A Case Study of the Spatial Relationship between Bat Pass Frequency and Artificial Light Pollution along a Bike Trail in Portage County, Ohio

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ABSTRACT

Northeastern Ohio bats are important in maintaining insect populations, thus minimizing crop damage. However, because bat populations are decreasing due to factors such as habitat loss and White Nose Syndrome, attention should be placed on evaluating habitat requirements to maximize conservation efforts. Understanding anthropogenic disturbances such as ecological light pollution, as an indicator of bat habitat quality, has been historically neglected. Studies have shown that the presence of light pollution can alter the activity of several animals, including bats (Frank 1988; Svensson and Rydell 1998; Yurk and Trites 2000; Rydell 2006; Santos et al. 2010). To better understand the effects of light pollution on bat activity, this study examined frequency of bat activity along a light gradient at a field site in Portage County, Ohio in the summer of 2014. Spatial modeling of bat pass frequency suggested greatest activity in regions of medium light intensities, versus high and low light intensities. A preliminary species identification study indicated the presence of hoary, eastern red, and big brown bats, all of which tend to prefer lit environments and thus are likely foraging in the lit areas at the field site. As activity was lowest in the brightest areas, a threshold might exist beyond which light-tolerant bats at this site will avoid. Light-avoiding species present in Portage County and neighboring Summit and Trumbull Counties may be deterred by the light gradient at the field site. This study suggests that artificial light may be a variable of concern for bat populations at this location and that the effects of light should be studied further to better understand how different bat species react to light. Moreover, bat species composition should be determined at the field site in order to promote holistic bat habitat management plans.

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INTRODUCTION

1.0 Overview of Project

Light pollution is the result of misdirected or excessive artificial illumination from human activities. The occurrence of artificial light pollution coincides with the nocturnal foraging activity of bat populations and should be studied as a qualifying characteristic of suitable habitat. In the presence of artificial illumination, bats have been shown to display unnatural behaviors, including: attraction or repulsion to light, and delayed roost emergence (Childs and Buchler 1981; Downs et al. 2003; Stone et al. 2012). Some bat species experience increased foraging success in the presence of artificial lights (Belwood and Fullard 1984; Schnitzler et al. 1987; Barak and Yom-Tov 1989; Hickey and Fenton 1990; Dunning et al. 1992; Acharya and Fenton 1999; Fullard 2001). Kuijper et al. (2008) and Perkin et al. (2014) anticipate bat-bat competition resulting from differential artificial light tolerances while Lewanzik and Voigt (2012) have predicted decreases in biodiversity.

As several bat species are endangered or threatened (International Union for Conservation of Nature 2014), and global bat populations are already declining due to White Nose Syndrome (United States Fish and Wildlife Service 2015a) and habitat loss (Geggie and Fenton 1985), increased bat competition could be devastating for light sensitive species. Accelerated bat population declines may impact ecological services such as insect control (McCracken 1996; Kalka et al. 2008; Williams-Guillén et al. 2008), which results in decreased agricultural productivity (Boyles et al. 2011) and nutrient cycling (Kunz 1982; Keleher and Sara 1996).

Habitat management that includes light components may better secure the ecological services associated with bat biodiversity. However, illumination has been neglected as a critical aspect of habitat quality in species management plans (Gaston et al. 2013; Lyytimäki 2013). Based on suggestions by Gaston et al. (2012), ecologists, wildlife managers, and engineers can lessen ecological consequences for light-sensitive species by: (1) maintaining the darkness of unlit areas; (2) decreasing the duration of light; (3) altering existing habitat to block light trespass; and (4) changing the intensity and spectral composition of lights. Applying these options to bat management plans requires additional research to understand how bats respond to introduced light in dark habitats, light duration, light trespass, light intensity, and light spectrum. In this way, communities situated near light-sensitive species can be encouraged to adopt ecologically responsible lighting designs and methods (Falchi et al. 2011).

The population of Kent, Ohio doubled around the middle of the 20th century in response to the development and subsequent growth of Kent State University (KSU) (Darrow 1999). Recent estimates indicate an almost 12% increase in Kent's population, and the city is expected to continue growing (United States Census Bureau 2015). Cinzano et al. (2001) recognized that there is an increase in artificial light use relative to human population growth and cities. Thus, artificial light usage in Kent may also increase in the future. Artificial lights can affect wildlife (Rich and Longcore 2006; Gaston et al. 2013) and studying wildlife response to artificial light in Kent could provide valuable insight for other growing cities.

In the fall of 2013, the KSU Biology and Geography Departments expressed interest in initiating bat research at the university's properties in Portage County, Ohio.

This thesis project examines the relationship between bat activity and light pollution on KSU property, in an area with suitable bat habitat and urban-induced light pollution. Knowledge gained from this study could improve conservation plans at this and other urban landscapes by understanding the potential relationship between a light intensity gradient and bat activities.

1.2 Thesis Question and Objectives

Bat population distributions can extend over tens of thousands of kilometers (Bat Conservation International 2011) and light pollution is a global problem (Cinzano et al. 2001). Current knowledge of bat-light interactions is focused primarily on discrete point light sources, as in studies by Polak et al. (2011), Stone et al. (2012), and Lacoeuilhe et al. (2014). These studies may not accurately represent behavioral patterns relative to continuous light conditions. Spatial analysis of a local area could provide fundamental information about bat responses to artificial illumination. Moreover, this study investigates ground-level light data with GIS as opposed to satellite data, which is typically used, as satellite data is too general for smaller study areas. This thesis uses Geographic Information Systems (GIS) to model the local spatial relationship of bat activity along a light intensity gradient. GIS has already been used to illustrate the relationship between bats and anthropogenic influences (Sparks et al. 2009; Barber et al. 2011; Graham and Hudak 2011; Bennett et al. 2013) including light pollution (Schoeman 2015; Hale et al. 2015).

The intensity of artificial illumination can alter animal behavior (Hölker et al. 2010; Gaston et al. 2013). Half of the ten Ohio-native bat species are likely to avoid foraging in artificially lit environments (Geggie and Fenton 1985; Furlonger et al. 1987;

Rydell 1992; McGuire and Fenton 2010; Stone et al. 2012) while three Ohio-native species are attracted to artificially lit foraging environments (Geggie and Fenton 1985; Furlonger 1987). It was anticipated that the number of bat passes, or the number of times that a bat flies overhead, will vary with light intensity in areas with similar habitat quality. Therefore, this thesis examines light pollution intensity across the study area through a count of the number of bat passes per unit of time or bat pass frequency (BPF) relative to light pollution intensity. The following research question was investigated: What is the relationship between various light pollution intensities and bat pass frequency?

The research question was addressed by meeting the following three objectives: (1) determine the light intensity gradient at the field site by measuring and interpolating light intensities along a transect; (2) establish a BPF by performing a count of bat passes at designated points along the transect; and (3) compare light intensity to BPF using a spatial model.

A detailed methodology, the corresponding results, a discussion, and concluding thoughts are presented, following a review of the literature examining light pollution and bats.

LITERATURE REVIEW

2.0 Introduction

Artificial light begets light pollution when misdirected or used excessively (Smith 1979). Light pollution is concentrated around cities and increases with human population growth (Cinzano et al. 2001). The presence of light pollution often disrupts the natural behaviors of many organisms (Rich and Longcore 2006). Spatial modeling of light pollution indicated a continuing decline of naturally dark skies across the United States (Cinzano et al. 2000), prompting researchers to document effects on wildlife in response to light pollution (Gaston et al. 2013).

Artificial lights affect the natural nighttime behaviors of bats (Rydell 2006; Stone et al. 2015). Although some bat species are attracted to and increase foraging around artificial lights (Fenton and Morris 1976; Geggie and Fenton 1985; Furlonger et al. 1987; Blake et al. 1994), other bat species avoid artificially lit environments (Rydell 1992; McGuire and Fenton 2010; Polak et al. 2011). Species-specific discrepancies in response to artificial light could create competition, with the species that avoid artificial light at a disadvantage (Tuttle et al. 2006). Potential bat population decreases resulting from competition could be devastating, as global numbers are already declining due to White Nose Syndrome (United States Fish and Wildlife Service 2015a) and habitat loss (Geggie and Fenton 1985).

Two technologies in particular provide researchers with relatively novel approaches to modeling and measuring bat and light information: Geographic Information Systems (GIS) and acoustic monitoring methods. While GIS provides a platform to analyze the spatial relationships of bat activity, acoustic monitoring methods offer a non-invasive yet efficient means of collecting spatial bat activity data. Both GIS and acoustic monitoring are currently being used to promote bat conservation (Wilson and Bayless 2009; Walters et al. 2012; Bennett et al. 2013; Bergeson et al. 2013; Womack et al. 2013; Vulinec 2013; Surlykke et al. 2014; White et al. 2014; Hale et al. 2015).

2.1 Artificial Light

2.1.1 Artificial Light Pollution

In 1879, the invention of the first electric artificial light (Thomas Edison's incandescent bulb) initiated a pronounced increase in the volume of artificial light usage (Jakle 2001). Historically, artificial illumination, such as streetlights, building lights, security lights, and car headlights, has had a positive connotation to many people as lighting is associated with modern applications for the economy, aesthetics, safety, and transportation (Jakle 2001). The potential adverse effects of artificial light were not considered until astronomers became concerned with the reduced visibility of the natural night sky due to unnatural sky brightness (Riegel 1973).

Restricted viewing of celestial objects is globally widespread, as population growth coupled with increased use of artificial lights has created more and larger areas of unnatural nighttime sky brightness (Cinzano et al. 2000). Sky brightness is commonly caused by sky glow, which is misdirected or excess lighting that can extend for hundreds of miles in all directions around cities and other developed areas (British Astronomical Association 2015). Sky glow is the nighttime halo of light over cities resulting from inefficient light structures which scatter light in the presence of atmospheric particles (British Astronomical Association 2015). Visible from space, sky glow can be detected by satellites and is present globally, as is evidenced in Figure 2.0 (National Oceanic and Atmospheric Association 2012).

Figure 2.0 – Distribution of Global Light Pollution in 2013. Image and data processing by National Oceanic and Atmospheric Association's National Geophysical Data Center (Defense Meteorological Satellite Program data collected by US Air Force Weather Agency).

Sky brightness is a reduction of natural night sky darkness, which contributes to environmental and ecological effects and is recognized as light pollution (Rich and Longcore 2006). A sky is considered to be polluted with light if it is at least 10% brighter than natural starlit skies (Smith 1979). In 2001, The First World Atlas of the Artificial Night Sky Brightness indicated that 63% of the human population was living under light-polluted skies (Cinzano et al. 2001). Recent global modeling of artificial light by Kyba et al. (2015) indicated that a majority of developed countries have night skies which are at least twice as bright as natural starlit skies.

Since the 1950s, global artificial light use has increased annually by an estimated 6% (Hölker et al. 2010). Furthermore, the Cinzano et al. (2000) model suggested that by 2025 only small disconnected patches of the western United States will have visible natural night skies while many areas of the country will have light levels that are up to 243 times brighter than natural night skies (Figure 2.1).

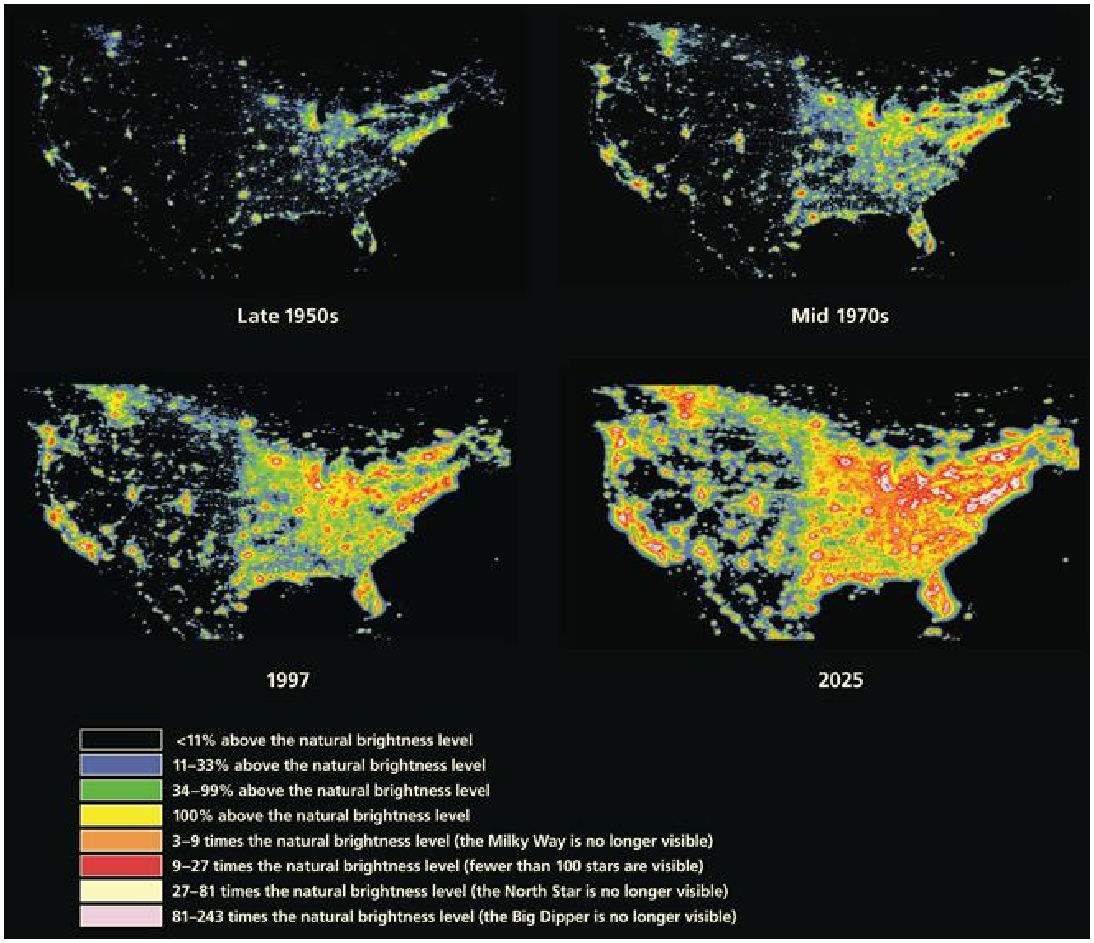


Figure 2.1 – Modeled growth of light pollution in the United States and parts of Canada and Mexico, from the late 1950s to 2025. Black areas represent light levels less than 11% brighter than natural starlit skies. Source: http://www.lightpollution.it/ ©2001 P. Cinzano, F. Falchi, & C.D. Elvidge

Satellite images are useful for modeling global areas of light pollution (Cinzano et al. 2001; Chalkias et al. 2006), but these datasets may not accurately portray the quantities of light at ground-level. Therefore, collecting ground-level data is valuable in determining local light pollution conditions. Several current studies have relied on constellation visibility as a qualitative determination of sky glow volumes at ground level

(Bortle 2001; Kyba et al. 2013, 2015). Quantitative tools, such as light meters used by Santos et al. (2010), Kyba et al. (2011), and Lacoeuilhe et al. (2014), can analyze light pollution at ground level. Understanding local conditions of site-specific artificial light quantities is important, given the increasing evidence for a negative relationship between light pollution and human health (Chepesiuk 2009). As well, numerous ecological and environmental effects have been documented, including organism attraction and repulsion to light sources, temporary blindness, disorientation, and other behavioral changes (Rich and Longcore 2006).

2.1.2 Ecological Consequences

Many organisms have evolved behaviors that correspond to both the lunar cycle and changes in natural light from dusk to dawn, and thus would be directly affected by artificial nighttime illumination (Beier 2006). By creating a perpetual full moon, artificial illumination is likely to affect nocturnal organisms, or 30% of all vertebrates and >60% of all invertebrates (Hölker et al. 2010). Artificial light can also impact a multitude of diurnal organisms (Hill 1990; Schwartz and Henderson 1991). These effects can be both behavioral and physiological (Bartness and Goldman 1989) and not only affect daily routines (Foster and Provencio 1999) but also annual routines (Vaughan 1978; Gwinner 1986).

Light pollution has been observed to disrupt natural behaviors in many taxa, leading to disorientation, attraction, changes in reproductive habits or communication, and altered competition or predation (Rich and Longcore 2006). For instance, artificial illumination attracts large volumes of invertebrates (Frank 1988; Summers 1997; Eisenbeis and Hassel 2000; Kolligs 2000). Birds, reptiles, and mammals (such as harbor seals), take advantage of large prey concentrations around artificial light by increasing foraging (Hill 1990; Schwartz and Henderson 1991; Yurk and Trites 2000; Santos et al. 2010) while other mammals (such as rodents and rabbits) avoid artificial light (Kotler 1984; Gilbert and Boutin 1991). Depending on the species, bats can show both attraction to and repulsion from artificial light (Furlonger et al. 1987).

All bat species are nocturnal or crepuscular, therefore bats may be directly impacted by changes in nighttime lighting (Hölker et al. 2010). Varying levels of light intensity correspond to changes in bat activities (Negraeff and Brigham 1995; Rydell et al. 1996; Hecker and Brigham 1999; Shiel and Fairley 1999; Erkert 2000). Literature on bat-light interactions focuses on insectivorous bats. For instance, it is acknowledged that insectivorous bats congregate around streetlights to consume prey (Belwood and Fullard 1984; Schnitzler et al. 1987; Barak and Yom-Tov 1989; Hickey and Fenton 1990; Dunning et al. 1992; Acharya and Fenton 1999; Fullard 2001).

Moths (Lepidoptera), a common prey for many bat species, are attracted to and congregate around artificial light (van Langevelde et al. 2011). Consequently, bats that forage in lit areas consume higher amounts of prey and expend less energy (Svensson and Rydell 1998; Acharya and Fenton 1999; Svensson et al. 2003). Moths are generally larger than other prey, so foraging at moth-rich streetlights maximizes food intake (Belwood and Fullard 1984; Geggie and Fenton 1985; Hickey and Fenton 1990; Dunning et al. 1992; Acharya and Fenton 1992, 1999; Fullard 2001). This increased foraging success associated with artificial lights could then be a reason why many bat species prefer to forage in urban environments (Rydell 1992; Gehrt and Chelsvig 2003).

Both developed and undeveloped areas have high insect biodiversity (Tuttle et al. 2006). Bat species that tolerate artificial light have a competitive advantage for prey as they can access both developed and undeveloped foraging areas, whereas bats that avoid light are restricted to dark foraging areas only (Kuijper et al. 2008; Perkin et al. 2014). In this way, sympatric species with differing light tolerances could experience competition. For example, sympatric Kuhl's pipistrelle (*Pipistrellus kuhli*) and Botta's serotine (*Eptesicus bottae*) are similar desert-dwelling species, yet differ in foraging success under lit conditions because Botta's serotine bats were observed to have decreased activity in lit areas (Polak et al. 2011). Similarly, two species studied in Switzerland experienced different foraging success. Arlettaz et al. (2000) noted that the common pipistrelle (*Pipistrellus pipistrellus*) exploited prey under street lamps, which were unapproached by the lesser horseshoe bat (*Rhiolophus hipposideros*). Schoeman (2015), who observed disproportionate usage of brightly lit stadiums over darkly lit stadiums with light tolerant species, commented on the potential for such differential foraging success to create homogenized bat communities with low species richness. As bat biodiversity is crucial to secure ecological services such as pest control (Belwood 1998), homogenized bat communities could be detrimental to local regions with artificial light pollution.

Bats that avoid artificial light are typically smaller, slower-flying species (Furlonger et al. 1987; Rydell 1992, 2006; Boldogh et al. 2007). These smaller bats are thought to avoid light to minimize predation from predators such as hawks, owls, cats, and kestrels (Hartley and Hustler 1993; Jones 2000) or to reduce death from vehicle collisions resulting from attraction to headlights (Rydell 1991). Light-avoiding species typically alter flight routes and postpone commuting behavior to avoid artificial light sources (Woodsworth et al. 1981; Buchler and Childs 1982; Leonard and Fenton 1983; Wai-Ping and Fenton 1989; Jones and Morton 1992; Jones et al. 1995; Stone et al. 2009, 2012) or delay roost emergence in the presence of artificial light (Downs et al. 2003). Avoidance behaviors can reduce the amount of foraging time for bat species, thereby reducing prey consumption (Verkem and Moermans 2002). Although numerous species have documented preferences for and against foraging in artificial light, knowledge of distinct bat species' light responses is not comprehensive (Table 2.0).

2.2 Ohio Bats

2.2.1 Species

Northeast Ohio falls within the known population ranges of ten bat species, including: eastern small-footed (*Myotis leibii*); Indiana (*Myotis sodalis*); tricolor (*Perimyotis subflavus*); northern long-eared (*Myotis septentrionalis*); eastern red (*Lasiurus borealis*); silver-haired (*Lasionycteris noctivagans*); big brown (*Eptesicus fuscus*); little brown (*Myotis lucifugus*); hoary (*Lasiurus cinereus*); and evening (*Nycticeius humeralis*) (International Union for Conservation of Nature 2014). Of these ten species, three have a known light preference, two are undocumented, and the remaining five are *Myotis* species, and therefore are likely to avoid light because they are small, slow flyers (Table 2.0). Light avoidance behaviors could result in lowered foraging success for the *Myotis* species, prompting a need for artificial light as a component of species management plans.

Table 2.0 – Examples of known bat foraging preferences with respect to light conditions. Species with an asterisk are native in Ohio. *Myotis* and *Rhinolphus* species are not subdivided, as many acoustic software programs cannot yet distinguish among their similar calls.

Species	Source	Light Preference
*Eptesicus fuscus**	Geggie and Fenton 1985; Furlonger et al. 1987	Prefers to forage in light
Pipstrellus pygmaeus	Bartonicka et al. 2008	
Eptesicus serotinus	Catto 1993	
Eptesicus nilssonii	Rydell 1991, 1992	
Vespertilio murinus	Rydell 1992	
Nyctalus noctula	Kronwitter 1988	
*Lasiurus borealis**	Furlonger et al. 1987	
*Lasiurus cinereus**	Furlonger et al. 1987	
Pipistrellus kuhlii	Haffner and Stutz 1985/1986	
Pipistrellus pipistrellus	Haffner and Stutz 1985/ 1986; Rydell and Racey 1995; Blake et al. 1994	
Myotis spp.*	Furlonger et al. 1987; Rydell 1992; McGuire and Fenton 2010; Stone et al. 2012	Avoids foraging in light
Rhinolophus spp.	Stone et al. 2012	
Eptesicus bottae	Polak et al. 2011	
Plecotus auritus	Rydell 1992	

Ohio bat species mate in late fall and then hibernate in caves, abandoned mines, trees, or anthropogenic structures in Ohio and neighboring states or migrate over 1000 kilometers to southern locations (Bat Conservation International 2011). In April, females typically form maternity colonies separate from the males and give birth to pups between May and June (Belwood 1998). During the summer months, bats day roost in trees or anthropogenic structures and emerge at twilight to forage for insects. Foraging activity typically peaks after sunset and before sunrise (Murray and Kurta 2004).

Most Ohio bat species prefer roosting and foraging near riparian areas (Ford et al. 2005; Menzel et al. 2005; Carter 2006; Bergeson et al. 2013). However, variations exist among bat species in terms of summer roosting preferences. Big brown bats tend to roost in anthropogenic structures such as barns, the eastern-small footed bats prefer buildings and rock crevices, Indiana bats use exfoliating bark and tree hollows, and tricolor bats roost in tree cavities. Silver-haired, little brown, and northern long-eared bats will use anthropogenic or tree roosts while eastern red bats roost exclusively in trees, shrubs, and weed clusters (Belwood 1998). However, many bats do not emerge from their roosts until ambient light reaches species-specific post-sunset intensities, which are not met under constant artificially illuminated conditions (Swift 1980). Therefore, nightly roost emergence can be delayed by the presence of high intensity light (Downs et al. 2003).

All Ohio bats are insectivorous, so roosting locations are usually adjacent to or close by insect-rich foraging locations (Bat Conservation International 2011). Insectivorous bats are important primary predators of at least nine orders of insects (Feldhamer et al. 2009). Bats depend on short range ultrasonic echolocation (Barclay and Brigham 1991; Waters et al. 1995) to locate flying insect prey (Kick 1982). Slight differences in echolocation and morphology characteristics result in varying degrees of speed, maneuverability, and prey detection (Norberg and Rayner 1987). As a result, different species have distinct specialized foraging niches (Barclay 1985, 1986; Jones and Rydell 2003). Studies indicate that artificial light segregates foraging areas among species with differing light tolerances (Kuijper et al. 2008; Perkin et al. 2014). Thus, foraging niches can be partially described in relation to artificial light conditions (Table 2.1).

Table 2.1 – General differences in bat foraging locations relative to artificial light sources, modified from Rydell 2006.

Foraging location relative to light	Typical Morphology Characteristics	Source
High above light source	Fast-flying, large bats, usually 30-100 grams in mass.	Gould 1978; Bowles et al. 1990
Parallel to light source	Fast-flying, medium-size bats, usually 10-30 grams in mass.	Belwood and Fullard 1984; Geggie and Fenton 1985; Haffner and Stutz 1985/1986; Schnitzler et al. 1987; Kronwitter 1988; Barak and Yom-Tov 1989; Rydell 1992; Gaisler et al. 1998
Around or below light source	Fast-flying, small-size bats, usually less than 10 grams in mass.	Haffner and Stutz 1985/1986; Rydell and Racey 1995
Far away from light source	Slow-flying, small-size bats, usually less than 10 grams in mass.	Rydell and Racey 1995

2.2.2 Population Declines

Many bat species have large population distributions, which extend outside of the state and include large portions of the Americas (International Union for Conservation of Nature 2014) (Figure 2.2). However, Ellison et al. (2003) found that historic bat data consisted mostly of local population data, and O'Shea et al. (2003) noted that such local population trends should be monitored separate from range-wide trends. While historic population data for Ohio is incomplete (O'Shea et al. 2003), recent summer bat acoustic surveys indicated a 47% decrease across all Ohio bat species between 2011 and 2014 (Norris 2014a). Two explanations for these Ohio bat population declines are White Nose Syndrome (Francl et al. 2012) and habitat fragmentation (Bennett et al. 2013).

The United States Fish and Wildlife Service (2015a) attributed approximately 5.7 million bat deaths in the United States since 2006 to the fungal disease White Nose Syndrome (WNS). WNS is credited with range-wide population declines of several bat species found in Ohio, including: little brown, northern long-eared, eastern small-footed, tricolor, hoary, and Indiana bats (United States Fish and Wildlife Service 2015a). Furthermore, the endangered and light-avoiding Indiana bat is expected to experience population-level contamination exceeding 90% in twenty years resulting in annual population declines of 10.3% (Thogmartin et al. 2012, 2013). Even the common little brown bat population is expected to decline to less than 1% of pre-WNS population size (Frick et al. 2010). However, accurate mortality patterns are difficult to obtain and predict as a result of current surveying techniques (Turner et al. 2011).

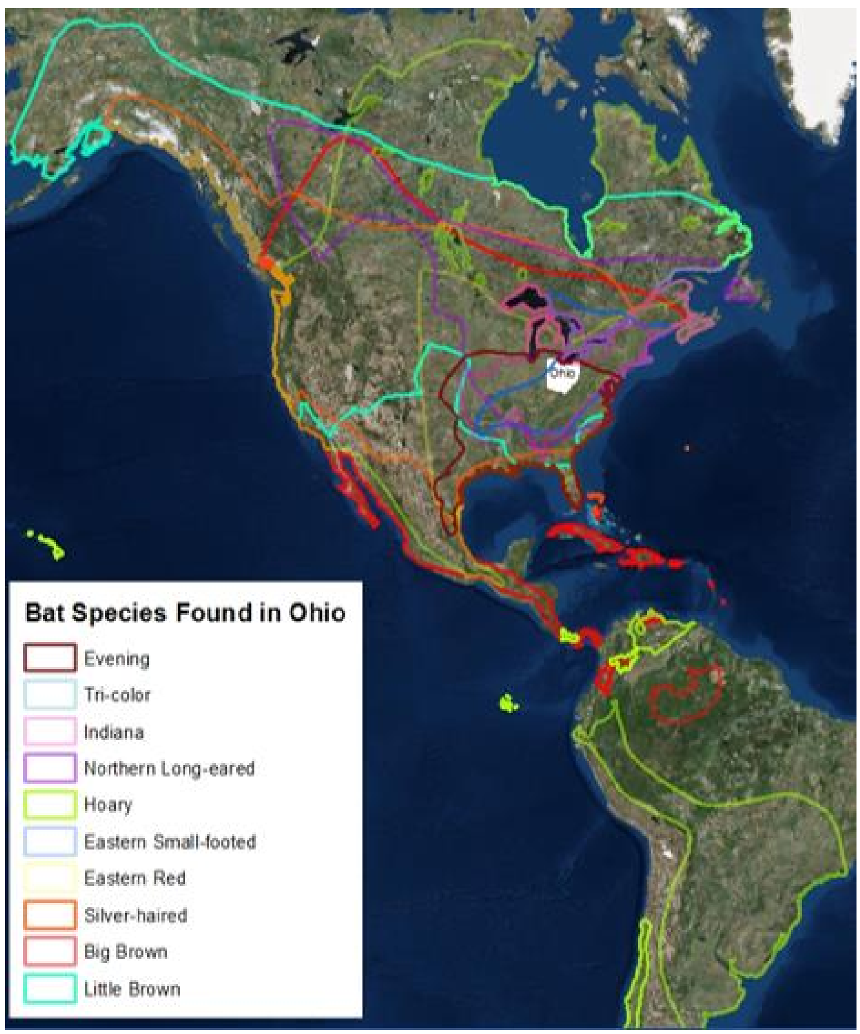


Figure 2.2 – North and South American Ranges of Bat Species Found in Ohio.

Habitat fragmentation, which is a reduction in the continuity and connectivity of habitat patches, limits the availability of and access to roosts sites (Hutson et al. 2001). Urban land development contributes to habitat fragmentation for bats through the creation of physical barriers, such as roads (Zurcher et al. 2010; Bennett et al. 2013). Less obvious barriers, which might not necessarily reduce the extent of the habitat, can also minimize bat movement to or through otherwise ideal habitat. Specifically, the presence of nocturnal illumination near a city could alter the natural behavior of organisms and effectively fragment a landscape for bat populations who avoid nocturnally lit conditions (Bennett et al. 2013).

2.3 Conservation Efforts and Research

2.3.1 State and Federal Listings

Historically feared and misunderstood by humans despite attempts by early biologists to demystify them (Grinnell 1918; Bailey 1925; Allen 1940), bat species were not protected until the middle of the 20th century when researchers noted the vulnerability of populations resulting from dense hibernacula aggregations (Mohr 1952, 1953; Graham 1966). Initial conservation efforts, therefore, focused only on winter hibernacula preservation. However, conservation of summer habitat is equally important, as preserving winter hibernacula alone did not allow the endangered Indiana bat populations to rebound (Clawson 1987). As a result of continued population declines of the Indiana bat and other species, a bat conservation movement gained momentum globally in the late 20th and early 21st centuries (Hutson et al. 2001; Jones et al. 2003).

Today, the bat conservation movement is still widespread, particularly due the threat of climate change (Adams 2010) and the associated importance of bats as bioindicators (Jones et al. 2009). In economic terms, bat conservation is critical given that bats save the agricultural industry an estimated $3.7 billion annually in pest control costs (Boyles et al. 2011). Bats also play large ecological roles, primarily by suppressing insect populations (Kalka et al. 2008; Williams-Guillén et al. 2008) and by depositing nutrient-rich guano on the ground (Kunz 1982; Keleher and Sara 1996).

Federal agencies categorize bat species in need of conservation as threatened or endangered (The United States Fish and Wildlife Service 2015b). According to the United States Fish and Wildlife Service (2015b), two Ohio species are federally-listed. The Indiana bat is listed as endangered and the northern long-eared bat is listed as threatened. Federal listings indicate that species are in danger of range-wide extinction (United States Fish and Wildlife Service 2015b). Both species have reduced occupancy in areas with habitat fragmentation (Yates and Muzika 2006; Womack et al. 2013) and decreased populations as a result of WNS (Ford et al. 2011). In addition, both species are known to avoid artificial light (Furlonger et al. 1987; Rydell 1992; McGuire and Fenton 2010), as a result of their small size (Rydell 2006; Boldogh et al. 2007), and therefore may be restricted to foraging in dark habitats.

To protect declining populations of plants and animals and appropriately allocate state funds, agencies such as the Ohio Department of Natural Resources (ODNR) Division of Wildlife have taken steps to identify and classify native species. ODNR created six categories of state-listings, which are as follows: extinct, extirpated, special interest, species of concern, threatened, and endangered. According to the ODNR (2014), all ten species of Northeastern Ohio bat are state-listed as either special interest, species of concern, or endangered (Table 2.2). As implied by the listings, all native bat species have the potential to become extirpated from Ohio, especially given the combined threats of WNS and habitat destruction.

Table 2.2 – Conservation State-listings for Native NE Ohio Bats, modified from the Ohio Department of Natural Resources (2014).

Ohio Bat Species	State Listing	Definition
Indiana	Endangered	High risk of state-wide extirpation
Little brown Big brown Silver-haired Eastern red Hoary Eastern small-footed Northern long-eared Tri-colored	Species of concern	High risk of becoming threatened or endangered
Evening	Special Interest	Not common in Ohio

2.3.2 Spatial Modeling

Geographic Information Systems (GIS) are computer-based systems which can manage and analyze geospatial data (Lo and Yeung 2007). Spatial data are typically associated with geographic coordinates allowing for a spatial analysis of the data (Jensen et al. 2005). Spatial data modeling with GIS applications have been implemented to promote conservation of a wide array of animals, including: black bears (Clevenger et al. 2002); snakes (Santos et al. 2006); caribou (Johnson et al. 2004); songbirds (Dettmers and Bart 1999); red pandas (Kandel et al. 2015); owls (Grilo et al. 2014); and tortoises (Dade et al. 2014). Similarly, bat studies that include GIS have the potential to increase understanding of species ranges, habitat use, and response to threats. For instance, GIS has become a valuable tool for mapping the spread of WNS and designed conservation management strategies for bat populations (Wilson and Bayless 2009).

Bat species distribution models created in GIS, such as those used in Switzerland (Jaberg and Guisan 2001), Israel (Yom-Tov and Kadmon 1998), and the United States (Cook and Gardner 1990; Gardner et al. 1990), are a valuable conservation tool. For example, existing winter and summer capture records for the endangered Indiana bat were compiled from a variety of sources in order to create a predicted species distribution model (Gardner and Cook 2002). Bat habitat use can also be modeled in GIS by incorporating data of the ecological functions and requirements of bat species, such as: insect prey availability (Rainho et al. 2010); locations of roost trees (Carter and Feldhamer 2005); foraging distance and preferences (Cook et al. 1987; Gardner et al. 1987; Gardner et al. 1991; Menzel et al. 2005); habitat characteristic preferences (Yates and Muzika 2006; Watrous et al. 2006; Womack et al. 2013); interspecies competition (Bergeson et al. 2013); and hibernacula activities (Brack 2006, 2007). Although spatial bat models often include radio-tracked data (Carter and Feldhamer 2005; Menzel et al. 2005; Watrous et al. 2006; Brack 2006; Womack et al. 2013; Bergeson et al. 2013), acoustic data is also sufficient if the samples are evenly distributed across the sample area (Stevens and Olsen 2004; Rodhouse et al. 2011).

GIS has been used illustrate the distribution of bats in relation to anthropogenic influences, such as roads (Bennett et al. 2013), urban sprawl (Sparks et al. 2009), vehicular noise (Barber et al. 2011), and windmills (Graham and Hudak 2011). In addition, the relationship between light pollution and bat behavior can be represented by GIS spatial models (Schoeman 2015; Hale et al. 2015). Often, bat-light studies focus on discrete point light sources such as streetlights. Urban areas contain many discrete point light sources, and bat response to the combined light of multiple sources could be different from bat response to a singular light source. The use of GIS technology allows light to be represented as a continuous variable across space, and therefore provides a valuable tool for assessing the relationship between bats and light in an urban-induced light gradient.

2.3.3 Acoustic Monitoring

Acoustic monitoring is the recording of sound waves emitted by organisms. For animals that emit sounds at the ultrasonic range, ultrasonic detectors are used for acoustic monitoring and species identification. Ultrasound-capable animals include species of insects, rodents, cetaceans, birds, and bats (Sales and Pye 1974). The study of ultrasonic echolocation calls can provide vital conservation information for species, including bats (Fenton 1997).

The evolution of echolocation allows bats to produce a series of ultrasonic clicks several hundred times per second and subsequently determine the proximity of nearby objects based on the returned sound waves (Losos et al. 2008). By detecting and recording ultrasonic sounds, bat detectors act as acoustic recorders and display bat calls as pulses (Figure 2.3). Depending on the device, bat call data is either stored directly on the device or to a connected computer. Bat calls can be sorted and analyzed by viewing the files manually or through automatic species identification software. Acoustic monitoring provides a quantitative survey method and has been used in bat studies such as Walters et al. (2012), Vulinec (2013), Weber and Sparks (2013), Surlykke et al. (2014), and White et al. (2014).

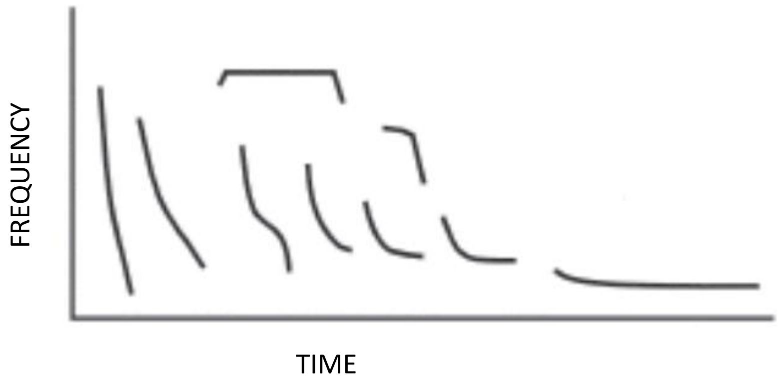


Figure 2.3 – Examples of bat call pulses from European bats. Image modified from Limpens 2002.

There are two significant drawbacks of acoustic monitoring. First, a true bat count cannot be achieved with acoustic monitoring alone, as the same individual could emit multiple calls and therefore be counted multiple times. Second, although differences in morphology result in relatively unique, characteristic species-specific bat calls, species identifications can be very difficult to deduce from the acoustic recordings because many bats have calls that overlap in frequency (Fenton and Bell 1981). Moreover, call characteristics can vary depending on acoustic clutter, morphology, age, and foraging strategy (Griffin et al. 1960; Rydell 1990; Kalko and Schnitzler 1993; Jones et al. 1992; Jones and Kokurewicz 1994; Masters et al. 1995; Obrist 1995; Bogdanowicz et al. 1999; Jensen and Miller 1999; Jones 1999). Calls can also appear distorted depending on the presence of vegetation (Limpens 2002), amplitude of the call, orientation of the bat to the detector microphone, and atmospheric conditions (Brigham et al. 2004). Additionally, bats can alter call characteristics when foraging in the presence of other individuals (Fenton 1988; Neuweiler and Fenton 1988; Rydell 1990; Kalko and Schnitzler 1993; Kapteyn 1993; Obrist 1995).

With so many variables contributing to bat call characteristics, automatic identification software programs are implemented to search sound files for probable bat calls. These software programs have flexibility to account for natural variations in bat call patterns. However, the accuracy of such programs likely differs from one species to the next (Parsons and Jones 2000; Adams et al. 2010), as several species have overlapping call frequencies (Fenton and Bell 1981). However, experienced observers familiar with flight patterns and other species-specific behavioral tendencies can differentiate among similar calls within the automatic identification software programs (Limpens 2002).

Acoustic monitoring is usually cheaper than other bat sampling methods, does not require permits, and is efficient for gathering data at multiple sampling points. Given these reasons, acoustic surveys provide an efficient way to obtain bat data. When possible, acoustic studies should be accompanied or followed by other sampling techniques, such as mist-netting (O'Farrell and Gannon 1999).

METHODOLOGY

3.0 Introduction

There are a number of components to the methods used in this investigation of the relationship among bat frequencies and various light intensities. These methods include field site selection, determination of sampling criteria, establishment of sampling points, collection of acoustic data, and the measurement of light intensities. Additionally, data organization and analysis included calculating BPF values, categorizing sampling points based on measured light intensities, and creating a spatial model of the bat and light data along the bike trail. A description of the study methods follow.

3.1 Kent, Ohio

3.1.1 Geographic Location

Near the eastern border of the city of Kent, Ohio (41°9’2”N, 81°21’40”W), the field site lies along the Cuyahoga River in the northeastern portion of the state. Located along the western edge of Portage County, Kent sits approximately 10 miles southwest of Cleveland, 30 miles northwest of Akron, 30 miles northeast of Canton, and 40 miles west of Youngstown (Figure 3.0). These large cities produce sky glow, which can extend over a hundred miles (British Astronomical Association 2015) and contribute to existing light pollution conditions at Kent.

3.1.2 Urban Environment

As a college town, the structure of Kent’s urban environment can be largely attributed to the presence of KSU (Locke 2004). During the middle of the 20th century, Kent experienced a period of rapid growth related to the expansion of the university.

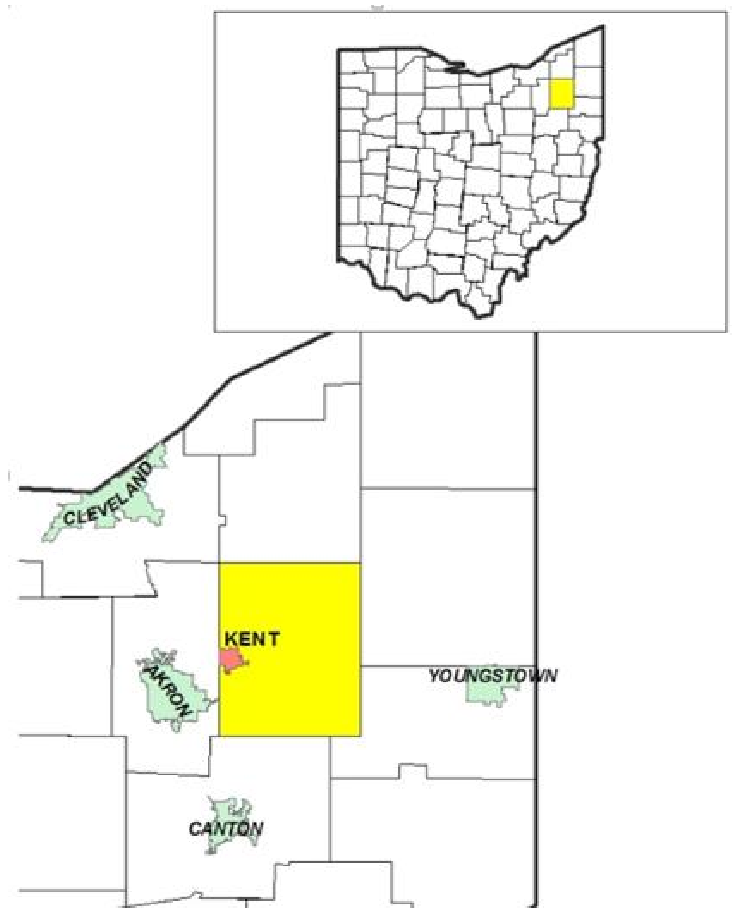


Figure 3.0 – City of Kent is shown in red, and located in Portage County which is highlighted in yellow. Nearby large cities include: Cleveland, Akron, Canton, and Youngstown.

Between 1950 and 1970, the population more than doubled from 12,000 to over 28,000 (Darrow 1999). KSU's role in the urban development of the surrounding city is apparent, as several local companies are associated with the university (Nichols 2009) adding to the city's urban footprint. Today, Kent is the most populous city in Portage County with a population over 32,000 and anticipates positive growth (United States Census Bureau 2015). Moreover, the university is currently undertaking a $150 million construction project, which is anticipated to draw additional people to the area (Kent State University 2012).

According to the 2011 Multi-Resolution Land Characteristics' National Land Cover Database, Kent's land cover is dominated by development, including: residential neighborhoods, student housing complexes, a downtown area, the KSU campus, and manufacturing facilities (Homer et al. 2015) (Figure 3.1). Despite this development, small, discontinuous forest patches interrupt the urban environment. These forest patches likely receive artificial illumination from the proximity of the surrounding urban development (Eisenbeis and Hänel 2009).

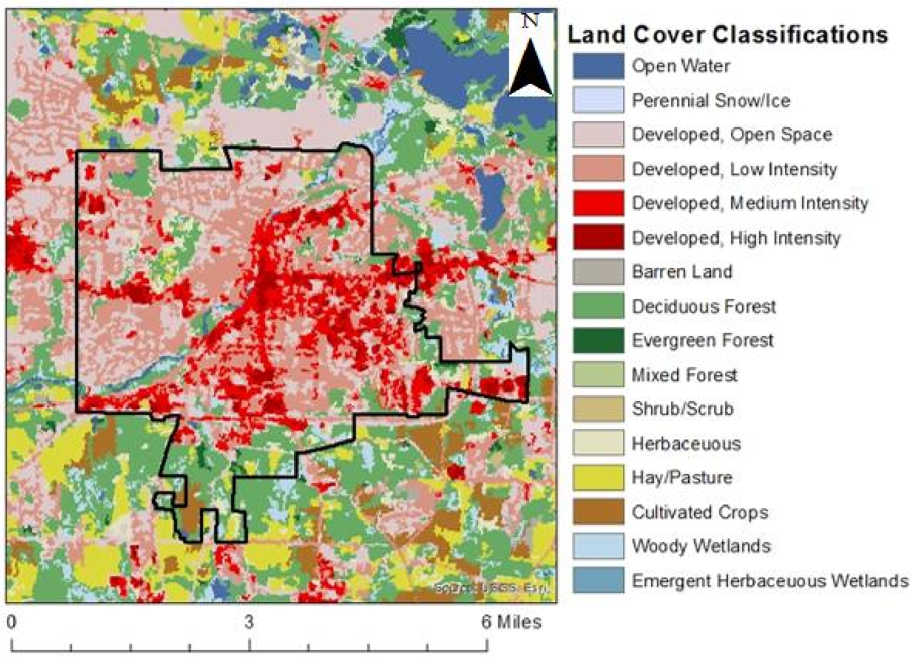


Figure 3.1 – The City of Kent, outlined in black, shown with land cover based on NLCD 2011 data. Kent is dominated by developed land cover, displayed in red and pink, with patches of forested area shown in green.

3.2 Field Site

3.2.1 Field Site Selection

The field site location for this study was selected from 17 available KSU field research sites located throughout Portage County, which range in size, proximity to developed land, and landscape characteristics, such as tree and water coverage. Through discussions with Dr. Emariana Widner of KSU's Geography Department and Dr. Patrick Lorch, formerly of KSU's Biology Department, permission was granted to study bat habitat use at these sites during the summer of 2014. Preliminary analysis, performed through Google Earth and discussions with Dr. Dawna Cerney of Youngstown State University's Geography Department, determined which sampling locations met the criteria to undertake the study based on satellite images of the landscapes. Important criteria included: (1) a water source (Esteban 2015); (2) a variety of trees for potential bat roosts (Esteban 2015); (3) close proximity to nocturnally lit structures; and (4) a surrounding urban matrix. Four sites met the criteria through visual assessment of satellite images and were ground-truthed in May 2014 to determine if sampling for bat presence and light conditions could be accomplished. Three of the sites were not entirely bordered by urbanization. The chosen site and surrounding developed land met conditions suitable for bat populations and offered a light intensity gradient. Moreover, the site's paved bike trail was deemed ideal for collecting bat data as it is free of overhead vegetation, reducing interference when recording echolocation calls. The likelihood of some bat species to forage along forest edges (Belwood 1998) supported the decision to sample along the bike trail, as the bike trail creates forest edges.

The chosen site is located on the western edge of Kent and is situated directly southeast of the KSU main campus. The site contains a mile long segment of the Portage Hike and Bike Trail, transecting the property diagonally from northwest to southeast (Figure 3.2). Access to the bike trail and two primitive trails is available on Horning Road, East Summit Street, and Loop Road. Over 60 acres in total, the property is dominated by mixed hardwood forest (Deibel 2012). This variety in tree type was anticipated to meet habitat needs for a range of bat species (Belwood 1998), including species known to avoid light. The site contains two ponds and surrounding wetlands which were expected to furnish large insect populations and consequently provide bats with a consistent food source.

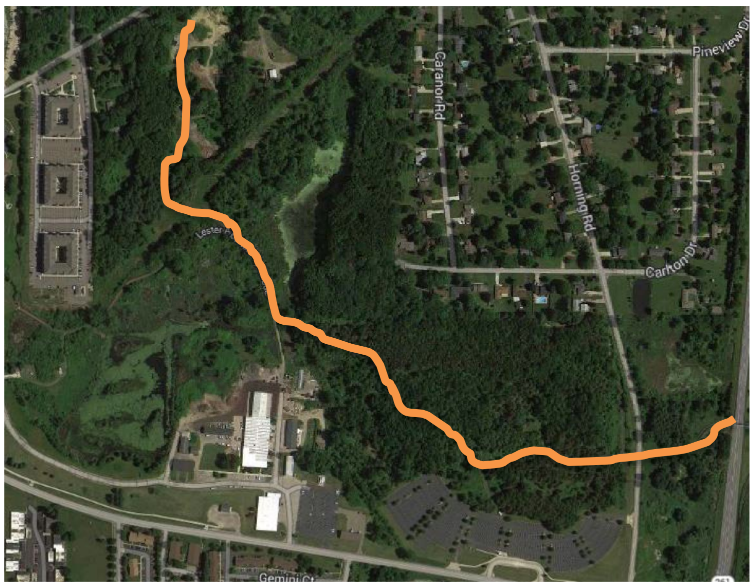


Figure 3.2 – Aerial image of the field site, containing: the bike trail delineated in orange, two ponds, parking lot, vegetation, and surrounding development. Image extracted and modified from Google Maps on March 14, 2015.

3.2.2 Site Characteristics

Located less than a mile southeast of the KSU campus on a forested piece of property, the field site is owned and managed by the university. It is physically fragmented from nearby patches of woods by residential neighborhoods to the north and the university campus and downtown Kent on the northwest and west. The site is bordered by Ohio State Route 261 and Dix Football Stadium to the east and East Summit Street and a parking lot to the south. The field site is adjacent to a ribbon of wooded and agricultural land that stretches from the southwest to the northeast, which, however, is also fragmented by roads.

The field site is a portion of the Portage County Hike and Bike Trail constructed by KSU in 2013 (Fredmonsky 2013). The paved bike trail crossing the site is approximately a mile in length and runs southeast to north across the property to connect Dix Stadium with the campus and downtown Kent. Surrounding land cover includes approximately 50 acres of vegetation dominated by 13.5 acres of conifer and 27.5 acres of deciduous trees. Other land cover features include: two ponds covering 2.3 acres, a small creek extending 385.7 meters, a six acre paved parking lot, and a compost/refuse area for KSU grounds managers covering approximately one acre. The southeastern part of the site is transected by Horning Road, which runs north-south.

3.2.3 Artificial Light Conditions

The field site contains no artificial illumination sources. However, adjacent developed areas contribute varying volumes of artificial light to the property. The most significant contributors to artificial light at the field site are: a residential neighborhood (A), the KSU campus (B), Dix Football Stadium (C), a KSU facilities complex (D), a parking lot for the bike trail (E), nearby roads (F), and an apartment complex (G) (Figure 3.3).

To the northeast, a residential neighborhood consisting of four streets (Caranor Road, Carlton Drive, Pineview Drive, and Horning Road) contains approximately 70 single family houses distributed over roughly 50 acres. These houses and the associated roads contain light sources typical of urban neighborhoods, such as light posts, security lights, decorative lighting, window candles, and streetlights. Trees, shrubs, and other vegetation in the neighborhood blocked the extent to which these lights penetrated the field site itself.

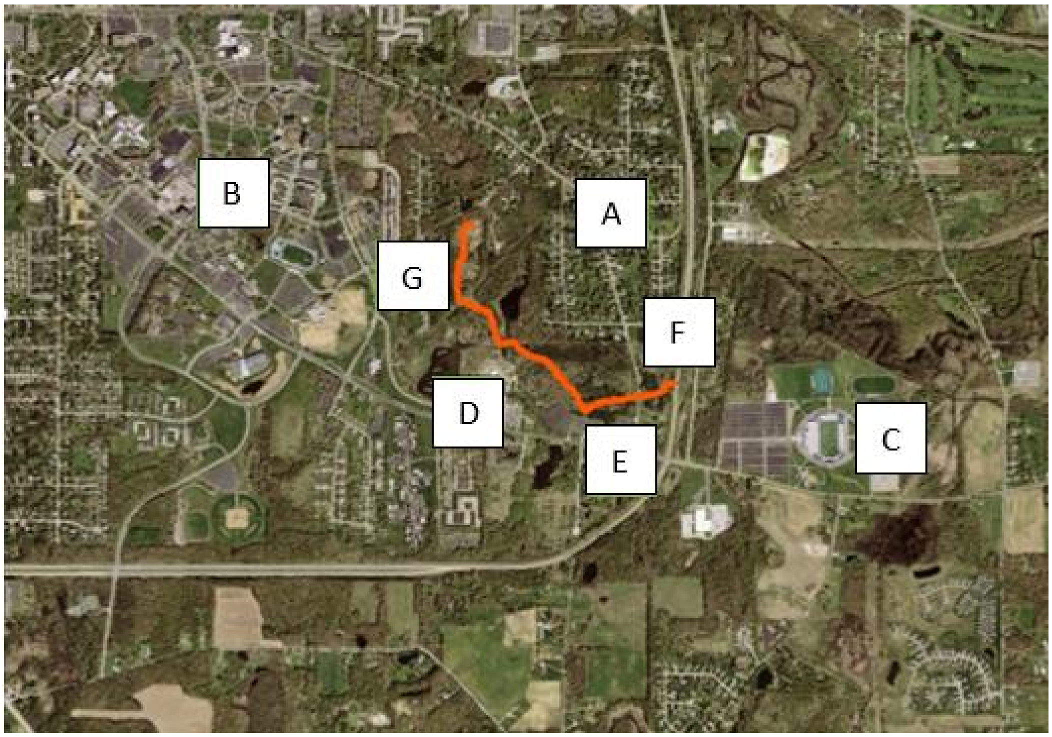


Figure 3.3 – Field site bike trail delineated in orange, and surrounding land features contributing to artificial light: neighborhoods, KSU campus, Dix Football Stadium, university facilities complex, parking lot, roads, and apartments.

Over 800 acres of the KSU's main campus, located northwest of the field site, contains numerous academic, administrative, student housing complexes and ancillary buildings. Nighttime lighting around the entire campus illuminates not only the university structures, but also contributes to sky glow above the campus. This sky glow is visible from the field site.

KSU's Dix Football Stadium is approximately a half mile from the southeastern border of the field site. The adjacent stadium parking lot has four large security lights, which remain lit every night. The ground between the stadium parking lot and the field site is relatively flat and contains only small shrubs and grasses, so light from the security lights constantly illuminates the southeastern-most part of the field site during nighttime hours. This illumination is so bright that reading and writing was possible in the middle of the night at the southeastern-most part of the field site without the use of additional illumination.

To the south, a KSU facilities complex and a parking lot adds illumination to the field site. The facilities complex consists of ten buildings for various storage and maintenance purposes. Each of these buildings are illuminated with security lights. The light cast from this area is particularly bright around the pond and wetland areas of the field site that are nearby and have no tall or dense vegetation to block the light. The approximately six acre parking lot has ten large security lights. Daily, these lights shine beginning around twilight and dim around midnight. A row of trees between the parking lot and the field site blocks some of this light from shining directly into the field site.

To the northwest, three four-story apartment buildings sit adjacent to the field site. The buildings have both internal illumination and exterior security, safety, and decorative lighting. The resulting illumination was partially visible through trees between the lights and the northwestern corner of the field site.

A series of roads added to the overall amount of artificial light at the field site via streetlights and headlights on passing vehicles: two-lane Horning Road runs north to south through the eastern part of the field site; four-lane Ohio State Route 261 passes northeast to southwest along the eastern portion of the field site; and two-lane Rhodes Road cuts southwest to northeast along the northern boundary of the field site.

3.2.4 Bat Presence

Although there are no published records of specific bat colonies or roost locations for the field site, ten bat species are native to Ohio (International Union for Conservation of Nature 2014) and there is evidence of bat occurrence in the area. Two nearby Summit Metro Park properties have eight identified bat species: (1) Liberty Park in Twinsburg less than 15 miles north of the field site contains little brown, northern long-eared, big brown, Indiana, tri-colored, eastern red, hoary, and silver-haired bats, and (2) Munroe Falls Park in Munroe Falls less than six miles southwest of the field site contains little brown, northern long-eared, big brown, Indiana, tri-colored, and eastern red bats (Perdicas 2015). In addition, Brack and Duffey (2006) identified six bat species at a Ravenna site in Portage and Trumbull Counties: big brown, little brown, northern long-eared, eastern red, hoary, and tricolor. For these identified species, foraging distances, which are the distances from roost to foraging ground, are generally less than 4 miles (Brigham 1991; Hutchinson and Lacki 1991; Campbell et al. 1996; Cryan et al. 2001; Elmore et al. 2005; Broders et al. 2006), with the exception of the hoary bat which has been documented flying over 12 miles (Barclay 1989). Assuming bat roosts are located at the Summit Metro Park properties or the Ravenna site, the expected foraging distances would indicate that these bats, with a possible exception of the hoary bat, are probably not traveling to the Kent field site to forage as the field site is in excess of six miles of both locations. As all of Ohio is within the range of the listed species, additional roost locations may be located elsewhere in Portage County or at the Kent site, permitting foraging from alternative closer locations. However, a survey of roost locations in Kent and the surrounding area has not been completed. The anticipation that the Kent field site would support bat activities as a result of its location within the summer habitat ranges of listed Ohio native species was justified, along with initial visual assessment visits in spring 2014 that confirmed the presence of bats.

3.3 Data Collection

3.3.1 Bat Frequency Sampling Criteria

In order to determine bat pass frequency (BPF) at the field site, Indiana Bat Summer Survey Guidelines created by the United States Fish and Wildlife Service (2014) were employed. The guidelines were created to accurately collect and report Indiana bat population data across the country. Although it is unknown if Indiana bat colonies are present at the field site, it is assumed that the criteria outlined by the United States Fish and Wildlife Service for Indiana bat surveys are suitable for surveying other native bat species.

As bats are less likely to be exposed to artificial light during winter hibernation, sampling was undertaken during summer months when bats roost on or near developed land. Sampling nights were planned to occur during the summer acoustic survey season outlined by the United States Fish and Wildlife Service (2014): May 15 to August 15. Sampling within these dates serves to limit bat activity fluctuations associated with migration or hibernation (Belwood 1998). Sampling dates for this study occurred between June 28 and August 9, 2014, and specific sampling nights were planned to avoid unfavorable weather criteria, which would reduce bat activity (United States Fish and Wildlife Service 2014). Unfavorable weather included: temperatures below 10 degrees Celsius, rain or fog that exceeds 30 continuous minutes, and winds greater than nine miles/hour. Each sampling night began at sunset coinciding with roost emergence and peak foraging time of bats (Erkert 1982; Rydell and Speakman 1995; Erkert 2000; Viele et al. 2002), as well as artificial light usage around the field site. Recording lasted up to two hours (usually 21:00 to 23:00). Changes in moonlight resulting from lunar phase were not anticipated to affect bat activity levels (Negraeff and Brigham 1995) and, therefore, were not recorded or considered in determining sampling nights.

3.3.2 Establishing Sampling Point Locations

Data on BPF and light intensity were gathered at sampling points along the bike trail, traversing forest, pond/wetland, and grassy areas. The bike trail was identified on a satellite image from August 2013 acquired through Google Earth and measured to be one mile long. The bike trail was selected as a sampling transect and sampling points were equidistantly distributed (Stevens and Olsen 2004; Rodhouse et al. 2011) every 150 meters along the bike trail. This resulted in establishing a total of nine sampling points with relatively unique landscape and light characteristics. The coordinates for each point were chosen using Google Earth and recorded in order to locate them at the field site (Figure 3.4).

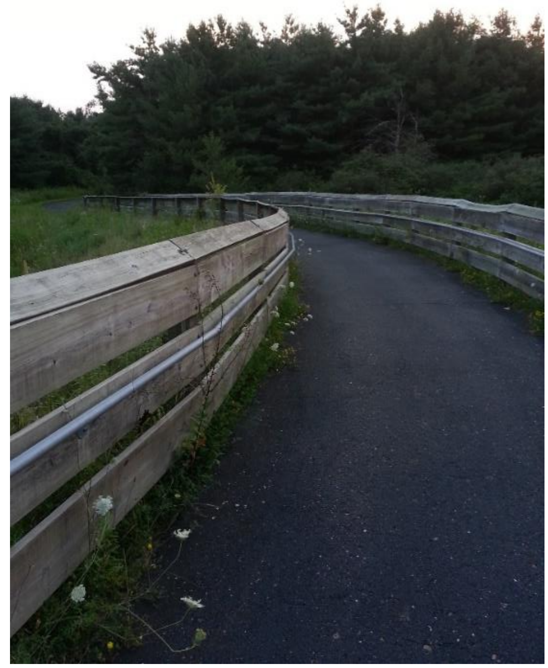
The coordinates of each sampling point were verified and established using the free smart phone app "My GPS Coordinates" on June 21, 2014. After verifying sampling points, locations where sampling equipment would be placed were marked on the bike trail with blue painters tape, allowing for a visual identification of the sampling points along the bike trail throughout the sampling period. If the tape appeared molested at any point during the data collection period, coordinates would be re-established using the phone app. During the initial site visit, photographs and general characteristics of the vegetation and nearby structures for each sampling point were recorded (Table 3.0).

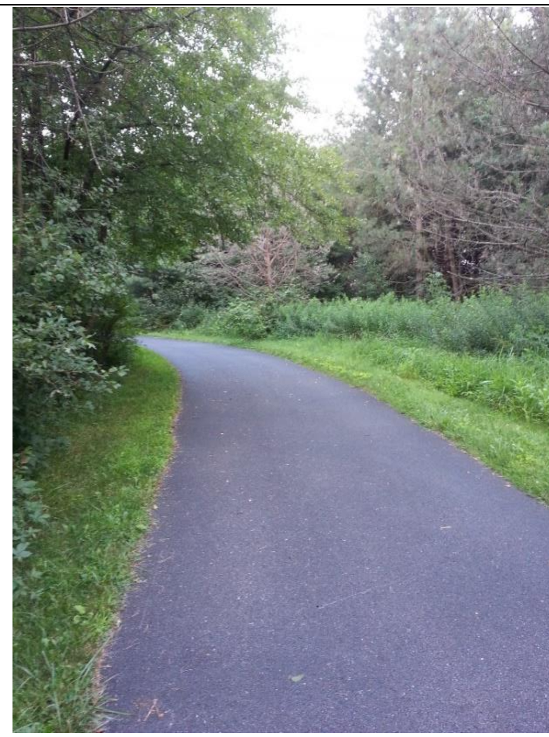
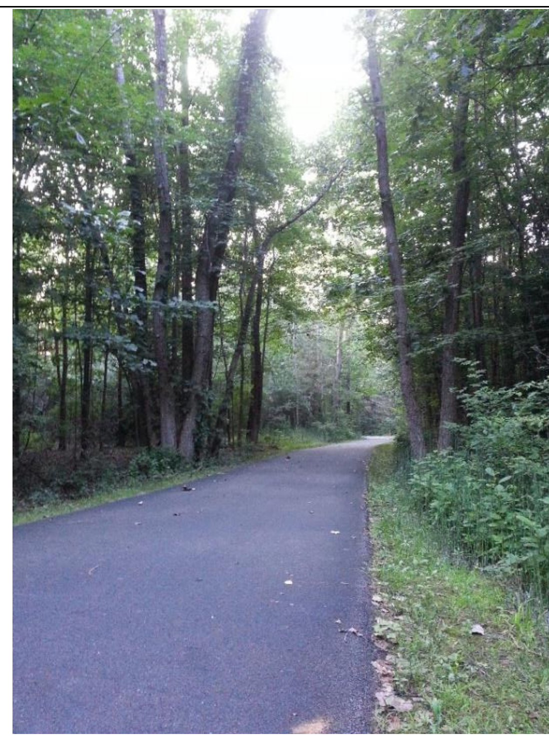
Figure 3.4 - Location of bat sampling points along bike trail

3.3.3 Bat Activity Counts

At each of the nine sampling points, bat activity counts were conducted twice (each on a separate night), yielding a total of 18 sampling nights. Each sampling point was sampled twice for BPF in order to be able to establish an average frequency value for each point and account for abnormal results. No two sampling points were sampled on the same night because bat activity tends to decrease after initial peaks around sunset. Sampling multiple points on the same night would result in lower activity counts at points sampled later in the night, producing inaccurate count values as a result of this temporal variance.

Table 3.0 - Bat Sampling Points

Bat Sampling Point	Latitude/ Longitude	Description	Image
1.0	41° 8’ 27.33” 81° 19’ 14.43”	• Adjacent to the bike trail bridge over Ohio State Route 261, which receives minimal road traffic in the evenings. • Vegetation includes trees, which block nearby artificial light, and grasses. • Dix Football Stadium security lights are visible at night.	
2.0	41° 8’ 25.70” 81° 19’ 20.54”	• Adjacent to Horning Road. • Vegetation is primarily grass and low shrubs. • Artificial light comes from passing vehicle headlights and parking lot security lights.	

3.0	41° 8' 24.42" 81° 19' 26.84"	• Surrounded by dense mixed species trees on either side of the bike trail. • Dark despite being a few feet away from the parking lot's artificial lights. • Points of artificial light are visible through gaps in the vegetation.	
4.0	41° 8' 27.28" 81° 19' 32.09"	• Tall trees occur on both sides of the bike trail. • Illuminated faintly by lights from the KSU facilities complex.	

5.0	41°8' 30.54" 81° 19' 36.97"	• Tall trees with little understory on the east side of the trail, and low shrubs on the western side. • Artificial lights from the residential neighborhood to the west is significantly blocked, whereas artificial lights from the facilities complex to the east shine through vegetation.	
6.0	41° 8' 32.50" 81° 19'42.91"	• Between the two pond and wetland areas • Surrounded by low vegetation including shrubs, grasses, and cattails; few trees occur in the immediate area. • Artificial light from the facilities complex is evenly distributed around the area. • Sky glow from the KSU campus is also apparent overhead.	

7.0	41° 8’ 36.81” 81° 19’ 46.04”	• At the fork that separates the paved bike trail from the dirt path which leads to the compose/refuse area. • Surrounded by predominately grasses, tall shrubs, and sporadic tall trees. • Artificial light comes from the nearby KSU sky glow and the apartment buildings.	
8.0	41° 8’ 41.33” 81° 19’ 48.57”	• Blocked from nearby apartment buildings by tall trees to the west. • Contains cement pavers, trash cans, light posts, and other KSU facility refuse. • An open dirt area is located to the east.	

9.0	41° 8' 46.29" 81° 19' 48.33"	• A compost dump for KSU vegetative waste. • Mostly devoid of vegetation except for trees that border the compost heap. • Bordering trees block artificial light from the apartment buildings, adjacent Rhodes Road, and residential homes.	

Each bat activity count started at sunset and lasted up to two hours. Recording was terminated prior to the two hour mark if raining commenced or if battery life for the equipment became depleted. To minimize seasonal bat activity fluctuations resulting from migrations or irregular juvenile flight patterns (Belwood 1998), sampling point order was randomized by drawing numbered pieces of paper out of a cup (Table 3.1).

To determine bat activity, a Pettersson ultrasonic heterodyne detector (D240X) was used to record acoustic data on each sampling night. According to the manual, the detector records acoustic wavelength data based on echolocation calls of bats flying overhead. Ultrasonic detectors are a noninvasive tool for sampling animal populations that emit ultrasonic sounds and are difficult or illegal to capture and study (United States Fish and Wildlife Service 2014). The ultrasonic detector was set to a frequency of 35 kHz with a 10 kHz range, which recorded bats emitting wavelengths between 25 and 45 kHz. This would capture the bat call frequencies of most Ohio bats, which range from 20.1 to 44.3 kHz (Humboldt State University, unpublished data).

The ultrasonic detector was connected to an Acer netbook computer. Audacity, an open-source, multi-track audio editor and recorder, was used to display and record the incoming acoustic monitoring data. Audacity has been successfully used in bioacoustics studies, such as those recording bees, dogs, birds (Hockicko and Jurečka 2007), and marine mammals (Matzner et al. 2011), as well as bats (Jonker et al. 2010; Herrera et al. 2015; Weterings et al. 2015). Each night, the equipment was tested initially by jingling a set of keys to determine if the equipment was working. Jingling keys emit ultrasonic wavelengths and therefore provide an opportunity to compare noise wavelengths to wavelengths produced as a result of visual bat passes. Moreover, the generation of sound files was visually confirmed at the beginning of each sampling night by checking that the Pettersson ultrasonic detector and Audacity software were detecting and recording bat calls.

Both the ultrasonic detector and the Acer netbook were placed on a specially constructed stand made of a metal base and a wooden platform (Figure 3.5). The metal base elevated the ultrasonic detector 1.5 meters above ground level to minimize the reflection of bat call sound waves, which would result in inaccurate bat call recordings or not recording bat calls at all (United States Fish and Wildlife Service 2014). The stand was placed along the edge of the bike trail on the blue tape at each designated sampling point to avoid collisions with late night trail users.

Table 3.1 - 2014 Dates for bat activity counts and randomized sampling order

Date of Sampling Night	Bat Sampling Point
06-28-14	1.0
07-10-14	1.0
07-11-14	6.0
07-15-14	5.0
07-16-14	7.0
07-21-14	2.0
07-22-14	8.0
07-25-14	4.0
07-29-14	7.0
07-31-14	3.0
08-01-14	5.0
08-03-14	3.0
08-04-14	9.0
08-05-14	6.0
08-06-14	9.0
08-07-14	8.0
08-08-14	2.0
08-09-14	4.0

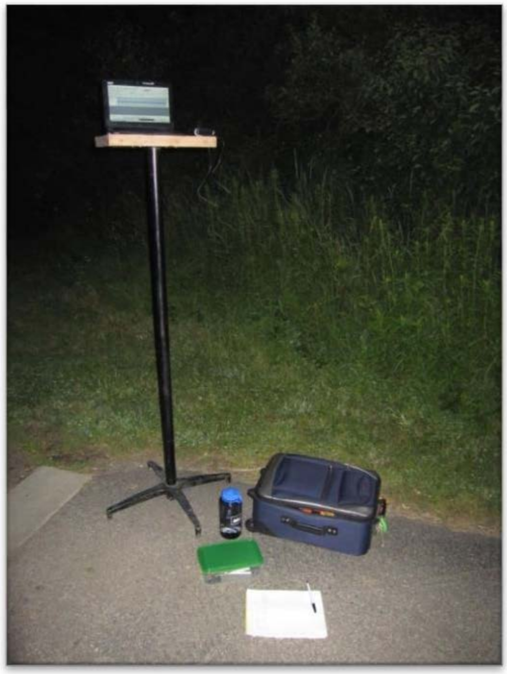


Figure 3.5 – Acoustic data collection equipment setup: ultrasonic detector and Acer netbook elevated on 1.5 m stand with a notebook and pen and equipment cases on the ground.

Acoustic equipment cannot establish that all recorded sounds originated from a bat, as bats are not exclusive in having ultrasonic capabilities (Sales and Pye 1974). For example, rodents rely on ultrasonic songs at frequencies of 30 kHz and above to facilitate mating behavior (Sales 1972). For this reason, the detector could have recorded rodent songs, although this is unlikely given that the detector was elevated 1.5 meters off the ground with the microphone facing skyward. Some birds and amphibians can produce ultrasonic call components, referred to as harmonics, but are thought to only do so in particularly noisy environments such as along loud rivers (Slabbekoorn and Peet 2003; Feng et al. 2006). Furthermore, birds are visual hunters and not typically active at night (Losos et al. 2008). Amphibians are found at ground level and unlikely to be recorded by the detector.

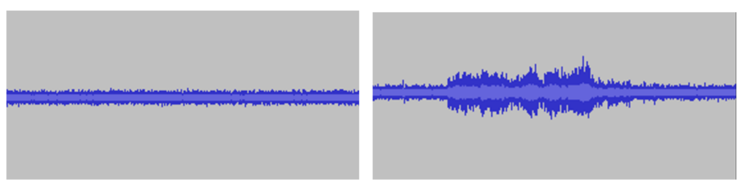
Most insect sounds are not ultrasonic, although ultrasonic calls have been documented among specific species of insects, such as crickets, katydids, and moths (Sales and Pye 1974). These insects use ultrasonic sounds for mating behaviors, but are undetectable at distances greater than 20 centimeters from the insect (Nakano et al. 2008; Nørum et al. 2012). As cicadas, crickets, and katydids typically emit sounds at or below 16 kHz, these insects would not be recorded by the detector (Gullan and Cranston 2014) and should not be confused with bat signals.

3.3.4. Determining BPFs

Acoustic data recorded by the ultrasonic detector was saved in Audacity as sound files. The sound files were intended to be analyzed through software programs designed to count and identify bat calls by species. Two software programs approved by the United States Fish and Wildlife Service were selected for analysis: EchoClass developed by Dr. Eric Britzke of the United States Army Engineer Research and Development Center in Mississippi, and Kaleidoscope Pro® designed by Wildlife Acoustics, Incorporated (United States Fish and Wildlife Service 2015c). The results from the software programs were intended to establish a preliminary species composition at the field site as well as identify species-specific light preferences at the field site.

Following failed attempts to analyze the bat sound files with both EchoClass and Kaleidoscope Pro®, a decision was made to analyze the sound files using a method of identifying and counting possible bat calls in Audacity (Haceková et al. 2014; Foxley 2015). Species identification can be performed in Audacity using visual call characteristics including frequency range (Foxley 2015; Weterings et al. 2015), but due to the researcher's lack of experience with visual identification, this method was not undertaken. Although a species identification could not be performed, the count of probably bat calls provided preliminary information necessary to determine areas of high and low bat activity across the field site in comparison to light intensity.

To count bat calls, it was first necessary to differentiate between probable bat calls and extraneous background sounds (Haceková et al. 2014; Foxley 2015). Trial recordings, performed during the initial site visits, were conducted to ascertain a baseline recording of background noise. Background noise displayed minimal fluctuations in amplitude (Figure 3.6a). These trial recordings also captured non-animal ultrasonic sounds, such as the jingling of keys. Non-animal sounds altered the amplitude of the baseline recording with random, un-patterned shapes (Figure 3.6b).



(a) (b)

Figure 3.6 – Non-animal acoustic recordings. Baseline recording of background noises (a) and amplitude fluctuations of the baseline background noise associated with the ultrasonic waves of jingling keys (b).

When bats emitting ultrasonic sound waves flew over or around the ultrasonic detector, the series of pulses appearing on the screen were recorded. The pulses create a unique image completely unlike the images produced by the jingling keys, thus making probable bat calls distinguishable from other sounds. Each cluster, or group of closely situated pulses, was visually identified and counted as a separate bat call. This method is comparable to that used by Murray and Kurta (2004). Pulse clusters varied in the number of pulses per cluster and in the amplitude of the pulses. All clusters, however, included 3 or more pulses (Walsh and Harris 1996). These clusters were temporally distinct and separated by baseline noises, making separate calls clearly discernable (Figure 3.7).

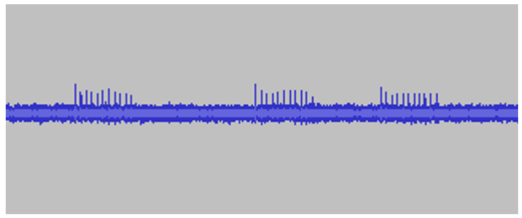


Figure 3.7 – Three pulse clusters separated by the baseline noise. This image represents three bat calls.

Frequency is defined as the number of events per unit time (Kenney and Keeping 1962). The number of bat calls were averaged from sampling counts measured over hours, which varied nightly between 0.250 and 2.02 hours. This established a frequency of bat passes with the following formula:

BPF = (Number of Calls) / (Recording Duration in Hours).

Calculated averages standardized the data acquired during sampling nights with differing recording durations. It is important to note that the method of counting bat calls described in this methodology did not distinguish among species and it is possible that the same individual was counted multiple times.

The BPF values from both nights at each sampling point were averaged together to determine an average BPF per sampling point. Averaging the BPF counts at each point minimizes influence of any abnormal recordings. Averaging both nights also accounted for frequency differences resulting from seasonal changes in activity and different recording durations, allowing for a standardized comparison among sites. A disadvantage of this method is that, by averaging the two sampling nights from each sampling point, the sample size was reduced to nine instead of 18.

3.3.5 Measuring Artificial Light Intensities

To quantitatively compare BPF to existing light conditions, light intensity was measured at designated points along the bike trail on August 4th, 2014. The nine BPF sampling points, as well as 16 additional points, were sampled for light intensity (Figure 3.8). Two additional sample points were selected between each of the BPF sampling points, producing a series light intensity values across the bike trail (Table 3.2).

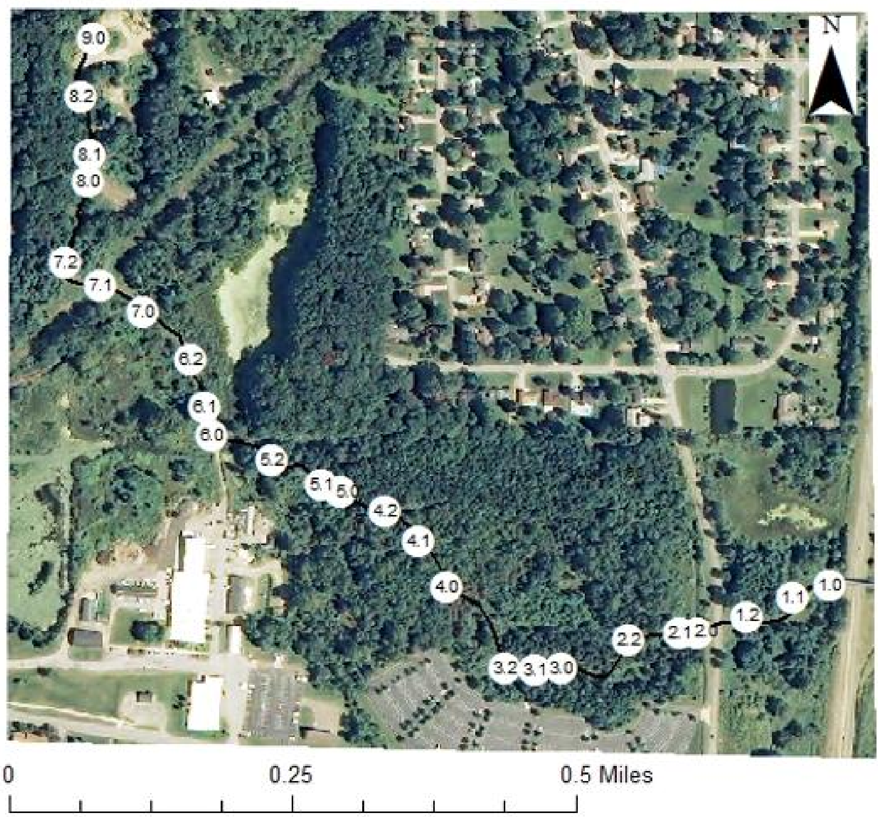


Figure 3.8 - Location of light sampling points along the bike trail.

These 16 additional points were chosen in areas where the light intensity was expected to abruptly change, such as areas where vegetation height or density changed dramatically. It was expected that sampling these areas representing abrupt change would capture the brightest and darkest zones between the BPF sampling points.

The 16 additional points were chosen in August 2014. Points were chosen after the researcher had become sufficiently familiar with the bike trail and could select light sample sites based on the distinct lighting characteristics. The coordinates of each sampling point were verified and recorded in the field with GPS technology via the free smart phone app “My GPS Coordinates”.

Light intensity was measured and recorded at these points on August 4, 2014. Light data was collected on one night in order to compare light intensities at each sampling point under identical cloud cover, which can amplify existing urban light pollution intensities by a factor of 10 (Kyba et al. 2011). Although the lunar phase was not anticipated to have a significant effect on the light intensity readings (Lacoeuilhe et al. 2014), the light sampling night was conducted on the first quarter (half) moon. Sampling on a half-moon night represents median lunar light influence between full and new moon conditions. To avoid the rapidly changing light conditions associated with twilight, light intensities were measured between 22:30-23:30.

Table 3.2 - Light intensity sampling locations and corresponding coordinates. Points shaded in grey represent locations that were also sampled for BPF.

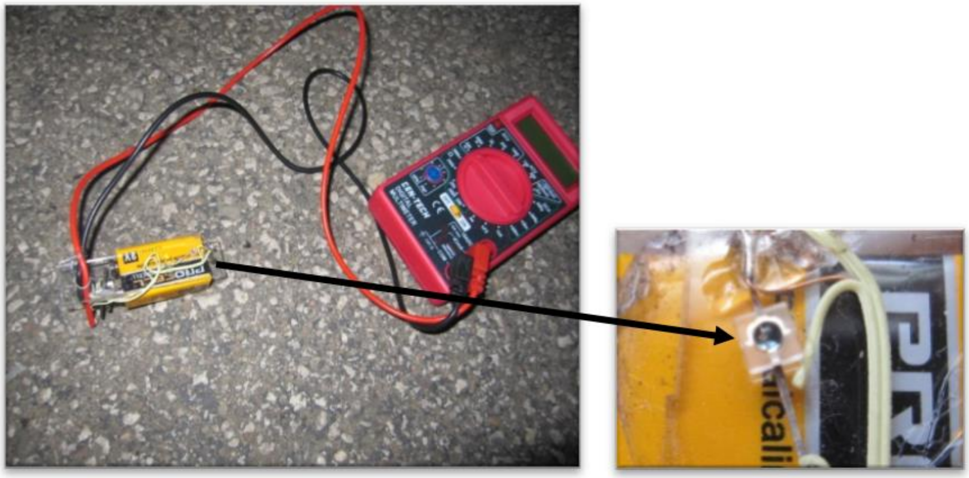
Light Sampling Points	Latitude/Longitude
1.0	41° 8' 27.33" / 81° 19' 14.43"
1.1	41° 8' 26.87" / 81° 19'16.16"
1.2	41° 8' 26.25" / 81° 19' 18.3"
2.0	41° 8' 25.70" / 81° 19' 20.54"
2.1	41° 8' 25.68" / 81° 19' 21.37"
2.2	41° 8' 25.4" / 81° 19' 23.71"
3.0	41° 8' 24.42" / 81° 19' 26.84"
3.1	41° 8' 24.41" / 81° 19' 28.03"
3.2	41° 8' 24.45" / 81° 19' 29.41"
4.0	41° 8' 27.28" / 81° 19' 32.09"
4.1	41° 8' 28.87" / 81° 19' 33.4"
4.2	41° 8' 29.91" / 81° 19' 34.94"
5.0	41°8' 30.54" / 81° 19' 36.97"
5.1	41° 8' 30.78" / 81° 19' 37.86"
5.2	41° 8' 31.67" / 81° 19' 40.14"
6.0	41° 8' 32.50" / 81° 19' 42.91"
6.1	41° 8' 33.49" / 81° 19' 43.25"
6.2	41° 8' 35.16" / 81° 19' 43.84"
7.0	41° 8' 36.81" / 81° 19' 46.04"
7.1	41° 8' 37.72" / 81° 19' 48.00"
7.2	41° 8' 38.52" / 81° 19' 49.65"
8.0	41° 8' 41.33" / 81° 19' 48.57"
8.1	41° 8' 42.27" / 81° 19' 48.49"
8.2	41° 8' 44.26" / 81° 19' 48.87"
9.0	41° 8' 46.29" / 81° 19' 48.33"

A disadvantage of sampling light on only one night is that fluctuations across the summer sampling season could not be minimized, as would have been the case through averaging samples across multiple nights. However, in keeping the research question's goal of comparing bat activity to light intensity, seasonal light variation was not a concern and therefore measurement of light changes was not necessary. It was determined that collecting one night of light data would be sufficient for delineating general areas of high and low light intensity across the site.

A light meter was used to collect the light intensity data. The light meter used in this study was constructed by Dr. Michael Crescimanno of the Youngstown State University's Physics Department. The meter consists of a silicon phototransistor connected to a multimeter and a 9V battery (Figure 3.9). Incident light received by the phototransistor alters the voltage displayed on the multimeter, with higher readings corresponding to higher light intensities. Starting at sampling point 1.0 and ending at sampling point 9.0, the bike trail was walked in one direction while holding the light meter at chest height. At each of the 25 sampling points, walking halted for 2 or 3 seconds to record the voltage reading displayed instantaneously on the digital multimeter in millivolts.

3.4 Spatial Modeling

A spatial model of light intensity data was created in ArcMap with an interpolation of the measured light intensity data. The goal of this portion of the analysis was twofold. First, to display the spatial distribution of light intensity with the geographic locations of the sampling points. Second, to determine areas of high and low light intensity across the bike trail.



(a) (b)

Figure 3.9 – The light meter, used to determine light intensities at the field site, consisting of a multimeter, silicon phototransistor, and a 9V battery (a). A close-up of the phototransistor "eye", capable of detecting changes in light intensity (b).

The bike trail was digitized to establish the sampling transect in a GIS platform. Although the literature lacks specifics about the implementation of spatial buffers in light intensity studies, a buffer zone of 20 meters was applied to the digitized bike trail polyline to focus the subsequent analyses around the sampled area only and not the entire property. The buffer was established to eliminate areas of the interpolation far removed from the sample points and reduce model error generated from an insufficient number of measured points in distant parts of the property.

The light intensity data for each sample point was input to the attribute table of the point layer "Light_Sampling_Points". Data was interpolated using an inverse distance weighted (IDW) algorithm, a tool which uses the Pythagorean theorem to weight points based on proximity, with closer points being weighted more heavily than farther points (Jensen and Jensen 2013). The light intensity IDW created a continuous raster dataset based on the measured points with a processing extent equal to the bike trail's buffer zone. The light intensity IDW was trimmed to the bike trail buffer zone using the extract by mask tool. Next, the light intensity IDW was converted from a raster layer to a point layer. By doing this, un-sampled points within the buffer zone were assigned a predicted light intensity value based on the measured light intensity values.

Graduated symbols were created for the “Bat_Sampling_Points” layer based on the calculated BPF values. The BPF layer and light intensity IDW were overlaid to visually compare areas of high and low BPF values with corresponding light intensities, thus providing a spatial map summarizing all the data which could be used to answer the research question: What is the relationship between various light pollution intensities on bat pass frequency?

RESULTS

4.0 Introduction

The resulting BPF and light intensity datasets along with analysis results are presented in this chapter. The bat call counts are first described, followed by the results of the calculated BPF values for each of the nine bat sampling points. These BPF values, which were also modeled in GIS, are provided. Next, the light intensity recordings at the 25 light sampling points are listed, followed by an interpolated presentation of a light gradient modeled along the bike trail. Finally, the spatial modeling results are presented.

4.1 Bat Pass Frequency

Nine hundred and thirty-three bat calls representing BPF were counted over 21.87 hours of sound files from 17 sampling nights. Although 18 nights of data were originally recorded, the second night of recording at sampling point 7.0 was omitted due to a repeating pattern that dominated over 75% of the sound file (Figure 4.0). The repetition of the calls in combination with the duration of this pattern indicated that it was some type of interference rather than a bat call.

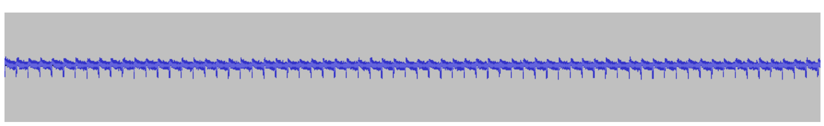


Figure 4.0 – Repeating pattern found in the sound file recorded July 29th at sampling point 7.0. The entire sound file was omitted from data analysis.

The BPF values per night ranged from 1.18 to 100 calls per hour, averaging 50.59 calls per hour. Each sampling point's BPF values were averaged, producing a range in values from 7.54 to 87.3 calls per hour, with an average of 47.42 calls per hour. The greatest averaged BPF value was at sampling point 2.0, and followed in decreasing order by sampling points: 8.0, 1.0, 6.0, 3.0, 5.0, 7.0, 9.0, and 4.0. Table 4.0 provides an account of the number of calls which occurred at each sampling point during each night in addition to calculated BPF values.

4.2 Light Data

Light intensities collected along the bike trail ranged from 1.6 to 18.1 millivolts (Table 4.1), with an average of 7.3 millivolts. Higher millivolt recordings indicate higher levels of light intensity. The light intensities were interpolated with an IDW algorithm to cover the bike trail and the associated 20 meter buffer (Figure 4.1). The resulting interpolation, which used measured points to estimate light intensities in non-sampled areas, represented patches of high and low light intensity in white and black, respectively. Varying shades of each color reflect a light gradient between the brightest and darkest areas. Areas of medium light intensity were represented in the interpolation with a gray color. In general, the highest light intensities were located at both ends of the bike trail, particularly near sampling point 1.0, and around sampling points 6.0 and 7.0. Conversely, the darkest areas were located between sampling points 3.0 to 5.0.

4.3 Spatial Model of BPF to Light Intensity

A GIS model depicted interpolated light values associated with measured BPF values at each bat sampling point (Figure 4.2). Light intensity is represented using a graduated color gradient of white to black, with white indicating higher light intensities and black representing lower light intensities. The model displays lower BPF values along the darker sections of the bike trail and higher BPF values in the brighter sections. In general, the greatest BPF values occurred in regions of the light gradient with medium light intensities. Moreover, BPF appears to be higher in brighter regions than in darker regions, although the brightest sampling point did not have the highest BPF.

Table 4.0 - Bat call counts and call duration for each sample point and each sample night along with the BPF per night. Data from July 29th was not analyzed due to interference.

Sampling Point	Date of Count	Number of Calls	Recording Duration (h)	Average BPF per Night	Average BPF per Site
1.0	6/28/2014	39	1.98	19.7	**59.9**
	7/10/2014	40	0.400	100	
2.0	7/21/2014	158	1.87	84.5	**87.3**
	8/8/2014	126	1.40	90.0	
3.0	7/31/2014	105	1.97	53.3	**50.2**
	8/3/2014	66	1.40	47.1	
4.0	7/25/2014	25	1.80	13.9	**7.54**
	8/9/2014	1	0.850	1.18	
5.0	7/15/2014	95	1.99	47.7	**25.6**
	8/1/2014	7	2.02	3.47	
6.0	7/11/2014	15	0.610	24.6	**59.2**
	8/5/2014	45	0.480	93.8	
7.0	7/16/2014	8	0.380	21.1	**21.1**
	7/29/2014*	**X**	**X**	**X**	
8.0	7/22/2014	157	2.01	78.1	**67.1**
	8/7/2014	14	0.250	56.0	
9.0	8/4/2014	26	2.00	13.0	**13.0**
	8/6/2014	6	0.460	13.0	

*Data not analyzed due to interference

Table 4.1 - Light sampling points and corresponding intensities.

Light Sampling Location	Light Intensity (mV)
1.0	18.1
1.1	8.3
1.2	9.3
2.0	9.8
2.1	8.9
2.2	5.0
3.0	4.8
3.1	2.3
3.2	6.9
4.0	2.4
4.1	2.4
4.2	1.6
5.0	2.6
5.1	9.8
5.2	4.7
6.0	12.8
6.1	6.2
6.2	9.3
7.0	11.0
7.1	11.4
7.2	5.3
8.0	7.1
8.1	5.6
8.2	4.9
9.0	12.1

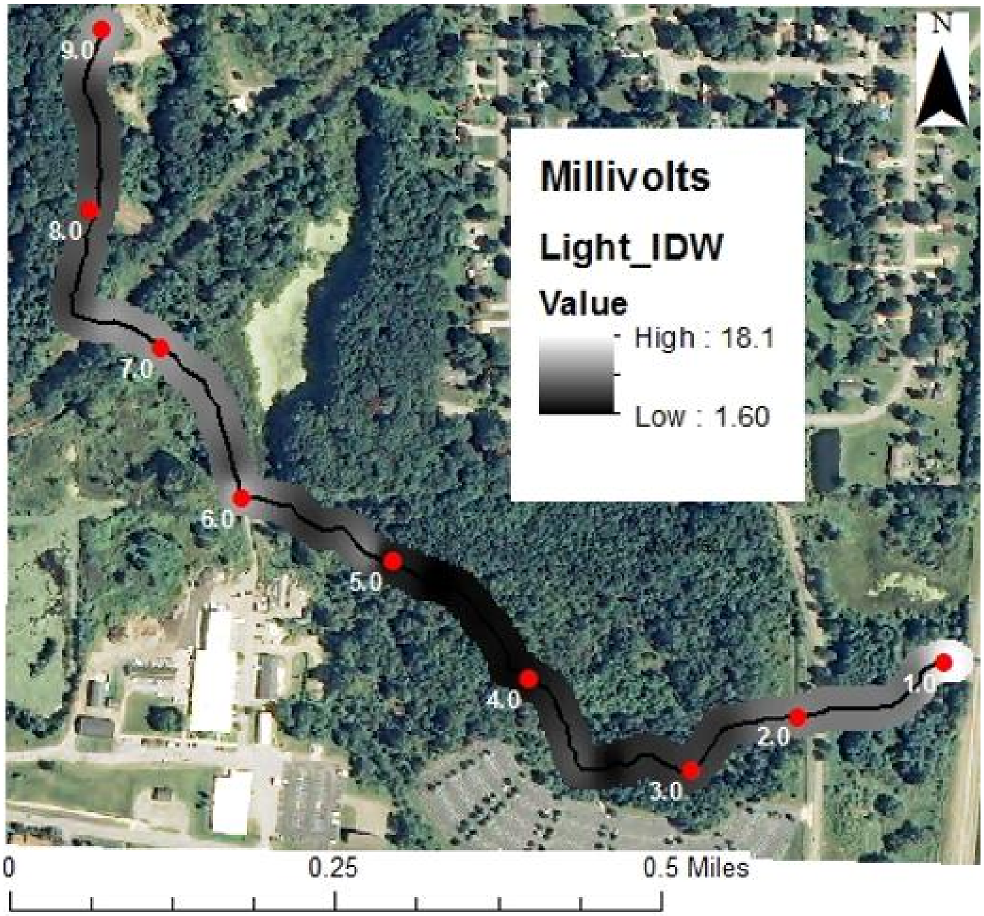


Figure 4.1 – Light intensities from the 25 sampling points were interpolated in a 20 meter buffer around the bike trail, designated as a black line. Labeled red sampling points denote locations where bat frequency data was collected.

4.4 Species Identification

Initial methodology plans incorporated automatic species identification software programs for bat call analysis. Following the completion of the sampling season, recorded bat sound files were repeatedly run through two software programs: EchoClass and Kaleidoscope Pro®. The EchoClass software yielded only error messages while the Kaleidoscope Pro® software failed to analyze entire recording nights. Norris (2014b) examined the bat sound files through Bat Sound Identification Inc.'s BCID program in December 2014 using Ohio-specific filters within BCID to capture native bat calls. BCID identified only a single big brown bat on the July 31 night of recording, although bats were observed flying over the acoustic detector at the field site on every sampling night. In January 2015, a decision was made to analyze the sound files for bat calls following Foxley's (2015) method of identifying possible bat calls in Audacity without species identification.

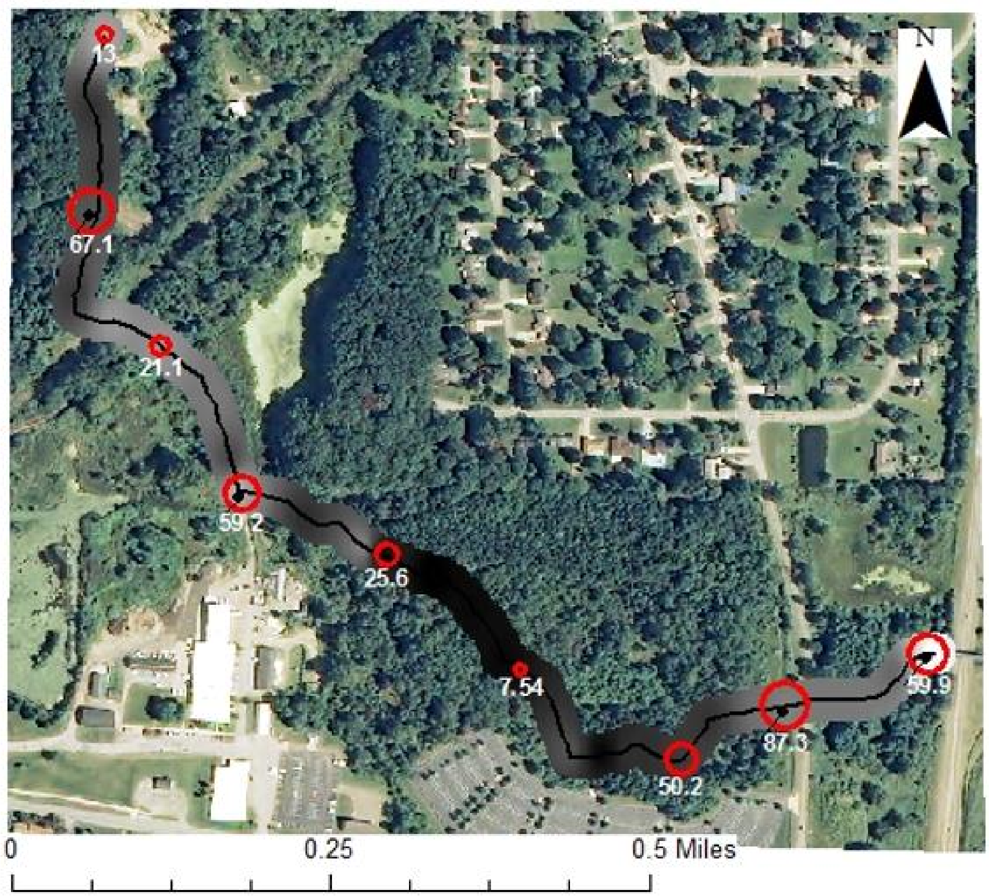


Figure 4.2 – BPF, labeled and displayed through red graduated symbols, as associated with the light intensity gradient along the bike trail.

DISCUSSION

5.0 Introduction

This chapter interprets the results of this study as related to the thesis research question: What is the relationship between various light pollution intensities on bat pass frequency? Answering this question was accomplished by meeting three objectives: (1) determining the light gradient at the field site by measuring and interpolating light intensities along a transect; (2) establishing a BPF by performing a count of bat passes at designated points along the transect; and (3) comparing light intensity to BPF using spatial modeling. The subsequent data suggests bat activity tends to increase with increasing light intensity to a particular light intensity threshold. The limitations and recommendations for future research on bats and light pollution at this field site, as an outcome of this study, conclude the chapter.

5.1 Bat Activity along the Bike Trail

Acoustic results throughout the sampling period confirmed the principal assumption of this study: that the field site characteristics are conducive to bat activity. Throughout the sampling period, over 900 acoustically recorded bat calls were distributed among all nine bat sampling points along the bike trail, indicating that the bats utilize a majority of the bike trail, albeit not uniformly. Average site BPF values ranged from 7.54 to 87.3 calls per night, which may suggest a bat preference or avoidance of resources or environmental conditions, such as artificial light, at certain locations of the field site.

5.2 Light Intensities along the Bike Trail

The surrounding urban areas contribute to the alteration of the natural light conditions at the field site. Because all light data samples were collected on the same night, light variations due to lunar phase, cloud cover, and other atmospheric conditions were minimized. Artificial light sources surrounding the field site include, but are not limited to: the residential neighborhood, Dix Football Stadium Kent State University, roadways, and parking lots. These sources likely contributed to the range of light intensities recorded along the bike trail, which varied between 1.6 and 18.1 millivolts at the darkest and brightest spots, respectively. For example, at the higher light intensity regions, ambient light levels allowed for the reading and writing of field notes without a flashlight or other artificial light supplement. Contrariwise, reading and writing at the low light intensity regions was impossible without a flashlight.

The variation in light intensity was established through the IDW interpolation model, which indicated alternating segments of bright areas and dark areas along the trail. The bright areas of the bike trail can disorient, repulse, temporarily blind, or otherwise alter the behavior of fauna in the area, such as: insects (Frank 1988; Summers 1997; Eisenbeis and Hassel 2000), birds (Ogden 1996; Le Corre et al. 2002; Jones and Francis 2003), frogs (Schwartz and Henderson 1991; Buchanan 1993; Rand et al. 1997), and rabbits (Gilbert and Boutin 1991). The high light intensities may also negatively impact the foraging success of light-avoiding *Myotis* bat species if they are foraging in the area (Furlonger et al. 1987; Rydell 1992; Downs et al. 2003). However, as eastern red, big brown, and hoary bats increase foraging in lit environments (Svensson and Rydell 1998; Acharya and Fenton 1999; Svensson et al. 2003) to exploit prey that are light-attracted, the increased activity of bats at lit sampling points suggests the presence of light-tolerant species that may be benefiting from the light.

5.3 BPF as Related to Artificial Light

Overall, bat activity is greater in light conditions than dark conditions, although medium light intensities appear to be most favorable to bat activity at this field site. The BPF values indicate that the bats were not frequenting low light intensity areas as much as the midrange to high light intensity areas during the sampling period. Such results may support the presence of larger, fast-flying bat species, which are more likely to forage in artificial light than smaller species (Rydell 2006). Although foraging in light increases overall risk of predation from visual predators such as birds of prey, fast-flying species are at reduced risk of predation than smaller species and, thus, are more likely to forage in lit environments (Furlonger et al. 1987; Rydell 1992, 2006). These findings are consistent with Navarro's (2014) unpublished undergraduate project from Kent State University, which identified big brown, eastern red, and hoary bats at the property. All three of these species are generally larger and known to have a light preference (Geggie and Fenton 1985; Furlonger et al. 1987). Rydell (2006) recognized that foraging bats often exploit light sources for prey consumption, so it follows that bats are likely increasing prey intake by foraging in the field site's bright areas.

5.4 Bat Conservation Implications

As this field site is situated within the ranges of ten bat species (International Union for Conservation of Nature 2014), and two of these species are federally-listed as having the potential to become nationally extinct (United States Fish and Wildlife Service 2015b), preservation of the site's habitat quality is necessary to provide summer roosting and foraging opportunities. Navarro's (2014) acoustic records did not identify northern long-eared or Indiana bats, which are federally-listed (United States Fish and Wildlife

Service 2015b) and are known to avoid light (Furlonger et al. 1987; Rydell 1992). However, northern long-eared bats are found in Ravenna, Ohio (Brack and Duffey 2006), and both northern long-eared and Indiana bats are found at Summit Metro Parks (Summit Metro Parks 2015). Although other limiting factors must be considered and studied before drawing definite conclusions regarding absence from the field site, northern long-eared and Indiana bats could be avoiding the field site as a result of the artificial light.

The likely presence of light-tolerant species foraging in the light at the field site generates additional concerns. First, adaptations of bat species to exploit artificial light conditions may create competition with bat species that avoid light (Tuttle et al. 2006; Kuijper et al. 2008). Viable population sizes of light-avoiding species could decrease as a result of competition around artificial lights (Arlettaz et al. 2000) resulting in exclusion from the area. Second, light-tolerant bat species are expected to rapidly diminish insect prey populations (Fullard 2001; Minnaar et al. 2014). While bat predation of insects is economically valuable for the agricultural industry (Boyles et al. 2011), bats consume several different orders of insects (Jones and Rydell 2003) capable of other economically valuable services such as pollination, waste decomposition, and wildlife nutrition (Losey and Vaughan 2006). As a result, increased bat foraging success around artificial light could reduce insect populations providing economic services. Although the increase in BPF relative to light intensity at the field site could be beneficial to light-tolerant bat foraging, these benefits should be carefully considered with respect to potential negative consequences.

According to Gaston et al. (2013), future research is necessary to determine thresholds of light intensity at which point ecological effects occur. A light intensity threshold could exist at which point light is directly detrimental to even light tolerant bat species (Hale et al. 2015). The data from this study suggests bats at this field site with a light preference may have a maximum light intensity tolerance relative to the site's light conditions. Moreover, Bennett et al. (2013) demonstrated that artificial light could act as a habitat fragmentation mechanism for bats who avoid light. This light threshold and associated BPF should be studied further. Additional research is particularly necessary, given that illumination is often ignored in species management plans (Gaston et al. 2013).

5.5 Limitations

There were four main limitations that may have affected the outcome of data collection. First, the unequal sampling times among sampling nights might have created a bias in the BPF values. Although the bat call counts were averaged by recording time for a standardized comparison, bat activity spikes or declines on sampling nights, which were not sampled the full two hour period, may not accurately represent BPF.

Second, the locations of roosts throughout the field site were not established, so it is unknown if BPFs were heavily influenced by roost proximity to sampling sites (Carter and Feldhamer 2005). If sampling points were unknowingly close to roosting trees, the BPF may have been high as a result of bats returning to the roost tree multiple times throughout the night (Belwood 1998; Murray and Kurta 2004).

Third, this study did not determine roost emergence times, which have been shown to (1) be delayed by the presence of high intensity light and (2) exhibit natural variations across species and seasons (Downs et al. 2003). Emergence times that occurred after the completion of the Audacity recordings each night would not be counted toward overall BPF, so later emerging individuals that could be present at the field might have been excluded from the counts.

Fourth, BPF values as modeled in this study can be misleading without species identification information. First, it is possible that calls of other ultrasonic-capable animals might have been recorded (Sales and Pye 1974) and mistaken for bat calls. Moreover, calls were not separated by bat species. Thus, without species information, it uncertain if the recorded BPF values across the light gradient could be a product of: (1) light tolerant species with high activity in bright areas and lower activity in dark areas as a result of fewer prey resources in darker areas, or (2) light tolerant species in the bright areas and light avoiding species in the dark areas.

5.6 Recommendations for Future Study

Identification of Bat Species and Habitat-Use Characteristics

Ultimately, further studies regarding species composition at this field site are required before drawing any definitive conclusions regarding bat activity and light intensity. A comprehensive bat biodiversity study could determine species composition across the light gradient of the study site. Mist netting in conjunction with the ultrasonic detection could identify species composition (Robbins et al. 2008). Mist-netting studies associated with species identification could also provide a more accurate description of bat activity types relative to light conditions. For instance, mist-netting would provide data on the presence of pregnant versus lactating females, the latter of which have higher average activity levels (Viele et al. 2002; Murray and Kurta 2004). Knowing activity type would indicate site usage and provide rationale for bats' activity levels associated with varying light conditions.

Establishing any presence of bat roosts and monitoring roost emergence times in relation to artificial light conditions could clarify the nature of bat-light relationship at this field site. Identification of roost sites and emergence times would minimize bias in sampling methods of future light-related studies. Roost identification, in order to perform subsequent emergence studies, is typically accomplished through radio-tracking technology.

Light Intensity Manipulation and Modeling

Longitudinal study of light conditions was not undertaken. Additional investigation of effects of variations in light levels, both natural and anthropogenic, would be useful in evaluating changes in bat behavior relative to specific light phenomena. This information would account for seasonal light changes and wide variations in intensity of anthropogenic light as well. For example, Dix Football Stadium did not have the stadium lights on during any nights of data collection in this study. However, stadium activities on certain nights could dramatically increase the amount of artificial light affecting the field site, and the additional artificial light should be measured and compared to the light gradient from this study.

Experimentally manipulated light intensities could be beneficial for examining the relationship among BPF variables and specific light conditions. Manipulated light conditions could be accomplished through the addition and subtraction of floodlights at the field site and, then, recording bat activity and species behavior in response to these changes. As Kent is a growing city which will most likely incur additional artificial lights (United States Census Bureau 2015), predicting bat responses to increases in artificial light at this site would be beneficial. Experimentally manipulated lights could also be used to examine the effects of light type. For instance, light-emitting-diode (LED) lights, colored lights, and high pressure sodium lights have various effects on specific species (Downs et al. 2003; Stone et al. 2009; Stone et al. 2012). Experimental manipulations with different light variables could be performed at the field site.

Previous light pollution studies rely heavily on coarse resolution satellite data, which may not accurately portray light intensity at ground level. The use of ground level light data collection and subsequent GIS modeling documented in this thesis allows geographers and biologists to study light pollution at small scale, local study sites more accurately than satellite-captured light data. Furthermore, satellite data represents light reflected from the ground, not actual light conditions at ground level. To improve the accuracy of ground level light data collection, subsequent studies at this field site and others should also consider the use of a grid system, as opposed to a singular transect, for light data collection, as it would allow for a cross-validation and, therefore, improvement of the existing light model created in this thesis. A grid model would be of benefit in bat-light studies, as it could depict site-wide variations in light intensity and, thus, could be used as a tool for predicting areas of high and low bat activity, which could aid in species-specific bat conservation programs.

Light data could be measured with respect to light trespass versus sky glow and its relationship with light intensity recordings. This could be accomplished by using the Bortle Dark-Sky Scale, which rates overhead skies into a series of classes depending on observable constellations (Bortle 2001). By classifying illumination of the nighttime sky over the field site using the Bortle Dark-Sky Scale, the field site could be compared with other bat-occupied regions of similar landscape using the same Bortle classification.

CONCLUSIONS

6.0 Conclusions

Light pollution occurs in areas of excess artificial light usage associated with human activities (Cinzano et al. 2001). Despite research indicating an adverse effect on nocturnal organisms (Rich and Longcore 2006), especially bats (Childs and Buchler 1981; Downs et al. 2003; Stone et al. 2012), artificial light is still not considered a major indicator for bat habitat quality (Rydell 2006). To that end, the goal of this thesis was to answer the research question, "What is the relationship between various light pollution intensities and bat pass frequency?" through the collection of acoustic bat data and light intensities along a bike trail at a field site in Kent, Ohio. The combination of GIS and acoustic monitoring techniques revealed a potential bat preference for medium light intensities along a light gradient at the field site. The results presented here provide an initial assessment, and follow-up research should be conducted to either support or reject the inclusion of light pollution management for this field site.

The number of acoustic bat calls per hour varied from one sampling point to the next, which is argued to be a product of artificial light conditions that are unique at each sampling point. Bat activity was greatest at middle level light intensities, suggesting that the bats using this field site may have a preference for artificial light. However, acoustic activity decreased at the brightest sampling points, indicating the potential of a light intensity threshold above which even light tolerant bats at this location might avoid. Because all Ohio bats are state-listed (Ohio Department of Natural Resources 2014), and most species are declining in number (Norris 2014a), conservation efforts in Ohio must not dismiss the potential that artificial lights may alter summer bat behavior. Bat conservation is particularly important for the sustainability of Ohio's agriculture industry, as bats provide billions of dollars in pest control (Boyles et al. 2011). Although certain species of bat have increased foraging success in the presence of the artificial light, differential light preferences among bats creates competition (Tuttle et al. 2006; Kuijper et al. 2008), prey reduction (Fullard 2001; Minnaar et al. 2014), and food web shifts (Lewanzik and Voigt 2012). Negative effects resulting from the presence of artificial light can be minimized by removing light sources, dimming lights, reducing intensity of lights, and changing light type (Stone et al. 2015). Altering the impact of artificial light without removing all light sources also allows the human value of and use for artificial light as described by Jakle (2001) to be conserved.

This research provides only an introductory examination into the relationship between bat activity and light conditions at this field site. Based on the results presented, light pollution may be a variable of concern for bat populations and should be investigated further at the field site as the current light gradient might be deterring light-avoiding species present in the region. Kent is a growing city (United States Census Bureau 2015) and will most likely incur additional artificial lights in coming years. Additional data, such as species identification, artificial light changes, and vegetation characteristics, from this property are necessary to better understand the relationship between bat activity and artificial light intensities. Furthermore, research should continue by examining the effects of differing light intensities on bat activity levels. Ultimately, the results presented within this thesis argue for additional research on illumination in bat habitat in order to better construct species management plans.

REFERENCES

Acharya, L., and M.B. Fenton. 1992. Echolocation behaviour of vespertilionid bats (*Lasiurus cinereus* and *Lasiurus borealis*) attacking airborne targets including arctiid moths. *Canadian Journal of Zoology* 70: 1292-1298.

Acharya, L., and M.B. Fenton. 1999. Bat attacks and moth defensive behaviour around street lights. *Canadian Journal of Zoology* 77: 27-33.

Adams, M.D., B.S. Law, and M.S. Gibson. 2010. Reliable automation of bat call identification for Eastern New South Wales, Australia, using classification trees and AnaScheme software. *Acta Chiropterologica* 12(1): 231-245.

Adams, R.A. 2010. Bat reproduction declines when conditions mimic climate change projections for western North America. *Ecology*, 91(8), 2437-2445.

Allen, G.M. 1940. Bats. Harvard University Press, Cambridge.

Arlettaz, R., S. Godat, and H. Meyer. 2000. Competition for food by expanding pipistrelle bat populations (*Pipistrellus pipistrellus*) might contribute to the decline of lesser horseshoe bats (*Rhinolphus hipposideros*). *Biological Conservation* 93: 55-60.

Bailey, V. 1925. Bats of the Carlsbad Cavern. National Geographic 48: 320-330.

Barak, Y., and Y. Yom-Tov. 1989. The advantage of group hunting in Kuhl's bat *Pipistrellus kuhli* (Microchiroptera). *Journal of Zoology, London* 219: 670-675.

Barber, J. R., C.L. Burdett, S.E. Reed, K.A. Warner, C. Formichella, K.R. Crooks, D.M. Theobald, and K.M. Fristrup. 2011. Anthropogenic noise exposure in protected natural areas: estimating the scale of ecological consequences. *Landscape ecology*, 26(9): 1281-1295.

Barclay, R.M.R. 1985. Long- versus short-range foraging strategies of hoary (*Lasiurus cinereus*) and silver-haired (*Lasionycteris noctivagans*) bats and the consequences for prey selection. *Canadian Journal of Zoology* 63: 2507-2515.

Barclay, R.M.R. 1986. The echolocation calls of hoary (*Lasiurus cinereus*) and silver-haired (*Lasionycteris noctivagans*) bats as adaptations for long- versus short-range foraging strategies and the consequences for prey selection. *Canadian Journal of Zoology* 64: 2700-2705.

Barclay, R.M.R. 1989. The effect of reproductive condition on the foraging behavior of female Hoary Bats, *Lasiurus cinereus*. *Behavioral Ecology and Sociobiology* 24(1): 31-37.

Barclay, R.M.R., and R.M. Brigham. 1991. Prey detection, dietary niche breadth, and body size in bats: why are aerial insectivorous bats so small? *American Naturalist* 137: 693-703.

Bartness, T.J., and B.D. Goldman. 1989. Mammalian pineal melatonin: a clock for all seasons. *Experientia* 45: 939-945.

Bartonicka, T., A. Bielik, and Z. Rehak. 2008. Roost switching and activity patterns in the soprano pipistrelle, *Pipistrellus pygmaeus*, during lactation. *Annales Zoologici Fennici* 45: 503-512.

Bat Conservation International, Inc. 2011. Bat conservation and management workshop course book: Carter Caves State Resort Park, KY.

Beier, P. Effects of Artificial Night Lighting on Terrestrial Mammals. In *Ecological consequences of Artificial Nighttime Lighting*, ch.2. Rich, C. and T. Longcore (eds.). 2006. Island Press, Washington, D.C., USA.

Belwood, J.J. 1998. In Ohio's Backyard: Bats. Ohio Biological Survey Backyard Series No. 1. x + 196 pp.

Belwood, J.J., and J.H. Fullard. 1984. Echolocation and foraging behavior in the Hawaiian hoary bat, *Lasiurus cinereus semotus. Canadian Journal of Zoology* 62: 2113-2120.

Bennett, V.J., D.W. Sparks, and P.A. Zollner. 2013. Modeling the indirect effects of road networks on the foraging activities of bats. *Landscape Ecology* 28: 979-991.

Bergeson, S.M., T.C. Carter, and M.D. Whitby. 2013. Partitioning of foraging resources between sympatric Indiana and little brown bats. *Journal of Mammalogy* 94(6): 1311-1320.

Blake, D., A.M. Hutson, P.A. Racey, J. Rydell, and J.R. Speakman. 1994. Use of lamplit roads by foraging bats in southern England. *Journal of Zoology, London* 234: 453-462.

Bogdanowicz, W., M.B. Fenton, and K. Daleszczyk, 1999. The relationship between echolocation calls, morphology and diet in insectivorous bats. *Journal of. Zoology, London* 247: 381–393.

Boldogh, S., D. Dobrosi, and P. Samu. 2007. The effects of illumination of buildings on house-dwelling bats and its conservation consequences. Acta Chiroptera 9: 527-534.

Bortle, J.E. 2001. Introducing the Bortle Dark-Sky Scale. *Sky and Telescope*: 126-129.

Bowles, J.B., P.D. Heideman, and K.R. Erickson. 1990. Observations on six species of free-tailed bats (Molossidae) from Yucatan, Mexico. *Southwestern Naturalist* 35: 151-157.

Boyles, J. G., P.M. Cryan, G.F. McCracken, and T.H. Kunz. 2011. Economic importance of bats in agriculture. *Science*, 332(6025): 41-42.

Brack, V., Jr. 2006. Autumn activity of *Myotis sodalis* (Indiana bat) in Bland County, Virginia. *Northeastern Naturalist* 13(3): 421-434.

Brack, V., Jr. 2007. Temperatures and locations used by hibernating bats, including *Myotis sodalis* (Indiana bat), in a limestone mine: implications for conservation and management. *Environmental Management* 40: 739-746.

Brack, V., Jr., and J.A. Duffey. 2006. Bats of Ravenna Training and Logistics Site, Portage and Trumbull Counties, Ohio. *Ohio Journal of Science* 106(5): 186-190.

Brigham, R.M. 1991. Flexibility in foraging and roosting behavior by the Big Brown Bat (Eptesicus fuscus). *Canadian Journal of Zoology* 69: 117-121.

Brigham, R. M., E.K.V. Kalko, G. Jones, S. Parsons, and H.J.G.A. Limpens (eds.) 2004. *Bat Echolocation Research: tools, techniques and analysis*. Bat Conservation International. Austin, Texas.

The British Astronomical Association. Commission for dark skies. Retrieved on March 11, 2015 from http://www.britastro.org/dark-skies/index.html.

Broders, H.G., G.J.Forbes, S. Woodley, and I.D. Thompson. 2006. Range extent and stand selection for roosting and foraging in forest-dwelling Northern Long-eared Bats and Little Brown Bats in the Greater Fundy Ecosystem, New Brunswick. *Journal of Wildlife Management* 70(5): 1174-1184.

Buchanan, B.W. 1993. Effects of enhanced lighting on the behaviour of nocturnal frogs. *Animal Behavior* 45: 893-899.

Buchler, E.R., and S.B. Childs. 1982. Use of the post-sunset glow as an orientation cue by big brown bats (*Eptesicus fuscus*). *Journal of Mammalogy* 63: 243-247.

Campbell, L.A., J.G. Hallet, and M.A. O'Connell. 1996. Conservation of bats in managed forests: use of roosts by Lasionycteris noctivagans. *Journal of Mammalogy* 77(4): 976-984.

Carter, T. C. 2006. Indiana bats in the Midwest: the importance of hydric habitats. *Journal of Wildlife Management* 70(5): 1185-1190.

Carter, T.C., and G.A. Feldhamer. 2005. Roost tree use by maternity colonies of Indiana bats and northern long-eared bats in southern Illinois. *Forest Ecology and Management* 219: 259-268.

Catto, C.M.C. 1993. *Aspects of the ecology and behavior of the serotine bat* (Eptesicus serotinus). Ph.D. thesis, University of Aberdeen, Scotland.

Chalkias, C., M. Petrakis, B. Psiloglou, and M. Lianou. 2006. Modelling of light pollution in suburban areas using remotely sensed imagery and GIS. *Journal of Environmental Management* 79(1): 57-63.

Chepesiuk, R. 2009. Missing the dark: Health effects of light pollution. *Environmental Health Perspectives* 117(1): 21-27.

Childs, S.B., and E.R. Buchler. 1981. Perception of simulated stars by *Eptesicus fuscus* (Vespertilionidae): A potential navigational mechanism. *Animal Behaviour* 29(4): 1028-1035.

Cinzano, P., F. Falchi, and C.D. Elvidge. 2001. The first World Atlas of the artificial night sky brightness. *Monthly Notices of the Royal Astronomical Society* 328: 689-707.

Cinzano, P., F. Falchi, C.D. Elvidge, and K.E. Baugh. 2000. The artificial night sky brightness mapped from DMSP satellite Operational Linescan System measurements. *Monthly Notices of the Royal Astronomical Society* 318(3): 641-657.

Clawson, R.L. 1987. Indiana bats: down for the count. Endangered Species Technical Bulletin 22: 9-11.

Clevenger, A. P., J. Wierzchowski, B. Chruszcz, and K. Gunson. 2002. GIS-generated, expert-based models for identifying wildlife habitat linkages and planning mitigation passages. *Conservation biology*, 16(2): 503-514.

Cook, E.A., and J.E. Gardner. 1990. Describing Indiana bat (*Myotis sodalis*) habitats in Illinois using a GIS. Pp. 116-117 *in* Program of the 52nd Midwest Fish and Wildlife Conference, Minneapolis, Minnesota.

Cook, E.A., J.E. Gardner, J.D. Gardner, and J.E. Hofmann. 1987. Foraging range and habitat utilization of male *Myotis sodalis* in Illinois determined by radio telemetry and computer analysis techniques. Bat Research News 28: 34.

Cryan, P.M., M.A. Bogan, and G.M. Yanega. 2001. Roosting habits of four bat species in the Black Hills of South Dakota. *Acta Chiropterologica* 3(1): 43-52.

Dade, M.C., N. Pauli, and N.J. Mitchell. 2014. Mapping a new future: using spatial multiple criteria analysis to identify novel habitats for assisted colonization of endangered species. *Animal Conservation* 17(S1): 4-17.

Darrow, R., (ed.). 1999. *Kent, Ohio: the dynamic decades*. Kent, Ohio, United States: Kent Historical Society. p.1.

Deibel, S. 2012. Site 1 Report: Battaglia. Center for Ecology and Natural Resource Sustainability, Kent State University, Kent, Ohio.

Dettmers, R., and J. Bart. 1999. A GIS modeling method applied to predicting forest songbird habitat. *Ecological applications*, 9(1): 152-163.

Downs, N.C., V. Beaton, J. Guest, J. Polanski, S.L. Robinson, and P.A. Racey. 2003. The effects of illuminating the roost entrance on the emergence behavior of *Pipistrellus pygmaeus*. *Biological Conservation* 111: 247-252.

Dunning, D.C., L. Acharya, C.B. Merriman, and L. Dal Ferro. 1992. Interactions between bats and arctiid moths. *Canadian Journal of Zoology* 70: 2218-2223.

Eisenbeis, G., and A. Hänel. Chapter 15: Light pollution and the impact of artificial night lighting on insects *In* Ecology of Cities and Towns, (McDonnell, M. J.;, Hahs, A. H., Breuste, J. H., eds.), Cambridge University Press, Cambridge. 2009, p. 243-263.

Eisenbeis, G., and F. Hassel. 2000. Attraction of nocturnal insects to streetlights: a study of municipal lighting systems in a rural area of Rheinhessen (Germany). Natur und Landschaft 75(4): 145-156.

Ellison, L.E., T.J. O'Shea, M.A. Bogan, A.L. Everette, and D.M. Schneider. 2003. Existing data on colonies of bats in the United States: summary and analysis of the U.S. Geological Survey's bat population database. *U.S. Geological Survey Technical Report* 0003: 127-237.

Elmore, L.W., D.A. Miller, F.J. Vilella. 2005. Foraging area size and habitat use by red bats (*Lasiurus borealis*) in an intensively managed pine landscape in Mississippi. *The American Midland Naturalist* 153(2): 405-417.

Erkert, H.G. 1982. Ecological aspects of bat activity rhythms. Pages 201-242 in T.H. Kunz (ed.), *Ecology of bats*. Plenum Press, New York.

Erkert, H.G. 2000. Bats—flying nocturnal mammals. In *Activity Patterns in Small Mammals* (pp. 253-272). Springer Berlin Heidelberg.

Esteban, T.R.E. 2015. Multiscale habitat preferences and selectivity in bats across urban to rural landscapes. Conservation Biology, School of Biology, Faculty of Biological

Science, University of Leeds, UK, LS2 9JT. Available from https://taniaroseesteban.files.wordpress.com/2014/12/research-dissertation-tania-esteban.pdf.

Falchi, F., P. Cinzano, C.D. Elvidge, D.M. Keith, and A. Haim. 2011. Limiting the impact of light pollution on human health, environment and stellar visibility. *Journal of environmental management* 92(10): 2714-2722.

Feldhamer, G.A., T.C. Carter, and J.O. Whitaker, Jr. 2009. Prey consumed by eight species of insectivorous bats from southern Illinois. *The American Midland Naturalist* 162: 43-51.

Feng, A. S., P.M. Narins, C.H. Xu, W.Y. Lin, Z.L. Yu, Q. Qiu, Z.M. Xu, and J.X. Shen. 2006. Ultrasonic communication in frogs. *Nature*, 440(7082): 333-336.

Fenton, M. B. 1988. Variation in foraging strategies in five species of insectivorous bats – implications for echolocation call design. Pp. 607-611*In* Animal sonar: processes and performance (P. E. Nachtigall and P. W. B. Moore, eds.). Plenum Press, New York.

Fenton, M. B. 1997. Science and the conservation of bats. *Journal of Mammalogy* 78: 1–14.

Fenton, M. B., and G.P. Bell. 1981. Recognition of species of insectivorous bats by their echolocation calls. *Journal of Mammalogy* 62: 233–243.

Fenton, M.B., and G.K. Morris. 1976. Opportunistic feeding by desert bats (*Myotis* spp.). *Canadian Journal of Zoology* 54: 526-530.

Ford, W.M., E.R. Britzke, C.A. Dobony, J.L. Rodrigue, and J.B. Johnson. 2011. Patterns of acoustical activity of bats prior to and following White Nose Syndrome occurrence. *Journal of Fish and Wildlife Management* 2(2): 125-134.

Ford, W. M., M.A. Menzel, J.L. Rodrigue, J.M. Menzel, and J.B. Johnson. 2005. Relating bat species presence to simple habitat measures in a central Appalachian forest. *Biological Conservation* 126(4): 528-539.

Foster, R.G., and I. Provencio. 1999. The regulation of vertebrae biological clocks by light. Pages 223-243 in S.N. Archer, M.B.A. Djamgoz, E.R. Loew, J. C. Partridge, and S. Vallerga (eds.), *Adaptive mechanisms in the ecology of vision*. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Foxley, T. 2015. Guide to analyzing full spectrum/frequency division bat calls with Audacity (v.2.0.5). Retrieved on August 1, 2015 from https://batsofbelize.wordpress.com/resources/.

Francl, K.E., W.M. Ford, D.W. Sparks, and V.B. Brack, Jr. 2012. Capture and reproductive trends in summer bat communities in West Virginia: Assessing the impact of White Nose Syndrome. *Journal of Fish and Wildlife Management* 3(1): 33-42.

Frank, K.D. 1988. Impact of outdoor lighting on moths: an assessment. *Journal of the Lepidopterists' Society* 42: 63-93.

Fredmonsky, M. Mayor: Destination Kent, College Town USA. *Kent Patch*, March 2, 2013.

Frick, W.F., J.F. Pollock, A.C. Hicks, K.E. Langwig, D.S. Reynolds, G.G. Turner, C.M. Butchkoski, and T.H. Kunz. 2010. An emerging disease causes regional population collapse of a common North American bat species. *Science* 329: 679-682.

Fullard, J.H. 2001. Auditory sensitivity of Hawaiian moths (Lepidoptera: Noctuidae) and selective predation by the Hawaiian hoary bat (Chiroptera: *Lasiurus cinereus semotus*). *Proceedings of the Royal Society of London. Series B, Biological Sciences* 268: 1375-1380.

Furlonger, C.L., H.J. Dewar, and M.B. Fenton. 1987. Habitat use by foraging insectivorous bats. *Canadian Journal of Zoology* 65(2): 284-288.

Gaisler, J., J. Zukal, Z. Rehak, and M. Homolka. 1998. Habitat preference and flight activity of bats in a city. *Journal of Zoology, London* 244: 439-445.

Gardner, J. E., and E.A. Cook. 2002. Seasonal and geographic distribution and quantification of potential summer habitat. *In* The Indiana bat: biology and management of an endangered species (A. Kurta and J. Kennedy, eds.). Bat Conservation International, Austin, Texas, 9-20.

Gardner, J.E., J.D. Garner, and J.E. Hofmann. 1991. Summary of *Myotis sodalis* summer habitat studies in Illinois: with recommendations for impact assessment. Unpublished report, Illinois Natural History Survey, Champaign, Illinois.

Gardner, J.E., J.E. Hofmann, and J.D. Garner. 1987. Discovery of Indiana bat (*Myotis sodalis*) maternity roost trees in western Illinois. Transactions of the Illinois State Academy of Science, Supplement 80: 59.

Gardner, J.E., K.J. Hunter, and P.I. Lusinski. 1990. Use of a GIS for managing the habitats of endangered bat species on the Shawnee National Forest in southern Illinois. Page 338 *in* Program of the 52nd Midwest Fish and Wildlife Conference, Minneapolis, Minnesota.

Gaston, K. J., J. Bennie, T.W. Davies, and J. Hopkins. 2013. The ecological impacts of nighttime light pollution: a mechanistic appraisal. *Biological reviews* 88(4): 912-927.

Gaston, K.J., T.W. Davies, J. Bennie, and J. Hopkins. 2012. Reducing the ecological consequences of night-time light pollution: options and developments. *Journal of Applied Ecology* 49: 1256-1266.

Geggie, J.F., and M.B. Fenton. 1985. A comparison of foraging by *Eptesicus fuscus* (Chiroptera: Vespertilionidae) in urban and rural environments. *Canadian Journal of Zoology* 63: 263-266.

Gehrt, S. D., and J.E. Chelsvig. 2003. Bat activity in an urban landscape: patterns at the landscape and microhabitat scale. *Ecological Applications* 13(4): 939-950.

Gilbert, B.S., and S. Boutin. 1991. Effect of moonlight on winter activity of snowshoe hares. *Arctic and Alpine Research* 23: 61-65.

Gliwicz, Z.M. 1986. A lunar cycle in zooplankton. *Ecology* 67: 883-897.

Gould, E. 1978. Opportunistic feeding by tropical bats. *Biotropica* 10: 75-76.

Graham, R.E. 1966. Observations on the roosting habits of the big-eared bat, *Plecotus townsendii*, in California limestone caves. *Cave Notes* 8: 17-22.

Graham, T. L., and P.F. Hudak. 2011. Potential hazards of wind energy for rare, threatened, and endangered birds and bats in Texas. *International Journal of Environmental Research*, 5(4): 917-922.

Griffin, D. R., F. A. Webster, and C.R. Michael. 1960. The echolocation of flying insects by bats. *Animal Behavior* 8: 141–154.

Grilo, C., D. Reto, J. Filipe, F. Ascensão, and E. Revilla. 2014. Understanding the mechanisms behind road effects: linking occurrence with road mortality in owls. *Animal Conservation* 17(6): 555-564.

Grinnell, H.W. 1918. A synopsis of the bats of California. *University of California Publications in Zoology* 17: 223-404.

Gullan, P.J., and P.S. Cranston. *The insects: an outline of entomology, fifth edition*. 2014. John Wiley and Sons, Ltd., The Atrium, Southern Gate, Chinchester, West Sussex, PO198SQ, UK.

Gwinner, E. 1986. *Circannual rhythms: endogenous annual clocks in the organization of seasonal processes*. Springer-Verlag, Berlin.

Haceková, Z., B. Lehotská, and J. Ružičková. 2014. The influence of landscape structure to the activity of bats. *Studia Universitatis" Vasile Goldis" Arad. Seria Stiintele Vietii (Life Sciences Series)* 24(2): 257.

Haffner, M., and H.P. Stutz. 1985/1986. Abundance of *Pipistrellus pipistrellus* and *Pipistrellus kuhlii* foraging at street-lamps. *Myotis* 23/24: 167-172.

Hale, J. D., A.J. Fairbass, T.J. Matthews, G. Davies, and J.P. Sadler. 2015. The ecological impact of city lighting scenarios: exploring gap crossing thresholds for urban bats. *Global Change Biology* 21: 2467-2478.

Hartley, R., and K. Hustler. 1993. A less-than-annual breeding cycle in a pair of African bat hawks *Machaeramphus alcinus*. *Ibis* 135: 456-458.

Hecker, K.R., and R.M. Brigham. 1999. Does moonlight change vertical stratification of activity by forest-dwelling insectivorous bats? *Journal of Mammalogy* 80(4): 1196-2101.

Henry, M., D.W. Thomas, R. Vaudry, and M. Carrier. 2002. Foraging distances and home range of pregnant and lactating little brown bats (*Myotis lucifugus*). *Journal of Mammalogy* 83(3): 767-774.

Herrera, J.M., P. Costa, D. Medinas, J.T. Marques, and A. Mira. 2015. Community composition and activity of insectivorous bats in Mediterranean olive farms. The Zoological Society of London, Animal Conservation 18(4): 1-10.

Hickey, M.B.C., and M.B. Fenton. 1990. Foraging by red bats (*Lasiurus borealis*): do intraspecific chases mean territoriality? *Canadian Journal of Zoology* 68: 2477-2482.

Hill, D. 1990. *The impact of noise and artificial light on waterfowl behaviour: a review and synthesis of the available literature*. Norfolk, United Kingdom: British Trust for Ornithology Report No. 61.

Hockicko, P., and S. Jurečka. 2007. Frequency analysis of sounds of animals. New Trends in Physics. Department of Physics, FEEC, Brno University of Technology, Brno, Czech Republic

Hölker, F., C. Wolter, E.K. Perkin, and K. Tockner. 2010. Light pollution as a biodiversity threat. *Trends in Ecology and Evolution* 25(12): 681-682.

Homer, C.G., Dewitz, J.A., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N.D., Wickham, J.D., and Megown, K. 2015. Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. *Photogrammetric Engineering and Remote Sensing*, v. 81, no. 5, p. 345-354.

Humboldt State University. 2011. Echolocation call characteristics of eastern US bats. Unpublished data. Available from http://www.sonobat.com/download/EasternUS_Acoustic_Table_Mar2011.pdf.

Hutchinson, J.T., and M.J. Lacki. 1991. *Foraging behavior and habitat use of red bats in mixed mesophytic forests of the Cumberland Plateau, Kentucky*. P. 171-177 in J.W. Stringer and D.L. Loftis (eds.). 12th Central Hardwood Forest Conference, U.S. Forest Service Southeast Experiment Station, Asheville, North Carolina.

Hutson, A.M., S.P. Mickleburgh, and P.A. Racey. 2001. *Microchiropteran bats: global status survey and conservation action plan*. IUCN, Gland, Switzerland.

International Union for Conservation of Nature (IUCN) Red List of Threatened Species. 2014. Version 2014.3. <www.iucnredlist.org>. Downloaded on 09 April 2015.

Jaberg, C., and A. Guisan. 2001. Modelling the distribution of bats in relation to landscape structure in a temperate mountain environment. *Journal of Applied Ecology*, 38(6): 1169-1181.

Jakle, J.A. 2001. *City lights: Illuminating the American night (landscapes of the night)*. John Hopkins University Press, Baltimore, MD, USA.

Jensen, J.R. and R.R. Jensen. 2013. Introductory Geographic Information Systems. Pearson Education, Inc., Glenview, IL, USA.

Jensen, M. E. and Miller, L. A. 1999. Echolocation signals of the bat *Eptesicus serotinus* recorded using a vertical microphone array: effect of flight altitude on searching signals. *Behavioral Ecology and Sociobiology* 47: 60–69.

Jensen, J.R., A. Saalfeld, F. Broome, D. Cowen, K. Price, D. Ramsey, L. Lapine, and E.L. Usery. 2005. Chapter 2: Spatial data acquisition and integration *In* A Research Agenda for Geographic Information Science. Boca Raton, CRC Press, p. 17-60.

Johnson, C. J., D.R. Seip, and M.S. Boyce. 2004. A quantitative approach to conservation planning: using resource selection functions to map the distribution of mountain caribou at multiple spatial scales. *Journal of Applied Ecology*, 41(2): 238-251.

Jones, G. 1999. Scaling of echolocation call parameters in bats. *Journal of .Experimental Biology* 202: 3359–3367.

Jones, G., P.L. Duvergé, and R.D. Ransome. 1995. Conservation biology of an endangered species: field studies of greater horseshoe bats. Pages 309-324 in P.A. Racey and S.M Swift (eds.), *Ecology, evolution and behaviour of bats*. Symposia of the Zoological Society of London No. 67. Clarendon Press, Oxford.

Jones, G., T. Gordon, and J. Nightingale. 1992. Sex and age differences in the echolocation calls of the lesser horseshoe bat, *Rhinolophus hipposideros*. *Mammalia* 56: 189–193.

Jones, G., D.S. Jacobs, T.H. Kunz, M.R. Willig, and P.A. Racey. 2009. Carpe noctum: the importance of bats as bioindicators. *Endangered Species Research* 8: 93-115.

Jones, G., and T. Kokurewicz. 1994. Sex and age variation in echolocation calls and flight morphology of Daubenton's bats *Myotis daubentonii*. *Mammalia* 58: 41–50.

Jones, G., and M. Morton. 1992. Radio-tracking studies on habitat use by greater horseshoe bats (*Rhinolophus ferrumequinum*). Pages 521-537 in I. G. Priede and S.M. Swift (eds.), *Wildlife telemetry: remote monitoring and tracking of animals*. Ellis Horwood Ltd., New York.

Jones, G., and J. Rydell. 2003. Attack and defense: interactions between echolocating bats and their insect prey. Pages 301-345 in T.H. Kunz and M.B. Fenton (eds.), *Bat ecology*. University of Chicago Press, Chicago.

Jones, J. 2000. Impact of lighting on bats. Available from www.lbp.org.uk/downloads/Publications/Management/lighting_and_bats.pdf.

Jones, J., and C.M. Francis. 2003. The effects of light characteristics on avian mortality at lighthouses. *Journal of Avian Biology* 34(4): 328-333.

Jones, K. E., A. Purvis, and J.L. Gittleman. 2003. Biological correlates of extinction risk in bats. *The American Naturalist* 161(4): 601-614.

Jonker, M. N., W. F. D. Boer, R.H. Kurvers, and J.J. Dekker. 2010. Foraging and public information use in common pipistrelle bats (*Pipistrellus pipistrellus*): a field experiment. *Acta Chiropterologica*, 12(1): 197-203.

Kalka, M. B., A.R. Smith, and E.K. Kalko. 2008. Bats limit arthropods and herbivory in a tropical forest. *Science*, 320(5872): 71-71.

Kalko, E. K. V., and H.U. Schnitzler. 1993. Plasticity in echolocation signals of European pipistrelle bats in search flight – implications for habitat use and prey detection. *Behavioral Ecology and Sociobiology* 33: 415–428.

Kandel, K., F. Huettmann, M.K. Suwal, G.R. Regmi, V. Nijman, K.A.I. Nekaris, S.T. Lama, A. Thapa, H.P. Sharma, and T.R. Subedi. 2015. Rapid multi-nation distribution assessment of a charismatic conservation species using open access ensemble model GIS predictions: Red panda (*Ailurus fulgens*) in the Hindu-Kush Himalaya region. *Biological Conservation* 181: 150-161.

Kapteyn, K. 1993. Intra-specific variation in echolocation of vespertilionid bats, and its implications for identification. Pp. 45-57 *In* Proceedings of the first European bat detector workshop (K.Kapteyn, ed.,). The Netherlands Bat Research Foundation, Amsterdam, The Netherlands.

Keleher, S., and A. Sara. 1996. Guano: bats' gift to gardeners. *Bats* 14: 15-17.

Kenney, J.F., and E.S. Keeping. 1962. *Mathematics of statistics, part 1*. Third edition. Van Nostrand Reinhold, Princeton, NJ.

Kent State University. 2012. Kent state gets green light for historic campus transformation. Kent State University Website (www.kent.edu/news). September 12, 2012.

Kick, S.A. 1982. Target-detection by the echolocating bat, *Eptesicus fuscus*. *Journal of Comparative Physiology A* 145: 431-435.

Kniowsky, A., S. Gehrt, and W.M. Ford. 2014. Roosting and foraging social structure of the endangered Indiana bat (*Myotis sodalis*). *PLoS ONE* 9(5): e96937.

Kolligs, D. 2000. Ecological effects of artificial light sources on nocturnally active insects, in particular on moths (Lepidoptera). *Faunistisch-Ökologische Mitteilungen Suppl* 28: 1-136.

Kotler, B.P. 1984. Effects of illumination on the rate of resource harvesting in a community of desert rodents. *American Midland Naturalist* 111: 131-138.

Kronwitter, F. 1988. Population structure, habitat use and activity patterns of the noctule bat *Nyctalus noctula* Schreb., 1774 (Chiroptera: Vespertilionidae) revealed by radio-tracking. *Myotis* 26: 23-85.

Kuijper, D.P.J., J. Schut, D. van Dullemen, H. Toorman, N. Goossens, J. Ouwehand, and H. J. G. A. Limpens. 2008. Experimental evidence of light disturbance along commuting routes of pond bats (*Myotis dasycneme*). *Lutra* 51(1): 37-49.

Kunz, T. H. 1982. Roosting ecology of bats. In *Ecology of bats.* pp. 1-55. Springer US.

Kyba, C.C.M., T. Ruhtz, J. Fischer, and F. Hölker. 2011. Cloud coverage acts as an amplifier for ecological light pollution in urban ecosystems. *PLoS ONE* 6(3): e17307.

Kyba, C.C.M., K.P. Tong, J. Bennie, I. Birriel, J.J. Birriel, A. Cool, A. Danielsen, T.W. Davies, P.N. den Outer, W. Edwards, R. Ehlert, F. Falchi, J. Fischer, A. Giacomelli, F. Giubbilini, M. Haaima, C. Hesse, G. Heygster, F. Hölker, R. Inger, L.J. Jensen, H.U. Kuechly, J. Kuehn, P. Langill, D.E. Lolkema, M. Nagy, M. Nievas, N. Ochi, E. Popow, T. Posch, J. Puschnig, T. Ruhtz, W. Schmidt, R. Schwartz, A. Schwope, H. Spoelstra, A. Tekatch, M. Trueblood, C.E. Walker, M. Weber, D.L. Welch, J. Zamorano, and K.J. Gaston. 2015. Worldwide variations in artificial skyglow. Scientific Reports 5: Article 8409.

Kyba, C.C.M., J.M. Wagner, H.U. Kuechly, C.E. Walker, C.D. Elvidge, F. Falchi, T. Ruhtz, J. Fischer, and F. Hölker. 2013. Citizen science provides valuable data for monitoring global night sky luminance. Scientific Reports 3: Article 1835.

Lacoeuilhe, A., N. Machon, J.-F. Julien, A. Le Bocq, and C. Kerbiriou. 2014. The influence of low intensities of light pollution on bat communities in a semi-natural context. *PLoS ONE* 9(10): e103042.

Le Corre, M., A. Ollivier, S. Ribes, and P. Jouventin. 2002. Light-induced mortality of petrels: a 4-year study from Réunion Island (Indian Ocean). *Biological Conservation* 105(1): 93-102.

Leonard, M.L., and M.B. Fenton. 1983. Habitat use by spotted bats (*Euderma maculatum*, Chiroptera: Vespertilionidae): roosting and foraging behaviour. *Canadian Journal of Zoology* 61: 1487-1491.

Lewanzik, D., and C.C. Voigt. Effects of artificial light at night on obligatory nocturnal mammals. 97th ESA Annual Convention, August 2012. Portland, Oregon. Unpublished Conference Paper. Accessed on July 12, 2015 from https://www.researchgate.net/publication/267292312_Effects_of_artificial_light_at_night_on_obligatory_nocturnal_mammals.

Limpens, H.J.G.A. 2002. Field identification: Using bat detectors to identify species. *In* Bat Echolocation Research: tools, techniques and analysis (Brigham, R.M. et al., eds), Bat Conservation International, Texas.

Lo, C.P., and A.K.W. Yeung. 2007. *Concepts and Techniques in Geographic Information Systems*. Upper Saddle River, Pearson Prentice-Hall, Inc., p.532.

Locke, G. 2004. Demographic profile (http://www.kentohio.org/reports/BICENTENNTIAL.pdf). *Kent Bicentennial Plan*, City of Kent, Ohio. Pp 13-36.

Losey, J.E., and M. Vaughan. 2006. The economic value of ecological services provided by insects. *Bioscience* 56(4): 311-323.

Losos, J.B., K.A. Mason, and S.R. Singer. 2008. *Biology*. Eighth edition. McGraw-Hill, New York, NY.

Lyytimäki, J. 2013. Nature's nocturnal services: Light pollution as a non-recognised challenge for ecosystem services research and management. *Ecosystem Services* 3: 44-48.

Masters, W. M., K.A.S. Raver, and K.A. Kazial. 1995. Sonar signals of big brown bats, *Eptesicus fuscus*, contain information about individual identity, age and family affiliation. *Animal Behaviour* 50: 1243–1260.

Matzner, S., T. Fu, H. Ren, Z.D. Deng, Y. Sun, and T. Carlson. 2011. Operational performance analysis of passive acoustic monitoring for killer whales. In *OCEANS 2011* pp. 1-6. IEEE.

McCracken, G.F. 1996. Bats aloft: a study of high-altitude feeding. *Bats* 14(3):7-10

McGuire, L.P., and M.B. Fenton. 2010. Hitting the wall: Light affects the obstacle avoidance ability of free-flying little brown bats (*Myotis lucifugus*). *Acta Chiropterologica* 12(1): 247-250.

Menzel, J. M., M.A. Menzel, J.C. Kilgo, W.M. Ford, J.W. Edwards, and G.F. McCracken. 2005. Effect of habitat and foraging height on bat activity in the coastal plain of South Carolina. *Journal of Wildlife Management* 69(1): 235-245.

Minnaar, C., J.G. Boyles, I.A. Minnaar, C.L. Sole, and A.E. Mckechnie. 2014. Stacking the odds: light pollution may shift the balance in an ancient predator-prey arms race. *Journal of Applied Ecology* 52(2): 522-531.

Mohr, C.E. 1952. A survey of bat banding in North America, 1932-1951. National Speleological Society Bulletin 14: 3-13.

Mohr, C.E. 1953. Possible causes of an apparent decline in wintering populations of cave bats. National Speleological Society News 11: 4-5.

Murray, S.W., and A. Kurta. 2004. Nocturnal activity of the endangered Indiana bat (*Myotis sodalis*). *The Zoological Society of London* 262: 197-206.

Nakano, R., N. Skals, T. Takanashi, A. Surlykke, T. Koike, K. Yoshida, H. Maruyama, S. Tatsuki, and Y. Ishikawa. 2008. Moths produce extremely quiet ultrasonic courtship songs by rubbing specialized scales. *Proceedings of the National Academy of Sciences* 105(33): 11812-11817.

National Oceanic and Atmospheric Association. 2012. Our Earth, at night: Suomi NPP satellite offers new, unprecedented views of our planet in amazing detail. Retrieved on March 3, 2015 from http://www.noaa.gov/features/02_monitoring/earthnightlights_images.html.

Navarro, D. 2014. Biology Undergraduate Student at Kent State University. Personal communication.

Negraeff, O.E., and R.M. Brigham. 1995. The influence of moonlight on the activity of little brown bats (*Myotis lucifugus*). *Zeitschrift für Säugetierkunde* 60: 330-336.

Neuweiler, G., and M. B. Fenton .1988. Behaviour and foraging ecology of echolocating bats. Pp. 535-549 *In* Animal sonar: processes and performance (P. E. Nachtigall, and P. W. B. Moore, eds.).Plenum Press. New York.

Nichols, J. Downtown Kent, Ohio, rising Phoenix-like as city, KSU and business coalesce. *The Plain Dealer* November 26, 2009.

Norberg, U.M., and J.M.V. Rayner. 1987. Ecological morphology and flight in bats (Mammalia; Chiroptera): wing adaptations, flight performance, foraging strategy and echolocation. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 316: 335-427.

Nørum, U., S. Brinkløv, and A. Surlykke. 2012. New model for gain control of signal intensity to object distance in echolocating bats. *The Journal of Experimental Biology* 215: 3045-3054.

Norris, J.L. 2014a. Ohio Division of Wildlife. Mobile Bat Acoustic Survey 2014 Report.

Norris, J.L. 2014b. Wildlife Research Biologist at Ohio Department of Natural Resources Division of Wildlife. Personal communication.

Obrist, M. K. 1995. Flexible bat echolocation – the influence of individual, habitat and conspecifics on sonar signal design. *Behavioral Ecology and Sociobiology* 36: 207–219.

O'Farrell, M.J., and W.L. Gannon. 1999. A comparison of acoustic versus capture techniques for the inventory of bats. Journal of Mammalogy 80(1): 24-30.

Ogden, L.J.E. 1996. Collision course: the hazards of lighted structures and windows to migrating birds. Toronto, Canada: World Wildlife Fund Canada and Fatal Light Awareness Program.

Ohio Department of Natural Resources: Division of Wildlife. Wildlife that are considered to be endangered, threatened, species of concern, special interest, extirpated, or extinct in Ohio. August 2014. Publication 5356. PDF obtained from http://wildlife.ohiodnr.gov.

O'Shea, T.J., M.A. Bogan, and L.E. Ellison. 2003. Monitoring trends in bat populations of the United States and territories: status of the science and recommendations for the future. United States Geological Survey Staff Published Research, available on http://digitalcommons.unl.edu/usgsstaffpub.

Parsons, S., and G. Jones. 2000. Acoustic identification of twelve species of echolocating bat by discriminant function analysis and artificial neural networks. *The Journal of Experimental Biology* 203: 2641-2656.

Perdicas, M. 2015. Park Biologist at Summit Metro Parks. Personal communication.

Perkin, E.K., F. Hölker, and K. Tockner. 2014. The effects of artificial lighting on adult aquatic and terrestrial insects. *Freshwater Biology* 59: 368-377.

Polak, T., C. Korine, S. Yair, and M.W. Holderied. 2011. Differential effects of artificial lighting on flight and foraging behavior of two sympatric bat species in a desert. *Journal of Zoology* 285: 21-27.

Rainho, A., A.M. Augusto, and J.M. Palmeirim. 2010. Influence of vegetation clutter on the capacity of ground foraging bats to capture prey. *Journal of Applied Ecology*, 47(4): 850-858.

Rand, A.S., M.E. Bridarolli, L. Dries, and M.J. Ryan. 1997. Light levels influence female choice in Tungara frogs: predation risk assessment? *Copeia* 1997: 447–50.

Rich, C. and T. Longcore. Introduction. In *Ecological consequences of Artificial Nighttime Lighting*, ch.1. Rich, C. and T. Longcore (eds.). 2006. Island Press, Washington, D.C., USA.

Riegel, K. W. 1973. Light Pollution Outdoor lighting is a growing threat to astronomy. *Science* 179(4080): 1285-1291.

Robbins, L.W., K.L. Murray, and P.M. McKenzie. 2008. Evaluating the effectiveness of the standard mist-netting protocol for the endangered Indiana bat (*Myotis sodalis*). *Northeastern Naturalist* 15(2): 275-282.

Rodhouse, T. J., K.T. Vierling, and K.M. Irvine. 2011. A practical sampling design for acoustic surveys of bats. *The Journal of Wildlife Management*, 75(5): 1094-1102.

Rydell, J. 1990. Behavioural variation in echolocation pulses of the northern bat, *Eptisicus nilssoni*. *Ethology* 85: 103–113.

Rydell, J. 1991. Seasonal use of illuminated areas by foraging northern bats *Eptesicus nilssoni*. *Holarctic Ecology* 14: 203-207.

Rydell, J. 1992. Exploitation of insects around streetlamps by bats in Sweden. *Functional Ecology* 6: 744-750.

Rydell, J. Bats and their insect prey at streetlights. In *Ecological consequences of Artificial Nighttime Lighting*, ch.3. Rich, C. and T. Longcore (eds.). 2006. Island Press, Washington, D.C., USA.

Rydell, J., Entwistle, A., and P.A. Racey. 1996. Timing of foraging flights of three species of bats in relation to insect activity and predation risk. *Oikos* 76(2): 243-252.

Rydell, J., and P.A. Racey. 1995. Street lamps and the feeding ecology of insectivorous bats. Pages 291-307 in P.A. Racey and S.M. Swift (eds.), *Ecology, evolution and behavior of bats*. Symposia of the Zoological Society of London No. 67. Clarendon Press, Oxford.

Rydell, J., and J.R. Speakman. 1995. Evolution of nocturnality in bats: potential competitors and predators during their early history. *Biological Journal of the Linnean Society*, 54(2): 183-191.

Sales, G., and D. Pye. 1974. *Ultrasonic communication in animals*. Springer Science and Business Media.

Sales G.D. 1972. Ultrasound and mating behavior in rodents with some observations on other behavioural situations. *Journal of Zoology, London* 168: 149–164.

Santos, C. D., A.C. Miranda, J.P. Granadeiro, P.M. Lourenço, S. Saraiva, and J.M. Palmeirim. 2010. Effects of artificial illumination on the nocturnal foraging of waders. *Acta Oecologica* 36(2): 166-172.

Santos, X., J.C. Brito, N. Sillero, J.M. Pleguezuelos, G.A. Llorente, S. Fahd, and X. Parellada. 2006. Inferring habitat-suitability areas with ecological modelling techniques and GIS: a contribution to assess the conservation status of Vipera latastei. *Biological Conservation*, 130(3): 416-425.

Schnitzler, H.-U., E. Kalko, L. Miller, and A. Surlykke. 1987. The echolocation and hunting behavior of the bat, *Pipistrellus kuli*. *Journal of Comparative Physiology A* 161: 267-274.

Schoeman, C. 2015. Light pollution at stadiums favors urban exploiter bats. The Zoological Society of London, Animal Conservation: 1-15.

Schwartz, A., and R.W. Henderson. 1991. *Amphibians and reptiles of the West Indies: descriptions, distributions, and natural history*. Gainesville, FL: University of Florida Press.

Shiel, C.B., and J.S. Fairley. 1999. Evening emergence of two nursery colonies of Leisler's bat (*Nyctalus leiseri*) in Ireland. *Journal of Zoology* 247(4): 439-447.

Slabbekoorn, H., and M. Peet. 2003. Birds sing at a higher pitch in urban noise. *Nature London* 424: 267.

Smith F. G. 1979. International Astronomical Union Transcripts, XVIIA, 218.

Sparks, D.W., C.M. Ritzi, J.E. Duchamp, and J.O. Whitaker, Jr. 2009. Foraging habitat of the Indiana bat (*Myotis sodalis*) at an urban-rural interface. *Journal of Mammalogy* 86(4): 713-718.

Stevens, D.L., Jr., and A.R. Olsen. 2004. Spatially balanced sampling of natural resources. *Journal of the American Statistical Association* 99(465): 262-278.

Stone, E.L., S. Harris, and G. Jones. 2015. Impacts of artificial lighting on bats: a review of challenges and solutions. *Mammalian Biology*, unpublished manuscript.

Stone, E.L., G. Jones, and S. Harris. 2009. Street lighting disturbs commuting bats. *Current Biology* 19: 1123-1127.

Stone, E.L., G. Jones, and S. Harris. 2012. Conserving energy at a cost to biodiversity? Impacts of LED lighting on bats. *Global Change Biology* 18: 2458-2465.

Summers, C.G. 1997. Phototactic behavior of *Bemisia argentifolii* (Homoptera: Aleyrodidae) crawlers. *Annals of the Entomological Society of America* 90: 372-379.

Summit Metro Parks. Nature information: bats! Retrieved on March 14, 2015 from http://www.summitmetroparks.org/NatureInformation/Bats!.aspx.

Surlykke, A., T. Andreassen, and J. Hallam. 2014. Long-term acoustic surveying of bats. *The Journal of the Acoustical Society of America*, *135*(4), 2241-2241.

Svensson, A.M., J. Eklöf, N. Skals, and J. Rydell. 2003. Light dependent shift in the anti-predator response of a pyralid moth. *Oikos* 101: 239-246.

Svensson, A.M., and J. Rydell. 1998. Mercury vapour lamps interfere with the bat defence of tympanate moths (*Operophtera* spp.; Geometridae). *Animal Behaviour* 55: 223-226.

Swift, S. M. 1980. Activity patterns of pipistrelle bats (*Pipistrellus pipistrellus*) in north-east Scotland. *Journal of Zoology* 190(3): 285-295.

Thogmartin, W.E., R.A. King, P.C. McKann, J.A. Szymanski, and L. Pruitt. 2012. Population-level impact of White Nose Syndrome on the endangered Indiana bat. *Journal of Mammalogy* 93(4): 1086-1098.

Thogmartin, W.E., C.A. Sanders-Reed, J.A. Szymanski, P.C. McKann, L. Pruitt, R.A. King, M.C. Runge, and R.E. Russell. 2013. White Nose Syndrome is likely to extripate the endangered Indiana bat over large parts of its range. *Biological Conservation* 160: 162-172.

Turner, G. G., D. M. Reeder, and J. T. H. Coleman. 2011. A five-year assessment of mortality and geographic spread of White Nose Syndrome in North American bats and a look to the future. Bat Research News 52(2): 13–27

Tuttle, N.M., D.P. Benson, and D.W. Sparks. 2006. Diet of the *Myotis sodalis* (Indiana bat) at an urban/rural interface. *Northeastern Naturalist* 13(3): 435-442.

United States Census Bureau. 2015. State and County QuickFacts for Kent, Ohio. Data derived from Population Estimates, American Community Survey, Census of Population and Housing, County Business Patterns, Economic Census, Survey of Business Owners, Building Permits, Census of Governments. Accessed on June 21, 2015 from http://quickfacts.census.gov/qfd/states/39/3939872.html.

United States Fish and Wildlife Service. 2014. 2014 Range-wide Indiana bat summer survey guidelines. PDF obtained on May 12, 2014 from http://www.fws.gov.

United States Fish and Wildlife Service. 2015a. White Nose Syndrome: the devastating disease of hibernating bats in North America. Retrieved on November 17, 2014 from https://www.whitenosesyndrome.org/about-white-nose-syndrome.

United States Fish and Wildlife Service. 2015b. Ohio: Federally-listed threatened, endangered, proposed, and candidate species' county distribution. Last revised April 2015. Available from http://www.fws.gov/midwest/endangered/lists/ohio-spp.html.

United States Fish and Wildlife Service. 2015c. Automated Acoustic Bat ID Software Programs. Accessed on May 12, 2014 from http://www.fws.gov/midwest/endangered/mammals/inba/surveys/inbaAcousticSoftware.html.

van Langefeld, F., J.A. Ettema, M. Donners, M.F. WallisDeVries, and D. Groenendijk. 2011. Effect of spectral composition of artificial light on the attraction of moths. *Biological Conservation* 144: 2274-2281.

Vaughan, T.A. 1978. *Mammalogy*. Second edition. Saunders College Publishing, Philadelphia.

Verkem, S., and T. Moermans. 2002. The influence of artificial light on the emerging time of Geoffroy's bat *Myotis emarginatus*. Abstracts Bat Research Symposium, Le Havre, 2002. *Bat Research News*, fall 2002: 113.

Viele, D., A. Kurta, and J. Kath. 2002. Timing of Nightly Emergence. Pp. 199-207 in A Kurta, J Kennedy, eds. *The Indiana Bat: Biology and Management of an Endangered Species*. Austin, Texas: Bat Conservation International.

Vulinec, K. 2013. Acoustic analyses of bat activity in fragmented central Amazonian forest. *In* New Frontiers in Tropical Biology: The Next 50 Years (A Joint Meeting of ATBC and OTS). Atbc.

Wai-Ping, V., and M.B. Fenton. 1989. Ecology of spotted bat (*Euderma maculatum*) roosting and foraging behavior. *Journal of Mammalogy* 70: 617-622.

Walsh, A.L., and S. Harris. 1996. Foraging habitat preferences of vespterilionid bats in Britain. *Journal of Applied Ecology* 33: 508-518.

Walters, C. L., R. Freeman, A. Collen, C. Dietz, M. B. Fenton, G. Jones, M. K. Obrist, S.J. Puechmaille, T. Sattler, B.M. Siemers, S. Parsons, and K.E. Jones. 2012. A continental-scale tool for acoustic identification of European bats. *Journal of Applied Ecology* 49(5): 1064-1074.

Waters, D.A., J. Rydell, and G. Jones. 1995. Echolocation call design and limits on prey size: a case study using the aerial-hawking bat *Nyctalus leisleri. Behavioral Ecology and Sociobiology* 37: 321-328.

Watrous, K.S., T.M. Donovan, R.M. Mickey, S.R. Darling, A.C. Hicks, and S.L. Von Oettingen. 2006. Predicting minimum habitat characteristics for the Indiana bat in the Champlain Valley. *Journal of Wildlife Management* 70(5): 1228-1237.

Weber, T.C. and D.W. Sparks. 2013. Summer habitat identification of an endangered bat, *Myotis sodalis*, across its eastern range of the USA. *Journal of Conservation Planning* 9: 53-68.

Weterings, R., J. Wardenaar, S. Dunn, and C. Umponstira. 2015. Dietary analysis of five insectivorous bat species from Kamphaeng Phet, Thailand. Raffles Bulletin of Zoology 63: 91-96.

White, J. A., B.R. Andersen, H.W. Otto, C.A. Lemen, and P.W. Freeman. 2014. Winter Activity of Bats in Southeastern Nebraska: An Acoustic Study. *Transactions of the Nebraska Academy of Sciences and Affiliated Societies*, 34, 80–83.

Williams-Guillén, K., I. Perfecto, and J. Vandermeer. 2008. Bats limit insects in a neotropical agroforestry system. *Science*, 320(5872): 70-70.

Wilson, Z., and M. Bayless. 2009. Mapping the spread of White Nose Syndrome with GIS. *ArcWatch*, Esri. Retrieved from http://www.esri.com/news/arcwatch/0909/feature.html.

Womack, K.M., S.K. Amelon, and F.R. Thompson, III. 2013. Resource selection by Indiana bats during the maternity season. *The Journal of Wildlife Management* 77(4): 707-715.

Woodsworth, G.C., G.P. Bell, and M.B. Fenton. 1981. Observations of the echolocation, feeding behaviour, and habitat use of *Euderma maculatum* (Chiroptera: Vespertilionidae) in southcentral British Columbia. *Canadian Journal of Zoology* 59: 1099-1102.

Yates, M.D., and R.M. Muzika. 2006. Effect of forest structure and fragmentation on site occupancy of bat species in Missouri Ozark Forests. *The Journal of Wildlife Management* 70(5):1238-1248.

Yom-Tov, Y., and R. Kadmon. 1998. Analysis of the distribution of insectivorous bats in Israel. *Diversity and Distributions* 4(2): 63-70.

Yurk, H., and A.W. Trites. 2000. Experimental attempts to reduce predation by harbor seals on out-migrating juvenile salmonids. *Transactions of the American Fisheries Society* 129: 1360-1366.

Zurcher, A. A., D.W. Sparks, and V.J. Bennett. 2010. Why the bat did not cross the road? *Acta Chiropterologica* 12(2): 337-340.