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Cover Phograph: A silver-haired bat (Lasionycteris noctivagans) seen on the Bronx River Parkway in Bronxville, NY in the early spring of 2020. © Nic Comparato.

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Assessing the Relationship Between Land Cover Variables and the Diversity of Acoustic Bat Detections in Urban and Rural Areas

Nicholas Comparato[1*]

Abstract–Urbanization is a growing threat to native biodiversity around the world and one that is exacerbating a host of other conservation pressures currently impacting North American bat populations. Acoustic surveys are the most accessible means of monitoring how bats are responding to these pressures. This study examines the interaction between land cover variables and the species richness of acoustic bat detections in an effort to assess how urban land cover impacts the results of acoustic surveys. Five parks in Westchester County, New York, USA, a region located directly north of New York City, were surveyed for two seasons with an acoustic bat detector. These parks represent a diverse sampling of the urban-to-rural spectrum, ranging from a small park located in an urban city to an expansive park surrounded by rural areas. The land cover surrounding these 5 parks was quantified in 4 categories: urban, low development, water, and tree cover. To account for the varying roosting and foraging ranges of different bat species, this quantification was carried out at 4 different spatial scales: 3 km, 1 km, 500 m, and 100 m. The relationship between land cover variables at each scale and the species richness of acoustic detections was then modeled using linear mixed effects models. The results indicated that urban land cover and low-development land cover both had a negative impact on the diversity of acoustic bat detections, while tree cover has a positive impact.

Introduction

Urbanization describes a process in which natural habitats are destroyed and replaced with impervious structures, characteristic of urban environments, most notably roads and buildings. Such environments typically offer little in terms of habitat for wildlife beyond heavily manicured parks. Pushed by an ever-growing movement of human populations to urban centers, the spread of urbanization has been directly linked to a loss in native biodiversity and the emergence of monocultures of urban-tolerant species (McKinney 2002). Bats are among the many taxonomic families to have experienced shrinking diversity across habitat ranges due to this growth of urban environments. Previous research has suggested that the light pollution, roadways, reduced insect abundance, and reduced tree cover associated with urbanization have all contributed to the declining diversity of global bat populations (Moretto and Francis 2017).

In North America, urbanization is just one of a host of conservation pressures currently threatening bat populations. White-nose syndrome, a fatal condition caused by the fungal pathogen *Pseudogymnoascus destructans* Minnis and Lindner has devastated cave-hibernating obligate species throughout the eastern half of the continent. Spread of this fungal pathogen has caused population declines of >95% in some cases (Hoyt et al. 2021). The increased prevalence of utility-scale wind energy developments is also contributing to declining bat populations. Expansive fields of wind turbines constructed along the pathways of migratory species have resulted in large numbers of bat fatalities (Arnett and Baerwald 2013). These threats have each contributed a present state of crisis in North American bat conservation.

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Surveying and monitoring bat populations are crucial tasks in maintaining an accurate assessment of these conservation issues and their developing impacts. The use of specialized acoustic detection devices is the most accessible and least interruptive means of doing so. Unlike other methods, such as netting and roost counts, acoustic detection does not require any direct interaction or proximity between humans and bats (Szewczak and Morrison 2020). The development of low-cost detection devices, like the AudioMoth, have further increased the accessibility of this approach by addressing the once formidable barrier of equipment costs (Hill et al. 2019). Though acoustic detection has yet to achieve the level of species identification accuracy afforded by directly observing and handling bats, it has gained widespread adoption in the research literature and among large scale monitoring efforts (Loeb et al. 2009, 2015, Parkins and Clark 2015, Gallo et al. 2018).

This study analyzes the impact of urbanization on the diversity of bat species detected in Westchester County, New York during acoustic surveys conducted in 2020 and 2021. Westchester County is well suited to studies of urbanization as it is located directly north of New York City, the most densely populated urban region in the United States (US Census Bureau 2023). While the county is heavily developed and populated along its southern border with New York City, it gradually transitions to suburban and rural environments located in the northern half of the county (Westchester County Department of Planning 2011). Survey data came from five county parks located in the southern, central, and northern regions of this area (Fig. 1). Each park is surrounded by a different level of urban development, ranging from a small park located within a heavily developed city to a ~4000 acre park surrounded by rural townships. I chose the metric of species richness to examine how these surroundings impacted the biodiversity of local bat populations. Species richness measures biodiversity in its simplest terms, by counting the number of species present in the composition of a population. This metric works well with the limitations of acoustic detection as this method can establish the likely presence of a species but not how prevalent the species is (Loeb et al. 2009).

There is a substantial body of literature examining the relationship between urbanization and the health of bat populations. Previous studies have established that tolerance of urban environments varies and is based on land cover characteristics at different spatial scales, depending on the species (Dixon 2011, Gallo et al. 2018). Some bat species are quite tolerant of the urban environment, especially when provided with improved habitat options like green roofs (Parkins and Clark 2015). Other species, like *Myotis lucifugus* Le Conte (Little brown bat), may readily inhabit urban areas, but are actually most successful in transitional environments between urban and rural areas (Coleman and Barclay 2011). A general trend among studies of urban bats, however, is that species diversity is lower in urban areas than in less developed areas (Moretto et al. 2017).

This study contributes to the literature on bats and urbanization by specifically examining what impact urbanization can be expected to have on the number of species recorded by an acoustic bat detector on any given night. Following the examples of Dixon (2011) and Gallo et al., (2018), I chose to examine this potential impact at multiple spatial scales to account for the varying foraging and roosting ranges of the bat species present in the study area. Survey locations were placed along the urban-to-rural spectrum by quantifying what percentage of the surrounding land cover fell into four different categories: urban, low development, tree cover, and water. My primary hypothesis (H1) was that urban land cover would have a negative relationship with the number of bat species detected across all spatial scales. A related secondary hypothesis (H2) was that tree cover would have a positive relationship with the number of species detected at all spatial scales. The low development category covered pasture lands and similar areas dominated by open grass with sparse anthropogenic structures. Previous research has suggested such areas may benefit bat populations (Coleman and Barclay 2011), thus a tertiary hypothesis (H3) was that low development land cover would also have a positive relationship with the diversity of bat species detected.

Site Description

Westchester County encompasses 450 square miles (~1165 sq. km) in southern New York. It is bordered by large bodies of brackish water on both sides, with the western border defined by the Hudson River and the eastern border by the Long Island Sound. The county has maintained a consistent population of ~1,000,000 people in recent years, who inhabit a total of 45 cities and towns spread throughout the area (Westchester County Government 2022). The bat surveys generating data for this research were originally conducted on behalf of the county's Parks and Recreation Department with the intent of assessing local species diversity. Site selection for these surveys was heavily influenced by the onset of the COVID-19 pandemic and other stakeholder issues. Public health measures and park administrative complications limited access to potential survey locations. The five parks included were selected from a group of parks I was given permission to conduct bat surveys in. These parks were selected based on the diversity of the surrounding environments in terms of the rural-to-urban spectrum.

The most urban of these parks was Lenoir Preserve, a 40-acre park surrounding a historic mansion. It is located near the southwestern border Westchester County shares with the Bronx in the city of Yonkers. Marshlands Conservancy, located in Mamaroneck along the Long Island Sound, offers 147 acres of parkland in southeastern Westchester amidst an otherwise heavily developed suburban landscape. This park is unique from the other survey locations in that it is located on the coast and contains an extensive network of brackish wetlands. Cranberry Lake Preserve is a 190-acre park surrounding a glacial lake in central Westchester. The area immediately surrounding the park features relatively little development. However, it is only ~ 6.5 km from the urban center of White Plains. Muscoot Farms is an interpretive farm surrounded by an expansive 777 acres of parkland. It is located near the town of Katonah in northern Westchester, a region that is substantially less developed and densely populated than the county's southern reaches. At 4315 acres, Ward Pound Ridge Reservation is the largest park and most rural area surveyed in this study. It is located in northeastern Westchester along the Connecticut border (See Fig. 1).

Materials and Methods

Passive acoustic surveys

I conducted passive acoustic surveys from mid-May to mid-August of 2020 and 2021. For each survey, a single Pettersson D500X bat detector with an external microphone was set up at a location within one of the five parks. I selected survey locations based on their suitability for capturing high quality recordings of bat sonar. These were locations near forest edges in which the microphone could be aimed at an open area with no reflective surfaces that may cause recording interference. To further reduce the risk of interference, the microphone was elevated four meters from the ground on a telescoping pole (Szewczak and Morisson 2020). For each deployment, I left the bat detector in place until it recorded a minimum of five nights with optimal weather for bat activity. Ancillary data collected with each deployment consisted of location coordinates, microphone direction, and weather data for each night (precipitation, hourly wind speeds, and high and low temperatures). This survey protocol was based on the recommendations provided by the USGS NABat program (Loeb et al. 2015).

Bat calls recorded during surveys were analyzed using SonoBat 4.5.5, North America. SonoBat's automatic classification tool was used to initially classify recordings to the species level. To ensure the accuracy of SonoBat's classifications, I then manually vetted its suggested species classifications. Based on NABat's suggested protocol for data analysis, I examined calls for each survey night until I could find at least one high quality, conclusive recording for each species suggested to be present by the software (Reichert et al. 2018).

Land cover analysis

Land cover analyses of the five survey locations were performed using QGIS 3.28.3 and the 2019 National Land Cover Database (NLCD) map for the contiguous United States. The NLCD map classifies land cover into a number of different categories. Using the "Raster Calculator" tool on QGIS, I split the NLCD map into four component maps, each aggregating several NLCD categories into one overarching category. The map of urban land cover consisted of the NLCD categories "developed low intensity", "developed medium intensity", and "developed high intensity". A map of tree cover was created from the NLCD categories "deciduous forest", "evergreen forest", and "mixed forest". Another map was created of bodies of water by aggregating the NLCD categories "open water", "woody wetlands", and "herbaceous wetlands". A final map was made to account for areas that featured some development, but were not developed enough to be included on the urban map. This map of low development areas combined the NCLD categories of "developed open space" and "pasture/hay". Though there are other categories included in the NLCD map, none of them were present enough around the survey locations to collectively account for anything close to 1% of the total land cover.

The survey locations were plotted on the four component maps and a series of fixed-radius spatial buffers of 100 m, 500 m, 1 km, and 3 km were established around each survey location. Each buffer represents a different scope of interest for this analysis.

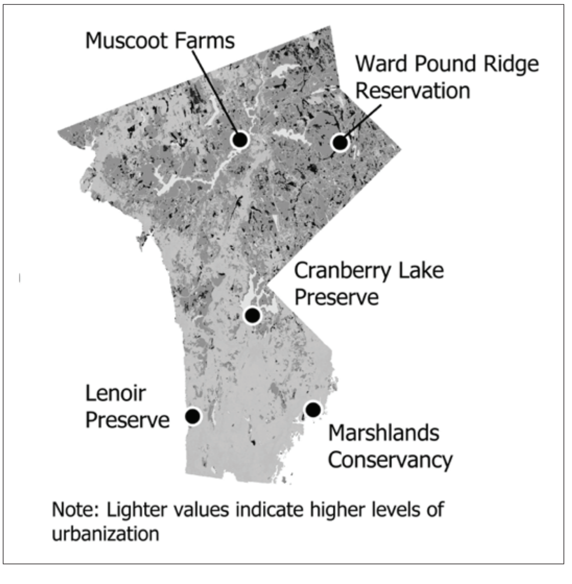

Figure 1. Survey locations.

The scales of 100 m, 500 m, and 1 km were taken from studies on multi-scale, spatial effects by Dixon (2011), and Gallo et al., (2018). These studies selected 100 m as a "local scale" because it was the smallest area at which substantial variation in land cover can be observed. The "broad scale" of 1 km was selected because it captures the known foraging ranges of multiple common bat species. An "intermediary scale" was added at the halfway point of 500 m between the local and broad scales. I added a fourth scale of 3 km to account for the occasional larger movements of migratory species like *Lasionycteris noctivagans* (McGuire et al. 2012). The percentages of each land cover type (urban, low development, tree cover, and water) present in the buffer zones at each scale were calculated using the "overlap analysis" tool in QGIS.

Statistical analysis

Five nights of detection data were selected from a deployment of the Pettersson D500X in each of the five survey locations, giving a total sample size of n=25 detector nights. Five was chosen because it was the minimum number of clear weather nights the detector was left in each location. For survey locations that had more than five nights of data, the first consecutive, or closest to consecutive five, nights were selected. For each night, the total number of verifiable species detected were recorded with the land cover percentages of the survey location at 100 m, 500 m, 1 km, and 3 km. Seasonality was not accounted for in the planning of the surveys, and the potential random influence of this factor needed to be accounted for in calculating any relationship between land cover and species diversity. To facilitate this, the month in which the survey was conducted was also included in the data.

All statistical analyses were performed on JASP 0.17.1. I first checked the normal distribution of all variables using Q-Q plots. Urban land cover at the 100 m scope was the only variable that did not have a normal distribution. Even after log10 transformation, this variable could not be normalized and it was subsequently removed from any further analysis. Linear mixed effects models (LMMs) were used to examine the relationships between land cover variables and species diversity. I chose this statistical approach because it allows for greater accuracy in calculating relationships between variables when there is potential influence from a random factor not accounted for in study design. A conventional rule of LMMs is that the random grouping variable should have at least 5 levels, however the validity of this convention has been disputed (Gomes 2022). In this case the grouping factor, month, only had 4 levels as the bat detection season runs from May to August. I chose to continue with LMMs after efforts to analyze this data with fixed-effect regressions consistently yielded high RMSE scores.

The small size of the data set required a simple LMM structure to avoid singular fit. For most land cover variables, a random intercept LMM was used to assess the relationship with diversity of detections. This suggests that the effect size of most variables on the number of species detected remained consistent from one month to the next, despite the seasonal presence or absence of different species. Tree cover at 1 km and water at 3 km both required a random slope-only LMM to avoid singular fit. This indicated that the effect size of these two variables on the richness of species detections differed from month to month. If the LMM for a land cover variable resulted in a singular fit even after simplification measures, the variable was discarded from the study. Tree cover at 500 m and 100 m, water at 1km and 100 m and low development at 3 km, 500 m and 100 m were all discarded due to singular fit.

Results

Passive acoustic surveys

In total, the equipment ran for 40 monitoring nights, producing 3236 recordings. Of these, 1608 (~50%) yielded calls that could be identified to the species level. The most common species detected was *Eptesicus fuscus* Beauvois (Big brown bat), with 1104 detections across all five parks. *Myotis leibii* Audubon and Bachman (Eastern small-footed bat) was the next most prominent species with 263 detections. This unique species, which prefers to roost under lose rocks on sunny talus slopes, was detected exclusively at Ward Pound Ridge Reservation (WPRR). *Lasiurus cinereus* Beauvois (Hoary bat) was another species detected at a single location. This species was detected 96 times at Muscoot Farms. *Myotis lucifugus* was detected in small numbers at all parks with the exception of Marshlands Conservancy (MC), producing a total of 94 detections. The long-distance migratory species *Lasionycteris noctivagans* Le Conte (Silver-haired bat) was detected at both MC and WPRR, however the WPRR detections proved to most likely be misidentified calls by *E. fuscus* upon vetting. Only the 36 detections from MC were included in subsequent analyses. *Perimyotis subflavus* Cuvier (Tri-colored bat) was detected once at WPRR and 8 times at Cranberry Lake Preserve (CLP). *Lasiurus borealis* Müller (Eastern red bat), a bat that is normally common in southern New York (Parkins and Clark 2015), was only detected 3 times, all of which came from Lenoir Preserve (LP, Table 1).

Land cover analysis

At the 3 km scope, MC and LP feature the most surrounding urban land cover at roughly 36% and 35% respectively. CLP was surrounded by 24% urban land cover at this scope and MF was surrounded by 9%. WPRR has the least surrounding urban land cover at 3 km with 2%, but the most surrounding tree cover at this scope with 76%. MF has the next most tree cover at 3 km with 65%, followed by CLP at 33% and LP at 16%. MC has the least surrounding tree cover at 3 km, with only 2%. A coastal park, MC also has the most water at the 3 km scope with 42%. LP is near the coast and features 30% water at this scope. CLP has 21% water at this scope, WPRR has 14%, and MF has 12%. CLP has the most low development land cover at 3km with 21%, followed by MC at 20% and LP at 18%. MF is surrounded by 13% low development land cover at 3 km and WPRR is surrounded by 8%.

At 1 km, the percentage of urban land cover surrounding LP increases to 41%. For MC, on the other hand, urban land cover percentage decreases to 19% at 1 km. Urban land cover percentage at this scope around CLP is 13%. MF is 3% and WPRR is 2%. WPRR continues to have the most tree cover, being surrounded by 85% tree cover at the 1 km scope. MF is surrounded by 58% tree cover at this scope and CLP is surrounded by 52%. LP features 19% tree cover at 1 km and MC features 13%. MC has the most water at 1 km with 34%. MF follows at 30%, LP at 18%, CLP at 13%, and WPRR at 6%. MC also features the most low development land cover at the 1 km scope with 34%. LP follows at 21% and CLP at 20%.

Table 1. Species detected in each park.

Park	Species Detected
Lenoir Preserve	*E. fuscus, M. lucifugus, L. borealis*
Marshlands Conservancy	*E. fuscus, L. noctivagans*
Cranberry Lake Preserve	*E. fuscus, M. lucifugus, P. subflavus*
Muscoot Farms	*E. fuscus, M. lucifugus, L. cinereus*
Ward Pound Ridge Reservation	*E. fuscus, M. lucifugus, P. subflavus, M. leibii*

WPRR features 8% low development land cover at 1 km and MF features 7%.

At 500 m, LP featured 37% urban land cover. MC followed at 12%, CLP and MF at 4%, and WPRR at 1%. WPRR is surrounded by 89% tree cover at 500 m. MF also features a lot of tree cover at this scope with 78%, as does CLP with 73%. MC features 39% tree cover at 500 m and LP features 34%. MC continues to feature the most water, with 25% water at 500 m. MF is surrounded by 13% water at this scope, CLP at 8%, WPRR at 6%, and LP at 2%. LP features the most low development land cover at 500 m with 25%, with MC following closely at 23%. CLP is surrounded by 14% low development at this scope, MF by 4%, and WPRR by 2%.

At 100 m, most parks did not have any urban land cover surrounding them. LP was the only one, with 16% urban land cover at this scope. Tree cover percentage was relatively high across all parks. MC features 74% tree cover at 100 m, WPRR features 71%, and CLP features 60%. LP is surrounded by 57% at this scope and MF by 51%. MF is surrounded by the most water at 100 m with 47%. CLP features 40% water at this scope and WPRR features 29%. MC and LP both feature 0% water at 100 m. CLP, WPRR, and MF all featured 0% low development land cover at this scope. LP is surrounded by 27% low development at 100 m and MC by 26% (Fig. 2).

Significant relationships with land cover variables

Urban, low development, and water all had a negative effect on the species richness of acoustic detections each night, while tree cover was the only land cover variable to have a positive effect. The effect size of all land cover variables had an inverse relationship

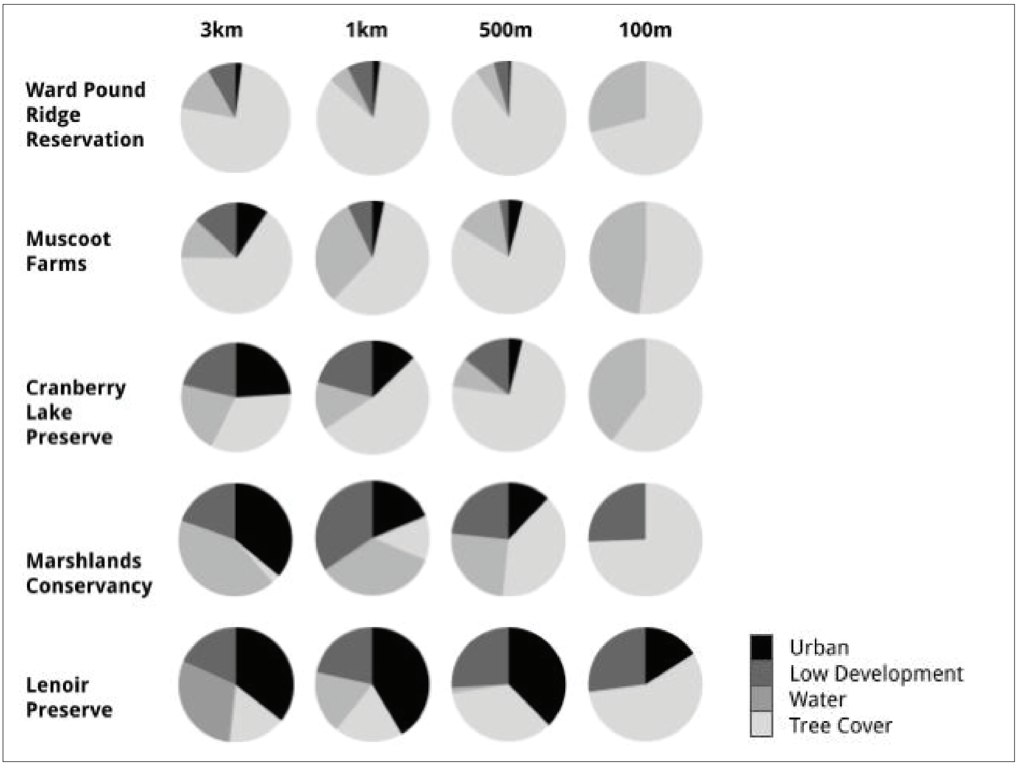

Figure 2. Land cover composition by park and spatial scale.

with spatial scale. Effect sizes grew slightly as the spatial scope of consideration was reduced. No significant relationship between any land cover variables and the number of species detected was found at 100 m. The effect sizes and estimated marginal means for all significant relationships are listed in Table 2.

Urban. Urban land cover was found to have a significant (p <0.05) negative relationship with the number of species detected on each night at the 3 km, 1 km, and 500 m scales. Spatial scale and the effect size of urban land cover had an inverse relationship, with the effect size growing by 0.01 species per percentage of urban land cover as the spatial scale got smaller. The estimated marginal means suggest that surveys in parks with a lower percentage of surrounding urban land cover were more likely to detect 1 additional species than parks surrounded by a high percentage on any given night. This estimate becomes less reliable at the 500 m scale, however, as the estimated marginal means were calculated on a range of 25% to − 2%, the latter of which is not an actual possibility.

Tree cover. Tree cover was found to have a significant (p <0.05) positive relationship with the number of species detected on each night at 3 km and 1km. Spatial scales and the effect size of tree cover had an inverse relationship, with effect size growing by 0.02 from 3 km to 1 km. The estimated marginal means indicate that surveys in parks surrounded by a high percentage of tree cover were more likely to detect 1 additional species than parks surrounded a low percentage on any given night.

Water. Water was found to have a significant (p <0.05) negative relationship with the number of species detected on each night at 3 km and 500 m. Spatial scales and the effect size of water had an inverse relationship, with the effect size growing by 0.08 between 3 km and 500 m. The estimated marginal means indicate that surveys in parks surrounded by a low percentage of water were more likely to detect 1 additional species than parks surrounded by a high percentage on any given night. Both the effect size and marginal means suggest water

Table 2. Effect size of each land cover variable and its related estimated marginal means.

	3 km (+/−)	Range at 3 km	1 km (+/−)	Range at 1 km	500 m (+/−)	Range at 500 m
Urban	−0.024 (0.008)	—	−0.025 (0.008)	—	−0.026 (0.009)	—
EMM* High	2.03 (0.163)	35.00%	2 (0.164)	30.00%	2.02 (0.174)	25.00%
EMM Low	2.7 (0.164)	7.00%	2.73 (0.167)	1.00%	2.73 (0.179)	−2.00%
L.D.**	—	—	−0.026 (0.012)	—	—	—
EMM High	—	—	2.09 (0.202)	28.00%	—	—
EMM Low	—	—	2.62 (0.197)	8.00%	—	—
Tree Cover	0.011 (0.004)		0.013 (0.005)	—	—	—
EMM High	2.7 (0.166)	67.00%	2.72 (0.197)	72.00%	—	—
EMM Low	2.04 (0.166)	10.00%	2.02 (0.159)	18.00%	—	—
Water	−0.03 (0.012)	—	—	—	−0.022 (0.017)	—
EMM High	2.015 (0.213)	35.00%	—	—	2.170 (0.309)	19.00%
EMM Low	2.7	12.00%	—	—	2.533 (0.294)	3.00%

*Estimated marginal means, ** Low Development
Note: EMM High represents areas with a high percentage of the relevant land cover variable and EMM low represents area with a low percentage. The adjacent column, "Range at x", describes the range of percentages the EMMs were calculated at.

had less impact on the number of species detected than urban land cover or tree cover.

Low development. Low development land cover was found to have a significant (p <0.05) negative relationship with the number of species detected on each night at 1 km. As this relationship could not be calculated at any other scale, the relationship between scale and effect size for low development land cover cannot be described from this data. It is interesting to note that the effect size of low development land cover at 1 km is 0.026 species per percentage of low development land cover, which is the same effect size urban land cover had at 500 m. The estimated marginal means suggest surveys in parks surrounded by a low percentage of low development land cover were more likely to detect 1 additional species than parks surrounded by a high percentage (See Table 2).

Discussion

Comparing species between Westchester and New York City

There are several recent studies of bat populations within New York City (NYC) that provide a valuable comparison for the results of acoustic surveys in Westchester. In their acoustic study of green roofs within NYC, Parkins and Clark (2015) found *Lasiurus borealis* to be the most common bat in the area, making up over 60% of the calls they were able to identify. The prevalence of this species in NYC was more recently confirmed by Partridge, et al. (2020) in a study that preceded my earliest surveys by only 1 year. That this species was only detected three times during the two years of acoustic bat surveys in neighboring Westchester County is very surprising. *L. borealis* is a migratory species and it may be the case that the timing of my surveys simply missed the seasonal window in which they would be passing through Westchester. Their prevalence in the results of these prior, season-long acoustic surveys suggests, however, that NYC hosts a resident population. This species has previously been found to be tolerant of urban environments and there is conflicting evidence as to whether it prefers them for foraging and roosting (Walters et al. 2007, Dixon 2011). It is notable that the three *L.borealis* detections were in the most urban location surveyed, Lenoir Preserve. These unexpectedly low numbers may also be cause for concern as they could be an indication that local *L. borealis* populations have been impacted by wind energy developments along their migratory path (Arnett and Baerwald 2013).

Eptesicus fuscus has consistently been found to have a limited presence in NYC, which is unexpected as this species is considered a habitat generalist tolerant of urban environments (Walters et al. 2007, Parkins and Clark 2015, Gallo et al. 2018, Partridge et al. 2020). A dedicated acoustic survey of the Bronx, the borough of NYC immediately bordering Westchester to the south, yielded higher numbers of recordings for *E. fuscus* than other boroughs, however *L. borealis* remained the dominant species (Parkins et al. 2016). In contrast, *E. fuscus* has a dominant presence in Westchester County, accounting for 69% of all recordings identified to the species level. True to its generalist nature, the presence of *E. fuscus* in Westchester did not appear to be influenced by any land cover variable as it was the only species to be present in all five parks surveyed. This result, when combined with the results of acoustic surveys of NYC, suggests there may be some feature of the city's more southern boroughs, specifically Manhattan and Queens, which makes them less desirable for *E. fuscus* (Parkins and Clark, 2015, Partridge et al. 2020).

Lasionycteris noctivagans has been found to have a substantial presence in NYC during the brief period it passes through on its migratory route (Parkins and Clark 2015). This species' presence in neighboring Westchester follows a similar trend. *L. noctivagans* appeared almost exclusively during a May survey in Marshlands Conservancy, where it accounted for 60% of recordings identified to the species level. Though SonoBat suggested this species was present in a small number of recordings from other parks surveyed in later months, these recordings proved to most likely be misidentified calls from *E. fuscus* when manually vetted. Interestingly, Parkins et al. (2016) accumulated the majority of their *L. noctivagans* detections in October during their acoustic surveys of the Bronx. Taken together, my results and those of Parkins et al. suggest *L. noctivagans* travels northward through Southern New York early in the season and does not pass back through until well past the end of the standard monitoring season for bats. The 3 km spatial scale was included in this study to account for the large scale movements of *L. noctivagans*, which has been observed to travel up to 3 km in a single night during migration (McGuire et al. 2012). Previous studies have indicated, however, that this species can be sensitive to urban land cover at smaller spatial scales (Dixon 2011). The area surrounding MC at the 500 m and 100 m scales feature a substantial percentage of urban and low-development land cover. These results, in conjunction with the results from NYC surveys, suggest that impervious surfaces in the immediate environment may not be a major deterrent to *L. noctivagans* in choosing temporary habitat during migration.

Lasiurus cinereus, another migratory species, has been detected in NYC in small numbers, especially during the mid-to-late summer months (Parkins and Clark 2015, Parkins et al. 2016). In Westchester County, this species was only detected at Muscoot Farms during a June survey, where it accounted for 35% of all recordings identified to the species level. Previous comparisons between urban and rural locations hosting *L. cinereus* have found the species to be tolerant of urban environments, but preferential towards areas with high percentages of water and tree cover (Dixon 2011, Gallo et al. 2018). The area surrounding MF matches these preferences, featuring the highest percentages of open, fresh water at the 1 km, 500 m, and 100 m scales (See Fig. 2). It is surprising that this species was detected at no other park in Westchester during the two seasons of surveys. The area surrounding Cranberry Lake, for example, features similar percentages of tree cover and open, fresh water at the 500 m and 100 m scales. Seasonal timing for surveys at MF and CLP were also close, suggesting it is unlikely that a seasonal window of activity for *L. Cinereus* was missed in the survey of the latter park.

Perimyotis subflavus has been detected in very low numbers in NYC (Parkins and Clark 2015, Parkins et al. 2016). The results in Westchester were similar, with this species only being detected at Cranberry Lake Preserve, where it accounted for 4% of detections identified to the species level, and Ward Pound Ridge, where it accounted for less than 1%. Tree cover, water, and urban land cover have all been found to have a positive relationship with the presence of *P. subflavus* in previous studies, with at least one survey finding them to be more common in urban than rural areas (Dixon 2011, Gallo et al. 2018). These prior results suggest this species is most attracted to park locations adjacent to or within urban areas. As a relatively large park surrounding a lake near the city of White Plains, CLP fits this profile. The low number of detections of *P. subflavus* in this survey may be attributable to the impact of white-nose syndrome, which has caused an estimated population decline for this species of 95% in the Northeastern U.S. (Hoyt et al. 2021).

Myotis lucifugus has not been detected in any recent published results from acoustic bat surveys of NYC, though there is unpublished data suggesting it may be present there (Partridge et al. 2020). This species was detected in 4 of the 5 parks surveyed in Westchester, with the exception being MC. *M. lucifugus* has been established as an urban-tolerant species with a preference for transitional environments in the middle of the urban-to-rural spectrum (Coleman and Barclay 2011). Its willingness to inhabit a variety of habitats is evident from its wide distribution among areas of varying land cover compositions in Westchester. *M. lucifugus* is another species that has been heavily impacted by white-nose syndrome, with populations in the Northeastern U.S. experiencing an estimated decline of 96% (Hoyt et al. 2021). This substantial decline may be the reason the species has not recently been detected in NYC and is likely why *M. lucifugus* only accounted for a small percentage of the detections in Westchester.

Myotis leibii is a less common species that was detected exclusively at WPRR, where it accounted for 29% of detections identified to the species level. This species is known to use anthropogenic structures for roosting habitat, however its tolerance level for urban land cover is currently unknown (Harvey et al. 2011). *M. leibii* has never been detected by acoustic surveys in NYC. The area surrounding WPRR is the most rural location surveyed and the most distant from Westchester's urban border with NYC. *M. leibii's* exclusive presence here may indicate a habitat preference for areas with low percentages of urban land cover. That this species was present at WPRR and not MF, which features a similar surrounding land cover composition, may be attributable to the presence of large "riprap" embankments near WPRR. Riprap is a type of anthropogenic rock piling used for erosion control that can be attractive roosting habitat for *M. leibii* (P. Moosman, VA Military Institute, Lexington, VA, pers. comm.).

The relationship between land cover variables and species richness

The results of the LMMs estimating the relationship between the percentage of surrounding urban land cover and the diversity of acoustic detections confirm H1. Urban land cover negatively impacted the species richness of acoustic bat detections at all spatial scales considered (3 km, 1 km, and 500 m). In Westchester, where species richness of acoustic detections ranged between 1 and 3 species per night, the estimated marginal means of the LMMs indicated acoustic surveys in areas with less surrounding urban land cover are more likely to detect 1 additional species than areas with a high percentage. This result was consistent across the 3 spatial scales (See Table 2). The percentage of surrounding tree cover was found to have a positive relationship with the diversity of acoustic detections at the 2 spatial scales considered (3 km and 1 km), confirming H2. Estimated marginal means suggest that acoustic surveys in areas with a high percentage of surrounding tree cover in Westchester are more likely to detect 1 additional species than areas with a lower percentage.

Low-development land cover proved to have a negative relationship with the species richness of acoustic detections at the one spatial scale it could be modeled, 1 km. This refutes H3, which had proposed low-development land cover would positively impact species richness. Low development was included as a land cover category in this study to account for areas that fell into the NLCD categories of "developed open space" and "pasture/hay". The hypothesis that these areas would encourage greater species richness in acoustic detections was based on the presumption that they would feature ample amounts of forest edge, ideal foraging habitat for some bat species (Harvey et al. 2011). This land cover category was also the closest match to what Coleman and Barclay (2011) describe as "transitional" areas between urban and rural, which was found to be the preferred habitat of *Myotis lucifugus* in the Canadian prairie. Estimated marginal means of the statistical models indicated that surveys surrounded by higher percentages of low-development land cover in Westchester were likely to detect 1 less species than areas surrounded by a low percentage. It may be the case that roads and similar developments have made these areas less desirable for foraging and roosting (Moretto and Francis 2017).

Though water was found to have a significant negative relationship with species diversity at 3k m and 500 m, this result is compromised by the fact that the NLCD map does not differentiate between bodies of salt, brackish and fresh water. That fresh water is a crucial resource for bats has been shown in previous studies to encourage higher rates of bat activity for many species (Dixon 2011). The two areas with the highest percentages of water land cover in this study, MC and LP, are adjacent to large bodies of brackish water, which are likely of little value to bats. This study also appears to suggest that no land cover variable has a significant impact at the 100 m scale, contradicting previous studies that suggest many bat species react significantly to land cover composition at this scale (Dixon 2011, Gallo et al. 2018). In this case, the lack of significant impact from land cover variables at 100 m most likely reflects the increasing homogeneity of survey locations at smaller spatial scales. Though LP and MC both feature substantial percentages of developed land cover at 100 m, the land cover composition of all 5 survey locations is dominated by tree cover at this scale (See Fig. 2).

Acoustic surveys of Westchester detected a total of 7 species and the highest number detected at a single park was 4 (See Table 1). The average number of species detected among the parks was 2 with a standard deviation of 1. This relatively limited diversity likely restricted the degree to which any land cover variable could impact the species richness of acoustic detections. Note that the estimated marginal means for each LMM correspond to the standard deviation for species richness. In areas with greater diversity, the impact of land cover variables may be greater and show greater variation between spatial scales. In the context of bat conservation and monitoring, however, the presence of 1 additional species in acoustic detection results can be both valuable and informative. The presence of *L. cinereus* and *P. subflavus* in Westchester, for example, was limited to locations that featured very specific ratios of land cover variables that met these species' preferences. While these species are both present in the highly urban environment of NYC, this result suggests that they may avoid urban areas and form concentrations in more preferential habitat when it is available. The exclusive presence of *M. leibii* in Westchester's most rural areas, in conjunction with its complete absence in NYC, indicate that this species may have a strong preference for areas with a low percentage of developed land cover.

The ability of this study to draw greater conclusions regarding the impact of urban land cover and the preferences of individual species was limited by a small data set. This data set was excerpted from a small survey effort constrained by lack of equipment and technicians. Only one acoustic detector was available for surveys, of which I was the sole operator. Multiple detectors and technicians would have made it possible to survey urban and rural locations simultaneously, thus mitigating the influence of seasonality in comparisons between the two. Such a research design is exemplified in Parkins and Clark (2015). A greater variety of locations may have also brought greater heterogeneity to land cover composition at the 100 m scale, providing a greater sample to model the potential impact of land cover variables at this scale. Unfortunately, digital storage failure also limited the present study, as 2020 survey data was corrupted before site-by-night reports could be generated. Site-by-night data has previously been used to calculate species-specific activity levels from acoustic surveys. This data could have been used to model the impact of land cover variables on the activity levels of different species and the likelihood of detecting them during acoustic surveys, as exemplified by Dixon (2011).

Conclusion

Urbanization is a growing issue for native biodiversity around the world and one that is exacerbating a host of conservation pressures currently facing bats in North America. Acoustic detection is the most accessible means of monitoring how bats are responding to these pressures. With this study, I sought to examine the interaction between land cover variables and the species richness of acoustic bat detections. My hypotheses were that species richness would have a negative relationship with urban land cover and a positive relationship with tree cover and low-development land cover. The hypotheses regarding urban land cover and tree cover were both confirmed by statistical analyses. Estimated marginal means from statistical models indicated that surveys in areas surrounded by a high percentage of urban land cover were likely to detect 1 less species than less urban areas. Similarly, surveys in areas with a high percentage of surrounding tree cover were likely to detect 1 additional species than areas surrounded by lower percentages of tree cover. These results were consistent across spatial scales. The hypothesis regarding low-development land cover was refuted by statistical analysis, which revealed a negative relationship between this variable and species richness at the spatial scale of 1 km. These conclusions agree with several previous studies suggesting urban land development has a negative impact on species diversity. This study also provides limited evidence that certain bat species can have very specific preferences regarding the land cover composition surrounding their habitat.

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