THE EFFECTS OF LAND MANAGEMENT EDGES ON THE DIVERSITY, ABUNDANCE, AND DISTRIBUTION OF SMALL MAMMALS AND BATS

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ABSTRACT

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The distribution, abundance, and movement of mammals can be heavily influenced by the configuration of the landscape, including boundary effects. Management practices are commonly used by park managers to restore and conserve certain natural habitats (e.g., prairies, savannas), and may produce distinct edges. The challenge is that there can be unintended detrimental consequences to the organisms that depend on these managed habitats and the adjacent areas. Research on the effects of management usually focuses on vegetation or a specific focal species of management, but this research focused on the effects of management on native terrestrial mammals that are not usually the target species for early successional habitat management. My research focused on surveying nonvolant small mammals and bats at the managed and unmanaged level, site level, and landscape level and evaluating the effects of these managed edges on native mammals. I used tracking tubes to survey small mammals and stationary acoustic monitors to survey bats. I focused on prescribed burning as the main form of management for this project since prescribed burns produced the most distinct boundaries compared to herbicide and mechanical vegetation removal. My study took place in the Oak Openings Preserve in northwestern Ohio. My goal was to investigate how prescribed burning impacted wildlife, what structures and characteristics were the most important for organisms, and which could be maintained or created by burning. The results provide guidelines to help managers reach their goals of creating and maintaining viable natural remnants for native biodiversity. My results suggested that both groups of mammals value open areas and certain vegetation characteristics such as sapling and crypto-biotic crust that result from the prescribed burns. My study emphasizes the importance of having an unburned area adjacent to a burned

area to allow for dispersal and resource availability, and the importance of studying a variety of organisms for management research. Most importantly, my research suggests that habitat heterogeneity should be the main goal for management.

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GENERAL INTRODUCTION

Ecosystems can be impacted by edges that are naturally or anthropogenically created (Parkins et al. 2018). Edges are defined as the transition to and from areas of different characteristics (Parkins et al. 2018). Edges can affect the flow of nutrients, vegetation, and wildlife and the effects can be positive or negative depending on the plasticity of organisms and the environment (Parkins et al. 2018, Schneider- Maunoury et al. 2016, Morris et al. 2010). An increase in edges can lead to an increase of fragmentation and this can lead to a loss of biodiversity in an area (Wilson et al. 2010, Batary and Baldi 2004, Schneider-Maunoury et al. 2016). Management practices, which can create or maintain edges, are one way that fragmentation is increasing in the environment. Therefore, there is a need to better understand the impacts of these edges on native animal species. My research can address the question of how do changes in spatial environmental heterogeneity from management influence mammal diversity (Sutherland et al. 2013).

Land management practices such as, mechanical vegetation removal, prescribed fires, and herbicide treatment, are common tools used by land managers to maintain or create natural remnants. Many natural areas are suffering from woody encroachment, fire suppression, and native species are being outcompeted by invasive species (Gustafson 2018, Wood et al. 2011, Twidwell et al. 2016). This study took place in the Oak Openings Preserve, near Whitehouse, Ohio and is the largest Toledo Metropark (Kappler 2009). The Oak Openings Region is a unique natural area and is considered one of The Nature Conservancy's "200 Last Great Places on Earth" (Groove 2005). This study focused on prescribed fires as a management tool, the edges they create and the potential impacts on mammals. In areas like the Oak Openings Region in northwestern Ohio, prescribed fire is used to restore prairies, savannas, and grasslands that are threatened by clutter, woody encroachment, and invasive species (Brewer & Vankat 2004, Twidwell et al. 2016). Fires are natural in these ecosystems and some organisms rely on fires to thrive. Wildfires have been historically suppressed, and some areas are still suppressing fires (Iverson et al. 2008, Twidwell et al. 2016). This can lead to an increase of woody encroachment that destroys natural habitats and can also promote uncontrollable dangerous wildfires because of the buildup of fuel from vegetation (Iverson et al. 2008, Twidwell et al. 2016). Studies have shown that prescribed fires can increase heterogeneity in an area (Pastro et al. 2011, Newman et al. 2017) but questions remain as to the optimal amount of burning, the preferred frequency of burns, and the amount of edges created and the potential impacts on animals. Prescribed fires need to be highly controlled for the safety of humans. To ensure this, fire barriers are created around the perimeter of the burn area and fire barriers can create a hard edge. An edge could be detrimental for terrestrial vertebrates that need to pass through the edge to either escape the management practice, need access to a new area for resources, or continue their natural migrations (Parkins et al. 2018, Batary and Baldi 2004). There is a gap in our knowledge about how prescribed burning might impact mammals. The purpose of this study was to fill that gap in knowledge of the effects of management and managed edges on mammals, specifically bats and nonvolant small mammals.

Bats and nonvolant small mammals are important to ecosystems and can be bioindicators of the health of an ecosystem. Bats are the primary predators of nocturnal flying insects which aid in pest control for agricultural crops (Hart 2004, Morris et al. 2010, Turner 2018, Hollen 2017). Bats have been experiencing a large decline in numbers the past decade, largely as a result of habitat impacts, so it is important to study these organisms to limit the number of threats and increase favorable habitat so they can thrive once again (Hart 2004, Blakey et al. 2018, Law et al. 2019, Braun de Torrez et al. 2018). Habitat preference for different bat species depends on the body and wing size and shape (Hart 2004). Smaller bat species, such as little brown (*Myotis lucifugus*), northern long-eared (*Myotis septentrionalis*), eastern red (*Lasiurus borealis*), and tri-colored (*Perimyotis subflavus*) are able to maneuver quickly so they are able to forage in habitats with more canopy cover and clutter (Hart 2004, Kniowski & Gehrt 2014, Kurta 1995, White et al. 2015). Larger bat species, such as evening bat (*Nycticeius humeralis*), hoary (*Lasiurus cinereus*), and silver haired (*Lasionycteris noctivagans*) prefer to forage in more open areas because they are unable to maneuver through clutter easily (Hart 2004, White et al. 2015, Whitaker and Mumford 2009). Prescribed burning can be used to open canopies for larger bat species and create snags for summer roosting for the majority of Ohio bats (Cox et al. 2016, O'Keefe and Leob 2017). Turner (2018) found bat activity was slightly less along edges when compared to core habitat. The edges in that study were bordering agricultural, residential, and open habitat (Turner 2018) but did not focus on managed edges. There has been little research on the effects of managed edges on bat diversity, abundance, and distribution. For this research, distribution is defined as the location of organisms of interest in relation to managed and unmanaged area and landcover types. Eight species of bats utilize the Oak Openings Region for critical foraging and roosting habitat. I expected to find larger species, such as hoary and silver haired bat, more frequently using the more open areas and foraging along edges. I also expected greater diversity of bats when management increased the heterogeneity in the surrounding landscape.

Small mammals are crucial to native ecosystems because they are seed and fungal spore dispersers, prey items for predators, aid in nutrient cycling, and habitat engineers (Jacques et al. 2017). Nonvolant small mammals rely on environmental structures such as downed trees, shrubs, and snags for cover from predators. Fire can eliminate ground cover, which can have short term negative effects of small mammals, but can also create snags and increase shrub growth, which can have a positive long term effect on small mammals (DeGolier and Schottler 2015, Jacques et al. 2017). Hard edges created by prescribed fires might make it hard for small mammals to move from a burned area to an unburned area for resources or avoiding predators (Parkins et al. 2018), resulting in a negative impact. More research is needed to evaluate the effects of management and managed edges on the abundance, diversity, and distribution of small mammals and is the focus of this study (Schneider-Maunoury et al. 2016). There are numerous small mammal species inhabiting Oak Openings Preserve, such as white-footed mice (*Peromyscus leucopus*), deer mice (*Peromyscus maniculatus*), short-tailed voles (*Microtus agrestis*), etc. However, the majority of species I expected to find in my study were white-footed mice (*Peromyscus leucopus*) and deer mice (*Peromsyscus maniculatus*), comparable to Kappler (2009). I expected to find the greatest abundance of mice in the unmanaged areas where there was more vegetation cover.

My study took place in Oak Openings Preserve, which is the largest preserve of the Oak Openings Region in Northwest, Ohio (Schetter and Root 2011). This region is considered a biodiversity hotspot and has a wide variety of ecosystems including; sand barrens, wet and sand prairies, oak savannas, and oak woodlands (Kappler et al. 2012, Schetter et al. 2013). This region is heavily impacted by human fragmentation and has a history of fire suppression (Kappler et al. 2012, Buckman-Sewald et al. 2014). Habitats in Oak Openings Preserve are managed with prescribed fire, herbicide, and mechanical vegetation removal (Kappler et al. 2012). Research in Oak Openings Region will be applicable to other natural areas experiencing the same issues (e.g., woody encroachment, fire suppression) and using the same management tools (e.g., prescribed fire, mechanical removal). It is likely that management will become increasingly important in the future to create and maintain natural ecosystems, as anthropogenic pressures continue to increase and in the face of global climate change, further underscoring the need for research on its effects.

My study took a two part, multi-species, and multi-scale approach to measure the effects of management and management edges on nonvolant small mammals and bats in the Oak Openings Region. The multi-scales consisted of managed versus unmanaged sides within a site, the entire site, and at the landscape scale. I also compared the surveying techniques for nonvolant small mammals of tracking tubes and live traps. I wanted to answer the following questions: (1) was there a difference in the distribution of bat activity, bat diversity, and small mammal activity between managed and unmanaged areas? (2) what type of burn frequency was beneficial for bat activity, bat diversity and small mammal activity? And (3) what vegetation and habitat structures were important to promote bat activity, bat diversity, and small mammal activity? I hypothesized that the frequency of management practice would be directly and indirectly influencing the distribution, abundance, and diversity of bats and small mammals in Oak Openings Preserve. Surveys for small mammals were conducted using tracking tubes and live traps. Surveys for bats were conducted using acoustic monitors.

Each part has been separated into its own chapter and written as a stand-alone manuscript. In Chapter 1, I used paired acoustic monitors with one monitor on the unmanaged side and the other monitor at least 65 meters away in the middle of the managed side of each site. Using this approach, I compared the diversity and abundance of bat species on managed and unmanaged sides of a site and compared various burn frequencies among all the sites. There were 9 sites selected, in total, throughout Oak Openings Preserve. In Chapter II, I used tracking tubes and live trapping in the same sites as the bat surveys. I used these surveys to compare activity of nonvolant small mammals on managed and unmanaged sides of a site and compare various burn frequencies among all sites. Through these two studies, my research addresses the question of how do changes in spatial environmental heterogeneity from management affect the abundance, diversity, and distribution of small mammals and bats in northwestern Ohio. In addition, it provides management recommendations to land managers on key habitat and vegetation aspects to focus on in order to create natural remnants that benefit the ecosystem as a whole.

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CHAPTER I: MANAGEMENT EDGES EFFECTS ON THE DISTRIBUTION, DIVERSITY, AND ABUNDANCE OF BATS

Introduction

Bats are important to study because they are essential to ecosystems and have been experiencing an increase in threats over the past decade (Hart 2004). Some of the threats affecting bats are white-nose syndrome, habitat loss, fragmentation, and the increasing demand for wind energy (Hart 2004, Austin et al. 2018). Bats are diverse, high trophic level predators that are the primary predators of nocturnal flying insect and aid in pest control (Blakey et al. 2018, Hart 2004, Morris et al. 2010, Turner 2018, Hollen 2017). Habitat structures heavily influence foraging and roosting of bat species in an area. Land management can have large impacts on the structure and composition of the habitat; therefore, it is critical to understand how that affects the activity, distribution and diversity of native bat species.

Weight, body size, and wing loading of bats determine if the bat can succeed in open or cluttered areas (Hart 2004). Wing loading is the proportion of the bat's weight to wings size/shape (Hart 2004). Large bodied bats with narrow wings are adapted to forage and thrive in more open areas and have difficulty maneuvering and detecting prey in cluttered areas (Blakey et al. 2018). Examples of bats that have higher wing loading, larger body size, and lower frequency calls are hoary bats, *Lasiurus cinerues*, and silver-haired bats, *Lasionycteris noctivagans* (Hart 2004). Smaller sized bats are specialized for maneuvering in cluttered areas and this allows for prey differentiation from larger sized bats (Blakey et al. 2018). Examples of smaller sized bats are *Myotis* species like little brown bats, *Myotis lucifugus* (Hart 2004). Some species of bats are considered generalist, and these species will use a variety of open and closed habitats (Hart 2004). Examples of these bats are big brown bats, *Eptesicus fuscus* and eastern red bats, *Lasiurus* *borealis* (Hart 2004). Heterogeneity in habitat can allow for a variety of species of bats to thrive in the area without competition and resource depletion, also bat species may need a variety of habitats for different ecological functions, e.g., reproduction, foraging, roosting. Clutter-adapted bats rely on vegetation for cover from predation and if their habitat is cleared it could become detrimental to that species (Blakey et al. 2018). Alternatively, if open adapted bats lose their open areas from overgrowth and woody vegetation encroachment then those species will not flourish. Land management is an important tool to maintain preferable habitat for various types of bat species in an area.

Common land management activities (management hereafter) for natural areas include prescribed fire, mechanical vegetation removal, and herbicide treatments. Many natural areas suffer from woody encroachment, fire suppression, and damage by invasive species (Gustafson 2018, Wood et al. 2011, Twidwell et al. 2016). Management practices open forest canopy, remove leaf litter, recycle nutrients back into the environment, remove competitive plant species, and promote wildlife conservation to create favorable conditions for native wildlife (Glasgow and Matlack 2006, Wood et al. 2011). Without management practices, forest may become overgrown, herbaceous vegetation may be suppressed, and there will be a loss of vegetation and wildlife diversity (Hanberry and Abrams 2018).

This study focused on prescribed burning because fauna is often overlooked in fire studies (Dixon et al. 2019). Fire history showed that wildfires caused by lightning strikes were common in many habitats before human influences (Iverson et al. 2008, Austin et al. 2018). Native Americans set fires to forests to preserve forest ecology before European settlers occupied the land (Boyles and Aubrey 2006, Brewer & Vankat 2004, Austin et al. 2018). European settlers began to suppress natural fires, which have altered vegetation structures and wildlife composition on natural remnants (Iverson et al. 2008, Twidwell et al. 2016). Human land use change, anthropogenic climate change, fire suppression, and drought have caused an increase in fire intensity and frequency and this is dangerous for humans and wildlife around the world (Blakey et al. 2018, Law et al. 2019). Park managers are using prescribed burning to restore grasslands, savanna, and prairie habitats that have been impacted by invasive species and woody encroachment (Cox et al. 2016, Braun de Torrez et al. 2018). Fires can alter forest structure by removing clutter and increasing open space to allow early successional species to thrive and benefit open area adapted species (Blakey et al. 2018, Nimmo et al. 2019, Austin et al. 2018). According to Dixon et al. (2019) areas burned between half a year to two years and six to twelve years before their study were more structurally complex when compared to areas that had gone longer unburnt. The majority of vegetation complexity for the burned areas was found in the shrub and understory areas (Dixon et al. 2019). This complexity (or the lack of it) should impact bat species differentially depending on their foraging and roosting needs.

The impact of prescribed burns on wildlife may vary from direct impact (e.g., mortality) to indirect effects (e.g., fragmentation). Some factors that can lead to the increase in mortality after a prescribed burn are: increased hard boundaries because of increase in size, frequency, severity, and intensity of burns; loss of stepping stones and unburned patches for refuge; loss of cover from predation; and increased travel time to safety (Nimmo et al. 2019). Fragmentation heavily impacts organisms during and after a burn because fragmentation interferes with the ability of an organism to move for better resources (Nimmo et al. 2019). Habitat patches that are closer in time since last fire (fire age) are more structurally similar than patches that are farther apart in fire age, so adjacent habitats with different fire ages may impact dispersal from one area to another depending on how hard or soft the edge appears (Nimmo et al. 2019).

According to Law et al. (2019), bats' response to fire is poorly known, but it is known that bats are sensitive to changes in forest structure and invertebrate availability. Bats can be directly impacted by fire through mortality and injury, and indirectly through roost availability, habitat structure, and prey availability (Blakey et al. 2018). Open and edge adapted bats benefit from fires through the removal of clutter and opening of canopies, but clutter adapted bats may not benefit from fires as the loss of vegetation can make them more vulnerable to predators and reduce foraging opportunities (Blakely et al. 2018). Heterogeneity in forest structure is important to benefit all native bat species. Bats that have been radio-tracked during a prescribed fire were moving away from the smoke of a fire, but quickly moving back to the burned area after the fire was put out because of the increase of insects and roost availability (Law et al. 2019). Studies that looked at bat responses longer after a fire found that there was higher bat activity within a few months after burning (Law et al. 2019). Some bats prefer to roost in snags and snags can be created by management practices (O'Keefe and Leob 2017). It is important to have a large amount and variety of snags as high snag density allows bats to increase bat roost switching to escape predators, parasites and select desirable microclimates (O'Keefe and Leob 2017). Bats rely on protected areas, such as parks and state forests, for protection, but may be impacted by management happening within these areas (Buckman-Sewald et al. 2014).

This study took place in Oak Openings Preserve in the Oak Openings Region of Northwest Ohio. This protected area has a large amount of management activity and conservation interest. The Oak Openings Region is a biodiversity hotspot and has many important natural ecosystems including: sand barrens, wet and sand prairies, oak savannas, and oak woodlands embedded in a matrix of agriculture and development (Brewer &Vankat 2004, Kappler et al. 2012, Schetter et al. 2013). Like many other regions in the Midwest, this area is heavily impacted by human involvement, fragmentation, and has a history of fire suppression (Brewer & Vankat 2004, Kappler et al. 2012, Buckman-Sewald et al. 2014). Park managers for Oak Openings Preserve, the largest protected area, rely on prescribed burning and other forms of management for invasive species removal, and restoration of oak savanna habitats. Because of the loss of natural disturbances, such as burning, oak forests are now being out competed by more shade-tolerant and fire intolerant species, such as hemlocks and maples, which are closing light gaps and dominating canopy cover in forests (Grennler et al. 2019, Austin et al. 2018). Park managers are relying on management strategies, such as prescribed burning, to reduce shade tolerant species and create open areas (Grennler et al. 2019). Park managers at Oak Openings Preserve try to burn across habitat types and utilize larger burn units to allow for flexibility in changing the perimeter of the burn to prevent from burning the same areas over and over (L. Sprow, Oak Openings Preserve Metropark, personal communication). When Toledo Metropark burns, they allow the unburned areas to remain unburned to allow refugia areas within the burn unit for wildlife and allow for a more heterogenous landscape (L. Sprow, Oak Openings Preserve Metropark, personal communication).

In Oak Openings Preserve, prairies and savannas are burned every three years, oak woodlands are burned every five to seven years, and oak forests are burned every seven to ten years (L. Sprow, Oak Openings Preserve Metropark, personal communication). Previous research on Oak Openings Preserve has found that this area is the summer home to eight Ohio native bat species and it is an important stopover site for many migratory species, including bats, making it an excellent location to evaluate potential impacts on these important taxa (Buckman-Sewald et al. 2014). This research is likely applicable to other natural areas also impacted by anthropogenic activities and land use as managers elsewhere face similar habitat management challenges. Additionally, since many natural areas are actively managed, it is important to understand how management is impacting vertebrates that are not regularly studied in fire research (Schneider-Maunoury et al. 2016).

The purpose of this research was to understand how management, especially prescribed burning, impacts bats and evaluate if the abundance (measured as relative activity) and diversity of bats were affected, especially by managed habitat edges. I used paired acoustic monitors to survey bats in habitats with different burn frequencies and along managed edges. The scales of this research consisted of the managed versus unmanaged side of each site, the entire site, and the landscape scale. I explored the following questions: (1) was there a difference in bat activity and diversity between managed and unmanaged areas? (2) what type of burn frequency increased bat activity and bat diversity and (3) what vegetation and habitat structures were important to promote bat activity and bat diversity? I hypothesized that the frequency of management activities was directly and indirectly influencing the distribution, abundance, and diversity of bats in Oak Openings Preserve by altering habitat and vegetation structure. For this research, distribution is defined as the location of organisms of interest in relation to managed and unmanaged area and landcover types. I expected to see the highest bat activity on the unmanaged side but close to the managed side, as bats are likely to be utilizing important resources created by prescribed burns while directly avoiding disturbance. Bats are heavily influenced by changes in foraging and roosting and prescribed burning can impact both. I also expected to see more bat activity in habitats that had specific landscape variables that can be created and/or maintained by burning. Vegetation characteristics that I think are important for bats are snags and tree density for roosting and downed logs for insect availability. I thought areas that were burned in the high category (3 or more burns in the last eight years) would have higher bat diversity and activity because these areas should be more open to allow variously sized bats to forage successfully. I also expected that having an unmanaged area adjacent to a managed area would be important because this could provide cover for smaller bat species and provide more trees for roosting. My overall goal was to identify important factors that can be maintained/ restored by management for park managers to provide the most favorable habitats for maximum bat distribution, activity, and diversity in the area.

Methods

Study sites

Bat and vegetation surveys took place from April 1st to October 1st 2019 in Oak Openings Preserve (Figure 1.1). Oak Opening Preserve is located 41” 32-34’N x 83’ 50-51’W, near Whitehouse, Ohio and is the largest protected area in the Oak Openings Region (Kappler 2009, Oak Openings 2020). Oak Openings Preserve is about 2023 hectares and consists of swamp forest, conifer forest, upland forest, floodplain forest, shrub forest, Eurasian meadows, prairies, sand barrens, savannas and wet prairies (Schetter & Root 2011, Oak Openings 2020). Oak Openings Preserve is managed by the Toledo Metroparks and their management plan for the savannas was to burn savannas once every three years (Kappler et al. 2012). The park was also managed by using herbicides, and manual target vegetation removal (Cross et al. 2015). Oak Openings Preserve is the warm season home to eight native bat species (Buckman-Sewald et al. 2014). Park managers plan burns for the spring and fall, and these burns can coincide with bat movement activities. Study sites were selected based on number of burns per area, if they were adjacent to an unmanaged area for comparison and mapped using ArcMap 10.2 (ESRI, 2011). Historical burn locations and Oak Opening Preserve management units were provided by the GIS Analyst from the Toledo Metroparks (Joshua Brenneman, pers. comm.). Sites were categorized based on the number of burns since 2012 in each management unit, i.e., high, medium and low categories (Figure 1.2). Low or no management areas had 0 burns in each management unit. Medium areas had 1-2 burns in each management unit. High areas had 3 or more burns in each management unit. All study sites were 60 meters by 80 meters (Figure 1.3). Each survey site was comprised of a managed area separated from an unmanaged area of equal size by an edge, which was usually a ~2m wide path. Even if the site had zero burns, the managed side was still labeled as managed for consistency. Other management may have been performed at these sites, but my focus was on the prescribed burning. The unmanaged sides were unburned since 2012 and not targeted for prescribed burns. I selected two sites for the low burn category, two sites for the medium burn category, and five sites for the high burn category. Since park managers often used hiking paths as fire barriers, almost all of the sites had paths in the middle separating the managed and unmanaged side, designated as the edge. Bat surveys took place on both sides at each study site.

Acoustic surveying

Bat surveys took place at nine sites throughout Oak Openings Preserve (Figure 1.2) using two stationary Anabat Swift detectors (Titley Electronics, Ballina, New South Wales, Australia). The Anabat Swift detectors were secured in a weatherproof case and stationed to a tree at 1.3 meters in height (Figure 1.4). These detectors allowed me to continuously record bat calls, which were used to identify individuals to species and estimate relative activity. The monitors used Anabat standard omnidirectional microphones that were attached directly to the monitors parallel to the ground that can detect bat calls within a 30 meter radius (Figure 1.4). The Anabat Swifts were set to a sensitivity value of 16, minimum frequency of 10 kHz, maximum frequency of 250 kHz, minimum event time of 2 milliseconds, and a recording widow of 2 seconds (Titley Scientific, Anabat Swift Bat Detector user Manual Version 1.6). One Anabat detector was placed near the edge of the site on the unmanaged side (Figure 1.3). The other detector was placed 65 meters away from the first Anabat detector on the managed side of the research site as each detector has a 30-meter recording radius. The detectors were left out overnight and collected the next day. Detectors were set to turn on automatically 30 minutes before sunset and recorded all night and turned off 30 minutes after sunrise. There was one recording session per month for each site. Acoustic sampling was not conducted on nights with wind speeds over 24 kph, temperatures below 10 ^{o}C, or with a high probability of rain. Bowling Green State University's Institutional Animal Care and Use Committee (IACUC) approved all research methods and protocols (Appendix C).

Environmental and landscape variable measurements

I measured vegetation characteristics once during the entire surveying period (June 26-28th 2019) along five 60 meter long transects parallel to the edge or path, Figure 1.3. Each transect was separated by 20 meters. Every 20 meters along each transect, vegetation measurements were taken with a 1 meter quadrat including: canopy cover, litter depth, percent cover, vegetation height, and vegetation density. Canopy cover, as a percent, was estimated visually from the center of the quadrat using Habitapp (Android App, Scrufster). Litter depth, in centimeters, was measured using a ruler at two points randomly chosen in each quadrat. I averaged the values at the two points to estimate average litter depth of each quadrat. Percent cover was measured by taking a photo of each quadrat at 1.2 meters above ground and applying a 10 by 10 grid using Abode Photoshop (Adobe Systems Incorporated, San Hose, California, USA). I categorized vegetation type as bare ground, leaf litter, graminoids (grass), crypto-biotic crust (soil crust containing moss/lichen/algae), ferns, angiosperms, trees, logs, and other vegetation (e.g. shrubs). In the grid, squares were counted that have the same vegetation type and results were converted into a percentage. I measured vegetation height in centimeters by placing a Robel pole next to the tallest vegetation in the quadrat. Vegetation density or obstruction in centimeters was estimated as the average of two Robel pole measurements. The Robel pole was placed in the middle of the quadrat at a height of 1.5 meters and measurements of the lowest point visible in centimeters were taken from the north and east cardinal direction by standing 3 meters away from the pole. Soil temperature, in degrees Fahrenheit was taken with a laser thermometer (IRT205, General Tools) and soil moisture, in percent water volume of soil, was measured with a moisture meter (HH150, Delta-T Devices).

At each study site, the total number of snags (i.e., fully dead standing trees), downed logs, and saplings (i.e., young trees below 1.65 meters in height) were visually estimated. Edge width (in centimeters) and types (e.g. paved, dirt, or no path) were also recorded at each study site.

I used GIS to measure the total area (square meters) of each landcover types within each site and the total areas of each landcover types for the managed and unmanaged side of each site. Landcover types were based on Root & Martin (2018) landcover map made for Oak Openings Region. The 15 landcover types for this layer were: turf/pasture, perennial ponds, wet shrubland, dense urban, cropland, upland prairie, floodplain forest, swamp forest, upland deciduous forest, sand barrens, upland savanna, residential/mixed, upland conifer forest, Eurasian meadow, and wet prairie (Schetter and Root 2011).

Call identification

Species calls were analyzed using AnalookW Software (Titley Scientific, version 4.4a) and location was mapped in ArcMap 10.2 (ESRI, 2011). Decisions on bat calls were based on various characteristics of the sonogram such as: frequency, amplitude, and shape of the call in comparison with the call library collected by previous research in the region (Sewald 2012, Nordal 2016, Turner 2018, Hollen 2017). For example, the hoary bat (*Lasiurus cinereus*) has the lowest call frequency, between 18 and 30 kHz and has some pulses under 25 kHz. The pulses are usually hooked at the bottom, and without a distinct pattern, can appear flat at the lower frequencies (Hollen 2017). Calls were only identified to species if a clean “pass” was recorded. Passes were defined as three or more clear and identifiable calls made by one species in one file (Parsons and Szewcwak 2009). In files with overlapping species, if passes were identifiable for two different species, those species were identified separately. Number of calls and number of each species were recorded through the duration of the evening, which was identified as 30 minutes after sunset and 30 minutes before official sunrise time (i.e., 10-12 hours). Calls that could not be identified to species were included in the activity analysis as unknown but not included in the diversity analysis. Two acoustic monitors were at each site, recording 10-12 hours per night, one night a month for each site, for five months. Number of calls was treated as a measure of relative bat activity and different calls based on sonogram characteristics were treated as a measure of bat diversity.

Statistical analysis

The total of bat calls and number of species were calculated at each site and also separated into managed and unmanaged sides for the entire surveying period. Vegetation characteristics were estimated once during the surveying season at the peak of vegetation growth for each site.

All tests were performed using JMP Statistical Analysis Software (JMP, Version 11. SAS Institute Inc, Cary, NC, 1989-2007). Pairwise Wilcoxon tests were run to test for significant differences in relative activity between sites, months, and managed and unmanaged sides (i.e., distribution). A Spearman’s rank correlation analysis was used to explore correlations and relationships for all variables individually (bat activity and diversity, vegetation characteristics and management characteristics) to see which management and habitat variables were impacting bat activity and diversity. Spearman's rank correlation analysis was also used to measure the correlations between bat data separated into totals, averages, minimums, maximums, and range and vegetation variables separated into totals, averages, minimums, maximums, and ranges. The totals, averages, minimums, maximums and ranges were highly correlated, so totals for bat activity and diversity were used for the rest of the analysis and for vegetation variables, averages and totals were used and specified. Variables were characterized as highly significant if the value was below the Bonferroni corrected value (used to correct for repeated measures) and nearly significant if above the Bonferroni corrected value but below 0.05.

A stepwise logistic regression was used to understand the relationship of bat responses (activity and diversity) to a combination of habitat variables (same set of non-correlated variables as the bivariate analysis). For the variables that were correlated in the spearman's rank correlation, one variable from each pair was eliminated for the multivariable analysis. The variables that were selected for inclusion in the model were chosen based on characteristics thought to be important for bats based on previous research (Sewald 2012, Nordal 2016, Turner 2018, Hollen 2017). The response variable of total calls was categorized into high, medium, and low using natural breaks in the data. This was to transform the data in order to use logistic regression. High activity represented between 760-1139 calls, medium represented 380-759 calls, and low represented 0-379 calls. For bat species (i.e., diversity), high represented 6-8 species, medium represented 3-5 species, and low represented 0-2 species.

I compared landcover types based on the landcover map created by Root & Martin (2018) in each site to the distribution of bat activity and number of bat species. I used the Spearman's rank correlation to look at relationships for bat activity and diversity to landcover types.

Variables were characterized as significantly correlated if $p < 0.05$ and $r > 0.5$. A stepwise logistic regression was used to understand the relationship of bat responses (abundance and diversity) to a combination of landcover types. For the variables that were correlated, one variable from each pair was eliminated for the multivariable analysis.

Results

Overall trends in diversity and activity

Summary of burn information was gathered from GIS layers provided by Toledo Metroparks and is shown for each site in Table 1.1. This study started in May and lasted for 45 nights over five months and consisted of approximately 500 recording hours. In total, there were 3,912 calls identified to species (Table 1.2). There were 20 calls that could not be identified to species. These calls were still included in estimates of total relative bat activity. All eight species known to be native in Oak Openings region were identified: *Eptesicus fuscus*, big brown bat (EPFU), *Lasiurus borealis*, eastern red bat (LABO), *Lasionycteris noctivagans*, silver-haired bat (LANO), *Nycticeius humeralis*, evening bat (NYHU), *Lasiurus cinereus*, hoary bat (LACI), *Myotis septentrionalis*, northern long-eared bat (MYSE), *Perimyotis subflavus*, tri-colored bat (PESU), *Myotis lucifugus*, little brown bat (MYLU), but I only detected all species at one site (Tables 1.1, 1.2, Figures 1.5, 1.6, 1.7, 1.8). On average there were 86 calls/night, which was highly correlated with total calls per night (Spearman, $p = <0.001$). Total calls per night were also highly correlated with total calls per hour (Spearman, $p=<0.001$). The number of calls varied across months from 0 to 807 per night across all sites (Table 1.3, Figure 1.9, Figure 1.10). The most common species was *E. fuscus* (Table 1.2, Figure 1.8, Figure 1.7).

Sites varied in bat diversity and activity. Site 8 had the highest total number of bat calls and site 6 had the lowest total number of bat calls (Figure 1.5 and Table 1.1). Site 5 had all eight species throughout the surveying period and sites 1, 2, 6, 7, and 9 all had a maximum of four species throughout the surveying period (Figure 1.6 and Table 1.1). Bat calls per night between sites were significantly different (Kruskal-Wallis, $p = 0.0237$). Nonparametric comparisons for each pair showed site 1 was significantly different than sites 2 and 5 (Wilcoxon, $p < 0.05$). Site 6 was significantly different than sites 9, 4, 5, and 2. Finally, site 7 was significantly different than sites 5 and 2 (Table 1.4). Bat species per night was not significantly different between sites (Kruskal-Wallis, $p = 0.4335$). Monthly bat activity between sites was significantly different for May and June (Kruskal-Wallis, $p = 0.0197$, $p = 0.044$, respectively). For May, site 4 was significantly different from sites 1, 7, 6, and 8. Also site 8 was significantly different from sites 9, 2, and 5 (Table 1.5). For June, site 1 was significantly different from sites 4, 8, 5, and 9. Also, site 8 was significantly different from site 6 (Table 1.6)

Influence of environmental features on bat activity and diversity

I evaluated significant relationships between bat activity and diversity to vegetation characteristics. For vegetation characteristics, I used averages, unless otherwise stated as average, minimum, maximum, and range were significantly correlated. Separated by site, total bat activity had a positive significant correlation with sapling number and average percent of bare ground (Spearman's, $\rho=0.75$ and $\rho=0.87$, respectively), Figures 1.11 and 1.12. Within sites, total number of bat species had a significant positive correlation to total sapling numbers (Spearman's, $\rho=0.92$), Figure 1.13, negative nearly significant correlation with average litter depth (Spearman's, $\rho=-0.76$), Figure 1.14, and average percent canopy cover (Spearman's, $\rho=-0.68$), Figure 1.15, and positive nearly significant correlation with average percent of other vegetation (Spearman's, $\rho=0.667$), Figure 1.16.

Influence of management on bat activity and diversity

The number of calls and the diversity of bats detected varied across sites and between the managed and unmanaged sides of each site, Table 1.2, Table 1.7, Table 1.8 and Figure 1.17, Figure 1.18, Figure 1.19. Overall bat activity was significantly different between treatments (managed and unmanaged) for all sites (Kruskal-Wallis, $p = 0.0011$). Total bat calls between managed and unmanaged sides were only significantly different in site 2 (Wilcoxon, $p =0.0119$). Number of bat species between treatments (managed and unmanaged) for each site, though, was not significantly different among sites (Kruskal Wallis, $p = 0.4060$).

My sites mostly consisted of dry open, dry forest, and wet forest habitat types such as sand barrens, upland prairie, upland deciduous forest, upland savanna, floodplain forest, and swamp forest (Figure 1.20 and Figure 1.21). Some sites had entirely different landcover compositions when comparing the managed and unmanaged sides (Figure 1.22 and Figure 1.23). For example, the managed side of site 7 was completely upland deciduous forest and the unmanaged side had floodplain forest, swamp forest, upland deciduous forest, and upland conifer forest (Figure 1.23). Also, the managed side of site 5 was almost entirely dry open habitat and the unmanaged side was largely wet forest (Figure 1.22). I found a significant negative relationship between bat diversity and total area of upland deciduous forest (Spearman's, ρ= 0.0228), Figure 1.24. In the case of site 2, where I found a significant difference in activity between sides, the managed side had ~163 square meters of upland prairie and the unmanaged side had zero square meters of upland prairie, but consisted of ~715 square meters of upland deciduous forest (Table 1.9 and Figure 1.23).

When sites were separated by treatments within sites, bat activity was significantly negatively correlated to average litter depth (Spearman's, ρ= -0.62), Figure 1.25, nearly significantly positively correlated with average vegetation height (Spearman's, ρ=0.50), Figure 1.26, significantly positively correlated to average vegetation density (Spearman's, ρ= 0.59), Figure 1.27, and negatively correlated with average percent canopy cover (Spearman's, ρ= -0.59), Figure 1.28. Number of bat species was nearly significantly negatively correlated to average litter depth (Spearman's, ρ= -0.52), Figure 1.29, and average percent canopy cover (Spearman's, ρ=-0.47), Figure 1.30. Number of bat species was also nearly significantly positively correlated to average percent of other vegetation (Spearman's, ρ=0.51), Figure 1.31, and significantly positively correlated to average vegetation density (Spearman's, ρ=0.62), Figure 1.32, and average percent of bare ground (Spearman's, ρ=0.61), Figure 1.33.

Influences of management on environmental variables

There were some significant relationships between the management characteristics and environmental variables. I found that total burn number since 2012 was significantly positively correlated to average soil temperature (Spearman's, ρ= 0.81) and nearly significantly negatively correlated with average soil moisture (Spearman's ρ= -0.67). Burn number since 2016 was significantly positively correlated with average soil temperature (Spearman's, ρ=0.88). Year since last burn was nearly significantly negatively correlated with average vegetation height (Spearman's ρ= -0.70), negatively correlated with average tree cover (Spearman's ρ = -0.67), and negatively correlated with average other vegetation for ground cover (Spearman's ρ = -0.70), Table 1.10.

Relationship between management and environmental variables on bat activity and diversity

I used stepwise logistic regression to understand what combination of variables most influenced bat activity and diversity. The best models, shown in Table 1.11 and Table 1.12, included management and vegetation characteristics. The best models for landcover types are in

Table 1.13 and Table 1.14. For bat activity the strongest model consisted of positive relationship with burn number since 2016, negative relationship with snag number, and positive relationship with crypto-biotic crust average (AICc=23.692, R-square= 0.958, p= 0.0007), Table 1.11. For bat species number the strongest model included positive relationship with sapling number (AICc=16.2329, R-square= 0.518, p=0.0288), Table 1.12.

I also examined the relationship between bat activity and diversity in relation to land cover types. The strongest model for bat activity consisted of a positive relationship with area of upland savanna, and area of wet prairie, and a negative relationship with area of residential/mixed (AICc= 8.257, R-square= 0.992, p= <0.0001) (Table 1.13). For bat diversity, the strongest model consisted of a negative relationship with area of upland deciduous forest (AICc=19.01, R-square= 0.344, p=0.0969) (Table 1.14).

Discussion

Overall trends in diversity and activity

Fire is an important process in shaping and maintaining ecosystems (Braun de Torrez et al. 2018). Fire suppression has altered vegetation structure, species assemblages, and ecological function in habitats so park managers reintroduced fire back into certain systems to alter some of those effects (Braun de Torrez et al. 2018). Multiple studies have shown that fire is important for opening canopies, removing invasive species, recycling nutrients, and removing leaf litter or fuel for wild fires, but it is not clear how fire impacts organisms such as bats (Glasgow and Matlack 2006, Wood et al. 2011). It is also uncertain how edges created from management impact bats. While studies on fires usually focus on the habitat quality as a whole, vegetation characteristics, or the species of concern that is the target of management, the purpose of this study was to evaluate how management, more specifically prescribed fire, is impacting bats, which are rarely the focus of management studies. According to Law et al. (2019), bats responses to fire are poorly known, but their responses to vegetation and habitat changes suggest that they may be very sensitive to fire and other management.

Bats can be impacted directly and indirectly by fire and it is important to fully understand the relationship of this impact because bats are essential to many ecosystems (Hart 2004, Blakey et al. 2019). In my study, I found that site 8, which was the site that was burned right before I started my field season, and burned the most (four burns) in the last eight years, had the greatest bat activity and the second largest bat diversity. These results are comparable to one study that found higher bat activity within a few months after burning (Law et al. 2019). On the other hand, sites 7 and 6 had the second largest number of burns since 2012 (three burns) and these sites had low levels of activity and little diversity. The differences in these sites with the same degree of burn management illustrate that management is not the only factor that is impacting bat species number and bat calls and it is important to consider the local context and characteristics of each site.

Influence of environmental features on bat activity and diversity

Through my research, I found some vegetation characteristics that had relationships with bat activity and bat species number. Bat activity had a positive relationship with average bare ground percentage and sapling number when looking at each site as a whole. Bat species had a positive relationship with total sapling number and average other vegetation for ground cover and a negative relationship with average litter depth and average percent canopy cover. It is important to keep in mind that this study focused on activity and not roosting. The relationship between bat activity and species and sapling number is something that is not recorded in the literature. This relationship may be so strong as saplings increase insect abundance and are low enough in the canopy that they do not form excessive clutter for bats to maneuver through (Castagneyrol et al. 2012). Austin et al. (2018) stated that many insect taxa, including Lepidoptera, which is a large source of bat prey, benefit from prescribed fire because fire increased the growth of nectar producing plants and new growth that provides substrate for egg laying and a food source for larva. Fires can promote new growth, such as sapling growth, so an increase in fires can lead to an increase in saplings which, based on these results, benefit bat activity and species (Blakely et al. 2018, Hanberry and Abrams 2018). These results underline the importance of measuring various vegetation and habitat structures to understand the effects of management on organisms.

Influence of management on bat activity and diversity

Blakey et al. (2018) found that low severity fire promotes growth of larger trees by thinning out smaller less developed trees and this benefits both small and medium sized bats. One study found that insect abundance increased soon after a prescribed fire and this may benefit bat species because nocturnal flying insects are a primary prey source (Law et al. 2019). Overall, bats will be impacted either positively or negatively by management by how it impacts their habitat and/or prey. Another study found that overall insect abundance increased soon after a prescribed fire and this shifted the foraging ranges of larger bats towards burned areas (Law et al. 2019). The same study also claims that the effects of prescribed fire on vegetation might have a greater effect on echolocating bats than insect abundance because high vegetation density can inhibit foraging efficiency, even when prey is abundant (Law et al. 2019). At the smallest scale, when each site was separated into managed and unmanaged sides for analysis, I found that bat activity increases with herbaceous vegetation (based on vegetation height and density), but decreases with canopy cover and ground cover. This is not similar to when bivariate vegetation analysis for bat activity was done on the site as a whole. This suggests a greater reliance of bat activity on increased vegetation in the understory which is something managers can monitor and manage. This could also explain why I found a negative relationship between the number of bat species and upland deciduous forest. Deciduous forest in this park has a lot of trees and clutter, so larger bats would have a hard time maneuvering through the habitat. Dixon et al. (2019) also suggested that low intensity fires will benefit bat activity and found understory vegetation density was negatively related to bat activity. The complexity of my results can be explained by the variety of bat species that I surveyed and that their responses are likely to vary depending of the species. My study emphasizes the importance of looking both at bat activity and diversity when studying the impact of management because it reveals dynamic community assemblages.

My results also showed that some sites had noticeable differences in the distribution of bat activity for managed and unmanaged sides within sites, although most were not statistically significant. For example, in site 8, I detected about 1000 bat calls on the unmanaged side versus 100 on the managed side. For site 2, there were about 600 bat calls detected on the managed side and 50 on the unmanaged side. This site was the only one with a significant difference between managed and unmanaged sides. I believe this is best explained by the fine-scale heterogeneity within my sites because some sites had differences in landcover between the managed and unmanaged side. The managed side of site 2 had zero square meters of deciduous forest and the unmanaged side had 46 square meters of deciduous forest. The managed side of site 2 had 163 square meters of upland prairie, which had been burned three times, and the unmanaged side had zero square meters of upland prairie. Burning and management opened up the managed side of site 2 and allowed more bat movement. One study mentioned that prescribed fire may lead to increased bat activity, especially for larger and less maneuverable bats, because of the lack of clutter as a result of fire (Law et al. 2019). Only site 2 had a significant difference in activity between managed and unmanaged sides, but there were differences between sites in general. Also, site 8 was burned a month before I started my research and yet there were no significant differences between managed and unmanaged sides. These results emphasize that the difference were based on the complexity within a site and not just the managed and unmanaged identity of the sides. So, managers can focus on the vegetation and structural aspects that I found as significant influences when managing an area, regardless of management approach.

Influence of management on environmental variables

Prescribed fire can open forest canopy, remove leaf litter, recycle nutrients back into the environment, remove competitive plant species, and promote wildlife conservation by creating environmental conditions that are favorable for native wildlife (Glasgow and Matlack 2006, Wood et al. 2011). Without fire management the herbaceous vegetation layer will be suppressed, and the forest floor can change from herbaceous vegetation to shade-tolerant woody shrubs and vines (Hanberry and Abrams 2018). If herbaceous plant diversity changes, then other wildlife species may decline as well as bats (Hanberry and Abrams 2018). During my study, I found a positive correlation between burn number since 2012 and average soil temperature and a negative correlation between burn number since 2012 and average soil moisture. This was likely a result of more open forest canopies, created by fire, allowing sun to hit the forest floor. I also found a negative correlation between years since last burn and average vegetation height, average percent of trees, and average percent of other vegetation, which is likely the result of changes in herbaceous vegetation layer the longer an area has not been burned. These relationships may provide an efficient way to monitor the potential impacts of management on bat activity. It is important to understand how management is impacting habitat characteristics because these can influence organisms and vegetation structure.

Relationship between management and environmental variables on bats

Effects of management on the habitat and organisms cannot be explained just by looking at individual characteristics of the site. The best models for bat activity suggested that bat activity was positively influenced by recent burns, sapling numbers and cryptobiotic crust ground cover but negatively influenced by the number of snags. I defined snags as fully dead standing trees. This study focused on bat activity (e.g., foraging, travel) and not roosting, which can occur in snags, so that may explain why I found a negative relationship with number of snags. One study that radio tracked Indiana bats to and from their roosting sites found that bats were captured with a range of 157 to 3731 meters from their roosts (O'Keefe and Loeb 2017). My sites were 80 meters by 60 meters so bats could be traveling to the sites to feed and then travel somewhere else to roost. Many studies have also found positive effects of burning on bat abundance because fires can open areas, reduce clutter, and provide favorable hunting environments for bats (Silvis and Williams 2015, Blakey et al. 2018, Law et al. 2019, Braun de Torrez et al. 2018, Austin et al. 2018, Burns et al. 2019), but frequency and intensity of fires can have a negative effect that I could not capture in a single season study. For example, overall bat activity was highest for Florida bonneted bats in sites that were burned in >3-5 year intervals but when burning intervals were 1 -5 years, Florida bonneted bat activity was low (Braun de Torrez et al. 2018). Braun de Torrez et al. (2018) stated that shorter burn intervals may create homogenous landscape with few resources because there would be a sparse understory and less structure. This can impact prey availability and roost availability for bats. On the other hand, longer burn intervals may create limited understory plant diversity and woody encroachment in the midstory which can impact flight maneuverability for larger bat species.

Top models for bat diversity also included a positive influence of crypto-biotic crust ground cover and burn number since 2016, but a negative influence of snag number, which suggests bat diversity was positively influenced by open areas. At the largest scale, the relationship between landcover types and bat activity and diversity was mostly consistent in that open canopy land cover types (e.g., savanna) usually had a positive influence while there was a slight negative influence of deciduous forest. These results reinforce the influence of structure on the bat communities.

A study done by Blakey et al. (2018) found that years since fire is an important predictor for bat occupancy in their study area, which was in California. Blakey et al. (2018) also emphasizes that importance of having rarely burned areas as well because clutter-adapted bats will benefit from more closed canopies. Another important factor that I would like to emphasize, and it has been emphasized in another study (Parkins et al. 2019), is the importance of having an unmanaged area adjacent to a managed area. This gives organisms a chance to escape during a burn and heterogeneity for species diversity. Fragmentation is a huge problem for organisms because it disrupts connectivity throughout a landscape and organisms are not able to find safety, food sources, habitat sources, and other organisms (Nimmo et al. 2019).

Conclusion

Measuring fauna can be a helpful tool for understanding the health of the habitat and how management might be impacting the environment. My study suggests that open areas created by management are valuable for bats, but also highlights important structural characteristics, such as saplings. Open areas facilitate maneuverability, but vegetation structure is needed to allow for protection from predators and food source availability, underscoring the complexity of habitat requirements for native bats. It is also important to highlight the importance of having an adjacent unmanaged area to allow for movement of organisms for protection from burns and increased resource access. My study also emphasizes the importance of studying both bat activity and diversity in order to get a fuller understanding of how management might be impacting bats because different species have different needs for foraging and roosting. Management is essential for maintaining and creating natural remnants but should allow for a mosaic of effects to increase heterogeneity and prove a variety of resources for native species.

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Figures

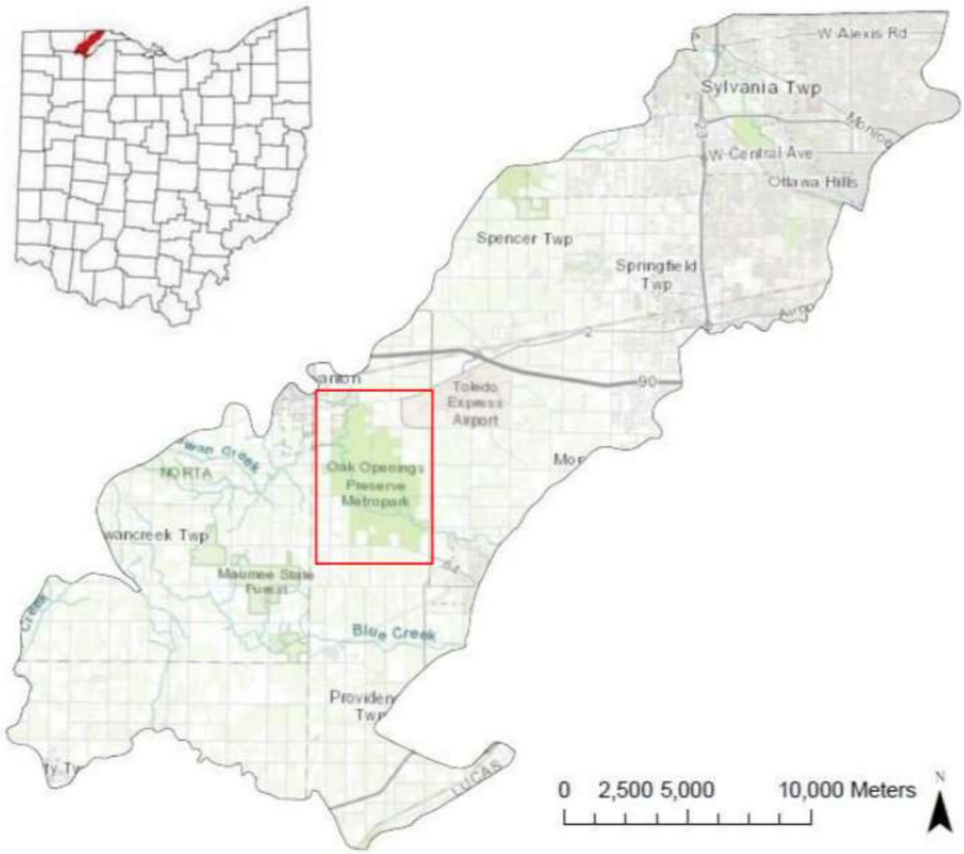

Figure 1. 1: The Oak Openings Region of Northwest Ohio (excluding Michigan portion) as defined by Brewer and Venkat (2004). Study area (Oak Openings Preserve) outline in red.

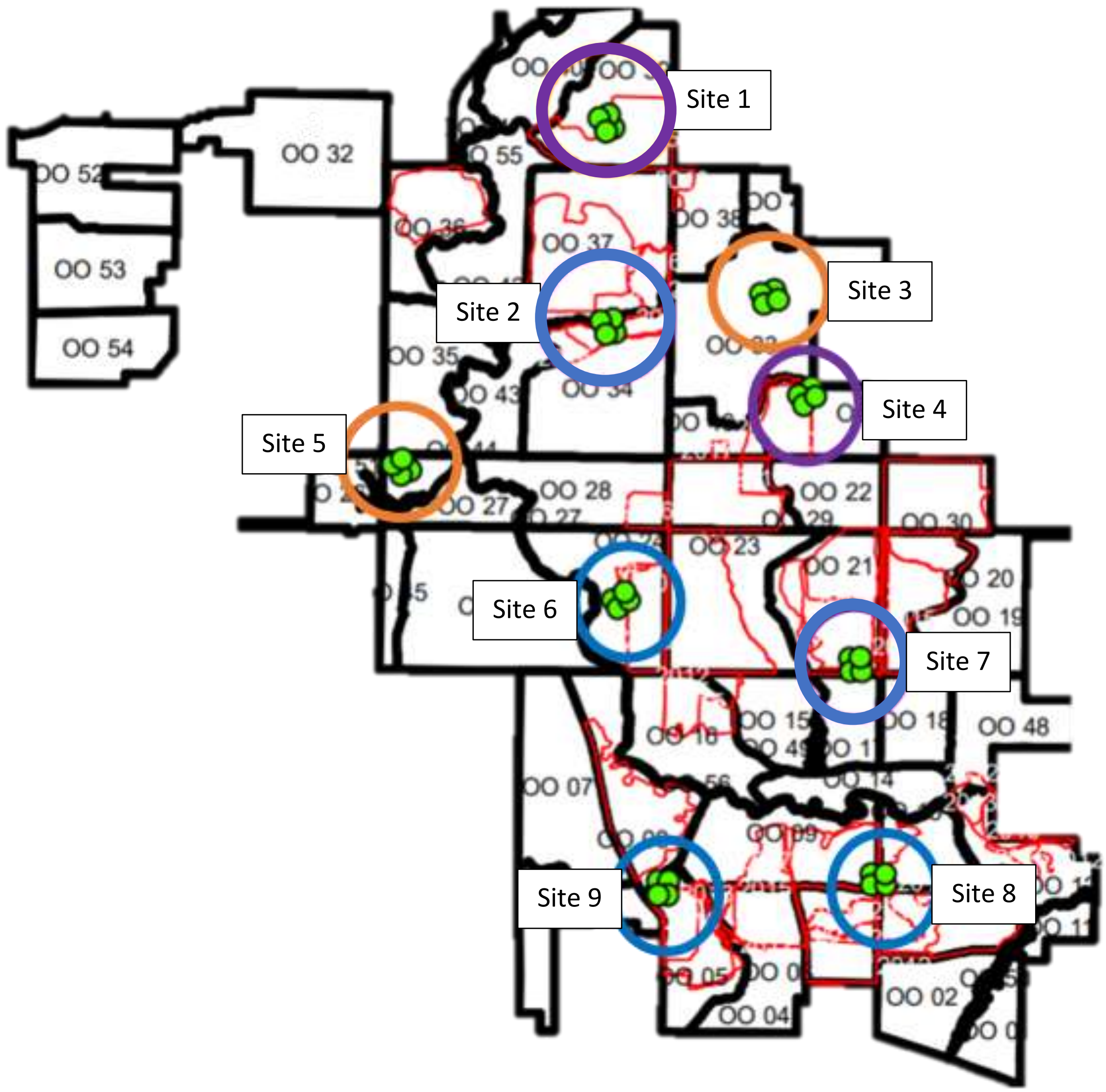

Figure 1. 2: Oak Opening Preserve separated by management units (black). Green dots are the 9 sites selected. Red lines are the outlines of burns since 2012-2019. Orange circles are sites in the low category (0 burns); purple circles are in the medium category (1-2 burns), and blue circles are in the high category (3-4 burns). Sites are labeled.

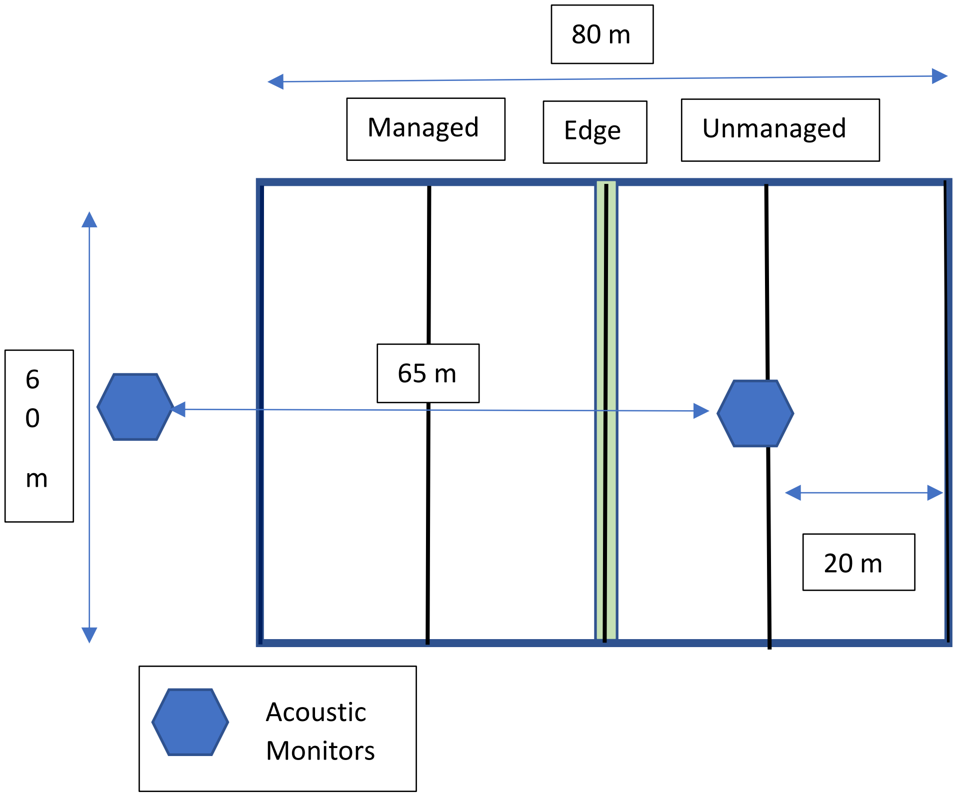

Figure 1. 3: The image above shows an example of a bat surveying site. At each site, two Anabat Swift acoustic monitors were placed one night each month. Acoustic monitors were 65 m apart. The sites are separated into a managed (burned) and unmanaged (not burned) side with an edge (path) in the middle. If the site was not burned, the managed side was still referred to as the managed side for consistency. The vertical black lines are the 60 meter transects used to survey vegetation.

Figure 1. 4: Picture of Anabat Swift mounted to a tree in the field.

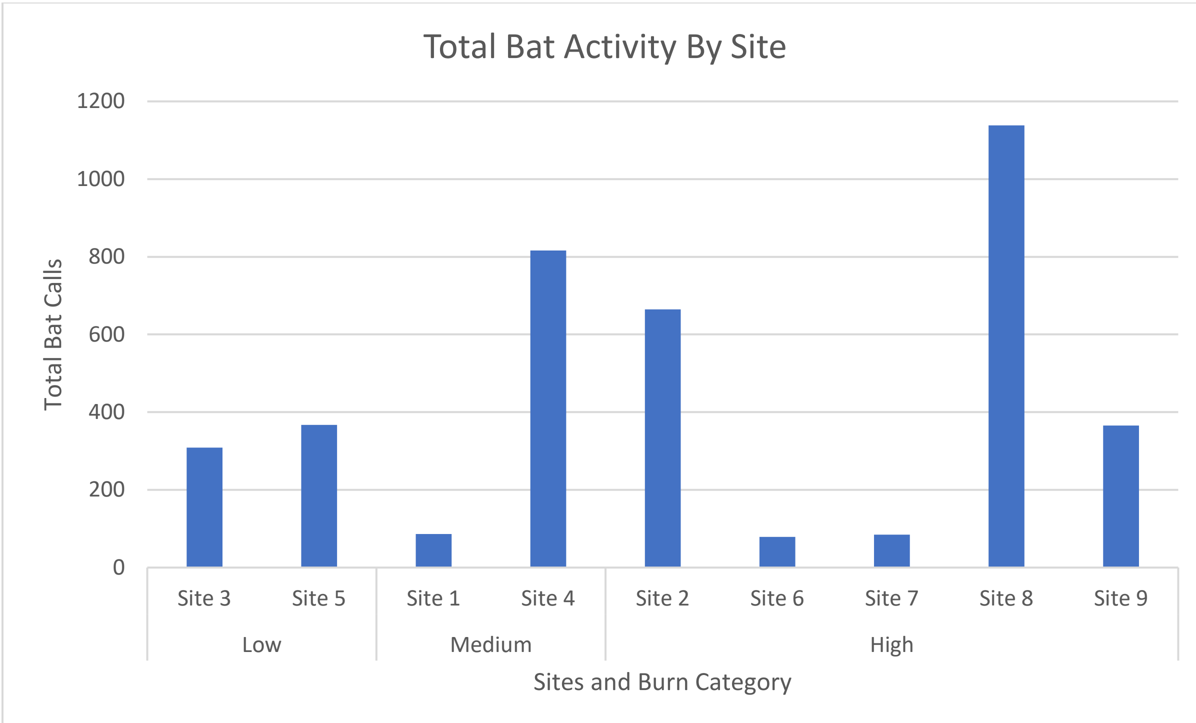

Figure 1. 5: Total number of bat calls for each site for the entire research season. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. Sites 4 and 8 had the highest amount of bat calls, while sites 1, 6, and 7 had the lowest.

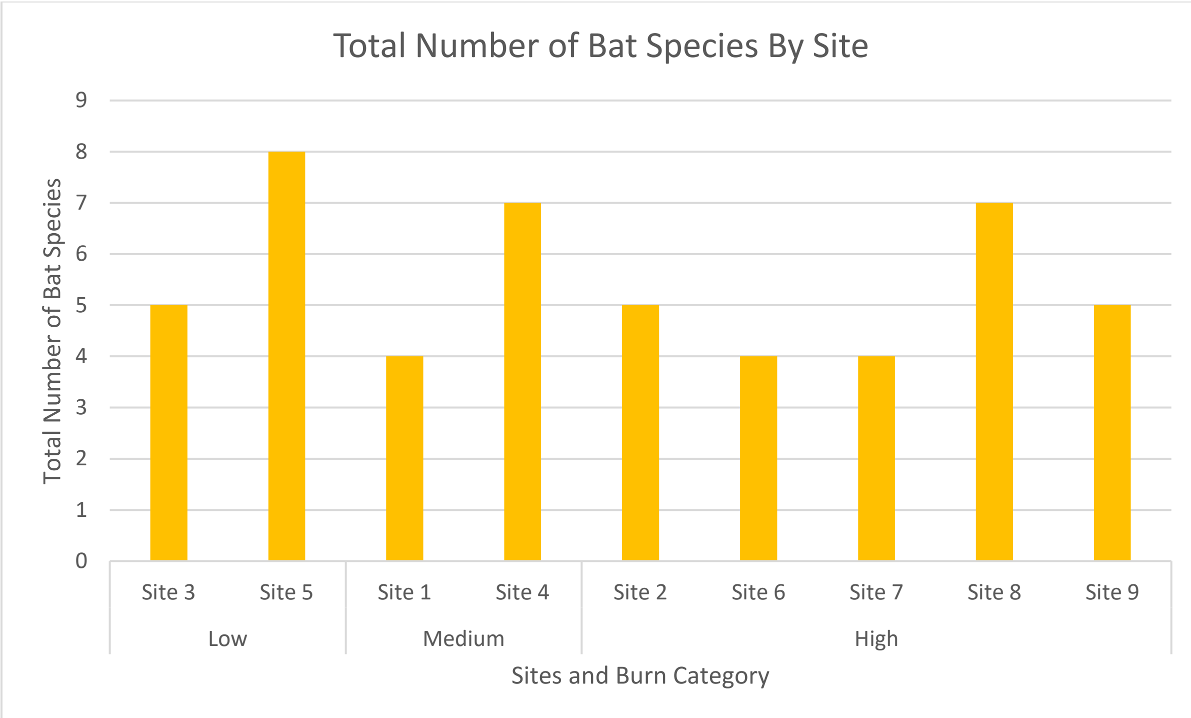

Figure 1. 6: Total number of bat species for each site for the entire research season. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. Site 5 was the only site that had all eight bat species recorded. Sites 1, 6, and 7 all had four species recorded.

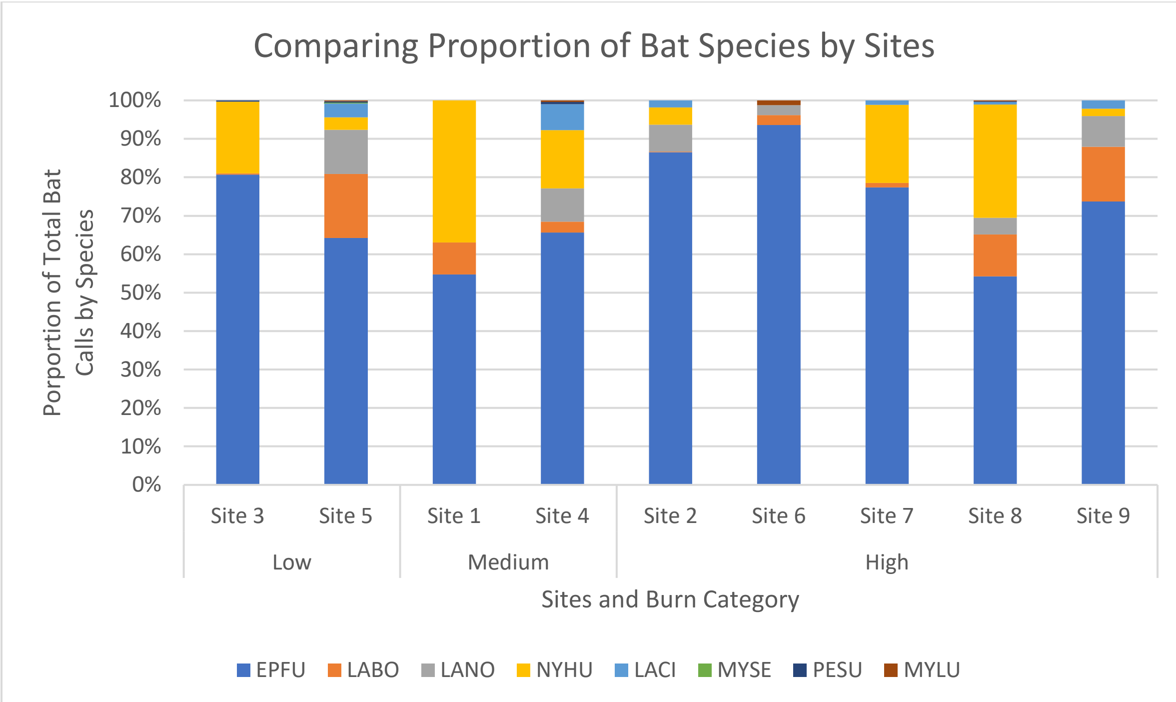

Figure 1. 7: Comparing the proportion of bat species for each site for the entire research season. The top of the bars represent 100% of the bat calls at that site and the individual colors represent the percentage of calls by each species at that site. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. *Eptesicus fuscus*, big brown bat (EPFU), *Lasiurus borealis*, eastern red bat (LABO), *Lasionycteris noctivagans*, silver-haired bat (LANO), *Nycticeius humeralis*, evening bat (NYHU), *Lasiurus cinereus*, hoary bat (LACI), *Myotis septentrionalis*, northern long-eared bat (MYSE), *Perimyotis subflavus*, tri-colored bat (PESU), *Myotis lucifugus*, little brown bat (MYLU).

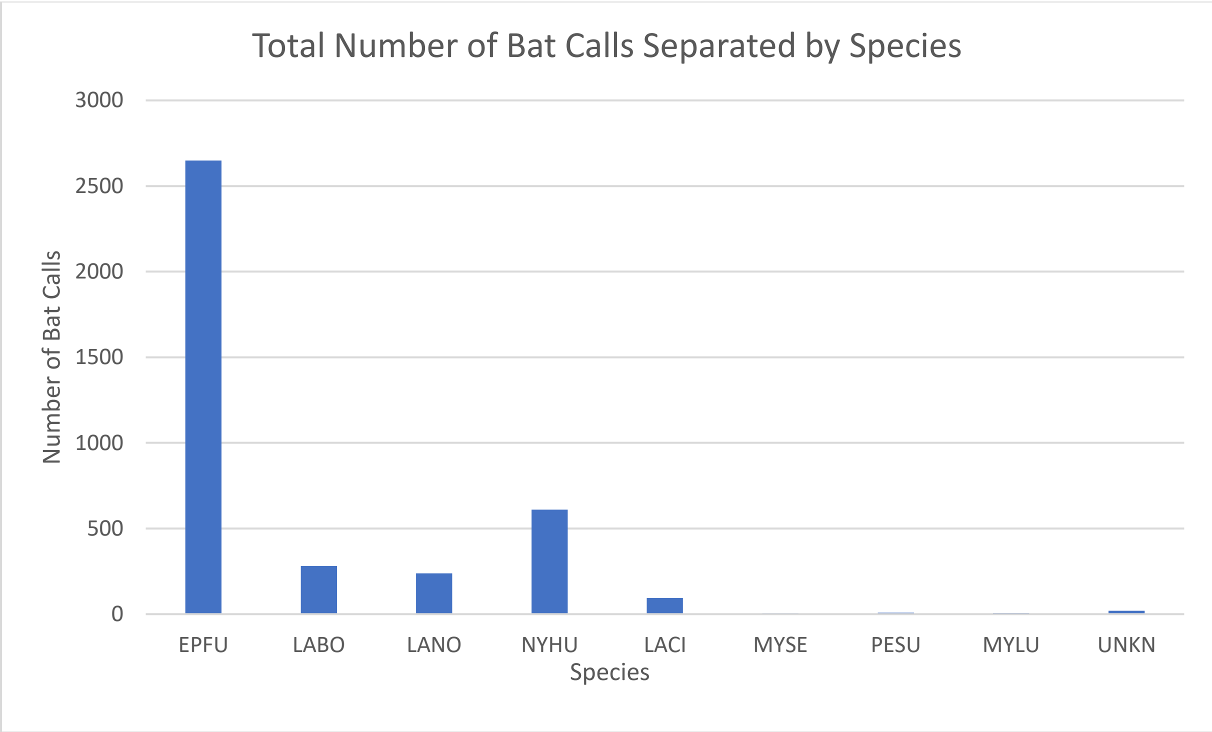

Figure 1. 8: Total number of bat call calls separated by species. *Eptesicus fuscus*, big brown bat (EPFU), *Lasiurus borealis*, eastern red bat (LABO), *Lasionycteris noctivagans*, silver-haired bat (LANO), *Nycticeius humeralis*, evening bat (NYHU), *Lasiurus cinereus*, hoary bat (LACI), *Myotis septentrionalis*, northern long-eared bat (MYSE), *Perimyotis subflavus*, tri-colored bat (PESU), *Myotis lucifugus*, little brown bat (MYLU), Unknown Species (UNKN). Unknown were calls that could not be identified to species. MYSE had 4 calls, PESU had 9 calls, and MYLU had 7 calls but because of scale, bars are hard to see on graph.

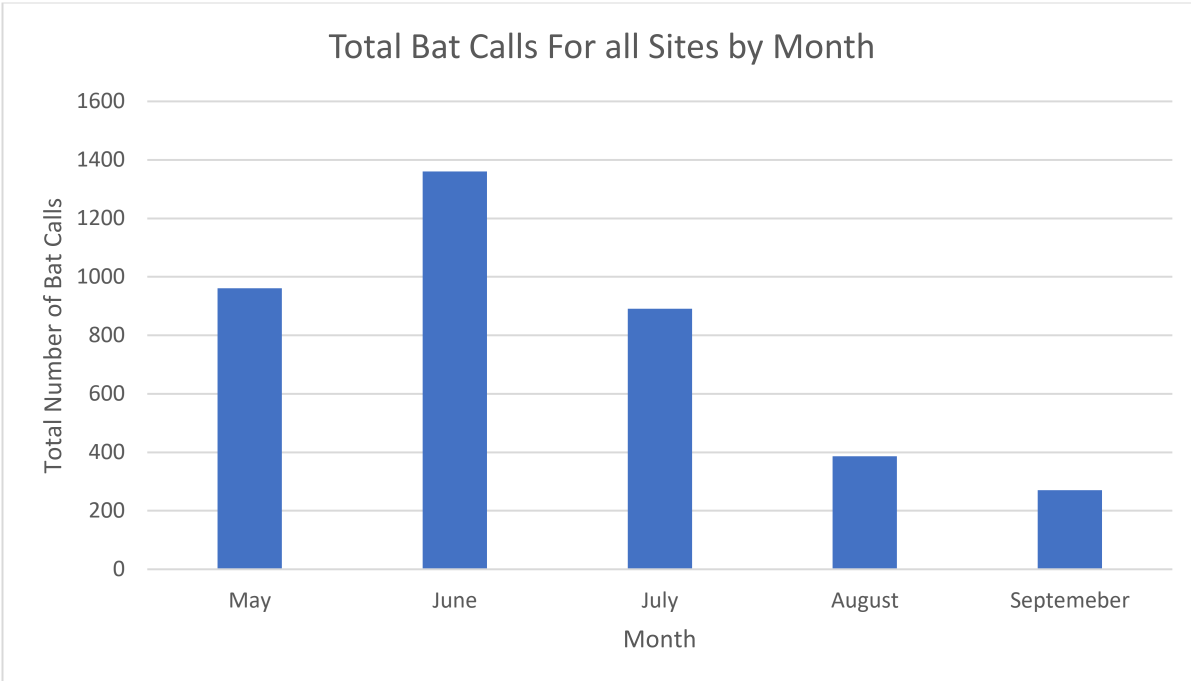

Figure 1. 9: Comparing total number of bat calls for all sites by each month. June had the most bat calls recorded and September had the least number of bat calls recorded.

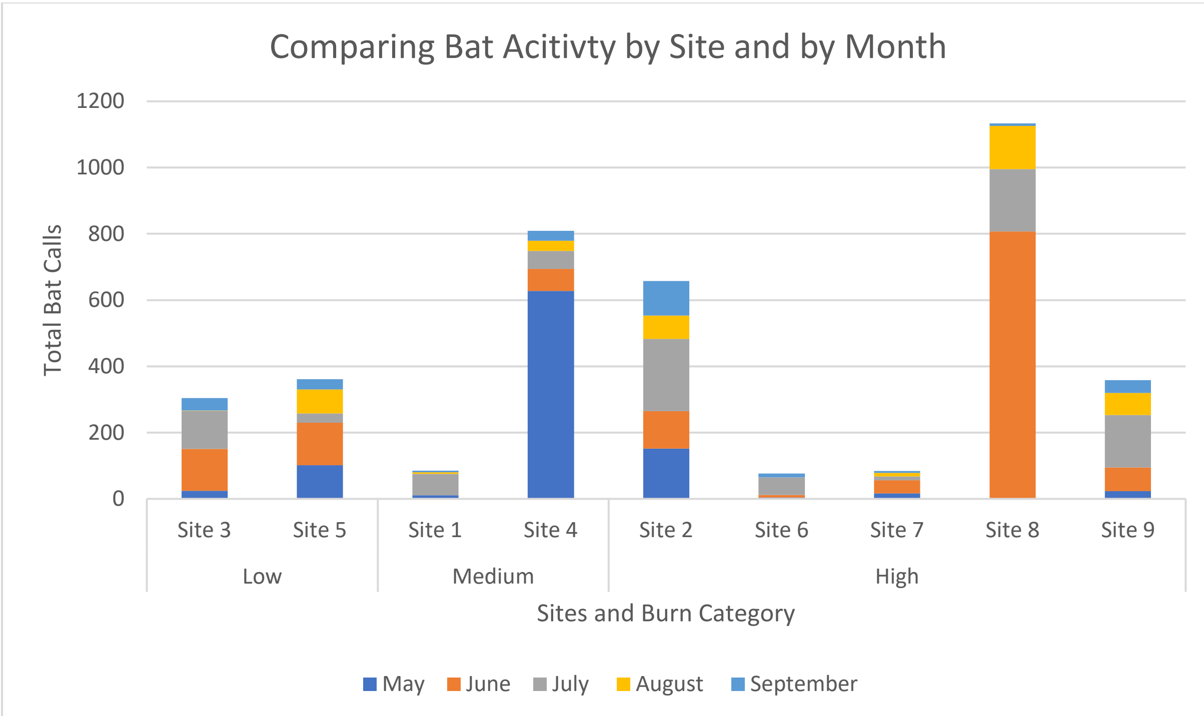

Figure 1. 10: Comparing the total number of bat calls for each site and by month. The different colors represent the number of bat calls for each month. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

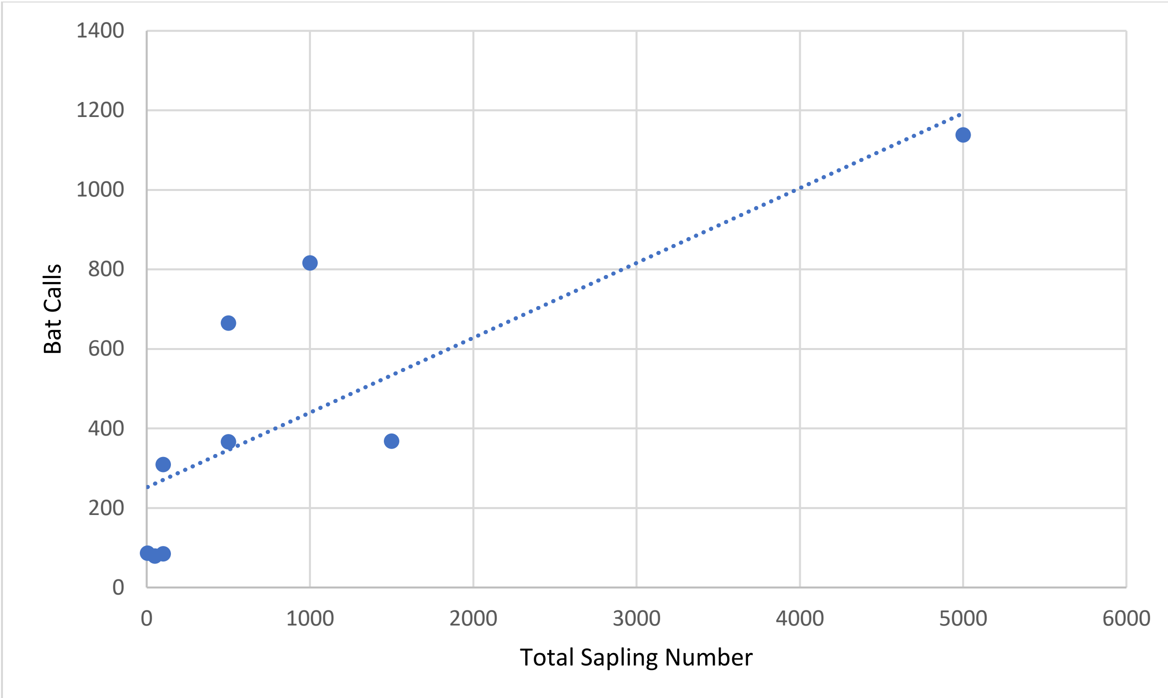

Figure 1. 11: Total bat activity by site compared to total sapling number across sites. Total bat activity had a positive significant correlation to total sapling number. Spearman's ρ=0.8740 p=0.0021*. Asterisk represents significance after Bonferroni Correction.

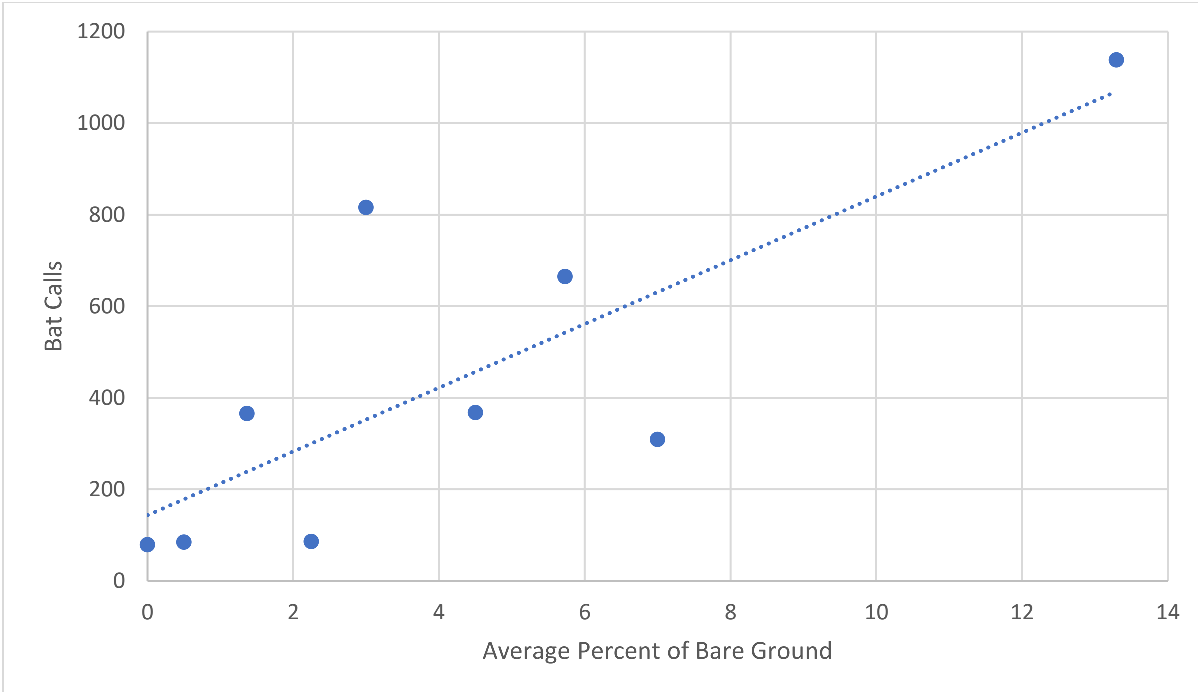

Figure 1. 12: Total bat activity by site compared to average percent of bare ground across sites. Total bat activity had a significant positive relationship with average percent of bare ground. Spearman's ρ=0.7500 p= 0.0199*. Asterisk represents significance after Bonferroni Correction.

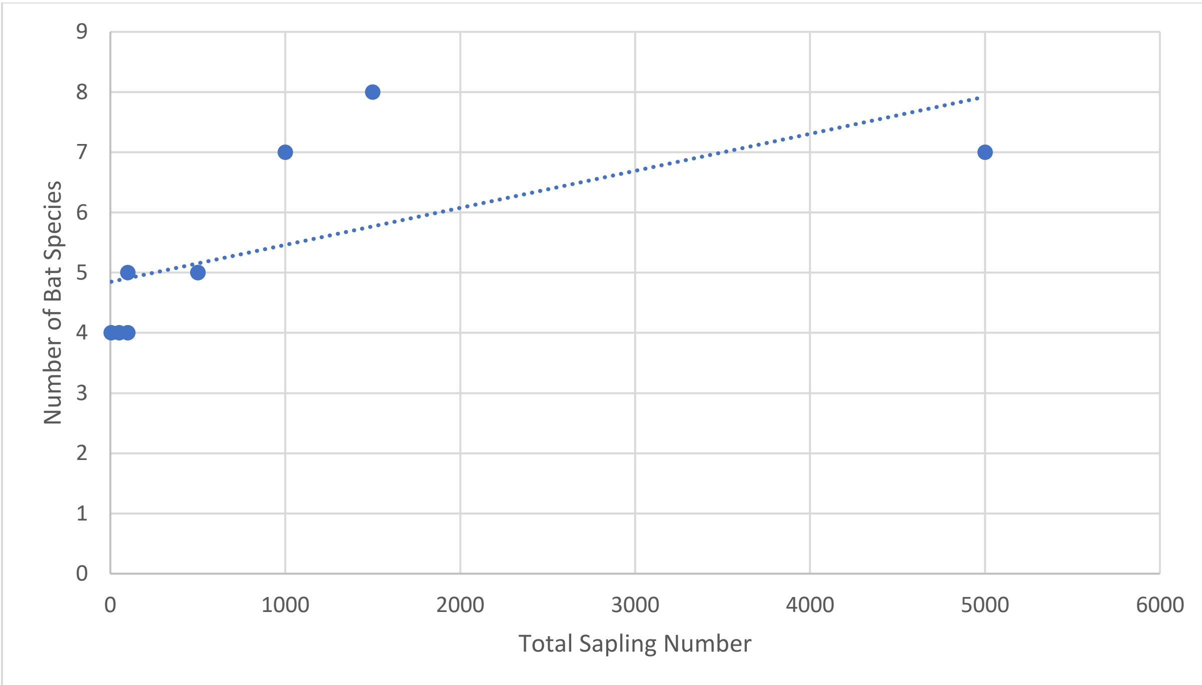

Figure 1. 13: Total number of bat species compared to total sapling number by site. Total number of bat species had a significant positive correlation with total sapling number. Spearman's ρ=0.9175, p= 0.0005*. Asterisk represents significance after Bonferroni Correction.

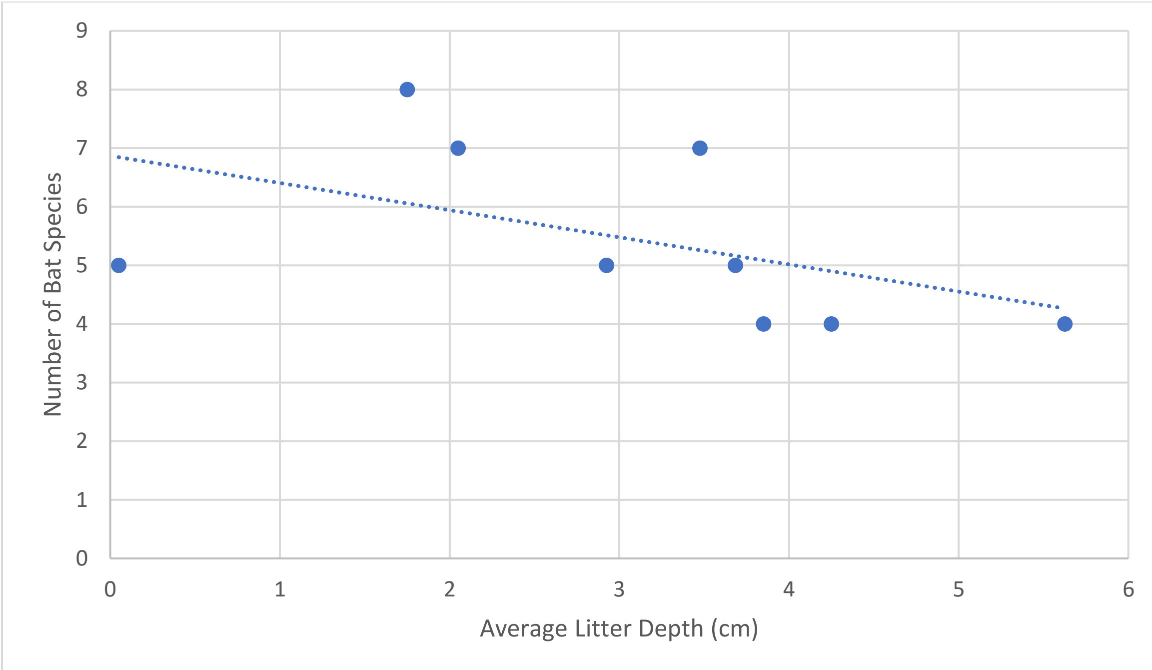

Figure 1. 14: Total number of bat species compared to average litter depth in centimeters by site. Total number of bat species had a nearly significant negative correlation with average litter depth. Spearman's ρ= -0.7625, p=0.0169.

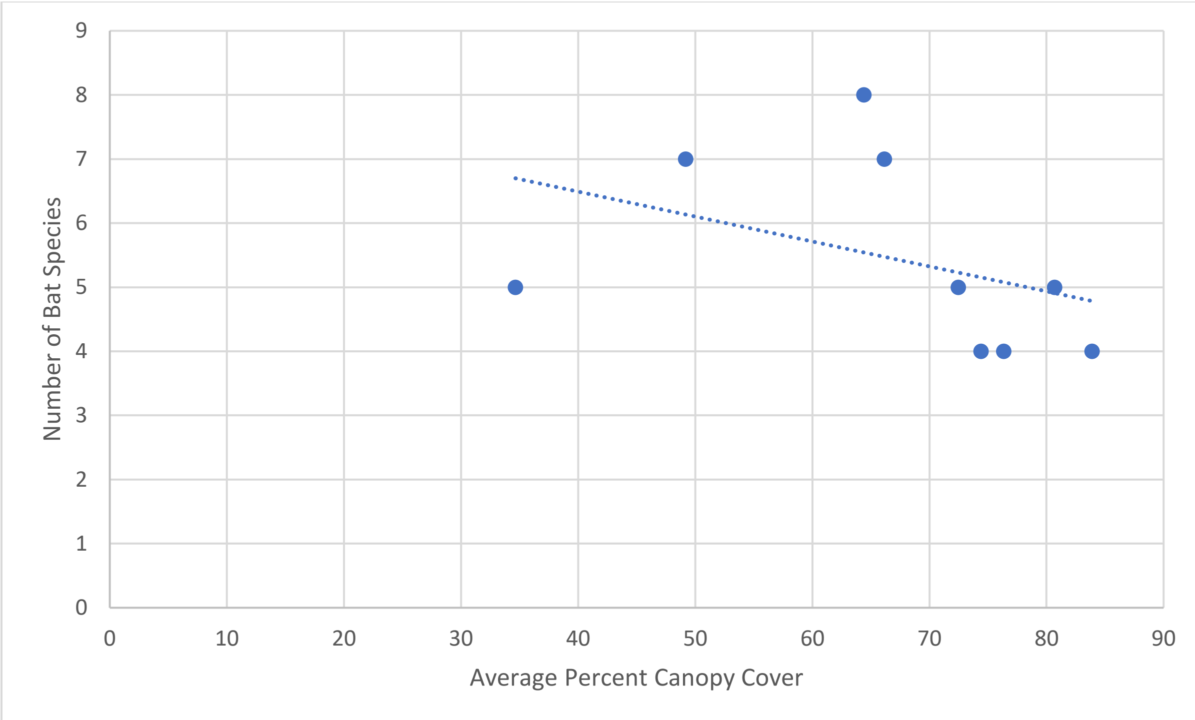

Figure 1. 15: Total number of bat species compared to average percent canopy cover across sites. Total number of bat species had a nearly significant negative relationship with average percent of canopy cover. Spearman's ρ= -0.6758, p = 0.0457.

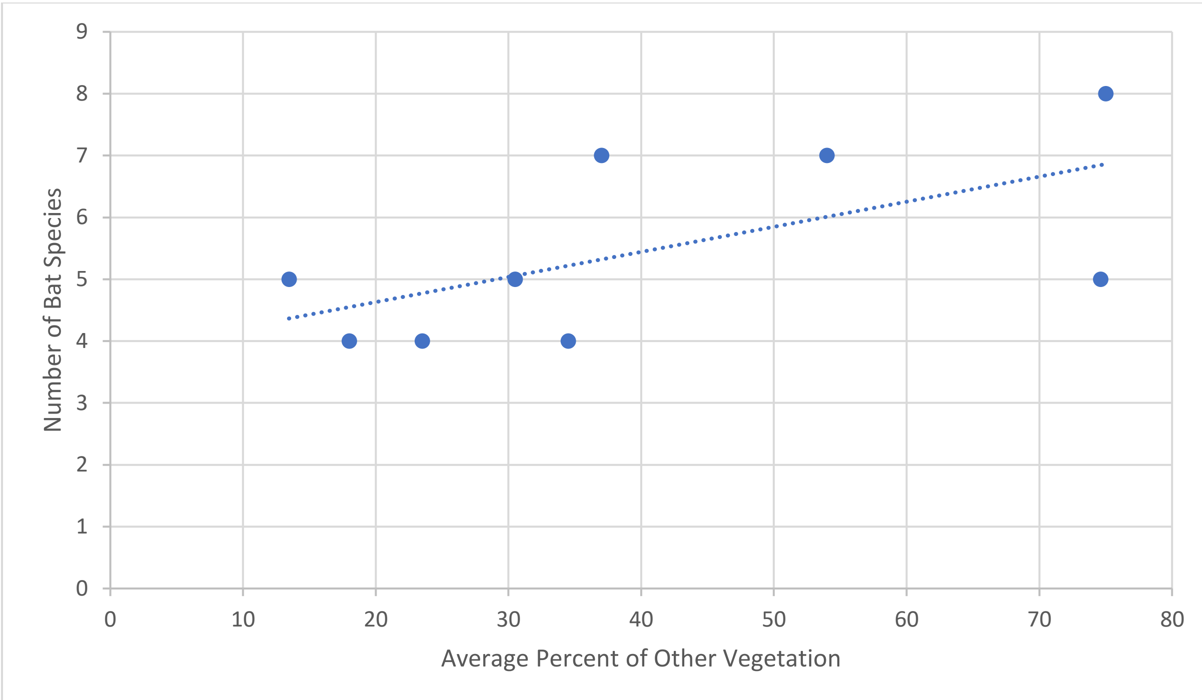

Figure 1. 16: Total number of bat species compared to average percent of other vegetation across sites. Total number of bat species had a nearly significant positive correlation with average percent of other vegetation. Spearman's ρ= 0.6672, p= 0.0496

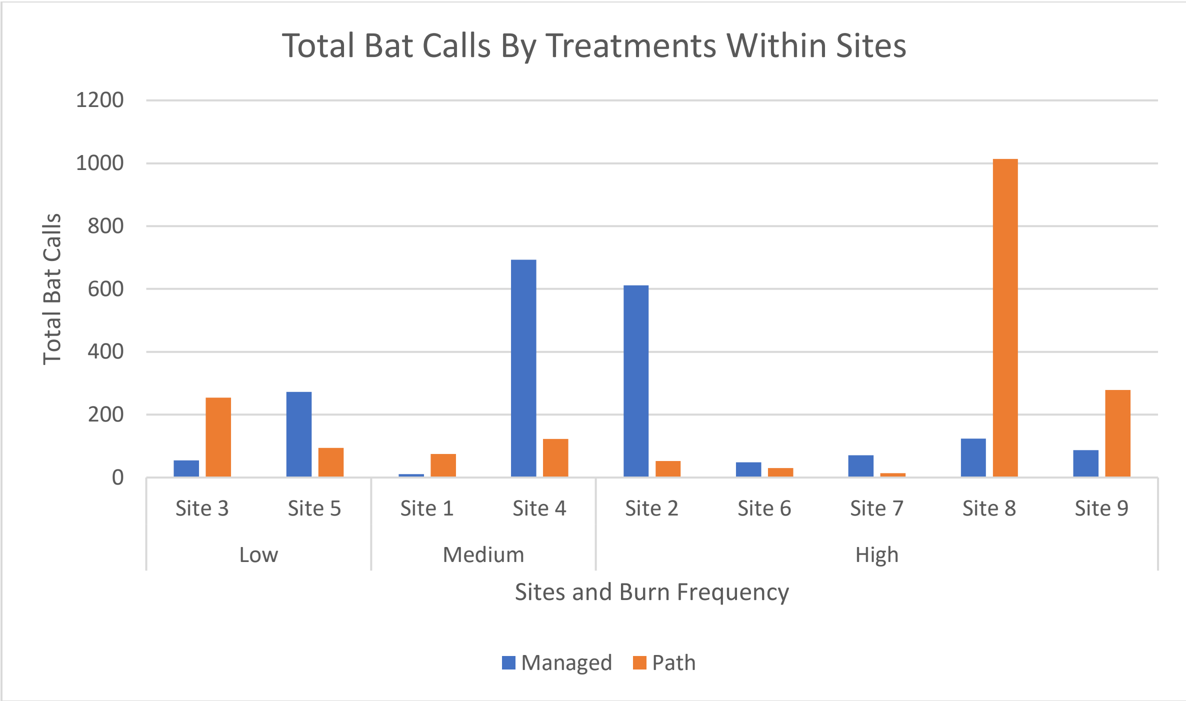

Figure 1. 17: Comparing total number of bat calls in managed (burned) and unmanaged (unburned) edge (path) within each site. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. The blue, or barker bar represents the managed side and the orange or lighter bar represents that unmanaged side near the path or edge. Site 8 had the biggest difference in small mammal tracks between the managed and unmanaged sides.

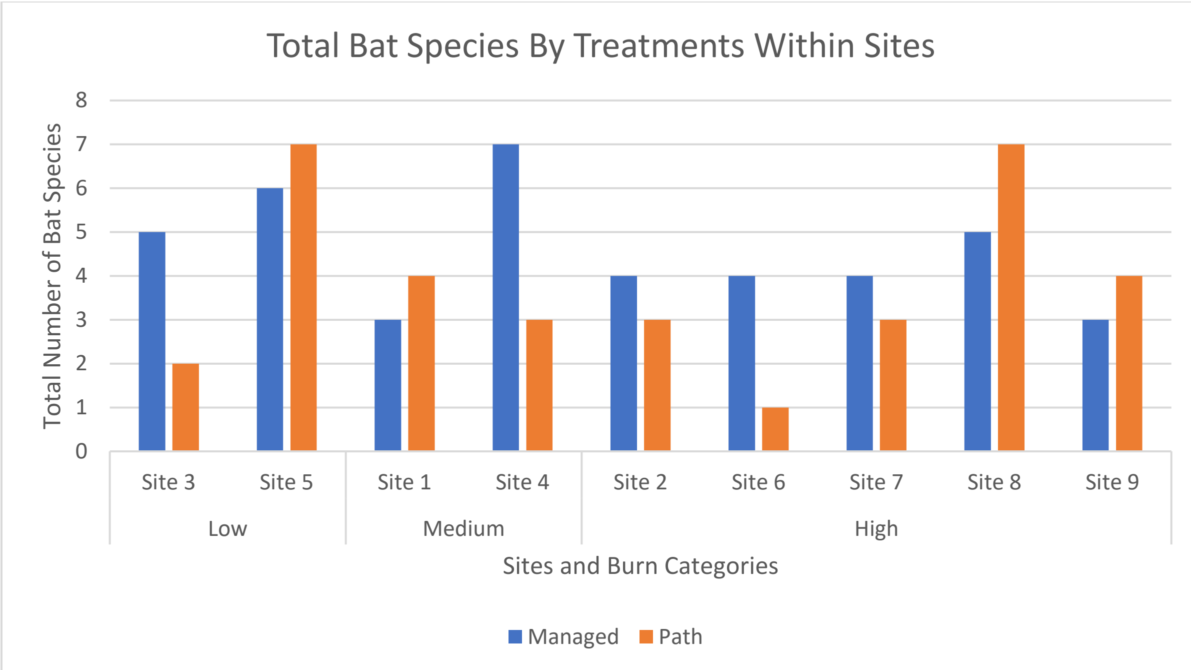

Figure 1. 18: Comparing total number of bat species in managed (burned) and unmanaged (unburned) edge (path) within each site. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. The blue, or barker bar represents the managed side and the orange or lighter bar represents that unmanaged side near the path or edge. Site 8 had the biggest difference in small mammal tracks between the managed and unmanaged sides.

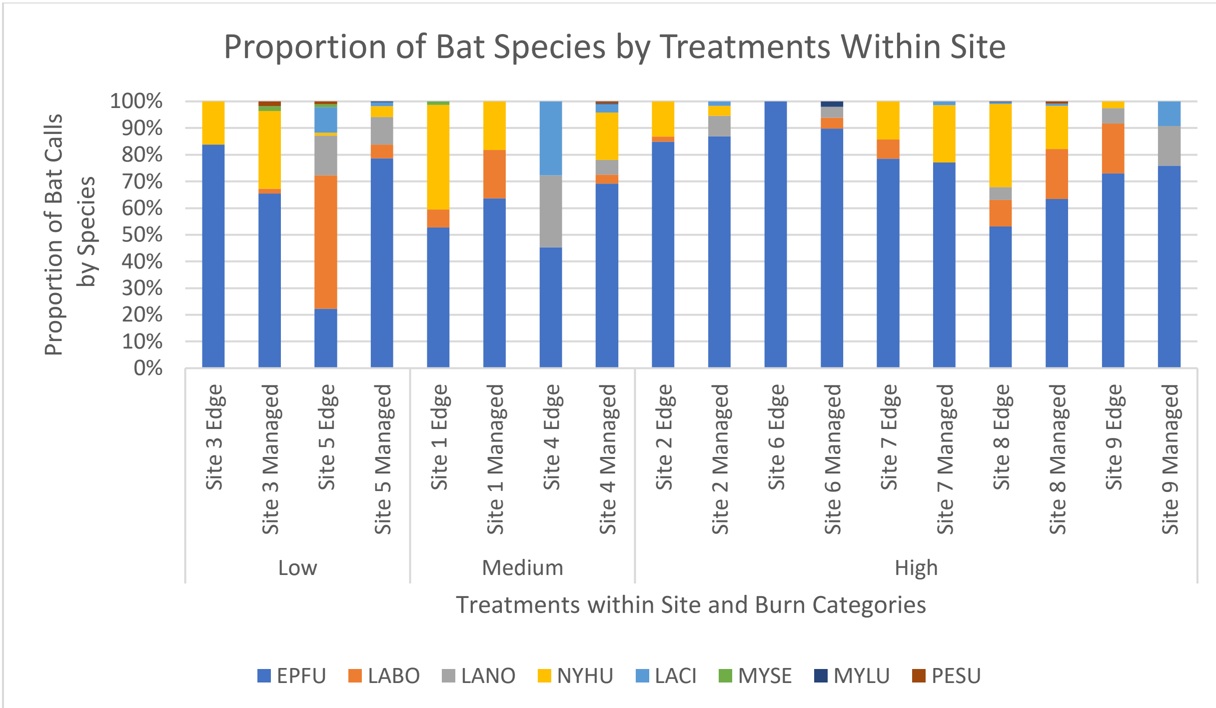

Figure 1. 19: Comparing the proportion of bat species for managed and edge sides for the entire research season. The top of the bars represents 100% of the bat calls at that site and the individual colors represent the percentage of calls by each species at that site. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. *Eptesicus fuscus*, big brown bat (EPFU), *Lasiurus borealis*, eastern red bat (LABO), *Lasionycteris noctivagans*, silver-haired bat (LANO), *Nycticeius humeralis*, evening bat (NYHU), *Lasiurus cinereus*, hoary bat (LACI), *Myotis septentrionalis*, northern long-eared bat (MYSE), *Perimyotis subflavus*, tri-colored bat (PESU), *Myotis lucifugus*, little brown bat (MYLU).

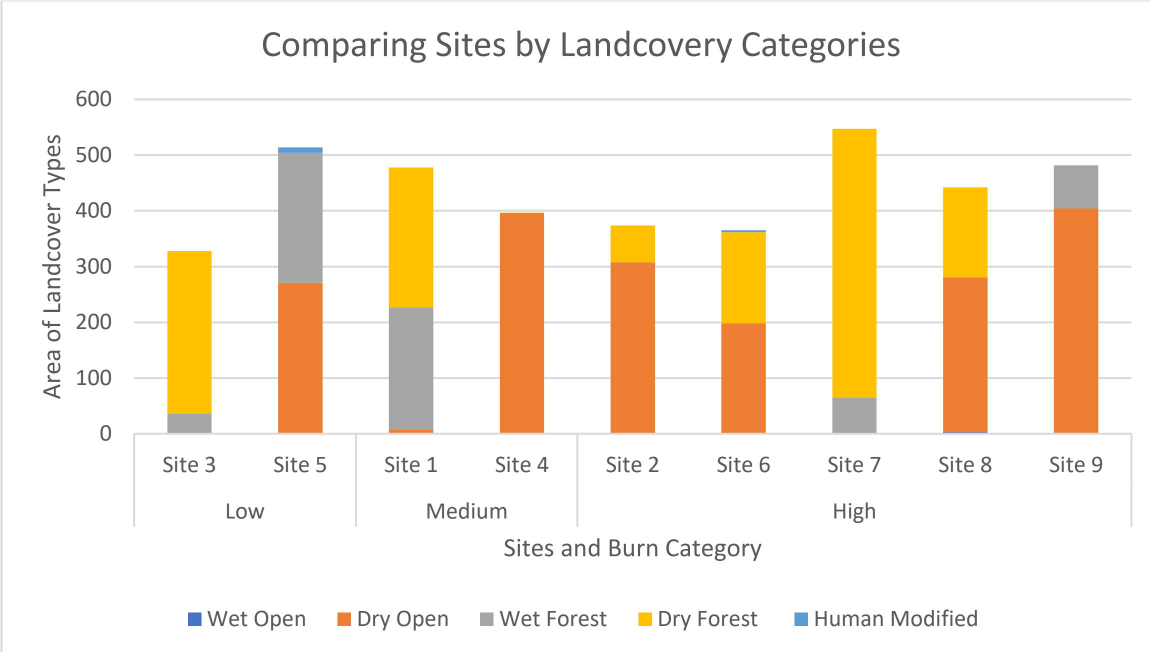

Figure 1. 20: Composition of the area (square meters) of each landcover category within each site. The sites are separated by burn categories as well. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. The wet open landcover category consisted of wet prairie. The dry open landcover category consisted of upland prairie, upland savanna, and sand barrens. The wet forest category consisted of floodplain forest and swamp forest. The dry forest category consisted of upland deciduous forest and upland conifer forest. The human modified landcover category consisted of Eurasian meadow and residential/mixed. The individual colors correlate to the different landcover categories.

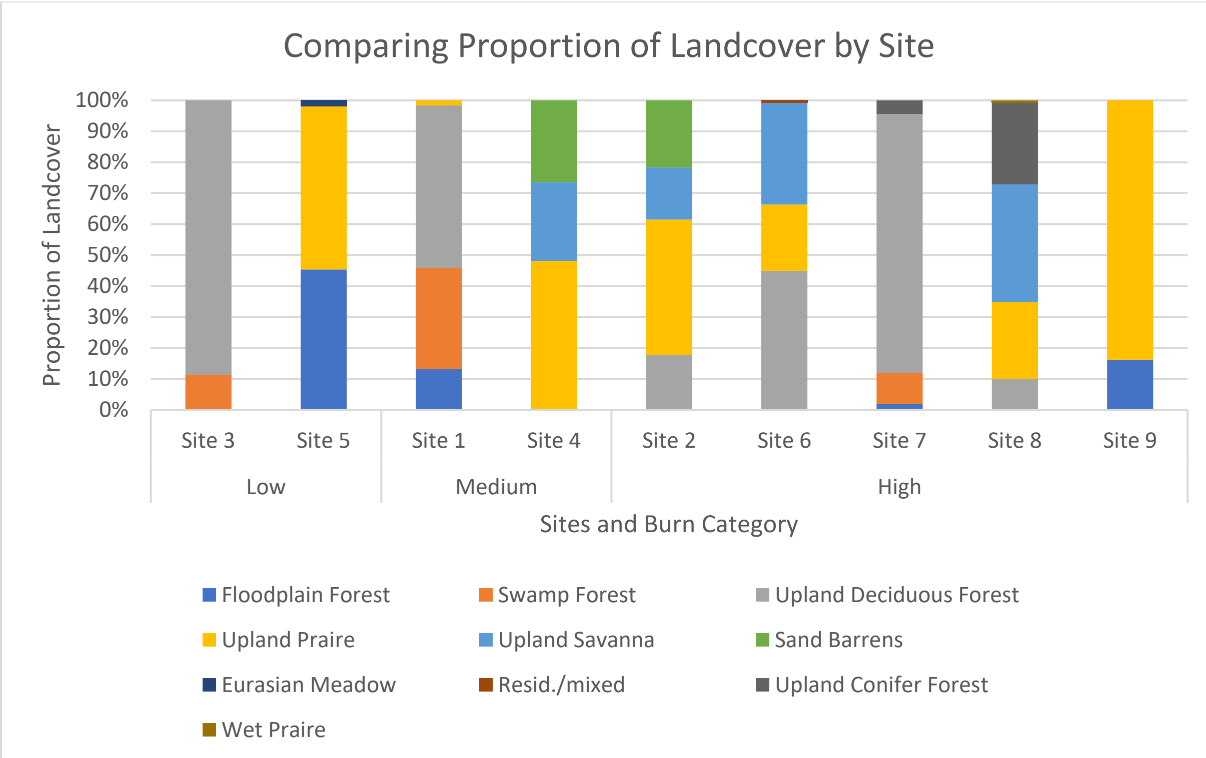

Figure 1. 21: Composition of the proportion of area (square meters) of each landcover type within each site. The top of the bars represents 100% of the area of landcover in each site. The individual colored bars represent the proportion of different landcover types (Based on categories from Schetter and Root 2011).

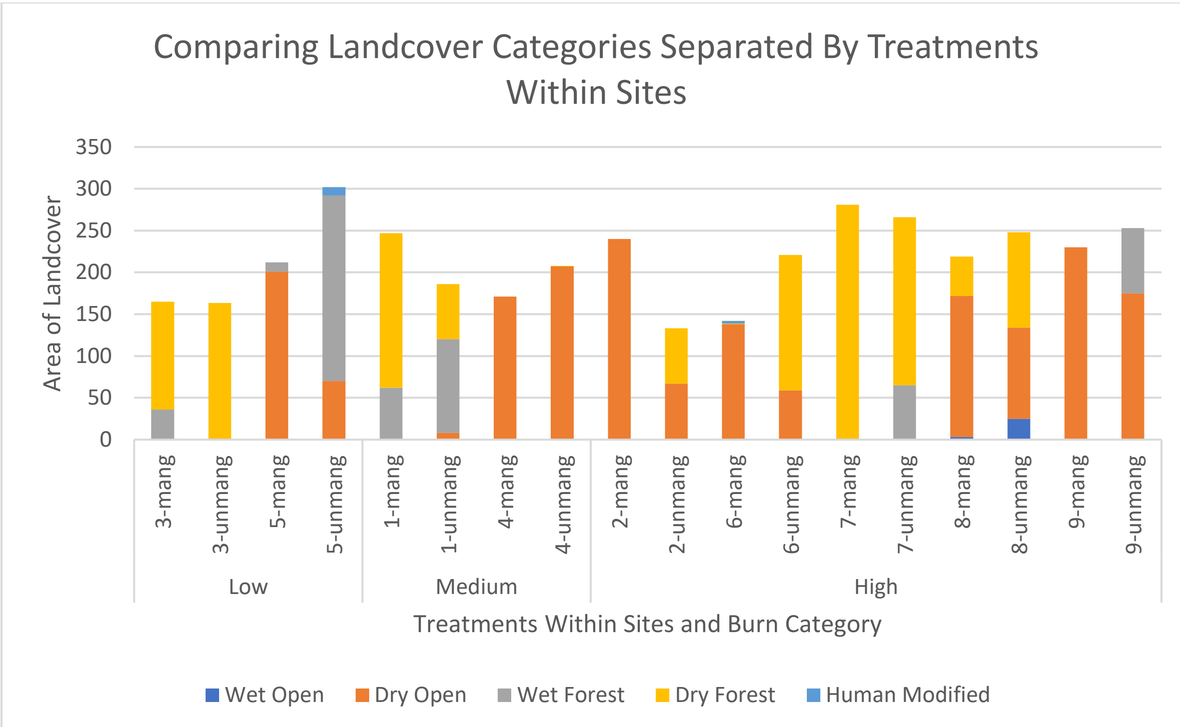

Figure 1. 22: Composition of the area (square meters) of each landcover category within each site and separated into managed (burned) and unmanaged (unburned) sides. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. The sites are separated by burn categories as well. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. The wet open landcover category consisted of wet prairie. The dry open landcover category consisted of upland prairie, upland savanna, and sand barrens. The wet forest category consisted of floodplain forest and swamp forest. The dry forest category consisted of upland deciduous forest and upland conifer forest. The human modified landcover category consisted of Eurasian meadow and residential/mixed. The individual colors correlate to the different landcover categories.

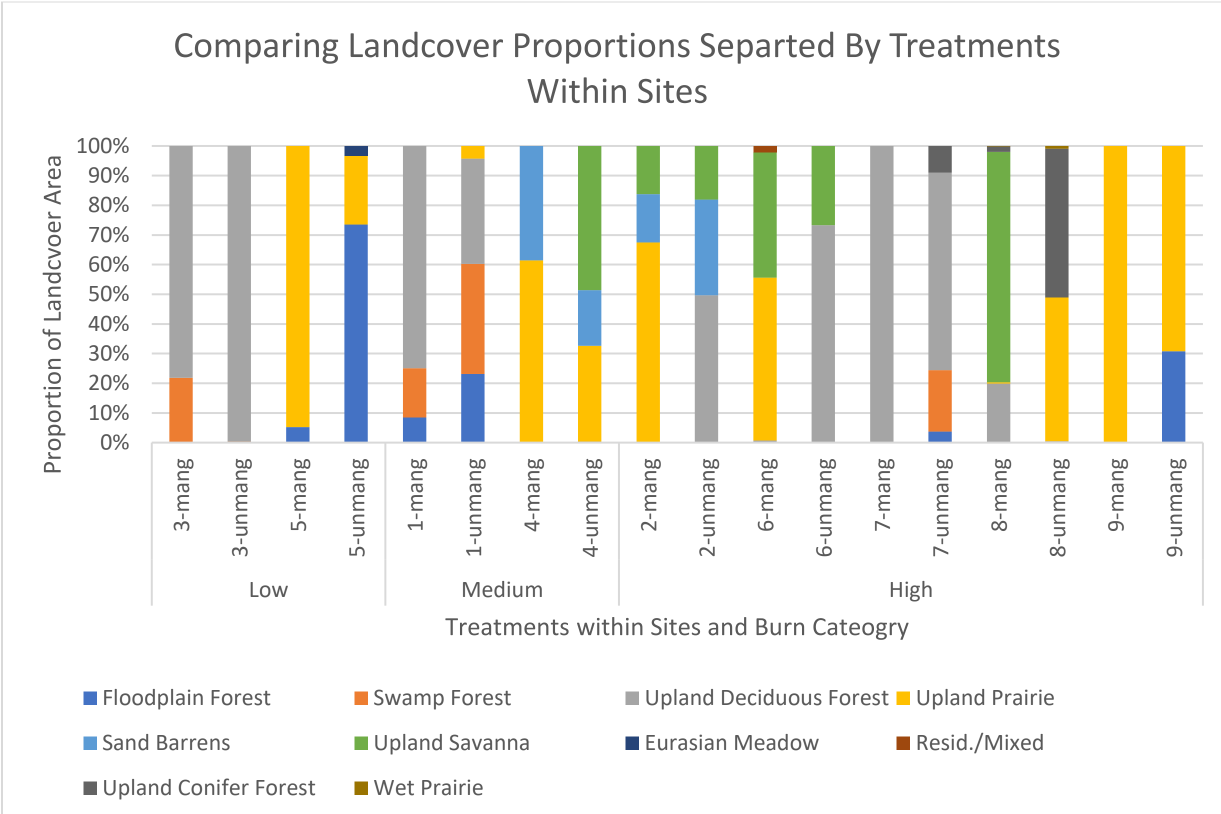

Figure 1. 23: Composition of the proportion of area (square meters) of each landcover type within each site and separated into managed (burned) and unmanaged (unburned) sides. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. The sites are separated by burn categories as well. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. The top of the bars represents 100 % of the areas of landcover on each side of each site and the individual colors correlate to the percentage of each landcover type for that area, based on categories from Schetter and Root 2011.

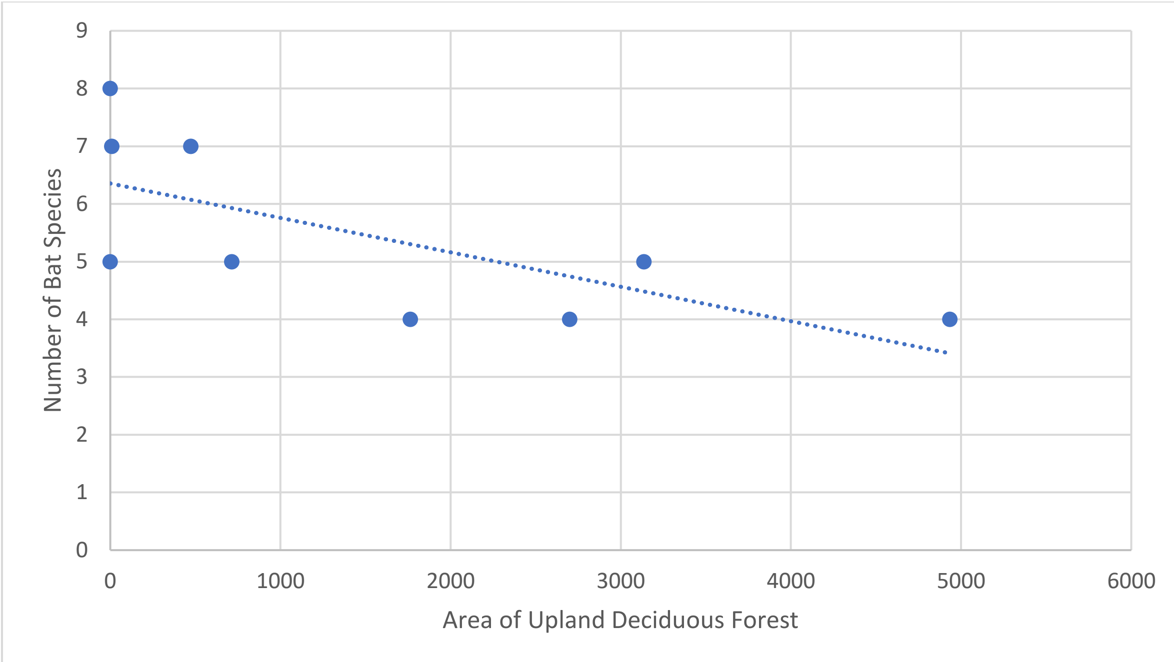

Figure 1. 24: Bat Species compared to area (square meters) of upland deciduous forest across sites. Total number of bat species had a significant negative correlation to area of upland deciduous forest. Spearman's ρ=-0.7396, p= 0.0228

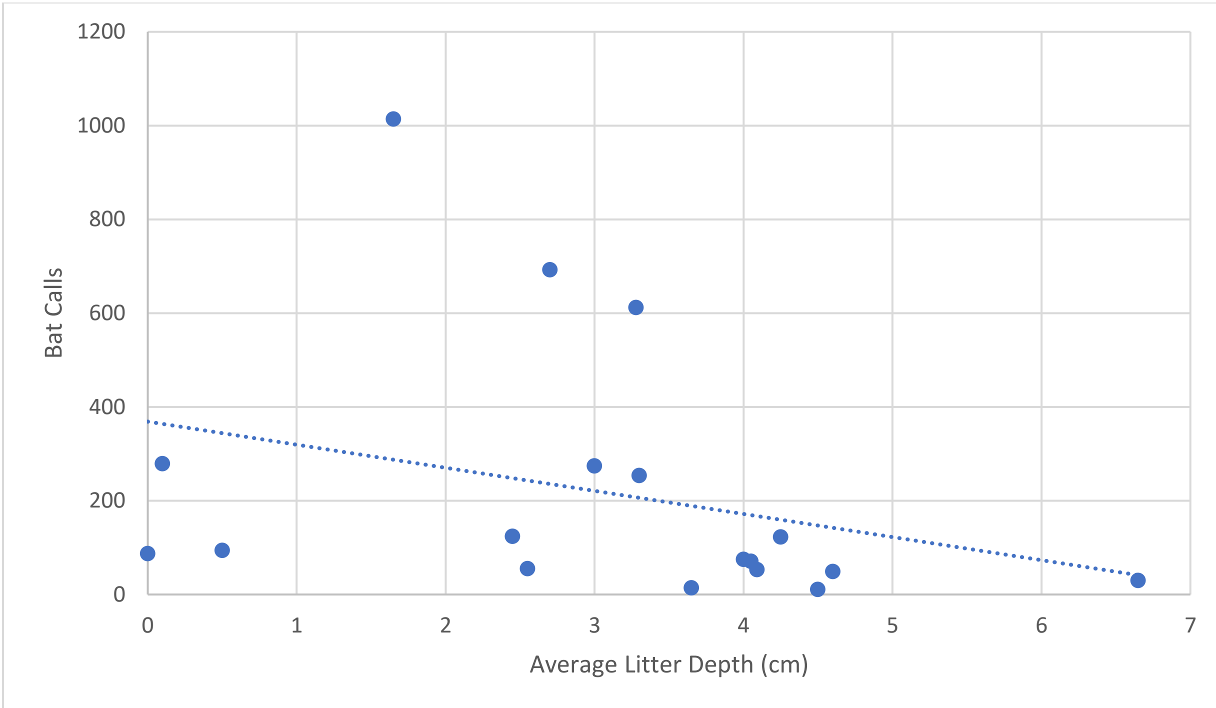

Figure 1. 25: Total bat activity compared to average litter depth in centimeters separated into managed (burned) and unmanaged (unburned sides) within sites. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. Total bat activity had a significant negative correlation to average litter depth. Spearman's ρ= -0.6202, p = 0.0060*. Asterisks represents significant after Bonferroni Correction.

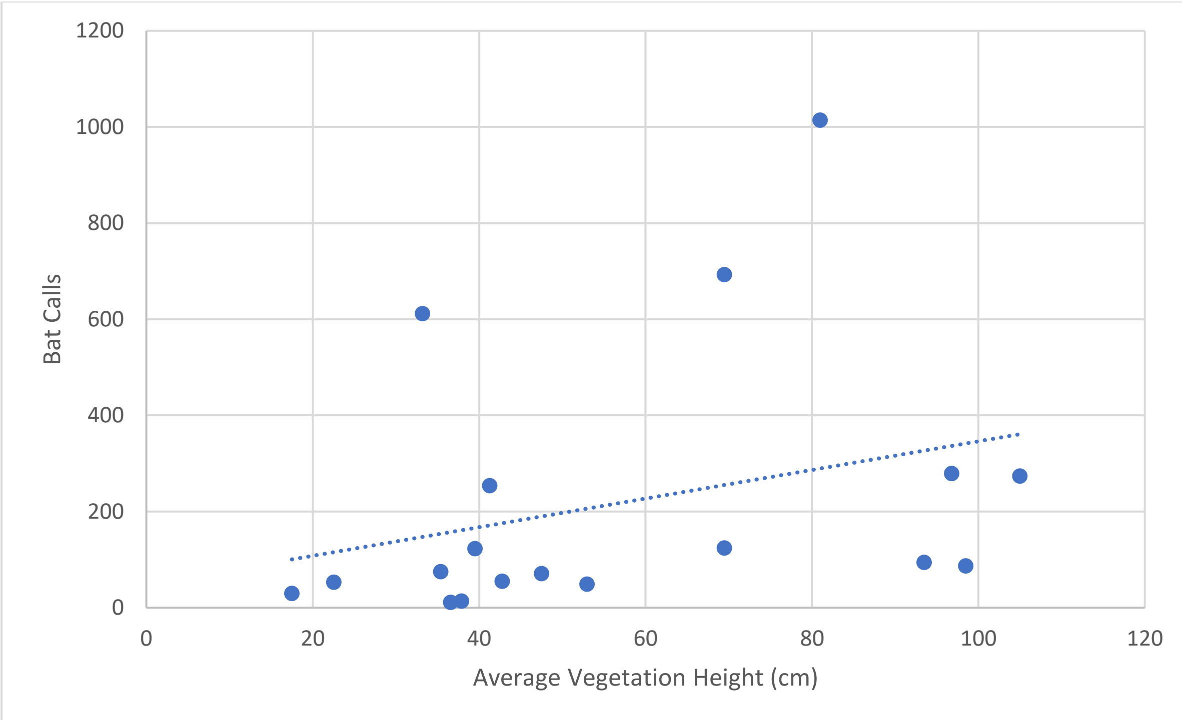

Figure 1. 26: Total bat activity compared to average vegetation height in centimeters separated into managed (burned) and unmanaged (unburned sides) within sites. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. Total bat activity had a nearly significant positive correlation to average vegetation height. Spearman's ρ= 0.5039, p= 0.0330.

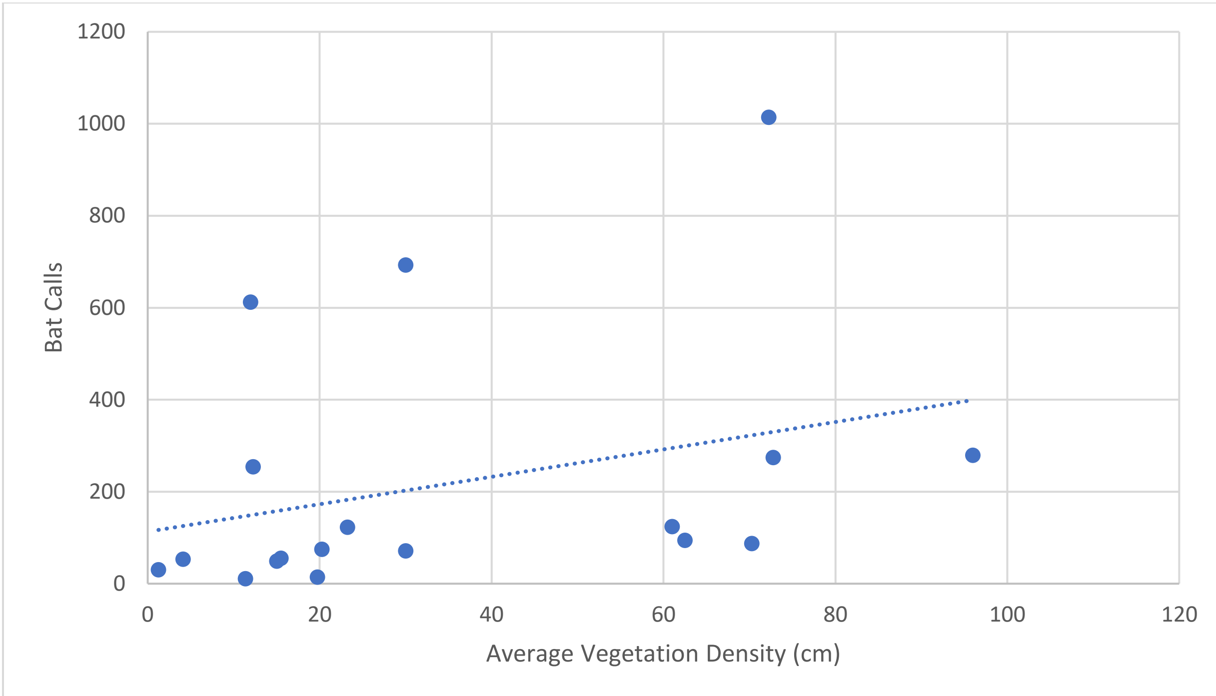

Figure 1. 27: Total bat activity compared to average vegetation density in centimeters separated into managed (burned) and unmanaged (unburned sides) within sites. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. Total bat activity had a significant positive correlation with average vegetation density. Spearman's $\rho = 0.5937$, $p = 0.0094$*. Asterisk represents significance after Bonferroni Correction.

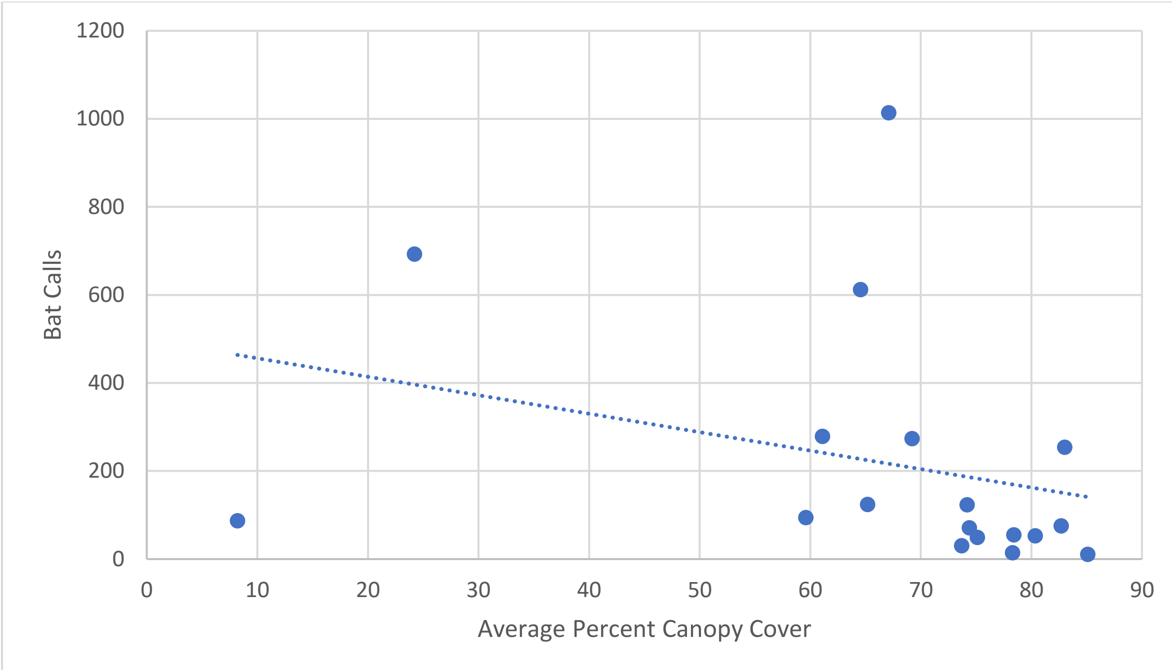

Figure 1. 28: Total bat activity compared to average canopy cover as a percent separated into managed (burned) and unmanaged (unburned sides) within sites. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. Total bat activity had a significant negative correlation to average percent canopy cover. Spearman’s ρ= -0.5934, p= 0.0094*. Asterisk represents significance after Bonferroni Correction.

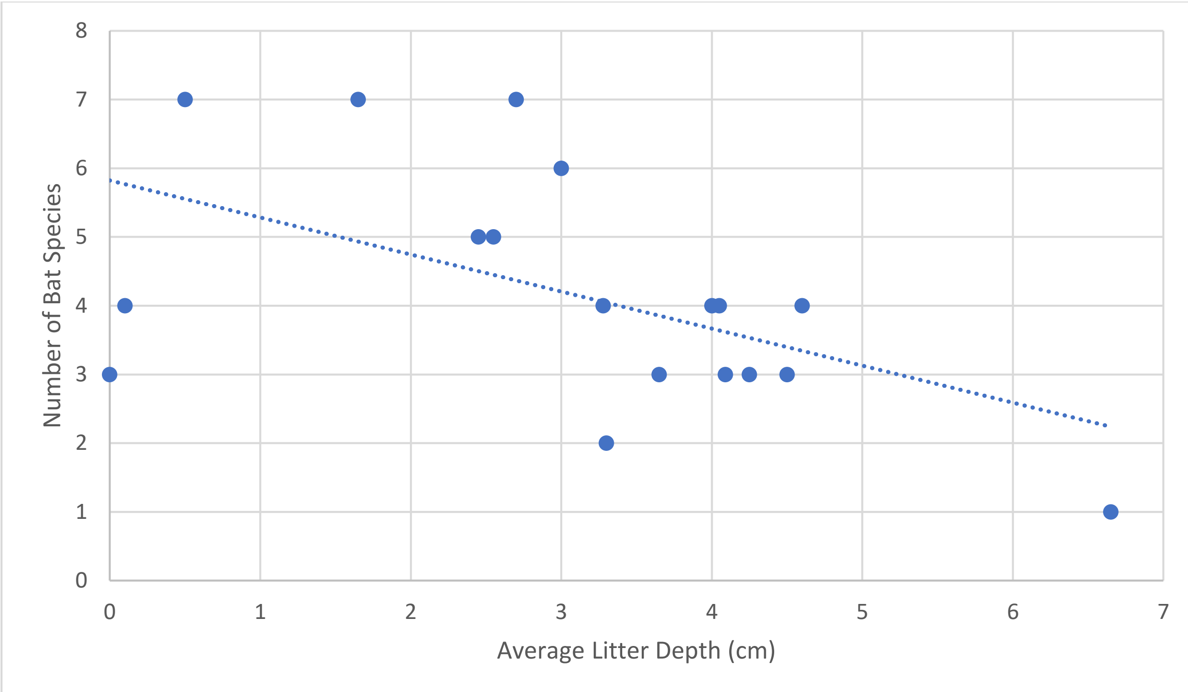

Figure 1. 29: Total number of bat species compared to average litter depth in centimeters separated into managed (burned) and unmanaged (unburned sides) within sites. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. Total number of bat species had a nearly significant negative correlation to average litter depth. Spearman's ρ= -0.5601, p=0.0156.

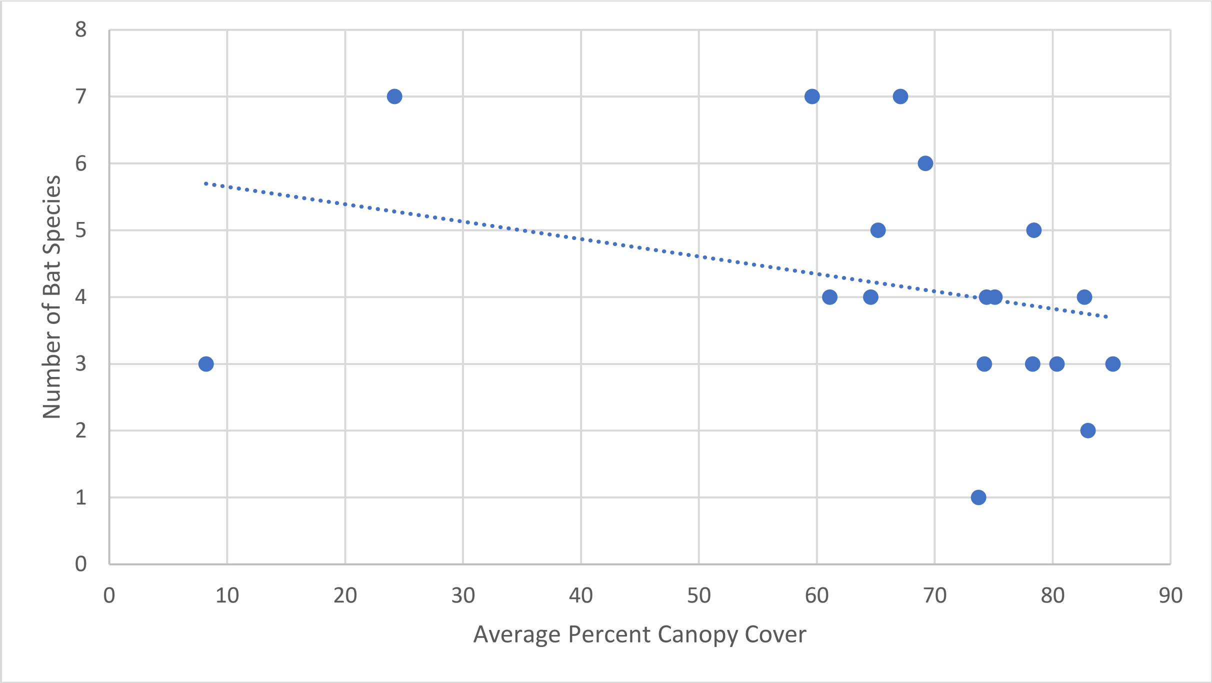

Figure 1. 30: Total number of bat species compared to average percent canopy cover separated into managed (burned) and unmanaged (unburned sides) within sites. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. Total number of bat species had a nearly significant negative correlation to average percent of canopy cover. Spearman's ρ= -0.4703, p = 0.0489.

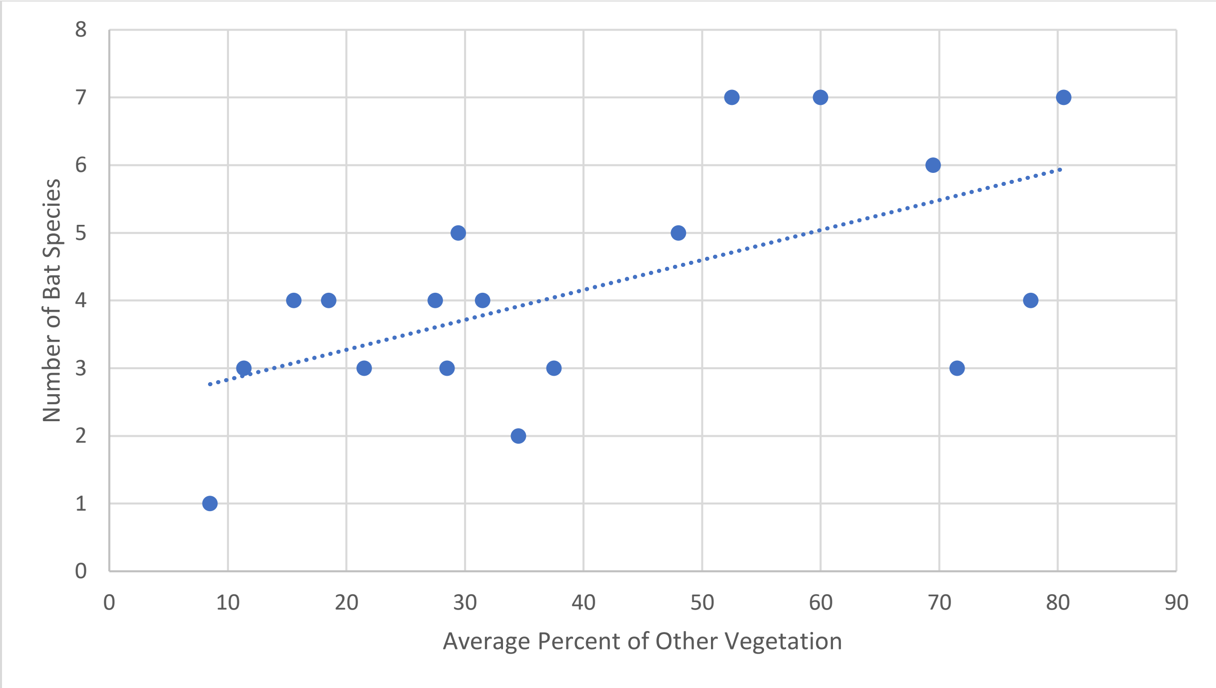

Figure 1. 31: Total number of bat species compared to average percent of other vegetation separated into managed (burned) and unmanaged (unburned sides) within sites. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. Total number of bat species had a nearly significant positive correlation to average percent of other vegetation. Spearman's ρ=0.5062, p= 0.0321.

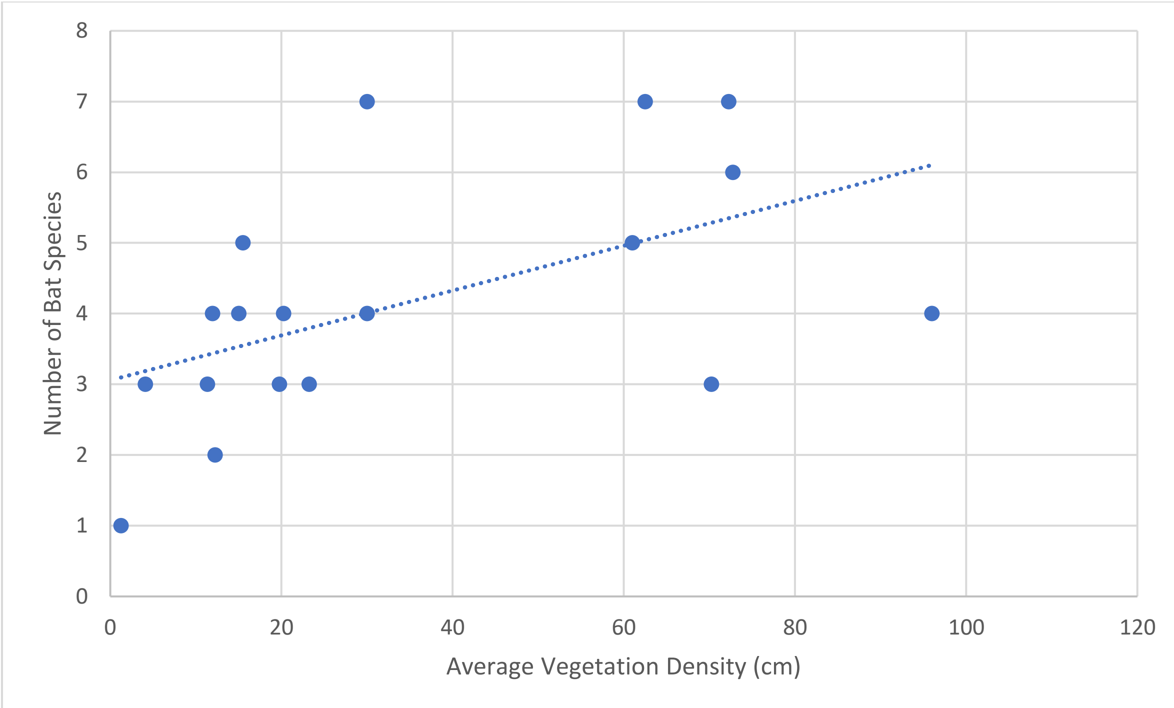

Figure 1. 32: Total number of bat species compared to average vegetation density in centimeters separated into managed (burned) and unmanaged (unburned sides) within sites. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. Total number of bat species had a significant positive relationship to average vegetation density. Spearman's ρ= 0.6175, p= 0.0063*. Asterisk represents significance after Bonferroni Correction.

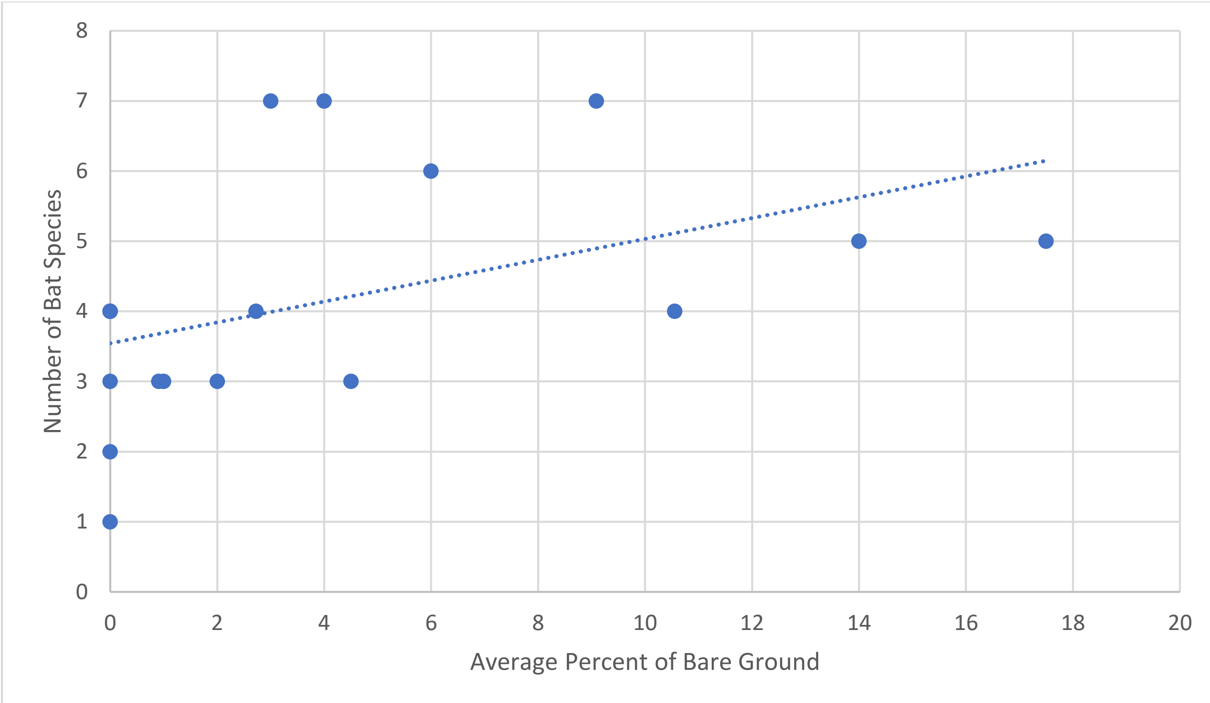

Figure 1.33: Total number of bat species compared to average percent of bare ground separated into managed (burned) and unmanaged (unburned sides) within sites. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. Total number of bat species had a nearly significant positive correlation to average percent of bare ground. Spearman's ρ= 0.6071, p = 0.0075.

Tables

Table 1. 1: Burn characteristics for each site (including total burns since 2012, years since last burn, number of burns since 2016), total number of bat calls, and number of bat species at each site. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

Burn Category	Sites	Total Burn # Since 2012	Years Since Last Burn	Burn # Since 2016	Number of Species	Total Number of Bat Calls
Low	**Site 3**	0	12	0	5	309
	Site 5	0	12	0	8	367
Medium	**Site 1**	1	4	0	4	86
	Site 4	2	2	1	7	816
High	**Site 2**	3	3	1	5	665
	Site 6	3	4	0	4	79
	Site 7	3	1	2	4	85
	Site 8	4	0	3	7	1138
	Site 9	3	1	1	5	366

Table 1. 2: Total number of bat calls for each site separated by managed (burned) and unmanaged (unburned) with the edge in between the two sides by species. *Eptesicus fuscus*, big brown bat (EPFU), *Lasiurus borealis*, eastern red bat (LABO), *Lasionycteris noctivagans*, silver-haired bat (LANO), *Nycticeius humeralis*, evening bat (NYHU), *Lasiurus cinereus*, hoary bat (LACI), *Myotis septentrionalis*, northern long-eared bat (MYSE), *Perimyotis subflavus*, tri-colored bat (PESU), *Myotis lucifugus*, little brown bat (MYLU). Unknown were calls that could not be identified to species. Low is zero burns. Medium is 1-2 burns and high is 3 or more burns.

Burn Category	Sites	EPFU	LABO	LANO	NYHU	LACI	MYSE	PESU	MYLU	Unknown	Total
Low	**Site 3 Managed**	36	1	0	16	0	1	1	0	0	55
	Site 3 Edge	212	0	0	41	0	0	0	0	1	254
	Site 3 Total	248	1	0	57	0	1	1	0	1	309
	Site 5 Managed	214	14	28	11	4	0	0	1	2	274
	Site 5 Edge	21	47	14	1	9	1	1	0	0	94
	Site 5 Total	235	61	42	12	13	1	1	1	2	368
Medium	**Site 1 Managed**	7	2	0	2	0	0	0	0	0	11
	Site 1 Edge	39	5	0	29	0	1	0	0	1	75
	Site 1 Totals	46	7	0	31	0	1	0	0	1	86
	Site 4 Managed	479	23	38	123	22	0	5	3	0	693
	Site 4 Edge	54	0	32	0	33	0	0	0	4	123
	Site 4 Total	533	23	70	123	55	0	5	3	4	816
High	**Site 2 Managed**	532	0	47	23	10	0	0	0	0	612
	Site 2 Edge	45	1	0	7	0	0	0	0	0	53
	Site 2 Totals	577	1	47	30	10	0	0	0	0	665
	Site 6 Managed	44	2	2	0	0	1	0	0	0	49
	Site 6 Edge	29	0	0	0	0	0	0	0	1	30

	Site 6 Total	73	2	2	0	0	1	0	0	1	79
	Site 7 Managed	49	5	0	15	1	0	0	0	1	71
	Site 7 Edge	11	1	0	2	0	0	0	0	0	14
	Site 7 Total	60	6	0	17	1	0	0	0	1	85
	Site 8 Managed	73	28	0	20	1	0	1	0	1	124
	Site 8 Edge	534	100	49	313	6	0	1	3	8	1014
	Site 8 Total	607	128	49	333	7	0	2	3	9	1138
	Site 9 Managed	66	0	13	0	8	0	0	0	0	87
	Site 9 Edge	203	52	16	7	0	0	0	0	1	279
	Site 9 Total	269	52	29	7	8	0	0	0	1	366
	Species Totals	2648	281	239	610	94	4	9	7	20	3912

Table 1. 3: Summary of bat calls separated by site and by month. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

Category	Site	May	June	July	August	September	Average	Standard Deviation
	3	24	127	115	1	37	60.8	56.60565
Low	**5**	102	128	28	72	31	72.2	43.74014
	1	11	0	65	4	5	17	27.1201
Medium	**4**	628	66	54	31	30	161.8	261.0655
	2	152	113	218	70	105	131.6	56.41188
	6	4	8	53	0	12	15.4	21.48953
	7	17	39	12	10	6	16.8	13.0269
	8	0	807	188	131	7	226.6	334.3147
High	**9**	23	72	158	67	38	71.6	52.38607

Table 1. 4: Nonparametric comparisons for each pair using Wilcoxon Methods for bat activity per night by site. Only significant pairs are shown.

Site Pairs	**p-value**
2 & 1	0.0122
5 & 1	0.0367
9 & 6	0.0367
6 & 4	0.0465
6 & 5	0.0367
7 & 5	0.0367
6 & 2	0.0122
7 & 2	0.0122

Table 1. 5: Nonparametric comparisons for each pair using Wilcoxon Methods for bat activity in May by site. Only significant pairs are shown.

Site Pairs	**p-value**
4 & 1	0.0483
9 & 8	0.0325
8 & 2	0.0325
8 & 5	0.0325
7 & 4	0.0177
6 & 4	0.0128
8 & 4	0.0046

Table 1. 6: Nonparametric comparisons for each pair using Wilcoxon Methods for bat activity in June by site. Only significant pairs are shown.

Site Pairs	**p-value**
4 & 1	0.0045
8 & 1	0.0046
5 & 1	0.0127
6 & 8	0.0287
9 & 1	0.0127

Table 1. 7: Total bat activity separated by managed (burned) and unmanaged (unburned). Even if the site had 0 burns, the managed site was still labeled as managed for consistency. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

Category	**Site**	**Managed**	**Unmanaged**
Low	**Site 3**	55	254
	Site 5	273	94
Medium	**Site 1**	11	75
	Site 4	693	123
High	**Site 2**	612	53
	Site 6	49	30
	Site 7	71	14
	Site 8	124	1014
	Site 9	87	279

Table 1. 8: Total number of bat species separated by managed (burned) and unmanaged (unburned) within sites. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

Category	Site	Managed	Unmanaged
Low	Site 3	5	2
	Site 5	6	7
Medium	Site 1	3	4
	Site 4	7	3
High	Site 2	4	3
	Site 6	4	1
	Site 7	4	3
	Site 8	5	7
	Site 9	3	4

Table 1. 9: Area (square meters) of landcover types broken into managed (burned) and unmanaged (unburned) within sites. Even if the site had 0 burns, the managed site was still labeled as managed for consistency.

Site	Floodplain Forest	Swamp Forest	Upland Deciduous Forest	Upland Prairie	Sand Barrens	Upland Savanna	Eurasian Meadow	Resid. /Mixed	Upland Conifer Forest	Wet Prairie
3-mang	0	36	129	0	0	0	0	0	0	0
3-unmang	0	0.56	163	0	0	0	0	0	0	0
5-mang	11	0	0	201	0	0	0	0	0	0
5-unmang	222	0	0	70	0	0	10	0	0	0
1-mang	21	41	185	0	0	0	0	0	0	0
1-unmang	43	69	66	8	0	0	0	0	0	0
4-mang	0	0	0	105	66	0	0	0	0	0
4-unmang	0	0	0.83	67	39	101	0	0	0	0
2-mang	0	0	0	162	39	39	0	0	0	0
2-unmang	0	0	66	0	43	24	0	0	0	0
6-mang	0	0	1	78	0	60	0	3	0	0
6-unmang	0	0	162	0	0	59	0	0	0	0
7-mang	0	0	281	0	0	0	0	0	0	0
7-unmang	10	55	177	0	0	0	0	0	24	0
8-mang	0	0	43	1	0	168	0	0	4	0.3

8-unmang	0	0	1	109	0	0	0	0	113	2
9-mang	0	0	0	230	0	0	0	0	0	0
9-unmang	78	0	0	175	0	0	0	0	0	0

Table 1. 10: Spearman's rank correlation comparing management and vegetation characteristics. Significant relationships (after Bonferroni correction) are indicated with an asterisk *. All were considered nearly significant.

Management	Vegetation Characteristic	Spearman ρ	p-value
Burn Number Since 2012	**Average Soil Temperature**	0.8132	0.0077
Burn Number Since 2012	**Average Soil Moisture**	-0.6733	0.0468
Burn Number Since 2016	**Average Soil Temperature**	0.8778	0.0019
Years Since Last Burn	**Average Vegetation Height**	-0.7011	0.0354
Years Since Last Burn	**Average Percent of Trees**	-0.6681	0.0492
Years Since Last Burn	**Average Percent of Other Vegetation**	-0.7011	0.0354

Table 1. 11: Best models using stepwise logistic regression for bat activity in relation to vegetation and management characteristics. Models are considered the best if change in AIC is below 2.

K	Predictor variables	Parameter estimate	Prob >F	R^2	AICc	ΔAICc
3	**Burn number since 2016**	0.825	0.0007	0.958	23.692	0
	Snag Number	-0.008				
	Crypto-Biotic Crust Average	0.09				
2	**Sapling Number**	0.0004	0.0066	0.813	25.14	1.44
	Crypto-Biotic Crust Average	0.12				
2	**Crypto-Biotic Crust Average**	0.112	0.009	0.792	26.10	2.41
	Fern Average	0.185				

Table 1. 12: Best models using stepwise logistic regression for bat species in relation to vegetation and management characteristics. Models are considered the best if change in AIC is below 2.

K	Predictor variables	Parameter estimate	Prob >F	R^2	AICc	ΔAICc
1	**Sapling Number**	0.0002	0.029	0.518	16.23	0
3	**Sapling Number**	0.0005	0.0016	0.943	16.29	0.06
	Average Percent of Crypto-Biotic Crust	0.06				
	Average Percent of Ferns	-0.164				
2	**Sapling Number**	0.0002	0.017	0.743	17.78	1.56
	Average Percent of Crypto-Biotic Crust	0.054				
2	**Sapling Number**	0.00049	0.036	0.67	20.04	3.82
	Fern Average	0.142				

Table 1. 13: Best models using stepwise logistics regression for bat activity in relation to landcover types. Models are considered the best if change in AIC is below 2.

K	Predictor variables	Parameter estimate	Prob >F	R^2	AICc	ΔAICc
3	**Upland Savanna**	0.0002	<0.0001	0.992	8.26	0
	Residential/ mixed	-0.06				
	Wet Prairie	-0.04				
2	**Sand Barrens**	0.0015	<0.0001	0.971	8.49	0.236
	Wet Prairie	0.072				
3	**Upland Savanna**	0.0011	<0.001	0.99	13.64	5.39
	Sand Barrens	0.00055				
	Residential/mixed	-0.0387				

Table 1. 14: Best models using stepwise logistic regression for bat species in relation to landcover types. Models are considered the best if change in AIC is below 2

K	Predictor variables	Parameter estimate	Prob >F	R^2	AICc	ΔAICc
1	**Upland Deciduous Forest**	-0.0002	0.09	0.344	19	0
1	**Eurasian Meadow**	0.007	0.17	0.25	20.21	1.2
1	**Wet Prairie**	0.03	0.17	0.25	20.21	1.2
1	**Upland Savanna**	0.0003	0.221	0.205	20.74	1.7
2	**Upland Savanna**	0.0004	0.047	0.64	20.84	1.8
	Eurasian Meadow	0.010				
2	**Eurasian Meadow**	0.008	0.079	0.57	22.38	3.37
	Wet Prairie	0.031				

CHAPTER II: MANAGEMENT EDGES EFFECTS ON DISTRIBUTION, DIVERSITY, AND ABUNDANCE OF SMALL MAMMALS

Introduction

Small mammals, such as *Peromyscus, Tamias striatus, Cryptotis parva*, are important to study because they are crucial to the environment processes. They are seed and fungal spore dispersers, are important prey for many predators, can aid in nutrient cycling, and are habitat engineers (Jacques et al. 2017, Hamilton et al. 2019). For example, some plants rely on seed caching, done by small mammals, to enhance germination (Hamilton et al. 2019). Small mammal communities include keystone species, habitat specialists and generalists, habitat engineers, have diverse feeding ecologies, and are both consumers and prey (Hamilton et al. 2019). One study found that when an area has low small mammal species richness, it can negatively influence plant diversity and habitat structure because small mammals can play a critical role in creating shelters for other organisms and disperse seeds; without small mammals, these processes will not happen (Johnson and Karels 2016). Conversely, habitat structures such as downed logs and vegetation density can also influence small mammal species in an area (Johnson and Karels 2016, Homyack et al. 2005, Jacques et al. 2017). For example, Homyack et al. (2005) stated that small mammal abundance was positively associated with the increase of downed and decaying dead wood in an environment. As management can have large impacts on the structure and composition of the habitat, it is critical to understand how that affects the activity, distribution and diversity of native small mammal species.

Small mammals may need a mosaic of habitat structures in order to thrive in an ecosystem. Some small mammal species may require both open areas such as prairies and savannas to forage and areas such as woodlands and forest with dense vegetation for shelter

(Dixon et al. 2019). One study found that increased habitat heterogeneity such as grasslands, woodlands, and scrub habitats, was one of the greatest predictors for rodent species richness in an urban landscape when compared to low habitat heterogeneity such as just grasslands (Johnson and Karels 2016). Small mammals have small home ranges (for example 0.2 ha for white-footed mice) and are closely tied to local changes in resource availability; they are good models for studying the effects of management on an ecosystem (Hamilton et al. 2019, Kappler 2009). For example, Larson (2001) studied the effects of small mammal abundance on thinned areas from vegetation mechanical removal and found higher abundance of small mammal species when comparing thinned areas to unthinned areas in Oregon. This was explained by the increase of shrub growth, which can provide cover for small mammals, due to opening of the forest canopy (Larson et al. 2001). A study in southern Australia found that smaller mammal species, such as *Rattus lutrelous*, Australian swamp rat, depends on structurally complex understories with shrubs and increased ground vegetation density (Dixon et al. 2019). Habitat composition and structure is very important for small mammal survival.

Common land management activities for natural areas that may affect habitat characteristics include prescribed fire, mechanical vegetation removal, and herbicide treatments. Many natural areas suffer from woody encroachment, fire suppression, and invasion by non-native species (Gustafson 2018, Wood et al. 2011, Twidwell et al. 2016). Management practices open forest canopy, remove leaf litter, recycling nutrients back into the environment, remove competitive plant species, and promote wildlife conservation to create favorable conditions for native wildlife (Glasgow and Matlack 2006, Wood et al. 2011). Without management practices, forest may become overgrown, herbaceous vegetation will be suppressed, and there will be a loss of vegetation diversity and wildlife diversity (Hanberry and Abrams 2018). So, not only is it important to understand what habitat characteristics may affect the activity and distribution of small mammals, but also how management activities affect those characteristics.

This study focused on the particular management activity of prescribed burning because fauna is often overlooked in fire studies (Dixon et al. 2019). Fire history showed that wildfires caused by lightning strikes were common in many habitats before human influences (Iverson et al. 2008, Austin et al. 2018). Native Americans set fires to forests to preserve forest ecology before European settlers occupied the land (Boyles and Aubrey 2006, Brewer & Vankat 2004, Austin et al. 2018). European settlers began to suppress natural fires, which have altered vegetation structures and wildlife composition on natural remnants (Iverson et al. 2008, Twidwell et al. 2016). Human land use change, anthropogenic climate change, fire suppression, and drought have caused an increase in fire intensity and frequency and this is dangerous for humans and wildlife around the world (Blakey et al. 2018, Law et al. 2019). Park managers are using prescribed burning to restore grasslands, savanna, and prairie habitats that have been impacted by invasive species and woody encroachment (Cox et al. 2016, Braun de Torrez et al. 2018). Fires can alter forest structure by removing clutter and increasing open space to allow early successional species to thrive and benefit open area adapted species such as big bluestem (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans*), and wild lupine (*Lupinus perennis*) (Blakey et al. 2018, Nimmo et al. 2019, Austin et al. 2018, Gustafson 2018). According to Dixon et al. (2019) areas burned between half a year to two years and six to twelve years before the study were more structurally complex when compared to areas that had been unburned for a long term. The majority of the structural complexity for the burned areas was found in the shrub and understory areas (Dixon et al. 2019). This complexity (or the lack of it) should impact small mammals differentially depending on their habitat needs.

The impact of prescribed burns on wildlife may vary from direct impact (e.g., mortality) to indirect effects (e.g., fragmentation). Some factors that can lead to the increase in mortality after a burn are: increased hard boundaries because of increase in size, frequency, severity, and intensity of burns; loss of stepping stones and unburned patches for refuge; cover from predation; and increased travel time to safety (Nimmo et al. 2019). Fragmentation heavily impacts organisms during and after a burn because fragmentation can interfere with the ability of an organism to move for better resources (Nimmo et al. 2019). Nimmo et al. (2019) states that habitat patches that are closer in fire age are more structurally similar than patches that are farther apart in fire age. Adjacent habitats with different fire ages may impact dispersal from one area to another depending on how hard or soft the edge is (Nimmo et al. 2019).

Research on small mammal responses to prescribed burning produces mixed results among studies. A fire can: eliminate ground cover which can open an area to predation (DeGolier and Matlack 2015); increase snags which can increase nesting habitat; create new vegetation and recruit insects which will increase foraging; and alter edges which can limit movement (Jacques et al. 2017). One study claims that some small mammal species, such as bush rats (*Rattus fuscipes*) and antechinus (*Antechinus stuartii*) in the Central Highlands of Victoria, may avoid fire edges for four to five years after a fire, until vegetation cover returns to its previous levels (Parkins et al. 2018). If an area is burned more frequently than this, then the vegetation cover will never return to desired conditions and small mammal populations may never return to original numbers (Parkins et al. 2018). If small mammals are trying to move from a burned area to an unburned area for resource availability or predator avoidance, a hard edge may be difficult for them to cross and can affect the survival of the organism (Parkins et al. 2018). In contrast, one study in Australia that studied species like bush rats (*Rattus fuscipes*), swamp wallaby (*Wallabia bicolor*), and short-beaked echidna (*Tachyglossus aculeatus*) stated that spatial heterogeneity can be created with the use of prescribed fires, and therefore promotes species diversity by providing a variety of habitats that benefit a variety of species (Dixon et al. 2019). These conflicting studies suggest that more research is needed to examine the relationship between managed edge characteristics and the abundance, diversity, and distribution of small mammals.

This study took place in Oak Openings Preserve in the Oak Openings Region of Northwest Ohio. The region has a large amount of management activity and conservation interest. The Oak Openings Region is a biodiversity hotspot and has many important ecosystems including: sand barrens, wet and sand prairies, oak savannas, and oak woodlands embedded in a matrix of agriculture and development (Kappler et al. 2012, Schetter et al. 2013). Like many other regions in the Midwest, this area is heavily impacted by human involvement, fragmentation, and history of fire suppression (Kappler et al. 2012, Buckman-Sewald et al. 2014). Park managers for Oak Openings Preserve, the largest protected area, rely on prescribed burning and other forms of management for invasive species removal, and restoration of oak savanna habitats (Metroparks Toledo 2020). Because of the loss of natural disturbances, such as burning, oak forests are now being out competed by more shade-tolerant and fire intolerant species like hemlocks and maples which are closing light gaps and dominating canopy cover in forests (Grennler et al. 2019, Austin et al. 2018). Park managers are relying on management strategies, such as prescribed burning, to reduce shade tolerant species and create open areas (Grennler et al. 2019). In Oak Openings Preserve, managers try to burn across habitat types and in larger burn units to allow for flexibility and to prevent burning the same areas over and over; in addition, they allow the unburned areas to remain unburned to allow refugia areas within the burn unit for wildlife and provide a heterogenous landscape (L. Sprow, Oak Openings Preserve Metropark, personal communication). In Oak Openings Preserve, prairies and savannas are burned every three years, oak woodlands are burned every five to seven years, and oak forests are burned every seven to ten years (L. Sprow, Oak Openings Preserve Metropark, personal communication). While focused on one large park, this research is likely applicable to other natural areas also impacted by anthropogenic activities and land use as managers elsewhere face similar habitat management challenges. Additionally, since many natural areas are actively managed, it is important to understand how management is impacting vertebrates that are not regularly studied in fire research (Schneider-Maunoury et al. 2016).

To survey small mammals, I used both tracking tubes and live trapping. I compared these two surveying techniques in order to evaluate how management impacts small mammals. Each technique has its strengths. Mark-recapture live trapping is the most popular surveying technique for small mammals (Wilkinson et al. 2012). Trapping allows for hands on surveying but is costly, require a lot of sampling effort, and has potential to cause harm if surveyor is careless (Wilkinson et al. 2012). Mark-recapture allows researchers to gather data on individual's sex, age, condition, and characteristics (Wiewel et al. 2007). Tacking tubes are a hands-off surveying technique. Tracking tubes are inexpensive, easy to monitor, reduces stress for the animal, and reduces researcher's exposure to animal-borne diseases (Wilkinson et al. 2012, Wiewel et al. 2007). Tracking tubes allow researchers to gather information on species abundance and distribution on a large spatial scale, and habitat preferences (Wiewel et al. 2007).

The purpose of this research was to understand how management, especially prescribed burning, impacted small mammals and evaluate if the abundance and diversity of small mammals were affected by managed edges. The scales of this research consisted of managed versus unmanaged sides of each site, the entire site, and the landscape scale. I used tracking tubes and live trapping to survey small mammals in locations with difference burning frequencies and along managed edges. I explored the following questions: (1) was there a difference in small mammal activity between managed and unmanaged areas? (2) what type of burn frequency was beneficial for small mammal activity? (3) what vegetation and habitat structures were important to promote small mammal activity? I hypothesized that the frequency of management practices could directly (e.g., mortality) and indirectly (e.g., avoidance) influence the distribution, abundance, and diversity of small mammals in Oak Openings Preserve by altering habitat and vegetation structures. I expected to see the highest distribution of small mammal activity on the unmanaged side because these areas would have higher vegetation densities for cover and protection from predators. I also expected small mammal activity to be positively influenced by certain vegetation characteristics such as snags, downed logs, and high vegetation density, all for nesting and foraging. Areas that were burned in the low category (one burn in the last 8 years) should have higher small mammal activity because these areas would have fewer open areas and fewer fire-created features such as downed logs or snags, but still have high vegetation density for cover and food resources. My overall goal was to identify important factors that can be maintained or restored by management for park managers to provide the most favorable habitats for maximum small mammal abundance and diversity in the area.

Methods

Study sites

Small mammal and vegetation surveys took place from April 1st to October 1st 2019 in Oak Openings Preserve (Figure 2.1). Oak Opening Preserve is located 41” 32-34’N x 83’ 50-

51’W, near Whitehouse, Ohio and is the largest protected area in the Oak Openings Region (Kappler 2009). Oak Openings Preserve is about 2023 hectares and consists of swamp forest, conifer forest, upland forest, floodplain forest, shrub forest, Eurasian meadows, prairies, sand barrens, savannas and wet prairies (Schetter & Root 2011, Oak Openings 2020). It is managed by the Toledo Metroparks and their management plan for the savannas was to burn savannas once every three years (Kappler et al. 2012). In addition to fire, the park was also managed by using herbicides and manual targeted vegetation removal (Cross et al. 2015). Oak Openings Preserve is home to numerous species of small mammals such as white footed mice (*Peromyscus leucopus)*, deer mice (*Peromyscus maniculatus)*, eastern chipmunk (*Tamias striatus)* and meadow vole (*Microtus pennsylvanicus)*. Park managers plan prescribed burns (hereafter referred to as burns/burning) for the spring and fall, which can coincide with small mammal movement activities.

Study sites were mapped using Geographical Information System (GIS) in ArcMap 10.2 (ESRI, 2011). Historical burn locations, i.e., since 2012, and Oak Opening Preserve management units were provided by the Toledo Metroparks (Joshua Brenneman, pers. comm.). Sites were categorized based on the number of burns since 2012 in each management unit, i.e., high, medium and low categories (Figure 2.2). Low or no management areas had 1 or 0 burns in each management unit. Medium areas had 2 burns in each management unit. High areas had 3 or more burns in each management unit. Study sites were selected based on number of burns per area and if the burned area was adjacent to an unmanaged area for comparison. The unmanaged sites were unburned since 2012 and not targeted for prescribed burns. All study sites are the same size, 60 meters by 80 meters (Figure 2.3). Each survey site was comprised of a managed area separated from an unmanaged area of equal size by an edge, which was usually a ~ 2 m wide path. Even if the site had zero burns, the managed side was still labeled as managed for consistency. Other management may have been performed at these sites, but my focus was on the prescribed burning. I selected two sites for the low burn category, two sites for the medium burn category, and five sites for the high burn category. Since park managers tend to use hiking paths as fire barriers, almost all of the sites had paths in the middle separating the managed and unmanaged side, designated as the edge. Mammal surveys took place on both sides at each study site.

Small mammal surveys

Mammal surveys took place within the entire (managed and unmanaged areas) study site. I used small mammal surveying techniques similar to Kappler (2009). Tracking tubes with fluorescent ink were used to survey small mammals (Figure 2.4). I used tracking tubes to estimate the number of individuals (i.e., relative abundance), and identify the species, location, and direction traveled of small mammals that entered the tubes. The tracking tubes were cut into 36-centimeter-long tubes from 3.81 centimeter diameter PVC piping. There was a slit cut in the bottom of each tube 3 centimeter in from each end to allow for drainage. Tubes were placed in alternating orientations, East-West and North-South, along each transect. Each tube was held in place by an 18-gauge wire U-hook wrapped around the tube and pushed into the ground to secure position. Tracking paper was placed in the tracking tube made out of inkjet printer paper and cut into 28 by 7 centimeter rectangles with 6 by 6 centimeter wax paper squares glued with a glue stick or all-purpose glue to each end of the paper. Ink was applied to the wax paper with a paintbrush comprised of blue or orange fluorescent powder (DayGlo, Cleveland Ohio) and mineral oil in a 1:3 gram ratio (Figure 2.5). Tracking paper in each tube was changed once every week during the survey period. Tracks on the used tracking paper were categorized for relative abundance, species and direction of travel in the lab, and the location of the tube and date of collection noted. Relative abundance was categorized as one if there was one visible set of tracks on the paper, two if there were two visible set of tracks and as three if there were three or more visible set of tracks on the paper (Figure 2.6). Tracking tubes were separated by a distance of 20 meters and transects were separated by a distance of 20 meters away. Tracking tubes were laid out along a 60-m transect (Figure 2.3) and there were five 60 meter long transects parallel to the edge for each survey site. One transect started in the middle of the edge (or path), two transects were on either side of the edge, and one each on the far edge of the managed and unmanaged areas of the survey site. Tracking tubes were left empty for one month prior to the start of surveying to allow small mammals to acclimate to the tubes. Tracking tubes were left out over the entire surveying season.

As a complementary survey method, I set up live trapping along the same transects used for the tracking tubes for sites 1, 3, 4, and 8 using Sherman live traps (7.62 x 8.89 x 22.86 centimeters or 3 x 3.5 x 9”). They were set up nightly on three nights surrounding the new moon between May and September. If temperatures were below 0 ^{O}C (32^{O}F) at night, trapping did not occur. The traps were set out for three consecutive days for trapping and then collected at the end of that period. Traps were set up in the evening by opening the trap door and baiting the trap with a tablespoon of oats mixed with peanut butter. When temperatures were below 4.5^{O}C (40^{O}F) a small amount of cotton was inserted into the trap for insulation. Traps were checked the next morning before dawn. Species, sex, age by pelage color, mass in grams, reproductive status (e.g., pregnant, lactating), ear tag number, and trap number were collected from each animal captured. Newly captured animals were ear tagged. All animals were released after capture. To distinguish between *P*. *leucopus* and *P*. *maniculatus*, I used the criteria that *P*. *leucopus* have a tail longer than body length and *P*. *maniculatus* have a tail shorter than body length. Bowling Green State

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

Environmental and landscape variable measurements

I measured vegetation characteristics once during the entire surveying period (June 26-28th, 2019) at each tracking tube. Vegetation measurements were taken with a 1 meter squared quadrat and included: canopy cover, litter depth, percent ground cover of vegetation categories, vegetation height, and vegetation density. Canopy cover, as a percent, was estimated visually from the center of the quadrat using Habitat app (Android App, Scrufster). Litter depth was measured using a ruler in centimeters at two points randomly chosen in each quadrat. I averaged the values at the two points to estimate average litter depth of each quadrat. Percent cover was measured by taking a photo of each quadrat and applying a 10 by 10 grid using Abode Photoshop (Adobe Systems Incorporated, San Hose, California, USA). I categorized vegetation type as bare ground, leaf litter, graminoids (grass), crypto-biotic crust (soil crust containing moss/lichen/algae), ferns, angiosperms, trees, and other vegetation (e.g., shrubs). In the grid, squares were counted that have the same vegetation type and results were converted into a percentage. I measured vegetation height in centimeters by placing a Robel pole next to the tallest vegetation in the quadrat. Vegetation density in centimeters was estimated as the average of two Robel pole measurements; the Robel pole was placed in the middle of the quadrat at a height of 1.5 meters and the visible height in centimeters were taken from the north and east cardinal direction by standing 3 meters away from the pole. Soil temperature, in degrees Fahrenheit, was measured using a laser thermometer (IRT205, General Tools) and soil moisture, in percent water volume of soil, was measured with a moisture meter (HH150, Delta-T Devices).

At each study site, the total number of snags (i.e., fully dead standing trees), downed logs, and saplings (i.e., young trees below 1.65 meters in height) were visually estimated. Path width, in centimeters, and path types (e.g. paved, dirt, or no path) were also recorded at each study site.

I used GIS to measure the total area of each landcover types within each site and the total area of each landcover type for the managed and unmanaged side of each site. Landcover types were based on Root & Martin (2018) landcover map made for Oak Openings Region. The 15 landcover types for this layer were: turf/pasture, perennial ponds, wet shrubland, dense urban, cropland, upland prairie, floodplain forest, swamp forest, upland deciduous forest, sand barrens, upland savanna, residential/mixed, upland conifer forest, Eurasian meadow, and wet prairie, based on the classification by Schetter and Root (2011).

Statistical analysis

The total number of small mammals captured were calculated at each site and also separated by managed and unmanaged side for the entire surveying period. Tracks on the papers that were categorized and animals caught in traps were treated as a relative measure of small mammal activity. Vegetation characteristics were estimated once during the surveying season at the peak of vegetation growth for each site.

All tests were performed using JMP Statistical Analysis Software (JMP, Version 11. SAS Institute Inc, Cary, NC, 1989-2007). Pairwise Wilcoxon tests were run to test for significant differences in relative activity between sites, months, and management and unmanaged sides of each site. I used a Spearman's rank correlation analysis to look at relationships among all variables individually (mice activity, vegetation characteristics, management characteristics, and area of landcover types) to see which management, habitat variables, and landcover types were impacting relative activity. Spearman's rank correlation analysis was also used to measure the correlations between small mammal activity data separated into totals, averages, minimums, maximum, and range and vegetation variables separated into totals, averages, minimums, maximums, and range. These were highly correlated with each other, so totals for small mammal activity were used for the rest of analysis and for vegetation variables we used averages and totals. Variables were characterized as highly significantly correlated if the p-value was below the Bonferroni corrected value and nearly significant if above the Bonferroni corrected value but below 0.05.

I used logistic regression to analyze relationships between small mammal activity and vegetation and management characteristics. Small mammal responses were categorized using natural breaks into low (0-63 tracks, 0-15 trapped), medium (64-126 tracks, 16-32 trapped), and high (127-192 tracks, 33-48 trapped) groupings. This was done to transform the data in order to use logistic regression. Similarly, we examined the relationship of small mammal responses to a combination of habitat variables. For the habitat variables that were correlated in the Spearman's rank correlation, one variable from each pair was eliminated for the stepwise regression analysis. The variable that was kept was chosen as most relevant for small mammals based on previous studies. Akaike's Information Criteria adjusted for small sample size (AICc) was used to select the "best" model among all possible candidate models and models with in 2 AICc units were considered equal (Burnham and Anderson 2002).

To compare tracking tubes and live trapping I used the Schnabel Method (Krebs 1999) because it estimates abundances over more than one mark and recapture period. The Schnabel Method assumes a closed population with no migration or immigration and no births or deaths in order to estimate the abundance of mice for the season. To estimate capture and recapture data for tracking tubes, each tube was treated as an individual because I conservatively assumed that only one mouse was using an individual tube. Therefore, the first time the tube had tracks was the initial capture and any other dates tracks were found were considered recaptures.

Results

Overall trends activity

Summary of burn information was collated from GIS layers provided by Toledo Metroparks. The summary of burn information for each site can be found in Table 2.1. The tracking tubes survey started in May and lasted for five months. Tracking tube surveys were conducted for 14 weeks and a total of 923 tracks were counted. All tracks appeared to be made by mice. It was difficult to distinguish between white footed mice (*Peromyscus leucopus*) and deer mice (*Peromyscus maniculatus*), therefore all were identified as *Peromyscus*. On average there were about 66 tracks per week in total. The number of small mammal tracks varied across sites ranging from 20 to 93 total per week (Table 2.2, Figure 2.7).

Sites varied in small mammal activity for tracking tubes across and within burn categories. Site 8, the site burned a month before I started my research, had the highest number of tracks and site 9, both in the high burn category, had the lowest number (Figure 2.7). Tracks totals were significantly different between sites (Kruskal-Wallis, $p < 0.0001$). Site 8 was significantly different than sites 6, 7, 1, and 2 (Wilcoxon, $p < 0.01$). Site 4 was significantly different than sites 1 and 2. Site 3 was significantly different than sites 1 and 2 (Wilcoxon, $p < 0.01$). Site 9 was significantly different than sites 5, 1, 2, 3, 8, and 4 (Wilcoxon, $p < 0.01$). Site 6 was significantly different than sites 1, 3, and 4. Site 7 was significantly different than sites 3 and 4 (Wilcoxon, $p < 0.01$, Table 2.3).

The live trapping survey started in May and lasted for four months. Live trapping was done for 14 nights and caught a total of 106 small mammals of three different species, 3 deer mice, 89 white footed mice, one North American Least Shrew (*Cryptotis parva*), and 13 unknown mice (Figure 2.8). The undesignated mice were unidentifiable to species because of loss or short tails and the difficulty distinguishing between deer mice or white footed mice. These mice were still included in estimates of total relative small mammal activity. On average there were about 11 small mammals caught per night for all sites. The number of small mammals trapped varied across sites from 1 to 25 per night (Table 2.4). The most common species was white footed mice. Sites varied in small mammal activity for live trapping. Site 4 had the highest number of small mammals caught and site 3 had the lowest number (Figure 2.9). Small mammal numbers trapped were not significantly different between sites (Kruskal-Wallis, p =0.4783).

Influence of environmental features on small mammal activity

I evaluated significant relationships between small mammal activity and vegetation characteristics. For vegetation characteristics, I used averages unless otherwise stated, since average, minimum, maximum, and ranges were significantly correlated with each other. The summary of small mammal tracks and small mammals live trapped (totals, averages, minimums, maximums, and ranges) were also highly significant, so totals were used for small mammal activity analysis. Separated by site, the total number of small mammal tracks were positively correlated to average bare ground (Spearman's, ρ=0.8333; Figure 2.10). Total small mammal tracks were negatively related to vegetation height (Logistic Regression, x^2=5.313), average percent of other vegetation (Logistic Regression, x^2= 4.774), burn number since 2016 (Logistic Regression, x^2= 10.869), and sapling number (Logistic Regression, x^2= 20.848)(Table 2.5). Total small mammal tracks were positively related to percentage of grass (Logistic Regression, x^2=

6.344) (Table 2.5). Total small mammals trapped was negatively related to average vegetation density (Logistic Regression, x^2=3.905) and burn number since 2012 (Logistic Regression, x^2=4.285) and positively related to years since last burn (Logistic Regression, x^2=5.187) (Table 2.6).

Influence of management on small mammal activity

For tracking tubes, overall small mammal activity was significantly different between managed and unmanaged sides for all managed and unmanaged areas (Kruskal-Wallis, $p<0.0001$). The number of tracks varied across treatments within sites (Table 2.7, Figure 2.11). I found only site 2 showed significant differences in the total number of tracks between managed and unmanaged sides (Kruskal Wallis, $p = <0.0001$). The managed side of site 2 had three small mammal tracks and the unmanaged side had 91 small mammal tracks (Table 2.7). The unmanaged side of site 2 had cooler soil temperature and higher soil moisture than the managed side (Table 2.8). Also, the unmanaged side had lower vegetation height and reduced density compared to the managed side (Table 2.8). There were no vegetation characteristics that were significantly correlated with total track numbers when sites were separated into managed and unmanaged.

For live trapping, overall small mammal activity was not significantly different between managed and unmanaged locations (Kruskal-Wallis, $p =0.524$). Number of small mammals trapped varied slightly across treatments within sites (Table 2.9, Figure 2.12). Live trapping small mammal activity was significantly positively correlated with area of upland prairie within each site (Spearman's, $\rho = 1.000$) and significantly negatively correlated with area of upland deciduous forest (Spearman's, $\rho =-1.000$) (Figures 2.13 & 2.14).

Relationship between management and environmental variables

I found some significant relationships between the management characteristics and environmental variables. Total burn number since 2012 was significantly positively correlated with average soil temperature (Spearman's, ρ =0.8132) and negatively correlated with average soil moisture (Spearman's ρ= -0.6733). Burn number since 2016 was significantly positively correlated with average soil temperature (Spearman's ρ= 0.8778). Year since last burn was significantly negatively correlated with average vegetation height (Spearman's ρ=-0.7011), negatively correlated with average percent of trees (Spearman's ρ= -0.6681), and negatively correlated with average percent of other vegetation (Spearman's ρ= -0.7011) (Table 2.10).

Relationship between environmental and management variables on small mammal activity

My stepwise models explored what combination of variables most influenced small mammal activity. The top models, shown in Table 2.11, included vegetation characteristics such as ground cover. For tracking tubes, the strongest model explaining total activity included average percentage of bare ground and average percentage of crypto-biotic crust (AICc=21.46, R-square=0.871, p =0.0021 (Table 2.11). Both average percent of crypto biotic crust and average percent of bare ground had a positive relationship with small mammal activity. The sample size for activity from trapping was too small for this analysis. I also examined small mammal activity in relation to land cover types within the sites. The strongest model for tracking tube activity included residential/ mixed (AICc=30.823 R-square=0.1875, p-value=0.2443) (Table 2.12). Residential and mixed had a negative relationship with small mammal activity. Other strong models for small mammal activity and landcover included wet prairie (AICc=30.823, R-square=0.1875, p =0.2443), sand barrens (AICc=31.399, R-square= 0.1338, p = 0.3331), and upland savanna (AICc= 31.656, R-square=0.109, p =0.386) (Table 2.12).

Some of the differences within and across sites were driven by characteristics independent of burn category. For example, Site 8, in the highest burn category, had the most small mammal activity with tracking tubes, the most landcover types, and the largest area of upland savanna (Figure 2.15, Figure 2.18), while Site 9, also in the highest burn category, had the least number of small mammal tracks had only two different landcover types (Figure 2.15, Figure 18). The managed side of site 8 had the upland savanna and had slightly more small mammal tracks than the unmanaged side (Figure 2.16). The managed side on site 2, also in the highest burn category, consisted of entirely dry open habitat and the unmanaged side of site 2 had a combination of dry forest and dry open habitats (Figure 2.17). Figure 2.19 shows the breakdown of landcover types for small mammal activity based on low, medium, and high categories. The high small mammal activity category consisted of a lot of the open habitats (upland prairie, upland savanna, and sand barrens). The low small mammal activity category consisted of a large portion of upland deciduous forest (Figure 2.19). Figure 2.20 shows the breakdown of landcover types in the high, medium, and low burn categories. Large portions of landcover for the high burn category consisted of upland deciduous forest and upland prairie (Figure 2.20).

Comparing live trapping and tracking tubes

Using the Schnabel Method, I compared estimates of abundance for live trapping and tracking tubes in sites 1, 3, 4, and 8 and found that live trapping and tacking tubes did not produce the same abundance estimates (Table 2.13). Since I could not distinguish individuals for the tracking tube data, I used a very conservative assumption and assumed that the first tracks found at that tubes were a new capture and tracks after that were considered recapture. The estimates of abundances for tracking tubes were consistently smaller for each site than the estimate of abundances for live trapping for each site.

Discussion

Overall trends in activity

Fire is an important process in shaping and maintaining ecosystems (Braun de Torrez et al. 2018). Fire suppression has altered vegetation structure, species assemblages, and ecological function in habitats, so park managers reintroduced fire back into certain systems to alter some of those effects (Braun de Torrez et al. 2018). Multiple studies have shown that fire is important for opening canopies, removing invasive species, recycling nutrients, and removing leaf litter or fuel for wildfires but it is not clear how fire impacts organisms such as small mammals (Glasgow and Matlack 2006, Wood et al. 2011). It is also uncertain how edges created by management impact small mammals, such as mice. Studies on fires usually focus on the habitat quality as a whole, vegetation characteristics, or the species targeted for management, but the purpose of this study was to explore how management, more specifically prescribed fire, was impacting nonvolant small mammals, which are rarely the focus of management studies. Small mammals are closely tied to local habitat changes based on resource availability and protection, so it is important to understand how changes in habitat structure and vegetation through management are impacting these animals (Hamilton et al. 2019).

Small mammals can be impacted directly and indirectly by fire and it is important to fully understand the relationship of this impact because small mammals are essential to an ecosystem’s dynamic (Hamilton et al. 2019). For tracking tubes, the site that had the most burns and was the most recently burned prior to my study also had the greatest number of small mammal tracks. Similar to my live trapping small mammal results, I found the highest number of small mammals trapped were at the sites that were in the medium and high burn categories, which is the opposite of what I predicted. My results differed from another study that found areas that were not burned had higher small mammal activity when compared to areas that had a burn age of 0.5- 12 years prior to sampling (Dixon et al. 2019). This study used camera trapped to survey mammals and investigated the response of mammals to fire history, habitat, and environmental variables. On the other hand, other sites that were also in the high category, sites 9, 6, and 7, had the lowest number of small mammal tracks. These results illustrate that management is not the only factor that is impacting small mammal activity and that sites and the animals that use them may respond differentially to prescribed fire.

Influence of environmental features on small mammal activity

Small mammals, such as mice, rely on fine-scale habitat structure and vegetation characteristics for food resources and protection from predators (DeGolier and Matlack 2015). At the smaller scale, through my research, I found some vegetation characteristics significantly influenced small mammal activity. I found that small mammal activity was positively related to average percent of bare ground and average percent of grass but negatively related to average vegetation height, average percent of other vegetation, and total sapling number. Small mammals trapped had a negative relationship with average vegetation density. It is important to keep in mind that this study focused on activity (e.g., foraging, travel) and not nesting. These results provide some insight into the complex response of these species to the fine-scale heterogeneity of the environment. The positive relationship with grass could result from the food source that grass seeds provide to small mammals (Horncastle et al. 2019). The negative relationships with certain vegetation characteristics such as vegetation height and sapling number and positive relationships with bare ground suggest that open areas were more preferred by small mammals than areas with a lot of understory clutter and vegetation. Several studies found that fire eliminated ground cover and small mammals may avoid the area until the vegetation grows back, but my study found that small mammals had a positive relationship with bare ground (Parkins et al. 2018, DeGolier and Matlack 2015). I hypothesized that the difference in my results compared to the other studies' results was likely influenced by greater amounts of fine-scale heterogeneity in landscape of my study. Parkins et al. (2018) study was conducted in all forest habitats, while my study had a variety of open and closed habitats. One study concluded that smaller mammal species depend on structurally complex understory and found that small mammal activity increased as vegetation density increased as well (Dixon et al. 2019). In my research, I found the opposite. Another study found that certain small mammal species such as the white-footed dunnart (*Sminthopsis leucopus*), agile antechinus (*Antechinus agilis*), and bush rat (*Rattus fuscipes*) in south-eastern Australia had a negative relationship with vegetation cover (Rochelmeyer et al. 2019), which is similar to my results. Dixon et al. (2019) found that spatial heterogeneity promotes species diversity and activity and this can be created by having habitats with various successional stages from differing times since fire. This study had a similar small-scale site setup as my study. The complexity of my results supports this finding because small mammals had a mixture of relationships with vegetation and habitat structures. Overall, fire affects flora and fauna differently and this may differ by region and by taxa so habitat heterogeneity should be an important goal for management (Parkins et al. 2019).

Influence of management on small mammal activity

Through my research, I found some sites had noticeable differences in the distribution of small mammal activity between managed and unmanaged sides within sites. For example, site 2 had over 90 small mammal tracks on the unmanaged side and only three tracks on the managed side. This is comparable to one study in the Central Highlands of Victoria that found that, generally, small mammals such as bush rats (*Rattus fuscipes)* and agile antechinus (*Antechinus agilis)* were less active on the burnt side of edges for at least three years (Parkins et al. 2019). I hypothesized that the difference would be a result of soil temperature or soil moisture because the managed side of site 2 was hotter and dryer than the unmanaged side, but soil moisture and soil temperature did not have a significant relationship with small mammal activity. Another explanation could be that the managed site of site 2 had higher vegetation height and higher vegetation density than the unmanaged side and I found that small mammal activity had a negative relationship with vegetation height and vegetation density. Also, site 8 was burned a month before I started my research and I found no significant differences between managed and unmanaged sides. These results suggest that the differences were based on the complexity within a site and not just the managed and unmanaged identity of sides. So, managers can focus on the vegetation and structural aspects that were significant influences when managing an area, regardless of management approach.

For live trapping activity I found a negative correlation with burn number since 2012 and a positive correlation with year since last burn suggesting that high frequency of burning may not be beneficial for small mammals. My study only surveyed over one season and that would make it challenging to tease apart long versus short term effects of prescribed fire, especially across sites that varied so much in their characteristics (e.g., diversity of land cover types, vegetation structure). I also treated all fire events as equal in intensity and assumed the entire managed side was affected. In reality, the differences in intensity and extent have been shown to have impacts on the small mammal response in addition to frequency of and interval between fires (Parkins et al. 2018). In short term effects after a fire, small mammals may need to move from that area to avoid being burned but in the long term, they may return for the resources that develop following a fire (Nimmo et al. 2019). It would be helpful for future studies to examine some of these fire characteristics more carefully and to assess their impacts over a longer period of time.

For my study, I focused on an unburned area adjacent to the burned area assuming the unmanaged areas would allow for escape from the fire or ability to use resources. Dispersal is important for small mammal populations because without the ability to disperse, these animals risk reduced fitness and increase mortality (Nimmo et al. 2019). Parkins et al. (2019) found that small mammals were generally less active on burnt edges up to 6-7 years after a fire. In my research, I found in site 8, which was the site that was burned about a month before my research, the managed side had slightly higher small mammal activity than the unmanaged side. This might be a result of increased nutrient inputs from a fire that increase vegetation and food sources (Glasgow and Matlack 2006, Wood et al. 2011). Unburnt patches in fire habitats are refuges for animals, enabling animals to survive the fire, persist after a fire, and possibly recolonize after a fire (Parkins et al. 2019), which again speaks to the potential influence of fire intensity and extent.

Dixon et al. (2019) pointed out that one fire age class is not usually suitable for all taxa so one must be careful when generalizing results. A variety of successional habitat stages is important for vertebrates so an even distribution of fire age classes may, in fact, be detrimental for biodiversity conservation (Dixon et al. 2019). At a larger scale, in my results, I found that site 8, which had the most small mammal tracks, had 5 different landcover types within the site and had the most area of upland savanna. Site 9 had only two landcover types within the site and had the smallest number of small mammal tracks. Landcover types are not the only explanation for increased small mammal activity because site 3 had two landcover types and had the third most small mammal tracks and site 6 had four landcover types and had the second least number of small mammal tracks. These results suggest that fine-scale composition may be more important than quantity, at least at the extremes, but a larger sample size is needed for confirmation. It is essential to use management to create a mosaic of fire histories to maintain heterogeneous habitat (Dixon et al. 2019). Rochelmeyer et al. (2019) suggests that in flammable landscapes, habitat measurements, not just fauna, remain important for conservation management. Fire affects flora and fauna differently and edge effects may differ by region and by taxa (Parkins et al. 2019).

Influence of management on environmental variables

Prescribed fire can open forest canopy, remove leaf litter, recycle nutrients back into the environment, remove competitive plant species, and promote wildlife conservation by creating environmental conditions that are favorable for native wildlife (Glasgow and Matlack 2006, Wood et al. 2011). Without fire management the herbaceous vegetation layer will be suppressed, and the forest floor can change from herbaceous vegetation to shade-tolerant woody shrubs and vines (Hanberry and Abrams 2018). If herbaceous plant diversity changes, then other wildlife species may decline as well as small mammals (Hanberry and Abrams 2018). During my study, I found a positive correlation between burn number since 2012 and average soil temperature and a negative correlation between burn number since 2012 and average soil moisture. This is likely a result of more open forest canopies created by fire allowing sun to hit the forest floor. I also found a negative correlation between years since last burn and average vegetation height, average percent of trees, and average percent of other vegetation, which could be the result of the changes in herbaceous vegetation layer the longer an area has not been burned. These relationships may provide an efficient way to monitor the potential impacts of management activities on small mammal activity. It is important to understand how management is impacting habitat characteristics because these can influence organisms and can be a tool for monitoring what management is affecting structurally.

Relationship between management and environmental variables on small mammals

Effects of management on the habitat and organisms cannot be explained fully examining one variable at a time. My multivariate models showed that open types of habitat (e.g. wet prairie, sand barrens and upland savanna) had positive relationships with small mammal tracks. I also found that small mammal activity from traps was negatively related to the amount of upland deciduous forest. This contrasts with one study that found that long-unburnt forest and woodlands were more important for small mammals (Dixon et al. 2019). The best model for small mammal activity from tracks included bare ground and crypto-biotic crust. Parkins et al. (2019) found that small mammal activity was not correlated with understory complexity, which supports my results. Dixon et al. (2019) found that increasing shrub height had a positive association with small mammals and increasing shrub cover had a negative association with small mammals. The negative association with vegetation cover is similar to my study where I found a positive relationship with bare ground. Kappler (2009) also found crypto-biotic crust to have a positive relationship with small mammal activity. The crypto-biotic crust may be providing hydration from the dew on the moss or it can be an area where fungi, a potential food source, are found (Kappler 2009). The finding that small mammal activity for tracking tubes was higher in open areas may also be explained as the tracking tubes providing a source of cover for the small mammals (Kappler 2009).

Comparing live trapping and tracking tubes

I did not get similar small mammal abundance estimates when comparing live trapping to tracking tubes. I also did not get completely similar results for vegetation and management effects for live trapping and tracking tubes. Live trapping requires a lot of sampling effort and this limited the number of sites that I could reasonably survey with this method, which is a recognized challenge of mark-recapture with live traps (Wilkinson et al. 2012). Live trapping does allow for researchers to gather data on individual's sex, age, condition, and characteristics while tracking tubes does not allow for this information to be gathered (Wiewel et al. 2017). Tracking tubes are inexpensive, easy to monitor and reduces stress for the animal (Wilkinson et al. 2012, Wiewel et al. 2007). Tracking tubes allow researchers to gather information on species abundance on a large spatial scale, changes in relative abundance, and habitat preference (Wiewel et al. 2007). One study showed that tracking tubes can be used to track large fluctuations in a species relative abundance over time (Wilkinson et al. 2012). Also, tracking tubes have been shown to have approximately proportional detection rates of commonly captures species compared to mark-recapture live trapping (Wiewel et al. 2007) With this study, there was an exception with meadow voles, they were underrepresented with tracking tubes surveying when compare to mark-recapture (Wiewel et al. 2007). Similarly, we may have underrepresented shrews in our sites as one was caught but no tracks were found. At the conclusion of the study, I was able to gather more information (e.g., more sampling) and have stronger statistical analyses on the effects of management on small mammals by using tracking tubes.

Comparison to other studies

Throughout my study, the majority of my results have been the opposite of what I have found in the literature. I think there are two main reasons for these differences. The first reason is that the area where I did my research is rich in fine-scale landscape heterogeneity. All of my sites had different compositions of landcovers and habitat characteristics. For example, Dixon et al. (2019) studied the effects of burning on mammals in Australia in sites that were entirely in forest and woodlands. Their habitats included, dry sclerophyll forest, sub-alpine woodlands, wet sclerophyll forest, and montane wet sclerophyll forest (Dixon et al. 2019). Another study that was looking at the links between fuel, habitat, and ground-dwelling mammals in flammable landscapes in south eastern-Australia had research sites in woodlands, tall mixed forest, foothills forest, forby forest and wet forest (Rochelmeyer et al. 2019). A study measuring the effects of grazing and wildfire effects on small mammals in Arizona consisted entirely in meadows (Harncastle et al. 2019). Johnson and Karels (2016) researched the effects of habitat fragmentation on rodent species richness in an urban landscape in California emphasizing that habitat heterogeneity had a positive direct effect on species richness. Their habitats consisted of grasslands, coastal sage scrub, chaparral and woodland surrounded by residential and commercial areas (Johnson and Karels 2016). My study consisted of wet open, dry open, wet forest, dry forest, and human modified landscapes. I think my study area, consisting of various habitats and being in a unique diversity hotspot, providing invaluable insights and fills important knowledge gaps in management research.

The second reason is I used tracking tubes and live trapping while a vast majority of small mammal research uses live trapping (Johnston and Karels 2016, Parking et al. 2019, Hamilton et al. 2019, and Horncastle et al. 2019). Kappler (2009) used both live trapping and tracking tubes as surveying methods as well and indicated that traps that were baited could have been preferred by individuals for the bait reward, while non-baited tracking tubes allows researchers to measure small mammal activity and distribution naturally without incentives (Kappler 2009). It can also be suggested that small mammal activity for tracking tubes were higher in open areas, because the tracking tubes could have acted as a source of cover for the small mammals (Kappler 2009).

Conclusion

Measuring fauna can be a helpful tool for understanding the health of the habitat and how management might be impacting the environment. This research, consisting of various habitats and being in a unique biodiversity hotspot, fills important knowledge gaps in land management research. Through this multiscale research, my results suggest that open areas created by management are valuable for small mammals, such as *Peromyscus*, but also highlights important structural characteristics that provide more favorable outcomes for mammals, such as crypto-biotic crust. Open areas may provide better maneuverability, but vegetation structure is needed to allow for protection from predators and food source availability, underscoring the fine-scale complexity of habitat requirements for these organisms. It is also important to highlight the importance of having an adjacent unmanaged area to allow for movement of organisms for protection and resource access. Management is essential for maintaining and creating natural remnants but should allow for a mosaic of effects to increase heterogeneity and provide a variety of resources for native organisms.

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Figures

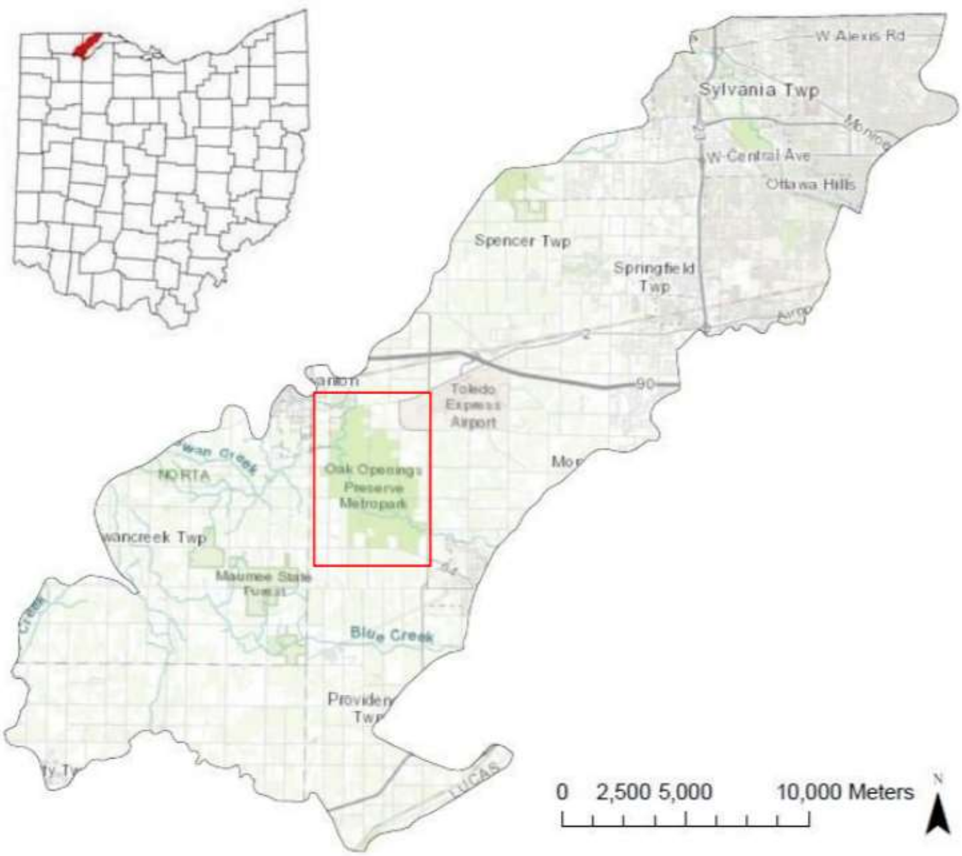

Figure 2. 1: The Oak Openings Region of Northwest Ohio (excluding Michigan portion) as defined by Brewer and Vankat (2004). Study area (Oak Openings Preserve) outline in red.

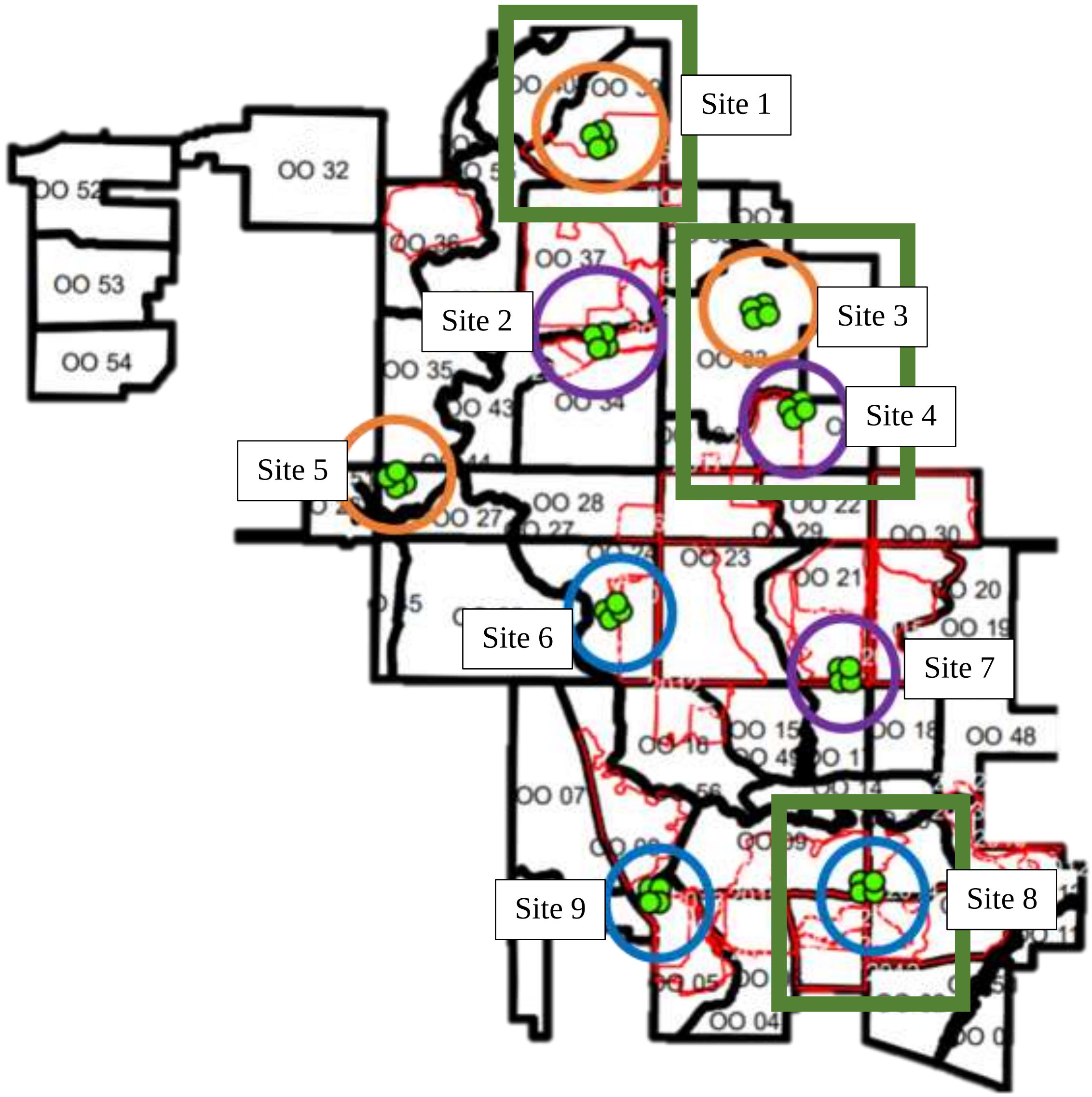

Figure 2. 2: Oak Opening Preserve separated by management units (black). Green dots are the 9 sites selected. Red lines are the outlines of burns since 2012-2019. Orange circles are sites in the low category (0 burns); purple circles are in the medium category (1-2 burns), and blue circles are in the high category (3-4 burns). Green Squares represent the four sites for live trapping.

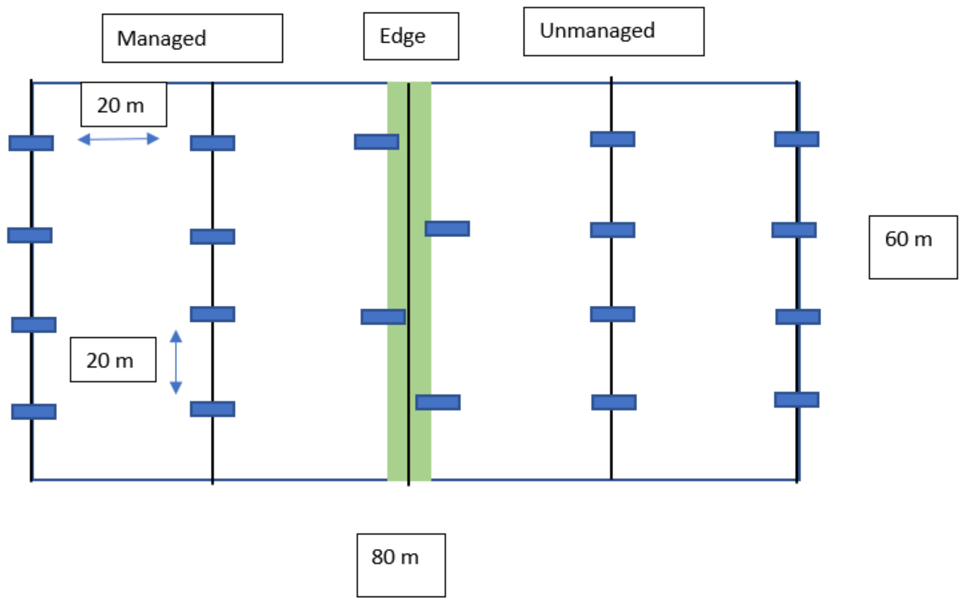

Figure 2. 3: The image above shows an example of a tracking tube and live trapping study site. The vertical black lines are the transects and the blue rectangles represent the tracking tubes (not to scale). The sites were separated into a managed (burned) and unmanaged (not burned) side with an edge (path) in the middle. If the site was not burn, the managed side was still referred to as the managed side for consistency. The tracking tubes and live traps were staggered along the path, so they were not directly on the path.

Figure 2. 4: Pictures above to the left is of a tracking tube. The picture above to the right is of the paper that will be inside the tracking tube to capture the small mammal tracks running through the tube. The gray rectangles on both sides of the paper are the wax paper squares that will have the ink, i.e., fluorescent powder in mineral oil. (Kappler 2009)

Figure 2. 5: Shown is the tracking paper that was inside a tracking tube in the field at a research site. (Picture courtesy of V. Freter)

Figure 2. 6: These are tracking papers after they have been collected from the field. From left to right, paper one represents category one (one set of tracks visible). Paper two represents category two (two-three set of tracks visible). Paper three represents category three (more than three set of tracks visible.

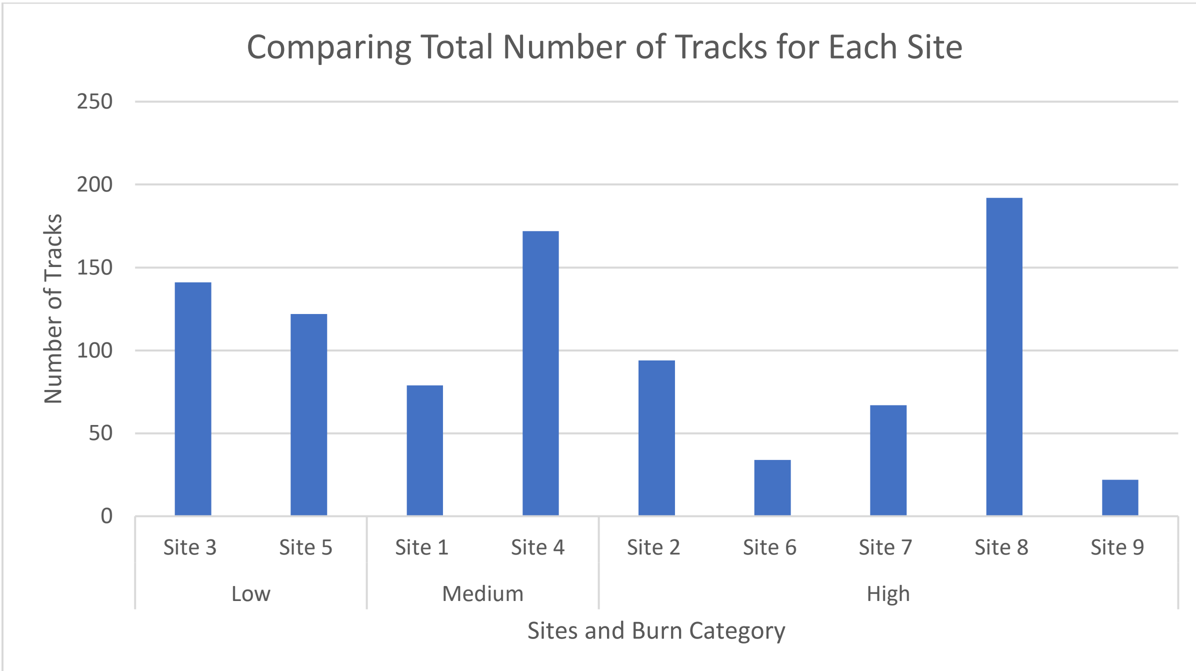

Figure 2. 7: Total number of tracks for each site for the entire research season. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. Sites 4 and 8 had the highest amount of small mammal tracks, while sites 6 and 9 had the lowest.

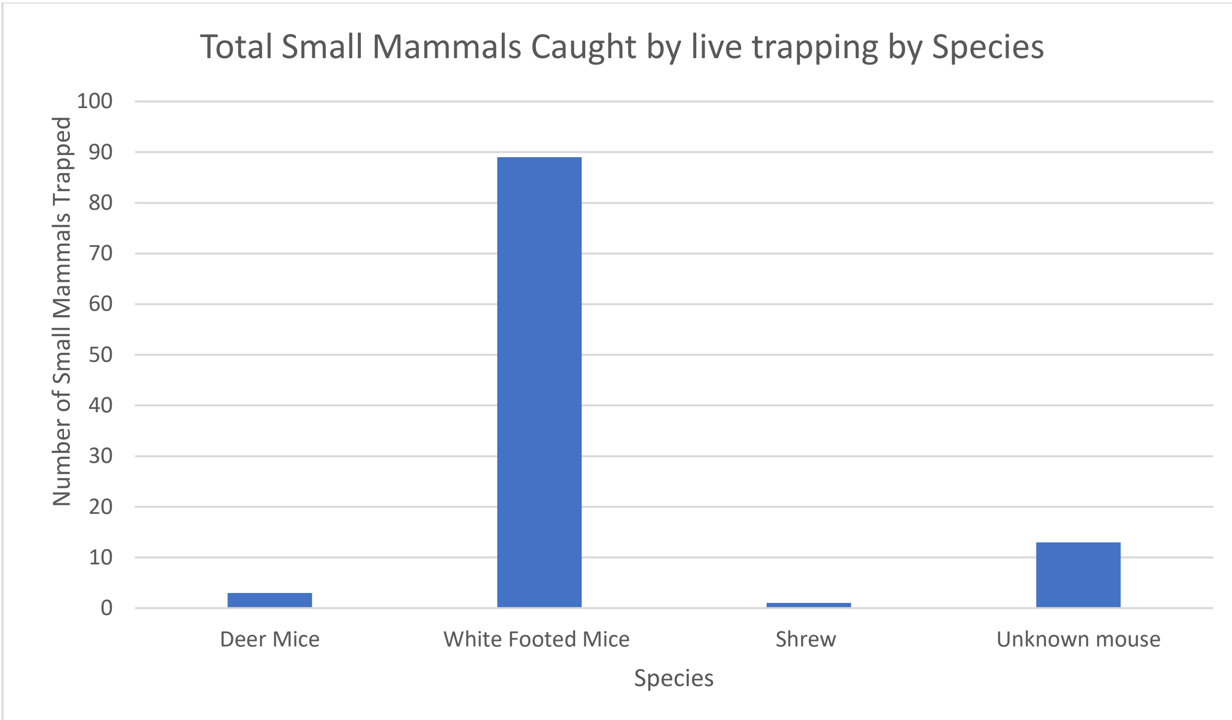

Figure 2. 8: Total number of small mammals trapped separated by species for the entire research season and for all four sites. The majority of mice that were trapped were white footed mice (*Peromyscus leucopus*). Uncategorized mouse means that the mouse captured had a stubbed or no tail, so researchers were unable to distinguish between deer mice (*Peromyscus maniculatus*) or white footed mice.

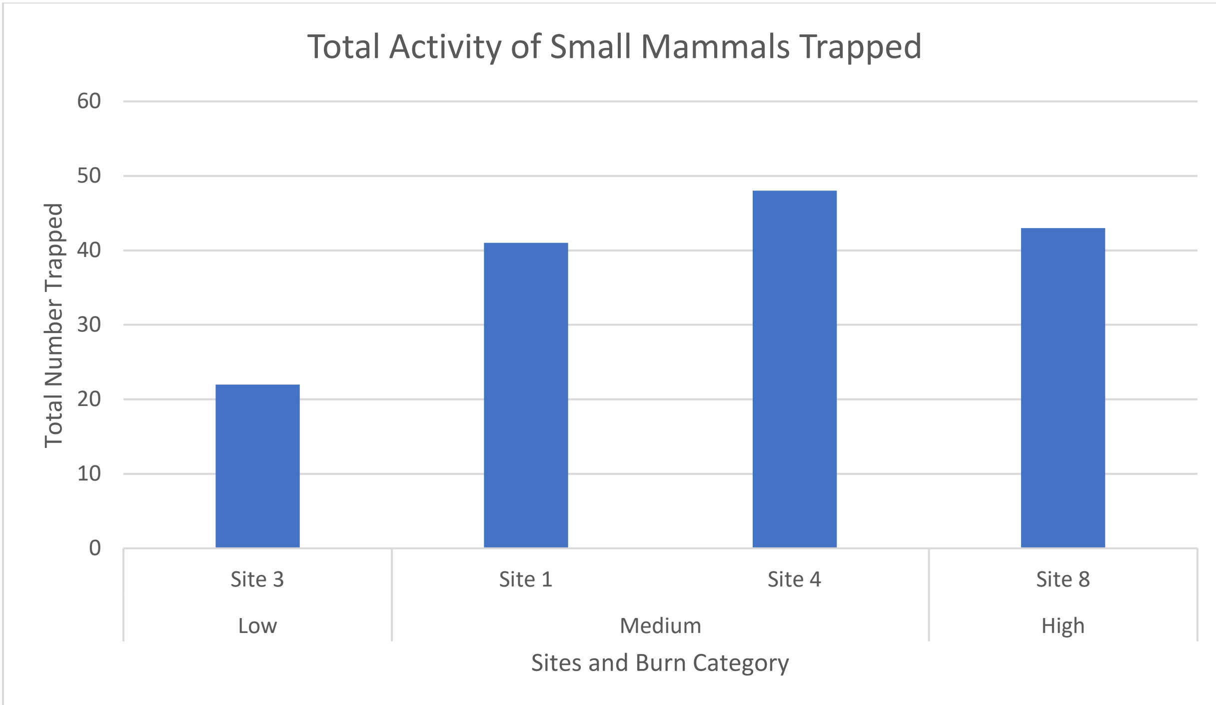

Figure 2. 9: Total number of small mammals trapped by site for the entire research season. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. Site 4 had the highest number of small mammals trapped and site 3 had the lowest number of small mammals trapped.

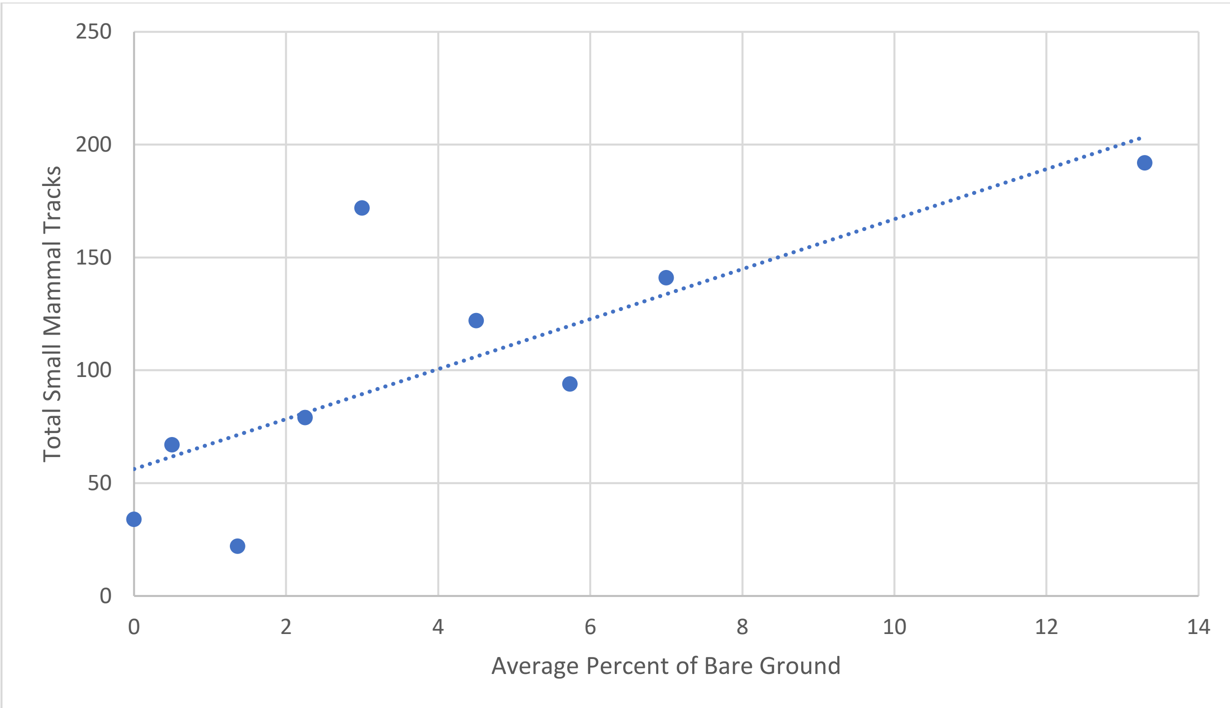

Figure 2. 10: Total number of small mammal tracks compared to average percent of bare ground across sites. Small mammal tracks had a positive significant correlation to average percent of bare ground. Spearman's p=0.8333, p= 0.0053*. Asterisk represents significance after Bonferroni Correction.

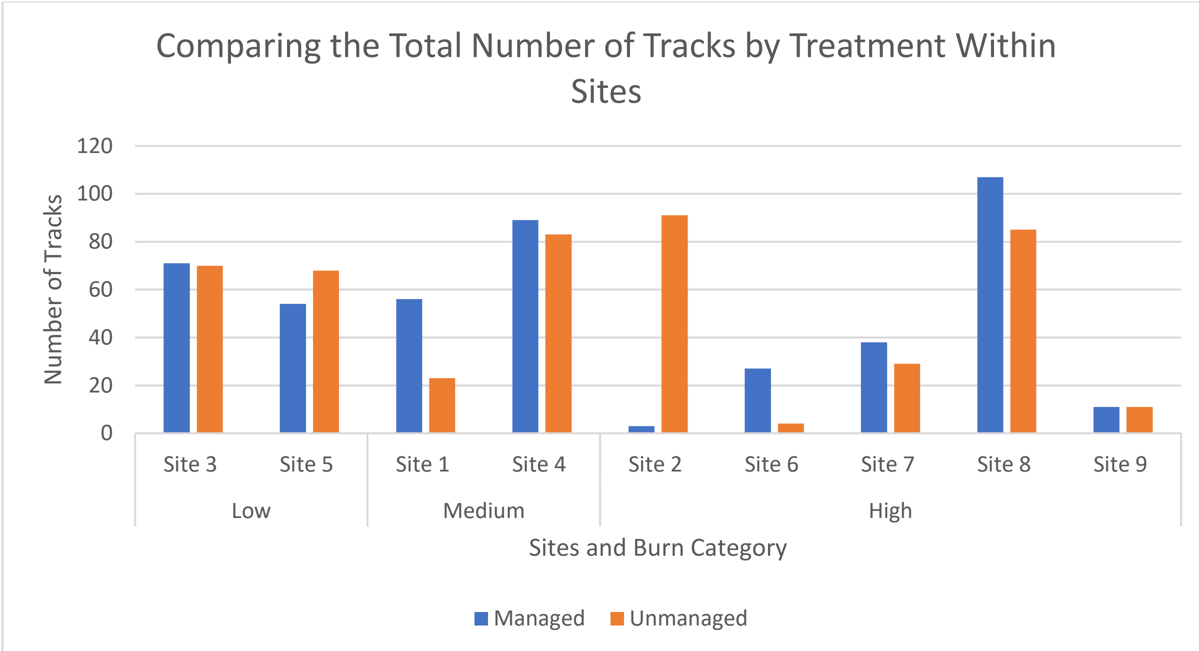

Figure 2. 11: Comparing the total number of tracks in managed (burned) and unmanaged (unburned) areas within each site. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. The blue, or barker bar represents the managed side and the orange or lighter bar represents that unmanaged side. Site 2 had the biggest difference in small mammal tracks between the managed and unmanaged sides.

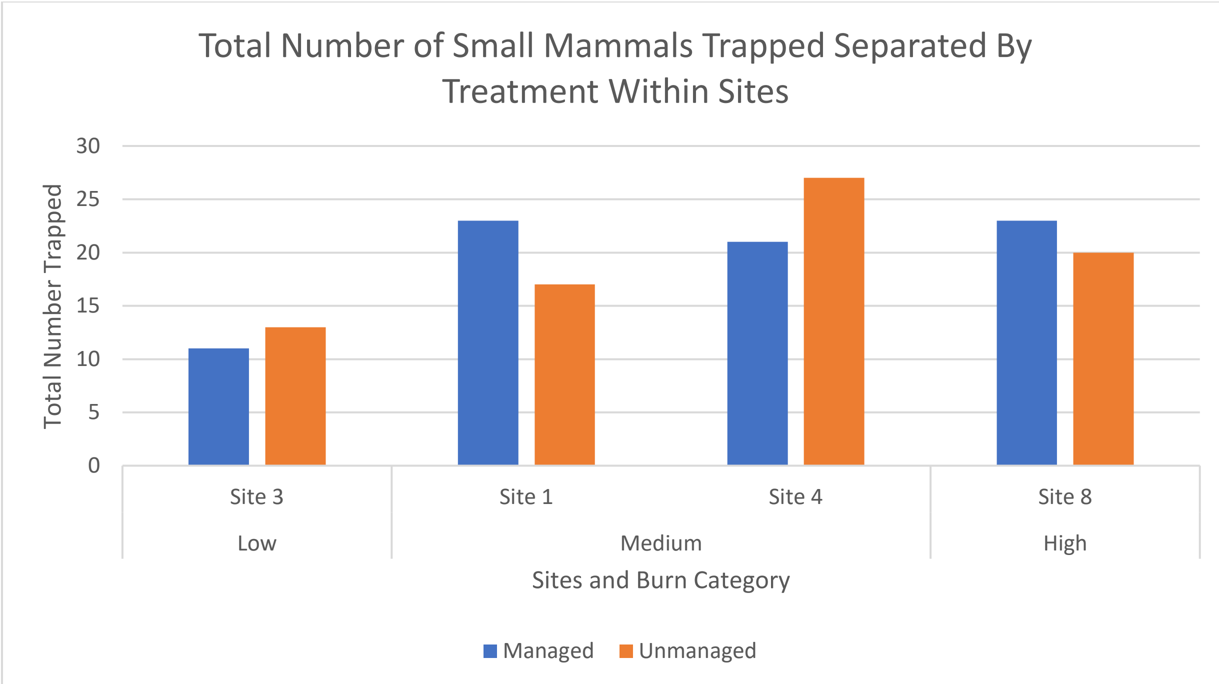

Figure 2. 12: Total number of small mammals trapped separated into managed (burned) and unmanaged (unburned) areas. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. The blue, or barker bar represents the managed side and the orange or lighter bar represents that unmanaged side. There was no significant difference between managed and unmanaged sides for small mammals trapped. Site 1 had the largest difference is small mammals trapped for managed and unmanaged sides.

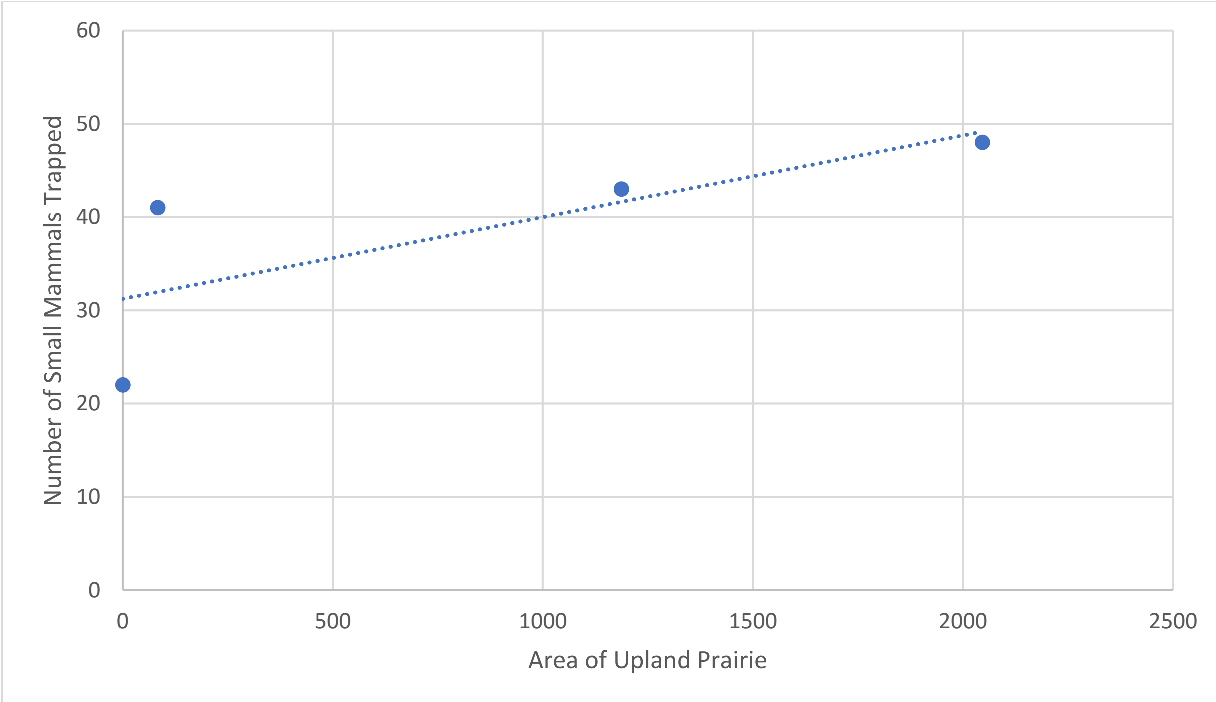

Figure 2. 13: Comparing number of small mammals trapped and area (square meters) of upland prairie within sites. Number of small mammals trapped had a significant positive correlation to area of upland prairie within sites. Spearman's ρ=1.000, p =<0.0001.

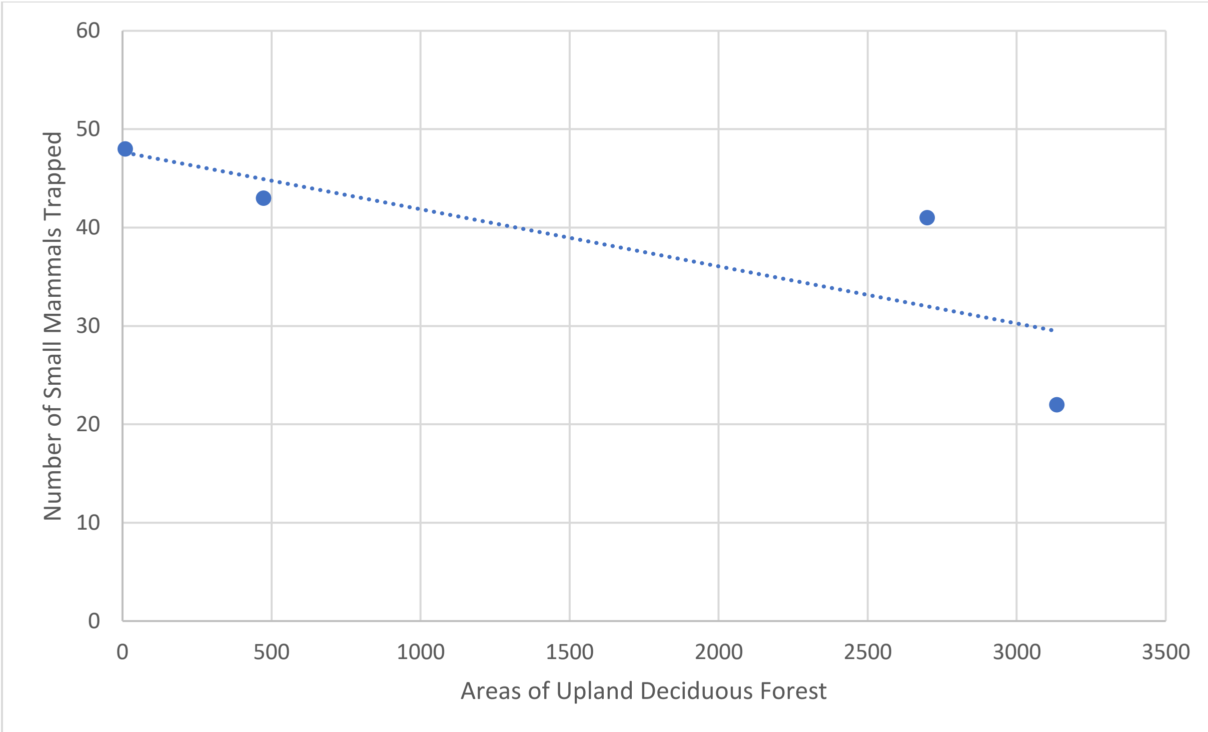

Figure 2. 14: Comparing number of small mammals trapped and area (square meters) of upland deciduous forest within sites. Number of small mammals trapped had a negative significant correlation to area of upland deciduous forest within sites. Spearman's ρ= -1.000, p= <0.0001.

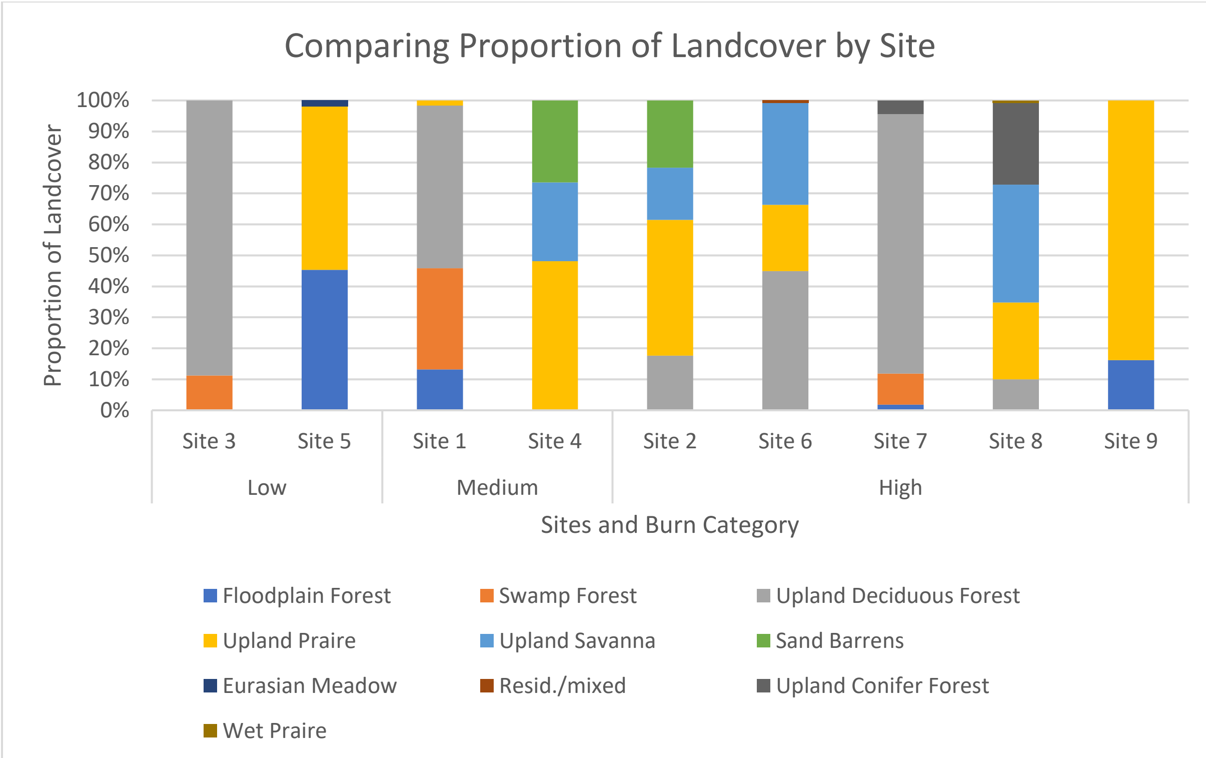

Figure 2. 15: Composition of the proportion of area (square meters) of each landcover type within each site. The top of the bars represents 100% of the area of landcover in each site. The individual colored bars represent the proportion of different landcover types (Based on categories from Schetter and Root 2011).

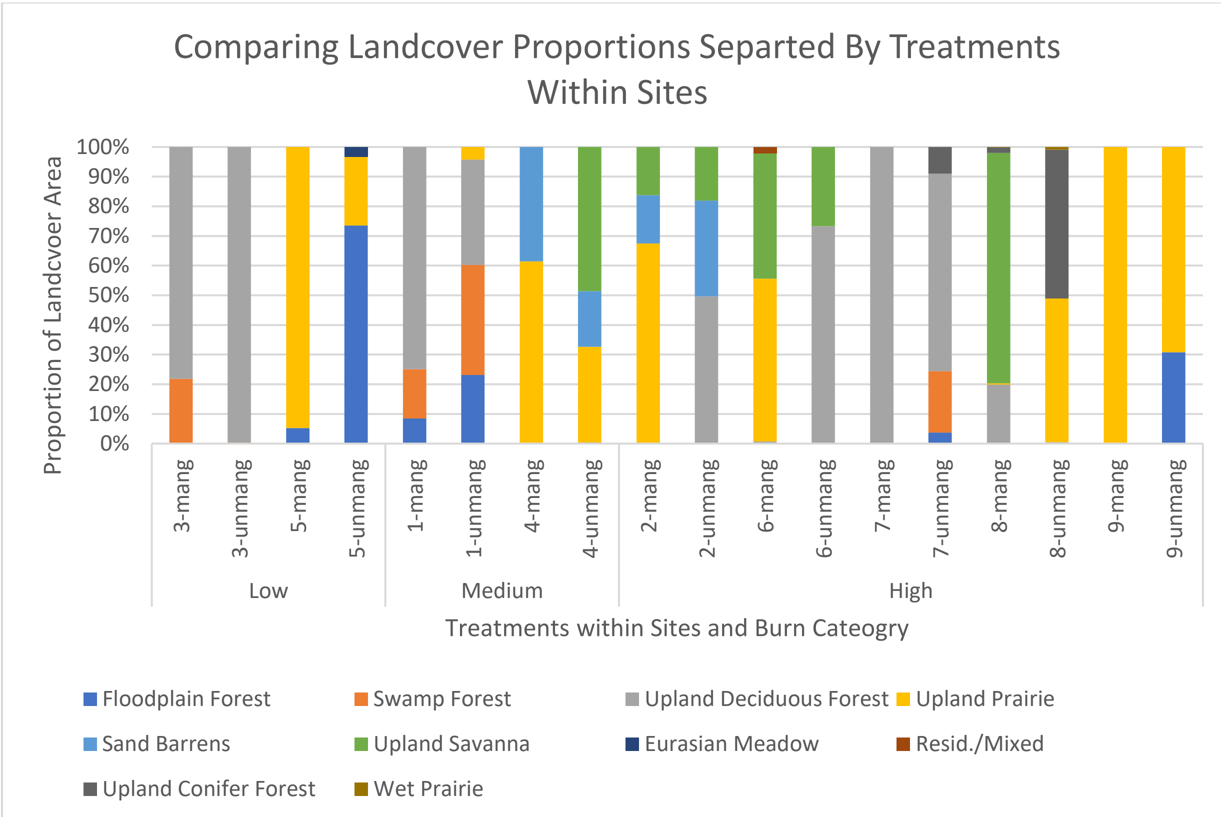

Figure 2. 16: Composition of the proportion of area (square meters) of each landcover type within each site and separated into managed (burned) and unmanaged (unburned) sides. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. The sites are separated by burn categories as well. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. The top of the bars represents 100 % of the areas of landcover on each side of each site and the individual colors correlate to the percentage of each landcover type for that area, based on categories from Schetter and Root 2011.

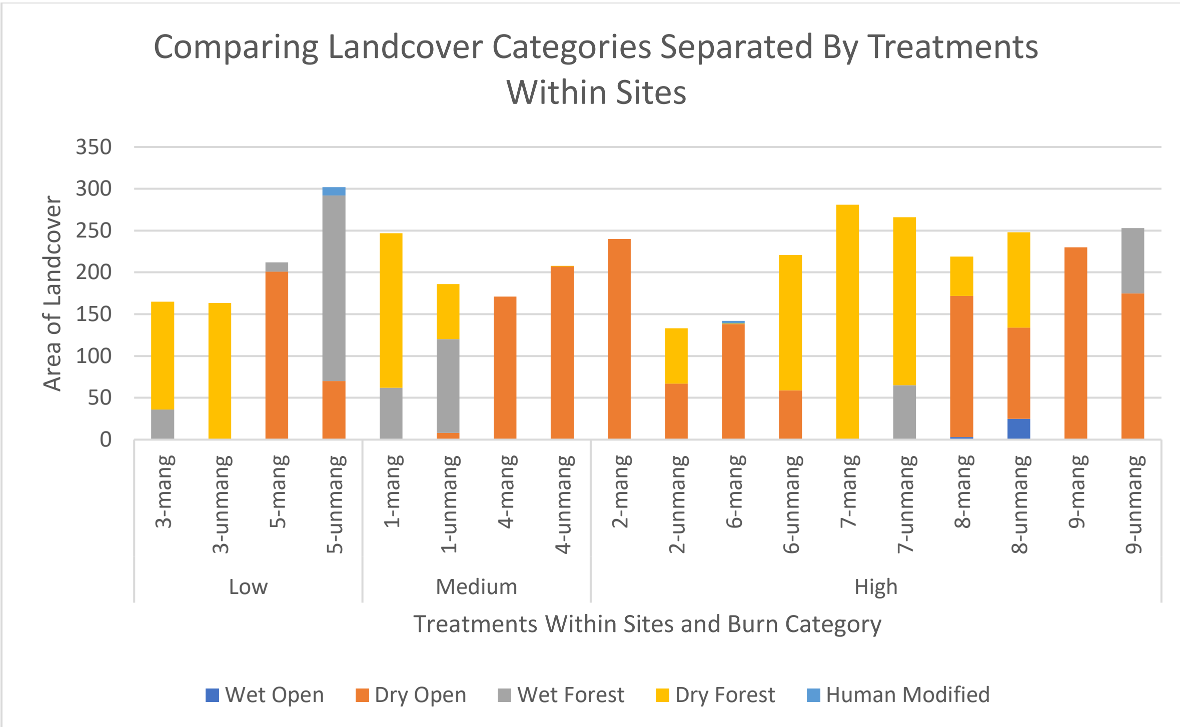

Figure 2. 17: Composition of the area (square meters) of each landcover category within each site and separated into managed (burned) and unmanaged (unburned) sides. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. The sites are separated by burn categories as well. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. The wet open landcover category consisted of wet prairie. The dry open landcover category consisted of upland prairie, upland savanna, and sand barrens. The wet forest category consisted of floodplain forest and swamp forest. The dry forest category consisted of upland deciduous forest and upland conifer forest. The human modified landcover category consisted of Eurasian meadow and residential/mixed. The individual colors correlate to the different landcover categories.

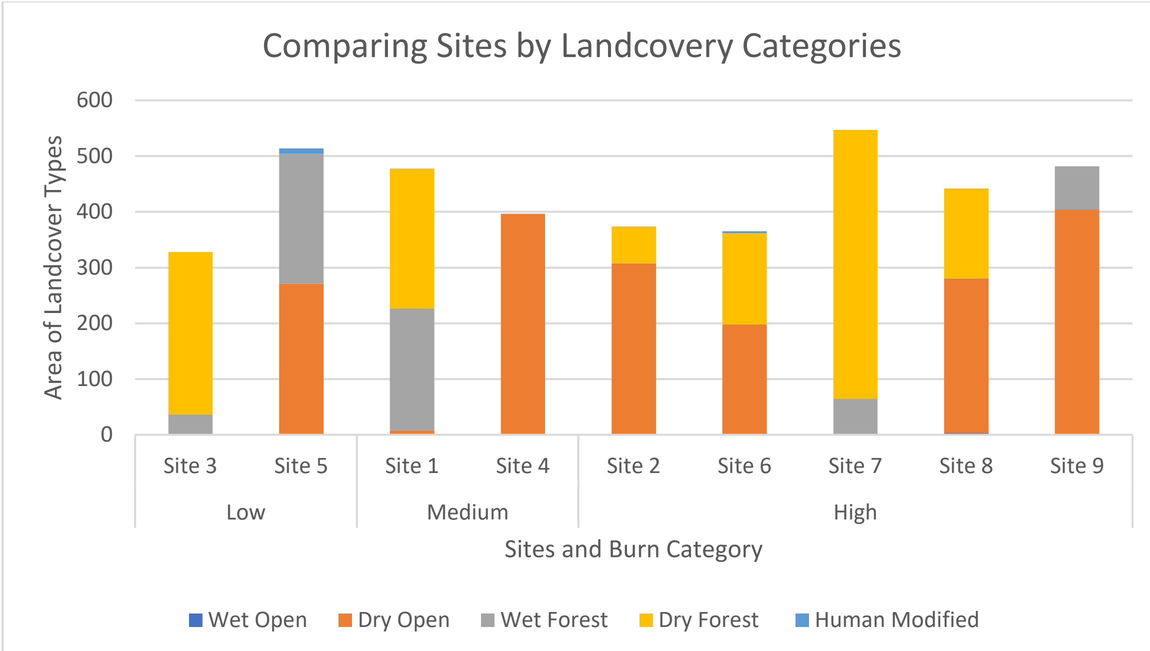

Figure 2. 18: Composition of the area (square meters) of each landcover category within each site. The sites are separated by burn categories as well. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. The wet open landcover category consisted of wet prairie. The dry open landcover category consisted of upland prairie, upland savanna, and sand barrens. The wet forest category consisted of floodplain forest and swamp forest. The dry forest category consisted of upland deciduous forest and upland conifer forest. The human modified landcover category consisted of Eurasian meadow and residential/mixed. The individual colors correlate to the different landcover categories.

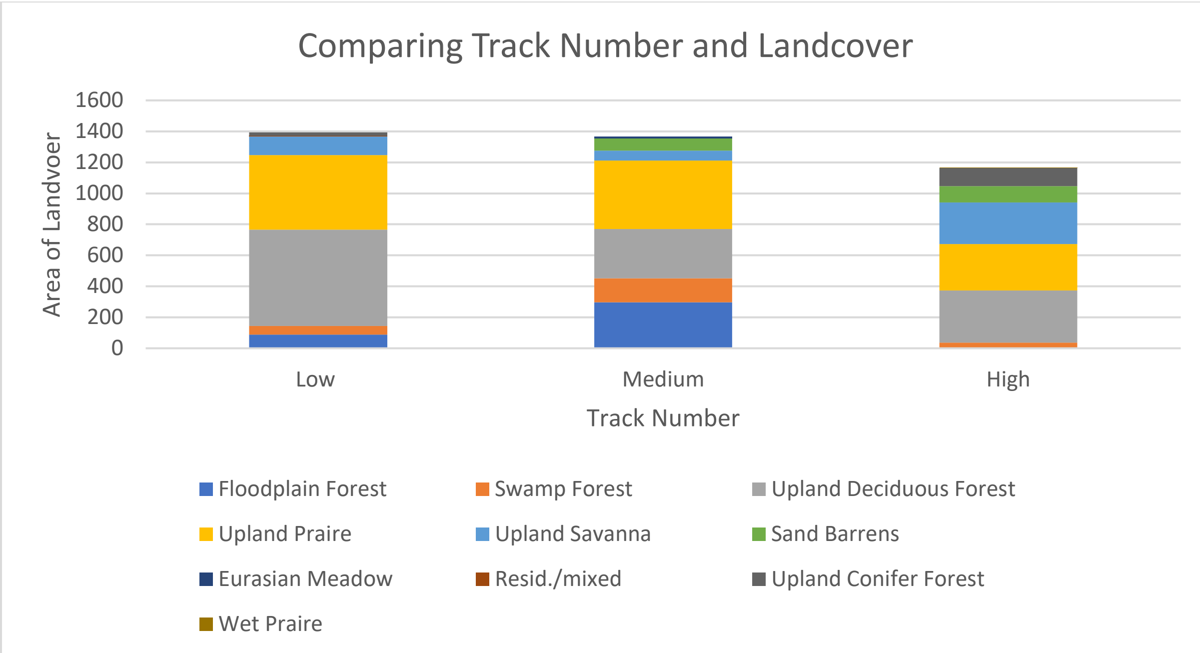

Figure 2. 19: Comparing track number and area (square meters) of each landcover type. Sites were categorized into low, medium, and high by track number. Sites 6, 7, 9 were in the low category. Site 1, 2, 5 are in the medium category. Sites 3, 4, 8, are in the high category. The individual colors correlate to the different landcover categories.

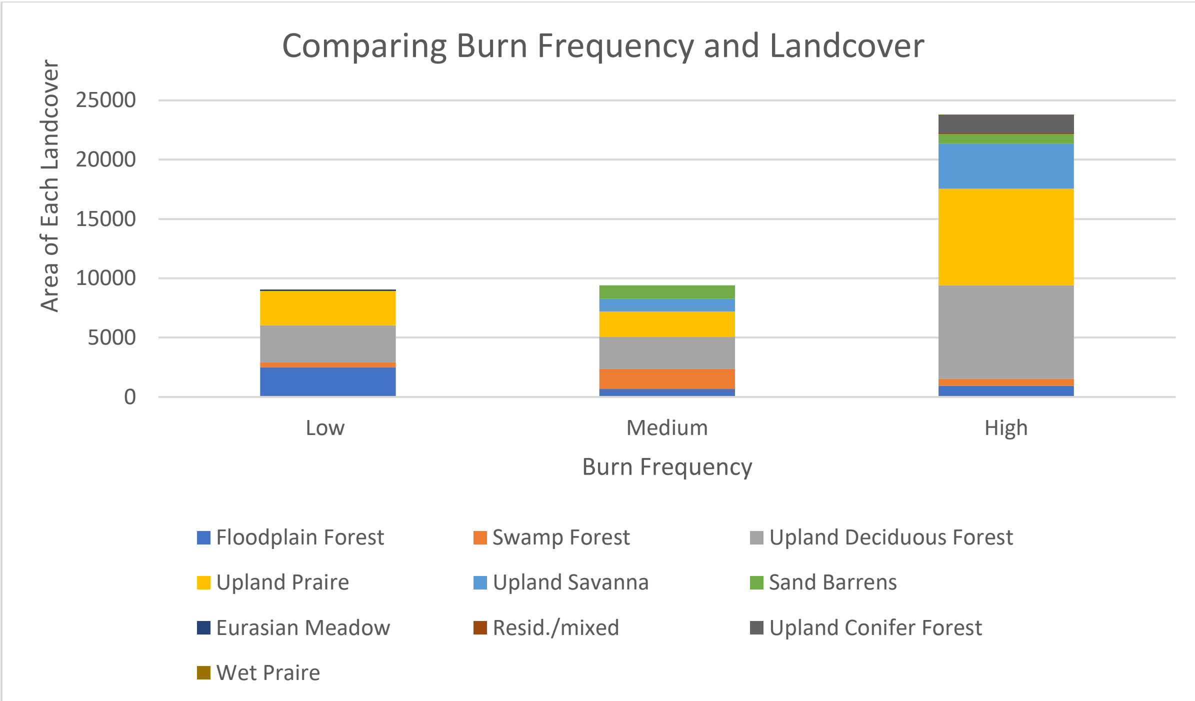

Figure 2. 20: Comparing burn frequency to area (square meters) of each landcover type. Sites were categorized as low, medium, and high by burn frequency. Sites 3 and 5 are in the low category. Sites 1 and 4 are in the high category. Sites 2, 6, 7, 8, and 9 were in the high category. The individual colors correlate to the different landcover categories.

Tables

Table 2. 1: Summary of fire history in the Oak Opening Preserve by site. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

Burn Category	Sites	Total Burn # Since 2012	Years Since Last Burn	Burn # Since 2016
Low	**Site 3**	0	7	0
	Site 5	0	7	0
Medium	**Site 1**	1	4	0
	Site 4	2	2	1
High	**Site 2**	3	3	1
	Site 6	3	4	0
	Site 7	3	1	2
	Site 8	4	0	3
	Site 9	3	1	1

Table 2. 2: Total number of small mammal tracks by site for the entire research season. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

Burn Category	Site	Number of Small Mammal Tracks
Low	**Site 3**	141
	Site 5	122
Medium	**Site 1**	79
	Site 4	172
High	**Site 2**	94
	Site 6	34
	Site 7	67
	Site 8	192
	Site 9	22

Table 2. 3: Nonparametric comparisons for each pair using Wilcoxon Method for small mammal tracks. P-value is provided.

Site Pairs	**p-value**
8 & 6	0.001
4 & 1	0.001
4 & 2	0.002
8 & 7	0.005
3 & 1	0.02
8 & 1	0.02
3 & 2	0.02
8 & 2	0.03
9 & 5	0.02
6 & 1	0.02
7 & 3	0.01
7 & 4	0.002
9 &1	0.002
6 & 3	0.0007
9 & 2	0.0003
9 & 3	0.0002
9 & 8	0.0002
6 & 2	0.0002
9 & 4	<0.0001
6 & 4	<0.0001

Table 2. 4: Number of small mammals trapped by site. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

Burn Category	Site	Number of Small Mammals Trapped
Low	**Site 3**	22
Medium	**Site 1**	41
	Site 4	48
High	**Site 8**	43

Table 2. 5: Logistic Regression comparing total small mammal tracks to vegetation and environmental characteristics. P-value are provided. The p-values that were still significant after Bonferroni Correction have asterisks.

Environmental Characteristic	Parameter Estimate	Chi-square	p-value
Average Vegetation Height	-0.01	5.313	0.0212
Average Percent of Grass	0.042	6.344	0.0118
Average Percent of Other Vegetation	-0.012	4.774	0.0289
Burn # Since 2016	-0.544	10.869	0.0010*
Total Sapling Number	-0.0005	20.848	<0.0001*

Table 2. 6: Logistic Regression comparing total small mammals trapped to vegetation and management characteristics. P-values are provided. The p-values that were still significant after Bonferroni Correction have asterisks. All values were considered nearly significant.

Environmental Characteristic	Parameter Estimate	Chi-square	p-value
Average Vegetation Density	-0.013	3.905	0.0481
Burn # Since 2012	-0.313	4.285	0.0384
Years Since Last Burn	0.113	5.187	0.0228

Table 2. 7: Total number of small mammal tracks separated into managed (burned) and unmanaged (unburned) sides. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

Burn Category	Sites	Managed	Unmanaged
Low	**Site 3**	71	70
	Site 5	54	68
Medium	**Site 1**	56	23
	Site 4	89	83
High	**Site 2**	3	91
	Site 6	27	4
	Site 7	38	29
	Site 8	107	85
	Site 9	11	11

Table 2. 8: The composition of vegetation characteristics for the managed (burned) and unmanaged (unburned) side of site 2. Even if the site had 0 burns, the managed site was still labeled as managed for consistency.

	Soil Temp	Soil Moisture	Litter Depth	Veg Height	Veg Density	% Canopy Cover	Bare Ground	Leaf Litter	Grass	Other Vegetation
Site 2 managed	95	6	3	33	12	65	11	61	13	16
Site 2 unmanaged	86	8	4	23	4	80	1	95	1	11

Table 2. 9: Total number of small mammals trapped for each site separated by managed (burned) and unmanaged (unburned) for the entire research season. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

Burn Category	Sites	Managed	Unmanaged
Low	Site 3	11	13
Medium	Site 1	23	17
	Site 4	21	27
High	Site 8	23	20

Table 2. 10: Spearman's rank correlation comparing management and vegetation characteristics. P-values are provided. The p-values that were still significant after Bonferroni Correction have asterisks.

Management	**Vegetation Characteristic**	**Spearman ρ**	**p-value**
Burn Number Since 2012	**Average Soil Temperature**	0.8132	0.0077*
Burn Number Since 2012	**Average Soil Moisture**	-0.6733	0.0468
Burn Number Since 2016	**Average Soil Temperature**	0.8778	0.0019*
Years Since Last Burn	**Average Vegetation Height**	-0.7011	0.0354
Years Since Last Burn	**Average Trees for Ground Cover**	-0.6681	0.0492
Years Since Last Burn	**Average Other Vegetation for Ground Cover**	-0.7011	0.0354

Table 2. 11: Best models created using a stepwise logistic model for small mammal tracks in relation to vegetation and management characteristics. The best model is bolded and underlined.

K	**Predictor variables**	**Parameter estimate**	**Prob >F**	**R^2**	**AICc**	**ΔAICc**
2	**Bare Ground Average**	0.1656	0.0021	0.871	21.458	0
	Cryto-Biotic Crust Average	0.112				
1	Average Percent of Bare Ground	0.1557	0.021	0.556	25.378	3.9

Table 2. 12: Best models using a stepwise logistic model for small mammal tracks in relation to landcover types. The best models are bolded and underlined.

K	Predictor variables	Parameter estimate	Prob >F	R^2	AICc	∆AICc
1	**<u>Residential/mixed</u>**	-0.03	0.2443	0.1875	30.823	0
1	**<u>Wet Prairie</u>**	0.04	0.2443	0.1875	30.823	0
1	Sand Barrens	0.0007	0.3331	0.1338	31.399	0.576
1	Upland Savanna	0.0004	0.386	0.1087	31.656	0.8335

Table 2. 13: Abundance estimates for small mammals for live trapping and tracking tubes using the Schnabel Method.

Site	Live Trapping Abundance Estimate	Tracking Tube Abundance Estimate
3	48	16
1	43	21
4	56	19
8	70	22

GENERAL CONCLUSION AND MANAGEMENT RECOMMENDATIONS

General Conclusion

In my thesis, I explored the effects of management on the diversity, abundance, and distribution of bats and small mammals. In my first chapter, I used acoustic monitoring and vegetation surveys to understand how prescribed burning may be impacting eight native species of bats in the Oak Openings Preserve. Bats are heavily impacted by changes in their foraging and roosting habitat. I found that bat activity had a positive relationship with recent burns, average percent of bare ground and total sapling number. I also found that bat activity increases with herbaceous vegetation but decreases with canopy cover and ground cover. These results suggest a greater reliance on increased vegetation in the understory, which is a feature that managers can monitor and manage. At a larger scale, bat activity and diversity had a positive relationship with open habitats, such as savannas and prairies, and negative relationships with deciduous forest. My results suggest that when studying the effects of management on bats, it is important to use a multi-scale and multi-species approach.

In my second chapter, I used tracking tubes and live trapping to survey for small mammals, especially *Peromyscus*, and vegetation surveys to understand how prescribed burning may be impacting the distribution and activity of non-volant small mammals in the Oak Openings Preserve. Small mammals are closely tied to local habitat changes as they seek food and refuges. I found that small mammal activity had a positive relationship with average percent of bare ground and negative relationship with certain vegetation characteristics such as vegetation height and sapling number. This suggests that opens areas were more preferred by small mammals than areas with a lot of understory clutter and vegetation. Similarly, at a larger landscape scale, I found that small mammal activity had a positive relationship with open habitats, such as savannas and prairies. Small mammal activity may benefit from prescribed burns as they are negatively impacted by obstacles such as understory vegetation or saplings and positively impacted with features that increase ease of access.

Overall, measuring fauna can be a helpful tool for understanding the health of the habitat and how management might be impacting the environment. My research suggests that open areas created by management are valuable for mammals, but also highlights important structural characteristics that provide more favorable outcomes for a diverse set of mammal species. I found that bats and small mammals are heavily impacted by changes affecting their foraging and roosting/nesting so that should be a main focus for managers. My results suggest that for bat activity and diversity, habitat structure and landcover types (larger scale), such as open versus closed, is more important. For small mammal activity, vegetation composition and habitat structure on a small scale, e.g. ground cover, are more important. This highlights the importance of studying a variety of organisms because one management plan might not be beneficial for all organisms. Open areas may increase maneuverability, but vegetation structure may be needed to allow for protection from predators and food source availability, underscoring the complexity of habitat requirements for these organisms. Management is essential for maintaining and creating natural remnants, but should allow for a mosaic effect to increase heterogeneity and provide a variety of resources for native organisms.

I recommend having an unburned area adjacent to the burned area to allow to for dispersal and resource availability. I found that two to three burns within seven years had positive effects, in general, for bats and small mammals based on habitat structure and vegetation. Most importantly, habitat heterogeneity should be the main goal for management. My conclusions should be taken with caution because this study is one field season and it is very complex, but most of my results have been supported by literature and even with the complexity, I was able to detect significant relationships. In addition, these conclusions are likely to be applicable to other landscapes that have small fragmented remnants of native ecosystems that are actively managed.

APPENDIX A: CHAPTER I SUPPLEMENT

Figures

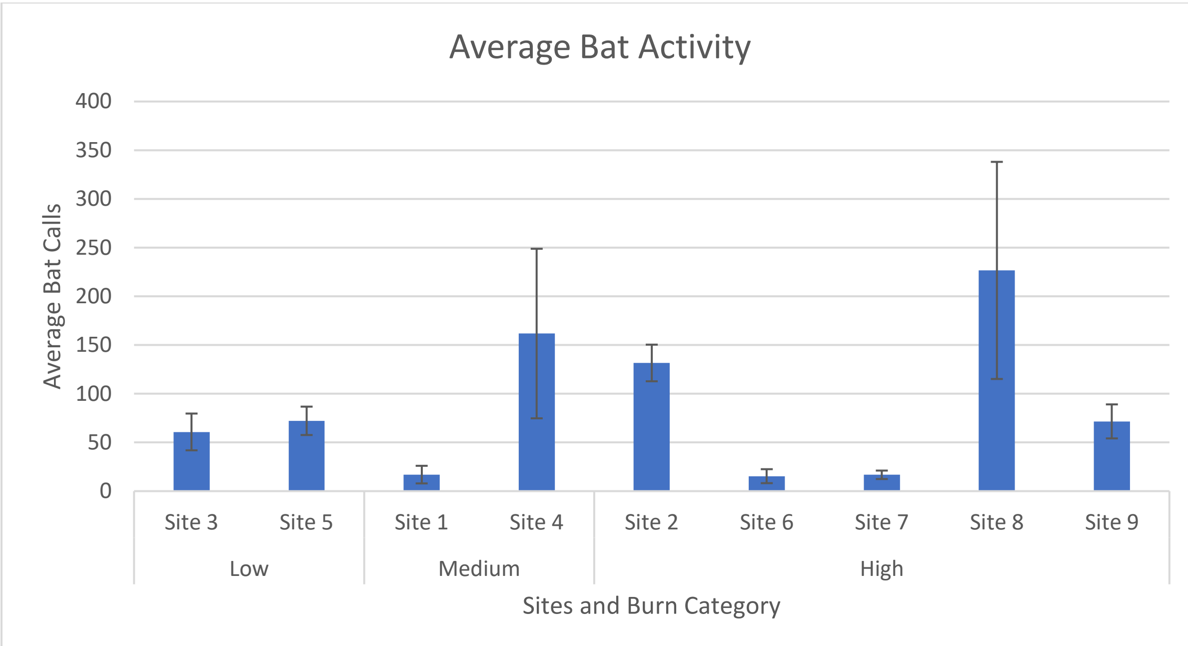

Figure 1.34: Average number of bat calls by site. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

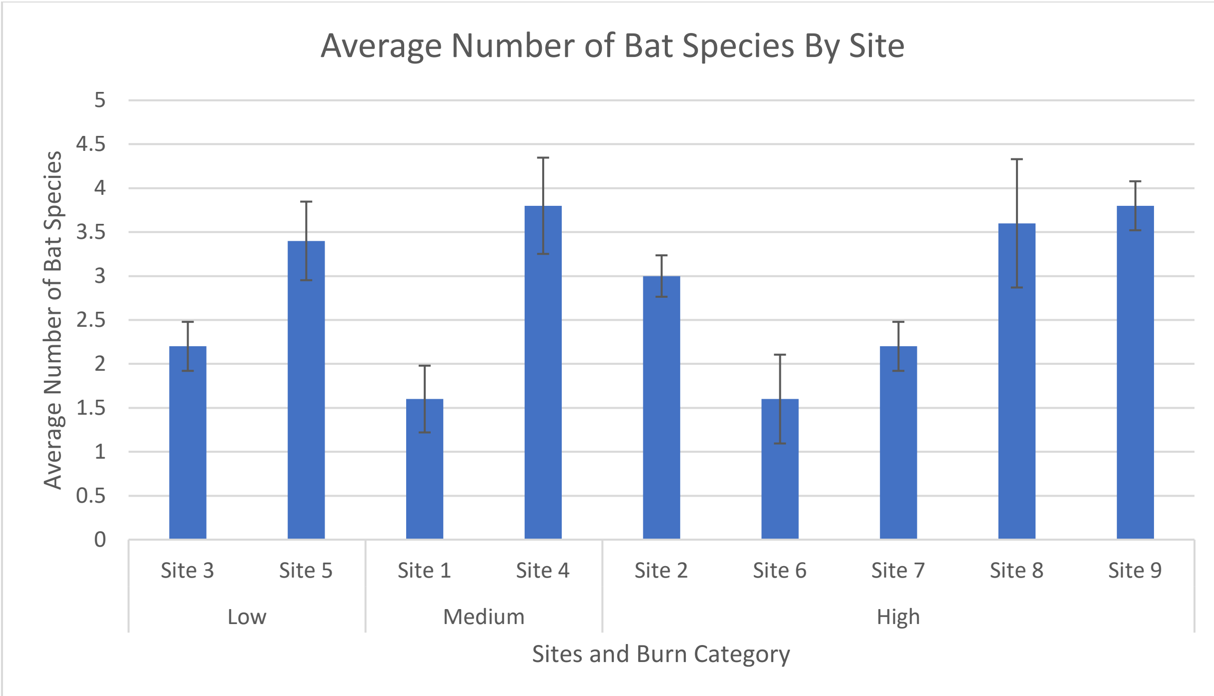

Figure 1.35: Average number of bat species by site. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

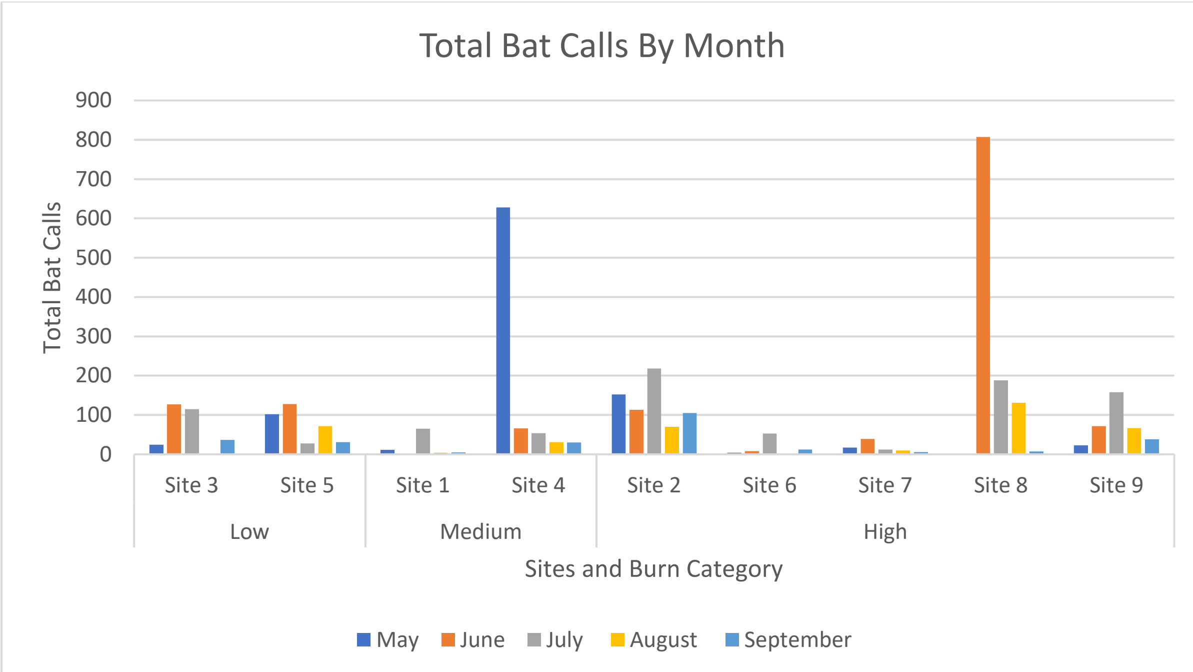

Figure 1.36: Total number of bat calls separated by site and by month. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

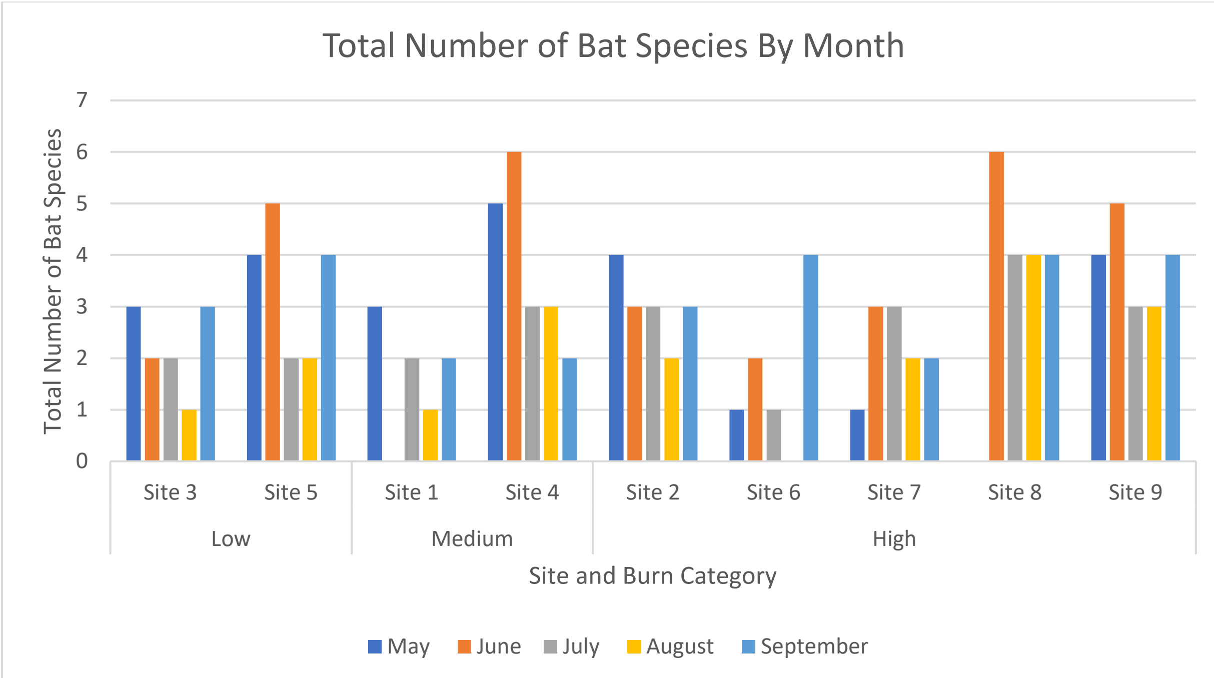

Figure 1.38: Total number of bat species separated by month for each site. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

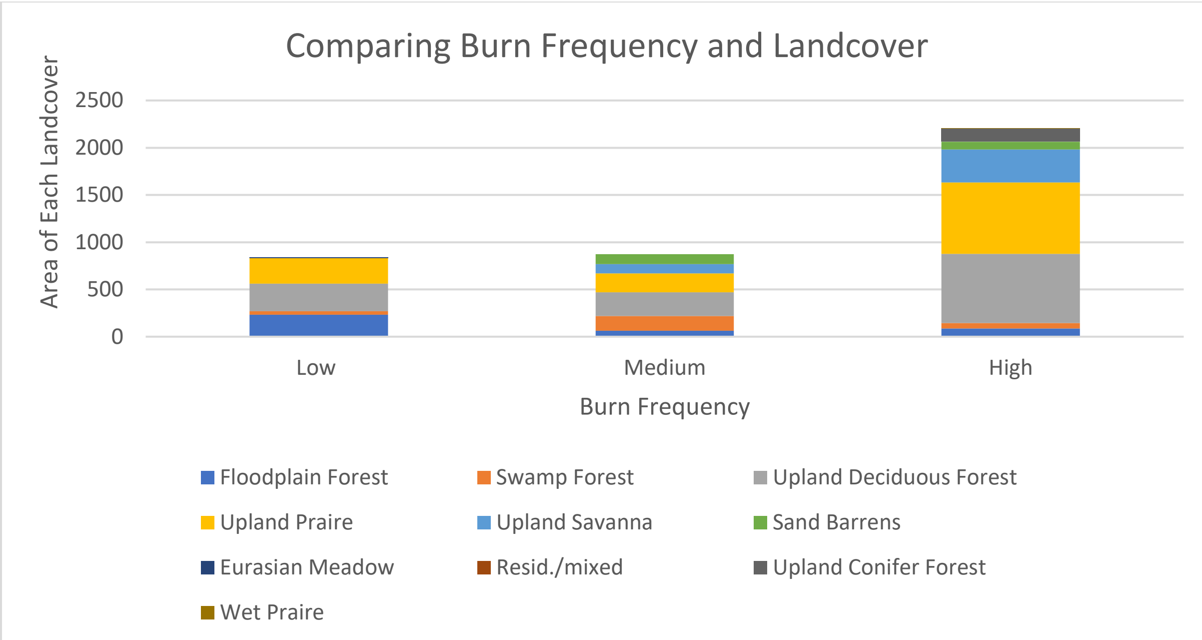

Figure 1.39: Comparing burn frequency to area of landcover types (square meters). Sites were categorized as low, medium, and high by burn frequency. Sites 3 and 5 are in the low category. Sites 1 and 4 are in the high category. Sites 2, 6, 7, 8, and 9 were in the high category.

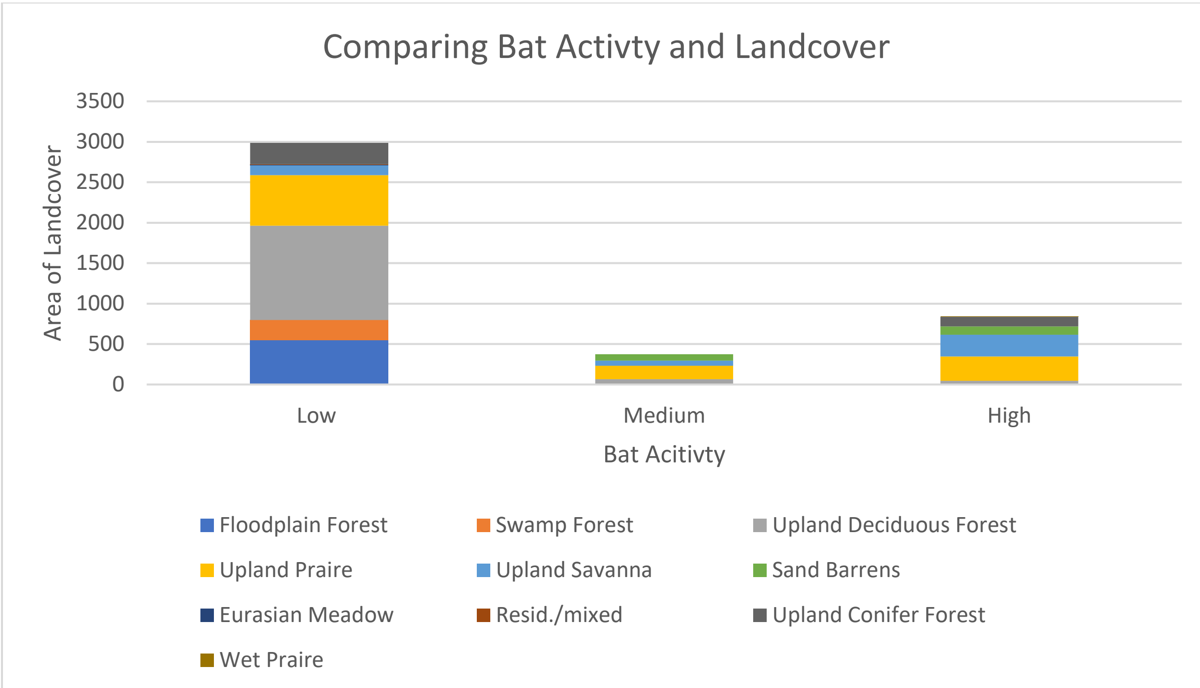

Figure 1.40: Comparing bat activity and area of landcover types (square meters). Sites were categorized into low, medium, and high by bat activity. Sites 1, 3, 5, 6, 7, are in the low category. Site 2 is in the medium category. Sites 4 and 8 are in the high category.

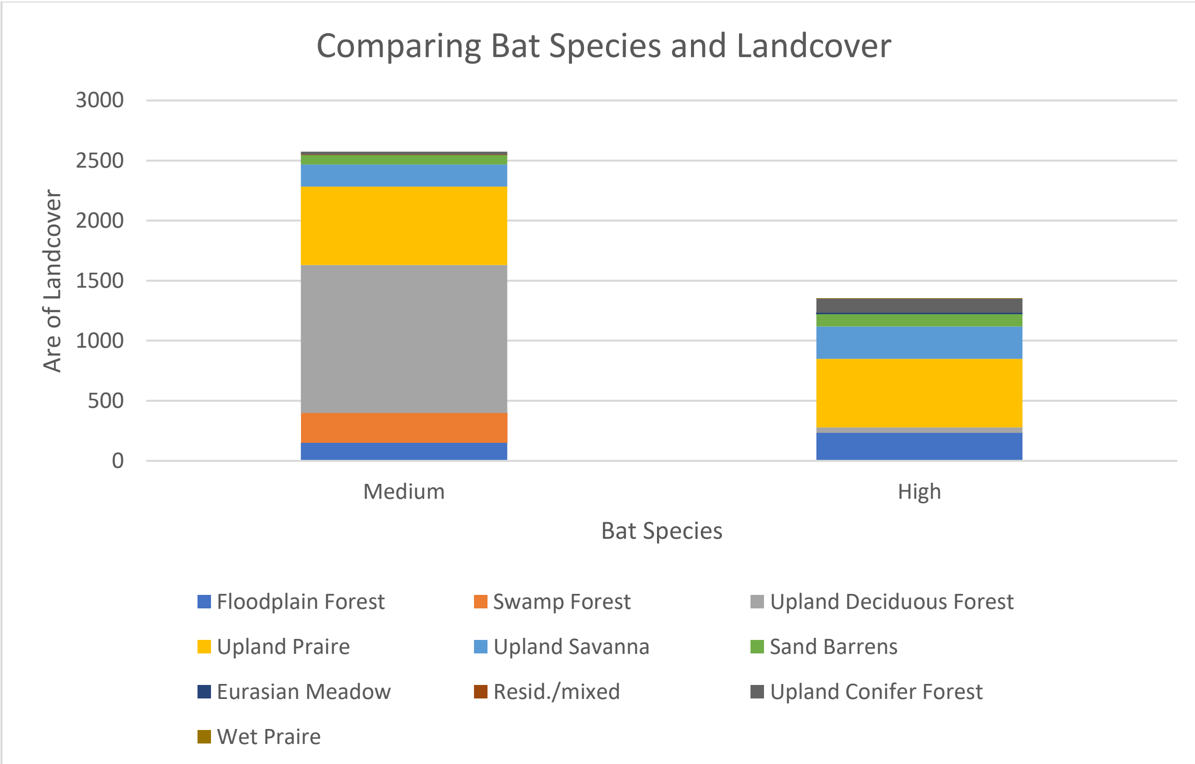

Figure 1.41: Comparing bat species and area of landcover types (square meters). Sites were categorized into low, medium, and high based on number of bat species. No sites were in the low category. Sites 1, 2, 3, 6, 7, 9 were in the medium category and sites 4, 5, 8 were in the high category.

Tables

Table 1.12: Summary of total, average, standard deviation, minimum, and maximum bat activity by sites. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

Burn Category		Total Bat Calls	Minimum	Maximum	Average	Standard Deviation
Low	**Site 3**	309	1	127	60.8	56.60565
	Site 5	367	28	128	72.2	43.74014
Medium	**Site 1**	86	0	65	17	27.1201
	Site 4	816	30	628	161.8	261.0655
High	**Site 2**	665	70	218	131.6	56.41188
	Site 6	79	0	53	15.4	21.48953
	Site 7	85	6	39	16.8	13.0269
	Site 8	1138	0	807	226.6	334.3147
	Site 9	366	23	158	71.6	52.38607

Table 1.13: Total number of bat calls separated by species and by month. *Eptesicus fuscus*, big brown bat (EPFU), *Lasiurus borealis*, eastern red bat (LABO), *Lasionycteris noctivagans*, silver-haired bat (LANO), *Nycticeius humeralis*, evening bat (NYHU), *Lasiurus cinereus*, hoary bat (LACI), *Myotis septentrionalis*, northern long-eared bat (MYSE), *Perimyotis subflavus*, tri-colored bat (PESU), *Myotis lucifugus*, little brown bat (MYLU).

	May	June	July	August	September
EPFU	606	850	527	267	193
LABO	17	11	58	113	6
LANO	130	60	13	4	32
NYHU	133	345	82	8	39
LACI	74	14	5	0	3
MYSE	0	0	0	0	1
MYLU	0	5	0	0	2
PESU	0	6	0	1	2
Total	960	1291	680	393	278

Table 1.14: Total number of bat species separated by site by month. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

Burn Category		**May**	**June**	**July**	**August**	**September**
Low	**Site 3**	3	2	2	1	3
	Site 5	4	5	2	2	4
Medium	**Site 1**	3	0	2	1	2
	Site 4	5	6	3	3	2
High	**Site 2**	4	3	3	2	3
	Site 6	1	2	1	0	4
	Site 7	1	3	3	2	2
	Site 8	0	6	4	4	4
	Site 9	4	5	3	3	4

Table 1.15: Summary of bat activity by managed (burned) and unmanaged (unburned) sides within sites. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

Burn Category		**Minimum**	**Maximum**	**Average**	**Standard Deviation**
Low	**3 managed**	0	22	11	1.878238
	3 unmanaged	0	121	50.6	13.77155
	5 managed	23	115	54.4	9.11592
	5 unmanaged	1	42	18.8	4.066803
Medium	**1 Managed**	0	5	2.2	0.453382
	1 unmanaged	0	63	14.8	6.364834
	4 managed	22	537	138.6	52.58765
	4 unmanaged	1	89	23.8	8.684917
High	**2 managed**	69	217	122.4	13.63166
	2 unmanaged	2	24	10.6	2.49221
	6 managed	0	27	9.8	2.457415
	6 unmanaged	0	28	5.8	2.926887
	7 managed	4	36	14	3.036811
	7 unmanaged	0	6	2.8	0.51099
	8 managed	0	81	24.6	8.101097
	8 unmanaged	0	719	201.2	70.53632
	9 managed	5	31	17.4	2.721315
	9 unmanaged	12	129	55.6	10.96155

Table 1.16: Summary of bat species by treatments within sites. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. The sites are separated by burn category. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

Burn Category		**Minimum**	**Maximum**	**Average**	**Standard Deviation**
Low	**3 managed**	1	3	2.2	0.83666
	3 unmanaged	0	3	1.8	1.095445
	5 managed	2	4	2.6	0.894427
	5 unmanaged	1	4	2.4	1.140175
Medium	**1 Managed**	0	3	2	1.224745
	1 unmanaged	0	4	2.6	1.67332
	4 managed	2	6	4	1.870829
	4 unmanaged	1	3	1.6	0.894427
High	**2 managed**	1	4	2.4	1.140175
	2 unmanaged	1	2	1.8	0.447214
	6 managed	0	4	1.6	1.516575
	6 unmanaged	0	1	0.4	0.547723
	7 managed	1	3	1.8	0.83666
	7 unmanaged	1	3	1.4	1.140175
	8 managed	0	4	2.4	1.67332
	8 unmanaged	0	6	3.2	2.167948
	9 managed	1	3	2.4	0.894427
	9 unmanaged	2	4	3	0.707107

Table 1.17: Area (square meters) of each landcover type within each site.

Site	Floodplain Forest	Swamp Forest	Upland Deciduous Forest	Upland Prairie	Upland Savanna	Sand Barrens	Eurasian Meadow	Resid. /mixed	Upland Conifer Forest	Wet Prairie
Site 3	0	37	291	0	0	0	0	0	0	0
Site 5	233	0	0	271	0	0	10	0	0	0
Site 1	63	156	251	8	0	0	0	0	0	0
Site 4	0	0	0.84	190	101	105	0	0	0	0
Site 2	0	0	66	164	63	81	0	0	0	0
Site 6	0	0	164	78	120	0	0	3	0	0
Site 7	10	55	458	0	0	0	0	0	24	0
Site 8	0	0	44	110	168	0	0	0	117	3
Site 9	78	0	0	404	0	0	0	0	0	0

APPENDIX B: CHAPTER II SUPPLEMENT

Figures

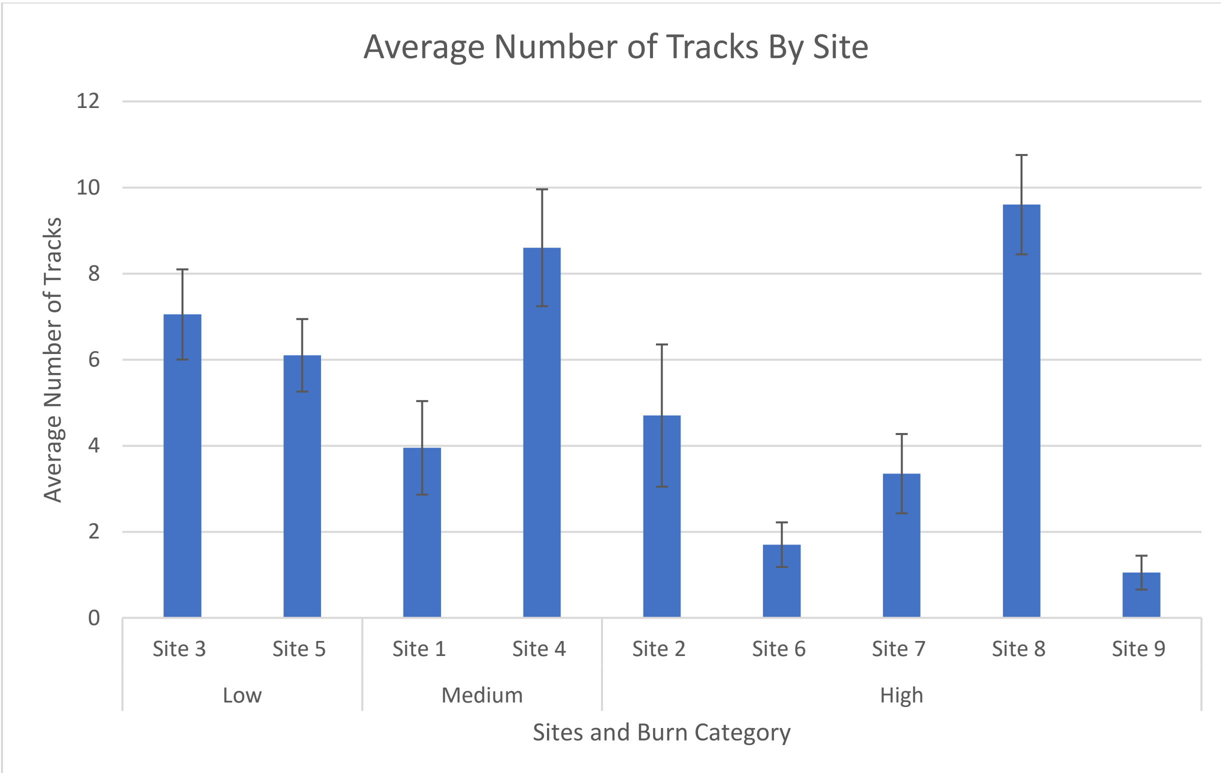

Figure 2.21: Average number of small mammal tracks for each site for the entire research season. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. The lines represent error bars. Sites 4 and 8 had the most small mammal tracks and sites 6 and 9 had the least number of small mammal tracks.

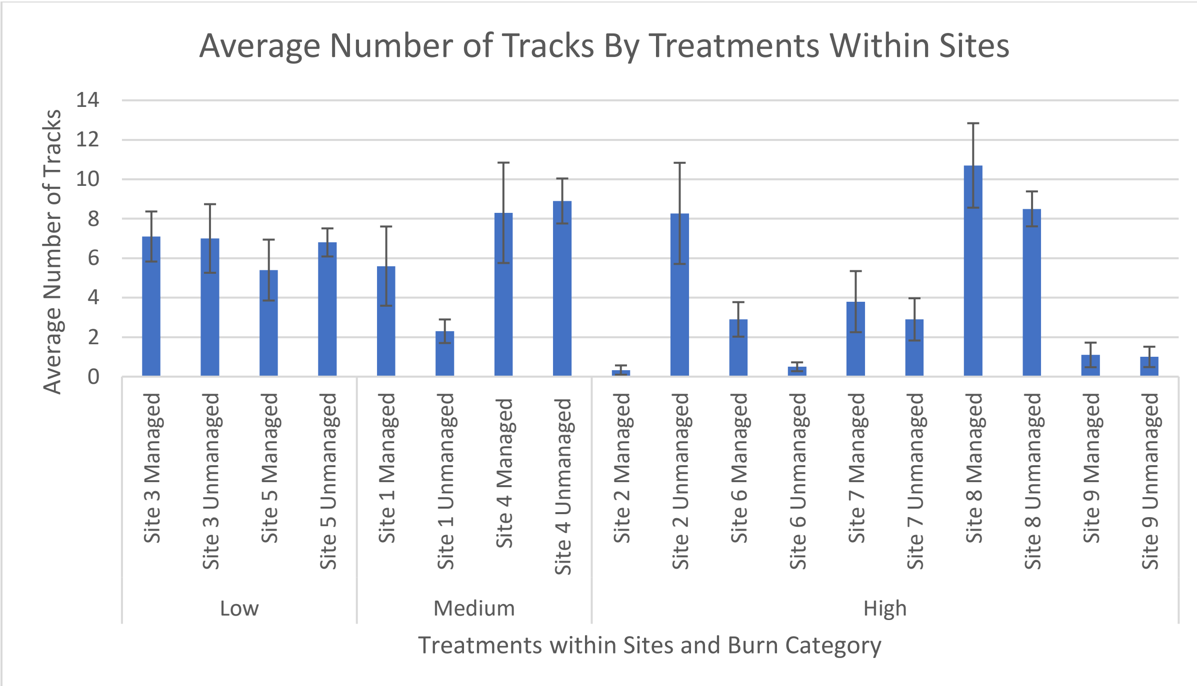

Figure 2.22: Average number of small mammal tracks for managed (burned) and unmanaged (unburned) areas for the entire research season. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. The lines represent error bars. Site 2 had the largest difference of small mammal tracks between the managed and unmanaged side.

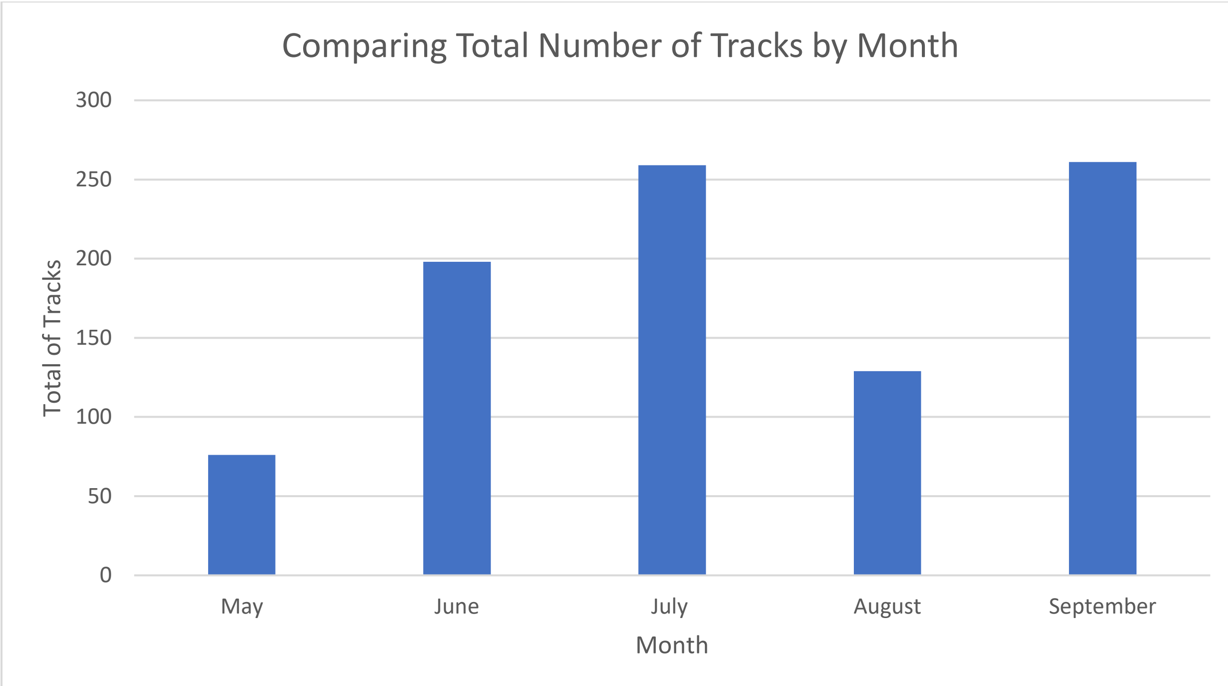

Figure 2.23: Total Number of small mammal tracks separated by month. July and September had the largest number of small mammal tracks and may and the lowest number of small mammal tracks.

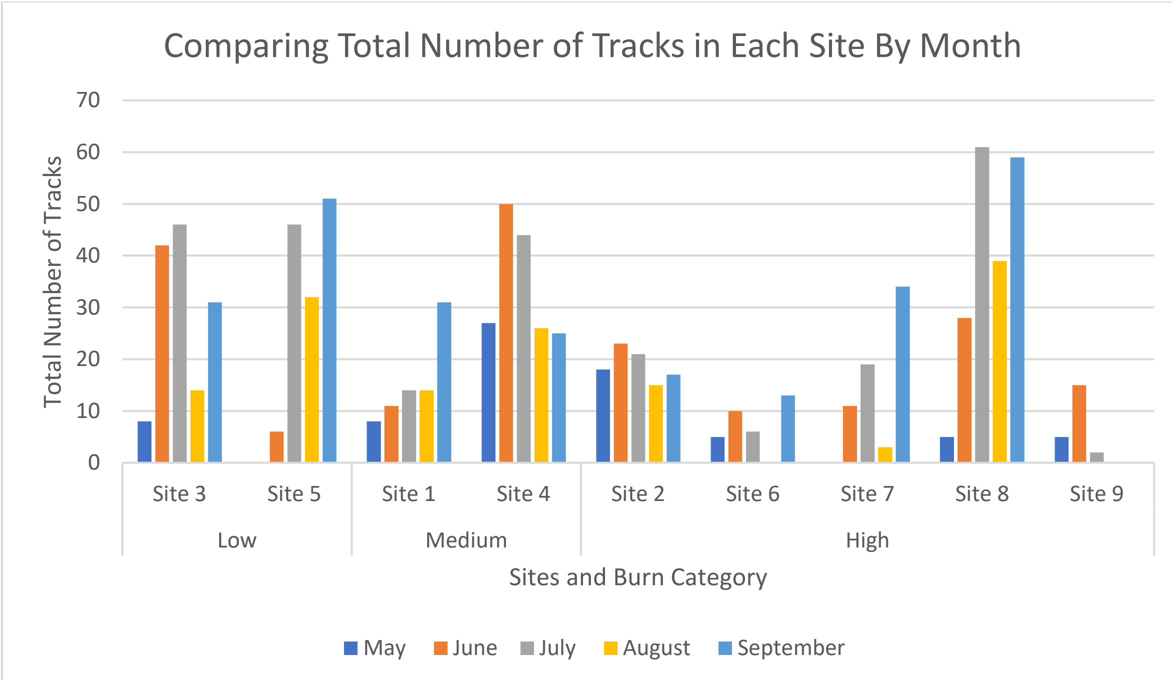

Figure 2.24: Total number of tracks separated by month for each site. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. The different colors correlated to different months.

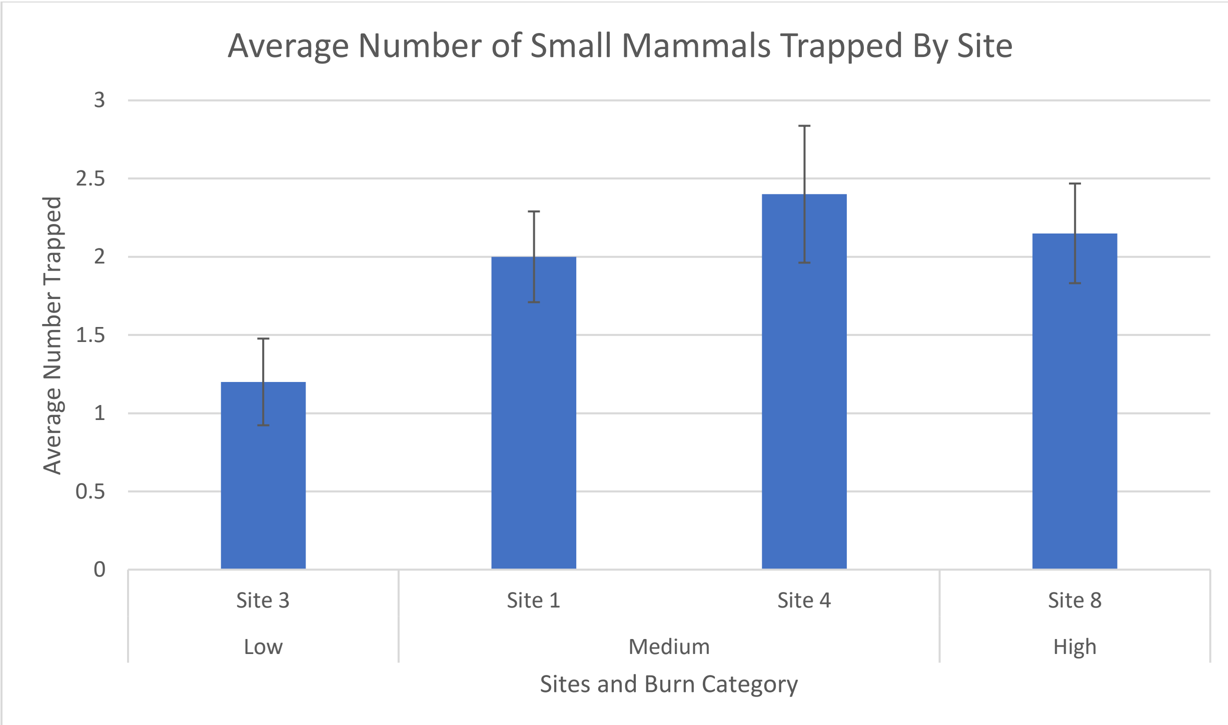

Figure 2.25: Average Number of small mammals trapped by site for the entire research season. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. The lines represent error bars. Site 4 had the greatest number of small mammals trapped and site 3 had the lowest number of small mammals trapped.

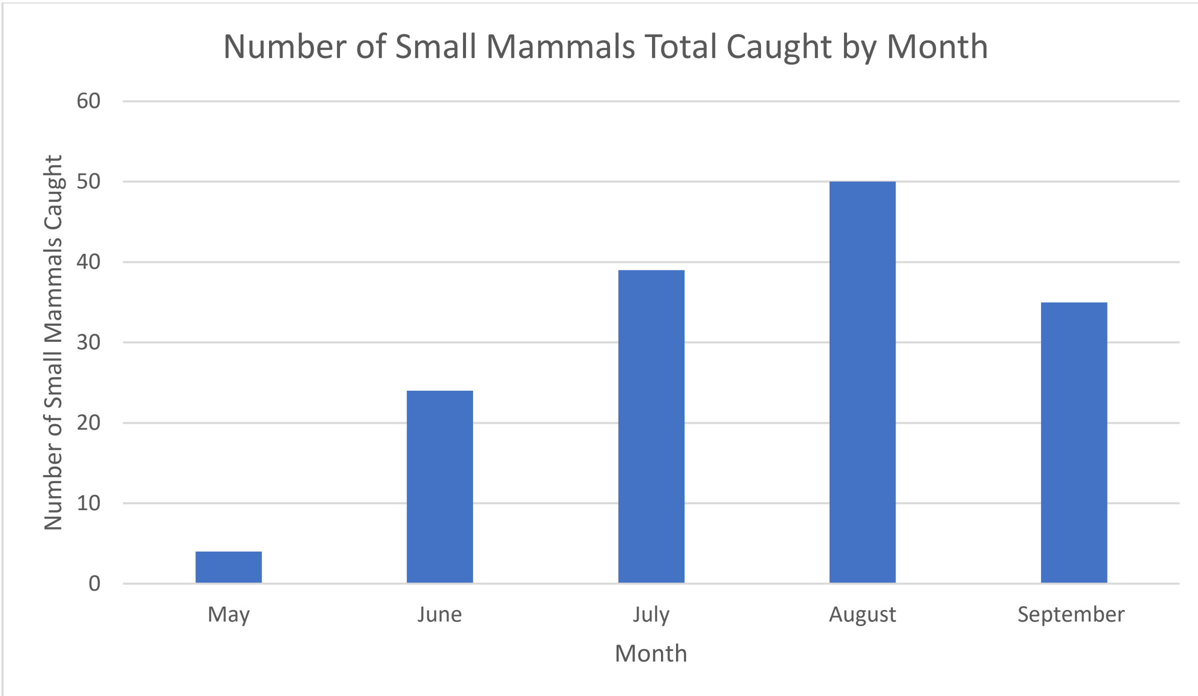

Figure 2.26: Total number of small mammals trapped separated by month. August had the greatest number of small mammals trapped and May had the least number of small mammals trapped.

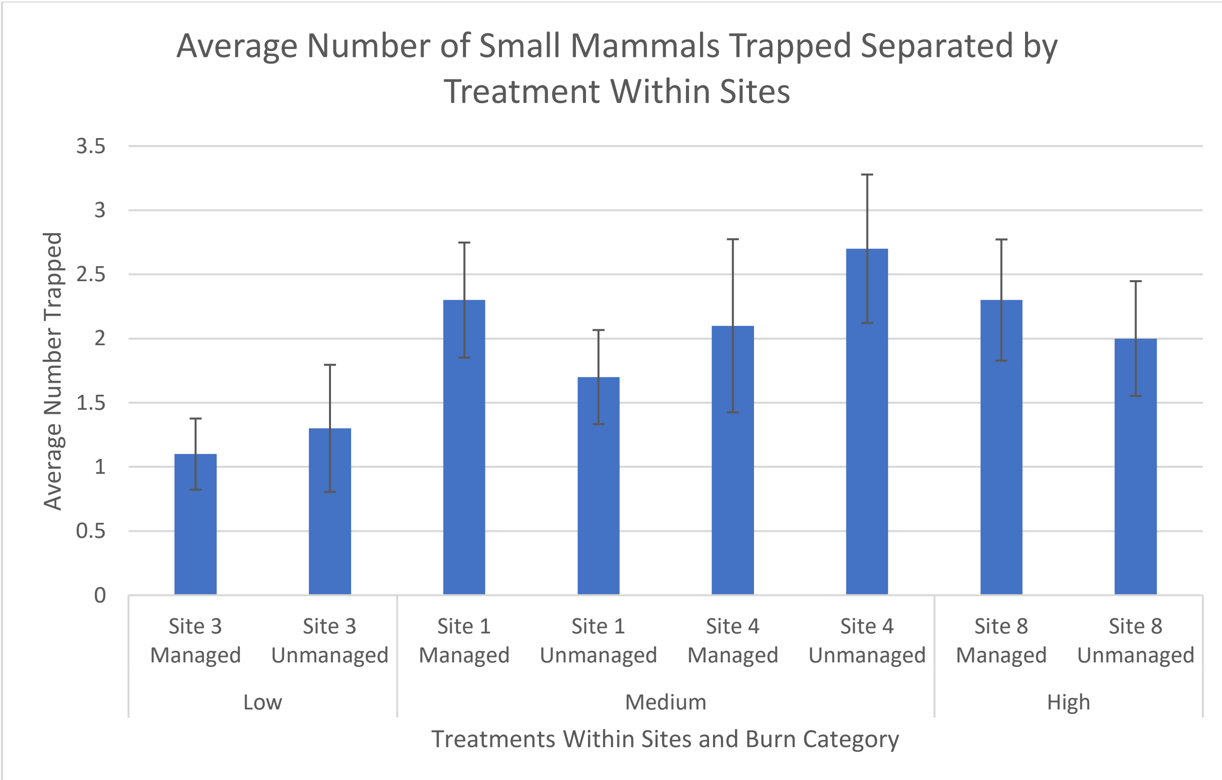

Figure 2.27: Average number of small mammals trapped separated by managed (burned) and unmanaged (unburned) areas for the entire research season. Even if the site had 0 burns, the managed site was still labeled as managed for consistency. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns. The lines represent error bars.

Tables

Table 2.14: Summary of small mammal tracks by site for the entire research season. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

Burn Category	Site	Minimum	Maximum	Average	Standard Deviation
Low	**Site 3**	0	18	7.05	4.684521
	Site 5	0	13	6.1	3.768289
Medium	**Site 1**	0	22	3.95	4.860962
	Site 4	2	28	8.6	6.073237
High	**Site 2**	0	22	4.7	7.39203
	Site 6	0	8	1.7	2.319256
	Site 7	0	15	3.35	4.120232
	Site 8	0	20	9.6	5.164657
	Site 9	0	6	0	1.761429

Table 2.15: Summary of small mammal track data separated by managed (burned) and unmanaged (unburned) areas for each site and for the entire research season. Even if sites had zero burned, the managed side was still labeled managed for consistency. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

Burn Category	Sites	Minimum	Maximum	Average	Standard Deviation
Low	Site 3 Managed	0	12	7.1	4.012481
	Site 3 Unmanaged	1	18	7	5.497474
	Site 5 Managed	0	13	5.4	4.880801
	Site 5 Unmanaged	2	10	6.8	2.250926
Medium	Site 1 Managed	1	22	5.6	6.345602
	Site 1 Unmanaged	0	7	2.3	1.888562
	Site 4 Managed	2	28	8.3	8.04225
	Site 4 Unmanaged	4	16	8.9	3.60401
High	Site 2 Managed	0	2	0.333333	0.707107
	Site 2 Unmanaged	0	22	8.272727	8.498128
	Site 6 Managed	0	8	2.9	2.766867
	Site 6 Unmanaged	0	2	0.5	0.707107
	Site 7 Managed	0	15	3.8	4.894441
	Site 7 Unmanaged	0	9	2.9	3.381321
	Site 8 Managed	0	20	10.7	6.766749
	Site 8 Unmanaged	4	13	8.5	2.798809
	Site 9 Managed	0	6	1.1	1.969207
	Site 9 Unmanaged	0	4	1	1.632993

Table 2.16: Total number of small mammal tracks separated by month.

Month	Total of Tracks by Month
May	76
June	198
July	259
August	129
September	261

Table 2.17: Summary of small mammals trapped by site and for the entire research season. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

Burn Category	Sites	Minimum	Maximum	Average	Standard Deviation
Low	**Site 3**	0	4	1.2	1.239694
Medium	**Site 1**	0	4	2	1.297771
	Site 4	0	7	2.4	1.957442
High	**Site 8**	0	5	2.15	1.424411

Table 2.18: Total number of small mammals trapped separated by month.

	Number of Small Mammals total caught by month
May	4
June	24
July	39
August	50
September	35

Table 2.19: Summary of small mammals trapped separated by managed (burned) and unmanaged (unburned). Even if sites had zero burned, the managed side was still labeled managed for consistency. The sites are separated by burn categories. Low represents 0 burns, medium represents 1-2 burns, and high represents 3 or more burns.

Burn Category	Sites	Minimum	Maximum	Average	Standard Deviation
Low	**Site 3 Managed**	0	2	1.1	0.875595
Medium	**Site 3 Unmanaged**	0	4	1.3	1.567021
	Site 1 Managed	0	4	2.3	1.418136
	Site 1 Unmanaged	0	4	1.7	1.159502
	Site 4 Managed	0	7	2.1	2.13177
	Site 4 Unmanaged	1	7	2.7	1.828782
High	**Site 8 Managed**	0	5	2.3	1.494434
	Site 8 Unmanaged	0	5	2	1.414214

Table 2.20: Area (square meters) of each landcover type within each site.

Site	Floodplain Forest	Swamp Forest	Upland Deciduous Forest	Upland Prairie	Upland Savanna	Sand Barrens	Eurasian Meadow	Resid. /mixed	Upland Conifer Forest	Wet Prairie
Site 3	0	37	291	0	0	0	0	0	0	0
Site 5	233	0	0	271	0	0	10	0	0	0
Site 1	63	156	251	8	0	0	0	0	0	0
Site 4	0	0	0.84	190	101	105	0	0	0	0
Site 2	0	0	66	164	63	81	0	0	0	0
Site 6	0	0	164	78	120	0	0	3	0	0
Site 7	10	55	458	0	0	0	0	0	24	0
Site 8	0	0	44	110	168	0	0	0	117	3
Site 9	78	0	0	404	0	0	0	0	0	0

Table 2.21: Area (square meters) of landcover types broken into unmanaged (unburned) and managed (burned) within each site. Even if sites had zero burned, the managed side was still labeled managed for consistency.

Site	Floodplain Forest	Swamp Forest	Upland Deciduous Forest	Upland Prairie	Sand Barrens	Upland Savanna	Eurasian Meadow	Resid. /Mixed	Upland Conifer Forest	Wet Prairie
3-mang	0	36	129	0	0	0	0	0	0	0
3-unmang	0	0.56	163	0	0	0	0	0	0	0
5-mang	11	0	0	201	0	0	0	0	0	0
5-unmang	222	0	0	70	0	0	10	0	0	0
1-mang	21	41	185	0	0	0	0	0	0	0
1-unmang	43	69	66	8	0	0	0	0	0	0
4-mang	0	0	0	105	66	0	0	0	0	0
4-unmang	0	0	0.83	67	39	101	0	0	0	0
2-mang	0	0	0	162	39	39	0	0	0	0
2-unmang	0	0	66	0	43	24	0	0	0	0
6-mang	0	0	1	78	0	60	0	3	0	0
6-unmang	0	0	162	0	0	59	0	0	0	0
7-mang	0	0	281	0	0	0	0	0	0	0
7-unmang	10	55	177	0	0	0	0	0	24	0
8-mang	0	0	43	1	0	168	0	0	4	0.3
8-unma	0	0	1	109	0	0	0	0	113	2

ng										
9-mang	0	0	0	230	0	0	0	0	0	0
9-unmang	78	0	0	175	0	0	0	0	0	0

APPENDIX C: INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE APPROVAL

IACUC for Acoustic Bat Monitoring

1

HC

Howard Casey Cromwell

|

Wed 1/23, 1:32 PM

Hello Kelsey,

I have heard back from the IACUC administrator and you do not need an IACUC protocol for this study.

Good luck with your research and feel free to move forward on the project- thanks for checking on this with the IACUC committee representatives,

Hcc

Howard Casey Cromwell, PhD
Department of Psychology
Room 348 Psychology Building
JP Scott Center for Neuroscience, Mind and Behavior
Bowling Green State University
Bowling Green Ohio
Phone: 419 372-9408
HC Cromwell Webpage
Biology of Affect and Motivation Laboratory

See new paper on relative reward processing: *Variety can be a entity of relative reward valuation* CLICK: https://doi.org/10.1016/j.appet.2018.12.024

Thank you so much for the feedback.Thank you so much for the update.Thanks for the quick feedback.

Report inappropriate text

KS

Kelsey Nichole Stoneberg

Reply all

Tue 1/22, 4:45 PM

Howard Casey Cromwell;
Montana Caitlin Miller;
Jenifer Marie Baranski;
+2 more

Bat Acoustic Monitoring Research (1).doc
4 MB

Download

Save to OneDrive - Bowling Green State University

Hello Dr. Cromwell,

Attached are the answers you requested about Kelly and I's research with acoustic monitoring of bats. Please let me know if you need more information.

Thank you,

Kelsey Stoneberg

BGSU.

BOWLING GREEN STATE UNIVERSITY

Office of Research Compliance

DATE:	January 16, 2019
TO:	Karen Root
FROM:	Bowling Green State University Institutional Animal Care and Use Committee
PROJECT TITLE:	[1358451-1] The Effects of Prescribed Fire Edges of Small Mammals
IACUC REFERENCE #:	
SUBMISSION TYPE:	New Project
ACTION:	APPROVED
APPROVAL DATE:	January 16, 2019
EXPIRATION DATE:	January 15, 2022
REVIEW TYPE:	Full Committee Review

Thank you for your submission of New Project materials for the above referenced research project. The Bowling Green State University Institutional Animal Care and Use Committee has APPROVED your submission. All research must be conducted in accordance with this approved submission. Please make sure that all members of your research team read the approved version of the protocol.

The following materials have been approved:

- Protocol - Protocol Form Small MammalsStonebergFinal.docx (UPDATED: 01/9/2019)

Report all NON-COMPLIANCE issues regarding this project to this committee.

Please note that any revision to previously approved materials must be approved by this committee prior to initiation. Please use the Addendum Request form for this procedure.

This project requires Continuing Review by this office on an annual basis. Please use the Annual Renewal form for this procedure.

If you have any questions, please contact the Office of Research Compliance at 419-372-7716 or orc@bgsu.edu. Please include your project title and reference number in all correspondence with this committee.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within Bowling Green State University Institutional Animal Care and Use Committee's records.