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HABITAT USE AND NIGHTLY ACTIVITY PATTERNS OF BATS ON A
MILITARY LANDSCAPE IN WESTERN KENTUCKY

BY

CARSON E. MCNAMARA

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HABITAT USE AND NIGHTLY ACTIVITY PATTERNS OF BATS ON A
MILITARY LANDSCAPE IN WESTERN KENTUCKY

BY

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Bachelor of Science
Saint Louis University
St. Louis, MO
2016

Submitted to the Faculty of the Graduate School of
Eastern Kentucky University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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ABSTRACT

Bat populations of eastern North America continue to decline due to the cumulative effects of White-nose Syndrome, habitat loss, and anthropogenic disturbances across the landscape. Unique stressors exist on military installations, such as noise created during training activities. Given the scarcity of data that exists for these widespread ownerships, I created predictive models for nightly bat activity related to local habitat, landscape, and military use parameters. Bat activity was assessed during the summers of 2016 and 2017 using full-spectrum acoustic detectors across the Wendell H. Ford Regional Training Center (WHFRTC), a ca. 4200 ha military landscape in the Interior Rivers and Valleys ecoregion of Muhlenberg County in western Kentucky. Local habitat data was collected on site, and landscape-level data was extracted using geographic information systems. Ongoing military activities as reported by the Kentucky Army National Guard were summarized on the temporal and spatial bases that I hypothesized might impact bat activity. I then used regression techniques in combination with Akaike's Information Criterion (AIC) to identify the most parsimonious model for predicting bat activity across the landscape. Distinct habitat models were developed to explain bat activity based on: landscape-level habitat characteristics, site-level habitat characteristics, and both temporal and spatial disturbance models resulting from military training. The principal response variable considered was the total number of bat passes observed per detector-night. This variable was further divided into calls identified by Kaleidoscope Pro as Indiana bats (*Myotis sodalis*) and northern long-eared bats (*Myotis septentrionalis*). In total 13 unique bat species were identified across the WHFRTC property, including two focal threatened and endangered species, northern long-eared

bats and Indiana bats. Predictive models from each model suite identified parameters that influence bat activity within the three focal categories. The minimum distance to a firing range, firing activity in relation to sunset time, tree community composition, and distances to various natural and modified landscape types were identified as important predictors for bat activity. When planning future training activities on the landscape, precautions can be taken to minimize the potential detrimental impacts on foraging and commuting bats. Additionally, habitat management, such as planting native vegetation and removing excess snag trees can promote the foraging potential of the area. Overall, bat species conservation goals should be clearly defined by the managing agency in order to effectively and efficiently protect species of concern and the preferred habitat.

Beyond my assessment of bat activity across the military landscape of WHFRTC, I conducted an additional study to identify if bats would alter within- or across-night behaviors in response to an auditory predation cue in the form of broadcast owl calls. Bat activity was assessed using passive acoustic monitoring at WHFRTC from June to August of 2017. Bat detectors were paired with waterproof speakers that broadcast one of three possible treatments every ten minutes throughout nights. Treatments included predation cues (owl calls), noise (nocturnal frogs and insects), and a control (silence). On a given sampling night, six detectors were deployed with a randomly selected auditory treatment so that all treatments were represented. Approximately 9,000 bat passes were recorded during 990 detector-hours of sampling. Total bat activity was not altered by predation cues or noise ($p > 0.05$). For the most commonly recorded species, big brown bat (*Eptesicus fuscus*), eastern red bat (*Lasiurus borealis*), and tri-colored bat (*Perimyotis subflavus*), activity did not change in response to auditory treatment between nights or

within nights ($p > 0.05$). However, subtle differences in hourly accumulation trends were realized across species. While big brown bat and tri-colored bat activity patterns suggest unimodal trends, eastern red bat activity was more consistent throughout the night. The results of this study suggest that bats do not respond to the auditory predation cues of a nocturnal avian predator; the robust sampling framework and effort presented here provides a benchmark for future auditory investigations of predator avoidance by bats.

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I.

DEVELOPMENT OF PREDICTIVE MODELS OF BAT ACTIVITY ON AN ACTIVE MILITARY TRAINING FACILITY IN WESTERN KENTUCKY

INTRODUCTION

Bat populations in North America have been declining due to anthropogenic landscape alteration, principally resulting from habitat destruction and fragmentation of forested habitats (Voigt and Kingston 2015). The recent impacts of White Nose Syndrome (WNS) (Frick et al. 2016) have more recently devastated many bat populations. Hibernaculum surveys have reported population declines exceeding 75% (Blehert et al. 2009), and total estimates of mortality are conservatively estimated in the millions of bats across multiple species (Coleman 2016). Given the variety of threats impacting bat communities as a whole, land management practices have been revised to account for the growing number of threatened and endangered species in the southeastern United States (Hayes and Loeb 2007). Even so, the development of successful, holistic management action plans for bats is challenging, given these species are due to this species group consisting of nocturnal, highly mobile organisms. For example, Indiana bats (*Myotis sodalis*) and big brown bats (*Eptesicus fuscus*) are reported to have maximum foraging areas of up to 3,026 ha and 2,906 ha, respectively (Menzel et al. 2001, Lacki et al. 2007). As a further complication, the impacts of habitat fragmentation also differ across bat species. For example, silver-haired bats (*Lasionycteris noctivagans*) and tri-colored bats (*Perimyotis subflavus*) prefer more fragmented, open areas for foraging (Ethier and Fahrig 2011), whereas northern long-eared bats (*Myotis*

septentrionalis) prefer to forage in cluttered, less fragmented landscapes (Henderson and Broders 2008). Other species, such as big brown bats, eastern red bats (*Lasiurus borealis*), and hoary bats (*Lasiurus cinereus*), are considered foraging generalists (Agosta 2002, Ford et al. 2006). While fluid and oft-times site-specific, this varied tolerance suggests differential impacts of fragmentation across species.

Differences in foraging preference are attributed to variation in morphology, diet preference, and echolocation call structure (Norberg and Rayner 1987). Wing loading, or the ratio of body mass to wing area, is often a predictor of habitat use and foraging activities. Bats with greater wing loading values fly faster, are less maneuverable, and produce low frequency echolocation calls that cover a narrow bandwidth, whereas bats with lower wing loading fly slower, are more maneuverable, and produce high frequency calls with a wide bandwidth (Simmons and Stein 1980, Aldridge and Rautenbach 1987). These characteristics make bats with low wing loading better suited for foraging in forested habitats with moderate to dense structural clutter; bats with high wing loading bats are better suited for open, uncluttered foraging habitats (Aldridge and Rautenbach 1987). However, bats display plasticity in echolocation calls in relation to environmental factors (Obrist 1995). Little brown bats, northern long-eared bats, and *Pipistrellus* spp. alter echolocation calls both temporally and spectrally in response to increased structural clutter (Kalko and Schnitzler 1993, Broders et al. 2004), suggesting that echolocation call structure cannot be used alone to predict bat species presence in various habitat types (e.g. cluttered vs. uncluttered) or foraging habitat preference.

In previous studies of nightly bat activity across fragmented forest landscapes, non-forested areas have consisted of agricultural row crops, pasture, or urban landscapes

(Gehrt and Chelsvig 2003, Yates and Muzika 2006). However, the altered landscape of the Western Coal Field region of Kentucky (Newell 1986), with many reclaimed coal mines and abundant non-native vegetation, has been understudied. The first commercial coal mine in Kentucky opened in 1820 in Muhlenberg County (Goode 2016). Since the introduction of industrial coal operations, 2.58 billion tons of coal have been extracted from the western Kentucky coal fields (Carey et al. 2001). During the mining process, areas are cleared, thus altering the structure of the landscape. Mass extraction of mineral resources continues to be coupled with environmental issues such as polluted water resources, toxic runoff, soil compaction, and deforestation (Wickham et al. 2013, Goswami 2015). Additionally, in terms of public health, people living in heavily mined areas have been reported to display higher rates of mortality due to heart, respiratory, and kidney disease (Hendryx 2009). Intense mining effort in western Kentucky has resulted in a shift from forest-dominated habitat to more open areas with herbaceous vegetation (Mitsch et al. 1983, Ainslie et al. 1999, Woods et al. 2002). Further, if mining activities concluded prior to 1977, the federally mandated reclamation process often introduced non-native vegetation which can modify ecosystems and has been reported to result in a decline of the number and taxa of available insect prey items (Burghardt et al. 2010). By defining habitat characteristics that best predict nightly bat activity, to the generalization of habitats preferred by bats would contribute to the improvement of reclamation practices, potentially mitigate habitat loss, and improve existing poor-quality habitat.

Managing wildlife habitat on anthropogenic landscapes presents additional challenges. While common concerns focus on the physical modification of the habitat, the light regime and soundscape of human-modified habitats are become increasingly

different from non-modified habitats. Ecological light pollution stems from artificial lights disturbing the natural spatial and temporal distribution of light and dark within an environment (Longcore and Rich 2004). This alteration has been shown to impact spatial orientation, circadian rhythms, reproduction, and intraspecific communication in wildlife species (Longcore and Rich 2004). Multiple taxa are adversely impacted by ecological light pollution, which can result in reduced nocturnal activity, reduced feeding, disrupted movement patterns, and potentially death (Gaston et al. 2013). Nocturnal species rely on intact light regimes. Bats, as nocturnal foragers, are negatively impacted by ecological light pollution. Street lights deter commuting bats and can impact the timing of emergence (Stone et al. 2009). Additionally, structure dwelling bats display poor body condition in buildings under constant illumination when compared to bats roosting in buildings in dark conditions (Boldogh et al. 2007). In addition to disrupting natural light regimes, anthropogenic developments introduce artificial noise pollution to the environment (Blickley and Patricelli 2010). This novel acoustic landscape impacts wildlife at both the individual and population levels. Chronic stress, hearing damage, and reduced detection of critical auditory survival and reproduction cues can manifest in species exposed to noise pollution (Blickley and Patricelli 2010, Francis and Barber 2013). Additionally, predatory species, such as bats and owls, frequently rely on hearing for successful foraging (Konishi 1973, Simmons et al. 1979). When additional noise is introduced, acoustically reliant predators are unable to forage effectively (Jones 2008, Siemers and Schaub 2011, Senzaki et al. 2016).

On military properties, ecological light and noise pollution should be taken into consideration when forming management plans. Training activities of soldiers, off-road

vehicle traffic, artillery training, and aircraft use are additional potential disturbances that are unique to the military landscapes. For instance, wildlife species may experience individual and population level impacts due to noise generated by training activities. Proximity to the sound source, sound energy (dB), frequency, and level of seismic vibrations are used to assess the response of wildlife to military training noise (Larkin et al. 1996, Shapiro and Hohmann 2005). Research has been performed to analyze the impact of military training noises on a variety of taxa, including black bears (*Urus americanus*) (Telesco and Manen 2006), bald eagles (*Haliaeetus leucocephalus*) (Brown et al. 1999), red-cockaded woodpeckers (*Leuconotopicus borealis*) (Delaney et al. 2002), and vulnerable bat species (Martin et al. 2004, Shapiro and Hohmann 2005). While impacts to wildlife species on federally owned military land may seem narrow in scope, it is important to consider the expanse of these properties across the United States. Currently, the United States federal government owns approximately 640 million acres of land, or roughly a third of the area of the United States. The Department of Defense (DOD) operates 4,127 military defense sites, which comprise only 3 percent (19 million acres) of the total federally owned acreage (Gorte et al. 2012). The land area owned by the DOD could be considered negligible in terms of wildlife management potential; however, this property supports a disproportionately high amount of threatened and endangered species – 26 percent of total listed species. Additionally, this percentage is greater than the percentage of threatened and endangered species supported on properties owned by the U.S. Forest Service, U.S. Fish and Wildlife Service, and the National Park Service (Flather et al. 1994). As of 2013, 492 threatened and endangered species were identified on DOD property (Boice 2013). With a high proportion of the nation's

threatened and endangered species occurring on DOD properties, it is crucial to understand the impacts of training associated noises on populations of both vulnerable and stable species.

The first objective of this study was to create predictive models of nightly bat activity based on land use, as well as local and landscape-level habitat parameters on a military training installation in eastern North America. The second objective was to define spatial and temporal variables pertaining to noise pollution generated by firing range use, and to determine to what extent firing range use influences habitat use by bats. Models were created for Northern long-eared bats and Indiana bats, two federally-listed species of immediate management importance. Using best-fitting models, the most useful habitat predictors were determined for Indiana bats, northern long-eared bats, and more generally for total bat activity. Specifically, I sought to determine if military training activity was a stronger predictor of bat activity than habitat structure. In regard to habitat structure, I further aimed to determine if broad landscape characteristics, or local microsite characteristics were stronger predictors of bat activity in the understudied Western Coal Field region of Kentucky. In regard to military training activity, I evaluated the relative importance of spatial versus temporal characteristics of firing range use as predictors of bat activity. I hypothesized that if temporal variation in firing range use was an important determinant of bat activity, it could be the intensity of training activities explains more variation in bat activity than the timing of training activities, or conversely, that timing explains more variation than the intensity of training activities. Due to widespread habitat alteration and military training activity across the United States, I sought to identify those factors that most influence bat habitat use in order to aid in the

creation of military management plans that will mitigate the adverse human impacts on bat populations.

STUDY AREA

The study was conducted at the Wendell H. Ford Regional Training Center (WHFRTC) in Muhlenburg County, Kentucky (Figure 1-1)¹. The area is owned and managed by the Kentucky Army National Guard (KYARNG) and is divided into eastern and western blocks by KY Route 181. These two blocks encompass approximately 2,400 ha and 2,000 ha, respectively (D. Sherratt, KYARNG, pers. comm.). The area is located in the Green River–Southern Wabash Lowlands Level IV ecoregion of the Interior River and Valleys Level III ecoregion, and is characterized by poorly drained flood plains, agricultural fields, and numerous coal deposits (Woods et al. 2002). Bottomland forest, upland oak-hickory forest, and wetlands once comprised much of this region. However, pasture land, agricultural fields, and both active and reclaimed coal mining now comprise the majority land use in the area. Historic strip-mining activity for coal occurred across approximately 3,400 ha of WHFRTC. While records are incomplete, the most recent mining activities concluded in the 1990's (D. Sherratt, KYARNG, pers. comm.). The landscape of WHFRTC is generally composed of pine and hardwood forest (34%), water resources including lakes, ponds, streams, and both natural and man-made wetlands (10%), and mostly open grassland or shrub land (54%) (Calibre Systems 2002). Dominant species in the lattermost category generally consist of non-native flora, such as invasive reeds

¹ All figures and tables are presented as appendices at the end of this document

(*Phragmites* spp.), Musk thistle (*Carduus nutans*), Chinese bush clover (*Lespedeza cuneate*), and Johnson grass (*Sorghum halepense*) (C. McNamara, pers. obs.).

METHODS

Federal Survey Requirements. – Full spectrum acoustic monitoring was performed across the eastern block in 2016. In accordance with U.S. Fish and Wildlife Service’s Range-Wide Indiana Bat Summer Survey Guidelines, sampling occurred between 15 May and 15 August (U.S. Fish and Wildlife Service 2016). For non-linear sampling projects, a minimum of two detector locations per 50 ha for four detector nights was required. (i.e., sampling with two detectors for two nights fulfills the requirement of four detector nights). Thus, a minimum of 97 sites and 195 detector nights in the eastern portion of WHFRTC were required. To meet the minimum requirements and account for any seasonality or temporal variation across the allotted period, five week-long trips were completed in 2016. The first week trip occurred from 13 – 18 June and continued every other week over the course of the sampling period with the final trip from 7 – 13 August. Detectors were deployed every other day, and passively sampled over the course of two consecutive nights. On the day of departure from the field site, a final deployment was conducted. These detectors remained throughout the week for an additional sampling interval and averaged an additional four detector nights per detector.

In the 2017 season full spectrum acoustic monitoring was performed across the western block. Once again, to comply with U.S. Fish and Wildlife Service’s Range-Wide Indiana Bat Summer Survey Guidelines sampling occurred between 15 May and 15

August (U.S. Fish and Wildlife Service 2017). A minimum of 73 sites and 146 detector nights of data needed be collected on the western block of WHFRTC to meet federal survey guidelines. To meet the minimum requirements and account for any seasonality or temporal variation across the allotted period, five trips were completed in 2017. The first week trip occurred from 15 – 19 May and continued every other week until the federal sampling minimum was reached during the 24 – 28 June trip. Detectors were deployed and passively sampled bat activity for at least two consecutive nights.

Acoustic Deployment. – Selection of detector locations was determined using a stratified systematic approach (Forthofer et al. 2007). With this approach, the entirety of WHFRTC area was divided into equal, square units, or the main units. The main units were then divided into fourths, or the sub-units. A main unit was selected at random, and a sub-unit within the selected main unit was then chosen at random. A map of the area was divided into non-overlapping, 1-km² units. These units were labeled numerically and divided further into four 0.25-km² sub-units. A random number generator was utilized to randomly select one main unit, and then used again to select one sub-unit within the selected main unit. Within this sub-unit, two detectors were placed at least 200 m apart in suitable areas that allowed the microphone of the detector to be free of vegetation or other obstruction in all directions (U.S. Fish and Wildlife Service 2016). As the survey took place on an active military installation, the placement and schedule of detector deployment was dependent on accessibility to areas without training activities occurring. In an unobstructed sampling radius, the detectors are capable of sampling approximately 20 to 25 m from the microphone position (Adams et al. 2012). The location of each detector was recorded using a Global Positioning System (GPS) (Figure 1-2). Detectors

were programmed to begin recording 30 min prior to sunset and cease recording 30 min after sunrise. Each deployment lasted a minimum of two consecutive nights. During weeks when detectors are deployed continuously, approximately eight detector nights were recorded per detector. Recordings collected by the detectors were stored on two 32 gigabyte memory cards. Following each deployment, cards were collected, and the data was offloaded. Fresh batteries and memory cards were inserted before each deployment.

During the 2016 sampling season on the eastern portion of the property, six full-spectrum detectors, Song Meter 2 with “Bat+” option (SM2BAT+) with SMX-U1 external microphone and directional horn (Wildlife Acoustics, Maynard, MA), were utilized. In the 2017 sampling season on the western portion of the property, a combination of six SM2BAT+ detectors and five Song Meter 3 BAT recorders were used with the SMM-U1 microphone and directional horn. A total of eleven detector units were used throughout the season. Microphones were mounted on a 3-m-high pole, attached to the detectors via a 4-m microphone cable (U.S. Fish and Wildlife Service 2016) (Figure 1-3). In areas of high clutter, detectors are still capable of recording bat calls; however, these calls may not be of the highest quality due to emitted calls reflecting multiple times off obstructing vegetation. Poor quality calls are more difficult to identify manually and automatically. Thus, to minimize the number of poor quality calls recorded and maximize overall call quality, microphones were positioned 3 m away from sources of clutter (U.S. Fish and Wildlife Service 2016). Detectors were deployed consistently, regardless of weather conditions because bats forage immediately after rainfall and during light rain events (Andreassen et al. 2014).

Local Habitat Assessment. – Habitat data was collected at the center of each detector location and at a distance of 3 m from plot center in each cardinal direction to access the fine-scale habitat conditions of the detector location. Data from the five points were averaged to obtain the estimated value of each habitat variable for each detector location. With a 3-m distance from the center in each direction, a sampling area with a diameter of 6 m was established. This diameter served to remove sampling bias if the center of the plot was located underneath the canopy of a mid-sized tree. Canopy cover was estimated using a densitometer, and canopy closure using a spherical densiometer (Lemmon 1956, Stumpf 1993). Basal area was estimated using a basal area wedge prism with a basal area factor (BAF) of 10 at the center of the sampling point and each cardinal direction (Hovind and Rieck 1961). For detector locations in open areas, all values were recorded as zero. All values were averaged to estimate the basal area of the detector location. The two trees located nearest to the center of sampling points were determined. The heights of these trees and the distance from the center point was determined using a hypsometer and 60° transponder (Vertex IV, Haglöf, Sweden). Trees exceeding a distance of 150 m were excluded due to hypsometer limitations. Additionally, the diameter of the two nearest trees was measured at breast height (units). Local habitat parameter distributions were tested for normality using a Shapiro-Wilk Normality Test (Shapiro and Wilk 1965, Ghasemi and Zahediasl 2012). Differences between the eastern and western landscapes were then assessed using either a Student's t-test for parameters following a normal distribution (Kim 2015) or a Wilcoxon Rank-Sum test for non-normally distributed parameters (Wilcoxon 1945).

Landscape Level Assessment. – While fine-scale habitat data was collected at detector locations, landscape-level habitat variables were obtained from a geographic information system (ArcGIS V 10.3.1, ESRI, Redlands, CA). Parameters defined for each detector location included: elevation (m), aspect (m), slope (%), proximity to standing water (m), proximity to streams (m), proximity to roads (m), proximity to human modified land cover (m), proximity to grassland (m), and proximity to forest (m) (Loeb and O’Keefe 2006). Proximity measure were derived using the ‘Point Distance Tool’ within the Proximity toolset. Topographic elements were derived using the Spatial Analyst tool set. Data layers used to derive these habitat variables included: National Landcover Database (U.S. Geological Survey 2011), National Hydrography Dataset (U.S. Geological Survey et al. 2008) and Kentucky State Road Dataset (Kentucky Transportation Cabinet 2018).

Military Land Use. –While the entirety of WHFRTC experiences some degree of human use, more detailed and unique disturbance data exist for training activities that occur at firing ranges. Data regarding the timing, duration, and intensity of firing activities across all six firing ranges at WHFRTC were obtained from KYARNG through the Range Facility Management Support System (RFMSS) (D. Sherratt, KYARNG, unpublished data, 2017). Thus, the following temporal variables were generated on a nightly basis: duration of training activity in preceding day (min), duration of training activities occurring after sunset for current day (min), the length of time between the concluding time of training activities and the time of sunset for current day (min), and the number of rounds fired per hour for current day. On days when no firing range activity was taking place, the number of rounds fired for that day were represented by a zero

value. The three former variables allow for an assessment of the impact of the timing of firing range use, whereas the latter allow an assessment of the impact of the intensity of firing range use. Additionally, the firing locations for each firing range were georeferenced using Google Earth Pro (V 7.3.1.4507, Google Inc. Mountain View, CA) and operations information from KYARNG (D. Sherratt, pers. comm., 25 April 2018). Firing ranges were assigned alphabetic identifiers to retain a level of confidentiality. The distances between all firing ranges and all acoustic detector sites were measured using the near tool / point distance tool from a geographic information system (ArcGIS V 10.3.1, ESRI, Redlands, CA). These final spatial variables allow an assessment of the impacts of firing range proximity on bat activity, and to identify specific firing range locations that may have greater impacts on bat activity.

Acoustic Data Processing. – Data were downloaded from detectors after each deployment. Metadata were attributed to each recording file using the SonoBat Batch Attributer (V 6.5, SonoBat, Arcata, CA). Metadata included site name, GPS coordinates, deployment dates, and a time stamp. Data were scrubbed for noise using Kaleidoscope Pro (V 3.1.7, Wildlife Acoustics, Maynard, MA). Automatic identifications were assigned to each call file containing a minimum of five pulses using the software’s native reference library for Kentucky bats. This minimum prevents classifications made on singular call pulses and improves the overall reliability of identifications. A sensitivity setting of “(-1) more sensitive, Liberal” was used in compliance with U.S. Fish and Wildlife Service’s Range-Wide Indiana Bat Summer Survey Guidelines (U.S. Fish and Wildlife Service 2016). This is the most accurate setting and meets or exceeds the requirements set by the USFWS (United States Department of The Interior, U.S.

Geological Survey, 2015, unpublished document). Identifications from Kaleidoscope Pro were relied upon for subsequent modeling efforts. With these identifications, passes per night for all bat identified species were determined. Additionally, Bat Call Identification (BCID; V 2.7 d, Bat Call Identification, Kansas City, MO) was used as a second classification program to fulfill U.S. Fish and Wildlife requirements. The identifications made with BCID were solely used to reaffirm the likely presence of threatened and endangered species on the landscape. When comparing the accuracy of manual identification and automated programs in a previous study, no significant difference was detected (Jennings et al. 2008).

Data Analysis. – In order to determine the most parsimonious model for predicting bat activity patterns across the landscape, I used multiple linear regression in combination with Akaike’s Information Criterion (AIC) model ranking (Burnham and Anderson 2002, Lacki et al. 2012). The suitability of created models was tested using the number of bat passes per night per focus category (i.e., Indiana bats, northern long-eared bats, and all bats) as the response variable. The focus categories of Indiana bats and northern long-eared bats were selected as these species are federally listed as endangered or threatened. As all response variables were over-dispersed count data, models were built using a negative binomial distribution (Bliss and Fisher 1953, White and Bennetts 1996). Initially, all parameters were included within the models (Table 1-1). However, to account for multi-collinearity across model parameters, I used variance inflation factors (VIF) with a cut-off value of two restrict the predictors for inclusion in my candidate models (Zuur et al. 2010). Parameters with a VIF value exceeding the cut-off value were excluded from the model building process (Table 1-2). Models for ranking were created

for all single variable and double variable combinations within each category.

Additionally, the full model and a null model were included. In total, four distinct model groups were developed as discrete hypotheses to best explain bat activity: landscape-level habitat conditions, local habitat conditions, and either the temporal or spatial effects due to disturbance from firing range use activities (Table 1-3). In the landscape level category, three sub-categories (or sub-hypotheses) were necessary due to the large number of parameters. Sub-categories include natural landscape parameters, modified landscape parameters, and topographic parameters. Model rankings were determined by calculating the Akaike's Information Criterion (AIC), AIC differences (ΔAIC), and Akaike weights (w_i) (Ford et al. 2006, Loeb and O'Keefe 2006, Lacki et al. 2012). The model with the smallest AIC was considered the best-fitting model. Additionally, models with differences of less than 2 units from the AIC_{min} were considered to have substantial support (Burnham and Anderson 2004, Loeb and O'Keefe 2006, O'Keefe et al. 2009). Overall model significance was determined by comparing the model of interest to a null model using an analysis of variance and Pearson chi-square (χ^2) test. A p-value and likelihood ratio test statistic was calculated (Venables and Ripley 2002, McHugh 2013). Within the model groupings, parameter estimates and standard errors were obtained through the model averaging; values from the conditional average were used to calculate 85% confidence intervals (Burnham and Anderson 2002, 2004, Arnold 2010). Parameters with no zero overlap were identified as important predictors of bat activity (O'Keefe et al. 2009, Lacki et al. 2012). In the instance of a positive beta estimate, a one unit increase in the predictive parameter will result in an increase in the response variable by the value of the beta estimate. In the opposite case, a negative beta estimate value, a one unit

increase in the predictive parameter will result in the decrease of the response variable by the value of the beta estimate. Analyses were performed in R (R Core Team 2017).

RESULTS

Sample Effort. – In order to fulfill U.S. Fish and Wildlife Service federal survey standards of threatened and endangered bat species, a total of 97 sites and 195 detector-nights must have been completed on the eastern portion of the landscape. By the season's end, 286 detector nights at 98 sites were recorded. Throughout the sampling season a total of 12,907 passes were recorded, and 11,429 passes (88.5%) were identified to species. In addition, the western portion of the landscape must have received a sampling effort greater than or equal to 73 sites and 146 detector-nights. Federal sampling minimums were exceeded, with a final count of 323 detector-nights at 75 sites. A total of 11,674 passes were recorded, and 9,519 passes (81.5%) were identified to species. In total 20,948 passes and 609 detector nights were used in the analysis.

Bat Species Composition and Activity Patterns. – On both the eastern and western portion of the landscape, 13 bat species were identified (Table 1-4). While the number of species detected was consistent across the landscape, the composition of total passes recorded differed. In the east, 38.2% of total passes were identified as big brown bats and 36.1% of total passes were identified as eastern red bats (Table 1-4). However, in the west, 2.9% of total passes were identified as big brown bats and 66.8% were identified as eastern red bats (Table 1-4). The average number of bat passes per detector night was calculated for each property block. On the eastern property block, an average

of 44.32 ± 8.08 passes were recorded per detector night. On the western property block, an average of 32.07 ± 6.17 passes were recorded per detector night (Figure 1-4). Total bat passes were compared between the eastern and western property blocks using a Wilcoxon-Rank Sum test. There was no significant difference detected in total bat activity between the two property blocks ($W_{98,75} = 4101$, $p = 0.1911$).

Patterns of Threatened and Endangered Bat Species. – In order to confirm presence of threatened and endangered bat species on the landscape, two acoustic identification programs were utilized. BCID identified Indiana bat passes across three training areas; Kaleidoscope Pro identified this species across nine training areas (Table 1-5). BCID was similarly more conservative in identification of the northern long-eared bat, with passes for this species identified in only a single training area versus the eight training areas wherein this species was identified using Kaleidoscope Pro (Table 1-5). After combining the total number of passes recorded between the two sampling periods, only a single pass was identified as belonging to the northern long-eared bat by BCID; in contrast, Kaleidoscope Pro identified 68 passes as this species. After combining the total number of passes recorded between the two sampling periods, BCID identified four passes and Kaleidoscope Pro identified 63 passes as belonging to the Indiana bat. In total, the Indiana bat was identified by automated classifiers at 24 sites (Table 1-6). Of the 24 sites, 10 were located on the eastern property block and 14 were located on the western property block. Northern long-eared bat passes were identified by automated classifiers at 24 sites: 18 on the eastern property block and six on the western property block (Table 1-7). There were no patterns in monthly activity for these species (Table 1-8). The average number of passes for each species per detector night were calculated. On the

eastern property block, 0.102 ± 0.034 Indiana bat passes were recorded per detector night; however on the western property block, 0.067 ± 0.055 Indiana bat passes were recorded per detector night (Figure 1-5). The difference observed between average Indiana bat passes per night was not significant ($W_{98,75} = 3765.5$, $p = 0.5596$). On the eastern property block, 0.133 ± 0.047 northern long-eared bat passes were recorded per detector night; however on the western property block, 0.080 ± 0.037 northern long-eared bat passes were recorded per detector night (Figure 1-5). The difference observed between average Indiana bat passes per night was not significant ($W_{98,75} = 3911.5$, $p = 0.087$). Additionally, the differences between Indiana bat and northern long-eared bat activity on each property block was compared between species; neither comparison was significant (both $p > 0.05$).

Military Use. – Throughout the duration of sampling, firing range use occurred on 14 dates when detectors were deployed across the landscape. Since multiple detectors were deployed during each sampling event, a total of 61 detector nights occurred on the nights corresponding with single firing range use in the corresponding day (10.01% of all detector nights). Additionally, 32 detector nights occurred on nights following days with at least two firing ranges in use (5.25% of all detector nights). The majority of these events occurred in August ($n = 41$, 45.15%) (Figure 1-6). The average duration of a firing range event was 4.85 ± 0.79 hours with 5361.95 ± 1897.51 rounds expended per event (Table 1-9). Firing range D was not included in further analysis due to the lack of firing range events occurring on dates with detector deployments.

Local Habitat Parameters. – Habitat parameters were collected and summary statistics were calculated for eastern points, western points, and all points (Table 1-10).

All parameters displayed a non-normal distribution; therefore, a Wilcoxon Rank Sum test was performed for all comparisons. Tree distance and height was greater for trees at eastern points ($p \leq 0.05$). However, average canopy closure, canopy cover, and total and live tree basal area was greater for western points ($p \leq 0.05$). Overall, all variables but two were significantly different between the eastern and western landscape ($p \leq 0.05$); basal area of snag trees and the DBH of the second closest tree was not significantly different ($p > 0.05$).

Landscape Parameters. – Landscape parameters were derived from ArcMap and summary statistics were calculated for eastern points, western points, and all points (Table 1-11). All landscape parameters displayed non-normal distributions. As a result, Wilcoxon Rank Sum test was used to assess differences for all comparisons. The distances from detector points to forest, human modified areas, standing water, streams and grasslands were significantly different between eastern and western points ($p \leq 0.05$). The remaining landscape parameters, distance to roads, aspect, elevation, and percent slope, did not differ significantly between eastern and western points.

Total Bat Activity Model Ranking. – Across all model groupings, no single model was found to have clear, isolated support. Therefore, the top four models based on the lowest AIC scores were analyzed (Table 1-12).

Within the spatial firing range model group, the top three models with ΔAIC_i less than 2 had a combined weight of 0.89. The top model, SR 4, was comprised of a single parameter: multiple firing ranges in use. When comparing the spatial firing range models to a null model, all four top models were significantly different (Table 1-13).

All four top models within the temporal firing range use model group were less than 2 ΔAIC_i units apart and had a combined weight of 0.42. The model with the lowest AIC score, TR5, was comprised of a single parameter: duration of activity after sunset. This model was singular within the subset to differ significantly from the null model (Table 1-13).

In the local habitat model group, two models, LH 11 and LH 1, were within 2 ΔAIC_i units. These two models had a combined weight of 0.83. The top model, LH 11, contained the following parameters: average basal area of live trees and average basal area of snag trees. All four top models in the local habitat model group were significantly different from the null model (Table 1-13).

The four top models in the natural landscape model group had ΔAIC_i values equal to or less than 2 units. Combined, the models within this subset had a weight of 0.89. The top model, LN 2, had the single parameter of distance to forest from the detector location. The other three subsequent models were two parameter combinations with forest distance as the first parameter and distance to standing water, distance to stream, and distance to grassland as the second parameter respectively. All four top models in the natural landscape model group were significantly different from the null model (Table 1-13).

In the modified landscape category, the top two models held the majority of the weight at 0.99. The top model, LM1, was comprised of distance to human modification on the landscape and the distance to drivable roads. Only the top two models, LM1 and LM2, differed significantly from the null model (Table 1-13).

Finally, the landscape topography model category had two top models holding a weight of 0.98. The top model was LT5; parameters within this model included property

orientation and aspect. From the topographic landscape model group, the top four models all were significantly different from the null model (Table 1-13).

Northern long-eared bat Activity Model Ranking. – Within the northern long-eared bat response groupings, no single model was found to have all the support. Therefore, the top four models within each group based on ΔAIC_i were analyzed (Table 1-14).

The spatial firing range use model group has two models within the ΔAIC_i criteria. The top model was SR 6; the following parameters were included in the top model: single firing range in use and multiple firing ranges in use. This model had a weight of 0.64. All four of the top models (SR 6, SR 1, SR 2, SR 5) were significantly different from the null model (Table 1-15).

In the temporal firing range use model group, the global model, TR1, had the majority of the support with a weight of 0.76. Additionally, the top four models in the temporal firing range model group were significantly different from the null model (Table 1-15). Three models in the local habitat had a ΔAIC_i value equal to or less than two. The top three models, LH 8, LH 2, and LH6, had a combined weight of 0.63 and were significantly different from the null model (Table 1-15). The top model (LH 8) included the parameters distance to the nearest tree and average basal area of snag trees.

The top four models in the natural landscape model group were able to be used within the analysis due to the ΔAIC_i values being equal to or less than two. The combined weight of all four models was equal to 0.75; the top model has a weight of 0.29. The top model, LN 10, included two parameters: distance to grassland from detector location and distance to stream from detector location. All top four models from

the natural landscape model group differed significantly from the null model (Table 1-15).

For the modified landscape category, three of the top four models met the ΔAIC_i criteria. The combined weight of these models was equal to 0.91. The top model, LM 2, contains distance to human modification as a single parameter. However, none of the top four models differed significantly from the null model (Table 1-15).

The final model group, landscape topography, had two of the top four models with ΔAIC_i equal to or less than two. The combined weight of the two models was equal to 0.75. The top model, LT 5, contained a combination of two parameters: property orientation and aspect. All of the top models differed significantly from the null model (Table 1-15).

Indiana Bat Activity Model Ranking. – The Indiana bat model groups did not have a single model with all of the support. Due to this, the top four models within each parameter category were analyzed (Table 1-16). Models with a ΔAIC_i value equal to or less than 2 were considered in the analysis.

Within the spatial firing range model group, all four top models met the ΔAIC_i criteria. The combined weight of all four models was equal to 0.77. The top model, SR 4, had a weight of 0.35 and consisted of two parameters: single firing range use and multiple firing range use. None of the top four models differed significantly from the null model (Table 1-17).

The temporal firing range use model group also had all four models meet the ΔAIC_i criteria. These models had a combined weight of 0.43; the top model, TR 4, had a weight value equal to 0.13. Duration of activity after sunset was the sole parameter within

the top model. No model within the top performing group differed significantly from the null model (Table 1-17).

For the local habitat grouping, only the top model, LH 8, had a ΔAIC_i value equal to or less than two. The weight for the top model was 0.59 and contained the distance to the nearest tree and average basal area of snag trees as parameters. The top three models in the local habitat model group, LH 8, LH 2, and LH 1, were significantly different from the null model (Table 1-17).

The four top models in the natural landscape model group met the ΔAIC_i criteria; the combined weight for the four models was 0.83. The top model, LN2, contains distance to forest from detector location as a single predictive parameter. This top model has a weight of 0.36. All four models in the natural landscape model group were significantly different from the null model (Table 1-17).

In the modified landscape model group, two models were within the supporting firing range of ΔAIC_i values. The combined weight for the two models was equal to 0.87. The top model, LM 2, contained distance to human modification from detector location as the sole predictor. Only the top two models (LM 2 and LM 1) were significantly different from the null model (Table 1-17).

Finally, the landscape topography model had three models meet the ΔAIC_i requirements. The combined weight for the three models was 0.72. The top model, LT 4, had percent slope as the sole parameter. This model had a weight of 0.33. The top two models in the topographic landscape model group (LT 4 and LT 6) differed significantly from the null model (Table 1-17).

Total Bat Activity Parameter Estimates. – Parameter estimates were based on averaging all models within each respective grouping. If the confidence interval of the parameter overlapped zero, the parameter was not considered to be associated with total bat activity.

Within the spatial firing range model, minimum firing range distance was a weak predictor of total bat activity ($\beta_{\text{MINRNG}} = 0.00015$, CI = [0.00021, 0.00009]) (Table 1-18, Figure 1-7a). As distance from a firing range increased, bat activity increased.

In the temporal firing range model group, duration of activity after sunset was associated with total bat activity ($\beta_{\text{DASRN1}} = 0.05890$, CI = [0.11091, 0.00689]) (Table 1-18, Figure 1-7b). When training activities occurred after sunset, bat activity decreased.

Local habitat predictors with no zero-overlap included average basal area of live trees with a positive association to total bat activity ($\beta_{\text{BASLIV}} = 0.00530$, CI = [0.00848, 0.00212]) and average basal area of snag trees with a negative association ($\beta_{\text{BASSNG}} = -0.08147$, CI = [-0.06211, -0.10083]) (Table 1-18, Figure 1-7c).

Landscape level parameters with confidence intervals that did not overlap zero include: aspect, distance to forest, distance to human modification, distance to drivable roads from detector location, and property orientation. The strongest association was found between total bat activity and property orientation ($\beta_{\text{DTSIDE}} = -0.40830$, CI = [-0.22858 -0.58801]) (Table 1-18, Figure 1-7d). Total bat activity on the landscape was more strongly associated with the eastern block of the property than the western block.

Northern Long-eared Bat Activity Parameter Estimates. – Parameter estimates were based on averaging all models within each respective grouping. If the confidence

interval of the parameter overlapped zero, the parameter was not considered to be associated with northern long-eared bat activity.

In the spatial firing range model group, minimum firing range distance was weakly associated with northern long-eared bat activity ($\beta_{\text{MINRNG}} = 0.00033$, CI = [0.00051, 0.00015]) (Table 1-19, Figure 1-8a). As the distance from a firing range increased, northern long-eared bat activity increased. Additionally, the occurrence of military activity at a single firing range was positively associated with northern long-eared bat activity ($\beta_{\text{SNGLRN}} = 1.80280$, CI = [1.1380, 2.4675]) (Table 1-19, Figure 1-8a).

Temporal firing range model parameters with no confidence interval overlap of zero included duration of activity after sunset ($\beta_{\text{DASRN1}} = 0.67236$, CI = [1.0859, 0.25885]); when training activities occurred after sunset, bat activity decreased. Additionally, two parameters describing the number of rounds fired per training event and number of rounds fired per hour had confidence intervals with no zero overlap ($\beta_{\text{NRFRN1}} = 0.00113$, CI = [0.00196, 0.00031], $\beta_{\text{RPHRN1}} = -0.01098$, CI = [-0.00335, -0.01861]) (Table 1-19, Figure 1-8b).

Only one parameter within the local habitat model suite was associated northern long-eared bat activity: distance to nearest tree ($\beta_{\text{TR1DIS}} = 0.01081$, CI = [0.01802, 0.00360]) (Table 1-19, Figure 1-8c). As distance to the nearest tree increased, bat activity increased.

Finally, within the landscape level model group, the following parameters were found to be associated with northern long-eared bat activity: aspect, distance to forest, distance to grassland, distance to human modification, distance to stream from detector location, and property orientation. The strongest association between a parameter and

northern long-eared bat activity was found in property orientation ($\beta_{DTSIDE} = -0.94729$, CI = $[-0.35519 -1.5394]$) (Table 1-19, Figure 1-8d) with the eastern property block being more strongly associated with northern long-eared bat activity than the western block.

Indiana Bat Activity Parameter Estimates. – Parameter estimates were based on averaging all models within each respective grouping. If the confidence interval of the parameter overlapped zero, the parameter was not considered to be associated with Indiana bat.

Minimum distance to firing range was the only predictor within the spatial firing range group to be associated with Indiana bat activity ($\beta_{MINRNG} = 0.00016$, CI = $[0.00032, 0.00001]$) (Table 1-20, Figure 1-9a). With an increase in minimum distance from a firing range, a predicted increase in Indiana bat activity was observed.

There were no parameters in the temporal firing range model group that fit the confidence interval requirements (Table 1-20, Figure 1-9b); therefore, none of the temporal firing range parameters were found to be associated with Indiana bat activity.

Within the local habitat model group, there was a negative association between Indiana bat activity and distance to the nearest tree ($\beta_{TRIDIS} = -0.03849$, CI = $[-0.01518, -0.06179]$), as well as average basal area of snag trees ($\beta_{BASSNG} = -0.13141$, CI = $-0.02934, -0.23349]$) (Table 1-20, Figure 1-9c). As the distance to the nearest tree increases, Indiana bat activity decreases. Additionally with an increase in basal area of snag trees, a decrease in Indiana bat activity was displayed.

Finally, within the landscape level model group, parameters with confidence intervals that do not overlap zero include: distance to forest, distance to human modification, and percent slope. The strongest association between Indiana bat activity

and a landscape level parameter was found to be distance to forest from detector location ($\beta_{\text{FORDIS}} = -0.02175$, CI = [-0.00678, -0.03672]) (Table 1-20, Figure 1-9d). With an increase in distance to forest, a decrease in Indiana bat activity was observed.

DISCUSSION

Site-Level Habitat and Landscape-Level Patterns. – This research sought to explain the patterns of bat activity on Wendell H. Ford Regional Training Center (WHFRTC) in Muhlenburg County, Kentucky. The landscape, bisected into conspicuously different eastern and western parcels, contributes to a varied overall composition of bat species across the military installation. Local habitat measurements of tree distances, average closure, average cover, and basal area indicate that the western portion of the landscape is more densely forested than the eastern landscape. While trees on the eastern portion are larger in terms of height and diameter, they are considerably sparser than in the western landscape. In the western portion, the habitat has more vegetative clutter than on the eastern landscape. Clutter has the ability to alter foraging patterns in insectivorous bat species, principally by increasing the difficulty of identifying insect prey items and decreasing the overall maneuverability within the habitat (Brigham et al. 1997, Ciechanowski et al. 2007). The detection rate of species is differentially impacted by structural clutter; larger bat species pulses can be recorded as they navigate over cluttered areas. In terms of landscape measures, my western survey locations were closer to forests than the eastern detector locations; this unavoidable bias in my survey effort illustrates the cluttered nature of the western portion of WHFRTC. Conversely, the

distance to grassland was greater on average for western detector locations than eastern detector locations. The proximity to water can often serve as a measure of habitat quality with water from streams and standing sources being an important resource for foraging bats (Korine et al. 2016). Water resources were on average closer to western detector locations than eastern detector locations. One final landscape characteristic that has been frequently documented to influence bat community composition is the expanse of human modification on the landscape. The eastern block has a much greater level of human influence, with numerous structures and increased vehicle and foot traffic. The influence of human modification is substantially less on the western block. Significant differences were observed in many of the site-level and landscape-level parameters. These differences become apparent as one travels throughout the property blocks of WHFRTC. Based on these differences, more open-air foragers and habitat generalist species, like eastern red bats, big brown bats, and evening bats are expected to be recorded more frequently on the eastern property block (Agosta 2002, Elmore et al. 2003, Lacki et al. 2007). In contrast, species such as northern long-eared bat, Indiana bats, and tri-colored bats have more specific habitat needs. For example, northern long-eared bats are found to utilize the interior portion of intact deciduous forests with closed canopies and riparian habitats as foraging areas (Owen et al. 2003, Schirmacher et al. 2007, Henderson and Broders 2008). Indiana bat foraging habitats overlap with the northern long-eared bat in some aspects, and while covered canopies are important, Indiana bats are more dependent on riparian habitats, such as forested wetlands or floodplains, and wooded corridors (Murray and Kurta 2004, Ford et al. 2005). The tri-color bats forage more frequently in low clutter habitats, such as fields, forest openings, open water, and above forest canopies

(Fujita and Kunz 1984, Kalcounis-Ruppell et al. 2007, Quinn and Broders 2007).

Riparian habitats also serve as important foraging resources for the tri-colored bat. Due to these habitat requirements, the aforementioned species are expected to be recorded more frequently on the western property block where environmental needs such as riparian habitats, intact forests, and wooded edge habitats are more likely to be observed (Lacki et al. 2007).

Total Bat Activity and Species Composition. – The differences seen in habitat and landscape characteristics are reflected in the species composition observed in each block. The difference between property blocks in terms of total passes per detector night was not found to be significant, indicating that both blocks provide suitable bat foraging habitat. However, the species composition of each blocks suggests that bats select varied foraging habitats on the landscape. Eastern red bats use dense foliage as over-night roost sites (O’Keefe et al. 2009). On the western block with more forested cover and clutter, an increased number of eastern red bats were recorded. Additionally, the habitat characteristics influence the number of open area foragers documented on each property block. Big brown bats, a common aerial forager, was found to have greater levels of activity on the eastern block than the western block. The impact of anthropogenic modification does not impact big brown bats to the same degree as other bat species, as these bats frequently use buildings and other structures for roost sites (Agosta 2002, Lausen and Barclay 2006). Additionally, as no clear habitat associations have been identified for big brown bats, these bats are more likely utilize the expansive grasslands on the eastern landscape for food resources compared to other species that are less tolerant of anthropogenic habitat influences (Agosta 2002). Between the two property

blocks, the identification rate for calls recorded on the eastern block was greater than identification rate on the western block. An additional factor that may influence the patterns observed across the landscape is the differential detection rate for individual species, as well as overall bat activity, due to increased structural clutter on the western portion of the landscape. The presence of clutter can obscure calls from the bat detector microphone (Weller and Zabel 2002, Patriquin et al. 2003). These poor-quality calls may not be assigned the appropriate bat identification or may be eliminated from the analysis entirely due to the resemblance to noise. Some bat species, such as little brown bats and *Pipistrellus* species are also capable of altering their echolocation calls in order to more effectively forage in high clutter areas (Kalko and Schnitzler 1993, Wund 2006). These non-characteristic calls may not be properly assigned an identification in automated software due to differences between the altered calls and the representative calls for the species on which the software has been trained.

Endangered and Threatened Species. – The focal species of conservation interest, northern long-eared bat and Indiana bat were detected on both the eastern and western landscapes. A greater number of northern long-eared bat passes were detected on the eastern block than the western block. Eastern detector locations where this species was detected were primarily located along edge habitats and near water features. On the western property block, the majority of northern long-eared bat detections were in locations near water features. Indiana bat was more frequently recorded on the western property block; the greatest number of passes for this species were recorded in the northwest portion of the property. A greater number of detector locations with Indiana bat detections were located on the western portion of the property. On the eastern property

block, Indiana bat passes were identified at detector locations along edge habitats and grassland corridors. Western block detector locations where this species was detected were primarily located near water features on the landscape.

The overall patterns of northern long-eared bat and Indiana bat activity on the landscape are supported by foraging patterns observed in similar studies and accounts. Indiana bats have been documented to forage in riparian areas, old field sites, upland forests, and crop- and forest-edge (Humphrey et al. 1977, Thompson 1982, Murray and Kurta 2004). It has also been suggested that suitable maternity roost locations determine the presence of Indiana bats on that landscape (U.S. Fish and Wildlife Service 2007). Detector locations with recorded Indiana bat activity were located primarily in areas with accessible water features and related riparian habitats, as well as along forested edge habitats. The northern long-eared bat has been documented to forage along forested hillsides, ridges, intact forests, and road corridors (Brack Jr. and Whitaker 2001, Owen et al. 2003, Lacki et al. 2007). The majority of northern long-eared bat passes were recorded near water features and edge habitat, indicating that these habitat qualities are potentially important for the species while foraging or commuting between resources. However, bias may exist in the recording of bat passes in these generally more open areas. The lack of clutter increases the overall number of passes recorded, call quality, and identification ability of the software. More bat activity may be occurring within highly cluttered areas that are unable to be properly sampled due to federal survey requirements determining proper detector placement (U.S. Fish and Wildlife Service 2017).

Military Firing Range Use Patterns. – As this study occurred on an active Kentucky National Guard training site, firing range activity is an important aspect to

include in analyses involving influences on wildlife populations. The current data regarding seasonal firing range activity is ideal for bat conservation and management. The greatest numbers of firing range events occurred in May and August, with the lowest number of events occurring in June and July. The mid-summer months are critical for reproductive female bats and developing juveniles. For female bats, gestation and lactation are extremely energy expensive tasks, with some species increasing total expended energy by up to 40% during the lactation period (Gittleman and Thompson 1988). Pups are usually born in late June or early July (Thompson 1982, Caceres et al. 2000). After pups are born, they are nonvolant for several weeks before taking flight. Juvenile bats on the landscape must learn how to effectively navigate the airspace and capture insect prey. During this initial period of trial-and-error, they are particularly vulnerable until they gain the proper experience (Brigham and Brigham 1989). Noise, light, and fumes introduced by firing range events may decrease the ability of juveniles to effectively learn foraging skills. By avoiding firing range events during June and July, land manager may reduce unnecessary stressors to reproductive females and juveniles, thus ensuring higher survival rates.

During the sampling efforts over the 2016 and 2017 survey seasons, approximately 10% of detector nights occurred on days with firing range activity. While survey efforts did not occur on every night during the summer season, the activity on the firing ranges during sampling nights was fairly representative of firing range activity throughout the season.

Spatial and Temporal Firing Range Models. – Landscape- and site-level scales of habitat both contribute to total bat activity; however, habitat features may be difficult

to manipulate at a large scale. Careful consideration should be given when planning military training activities in order to mitigate impacts on bat activity. Given the nature of the training activities occurring on the landscape, variation in firing range activities was partitioned according to spatial and temporal parameters. One parameter was found to have a significant positive impact on activity in all three focal categories of bat activity: minimum firing range distance. Additionally, activity at a single firing range was found to positively impact northern long-eared bat activity. This observation of northern long-eared bat activity is contrary to the prior expectation that firing range activity would reduce bat activity. This pattern of activity could be potentially attributed to the combination of a small sample size of northern long-eared bat calls and infrequent firing range activity.

During training activities, the firing ranges can produce a considerable amount of noise, light, and fumes (Pawlaczyk-Luszczynska et al. 2004, Orru et al. 2018). These by-products of firearm training activities can serve as deterrents to bat populations on the landscape, as bats rely primarily on hearing to effectively forage during the evening. Additionally, bat colonies roost during the day time hours. The external stimuli can disturb roosting bats during the maternity season, potentially impacting juvenile growth and development. Bats are capable of responding to stimuli while in a state of torpor (Doty et al. 2018). However, bat colonies are frequently located in locations with high levels of anthropogenic noise, such as under bridges (Keeley and Tuttle 1999). A study by Luo et al. examined the impacts of noise on bats in a day roost and found that bats can become habituated to frequent noises on the landscape (Luo et al. 2014). The location of the firing range itself may not be the driving factor influencing bat activity; the habitat

quality and features associated with ranges may be contributing to the observed patterns on bat activity. These areas are often comprised of mowed, dirt, gravel, or concrete ground cover that is not conducive to high levels of bat activity. If possible, facilitating the growth of natural plants around these areas may introduce more foraging opportunities for bat populations, thus reducing the avoidance of firing range areas. For example, the planting of shelterbelts, a linear array of trees and shrubs, have been used to mitigate the impacts of several anthropogenic wildlife stressors (Mize et al. 2007). Branches and leaves of vegetation reflect and absorb sound energy; noise is reduced by 7 to 15 dB per 30 meters of forest (Coder 2011). Studies have demonstrated that mixed species stands are more effective in terms of noise reduction than monospecific stands (Maleki and Hosseini 2011). With careful planning, the most effective mixture of tree and shrub species can be planted at a determined distance from the noise source to aid in sound pollution abatement.

For total bat activity and northern long-eared bat activity, duration of firing activity after sunset was found to be the most important predictive parameter. The relationship between this parameter as total bat and northern long-eared bat activity was positive; if range use occurs earlier in the day in relation to sunset time, then bat activity in the previous focal groups was predicted to increase. However, temporal firing range models for Indiana bats did not provide the same predictive ability as the models for total bat activity and northern long-eared bat activity. No single model was found to be the best predictive models; the top four models had relatively low weights (> 0.14) and no model differed significantly from the null model.

The duration of firing range activity and the time of cessation are important factors that influence the activity of bats on the landscape. Anthropogenic noise on the landscape can negatively impact the ability of these nocturnal predators to forage efficiently as bats are highly dependent on hearing both echolocation calls and prey items on the landscape. Areas with high levels of noise, like those around firing ranges, have been found to have decreased levels of bat activity and decreased foraging efficiency (Siemers and Schaub 2011, Bunkley and Barber 2015, Bunkley et al. 2015). Within the nocturnal food web, insectivorous bats are not the only trophic level influenced by noise pollution. Prey populations on which insectivorous bat species are reliant are influenced by anthropogenic noise resulting in reduced population sizes, failed conspecific communication, and reduced abilities to avoid predation (Morley et al. 2013, Schmidt and Balakrishnan 2015, Bunkley et al. 2017). Duration of firing range activity and the time of cessation are parameters that can be easily manipulated and the impacts on bat populations can be reduced through careful planning. Scheduling training start times for as early as possible in the day coupled with decreased activity in the late afternoon is expected to reduce the impact to bat species. This again reinforces the potential sensitivity of bat species and the resulting avoidance of areas with frequent disturbances in the evening hours.

Site-Level Habitat Models. – The suitability of habitat for wildlife species is dependent on the interaction of biotic and abiotic factors as multiple spatial scales. Site-level characteristics, or the microhabitat, is the finest scale on which wildlife are reliant for food and shelter resources. For predictive models using site-level habitat parameters, all significant parameters across the focal categories involve tree community composition

and spacing. The basal areas of both snag and live trees were found to be important parameters predicting total bat activity. These parameters display a contrasting relationship to total bat activity; an increase in the basal area of snag trees predicts a decrease in total bat activity, while an increase in the basal area of live trees predicts an increase in total bat activity. For northern long-eared bats, a positive relationship was predicted between the distance to the nearest tree and activity. Finally, Indiana bat activity was predicted to be influenced negatively by both the distance to the nearest tree and basal area of snag trees.

Site-level habitat composition is a critical component of bat foraging and reproductive success. One aspect of site-level habitat that is frequently investigated is the presence of snag trees. Crevices and exfoliating bark associated with dead or dying trees can provide suitable roosts for both maternity colonies and single bats on the landscape (Callahan et al. 1997, Carter and Feldhamer 2005). However, an unproportionate amount of snag trees in an area may indicate that the overall local habitat is in poor health due to parasite load, inadequate nutrient availability, or environmental pollutants (Franklin et al. 1987, Herms and McCullough 2014). Poor quality habitats with an abundance of snag trees do not provide the proper foraging grounds bats require. There is a balance between the basal areas of live and snag trees that create appropriate habitat for successful general bat foraging. For the two *Myotis* species of concern proximity to the nearest tree was an important predictor. The northern long-eared bat, a clutter adapted species, is often associated with habitats with more structural clutter and more densely dispersed trees. In this analysis, increasing the distance from the nearest tree, thus creating a less cluttered airspace, predicted an increase in northern long-eared bat activity. The structural clutter

of preferred habitat types and the high characteristic frequency of echolocation pulses may reduce the ability of this species to be recorded and identified. The differing detection rates of bat species on the landscape could influence model results and habitat associations.

Natural Landscape-Level Habitat Models. – While site-level habitat features influence bat activity at a localized scale, landscape-level parameters influence microhabitat parameters across the property and can be used to define the spatial needs of bat species at a much larger scale. Natural landscape features include landcover information of naturally occurring types, such as forests and water features. In the natural landscape models, the distance to forested landcover was important for all three focal categories. The relationship between total bat activity and distance to forested landcover was positive; however a negative influence was predicted for this parameter and northern long-eared bat and Indiana bat activity. Additionally, distance to grassland and streams were significant negative parameters in northern long-eared bat models but did not have large effect sizes in comparison to distance to forested landcover.

Of the three landscape model categories, the natural landscape parameters are easier to manipulate. Distance to forested landcover was found to be an important predictor for all three focal categories of bat activity. For total bat activity, the relationship to forest distance was positive. This can likely be attributed to the proportion of open-air foragers identified. A large portion of total bats recorded were assigned an identification of big brown bat or eastern red bat. Big brown bats are often considered a habitat generalist without strong habitat associations. This lack of specialization allows for the bat to utilize a variety of habitats for food resources (Furlonger et al. 1987, Agosta

2002). Eastern red bats are also considered to be open, area foragers or habitat generalists. This quality could be responsible for the observed negative effect of distance to forest, as a large percentage of bats were identified as eastern red bats. Other studies have found that eastern red bats foraged frequently over pasture land, cemeteries, parks, and forested habitats (Walters et al. 2004). The wing structure and diet composition of eastern red bats contribute to its success in a wide variety of habitats (Clare et al. 2009). Additionally, due to the compliance to federal survey regulations, detectors were primarily deployed in areas relatively free of clutter. While this requirement allows for bat pulses to be more clearly recorded and identified, the species composition may also be impacted. For the *Myotis* species of concern, northern long-eared bat and Indiana bat, a negative relationship to forest distance was observed, indicating that these species require forested landcover in relatively close proximity for successful foraging and roosting. Other studies have found Indiana bats to be dependent on forested landcover for roosting habitat, foraging grounds, and commuting corridors (Murray and Kurta 2004, Sparks et al. 2011). Northern long-eared bats are considered to be more forest-dependent than Indiana bats due to its physical adaptations to clutter. Similar studies have found that northern long-eared bats were constrained to forest features and water features with high levels of forested cover (Broders et al. 2004, Henderson and Broders 2008). Northern long-eared bat activity was also observed to have a negative relationship to stream distance, which may indicate an interaction between forested landcover and stream availability on the landscape. While *Myotis* species may not be using the forested areas directly as a foraging resource in all cases, the cover provided by the forest and its edge allow for a safer opportunity to access water resources and commute between areas.

Modified Landscape-Level Habitat Models. – Anthropogenic landscape features, such as distance to buildings or roads, and the related disturbance, impact wildlife species differentially. Bat populations are declining, partially due to increased anthropogenic modifications. While some of these features are relatively permanent, understanding the impacts of habitat alteration can influence the planning process and feature placement for future projects. The distance to human modification was found to be a significant parameter in all three focal groups. For total bat and northern long-eared bat activity, the relationship was negative; as the distance from human modification increases, bat activity in the previous groups decrease. Indiana bat activity was predicted to have the opposite directionality with a positive relationship. Distance to drivable roads was only significant in models predicting total bat activity. With an increase in distance from drivable roads, total bat activity was predicted to increase.

Both distance to human modifications and distance to roads were found to be significant predictors in at least one of the focal categories of bat activity. The presence of human modifications can potentially have both a positive and negative impact on bat activity. For example, artificial light sources on the nighttime landscape serve as foraging resources for some bat species. Insects are found to aggregate around light sources, and several bat species exploit these artificial concentrations of insects (Gehrt and Chelsvig 2003, Adams et al. 2005). The big brown bat and eastern red bat are two of the species that are found to exploit congregations of insects around artificial light sources (Geggie and Fenton 1985, Furlonger et al. 1987, Hickey et al. 1996). Since the large majority of bat pulses were identified as big brown bats or eastern red bats, the behaviors of these species drive the negative relationship exhibited as distance to human modifications and

total bat activity. However, not all species are tolerant of artificial lights. Another study examined the impact of light pollution on species groups, and found that *Myotis* species found in the region were light intolerant (Lacoeuilhe et al. 2014). The presence of artificial light sources can also negatively influence the movement of bat species and delay commuting times (Stone et al. 2009). Indiana bats could be deemed more light intolerant than northern long-eared bats as these species displayed contradicting effect directionality in relation to distance from human-modified landscapes. An additional component of anthropogenically modified habitats is the presence of roadways. Habitat loss, movement barriers, and direct mortality are considered some of the main threats to bats imposed by the presence of roads (Fensome and Mathews 2016). The type of habitat surrounding the roadway influences bat activity as well. Woodland habitats surrounding roads have been found to have higher bat activity than open field habitats around roads, as the impact of roads travel further into the field habitats (Medinas et al. 2019). On the landscape of WHFRTC, the majority of roadways are bordered by field habitats, so the impact of the roadway can penetrate further into environment, reducing the amount of bat activity. Other studies have found similar results of decreased bat activity around roadways, with an increased probability of recording bat species as distance from a road increases (Loeb and O’Keefe 2006, Berthinussen and Altringham 2012, Kitzes and Merenlender 2014).

Topography Landscape-Level Habitat Models. – Topographic landscape features are another suite of factors that can largely determine microhabitat characteristics. The slope and aspect of the landscape can influence environmental parameters such as ground temperature, wind speeds, and moisture content of soils (Porter et al. 2002). Additionally,

elevational gradients influence the vegetation patterns (Wall and Darwin 1999). Models were created using topographic parameters to determine how the landscape topography influences bat activity. Aspect and property orientation were found to be significant parameters for predicting both total bat activity and northern long-eared bat activity. A negative relationship was displayed between total bat activity and aspect; a contrasting positive relationship was predicted between northern long-eared bat activity and aspect. Property orientation was also an important parameter. The eastern property block being more strongly associated with activity in the previously mentioned focal categories. Slope was the only significant parameter observed in models predicting Indiana bat activity. The relationship was positive; an increase in slope predicts an increase in Indiana bat activity.

The physical topography of an area influences multiple microclimatic features upon which bat species are reliant. The aspect of a slope can impact wind speeds, temperature and moisture of the soil and atmosphere, and light intensity (Cantlon 1953). South-facing slopes in the northern hemisphere have been demonstrated to receive more solar exposure throughout the day which results in the microclimate being warmer and drier than northern slopes. In contrast northern-facing slopes are typically cooler and retain moisture more efficiently than southern slopes (Pielke and Avissar 1990, Stage and Salas 2007). These microclimatic differences due to aspect can be drastic enough to influence the composition of vegetation and wildlife populations, especially those that are highly dependent on specific temperature and moisture patterns for successful growth and development (Cantlon 1953, Holland and Steyn 1975).

Reproductive female bats and juveniles are highly dependent on temperature, as low temperatures can result in delayed gestation and development of juveniles (Hamilton and Barclay 1994, Callahan et al. 1997). Due to this temperature dependency, suitable roost structures with appropriate temperature gradients must be available on the landscape. As southern-facing slopes are typically warmer, northern long-eared bat may select roosts in these areas to facilitate thermoregulation of developing juvenile bats resulting increased activity levels as the aspect of the slope transitions from north-facing to south-facing (Carter and Feldhamer 2005). Additionally, as the slope gradient increases, Indiana bat activity was found to increase. As the slope increases, trees receive additional solar exposure. Reproductive Indiana bat seek out roosts with high ambient temperatures, so these trees with greater solar exposure can be utilized by maternity colonies. However, northern long-eared bat and Indiana bat activity comprise a small percentage of the total bat activity. Total bat activity was predicted to decrease as the aspect of the slope transitions from north- to south-facing. The larger proportion of total bat activity was composed of big brown bats and eastern red bats. These bat species may be utilizing the northern-facing slopes as foraging areas. Moist habitats support multiple insect life stages and may produce more insects than drier slopes (Tauber et al. 1998).

In addition to physical habitat characteristics, the two blocks of the property differed in terms of bat activity patterns. Total bat and northern long-eared bat activity was predicted to be higher at detector locations on the eastern property block. The impact of property block is dependent on multiple factors that are included in the other model suites. The detector locations on the eastern block of the property experienced the general trends of being surround by a decreased level of structural clutter with the presence of

larger trees. These site-level parameters may contribute to an increased level of bat pulses detection, as a decreased level of structural clutter allows for a greater number of pulses to be detected with greater clarity. Additionally, these detector locations were closer to grassland and human modified landcover types which serve as foraging resources. Live firing ranges were not found on the eastern property block which may reduce the overall impacts

Management Implications. – The WHFRTC property is commendably managed for multiple uses, notably military training, outdoor recreation, and wildlife conservation. In order to formulate the most effective plan for bat conservation and management on the landscape, it is important to define clear goals and objectives. As shown through the previously discussed results, Indiana bats and northern long-eared bats use the habitat resources of WHFRTC differently than the total bat population on the landscape.

If managing for the bat population as a whole, several precautions can be made in regard to firing range activities. Reducing activity in the late afternoon and early evening would decrease the disturbance to foraging and roosting bats. Additionally, scheduling fewer firing range events during June and July would decrease potential stressors to pregnant and lactating females, as well as juvenile bats. Habitat manipulation could also benefit bat populations. As shown in site-level habitat models, basal area of live trees was an important parameter; planting native trees in relatively open areas can provide cover while foraging, as well as potential roost sites, thus increasing total bat activity. Human modification to the natural landscape impacts wildlife populations. Reducing the amount of light on the nocturnal landscape would be a simple way to reduce human impacts to bat populations. One potential alternative would be to replace white lights with red lights.

Red lights do not disturb wildlife species to the same degree as traditional lighting (Spoelstra et al. 2017). Finally, a potential trend was observed between bat activity, property orientation, and minimum distance to a firing range. Bat activity was predicted to be greater on the eastern landscape and lower near firing ranges. Firing range location and property orientation are closely related parameters and may be driving the trends observed. As a result, future firing range construction should be limited to the western landscape in order to avoid firing range impacts on the eastern landscape.

The aforementioned management suggestions would be beneficial to the bat population as a whole. However, more specific recommendations can be made if the conservation and management goals are focused on the threatened and endangered bat species found across the landscape. Water is an important resource for bats. Northern long-eared bat activity was found to decrease as the distance from streams increased. Additionally, the Indiana bat, a riparian specialist, depends on accessible water sources. Reducing the amount of clutter surrounding water sources and removing excess surface vegetation will create more convenient access points for these bats. Improvement of overall stream and standing water quality would be a larger step to take towards bat and wildlife conservation as a whole. Distance to forest was also an important predictor for northern long-eared and Indiana bats. While these species are capable of navigating cluttered forest environments, impenetrable understory cover can hinder the ability of bats to navigate and locate prey effectively. Thinning the ground and understory levels of forested habitats, especially on the western property block would increase the likelihood of bats utilizing the space.

II.

AN INVESTIGATION OF NOCTURNAL PREDATOR-PREY RELATIONSHIPS: DO BATS ALTER NIGHTLY BEHAVIOR IN RESPONSE TO BROADCAST OWL CALLS?

INTRODUCTION

Bats are not solo actors on the landscape; these mammals interact with other species within their biotic community. Many of these interactions can be classified as predator-prey relationships, with bats capable of filling both roles. The dynamics between prey species and their predators have been explained through a variety of models. These interactions influence numerous concepts in the field of population ecology, such as density dependence of populations and ecosystems (Drossel et al. 2001). The interactions between predator and prey also influence behavior and adaptation. Predation risk can drive the evolution of structures used in anti-predator defense or cryptic coloration (McCollum and Leimberger 1997, Eklöv and Vankooten 2001, Werner and Peacor 2003, Conner and Corcoran 2012). More subtly, however, is the development of behaviors which minimize the risk of potential predation. For example, lunar phase and resultant luminosity elevate predation risk for many nocturnal species. In response, prey species may decrease levels of activity or vocalizations during these periods of heightened predation risk (Daly et al. 1992, Mougeot and Bretagnolle 2000). Additionally, chemical signals indicating the presence of a predator can elicit behavioral responses, such as reduced movement, avoidance, or habitat shifts (Apfelbach et al. 2005, Bucciarelli and Kats 2014). Decisions made by individuals are influenced by variable levels of predation risk and the trade-off between safety, feeding, securing a mate, or other objectives (Lima

and O’Keefe 2013). Virtually all vertebrate species experience the pressures of predator-prey interactions and have been studied in depth; however, bat species are generally underrepresented due to challenges associated with observing free-flying bat behavior (Lima and O’Keefe 2013).

Of the existing studies involving bats and their predation risk, the majority occur in tropical ecosystems. In such studies, bats have been documented as prey for diurnal birds, nocturnal birds, mammals, large arthropods, fish, amphibians and other bats (Boinski and Timm 1985, Rodriguez-Duran 1996, Vargas et al. 2002, Molinari et al. 2005, Mikula 2015, Mikula et al. 2016). Due to the wide potential predation risk from multiple sources, many tropical bats have developed anti-predator defenses in the form of behavioral adaptations. Delaying emergence times from the roost has been shown to minimize the threat of diurnal birds attacking during dusk and other predation threats (Duverge et al. 2000, Thomas and Jacobs 2013). Additionally, bats have been shown to be lunar phobic, and decrease activity levels on nights with high levels of lunar light. Doing so may reduce the risk of the predation from nocturnal birds, such as owls (Reith 1982, Lang et al. 2006).

Bats in temperate regions, such as across the eastern United States, likely experience a predation risk lower than their tropical counterparts. No predators are known to specialize on bats, but various species have been reported to eat bats opportunistically (Lima and O’Keefe 2013). Diurnal avian predators and omnivores have been reported to attack colonial bats as they emerge from maternity roosts and hibernacula (Macy and Macy 1939, Lee and Kuo 2001, Hernández et al. 2007). Bats have also been reportedly taken as prey by large fish and frogs while utilizing water resources

(Mikula 2015). Mammalian predators have been observed exploiting roosting bats within caves (Goodpaster and Hoffmeister 1950). Additionally, dissected owl pellets have also been reported to contain remains of multiple bat species (Jung et al. 2011, Khalafalla and Iudica 2012, Bergstrom and Smith 2017). Of these documented predators, owls form the most logical group of natural predators. Considering this, seven species of owls are known to occur across western Kentucky (Rasmussen et al. 2015).

Like tropical bats, temperate bats are reported to vary their emergence time to potentially avoid predation risk by opportunistic diurnal raptors at the roost site (Jones and Rydell 1994). Additionally, lunar phase and ambient light conditions have been shown to affect the temporal foraging patterns of insectivorous bats (Lang et al. 2006). Studies involving the manipulation of perceived predation risk at the roost site have also been conducted (Petrželková and Zúkal 2003); however, the anti-predator response behaviors of foraging bats away from the roost have not been studied in detail (Baxter et al. 2006, Janos 2013).

Body size has the potential to influence the behavior of prey species. Larger-bodied species may not be as susceptible to predation events due to a size incompatibility between predator and the prey. For example, an Eastern screech owl (*Megascops asio*) with an average wingspan of approximately 48-61 cm (Ritchison et al. 2017), could be assumed to have some difficulty capturing and consuming a hoary bat (*Lasiurus cinereus*) with a reported average wingspan of 34 - 41 cm (Harvey et al. 1999). However, larger owl species such as Great horned owls (*Bubo virginianus*) and barred owls (*Strix varia*) would be more capable of consuming bat prey items, especially smaller-bodied bats which are common within nocturnal communities in the eastern United States.

The objectives of this study were to determine if bats alter activity across nights or within nights in response to an auditory predation threat. Due to the potential influence of body size on predator response, three bat species with differing body sizes were also examined in addition to total bat activity. These focal bat species include the big brown bat (*Eptesicus fuscus*), eastern red bat (*Lasiurus borealis*), and tri-colored bat (*Perimyotis subflavus*). Big brown bats are found throughout most of the United States, and with a wingspan of 32-40 cm and an average weight of 14-21 g, it is considered one of the larger bats in Kentucky (Agosta 2002). Eastern red bats can be considered a medium sized bat with a wingspan of 28-33cm and an average body weight of 9-15 g. It ranges throughout most of the eastern United States (Shump and Shump 1982). Finally, tri-colored bats are one of the smallest bat species in Kentucky with a wingspan of 21-26 cm and an average weight of 6-8 g (Harvey et al. 1999). Due to the recorded differences in body size and weight, these focal bat species may display differential responses to predation cues. The hypotheses of this study were that total bat activity will decrease in response to a predation threat and that small-bodied bat species, such as tri-colored bats, will decrease overall activity in response to predator cues while larger bodied species, big brown bats and eastern red bats will not show decreases in activity.

STUDY AREA

The study was conducted at the Wendell H. Ford Regional Training Center (WHFRTC), a property owned and managed by the Kentucky Army National Guard (KYANG), in Muhlenburg County, Kentucky. The property encompasses approximately 4,400 ha and is bisected into an eastern and western portion by KY Highway 181 (Figure

2-1). The area is located in the Green River–Southern Wabash Lowlands Level IV ecoregion (Woods et al. 2002). Bottomland forest, upland oak-hickory forest, and wetlands once comprised much of this region. However, pasture land, agricultural fields, and both active and reclaimed coal mining now comprise the majority land use in the area. Historic coal mining activity occurred across approximately 3,400 ha of WHFRTC; contemporary landscape composition is as follows: 34% pine or hardwood forest, 10% water resources including lakes, ponds, streams, and both natural and man-made wetlands, and 54% open grassland or shrub land (Calibre Systems 2002). Dominant species in the lattermost category generally consist of non-native flora such as invasive reeds (*Phragmites* spp.), Musk thistle (*Carduus nutans*), Chinese bush clover (*Lespedeza cuneate*), and Johnson grass (*Sorghum halepense*) (C. McNamara, pers. obs.).

METHODS

Owl playbacks at acoustic detector locations – To assess the response of bats to a perceived predation threat, broadcast owl calls were coupled with full spectrum acoustic detectors, Song Meter 2 BAT+ (Wildlife Acoustics). Owl vocalizations and all other sound files were obtained from the Macaulay Library at the Cornell Lab of Ornithology and the Borror Lab of Bioacoustics at Ohio State. Great horned owl and barred owl calls were selected due to the likelihood of these owl species preying upon bats (Bergstrom and Smith 2017). A total of four differing vocalizations were selected for each owl species. Files were used if the audio file was at least 30 sec in length and of high acoustic quality. A master file of all vocalizations was created using Audacity v. 2.1.3 (Audacity

Team 2017); one owl species vocalization played for 30 sec with a 10-min silent period separating each call. The order of owl vocalizations within the master audio files was randomly generated. The sequence of owl calls and silence was repeated throughout the night, beginning 30 min prior to sunset and ending 30 min after sunrise. An ambient night time noise sound file was created with sounds from nocturnal insects and amphibians inhabiting the study area (Table 2-1); broadcasting followed the same sequence as the owl call treatment. Waterproof speakers (Bliiq Infinite X) were used to broadcast playbacks (Figure 2-2). The amplitude of playbacks with this system was measured to be 80.5 ± 0.8 db at 1.0 m from the speaker ($n = 16$ observations) and were audible to the investigators up to a distance of 89.8 ± 2.4 m ($n = 16$ observations) under standardized conditions (Taylor Fork Ecological Area, 5 May 2017).

Each sampling unit consisted of three acoustic detectors with one of three unique treatments assigned at random: owl calls, ambient nighttime noise, and no sound playback. Simultaneous sampling occurred concurrently across two sampling units during the study (i.e., 6 acoustic detectors were deployed at any given time); sampling units corresponded to discrete training areas designated by KYANG. Within each sampling unit, three acoustic detectors were deployed, each with a unique audio treatment. Each individual detector was placed at a randomly generated point within the selected unit. A deployment occurred across three consecutive nights. Each night a different auditory treatment accompanied a detector; the order of auditory treatments was randomly generated. A 200-meter minimum distance separated detector locations to minimize auditory playbacks being heard at multiple sampling locations (Janos 2013). Microphones were mounted on a 3-m-high pole and attached to the detectors via a 4-m

microphone cable. Detectors were placed 3 m away from sources of obstruction. Speakers were attached to a separate pole at height of 1.5 m with a distance of at least 1.5 meters separating the speaker and the detector (Figure 2-2). All sampling took place from June to August 2017 in compliance with survey protocol for threatened and endangered bat species (USFWS 2017).

Acoustic data processing – After each deployment, metadata was assigned to each recording file using the SonoBat Batch Attributer (Szewczak 2016). Through Kaleidoscope Pro (Wildlife Acoustics 2017) files were scrubbed, and files containing only noise were eliminated. Automatic identifications were then assigned to each recording containing a minimum of five call pulses using the Kaleidoscope Pro call reference library for Kentucky. A call pulse minimum prevents classifications made on singular call pulses and improves the reliability of identifications. A sensitivity setting of “(-1) more sensitive, liberal” was used in compliance with U.S. Fish and Wildlife Service’s Range-Wide Indiana Bat Summer Survey Guidelines (USFWS 2017). This is the program’s most robust setting for the identification of Indiana and northern long-eared bats, and exceeded the requirements set by the USFWS at the time of investigation (Ford 2016).

Assessing bat response to predation threats – When assessing bat response to predation threats, the mean number of bat passes per detector-night and mean number of bat passes per detector-hour post sunset were determined to assess activity for all bat species identified as well as species-specific activity. Response variables included total bat passes from all bat species identified through Kaleidoscope, as well as passes identified as big brown bat, eastern red bat, and tri-colored bat. These species were

selected due to differences in mean body size and commonality. Differences between auditory treatments within focal categories were examined using a Kruskal-Wallis test, as the data did not follow a normal distribution (Ostertagova et al. 2014). Additionally, temporal response variables were included in the analysis, such as hour-post sunset (USNO 2016) and monthly variation in bat passes recorded. Analyses were performed in R (R Core Team 2017).

RESULTS

Sampling effort – The total sampling effort from June through August of 2007 occurred across 36 sites (Figure 2-3) and resulted in 90 detector-nights and 990 detector-hours across four sampling units (Table 2-2). A total of 9,391 bat passes were recorded. Of these, 7,754 bat passes (82%) were identified and attributed to 13 species (Table 2-3). The focal species of my study, big brown bat, eastern red bat, and tri-colored bat, were the most commonly identified species during the sampling period (accounting for 16%, 45%, and 4% of all calls recorded, respectively).

Overall activity patterns – The data suggest total bat activity did not vary at the nightly level. No differences in total bat activity were observed across sampling units ($H_3 = 5.741$, $p = 0.125$) (Figure 2-4). Total bat activity did not vary across months ($H_2 = 1.056$, $p = 0.590$). The same monthly patterns were displayed when calls are divided into auditory treatments (Figure 2-5). Total bat activity in each sampling area did not vary in response to the auditory treatments. (Figure 2-6). There were no significant differences observed in total bat activity between auditory treatments ($H_2 = 0.383$, $p = 0.826$). Total

bat passes accumulated at similar rates regardless of auditory treatment. A 50 percent accumulation of total bat passes occurred between the third and fourth hour post-sunset; a 100 percent accumulation was observed between the eighth and ninth hour post-sunset (Figure 2-7a). When comparing the deviation between passes recorded during the control treatment and passes recorded during the auditory treatments, the predator treatment displayed fewer passes in eight out of eleven hours post-sunset. The largest deviation was observed in the first five hours of the night (Figure 2-8a).

Species-specific activity patterns – While the data do not suggest predator avoidance, the results do suggest within-night variation in activity across species. No differences were observed between auditory treatments in the overall activity of big brown bats ($H_2 = 0.052$, $p = 0.974$), eastern red bats ($H_2 = 0.443$, $p = 0.801$), or tri-colored bats ($H_2 = 0.626$, $p = 0.731$). However, graphical analysis indicates within-night variation across the focal species. Big brown bat passes accumulate more quickly on average within the night than other focal species. Between the first and second hour after sunset, 50 percent of big brown bat passes were recorded during nights with the control auditory treatment. During the predatory auditory treatment, 50 percent accumulation of passes was achieved between the third and fourth hours of the night (Figure 2-7b). In a comparison in the deviation from control treatment passes, the most deviation in big brown bat passes were displayed in the first two hours post sunset with more passes being recorded during the noise auditory treatment than the predator treatment. However, the deviation was fairly consistent with the control from the fifth through tenth hour of the night (Figure 2-8b). The average accumulation of eastern red bat passes within nights was consistent between auditory treatments as the 50 percent accumulation mark was reached

between hours three and four for all auditory treatment types (Figure 2-7c). The average deviation from eastern red bats passes recorded during the control treatment was consistently lower from the first to sixth hour post sunset for both noise and predator treatments (Figure 2-8c). The average accumulation of tri-colored bat passes reached 50 percent between the fifth and six hour during the control treatment. The 50 percent accumulation mark was reached between the fourth and fifth hour in nights with noise or predator treatments (Figure 2-7d). The average deviation from control passes was greater in the predator treatment within the first hour. Both treatments, predator and noise, were somewhat consistent with the control throughout the night, with a slight decrease in activity around the fifth hour (Figure 2-8d). Overall, patterns of avoidance of predator cues between nights was not displayed by the three focal species. However, unique within-night activity patterns were displayed by the focal species in response to the auditory treatments.

DISCUSSION

Sampling effort – This study builds upon an existing body of literature examining the responses of foraging and commuting bats to predator and noise stimuli. Similar studies have assessed the impacts of predation cues on bat activity portions of the night, ranging from a recording time of 20 minutes to one hour (Baxter et al. 2006, Janos 2013). The sampling design allowed for efforts that were an order of magnitude greater than previous investigations and, as such, provides far greater statistical power than any other

previous reports in the literature. This study can serve as a benchmark design for future efforts aiming to detect bat responses to predatory cues.

Spatial and Temporal Variation – Across the four sampling units, the number of bat passes recorded were similar. This observed similarity in bat activity can be attributed to the overall homogeneity of the landscape. As described previously, the landscape is primarily composed of open, shrub and grasslands. Additionally, activity patterns were consistent over the course of the study; no large increases or decreases were observed in bat activity into the later summer months. The consistent levels of bat activity indicate that bats do not alter activity patterns throughout the summer season. Sampling unit habitat variation and temporal effects did not impact bat activity throughout this study.

Overall activity patterns – This study indicates that bats do not alter nightly behaviors in response to an auditory predation threat. These results support findings by Janos and Root (2014). In contrast to the hypothesis, the amount of bat passes did not vary across treatments, be it owl playbacks or the ambient nighttime noise playback which is contrary to previous studies in which the avoidance of noise was documented (Baxter et al. 2006, Schaub et al. 2008). I speculate owl calls broadcast across the landscape may not have been interpreted as a predation treat or indication by bats. Typically, owls vocalize to defend territories or nests and to establish and maintain pair bonds during the mating season (Johnsgard 1988). Vocalizations are not made while hunting, as this would announce the location of the owl to prey species. While there is no response to an auditory threat, visual cues of an owl predator may elicit an avoidance response in bats.

Species-specific activity patterns – While the data do not suggest predator avoidance, the results do suggest within-night variation in activity across species. Foraging bat activity usually peaks within the first five hours after sunset and tapers off over the course of the night (Kunz 1973, Brooks 2009). However, some species display a unimodal pattern of activity with one peak in the early evening and reduced activity for the remainder of the night. Additionally, a bimodal pattern of activity can be exhibited with both an early evening peak in activity and a second spike in activity occurring before sunrise (Hayes 1997). Foraging activity of bats can be influenced by abundance of insect prey items, weather conditions, energy demands during pregnancy, and intraspecific competition (Hayes 1997). The data suggests big brown bats and tri-colored bats display a unimodal activity pattern, while eastern red bats display a more consistent activity level throughout the night.

The observed differences in nightly activity patterns between the three focal species could be linked to life history differences. Female eastern red bats have been documented to produce an annual litter size of one to five pups per season, with the average litter size being 2.3 pups (Shump and Shump 1982). Big brown bats typically have one pup per season, and tri-colored bats have been documented to have two pups per season with the rare occurrence of triplets in both species (Fujita and Kunz 1984, Kurta and Baker 1990). The larger average litter size corresponds to a greater overall expenditure of energy due to reproductive effort. This increased need for resources may drive eastern red bats to forage more often throughout the night. Additionally, these species differ in maternity roost site selection. Big brown bats are commonly found to utilize a broad range of roost locations, such as human structures, rock crevices, bat

boxes, snag trees, and exfoliating bark (Brigham 1991, Williams and Brittingham 1997). These locations typically provide more cover for bats, which results in more stability in microhabitat characteristics such as temperature and humidity (Lausen and Barclay 2003). In contrast to the maternity roost habits of big brown bats, tri-colored bats and eastern red bats utilize foliage roosts (Mager and Nelson 2001, Veilleux et al. 2003). These foliage day roosts are exposed to weather conditions that more protected roosts may not experience. Foliage roosts have been assigned a classification as a highly unstable roost type due to large fluctuations in temperature and humidity (Menzies et al. 2016). Due to summer conditions, bats in foliage roosts may experience higher rates of evapotranspiration. The water reserves of pregnant or lactating bats are stressed; lactating and pregnant females visit water resources more often than non-reproductive females (Adams and Hayes 2008). The added water loss due to environmental conditions may drive these bats to seek out water resources more frequently throughout the evening, resulting in high levels of eastern red bat activity throughout the entirety of the night.

Acoustic monitoring is a valuable tool for assessing bat activity and behavior but is not without limitations. Acoustic monitors are unable to accurately distinguish the number of bats calling within an area (Limpens and McCracken 2004). Additionally, it is important to acknowledge that all species are not equally detectable by acoustic detectors. Climatic factors (temperature, humidity), environmental factors (canopy structure), and echolocation capabilities (frequency range, amplitude, orientation to microphone) can impact the detectability of bats on the landscape (Gannon and Sherwin 2004, Kaiser and O'Keefe 2015). However, through repeated sampling, and limiting inferences to within species trends, my design aimed to account for these sources of variation. Through

conscious efforts to circumvent bias, this non-intrusive method technique allows for the generation of large datasets that span multiple hours and nights.

Future directions and conclusions –While this study suggests that total bat activity is not altered by auditory predation cues or noise, subtle differences in within-night activity patterns were detected across focal species. Future efforts may seek to address these fine-scale differences. Within the current study, predator cues were only presented through auditory playbacks. However, predators can also broadcast their presence using visual or olfactory indicators; bat response to these cues has been assessed with mixed results (Petrželková and Zúkal 2001, Boyles and Storm 2007, Driessens and Siemers 2010, Breviglieri et al. 2013). Future studies may aim to investigate the influence of multiple predation cues, such as coupling auditory playbacks with a predator model and chemical cues. This study contributes to the existing body of literature seeking to describe activity patterns of foraging and commuting bats on the landscape and provides a suggested benchmark for survey effort and design to assess the behavioral response of bats using acoustic techniques.

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APPENDICES

Appendix A

Tables

Table 1-1. All candidate parameter definitions and abbreviations.

Model Name	Parameter	Abbreviation
Spatial Firing range	Average Firing range Distance	AVGRNG
	Distance to Firing range in Use	DISUSE
	Maximum Firing range Distance	MAXRNG
	Minimum Firing range Distance	MINRNG
	Multiple Firing ranges in Use	MULTRN
	Property Block	DTSIDE
	Single Firing range in Use	SNGLRN
Temporal Firing range	After Sunset Activity (Firing range 1)	ASARN1
	Duration in Hours (Firing range 1)	DHRRN1
	Duration in Hours (Firing range 2)	DHRRN2
	Duration of Activity After Sunset (Firing range 1)	DASRN1
	Number of Rounds Fired (Firing range 1)	NRFNR1
	Number of Rounds Fired (Firing range 2)	NRFNR2
	Property Block	DTSIDE
	Rounds per Hour (Firing range 1)	RPHRN1
	Rounds per Hour (Firing range 2)	RPHRN2
	Time of First Fire (Firing range 1)	TFFRN1
	Time of First Fire (Firing range 2)	TFFRN2
	Time of Last Fire (Firing range 1)	TLFRN1
	Time of Last Fire (Firing range 2)	TLFRN2
Local Habitat	Average Canopy Closure	AVGCLO
	Average Canopy Cover	AVGCOV
	Basal Area Live	BASLIV
	Basal Area Snag	BASSNG
	Basal Area Total	BASTOT

Table 1-1. Continued.

Model Name	Parameter	Abbreviation
	Property Block	DTSIDE
	Tree 1 DBH	TR1DBH
	Tree 1 Distance	TR1DIS
	Tree 1 Height	TR1HGT
	Tree 2 DBH	TR2DBH
	Tree 2 Distance	TR2DIS
	Tree 2 Height	TR2HGT
Landscape Level	Aspect	ASPECT
	Drivable Road Distance	DRDDIS
	Elevation	ELEVAT
	Forest Distance	FORDIS
	Grassland Distance	GRSDIST
	Human Modification Distance	HMDDIS
	Percent Slope	PRTSLP
	Property Block	DTSIDE
	Standing Water Distance	STWDIS
	Stream Distance	STRDIS

Table 1-2 Parameters displaying variance inflation factors (VIF) less than the cut-off value of two. These predictors were included in the final candidate models.

Model Name	Parameter	Abbreviation
Spatial Firing range	Minimum Firing range Distance	MINRNG
	Multiple Firing ranges in Use	MULTRN
	Single Firing range in Use	SNGLRN
Temporal Firing range	After Sunset Activity (Firing range 1)	ASARN1
	Duration of Activity After Sunset (Firing range 1)	DASRN1
	Number of Rounds Fired (Firing range 1)	NRFRN1
	Number of Rounds Fired (Firing range 2)	NRFRN2
	Rounds per Hour (Firing range 1)	RPHRN1
Local Habitat	Basal Area Live	BASLIV
	Basal Area Snag	BASSNG
	Tree 1 Distance	TR1DIS
	Tree 2 DBH	TR2DBH
Landscape	Aspect	ASPECT
	Drivable Road Distance	DRDDIS
	Forest Distance	FORDIS
	Grassland Distance	GRSDIST
	Human Modification Distance	HMDDIS
	Percent Slope	PRTSLP
	Property Block	DTSIDE
	Standing Water Distance	STWDIS
	Stream Distance	SRMDIS

Table 1-3 Candidate generalized linear mixed models with negative binomial distribution used to model associations between collected parameters and bat focal group activity at Wendell H. Ford Regional Training Center. Focal groups include total bats, *Myotis septentrionalis*, and *Myotis sodalis*.

Model Group	Model ID	Parameters
Spatial Firing range	SR 1	Global Model
	SR 2	SNGLRN
	SR 3	MULTRN
	SR 4	MINRNG
	SR 5	SNGLRN + MULTNR
	SR 6	SNGLRN + MINRNG
	SR 7	MULTRN + MINRNG
Temporal Firing range	TR 1	Global Model
	TR 2	NRFRN1
	TR 3	RPHRN1
	TR 4	ASARN1
	TR 5	DASRN1
	TR 6	NRFNR2
	TR 7	NRFR1 + RPHRN1
	TR 8	NRFRN1 + ASARN1
	TR 9	NRFRN1 + DASRN1
	TR 10	NRFRN1 + NRFNR2
	TR 11	RPHRN1 + ASARN1
	TR 12	RPHRN1 + DASRN1
	TR 13	RPHRN1 + NRFNR2
	TR 14	ASARN1 + DASRN1
	TR 15	ASARN1 + NRFNR2
	TR 16	DASRN1 + NRFNR2

Table 1-3. Continued

Model Group	Model ID	Parameters
Local Habitat	LH 1	Global Model
	LH 2	TR1DIS
	LH 3	TR2DBH
	LH 4	BALIV
	LH 5	BASSNG
	LH 6	TR1DIS + TR2DBH
	LH 7	TR1DIS + BASLIV
	LH 8	TR1DIS + BASSNG
	LH 9	TR2DBH + BASLIV
	LH 10	TR2DBH + BASSNG
	LH 11	BASLIV + BASSNG
Landscape - Natural	LN1	Global Model
	LN2	FORDIS
	LN3	GRSDIS
	LN4	STWDIS
	LN5	SRMDIS
	LN6	FORDIS + GRSDIS
	LN7	FORDIS + STWDIS
	LN8	FORDIS + SRMDIS
	LN9	GRSDIS + STWDIS
	LN10	GRSDIS + SRMDIS
	LN11	STWDIS + SRMDIS
Landscape - Modified	LM 1	Global Model
	LM 2	HMDDIS
	LM 3	DRDDIS
Landscape - Topography	LT1	Global Model

Table 1-3. Continued

Model Group	Model ID	Parameters
	LT2	DTSIDE
	LT3	ASPECT
	LT4	PRTSLP
	LT5	DTSIDE + ASPECT
	LT6	DTSIDE + PRTSLP
	LT7	ASPECT + PRTSLP

Table 1-4. Summary of Chiropteran species identified from acoustic surveys at Wendell H. Ford Regional Training Center from June-August of 2016 on the eastern property block and May-June 2017 on the western property block. Kaleidoscope Pro was used to determine species level identifications

Species Identification	2016	2017
<i>Corynorhinus townsendii</i> / <i>C. rafinesquii</i>	16	2
<i>Eptesicus fuscus</i>	4367	269
<i>Lasiurus borealis</i>	4124	6378
<i>L. cinereus</i>	145	241
<i>Lasionycteris noctivagans</i>	1191	479
<i>Myotis austroriparius</i>	19	77
<i>M. grisescens</i>	77	92
<i>M. leibii</i>	8	49
<i>M. lucifugus</i>	377	364
<i>M. septentrionalis</i>	47	21
<i>M. sodalis</i>	23	40
<i>Nycticeius humeralis</i>	325	767
<i>Perimyotis subflavus</i>	710	740

Table 1-5. Bat passes identified as threatened and endangered species, *Myotis septentrionalis* (MYSE) and *Myotis sodalis* (MYSO), per training area at Wendell H. Ford Regional Training Center in summer 2016 and 2017. Identifications were made using two USFWS approved programs: Kaleidoscope Pro and Bat Call Identification Software (BCID).

Training Area	BCID		Kaleidoscope Pro	
	MYSE	MYSO	MYSE	MYSO
TA 1	0	2	16	4
TA 2	0	1	11	7
TA 3	0	0	4	1
TA 4	0	0	12	1
TA 5	0	0	12	5
TA 6	0	0	0	8
TA 7	1	1	9	27
TA 8	0	0	0	0
TA 9	0	0	3	9
Flight Strip	0	0	1	7

Table 1-6. Site locations of *Myotis sodalis* detections using Kaleidoscope Pro and Bat Call Identification Software at Wendell H. Ford Regional Training Center. Sites noted with an asterisk had identifications of MYSO using both software packages.

Site Name	Latitude	Longitude
WHF001*	37.280	-87.179
WHF009	37.268	-87.167
WHF010*	37.265	-87.167
WHF023	37.285	-87.167
WHF030	37.271	-87.187
WHF037	37.270	-87.171
WHF040*	37.281	-87.170
WHF041*	37.292	-87.171
WHF087	37.283	-87.161
WHF102	37.291	-87.194
WHF104	37.293	-87.240
WHF107	37.294	-87.240
WHF108*	37.298	-87.236
WHF109	37.293	-87.234
WHF122	37.266	-87.239
WHF128	37.266	-87.217
WHF153	37.272	-87.223
WHF155	37.275	-87.218
WHF163	37.294	-87.259
WHF167	37.291	-87.251
WHF170	37.296	-87.248
WHF171	37.295	-87.245
WHF176	37.282	-87.221
WHF181	37.291	-87.236

Table 1-7. Site locations of *Myotis septentrionalis* detections using Kaleidoscope Pro and Bat Call Identification Software at Wendell H. Ford Regional Training Center. Sites noted with an asterisk had identifications of MYSE using both software packages.

Site Name	Latitude	Longitude
WHF002*	37.281	-87.179
WHF003	37.279	-87.179
WHF007	37.263	-87.174
WHF010*	37.265	-87.167
WHF012*	37.277	-87.162
WHF015*	37.282	-87.191
WHF020	37.298	-87.191
WHF024	37.281	-87.165
WHF037	37.270	-87.171
WHF044	37.293	-87.180
WHF061	37.270	-87.195
WHF064	37.262	-87.207
WHF068	37.277	-87.206
WHF078	37.260	-87.167
WHF081	37.280	-87.153
WHF086	37.286	-87.160
WHF100	37.290	-87.182
WHF102	37.291	-87.194
WHF104	37.293	-87.240
WHF108	37.298	-87.236
WHF128	37.266	-87.217
WHF151	37.271	-87.233
WHF153	37.272	-87.223
WHF155	37.275	-87.218

Table 1-8. Monthly patterns of threatened and endangered bat activity, *Myotis septentrionalis* (MYSE) and *Myotis sodalis* (MYSO), on Wendell H. Ford Regional Training Center between June to August 2016 and May to July 2017. Identifications were made using Kaleidoscope Pro and Bat Call Identification Software (BCID).

Year	Month	BCID		Kaleidoscope Pro	
		MYSE	MYSO	MYSE	MYSO
2016	June	0	1	9	4
	July	0	2	9	17
	August	0	0	29	2
2017	May	1	0	10	18
	June	0	0	11	21
	July	0	1	0	0

Table 1-9. Summary of military firing range use parameters from dates with corresponding acoustic detector deployments from summer 2016 and 2017 at Wendell H. Ford Regional Training Center. Means are presented with standard errors.

Range ID	Events	Detector Nights	Rounds Fired	Average Rounds per Event	Average Duration (hr)
A	1	11	20481	20481	7.35
B	6	38	21866	3644.34 ± 1632.93	3.87 ± 1.45
C	4	23	16992	4248 ± 2755.29	5.52 ± 2.54
E	3	21	38790	12930 ± 9390.22	7.73 ± 1.16
F	5	32	3748	749.60 ± 299.06	3.27 ± 0.85
61 single use;					
Total	19	32 multiple use	101877	5361.95 ± 1897.51	4.85 ± 0.79

Table 1-10. Summary of site-level habitat parameters collected from acoustic detector survey locations at Wendell H. Ford Regional Training Center in summer 2016 and 2017. Means are presented with standard errors. Differences were assessed with Wilcoxon Rank Sum Tests; an asterisk (*) denotes significance between east and west variables.

Habitat Parameter	East	West	p-value	$W_{98,75}$	All Points
Avg. Canopy Closure*	25.73 ± 2.52	43.52 ± 3.73	0.0004	3047.5	33.38 ± 2.25
Avg. Canopy Cover*	28.57 ± 3.66	37.60 ± 4.31	0.0442	3047.5	32.49 ± 2.80
Basal Area – Live*	15.37 ± 2.39	30.05 ± 3.91	0.0026	2711	21.69 ± 2.23
Basal Area – Snag	1.86 ± 0.645	1.57 ± 0.441	0.4595	3511	1.73 ± 0.413
Basal Area – Total*	17.20 ± 2.60	29.63 ± 3.97	0.0087	2831.5	22.59 ± 2.31
Tree DBH 1*	7.51 ± 0.625	5.48 ± 0.494	0.0152	4143.5	6.60 ± 0.417
Tree DBH 2	6.88 ± 0.655	5.94 ± 0.553	0.8147	3752	6.45 ± 0.437
Tree Distance 1*	30.10 ± 4.25	3.83 ± 0.616	0.0001	4900	18.98 ± 2.65
Tree Distance 2*	43.87 ± 4.14	6.16 ± 0.606	< 0.0001	6416.5	27.94 ± 2.81
Tree Height 1*	32.27 ± 2.00	12.59 ± 0.742	< 0.0001	5967	23.52 ± 1.39
Tree Height 2*	32.26 ± 2.04	12.88 ± 0.828	< 0.0001	5830	23.49 ± 1.40

Table 1-11. Summary of landscape-level parameters collected using ArcMap. Data was derived from acoustic detector survey locations at Wendell H. Ford Regional Training Center in summer 2016 and 2017. Means are presented with standard errors. Differences were assessed with Wilcoxon Rank Sum Tests; an asterisk (*) denotes significance between east and west variables

Landscape Parameter	East	West	p-value	$W_{98,75}$	All Points
Aspect	193.97 ± 10.21	172.55 ± 11.67	0.1768	4557	184.55 ± 7.7
Distance to Forest*	71.81 ± 10.59	21.77 ± 5.44	< 0.0001	5561.5	49.81 ± 6.64
Distance to Grassland*	69.66 ± 15.84	293.71 ± 44.74	< 0.0001	2253.5	168.15 ± 23.04
Distance to Human Mod.*	484.41 ± 45.25	1284.82 ± 106.52	< 0.0001	2020.5	836.24 ± 60.74
Distance to Road	244.54 ± 38.82	225.09 ± 40.13	0.8929	4032	235.99 ± 27.94
Distance to Standing Water*	1325.36 ± 80.14	1086.16 ± 94.07	0.0297	4847.5	1220.22 ± 61.52
Distance to Stream*	1912.41 ± 148.62	1122.44 ± 77.55	0.0015	5200	1565.17 ± 94.4
Elevation	473.36 ± 3.62	482.04 ± 5.05	0.1976	3625	477.18 ± 3.02
Percent Slope	24.72 ± 2.38	28.2 ± 3.25	0.7888	3985	26.25 ± 1.95

Table 1-12. The top ranked generalized linear mixed models with negative binomial distribution of spatial firing range, temporal firing range, site-level habitat, and landscape-level associations for total bat activity at Wendell H. Ford Regional Training Center. Model names refer to those described in Table 4. An asterisk (*) denotes that the model differs significantly from the null model.

Model Group	Model	K_i	AIC_i	Δ_i	w_i
Spatial Firing range	SR 4*	2	5212.747	0	0.39805
	SR 6*	3	5213.321	0.6	0.29869
	SR 7*	3	5214.229	1.5	0.18969
	SR 1*	4	5215.312	2.6	0.11037
Temporal Firing range	TR 5*	2	5224.787	0	0.17517
	TR 14	3	5225.992	1.2	0.09589
	TR 6	2	5226.478	1.7	0.07521
	TR 9	3	5226.442	1.7	0.07658
Local Habitat	LH 11*	3	5201.654	0	0.60324
	LH 1*	5	5203.617	2	0.22608
	LH 5*	2	5206.03	4.4	0.06765
	LH 8*	3	5206.367	4.7	0.05717
Landscape - Natural	LN 2*	2	5220.247	0	0.35685
	LN 7*	3	5220.879	0.6	0.26013
	LN 8*	3	5222.186	1.9	0.13531
	LN 6*	3	5222.201	2	0.1343
Landscape - Modified	LM 1*	2	5216.434	0	0.58103
	LM 2*	2	5217.125	0.7	0.41121
	Null	1	5225.965	9.5	0.00495
	LM 3	2	5227.097	10.7	0.00281
Landscape - Topography	LT 5*	3	5196.843	0	0.5032
	LT 1*	4	5196.931	0.1	0.48166
	LT 3*	2	5205.173	8.3	0.00782
	LT 7*	3	5205.306	8.5	0.00731

Table 1-13. Model significance for the top four ranked models within in each model grouping, spatial firing range, temporal firing range, site-level habitat, and landscape-level, for total bat activity at Wendell H. Ford Regional Training Center. A bold p-value denotes that the model differs significantly from the null model when a Likelihood ratio tests of Negative Binomial Models was performed. Lambda (Λ) represents the Likelihood ratio test statistic.

Model Group	Model	$\Delta_{d.f.}$	Λ	p-value
Spatial Firing range	SR 4*	1	15.21766	9.58E-05
	SR 6*	2	16.64336	0.00024319
	SR 7*	2	15.7353	0.00038293
	SR 1*	3	16.65227	0.00083318
Temporal Firing range	TR 5*	1	3.177847	0.07464302
	TR 14	2	3.972766	0.1371908
	TR 9	2	3.20944	0.1718007
	TR 6	1	1.48686	0.2227044
Local Habitat	LH 11*	2	28.31048	7.12E-07
	LH 1*	4	30.34764	4.16E-06
	LH 5*	1	21.93454	2.82E-06
	LH 8*	2	23.59777	7.51E-06
Landscape - Natural	LN 2*	1	7.717696	0.00546822
	LN 7*	2	9.085452	0.01064435
	LN 8*	2	7.778148	0.02046429
	LN 6*	2	7.763195	0.02061786
Landscape - Modified	LM 1*	2	13.53078	0.001153
	LM 2*	1	10.83943	0.00099362
	Null	0	0	1
	LM 3	1	0.8673904	0.3516788
Landscape - Topography	LT 5*	2	33.12121	6.42E-08
	LT 1*	3	35.0337	1.20E-07
	LT 3*	1	22.79174	1.81E-06
	LT 7*	2	24.65893	4.42E-06

Table 1-14. The top ranked generalized linear mixed models with negative binomial distribution of spatial firing range, temporal firing range, site-level habitat, and landscape-level associations for *Myotis septentrionalis* activity at Wendell H. Ford Regional Training Center. An asterisk (*) denotes that the model differs significantly from the null model.

Model Group	Model	K_i	AIC_i	Δ_i	w_i
Spatial Firing range	SR 6*	3	355.965	0	0.64174
	SR 1*	4	357.842	1.9	0.25116
	SR 2*	2	360.196	4.2	0.07738
	SR 5*	3	362.188	6.2	0.02859
Temporal Firing range	TR 1*	7	362.118	0	0.75731
	TR 5*	2	366.852	4.7	0.07098
	TR 14*	3	367.075	5	0.06351
	TR 9*	3	367.786	5.7	0.04451
Local Habitat	LH 8*	3	371.5252	0	0.27971
	LH 2*	2	371.8291	0.3	0.24028
	LH 6*	3	373.4759	2	0.10547
	LH 7	3	373.7511	2.2	0.09191
Landscape - Natural	LN 10*	3	369.769	0	0.28912
	LN 1*	5	370.274	0.5	0.22458
	LN 6*	3	371.315	1.5	0.13347
	LN 5*	2	371.76	2	0.1068
Landscape - Modified	LM 2	2	374.176	0	0.38158
	LM 1	3	374.354	0.2	0.3491
	LM Null		375.661	1.5	0.18169
	LM 3	2	377.119	2.9	0.08763
Landscape - Topography	LT 5*	3	368.259	0	0.52763
	LT 1*	4	369.977	1.7	0.22348
	LT 3*	2	371.586	3.3	0.09999
	LT 2*	3	372.651	4.4	0.0587

Table 1-15. Model significance for the top four ranked models within in each model grouping, spatial firing range, temporal firing range, site-level habitat, and landscape-level, for *Myotis septentrionalis* activity at Wendell H. Ford Regional Training Center. A bold p-value denotes that the model differs significantly from the null model when a Likelihood ratio tests of Negative Binomial Models was performed. Lambda (Λ) represents the Likelihood ratio test statistic.

Model Group	Model	$\Delta_{d.f.}$	Λ	p-value
Spatial Firing range	SR 6*	2	23.69504	7.16E-06
	SR 1*	3	23.81887	2.73E-05
	SR 2*	1	17.46411	2.93E-05
	SR 5*	2	17.473	0.00016062
Temporal Firing range	TR 1*	5	23.54293	0.00026572
	TR 5*	1	10.80814	0.00101055
	TR 14*	2	12.58574	0.00184945
	TR 9*	2	11.87494	0.0026387
Local Habitat	LH 8*	2	8.135326	0.01711735
	LH 2*	1	5.8314	0.01574259
	LH 6*	2	6.184611	0.04539718
	LH 7	2	5.909462	0.05209267
Landscape - Natural	LN 10*	2	9.891793	0.00711254
	LN 1*	4	13.38658	0.00953351
	LN 6*	2	8.345941	0.01540643
	LN 5*	1	5.900089	0.01514012
Landscape - Modified	LM 2	1	3.484066	0.06196231
	LM 1	2	5.30617	0.0704336
	LM Null	0	0	1
	LM 3	1	0.5416983	0.4617298
Landscape - Topography	LT 5*	2	11.40174	0.00334306
	LT 1*	3	11.68355	0.00854968
	LT 3*	1	6.075004	0.0137108
	LT 2*	1	5.009877	0.0252031

Table 1-16. The top ranked generalized linear mixed models with negative binomial distribution of spatial firing range, temporal firing range, site-level habitat, and landscape-level associations for *Myotis sodalis* activity at Wendell H. Ford Regional Training Center. Model names refer to those described in Table 4. An asterisk (*) denotes that the model differs significantly from the null model.

Model Group	Model	K_i	AIC_i	Δ_i	w_i
Spatial Firing range	SR 4	2	392.072	0	0.34994
	SR 2	2	393.92	1.8	0.13886
	SR 7	3	393.851	1.8	0.14379
	SR 6	3	393.978	1.9	0.13489
Temporal Firing range	TR 4	2	393.2187	0	0.13885
	TR 5	2	393.6395	0.4	0.11251
	TR 6	2	394.0373	0.8	0.09221
	TR 2	2	394.0933	0.9	0.08967
Local Habitat	LH 8*	3	380.5392	0.0	0.5975
	LH 2*	2	383.0382	2.5	0.17127
	LH 1*	5	384.4584	3.9	0.0842
	LH 6	3	384.8516	4.3	0.06917
Landscape - Natural	LN 2*	2	387.73	0.0	0.36315
	LN 7*	3	389.243	1.5	0.17036
	LN 6*	3	389.359	1.6	0.16078
	LN 8*	3	389.701	2.0	0.13554
Landscape - Modified	LM 2*	2	388.328	0.0	0.59023
	LM 1*	3	389.793	1.5	0.2837
	LM Null	0	392.1	3.8	0.08955
	LM 3	2	393.894	5.6	0.03652
Landscape - Topography	LT 4*	2	389.118	0.0	0.32773
	LT 6*	3	389.754	0.6	0.23842
	LT 7	3	390.69	1.6	0.14932
	LT 1	4	391.398	2.3	0.10479

Table 1-17. Model significance for the top four ranked models within in each model grouping, spatial firing range, temporal firing range, site-level habitat, and landscape-level, for *Myotis sodalis* activity at Wendell H. Ford Regional Training Center. Model names refer to those described in Table 4. A bold p-value denotes that the model differs significantly from the null model when a Likelihood ratio tests of Negative Binomial Models was performed. Lambda (Λ) represents the Likelihood ratio test statistic.

Model Group	Model	$\Delta_{d.f.}$	Λ	p-value
Spatial Firing range	SR 4	1	2.027895	0.1544344
	SR 2	2	2.249069	0.3248036
	SR 7	1	0.1793531	0.6719298
	SR 6	2	2.121218	0.3462449
Temporal Firing range	TR 4	1	0.8809007	0.3479551
	TR 5	1	0.4601034	0.4975757
	TR 6	1	0.06231705	0.8028705
	TR 3	1	0.01771097	0.8941281
Local Habitat	LH 8*	2	11.0962	0.00389486
	LH 2*	1	11.06138	0.00088145
	LH 1*	4	15.64121	0.00354041
	LH 6	1	2.386582	0.122381
Landscape - Natural	LN 2*	1	6.369954	0.01160686
	LN 7*	2	6.856165	0.0324491
	LN 6*	2	6.740411	0.03438257
	LN 8*	2	6.398917	0.04078427
Landscape - Modified	LM 2*	1	5.771352	0.0162895
	LM 1*	2	6.306163	0.04272028
	LM Null	0	0	1
	LM 3	1	0.2059746	0.649941
Landscape - Topography	LT 4*	1	4.982076	0.02561123
	LT 6*	2	6.345775	0.04188249
	LT 7	2	5.409842	0.06687559
	LT 1	3	6.701616	0.08204153

Table 1-18. Model averaged estimates (β) of explanatory parameters with their respective conditional standard error (\pm SE) for total bat activity models. Estimates in bold indicate that the 85% confidence interval did not include zero, showing an effect.

Model Group	Parameter	$\beta \pm$ SE	CI 7.5%	CI 92.5%
Spatial Firing range	MINRNG	0.00015 \pm 0.00004	0.00009	0.00021
	MULTRN	0.14000 \pm 0.31590	-0.31523	0.59532
	SNGLRN	0.20600 \pm 0.18640	-0.06260	0.47466
Temporal Firing range	ASARN1	-0.76660 \pm 0.66600	-1.72649	0.19339
	DASRN1	0.05890 \pm 0.03612	0.00684	0.11095
	NRFRN1	0.00002 \pm 0.00002	-0.00001	0.00004
	NRFRN2	0.00030 \pm 0.00032	-0.00017	0.00076
	RPHRN1	0.00004 \pm 0.00006	-0.00005	0.00012
Local Habitat	BASLIV	0.00530 \pm 0.00221	0.00211	0.00849
	BASSNG	-0.08147 \pm 0.01345	-0.10085	-0.06209
	TR1DIS	-0.00169 \pm 0.00197	-0.00453	0.00115
	TR2DBH	-0.01402 \pm 0.01030	-0.02886	0.00083
Landscape Level	ASPECT	-0.00312 \pm 0.00061	-0.00400	-0.00224
	DRDDIS	0.00135 \pm 0.00064	0.00042	0.00227
	DTSIDE	-0.40830 \pm 0.12480	-0.58825	-0.22835
	FORDIS	0.00553 \pm 0.00218	0.00239	0.00867
	GRSDIST	-0.00022 \pm 0.00077	-0.00133	0.00088
	HMDDIS	-0.00097 \pm 0.00026	-0.00135	-0.00059
	PRTSLP	0.00337 \pm 0.00245	-0.00017	0.00690
	SRMDIS	0.00002 \pm 0.00018	-0.00023	0.00027
STWDIS	0.00028 \pm 0.00024	-0.00007	0.00062	

Table 1-19. Model averaged estimates (β) of explanatory parameters with their respective conditional standard error (\pm SE) for *Myotis septentrionalis* activity models. Estimates in bold indicate that the 85% confidence interval did not include zero, showing an effect.

Model Group	Parameter	$\beta \pm$ SE	CI 7.5%	CI 92.5%
Spatial Firing range	MINRNG	0.00033 \pm 0.00013	0.00015	0.00051
	MULTRN	-0.24235 \pm 0.79411	-1.38691	0.90221
	SNGLRN	1.80280 \pm 0.46118	1.13808	2.46752
Temporal Firing range	ASARN1	-0.71416 \pm 2.14513	-3.80320	2.37483
	DASRN1	0.67236 \pm 0.28715	0.25890	1.08586
	NRFRN1	0.00113 \pm 0.00058	0.00030	0.00196
	NRFRN2	0.00082 \pm 0.00089	-0.00047	0.00212
	RPHRN1	-0.01098 \pm 0.0053	-0.01861	-0.00335
Local Habitat	BASLIV	-0.00476 \pm 0.00883	-0.01748	0.00796
	BASSNG	-0.11353 \pm 0.08651	-0.23810	0.01104
	TR1DIS	0.01081 \pm 0.00501	0.00359	0.01802
	TR2DBH	0.01072 \pm 0.03519	-0.03998	0.06143
Landscape Level	ASPECT	0.00574 \pm 0.00208	0.00273	0.00874
	DRDDIS	0.00238 \pm 0.00202	-0.00053	0.00529
	DTSIDE	-0.94729 \pm 0.41119	-1.53997	-0.35463
	FORDIS	-0.01451 \pm 0.00938	-0.02803	-0.00100
	GRSDIST	-0.00807 \pm 0.00411	-0.01399	-0.00215
	HMDDIS	-0.00207 \pm 0.00100	-0.00351	-0.00062
	PRTSLP	-0.00573 \pm 0.00840	-0.01784	0.00638
	SRMDIS	-0.00141 \pm 0.00065	-0.00235	-0.00047
	STWDIS	0.00013 \pm 0.00086	-0.00110	0.00136

Table 1-20. Model averaged estimates (β) of explanatory parameters with their respective conditional standard error (\pm SE) for *Myotis sodalis* activity models. Estimates in bold indicate that the 85% confidence interval did not include zero, showing an effect.

Model Group	Parameter	$\beta \pm$ SE	CI 7.5%	CI 92.5%
Spatial Firing range	MINRNG	0.00016 \pm 0.00011	0.00002	0.00032
	MULTRN	-0.11373 \pm 0.86769	-1.36435	1.13689
	SNGLRN	-0.23070 \pm 0.53654	-1.00405	0.54265
Temporal Firing range	ASARN1	-1.77710 \pm 1.59110	-4.06804	0.51404
	DASRN1	-0.09239 \pm 0.11990	-0.26525	0.08048
	NRFRN1	0.00001 \pm 0.00004	-0.00005	0.00007
	NRFRN2	0.00035 \pm 0.00085	-0.00087	0.00156
	RPHRN1	-0.00002 \pm 0.00019	-0.00029	0.00025
	BASLIV	0.00082 \pm 0.00687	-0.00907	0.01072
Local Habitat	BASSNG	-0.13141 \pm 0.07089	-0.23359	-0.02924
	TR1DIS	-0.03849 \pm 0.01619	-0.06182	-0.01515
	TR2DBH	0.00769 \pm 0.02594	-0.02970	0.04508
	ASPECT	-0.00089 \pm 0.00179	-0.00348	0.00169
Landscape Level	DRDDIS	-0.00150 \pm 0.00190	-0.00423	0.00124
	DTSIDE	0.41563 \pm 0.35546	-0.09671	0.92797
	FORDIS	-0.02175 \pm 0.01040	-0.03674	-0.00677
	GRSDIST	0.00111 \pm 0.00188	-0.00159	0.00382
	HMDDIS	0.00148 \pm 0.00064	0.00055	0.00240
	PRTSLP	0.01612 \pm 0.00573	0.00786	0.02438
	SRMDIS	-0.00010 \pm 0.00048	-0.00080	0.00059
	STWDIS	0.00051 \pm 0.00066	-0.00044	0.00147

Table 2-1. Digital files used in auditory treatments to assess bat response to potential predation threats and common nocturnal noises at Wendell H. Ford Regional Training Center from June to August of 2017. Audio files were sourced from the Borror Laboratory of Bioacoustics (BLB; <https://blb.osu.edu>) and Macaulay Library at the Cornell Lab of Ornithology (ML; <https://www.macaulaylibrary.org>).

Category	Species	Source	Catalog Number
Frog	<i>Anaxyrus fowleri</i>	BLB	8492
Frog	<i>Lithobates catesbeianus</i>	BLB	7589
Frog	<i>Lithobates clamitans</i>	BLB	44815
Frog	<i>Lithobates sylvaticus</i>	BLB	17194
Insect	<i>Pterophylla camellifolia</i>	BLB	13670
Insect	<i>Tibicen robinsoniana</i>	BLB	27039
Insect	<i>Tibicen tibicen</i>	BLB	7247
Insect	<i>Tibicen tibicen</i>	BLB	27044
Owl	<i>Bubo virginianus</i>	BLB	29110
Owl	<i>Bubo virginianus</i>	BLB	12991
Owl	<i>Bubo virginianus</i>	ML	22874
Owl	<i>Bubo virginianus</i>	ML	50548
Owl	<i>Strix varia</i>	BLB	17226
Owl	<i>Strix varia</i>	BLB	13418
Owl	<i>Strix varia</i>	ML	188896
Owl	<i>Strix varia</i>	ML	125364

Table 2-2. Number of detector nights recorded using passive acoustic detectors per sampling units to assess bat response to predator cues at Wendell H. Ford Regional Training Center June to August of 2017.

Sampling Unit	Detector Nights
TA F	21
TA 1	24
TA 3	24
TA 4	21

Table 2-3. Summary of Chiropteran species identified from acoustic surveys to assess bat response to predator cues at Wendell H. Ford Regional Training Center from June-August of 2017. Kaleidoscope Pro was used to determine species level identifications.

Species Identification	Passes Identified
<i>Corynorhinus townsendii</i> / <i>C. rafinesquii</i>	42
<i>Eptesicus fuscus</i>	1589
<i>Lasiurus borealis</i>	4290
<i>L. cinereus</i>	61
<i>Lasionycteris noctivagans</i>	440
<i>Myotis austroriparius</i>	22
<i>M. grisescens</i>	65
<i>M. leibii</i>	9
<i>M. lucifugus</i>	283
<i>M. septentrionalis</i>	47
<i>M. sodalis</i>	55
<i>Nycticeius humeralis</i>	436
<i>Perimyotis subflavus</i>	415

Appendix B

Figures

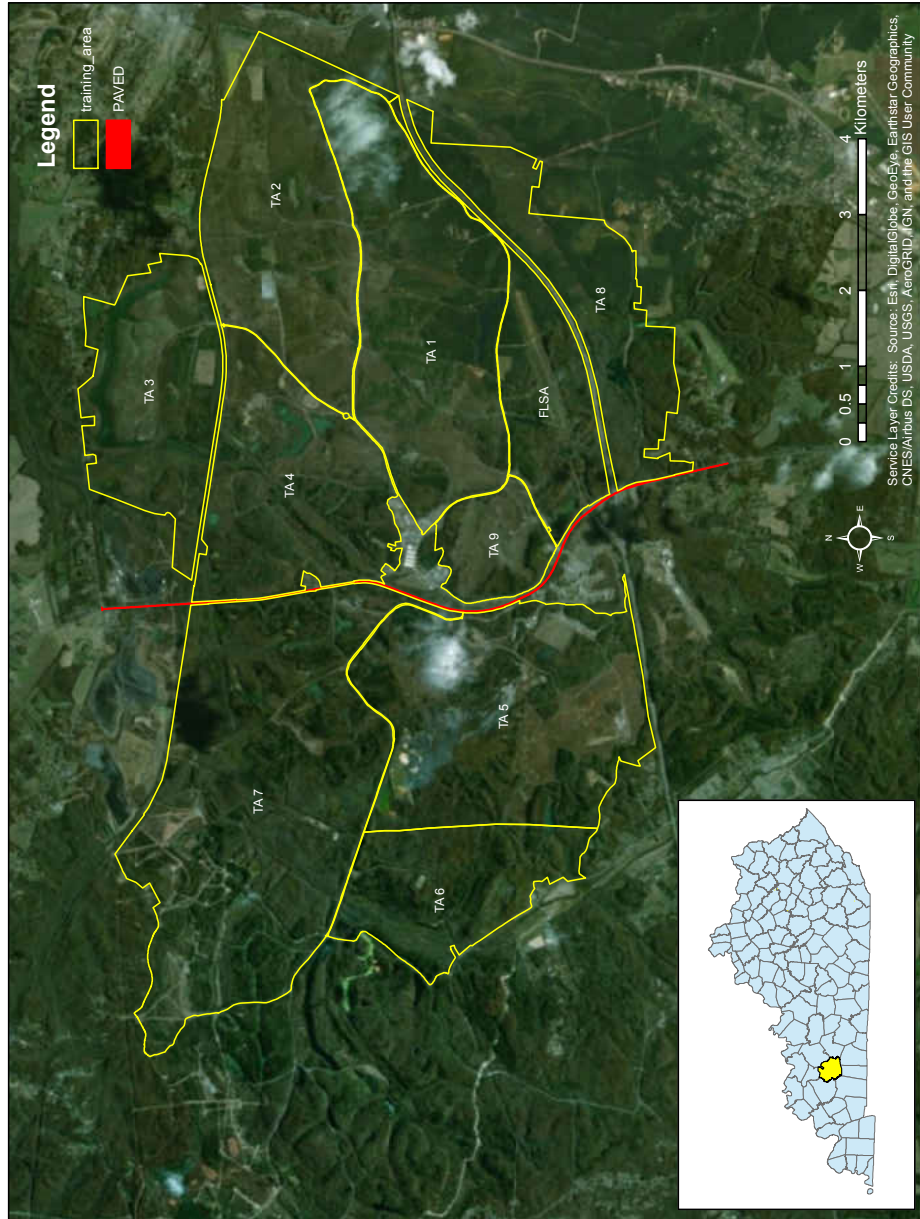


Figure 1-1. Map of Wendell H. Ford Regional Training Center in Muhlenburg County Kentucky. The property, owned by Kentucky Army National Guard, encompasses approximately 4,400 ha in the Green River–Southern Wabash Lowlands Level IV ecoregion. Training areas or sampling units are delineated in yellow. Kentucky Highway 181 bisects the property and is delineated in red.

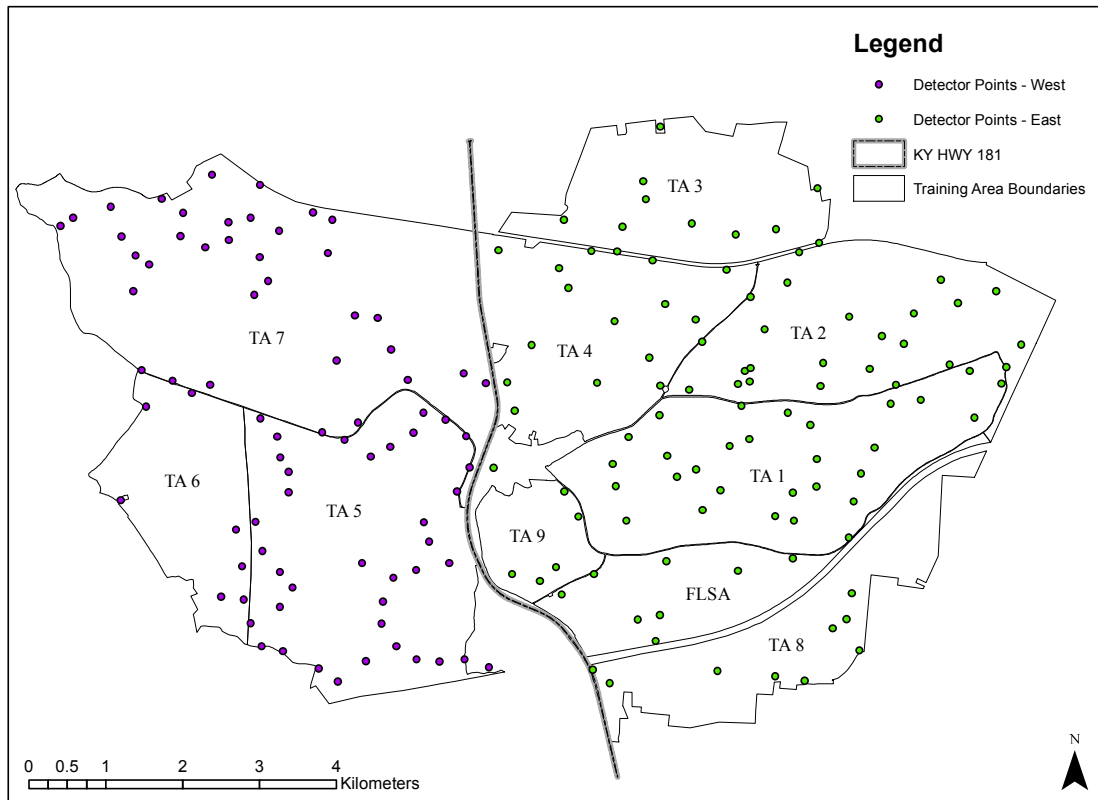


Figure 1-2. Map of acoustic detector locations deployed between 2017 and 2018 at Wendell H. Ford Regional Training Center in Muhlenburg County Kentucky.

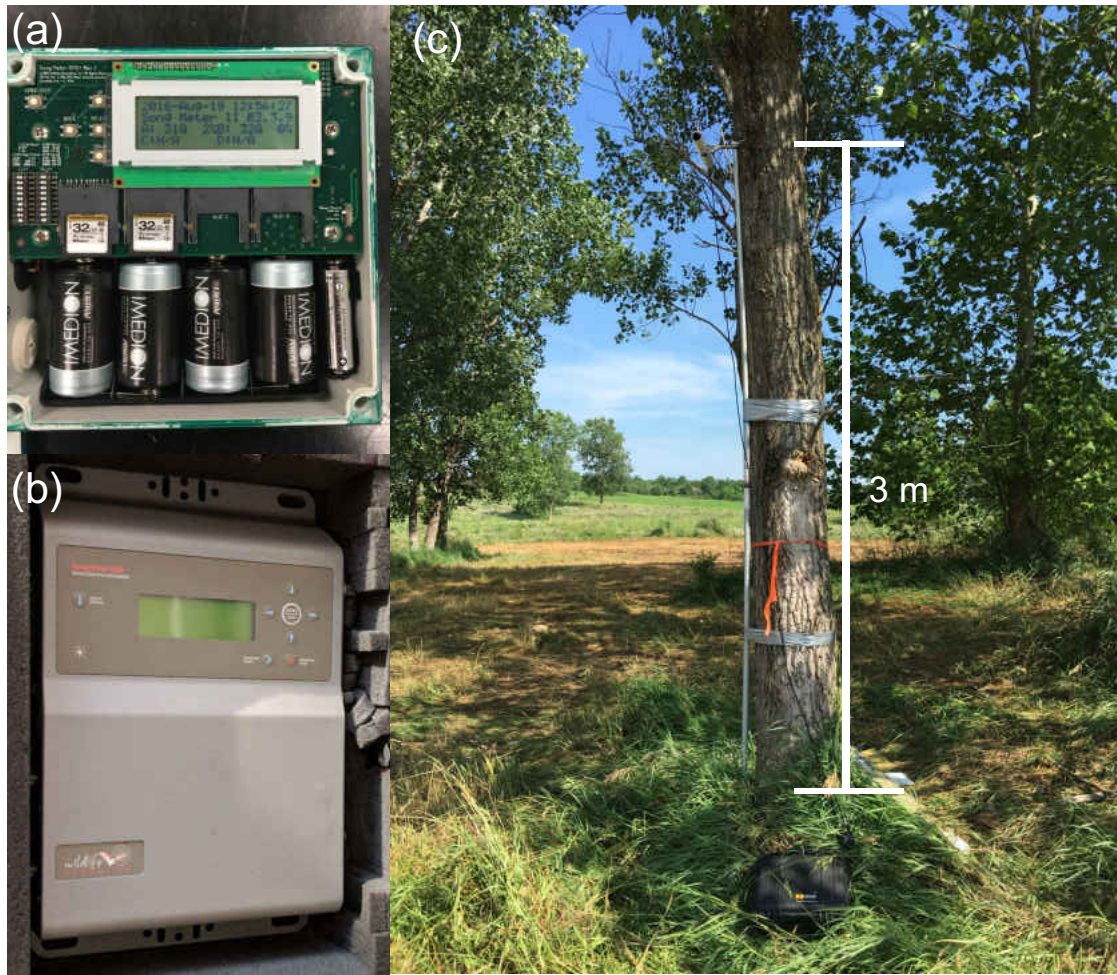


Figure 1-3. Example of acoustic detectors and deployment configuration used to assess bat activity at Wendell H. Ford Regional Training Center from June to August 2016 and May to July 2017. (a) Wildlife Acoustics Song Meter 2 BAT+ (SM2 BAT+) used from June to August 2016 and May to July 2017. (b) Wildlife Acoustics Song Meter 3 BAT (SM3 BAT) used in combination with SM2 detectors from May to July 2017. (c) Example of an acoustic detector deployment with microphone positioned at 3 m.

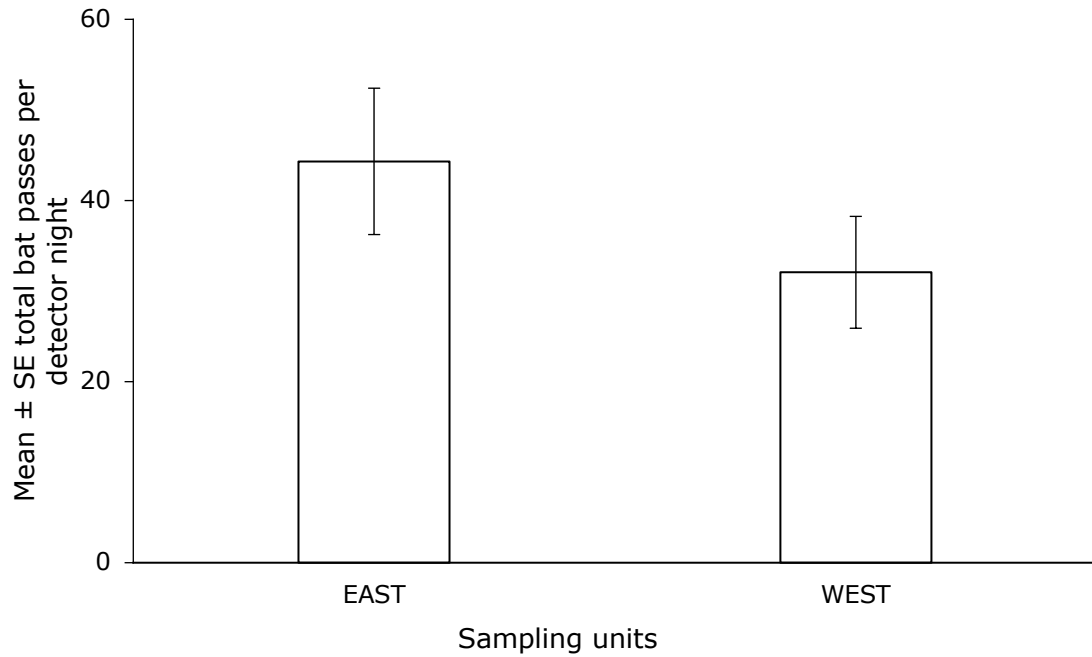


Figure 4-1. Mean bat passes per detector night for total bat activity recorded at Wendell H. Ford Regional Training Center. Sampling occurred from June to August 2016 on the eastern property block and May to July 2017 on the western property block.

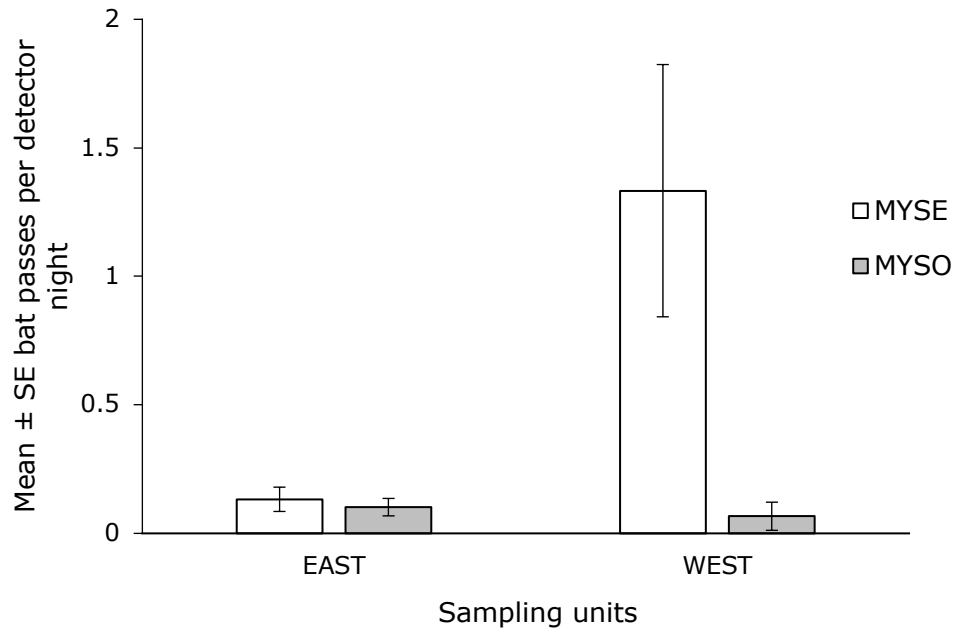


Figure 1-5. Mean bat passes per detector night for *Myotis septentrionalis* and *M. sodalis* activity recorded at Wendell H. Ford Regional Training Center. Sampling occurred from June to August 2016 on the eastern property block and May to July 2017 on the western property block.

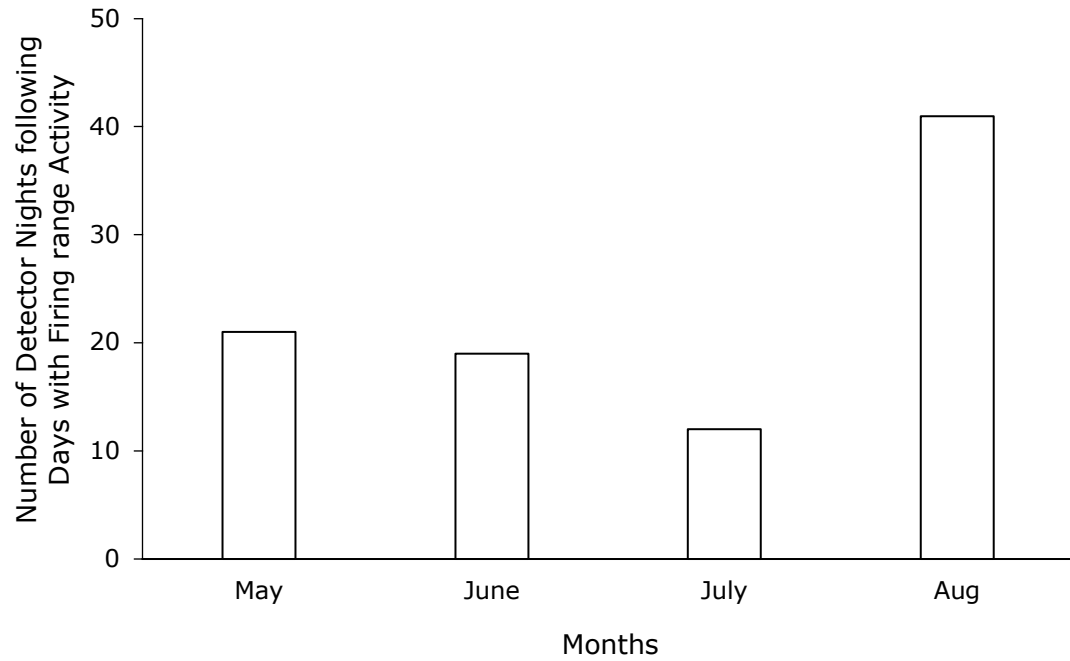


Figure 1-6. Number of days in the 2017 and 2018 summer season of military firing range use with acoustic detector deployments occurring on the corresponding night. Sampling occurred at Wendell H. Ford Regional Training Center, Muhlenburg County, Kentucky.

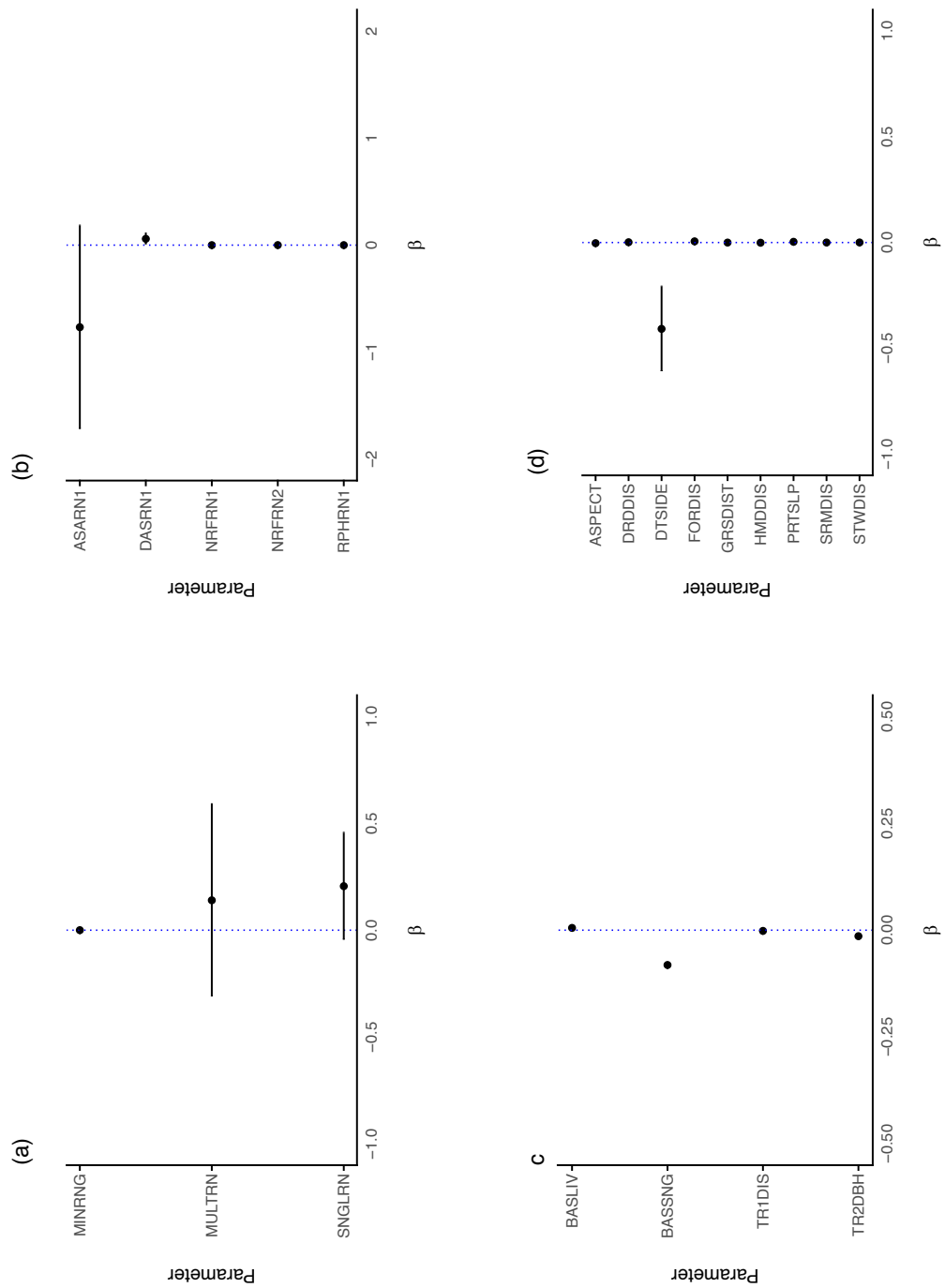


Figure 1-7. Model averaged estimates (β) of explanatory parameters with their respective conditional 85% confidence intervals for total bat activity. Parameters are grouped by model: a) spatial firing range, b) temporal firing range, c) site-level, and d) landscape-level.

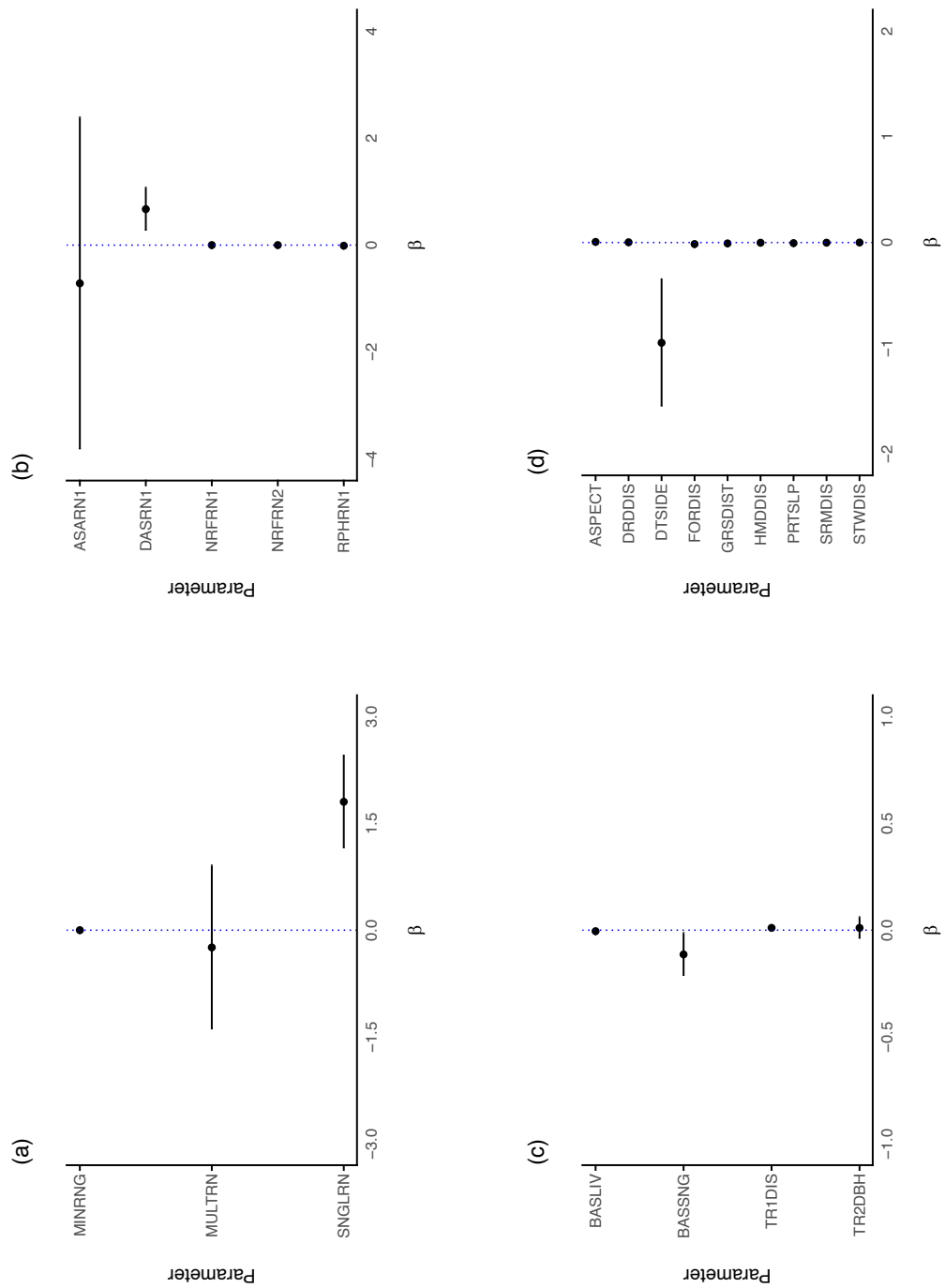


Figure 1-8. Model averaged estimates (β) of explanatory parameters with their respective conditional 85% confidence intervals for *M. septentrionalis* activity. Parameters are grouped by model: a) spatial firing range, b) temporal firing range, c) site-level, and d) landscape-level.

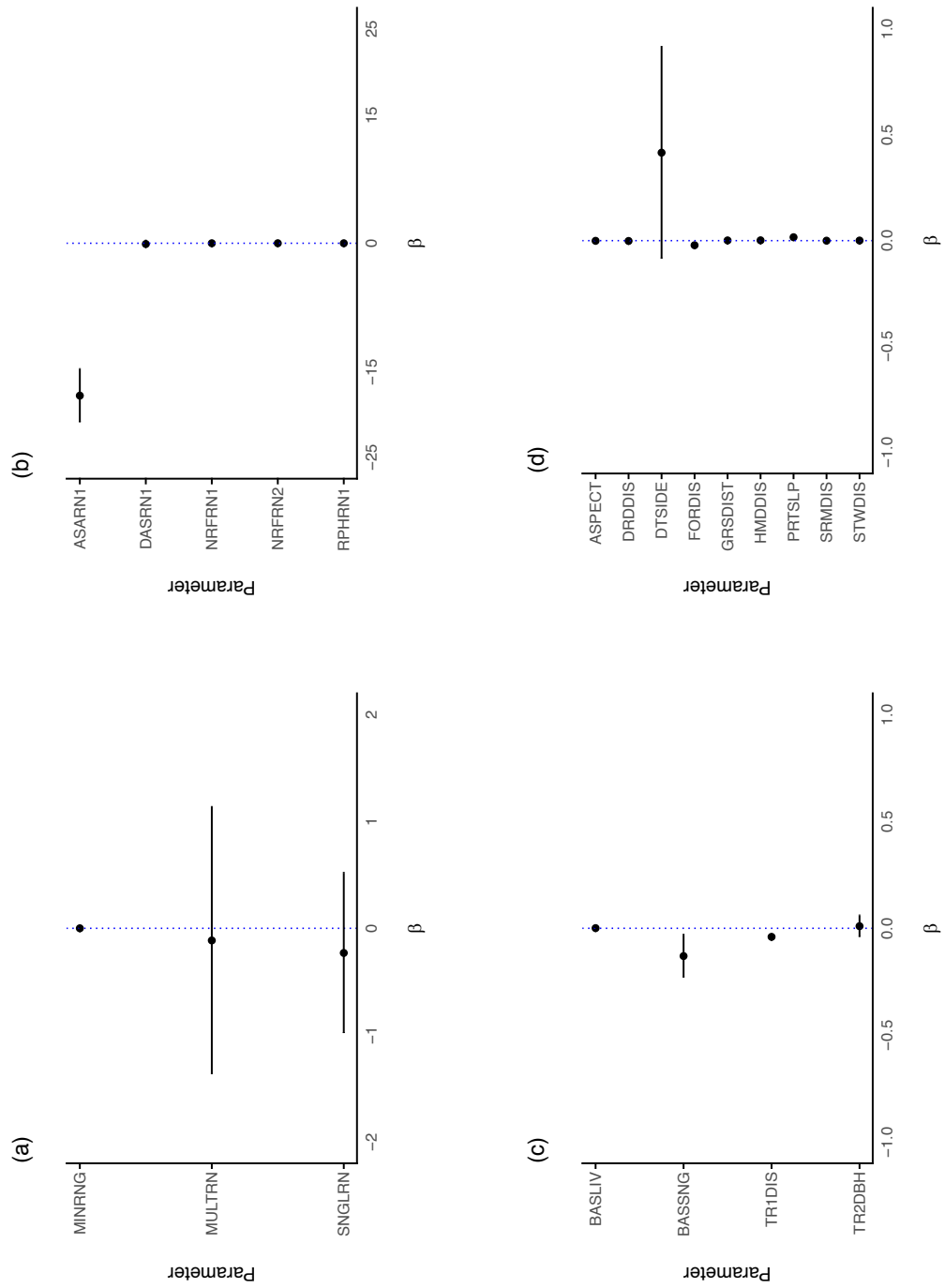


Figure 1-9. Model averaged estimates (β) of explanatory parameters with their respective conditional 85% confidence intervals for *M. sodalis* activity. Parameters are grouped by model: a) spatial firing range, b) temporal firing range, c) site-level, and d) landscape-level.

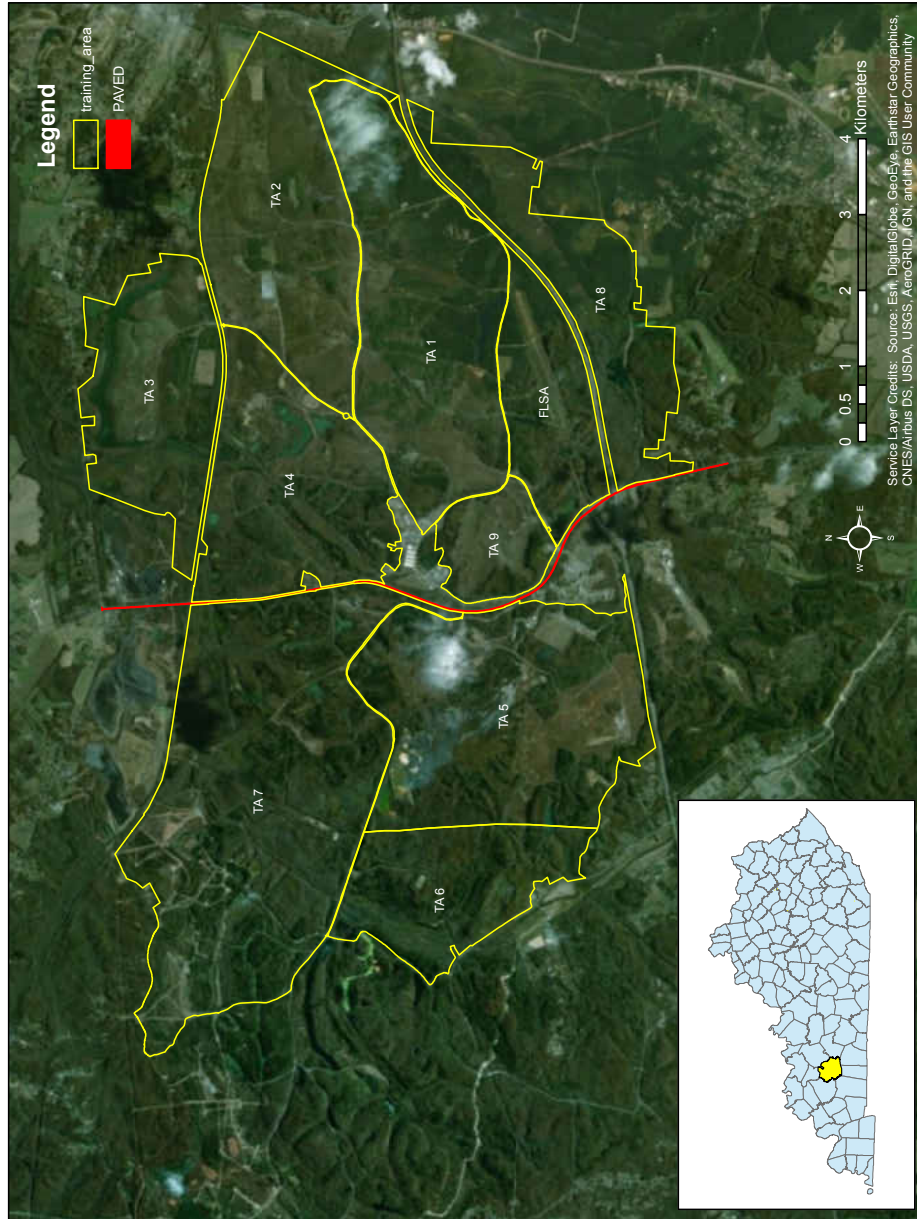


Figure 2-1. Map of Wendell H. Ford Regional Training Center in Muhlenburg County Kentucky. The property, owned by Kentucky Army National Guard, encompasses approximately 4,400 ha in the Green River–Southern Wabash Lowlands Level IV ecoregion. Training areas or sampling units are delineated in yellow. Kentucky Highway 181 bisects the property and is delineated in red.



Figure 2-2. Example of acoustic detector and audio speaker deployment configuration used to assess bat response to predator cues at Wendell H. Ford Regional Training Center from June to August 2017. (a) Bliiq Infinite X Bluetooth speakers were used to broadcast audio treatments. (b) Speaker is deployed at a height of 1.5 m and is placed approximately 1.5 m from the acoustic detector microphone.

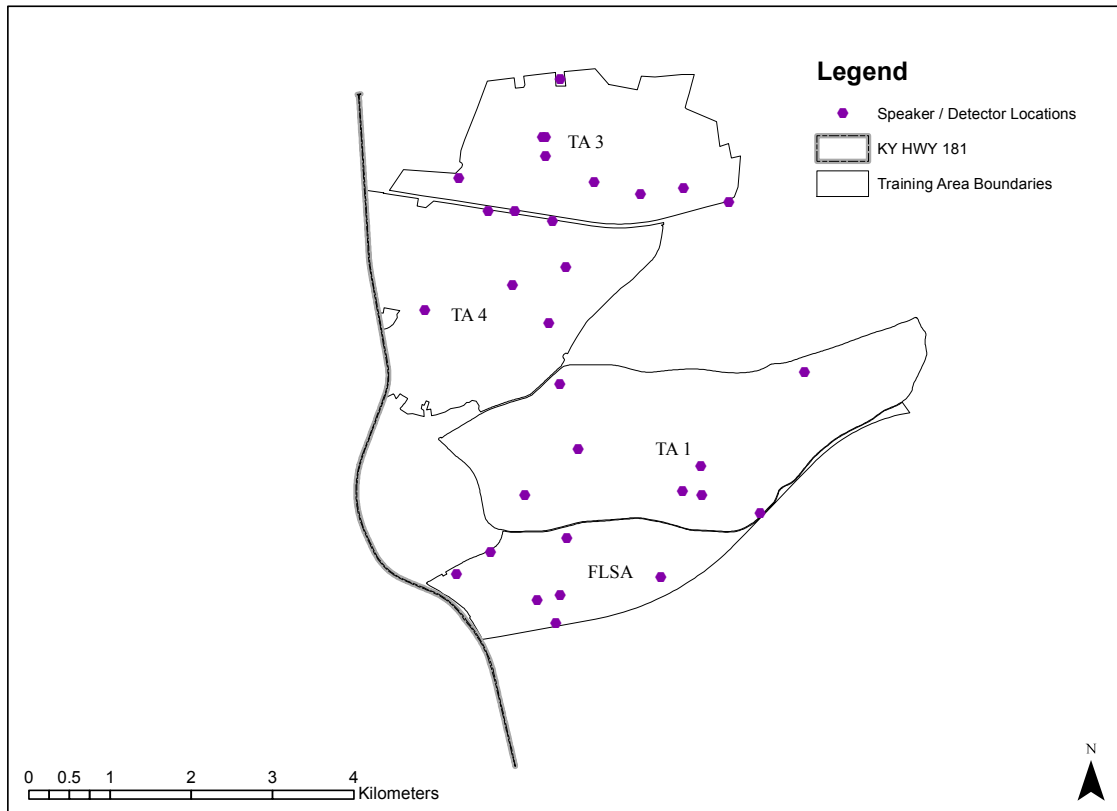


Figure 2-3. Site locations for coupled acoustic detector and audio speaker deployments at Wendell H. Ford Regional Training Center from June to August 2017. Map produced using ArcMap (ESRI 2015).

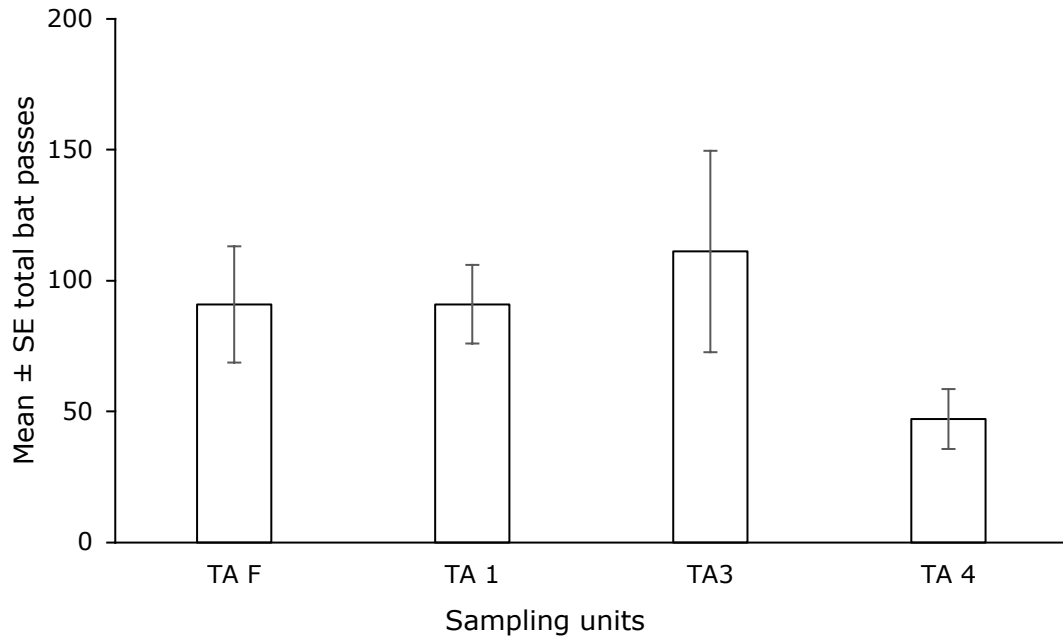


Figure 2-4. Total bat passes as a measure of total bat activity per detector night across sampling units at Wendell H. Ford Regional Training Center June to August of 2017.

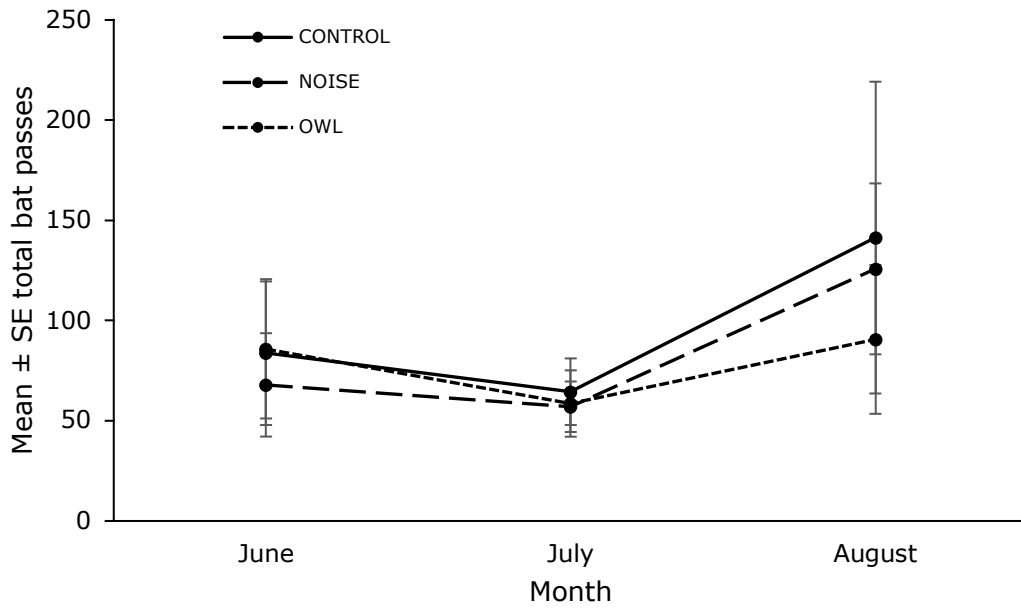


Figure 2-5. Total bat passes as a measure of total bat activity per detector night across month and auditory treatment type at Wendell H. Ford Regional Training Center June to August of 2017.

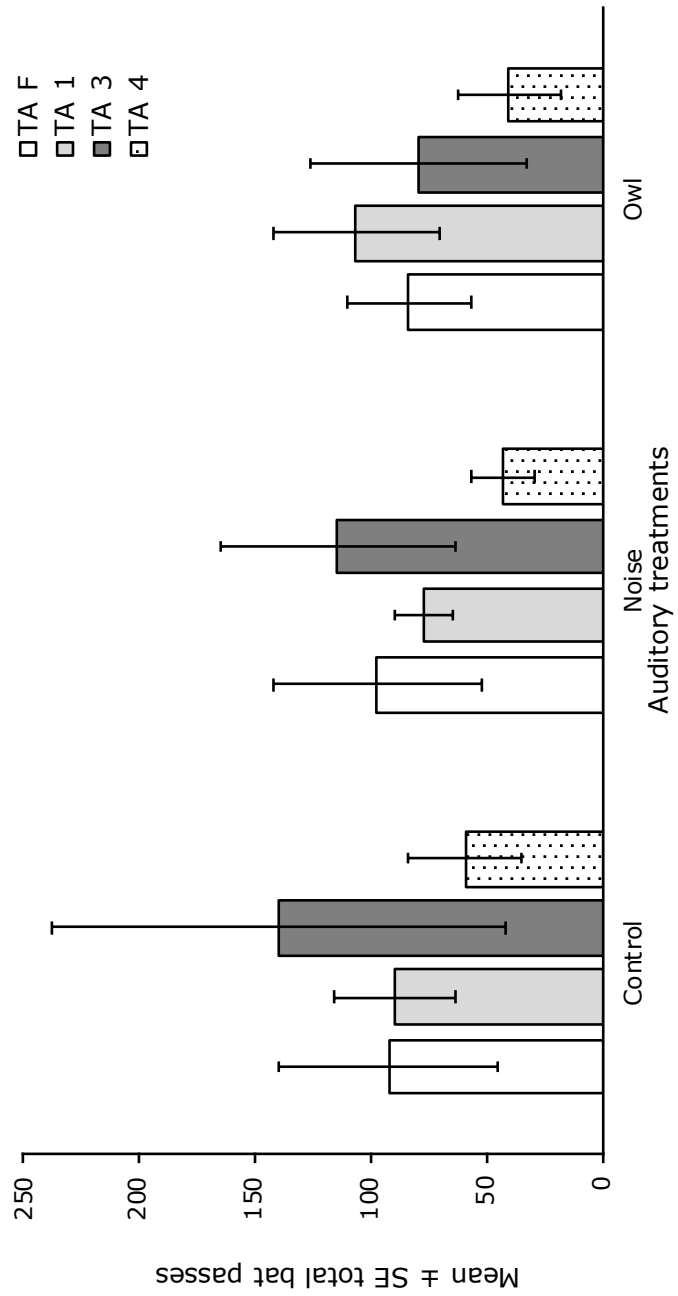


Figure 2-6. Total bat passes as a measure of total bat activity per detector night across sampling units and auditory treatments at Wendell H. Ford Regional Training Center June to August of 2017.

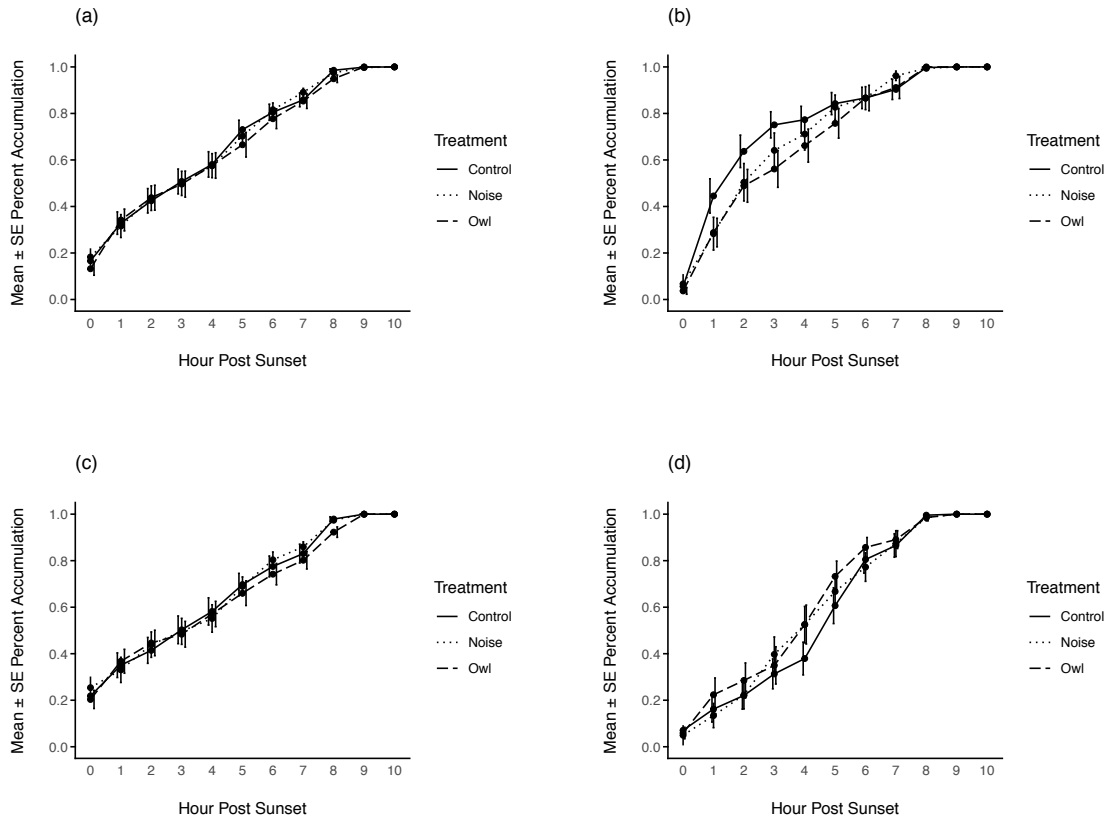


Figure 2-7. Hourly accumulation of bat passes per focal group by detector hour post sunset across auditory treatments at Wendell H. Ford Regional Training Center from June to August of 2017. Species level identification were made using Kaleidoscope Pro. Nights with zero bat passes recorded were excluded from the analysis. Passes serve as a measure of bat activity (a) Total bat activity, Control N = 30, Noise N = 30, Owl N = 30. (b) *Eptesicus fuscus* activity, Control N = 25, Noise N = 24, Owl N = 24. (c) *Lasiurus borealis* activity, Control N = 25, Noise N = 24, Owl N = 24. (d) *Perimyotis subflavus* activity, Control N = 23, Noise N = 23, Owl N = 23.

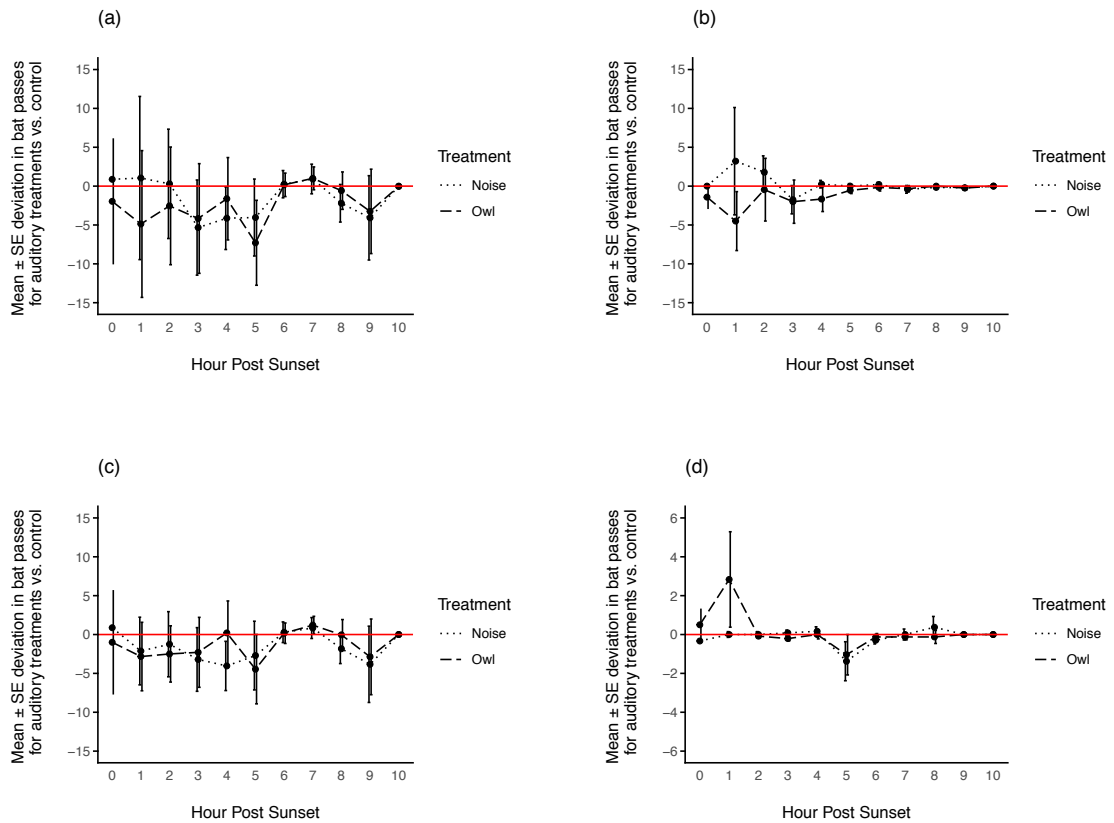


Figure 2-8. Hourly deviation from focal group passes recorded during control auditory treatments on a detector night basis recorded at Wendell H. Ford Regional Training Center June to August of 2017. Passes serve as a measure of bat activity. (a) Total bat activity. (b) *Eptesicus fuscus* activity. (c) *Lasiurus borealis* activity. (d) *Perimyotis subflavus* activity.