates. At the edge sites monitors were placed as close as possible to the forest edge with microphones directed toward the edges. In core sites the microphones were directed toward the interior of the habitat. Devices were turned on manually 30 minutes to one hour before sunset and allowed to record all night. Monitors were only set out on nights with favorable conditions (no rain, winds under 24 km/h, temperature over 12ºC, more than two days from full moons) (Voight et al, 2011). All methods and protocols were approved by Bowling Green State University's Institutional Animal Care and Use Committee (IACUC, Appendix A).

Environmental and Landscape Variable Measurements

Landscape and environmental variables were measured at the beginning of the month at each site. Landscape variables included canopy height (m) and density, vegetation height (m) and density, and distance to riparian systems (m). Canopy cover was measured via photographs

(Fiala et al, 2006), and percent cover was estimated by using HabittApp (version 1.2). Vegetation density was measured with a 6.5 m cloth scatterboard by counting the number of squares not covered by vegetation and subtracting those from the total number to get the number and percent coverage (Figure 15). Vegetation height (in meters) was measured with a measuring tape, while canopy height (m) was measured using a Nikon Prostaff 3 laser rangefinder. All of these variables were measured in four directions (N, S, E &W) within the 30 m radius of the Anabat monitor and then averaged for each site for each month. Distance to water was estimated by measuring the minimum distance (in meters) by measuring tape (in under 50 m) or by Google Earth (> 50 m). Landscape composition was recorded as a proportion of landcover type for each site and edge using a landcover map (Martin et al., 2017). Forest type (e.g. deciduous, coniferous, etc…) was recorded for each site, as forest composition has been seen to impact activity in bat species (Charbonnier et al, 2016).

Environmental measurements were taken at the beginning of each night of the study with a Brunton ADC-Pro handheld weather station for barometric pressure (inHg), temperature (°C), and humidity (%). Windspeed (km/h) and direction and hourly weather data were identified through a NOAA weather station at the Toledo Airport (http://w1.weather.gov/obhistory/KTOL.html). Moon phase and percent illumination was identified through MoonGiant (http://www.moongiant.com/phase/today/). Environmental data were taken for each call based on the hour it was recorded. All data were averaged over the night of the study based on call numbers for each site.

Call Identification

Calls were download from CF cards and analyzed with Kaliedoscope (Wildlife Acoustics, 2016) and AnalookW Software (Titley Scientific, version 4.1). Calls were identified to species using the sonograms based on existing call libraries and checked with BCID Software (BCID, BCID version 9 2.7c). When identifications disagreed, final decision was made based on the authors' knowledge of calls and the previously developed call libraries (Sewald, 2012; Janos, 2013; Nordal, 2016; Hollen, 2017). Identification only occurred when a clear pass was recorded on a file, defined as three or more clear, identifiable calls from one species in one file (Parsons and Szewczak, 2009). In files with overlapping species, if passes were identifiable for two different species, those species were identified separately. Calls were recorded and identified through the duration of the evening (from 30 minutes after sunset to 30 minutes before official sunrise time). The number of calls was treated as a measure of relative activity.

Statistical Analysis

To normalize the number of calls in each site type (interior edge, exterior edge, core savanna, and core forest), we calculated the mean for each site type based on the number of recordings and number of sample nights. This was also done per month to analyze monthly patterns. Mean canopy cover and vegetation density were estimated across all four months as well. Environmental variables were estimated hourly from the Toledo Airport NOAA station and matched with call times, then averaged for each site by number of calls.

A Spearman's rho correlation analysis was utilized to look for relationships among all variables. Variables were regarded as highly significantly correlated if $|r| > 0.6$ and $p < 0.05$.

One-way ANOVA's were run to assess species diversity, individual species activity and total relative activity based on site type. Kruskal Wallis tests were used to assess the relationship between environmental and landscape variables and individual and relative species totals. This was done for both overall comparisons and for comparing each pair of variables against total relative activity and individual species activity. Both Kruskal Wallis tests and Pearson's tests were run (based on type of data) to analyze landscape variables versus site type. Significance was only reported if it met the criteria for Bonferroni corrections to account for multiple comparisons. A Jaccard's Similarity Index was estimated between all possible pairs of sites to assess differences in species compositions between all possible pairs. All tests were performed using JMP Statistical Analysis Software (JMP®, Version 11. SAS Institute Inc., Cary, NC, 1989-2007), except for Jaccard's Similarity Index which was run in Excel.

Results

Beginning in June, this study lasted for four months over 32 nights and consisted of approximately 700 recording hours. In total, 1288 recorded calls were identified with all eight species detected. There were 35 calls that could not be identified to species or were not considered sufficient for a clear pass. Activity was detected at 14 of the 16 sites (Table 10). The most common species was the *E. fuscus* (identified at 14/16 sites), followed by *L. noctivagans* (12/16), then *L. borealis* (9/16), *N. humeralis* (6/16), *M. septentrionalis* (4/16), *L. cinereus* (3/16), and finally *P. subflavus* (2/16) and *M. lucifugus* (2/16). We found that individual sites had a significant impact on both total relative activity (Kruskal Wallis; ChiSquare = 31.330, DF = 15, $p = 0.008$) and on number of species (Kruskal Wallis; ChiSquare = 33.86, DF = 15, $p = 0.003$). Sites 2, 7, and 11 exhibited the highest total activity, while sites 2, 9, and 13 exhibited the highest species diversity. While all the sites with higher activity were core sites, two of the highest diversity sites were edge sites.

A Jaccard's Similarity Index was used to look at similarities between species compositions of all pairs of sites (Table 11). This index takes into account diversity by comparing the number of species at one site to the overall diversity for those two sites. We found that only seven of the 120 possible combinations had a 100% similarity, and only another five were above 80% similar. This suggested that there was a high amount of dissimilarity in species compositions within the landscapes in the park.

We found no significant difference in total relative bat activity between exterior and interior edge sites (Kruskal Wallis, $p = 0.89$). Core forest sites showed significantly more activity than exterior and interior edge sites (Kruskal Wallis, $p = 0.02$ and $p = 0.03$, respectively). Forest and savanna core sites did not have any significant differences (Kruskal Wallis, $p = 0.08$) in activity. Core savanna sites were not significantly different from exterior and interior edges (Kruskal Wallis, $p = 0.68$ and 0.60, respectively) in terms of activity. While all eight species were recorded, no one site type had all species detected in it. Forest, interior edges, and exterior edges all had 7 of the 8 native bat species, while savannas had 5 species (Table 12). Sites 2 (forest), 7 (forest), and 11 (savanna) displayed the highest activity, while sites 9 (exterior edge), 13 (interior edge) and 11 (savanna) recorded the highest number of different species (Figure 18). Again, using a pairwise Kruskal Wallis rank-sum analysis, we looked for any significant effect on species activity. The only landscape variable that affected species diversity was forest type. We found that floodplain forest habitat had the lowest mean (1.75) and was significantly different (Kruskal Wallis, $p = 0.044$) than savannas (mean 4.00).

These landscape variables had much more significance when looked at against site type (interior edge, exterior edge, core forest, and core savanna). We found that canopy cover, vegetation density, and distances to riparian system were all significantly different across site types (Kruskal Wallis, $p < 0.001$, $p < 0.001$, and $p = 0.004$, respectively). Next we looked at the dominant landcover for both the main part of the site, and the edge (if the site was an edge site). Both main landcover type (Pearson's, $p < 0.001$) and edge landcover (Pearson's, $p < 0.001$) were significantly related to site type (Table 13). In other words, site types differed in their landscape characteristics (e.g., canopy cover) and edge sites were significantly different in composition than non-edge sites.

Looking at species totals and total relative activity by month, we found the highest totals in August (497), then June (395) and July (363), with a sharp decline in September (33). June had the highest species totals (8/8), followed by August (7/8), then July (4/8) and September (4/8) (Figure 16). While none of the environmental variables significantly affected species totals or total relative activity, we did find that temperature and humidity were significantly affected by the month (Kruskal Wallis, $p = 0.001$ and $p = 0.029$, respectively).

We also examined foraging time over the course of the entire night. We were interested in identifying any second peak of activity, which would suggest that different species were foraging at different times. During the hours from 8:00 pm EST through 12:00 am EST we recorded 72.4 percent of total calls. The hour with the highest amount of activity was between 9:00 pm and 10:00 pm, with 572 calls (43.2% of total calls). There was a slight uptick in activity between 5:00 am and 6:00 am, but this was bolstered mostly by a large number of *L. noctivagans,* and still not enough to be considered significant. There was no indication of any significant second activity peak (Figure 17). This suggested that acoustic monitoring during the time frame from 21:00-1:00 sampled at the peak of foraging activity (Sewald, 2012; Janos, 2013; Nordal, 2016; Hollen, 2017; Turner, unpublished).

Discussion

This study looked at how bats were utilizing edges to forage within the Oak Openings Preserve. We wanted to look at how human impacts on edges affected foraging activity and diversity and how these edges compared in activity and diversity to core habitat sites. We also explored how time of night affected this foraging activity and diversity. Through this study, we gained a better understanding on how bats are using this natural preserve and the effects of human impacts on their foraging activity.

We recorded and identified all eight bats species that were confirmed to be in the Oak Openings area by previous studies (Sewald, 2012; Janos, 2013; Nordal, 2016; Hollen, 2017). Since we chose nights with preferential weather conditions (no rain, winds under 24 km/h, temperature over 12ºC), most environmental factors had no significant effect on total relative activity or species diversity. The only significant effect recorded was between barometric pressure and total number of species (Kruskal Wallis, $p = 0.031$).

However, we did expect forest composition and core sites to affect activity (Charbonnier et al, 2016). While core forest habitat had the highest total relative activity, there were some species-specific responses. *L. noctivagans* had a much higher percentage of calls at both edge and savanna sites. *N. humeralis* showed a high preference for savanna sites. Both *Myotis* species were only found in forest habitat. The most significant relationship, however, was between *L. borealis,* and core forest sites (Kruskal Wallis, $p = 0.039$). Many of these findings were similar to what was found in previous studies in Oak Openings Preserve (Sewald, 2012;

Janos, 2013; Nordal, 2016; Hollen, 2017). This also supports results found in similar studies in Europe, where both species behaviors and forest characteristics were found to have significant effect on activity and diversity (Fuentes-Montemayor et al., 2013).

Many of these previous studies focused on core habitat, however, this study attempted to find how bats were using edges both within and along the outskirts of the park. While our prediction held true that most bats preferred core forests sites, we were surprised by finding edge sites showed only slightly less activity than the core savanna sites and no significant change in total relative activity. Furthermore, edges sites were not significantly different in total activity whether they had high human impact edge or not. This suggests that bats will utilize edge and open habitat to forage, regardless of human impact. The more important aspect seemed to be structure. If vegetation was too sparse (such as site 5) or too dense (such as site 6), we saw dramatic decreases in activity and diversity.

Jaccard's similarity index showed very low similarity among sites. Only 12 out of a possible 120 pairs (10% of the combinations) were more than 80% similar in their species composition. This illustrates that heterogeneity in habitat type was important as these bats foraged in a variety of different areas. Species diversity did not seem to be affected much by site type; only savannas (5/8 species detected) were lower in species diversity than forest, interior edge, and exterior edge sites (7/8). Individual sites did have a significant effect for two species: *L. borealis* (Kruskal Wallis, $p = 0.017$) and *L. noctivagans* (Kruskal Wallis, $p = 0.013$), along with total relative activity (Kruskal Wallis, $p = 0.008$).

Site types themselves were significantly different from each other based on landscape variables such as canopy cover, vegetation density and distance to riparian systems.

Additionally, landcover type (based on Root and Martin, 2017), proved to be significantly different among site types. This demonstrated that bats are capable of foraging in a multitude of different landscapes. These landscapes had high variation in structural characteristics, indicating structural heterogeneity among sites.

We also examined temporal relationships of bats by both month and time of night. We saw trends in monthly activity similar to previous studies. Monthly totals were high in the months of June, July, and August, but dropped off significantly in September. Activity was fairly consistent between the first three months, though we did see a significant decrease in *E. fuscus* in September (ChisSquare, $p = 0.008$). This was expected as bats tend to end their summer foraging and begin leaving their summer foraging grounds around this time (Moosman et al., 2012).

Since these monitors were left on for the duration of the foraging window, we had an excellent view of foraging activity across time. The goal was to assess if there was some level of temporal segregation of species foraging times. If some species were foraging at later times it could explain the low call numbers of some of the high frequency bats (*P. subflavus, M. lucifugus,* and *M. septentrionalis*) in previous studies (Nordal, 2016; Hollen, 2017; Turner, Unpublished). Such a temporal niche separation has been documented in insectivorous bats in other areas, with different size bats foraging at different times of the night to avoid resource competition (Emerich et al, 2014). This, however, was not the case in our study. We found only one peak in activity, generally in a 4-hour window starting just after sunset, rejecting our prediction of different activity times for different species and confirming the peak foraging hours for all species.

Knowing how different species are using a park is key to knowing how to best manage natural preserves. However, to get a full picture, we must understand both spatial and temporal dynamics of the species in question. We found that these bat species are capable of using a wide variety of habitat types, including park edges that are directly impacted by human activity. The driving factor to all of this seems to be heterogeneity in both landscape type and structure. The fact that many of the sites varied in species diversity based on our Jaccard's index shows high variation among different areas of the preserve. Temporally, we did not observe any segregation of foraging times by species, thus these bats must rely on differences in the land for any species-specific behaviors. Thus, by maintaining high diversity of landscapes within the park, with plenty of forest habitat, we can protect our native bats and promote higher activity and diversity. Many of these bat species face serious threats, so proper management is critical to the future of these diverse and important animals.

Figures

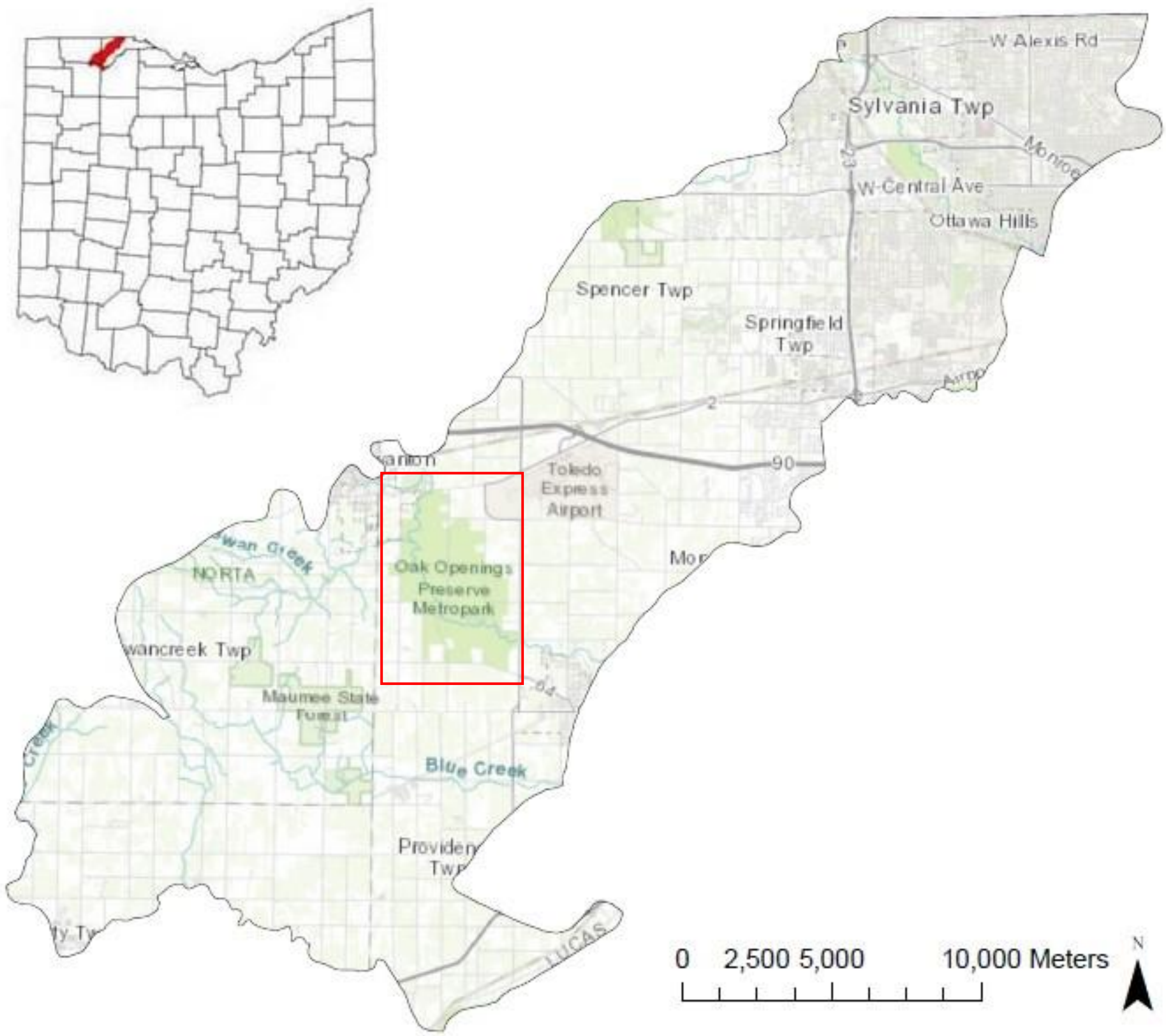

Figure 13: The Oak Openings Region of NW Ohio as defined by Brewer and Venkat (2004). Study area outlined in red. Basemap courtesy of USGS.

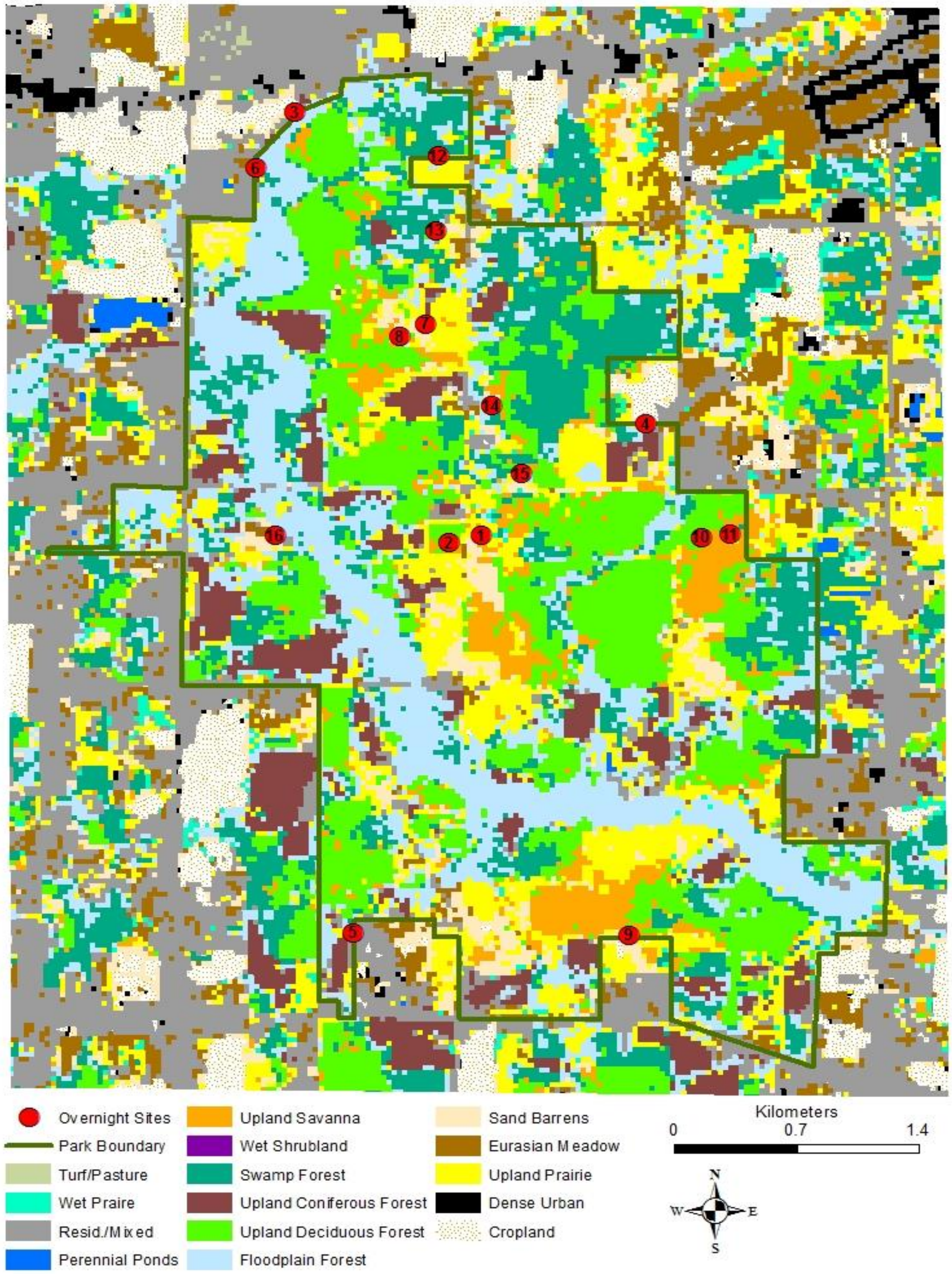

Figure 14: Overnight site locations within Oak Openings Preserve. Core sites were forest (sites 2, 7, and 11) and savanna habitat (1, 8, and 10). Edge sites were either exterior and bordering on residential/agricultural land (sites 3, 4, 5, 6, and 9) or interior forest bordering meadow or savanna habitat (12, 13, 14, 15, and 16). Landcover map based off of Martin and Root (2017).

Figure 15: Example of scatterboard being used for vegetation density measurements. The board was set up 15 m away from the stationary site and measured in all four cardinal directions then averaged for the site.

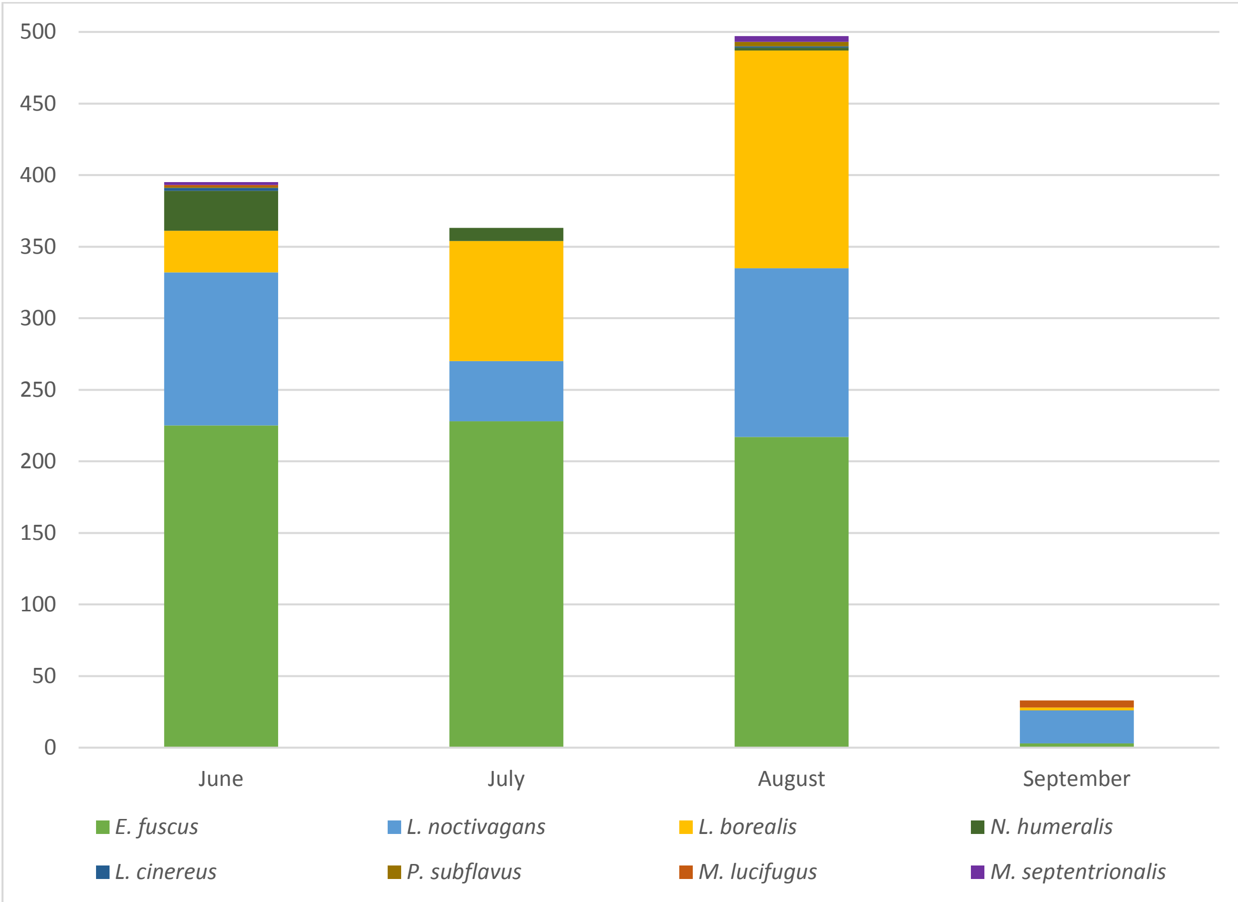

Figure 16: Monthly totals for bat species total relative activity. Top of the bar represents total activity, while each color correlates to the designated species. Peak activity observed in August, with a sharp decline in September.

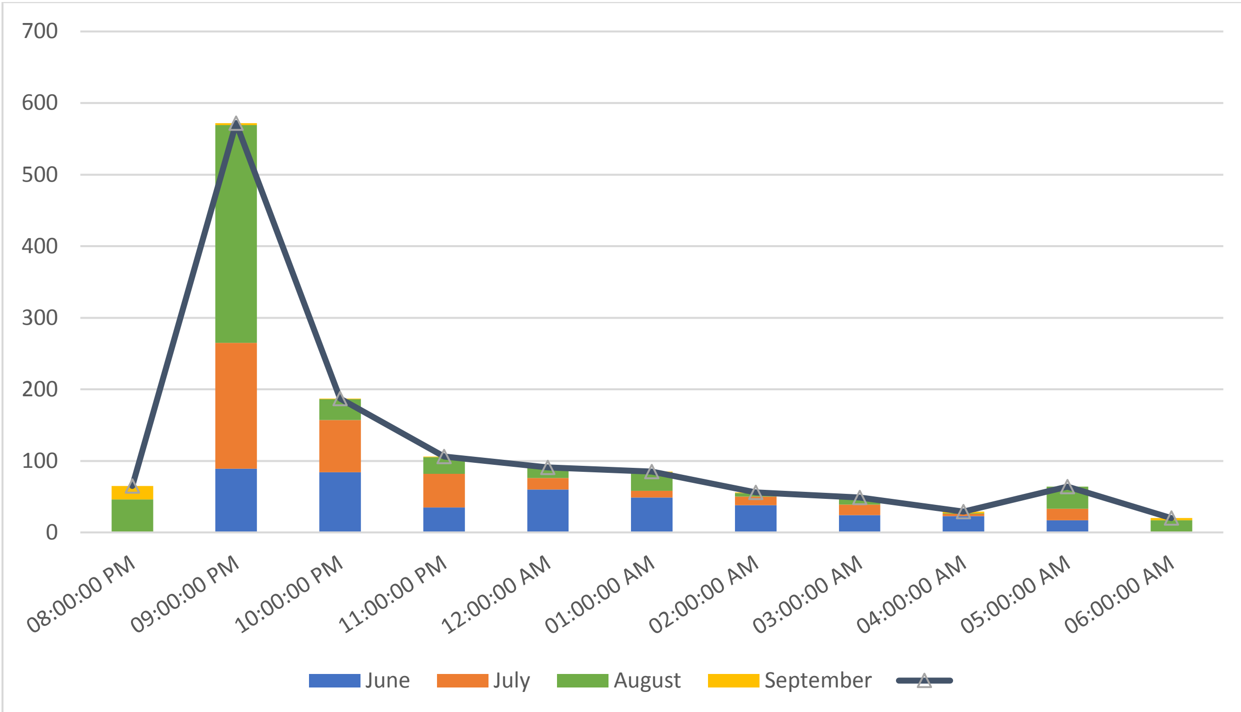

Figure 17: Total calls by hour for each month along with total activity for the entire 2017 study season. Peak activity was between 8:00 pm and 12:00 am (EST). Tope of the bars represents total activity, while each color is correlated to the activity for that month.

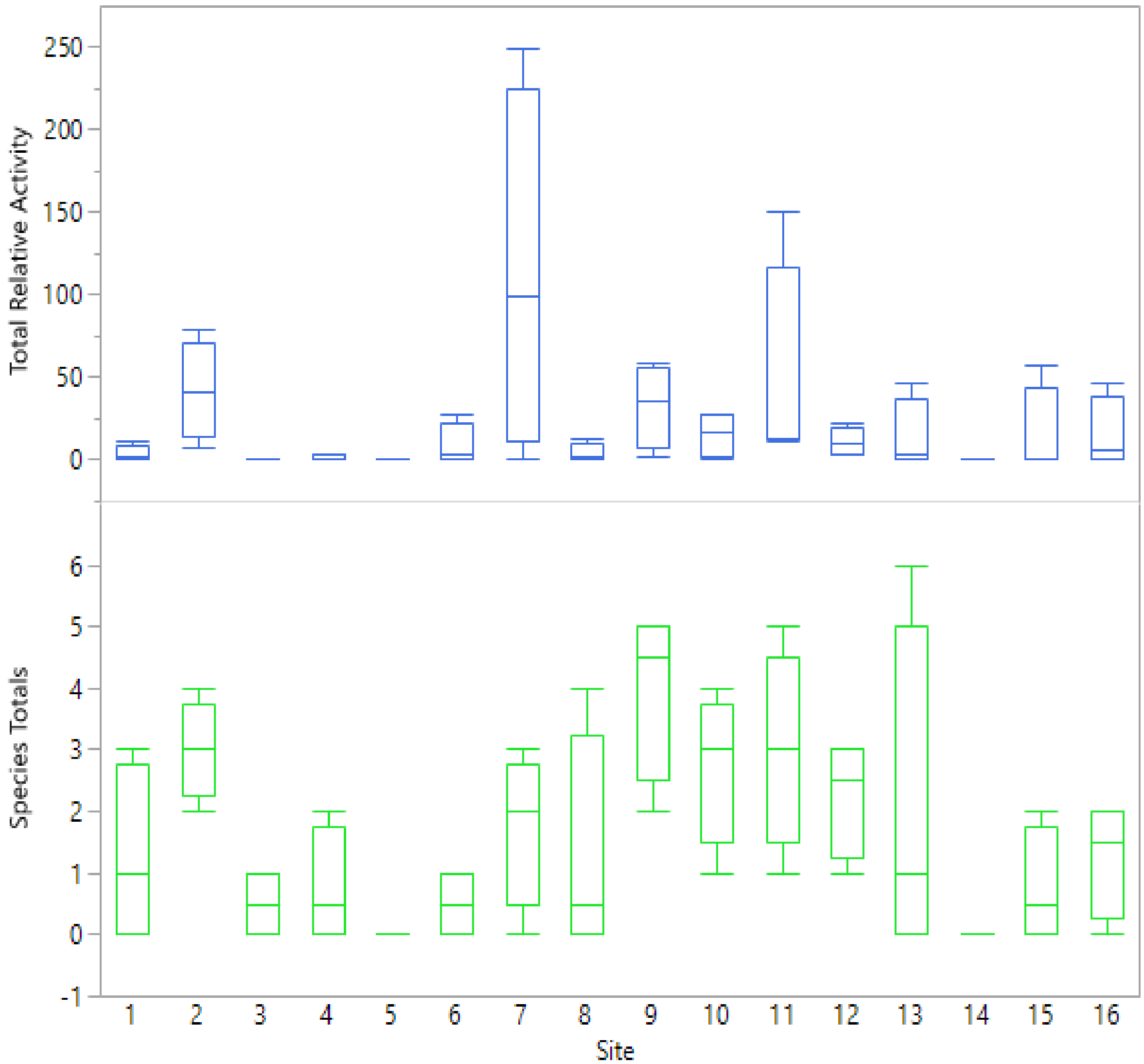

Figure 18: Total relative activity (top) and total number of recorded species (bottom) per site. Both were significantly related to total relative activity and total number of species (Kruskal Wallis; p = 0.008 and p = 0.004, respectively).

<u>Tables</u>

Table 10: Site landscape descriptions and species presence for each site. No edges were on core sites, represented with a hyphen (-). Species detections are for the duration of the study (June-September). Species are numbered as follows: 1) E. fuscus, 2) L. noctivagans, 3) L. borealis, 4) N. humeralis, 5) L. cinereus, 6) P. subflavus, 7) M. lucifugus, and 8) M. septentrionalis. Asterisks (*) indicate no species found at that site.

	Site Type	***Main Landscape***	***Edge Type***	***Species Detected***	***Total Calls Recorded***
Site 1	Savanna	Savanna	-	1, 2, 3	15
Site 2	Forest	Deciduous	-	1, 2, 3, 4, 7, 8	168
Site 3	Ext. Edge	Floodplain	Pasture	1	2
Site 4	Ext. Edge	Floodplain	Residential	1, 2	5
Site 5	Ext. Edge	Deciduous	Residential	*	0
Site 6	Ext. Edge	Floodplain	Residential	1, 2	34
Site 7	Forest	Coniferous	-	1, 3, 8	448
Site 8	Savanna	Savanna	-	1, 2, 3, 4	17
Site 9	Ext. Edge	Deciduous	Residential	1, 2, 3, 4, 5, 6, 8	133
Site 10	Forest	Deciduous	-	1, 2, 3, 4, 5	62
Site 11	Savanna	Savanna	-	1, 2, 3, 4, 6	189
Site 12	Int. Edge	Swamp	Prairie	1, 2, 3, 7	46
Site 13	Int. Edge	Swamp	Prairie	1, 2, 3, 4, 5, 8	53
Site 14	Int. Edge	Deciduous	Prairie	*	0
Site 15	Int. Edge	Deciduous	Prairie	1, 2	59

Table 11: Jaccard's Similarity index for each stationary site combination. Cells in green represent forest sites, yellow represent savanna, orange represents exterior edge and blue interior edge. Any site combination over 80% similar is indicated in bold. Sites with no calls recorded (sites 5 and 14) indicated with an asterisk (*).

Site	**1**	**2**	**3**	**4**	***5***	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	***14***	**15**
1															
2	50.0														
3	33.3	16.7													
4	66.7	33.3	50.0												
5	*	*	*	*											
6	66.7	33.3	50.0	**100.0**	*										
7	50.0	50.0	33.3	25.0	*	50.0									
8	75.0	66.7	25.0	50.0	*	50.0	40.0								
9	42.9	75.0	14.3	28.6	*	28.6	42.9	57.1							
10	60.0	57.1	20.0	40.0	*	40.0	33.3	**80.0**	71.4						
11	60.0	57.1	20.0	40.0	*	40.0	33.3	**80.0**	71.4	66.7					
12	75.0	66.7	25.0	50.0	*	50.0	40.0	**80.0**	37.5	50.0	50.0				
13	50.0	**100.0**	16.7	33.3	*	33.3	50.0	66.7	**85.7**	**83.3**	57.1	42.9			
14	*	*	*	*	*	*	*	*	*	*	*	*	*		
15	66.7	33.3	50.0	**100.0**	*	**100.0**	25.0	50.0	28.6	40.0	40.0	50.0	66.7	*	
16	66.7	33.3	50.0	**100.0**	*	**100.0**	25.0	50.0	28.6	40.0	40.0	50.0	66.7	*	**100.0**

Table 12: Average number of calls per site based on landscape type. Total is the sum of the averages and percentage is the percentage of average calls for that species. As can be seen, the majority were E. fuscus, L. noctivagans, and L. borealis. The four least common species (L. cinereus, P. subflavus, M. lucifugus, and M. septentrionalis) all make up half a percent or less of total calls.

	E. fuscus	***L. noctivagans***	***L. borealis***	***N. humeralis***	***L. cinereus***	***P. subflavus***	***M. lucifugus***	***M. septentrionalis***
Savanna	31.67	22.33	8.00	9.00	0.00	0.33	0.00	0.00
Forest	129.67	15.00	75.67	2.33	0.33	0.00	1.67	1.33
Ext. Edge	11.60	19.40	2.00	0.80	0.20	0.60	0.00	0.20
Int. Edge	25.60	15.80	1.20	0.20	0.20	0.00	0.20	0.20
Totals	198.53	72.53	86.87	12.33	0.73	0.93	1.87	1.73
% of Total	52.87%	19.31%	23.13%	3.28%	0.20%	0.25%	0.50%	0.46%

Table 13: Landscape variables compared to site type. Canopy cover, vegetation density, and distance to riparian system tested with Kruskal Wallis. Chi Square, degrees of freedom, and p values reported. Landcover type compared to site type tested with Pearson's test. Chi Square, degrees of freedom, p values, and R square reported.

	χ^2	**DF**	**p-value**	**R^2**
Canopy Cover	35.082	3	< 0.001	-
Vegetation Density	35.898	3	< 0.001	-
Distance to Riparian	13.119	3	0.004	-
Main Landcover	110.222	12	< 0.001	0.549
Edge Landcover	128.000	12	< 0.001	0.778

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CHAPTER III. USING CITIZEN SCIENCE TO ASSESS TEMPORAL TRENDS IN NATIVE BAT ABUNDANCE AND DIVERSITY

Introduction

The Oak Openings Region is a biodiversity hotspot in northwest Ohio that contains diverse land types such as sand barrens, oak savannas, wet prairies, and woodland habitats (Brewer & Vankat, 2004). This area also contains a large portion of Ohio's native biodiversity, including over a third of Ohio's rare flora and fauna (Schetter et al., 2013). The Oak Openings Region also supports substantial native bat diversity, with eight different species actively using the region, especially during the growing season. These species include the big brown bat (*Eptesicus fuscus*), silver-haired bat (*Lasionycteris noctivagans*), eastern red bat (*Lasiurus borealis*), hoary bat (*Lasiurus cineresus*), little brown bat (*Myotis lucifugus*), evening bat (*Nycticeius humeralis*), tri-colored bat (*Perimyotis subflavus*), and northern long-eared bat (*Myotis septentrionalis*). One species, the northern long-eared bat, is considered a threatened species under the US Endangered Species Act. Another, the tri-colored is being considered for national listing (USFWS, 2018). This represents 57% of Ohio's native bat diversity (Bellwood, 1998), all found within the 476 km^2 in northwest Ohio that make up the Oak Openings Region (Brewer & Vankat, 2004) (Figure 19).

While the region has been heavily utilized by humans in both urban and agricultural development, a number of preserves have been established to protect some of this unique landscape. The largest of these parks is the Oak Openings Metropark (1200 ha). A number of smaller parks have been established as well, including Secor (253 ha) and Wildwood Metropark

(199 ha), which is in a more urban setting than either Secor or Oak Openings Preserve (Figure 19). We have been surveying these parks since 2011 in collaboration with the Metroparks of the Toledo area, with the help of local citizen science volunteers (Sewald, 2012; Sewald et al., 2014; Janos, 2013; Nordal, 2016; Hollen, 2017).

While all three parks are within 20 km of each other (8.2 km between Secor and Wildwood, 9.8 km between Oak Openings and Secor, and 18.5 km between Oak Openings and Wildwood, linear), these parks do have differences in terms of both landcover and bat species diversity. Oak Openings, which is approximately six times larger than the other two parks, is a mix of floodplain forest, upland deciduous forest, swamp forest, upland savanna, upland prairie, and upland coniferous forest. It is surrounded by residential/mixed use land, cropland, Eurasian meadow, and prairie (Figure 20). Wildwood, the smallest park, is composed primarily of upland deciduous forest, floodplain forest, and upland prairie, with scattered savanna and residential/mixed use land. Surrounding this is a primarily residential/mixed use and dense urban landscape (Figure 21). Secor, relative in size to Wildwood, consists mostly of swamp forest, floodplain forest, and upland prairie, with some upland deciduous forest, Eurasian meadow, and savanna patches. The surrounding land is a mix of forest, prairie, residential, and cropland (Figure 22).

Not only did landcover vary among parks, but so did past species diversity. Based on previous studies (Sewald, 2012; Janos, 2013; Nordal, 2016; Hollen, 2017), we know that Oak Openings had all 8 bat species in 2011 and 2012, but has been losing species in the years since with a low of 6 species in 2016. Wildwood Metropark has consistently had the most bat species, with 7-8 species found every year in the previous studies. The number of bat species in Secor Metropark has typically fluctuated year to year much more than the other two, with a high of 8 species in 2011 and a low of 3 in 2013. Knowing how these populations are changing is very important, and long term data sets can provide insight into these changes. However, monitoring large areas over a long time can be difficult. Thus we have successfully implemented the use of citizen science volunteers to help with this task.

Citizen science is an increasingly useful tool for mass data gathering, allowing scientists to cover more with their studies than their typical resources would allow. This approach has been used extensively in countries such as Great Britain, who have set up yearly comprehensive volunteer bat surveys (National Bat Monitoring Programme), which led to the creation of their most accurate population models for 9/10 bat species in the country (Barlow et al., 2015). Citizen scientists are typically volunteers from the local community, thus they are provided an opportunity to become involved and engage in local conservation efforts. This participation can prove especially useful for changing opinions on species that have historically been seen in a negative light, such as bats (Kingston, 2016). Citizen science monitoring has also proven effective in monitoring a number of other species. The most common field for citizen science is ornithology, where birders acting as citizen scientists have contributed successfully to a number of different projects (Cooper et al., 2014; Coxen et al., 2017; Nugent, 2018). Another example of this is the eButterfly program developed by Cornell, which has also gathered mass amounts of usable data from citizen science volunteers (Prudic et al., 2017). This type of research will continue to grow in the future as technology advances and as scientists find new ways to engage and utilize the public. Thus, citizen science may be critical to monitoring bat species, especially those facing serious threats.

White-nose syndrome (WNS), is a lethal disease caused by the fungus *Pseudogymnoascus destructans.* This disease, first discovered in New Jersey in 2006, is characterized by a white fungal growth around nose and wings on bats and affects them while they overwinter in their hibernacula (Turner et al., 2010). In the past decade this disease has spread to 31 states and 5 Canadian provinces (USFWS, 2018). WNS is highly lethal, causing 90-100% collapse of the colony when they form hibernacula during the winter roosting months (Frick et al, 2010). It has rapidly become the leading cause of mortality for bats in the US (O'Shea, 2016). The first signs of this disease in Ohio were documented in Hocking County in 2010 (ODNR, 2013) and has caused mass mortalities of three of our native species (*Myotis septentrionalis, Myotis lucifugus,* and *Perimyotis subflavus*). A fourth species (*Eptesicus fuscus*) has confirmed mortalities in other states, but not yet in Ohio, while two more (*Lasionycteris noctivagans* and *L. borealis*) is a known carrier of the fungus (Bernard et al, 2015). The impact of WNS is likely to be complicated, different for individual species and change over time (Maslo and Fefferman, 2015) highlighting the need to long-term monitoring of bat populations.

This research used both previously collected data and data collected during 2017 using citizen scientists to study spatial and temporal trends in native bats since the first foraging season after the discovery of WNS in Ohio. The objectives were to (1) assess bat activity and diversity among these three different parks during the 2017 field season, (2) to look at temporal changes in native bat diversity and activity including previous years data, and (3) assess population changes since the outbreak of WNS. As the largest park and furthest from an urban center, we predicted that bat activity and diversity would be highest in the Oak Openings Metropark. We also predicted that we would see declines in bat activity in the three species affected by WNS throughout the years of this ongoing study. Finally, we predicted that we would see an increase in percentage of calls from non-WNS affected species, as they fill in the niches left behind by the declining species.

<u>Methods</u>

Acoustic Surveys

Once a month for three consecutive nights, each of the three different metroparks (Wildwood, Oak Openings, and Secor, respectively) were surveyed by citizen scientist volunteers. The largest of these parks, Oak Openings Preserve, is over 1,200 hectares and consists of numerous different landscape types from oak savannas to floodplain forests to sand barrens. The two smaller parks, Secor (253 ha) and Wildwood (199 ha), have slightly less habitat diversity. Survey nights were chosen as the Monday, Tuesday, and Wednesday nearest the new moon in the months of June, July, and August. A fourth night was chosen as a backup for the following Wednesday in case of inclement weather (heavy rain, winds over 24 km/h, or temperature under 12ºC), but was not needed for any month. Three trails were selected for the volunteers to walk each night at each park based on previous studies (Sewald, 2012; Janos, 2013; Nordal, 2016; Hollen, 2017).

Citizen scientist volunteers (6-9 individuals per night) were organized by the Metroparks of Toledo and met approximately 1 hour before sunset at the park being surveyed. Volunteers were then provided brief instructions of the study and in the proper use of Anabat SDII monitors (Titley Electronics, Ballina, New South Wales, Australia). Volunteers were then paired off, given monitors, and each pair was assigned a pre-determined trail to walk. They were given red light head lamps and a trail map and instructed to keep light and noise to a minimum. Assigned trails (between 0.8 km and 3.2 km, depending on the trail) were surveyed at a standard walking pace with monitors and GPS units turned on and passively recording. When volunteers returned monitors were collected and shut off. CF cards were collected, and files were downloaded for analysis. Research methods and protocols were approved by Bowling Green State University's Institutional Animal Care and Use Committee (IACUC, Appendix A).

Call Identification

Calls were recorded with Anabat SDII monitors (Titley Electronics, Ballina, New South Wales, Australia) and autotagged with GPS locations using connected global positioning satellite units (Garmin Ecotrax GPS Unit). Monitors used Anabat Standard omindirectional microphones and held at a comfortable height with the microphone directed outward in front of the volunteer as they walked. Division ratio was set at 16 and sensitivity at 8. This device has a detection radius of 30 meters and records all bat call frequencies.

Calls were analyzed in Kaleidoscope Viewer Software (Wildlife Acoustics, 2016) and checked with Bat Call Identification Software (BCID) (BCID, BCID version 9 2.7c). When identifications disagreed, final decision was made based on the authors' knowledge of calls and the previously developed call libraries (Sewald, 2012; Janos, 2013; Nordal, 2016; Hollen, 2017). Identification only occurred when a clear pass was recorded on a file, defined as three or more clear, identifiable calls from one species in one file (Parsons and Szewczak, 2009). GPS locations were recorded by time for each call and mapped on ArcMap 10.2 (ESRI, 2011) and provided data on the distribution of each species. The number of calls were treated as a measure of relative activity

Environmental Variables

Environmental variables were measured each night at both the start and the end of each survey using handheld Brunton ADC-Pro handheld weather stations and NOAA weather center at the Toledo Airport (http://w1.weather.gov/obhistory/KTOL.html). These measurements included time, temperature (°C), humidity (%), barometric pressure (inHg), wind speed (km/h) and wind direction. Moon phase and illumination percentage were recorded from the website Moon Giant (http://www.moongiant.com/phase/today/).

Statistical Analysis

Calls were counted and identified by trail each month and then averaged for the course of the year based on number of trails walked in total for each park. The calls from this year's study were analyzed against data from previous studies (Sewald, 2012; Janos, 2013; Nordal, 2016; Hollen, 2017). Since previous years data had some missing nights due to weather or lack of volunteers, data were standardized by averaging the species numbers recorded based on the number of total surveys done per park to control for sample effort.

Spearman's rho correlation analysis was run to test for significant correlations among environmental variables for the 2017 study; correlations were considered highly significant if $|r| > 0.6$ and $p < 0.05$. We used oneway AVOVA Kruskal Wallis analysis to look for significant relationships between environmental variables and species totals (both as individual species totals and as total relative activity). These tests were performed using JMP Statistical Analysis Software (JMP®, Version 11. SAS Institute Inc., Cary, NC, 1989-2007).

Species diversity indices were calculated (both Shannon-Weiner and Simpson's) for each individual park for each year. A Cochran's Q Test was run on binary presence/absence data for each park to look for significant changes in number of species observed year to year. Both diversity indexes and Cochran's Q Test were run in Excel.

Results

Over the course of this year's study, we recorded and identified 458 calls. There were only 6 additional calls that could not be identified to species or did not meet the criteria for a clear pass. The majority of these calls (69%, 315 calls) were identified as *Eptesicus fuscus*. The next most frequent were both *Lasionycteris noctivagans* and *Lasiurus borealis,* each comprising 10% of the total recorded calls (47 and 48 calls, respectively). The other five species combined accounted for less than 11% of the total calls (Table 14).

Only a few environmental variables were strongly significantly correlated with each other in the 2017 study. Windspeed and direction were found to be correlated (Spearman; $r = 0.839$, $p < 0.001$), along with wind direction and time (Spearman; $r = -0.612$, $p <0.001$). There was also a negative correlation between barometric pressure and temperature (Spearman; $r = -0.693$, $p <0.001$). While all other p-values were 0.004 or lower, no other rho values were strong enough to meet our criteria for a strongly significant correlation.

For the parks totals, 249 of the calls (54%) were recorded in Oak Openings, 123 calls (27%) were recorded in Secor, and 86 calls (19%) from Wildwood. However, while Wildwood Metropark had the smallest number of calls, it was the only park where all eight species of bats were recorded and identified including 9 calls from the threatened species, *Myotis* *septentrionalis*. Wildwood not only had the highest number of species identified (8/8), but when evenness was included it also had the highest species diversity (Shannon-Wiener = 1.69). Despite having the most calls, Oak Openings had the lowest diversity (Shannon-Wiener = 0.94) and second lowest number of species detected (7/8), while Secor was between the other two in terms of diversity (Shannon-Wiener = 0.70) but had the lowest number of species detected (6/8) (Figure 23).

This lack of diversity in Oak Openings can partially be explained by the large number of *E. fuscus* calls recorded there. This was the only species where the site had a significant effect on total relative activity (Kruskal Wallis, $p = 0.027$). None of the environmental variables significantly influenced activity when tested with Kruskal Wallis. This was likely due to the fact that the weather this summer was very stable, and nights were chosen for favorable conditions.

These patterns were similar to those of the previous years. Wildwood was the most diverse park in every year except for 2012, though all three parks displayed high diversity that year due to low numbers of *E. fuscus* (Table 15). Both diversity and total activity showed the most variation between years at Secor (Table 16). Oak Openings had the highest total activity from 2013 onward (Table 17).

Observed number of species did not change significantly year to year in any park (Cochran's Q Test. Oak Openings $p = 0.994$, $Q = 0.439$; Wildwood $p = 0.999$, $Q = 0.167$; Secor $p = 0.751$, $Q = 2.667$), however, we might not have been able to detect a significant difference because of the small sample size. We did see a 25% decline in species totals in Oak Openings between 2011 and 2017. Wildwood's largest change was 12.5% decline between 2012 and

2013, with no total change between 2011 and 2017. Secor had a 133% increase in species totals between 2013 and 2015, with a 12.5% decline from 2011 and 2017 (Figure 27).

Total activity followed similar patterns, with the highest total activity being observed in 2011 and the lowest in 2017. Total number of calls and number of *E. fuscus* showed a large decline from 2011-2012 (Figure 24). The four species that were not affected by WNS (*L. borealis, L. noctivagans, N. humeralis,* and *L. cinereus*) tended to fluctuate from year to year (Figure 25). The three WNS affected species (*P. subflavus, M. lucifugus,* and *M. septentrionalis*) all recorded their highest numbers in 2011 and stayed very low for each year forward (Figure 26).

Discussion

Bats face serious large-scale population declines both locally and globally (Frick et al., 2016). While the threats range from habitat destruction to wind farms, by far the most concerning in the United States is that of white-nose syndrome (O'Shea et al., 2016). This disease is responsible for mass mortalities of three species (*M. lucifugus, M. septentrionalis* and *P. subflavus*) that are found in our study area (ODNR, 2013). These also happen to be the three species that have been least common both in this and previous studies. One tool that may prove useful in monitoring long-term population trends and changes is citizen science. This technique allows for mass data gathering while engaging the public and keeping down project costs. Citizen scientists have been used successfully in our previous studies (Sewald, 2012; Janos, 2013; Nordal, 2016; Hollen, 2017), and was put to use in this study as well.

While the highest number of calls was found at Oak Openings, the largest of the parks, the species diversity and total number of identified species were highest in Wildwood. This was surprising since it is the smallest park of the three surveyed and closest to an urban center. However, these trends seem to go back to 2011. Wildwood consistently had the highest species diversity of all three parks. This could suggest that the forest quality, which has been observed to be a driving factor in activity (Charbonnier, 2016), is more conducive to bat activity in this particular preserve. Another reason for Wildwood to have the highest diversity could also be that bats are using this park as an urban refuge given its landscape context. This would suggest that it is not necessarily forest quality, but quality of land surrounding the forest (i.e., the matrix) that is driving activity in this park.

We know certain species, such as *M. lucifugus*, will utilize forest remnants and patches within urban centers (Gehrt and Chelsvig, 2004). While it is the smallest park we studied, Wildwood may represent the largest nearby forest patch. Certain species can also utilize nearby urban sites and human structures to roost (Diamond et al., 2015), which may be the case for species foraging in Wildwood Metropark. Studies have also show that forest patches do not need to be large for these bats to forage, and that they will utilize edge habitats and small forest patches (Etheir and Fahrig, 2011; Arroyo-Rodrigues et al, 2016). It may be that this park is acting as a mix of both a refuge and providing quality foraging habitat for these bat species. If we look at the land surrounding Wildwood (Figure 21) compared to Oak Openings (Figure 20) and Secor (Figure 22) we can see there is much less natural land available, therefore these animals are likely limited to this park when foraging.

Unfortunately, we did see a decline in total bat activity after the 2011 foraging season. The total relative activity showed trends of a decline throughout the study years. This was likely due to the high numbers of *E. fuscus,* which was closely correlated to total relative activity. We also saw downward trends in *L. borealis, P. subflavus, M. lucifugus,* and *M. septentrionalis*. Three species (*L. noctivagans, L. cinereus,* and *N. humeralis*) did not show the same downward trends.

While we did see fluctuations or declines in most species, the three species affected by WNS (*P. subflavus, M. lucifugus,* and *M. septentrionalis*) showed the largest declines in total calls. The study year in 2011 was the only year where we recorded more than 5 calls, on average, from these species. This is especially disheartening when looking at decreases in *M. lucifugus* populations, as this was once a very common species and is considered one of the species most able to thrive in environments that have heavy anthropogenic influence (Bergeson et al, 2015). We know that WNS was first discovered in Ohio in the winter of 2010 (ODNR, 2013), so 2011 represented the first foraging year after discovery of this disease. It is likely that the disease spread after this season and began affecting more colonies and species as this is a rapid spreading fungus (Turner et al, 2011). Going forward we will likely see continued declines of these species, with up to 90% collapse of the populations (Frick et al, 2010). However, those individuals that survive and their offspring may be genetically robust enough to survive future outbreaks (Maslo and Fefferman, 2015), so ensuring that there is quality foraging habitat for these animals is critical for species survival.

This study not only highlights how bats are using these parks over time, but also illustrates the value of citizen science research. This large data set could not have been collected without the help of public volunteers. While citizen science has been questioned in terms of accuracy, in situations such as this, where identification is performed by trained individuals, citizen science can be very useful (Kosmala, 2016). A big reason why citizen scientists were so effective in this survey were the tools that were used. Since the Anabat monitors did the recording and the author performed the identifications, volunteers were in effect mobile data gathering stations. These data were collected by the volunteers, but not interpreted, thus there was minimal influence by our citizen science volunteers on any errors in the data.

Through citizen science studies we not only engage the local community in research and conservation efforts, but we gain a large resource for mass data gathering and long term data sets. These long term data will be invaluable for monitoring species changes, and should continue as long as possible. Monitoring of threatened populations is essential to their survival. This research, and that of previous years, demonstrate that this type of monitoring can be done easily and accurately with the help of citizen scientists. If we continue to incorporate citizen science with other research methods we can gather data on a scale, both temporally and spatially, that simply would not be possible within the budget or time constrains of a typical study. This research may prove to be indispensable as we fight to mitigate the threats that bats face and work towards improving and refining management techniques.

Acknowledgements

I would like to acknowledge the Metroparks of Toledo for working with us to organize the volunteers for this study, as well as the past Root Lab members who organized the studies themselves. I would also like to acknowledge the citizen science volunteers who came out every

night to walk the trails and gather data, especially those who came month after month, year after year, and hope they continue to do so well into the future.

<u>Figures</u>

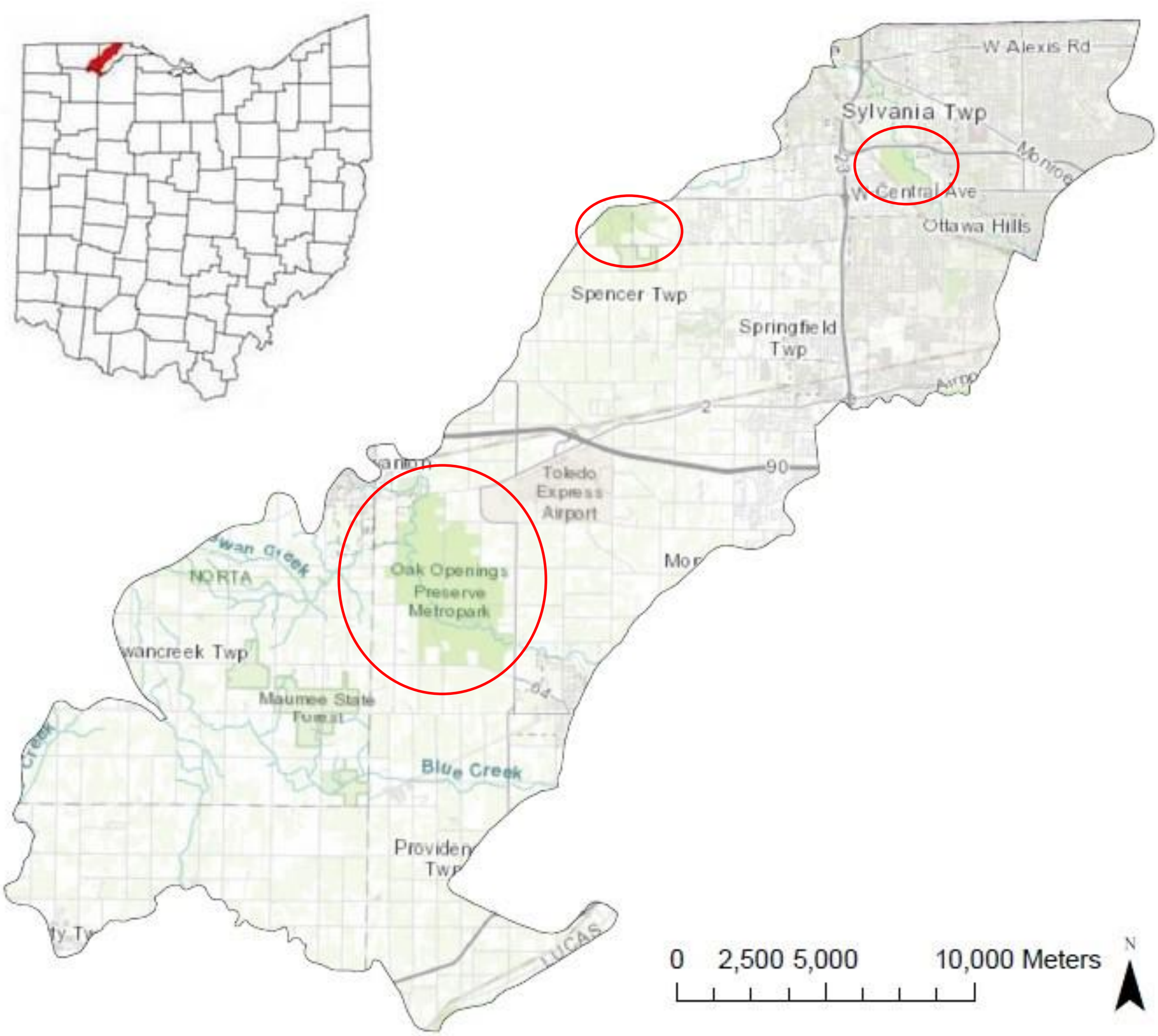

Figure 19: The Oak Openings Region of NW Ohio as defined by Brewer and Venkat (2004). Parks surveyed in this study circled in red (Secor, Wildwood, and Oak Openings Preserve). Basemap courtesy of USGS.

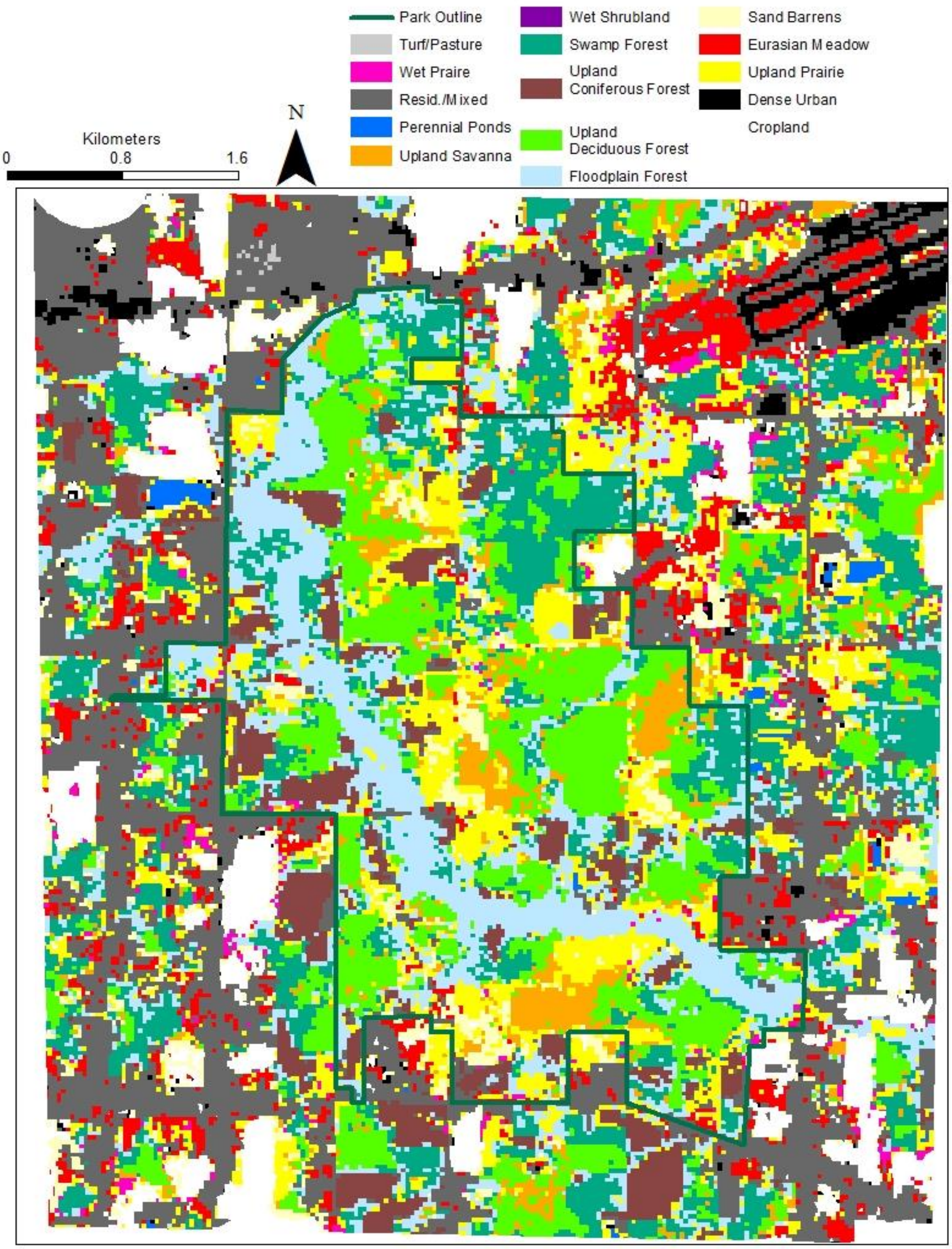

Figure 20: Landcover map and outline of Oak Openings Preserve and the surrounding area (Root and Martin, 2017).

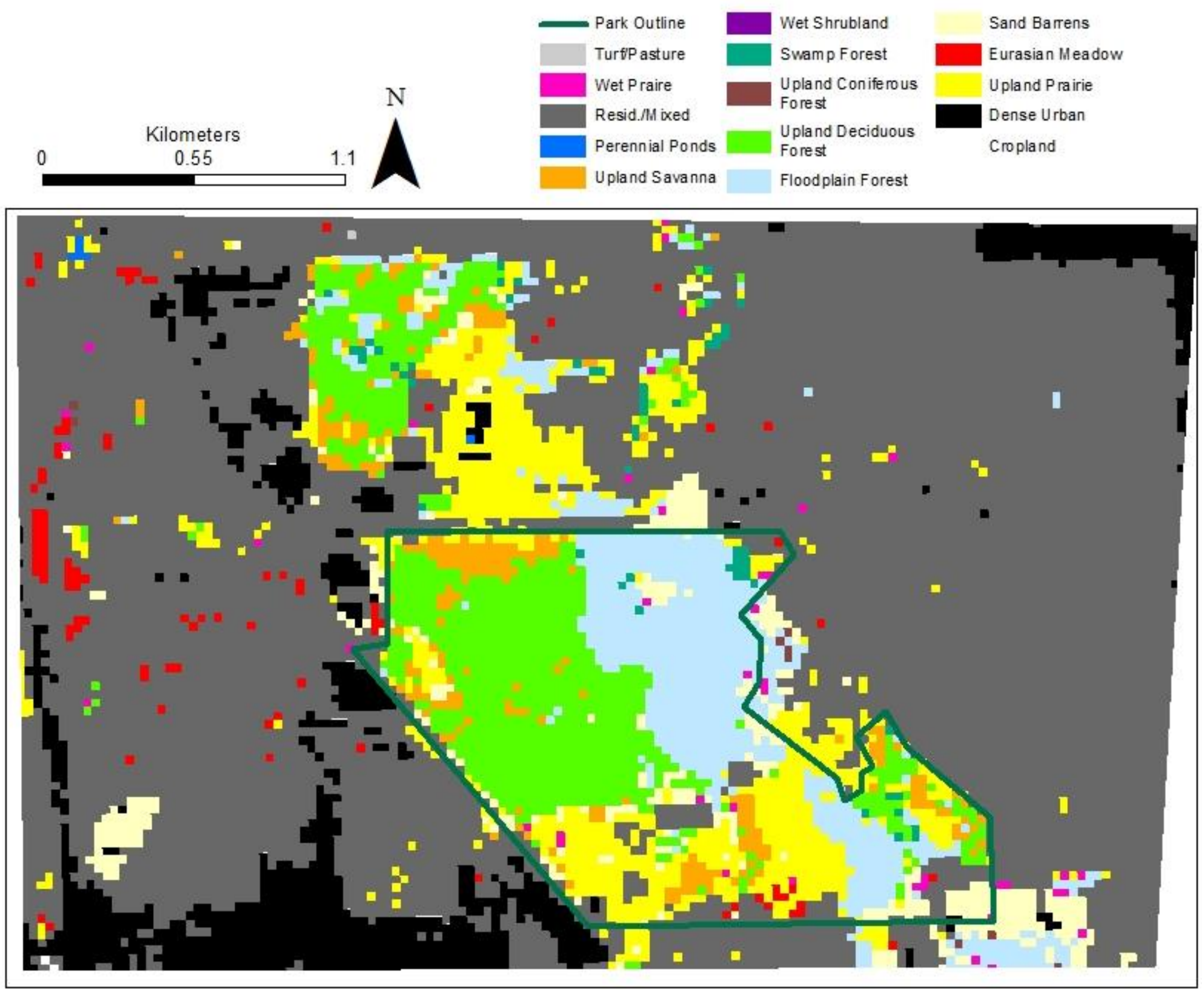

Figure 21: Landcover map and outline of Wildwood Metropark and the surrounding area (Root and Martin, 2017).

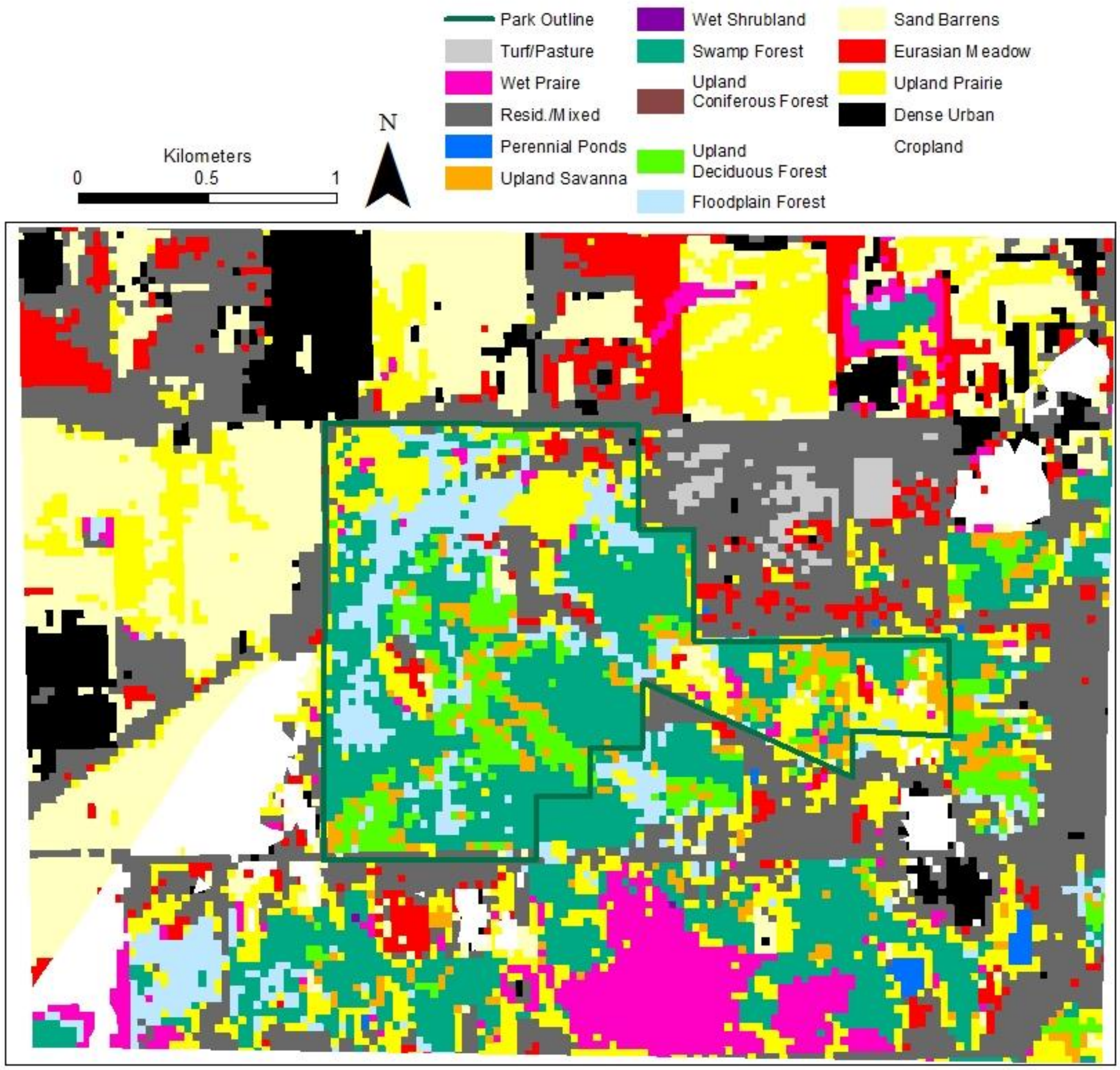

Figure 22: Landcover map and outline of Secor Metropark and the surrounding area (Root and Martin, 2017).

Figure 23: Species Diversities between the three parks (Wildwood, Oak Openings, and Secor) in 2017. Diversities are measured by both Shannon-Weiner (green) and Simpsons (blue) Diversity Indices. In both cases, highest diversity was recorded at Wildwood Metropark, while lowest were recorded at Oak Openings preserve.

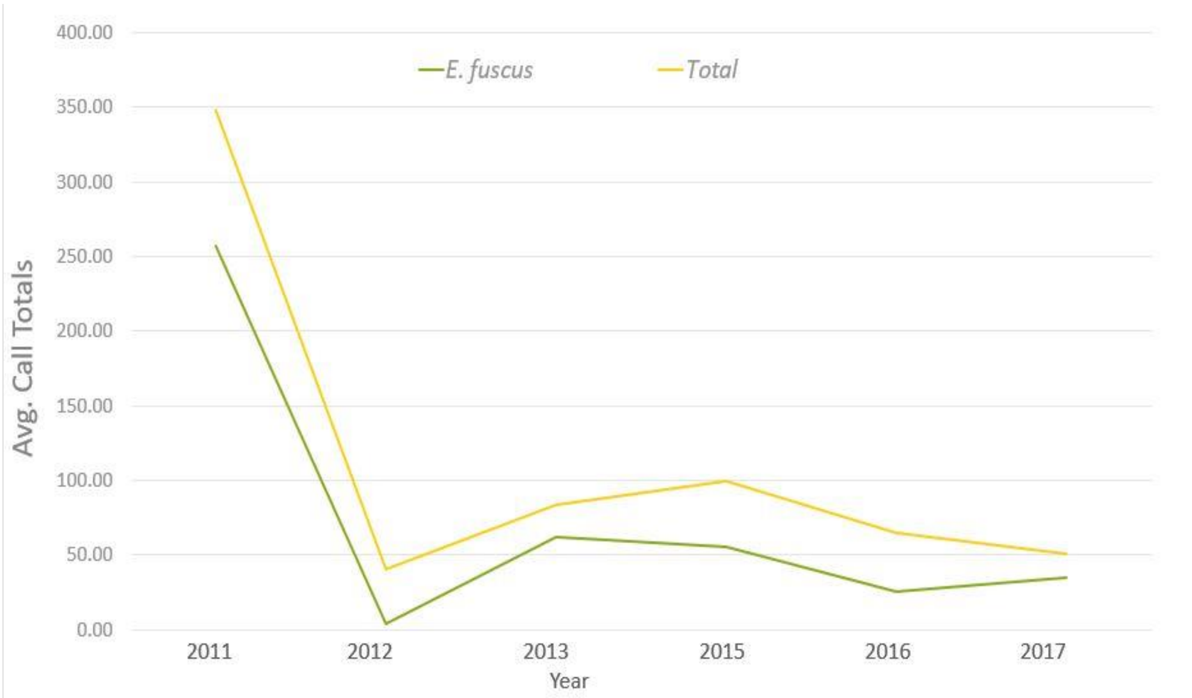

Figure 24: Average abundance of total calls and calls from E. fuscus based on number of trail surveys conducted for each survey year. Because of the high totals of E. fuscus every year they are relatively comparable to total activity of all species and thus the two were graphed together.

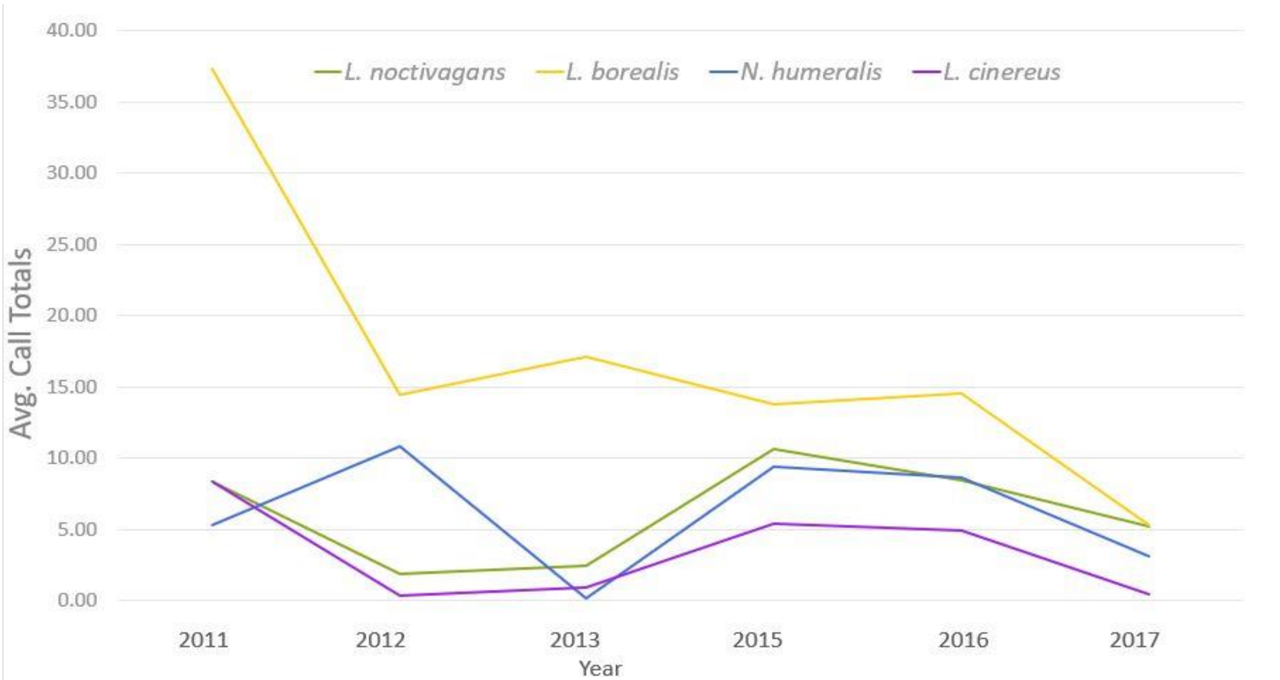

Figure 25: Average total call numbers based on number of trails surveyed for each survey year. These four species, along with E. fuscus, represent the species unaffected by WNS.

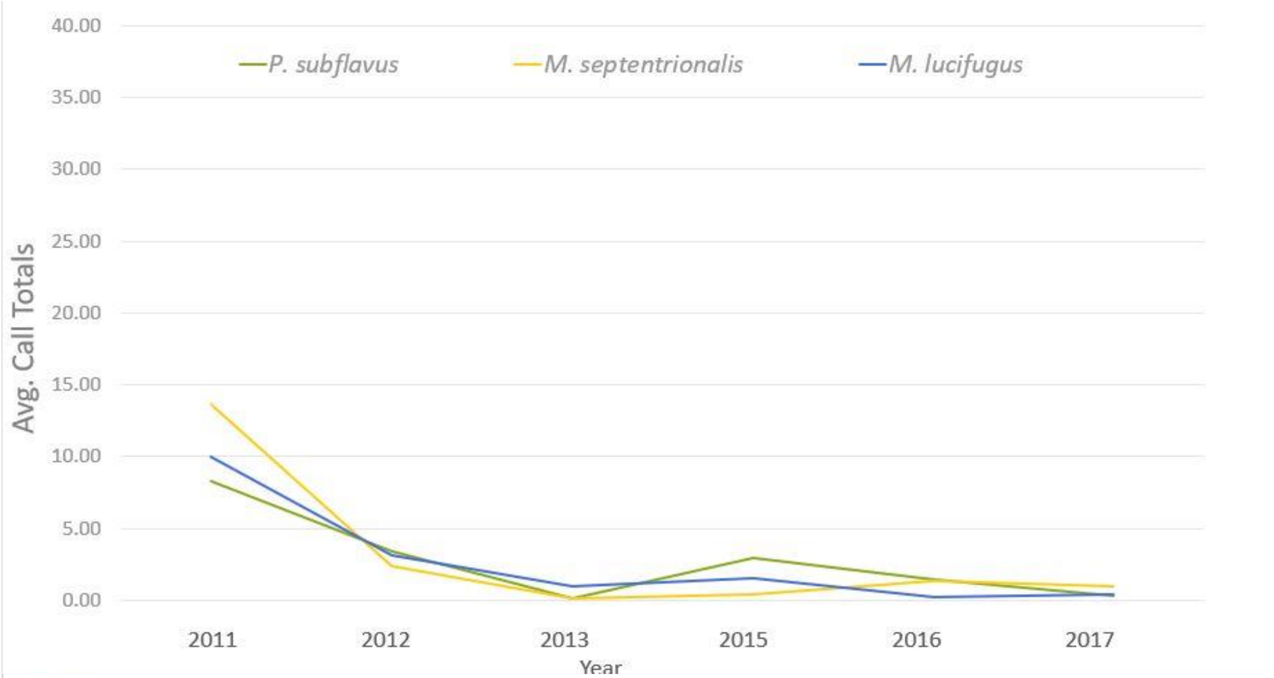

Figure 26: Average total call numbers based on number of trails surveyed for each survey year for the three species that have seen mass mortalities in Ohio from WNS. The y-axis is kept the same as Fig. 3-4 for comparison.

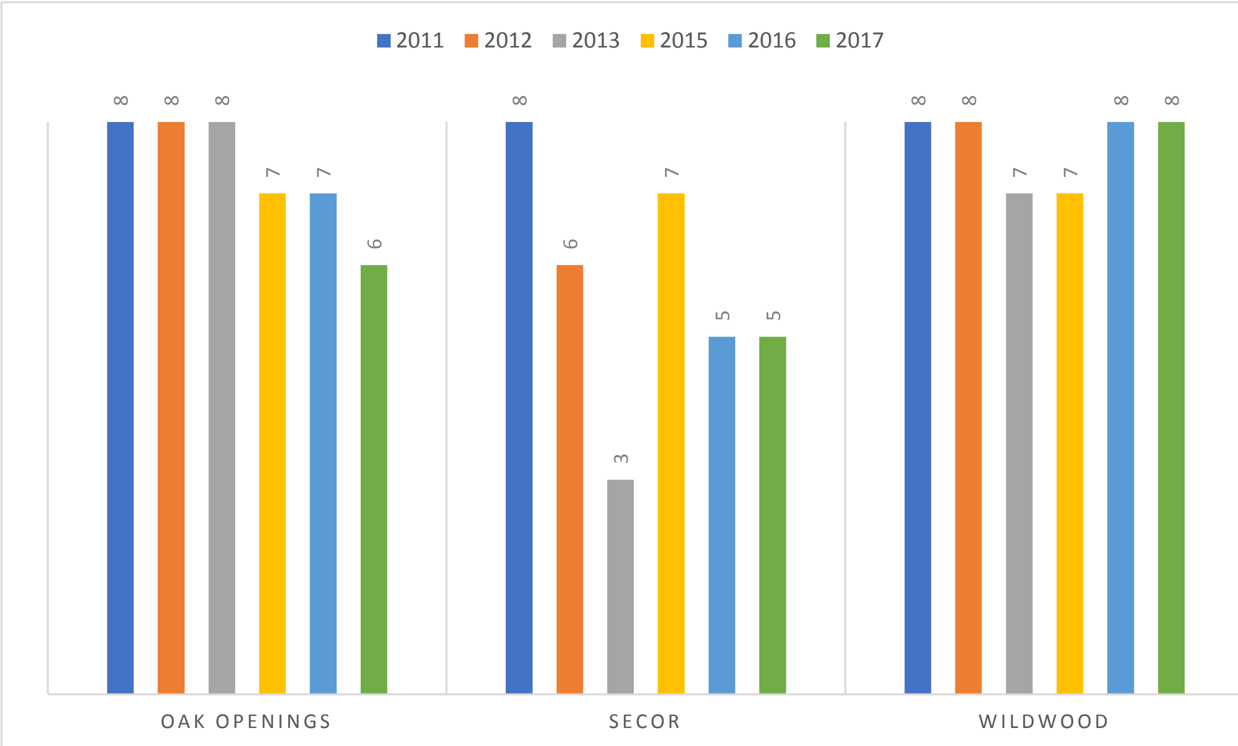

Figure 27: Total number of species identified in each park for each study year.

Tables

Table 14: Total number of calls for each park and the totals for the 2017 field season. Percentages represent the percent of the total number of calls for this study for the field season across all parks

2017	Wildwood		Oak Openings		Secor		Total	
Species	Calls	% of Total	Calls	% of Total	Calls	% of Total	Calls	%
E. fuscus	23	5.02	204	44.54	88	19.21	315	68.78
L. noctivagans	8	1.75	25	5.46	14	3.06	47	10.26
L. borealis	27	5.90	7	1.53	14	3.06	48	10.48
N. humeralis	15	3.28	8	1.75	5	1.09	28	6.11
L. cinereus	4	0.87	0	0.00	0	0.00	4	0.87
P. subflavus	1	0.22	1	0.22	1	0.22	3	0.66
M. lucifugus	7	0.22	1	0.22	1	0.22	9	1.97
M. septentrionalis	1	1.53	3	0.66	0	0.00	4	0.87
Total	86	18.78	249	54.37	123	26.86	458	100.00

Table 15: Total number of calls for each bat species for each study year of the study at Wildwood Metropark. Percentages represent percentage of that year's totals. Species diversity for each year is listed under totals using Shannon-Weiner index.

	2017		2016		2015		2013		2012		2011	
Wildwood	Calls	%	Calls	%	Calls	%	Calls	%	Calls	%	Calls	%
E. fuscus	23	26.7	26	13.1	37	28.7	108	54.3	16	7.8	130	49.2
L. noctivagans	8	9.3	14	7.1	9	7.0	10	5.0	8	3.9	16	6.1
L. borealis	27	31.4	72	36.4	41	31.8	77	38.7	81	39.5	70	26.5
N. humeralis	15	17.4	46	23.2	22	17.1	0	0.0	59	28.8	14	5.3
L. cinereus	4	4.7	22	11.1	10	7.8	1	0.5	2	1.0	10	3.8
P. subflavus	1	1.2	13	6.6	5	3.9	0	0.0	19	9.3	5	1.9
M. lucifugus	7	8.1	4	2.0	1	0.8	0	0.0	9	4.4	5	1.9
M. septentrionalis	1	1.2	1	0.5	4	3.1	3	1.5	11	5.4	14	5.3
Total	**86**		**198**		**129**		**199**		**205**		**264**	
Species Diversity		**1.692**		**1.689**		**1.68**		**0.986**		**1.611**		**1.456**

Table 16: Total number of calls for each bat species for each study year of the study at Secor Metropark. Percentages represent percentage of that year's totals. Species diversity is listed under totals using Shannon-Weiner index

	2017		**2016**		**2015**		**2013**		**2012**		**2011**	
Secor	Calls	%	Calls	%	Calls	%	Calls	%	Calls	%	Calls	%
E. fuscus	88	71.5	77	53.1	146	73.0	63	88.7	9	20.0	300	75.6
L. noctivagans	14	11.4	28	19.3	23	11.5	0	0.0	6	13.3	3	0.8
L. borealis	14	11.4	17	11.7	2	1.0	5	7.0	13	28.9	27	6.8
N. humeralis	5	4.1	10	6.9	12	6.0	0	0.0	8	17.8	2	0.5
L. cinereus	0	0.0	12	8.3	14	7.0	3	4.2	0	0.0	10	2.5
P. subflavus	1	0.8	0	0.0	1	0.5	0	0.0	2	4.4	16	4.0
M. lucifugus	1	0.8	0	0.0	1	0.5	0	0.0	4	8.9	29	7.3
M. septentrionalis	0	0.0	1	0.7	1	0.5	0	0.0	3	6.7	10	2.5
Total	**123**		**145**		**200**		**71**		**45**		**397**	
Species Diversity		**0.934**		**1.33**		**0.959**		**0.427**		**1.79**		**0.964**

Table 17: Total number of calls for each bat species for each study year of the study at Oak Openings Preserve. Percentages represent percentage of that year's totals. Species diversity is listed under totals using Shannon-Weiner index

	2017		**2016**		**2015**		**2013**		**2012**		**2011**	
Oak Openings	Calls	%	Calls	%	Calls	%	Calls	%	Calls	%	Calls	%
E. fuscus	204	81.9	125	51.9	176	65.2	373	82.0	6	10.2	340	88.8
L. noctivagans	25	10.0	34	14.1	36	13.3	12	2.6	0	0.0	6	1.6
L. borealis	7	2.8	42	17.4	23	8.5	58	12.7	17	28.8	15	3.9
N. humeralis	8	3.2	22	9.1	15	5.6	2	0.4	16	27.1	0	0.0
L. cinereus	0	0.0	10	4.1	6	2.2	1	0.2	1	1.7	5	1.3
P. subflavus	1	0.4	0	0.0	11	4.1	1	0.2	5	8.5	4	1.0
M. lucifugus	1	0.4	8	3.3	0	0.0	1	0.2	5	8.5	7	1.8
M. septentrionalis	3	1.2	0	0.0	3	1.1	7	1.5	9	15.3	6	1.6
Total	**249**		**241**		**270**		**455**		**59**		**383**	
Species Diversity		**0.703**		**1.385**		**1.183**		**0.671**		**1.719**		**0.54**

References

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CHAPTER IV. SUMMARY, MANAGEMENT IMPLICATIONS, AND FUTURE DIRECTIONS

It is critical to understand the effects of human activity on the distribution, activity, and diversity of native bats due to the important roles bats play in ecosystems. Along with the inherent value in protecting biodiversity, bats provide many ecological services such as pollination, nutrient cycling and pest control. These studies examined how bats are using their landscapes, particularly those that are primarily dominated by human land use. By understanding how bats are using the landscape, we can better manage landscapes to buffer bat species against both existing and developing threats.

These studies found that bats can and will adapt to human dominated landscapes, provided the conditions are right. Our first study showed that native bats will actively forage in human dominated landscapes. This forging, however, becomes limited when we start to lose structural diversity. Characteristics such as distance to tree stands, canopy cover, vegetation height, and vegetation density all help create structural diversity which promotes bat activity and diversity. In our second study, we found that in a natural area structural diversity still remains key, as forest habitats had the highest activity. However, bats will forage in lower diversity areas, be it open savannas or edges sites. This foraging was not limited by human pressures on those edge sites. Finally, in our third study, we found that some local bat species are declining over time, but that local preserves can be important refuges for species diversity.

We can make some management recommendations based on our findings from these studies. The most obvious is that forest habitat is critical for these bats and must be preserved for them to flourish. However, even in natural preserves, habitat heterogeneity is important.

Having both diversity in habitat types and structural diversity within that habitat will promote bat activity and diversity. This structural diversity is also key in human dominated landscapes. Therefore, land managers should keep this in mind. Small farms can benefit greatly by leaving tree stands or incorporating patches of vegetation. By increasing and protecting natural structures such as tree stands and vegetation, human dominated landscapes can become active foraging grounds for native bat species. This can be very beneficial to those using these lands.

There are a few areas that were not addressed or that we did not have time to address. The first, and most obvious, is the fact that we did not include insect prey as a variable during this study. This was excluded for a number of reasons. One reason was simply due to lack of time and resources to conduct an accurate survey of insects. With all eight bat species in our study being generalist insectivorous hunters (Tuttle, 1988; Gehrt and Chelsvig, 2004; Henderson and Broders, 2008; Kniowski and Gehrt, 2014; Kurta, 1995) it is difficult to devise a proper sampling technique to adequately sample the breadth of prey. Furthermore, the techniques that seem to be most accurate for identifying local diets of bat species are genetic (Maslo at al., 2017) or molecular analyses (Claire et al., 2009) of guano. Research that focused on these aspects would undoubtedly yield useful information, but as stated was beyond the scope of these studies and has proven challenging for other researchers as well due to insect sampling techniques (Leskey et al., 2012; Rice et al., 2014; Welch et al., 2016).

MaxEnt models are an extremely useful tool for making biological models and predictions, and the implications from it are very useful for making management decisions. Based on previous studies (Sewald, 2014; Nordal, 2016), presence data recorded through these three studies would be ideal for creating MaxEnt habitat suitability models. While the data from any of the studies would work for the four most common species (*E. fuscus, L. noctivagans, L. borealis,* and *N. humeralis*), the data for other four species (*L. cinereus, P. subflavus, M. lucifugus,* and *M. septentrionalis*) would likely need to be combined across all three studies to obtain a large enough sample (Merow et al., 2013). With the information gathered from these studies, models are likely to be created using these data in the near future. We gathered enough information, and informal models have already been tested, but we ran out of time to add them.

Another analysis that would be useful would be detailed edge analysis of the edge habitats in Chapter II. Using a program such as Fragstats could offer more data on how these sites are unique from one another and help detail the exact habitats that these bats prefer for foraging. With another field season, we could have further expanded our landscape measurements to include things such as tree densities, vegetation type, soil type, and others that were not taken into account by these studies. A more fine scale analysis could lead to more significant results, particularly in Chapter II.

Finally, it will be important to continue our long-term data set from Chapter III in order to observe trends in bat populations over time. We must carefully monitor these to understand not only which species and populations are declining, but also to see if there are any that are filling the niches left behind by those disappearing species. It is my hope that these studies will continue for years to come to increase our knowledge of these fluctuating populations. While we know there are some species that are declining, we may see species that are unaffected by WNS, such as *L. borealis,* begin to fill in the niches opened by declining species. We also may see the remnants of the populations that are affected by WNS recover with proper management. The best way to do so is by continuing these studies. We also have six sites from Chapter II that have been surveyed nearly every year, so using that as a long term data set may also yield some interesting results.

While bats do face serious threats and significant population declines, we have found that these animals are able to adapt if given the right conditions. Studies have suggested that even for those bats under the most serious threats, such as *M. septentrionalis* and *M. lucifugus* (Frick et al., 2010), recovery can still be possible (Maslo and Fefferman, 2015). The best way to aid these species is by ensuring that there is preferential habitat for these bats. We have identified certain features that will increase bat activity, diversity, and distribution of species. We have also seen that these features help in both natural and human dominated landscapes. Therefore, with the right tools and the right knowledge, we can make sure that these bats continue to provide us with their valuable ecosystem services.

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APPENDIX A. INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE AGREEMENT

1/17/2017 RE: IACUC Approval - Tyler N Turner

RE: IACUC Approval

Office of Research Compliance

Wed 1/11/2017 9:07 AM

To: Tyler N Turner <tylernt@bgsu.edu>;

Hi Tyler,
If you're just recording with the Anabat Acoustic Detectors, you do not need IACUC approval.
Thank you for asking.

Hillary

BGSU.

Hillary Snyder, Ph.D.
Research Compliance Officer
Office of Research Compliance
Bowling Green State University
280 Hayes Hall
Bowling Green, OH 43403
Office: 419-372-7722