A SPATIAL AND TEMPORAL ANALYSIS OF BAT ACTIVITY AND DIVERSITY WITHIN A HEAVILY FRAGMENTED LANDSCAPE

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ABSTRACT

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The Oak Openings Region of Northwest Ohio of Northwest Ohio is an incredibly biodiverse area that is home to many rare and endangered plant and animal species. Furthering our knowledge and understanding on the resident bat species within the region is critical as populations of many species have declined from White-nose Syndrome, habitat loss and fragmentation, and wind energy barotrauma. To further bat-specific research in the region, my thesis research focused on: 1) identifying the relationships between bat activity and diversity and fragmentation features; 2) monitoring trends in activity and richness between forested and savanna sites over time; and 3) developing refined spatially explicit habitat models of bat occupancy using data collected from protected and unprotected habitat and comparing them to models created from strictly protected habitat.

Ecological knowledge on bats and their response to features commonly associated with habitat fragmentation is lacking, so I acoustically surveyed thirty roads with Anabat SDII monitors within and outside of protected areas. I utilized logistic regression analysis to examine the relationship between presence/absence and activity of each species with each feature (*e.g.* proportion of road with overstory) to select candidate variables for multivariate models. I then created candidate multivariate models for each species and selected final models based on parsimony, AIC values, and adjusted R square values. Bats had a differential response to features between species, and park managers must consider the management of roads on a species-specific viewpoint if they plan to focus conservation efforts on bats.

For the second part of my research, I surveyed bat relative activity within forest and savanna sites and compared the data to previous monitoring efforts. Within the single year I monitored, savanna sites appeared to host a greater activity for many species and a greater species richness. Between years, savanna sites remained predominantly stable in species composition and activity, but forested sites had declines in activity among certain species and declines in species richness. Results demonstrate a need for further investigation of forest habitat and additional comparisons between savannas and other open habitat to determine their role for bats in the region.

For the third part, I developed Maxent species distribution models for seven species of bats that occur in the region and compared them to existing models. I tested previously developed occupancy models' predictive power using new data. Once data were demonstrated to be comparable through model performance, I created new models from a combination of previous (prior to White-nose) and new data (post White-nose). I then tested previous and new models with an independent dataset and compared their performances and areas of predicted presence for each species. The addition of new data refined previous models and offered a species-specific view on the importance of prominent landscape characteristics for probability of presence. The results of this thesis research contribute to our knowledge of bats within the Oak Openings Region and provide tools for adaptive management in fragmented landscapes. This work is dedicated first and foremost to my parents, who have always supported me, and to my friends, both old, new and those to be made, who make every day an exciting adventure to look forward to.

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GENERAL INTRODUCTION

The Oak Openings Region of Northwest Ohio of Northwest Ohio is an incredibly biodiverse area that is home to many rare and endangered plant and animal species. Furthering our knowledge and understanding on the resident bat species within the region is critical as populations of many species have declined from White-nose Syndrome, habitat loss and fragmentation, and wind energy barotrauma. This thesis had three different objectives that are each written as stand-alone chapters. The first chapter's objective was to identify key features of habitat fragmentation and relate them to data on bat species presence, activity and diversity obtained from driving transects. Driving transects have become a more common technique for monitoring bats because of the large area that can be covered, and understanding how features associated with fragmentation by roads is important for bat species that are sensitive to habitat fragmentation. This chapter is formatted for publication in *The American Midland Naturalist*.

The second chapter focused on comparing trends in bat activity and diversity across different savanna and forest habitat types and across time. Acoustic data from stationary listening points were utilized that captured the relative activity and diversity of bats both before and after the establishment of White-nose syndrome in the region. Consistent monitoring for bat species is important when considering the multitude of threats they face from disease and habitat destruction and degradation. This chapter is formatted for submission to *The American Midland Naturalist*.

The third chapter utilized new data to refine previously developed species distribution models created for seven native bat species within the Oak Openings Region. These Maxent models examined the spatial distribution of seven of the eight species in 2009 versus 2015 and utilized both road transect acoustic survey data as well as stationary point sampling data. Comparisons in model performance, area predicted, and variable importance are highlighted, and inclusive models suggest that roads may be utilized by open-adapted species as potential foraging habitat. This chapter is formatted for submission to *Natural Areas*.

CHAPTER I: FORAGING BATS HAVE A DIFFERENTIAL RESPONSE TO FRAGMENTATION FEATURES

ABSTRACT

Protected areas in northwestern Ohio provide summer foraging habitat to eight bat species within a mixed disturbance matrix composed primarily of intensive agriculture and urban development. Many of these species face threats such as White-Nose Syndrome and habitat loss, and continuous monitoring efforts are required for effective management. We utilized acoustic monitoring along driving transects to monitor 30 km of roads to determine the effects of this common form of habitat fragmentation on the presence, relative activity, and diversity of bat species. We successfully detected all eight species and used logistic regression models to examine the potential effects of common roadside features including amount of overstory, presence of telephone poles, and the degree of roadside slope on all three responses. Model results varied among species, suggesting a differential response to these features, including a positive relationship between road width and silver-haired (Lasionycteris noctivagans) bat presence and a negative relationship between road width and evening (Nycticeiuss humeralisi) bat presence. We conclude that driving transects in this region may thereby offer an effective monitoring strategy for managers in charge of a variety of taxa, but supplementation with interior forest habitat monitoring may reduce chances of bias towards detecting edge-specialist species near roads.

INTRODUCTION

Habitat fragmentation is the process by which a large area of natural habitat becomes broken into smaller patches. These smaller patches are often insufficient to maintain large population sizes and affect dispersal, which ultimately affects extinction rates (Wilcove et al 1986). Fragmentation can occur naturally through disturbance processes such as fire or from natural openings, yet anthropogenic habitat fragmentation is ultimately a larger concern among conservation biologists because of the large scales at which it occurs (Wade et al, 2003). Anthropogenic habitat fragmentation can occur through many processes including logging, land conversion, and roadways (Wilcove et al, 1986; Wade et al, 2003). The increase in edge habitat created by fragmentation may also influence the distribution, diversity, and abundance of species across multiple taxa, including highly mobile species such as bats. Ether and Fahrig (2011) found effects of fragmentation and patch size on the relative activity of multiple bat species, indicating differential species response and potential for managing fragmentation to support a higher activity and diversity of bat species.

While all forms of fragmentation are under investigation, habitat fragmentation by roads has become a prominent issue in recent years. Estimates claim that 83% of land in the continental United States is approximately 1 km away from a road and 3% is approximately 5 km away from a road (Riiters and Wickham, 2003). Roads fragment many protected areas (Ramp et al, 2006), and there is increasing interest in how this specific form of fragmentation impacts a landscape. These impacts include alterations to the landscape's hydrology and water quality, erosion and sedimentation mechanics, concentration of chemical and noise pollutants, and an increase in linear edge habitat (Coffin, 2007). Wildlife studies aimed at these effects have determined that roads impact populations and communities by causing direct mortality, changing abiotic components of natural ecosystems, acting as barriers to movement, and providing corridors for movement for highly mobile, invasive, generalist, or disturbance-adapted species (Coffin, 2007; Donaldson & Bennet, 2004). While the vast majority of research studies the impacts of roads on remnant natural ecosystems (Geneletti, 2003; Haskell, 2000; Lee, 2012), there are several studies where the roads are studied themselves as potential habitat (Getz et al., 1978; Oxley et al., 1974; Brock and Kelt, 2004; Vermeulen, 1994). Roads can create heterogeneity in an ecosystem by changing hydrology (Jones et al., 2000; Forman and Alexander, 1998), providing niche resources (Lelievre et al, 2010), offering remnant habitat in a disturbed landscape (Getz et al., 1978; Oxley et al., 1974; Brock and Kelt, 2004; Vermeulen, 1994) and creating gaps in forest canopy. While forest canopy gaps are naturally occurring and provide an important source of heterogeneity for early succession species and ecotone specialists (Turner et al, 2001), forest fragmentation created by roads is ecologically unique because of its linear shape and ability to act as an efficient corridor system for humans and many wildlife species (Coffin, 2007). Road fragmentation also provides unique anthropogenic structures such as telephone poles, fences, and streetlights that may influence dispersal and foraging behavior (Hickey et al., 1996; Acharya and Fenton, 1999; Rydell, 2006).

Bats, an economically important species in agricultural pest control (Cleveland et al, 2006; Boyles et al, 2011; Kaika et al, 2008), may use the openings created by roads in forested habitat (Coffin, 2007; Grindal and Brigham, 1998), as forest clearings potentially act as cues for foraging bats that navigate above the canopy (Grindal and Brigham, 1999; Patriquin and Barclay, 2003). Many bat species in the Midwestern United States forage in forest clearings, gaps, and

edges (Lacki et al., 2007; Patriquin and Barclay, 2003), although differences in morphology between species may lead to differences in response to anthropogenic forest clearings.

Understanding these responses is critical for management of parks and reserves, which act as refugia for bats in urban and agriculture-dominated landscapes (Avila-Flores and Fenton, 2005; Jung and Kalko, 2011; Glendell and Vaughn, 2002; Duchamp and Swihart, 2008). Parks provide bats with roosting and foraging habitat (Mager and Nelson, 2001; Kurta and Termino, 2006), and most species depend on forested areas to meet both needs (Mager and Nelson, 2001; Broders and Forbes, 2004; Willis and Brigham, 2005). Sewald and Root (2012) successfully detected eight species within 1722 ha of protected area within the Oak Openings region, which is an agriculture and urban matrix with remnants of its historic heterogeneous habitat. Species ranged from the Northern long-eared bat (*Myotis septentrionalis*), a small bat that specializes in gleaning insects from surfaces and prefers intact forest interiors (Patriquin and Barclay, 2003) to the Hoary bat (*Lasiurus cinereus*), a larger species that flies low in open areas (Barclay, 1985). With a high diversity of bat species, management must find ways to effectively monitor resident species.

Driving transects have become a common monitoring tool in bat conservation when combined with acoustic technology (Loeb et al., 2015). Acoustic driving transects allow conservation biologists to cover large areas in fragmented landscapes, although biases in species detection do occur and are beginning to be addressed (Loeb et al., 2015). Despite the continued application of driving transects to monitor bat species, no studies exist on how common roadside features in habitat fragmented by roads influence the presence and absence of bat species that utilize roadways. Our study sought to determine what influence roadside characteristics and habitat has on the relative activity and diversity of bat species in a landscape heavily fragmented by roads within and outside of protected areas.

STUDY SITE

The Oak Openings Region is a 476 km² area in Northwestern Ohio characterized by large sand deposits left from past glaciation events and a heterogenic habitat composition (Brewer and Vankat, 2006). Among the various habitat types is the critically endangered oak savanna, reduced to a small fraction of its original distribution by urbanization and fire suppression (Brewer and Vankat, 2006). What little of the natural habitat remains still hosts an enormous amount of biodiversity, as Brewer and Vankat's (2006) surveys revealed at least 218 different plant species, with 24 of them state listed. The Oaks Opening Region's high biodiversity and habitat heterogeneity makes it an ideal study area for landscape ecology, and fragmentation from surrounding agriculture and urban use (Brewer and Vankat, 2006) provide areas to study anthropogenic effects on the natural landscape. Sewald and Root (2012) found eight species of bats within the region, including big brown (*Epesicus fuscus*, EPFU), silver-haired (*Lasionycteris noctivagans*, LANO), Eastern red (*Lasiurus borealis*, LABO), hoary (*Lasiurus cinereus*, LACI), evening (*Nycticeius humeralis*, NYHU), tri-colored (*Perimyotis subflavus*, PESU), little brown (*Myotis lucifugus*, MYLU), and Northern long–eared (*Myotis septentrionalis*, MYSE).

METHODS

Road Surveys

We monitored 30 roads from June 21st to August 22nd, 2015 three to four times each throughout the Oak Openings Region using a frequency division broadband acoustic recorder (Anabat SDII,

Titley Electronic, Ballina, New South Wales, Australia). We selected 15 roads within protected area boundaries of The Nature Conservancy's Kitty Todd Nature Reserve and Metroparks Toledo's Oak Openings Preserve and 15 roads outside park boundaries throughout the region. We classified roads inside or touching the park boundary as inside the park, and roads without contact of official park boundaries as outside park boundaries. We created 29 1-km transects and one 2-km transect by generating random starting and ending points in ArcGIS. All starting and ending points were located at least one hundred meters from each other, well outside of the 30 m radius Anabat SD2 detection range (Livengood, 2003). All transects chosen were within 500 meters of forest habitat, as all species rely on forest habitat to some degree. We monitored 1-km transects over a period of 20 minutes and monitored the 2-km transect over a period of 40 minutes.

We followed well-established methods (Brooks and Ford 2005, Johnson and Gates 2008, Brooks 2009, Francl et al. 2004, Francl 2008, Ford et al. 2006, Ford et al. 2005) for acoustic monitoring with the Anabat acoustic recorder. We began monitoring approximately 30 minutes after sunset and ended 3 hours after, covering the period of night when activity among bat species is most similar (Hayes, 1997). We did not sample during nights with rain or strong wind (>3 on Beaufort scale), as bats forage less during these conditions (Barclay, 1985; Voigt et al, 2011). We sampled transects to maximize the number of transects sampled in a single night by randomly selecting a transect to start and monitoring subsequent transects based on proximity to the last transect sampled.

We analyzed all call files with three or more calls and identified each to species (by the primary author) both qualitatively (via Analook version 4.1) and quantitatively (BCID version

2.7c). When a discrepancy on file identification between the two methods occurred, the file was qualitatively inspected again and identified by the primary author. The average number of calls for each transect (relative activity) for each species was then calculated for further analysis as well as the average total activity for each transect.

Roadside Variables

We recorded roadside characteristics at five points on each 1-km transect and at nine points on the 2-km transect. Two of the five or nine points marked the beginning and end of each transect. The remaining three points for the 1-km transects and six points for the 2-km transect were spaced along intervals 250 m apart. We recorded the occurrence of roadside habitat structure within a 100 m radius where points were located on the transect (defined as the center of the pavement). We classified mature coniferous and deciduous trees as overstory, saplings, hedges, and scrub as understory, and grasses, weeds, and other basal vegetation as herbaceous groundcover. If branches from mature trees were detected over the pavement of the road edges, we also scored the occurrence of shading canopy cover, as management and weather would change exact percentages through the sampling timeframe. We also recorded occurrence of anthropogenic habitat structures within each 100 m radius and classified corn and soy fields as agriculture and all buildings as residential. We then recorded the occurrence of roadside features within each 100 m radius, which included fences, telephone poles, and drainage ditches. When ditches were detected, we also recorded distance from the edge of the pavement (m), depth of the bottommost part of the ditch relative to the road (m), and width of the ditch from edge to edge (defined as when slope decreased relative to the surrounding landscape). We then scored the total number of occurrences of each habitat structure and roadside feature for each transect. We

divided the total number of occurrences within each transect by the number of points within each transect to create a value representing a proportion of the transect where each habitat structure and roadside feature was detected.

We also recorded features that remained consistent throughout each transect such as speed limit and road width (m). Speed limits were obtained from traffic signs and were then categorized as low (35 miles per hour and slower), medium (45 or 50 miles per hour), and high (55 miles per hour or faster) for further analysis. Road width was determined by using a measuring distance wheel and traveling perpendicular from the paved edge of the road until the wheel reached the other paved edge. Road width ranged from 5.2 m- 10.0 m and all roads were single lane for each direction of traffic.

Nightly Variation

We recorded temperature (degrees C) and humidity (relative percent humidity) at the start of each transect using a Brunson ADC-Pro weather station and took note of any major disturbance during each transect (*e.g.* train passing, plane flying close overhead, police interruption, etc.). We collected fastest 2 minute wind speed data from the National Climatic Data Center and moon phase data from a lunar calendar for each night. We extracted the precise duration and time of night of each transect from data within active recording sessions logged by the Anabat.

Protected and Unprotected Variation

We utilized Wilcoxon signed-rank tests to determine differences in environmental features between transects. We classified transects as protected if they were within or touching park boundaries, and as unprotected if they were outside of park boundaries.

Model Development

We used Spearman's rank correlation coefficient in JMP (version 11; SAS) for a nonparametric measure of statistical dependence among all roadside variables, and those that were correlated r>0.6, P<0.05 were assessed. We used this approach to identify a set of candidate variables that would explain variation in bat species presence and activity and would remain consistent in future field seasons. Canopy cover providing shade over the road and overstory were highly correlated (Spearman P= 0.8037); we chose to use overstory in models as canopy cover would be dependent on the presence of overstory along the roadside. Understory and herbaceous cover were highly correlated with agriculture (Spearman P=-0.6411 and P=-0.6161, respectfully), and we chose to use agriculture because of the prominence of the habitat type throughout the Oak Openings region. Presence of telephone poles and residential features were highly correlated (Spearman P= 0.6939); telephone poles were chosen as all residential areas had telephone poles, but telephone poles were found in areas without residential structures. Temperature and humidity (Spearman P=-0.6608) were also correlated and temperature was chosen.

To further refine the set of candidate variables to consider in each multivariate regression model, we built univariate logistic regression models for presence and activity (i.e., average number of calls) with each species' presence or relative activity as the response variable and each roadside variable as a predictor variable. We also created univariate logistic regression models with the species richness and average total activity of each transect as the response variable and each roadside variable as a predictor variable. We selected candidate variables by selecting the model for each species' presence and activity, total activity, and richness with the lowest Aikaike Information Criterion (AICc) value and including all models with an AICc value ≤ 3 into the multivariate model selection process.

We then developed multiple multivariate logistic regression models for species presence and activity, richness, and total activity for each species with more than 10 call files. Northern long ear bats were excluded in both analyses since we only captured three of their calls. We built models with the presence, total and species-specific activity, or species richness as the response variable and various combinations of roadside features as predictor variables. We selected final models for parsimony by removing variables that contributed <0.01 to the multivariate model's adjusted RSquare value (RSquare(U)). If univariate selection by AIC value resulted in a single explanatory variable, then the multivariate model consisted of the single explanatory variable.

RESULTS

Species Detected

Over the summer of 2015, we recorded a total of 972 identifiable call files through road transect surveys. We detected big brown (EPFU) (396 files), silver-haired (LANO) (208 files), hoary (LACI) (149 files), Eastern red (LABO) (130 files), evening (NYHU) (51 files), tri-colored (PESU) (19 files), little brown (MYLU) (16 files), and Northern long-eared (MYSE) (3 files); and all species were found within and outside of protected areas. Previous research and management in the region had confirmed the presence of all species recorded (Sewald, 2012; Karen Menard, pers. comm.).

Protected Versus Unprotected Transects

We detected significant differences in the environmental features between protected and unprotected transects. The Wilcoxon signed-rank test revealed that protected transects had a higher proportions containing overstory (p < 0.0001), drainage ditches (p = 0.0334), and negative slopes (p = 0.0023), whereas unprotected transects had higher proportions of agriculture (p = 0.0002), telephone poles (p < 0.0001), and positive slopes (p = 0.0151). Unprotected transects also had wider road width's on average (p = 0.0435) and higher temperatures during monitoring (p = 0.0204) than protected transects.

Logistic Regression Models

We found overstory and agriculture to have the highest frequencies of candidate model selection (Tables 1 & 2; Figure 1). Overstory was significantly positively related to the presence of LABO, NYHU, and MYLU and negatively related to the relative activity of EPFU, LANO, MYLU, and LABO as well as the total activity. Overstory also had a significant negative relationship with species richness and was included in multivariate models for LANO, LABO, and MYLU presence and activity and NYHU presence (Tables 3 & 4). Agriculture had a significant negative relationship with EPFU, LABO, and NYHU presence and a positive relationship with EPFU, LABO, and total relative activity. Agriculture also had a positive significant relationship with species richness, and was included into the model selection process for LANO presence. We included agriculture into final multivariate models for EPFU, LABO, and total relative activity and total relative activity and a negative model selection process for LANO presence. We included agriculture into final multivariate models for EPFU, LABO, and total relative activity and have a significant models for EPFU, LABO, and EPFU presence.

Our univariate analysis for candidate variables also revealed a negative relationship between telephone poles and LACI and MYLU presence, and a positive relationship with species richness and the relative activity for EPFU, LANO, and PESU. The relationship between proportion of the road with telephone poles and LACI and MYLU presence and LANO activity was not significant, but was significant in all other mentioned relationships. Roadside slope, when negative, made initial univariate selection for PESU presence and activity and EPFU presence. The relationship between a negative slope and the presence of EPFU, NYHU, and PESU was negative whereas the relationship between a negative slope and the relative activity of PESU was positive. We included negative slope in multivariate models for EPFU and PESU presence and PESU activity. Road width passed model selection for LANO, NYHU, and MYLU presence, where its relationship with NYHU and MYLU was negative and LANO was positive. Road width was also the only feature to pass model selection for NYHU activity, where the relationship was positive. We included road width in multivariate models for LANO presence and NYHU presence and activity. None of the nightly variables recorded (temperature, wind speed, and moon phase), passed model selection by AIC value.

The Chi-square test on species presence, activity, and richness with categorical variables (speed limit for all, month for presence models only) revealed significant effects of traffic on EPFU and NYHU presence and month on LACI presence. NYHU and EPFU presence detection was significantly higher in low traffic areas than middle and high traffic areas (EPFU p= 0.0401; NYHU p= 0.0286), and traffic was included in best multivariate models for EPFU and NYHU presence. Hoary bats had significantly more detections in July than other months (p= 0.0191). We successfully created significant final multivariate presence and activity models for all species except the hoary bat, which had a significant multivariate presence model but not for activity.

DISCUSSION

We successfully detected all eight bat species both within and outside of protected areas during our driving transect surveys. Only three call files were identified as Northern long-ear, a species recently listed as Threatened under the Endangered Species Act (USFWS). However, Northern long-ear bats prefer forest interior habitat (Carter & Feldhamer, 2005; Broders et al, 2006) and low detection rates of the species may be an artifact of sampling forest edges rather than low relative activity in the region. A combination of monitoring techniques is likely to produce optimal detection rates for areas with high species richness, as driving transects offer an efficient method of monitoring forest edges and capturing edge specialists, while fixed location monitoring may allow detection of forest interior specialists (Loeb et al., 2015). Our analysis of environmental variation between protected areas differed. Protected transects had, on average, more proportion containing agriculture, telephone poles, positive slope, and during monitoring were hotter on average.

Our logistic regression models revealed differential responses between bat species to various roadside features, and thus differential species responses to habitat fragmentation. Proportion of the road containing overstory was positively related to Eastern red, evening, silverhaired, and little brown presence, all of which roost or forage among forest edges (Patriquin and Barclay, 2003; Menzel et al. 2001, Mager & Nelson, 2001) and contributed to the best multivariate models for these species. Road width was significant for silver-haired and evening models, although response was positive for silver-haired and negative for evening. This difference could potentially indicate a slight preference in silver-haired bats for larger foraging space near forest edges (Barclay, 1986) or avoidance by evening bats for open areas lacking vegetation (Duchamp et al, 2004). Topography of the landscape appears to play a role in the foraging behavior of bats, as slope had an influence in many of our multivariate models, although the relationship was dependent on species and whether slope was positive or negative. Slope near roadways alters the direction of water runoff and drainage in forests (Toman, 2004; Gilbert, E.H., 2004), which can thereby affect vegetation (Forman and Alexander, 1998) and insect abundance and diversity (Noordijk et al, 2009; Samways et al, 1997; Carchola and Dunn, 1999) and influence foraging behavior of bat species (Rydell, 1992; Blake, 1994; Rydell, 2006).

Our models should be interpreted modestly, as results could be an effect of scale, but they do provide insight into some of the local features of roads that may influence bat activity, diversity and presence. Bats are highly vagile species and successful modeling attempts by other studies have been done at larger scales (Ethier and Fahrig, 2001; Milne and Pavey, 2005; Grindal et al., 1999; Gehrt and Chelsvig, 2004). Our transects may also not have been an accurate representation of all roads, as none of the thirty transects contained street lamps, which attract insects and foraging by bat species (Hickey et al, 1996; Blake et al, 1994). Large agricultural drainage ditches are also another potential source of insect prey and water for many wildlife species (Williams et al, 2004). Only three of our transects were located by these large ditches, and future studies could select transects in proximity to agricultural drainage ditches to determine if these anthropogenic structures could result in higher bat activity.

Our results also suggest there are other factors operating at larger scales. Other variables included in larger scale models include amount of fragmentation (Either and Fahrig, 2011; Milne

and Pavey, 2005), patch isolation (Swystun et al, 2001), distance to water (Grindal et al., 1999) and distance to anthropogenic habitat types such as agricultural fields and residential areas (Gehrt and Chelsvig, 2004). Many of these variables have been used in species presence models for the bat species detected in the Oak Openings Region (Sewald and Root, 2012). These models performed well with training data and included large-scale variables such as distance to agriculture, percent of the area with savanna, and distance to water. Longer transects could allow for larger scale modeling that would provide data required for species distribution modeling well outside of reserves and may highlight continuous features along areas of fragmentation that are actively being used by many bat species. Management decisions must consider what species should receive priority in areas with high species richness. Our results demonstrate a modest, but differential response of bat species to various roadside features and demonstrate the effectiveness of road monitoring for bats.

MANAGEMENT IMPLICATIONS

Based on our results, we recommend continued surveys within the Oak Openings Region to assess the influence of fragmentation on bat species of concern. We recommend a mixture of sampling techniques, as road transects are efficient at covering large areas but have low detection rates of forest interior specialists, such as the Northern long-eared bat. Continued maintenance of a heterogeneous landscape is important to maintain a rich suite of bat species, and utilization of a variety of monitoring techniques will be needed to monitor species that vary with foraging strategies. Management can alter roadside maintenance to promote presence of species of concern, such as little brown bats, which forage along forest edges (Patriquin and Barclay, 2003). Road verge management can influence the abundance of insects that forage within the vegetation (Habritter et al, 2015), and indirectly affect foraging bats. Promoting presence for concerned species may, however, create an ecological trap, as low-flying bat species are often struck by traffic (Russel et al, 2009). Structures that deter species presence may be an alternative form of conserving populations that reside by natural edges or within the forest interior. We also recommend complete overnight surveys to capture the time frame that bats may be using the roads to better understand fluctuations of bat activity in relation to specific fragmentation characteristics.

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Table 1: Shown are candidate univariate logistic regression models where each species' presence/absence is the response variable and each environmental feature as the predictor variable. We selected candidate models by selecting the model with the lowest AIC value and including all models with AIC values \leq 3 of the lowest AIC model. Coefficient estimates for each variable \pm the standard error are given, and p values are included for each model.

Presence/ Absence (Univariate)							
	Big Brown	Silver-Haired	Hoary	Eastern Red	Evening	Tri-Color	Little Brown
Overstory	/	1.56 ± 0.90 p= 0.083	/	$2.63 \pm 1.02;$ p= 0.0055	$3.70 \pm 1.40;$ p= 0.0029	/	$3.08 \pm 1.68;$ p= 0.0435
Agriculture	$-2.95 \pm 1.09;$ p=0.0062	-1.70 ± 1.08 p= 0.117	/	$-3.17 \pm 1.47;$ p=0.0102	$-7.54 \pm 4.45;$ p= 0.0045	/	/
Ditched	/	/	/	/	/	/	2.32 ± 1.70 p= 0.187
Negative Slope	-2.14 ±0.95; p= 0.020	/	/	/	$-2.54 \pm 1.04;$ p=0.0089	$-0.54 \pm 2.45;$ p= 0.04	/
Telephone Poles	/	/	-1.07 ± 0.63 p= 0.0882	/	/	/	-1.19 ± 0.92 p= 0.192
Fences	/	/	/	/	$-11.77 \pm 6.92;$ p= 0.0345	/	/
Road Width	/	$0.35 \pm 0.16;$ p= 0.0244	/	/	'-0.70 ± 0.26; p=0.0016	/	-0.26 ± 0.25 p= 0.280
Moon Phase	/	/	0.006 ± 0.006 p= 0.281	/	/	/	/
Date (continuous)	/	/	/	2.88e-7 ± 1.32e-7 p= 0.0291	/	/	/

Table 2: Shown are candidate univariate logistic regression models where each species' relative activity, total relative activity, or species richness is the response variable and each environmental feature as the predictor variable. We selected candidate models by selecting the model with the lowest AIC value and including all models with AIC values ≤ 3 of the lowest AIC model into multivariate analysis. Coefficient estimates for each variable \pm the standard error are given, and p values are included for each model

Activity (Univariate)									
	Big Brown	Silver-hair	Hoary	Eastern Red	Evening	Tri-color	Little Brown	Total Species	Total Activity
Overstory	-5.94± 1.68; p=0.0002	$-3.23 \pm$ 1.50; p= 0.032		-3.94 ± 1.55; p=0.01			-4.62 ± 2.39 p= 0.027	-3.95 ± 1.59 p= 0.012	
Agriculture	6.81 ± 2.14 p= 0.0006			4.74 ± 1.98 p=0 .0083				7.08 ± 2.118 p= 0.0005	6.82 ± 2.09; p= 0.0007
Negative Slope						7.89 ± 3.12 p= 0.0005			
Positive Slope									
Telephone Poles	3.90 ± 1.20 p= 0.0006	1.69 ± 1.06 p= 0.118				3.02 ± 1.48 p=0.023		3.35 ± 1.16 p= 0.0015	
Road Width					0.95 ± 0.34 p= 0.0057				

Table 3: Multivariate logistic regression models with species presence as the response variable and a combination of roadside characteristics as the predictor variables. Lead numbers indicate the coefficient for each variable and second numbers indicate the standard error of the coefficient. P values are included for each model based on the Chi-square test and is indicated at the bottom of each cell.

Presence/ Absence (Multivariate)							
	Big Brown	Silver-haired	Hoary	Eastern Red	Evening	Tri-color	Little Brown
Overstory		$4.19 \pm 1.22;$ p=0.0008		$2.80 \pm 1.04;$ p=0.0074	$2.52 \pm 1.48;$ p=0.0898		$3.08 \pm 1.68;$ p= 0.0435
Agriculture	-2.19 ± 1.19; p=0.0643						
Negative Slope	-1.56 ± 1.09; p=0.1501					$-0.54 \pm 2.45;$ p= 0.04	
Telephone Poles			-1.38 ± 0.69 p= 0.0442				
Road Width		$0.77 \pm 0.22;$ p= 0.0004			$-0.47 \pm 0.31;$ p= 0.1286		
Date (continuous)				3.16e-7 ± 1.37e-7 p= 0.0210			
Month (June)			-0.83 ± 0.44 p= 0.058				
Date (July)			0.90 ± 0.31 p= 0.0035				
Traffic (low)	0.60 ± 0.56 p= 0.2843				$0.39 \pm 0.37;$ p= 0.2950		
Traffic (mid)							
Traffic (high)	-0.12 ± 0.41 p= 0.7721				$-0.86 \pm 0.45;$ p= 0.0588		
Model p value	0.0124	<.0001		0.0009	0.0015	p=0.04	p=0.0435
Model RSquare (U)	0.1237	0.1344		0.1345	0.1619	0.1478	0.0526

Table 4: Multivariate ordinal logistic regression models with species' relative activity as the response variable and roadside features as the predictor variables. Lead numbers indicate the coefficient for each variable and second numbers indicate the standard error of the coefficient. The p value for each variable is based on the Chi-square test and is indicated at the bottom of each cell.

Activity (Multivariate)								
	Big Brown	Silver- Haired	Eastern Red	Evening	Tri-Color	Little Brown	Total Activity	Total Species
Overstory		-6.57 ± 1.99 p= 0.001	-6.08 ± 1.96 p= 0.002			-5.80 ± 2.57 p= 0.024		
Agriculture	6.61 ± 2.07 p= 0.0014		4.74 ± 1.98 p= 0.0083				$6.82 \pm 2.09;$ p= 0.0007	6.78 ± 2.11 p= 0.0013
Ditched								
Negative Slope					6.93 ± 3.18 p= 0.0291			
Positive Slope								
Telephone Poles	3.80 ± 1.24 p= 0.0023	1.08 ± 1.11 p= 0.33			1.42 ± 1.63 p= 0.03835			3.31 ± 1.21 p= 0.0059
Road Width				0.95 ± 0.34 p= 0.0075				
Temperature								
Model P Value	<0.0001	0.0425	0.0167	0.0013	0.0015	p= 0.024	p=0.0007	p< 0.0001
Model Rsquare (U)	0.13	0.038	0.053	0.096	0.21	0.08	0.06	0.11

Table 5: Contingency Analysis results for categorical variables recorded at transect locations that were included in models. Traffic indicated if the transect was located in a low traffic area (0-30 miles per hour), medium traffic area (35-45 miles per hour), or high traffic area (55+ miles per hour). The month category indicated if a species was more likely to be detected between June, July, and August; the month a species was most likely detected is included. As relative activity is a measure across the entire field season, it could not be analyzed on a monthly category. Significant p values from the Chi-square test are shown determining a difference in the presence or activity of a species between categories in a variable.

	Traffic	Month (Categorical)
EPFU Presence	p= 0.0401	NS
EPFU Activity	NS	/
LABO Presence	NS	NS
LABO Activity	NS	/
LANO Presence	NS	NS
LANO Activity	NS	/
LACI Presence	NS	p= 0.0191 ; July
LACI Activity	NS	/
NYHU Presence	p=0.0286	NS
NYHU Activity	NS	/
PESU Presence	NS	NS
PESU Activity	NS	/
MYLU Presence	NS	NS
MYLU Activity	NS	/
Species Richness	NS	/
Total Activity	NS	/

Table 6: Wilcoxon signed-rank results for environmental variables across protected versus unprotected transects. P values indicate a significantly higher proportion of an environmental variable's presence or value between protected and unprotected areas.

Variable	Protected	Unprotected
Proportion Overstory	p< 0.0001	
Proportion Agriculture		p= 0.0002
Proportion Ditched	p=0.0334	
Proportion With Telephone Poles		p<0.0001
Proportion With Negative Slope	p=0.0023	
Proportion With Positive Slope		p= 0.0151
Road Width		p= 0.0435
Temperature		p= 0.0204

Table 7: Shown are candidate models for each species' presence and/or activity based on road transects. Models with text in bold indicate the final model selected. Included are each model's p value, Akaike information criterion (AICc), and adjusted RSquare value (RSquare (U)). Candidate models were selected by taking models with AICc values ≤ 3 of the model with the lowest AICc value. Final models were selected for parsimony by including variables that contributed ≥ 0.01 to the model's RSquare(U) value. Species presence/activity that are not included resulted in a single model from the candidate model selection process or the univariate model selection process (tables 1&2).

Big Brown (EPFU)	Variables Included	p Value	AICc	RSquare (U)
Presence Candidate 1	Proportion Agriculture Proportion With Negative Slope Traffic Group	0.0124	101.11	0.12
Presence Candidate 2	Proportion Agriculture Proportion With Negative Slope	0.0039	98.44	0.10
Activity Candidate 1	Proportion Agriculture Proportion With Telephone Poles	<0.0001	309.04	0.130
Activity Candidate 2	Proportion Overstory Proportion With Telephone Poles	<0.0001	310.04	0.125

Silver-Hair (LANO)	Variables Included	p Value	AICc	RSquare (U)
Presence Candidate	Proportion Overstory	0.0002	125.60	0.16
1	Proportion Agriculture			
	Road Width			
Presence Candidate	Proportion Overstory	<0.0001	122.57	0.18
2	Road Width			

Eastern Red (LABO)	Variables Included	p Value	AICc	RSquare (U)
Presence Candidate	Proportion Overstory	0.0024	132.84	0.10
1	Proportion Agriculture			
	Date			
Presence Candidate	Proportion Overstory	0.0013	131.70	0.10
2	Date			

Hoary (LACI)	Variables Included	p Value	AICc	RSquare (U)
Presence Candidate	Telephone Poles	0.0062	136.04	0.09
1	Month (categorical)			
Presence Candidate	Moon Phase	0.0130	137.97	0.09
2	Proportion With Telephone			
	Poles			
	Month (categorical)			

Evening (NYHU)	Variables Included	p Value	AICc	RSquare (U)
Presence Candidate	Proportion Overstory	0.0013	101.18	0.16
1	Proportion With Negative Slope			
	Road Width			
	Proportion Agriculture			
Presence Candidate	Proportion Overstory	0.0015	101.46	0.16
2	Road Width			
	Traffic Group			

Species Richness	Variables Included	p Value	AICc	RSquare (U)
Candidate Model 1	Proportion Overstory	0.0002	262.98	0.102
	Proportion With Telephone			
	Poles			
Candidate Model 2	Proportion Agriculture	<0.0001	258.866	0.127
	Proportion With Telephone			
	Poles			



Figure 1: Example of univariate logistic analysis with the presence of little brown bat (*Myotis lucifugus* aka. MYLU) as the response variable and the proportion of the road with overstory as the predictor variable from road transect data.

CHAPTER II: TEMPORAL ANALYSIS OF BAT ACTIVITY WITHIN OAK SAVANNAS VERSUS WOODLAND HABITAT

ABSTRACT

Many bat species are declining in the United States from habitat loss, wind energy, and White-nose Syndrome. Eight species of bats occur in the Oak Openings Region of Northwest Ohio, and most are affected by some form of anthropogenic stress. We acoustically surveyed for bats in forested and savanna sites within the region. We compared species activity and richness between sites and across previous years of data and assessed how activity and richness varied through time. We found a decline compared to previous years in *Myotis septentrionalis*, a species with recorded population declines from White-nose. We also found a decline in richness within forested sites and in activity from July to August. We found no significant difference in habitat use between forested and savanna sites for most species in 2015 excluding Hoary, Silver-haired, and Tri-color, which were consistently more active in savanna sites. The Oak Opening Region's suite of bat species utilize different habitat types, which further emphasizes the need for continued maintenance of heterogeneity of habitat. We recommend continued surveys to monitor further changes in time and consistencies in activity trends.

INTRODUCTION

Declines in bat populations worldwide may be attributed to several factors such as habitat destruction and degradation, anthropogenic mortality through persecution and windmills, and the introduction of diseases such as White-Nose Syndrome (Lane et al. 2006, Winhold et al. 2008, Frick et al. 2010, Lametti 2010, Bat Conservation International 2012). These threats are of varying concern depending on the species, intensity, and time of season. For example, White-Nose Syndrome, a disease responsible for substantial crashes of hibernating bat populations

(Frick 2010), only infects particular species and is primarily transmitted during the winter. Most studies on wintering bats take place in hibernacula where individuals are sessile (Thomas and Cloutier, 1992; Thomas 1995; Foley et al, 2011), whereas studies on summer foraging face the challenge of sampling the animals when they are mobile (Elmore et al, 2005). Within summer foraging habitat, bats will be exposed to threats such as habitat fragmentation which can lead to increased stochasticity of insect populations in an urban landscape (Tscharntke et al., 2002), particularly of common prey taxa such as lepidopteron (Hanski and Woiwood, 1993).

As bats are prominent insectivores in most natural and agricultural landscapes, species reduction and extirpation can disrupt natural ecosystems and lead to expensive agricultural losses (Cleveland et al, 2006; Boyles et al, 2011; Kaika et al, 2008). In addition, the insect populations that these native bats depend upon can be greatly affected by invasive pests (e.g., Emerald Ash Borer), land use changes (e.g., pesticide use), and changing climate conditions that influence population sizes and distributions (Conrad et al. 2002; Robinet and Roques, 2010). Summer foraging habitat is critical to bats, as the season allows them to store body fat and meet the energy demands for breeding (Anthony and Kuntz, 1977; Barclay, 1991). Therefore, successfully managing foraging habitat may result in healthy bat populations with more resilience to White-Nose and other detrimental impacts. Understanding differential species use of potential foraging habitat allows managers to more effectively maintain areas important for summer foraging.

Many species such as the hoary and silver-haired bats forage in ecotones and open areas (Anthony and Kuntz, 1977; Furlonger et al, 1987; Barclay, 1985), while others such as the Northern long-ear, a federally threatened species, specializes in foraging within forest interiors (Patriquin and Barclay, 2003). As habitat components are dependent on the species, anthropogenic influences that benefit one or a few species may inherently be detrimental to

others (Elmore et al, 2005; Yates & Muzika, 2006). Managers in areas historically associated with natural disturbance often make decisions that will ultimately favor either disturbanceadapted species or old-growth adapted species. Studies on bats in forested and savanna mosaics at multiple scales highlighted the importance of heterogeneity at the landscape-scale for bat biodiversity and of habitat type for community composition (Fahr and Kalko, 2010). It is important for management to not only maintain high quality habitat, but a diversity of habitats as well (*e.g.*, savanna and woodland rather than just woodland) to promote bat communities and community diversity.

The Oak Openings Region is a 476 km² region of Northwest Ohio that was historically a mosaic of a number of ecosystems including oak savanna. Oak savanna, a disturbancedependent habitat has been reduced to less than 1% of its original geographical distribution and is considered a globally endangered habitat (Brewer and Vankat, 2006). The region is a biodiversity hotspot, with at least 218 different plant species (Brewer and Vankat, 2006) and several state-listed species. Previous research in the area by Sewald and Root (2012) confirmed the presence of eight different bat species. Species successfully detected included big brown (Eptesicus fuscus, EPFU), silver-haired (Lasionycteris noctivagans, LANO), hoary (Lasiurus cinereus, LACI), Eastern red (Lasiurus borealis, LABO), tri-color (Perimyotis subflavus, PESU), evening (Nycticeius humeralis, NYHU), little brown (Myotis lucifugus, MYLU), and Northern long-eared (Myotis septentrionalis, MYSE) bats. These species have differing habitat demands for foraging in the region, as an initial study of oak savanna and forested sites identified that savanna sites were used significantly more by big brown, tri-color, hoary, and Eastern red bats, while forested sites were used significantly more by little brown, Northern long-eared, and evening bats (Sewald and Root, 2012). These results were confirmed in a subsequent study

(Janos 2013), which also reported a decline in the number of call files for species that have documented population declines from White-Nose, such as the little brown bat and Northern long-ear (Frick et al, 2010; Langwig et al, 2012). High bat species richness in this region is likely a result of the heterogeneity provided by management of the region, which maintains a heterogeneous habitat matrix that includes but is not limited to savanna, woodland, wet prairie, and sand dunes (Schetter and Root, 2011).

Continued monitoring efforts are necessary to determine long-term trends of relative activity and species inventory, as bat activity can vary greatly temporally and bias sampling designs (Hayes, 1997). Studies have indicated lower activity levels of bats affected by White-Nose when compared to existing data prior to the disease's establishment (Dzal et al, 2011; Brooks, 2011). We monitored areas historically associated with high bat activity within the Oak Openings Region to determine trends in species' relative activity when compared across years and across habitat types. Based on previous research in comparing forested and open sites in the region (Sewald and Root, 2012), we expected to see higher activity levels of Northern long-ear, little brown, and evening bats in forested sites, and higher activity levels of big brown, red, hoary, and silver-haired bats in open sites. We also expected to see lower activity levels of little brown and Northern long-eared bats in 2015 when compared to earlier years.

METHODS

We surveyed 16 paired forest and oak savanna sites twice each within the Oak Openings Preserve Metropark from July 23 through August 22, 2015. All pairs were previous monitored by Sewald and Root (2012) and four pairs by Janos and Root (2013). We surveyed sites using an Anabat SD1 broadband, frequency division acoustic monitor (Titley Electronics, Ballina, New South Wales, Australia). Acoustic monitors are able to collect species data in areas where mist netting is difficult or ineffective such as open areas like savannas and are often more successful at capturing the full species assemblage of a habitat (MacSwiney et al. 2008; Murray et al. 1999; O' Farrel and Gannon, 1999; Ochoa et al. 2000).

All sites were located at least 100 m apart, well outside the range of detection by the Anabat (Livengood, 2003). We began stationary surveys 30 minutes after sunset and ended them three hours after during nights with low wind activity and no rain. We surveyed 2 to 10 paired sites each night, with each pair consisting of one savanna and one woodland site. We randomly selected sites to begin surveys; however, sites within close geographical range were surveyed in the same night to maximize the number of sites surveyed in a single night.

Anabat systems record 15 second files that contain bat call characteristics including frequency, slope, and curvature (Gannon et al., 2004) that can be used for species identification. We identified files with three or more calls to species both qualitatively (by primary author, Analook version 4.1) and quantitatively (Allen, BATcall ID version 2.7c). When the two methods resulted in a different identification, the call file was inspected again qualitatively and the primary author made the final identification. The average number of call files recorded per species at a site for the summer field season was used to represent the relative activity (Brooks and Ford, 2005), and this measure was used in further analysis.

We utilized Wilcoxon signed-rank tests in JMP® 9 (SAS Institute, Inc., Cary, NC) to compare the relative activity of bat species across sites. We tested across each species, total relative activity, and species richness in our data collected in 2015 to determine differences between forested sites and open sites. We also applied the Wilcoxon signed-rank test to compare species-specific relative activity, species richness, and total relative activity across data collected in 2010, 2011, 2012 and 2015. We used the Wilcoxon signed-rank test for forested sites over

specified years and savanna sites over specified years to determine changes in community composition for each habitat type.

During our August surveys, many sites that were previously active in July and previous years had little or no bat activity during the survey period, with 53% of sites completely silent. To examine the difference in activity between July and August, we used Wilcoxon signed-rank tests to compare species-specific relative activity and total relative activity for all sites between July and August. To test whether management of insect populations played a role in the sudden drop in activity, we collected spray dates and locations from the Toledo Area Sanitary District. The insecticide used targets dipterans and breaks down when exposed to water, soil, and sunlight within 24 hours of application (Paul Bauman, pers communication).

RESULTS

Over the course of July-August 2015, we recorded and identified a total of 408 calls from our forested and open sites. Of these calls, the vast majority were big brown with 230 calls and eastern red with 91 calls. Forty-four call files were attributed to silver-haired bats, 15 to evening, 7 to hoary, and 10 to tri-color. The least detected bats were little brown with 6 call files and Northern long-eared with 5 call files.

2015 Open and Forested Site Comparisons

Species richness (Figure 1) and total relative activity (Figure 2) were higher in open sites than in forested sites (p=0.0033 and p=0.002, respectfully) in 2015. We found differences in relative activity between forested and open sites for the hoary, silver-haired, and tri-color bats (Figures 2 and 3). All three species were significantly less active in forested sites than in open

areas (Hoary p= 0.0313; Silver-Haired p= 0.0034; Tri-color p=0.0313) during 2015. We detected no significant differences in activity between forested and open sites among other species.

2015 Between Month Comparison

Species richness in July was significantly higher than species richness (p<0.0001; Figure 4) in August and average total relative activity was also significantly higher in July than August (358 calls vs 50 calls; p<0.0001; Figure 5). Our species-specific investigation of relative activity between the two months revealed that hoary (7 calls vs. 0 calls; p=0.0313), silver-haired (43 calls vs. 1 call; p=0.0034), and big brown (209 calls vs. 21 calls; p<0.0001) had significantly more relative activity in July than August (Figures 5 & 6) whereas all other species had no significant differences (Table 1). When comparing spray dates and locations to our monitoring dates and locations, there was no overlap in spraying dates and monitoring dates with respect to locations and spraying intensities were consistent among July and August.

Between Year Habitat Comparison

Our Wilcoxon signed-rank test revealed differences in species' relative activity between data collected during 2015 and data collected in 2010, 2011, and 2015. Within forested sites, average species richness per site (Figure 7) was significantly lower in 2015 when compared to 2012 (p=0.0156) and 2011 (p=0.0156). Eastern red activity, big brown activity, and total activity (Figure 8) were lower in 2015 per site when compared to 2012 (p= 0.0078 and p= 0.0027, and p= 0.0156, respectfully) and 2011 (p= 0.0078 and p=0.0020, and p= 0.0156, respectfully), and total relative activity was lower per forest site when compared to 2010 as well (p= 0.0313). Evening bats activity (Figure 9) was significantly lower in 2015 when compared to 2011 (p= 0.0234). Also, of concern is the Federally listed as threatened Northern long-eared bat, with relative

activity significantly lower in 2015 (Figure 9) when compared to 2011 (p=0.002) and 2010 (p=0.0001) and almost significantly lower than 2012 (p=0.0625). All other species, including tricolor, little brown, silver-hair, and hoary did not have significantly different activity levels in forested sites for 2015 when compared to earlier years (Table 2).

Within savanna sites, big brown bats (Figure 10) were the only species with significantly lower relative activity in 2015 when compared to 2012 (p=0.0020) and 2011 (p=0.0027). There were no significant differences for other species' relative activity in 2015 when compared to previous years in savanna sites. Average species richness for each savanna site also had no significant differences from 2015 compared to earlier years, but total relative activity was significantly lower in 2015 (Figure 10) when compared to 2012 (p=0.0156) and 2011 (p=0.0156).

DISCUSSION

We successfully detected all eight bat species known to inhabit the Oak Openings Region. While the average activity of big brown bats was significantly lower than in previous years monitored for both forested and savanna sites, their calls still were the vast majority of all call files recorded and were recorded at all locations, which is consistent with previous monitoring efforts in the region and in other studies on bat distributions (Sewald and Root, 2012; Janos and Root, unpublished data; Johnson et al., 2008; Loeb et al., 2009; Gehrt and Chelsvig). Lower relative activity for this abundant and generalist species also explains the significantly lower total activity found in 2015 for forested and savanna sites. Lower total activity may also have been an artifact of the low number of calls detected in August for big brown, hoary, and silver-hairs relative to July and may not have been the best indicator for the community's total activity.

Eastern red calls and silver-haired calls were also the next two most common species detected, which was consistent with previous monitoring efforts and other studies (Sewald and Root, 2012; Janos and Root, unpublished data; Gehrt and Chelsvig, 2003; Loeb et al., 2009; Johnson et al., 2008). However, previous monitoring in the region detected more silver-haired calls than eastern red, although this discrepancy could be attributed to our low sample size. We also detected significantly less relative activity from Eastern red bats in forested sites than in previous years despite the species making up the second largest proportion of our recorded calls. Evening bat activity was lower in 2015 when compared to 2011 but not 2012 or 2010. Lower activity levels for evening bats cannot be attributed to White-Nose since the disease has not been documented to affect the species (OhioDNR) and studies on population dynamics for the species are lacking. Potential declines could be attributed to changes in forest community structure since the EAB invasion or as a result of management activities, but more research on the factors that affect the population dynamics of the evening bat is needed before any conclusions can be made.

Of concern, though, was the significantly lower relative activity of Northern long-ear bats in forested areas. This species is a forest interior specialist, so while it was unsurprising to see little activity in savanna sites that was no different than previous years, it was concerning to see significantly less activity in its primary habitat since populations in the Northeast have declined by up to 99 percent (USFWS). There are many studies indicating that relative activity may be a comparable metric to the percentage of bats captured from mist netting (Johnson and Gates, 2008), which suggests that the measured declines might have serious implications for the population residing in the Oak Openings Region. Northern long-ear activity in 2015 was much lower than in 2010 and 2011 and almost significantly lower than in 2012 (p= 0.0625). This trend may have been largely be a result from White-Nose impacts, however interior forest habitat in the region has also changed dramatically with the introduction of the emerald ash borer (EAB) in 2003 (Ohio Department of Agriculture). Declines in the activity of a forest interior specialist bat may thereby be a combination of impacts from introduced disease and degradation of interior forest habitat, and therefore, conservation actions to promote forest interior habitat may be required to promote Northern long-ear activity.

Of even more concern for forested habitat is the significantly lower average species richness when compared to all previous years. This metric may have been influenced by lower activity, and thus detection, of Eastern red, big brown, evening, and Northern long-ear bats in 2015, but the structural characteristics that these species rely on may have also degraded. Emerald ash borer changes forest characteristics including canopy cover, mass die offs of ash trees, woody debris, and insect abundance (Gandhi and Herms, 2010; Smith, 2006) and could be a potential contributor to interior forest degradation; however, further monitoring efforts will be needed to determine if decline in richness and forest species activity is a consistent trend or a stochastic event. It would be useful to examine forest habitat quality to further assess how changes such as that caused by Emerald Ash Borer, succession or management activities can influence bat occupancy and activity.

Our comparison of open sites to forested sites for 2015 yielded fairly expected results. We detected more tri-color, silver-hair, and hoary bats in open sites than in forested sites, which was consistent with previous findings in the area (Sewald and Root, 2012). Many studies have demonstrated that these species forage in open areas rather than the forest interior (Anthony and Kuntz, 1977; Furlonger et al, 1987; Barclay, 1985). However, we found no significant differences among the other species between each habitat type, which could be an artifact of our low sample size or the relative small size of the oak savanna since the largest single patch of savanna was 0.242 hectares (derived from the landcover map). Many bat species in the region are influenced by variability in canopy gap sizes approximately one tenth of the largest fragment of oak savanna (Ford et al., 2005), yet all eight species were successfully detected in savanna sites, including forest interior specialists. Oak savannas by definition are an ecotone between prairie and oak forest and the sites available may not be functioning effectively enough as open habitat to deter forest interior specialists. More acoustic sampling of these sites in relation to patch size may reveal patterns commonly seen among these species, such as the Northern long-eared bat's preference of forest interior habitat (Patriquin and Barclay, 2003).

Our investigation of the sudden drop in activity from July to August yielded no confirmed explanation for the decline. Most studies on temporal declines in bat activity are done over annual temporal scales (Dzal et al, 2011; Brooks, 2011), and though bat activity is known to fluctuate temporally (Hayes, 1997), the sudden and consistent drop in activity during peak activity hours is concerning. Studies on insecticide and bat activity have found little influence of spraying on bat activity itself during the year of spraying (Davy et al, 2007), and our follow-up with the Toledo Sanitary District confirmed no clear match between dates of spraying and dates of monitoring (Paul Bauman, pers communication). The Oak Openings Preserve Metropark is surrounded by residential and agricultural landcover, and private insecticide use may have occurred. However, we cannot confirm the use of private insecticides or if their use would have influenced August's drastic drop in activity. Despite having a modest influence on bat activity on a short temporal scale, bats do accumulate pesticides because of their relatively long lifespans and prominent role as insectivores (Eidels et al, 2007; O'shea et al, 2001; Senthilkumar et al, 2001) and their use in protected areas is cause for concern in long-term conservation

management. Subsequent monitoring efforts across sites and years that factor in disturbances such as fire, spraying, and extreme weather will be needed to determine if the drop in August activity is a stochastic event or a consistent trend.

It is also unlikely that many bats may have already migrated, as migratory species such as the tri-color and little brown bat were still detected in August and there were no significant differences in their relative activity between the two months. Previous literature for Eastern red and hoary bats suggests that neither species leaves the region until September (Cryan, 2003). Our results, while inconclusive in explanation, do further emphasize the need for continuous and consistent monitoring to allow for a more complete picture of the activity of the Oak Opening Region's bat species assemblage and separate stochastic events from longer-term trends. Monitoring efforts could take place over more nights to factor in nightly variation and could include more habitat classes. As oak savannas are ecotones between forested and open habitat, open-adapted species such as the hoary bat may be more successfully detected in true prairie ecosystems. Comparisons between oak savannas and open habitat pairs could be studied rather than only forest and oak savanna pairs and allow for a more complete picture of how the community composition changes over a successional gradient.

Our results suggest that interior forest habitat for bats was declining in its ability to support Northern long-eared bat activity and overall species richness. While savanna sites have remained stable in their community composition and their ability to support a high species richness and activity, their total area was relatively small and their value as refuge habitat was limited. Savanna sites may be functioning as a gap in the canopy cover for many bat species rather than a distinct alternative habitat, as even the forest interior specialist Northern long-eared was still detected at these sites. Further examination of the composition of forest interior habitat within this region is needed to determine the influence of the habitat's dynamic composition on the activity and community composition of its bat species. With so many threats that affect bats that utilize a range of habitat types, it is important for management to protect high quality summer foraging habitat of a heterogeneous design to support the full suite of native bat species.

MANAGEMENT IMPLICATIONS

Based on our results, we recommend continued surveys within the Oak Openings region to monitor the declining activity of the Northern long-eared bat and to monitor the forest community, as the community compositions appears to be losing its richness. We also recommend more analysis of monthly comparisons to determine if sharp declines in activity from July to August are consistent and to monitor for potential explanations in activity levels. Forested habitat is considered important for *Myotis* species, yet more richness was found in savanna sites. We therefore recommend maintaining a heterogeneous habitat structure to support a full and rich suite of bat species in the region. We also recommend overnight surveys to be conducted to better understand associations between habitat and time of night each species may utilize. Improved understanding of these temporal and spatial dynamics can aid management decisions by considering monitoring biases and determining true declines in activity rather than chance fluctuations in activity.

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Table 1: Shown are a comparison of all bat species recorded in July 2015 compared to August 2015 as relative activity for each species, total relative activity, and species richness. Bolded p values indicate that there is significantly less relative activity or richness for species in August based on the Wilcoxon signed-rank test.

Wilcoxon signed-rank Test p value

July-August Comparison Hoary 0.031 Silver-Haired 0.0002 Eastern Red 0.13 Big Brown < 0.0001 Tri-Color 0.25 Evening 0.11 Little Brown 0.5 Northern Long-Eared 0.13 Richness < 0.0001 Total Relative Activity < 0.0001

Species/Richness/Total
Table 2: Shown are a comparison of all bat species recorded in 2015 compared to previous years in forest sites as relative activity for each species, total relative activity, and species richness.P values in bold indicate that there was significantly less relative activity or richness for species in August based on the Wilcoxon signed-rank test.

Species/Richness/Total			
	2010 vs 2015	2011 vs 2015	2012 vs 2015
Hoary	0.5	0.5	0.25
Silver-Haired	0.88	0.88	0.38
Eastern Red	0.13	0.008	0.008
Big Brown	0.055	0.0027	0.002
Tri-Color	0.5	0.5	0.5
Evening	0.1	0.023	0.5
Little Brown	0.5	0.34	0.63
Northern Long-Eared	0.0001	0.0002	0.063
Richness	0.016	0.016	0.016
Total Relative Activity	0.031	0.016	0.016

Table 3: Shown are a comparison of all bat species recorded in 2015 versus previous years in savanna sites as relative activity for each species, total relative activity, and species richness. P values in bold indicate that there was significantly less relative activity or richness for species in August based on the Wilcoxon signed-rank test.

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	2010 vs 2015	2011 vs 2015	2012 vs 2015
Hoary	0.63	0.41	0.27
Silver-Haired	0.63	0.23	0.092
Eastern Red	0.59	0.5	0.53
Big Brown	0.026	0.003	0.0008
Tri-Color	0.94	0.94	0.7
Evening	0.56	0.2	0.63
Little Brown	0.25	0.5	0.5
Northern Long-Eared	0.5	0.5	0.5
Richness	0.94	0.5	0.078
Total Relative Activity	0.16	0.016	0.016

Species/Richness/Total



Figure 1: Shown are the average species richness per site in 2015 for woodland sites (purple bar) compared to savanna sites (grey bar). Asterisks indicate a significant difference, based on the Wilcoxon signed-rank test (p=0.0033).



Figure 2: Shown are the average relative activities for big brown and eastern red bats per site and average total relative activity per site in 2015 for woodland sites (purple bar) compared to savanna sites (grey bar). Asterisks indicate a significant difference, based on the Wilcoxon signed-rank test (Total Relative Activity p=0.002).



Figure 3: Shown are the average relative activities for silver-haired, hoary, tri-color, little brown, and Northern long-eared bats per site in 2015 for woodland sites (purple bar) compared to savanna sites (grey bar). Asterisks indicate a significant difference, based on the Wilcoxon signed-rank test (Silver-Haired p= 0.0034; Hoary p= 0.0313; Tri-color p= 0.0313).



Figure 4: Shown are the average species richness per site in July 2015 compared to August 2015. Asterisks indicate a significant difference, based on the Wilcoxon signed-rank test (p<0.0001).



Figure 5: Shown are the average relative activities per site for big brown and average total relative activity per site for July 2015 compared to August 2015. Asterisks indicate a significant difference, based on the Wilcoxon signed-rank test (Big Brown p< 0.0001; Total Relative Activity p< 0.0001).



Figure 6: Shown are the average relative activities per site for silver-haired and hoary bats for July 2015 compared to August 2015. Asterisks indicate a significant difference, based on the Wilcoxon signed-rank test (Silver-Haired p=0.0034; Hoary p=0.0313).



Figure 7: Shown are the average numbers of species per forest site for each year of data. Asterisks indicate a significant difference, based on the Wilcoxon signed-rank test (2015 vs 2012 p=0.0156; 2015 vs 2011 p=0.0156).



Figure 8: Shown are the average relative activities of big brown and eastern red bats and average total relative activity per forest site for 2015 when compared to previous years. Unshared letters significant difference, based on the Wilcoxon signed-rank test (Big Brown 2015 vs 2012 p= 0.0027, 2015 vs 2011 p= 0.0020; Eastern red 2015 vs 2012 p= 0.0078, 2015 vs 2011 p= 0.0078; Total Relative Activity 2015 vs 2012 p= 0.0156, 2015 vs 2012 p= 0.0156, 2015 vs 2010 p= 0.0313)



Figure 9: Shown are the average relative activities of evening and Northern long-eared bats per forest site for 2015 when compared to previous years. Unshared letters indicate a significant difference, based on the Wilcoxon signed-rank test (Evening p= 0.0234; Northern Long-eared 2015 vs 2011 p= 0.002, 2015 vs 2010 p= 0.0001).



Figure 10: Shown are the average relative activities of big brown and average total relative activity per savanna site for 2015 when compared to previous years. Asterisks indicate a significant difference, based on the Wilcoxon signed-rank test (Big Brown 2015 vs 2012 p= 0.0020, 2015 vs 2011 p= 0.0027; Total Relative Activity 2015 vs 2012 p= 0.0156, 2015 vs 2011 p= 0.0156).

CHAPTER III: REFINING MAXENT MACROHABITAT MODELS FOR BATS WITHIN THE OAK OPENINGS REGION

ABSTRACT

Species distributions are dynamic through time, and understanding where species are likely to occur is important for management. Using data collected in 2009 and 2015 from different monitoring techniques, we built spatially explicit species distribution models for seven bat species using maximum entropy modeling (Maxent). We compared our models to models built with data from only 2009 by examining importance of environmental variables, amount of high occurrence habitat predicted, and performance under independent test data collected in 2015. All models performed well under test data, although models created from 2009 and 2015 data predicted less high probability of occurrence habitat than those created from 2009 and 2015 data predicted less high probability of sampling techniques to monitor for species that utilize different foraging habitat as well as the need to maintain heterogeneous habitat to allow for foraging habitat for a full suite of species.

INTRODUCTION

Long-term conservation efforts for species undergoing rapid environmental changes require a full understanding of their response to disturbances in a dynamic environment. With the large prevalence of habitat degradation, invasive species, and overharvesting, management must often make decisions from incomplete information that may have unintended consequences for the species of concern (Spencer et al, 1991). Identifying and protecting potential habitat for species of concern may thereby be a challenge if responses to disturbances have effects that alter a species' realized niche (Sykes and Prenctice, 1996; Kearney and Porter, 2009; Swart et al., 1994) and require adaptive management practices.

Bats, an important taxa in both agricultural and ecological systems (Cleveland et al, 2006; Boyles et al, 2011; Kaika et al, 2008), have undergone large population crashes across many species in North America resulting from the introduction of White-nose syndrome (Frick et al., 2010). White-nose, a pathogenic fungal infection first discovered in 2006 (Blehert et al., 2009), has had lasting impacts beyond reducing bat population abundance and survival rates. Reductions in what were once more common species have potentially provided opportunities for other species, thereby changing both the spatial and temporal niches of sympatric bat species (Jachowski et al, 2014). These indirect changes from White-nose may confound management efforts to protect species of concern that have suffered dramatic population crashes from the disease, as their previous spatial niches may instead be occupied by previously less common species, which highlights the need for spatially-explicit models of bat occupancy patterns.

Understanding the distribution and composition of summer foraging habitat is essential for bat conservation (Keeley et al. 2003), as summer foraging allows bats to build fat reserves for hibernation and provide energy for the breeding season (Anthony and Kuntz, 1977; Barclay, 1991). Summer foraging habitat may be provided in protected areas such as metroparks, where a higher amount of species diversity can be found when compared to areas well outside of their boundaries (Avila-Flores and Fentron, 2005; Duchamp and Swihart, 2008; Glendell and Vaughn, 2002; Jung and Kalko, 2011). Acoustic methods provide effective methods for measuring bat occupancy and activity across a wide variety of habitats and can readily reveal the full species assemblage of an area (MacSwiney et al., 2008; Murray et al., 1999; O'Farrel and Gannon, 1999; Ochoa et al., 2000). Acoustic data has also allowed researchers to successfully model species presence in relation to macrohabitat characteristics (Brooks and Ford, 2005; Erickson and West, 2003; Ford et al., 2005; Francl et al., 2004; Johnson and Gates, 2008; Loeb and O'Keefe, 2006; Zimmerman and Glanz, 2000).

Many techniques have been used to model bat species distributions, including general linear mixed models (Jaberg and Guisan, 2002) and maximum entropy modeling (Bellamy et al., 2013; Roscioni et al., 2013; Flory et al., 2012). Maximum entropy modeling with the program Maxent is a robust way to model species distribution using presence-only data (Phillips et al., 2006) and small sample sizes (Hernandez et al., 2006). The program uses defined environmental layers within a defined geographic area and uses presence localities to estimate the species' distribution over the area. It has been successful in modeling a wide variety of taxa including exotic ants (Ward et al., 2007), geckos (Pearson et al., 2007), plants (Schetter, 2012; Kumar and Stohlgren, 2009), and bats (Lamb et al., 2008; Hughes et al., 2012; Rebelo et al., 2010). The program also allows for independent test data to be added and analyzed using "Area Under The Curve" (AUC) of a "Receiver Operating Characteristics" (ROC), which reports how test data compares to random predictions.

Our aim was to evaluate macrohabitat models of bat presence developed from data prior to a major community disturbance with data collected post-disturbance. We also wanted to compare species distribution models created from a single survey method versus models that utilize data from a variety of survey techniques and years and to compare them on their performance using test data and the area of habitat considered suitable for each species.

STUDY AREA

The Oak Openings Region is a 476 km² area in Northwestern Ohio characterized by large sand deposits left from past glaciation events and a heterogenic habitat composition (Brewer and

Vankat, 2006). Among the various habitat types is the critically endangered oak savanna, reduced to a small fraction of its original distribution by urbanization and fire suppression (Brewer and Vankat, 2006). What little of the natural habitat remains still hosts an enormous amount of biodiversity, as Brewer and Vankat's (2006) surveys revealed at least 218 different plant species, with 24 of them state listed. The Oaks Opening Region's high biodiversity and habitat heterogeneity makes it an ideal study area for landscape ecology, and fragmentation from surrounding agriculture and urban use (Brewer and Vankat, 2006) provide areas to study anthropogenic effects on the natural landscape. Sewald and Root (2012) found eight species of bats within the region, including big brown (*Epesicus fuscus*, EPFU), silver-haired (*Lasionycteris* noctivagans, LANO), Eastern red (Lasiurus borealis, LABO), hoary (Lasiurus cinereus, LACI), evening (Nycticeius humeralis, NYHU), tri-colored (Perimyotis subflavus, PESU), little brown (Myotis lucifugus, MYLU), and Northern long-eared (Myotis septentrionalis, MYSE). Subsequent Maxent modeling efforts produced species distribution maps for non-generalist species that were successfully tested with independent data collected from citizen science efforts (Sewald and Root, 2012).

METHODS

Data Collection For Presence Localities

Sewald and Root (2012) developed Maxent models from data collected by stationary acoustic surveys during June 1st to September 2nd, 2009, well before White-Nose Syndrome's first detection in Ohio in March 2011 (OhioDNR). They surveyed 32 sites five times each for 20 minutes using Anabat SDII monitors (Titley Electonic, Ballina, New South Wales, Australia) within protected areas maintained by the Metroparks Toledo within Lucas County, Ohio. Surveys were stationary and encompassed all natural habitat types within the region. They successfully detected eight species; big brown bats were present at all locations and dropped from further modeling, while the remaining seven were present from a range of 5-19 sites. *Road Transect Data*

We monitored 30 roads from June 21st to August 22nd 2015 three to four times each throughout the Oak Openings Region using Anabat SDII monitors. We selected 15 roads within protected area boundaries of The Nature Conservancy's Kitty Todd Nature Reserve and Metropark's Oak Opening's Preserve and 15 roads outside park boundaries throughout the region. We classified roads inside or touching the park boundary as inside the park, and roads without contact of official park boundaries as outside park boundaries. We created 30 1-km transects by generating random starting and ending points in ArcGIS. All starting and ending points were located at least one hundred meters from each other, well outside of the 30 m radius for the Anabat SD2 detection range (Livengood, 2003). All transects chosen were within 500 meters of forest habitat, as all species rely on forest habitat to some degree. We monitored 1-km transects over a period of 20 minutes.

We followed the same well-established methods (Brooks and Ford 2005, Johnson and Gates 2008, Brooks 2009, Francl et al. 2004, Francl 2008, Ford et al. 2006, Ford et al. 2005) for acoustic monitoring with the Anabat as Sewald and Root (2012). We began monitoring approximately 30 minutes after sunset and ended 3 hours after, covering the period of night when activity among bat species is most similar (Hayes, 1997). We did not sample during nights with rain or strong wind (>3 on Beaufort scale) as bats forage less during these conditions (Barclay, 1985; Voigt et al, 2011). We monitored sites in close proximity to each other in clusters to reduce travel time from one site to the next, but randomized the order of transects. All active

recording sessions included an integrated GPS device to the Anabat devices that fixes GPS coordinates to each call recorded. We extracted presence localities with GPS data to use in our modeling process, with species presence ranging from 2-30 transects. We successfully detected all eight species, but dropped big brown bats from further modeling because they were found at all locations.

Core Habitat Test Data

We also surveyed 16 paired forest and oak savanna sites two times each through the Oak Openings Preserve Metropark from July 23 through August 22, 2015. All pairs were previous monitored by Sewald and Root (2012) and four by Janos and Root (2013). All pairs were located at least 100 m apart, well outside the range of detection by the Anabat (Livengood, 2003). We began stationary surveys 30 minutes after sunset and ended them three hours after during nights with low wind activity and no rain. We surveyed 2 to 10 paired sites each night, with each pair consisting of one savanna and one woodland site. We randomly selected sites to begin surveys; however, sites within close geographical range were surveyed in the same night to maximize the number of sites surveyed in a single night.

Call Analysis

We analyzed all call files with identical procedures to Sewald and Root (2012). We analyzed all files with three or more calls and identified each to species (by the primary author) both qualitatively (via Analook version 4.1) and quantitatively (BCID version 2.7c). When a discrepancy on file identification between the two methods occurred, the file was qualitatively inspected again and identified by the primary author.

Macrohabitat Characteristics

To make models comparable, we used identical procedures as Sewald and Root (2012) to extract macrohabitat features using ArcMap 10.0 (ESRI, Redlands, California, USA) from the landcover map of the Oak Openings Region created by Schetter and Root (2011). The landcover map was a 30 m resolution map composed of 15 different classes: turf, asphalt, shrub/scrub, conifer, pond, crop, meadow, barren, prairie, wet prairie, floodplain forest, upland forest, savanna, residential, and swamp. Wet prairie, barren, conifer, and shrub/scrub were excluded in original model development because of low sample size and frequency within the region. Raster files for Maxent's environmental layers input were created using the program FRAGSTATS (McGarigal and Marks, 1995) and a 60m circular moving window to determine measures of fragmentation (cohesion, number of patches, landscape shape index, and Simpson Diversity index), percentages of landcover for each class, and distance to nearest road, stream, residential, and agricultural areas. Correlation analysis on all variables revealed dependencies between specific variables and we selected the same variables as Sewald and Root from groups correlated r > 0.6, p < 0.05. Distance to residential, roads, and percentage residential were correlated and we selected roads in all models because of the region's high level of fragmentation by roads. All measures of fragmentation and heterogeneity were correlated and number of patches was selected as a general measure of fragmentation. All models included distance to stream, distance to agriculture, and number of patches in all models because of their importance to bats in urban and agricultural matrices (Yates and Muzika, 2006; Either and Fahrig, 2011; Grindal et al., 1999; Gehrt and Chelsvig, 2004; Duchamp and Swihart, 2008). All measures of forest and open cover were kept in each model, as all bats in the region require each to various extends.

Model Testing

We ran ten replicates in Maxent with default settings (Phillips and Dudik, 2008) to create distribution models for each of the seven species. The Maxent model outputs were on a logistic scale where each pixel for the raster is given a value between 0 and 1, with 0 being low probability of occurrence and 1 being high probability of occurrence. Sewald and Root (2012) created their original models from 2009 training data and tested them with independent presence localities collected from citizen science efforts during the summers of 2010 and 2011. The data was used to evaluate the model using the area under the receiver operator curve (AUC of ROC), and all models performed greater than an AUC of 0.80, indicating the models performed well under the citizen science test data. To determine if 2009 training data still held predictive power after White Nose Syndrome's establishment, we built the models using the same 2009 training data and tested them with 2015 data collected by road transects. When the data was demonstrated to be comparable by meeting AUC thresholds greater than 0.80 (Table 1), we built new distribution models for each species using both 2009 presence localities and presence localities collected from our 2015 transects. We tested both 2009 data-only models and 2009+2015 data models with independent data from our 2015 paired oak savanna-woodland sites and compared AUC values for each species (Table 2). Each model output was then averaged to create a species richness model map composed of pixels ranging from 0-7, with 0 representing a high likelihood of no species present and a 7 representing all species likely present.

To compare areas on the landscape considered high probability of presence between the two models, we reclassified pixel values for both model groups ranging from 0.0-0.5 (considered less likely to be present) to 0 and values ranging from 0.5-1.0 (considered more likely to be present) to 1. We then summed raster cells for each species to give a range of three values, with 0 representing areas both models found less likely for presence, 1 representing areas where one

model found likely for presence, and 2 representing where both models found likely for presence. To compare our richness models, we partitioned pixel values from 0.0-1.0 into eight equal ranges (to represent any discrete value from 0-7) and compared areas on the landscape between models where each number of species was likely to be present.

RESULTS

Testing 2009 Models With 2015 Data

Sewald and Root's 2009 models performed well under transect data, with all AUC of the ROC values being greater than 0.80 and are presented in Table 1. Four of the seven original models exceeded a test AUC value of 0.90, indicating "very good" fit of the test data to the original models (Swets, 1988). The species for these models included Eastern red, little brown, Northern long-ear, and tri-color bats. The three remaining models for hoary, evening, and silver-haired bats were all above 0.8 and well above the threshold of 0.75, where the model's discriminatory ability is considered useful for predicting species' ranges (Elith et al., 2006). *Contribution of Variables to Models Made From 2009 and 2009+2015 Data*

The percentage of contribution for each environmental variable to each species' 2009 Maxent model are displayed in Table 2, whereas the contributions to the Maxent models made from 2009+2015 data are shown in Table 3. Distance to water was the most common large contributor to 2009-only models, whereas the variable only contributed 7-16% to 2009+2015 models for little brown, Eastern red, tri-color, and Northern long-eared bats. All species were more likely to be found near water sources in all models. Whereas distance to roads played a negligible role in models made from only 2009 data, it had varying contributions to models made from 2009+2015 data. Distance to roads made a large contribution towards hoary and silverhaired models, but also contributed to models for Eastern red, tri-color, and evening bats; these species were more likely to be found near roads.

Distance to agriculture contributed to many 2009 data models, and its importance was retained in 2009+2015 data models. Distance to agriculture contributed heavily to Northern longeared, evening, and little brown bat models and contributed 20-26% to all other species. Tricolor, little brown, and Northern long-eared bats were more likely to be found at intermediate distances from agriculture, whereas hoary, Eastern red, and silver-haired bats were more likely to be found at closer distances to agriculture. Evening bats were likely to be found at distances close to agriculture and at intermediate distances from agriculture. Number of patches contributed to 2009 data models for silver-haired and evening bats, whereas this metric contributed to 2009+2015 models for Eastern red and evening bats. Measures of open area (prairie, meadow, and savanna) were contributors to 2009 data models for hoary, silver-haired, and tri-color bats, but were not important contributors in 2009+2015 data models. Measures of forest (floodplain, swamp, and upland forests) were contributors in 2009 data models for hoary, silver-haired, Eastern red, and evening models, whereas they contributed to 2009+2015 models for Eastern red, tri-color, and little brown bats. Upland forest alone contributed about 10% to both models for Northern long-eared, but the other two measures of forest had negligible contributions for this species.

Testing Models With Paired Site Data

Our test AUC values for our 2009 and 2009+2015 models differed depending on the species (Table 4). All test AUC values were above a 0.8 threshold, when a 0.75 threshold is the cutoff that a model is considered 'useful' (Elith et al., 2006). Hoary, evening, and silver-haired bats all had over a 0.10 increase each in test AUC when data from 2015 was included into the

training data, indicating the additional data may have improved the models. Eastern red, little brown, and Northern long-eared bats all decreased in test AUC when 2015 data was included, but this change was less than 0.07 for these species. Tri-color bats had a 0.09 decrease in test AUC value when 2015 data was included. When compared at 0.9 and 0.8 thresholds, our 2009 models had four species that exceeded the 0.9 threshold whereas our 2009+2015 models had five species. The three 2009 models with AUC values below the 0.9 threshold were all above the 0.8 threshold but still lower than 0.85, whereas only one of our two 2009+2015 models below the 0.9 threshold was also below 0.85.

Amount of Agreed Area Predicted to Have a High Probability of Presence

The percentages of the landscape considered more or less likely to have a high probability of presence for each species is shown in Table 5 and model comparisons are shown in Figures 2-8. The results of these models suggest that a very small proportion of the habitat (3.4 to 14.4%) was likely to be occupied for these seven species of bats. Models built from 2009 data generally predicted far more habitat likely to be occupied on the landscape than models built from 2009 and 2015 data. For species where our combined data models predicted more high probability of presence area than our 2009 models, the difference in area predicted was less than 3%. The proportion of area considered to have a high probability of presence where both models agreed was generally a small fraction of the total area predicted by either model (0.3%-2.8% agreed, 1.2%-12.9% predicted by one model), with the exceptions being the little brown and Northern long-eared models for which there was an increase (1.0%-1.0% agreed, 1.1%-3.3% predicted by one model).

The percentages of the landscape considered to have a high probability of presence for a certain number of species is shown in Table 6 and the two richness models are displayed in

Figure 9. Areas for each class varied between models, with our 2015+2009 richness model predicting less area for a richer suite of species than the 2009 richness model (0.0003% vs 0.0008% for 7 species, respectfully) and more area for fewer species than the 2009 richness model (73.62% vs 47.90% for 0 species, respectfully).

DISCUSSION

We successfully developed macrohabitat models for seven species that occur within the Oak Openings Region using data collected from protected areas and outside protected areas using both stationary monitoring and driving transects. We wanted to refine old models to help gain more understanding on where bats may be present within an urban/agricultural matrix heavily fragmented by roads and if there have been any temporal or spatial changes.

Our AUC values for 2009 models when tested by 2015 data (both road transect and core habitat) suggest that old models still hold high predictive power and were robust despite small sample size. Road surveys may thereby provide comparable data for most species in the region compared to fixed location surveys. Of concern is the relatively low percentage of the landscape considered to have a high probability of occurrence for many species in the region (Table 5), including those with decreasing relative activity (see Chapter 2) and documented population declines (Frick et al., 2010). It is important to protect these areas, as they may be acting as refuge habitat for many species in what could potentially be a matrix that cannot otherwise be occupied and further monitoring could refine models even further. Our additional data helped refine some of the resulting species distributions and improved the accuracy of the predictions.

Our models created from a combination of 2015 and 2009 presence localities had varying contributions from distance to roads, which were a stark contrast to the 2009-only models, where the variable was negligent in all models. The percent contribution to each species' model was

directly related to their foraging strategies. The largest contributions were towards hoary and silver-haired bat models, which are the two most 'open-adapted' species in the region (Owen et al., 2004; Barclay, 1985; Barclay, 1986). In contrast, the smallest contributions were towards little brown and Northern long-eared bat models, which are the two most 'clutter-adapted' species in the region (Broders et al., 2006; Henderson and Broders, 2008; Krusic et al., 1996). Roads may thereby be functioning as open habitat, and many species in the region are known to forage around roads (Rydell, 2006). A wider road width was also positively associated with silver-haired presence in the region (see Chapter 1), which provides evidence that roads may thereby be acting as open foraging habitat for species that forage in open spaces and creating edge foraging habitat for species that forage on the edge. It is also possible that systematic sampling of roads created a bias of importance for the variable, and further sampling of open foraging habitat such as residential yards could give insight into the importance of roads to each species.

Perhaps most surprising was the decrease in the distance to water's contribution to each species' model when 2015 data was included into the model development. Water has consistently been demonstrated as important to bat distribution and activity by providing water and forest clearings for areas of high insect activity (Barclay, 1991; Rydel et al., 1994; Walsh et al., 1995; Vaughan et al., 1997; Racey, 1998; Grindall et al., 1999; Russo & Jones, 2003). To see its contribution to each model decrease dramatically was suggestive that major water bodies on the map were not the only source of water and foraging habitat for bats in the region. Road verges also provide habitat for Lepidopteron species (Valtonen et al., 2006; Saarinen et al., 2005; Munguira & Thomas, 1992) and other insects (Raemakers et al., 2001; Noordijk et al., 2009), which constitute a large portion of the diets of many of the native bat species in the region (Clare

et al., 2009; Anthony and Kunz, 1997; Agosta, 2002; Whitaker, 2004). Roads in the Oak Openings Region may thereby be subsidizing foraging habitat that would otherwise be provided by open areas created by natural disturbances or sources of water. Further investigation on composition and activity of the bat species assemblage at paired road and water sites may allow managers to understand how functional roads are as open habitat for each species in the Oak Openings Region.

CONCLUSION AND MANAGEMENT IMPLICATIONS

Overall, road surveys seem to increase our model accuracy for more open-dependent species and our models are useful for examining the spatial variability in occupancy of summer foraging habitat. Further investigation on water bodies, roads, and other sources of open foraging habitat can refine models further, but they still can guide management actions in an area with a rich suite of species that utilize a range of foraging techniques. While we incorporated data collected from a variety of techniques within and outside protected areas, further monitoring well outside of park boundaries will be needed to refine extrapolation of these models into the agricultural and urban core of the Oak Openings Region. Now that we have models suggesting that a combination of survey techniques can be used for modeling that can also be done at larger scales, we can build onto our current models and guide management action to areas that may not be considered traditional habitat. Our distribution models suggest the importance of protected areas as potential refuge habitat for a rich suite of species within an urban and agricultural matrix and further emphasize the importance of the conservation and restoration of these areas.

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Table 1: Results of Maxent models' "Area Under the Curve" ROC analysis for each of seven bat species when created from 2009 data (Training) and tested with 2015 road transect data (Test). Values closer to 1.0 indicate a more discriminatory model.

	Hoary	Silver- haired	Eastern red	Tri-color	Evening	Little Brown	Northern Long- eared
Training AUC	0.974	0.95	0.98	0.959	0.983	0.983	0.978
Test AUC	0.825	0.835	0.95	0.912	0.809	0.941	0.917

Table 2: Percentage of contribution for the ten environmental variables to each 2009 data-onlyMaxent species distribution model within the Oak Openings Region.

Environmental Variable	Hoary	Silver- haired	Eastern Red	Tri- color	Evening	Little Brown	Northern long- eared
Distance to roads (m)	0.1	0.0	2.0	0.1	0.3	2.9	0.2
Distance to agriculture							
(m)	1.2	1.3	39.4	16.0	12	39.9	23.2
Distance to water (m)	49.2	64.4	35.1	56.5	37.9	42.4	66.5
Floodplain forest (%)	0	0.8	0.9	5.4	0	1.6	0.1
Swamp forest (%)	0	0.1	0.2	1.2	9.8	0.1	0
Upland forest (%)	27.5	0.2	8.9	1.5	12.5	4.8	9.1
number of patches	2.8	14.4	2.7	1.6	17.9	0.4	0.6
Prairie (%)	0.3	0.2	3	11.3	1.5	0.7	0.3
Meadow (%)	18.6	9.2	0.1	0.6	2.8	0.2	0
Savanna (%)	0.3	9.5	7.6	5.8	5.3	7	0

Table 3: Percentage of contribution for the ten environmental variables to each 2015+2009 data Maxent species distribution model within the Oak Openings Region.

Environmental Variable	Hoary	Silver- haired	Eastern Red	Tri- color	Evening	Little Brown	Northern long- eared
Distance to roads (m)	62.4	58.8	28.5	34.1	19.4	10.2	0.9
Distance to							
agriculture (m)	22.1	22.1	24.7	25.5	49.3	38.3	70.6
Distance to water (m)	4.1	3.0	11.7	9.7	0.9	15.5	7.3
Floodplain forest (%)	3.3	1.8	6.7	9.7	0.1	7.6	0
Swamp forest (%)	1.1	0.4	2.3	0	1.5	0	0
Upland forest (%)	3.6	1.3	4.2	8.4	8.1	14.8	10.8
number of patches	2.3	6.4	14.9	2.3	17.4	5.2	5.2
Prairie (%)	0.8	1.2	2.2	3.1	0.4	0.7	4.6
Meadow (%)	0.3	2.4	2.0	5.2	2.1	2.9	0.2
Savanna (%)	0.2	2.6	2.9	2.1	0.8	4.7	0.4

Table 4: Results of Maxent models' "Area Under the Curve" ROC analysis for each of seven bat species when created from 2009 data only and from 2009+2015 data and tested with independent 2015 data collected from paired woodland-savanna sites.

	Hoary	Silver- haired	Eastern red	Tri- color	Evening	Little Brown	Northern Long- eared
Training AUC							
2009	0.974	0.950	0.980	0.959	0.983	0.983	0.978
Test AUC							
2009	0.828	0.835	0.950	0.912	0.809	0.941	0.917
Training AUC							
2015	0.961	0.965	0.950	0.924	0.970	0.955	0.943
Test AUC							
2015	0.935	0.950	0.916	0.834	0.926	0.912	0.876

Table 5: Area of less (Maxent output values ranging from 0-0.5) and more (Maxent output values ranging from 0.5-1) likelihood of predicted presence within the Oak Openings Region (in percentage of total area) for each of seven bat species in models built with 2009-only data and models built with 2009+2015 data.

							Northern
		Silver-	Eastern	Tri-		Little	Long-
	Hoary	Haired	Red	Color	Evening	Brown	eared
Less in Both	89.90%	85.60%	95.00%	90.90%	86.20%	96.60%	96.60%
More In One	9.80%	13.90%	4.50%	6.30%	13.40%	2.40%	2.40%
More In Both	0.30%	0.50%	0.50%	2.80%	0.40%	1.00%	1.00%
More In 2009 Model	7.80%	12.40%	1.70%	6.90%	12.90%	1.10%	1.10%
More In 2015+2009							
Model	2.60%	2.40%	3.70%	5.10%	1.20%	3.30%	2.30%

Table 6: Area of high likelihood of predicted number of species within the Oak Openings Region (in percentage of total area) for seven bat species in models built with 2009-only data and models built with 2009+2015 data.

Number of Species Likely	2015+2000 Pichness Model	2000 Pichnoss Model
Fiesent	2013+2009 Kichness Wodel	2009 Kichiness Model
0	73.62%	47.90%
1	15.71%	39.73%
2	6.26%	15.52%
3	2.68%	6.15%
4	1.14%	2.42%
5	0.42%	0.93%
6	0.15%	0.27%
7	0.03%	0.09%


Figure 1: Landcover map of the Oak Openings Region, showing the high amount of fragmentation by roads in the region as well as the urban/agriculture matrix that natural habitat is embedded in (adapted from Schetter and Root 2011).





Figure 2. Shown are the two Maxent models and their comparison for Eastern red bats when data from 2009+2015 (a) are used as training data and when data from 2009 only (b) are used. The comparison map (c) was made by reclassifying all output values from 0-0.5 to 0 and all output values from 0.5-1 to 1 and summing the two raster maps. Values of 2 represent areas where models agreed were 'more likely to have presence', values of 1 represent areas where one model





Figure 3. Shown are the two Maxent models and their comparison for Hoary bats when data from 2009+2015 (a) are used as training data and when data from 2009 only (b) are used. The comparison map (c) was made by reclassifying all output values from 0-0.5 to 0 and all output values from 0.5-1 to 1 and summing the two rasters. Values of 2 represent areas where models agreed were 'more likely to have presence', values of 1 represent areas where one model assigned





Figure 4. Shown are the two Maxent models and their comparison for Silver-haired bats when data from 2009+2015 (a) are used as training data and when data from 2009 only (b) are used. The comparison map (c) was made by reclassifying all output values from 0-0.5 to 0 and all output values from 0.5-1 to 1 and summing the two rasters. Values of 2 represent areas where models agreed were 'more likely to have presence', values of 1 represent areas where one model assigned 'more likely to have presence', and values of 0 represent areas where both models found 'less likely to have presence'.





Figure 5. Shown are the two Maxent models and their comparison for little brown bats when data from 2009+2015 (a) are used as training data and when data from 2009 only (b) are used. The comparison map (c) was made by reclassifying all output values from 0-0.5 to 0 and all output values from 0.5-1 to 1 and summing the two rasters. Values of 2 represent areas where models agreed were 'more likely to have presence', values of 1 represent areas where one model assigned





Figure 6. Shown are the two Maxent models and their comparison for Northern long-eared bats when data from 2009+2015 (a) are used as training data and when data from 2009 only (b) are used. The comparison map (c) was made by reclassifying all output values from 0-0.5 to 0 and all output values from 0.5-1 to 1 and summing the two rasters. Values of 2 represent areas where models agreed were 'more likely to have presence', values of 1 represent areas where one model





Figure 7. Shown are the two Maxent models and their comparison for Evening bats when data from 2009+2015 (a) are used as training data and when data from 2009 only (b) are used. The comparison map (c) was made by reclassifying all output values from 0-0.5 to 0 and all output values from 0.5-1 to 1 and summing the two rasters. Values of 2 represent areas where models agreed were 'more likely to have presence', values of 1 represent areas where one model assigned





Figure 8. Shown are the two Maxent models and their comparison for Tri-color bats when data from 2009+2015 (a) are used as training data and when data from 2009 only (b) are used. The comparison map (c) was made by reclassifying all output values from 0-0.5 to 0 and all output values from 0.5-1 to 1 and summing the two rasters. Values of 2 represent areas where models agreed were 'more likely to have presence', values of 1 represent areas where one model assigned



Figure 9: Shown is our species richness models (multispecies models) for all seven bat species in the Oak Openings Region of northwest Ohio. Richness models for 2015+2009 data (a) and 2009 data only (b) were created by combining each species model created in Maxent. Values of zero indicate no species likely present, and values of seven indicate all species likely present.

CHAPTER IV: CONCLUSIONS

In Chapter I, I conducted acoustic surveys during driving transects to record the presence and activity of bat species along areas of fragmentation and relate them to features commonly associated with fragmentation. I chose to investigate this topic because driving transects are becoming a more common form of acoustic monitoring and I wanted to determine the influence of these features on the presence and activity of different bat species. I was successful in detecting all eight species, and successful in relating fragmentation features to six species using logistic regression analysis. Model results varied among species and suggested a differential response to features, which implies management must consider which species need to benefit from actions as not all species will react the same.

In Chapter II, I conducted acoustic surveys to assess activity levels and species richness across savanna and forest habitat types and to determine how activity and species richness has changed compared to previous years. Bat activity and richness were greatest in savanna sites, and tri-color, silver-haired, and hoary bats had higher activity levels in savanna sites. Analysis across years indicate a decline in many species' activity levels, including the Federally listed as threatened Northern long-eared bat, within forested sites and a decline in species richness within forested sites as well. Big brown bats had lower activity levels across all sites, and we recorded a significant decline in overall activity from July to August 2015. The results indicate the importance of maintaining a heterogeneous landscape and prompt further investigation of forest habitat to determine potential factors for activity decline. I also recommend conducting overnight surveys within these sites to determine if trends are consistent across entire nights.

In Chapter 3, I refined macrohabitat Maxent models created from data collected in 2009 by including data collected from 2015 road transects. I compared models on performance

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through AUC values from independent test data, amount of high occurrence area predicted, and importance of individual environmental variables to the models. Overall, I found both models had high predictive power, but models that included 2015 data increased in AUC values for more species when compared to models created from 2009 data only. Models that included 2015 data also predicted much less area of high occurrence than 2009 data-only models. Distance to roads was a much more important feature in models that included 2015 data than 2009 models, and its importance appeared to increase in models for species that are considered open-adapted. Roads may be providing open foraging habitat for these species, and I suggest additional comparison studies between roads and other open areas such as prairies and water bodies to further our understanding on their role in the bat community of the Oak Openings Region.

Overall, this research 1) demonstrates the influence of features associated with a common form of fragmentation on the presence and activity of bats. 2) It shows that a rich suite of bat species utilize different habitats and emphasizes the need for a heterogeneous landscape. Continued monitoring is also required to determine changes in the activity composition of an entire night and further investigation in sites with species activity and richness declines may provide additional explanation for trends we are observing. 3) Comparable data can be collected with a variety of techniques and models can be refined by providing additional data. Results indicate that models are robust and can be used by land managers to prioritize areas for conservation.

APPENDEX A: INTITUTIONAL ANIMAL CARE AND USE COMMITTEE

APPROVAL

IACUC Inquiry Hillary Snyder Wed 6/3/2015 2:18 PM To: Christian Edward Nordal <cnordal@bgsu.edu>; Cc: Karen V Root <kvroot@bgsu.edu>;

Christian,

Thank you for coming in today.

Based on the study procedures you described to me (i.e., no environmental manipulations, only using the Anabat SD2), you do not need IACUC approval to conduct this work. If you plan to change the study procedures, please contact me beforehand so we can reevaluate if you need IACUC approval.

Hillary

Hillary Snyder, Ph.D. Research Compliance Officer Office of Research Compliance 305A University Hall Bowling Green State University Bowling Green, OH 43403 Phone: 419-372-7722