A Small-scale Response of Urban Bat Activity to Tree Cover

by

Lauren Moretto

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Abstract

Bats in urban areas depend on trees, and bat activity increases with tree cover. To effectively manage bat habitat in cities, it is important to know the distance to which tree cover most strongly influences bats (i.e., the ‘scale of effect’). The aim of this study was to estimate the scale of effect of tree cover on bats in Toronto, Canada. I measured bat activity at 52 sampling sites across the city. I then examined the relationships between bat activity and percent tree cover measured within each of 19 landscape scales, 0.025 – 3.5km in radius, surrounding each sampling site. My results suggest that adding or removing urban trees influences bats up to 200m away. Urban tree management decisions should consider the impacts to bats beyond the site of management and within the surrounding landscape of a 200m-radius scale.

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1. Introduction

Areas of primarily natural or semi-natural land cover provide habitat for wildlife in urban areas, containing resources for feeding, nesting, and refuge from human disturbance. Although large parks, including ravine systems or woodlots, contain the greatest biodiversity in urban environments (Blair and Launer 1997, Cornelis and Hermý 2004, Avila-Flores and Fenton 2005, Beninde et al. 2015), this natural habitat need not be a large, contiguous area to be important; a collection of many small areas of natural habitat can be just as valuable to wildlife as a single large area of the same total size (Fahrig 2017). For example, Smith et al. (2014) found that bird diversity responded as strongly to small residential green spaces (e.g., backyards) as to larger non-residential green spaces, on a per-area basis. In other words, the summed effect of a large number of small green spaces was equivalent to the effect of a large green space of the same total area.

Since areas of natural habitat in urban environments are often small, many species access habitat over a large area to obtain sufficient resources. For example, Fox Squirrels (*Sciurus niger*) in urban Texas must access multiple treed and grassy areas in urban environments for roosting and caching space, respectively (McCleery et al. 2007). Coyotes (*Canis latrans*) in Tucson, Arizona commute between multiple naturalized forests in golf courses for food and water, and between areas with sandy loam soils for constructing dens (Grubbs and Krausman 2009). The need to access multiple small areas of habitat is further reinforced by the seasonal changes in resource needs of species and the availability of resources within these areas. For instance, the network of nesting sites and foraging grounds between which birds and mammals commute in urban areas often

changes seasonally, thereby increasing the total area of habitat upon which they rely throughout the year (Law and Dickman 1998).

The use of multiple areas of natural habitat by urban species means that adding or removing habitat in an urban landscape can influence species within some distance away. For instance, Clark et al. (2007) found that the total amount of green space and number of flowering plants within the surrounding 1km in urban environments positively affected butterfly species richness. Furthermore, Melles et al. (2003) also found that urban green space influenced ground- and shrub-nesting bird species occurrence up to 1km away.

Tree cover comprises a large proportion of the natural habitat in urban environments and is important to urban species (Dixon 2012, Pardee and Philpott 2014, Ferenec et al. 2014, Smith et al. 2014), and knowing the distance to which tree cover influences urban species is informative for management. For example, Pardee and Philpott (2014) found that the total amount of tree cover in the surrounding 500m and 2km of backyard gardens positively influenced the abundance of cavity- and ground-nesting bee species, respectively. Similarly, Ferenec et al. (2014) found that the species richness of birds at sampling sites was positively related to the proportion of tree cover within 500m of sampling sites.

Urban bats rely on trees to satisfy their requirements for prey and roosts (van Zyll de Jong 1985). These trees are found throughout cities, in parks, along streets, and on private property such as in front and back yards. Bats move between trees in cities because they often forage some distance away from their roosts (Duchamp et al. 2004, Duchamp and Swihart 2008, Dixon 2012). The resource requirements of bats also change seasonally, so they may rely on different trees throughout the year (Law and Dickman

1998); while a street tree may provide an adequate summer roost, a tree in a woodlot with less ambient disturbance may be preferred for hibernation. Even bats that roost in buildings commute to trees to forage around their canopies, and may also rely on them to provide a second roosting space (Evelyn et al. 2004).

To maintain bat populations in urban areas, it is important to know the spatial extent over which tree cover in the surrounding landscape influences bat activity at a site, that is, the 'scale of effect' (Jackson and Fahrig 2012). The scale of effect of tree cover on temperate urban bats is not well known. Landscape-scale studies on urban bats often select only a single landscape scale for study, leading to uncertainty that the selected scale is in fact the scale of effect (e.g., Duchamp and Swihart 2008, Threlfall et al. 2012). Multi-scale studies typically use a small number of scales (i.e., three or fewer; e.g., Dixon 2012, Bazelman 2016, Gallo et al. in press). These studies suggest scales of effect between 0.1 and 3km for urban bats. Although one European study (Lintott 2015) measured habitat features within seven landscape scales, the scale of effect was not estimated. To date, Fabianek et al. (2011) and Ethier and Fahrig (2011) provide the most precise estimates of the scale of effect for bats in North America, by measuring the relationship between bat activity and land cover within five or more scales. In Montréal, Fabianek et al. (2011) found a 0.1km scale of effect of forest and non-woody plant cover for urban bats, which was also the smallest landscape scale that they examined. In agricultural eastern Ontario, Ethier and Fahrig (2011) found scales of effect of forest amount on bats of 1 – 5km, depending on the species. The goal of this study was to estimate the scale of effect of tree cover on bat activity in Toronto, Canada's largest city.

2. Methods

I estimated the scale of effect of tree cover on total bat activity and on the activity of individual species using bat recorders at 52 sampling sites across Toronto. I measured the percent tree cover within 19 landscape scales with radii from 0.025 – 3.5km that were centred on each sampling site. I then modelled the relationship between bat activity and percent tree cover at each spatial extent. I estimated the scale of effect as the radius with both a strong relationship between bat activity and percent tree cover and a good fit of the data to the model.

2.1 Tree Cover as Bat Habitat

I defined bat habitat as the area covered by tree canopies of 2m² or larger. Trees of this size are used as habitat by all seven bat species previously documented in Toronto. Some species roost among the foliage [Eastern Red Bat (*Lasiurus borealis*), Hoary Bat (*Lasiurus cinereus*), and Tri-colored Bat (*Perimyotis subflavus*)], while others roost in cavities or under loose bark [Big Brown Bat (*Eptesicus fuscus*), Little Brown Myotis (*Myotis lucifigus*), Northern Myotis (*Myotis septentrionalis*), and Silver-haired Bat (*Lasionycteris noctivagans*) (van Zyll de Jong 1985)]. All species also forage for insects either among trees or above the tree canopy (van Zyll de Jong 1985). Measuring tree cover of trees with a canopy of at least 2m² excluded isolated saplings that would be too small to provide roosting or foraging space for bats. Trees with a canopy of 2m² or

greater were available as a mapped raster dataset in the Forest and Land Cover layer (City of Toronto 2009).

Buildings can be considered habitat for bat species that also roost in artificial structures [Big Brown Bat (*Eptesicus fuscus*), Little Brown Myotis (*Myotis lucifugus*), Northern Myotis (*Myotis septentrionalis*), and Silver-haired Bat (*Lasionycteris noctivagans*) (van Zyll de Jong 1985, Whitaker et al. 2006, Geluso and Mink 2009)].

However, my objective was to estimate the scale of effect of tree cover on bats.

Therefore, I controlled for percent building cover in site selection (below). Depending on model fit, I also added an additional statistical control for percent building cover to the models of species that roost in buildings.

2.2 Sampling Site Selection and Measurement of Percent Tree Cover

The overall objective of site selection was to simultaneously maximize the total number of sampling sites and the range of percent tree cover in the surrounding landscapes across sampling sites, at each of the 19 scales. To achieve this, I first mapped percent tree cover in Toronto using the Forest and Land Cover raster dataset (City of Toronto 2009) at a 2m resolution. I then examined the range in percent tree cover across the city by conducting a moving window analysis in ArcGIS 10.3.1 (ESRI 2015), which calculated percent tree cover around each pixel in the raster dataset for a given window size. For this step, I used a circular window with a radius of 3.5km, the largest landscape scale I considered. To maximize the range of percent tree cover across sites, I first identified pixels (potential sampling sites) having the highest and lowest percent tree cover in the surrounding 3.5km-radius landscapes. I considered only pixels in residential

backyards with similar local characteristics (i.e., unpaved, with some trees, and without large, artificial structures, including swimming pools). I then verified that these potential sampling sites also maximized the range of percent tree cover at smaller scales. To achieve this, I performed moving window analyses at 1km and 2km-radius landscape scales.

The next step in sampling site selection was to add potential sites with intermediate percent tree cover. These were selected such that the number of sites in total was maximized, within the constraint that all selected sites were at least 1.8km apart to limit spatial autocorrelation in the bat responses. 1.8 km is the mean commuting distance of Big Brown Bat, a common, long-distance flying species in Toronto (Brigham 1991). Following this, I adjusted site locations at a fine scale to ensure that all sites were at least 200m from major arterial roads and highways. This was to eliminate the negative influences of roads, moving vehicles, and traffic noise on bat activity immediately surrounding the sampling sites (Kitzes and Merenlender 2014, Bennett and Zurcher 2013).

Lastly, I eliminated some sampling sites and shifted some others to limit the range in percent building cover in the surrounding landscapes across sampling sites, thus controlling for building roost availability. Older buildings with larger footprints are commonly used for bat roosting (Soper and Fenton 2007, Neubaum et al. 2007). My goal was to limit the range in availability of these buildings, but there was no available dataset for building age across the City of Toronto. However, Li and Wilkins (2014) documented a positive relationship between overall building density and bat activity. Therefore, I used percent building cover as a proxy of building roost availability, mapped with the Toronto

Building Outlines shapefile (City of Toronto 2014c). I measured percent building cover by converting the building outline polygons into 2m resolution raster datasets and conducting a moving window analysis with a 3.5km-radius, circular window to examine the range in percent building cover across the city. I adjusted the sampling site locations such that the surrounding landscapes had a building cover ranging from 14 – 19% of the total landscape, at the 3.5km-radius scale. This range in percent building cover prevented site placement in the downtown urban core, where building density is very high and there are likely very few building roosts (Neubaum et al. 2007), and in non-urban areas, such as an agricultural area in the east end of the city.

The site selection process resulted in a final set of 52 sampling sites (Figure 1), dispersed across the City of Toronto with a wide range in percent tree cover (15 – 49%) and a narrow range in percent building cover (14 – 19%) in the surrounding 3.5km-radius landscapes. I visited each site to verify the similarity among sites in local characteristics and to obtain the approval of homeowners to set up sampling equipment.

After confirming the sampling site locations, I measured percent tree cover in 19 circular landscape scales, centered around each site (i.e., 0.025, 0.05, 0.1, 0.2, 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, 2, 2.25, 2.5, 2.75, 3, 3.25, and 3.5km; Figure 2a, b) using the Forest and Land Cover raster dataset (City of Toronto 2009). I also verified that the range of percent tree cover across sites was similar among the 19 scales (Figure 3b).

The non-native Emerald Ash Borer (*Agrilus planipennis*) has killed most Ash trees (*Fraxinus* sp.) in Toronto since its arrival in 2008. The Forest and Land Cover raster dataset (City of Toronto 2009) that I used to measure percent tree cover predates most of the infestation and thus does not capture all of the Ash tree mortality. To ensure that this

discrepancy did not affect the accuracy of my measurements of percent tree cover, I tested for a relationship between the number of dead Ash trees and percent tree cover within 0.25km, 1km, 2km, and 3.5km of my sampling sites. I obtained the locations of all dead public Ash trees in the city (City of Toronto 2014a, b), summed them at each scale around each sampling site, and calculated the number of dead Ash trees per percent tree cover. This was then correlated to percent tree cover at each scale (Appendix 1). The pairwise Pearson correlations were non-significant and weak ($r = -0.21 - 0.02$, $p = 0.13 - 0.98$), except at the 3.5km scale, where there was a significant but weak negative correlation between percent tree cover and the number of dead Ash trees per percent tree cover ($r = -0.29$, $p = 0.03$). This suggests that the inclusion of Ash trees, predating their city-wide mortality, did not bias my measurements of percent tree cover.

2.3 Bat Surveys

I surveyed bat activity at each of the 52 sampling sites by recording bat calls using Wildlife Acoustic SM2+ recorders with SMX-U1 microphones. Calls were recorded between May 30 and August 8, 2017, the period of summer residency for Ontario bat species (van Zyll de Jong 1985). At each site, I positioned one recorder two meters above the ground with its microphone angled 45° downwards to protect the microphones from potential rain. I recorded bat calls continuously from sunset to sunrise over two, non-consecutive nights per site.

To ensure that date of sampling did not confound the effects of tree cover, I sampled bat activity at four sampling sites per night that varied in percent tree cover in the surrounding landscapes. The combination of four sites sampled each night contained

one site with low percent tree cover, one site with high percent tree cover, and two sites with intermediate percent tree cover at both the 1km and 3.5km-radius landscape scales (Figure 2, c – e). After all sites were sampled once, I began a second round of sampling on June 21, 2017. I ensured that each night's combination of sites visited in the second round was different from that of the first round.

2.4 Potential Confounding Variables

The main objective of the study was to identify the scale of effect of tree cover on bat activity in an urban environment. However, bat activity around a recorder is likely to be influenced by variables other than tree cover, which might obscure the relationship between bat activity and surrounding tree cover. I controlled for this by collecting data only during good weather (i.e., no rain, average wind speed below 20km/h, average wind gusts below 25km/h, and average nightly temperature above 9°C), and by ensuring minimal human disturbance during data collection (i.e., avoiding sampling overnight on Fridays, Saturdays, and holidays). At each site, I also deployed one Onset HOBO Pendant Temperature and Light Data Logger and one Digi-Sense Data Logging Light Meter to measure temperature (°C) and light intensity (lux) at 10 minute increments during the recording period.

Although I had tried to minimize variation in the surrounding building cover among sampling sites during site selection, there was a greater range in percent building cover at smaller landscape scales than at larger landscape scales (Figure 3a). Percent building cover was also negatively correlated with percent tree cover (Figure 4b), particularly when percent tree cover was measured at smaller scales (0.5 – 1km).

Therefore, I included percent building cover as a statistical control when appropriate (see below).

2.5 Quantifying Bat Activity and Identifying Bat Species

Bat activity was indexed as the number of bat passes per sampling site. A bat pass is a grouping of echolocation pulses separated by at least 1 second of silence (2 seconds for Hoary Bat) from the next pulse (Coleman and Barclay 2012, Griffin et al. 1960; Figure 5). A pass begins with a “Search Phase Call,” which the bat uses for navigation and general perception of the environment. As the bat approaches a prey item or attempts to land, pulse rate and frequency increase and the overall duration of the call decreases. This is the “Approach Phase.” Following the Approach Phase, there is often a “Feeding Buzz,” which the bat uses to gain precise information about prey location before it attempts a capture. The Feeding Buzz is characterized by a further increase in pulse rate, a decrease in overall call duration, and an immediate drop in pulse frequency at the end. Feeding Buzzes do not denote the end of a pass, as a single bat pass can contain multiple Feeding Buzzes, often followed by Search Phase Calls.

Bats can be identified to species using the acoustic characteristics of the echolocation pulses. To identify each pass to species, I used two identification software programs to account for discrepancies in their identification algorithms (Lemen et al. 2015). These were the Bats of North America 3.1.0 classifier package in Kaleidoscope Pro 3.1.1. (Wildlife Acoustics 2015) and the quadratic discriminate function analysis model (QDFA) created by Ethier and Fahrig (2011), which used reference calls from the Fenton Laboratory (Hooton and Adams, unpublished data, University of Western

Ontario) and was coded into R by J. Put (unpublished). I included only the seven species of bats that have been documented in Toronto as possible outcomes for each program [i.e., Big Brown Bat (*Eptesicus fuscus*), Eastern Red Bat (*Lasiurus borealis*), Hoary Bat (*Lasiurus cinereus*), Silver-haired Bat (*Lasionycteris noctivagans*), Little Brown Myotis (*Myotis lucifugus*), Northern Myotis (*Myotis septentrionalis*), and Tri-colored Bat (*Perimyotis subflavus*)].

I used the pulses of Search Phase Calls for species identification (Fenton and Bell 1981). Parameters of unidentified pulses were measured and compared to clusters of parameters from identified pulses. This process was automated in Kaleidoscope. For the QDFA, I input the Search Phase Calls of all passes into Scan'R 1.6.0 to obtain the parameters of pulses. This program measured pulse duration, interpulse interval, maximum frequency, minimum frequency, bandwidth, dominant frequency, characteristic frequency, slope, and curvature.

To identify each bat pass to species, I compared the results from the two identification programs, and reviewed each pass manually to confirm the identity. The identification of a pass was accepted if the results of Kaleidoscope's identification agreed with that of the QDFA. When the programs did not agree on the identity of a pass, it was classified as "unidentified." When possible, I classified these unidentified passes by visually comparing them to a temporally adjacent, identified pass.

I analysed bat activity for all bats combined, two individual species (Big Brown Bat and Eastern Red Bat), and two species groups, each of which contained two or three species with calls that are difficult to distinguish. The first group contained calls of

Myotis species (Little Brown Myotis and Northern Myotis) and Tri-colored Bat, and the second group contained calls of Hoary Bat and Silver-haired Bat.

2.6 Statistical Analysis

I used generalized linear mixed models (GLMM) to estimate the relationship between each of the five bat activity response variables (total bat activity and activity of each of the species and species groups) and percent tree cover measured within each of the 19 spatial scales. Therefore, for each bat response variable there were 19 models, one for each landscape scale. Since bat activity was surveyed twice at each sampling site, models contained a random effect of site, to account for variance within sites. Each model also contained the potential confounding effects of standardized mean nightly temperature (°C) and Julian date. The light-intensity loggers did not register any variance in light intensity (lux) among sites and nights, so lux was not included in any models. The inclusion of percent building cover at the 1km-radius landscape scale in the GLMM as a statistical control was based on model fit. Firstly, I controlled for percent building cover at the 1km-radius scale because the AIC values of the 19 models with percent building cover included at this scale were lower overall than with percent building cover included at other scales (e.g., 0.5km and 1.5km). Then, for each bat activity response variable, I compared AIC values of the 19 models with and without the control for percent building cover at the 1km scale. AIC values were lower in models without percent building cover for Little Brown Myotis/ Northern Myotis/ Tri-colored Bat and Eastern Red Bat, so percent building cover was not included in further analyses for these species groups. I

modeled bat activity with a negative binomial error and a log link function, based on the distributions of the response variables in histograms and residual plots.

Finally, I estimated the scale of effect of percent tree cover for each response variable by evaluating both the AIC values and regression coefficients of each model. AIC values were examined first and indicated the scale at which the data best fit the model. I then used the regression coefficients to verify that the model at the scale with the lowest AIC value showed a strong relationship between a bat activity response variable and percent tree cover. If there was less than a 0.1 difference in the AIC values between two or more scales, the scale with the largest regression coefficient was deemed the scale of effect.

I assessed spatial autocorrelation among the residuals of the models using Moran's *I* and by mapping the residuals. Additionally, I calculated the cross-scale, pairwise Pearson correlations in percent tree cover between all pairs of scales. I also calculated the correlations between percent tree cover at each scale and percent building cover at the 1km scale (i.e. the scale at which it was entered in models as a control). All analyses were conducted in R version 3.4.1. (R Core Team 2017), using the MASS, glmmADMB (Bolker et al. 2012), ape (Paradis et al. 2017), psych (Revelle 2017), ggplot2 (Wickham and Chang 2016), dplyr (Wickham et al. 2017), corrplot (Wei et al. 2017), maptools (Bivand et al. 2017), and GIStools (Brunsdon and Chen 2014) packages.

3. Results

I recorded 7,593 bat passes. Forty-nine percent of these were identified as Big Brown Bat (*Eptesicus fuscus*), 6% as Eastern Red Bat (*Lasiurus borealis*), 21% as Hoary

Bat (*Lasiurus cinereus*)/ Silver-haired Bat (*Lasionycteris noctivagans*), and 1% as Little Brown Myotis (*Myotis lucifugus*)/ Northern Myotis (*Myotis septentrionalis*)/ Tri-colored Bat (*Perimyotis subflavus*). Twenty-three percent of passes could not be identified to species or species group. The average number of bat passes per sampling site was 73 (range 7 – 296), with an average of 8.1 passes per hour (range 0.8 – 31.6). On average, there were 3 species/ species groups per site (range 1 – 4).

The range of percent tree cover across sites was fairly consistent across the 19 scales (Figure 3b). The pairwise Pearson correlations between percent tree cover at different scales (range 0.48 – 1), and between percent building cover at 1km and percent tree cover at different scales (range 0.002 – -0.65) are shown in Figure 4.

For total bat activity, the scale of effect of percent tree cover was the 0.2km-radius landscape scale (Figure 6a, Appendix 2 – 4). Total bat activity increased by 44% for each 10% increase in tree cover, with the predicted total number of passes ranging from 22 – 287 (Figure 7). The scale of effect of percent tree cover differed among species/ species groups. Big Brown Bat and Hoary Bat/ Silver-haired Bat showed scales of effect of 0.2km and 0.15km, respectively (Figure 6b, c). Little Brown Myotis/ Northern Myotis/ Tri-colored Bat and Eastern Red Bat both had smaller scales of effect at 0.025km (Figure 6d, e), but the relationship between percent tree cover and bat activity was not significant for Little Brown Myotis/ Northern Myotis/ Tri-colored Bat. There was also a positive effect of percent building cover within a 1km-radius landscape on total bat activity, Big Brown Bat, and Hoary Bat/ Silver-haired Bat at the scale of effect of percent tree cover for these bat activity responses (Appendix 2).

Residual plots suggested that most models fit the data well, with an even spread of residuals in most cases (Appendix 5). There was no significant spatial autocorrelation of the residuals for total bat activity, or for any species or species group (Appendix 6, 7).

4. Discussion

I found a relatively small scale of effect of percent tree cover on the activity of urban bats. Percent tree cover within 0.2km from my sampling sites had the strongest influence on total bat activity. Previously documented scales of effect for temperate bats generally range from 0.1 – 5km (Ethier and Fahrig 2011, Fabianek et al. 2011, Dixon 2012, Bazelman 2016, Gallo et al. in press), although 0.1km was the smallest scale measured in two previous studies (Fabianek et al. 2011, Dixon 2012). In my study, two species groups showed even smaller scales of effect than 0.1km, namely Little Brown Myotis/ Northern Myotis/ Tri-colored Bat and Eastern Red Bat at 0.025km.

It is possible that this small scale of effect of tree cover on all bats reflects the general influence of urban environments on bat activity and life histories. Since urban infrastructure, such major roads, traffic, and artificial lighting, disrupts the movement of bats (Russell et al. 2009, Bennett and Zurcher 2013, Moretto and Francis 2017), this could confine bat activity, and thus the greatest influence of tree cover, to a small landscape scale in cities. It is also possible that the tendency of insects to aggregate in urban environments (e.g., around trees or lights) drives localized bat foraging activity. Insectivorous bats frequently forage around insect aggregations (Müller et al. 2012), and most bats in Toronto forage within 40m of tree canopies (van Zyll de Jong 1985, Janzen and Fenton 2013). Street trees and trees on private property in cities are often spaced for

aesthetics, providing ample area for insects to aggregate and bats to forage. Especially in light of the small scales of effect of tree cover on Little Brown Myotis/ Northern Myotis/ Tri-colored Bat and Eastern Red Bat (0.025km), tree cover further away may not be as important to bats if tree cover in the vicinity is sufficient to provide insects.

Although not the primary goal of this study, my results also suggest that the total urban tree cover, not just that in parks, influences bats within 0.2km. All sampling sites in this study were in residential backyards, surrounded mostly by trees outside of parks. Using the Zoning By-law layer (City of Toronto 2014d) to map park space in the city, I found that at the 0.2km scale, greater than 70% of tree cover was not located in parks for 48 of 52 sampling sites, and none of the tree cover was in parks for 17 sites (Appendix 8). In addition, there is a weak correlation between total bat activity and the percent tree cover within parks at the 0.2km scale ($r^2 = 0.02$), indicating that non-park trees (i.e., street trees and trees on private property) are the main drivers of the overall positive relationship between tree cover and bat activity.

Although there are no North American studies that directly compare the importance of trees within parks and outside of parks to bats, my results are supported by other studies that have noted the importance of all local tree and vegetation cover in residential neighbourhoods to invertebrates, amphibians, birds, and other wildlife (Fernandez-Juricic 2000, Sperling and Lortie 2010, Lerman and Warren 2011, Scheffers and Paszkowski 2013, Pardee and Philpott 2014, Belaire et al. 2014, Smith et al. 2014). Conversely, one study in Vitória, Brazil that compared the influence of parks to other treed space on urban bat diversity found a much stronger effect of parks than wooded streets (Opera et al. 2009). I speculate that this difference between my results and those

of Opera et al. (2009) is due to differences among our studies in species and their resource requirements. Opera et al. (2009) reported that most of the captured bats (92%) in their study are frugivores, nectivores, and omnivores, and only 8% are insectivores. All of the bat species in my study are insectivores. Resources for insectivorous bats are often more abundant throughout urban environments than are resources for other bats (Bredt and Uieda 1996, Silva et al. 1996). It is possible, then, that resources for non-insectivorous bats were concentrated in urban parks in Vitória, which could explain the greater importance of park trees than street trees to bats in their study.

I also found a positive influence of percent building cover within 1km of my sampling sites for Big Brown Bat and Hoary Bat/ Silver-haired Bat. This was expected because both Big Brown Bat and Silver-haired Bat roost in artificial structures (van Zyll de Jong 1985, Whitaker et al. 2006, Geluso and Mink 2009). The positive response of the Hoary Bat/ Silver-haired Bat species group to building cover suggests that this species group could be dominated by Silver-haired Bat, because Hoary Bat is a tree-roosting obligate (van Zyll de Jong 1985) and thus should not show a positive response to building cover.

4.1 Implications

This study provides information useful for the management of bat habitat in cities. Firstly, the scale of effect of tree cover on bats suggests that land management decisions should consider the impacts of the addition or removal of tree cover not just at the site of addition or removal, but within approximately the surrounding two residential city blocks. Furthermore, while my study was not designed to evaluate the influence of

building cover on bats, my finding of a positive effect of building cover for two species (i.e., Big Brown Bat and Silver-haired Bat) suggests that artificial roost availability should be further explored in managing urban habitat for these species (Soper and Fenton 2007, Neubaum et al. 2007). Lastly, my results suggest that all urban trees, including privately-owned trees and street trees, and not just trees in parks, are important for bats. Private and public trees are often managed separately, and management of urban trees often occurs on a tree-by-tree basis (Carreiro et al. 2008). As the landscapes in my study primarily included privately-owned trees in residential neighbourhoods, this emphasizes the potential for small groups of property owners (e.g., the houses on a single residential street) to increase local bat activity. Management for bats in cities should therefore include education of property owners about the value of their trees for bats, and could even include a requirement for permission to remove trees on their property, as is the case in some jurisdictions (e.g., City of Toronto by-law No. 248-2013, City of Ottawa by-law No. 2009-200).

Figures

Figure 1. Locations of 52 bat sampling sites in Toronto, Canada. Sampling sites are indicated as black points. Circles around each site are not to scale, but represent percent tree cover in the surrounding, circular landscape with a 3.5km radius. Note that percent tree cover was analyzed as a continuous variable in models.

Figure 2. (a) An example sampling site surrounded by the 19 circular landscapes in which percent tree cover was measured. Landscapes ranged between 0.025km and 3.5km in radius. (b) A closeup of the smallest landscape scales in (a) measuring between 0.025km and 0.25km in radius. Examples of landscapes with (c) low, (d) medium, and (e) high percent tree cover within 1km of the sampling site.

Figure 3. Box and whisker plots showing the range across sampling sites in percent cover of (a) buildings and (b) trees measured within each of 19 circular landscape scales around the bat sampling sites. Black horizontal bars are the medians, red dots are the means, and grey regions show the interquartile ranges (i.e., IQR; 25th – 75th percentile). Whiskers represent percent cover values that lie outside of the IQR, but within 1.5 x IQR. Outliers are indicated with black dots.

Figure 4. (a) Pairwise Pearson correlations of percent tree cover between all pairs of landscape scales. Row and column labels indicate the radius of each scale. (b) Pairwise Pearson correlations between percent building cover at the 1km scale (row label) and percent tree cover at each landscape scale (column labels). Square size and intensity of colour indicate the strength of the correlation, while colour indicates the direction of the correlation, as shown in the colour ramp (red is a negative correlation and blue is a positive correlation).

Figure 5. A bat pass is series of echolocation pulses that are grouped into different types of calls (Griffin et al. 1960). A pass begins with a “Search Phase Call” used by the bat for navigation and general perception of the environment. An “Approach Phase Call” may follow if the bat approaches prey or tries to land. For this call, pulse rate and frequency are higher and the overall call duration is lower than in the Search Phase. Often following the Approach Phase is a “Feeding Buzz,” which the bat uses to gain precise information about prey location. Pulse rate increases and overall call duration decreases further, and pulse frequency immediately drops at the end. Since the characteristics of pulses in Search Phase Calls are fairly consistent within species, they are used for species identification (Fenton and Bell 1981).

Figure 6. Regression coefficients (black dots, solid line) $\pm$ SE (vertical lines) and Δ AIC values (open circles, dashed line) from generalized linear mixed models of the relationship between the percent tree cover in landscapes and **(a)** total bat activity and **(b – e)** species-specific activity. Bat activity was measured at 52 sampling sites distributed across Toronto, Canada. Percent tree cover was measured within each of 19 circular landscape scales with radii between 0.025km and 3.5km surrounding the sampling sites. The scale of effect (vertical dotted red line) was selected based on the model AIC value and regression coefficient of percent tree cover.

Figure 6. Continued.

Figure 6. Continued.

Figure 7. Total number of bat passes recorded at each site in relation to percent tree cover measured around each of the 52 sampling sites at the scale of effect for total bat activity, 0.2km. Colours of dots indicate the round of bat sampling. While the points are the raw data, the grey line shows the predicted number of bat passes for each percent tree cover. This predicted data was taken from the generalized linear mixed model for the relationship between total bat activity and percent tree cover at 0.2km, after controlling for potential confounding variables.

Appendices

Appendix 1A. Pairwise Pearson correlations and p-values between percent tree cover and the number of dead Ash trees (*Fraxinus* sp.) per percent tree cover measured within 0.25km, 1km, 2km, and 3.5km-radius circular landscape scales around each sampling site. Since the arrival of Emerald Ash Borer (*Agrilus planipennis*) to Toronto in 2008, most Ash trees in the city have been killed. However, the Forest and Land Cover raster dataset (City of Toronto 2009), which I used to measure percent tree cover, predates most of the Ash tree mortality. I used the results of these correlations to ensure that this discrepancy did not affect the accuracy of percent tree cover measurements.

	Percent Tree Cover vs. Number of Dead Ash per Percent Tree Cover			
	0.25km	1km	2km	3.5km
Pearson's r	0.0044	0.0151	-0.2135	-0.2935
p-value	0.9751	0.9152	0.1286	0.0347

Appendix 1B. The number of dead Ash trees (*Fraxinus* sp.) and number of dead Ash trees per percent tree cover measured within 0.25km, 1km, 2km, and 3.5km-radius circular landscape scales around each sampling site. The number of dead Ash trees per percent tree cover was calculated and correlated to percent tree cover at each scale.

Site	Radius of Circular Landscape							
	0.25km		1km		2km		3.5km	
	Number of Dead Ash	Number of Dead Ash per Percent Tree Cover	Number of Dead Ash	Number of Dead Ash per Percent Tree Cover	Number of Dead Ash	Number of Dead Ash per Percent Tree Cover	Number of Dead Ash	Number of Dead Ash per Percent Tree Cover
0	1	0.066	105	7.916	326	32.222	714	42.026
1	0	0	74	1.998	474	14.034	3019	109.282
2	0	0	8	0.598	132	8.749	564	37.222
3	5	0.483	30	3.938	170	14.542	543	32.253
4	3	0.084	13	0.927	146	9.061	444	24.235
5	0	0	126	3.311	410	12.765	772	25.281
6	0	0	23	1.453	84	5.258	561	27.334
7	3	0.078	69	1.702	324	7.200	1947	40.892
8	0	0	88	1.545	218	4.639	809	20.234
9	0	0	59	3.077	206	9.772	693	29.492
10	1	0.042	33	1.701	792	33.001	2161	82.672
11	7	0.591	376	13.619	1078	47.903	1407	75.581
12	0	0	32	0.680	118	2.908	509	14.611
13	0	0	31	1.284	85	2.955	528	18.063
14	2	0.078	33	1.493	308	12.606	929	41.032
15	1	0.035	33	1.191	168	7.274	451	18.118
16	0	0	76	2.114	160	5.193	1489	60.537
17	0	0	34	0.694	426	10.181	1524	38.855
18	22	0.346	393	8.182	958	21.769	1870	40.436
19	3	0.052	160	3.094	337	7.678	766	17.926
20	0	0	24	0.403	232	4.320	1099	22.392
21	0	0	45	1.049	106	2.872	621	16.102
22	0	0	19	0.480	124	2.793	656	15.759
23	1	0.034	38	1.437	128	4.862	652	21.241
24	0	0	54	1.403	487	10.952	1495	35.853
25	1	0.022	51	1.062	326	7.902	966	20.461

Appendix 1B. Continued.

Site	Radius of Circular Landscape							
	0.25km		1km		2km		3.5km	
	Number of Dead Ash	Number of Dead Ash per Percent Tree Cover	Number of Dead Ash	Number of Dead Ash per Percent Tree Cover	Number of Dead Ash	Number of Dead Ash per Percent Tree Cover	Number of Dead Ash	Number of Dead Ash per Percent Tree Cover
26	5	0.213	41	2.130	888	40.071	1687	74.264
27	3	0.132	163	4.801	452	17.305	1332	62.016
28	0	0	17	0.787	76	4.071	631	31.034
29	0	0	30	0.795	290	8.034	723	20.981
30	0	0	177	4.543	590	19.987	1321	56.500
31	0	0	62	2.041	182	6.406	630	18.851
32	0	0	32	1.227	234	7.890	597	21.846
33	5	0.099	233	4.102	1029	19.893	1713	36.243
34	28	0.541	306	5.894	1107	25.064	1962	49.809
35	0	0	6	0.246	301	9.203	1713	46.342
36	5	0.095	98	2.017	249	6.967	1254	36.836
37	64	1.393	160	4.099	284	9.049	1199	36.378
38	0	0	5	0.245	57	2.344	347	13.371
39	0	0	15	0.600	105	3.193	446	13.342
40	0	0	0	0	28	0.986	1021	31.999
41	0	0	61	2.031	284	9.478	807	27.421
42	4	0.169	211	6.391	499	18.113	1228	53.229
43	16	0.315	75	2.427	415	15.144	1100	41.924
44	0	0	72	1.973	284	7.002	627	16.323
45	9	0.208	107	2.568	296	7.823	803	22.925
46	1	0.041	66	3.078	217	10.372	444	21.500
47	0	0	36	2.068	219	11.098	717	27.719
48	0	0	55	3.074	229	9.308	3067	117.873
49	19	0.695	106	3.197	173	10.039	487	27.631
50	0	0	57	1.657	256	9.776	1677	81.752
51	5	0.081	77	1.683	431	10.470	1312	36.780

Appendix 2. Results of generalized linear mixed models examining the relationship between percent tree cover measured within each of 19 circular landscape scales and **(a)** total bat activity and **(b – e)** species-specific activity. Regression coefficients [$\beta \pm$ standard error (SE)] and p-values are shown for percent tree cover at each scale and for the control for percent building cover at the 1km-scale (if included in the model).

(a) Total Bat Activity						
Scale (km)	Percent Tree Cover β ($\pm$ SE)		p-value for Percent Tree Cover β	Percent Building Cover within a 1km-radius Landscape β ($\pm$ SE)		p-value for Percent Building Cover within a 1km-radius Landscape β
0.025	0.0128	($\pm$ 0.0046)	0.0052	0.0678	($\pm$ 0.0298)	0.0227
0.05	0.0217	($\pm$ 0.0059)	0.0003	0.0881	($\pm$ 0.0289)	0.0023
0.1	0.0304	($\pm$ 0.0071)	< 0.0001	0.1161	($\pm$ 0.0297)	0.0001
0.15	0.0356	($\pm$ 0.0077)	< 0.0001	0.1434	($\pm$ 0.0319)	< 0.0001
0.2	0.0368	($\pm$ 0.0077)	< 0.0001	0.1575	($\pm$ 0.0333)	< 0.0001
0.25	0.0365	($\pm$ 0.0081)	< 0.0001	0.1531	($\pm$ 0.0338)	< 0.0001
0.5	0.0292	($\pm$ 0.0105)	0.0056	0.1368	($\pm$ 0.0397)	0.0006
0.75	0.0256	($\pm$ 0.0109)	0.0184	0.1248	($\pm$ 0.0399)	0.0018
1	0.0258	($\pm$ 0.0111)	0.0198	0.1203	($\pm$ 0.0389)	0.0020
1.25	0.0261	($\pm$ 0.0113)	0.0206	0.1157	($\pm$ 0.0379)	0.0023
1.5	0.0262	($\pm$ 0.0112)	0.0195	0.1094	($\pm$ 0.0363)	0.0026
1.75	0.0335	($\pm$ 0.0126)	0.0077	0.1096	($\pm$ 0.0348)	0.0017
2	0.0311	($\pm$ 0.0114)	0.0061	0.1046	($\pm$ 0.0336)	0.0019
2.25	0.0312	($\pm$ 0.0114)	0.0059	0.0994	($\pm$ 0.0327)	0.0024
2.5	0.0318	($\pm$ 0.0114)	0.0054	0.0953	($\pm$ 0.0321)	0.0030
2.75	0.0313	($\pm$ 0.0117)	0.0072	0.0921	($\pm$ 0.0319)	0.0039
3	0.0318	($\pm$ 0.0118)	0.0072	0.0908	($\pm$ 0.0318)	0.0043
3.25	0.0323	($\pm$ 0.0119)	0.0068	0.0899	($\pm$ 0.0316)	0.0045
3.5	0.0336	($\pm$ 0.0121)	0.0055	0.0900	($\pm$ 0.0315)	0.0043

Appendix 2. Continued.

(b) Big Brown Bat						
Scale (km)	Percent Tree Cover β ($\pm$ SE)		p-value for Percent Tree Cover β	Percent Building Cover within a 1km- radius Landscape β ($\pm$ SE)		p-value for Percent Building Cover within a 1km-radius Landscape β
0.025	0.0199	($\pm$ 0.0070)	0.0043	0.0891	($\pm$ 0.0459)	0.0522
0.05	0.0319	($\pm$ 0.0091)	0.0004	0.1176	($\pm$ 0.0452)	0.0092
0.1	0.0455	($\pm$ 0.0108)	< 0.0001	0.1612	($\pm$ 0.0461)	0.0005
0.15	0.0503	($\pm$ 0.0116)	< 0.0001	0.1917	($\pm$ 0.0488)	0.0001
0.2	0.0513	($\pm$ 0.0118)	< 0.0001	0.2102	($\pm$ 0.0511)	< 0.0001
0.25	0.0527	($\pm$ 0.0123)	< 0.0001	0.2104	($\pm$ 0.0514)	< 0.0001
0.5	0.0464	($\pm$ 0.0155)	0.0028	0.2010	($\pm$ 0.0595)	0.0007
0.75	0.0385	($\pm$ 0.0163)	0.0181	0.1758	($\pm$ 0.0602)	0.0035
1	0.0377	($\pm$ 0.0168)	0.0246	0.1669	($\pm$ 0.0592)	0.0048
1.25	0.0401	($\pm$ 0.0171)	0.0189	0.1637	($\pm$ 0.0573)	0.0043
1.5	0.0420	($\pm$ 0.0171)	0.0137	0.1565	($\pm$ 0.0547)	0.0042
1.75	0.0531	($\pm$ 0.0192)	0.0056	0.1557	($\pm$ 0.0524)	0.0030
2	0.0499	($\pm$ 0.0173)	0.0040	0.1481	($\pm$ 0.0506)	0.0034
2.25	0.0509	($\pm$ 0.0173)	0.0032	0.1406	($\pm$ 0.0492)	0.0042
2.5	0.0523	($\pm$ 0.0173)	0.0026	0.1342	($\pm$ 0.0481)	0.0053
2.75	0.0521	($\pm$ 0.0177)	0.0032	0.1294	($\pm$ 0.0478)	0.0068
3	0.0531	($\pm$ 0.0179)	0.0031	0.1273	($\pm$ 0.0475)	0.0074
3.25	0.0541	($\pm$ 0.0180)	0.0027	0.1259	($\pm$ 0.0472)	0.0077
3.5	0.0569	($\pm$ 0.0182)	0.0018	0.1264	($\pm$ 0.0469)	0.0070

Appendix 2. Continued.

(c) Hoary Bat/ Silver-haired Bat						
Scale (km)	Percent Tree Cover β ($\pm$ SE)		p-value for Percent Tree Cover β	Percent Building Cover within a 1km- radius Landscape β ($\pm$ SE)		p-value for Percent Building Cover within a 1km-radius Landscape β
0.025	0.0032	($\pm$ 0.0048)	0.4986	0.0592	($\pm$ 0.0275)	0.0312
0.05	0.0095	($\pm$ 0.0060)	0.1132	0.0687	($\pm$ 0.0278)	0.0135
0.1	0.0160	($\pm$ 0.0071)	0.0232	0.0835	($\pm$ 0.0288)	0.0038
0.15	0.0183	($\pm$ 0.0080)	0.0217	0.0951	($\pm$ 0.0315)	0.0025
0.2	0.0182	($\pm$ 0.0082)	0.0254	0.1009	($\pm$ 0.0333)	0.0024
0.25	0.0160	($\pm$ 0.0087)	0.0668	0.0952	($\pm$ 0.0341)	0.0052
0.5	0.0132	($\pm$ 0.0104)	0.2013	0.0889	($\pm$ 0.0365)	0.0149
0.75	0.0155	($\pm$ 0.0102)	0.1266	0.0942	($\pm$ 0.0363)	0.0094
1	0.0167	($\pm$ 0.0103)	0.1025	0.0944	($\pm$ 0.0354)	0.0077
1.25	0.0161	($\pm$ 0.0105)	0.1247	0.0896	($\pm$ 0.0345)	0.0095
1.5	0.0148	($\pm$ 0.0104)	0.1547	0.0834	($\pm$ 0.0331)	0.0117
1.75	0.0182	($\pm$ 0.0117)	0.1198	0.0824	($\pm$ 0.0320)	0.0099
2	0.0169	($\pm$ 0.0104)	0.1053	0.0797	($\pm$ 0.0308)	0.0096
2.25	0.0171	($\pm$ 0.0103)	0.0964	0.0770	($\pm$ 0.0298)	0.0099
2.5	0.0179	($\pm$ 0.0104)	0.0836	0.0754	($\pm$ 0.0293)	0.0101
2.75	0.0180	($\pm$ 0.0105)	0.0862	0.0737	($\pm$ 0.0290)	0.0111
3	0.0182	($\pm$ 0.0106)	0.0875	0.0727	($\pm$ 0.0288)	0.0118
3.25	0.0183	($\pm$ 0.0107)	0.0886	0.0719	($\pm$ 0.0287)	0.0123
3.5	0.0183	($\pm$ 0.0111)	0.0988	0.0715	($\pm$ 0.0288)	0.0130

Appendix 2. Continued.

(d) Little Brown Myotis/ Northern Myotis/ Tri-colored Bat			
Scale (km)	Percent Tree Cover β ($\pm$ SE)		p-value for Percent Tree Cover β
0.025	0.0152	($\pm$ 0.0090)	0.0898
0.05	0.0191	($\pm$ 0.0123)	0.1184
0.1	0.0168	($\pm$ 0.0149)	0.2602
0.15	0.0173	($\pm$ 0.0159)	0.2762
0.2	0.0172	($\pm$ 0.0162)	0.2881
0.25	0.0178	($\pm$ 0.0172)	0.3003
0.5	0.0064	($\pm$ 0.0183)	0.7254
0.75	0.0030	($\pm$ 0.0177)	0.8665
1	0.0029	($\pm$ 0.0175)	0.8675
1.25	0.0016	($\pm$ 0.0182)	0.9294
1.5	0.0013	($\pm$ 0.0205)	0.9484
1.75	0.0022	($\pm$ 0.0235)	0.9267
2	0.0020	($\pm$ 0.0229)	0.9310
2.25	0.0029	($\pm$ 0.0237)	0.9034
2.5	0.0029	($\pm$ 0.0247)	0.9063
2.75	0.0024	($\pm$ 0.0262)	0.9259
3	0.0001	($\pm$ 0.0278)	0.9975
3.25	-0.0038	($\pm$ 0.0286)	0.8951
3.5	-0.0062	($\pm$ 0.0294)	0.8331

Appendix 2. Continued.

(e) Eastern Red Bat			
Scale (km)	Percent Tree Cover β ($\pm$ SE)		p-value for Percent Tree Cover β
0.025	0.0466	($\pm$ 0.0118)	0.0001
0.05	0.0499	($\pm$ 0.0172)	0.0038
0.1	0.0424	($\pm$ 0.0215)	0.0483
0.15	0.0298	($\pm$ 0.0215)	0.1656
0.2	0.0269	($\pm$ 0.0212)	0.2047
0.25	0.0254	($\pm$ 0.0219)	0.2459
0.5	0.0122	($\pm$ 0.0245)	0.6185
0.75	0.0130	($\pm$ 0.0256)	0.6105
1	0.0147	($\pm$ 0.0266)	0.5814
1.25	0.0119	($\pm$ 0.0277)	0.6679
1.5	0.0108	($\pm$ 0.0289)	0.7098
1.75	0.0139	($\pm$ 0.0342)	0.6843
2	0.0114	($\pm$ 0.0323)	0.7240
2.25	0.0101	($\pm$ 0.0332)	0.7605
2.5	0.0089	($\pm$ 0.0343)	0.7955
2.75	0.0070	($\pm$ 0.0353)	0.8432
3	0.0056	($\pm$ 0.0360)	0.8775
3.25	0.0030	($\pm$ 0.0364)	0.9348
3.5	0.0018	($\pm$ 0.0371)	0.9614

Appendix 3. Additional results of generalized linear mixed models examining the relationship between percent tree cover measured within each of 19 circular landscape scales and **(a)** total bat activity and **(b – e)** species-specific activity. Regression coefficients [$\beta \pm$ standard error (SE)] and p-values are shown for standardized temperature ($^{\circ}\text{C}$) and standardized Julian Date at each scale.

(a) Total Bat Activity						
Scale (km)	Standardized Temperature β (± SE)		p-value for Standardized Temperature β	Standardized Julian Date β (± SE)		p-value for Standardized Julian Date β
0.025	0.2079	(± 0.1255)	0.0977	0.0183	(± 0.0049)	0.0002
0.05	0.2296	(± 0.1210)	0.0577	0.0163	(± 0.0050)	0.0010
0.1	0.2401	(± 0.1175)	0.0411	0.0160	(± 0.0050)	0.0014
0.15	0.2207	(± 0.1166)	0.0585	0.0169	(± 0.0050)	0.0006
0.2	0.2108	(± 0.1170)	0.0716	0.0169	(± 0.0050)	0.0008
0.25	0.1884	(± 0.1195)	0.1151	0.0175	(± 0.0049)	0.0004
0.5	0.1952	(± 0.1264)	0.1225	0.0184	(± 0.0050)	0.0002
0.75	0.2036	(± 0.1264)	0.1073	0.0186	(± 0.0050)	0.0002
1	0.2105	(± 0.1256)	0.0937	0.0185	(± 0.0050)	0.0002
1.25	0.2141	(± 0.1252)	0.0873	0.0186	(± 0.0050)	0.0002
1.5	0.2176	(± 0.1249)	0.0813	0.0186	(± 0.0050)	0.0002
1.75	0.2182	(± 0.1237)	0.0777	0.0185	(± 0.0049)	0.0002
2	0.2167	(± 0.1236)	0.0795	0.0184	(± 0.0049)	0.0002
2.25	0.2130	(± 0.1238)	0.0852	0.0183	(± 0.0049)	0.0002
2.5	0.2126	(± 0.1236)	0.0853	0.0182	(± 0.0049)	0.0002
2.75	0.2118	(± 0.1239)	0.0875	0.0183	(± 0.0049)	0.0002
3	0.2085	(± 0.1242)	0.0932	0.0184	(± 0.0049)	0.0002
3.25	0.2038	(± 0.1243)	0.1010	0.0186	(± 0.0049)	0.0001
3.5	0.1978	(± 0.1245)	0.1121	0.0188	(± 0.0049)	0.0001

Appendix 3. Continued.

(b) Big Brown Bat						
Scale (km)	Standardized Temperature β ($\pm$ SE)		p-value for Standardized Temperature β	Standardized Julian Date β ($\pm$ SE)		p-value for Standardized Julian Date β
0.025	0.3028	($\pm$ 0.1518)	0.0461	0.0102	($\pm$ 0.0059)	0.0820
0.05	0.3318	($\pm$ 0.1488)	0.0257	0.0087	($\pm$ 0.0058)	0.1345
0.1	0.3321	($\pm$ 0.1472)	0.0241	0.0087	($\pm$ 0.0058)	0.1333
0.15	0.3253	($\pm$ 0.1470)	0.0269	0.0100	($\pm$ 0.0057)	0.0814
0.2	0.3187	($\pm$ 0.1471)	0.0303	0.0100	($\pm$ 0.0057)	0.0810
0.25	0.2959	($\pm$ 0.1484)	0.0461	0.0103	($\pm$ 0.0057)	0.0739
0.5	0.2837	($\pm$ 0.1523)	0.0624	0.0104	($\pm$ 0.0059)	0.0744
0.75	0.2937	($\pm$ 0.1527)	0.0545	0.0105	($\pm$ 0.0059)	0.0747
1	0.3028	($\pm$ 0.1522)	0.0467	0.0104	($\pm$ 0.0059)	0.0767
1.25	0.3042	($\pm$ 0.1519)	0.0452	0.0104	($\pm$ 0.0059)	0.0753
1.5	0.3074	($\pm$ 0.1514)	0.0423	0.0103	($\pm$ 0.0059)	0.0796
1.75	0.3083	($\pm$ 0.1506)	0.0407	0.0101	($\pm$ 0.0058)	0.0832
2	0.3066	($\pm$ 0.1505)	0.0417	0.0100	($\pm$ 0.0058)	0.0873
2.25	0.3025	($\pm$ 0.1506)	0.0446	0.0099	($\pm$ 0.0058)	0.0900
2.5	0.3027	($\pm$ 0.1504)	0.0441	0.0098	($\pm$ 0.0058)	0.0933
2.75	0.3021	($\pm$ 0.1506)	0.0449	0.0098	($\pm$ 0.0058)	0.0931
3	0.2987	($\pm$ 0.1509)	0.0477	0.0099	($\pm$ 0.0058)	0.0883
3.25	0.2922	($\pm$ 0.1511)	0.0531	0.0102	($\pm$ 0.0058)	0.0810
3.5	0.2848	($\pm$ 0.1512)	0.0596	0.0104	($\pm$ 0.0058)	0.0746

Appendix 3. Continued.

(c) Hoary Bat/ Silver-haired Bat						
Scale (km)	Standardized Temperature β ($\pm$ SE)		p-value for Standardized Temperature β	Standardized Julian Date β ($\pm$ SE)		p-value for Standardized Julian Date β
0.025	0.2841	($\pm$ 0.1355)	0.0359	0.0296	($\pm$ 0.0063)	< 0.0001
0.05	0.2841	($\pm$ 0.1305)	0.0295	0.0289	($\pm$ 0.0062)	< 0.0001
0.1	0.2893	($\pm$ 0.1285)	0.0243	0.0284	($\pm$ 0.0061)	< 0.0001
0.15	0.2868	($\pm$ 0.1279)	0.0250	0.0287	($\pm$ 0.0061)	< 0.0001
0.2	0.2880	($\pm$ 0.1282)	0.0246	0.0286	($\pm$ 0.0061)	< 0.0001
0.25	0.2767	($\pm$ 0.1302)	0.0335	0.0290	($\pm$ 0.0062)	< 0.0001
0.5	0.2675	($\pm$ 0.1335)	0.0451	0.0293	($\pm$ 0.0062)	< 0.0001
0.75	0.2534	($\pm$ 0.1334)	0.0575	0.0293	($\pm$ 0.0062)	< 0.0001
1	0.2511	($\pm$ 0.1328)	0.0586	0.0290	($\pm$ 0.0062)	< 0.0001
1.25	0.2553	($\pm$ 0.1327)	0.0545	0.0290	($\pm$ 0.0062)	< 0.0001
1.5	0.2630	($\pm$ 0.1349)	0.0511	0.0291	($\pm$ 0.0063)	< 0.0001
1.75	0.2655	($\pm$ 0.1338)	0.0473	0.0290	($\pm$ 0.0063)	< 0.0001
2	0.2632	($\pm$ 0.1334)	0.0485	0.0290	($\pm$ 0.0063)	< 0.0001
2.25	0.2602	($\pm$ 0.1316)	0.0480	0.0289	($\pm$ 0.0062)	< 0.0001
2.5	0.2591	($\pm$ 0.1311)	0.0482	0.0288	($\pm$ 0.0062)	< 0.0001
2.75	0.2579	($\pm$ 0.1312)	0.0493	0.0289	($\pm$ 0.0062)	< 0.0001
3	0.2556	($\pm$ 0.1314)	0.0518	0.0290	($\pm$ 0.0062)	< 0.0001
3.25	0.2527	($\pm$ 0.1317)	0.0551	0.0291	($\pm$ 0.0062)	< 0.0001
3.5	0.2509	($\pm$ 0.1339)	0.0609	0.0293	($\pm$ 0.0063)	< 0.0001

Appendix 3. Continued.

(d) Little Brown Myotis/ Northern Myotis/ Tri-colored Bat						
Scale (km)	Standardized Temperature β ($\pm$ SE)		p-value for Standardized Temperature β	Standardized Julian Date β ($\pm$ SE)		p-value for Standardized Julian Date β
0.025	-0.1037	($\pm$ 0.3126)	0.7400	0.0078	($\pm$ 0.0122)	0.5242
0.05	-0.0717	($\pm$ 0.3148)	0.8198	0.0056	($\pm$ 0.0127)	0.6577
0.1	-0.0749	($\pm$ 0.3212)	0.8157	0.0083	($\pm$ 0.0127)	0.5112
0.15	-0.0902	($\pm$ 0.3201)	0.7780	0.0093	($\pm$ 0.0125)	0.4567
0.2	-0.0982	($\pm$ 0.3201)	0.7591	0.0093	($\pm$ 0.0125)	0.4552
0.25	-0.1147	($\pm$ 0.3198)	0.7200	0.0094	($\pm$ 0.0125)	0.4547
0.5	-0.1260	($\pm$ 0.3238)	0.6972	0.0123	($\pm$ 0.0126)	0.3258
0.75	-0.1260	($\pm$ 0.3246)	0.6978	0.0131	($\pm$ 0.0125)	0.2933
1	-0.1262	($\pm$ 0.3245)	0.6973	0.0131	($\pm$ 0.0125)	0.2927
1.25	-0.1264	($\pm$ 0.3249)	0.6973	0.0134	($\pm$ 0.0125)	0.2842
1.5	-0.1267	($\pm$ 0.3357)	0.7059	0.0134	($\pm$ 0.0125)	0.2819
1.75	-0.1256	($\pm$ 0.3265)	0.7004	0.0134	($\pm$ 0.0125)	0.2840
2	-0.1254	($\pm$ 0.3291)	0.7031	0.0134	($\pm$ 0.0125)	0.2836
2.25	-0.1238	($\pm$ 0.3262)	0.7043	0.0132	($\pm$ 0.0125)	0.2905
2.5	-0.1232	($\pm$ 0.3269)	0.7064	0.0132	($\pm$ 0.0126)	0.2927
2.75	-0.1238	($\pm$ 0.3335)	0.7106	0.0133	($\pm$ 0.0126)	0.2900
3	-0.1308	($\pm$ 0.3413)	0.7015	0.0136	($\pm$ 0.0126)	0.2797
3.25	-0.1406	($\pm$ 0.3427)	0.6816	0.0140	($\pm$ 0.0126)	0.2661
3.5	-0.1446	($\pm$ 0.3405)	0.6712	0.0141	($\pm$ 0.0125)	0.2598

Appendix 3. Continued.

(e) Eastern Red Bat						
Scale (km)	Standardized Temperature β (± SE)		p-value for Standardized Temperature β	Standardized Julian Date β (± SE)		p-value for Standardized Julian Date β
0.025	-0.5735	(± 0.4077)	0.1595	0.0413	(± 0.0153)	0.0069
0.05	-0.4487	(± 0.4134)	0.2777	0.0420	(± 0.0154)	0.0064
0.1	-0.4106	(± 0.4210)	0.3295	0.0457	(± 0.0155)	0.0032
0.15	-0.4240	(± 0.4280)	0.3218	0.0476	(± 0.0157)	0.0024
0.2	-0.4279	(± 0.4296)	0.3192	0.0477	(± 0.0157)	0.0024
0.25	-0.4409	(± 0.4306)	0.3059	0.0480	(± 0.0158)	0.0024
0.5	-0.4614	(± 0.4353)	0.2891	0.0487	(± 0.0160)	0.0024
0.75	-0.4699	(± 0.4355)	0.2806	0.0488	(± 0.0160)	0.0023
1	-0.4681	(± 0.4354)	0.2823	0.0487	(± 0.0160)	0.0024
1.25	-0.4689	(± 0.4356)	0.2817	0.0491	(± 0.0160)	0.0021
1.5	-0.4683	(± 0.4357)	0.2825	0.0493	(± 0.0159)	0.0020
1.75	-0.4676	(± 0.4356)	0.2831	0.0493	(± 0.0159)	0.0020
2	-0.4688	(± 0.4358)	0.2821	0.0494	(± 0.0159)	0.0019
2.25	-0.4699	(± 0.4361)	0.2812	0.0496	(± 0.0159)	0.0018
2.5	-0.4697	(± 0.4362)	0.2815	0.0497	(± 0.0159)	0.0018
2.75	-0.4701	(± 0.4363)	0.2812	0.0498	(± 0.0159)	0.0017
3	-0.4705	(± 0.4363)	0.2809	0.0499	(± 0.0159)	0.0017
3.25	-0.4708	(± 0.4364)	0.2806	0.0500	(± 0.0159)	0.0016
3.5	-0.4710	(± 0.4365)	0.2806	0.0500	(± 0.0159)	0.0016

Appendix 4. AIC, Δ AIC, relative likelihood, and AIC weights from generalized linear mixed models (GLMM) examining the relationship between percent tree cover measured within each of 19 circular landscape scales and **(a)** total bat activity and **(b – e)** species-specific activity. AIC values are shown for GLMM without a statistical control for percent building cover, and with a statistical control for percent building cover included in models separately at the 0.5km, 1km, or 1.5km-radius landscape scales. Δ AIC, relative likelihood, and AIC weights correspond to the best-fitting model, which is shaded (i.e., either with or without percent building cover at 1km included as a statistical control).

(a) Total Bat Activity							
Scale (km)	AIC				ΔAIC	Relative Likelihoods	AIC Weight
	No Building Control	0.5km Building Control	1km Building Control	1.5km Building Control			
0.025	1079.102	1080.280	1076.176	1075.886	11.520	0.003	0.001
0.05	1077.898	1077.196	1071.516	1071.632	6.860	0.032	0.013
0.1	1078.478	1075.604	1067.232	1068.978	2.576	0.276	0.111
0.15	1080.198	1075.312	1065.198	1069.844	0.542	0.763	0.307
0.2	1081.324	1075.964	1064.656	1070.504	0	1.000	0.403
0.25	1082.018	1077.028	1066.594	1072.106	1.938	0.379	0.153
0.5	1085.124	1084.986	1076.318	1079.568	11.662	0.003	0.001
0.75	1085.298	1086.134	1078.162	1080.434	13.506	0.001	0
1	1085.228	1086.104	1078.262	1079.874	13.606	0.001	0
1.25	1085.104	1085.912	1078.306	1079.028	13.650	0.001	0
1.5	1084.832	1085.492	1078.212	1078.222	13.556	0.001	0
1.75	1084.080	1084.302	1076.726	1076.436	12.070	0.002	0.001
2	1083.478	1083.598	1076.346	1075.902	11.690	0.003	0.001
2.25	1082.980	1083.110	1076.282	1075.760	11.626	0.003	0.001
2.5	1082.470	1082.612	1076.138	1075.538	11.482	0.003	0.001
2.75	1082.494	1082.788	1076.608	1075.958	11.952	0.003	0.001
3	1082.338	1082.658	1076.598	1075.902	11.942	0.003	0.001
3.25	1082.144	1082.482	1076.490	1075.762	11.834	0.003	0.001
3.5	1081.896	1082.198	1076.168	1075.444	11.512	0.003	0.001

Appendix 4. Continued.

(b) Big Brown Bat							
Scale (km)	AIC				ΔAIC	Relative Likelihoods	AIC Weight
	No Building Control	0.5km Building Control	1km Building Control	1.5km Building Control			
0.025	904.862	906.540	903.202	903.752	8.648	0.013	0.004
0.05	904.042	904.430	899.604	900.786	5.050	0.080	0.022
0.1	904.296	902.740	895.128	898.280	0.574	0.751	0.205
0.15	906.332	903.318	894.554	899.948	0	1.000	0.273
0.2	907.682	904.442	894.686	900.956	0.132	0.936	0.255
0.25	908.042	904.706	895.206	901.612	0.652	0.722	0.197
0.5	911.204	911.316	902.686	907.464	8.132	0.017	0.005
0.75	911.708	913.018	905.644	908.902	11.090	0.004	0.001
1	911.702	913.134	906.126	908.726	11.572	0.003	0.001
1.25	911.458	912.758	905.694	907.764	11.140	0.004	0.001
1.5	910.992	912.108	905.188	906.712	10.634	0.005	0.001
1.75	910.124	910.920	903.758	905.096	9.204	0.010	0.003
2	909.366	910.070	903.214	904.388	8.660	0.013	0.004
2.25	908.652	909.342	902.872	903.928	8.318	0.016	0.004
2.5	907.946	908.642	902.526	903.456	7.972	0.019	0.005
2.75	907.892	908.714	902.886	903.704	8.332	0.016	0.004
3	907.692	908.540	902.832	903.584	8.278	0.016	0.004
3.25	907.402	908.264	902.602	903.308	8.048	0.018	0.005
3.5	906.924	907.732	901.982	902.698	7.428	0.024	0.007

Appendix 4. Continued.

(c) Hoary Bat/ Silver-haired Bat							
Scale (km)	AIC				ΔAIC	Relative Likelihoods	AIC Weight
	No Building Control	0.5km Building Control	1km Building Control	1.5km Building Control			
0.025	741.774	741.866	739.440	739.354	4.730	0.094	0.014
0.05	741.170	739.952	737.458	737.412	2.748	0.253	0.036
0.1	740.828	737.850	734.860	735.486	0.150	0.928	0.134
0.15	741.356	737.834	734.710	736.080	0	1.000	0.144
0.2	741.686	738.438	734.996	736.602	0.286	0.867	0.125
0.25	741.972	740.066	736.622	737.844	1.912	0.384	0.055
0.5	741.854	741.874	738.330	739.328	3.620	0.164	0.024
0.75	741.982	741.830	737.664	738.958	2.954	0.228	0.033
1	742.024	741.684	737.330	738.362	2.620	0.270	0.039
1.25	742.026	741.676	737.618	738.012	2.908	0.234	0.034
1.5	742.014	741.626	737.924	737.844	3.214	0.200	0.029
1.75	741.894	741.150	737.522	737.230	2.812	0.245	0.035
2	741.706	740.804	737.324	736.902	2.614	0.271	0.039
2.25	741.518	740.560	737.228	736.750	2.518	0.284	0.041
2.5	741.258	740.210	737.002	736.468	2.292	0.318	0.046
2.75	741.168	740.178	737.048	736.466	2.338	0.311	0.045
3	741.084	740.126	737.070	736.456	2.360	0.307	0.044
3.25	741.012	740.076	737.088	736.468	2.378	0.305	0.044
3.5	741.062	740.186	737.226	736.642	2.516	0.284	0.041

Appendix 4. Continued.

(d) Little Brown Myotis/ Northern Myotis/ Tri-colored Bat							
Scale (km)	AIC				ΔAIC	Relative Likelihoods	AIC Weight
	No Building Control	0.5km Building Control	1km Building Control	1.5km Building Control			
0.025	190.802	192.699	192.723	192.337	0	1.000	0.146
0.05	191.164	193.164	192.841	192.115	0.362	0.834	0.122
0.1	192.337	194.308	194.101	193.261	1.535	0.464	0.068
0.15	192.415	194.413	194.026	193.326	1.614	0.446	0.065
0.2	192.473	194.473	194.019	193.404	1.672	0.434	0.063
0.25	192.525	194.525	194.132	193.530	1.723	0.422	0.062
0.5	193.489	194.772	195.488	195.208	2.687	0.261	0.038
0.75	193.584	194.632	195.545	195.423	2.782	0.249	0.036
1	193.584	194.691	195.544	195.395	2.783	0.249	0.036
1.25	193.604	194.592	195.520	195.451	2.803	0.246	0.036
1.5	193.607	194.581	195.515	195.463	2.805	0.246	0.036
1.75	193.604	194.625	195.528	195.445	2.802	0.246	0.036
2	193.604	194.651	195.531	195.462	2.803	0.246	0.036
2.25	193.597	194.731	195.542	195.444	2.796	0.247	0.036
2.5	193.598	194.747	195.543	195.455	2.797	0.247	0.036
2.75	193.603	194.740	195.540	195.476	2.801	0.246	0.036
3	193.611	194.657	195.517	195.523	2.809	0.245	0.036
3.25	193.594	194.483	195.445	195.549	2.792	0.248	0.036
3.5	193.567	194.351	195.382	195.539	2.766	0.251	0.037

Appendix 4. Continued.

(e) Eastern Red Bat							
Scale (km)	AIC				ΔAIC	Relative Likelihoods	AIC Weight
	No Building Control	0.5km Building Control	1km Building Control	1.5km Building Control			
0.025	383.172	384.746	385.102	384.716	0	1.000	0.921
0.05	388.814	389.278	390.420	389.926	5.642	0.060	0.055
0.1	393.154	393.666	394.556	394.132	9.982	0.007	0.006
0.15	395.216	395.932	396.772	396.558	12.044	0.002	0.002
0.2	395.536	396.210	397.064	396.890	12.364	0.002	0.002
0.25	395.804	396.634	397.438	397.276	12.632	0.002	0.002
0.5	396.914	398.798	398.892	398.754	13.742	0.001	0.001
0.75	396.904	398.826	398.874	398.718	13.732	0.001	0.001
1	396.860	398.782	398.816	398.608	13.688	0.001	0.001
1.25	396.978	398.952	398.972	398.774	13.806	0.001	0.001
1.5	397.024	399.014	399.024	398.862	13.852	0.001	0.001
1.75	396.996	398.984	398.996	398.826	13.824	0.001	0.001
2	397.038	399.034	399.036	398.916	13.866	0.001	0.001
2.25	397.070	399.068	399.062	398.982	13.898	0.001	0.001
2.5	397.096	399.096	399.082	399.030	13.924	0.001	0.001
2.75	397.124	399.120	399.100	399.076	13.952	0.001	0.001
3	397.138	399.132	399.106	399.104	13.966	0.001	0.001
3.25	397.156	399.140	399.108	399.134	13.984	0.001	0.001
3.5	397.160	399.138	399.104	399.142	13.988	0.001	0.001

Appendix 5. Residual plots showing the spread of residuals relative to predicted values of total number of passes for **(a)** total bat activity and **(b – e)** species-specific activity at the 0.025km, 1km, and 3.5km-radius landscape scales. I used these plots to assess the fit of the generalized linear mixed models and negative binomial link functions in estimating the relationship between percent tree cover and bat activity.

Appendix 5. Continued.

Appendix 5. Continued.

Appendix 5. Continued.

Appendix 5. Continued.

Appendix 5. Continued.

Appendix 5. Continued.

Appendix 5. Continued.

Appendix 6. Results of Moran's *I* tests [observed and expected values, standard deviation (sd), and p-values] for all 19 landscape scales measuring spatial autocorrelation in residuals of generalized linear mixed models that related percent tree cover to **(a)** total bat activity and **(b – e)** activity for each species. Moran's *I* tests were performed separately for each round of sampling (i.e., round 1 or round 2).

(a) Total Bat Activity										
Round 1										
	0.025km	0.05km	0.1km	0.15km	0.2km	0.25km	0.5km	0.75km	1km	1.25km
observed	-0.0220	-0.0230	-0.0279	-0.0234	-0.0198	-0.0165	-0.0164	-0.0205	-0.0220	-0.0223
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196
sd	0.0216	0.0217	0.0216	0.0216	0.0216	0.0217	0.0217	0.0218	0.0218	0.0218
p-value	0.9134	0.8759	0.7002	0.8621	0.9927	0.8842	0.8824	0.9680	0.9114	0.9030
	1.5km	1.75km	2km	2.25km	2.5km	2.75km	3km	3.25km	3.5km	
observed	-0.0219	-0.0222	-0.0224	-0.0225	-0.0227	-0.0231	-0.0235	-0.0241	-0.0246	
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	
sd	0.0218	0.0218	0.0218	0.0217	0.0217	0.0217	0.0217	0.0217	0.0218	
p-value	0.9178	0.9069	0.8974	0.8948	0.8879	0.8741	0.8566	0.8378	0.8194	
Round 2										
	0.025km	0.05km	0.1km	0.15km	0.2km	0.25km	0.5km	0.75km	1km	1.25km
observed	-0.0263	-0.0271	-0.0294	-0.0338	-0.0343	-0.0343	-0.0299	-0.0284	-0.0270	-0.0265
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196
sd	0.0219	0.0218	0.0218	0.0218	0.0218	0.0218	0.0219	0.0219	0.0219	0.0219
p-value	0.7600	0.7324	0.6544	0.5156	0.5013	0.5010	0.6382	0.6900	0.7364	0.7527
	1.5km	1.75km	2km	2.25km	2.5km	2.75km	3km	3.25km	3.5km	
observed	-0.0261	-0.0263	-0.0265	-0.0266	-0.0262	-0.0262	-0.0267	-0.0277	-0.0283	
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	
sd	0.0219	0.0219	0.0219	0.0219	0.0218	0.0218	0.0218	0.0218	0.0218	
p-value	0.7677	0.7582	0.7544	0.7502	0.7635	0.7632	0.7450	0.7120	0.6902	

Appendix 6. Continued.

(b) Big Brown Bat										
Round 1										
	0.025km	0.05km	0.1km	0.15km	0.2km	0.25km	0.5km	0.75km	1km	1.25km
observed	-0.0257	-0.0246	-0.0247	-0.0220	-0.0209	-0.0191	-0.0191	-0.0240	-0.0254	-0.0253
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196
sd	0.0218	0.0218	0.0218	0.0218	0.0218	0.0218	0.0219	0.0219	0.0219	0.0219
p-value	0.7792	0.8181	0.8168	0.9131	0.9538	0.9805	0.9831	0.8392	0.7919	0.7945
	1.5km	1.75km	2km	2.25km	2.5km	2.75km	3km	3.25km	3.5km	
observed	-0.0247	-0.0244	-0.0239	-0.0236	-0.0235	-0.0239	-0.0240	-0.0240	-0.0238	
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	
sd	0.0219	0.0218	0.0218	0.0218	0.0218	0.0218	0.0218	0.0218	0.0218	
p-value	0.8168	0.8267	0.8426	0.8548	0.8601	0.8454	0.8421	0.8423	0.8494	
Round 2										
	0.025km	0.05km	0.1km	0.15km	0.2km	0.25km	0.5km	0.75km	1km	1.25km
observed	-0.0317	-0.0414	-0.0426	-0.0468	-0.0489	-0.0513	-0.0474	-0.0414	-0.0396	-0.0416
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196
sd	0.0217	0.0218	0.0219	0.0218	0.0218	0.0219	0.0218	0.0218	0.0218	0.0218
p-value	0.5785	0.3169	0.2925	0.2133	0.1805	0.1465	0.2039	0.3169	0.3595	0.3139
	1.5km	1.75km	2km	2.25km	2.5km	2.75km	3km	3.25km	3.5km	
observed	-0.0442	-0.0474	-0.0487	-0.0491	-0.0495	-0.0490	-0.0492	-0.0494	-0.0498	
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	
sd	0.0218	0.0218	0.0219	0.0218	0.0218	0.0218	0.0218	0.0218	0.0218	
p-value	0.2605	0.2029	0.1832	0.1769	0.1714	0.1788	0.1757	0.1729	0.1665	

Appendix 6. Continued.

(c) Hoary Bat/ Silver-haired Bat										
Round 1										
	0.025km	0.05km	0.1km	0.15km	0.2km	0.25km	0.5km	0.75km	1km	1.25km
observed	-0.0146	-0.0156	-0.0196	-0.0161	-0.0136	-0.0118	-0.0088	-0.0091	-0.0103	-0.0109
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196
sd	0.0207	0.0209	0.0207	0.0210	0.0209	0.0208	0.0208	0.0209	0.0208	0.0208
p-value	0.8092	0.8464	0.9995	0.8682	0.7719	0.7064	0.6032	0.6149	0.6532	0.6736
	1.5km	1.75km	2km	2.25km	2.5km	2.75km	3km	3.25km	3.5km	
observed	-0.0107	-0.0109	-0.0112	-0.0114	-0.0118	-0.0121	-0.0127	-0.0134	-0.0141	
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	
sd	0.0207	0.0208	0.0208	0.0208	0.0208	0.0208	0.0208	0.0207	0.0207	
p-value	0.6668	0.6731	0.6842	0.6940	0.7053	0.7167	0.7383	0.7635	0.7894	
Round 2										
	0.025km	0.05km	0.1km	0.15km	0.2km	0.25km	0.5km	0.75km	1km	1.25km
observed	-0.0137	-0.0147	-0.0141	-0.0157	-0.0155	-0.0148	-0.0119	-0.0117	-0.0112	-0.0103
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196
sd	0.0217	0.0217	0.0217	0.0216	0.0215	0.0216	0.0217	0.0217	0.0217	0.0217
p-value	0.7859	0.8216	0.7993	0.8569	0.8497	0.8238	0.7236	0.7156	0.6976	0.6673
	1.5km	1.75km	2km	2.25km	2.5km	2.75km	3km	3.25km	3.5km	
observed	-0.0101	-0.0097	-0.0096	-0.0095	-0.0092	-0.0092	-0.0096	-0.0102	-0.0114	
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	
sd	0.0217	0.0217	0.0216	0.0216	0.0216	0.0216	0.0216	0.0216	0.0216	
p-value	0.6606	0.6484	0.6432	0.6389	0.6316	0.6300	0.6413	0.6627	0.7021	

Appendix 6. Continued.

(d) Little Brown Myotis/ Northern Myotis/ Tri-colored Bat										
Round 1										
	0.025km	0.05km	0.1km	0.15km	0.2km	0.25km	0.5km	0.75km	1km	1.25km
observed	-0.0437	-0.0392	-0.0382	-0.0386	-0.0386	-0.0388	-0.0410	-0.0407	-0.0407	-0.0403
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196
sd	0.0205	0.0197	0.0188	0.0195	0.0197	0.0195	0.0193	0.0191	0.0191	0.0190
p-value	0.2402	0.3211	0.3239	0.3296	0.3360	0.3235	0.2675	0.2684	0.2692	0.2750
	1.5km	1.75km	2km	2.25km	2.5km	2.75km	3km	3.25km	3.5km	
observed	-0.0403	-0.0402	-0.0402	-0.0402	-0.0402	-0.0402	-0.0403	-0.0404	-0.0405	
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	
sd	0.0190	0.0190	0.0190	0.0190	0.0190	0.0190	0.0191	0.0192	0.0192	
p-value	0.2765	0.2771	0.2776	0.2773	0.2775	0.2779	0.2784	0.2784	0.2768	
Round 2										
	0.025km	0.05km	0.1km	0.15km	0.2km	0.25km	0.5km	0.75km	1km	1.25km
observed	-0.0426	-0.0412	-0.0406	-0.0397	-0.0396	-0.0389	-0.0417	-0.0431	-0.0430	-0.0435
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196
sd	0.0203	0.0201	0.0203	0.0200	0.0199	0.0196	0.0197	0.0199	0.0199	0.0200
p-value	0.2572	0.2826	0.3002	0.3162	0.3151	0.3254	0.2626	0.2386	0.2410	0.2314
	1.5km	1.75km	2km	2.25km	2.5km	2.75km	3km	3.25km	3.5km	
observed	-0.0437	-0.0435	-0.0435	-0.0433	-0.0433	-0.0436	-0.0443	-0.0453	-0.0457	
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	
sd	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0201	0.0202	0.0203	
p-value	0.2289	0.2322	0.2316	0.2360	0.2351	0.2314	0.2190	0.2042	0.1985	

Appendix 6. Continued.

(e) Eastern Red Bat										
Round 1										
	0.025km	0.05km	0.1km	0.15km	0.2km	0.25km	0.5km	0.75km	1km	1.25km
observed	-0.0044	-0.0022	-0.0041	-0.0024	-0.0021	-0.0007	-0.0001	-0.0003	-0.0001	0.0004
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196
sd	0.0206	0.0203	0.0201	0.0203	0.0204	0.0203	0.0202	0.0203	0.0203	0.0202
p-value	0.4589	0.3905	0.4415	0.3966	0.3906	0.3517	0.3351	0.3417	0.3358	0.3228
	1.5km	1.75km	2km	2.25km	2.5km	2.75km	3km	3.25km	3.5km	
observed	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0007	0.0007	
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	
sd	0.0202	0.0202	0.0202	0.0201	0.0201	0.0201	0.0201	0.0201	0.0201	
p-value	0.3179	0.3193	0.3180	0.3172	0.3161	0.3156	0.3156	0.3133	0.3117	
Round 2										
	0.025km	0.05km	0.1km	0.15km	0.2km	0.25km	0.5km	0.75km	1km	1.25km
observed	-0.0373	-0.0354	-0.0402	-0.0416	-0.0421	-0.0424	-0.0439	-0.0442	-0.0442	-0.0438
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196
sd	0.0209	0.0209	0.0207	0.0207	0.0208	0.0208	0.0208	0.0208	0.0208	0.0208
p-value	0.3984	0.4495	0.3209	0.2893	0.2787	0.2721	0.2424	0.2365	0.2370	0.2454
	1.5km	1.75km	2km	2.25km	2.5km	2.75km	3km	3.25km	3.5km	
observed	-0.0437	-0.0437	-0.0437	-0.0437	-0.0436	-0.0435	-0.0434	-0.0433	-0.0432	
expected	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	-0.0196	
sd	0.0208	0.0209	0.0209	0.0209	0.0209	0.0209	0.0209	0.0209	0.0209	
p-value	0.2482	0.2479	0.2484	0.2482	0.2495	0.2519	0.2540	0.2572	0.2588	

Appendix 7. Mapped residuals of generalized linear mixed models relating **(a)** total bat activity and **(b – e)** species-specific activity to percent tree cover. These results are displayed for the scale of effect for each bat activity response (i.e., 0.2km for Total Bat Activity and Big Brown Bat; 0.15km for Silver-haired Bat/ Hoary Bat; and 0.025km for Little Brown Myotis/ Northern Myotis/ Tri-colored Bat and Eastern Red Bat), and at the 1km and 3.5km-radius landscape scales. Results are shown separately for each round of sampling (i.e., round 1 or round 2). Red dots represent negative residuals, and blue dots represent positive residuals. Dot size reflects the absolute value of the residual. Overall, the residuals show an even spatial distribution for each response variable.

Appendix 7. Continued.

Appendix 7. Continued.

Appendix 7. Continued.

Appendix 7. Continued.

Appendix 7. Continued.

Appendix 7. Continued.

Appendix 7. Continued.

Appendix 7. Continued.

Appendix 7. Continued.

Appendix 7. Continued.

Appendix 7. Continued.

Appendix 7. Continued.

Appendix 7. Continued.

Appendix 7. Continued.

Appendix 8. Percent tree cover within 19 circular landscape scales (0.025 – 3.5km) around each of 52 bat sampling sites, and percent cover of trees in parks within the 0.2km-radius landscape scale around each site.

Site	Percent Tree Cover within Circular Landscapes									
	0.025km	0.05km	0.1km	0.15km	0.2km	0.25km	0.5km	0.75km	1km	1.25km
0	32	20	15	19	16	15	17	14	13	12
1	43	25	27	29	27	26	26	35	37	39
2	20	22	19	21	20	19	16	14	13	13
3	19	10	10	12	11	10	8	8	8	8
4	37	35	26	29	33	36	26	18	14	13
5	72	43	31	40	42	39	40	41	38	34
6	33	16	23	25	22	25	20	18	16	16
7	50	41	40	36	37	38	37	40	41	42
8	96	82	67	64	62	59	54	55	57	55
9	0	4	12	19	22	25	24	19	19	19
10	73	53	33	28	25	24	23	21	19	20
11	1	5	11	9	10	12	26	30	28	25
12	46	41	43	43	42	39	49	48	47	47
13	63	45	33	35	31	30	28	26	24	24
14	35	29	29	28	28	26	21	19	22	26
15	82	52	34	29	28	29	27	29	28	25
16	84	48	43	38	39	40	42	36	36	35
17	56	57	64	69	70	62	55	53	49	46
18	63	56	50	58	62	64	59	51	48	47
19	88	69	62	63	60	58	55	55	52	49
20	98	91	84	82	81	80	70	64	59	57

Appendix 8. Continued.

Site	Percent Tree Cover within Circular Landscapes									
	0.025km	0.05km	0.1km	0.15km	0.2km	0.25km	0.5km	0.75km	1km	1.25km
21	21	34	54	60	61	58	49	47	43	38
22	43	40	42	46	49	46	35	36	40	40
23	46	32	29	34	31	29	26	27	26	26
24	68	49	52	51	48	48	39	37	38	41
25	44	43	41	45	46	45	41	46	48	46
26	62	37	25	27	25	24	22	19	19	19
27	27	14	20	18	19	23	32	33	34	30
28	34	28	28	27	26	30	23	22	22	21
29	83	49	40	40	40	41	39	41	38	37
30	25	22	25	26	30	33	45	40	39	37
31	32	25	34	27	28	26	27	31	30	30
32	46	27	19	21	23	23	30	28	26	27
33	58	54	51	49	48	50	51	56	57	55
34	51	44	45	46	49	52	54	54	52	52
35	54	29	20	23	23	22	19	21	24	28
36	68	37	36	45	50	53	62	55	49	44
37	26	28	29	43	45	46	40	40	39	36
38	32	26	27	23	23	24	22	21	20	22
39	35	30	40	37	37	36	25	23	25	28
40	15	26	31	28	28	32	31	31	28	28

Appendix 8. Continued.

Site	Percent Tree Cover within Circular Landscapes									
	0.025km	0.05km	0.1km	0.15km	0.2km	0.25km	0.5km	0.75km	1km	1.25km
41	69	56	41	33	31	28	30	31	30	29
42	3	11	17	25	24	24	29	32	33	32
43	0	4	13	36	48	51	40	35	31	29
44	58	51	58	52	50	47	42	37	36	36
45	47	42	35	39	45	43	48	44	42	40
46	19	25	22	24	25	25	24	24	21	20
47	47	35	41	35	33	29	20	19	17	17
48	44	28	30	27	22	20	14	15	18	21
49	50	29	31	32	30	27	32	37	33	27
50	39	28	32	36	36	34	33	35	34	31
51	72	66	60	61	61	62	55	52	46	45

Appendix 8. Continued.

Site	Percent Tree Cover within Circular Landscapes									Percent Tree Cover in Parks within a 0.2km-radius Landscape
	1.5km	1.75km	2km	2.25km	2.5km	2.75km	3km	3.25km	3.5km	
0	11	9	10	10	11	12	14	16	17	0
1	36	31	34	31	29	29	28	28	28	0
2	13	13	15	15	15	15	15	15	15	7
3	11	10	12	13	14	14	15	16	17	0
4	13	13	16	17	18	18	18	18	18	13
5	32	29	32	31	30	30	30	30	31	25
6	15	14	16	17	17	18	19	19	21	5
7	43	40	45	46	47	47	47	47	48	19
8	52	44	47	46	45	44	43	41	40	0
9	19	18	21	22	22	22	23	23	23	0
10	23	21	24	24	24	25	25	26	26	1
11	25	21	23	21	20	20	19	19	19	1
12	46	39	41	39	38	37	36	36	35	0
13	26	25	29	29	29	30	30	30	29	18
14	26	23	24	24	24	24	23	23	23	0
15	23	20	23	23	23	24	24	25	25	0
16	34	29	31	30	28	26	26	25	25	0
17	44	39	42	40	40	40	39	39	39	65
18	46	40	44	44	45	44	45	46	46	24
19	48	40	44	44	44	43	43	43	43	0
20	56	49	54	53	53	52	51	50	49	1

Appendix 8. Continued.

Site	Percent Tree Cover within Circular Landscapes									Percent Tree Cover in Parks within a 0.2km-radius Landscape
	1.5km	1.75km	2km	2.25km	2.5km	2.75km	3km	3.25km	3.5km	
21	36	33	37	37	37	37	38	38	39	17
22	43	40	44	43	42	42	42	42	42	28
23	26	23	26	27	28	29	30	30	31	0
24	43	40	44	44	44	43	42	42	42	23
25	43	37	41	43	45	46	47	47	47	0
26	19	18	22	23	24	24	24	23	23	0
27	30	25	26	25	24	23	23	22	21	0
28	20	17	19	19	20	20	20	20	20	1
29	37	32	36	37	37	37	37	36	34	3
30	35	28	30	28	27	26	25	24	23	25
31	28	25	28	30	31	32	33	33	33	16
32	28	26	30	30	29	28	28	27	27	3
33	54	47	52	51	50	49	49	48	47	16
34	50	43	44	42	40	39	39	39	39	9
35	31	28	33	33	35	36	37	37	37	0
36	40	34	36	34	32	32	33	34	34	28
37	33	29	31	30	30	30	31	32	33	44
38	22	21	24	25	25	24	25	25	26	0
39	32	30	33	33	33	33	33	33	33	2
40	28	25	28	29	30	31	31	32	32	7

Appendix 8. Continued.

Site	Percent Tree Cover within Circular Landscapes									Percent Tree Cover in Parks within a 0.2km-radius Landscape
	1.5km	1.75km	2km	2.25km	2.5km	2.75km	3km	3.25km	3.5km	
41	29	26	30	30	29	29	28	29	29	1
42	31	26	28	27	26	26	25	24	23	33
43	30	26	27	26	25	26	27	27	26	54
44	38	36	41	41	41	41	40	40	38	8
45	38	34	38	38	38	38	37	36	35	27
46	19	19	21	21	21	21	21	21	21	0
47	18	17	20	21	23	25	26	26	26	0
48	23	21	25	25	26	26	26	26	26	15
49	22	17	17	17	17	17	17	17	18	6
50	28	24	26	25	24	23	22	21	21	6
51	44	38	41	39	38	37	37	36	36	0

Appendix 9. Percent building cover within 19 circular landscape scales (0.025 – 3.5km) around each of 52 bat sampling sites.

Site	Percent Building Cover within Circular Landscapes								
	0.025km	0.05km	0.1km	0.15km	0.2km	0.25km	0.5km	0.75km	1km
0	11	29	26	21	20	19	19	20	21
1	19	24	21	22	22	23	20	16	13
2	47	27	29	26	28	26	21	18	18
3	41	26	22	24	25	26	21	19	19
4	47	34	28	24	22	18	16	17	20
5	4	21	20	17	16	16	17	16	16
6	21	25	20	21	21	19	22	22	20
7	32	22	21	22	26	24	21	20	21
8	5	14	15	14	13	12	13	13	13
9	24	32	26	25	24	22	20	19	18
10	15	12	20	21	22	24	23	21	21
11	41	38	29	31	32	31	21	18	17
12	39	31	23	19	17	17	12	12	13
13	30	29	26	22	19	20	21	22	23
14	27	26	23	22	20	17	13	14	14
15	13	22	23	21	22	22	21	20	19
16	13	29	26	27	25	24	22	19	18
17	14	18	13	11	7	5	8	10	12
18	19	20	19	15	14	13	13	13	13
19	3	24	25	19	18	17	17	19	21
20	0	4	8	9	10	9	8	10	13

Appendix 9. Continued.

Site	Percent Building Cover within Circular Landscapes								
	0.025km	0.05km	0.1km	0.15km	0.2km	0.25km	0.5km	0.75km	1km
21	19	27	20	18	16	14	11	11	12
22	21	29	29	25	24	21	22	21	20
23	10	29	30	24	24	24	22	18	18
24	19	23	19	17	16	15	16	18	17
25	19	30	24	24	22	21	20	19	18
26	15	23	23	27	25	24	22	22	20
27	22	21	17	21	22	22	19	17	17
28	34	28	25	25	25	24	19	21	22
29	10	32	25	24	20	19	19	20	20
30	26	24	21	20	18	17	11	12	13
31	39	30	29	27	27	27	20	17	16
32	26	29	25	27	25	22	18	18	20
33	25	22	15	13	17	17	14	13	12
34	27	21	20	18	16	13	11	11	11
35	16	33	31	30	30	30	29	29	27
36	9	18	20	16	15	13	7	8	10
37	33	31	26	21	20	20	16	15	15
38	17	30	24	23	21	20	20	20	20
39	20	22	21	22	22	20	15	15	15
40	35	28	22	25	25	25	21	20	20

Appendix 9. Continued.

Site	Percent Building Cover within Circular Landscapes								
	0.025km	0.05km	0.1km	0.15km	0.2km	0.25km	0.5km	0.75km	1km
41	5	20	22	25	24	22	22	21	18
42	24	28	19	19	18	16	16	17	17
43	8	36	26	20	15	12	12	13	11
44	26	18	14	15	17	18	18	18	19
45	33	32	29	22	18	16	14	14	14
46	32	19	23	24	24	24	20	19	18
47	14	21	19	19	20	22	22	22	21
48	26	25	27	26	23	22	22	20	19
49	21	29	20	20	20	20	21	17	17
50	31	30	25	25	22	21	19	17	17
51	14	18	18	15	16	16	14	13	13

Appendix 9. Continued.

Site	Percent Building Cover within Circular Landscapes									
	1.25km	1.5km	1.75km	2km	2.25km	2.5km	2.75km	3km	3.25km	3.5km
0	21	20	17	18	17	17	17	16	15	15
1	12	13	12	13	13	13	13	14	14	14
2	18	18	16	18	19	19	19	19	19	19
3	19	17	15	17	17	17	17	17	18	18
4	20	20	17	20	20	20	20	19	19	19
5	18	19	17	19	20	19	19	19	19	19
6	20	20	17	19	19	19	19	19	19	19
7	22	21	19	20	19	19	18	18	17	17
8	12	13	12	14	14	15	15	15	15	16
9	19	19	17	19	19	19	19	18	18	18
10	20	18	15	17	16	16	16	16	16	17
11	18	18	16	18	18	17	17	17	17	18
12	14	15	14	15	15	15	16	16	17	16
13	23	22	18	19	18	18	18	19	19	19
14	12	12	11	12	13	13	14	14	14	15
15	20	20	18	20	21	20	20	19	19	19
16	18	18	16	18	18	19	19	19	19	19
17	13	14	14	16	16	16	16	16	15	15
18	14	14	13	15	15	14	14	14	14	14
19	22	23	21	23	22	22	21	20	19	19
20	14	15	13	15	15	15	15	16	16	16

Appendix 9. Continued.

Site	Percent Building Cover within Circular Landscapes									
	1.25km	1.5km	1.75km	2km	2.25km	2.5km	2.75km	3km	3.25km	3.5km
21	14	15	14	16	16	16	17	16	16	16
22	19	18	15	17	17	17	17	17	17	17
23	19	20	18	20	20	20	20	19	19	19
24	17	16	13	15	15	15	16	16	16	16
25	17	18	16	18	17	16	16	15	15	15
26	20	20	18	19	18	18	18	18	18	18
27	17	17	15	16	16	17	18	18	18	18
28	21	22	19	22	21	20	19	19	19	19
29	19	19	16	18	17	17	16	15	15	15
30	14	15	14	16	16	17	17	17	18	18
31	16	16	14	17	17	18	18	19	19	19
32	19	19	16	17	17	18	18	18	19	19
33	13	13	12	13	13	14	14	14	14	14
34	12	12	12	15	17	18	18	19	19	19
35	24	22	18	20	19	19	19	19	19	19
36	11	13	14	17	17	18	19	19	18	18
37	17	17	15	17	18	18	18	18	17	17
38	21	20	18	20	20	20	20	20	20	19
39	14	14	13	16	16	17	17	17	18	18
40	20	19	17	18	18	18	17	17	17	17

Appendix 9. Continued.

Site	Percent Building Cover within Circular Landscapes									
	1.25km	1.5km	1.75km	2km	2.25km	2.5km	2.75km	3km	3.25km	3.5km
41	16	15	14	16	16	16	17	17	16	16
42	17	17	16	17	17	16	16	16	16	17
43	12	13	12	15	16	17	17	17	17	17
44	19	19	16	17	18	18	17	17	17	17
45	15	16	14	16	16	16	16	16	16	16
46	18	17	16	18	18	18	19	19	19	19
47	20	20	17	19	19	19	18	18	18	18
48	18	17	15	17	17	16	16	16	16	16
49	18	19	18	20	20	20	20	19	19	19
50	17	18	17	19	19	18	18	19	19	19
51	13	15	13	15	15	15	16	16	16	17

Appendix 10. Date, Start and End Recording Time, and Mean Nightly Temperature (°C) from sampling round 1 (R1) and round 2 (R2) of bat recording at each sampling site.

Site	Date		Start Time		End Time		Mean Temperature (°C)	
	R1	R2	R1	R2	R1	R2	R1	R2
0	June 7, 2017	July 11, 2017	20:57	20:59	5:36	5:47	11.905	20.132
1	July 30, 2017	June 27, 2017	20:43	21:03	6:06	5:38	19.485	12.261
2	June 1, 2017	June 27, 2017	20:52	21:03	5:38	5:38	9.614	12.548
3	June 19, 2017	July 4, 2017	21:02	21:02	5:36	5:42	18.938	19.005
4	July 30, 2017	July 31, 2017	20:43	20:41	6:06	6:07	19.932	20.950
5	June 13, 2017	July 6, 2017	21:00	21:01	5:35	5:43	16.145	20.203
6	June 12, 2017	June 27, 2017	21:00	21:03	5:35	5:38	26.399	12.981
7	May 31, 2017	July 5, 2017	20:51	21:02	5:39	5:42	14.059	17.727
8	August 8, 2017	July 17, 2017	20:31	20:55	6:16	5:53	19.241	19.092
9	June 25, 2017	July 19, 2017	21:03	20:54	5:38	5:55	16.029	20.275
10	August 8, 2017	July 25, 2017	20:31	20:48	6:16	6:00	19.016	15.511
11	June 6, 2017	July 17, 2017	20:56	20:55	5:36	5:53	9.592	17.812
12	June 25, 2017	July 5, 2017	21:03	21:02	5:38	5:42	16.166	17.407
13	June 6, 2017	July 5, 2017	20:56	21:02	5:36	5:42	10.446	16.346
14	June 7, 2017	July 4, 2017	20:57	21:02	5:36	5:42	10.080	14.789
15	May 30, 2017	July 18, 2017	20:50	20:54	5:39	5:54	12.236	20.740
16	May 31, 2017	August 1, 2017	20:51	20:40	5:39	6:08	13.575	19.428
17	May 30, 2017	July 31, 2017	20:50	20:41	5:39	6:07	11.510	19.148
18	June 19, 2017	June 26, 2017	21:02	21:03	5:36	5:38	17.390	11.246
19	June 18, 2017	July 6, 2017	21:02	21:01	5:36	5:43	20.086	21.827
20	June 6, 2017	July 25, 2017	20:56	20:48	5:36	6:00	10.134	14.378
21	July 30, 2017	July 4, 2017	20:43	21:02	6:06	5:42	17.327	13.745
22	June 8, 2017	July 27, 2017	20:57	20:46	5:36	6:03	12.793	17.462
23	July 30, 2017	July 17, 2017	20:43	20:55	6:06	5:53	19.193	18.119
24	June 8, 2017	July 25, 2017	20:57	20:48	5:36	6:00	13.204	14.487
25	June 1, 2017	July 31, 2017	20:52	20:41	5:38	6:07	10.242	20.742

Appendix 10. Continued.

Site	Date		Start Time		End Time		Mean Temperature (°C)	
	R1	R2	R1	R2	R1	R2	R1	R2
26	June 25, 2017	July 27, 2017	21:03	20:46	5:38	6:03	13.848	17.913
27	June 18, 2017	July 25, 2017	21:02	20:48	5:36	6:00	19.998	15.114
28	June 8, 2017	August 1, 2017	20:57	20:40	5:36	6:08	14.248	19.483
29	August 7, 2017	July 18, 2017	20:33	20:54	6:15	5:54	14.869	21.495
30	August 7, 2017	July 27, 2017	20:33	20:46	6:15	6:03	13.585	17.358
31	August 8, 2017	July 19, 2017	20:31	20:54	6:16	5:55	19.591	19.935
32	June 18, 2017	June 21, 2017	21:02	21:03	5:36	5:36	20.002	15.696
33	June 12, 2017	July 11, 2017	21:00	20:59	5:35	5:47	25.871	20.697
34	May 31, 2017	August 1, 2017	20:51	20:40	5:39	6:08	13.827	19.541
35	May 31, 2017	July 31, 2017	20:51	20:41	5:39	6:07	14.582	22.212
36	June 12, 2017	July 27, 2017	21:00	20:46	5:35	6:03	24.914	19.488
37	May 30, 2017	July 4, 2017	20:50	21:02	5:39	5:42	12.587	16.210
38	June 12, 2017	June 26, 2017	21:00	21:03	5:35	5:38	25.134	11.088
39	June 13, 2017	July 18, 2017	21:00	20:54	5:35	5:54	16.782	19.379
40	June 1, 2017	July 11, 2017	20:52	20:59	5:38	5:47	8.546	19.937
41	August 7, 2017	July 19, 2017	20:33	20:54	6:15	5:55	13.998	18.014
42	June 6, 2017	July 19, 2017	20:56	20:54	5:36	5:55	9.744	17.282
43	June 18, 2017	July 5, 2017	21:02	21:02	5:36	5:42	19.681	14.736
44	August 8, 2017	July 18, 2017	20:31	20:54	6:16	5:54	19.866	20.737
45	August 7, 2017	July 17, 2017	20:33	20:55	6:15	5:53	14.392	18.304
46	August 1, 2017	June 27, 2017	20:40	21:03	6:08	5:38	19.022	12.068
47	May 30, 2017	June 26, 2017	20:50	21:03	5:39	5:38	11.988	11.035
48	June 7, 2017	July 6, 2017	20:57	21:01	5:36	5:43	11.827	22.058
49	June 19, 2017	July 11, 2017	21:02	20:59	5:36	5:47	17.727	20.467
50	June 1, 2017	June 26, 2017	20:52	21:03	5:38	5:38	8.652	10.369
51	June 25, 2017	June 21, 2017	21:03	21:03	5:38	5:36	14.747	14.881

Appendix 11. Total number of bat passes, passes with more than one bat, feeding buzzes, and duration of bat passes from sampling round 1 (R1) and round 2 (R2) of bat recording at each sampling site.

Site	Number of Passes		Number of Passes that Contain more than One Bat (+1 to Number of Passes)		Number of Feeding Buzzes		Total Duration of Passes (Seconds)	
	R1	R2	R1	R2	R1	R2	R1	R2
0	116	60	11	3	11	9	1567.827	632.717
1	59	11	2	0	1	0	369.192	28.921
2	3	79	0	3	0	2	13.698	288.114
3	3	11	0	3	0	0	15.130	30.806
4	356	232	24	21	59	26	2141.219	1346.675
5	170	99	10	3	15	19	1748.310	777.31
6	72	23	3	0	4	3	371.587	134.869
7	27	249	0	15	0	19	122.428	1767.016
8	97	233	6	17	5	8	348.758	1393.357
9	8	64	0	10	0	5	45.025	734.845
10	42	27	1	1	1	8	261.887	128.377
11	5	28	0	1	0	5	41.876	522.658
12	7	17	0	0	1	0	31.780	68.853
13	39	24	0	0	0	1	338.632	180.891
14	20	59	0	3	0	12	120.906	248.611
15	9	190	0	4	0	33	77.140	1029.189
16	12	115	0	9	0	8	64.843	518.783
17	48	165	2	10	1	15	338.577	1026.647
18	118	66	0	0	7	1	861.883	450.056
19	52	43	5	5	12	2	330.097	276.322
20	1	149	0	14	0	12	4.166	1143.613
21	203	32	6	0	26	2	1384.565	183.585
22	225	90	27	9	8	16	1445.527	808.344
23	40	44	3	2	24	2	463.847	304.533
24	188	156	8	14	7	18	1431.710	869.168
25	4	172	0	11	0	10	54.004	1558.075

Appendix 11. Continued.

Site	Number of Passes		Number of Passes that Contain more than One Bat (+1 to Number of Passes)		Number of Feeding Buzzes		Total Duration of Passes (Seconds)	
	R1	R2	R1	R2	R1	R2	R1	R2
26	20	35	0	0	7	3	216.953	303.134
27	12	34	0	0	0	1	70.820	173.645
28	155	116	0	5	3	8	1433.980	742.3492
29	56	76	0	7	1	2	265.418	388.391
30	7	36	0	2	0	5	53.179	292.127
31	40	90	0	4	1	3	230.365	410.685
32	122	73	3	3	19	5	1419.461	537.857
33	16	109	0	3	0	2	111.912	836.396
34	1	72	0	5	0	2	6.334	407.658
35	47	280	2	1	4	5	268.722	2856.634
36	28	31	0	1	1	2	171.727	125.537
37	10	16	1	1	0	0	67.977	69.382
38	17	68	0	0	0	0	110.713	169.358
39	25	37	1	3	1	3	181.305	201.533
40	5	93	0	4	0	26	31.759	704.144
41	73	113	9	2	68	31	1198.235	1261.311
42	1	33	0	2	0	1	5.857	224.562
43	15	13	0	1	1	6	99.951	180.92
44	384	208	53	24	50	4	2359.738	1776.725
45	16	31	0	1	0	2	72.329	277.987
46	90	8	6	0	4	0	729.463	14.573
47	36	62	1	2	0	3	216.087	235.452
48	15	30	1	0	0	0	62.312	242.507
49	14	100	1	6	1	7	72.219	661.829
50	23	113	0	1	0	4	82.829	301.997
51	28	96	0	12	6	38	306.654	502.155

Appendix 12. Total number of passes identified to each species or species group and unidentified passes (unknown) from sampling round 1 (R1) and round 2 (R2) of bat recording at each sampling site.

Site	Big Brown Bat		Hoary Bat/ Silver-haired Bat		Little Brown Myotis/ Northern Myotis/ Tri-colored Bat		Eastern Red Bat		Unknown	
	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
0	97	14	6	28	0	0	1	0	12	18
1	11	3	22	0	0	0	7	0	19	8
2	1	5	0	23	0	0	0	0	2	51
3	1	11	0	0	0	0	0	0	2	0
4	277	129	14	38	2	3	4	1	59	61
5	59	73	6	16	6	0	73	0	26	10
6	44	19	5	0	1	0	0	0	22	4
7	21	218	0	30	0	0	0	0	6	1
8	31	63	4	46	8	2	10	59	44	63
9	3	6	2	46	0	2	0	0	3	10
10	7	10	11	5	0	0	3	4	21	8
11	0	6	4	10	0	1	0	2	1	9
12	3	2	1	5	0	0	0	0	3	10
13	11	6	19	9	0	0	0	0	9	9
14	11	23	4	10	0	0	0	2	5	24
15	4	25	0	31	0	0	3	121	2	13
16	8	27	0	18	0	1	0	38	4	31
17	31	66	6	55	0	1	0	4	11	39
18	93	42	7	10	0	1	1	5	17	8
19	30	15	16	9	0	0	0	0	6	19
20	0	58	0	7	0	2	0	37	1	45
21	161	21	19	3	0	0	1	0	22	8
22	163	29	5	42	0	0	1	3	56	16
23	17	24	14	1	0	0	0	0	9	19
24	168	119	5	12	1	1	2	6	12	18
25	3	21	0	122	0	0	0	0	1	29

Appendix 12. Continued.

Site	Big Brown Bat		Hoary Bat/ Silver-haired Bat		Little Brown Myotis/ Northern Myotis/ Tri-colored Bat		Eastern Red Bat		Unknown	
	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
26	10	12	0	9	2	0	5	8	3	6
27	4	13	3	8	1	0	0	5	4	8
28	133	38	5	19	2	0	10	7	5	52
29	20	35	4	21	3	0	2	4	27	16
30	1	14	3	9	0	0	0	0	3	13
31	26	63	4	10	0	0	1	4	9	13
32	98	49	9	13	0	0	0	0	15	11
33	2	12	7	68	0	0	0	0	7	29
34	1	12	0	25	0	0	0	6	0	29
35	39	110	1	125	0	0	0	0	7	45
36	18	8	4	9	0	0	0	0	6	14
37	1	4	3	4	0	0	0	0	6	8
38	5	1	9	33	0	0	0	0	3	34
39	5	13	6	17	2	0	4	0	8	7
40	2	66	2	15	0	0	0	0	1	14
41	53	36	7	30	0	0	0	2	13	45
42	0	3	0	15	1	0	0	0	0	15
43	0	2	4	8	0	0	0	0	11	3
44	274	33	73	101	0	0	0	0	37	74
45	3	6	4	17	0	0	2	0	7	8
46	18	0	25	3	0	2	8	0	39	3
47	6	2	10	15	0	4	9	11	11	30
48	8	8	3	14	1	0	0	0	3	8
49	3	14	4	64	0	0	0	0	7	22
50	22	2	0	23	0	0	0	5	1	83
51	21	76	2	10	1	0	2	0	2	10

Appendix 13. Total number of feeding buzzes identified to each species or species group and unidentified feeding buzzes (unknown) from sampling round 1 (R1) and round 2 (R2) of bat recording at each sampling site.

Site	Big Brown Bat		Hoary Bat/ Silver-haired Bat		Little Brown Myotis/ Northern Myotis/ Tri-colored Bat		Eastern Red Bat		Unknown	
	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
0	11	4	0	1	0	0	0	0	0	4
1	0	0	0	0	0	0	0	0	1	0
2	0	2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	57	22	2	1	0	0	0	0	0	3
5	6	16	0	2	0	0	7	0	2	1
6	2	3	0	0	2	0	0	0	0	0
7	0	18	0	0	0	0	0	0	0	1
8	0	4	0	1	1	0	3	0	0	3
9	0	1	0	3	0	0	0	0	0	1
10	0	1	0	0	0	0	0	0	1	7
11	0	2	0	3	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	1	0
13	0	1	0	0	0	0	0	0	0	0
14	0	6	0	0	0	0	0	0	0	6
15	0	0	0	4	0	0	0	28	0	1
16	0	1	0	2	0	0	0	5	0	0
17	1	9	0	4	0	0	0	0	0	2
18	4	1	1	0	0	0	1	0	1	0
19	7	1	2	0	0	0	0	0	3	1
20	0	6	0	0	0	0	0	3	0	3
21	19	2	0	0	0	0	0	0	7	0
22	6	10	0	1	0	0	0	0	2	5
23	23	1	0	0	0	0	0	0	1	1
24	7	18	0	0	0	0	0	0	0	0
25	0	0	0	8	0	0	0	0	0	2

Appendix 13. Continued.

Site	Big Brown Bat		Hoary Bat/ Silver-haired Bat		Little Brown Myotis/ Northern Myotis/ Tri-colored Bat		Eastern Red Bat		Unknown	
	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
26	6	0	0	2	1	0	0	0	0	1
27	0	1	0	0	0	0	0	0	0	0
28	3	4	0	1	0	0	0	0	0	3
29	0	1	0	0	0	0	0	0	1	1
30	0	5	0	0	0	0	0	0	0	0
31	1	2	0	0	0	0	0	0	0	1
32	18	4	1	0	0	0	0	0	0	1
33	0	0	0	2	0	0	0	0	0	0
34	0	0	0	1	0	0	0	0	0	1
35	4	5	0	0	0	0	0	0	0	0
36	0	0	0	1	0	0	0	0	1	1
37	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0
39	0	3	0	0	0	0	1	0	0	0
40	0	26	0	0	0	0	0	0	0	0
41	68	29	0	1	0	0	0	0	0	1
42	0	0	0	0	0	0	0	0	0	1
43	0	0	0	6	0	0	0	0	1	0
44	44	2	3	0	0	0	0	0	3	2
45	0	1	0	1	0	0	0	0	0	0
46	1	0	1	0	0	0	0	0	2	0
47	0	0	0	0	0	0	0	0	0	3
48	0	0	0	0	0	0	0	0	0	0
49	0	0	0	5	0	0	0	0	1	2
50	0	2	0	1	0	0	0	1	0	0
51	6	38	0	0	0	0	0	0	0	0

References

- Avila-Flores, R., and M.B. Fenton. 2005. Use of spatial features by foraging insectivorous bats in a large urban landscape. *Journal of Mammalogy* 86:1193–1204.
- Bazelman, T.C. 2016. Effects of urbanization on bat habitat use in the Phoenix Metropolitan Region, Arizona, USA: a multi-scale landscape analysis. M.S. thesis, Arizona State University, Phoenix, Arizona, 117 pp.
- Belaire, J.A., C.J. Whelan, and E.S. Minor. 2014. Having our yards and sharing them too: the collective effects of yards on native bird species in an urban landscape. *Ecological Applications* 24:2132–2143.
- Beninde, J., M. Veith, and A. Hochkirch. 2015. Biodiversity in cities needs space: a meta-analysis of factors determining intra-urban biodiversity variation. *Ecology Letters* 18:581–592.
- Bennett, V.J., and A.A. Zurcher. 2013. When corridors collide: road-related disturbance in commuting bats. *The Journal of Wildlife Management* 77:93–101.
- Bivand, R., N. Lewin-Koh, E. Pebesma, E. Archer, A. Baddeley, N. Bearman, H.-J., Bibiko, S. Brey, J. Callahan, G. Carrillo, S. Dray, D. Forrest, M. Friendly, P. Giraudoux, D. Golicher, V. Gómez Rubio, P. Hausmann, K. Ove Hufthammer, T. Jagger, K. Johnson, S. Luque, D. MacQueen, A. Niccolai, E. Pebesma, O. Perpiñán Lamigueiro, T. Short, G. Snow, B. Stabler, M. Stokely, and R. Turner. 2017. maptools: Tools for Reading and Handling Spatial Objects. Written for R package version 3.4.4.
- Blair, R.B., and A.E. Launer. 1997. Butterfly diversity and human land use: species assemblages along an urban gradient. *Biological Conservation* 80:113–125.
- Bolker, B., H. Skaug, A. Magnusson, and A. Nielsen. 2012. glmmADMB. Version 8.3.3.
- Bredt A., and W. Uieda. 1996. Bats from urban and rural environments of Distrito Federal, Mid-western Brazil. *Chiroptera Neotropical* 2:54–57.
- Brigham, R.M. 1991. Flexibility in foraging and roosting behavior by the big brown bat (*Eptesicus fuscus*). *Canadian Journal of Zoology* 69:171–121.
- Brunsdon, C., and H. Chen. 2014. GISTools: Some further GIS capabilities for R. Written for R package version 3.4.3.

- Carreiro, M.M., Song, Y.C., and Wu, J. (eds.). 2008. Ecology, planning and management of urban forests. Springer, New York, 456 pp.
- City of Toronto. 2009. Forest and Land Cover. <https://www.toronto.ca/city-government/data-research-maps/open-data/open-data-catalogue/environment/#808bc73a-df10-284d-9df7-e60dc97b45ae>. Accessed Dec 2017.
- City of Toronto. 2014a. Ravine Removals. Accessed Dec 2017.
- City of Toronto. 2014b. Treeazin Injection Program. Accessed Dec 2017.
- City of Toronto. 2014c. Toronto Building Outlines. <https://library.carleton.ca/find/gis/geospatial-data/toronto-geospatial-data>. Accessed Dec 2017.
- City of Toronto. 2014d. Zoning-by Law. <https://www.toronto.ca/city-government/data-research-maps/open-data/open-data-catalogue/locations-and-mapping/#8fef077c-9a14-e922-0c57-f390cd68b8a0>. Accessed Mar 2018.
- Clark, P.J., J.M. Reed, and F.S. Chew. 2007. Effects of urbanization on butterfly species richness, guild structure, and rarity. *Urban Ecosystems* 10:321–337.
- Coleman, J. L., and R.M.R. Barclay. 2012. Urbanization and the abundance and diversity of prairie bats. *Urban Ecosystems* 15:87–102.
- Cornelis, J., and M. Hermy. 2004. Biodiversity relationships in urban and suburban parks in Flanders. *Landscape and Urban Planning* 69:385–401.
- Dixon, M.D. 2012. Relationship between land cover and insectivorous bat activity in an urban landscape. *Urban Ecosystems* 15:683–695.
- Duchamp, J.E., and R.K. Swihart. 2008. Shifts in bat community structure related to evolved traits and features of human-altered landscapes. *Landscape Ecology* 23:849–860.
- Duchamp, J.E., D.W. Sparks, and J.O. Whitaker, Jr. 2004. Foraging-habitat selection by bats at an urban-rural interface: comparison between a successful and a less successful species. *Canadian Journal of Zoology* 82:1157–1164.
- Evelyn, M.J., D.A. Stiles, and R.A. Young. 2004. Conservation of bats in suburban landscapes: roost selection by *Myotis yumanensis* in a residential area in California. *Biological Conservation* 115:463–473.
- ESRI. 2015. ArcMap 10.3.1. Environmental Systems Research Institute: Redlands, CA.

- Ethier, K., and L. Fahrig. 2011. Positive effects of forest fragmentation, independent of forest amount, on bat abundance in eastern Ontario, Canada. *Landscape Ecology* 26:865–876.
- Fabianek, F., D. Gagnon, and M. Delorme. 2011. Bat distribution and activity in Montréal Island green spaces: responses to multi-scale habitat effects in a densely urbanized area. *Écoscience* 18:9–17.
- Fahrig, L. 2017. Ecological responses to habitat fragmentation per se. *Annual Reviews of Ecology, Evolution, and Systematics* 48:1–23.
- Fenton, M., and G. Bell. 1981. Recognition of species of insectivorous bats by their echolocation calls. *Journal of Mammalogy* 62:233–243.
- Ferenec, M., O. Sedláček, and R. Fuchs. 2014. How to improve urban greenspace for woodland birds: site and local-scale determinants of bird species richness. *Urban Ecosystems* 17:625–640.
- Fernandez-Juricic, E. 2000. Avifaunal use of wooded streets in an urban landscape. *Conservation Biology* 14:513–521.
- Gallo, T., E.W. Lehrer, M. Fidino, R.J. Kilgour., P.J. Wolff, and S.B. Magle. In Press. Need for multiscale planning for conservation of urban bats. *Conservation Biology*.
- Geluso, K., and J.N. Mink. 2009. Use of bridges by bats (Mammalia: Chiroptera) in the Rio Grande Valley, New Mexico. *The Southwestern Naturalist* 54:421–429.
- Griffin, D., F. Webster, and C. Michael. 1960. The echolocation of flying insects by bats. *Animal Behaviour* 8:141–154.
- Grubbs, S.E., and P.R. Krausman. 2009. Use of urban landscape by coyotes. *The Southwestern Naturalist* 54:1–12.
- Jackson, H.B., and L. Fahrig. 2012. What is a biologically relevant landscape? *Landscape Ecology* 27:929–941.
- Janzen, M.K., and M.B. Fenton. 2013. The depth of edge influence among insectivorous bats at forest-field interfaces. *Canadian Journal of Zoology* 91:287–292.
- Kitzes, J., and A. Merenlender. 2014. Large roads reduce bat activity across multiple species. *PLoS One* 9:e96341.
- Law, B.S., and C.R. Dickman. 1998. The use of habitat mosaics by terrestrial vertebrate fauna: implications for conservation and management. *Biodiversity and Conservation* 7:323–333.

- Lemen, C., P.W. Freeman, J.A. White, and B.R. Andersen. 2015. The problem of low agreement among automated identification programs for acoustical surveys of bats. *Western North American Naturalist* 75:218–225.
- Lerman, S.B., and P.S. Warren. 2011. The conservation value of residential yards: linking birds and people. *Ecological Applications* 21:1327–1339.
- Li, H., and K.T. Wilkins. 2014. Patch or mosaic: bat activity responds to fine-scale urban heterogeneity in a medium-sized city in the United States. *Urban Ecosystems* 17:1013–1031.
- Lintott, P. 2015. The distribution and habitat preferences of bats in a temperate urban landscape. Ph.D. dissertation, University of Sterling, Sterling, Scotland, 265 pp.
- McCleery, R.A., R.R. Lopez, N.J. Silvy, and S.H. Kahlick. 2007. Habitat use of fox squirrels in an urban environment. *Journal of Wildlife Management* 71:1149–1157.
- Melles, S., S. Glenn, and K. Martin. 2003. Urban bird diversity and landscape complexity: species-environment associations along a multiscale habitat gradient. *Conservation Ecology* 7:5.
- Moretto, L., and C.M. Francis. 2017. What factors limit bat abundance and diversity in temperate, North American urban environments? *Journal of Urban Ecology* 2017:1–9.
- Müller, J., M. Mehr, M.B. Fenton, T. Hothorn, H. Pretzsch, H.-J. Klemmt, and R. Brandl. 2012. Aggregative response in bats: prey abundance versus habitat. *Oecologia* 169:673–684.
- Neubaum, D.J., K.R. Wilson, and T.J. O’Shea. 2007. Urban maternity-roost selection by big brown bats in Colorado. *Journal of Wildlife Management* 71:728–736.
- Opera, M., P. Mendes, T.B. Vieira, and A.D. Ditchfield. 2009. Do wooded streets provide connectivity for bats in an urban landscape? *Biodiversity and Conservation* 18:2361–2173.

- Paradis, E., S. Blomberg, B. Bolker, J. Brown, J. Claude, H.S. Cuong, R. Desper, G. Didier, B. Durand, J. Dutheil, R.J. Ewing, O. Gascuel, C. Heibl, A. Ives, B. Jones, F. Krah, D. Lawson, V. Lefort, P. Legendre, J. Lemon, R. McCloskey, J. Nylander, R. Opgen-Rhein, A-A. Popescu, M. Royer-Carenzi, K. Schliep, K. Strimmer, and D. de Vienne. 2017. ape: Analysis of Phylogenetics and Evolution. Written for R package version 3.4.3.
- Pardee, G.L., and S.M. Philpott. 2014. Native plants are the bee's knees: local and landscape predictors of bee richness and abundance in backyard gardens. *Urban Ecosystems* 17:641–659
- Pardee, G.L., and S.M. Philpott. 2014. Native plants are the bee's knees: local and landscape predictors of bee richness and abundance in backyard gardens. *Urban Ecosystems* 17:641–659.
- R Core Team. 2017. R: A Language and Environment for Statistical Computing. Vienna, Austria.
- Revelle, W. 2017. psych: Procedures for Psychological, Psychometric, and Personality Research. Written for R package version 3.4.2.
- Russell, A.L., C. Butchkoski, L. Saidak, and G.F. McCracken. 2009. Road-killed bats, highway design, and the community ecology of bats. *Endangered Species Research* 8:49–60.
- Scheffers, B.R., and C.A. Paszkowski. 2013. Amphibian use of urban stormwater wetlands: the role of natural habitat features. *Landscape and Urban Planning* 113:139–149.
- Silva, M.M.S., N.M.S. Harmani, E.B.F. Gonçalves, and W. Uieda. 1996. Bats from the metropolitan region of São Paulo, southeastern Brazil. *Chiroptera Neotropical* 2:39–41.
- Smith, A.C., C.M. Francis, and L. Fahrig. 2014. Similar effects of residential and non-residential vegetation on bird diversity in suburban neighbourhoods. *Urban Ecosystems* 17:27–44.
- Soper, K.D., and M.B. Fenton. 2007. Availability of building roosts for bats in four towns in southwestern Ontario, Canada. *Acta Chiropterologica* 9:542–546.
- Sperling, C.D., and C.J. Lortie. 2010. The importance of urban backgardens on plant and invertebrate recruitment: a field microcosm experiment. *Urban Ecosystems* 13:223–235.

- Threlfall, C.G., B. Law, and P.B. Banks. 2012. Sensitivity on insectivorous bats to urbanization: implications for suburban conservation planning. *Biological Conservation* 146:41–52.
- van Zyll de Jong, C.G. 1985. Handbook of Canadian Mammals II, Bats. National Museums of Canada, Ottawa, Canada, 212 pp.
- Wei, T., V. Simko, M. Levy, Y. Xie, Y. Jin, and J. Zemla. 2017. corrplot: Visualization of a Correlation Matrix. Written for R package version 3.4.2.
- Whitaker, J.O. Jr., D.W. Sparks, and V. Brack Jr. 2006. Use of artificial roost structures by bats at the Indianapolis International Airport. *Environmental Management* 38:28–36.
- Wildlife Acoustics. 2015. Kaleidoscope Pro 3. Maynard, U.S.A.
- Wickham, H., and W. Chang. 2016. ggplot2: Create Elegant Data Visualisations Using the Grammar of Graphics. Written for R package version 3.4.2.
- Wickham, H., R. Francois, L. Henry, and K. Müller. 2017. dplyr: A Grammar of Data Manipulation. Written for R package version 3.4.2.