AN INVESTIGATION OF URBAN BAT ECOLOGY

IN BALTIMORE, MARYLAND

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By:

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Table of Contents

List of Tables

Chapter 1 Tables Page

Chapter 2 Tables

Chapter 3 Tables

List of Figures

Chapter 1 Figures Page

Chapter 2 Figures

Chapter 3 Figures

List of Appendices

Page

Abstract

In North America, bats are a taxon of concern that play an important role in insect control, and their response to urbanization varies. I wanted to discover if evaluating environmental and socioeconomic variables present in an urban landscape can help determine what bat species were present and how active these species were. Research occurred in Baltimore, Maryland, a 'shrinking' city in the eastern US, which had no prior research on the bat community. For my first project, I used active acoustic monitoring to evaluate how bat activity levels (amount of detected acoustic sequences) and the bat community varied along both a direct and indirect rural to urban gradient. Nine sites along the Gwynns Falls watershed in Baltimore County and City were used the gradient. Over 1,500 sequences (detection files) were recorded from six species and I found that the direct and indirect measures of urbanization gradient used are not a predictor of bat presence and activity. For my next project I used passive acoustic monitoring to record bat activity at 32 vacant lots within Baltimore City to determine which environmental and socioeconomic variables best predict bat species richness and activity at these small, informal, understudied urban greenspaces. Environmental and socioeconomic data was obtained using on-site measures, GIS, and US Census data. There were no predictors for overall species richness. Canopy-associated measures at both the site and neighborhood scale, streetlights, site distance from water and the urban core, residential race and income, old housing, and rental housing were all common predictors of bat species' activity levels. Species relationships with these predictors varied and some species had additional predictors, suggesting that bats use the urban landscape to different degrees.

Some larger lots could potentially be managed to have vegetation structural complexity (allowing both canopy cover and open space to accommodate bat species with different traits), but many lots are too small to do this. Vacant lots closer to water and larger patches of forests have the most potential to be managed for bats.

Introduction

Bats are a taxon of concern in North America and provide ecosystem service in the form of insect control. This taxon is one of several that tend be understudied in urban settings, which often focus on birds and plants (Coleman & Barclay 2011). Urban bat studies that have been done suggest that urbanization can be both beneficial and harmful to bats (Russo and Ancilotto 2015). Many urban ecology studies tend to conduct research in large, formal sites like parks and gardens, or residential yards (Aronson et al 2017, Botzat et al 2016). Vacant lots are small, undeveloped land parcels that remain after a building has been razed. In Baltimore, Maryland, there are 1,750 ha of vacant lot parcels; studies have found that they support birds and plants (Rega-Brodsky 2016, Johnson et al 2018). With this in mind, my research goal was to determine if predictors exists that could explain patterns of bat use and activity across the urban landscape. Knowing this information could support management of vacant lots for wildlife.

In Chapter 1, I look at one of the simplest measures of urbanization, a gradient, to determine if species composition and activity changes along a watershed as it becomes increasingly urban. This was done using active acoustic monitoring and results suggested that species richness and the activity levels of bats were could not be predicted by an urban gradient.

In Chapters 2 and 3, I investigate several environmental and socioeconomic variables at different spatial scales, to determine if there are natural and anthropogenic factors in and around vacant lots that help determine how many species will use these

lots. This was done using passive acoustic monitoring and results found that environmental predictors at local and neighborhood scale, residential structure, and neighborhood structure predicted how active certain species were. I hope to eventually publish results from these chapters in *Urban Naturalist*, *Journal of Urban Ecology*, and/or *Urban Ecosystems*.

Literature Cited

Aronson, M. F. J., Lepczyk, C. A., Evans, K. L., Goddard, M. A., Lerman, S. B., Macivor, J. S., Nilon, C.H., and T. Vargo. 2017. Biodiversity in the city: key challenges for urban green space management. Frontiers in Ecology and the Environment, 15(4): 189-196.

Botzat, A., Fischer, L. K., and I. Kowarik. 2016. Unexploited opportunities in understanding liveable and biodiverse cities. A review on urban biodiversity perception and valuation. Global Environmental Change, *39*, 220–233.

Coleman, J. L., and R. M. R. Barclay. 2011. Influence of urbanization on demography of little brown bats *(Myotis lucifugus*) in the prairies of North America. PLoS ONE, 6(5): e20483.

Johnson, A. L., Borowy, D., and C.M. Swan. 2018. Land use history and seed dispersal drive divergent plant community assembly patterns in urban vacant lots. Journal of Applied Ecology, 55(1): 451–460.

Rega-Brodsky, C. C. 2016. Urban Vacant Lots: Ecological Quality and Social Opportunities in Baltimore, Maryland. Dissertation.

Russo, D., and L. Ancillotto, L. 2015. Sensitivity of bats to urbanization: A review. Mammalian Biology, 80(3): 205–212.

Chapter 1: Bat Community Composition along an Urban Gradient

Abstract

In urban ecology, urban-to-rural gradient studies have been conducted to determine how organisms or a community reacts to urbanization. The impact of urbanization on bats have revealed both positive and negative effects. Past use of the Gwynns Falls watershed (GFW) in Baltimore, Maryland, US for urban gradient studies made it an ideal place to determine how bats, a taxa of concern not previously studied in the area, may be affected by an urbanization gradient. I hypothesized that species richness and activity would decrease as sites transitioned from suburban to urban surroundings. From May to August 2016, I used active acoustic monitoring to record bat activity at nine sites adjacent to water gages along the GFW. Both direct (distance to city center) and indirect (landcover composition) measures of an urban gradient were calculated using GIS. Bray-Curtis polar ordination was used to depict similarity of bat communities at each site help and to create initial candidate models. Linear regression was used to determine which models best predict species richness and species' activity levels. Over 1,500 calls from six species were recorded. Big brown bats (*Eptesicus fuscus*) and red bats (*Lasiurus borealis*) were present at all sites. Bat species richness did not decrease as hypothesized; in fact, the most species-rich site was the second most urban site. Null models for species richness and the three most active species were top

models, suggesting that the measures of urbanization gradient used are not a predictor of bat presence and activity.

Introduction

The use of gradients as a tool in urban ecology studies started in the 1970-1980s (Andrzejewski et al 1978, Klausnitzer and Richter 1983, Nilon et al 1986). The gradual variation of an urban-associated factor(s) over space acts as type of experimental manipulation, and can help uncover patterns in ecological systems structure and function across this space (McDonnell and Pickett 1990). Urbanization can be defined as the presence of human occupation, which can take many forms: residential areas, built infrastructure, modification of the natural landscape, and introduced and/or cultivated biota. Studies have measured urbanization using population density, road or building density, impervious surface, and the most common result is that native species richness decreases as the urban core is approached (McKinney 2002, Zipperer and Guntenspergen 2009). McDonnell and Pickett's (1990) paper provided a framework for using urbanization gradient and its potential importance in research. In general, it is assumed that cities have an urban "core", where the landscape has its highest level of development. Radiating out from this urban core, urbanization decreases in a concentric, irregular pattern. Thus, studies with sites along a gradient act as a manipulative experiment in a sense, and can provide insight about the impacts of urbanization on urban

flora and fauna. However, McDonnell and Pickett (1990) also acknowledge that using urbanization gradients can be complex due to the possibility of many different interactions between and amongst anthropogenic and natural variables present, and these must be considered before conducting a study.

McDonnell and Pickett's framework states that an urbanization gradient "must account for the factors that constitute urbanization, the effects of urbanization on the biota and physical environment, and the resultant effects on ecosystems" (1990). Gradient analysis can be direct, focusing on one variable distributed in a linear pattern, or indirect, using more than one variable that may not be distributed linearly to define a gradient. Indirect gradients have been the recommended approach for urban gradient studies (Zipperer and Guntenspergen 2009).

Urban gradient studies have often focused on plants (Zipperer and Guntenspergen 2009) and birds (McDonnel and Hahs 2008), leaving the many other urban taxa underrepresented and understudied in this manner. There has been no published research on bats in Baltimore. Prior bat research in Maryland has occurred in the western mountainous and eastern shore regions (Johnson and Gates 2008, Johnson et al 2008, Johnson et al 2009, Johnson et al 2011). All 12 bat species that are believed to be present in Maryland have been listed as species of greatest conservation concern (MDNR 2016).

A review of studies on bats and urbanization have found both common themes uncovered in urban studies (Russo and Ancilotto 2015). Cities can benefit bats by providing additional roosts (i.e. buildings and bridges), water sources, urban greenspaces,

and for some species, access to prey (via streetlights). Conversely, light pollution, roads, opportunistic urban predators, increased likelihood of disease transmission in larger urban colonies, and human-bat conflicts are common sources of mortality for urban bats. This often results in urban areas being home to a reduced bat community, consisting primarily of generalist species.

The Gwynns Falls watershed (GFW) is located in both the Coastal Plain and Piedmont regions of the United States. This approximately 3600 ha watershed starts in western Baltimore County, running southeast until it merges with the Patapsco River near central Baltimore City (Figure 1). This watershed has been the site of several other gradient studies, all associated with the water itself (water balances: Bhaskar and Welty 2012, fish development: Fraker et al 2012, nutrient concentrations: Duan et al 2012, Shields et al 2008, and riparian sediment: Bain et al 2012, Colosimo et al 2007). Results from these prior studies found increased concentrations of calcium, nitrogen, and nitrate, an increase in channel shape and size, and smaller, shorter-lived fish as the watershed became increasingly urban. Past use of this watershed for gradient studies made it an ideal place to investigate how taxa not directly associated with to water may be affected by an urbanization gradient. The purpose of this study was to determine if an urbanization gradient acts as a predictor of bat species richness and species' activity levels. I hypothesized that an urbanization gradient would alter the bat community historically present, resulting in a decrease in both species richness and activity levels as sites became increasingly urban.

Methods

Study Area

The Baltimore Ecosystem Study (BES), an urban long-term ecological research site, has been monitoring water quality and nutrient cycling throughout the Gwynns Falls watershed via water gages. Nine of these gages are present along the main branch of the Gwynns Falls and are relatively equidistant from each other, making these already established locations ideal sites (Figure 1, Table 1).

Acoustic monitoring and sequence identification

Research was conducted from May 24 to August 4, 2016 at nine water gages along the Gwynns Falls watershed (Figure 1). Adjacent to each gage was a small field or open area, where the recordings occurred. Bat calls were recorded during 30-minute active acoustic monitoring sessions using an Anabat SD2 bat detector with an attached personal digital assistant (PDA) unit; this unit allowed me to collect GPS data and view sequences as they were being recorded. The bat detector was held at approximately a 45° angle. Most recording sessions occurred between 20:00 and 23:30, however one or two recordings for each site occurred later at night (between 02:00 and 05:00) to attempt to gather data at a broader temporal scale. A second or third sub-site near each gage was selected when feasible. Recording location at these sub-sites alternated between visits to ensure that results reflected the broader area and not just the recording's immediate location, which has an approximate recording radius of 40 m (Chris Corben, pers.

comm.), and the main location of some sites were prone to acoustic interference from nearby traffic noise. Data from sub-sites were summarized at the site level.

Three sites were visited each night, and the order of site visits was changed each time to ensure that each site was recorded at least once during different times of night. . Each site was visited seven times, except for the McDonogh (MD) site, which was visited five times due to limited security access. Acoustic monitoring did not occur on nights when moderate to heavy rain was expected. Bat sequences were transferred from the PDA to a laptop. Sequences were reviewed in AnalookW (Corben 2015) and sequences with four or more calls were kept and manually identified to species level whenever possible. I calculated an hourly detection rate for each species at each site using the total number of sequences recorded and the detection probability of species at each site.

Gradient measures

Site locations and shapefiles for the boundaries and landcover for the city and county were gathered from Baltimore Ecosystem Study, Baltimore City, and Baltimore County's open data websites (BES 2016, BCG 2016, COB 2016, LaGrosa and Welty 2017). I used ArcMap 10.6 software to calculate the distance of each site from the city center and landcover composition within 500 meter-radius of sites. Because most sites were a kilometer apart, I chose 500-meter radius to ensure landcover composition results would be independent; additionally, this was used as an intermediate range in another urban bat study (Dixon 2012).

Using the landcover composition within a 500 m radius, I calculated percent composition of high-density housing (HDH), greenspace (forested and natural areas), and a miscellaneous urban landcover (combining institutional, industrial and commercial landcover) to define an indirect gradient; these variables been used to quantify urbanization in other studies (Zipperer and Guntenspergen 2009). The distance to city center was used as a direct gradient measure.

Analysis

I used Bray-Curtis Polar ordination (BCPO) in PC-ORD (McCune and Mefford 2016) to visualize the similarity of bat communities at each site. For my BCPO I log-transformed total number of detections for each species at each site and modified the landscape data with a general relativization to re-scale the data, as distance to city center was on a different scale from the percent landcover composition of the other variables. BCPO establishes distances between the sites on two axes, with the first axis denoting the strongest differences in the primary matrix (the number of detections recorded from species at each site). I also included landscape data (the landcover types associated with urbanization gradient) as a secondary matrix. By doing so, I could use the correlations of each species and each landcover type to axes to generate preliminary hypotheses on which I can base my models (i.e., a species and landcover type(s) that have a strong correlation one axis suggests that that species' detection levels may be associated with the amount of that landcover type present).

For overall species richness and individual species' activity level (total number of detections), I conducted linear regression to determine which variables best explained activity along a gradient. Models were created for individual species that were recorded in at least six of the nine sites. Species total activity levels were log transformed to give data a normal distribution. Models included a null model, a model for distance to city center (a direct gradient), and indirect gradient models, based on literature regarding use of forested areas for all bat species and *Nycticeius humeralis* avoidance of urban areas (Duchamp et al 2004, Gehrt and Chelsvig 2003). Candidate models for species richness were based on models used for individual species.

Results

Bats and the landscape

Over 1,500 sequences were recorded, 76 of which were not easily identifiable to species level; these were noted (see Appendix 1), but not included in analysis. Recordings occurred for a total of 3.5 hours at each site, except for McDonogh (MD, 2.5 hours), due to restricted access on two nights. Six species were detected across the nine sites (Table 1). *Eptesicus fuscus* and *Lasiurus borealis* were present at all sites, while *Perimyotis subflavus* was the least common, recorded at three sites (Table 2). Additional species present include *L. cinereus*, *Lasionycteris noctivagans*, and *Nycticeius humeralis*. Delight (DE) had the most bat activity while Dead Run (DR) had the least amount of bat

activity (Appendix 1). The species curve plateaued around six, suggesting that all bat species present in the Baltimore metropolitan area were likely detected (Figure 2).

Sites varied in the amount of high-density housing, greenspace, and miscellaneous urban landcover within 500 meters. There appeared to be a greenspace gradient present: the percentage increased from Glyndon (GL) to McDonogh (MD), dropped at Scotts' Level (SL), and steadily increased again until it peaked at Dead Run (DR) (Table 3).

Ordination and Models

Sites at either end of the BCPO axes are the most distinct from each other: GL and SL are the most different from each other on the first axis, and VN and MD are the most dissimilar on the second axis. The remaining sites are more similar to each other in terms of species composition and activity levels (Figure 4). The species most strongly correlated with the first axis were *L. noctivagans* (negatively), *L. borealis*, and *E. fuscus* (both positively). This indicates separation of sites with more red bat and big brown bat activity, and less silver-haired bat activity. The species correlated positively with the second axis were *L. cinereus*, *N. humeralis*, and negatively with *P. subflavus*. In addition to the separation of sites by the prior three species, the second axis further separates sites by those with more hoary and evening bat activity, but less tricolor bat activity. The first axis had a strong negative correlation with high-density housing, while the second axis correlated positively with greenspace landcover. (Table 4).

General linear models were created for overall species richness and for *E. fuscus*, *L. borealis*, and *N. humeralis*. The direct gradient model (distance to city center) was

included as a candidate model, as well as landscape variables that correlated in the BCPO (HDH for *E. fuscus* and *L. borealis*, and greenspace for *N. humeralis*). None of the landscape variables were positively correlated with each other so multicollinearity wouldn't be an issue; however they were not checked for interaction effects.

For species richness and the three species modeled, the null model was the top model. For *E. fuscus*, the second top model slightly below the null model was distance to city center (Table 5). High-density housing was the second lowest model for *L. borealis* (Table 6). For overall species richness and *N. humeralis* activity, forested landcover was the next lowest model following null (Tables 7 and 8). Models for individual species and species richness that had a difference of less than 2 in AIC ranking were included in the table of top models, however none of these secondary models were significant at $P \leq 0.05$ (Table 9), suggesting that the null models were indeed the best models.

Discussion

The purpose of this study was to determine if a rural-to-urban gradient could predict bat species richness and activity. It seems unlikely that direct and indirect urban gradients can predict bat species richness or their activity levels. Literature reviews of urbanization gradient studies has found varying results regarding how organisms vary along such a gradient. McKinney (2002) noted several studies that found native plant, bird, and butterfly species richness decreased as the urban core was approached. Literature

reviews on urban bird studies (McDonnell and Hahs 2008) and non-avian studies (McKinney 2008) found responses to urbanization gradient varied tremendously. These reviews and my results suggest that study scale, landscape heterogeneity, and taxa traits (i.e., large terrestrial organisms show urban gradient effects) influence species richness or the extent to which gradients provide an understanding of patterns.

The BCPO suggested that a gradient of high-density housing and possibly greenspace may have existed, and showed that the bat community is primarily defined by the how active three most common species are: the big brown bat (*E. fuscus*), the red bat (*L. borealis*), and the evening bat (*N. humeralis*). Other urban bat studies have shown *E. fuscus* being the most predominantly recorded species, as well as *L. borealis* (Chelsvig and Gehrt 2004, Johnson et al 2008, Everette et al 2001.). The community being primarily defined by these common urban bats species is the same as what was seen in Russo and Ancilotto's (2015) review of urban bat studies, where the communities are primarily defined by a few species.

This study was a first attempt to investigate what bat species were present in the Baltimore metropolitan area. Species present at sites were comparable to results seen in studies conducted in other parts of Maryland and DC (Johnson et al 2008, Johnson et al 2009, and Johnson et al 2011). While the species accumulation curve suggests that all species present in the area were documented, *Myotis* species may also be present, as a *M. septentrionalis* specimen was collected from Baltimore County in 1940 (SNHM 2019). High mortality rates of *Myotis* spp. and *P. subflavus* in western Maryland hibernacula due

to white nose syndrome have been documented (MDNR biologist Kerry Wixted, pers. comm.), making their detection in the central Maryland region less likely.

While several measures were used for an indirect gradient, many other metrics could've been used. Urbanization measures that have been used in other studies include impervious surface (used for a GFW study, Bhasakar and Welty 2001), human population density, road density, and traffic volume (McKinney 2002, Zipperer and Guntenspergen 2009).

It is also possible that not enough recordings were done to accurately reflect the bat community present. Summer 2016 in Baltimore was unusually rainy and had below-average temperatures for most of June, which may have played a role in the limited amount of bat activity documented during this part of the season. Active acoustic monitoring occurred in 30-minute sessions, and it possible that conducting this research at a longer temporal scale may have changed the results. Skalak et al (2012) found that 2-5 nights of passive recording were needed to document the most common species present, and 10-22 nights of recording resulted in detecting 80-90% of species present.

Several bat species present in the study area have call patterns that overlap in similarity, so there is the potential that some calls were misidentified, as all sequences were manually identified. *E. fuscus* and *L. noctivagans* emit calls at 25 kHz, and *L. borealis* and *N. humeralis* do so at 35 kHz, sometimes in a manner that makes it difficult to differentiate between species.

Literature Cited

Andrzejewski, R., Babinska-Werka, J., Gliwicz, J., & Goszczynski, J. 1978. Synurbanization Processes in Population of *Apodemus agrarius* I. Characteristics of Populations in an Urbanization Gradient. Acta Theriologica, 23(20): 341–358.

Baltimore Ecosystem Study (BES) Data for Download. 2016. http://beslter.org/data_browser.asp.

Bain, D. J., Yesilonis, I. D., and R.V. Pouyat. 2012. Metal concentrations in urban riparian sediments along an urbanization gradient. Biogeochemistry, 107(1–3): 67–79.

Bhaskar, A. S., and C. Welty. 2012. Water balances along an urban-to-rural gradient of metropolitan Baltimore, 2001-2009. Environmental and Engineering Geoscience, 18(1): 37–50.

Boone, C. G., Cadenasso, M. L., Grove, J. M., Schwarz, K., and G.L. Buckley. 2009. Landscape, vegetation characteristics, and group identity in an urban and suburban watershed: why the 60s matter. Urban Ecosystems, 13(3): 255-271.

Chelsvig, J. E., and S.D. Gehrt, S. D. 2004. Species-Specific Patterns of Bat Activity in an Urban Landscape. Ecological Applications, 14(142):625–635.

City of Baltimore (COB). 2016. Baltimore City Open GIS Data. http://gis-baltimore.opendata.arcgis.com/

Baltimore County Government (BCG). 2016. Open Data Portal. https://data-bc-gis.opendata.arcgis.com/

Colosimo, M. F., and P.R. Wilcock. 2007. Alluvial Sedimentation and Erosion in an Urbanizing Water-shed, Gwynns Falls, Maryland. Journal of the American Water Resources Association, 43(2): 499–521.

Corben, C. 2016. AnalookW for Bat Call Analysis Using ZCA, Version 4.3I. http://users.lmi.net/corben/Beta/AnalookW.zip

Dixon, M. D. 2012. Relationship between land cover and insectivorous bat activity in an urban landscape. Urban Ecosystems, 15(3): 683–695.

Duan, S., Kaushal, S. S., Groffman, P. M., Band, L. E., and K.T. 2012. Phosphorus export across an urban to rural gradient in the Chesapeake Bay watershed. Journal of Geophysical Research: Biogeosciences, 117: G01025.

Duchamp, J. E., Sparks, D. W., and J.O Whitaker. 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.

Everette, A. L., O 'Shea, T. J., Ellison, L. E., Stone, L. A., and J.L. Mccance. 2001. Bat Use of a High-Plains Urban Wildlife Refuge. Wildlife Society Bulletin, 29(3): 967–973.

Fraker, M. E., Snodgrass, J. W., and F. Morgan. 2002. Differences in Growth and Maturation of Blacknose Dace (*Rhinichthys atratulus*) across an Urban-Rural Gradient. Source: Copeia, (4): 1122–1127.

Gehrt, S. D., and J.E. Chelsvig. 2003. Bat Activity in an Urban Landscape: Patterns at the Landscape and Microhabitat Scale. Ecological Applications, 13(4): 939-950.

Johnson, J. B., and J. E Gates. 2008. Bats of Assateague Island National Seashore, Maryland. The American Midland Naturalist, 160(1): 160–170.

Johnson, J. B., Gates, J. E., and W. M. Ford. 2008. Distribution and activity of bats at local and landscape scales within a rural–urban gradient. Urban Ecosystems, 11: 227–242.

Johnson, J. B., Gates, J. E., and N.P. Zegre. 2011. Monitoring seasonal bat activity on a coastal barrier island in Maryland, USA. Environmental Monitoring and Assessment, 173: 685–699.

Johnson, J. B., Gates, J. E., and W. M. Ford. 2009. Notes on Foraging Activity of Female *Myotis leibii* in Maryland. Newton Square. Res. Pap. NRS-8. Newtown Square, PA, U.S. Department of Agriculture, Forest Service, Northern Research Station. 8 p.

Klausnitzer, B., and K. Richter. 1983. Presence of an Urban Gradient Demonstrated for Carabid Associations. Oecologia, 59(1): 79–82.

Lagrosa J. and C. Welty. 2017. GIS Shapefile, Spatial boundaries and land cover summaries for eight sub-watersheds of the Baltimore Ecosystem Study LTER. Environmental Data Initiative.https://doi.org/10.6073/pasta/ad0cce16ef6165913ea26b97e295f985

Maryland Department of Natural Resources (MDNR). 2016. Maryland's Wildlife and Species of Greatest Conservation Need. Annapolis, MD, US. 105p. https://dnr.maryland.gov/wildlife/Documents/SWAP/SWAP_Chapter3.pdf

McCune, B. and M. J. Mefford. 2016. PC-ORD. Multivariate Analysis of Ecological Data. Version 7.06. MjM Software, Gleneden Beach, Oregon, U.S.A.

McDonnell, M. J., and A. K. Hahs. 2008. The use of gradient analysis studies in advancing our understanding of the ecology of urbanizing landscapes: Current status and future directions. Landscape Ecology, 23(10): 1143–1155.

McDonnell, M. J., and S. T. A. Pickett. 1990. Ecosystem Structure and Function along Urban-Rural Gradients: An Unexploited Opportunity for Ecology. Ecology, 71(4): 1232–1237.

McKinney, M. L. 2002. Urbanization, biodiversity, and conservation. BioScience, 52(10): 883–890.

McKinney, M. L. 2008. Effects of urbanization on species richness: A review of plants and animals. Urban Ecosystems, 11(2): 161–176.

Nilon, C. H., and R. C. Pais. 1997. Terrestrial vertebrates in urban ecosystems: developing hypotheses for the Gwynns Falls Watershed in Baltimore, Maryland. Urban Ecosystems, 1(4): 247–257.

Nilon, C. H., and L. W. VanDruff. 1986. Analysis of Small Mammal Community Data and Applications to Management of Urban Greenspaces (pp. 53–59). Integrating Man and Nature in the Metropolitan Environment. Proceedings of National Symposium on Urban Wildlife.

Ramalho, C. E., and R. J. Hobbs. 2012. Time for a change: dynamic urban ecology. Trends in Ecology & Evolution, 27(3):179–188.

Russo, D., and L. Ancillotto, L. 2015. Sensitivity of bats to urbanization: A review. Mammalian Biology, 80(3): 205–212.

Shields, C. A., Band, L. E., Law, N., Groffman, P. M., Kaushal, S. S., Savvas, K., Fisher, G.T., and , K. T. Belt .2008. Streamflow distribution of non-point source nitrogen export from urban-rural catchments in the Chesapeake Bay watershed. Water Resources Research, 44(9): W09416.

Skalak, S. L., Sherwin, R. E., and R. M. Brigham. 2012. Sampling period, size and duration influence measures of bat species richness from acoustic surveys. Methods in Ecology and Evolution, 3(3): 490–502.

Smithsonian National Museums of Natural History (SNMNH). 2019. Mammals Collection: *Myotis septentrionalis* USNM 270235. http://n2t.net/ark:/65665/37727ea0e-0888-4ba3-94bc-727585aa36a5 accessed 3/23/19.

Zipperer, W. C., and G. R. Guntenspergen. 2009. Vegetation composition and structure of forest patches along urban-rural gradients. Ecology of Cities and Towns: A Comparative Approach, (April), 274–286.

Tables and Figures

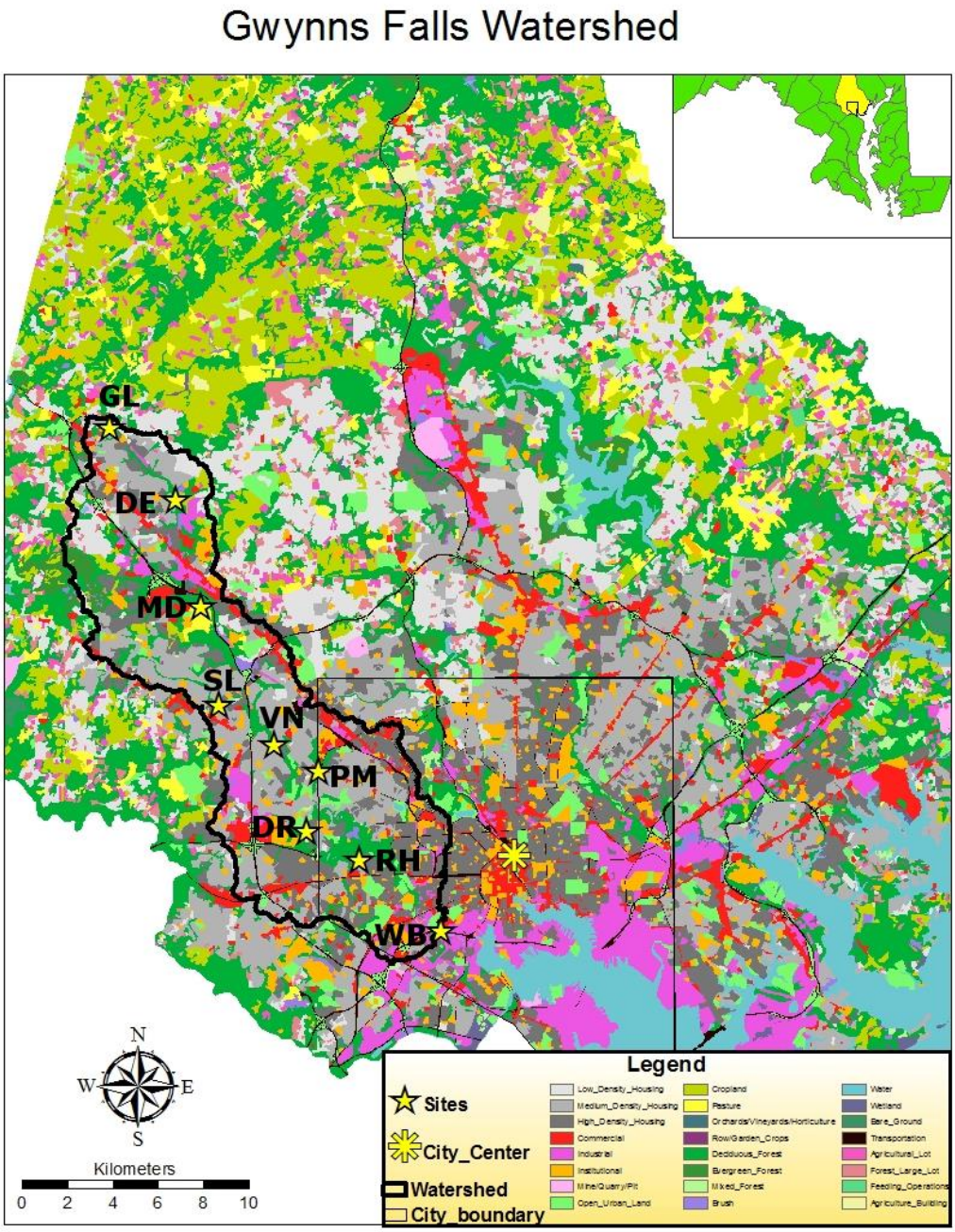


Figure 1. Gwynns Falls Watershed, located in Baltimore County and Baltimore City, Maryland. GL = Glyndon, DE = Soldier's Delight, MD = McDonogh School, SL = Scotts

Level Branch, VN = Villanova, PM = Powder Mill Run, DR = Dead Run, RH = Rognel Heights, WB= Washington Blvd.

Table 1. Mean hourly detection rate of bat species at GFW sites.

Site	***E. fuscus***	***L. borealis***	***L. cinereus***	***L. noctivagans***	***N. humeralis***	***P. tricolor***	**Total**
GL	4.86	10.57	0.00	0.00	0.00	0.00	15.43
DE	40.00	39.14	0.00	0.57	3.71	2.86	86.29
MD	17.60	6.00	3.60	1.20	1.60	0.00	30.00
SL	35.43	0.29	0.00	0.86	0.00	0.00	36.57
VN	29.71	2.00	0.00	0.29	0.00	9.43	41.43
PM	65.43	6.86	0.86	0.00	1.43	0.00	74.57
DR	10.57	1.43	0.00	0.00	0.29	0.00	12.29
RH	59.71	10.00	0.29	1.14	2.29	0.29	73.71
WB	45.71	19.71	0.00	0.00	3.43	0.00	68.86

Table 2. Detection probability of species at GFW sites.

	E. fuscus	***L. borealis***	***L. cinereus***	***L. noctivagans***	***N. humeralis***	***P. tricolor***
GL	0.31	0.69	0.00	0.00	0.00	0.00
DE	0.46	0.45	0.00	0.01	0.04	0.03
MD	0.59	0.20	0.12	0.04	0.05	0.00
SL	0.97	0.01	0.00	0.02	0.00	0.00
VN	0.72	0.05	0.00	0.01	0.00	0.23
PM	0.88	0.09	0.01	0.00	0.02	0.00
DR	0.86	0.12	0.00	0.00	0.02	0.00
RH	0.81	0.14	0.00	0.02	0.03	0.00
WB	0.66	0.29	0.00	0.00	0.05	0.00

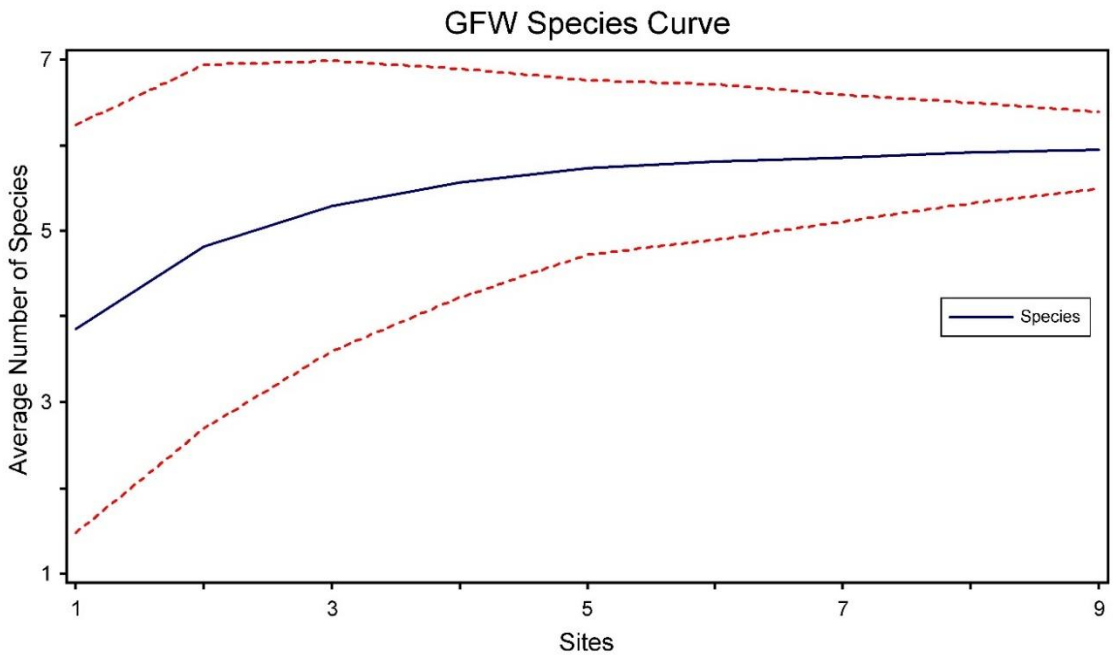


Figure 2. Species Curve for bat species recorded in GFW.

Table 3. Site names and measures of urbanization. Percentages are from the 500 m radius area surrounding sites. 'Greenspace' includes deciduous forest, mixed forest, and open urban land landcovers. 'Other urban' includes institutional, industrial, and commercial landcovers.

Site name	**Code**	**Distance from city center (km)**	**High-density housing (%)**	**Greenspace (%)**	**Other urban (%)**
Glyndon	GL	25.98	4.51	15.35	18.20
Soldier's Delight	DE	21.68	0.00	32.59	0.00
McDonogh School	MD	17.65	0.00	42.01	0.00
Scott's Level Branch	SL	14.66	45.97	11.00	10.84
Villanova	VN	11.68	15.03	20.17	7.83
Powder Mill Run	PM	9.40	12.74	36.00	10.21
Dead Run	DR	9.20	36.00	55.46	4.43
Rognel Heights	RH	6.85	40.19	49.29	3.16
Washington Blvd	WB	4.61	21.44	25.08	41.85

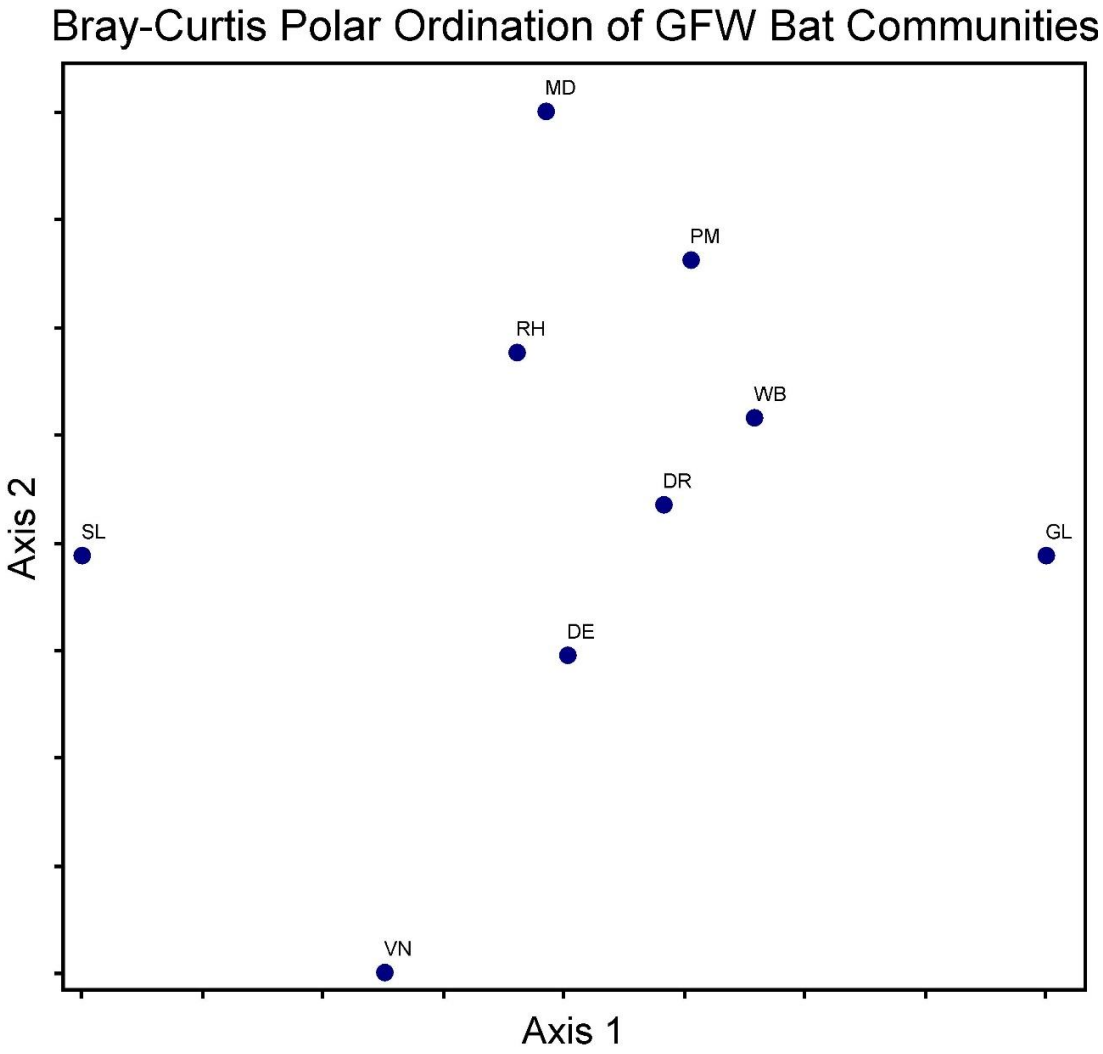


Figure 3. Bray-Curtis Polar ordination of sites. The first axis separates sites by low levels of *L. noctivagans* activity, and high levels *of L. borealis*, and *E. fuscus* activity. The second axis separates sites by those with more *L. cinereus*, *N. humeralis*, activity *and less P. subflavus* activity.

Table 4. Correlation table of variables and species with BCPO axes. The first axis separated sites primarily by the amount *L. borealis* and *L. noctivagans* detections and appeared to show a gradient of high-density housing, while the second axis further separated sites by the amount of *L. cinereus* and *P. subflavus* detections and suggested a greenspace gradient.

	Axis 1	**Axis 2**
City center distance	0.228	-0.159
Greenspace	0.147	0.474
HDH	**-0.505**	-0.045
Other urban	0.356	-0.008
E. fuscus	-0.46	0.034
L. borealis	**0.618**	0.149
L. cinereus	0.008	0.772
L. noctivagans	**-0.686**	0.088
N. humeralis	0.184	0.467
P. subflavus	-0.284	-0.778

Table 5. Candidate models for *E. fuscus*.

Model	**K**	**AICc**	**Delta AICc**	**AICc Wt**	**Cum. Wt**	**LL**
Null	2	13	0	0.51	0.51	-3.5
Distance	3	13.64	0.63	0.37	0.88	-1.42
HDH	3	17.03	4.03	0.07	0.95	-3.12
Greenspace	3	17.78	4.78	0.05	1	-3.49

Table 6. Candidate models for *L. borealis*.

Model	**K**	**AICc**	**Delta AICc**	**AICc Wt**	**Cum. Wt**	**LL**
Null	2	20.34	0	0.56	0.56	-7.17
HDH	3	21.45	1.11	0.32	0.89	-5.33
City center distance	3	24.94	4.6	0.06	0.94	-7.07
Greenspace	3	24.98	4.64	0.06	1	-7.09

Table 7. Candidate models for *N. humeralis*.

Model	**K**	**AICc**	**Delta AICc**	**AICc Wt**	**Cum. Wt**	**LL**
Null	2	17.45	0	0.71	0.71	-5.72
Greenspace	3	20.12	2.67	0.19	0.9	-4.66
City center distance	3	21.33	3.88	0.1	1	-5.27
HDH + other urban	4	28.88	11.44	0	1	-5.44

Table 8. Candidate models for species richness.

	K	**AICc**	**Delta AICc**	**AICc Wt**	**Cum. Wt**	**LL**
Null	2	35.23	0	0.54	0.54	-14.61
Greenspace	3	36.12	0.89	0.35	0.89	-12.66
City center distance	3	39.79	4.56	0.06	0.94	-14.49
HDH	3	40.01	4.78	0.05	0.99	-14.6
HDH + other urban	4	44.1	8.87	0.01	1	-13.05

Table 9. Top models for species and species richness. Models with < 2 difference in AIC_c ranking were included.

	AICc	**Model**	**Coefficient**	**P**
E. fuscus	13.00	Null	1.9607	< 0.01
	13.64	City center distance	-0.03248	0.082
L. borealis	20.34	Null	1.3006	< 0.01
	21.45	HDH	-0.01885	0.1016
N. humeralis	17.45	Null	0.5547	< 0.01
Species richness	35.23	Null	3.7778	< 0.01
	36.12	Greenspace	0.05051	0.09201

Chapter 2: Environmental predictors of Bat abundance in vacant lots

Abstract

Within Baltimore, there are over 1,750 ha of vacant lots. The extent to which bats use small, informal greenspaces such as these has not been investigated in any published studies. After discovering at least six bat species were present in Baltimore (see Chapter 1), I began investigating environmental factors in and surrounding vacant lots with the purpose of determining which variables best predict bat species richness and activity. During the summers of 2017 and 2018, I used passive acoustic monitoring to record bat activity for a total of nine nights at 32 randomly selected vacant lots. I measured site-scale variables such as canopy cover, ground cover height, and number of streetlights present. Neighborhood-scale variables (percent forest cover, canopy cover, vacant housing density, and road density) were obtained and analyzed using GIS. Both *a priori* and Bray-Curtis Polar ordination- based models were created for species richness and activity at these sites. Linear mixed modeling was used to discover potential predictors of species richness and bat activity levels. Over 33,000 sequences were recorded. Six species were present, with most detections coming from big brown bats (*Eptesicus fuscus*). Most sites had distinct communities with varying activity levels from 2-5 species. While there were no models for species richness that were better than the null model, common predictors in the best models for individual species activity were canopy

variables at the site scale (canopy height and percent canopy cover) and distance from water.

Introduction

Vacant lots have been defined in numerous ways based on their origins, their history, and current characteristics (Bowman and Pagano 2000, Kremer et al 2013, Pagano and Bowman 2000, Rega-Brodsky 2016) but in essence, vacant lots are land parcels in urban areas that lack development. They can vary in size, vegetation, and age. Within the field of urban ecology, the ecological significance of informal greenspaces have been understudied (Botzat et al 2016). Studies that have been done regarding this unique urban habitat suggest they can play an important role in providing ecosystem services and supporting wildlife (Rega-Brodsky 2016, Kremer et al 2013, Kim et al 2015, Elmquist et al 2013 Gardiner et al 2013). In “shrinking” cities like Baltimore, a 34% decline in residential population since the 1950’s has resulted in an increase in vacant houses, some of which eventually become vacant lots (Rega-Brodsky et al 2018).

Over16,500 vacant lot parcels in Baltimore City comprise approximately 1,750 ha of land. Age, shape, size, vegetation, and composition of these lots can vary. Rega-Brodsky (2016) created six classifications of vacant lot “settings” based on the lots’ surroundings, biota, and prior usage: vacant block, inner block, corner lot, missing tooth, suburban

yard, and waysides. These categories were used as part of a study on bird use and nesting habitat in these lots, which found that lots provide ideal nesting habitat for native birds, especially when in proximity to forested areas (Rega-Brodsky 2016, Rega-Brodsky and Nilon 2016, Rega-Brodsky and Nilon 2017). Other research in vacant lots in Baltimore has focused on plants and residential preference regarding these spaces. Results from these studies have found vacant lots' plant community do not suffer from an island biogeography effect (Tauzer and Pickett 1999) and are shaped by their prior land use and tend to stay stable over decades (Johnson et al 2018). Residents preferred well-maintained lots with trees, few shrubs, and more open space, which could be used for recreation or the community. These spaces also have the potential to be managed for wildlife while aligning with residential preferences for their neighborhoods (Rega-Brodsky et al 2018).

The extent to which bats use these smaller informal urban greenspaces has not been previously investigated. In a pilot study of active acoustic monitoring at parks and vacant lots within Baltimore, half of the vacant lots visited had more recorded bat activity than several medium-sized and large parks (unpublished). A habitat gradient study of bat activity in Baltimore City and County revealed that six bat species were present in the region, with one of the sites located within the city having the most species present (see Chapter 1). An urbanization gradient did not appear to affect bat species, suggesting that there may be other variables not investigated that predict bat species richness and the extent of bats' activity.

The purpose of this chapter is to determine if environmental measures of vacant can be used to predict species richness and bat activity levels, and if these variables are scale dependent. Because tree-associated variables were important for birds at these lots, I hypothesized that vacant lots with more canopy cover (on site and surrounding) would have more bats species present. Because big brown bats (*Eptesicus fuscus*) are known to roost in buildings, I also hypothesized that areas with more vacant buildings present would have more activity from this species. Results could potentially used to help manage vacant lots to increase biodiversity and ensure their ecosystem services (pest control) are present even in these informal greenspaces.

Methods

Study area

Baltimore City is located in central Maryland and straddles the Piedmont and Coastal Plain regions. It is part of the Chesapeake Bay watershed and three smaller watersheds run through the city: Gwynns Falls, Jones Falls, and Herring Run. Before colonization and city establishment in 1729, the land was temperature deciduous forest. Baltimore currently has a population of over 600,000, a 34% decline since the 1950s (Rega-Brodsky et al 2018). Vacant lots comprise 7% of the city's land.

Site selection

I used stratified random sampling to select sites evenly distributed throughout the city. After dividing the city into four regions (northwest, southwest, northeast, and southeast), four sites were randomly selected within each region each year (Figure 1). The sites were randomly selected from a group of 150 vacant lots used for a bird study (Rega-Brodsky 2016), though some were selected from outside of this group using Baltimore City's vacant lots shapefile (COB 2017). After random selection, sites were viewed using Google Earth and/or visited in person to ensure that there was at least one suitable tree present to attach the bat detector to, and enough open space to ensure calls recorded would be optimal quality. During the second year of the study, property status of sites were reviewed to ensure sites were city-owned. Sites were also checked in ArcMap to ensure they were a minimum of 500 m from nearby sites. If a randomly selected site didn't have these qualifications, then it was not used and another site was randomly selected. I also categorized sites into one of the six vacant lot settings categories; vacant block, inner block, corner lot, missing tooth, suburban yard, and waysides.

Acoustic monitoring and sequence identification

From May-August of 2017 and 2018, passive acoustic monitoring was conducted at 32 sites for nine, for a total of 288 nights. An Anabat Express bat detector was secured to a tree 2-3 m above the ground, with the microphone directed towards open space (Figure 2). The detector was set to "night mode" and a sensitivity level of seven out of nine to

ensure calls would be detected, while also limiting additional urban noises (vehicles, wind, rain, insects, etc.) from being recorded. The detector then recorded bat activity from sunset to sunrise for three consecutive nights (one recording session). All sites within one region were recorded simultaneously.

On the fourth day, I retrieved the detectors and downloaded the sequences onto a laptop. I manually identified bat sequences to species level using AnalookW software (Corben 2017). Sequences with less than four calls were not included. Sequences that could not be identified to species level were counted and categorized based on kHz frequency level (Q25, Q35, and Q40), but were not included in analysis. I calculated an hourly detection rate for each species at each site using the total number of sequences recorded (see Appendix 2) and the total number of recording hours.

Acoustic assumptions

It is important in acoustic monitoring studies to be mindful of what assumptions are being made and to clearly state how sequences will be interpreted (Sherwin et al 2000). All sequences that were more than four calls long and identifiable to species level will be interpreted as bat use of vacant lots, either as foraging habitat or as corridor habitat (i.e. traveling within the bats' home range). Because abundance cannot be quantified from acoustic recordings, sequences were treated as independent events. I assumed that all species present within 40 m of the detectors (the approximate range of detection) would have the same detection probability.

Environmental measurements

I measured several environmental variables at each site (Table 1). A concave densiometer was used to calculate percent canopy cover at the center of the site and near the location of the bat detector; the mean of these values was used as a measure of site-scale canopy cover. A Biltmore stick with a hypsometer and ruler was used to measure ground cover height in the center if the site, and estimate canopy height of tallest tree present. Vegetation height was used as a measure of vegetation structure, which can impact the insect abundance (Pöyry et al 2006, Strauss and Biedermann 2006). Because lots were mowed regularly the height did not change much and was only measured once. I also counted the number of streetlights visible around the site, as some species will take advantage of these to forage for prey, while others will avoid it (Russo and Ancilotto 2015). I categorized all 32 sites by lot type using vacant lot categories created by Rega-Brodsky (2016) to provide additional descriptive detail of the lots in terms of their shape and structure.

Analysis

I assembled site locations, landcover, canopy cover, water, road, and vacant building shapefiles in ArcMap 10.6 (ESRI 2017, COB 2017) to calculate several environmental variables at a larger scale. This included distance of each site to the city center and to the closest water body. Using a 500m radius of the area around each site, I calculated the percent greenspace (forests and urban open area landcovers), canopy cover area (ha), mean road density, and mean vacant building density (both /ha). Neighborhood-scale canopy cover was measured to include street trees, which wouldn't be measured in greenspace landcover. I chose 500 meters as radius around sites to ensure measurements

at this scale were independent; this distance was used as an intermediate range in another urban bat study (Dixon 2012).

I used Principal Component Analysis (PCA) to illustrate site similarity based on the environmental variables measured using PC-ORD software (McCune and Mefford 2016). PCA also allowed me to see variable correlation so that I could avoid multicollinearity in models. Components (axes) with eigenvalues ≥ 1 were retained and variables with loadings ≥ 0.5 and ≤ -0.5 were considered strong loadings within each principal component.

I then used Bray-Curtis Polar ordination (BCPO) in PC-ORD (McCune and Mefford 2016) to visualize the similarity of bat communities at each site. BCPO establishes distances between the sites on two axes, with the first axis denoting the strongest differences in the primary matrix (the number of detections recorded from species at each site). I also included vegetation data as a secondary matrix. By doing so, I could use the correlations of each species and each vegetation variable to an axis to generate preliminary hypotheses on which I can base my models (i.e., a species and variable (s) that have a strong correlation on one axis suggests that that species' detection may be associated with that variable). Candidate models were not created for species that did not have a strong correlation (≥ 0.5) with the first or second axis. For my BCPO I log-transformed total number of detections for each species at each site and modified the landscape data with a general relativization to normalize and re-scale the data, as variables were measured on different scales.

Candidate models for species included a null model and a model based on BCPO. To determine the importance of spatial scale, additional candidate models were created for local (site canopy cover, canopy height and streetlights), and neighborhood scale (canopy cover and greenspace within 500m radius, distance to city center, and distance to water). An urban model (city center distance, lights, and vacant building density) was created to determine if urban factors generally seen as deterrents to bat activity would be important predictors. Poisson-based generalized linear mixed effect models were created using the glmer function in RStudio, with region and year being random effects. Bat calls were log transformed and variables were scaled in R Studio to ensure normal distribution.

Results

Bat recordings

Over 19,000 sequences were recorded in 2017 and over 14,000 were recorded in 2018 for a total of over 33,000 sequences (Appendix 2). Six species were recorded: the big brown bat *Eptesicus fuscus*, red bat *Lasiurus borealis*, hoary bat *L. cinereus*, silver haired bat *Lasionycteris noctivagans*, evening bat *Nycticeius humeralis*, and tricolor bat *Perimyotis subflavus*. Hourly detection rates varied by species and site but the most active species at almost all sites was *E. fuscus* (Table 2) and comprising over 50% of detections at many of these sites (Table 3). The remaining species were detected less than twice an hour at all but one site. *P. subflavus*, was the least detected at only two sites with six sequences; it was removed from further analyses.

Vacant lot characteristics

About half of the sites were characterized as vacant blocks. Remaining sites were primarily inner block and corner lots (Table 4). Sites had enormous variation in canopy cover at the site and neighborhood scale. Within a 500 m radius of sites, the percentage of land that was categorized as greenspace (forested, open urban land, and brush) varied from zero to 36%. On average sites were within one kilometer of a water body (Table 5). Canopy height at sites ranged from 11 to 36 m. Sites were predominantly surrounded by high and medium-density housing, followed by mixed amounts of commercial, institutional, and industrial (Table 6).

Road density had a strong positive correlation with streetlights. Road density, vacant building density and distance to water were all highly correlated with each other (Table 7); models were created to avoid having these correlated variables within the same model. While doing preliminary analysis, it was discovered that canopy cover and greenspace within 500m had an interaction effect, as did site canopy cover and canopy height, and these interactions were included in the appropriate models.

Ordination and Models

A PCA for the environmental variables resulted in two principle components that explained 54% of the variance (Table 8). The first component explained 40% of the variance and had strong negative loadings for number of streetlights, distance from water, vacant building density, road density, and strong positive loadings for percent canopy cover at site scale, distance from city center, canopy cover within 500 m radius, and

percent greenspace within 500 m radius (Figure 3). Sites on the left side of this PCA are inner city vacant lots with more vacant buildings, roads, and lights, that have less canopy cover and do not have as much greenspaces nearby, while sites on the right are closer to water and have less roads, vacant buildings, and streetlights. The second axis explained 13.9% of variance and had a strong positive loading for canopy height; vacant lots along the top of the PCA had taller trees present on-site.

Bray-Curtis Polar Ordination arranged sites primarily by the amount of *E. fuscus*, *L. borealis*, and *N. humeralis* detections (Figure 4). For species correlation, an r-value of ≥ 0.5 or ≤ -0.5 was considered strong. These three species had a strong positive correlation to the first axis (Table 9); this indicated separation of sites by those that had more detections of these three species. *E. fuscus* also had a strong positive correlation to the second axis, which meant that sites in the upper right corner of the BCPO had the most recorded detections from this species. *L. cinereus*, and *Lasionycteris noctivagans* were only correlated to a third (discarded) axis, so models were not created for these.

For variable correlation, only canopy height had a strong (≥ 0.5 or ≤ -0.5) correlation to the second BCPO axis. Thus, for ordination models, variables with an r-value of ≥ 0.3 or ≤ -0.3 were included. The BCPO indicated a negative gradient of canopy height. There were several other variables that were correlated to a lesser extent. The first axis explained 47.16% of the variance and was negatively correlated with distance to city center, amount of canopy cover within 500m, and positively correlated with vacant building density. The second axis explained 19.06% of variance and in addition to canopy height, had a negative correlation with number of streetlights present

and positive correlated with percent canopy cover at the site scale. Ground cover height was not strongly correlated to any axes and was not included in any models.

The null model was the top model for species richness; the second best model was the urban deterrents model which included distance to city center, streetlights, and road density (Table 10). The top model for big brown bat detection with the lowest AIC_c value included both local and neighborhood-scale vegetation, streetlights, and distance from water and city center (Table 11). This suggests that big brown bats are most active in vacant lots that had less local vegetation but more streetlights, that were located further from city center, and closer to water. When both canopy cover and greenspace within 500 m was present, there was more big brown activity, but if only one or the other was present, then there were less detections.

L. borealis activity was best predicted by distance from city center, road density, and neighborhood-scale vegetation (Table 12). This species was detected more at lots that were surrounded by fewer roads located in the interior of the city. When canopy cover and greenspace had an interaction effect, less red bat activity was detected; if there wasn't an interaction effect, then red bats were detected more at vacant lots that were surrounded by more canopy cover but less greenspace (Table 14). The model that best predicted *N. humeralis* activity included both local and neighborhood scale variables (Table 13). More activity was detected from this species in vacant lots that had more local and neighborhood vegetation, less streetlights, closer to the city interior, and closer to water. When canopy cover and greenspace had an interaction effect, more evening bat

activity was detected; if there wasn't an interaction effect, evening bats were detected more at vacant lots that were surrounded by less canopy cover and greenspace (Table 14).

Discussion

By using simple environmental measures, the amount of acoustic activity of bat species in an urban environment can be predicted. The BCPO suggests that vacant lot bat communities are defined primarily by the amount of big brown, red, and evening bat activity detected. For these three species, vegetation present within 500 m and distance from the city center were the best predictors. Models that included vegetation at both the site and neighborhood scale were the top models for the big brown and evening bat, and for the red bat it was the second model, suggesting that factors at both scales are important for bats. Canopy cover and the presence of nearby forested land appear to be common predictors for both bats and birds in Baltimore vacant lots (Rega-Brodsky and Nilon 2017). The presence of additional predictors for different species and their varying response to these predictors supports the idea that different species use urban landscape to different degrees (Avila-Flores and Fenton 2003, Dixon 2012). Potential other variable that were not measured but that likely play a role in bat activity include noise levels, insect diversity and abundance, and tree diversity and age.

There were no ideal models to predict species richness that were better than the null model; this could mean either species richness is not influenced by urbanization or that

using species richness as a measure of bat diversity is not ideal (at least in Baltimore). All sites had 2-5 species present, and richness gave equal weight to species that were highly active (i.e. detected often) and species that may have been only passing through the area.

Though present at all sites, big brown bats, an urban generalist species were more active in lots that had less local vegetation, more streetlights, that were closer to water, and were surrounded by more greenspace. In a study comparing big brown and evening bat activity in an urban area, big browns spent more time flying and foraging, had multiple foraging sites, used more low density residential areas, successfully roosted in buildings in a variety of surroundings, and were able to cross large patches of urban areas to access foraging habitat (Duchamp et al 2004). This species is a fast flying, urban adapted species, and so local vegetation may not be as important since they are capable of flying longer distances over urban landscape to access foraging habitat. It was also the only species associated with streetlights, likely taking advantage of these for foraging.

The abundance of *E. fuscus* activity recorded in this study appears to be a common theme in other North American urban studies (Brigham 1991, Chelsvig and Gehrt 2004; DC, Johnson et al 2008, Everette et al 2001, Johnson et al 2008). My hypothesis that *E. fuscus* would be more active in areas with more vacant housing was rejected. This is likely because acoustic monitoring is detecting bats' *foraging* activity, while VBD reflects a potential *roosting* variable. This species is known to roost in anthropomorphic structures, and although not supported by my data, it is likely that some of Baltimore's numerous vacant buildings are being used as both night and day roosts.

The tree-roosting evening bat, *N. humeralis*, appeared to be more active in lots that both local and neighborhood vegetation present, closer to the city center, and closer to water. This is supported by Duchamp et al's (2014) comparison study of *E. fuscus* and *N. humeralis* urban activity. This study concluded that *N. humeralis* was not as well adapted to urban living, as they avoided traveling through urban areas unless it was adjacent to habitat patches, likely due to having a shorter wingspan and reduced ability to travel far distances. This species tends to alternate between several tree cavity roosts and have high fidelity to their foraging habitat, making their presence limited to urban areas with large amounts of greenspace present. Thus, this species may have been present in lots closer to their roosts. This does not explain however why they tended to be found in lots closer to the center of this city, which is the opposite of Duchamp et al (2014).

The red bat, *L. borealis*, a migratory, foliage-roosting species, appeared to be more active in lots surrounded by less roads, less surrounding greenspaces, and closer to the center of the city. This was surprising, given that the center of the city had the highest road densities. This species' sometimes-erratic flight pattern (Shump & Shump 1982) could potentially result in mortality in road-dense areas. However, much of the inner city consist of neighborhoods that have high amounts of vacant buildings, thus roads in these areas may not be high-traffic that one might normally associate with high road density. Similar to what has been seen in other studies (Amelon et al 2014, Dixon 2012, Li and Wilkins 2014, Walters et al 2007) there was a positive association between *L. borealis* activity and canopy-associated variables. Although streetlights did not come up as a predictor, *L. borealis* has been documented foraging around streetlights (Walters et al

2007), where smaller moth species may be present that they prefer to eat (Hickey et al 1996).

The silver-haired bat, hoary bat, and tricolor bats were uncommon species but are likely also associated with the presence of greenspace and distance to water. was uncommon. Limited detection of *L. noctivagans*, a migratory, tree-roosting specie,s may be the results of documenting individuals traveling to/from roosting or foraging habitat and not active use of vacant lots. Most research done with this species has occurred in western North America, where this species roosts in conifer snags in areas that had low canopy cover (Campbell et al 1996). In a study or urban greenspaces in Chicago, Chelsvig & Gehrt (2004) found this species associated with woodlands.

In a comparison study of *L. cinereus* and *L. borealis* foraging behavior around streetlights (Hicket et al 1996), it was found that the *L. cinereus* primarily ate larger moths, were less maneuverable in flight, and had lower echolocation call frequency better suited for detecting insects at long range. This would suggest that open spaces, and habitat necessary for larger moth species would be important. This species was uncommon in recordings, and the need for larger prey species may play a role. An unfortunately absent measurement in my research that may have been a useful was abundance and diversity of insects at these lots.

The tricolor bat, *P. subflavus*, was the least detected species in the study. However, the two sites were it was recorded have similar qualities to those associated with the species in Dixon's (2012) study: both sites had high percentage of canopy cover and were

very close (< 250 m) to water. Additionally, a third site that was initially selected (but was later removed due to not being city-owned) also had several recordings of *P. subflavus*, and like the other two sites, was adjacent to high-canopy cover area. During the summer, *P. subflavus* roost in clumps of dead leaves, alternating between several tree roosts. Their preferred habitat are upland and riparian-forested areas (Veilleux et al 2003). This uncommon type of habitat and the need for multiple similar trees in special types of forest may explain why they were not recorded more often. Additionally, *P. subflavus* is one of several species in Maryland that has been severely affected by white-nose syndrome (MDNR biologist Kerry Wixted, pers. comm.) and was recently listed in nearby Pennsylvania as a state-endangered species (Thomas 2019).

Results seen may also partially reflect the placement and location of detectors. The location of bat detector at sites was not in a controlled location, and so it is possible the location of detectors within the site and their distance from edge habitat (when present) may have also played a role in what activity and species were recorded. The distance of the recorders from edge habitat was an important predictor of bat activity in Gehrt and Chelsvig's (2003) study- the further the detectors were from the edge, the fewer sequences were detected. Detectors were placed 2- 4 m high, however a study on bat foraging height (Menzel et al 1996) found that detector height played a role in how much bat activity was recorded for bat species, many of which were present both here and in the study's location in South Carolina.

This was the first study within Baltimore City documenting what bat species are present and what factors likely encourage their presence here. Despite the urban location,

results reflect those seen in other parts of Maryland (Johnson et al 2008, Johnson and Gates 2008). In Johnson and Gates (2008), there was a possible capture of a Seminole bat, *Lasiurus seminolus*, which has a similar physical appearance and acoustical repertoire to *L. borealis*, making it impossible to know for sure if this species may have also been present.

However, unlike these other local studies, no *Myotis* species were recorded. Potential local *Myotis* species could include *M. lucifugus* and *M. septentrionalis*. A male *M. septentrionalis* specimen was collected near the Baltimore City/County border in February 1941 (SNMNH 2019), an area that is still has high canopy cover and little land modification. *Myotis* have been documented in other urban bat studies in the US (Chelsvig and Gehrt 2004, Li and Wilkins 2014, Johnson et al 2008, Dixon 2012). In addition to high mortality from white nose syndrome, *Myotis* can also face mortality from car strikes, especially in areas with large patches of forested landscape adjacent to areas of high road density (Russell et al 2008). In an urban setting like Baltimore that has several large forested parks that are adjacent to areas of high road density, it seems unlikely that *Myotis* would be active in vacant lots and, if present in the city, would likely be limited to the large forested urban parks.

At a landscape scale, lots that are located closer to water bodies and large patches of greenspace have the most potential for being used by bats, either as foraging habitat or as corridor habitat. Larger lots (like the vacant blocks and suburban yards) could potentially be managed to have a variety of vegetation structure allowing both canopy cover and open space. Smaller lots types (corner lots, inner blocks and missing tooths) could be

managed in groups where certain lots have more open space and others have more canopy cover. However, it is important to consider the values and needs of local residents around these sites before managing these lots for wildlife (Rega-Brodsky et al 2018). Though some vacant lots are used by residents, many are viewed negatively due to being locations of illegal dumping and potentially being a magnet for crime. Modifying the vegetation in these spaces to address biodiversity, sustainability or environmental justice concerns can result in higher property values and housing costs, potentially lead to displacement of residents and gentrification (Wolch et al 2014). A study of residential preference of lots in Baltimore found that residents prefer lots that show signs of maintenance and use, and have more trees present (Rega-Brodsky et al 2018); as trees are important for bats as well, it is certainly possible to manage these spaces for both residents and wildlife.

Literature Cited

Botzat, A., Fischer, L. K., and I. Kowarik. 2016. Unexploited opportunities in understanding liveable and biodiverse cities. A review on urban biodiversity perception and valuation. Global Environmental Change, 39:220–233.

Kim, G., Miller, P. A., and D. J. Nowak. 2015. Assessing urban vacant land ecosystem services: Urban vacant land as green infrastructure in the City of Roanoke, Virginia. Urban Forestry & Urban Greening, 14: 519–526.

Elmquist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P. J., Mcdonald, R. I., and C. Wilkinson. (Eds.). 2013. Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities A Global Assessment. Dordrecht: Springer.

Amelon, S. K., Thompson, F. R., and J. J. Millspaugh. 2014. Resource utilization by foraging eastern red bats (*Lasiurus borealis*) in the Ozark Region of Missouri. Journal of Wildlife Management, 78(3): 483–493.

Avila-Flores, R., and M. B. Fenton. 2003. Use of Spatial Features By Foraging Insectivorous Bats in a Large Urban Landscape. Journal of Mammalogy, 86(6): 1193–1204.

Brigham, R. M. 1991. Flexibility in foraging and roosting behaviour by the big brown bat (*Eptesicus fuscus*). Canadian Journal of Zoology, 69: 117–121.

Campbell, L. A., Halleti, J. G., and M. A. O'Connell. 1996. Conservation of Bats in Managed Forests: Use of Roosts by *Lasionycteris noctivagans*. Journal of Mammalogy, 77(4: 976–984.

City of Baltimore (COB). 2017. Baltimore City Open GIS Data. http://gis-baltimore.opendata.arcgis.com/

Corben, C. 2017. AnalookW for Bat Call Analysis Using ZCA, Version 4.3I. http://users.lmi.net/corben/Beta/AnalookW.zip

Chelsvig, J. E., and S.D. Gehrt, S. D. 2004. Species-Specific Patterns of Bat Activity in an Urban Landscape. Ecological Applications, 14(142):625–635.

Dixon, M. D. 2012. Relationship between land cover and insectivorous bat activity in an urban landscape. Urban Ecosystems, 15(3): 683–695.

Duchamp, J. E., Sparks, D. W., and J.O Whitaker. 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.

Environmental Systems Research Institute (ESRI) 2017. ArcGIS Desktop: Release 10.6. Redlands, CA

Everette, A. L., O 'Shea, T. J., Ellison, L. E., Stone, L. A., and J.L. Mccance. 2001. Bat Use of a High-Plains Urban Wildlife Refuge. Wildlife Society Bulletin, 29(3): 967–973.

Gardiner, M. M., Burkman, C. E., and S.P. Prajzner. 2013. The Value of Urban Vacant Land to Support Arthropod Biodiversity and Ecosystem Services. Environmental Entomology, 42(6): 1123–1136.

Gehrt, S. D., and J.E. Chelsvig. 2003. Bat Activity in an Urban Landscape: Patterns at the Landscape and Microhabitat Scale. Ecological Applications, 13(4): 939-950.

Hickey, M., Acharya, L., and S. Pennington. 1996. Resource Partitioning by two Species of Verspertilionid Bats (*Lasiurus cinereus* and *Lasiurus borealis*) Feeding around Streetlights.. Journal of Mammalogy, 77(2), 325–334.

Johnson, A. L., Borowy, D., and C.M. Swan. 2018. Land use history and seed dispersal drive divergent plant community assembly patterns in urban vacant lots. Journal of Applied Ecology, 55(1): 451–460.

Johnson, J. B., and J. E Gates. 2008. Bats of Assateague Island National Seashore, Maryland. The American Midland Naturalist, 160(1): 160–170.

Johnson, J. B., Gates, J. E., and W. M. Ford. 2008. Distribution and activity of bats at local and landscape scales within a rural–urban gradient. Urban Ecosystems, 11: 227–242.

Kim, G., Miller, P. A., and D.J. Nowak. 2015. Assessing urban vacant land ecosystem services: Urban vacant land as green infrastructure in the City of Roanoke, Virginia. Urban Forestry & Urban Greening, 14: 519–526.

Kremer, P., Hamstead, Z. A., and T. McPhearson. 2013. A social–ecological assessment of vacant lots in New York City. Landscape and Urban Planning, 120: 218–233.

Li, H., and K.T. Wilkins, K. T. 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.

Menzel, J. M., Menzel, M. A., Kilgo, J. C., Edwards, J. W., and G.F. McCracken. 1996. Effect of Habitat and Foraging Height on Bat Actvity in the Coastal Plain of South Carolina. Journal of Wildlife Management, 69(1): 235–245.

Pagano, MA, and A.O.M. Bowman. 2000. Vacant land in cities: An urban resource. Brookings Institution, Center on Urban and Metropolitan Policy, Washington, D.C

Pöyry, J., Luoto, M. , Paukkunen, J. , Pykälä, J. , Raatikainen, K., and M. Kuussaari. 2006. Different responses of plants and herbivore insects to a gradient of vegetation height: an indicator of the vertebrate grazing intensity and successional age. Oikos, 115: 401-412.

Rega-Brodsky, C. C. 2016. Urban Vacant Lots: Ecological Quality and Social Opportunities in Baltimore, Maryland. Dissertation.

Rega-Brodsky, C. C., and C.H. Nilon. 2016. Vacant lots as a habitat resource: Nesting success and body condition of songbirds. Ecosphere, 7(11): 1–11.

Rega-Brodsky, C. C., and C.H. Nilon. 2017. Forest cover is important across multiple scales for bird communities in vacant lots. Urban Ecosystems, 20: 561–571.

Rega-Brodsky, C., Nilon, C., and P. Warren, P. 2018. Balancing Urban Biodiversity Needs and Resident Preferences for Vacant Lot Management. Sustainability, 10(5): 1679.

Russell, A. L., Butchkoski, C. M., Saidak, L., and G.F. McCracken. 2008. Road-killed bats, highway design, and the commuting ecology of bats. Endangered Species Research, 8: 49–60.

Sherwin, R. E., Gannon, W. L., and S. Haymond. 2000. The efficacy of acoustic techniques to infer differential Use of habitat by bats. Acta Chiropterologica, 2(2): 145–153.

Shump, K. J., and A. Shump. 1982. *Lasiurus borealis*. Mammalian Species, 162(183): 1–9.

Smithsonian National Museums of Natural History (SNMNH). 2019. Mammals Collection: *Myotis septentrionalis* USNM 270235. http://n2t.net/ark:/65665/37727ea0e-0888-4ba3-94bc-727585aa36a5.

Strauss, B. and R. Biedermann, R. 2006. Urban brownfields as temporary habitats: driving forces for the diversity of phytophagous insects. Ecography, 29: 928-940.

Tauzer, E., & S.T.A. Pickett. 2009. The Phytogeography of Vacant Lots in Baltimore, MD, USA: a Test of Island Biogeography. https://www.academia.edu/2476979/THE_PHYTOGEOGRAPHY_OF_VACANT_LOTS_IN_BALTIMORE_MD_USA_A_TEST_OF_ISLAND_BIOGEOGRAPHY

Thomas, M. A. 2019. 3 varieties of bats added to Pa. endangered species list. Tribune Review. https://triblive.com/local/regional/14560278-74/3-new-varieties-of-bats-added-to-state-endangered-species-list.

Veilleux, J. P., Whitaker, J. O., and S.L. Veilleux. 2003. Tree-Roosting Ecology of Reprodctive Female Eastern Pipistrelles, *Pipistrellus subflavus*, in Indiana. Journal of Mammalogy, 84(3): 1068–1075.

Walters, B. L., Ritzi, C. M., Sparks, D. W., and J.O. Whitaker, J. O. 2007. Foraging Behavior of Eastern Red Bats (*Lasiurus Borealis*) at an Urban-rural Interface. The American Midland Naturalist, 157(2): 365–373.

Wolch, J. R., Byrne, J., and J.P. Newell. 2014. Urban green space, public health, and environmental justice: The challenge of making cities “just green enough.” Landscape and Urban Planning, 125: 234–244.

Tables and Figures

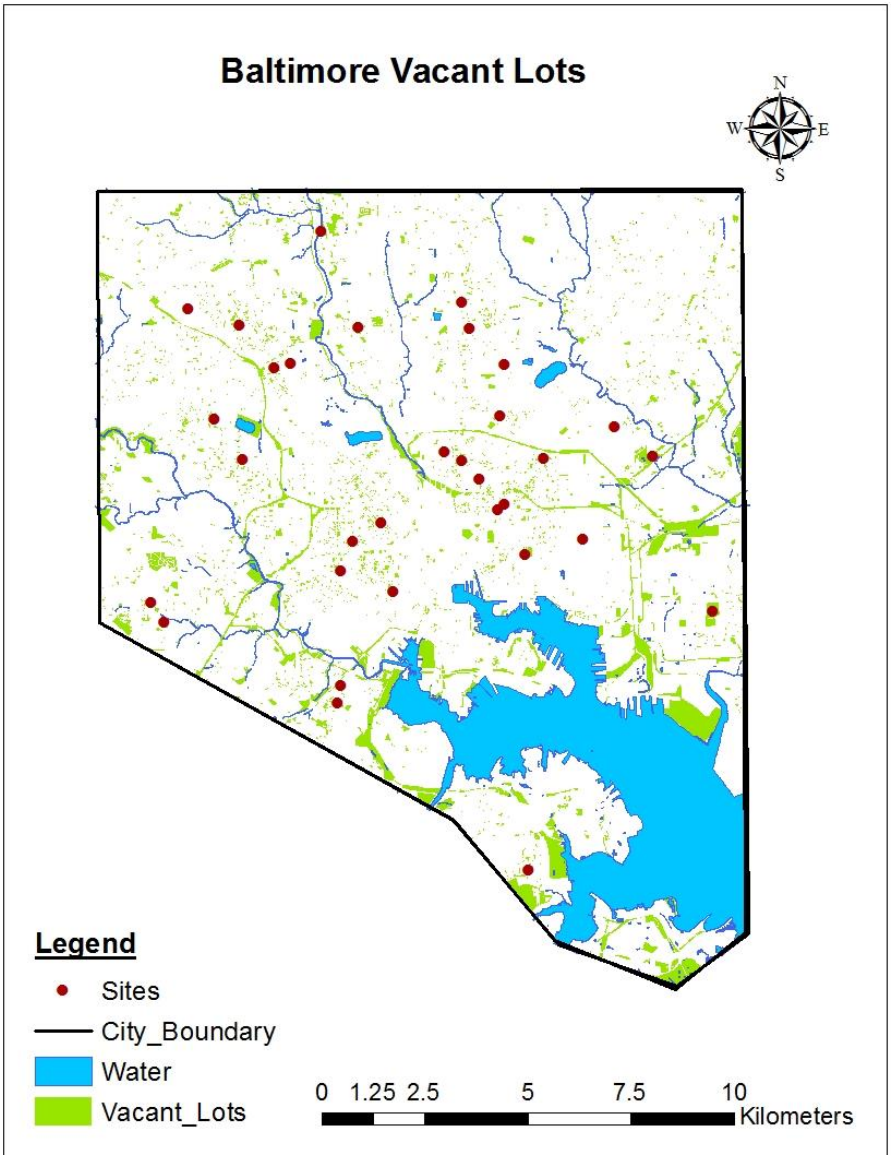


Figure 1. Site locations and vacant lots of Baltimore City, Maryland.

Figure 2. Placement of an Anabat Express detector at a vacant lot in southeast Baltimore. It was approximately 2-3 m above ground, with the microphone pointed towards open air. A sign was attached to the detectors to let local residents know what the device was (and was not) being used for, in addition to contact information.

Table 1. Environmental Variables and abbreviated code used in models.

Variable	Abbreviation
% canopy cover at site	ccsite
canopy height at site (m)	canopyH
Number of streetlights present around site	lights
Ground cover height (cm)	gr_cov
Distance from closest water body (m)	water
distance from city center (km)	citycent
Canopy cover area within 500 m radius (ha)	CC500
% of area within 500 m radius that is greenspace landcover	grsp500
Mean road density within 500 m radius (/ha)	road
Mean vacant building density within 500 m radius (/ha)	VBD

Table 2. Hourly detection rates for each species at each site.

Site	***E. fuscus***	***L. borealis***	***L. cinereus***	***L. noctivagans***	***N. humeralis***	***P. subflavus***
EAST	1.21	0.07	0.00	0.02	0.00	0.00
KENT	15.32	0.10	0.00	0.01	0.34	0.00
RADN	17.31	0.10	0.00	0.00	0.18	0.00
SHAN	5.66	0.40	0.00	0.08	0.14	0.05
DERB	28.48	0.67	0.15	0.04	0.15	0.00
DUPO	6.92	0.00	0.03	0.03	0.03	0.00
ROLA	0.04	1.03	0.00	0.00	0.00	0.00
TIPP	6.95	0.00	0.00	0.00	0.00	0.00
CHUR	10.07	1.31	0.01	0.04	0.12	0.00
MADI	22.56	0.09	0.00	0.29	0.03	0.00
ODON	6.42	0.14	0.02	0.13	0.04	0.00
WOLF	2.22	0.49	0.02	0.00	0.01	0.00
EDMO	16.12	0.11	0.00	0.04	0.05	0.00
HOLL	2.81	0.16	0.01	0.24	0.97	0.00
PARK	17.95	0.19	0.02	0.26	0.14	0.00
VINC	10.32	0.00	0.01	0.04	0.02	0.00

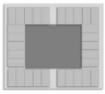
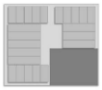
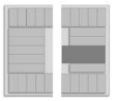
Site	*E. fuscus*	*L. borealis*	*L. cinereus*	*L. noctivagans*	*N. humeralis*	*P. subflavus*
ELLA	7.04	0.20	0.01	0.01	0.22	0.00
GRAN	7.83	1.52	0.00	0.01	1.64	0.00
KEYW	34.30	0.29	0.02	0.02	0.03	0.00
MATT	11.41	1.87	0.01	0.00	0.09	0.00
CHES	0.15	0.00	0.00	0.04	0.00	0.00
EFOR	9.15	0.10	0.00	0.00	0.01	0.00
HOME	0.97	0.07	0.00	0.04	0.11	0.00
NPAT	0.69	0.05	0.00	0.06	0.01	0.00
BOND	6.30	0.13	0.02	0.18	0.07	0.00
ENHO	1.90	0.22	0.02	0.41	0.02	0.00
NCAL	7.43	0.63	0.01	0.00	0.19	0.00
ORLE	4.02	0.06	0.00	0.07	0.02	0.00
OTTE	1.23	0.03	0.03	0.06	0.01	0.00
PIER	15.73	3.06	0.04	0.09	1.22	0.00
SWIC	14.44	0.64	0.07	0.51	0.26	0.00
WLAN	0.80	0.30	0.06	0.06	0.11	0.00

Table 3. Detection probability of species at sites.

Site	*E. fuscus*	*L. borealis*	*L. cinereus*	*L. noctivagans*	*N. humeralis*	*P. tricolor*
DUPO	0.98	0.00	0.00	0.00	0.00	-
TIPP	0.99	0.01	0.00	-	-	-
DERB	0.88	0.02	0.00	0.00	0.05	-
ROLA	0.37	0.53	-	-	-	-
EDMO	0.94	0.01	-	0.00	0.00	-
VINC	0.95	-	0.00	0.00	0.00	-
HOLL	0.63	0.04	0.00	0.06	0.22	-
PARK	0.93	0.01	0.00	0.02	0.01	-
RADN	0.97	0.01	-	-	0.01	-
SHAN	0.84	0.06	-	0.01	0.02	0.01
EAST	0.91	0.05	-	0.02	-	-
KENT	0.96	0.01	-	0.00	0.02	-
CHUR	0.83	0.11	0.00	0.00	0.01	-
MADI	0.93	0.00	-	0.01	0.00	-

Site	*E. fuscus*	*L. borealis*	*L. cinereus*	*L. noctivagans*	*N. humeralis*	*P. tricolor*
ODON	0.93	0.02	0.00	0.02	0.01	-
WOLF	0.73	0.17	0.01	-	0.00	-
ELLA	0.90	0.03	0.00	0.00	0.03	-
GRAN	0.70	0.14	-	0.00	0.15	-
KEYW	0.98	0.01	0.00	0.00	0.00	-
MATT	0.84	0.14	0.00	-	0.01	0.00
CHES	0.65	-	-	0.17	-	-
EFOR	0.95	0.01	-	-	0.00	-
HOME	0.62	0.20	-	0.02	0.07	-
NPAT	0.77	0.06	-	0.07	0.01	-
BOND	0.92	0.02	0.00	0.03	0.01	-
ENHO	0.68	0.08	0.01	0.15	0.01	-
NCAL	0.88	0.07	0.00	-	0.02	-
ORLE	0.95	0.01	-	0.02	0.00	-
OTTE	0.84	0.01	0.02	0.04	0.01	-
PIER	0.75	0.15	0.00	0.00	0.06	-
SWIC	0.90	0.04	0.00	0.03	0.00	-
WLAN	0.57	0.22	0.04	0.04	0.08	-

Table 4. Characteristics of Vacant Lot Sites. Dark grey indicates the lot and light grey indicates surrounding housing. Illustrations are included with permission from C. Rega-Brodsky.

Site	Vacant block (VB) 	Inner block (IB) 	Corner Lot (CL) 	Missing tooth (MT) 	Suburban yard (SY) 	Wayside (W) 
DUPO	x					
TIPP		x				
DERB		x				
ROLA				x		
EDMO		x				
VINC		x				
HOLL	x					
PARK	x					
RADN				x		
SHAN	x					
EAST	x					
KENT		x				
CHUR	x					
MADI	x					
ODON	x					
WOLF		x				
ELLA				x		
GRAN			x			
KEYW			x			
MATT	x					
CHES			x			
EFOR					x	
HOME			x			
NPAT	x					
BOND			x			
ENHO	x					
NCAL	x					
ORLE			x			
OTTE		x				
PIER	x					

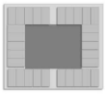
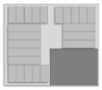
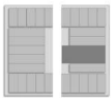
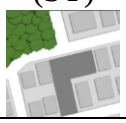
Site	Vacant block (VB)	Inner block (IB)	Corner Lot (CL)	Missing tooth (MT)	Suburban yard (SY)	Wayside (W)
						
SWIC	x					
WLAN	x					
Total	**15**	**7**	**6**	**3**	**1**	**0**

Table 5. Basic statistics of vegetation variables. Measurements for these variables are mentioned in Table 1.

	Mean	**Standard deviation**	**Minimum**	**Maximum**
ccsite	46.8	20.8	6.2	96.7
canopyH	19.9	5.8	11.5	36
lights	5	3.5	0	14
gr_cov	23.3	18.0	4	65
water	0.8	0.5	0.02	2.4
citycent	4.4	2.3	1.06	8.8
CC500	59.4	113.3	3.2	598.0
VBD	2.2	2.4	0.006	8.6
road	2.3	0.6	1.1	3.4
grsp500	8.3	10.6	0	36.1

Table 6. Percent land use composition of sites within a 500-meter radius. LDR = Low Density Housing, MDR = Medium Density Residential, HDR = High Density residential, Green space = deciduous forest, mixed forest, brush, and open urban land, Other urban = commercial, industrial, and institution, Transp. = transportation.

	LDR	**MDR**	**HDR**	**Other Urban**	**Green space**	**Bare ground**	**Transp.**
DUPO	0.0	5.9	73.5	15.8	2.2	0.0	2.6
TIPP	0.0	2.9	56.0	37.5	0.0	0.0	3.6
DERB	0.0	6.1	52.2	17.1	19.5	3.7	1.5
ROLA	10.5	22.0	50.6	12.2	0.5	0.0	4.2
ELLA	0.0	18.0	61.2	10.7	5.9	0.0	4.2
GRAN	0.0	75.5	21.9	1.3	0.2	0.0	1.2
KEYW	0.0	0.0	79.1	11.8	2.5	0.0	6.6
MATT	15.4	17.3	12.1	22.3	19.4	0.0	13.5
EDMO	0.0	0.0	69.9	16.0	0.0	0.0	14.1
VINC	0.0	0.0	82.4	14.8	1.9	0.0	0.9
HOLL	0.0	0.0	44.0	41.9	14.1	0.0	0.0
PARK	0.0	13.1	66.2	10.1	10.6	0.0	0.0
OTTE	0.0	0.0	56.7	34.0	1.9	0.0	7.3
PIER	0.0	12.3	43.7	28.0	16.0	0.0	0.0
SWIC	0.0	16.2	43.6	24.8	15.4	0.0	0.0
WLAN	0.0	0.0	91.8	8.0	0.0	0.0	0.2
RADN	0.0	44.7	39.0	16.3	0.0	0.0	0.0
SHAN	0.0	0.0	16.4	33.7	36.1	13.8	0.0
EAST	0.0	0.0	67.7	12.2	17.8	0.0	2.3
KENT	0.0	1.2	88.2	6.2	2.7	0.0	1.7
CHES	0.0	12.4	62.8	20.3	0.0	0.0	4.5
EFOR	0.0	13.3	71.8	14.9	0.0	0.0	0.0
HOME	0.0	0.0	59.9	38.5	0.3	0.0	1.3
NPAT	0.0	0.0	50.0	37.1	12.3	0.0	0.6
CHUR	0.0	2.3	40.5	32.0	25.2	0.0	0.0
MADI	0.0	0.0	86.8	11.1	0.0	0.0	2.2
ODON	0.0	11.0	51.8	11.7	22.6	0.0	2.9
WOLF	0.0	0.0	64.7	33.8	0.0	0.0	1.5
BOND	0.0	0.0	91.7	5.5	0.0	0.0	2.8
ENHO	0.0	0.0	56.4	9.6	33.2	0.0	0.9
NCAL	0.0	0.0	53.8	44.3	0.0	0.0	1.9
ORLE	0.0	0.0	80.8	12.6	5.2	0.0	1.4

Table 7. Correlation matrix of environmental variables.

	cc site	**canopy H**	**lights**	**gr cov**	**water**	**city cent**	**CC 500**	**VBD**	**road**
canopyH	0.25	x	x	x	x	x	x	x	x
lights	-0.61	-0.14	x	x	x	x	x	x	x
gr_cov	0.66	0.02	-0.24	x	x	x	x	x	x
water	-0.36	0.003	0.15	0.005	x	x	x	x	x
citycent	0.44	0.15	-0.40	0.093	-0.31	x	x	x	x
CC500	0.33	0.49	-0.18	0.09	-0.37	0.38	x	x	x
VBD	-0.42	-0.19	0.36	-0.05	0.70	-0.50	-0.32	x	x
road	-0.47	-0.15	0.51	-0.10	0.59	-0.68	-0.43	0.70	x
grsp500	0.23	-0.13	-0.32	0.020	-0.46	0.25	0.20	-0.18	-0.59

Table 8. Principle component loadings and eigenvalues for PCA biplot, bold text indicating which variables had the strongest loadings for each component.

Variable	PC 1	PC 2
Site canopy cover	**0.6909**	0.1942
Site canopy height	0.2899	**0.8177**
Streetlights	**-0.6294**	-0.0768
Ground cover height	0.1511	0.1697
Distance from water	**-0.6935**	0.3519
Distance from city center	**0.7224**	0.0477
Canopy cover present within 500m	**0.5874**	0.4489
Vacant Building Density	**-0.7735**	0.0674
Road Density	**-0.8991**	0.1806
Greenspace landcover within 500 m	**0.5343**	*-0.533*
Eigenvalue	4.02	1.39
% Variance	40.204	13.899
Sum variance	40.204	54.103

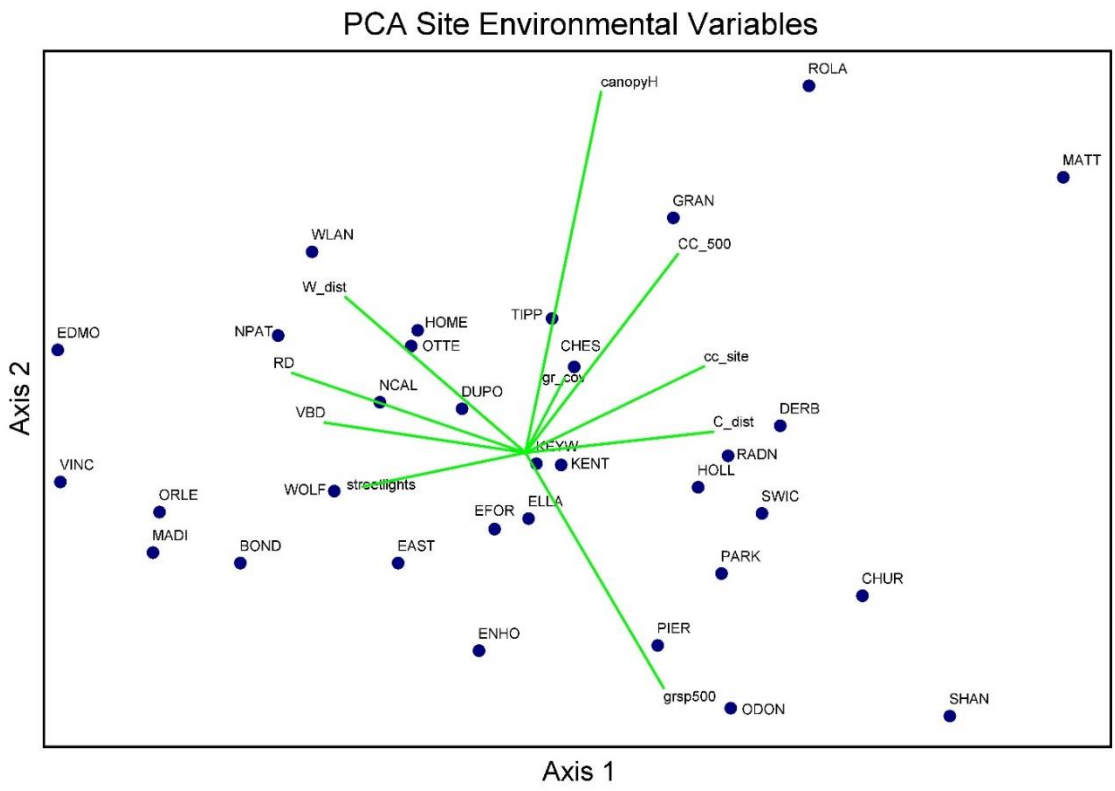


Figure 3. Principle Component Analysis of sites depicting similarity of sites based on the environmental variables in and around them.

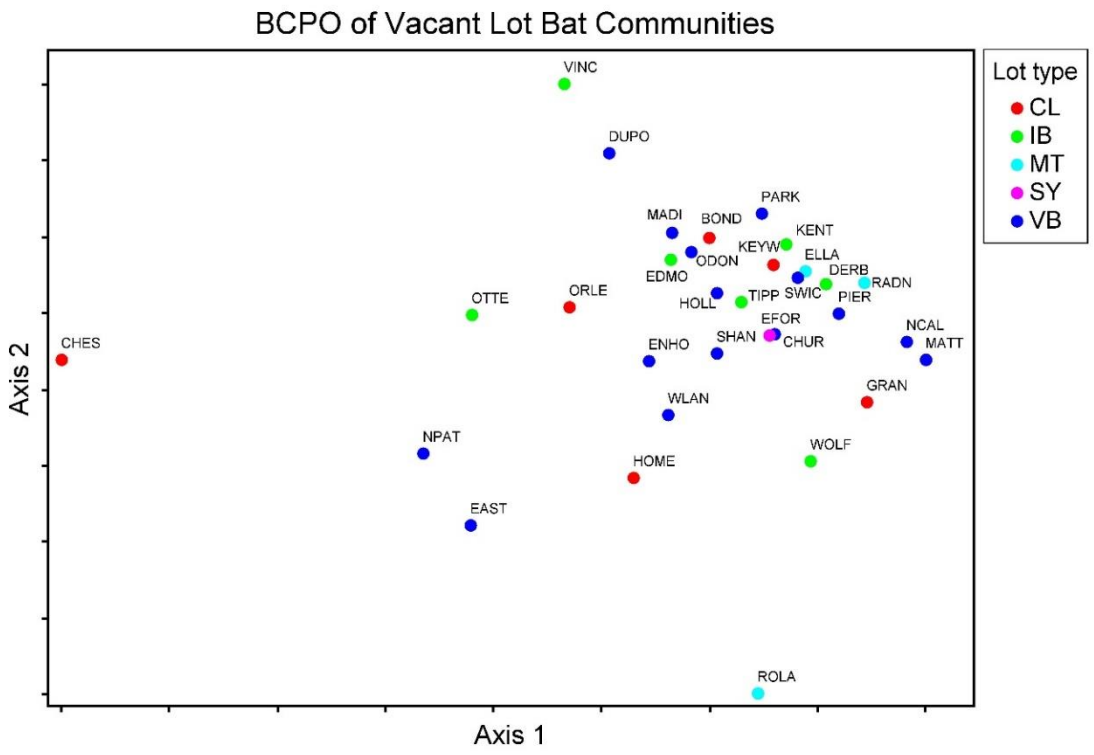


Figure 4. Bray Curtis Polar Ordination of sites depicting similarity based on bat community present. Colors indicate vacant lot setting. The first axis separated sites by those with high amounts of big brown, red, and evening bat detections. The second axis further separated sites by those with high amounts of big brown bat detections.

Table 9. Correlation table of variables and species with BCPO axes. The presence of correlations between species and variables on the same axis were used to create preliminary candidate models.

	Axis 1	**Axis 2**
E. fuscus	**0.699**	**0.62**
L. borealis	**0.741**	-0.397
L. cinereus	0.246	0.268
L. noctivagans	-0.247	0.319
N. humeralis	**0.564**	0.223
ccsite	0.178	-0.256
canopyH	0.042	**-0.545**
streetlights	-0.191	0.254
grcov	-0.059	-0.121
water	-0.353	-0.038
citycent	0.339	0.186
CC_500	0.321	-0.24
VBD	-0.305	0.228
road	-0.386	0.085
grsp500	0.087	-0.035

Table 10. Candidate models for species richness.

	K	**AICc**	**Delta AICc**	**AICc Wt**	**Cum. Wt**	**LL**
Null	3	119.16	0	0.97	0.97	-56.15
Urban	6	127.09	7.93	0.02	0.99	-55.87
Site scale	7	129.2	10.04	0.01	1	-55.27
Neighborhood scale	8	131.75	12.59	0	1	-54.74
Neighborhood + Site scale	11	144.16	25	0	1	-54.48

Table 11. Candidate models for *E. fuscus*.

	K	AICc	Delta AICc	AICc Wt	Cum. Wt	LL
Neighborhood + Site Scale	12	12095.55	0	1	1	-6027.56
Urban	6	18725.91	6630.36	0	1	-9355.27
Neighborhood	8	15577.89	3482.35	0	1	-7777.82
Site scale	7	15880.15	3784.6	0	1	-7930.74
Ordination (ccsite*canopy + CC500*grsp500 + citycent + lights + VBD)	12	13605.15	1509.6	0	1	-6782.36
Null	3	19692.73	7597.18	0	1	-9842.94

Table 1. Candidate models for *L. borealis*.

	K	AICc	Delta AICc	AICc Wt	Cum. Wt	LL
Ordination (CC500+citycent + road density)	8	931.12	0	1	1	-454.43
Neighborhood + site scale	11	1091.38	160.27	0	1	-528.09
Urban	6	1284.54	353.43	0	1	-634.59
Neighborhood scale	8	1367.64	436.52	0	1	-672.69
Site scale	7	1547.72	616.6	0	1	-764.53
Null	3	1970.86	1039.75	0	1	-982

Table 13. Candidate models for *N. humeralis*.

	K	AICc	Delta AICc	AICc Wt	Cum. Wt	LL
Neighborhood + site scale	11	594.23	0	1	1	-279.52
Ordination (CC500*grsp500 + citycent + road)	8	749.59	155.36	0	1	-363.67
Neighborhood scale	8	869.9	275.67	0	1	-423.82
Urban	6	1273.47	697.12	0	1	-629.06
Site scale	7	1318.66	724.42	0	1	-649.99
Null	3	1489.97	895.74	0	1	-741.56

Table 14. Coefficients and P values for predictors in top model for species richness and individual species. Parentheses indicate P value. Asterisks indicate interaction effects.

	E. fuscus	***L. borealis***	***N. humeralis***
ccsite* canopyH	-0.263 (<0.01)		1.037 (<0.01)
CC500 *grsp500	0.120 (<0.01)	-0.323 (<0.01)	1.364 (<0.01)
citycent	0.047 (<0.01)	-0.619 (<0.01)	-0.447 (<0.01)
lights	0.030 (<0.01)		-1.528 (<0.01)
road		-1.639 (<0.01)	
water	-0.429 (<0.01)		-2.005 (<0.01)
ccsite	-0.189 (<0.01)		0.171 (0.21)
canopyH	-0.387 (<0.01)		0.281 (<0.01)
CC500	0.114 (<0.01)	0.214 (<0.01)	-2.165 (<0.01)
grsp500	-0.315 (<0.01)	-0.310 (<0.01)	-0.176 (0.08)

Chapter 3: Socioeconomic predictors of bat abundance in vacant lots

"Cities are the product of thousands of individual and collective decisions, made in the context of larger social and economic cycles, environmental limitations and possibilities, and politics." Boone et al 2009

Abstract

Measures of race, wealth, education, family structure, and neighborhood condition may provide additional explanations for patterns and distribution of urban biodiversity in addition to traditional environmental measures. As part of my ongoing research into predictors of bat activity and species richness in Baltimore, I wanted to determine if these type of measures were present and if so, how might they be associated with vacant lots that had more species present or were sites of high activity. During the summers of 2017 and 2018, I used passive acoustic monitoring to record bat activity at 32 sites for nine nights each. Socioeconomic measures were obtained for census tracts where sites were located, using information from the most recent census, and 1940's Home Owners Loan Corporation map. Both *a priori* and Bray-Curtis Polar ordination-based models were created for species richness and activity at these sites. Linear mixed modeling was used in R to discover potential predictors of species richness and bat activity levels. Over 33,000 bat sequences were recorded. Six species were present, with most activity coming from big brown bats (*Eptesicus fuscus*). While there were no models for species richness that were better than the null model, a common predictor in

the top models for individual species was income. Additional predictors for individual species included Black residents, vacant housing and older housing, suggesting that the bat community is shaped not just by income and race, but also neighborhood structure.

Introduction

In some urban ecology studies, socioeconomic variables are included in analyses in addition to environmental variables. Socioeconomic factors (e.g., income, education level, cultural values, and institutional power) help uncover the ways and extent to which residents shape their surroundings, which in turn can drive biodiversity. Socioeconomic variables can influence biodiversity in either a bottom up (individual household choices that reflect cultural, social or economic ability) or top-down (city government level decisions and management) manner (Kinzig et al 2005). The impact of socioeconomic variables on biodiversity depends on the city, the type of habitat and taxa being investigated.

Two primary socioeconomic variables that are investigated are income and race. Vegetation preferences at the yard and neighborhood scale can vary by race and overall distributions of street trees and forests can be associated with race as well (Nilon 2014, Watkins and Gerrish 2018). The luxury effect, a relationship between income and biodiversity, has been documented in urban vegetation studies (Hope et al 2003,Gerrish and Watkins 2018, Leong et al 2018, Zivanovik et al 2016), though sometimes this

relationship is not seen (Zivanovik et al 2016, Nilon 2014). Residents can be influenced by fellow neighbors to maintain their landscapes in a similar conforming way, referred to as the ecology of prestige (Boone et al 2009b). Alternatively, residential greenspaces may be heterogeneous and unaffected by such an effect (Richard et al 1974).

A variety of socioeconomic variables can be used to represent measures of race, wealth, education, family structure, and social structure (Maloney and Auffrey 2013, Nilon 2014). Education level can be used as a measure of knowledge, which can affect how residents manage their yards. (Nilon 2014). The age of a neighborhood, often measured using median housing age or median year built, has been associated with surrounding tree cover as well (Roman et al 2018).

While studies that look into socioeconomic variables focus on information obtained from the most recent census data, it is important to note that legacy effects from prior decades can also shape current socioeconomic patterns in an urban landscape (Boone et al 2009, Roman et al 2018). Historical events or actions in cities will have an impact on current processes (Roman et al 2018). In Baltimore, the current demographic distribution of residents has been shaped by past segregation ordinances in the 1910's, designation of minority neighborhoods as hazardous by Home Owner Loan Corporation (HOLC) in the 1940s (Figure 1), and the practice of racist housing covenants in white neighborhoods, and later desegregation and "white flight". The same neighborhood associations that encouraged use of covenants restricting house sales to non-whites also had significant power to request (and receive) city street tree plantings and expansions of parks in their neighborhoods (Boone et al 2009), likely shaping the distribution of natural

amenities, and thus, urban habitat. A study by Boone et al (2009b) found that the demographics of residents from the 1960s was one of the best predictors of vegetation and tree coverage in the 1990s. Legacy effects have been documented in other locations as well: neighborhoods in Tlokwe, South Africa had distinct plant communities that were associated with the cultural group that resided in those areas during apartheid (Lubbe et al 2010). Thus, current species present in an area may actually be a result of the preferences and actions of previous residents.

In Baltimore, studies have been done looking at both legacy effects (Grove et al 2018) and more recent socioeconomic drivers of biodiversity and abundance (European starlings: Denison 2010, mosquitoes: LaDeau et al 2013, vegetation: Boone et al 2009b). Rega-Brodsky (2016) also investigated socioeconomic variables associated with abundance and distribution of vacant lots as a potential environmental justice issue. Very few studies have looked at the role of socioeconomics plays in the distribution and composition of an urban bat community. Li and Wilkins (2014) study of bats in Waco revealed an association was between tree-roosting bat species and income levels, but not with cave/building- dwelling bats.

The purpose of this chapter is to determine if socioeconomic measures of vacant lots' surroundings can be used to predict species richness and bat activity levels. Because previous studies have documented income as an important factor for other taxa, I hypothesized that vacant lots located in higher income block groups would have more species and activity detected. Demographic and family structure measures (Black residents, high-school educated residents, and female-led households with children) are

often also associated with income (usually negatively correlated), and so I hypothesized that an inverse pattern would be seen with these socioeconomic measures. I also hypothesized that the neighborhood structure (also referred to as social status) would play a role; areas with more vacant homes and rental homes would have less management of vegetation both locally and from the city government, and would have more activity from bat species that prefer open-space foraging. Older neighborhoods would have more mature trees (and thus more canopy cover) present which would have more foliage-roosting and canopy-associated bat species' activity.

Methods

Study area

Baltimore City is located in central Maryland and straddles the Piedmont and Coastal Plain regions. It is part of the Chesapeake Bay watershed and three smaller watersheds run through the city: Gwynns Falls, Jones Falls, and Herring Run. Before colonization and city establishment in 1729, the land was temperature deciduous forest. Baltimore currently has a population of over 600,000, a 34% decline since the 1950s (Rega-Brodsky et al 2018). Vacant lots comprise 7% of the city's land.

Socioeconomic measures

I obtained socioeconomic variables from 2010 Census block group data, 2017 American Community Survey Census estimates, City of Baltimore's Open Data website,

and an online database containing HOLC maps of cities during the 1940s (USCB 2019, COB 2018, Nelson et al 2019). I selected socioeconomic variables based on the five indicators used to create a socioeconomic status index in Maloney and Auffrey (2013) and categories of social drivers reviewed by Nilon (2014). These included measures of race (African American residents and RDI (racial diversity index)), wealth (median household income), education/knowledge (residents with high school education as their maximum level of education), family structure (female-only householders with children), and neighborhood structure (rental housing, vacant housing, housing built before 1939, and 1940's HOLC rating) (Table 1). Because census block groups can vary in size, population, and amount of housing present, the demographic and housing variables were converted from raw numbers to the percentage using either the total population or the total amount of housing present in a given block group.

Data for most socioeconomic variables were obtained at the census block group scale (Figure 2) and were converted from numbers to percentage of the census block group, as block groups vary in population, housing units present, and size. Data for the HOLC ratings and RDI (probability that two randomly selected residents in a neighborhood will be different races) was only available at a broader, neighborhood scale (usually consisting of several census tracts, Figures 1 and 3).

Site selection

I used stratified random sampling to select sites evenly distributed throughout the city. After dividing the city into four regions (northwest, southwest, northeast, and

southeast), four sites were randomly selected within each region each year. After random selection, sites were viewed using Google Earth and/or visited in person to ensure that there was at least one suitable tree present to attach the bat detector to, and enough open space to ensure calls recorded would be optimal quality. During the second year of the study, property status of sites were reviewed to ensure sites were city-owned. Sites were also checked in ArcMap to ensure they were a minimum of 500 m from nearby sites. If a randomly selected site didn't have these qualifications, then it was not used and another site was randomly selected.

Acoustic monitoring and sequence identification

From May-August of 2017 and 2018, passive acoustic monitoring was conducted at 32 sites for nine nights, for a total of 288 nights. An Anabat Express bat detector was secured to a tree 2-3 m above the ground, with the microphone directed towards open space (Figure 2). The detector was set to "night mode" and a sensitivity level of seven out of nine to ensure calls would be detected, while also limiting additional urban noises (vehicles, wind, rain, insects, etc.) from being recorded. The detector then recorded bat activity from sunset to sunrise for three consecutive nights (one recording session). All sites within one region were recorded simultaneously.

On the fourth day, I retrieved the detectors and downloaded the sequences onto a laptop. I manually identified bat sequences to species level using AnalookW software (Corben 2017). Sequences with less than four calls were not included. Sequences that could not be identified to species level were counted and categorized based on kHz

frequency level (Q25, Q35, and Q40), but were not included in analysis. I calculated an hourly detection rate for each species at each site using the total number of sequences recorded (see Appendix 2) and the total number of recording hours.

Analysis

I used Principal Component Analysis (PCA) to depict site similarity based on socioeconomic variables using PC-ORD software (McCune and Mefford 2016). PCA also allowed me to see variable correlation so that I could avoid multicollinearity in models. Components (axes) with eigenvalues ≥ 1 were retained and variables with loadings ≥ 0.5 and ≤ -0.5 were considered strong loadings within each principal component. A correlation matrix of these variables was also created to determine which were highly correlated with each other so that they would not be included in the same model.

Using this same software, I used Bray-Curtis Polar ordination (BCPO) with log-transformed bat species activity levels to visualize the similarity of bat communities at each site. This allowed me to determine the presence of a socioeconomic gradient that could be influencing the bat community. I also included socioeconomic data as a secondary matrix. By doing so, I could use the correlations of each species and each vegetation variable to an axis to generate preliminary hypotheses on which I can base my models (i.e., a species and variable (s) that have a strong correlation on one axis suggests that that species' detection may be associated with that variable). Candidate models were not created for species that did not have a strong correlation (≥ 0.5) with the first or

second axis. For my BCPO I log-transformed total number of detections for each species at each site and modified the landscape data with a general relativization to normalize and re-scale the data, as variables were measured on different scales.

Additional models included a luxury effect model (income only), residential structure (Black residents and RDI), a basic socioeconomic model (income and race), neighborhood structure (housing variables), and a model combining multiple socioeconomic measures (neighborhood and family structure, race, and income). I used generalized linear mixed effect models using the glmer function in R, with HOLC rating and year as random effects. Bat sequences were log transformed and income was scaled. I also compared HOLC ratings to individual species activity using boxplots in R.

Results

Bat recordings

Over 19,000 sequences were recorded in 2017 while over 14,000 were recorded in 2018 for a total of >33,000 sequences. Six species were recorded: *Eptesicus fuscus*, *Lasiurus borealis*, *L. cinereus*, *Lasionycteris noctivagans*, *Nycticeius humeralis*, and *Perimyotis subflavus*. The most commonly recorded bat species was the big brown bat *E. fuscus*, present at all sites and often comprising over 90% of sequences at many of these sites. The tricolor bat was the least recorded at only two sites with six sequences; it was removed from further analyses (Appendix 2).

Socioeconomic description of sites

The census block groups where sites were located reflected the socioeconomic variation of the city. There was noticeable variation in the median household income – $14,000 to $130,000 per year. On average 55% of housing around these sites were rentals, though there was extreme variation among block groups. The proportion of housing that was over 80 years old ranged from 4-77% of the sites' surroundings and was strongly correlated with percent of vacant housing. Sites were located in predominantly African-American neighborhoods, with only five sites being located in predominantly white areas (Table 2). The Racial Diversity Index (RDI) surrounding these sites varied from having almost no racial diversity (0.07) to being highly diverse (0.91). This measure was obtained from Baltimore City's website, and unlike the other socioeconomic variables was not measure at the block group scale but instead a broader, neighborhood scale (usually several census tracts).

Ordination analyses

The PCA consisted of three axes. The first axis explained 41% of the variation and had strong positive loadings for vacant housing, rental housing, high school graduates, female householder with children, and African-American residents, and strong negative loadings for median household income. This axis depicts separation of block groups with high amounts vacant housing that are home to low-income, high-school educated African-American residents in female-headed household with children residing in rental housing. The second axis explained 16% of the variation and had a strong

positive loading for housing built before 1939 and strong negative loading for racial diversity index. The second axis indicates older neighborhoods. The third axis explained 12 % of the variation and had strong negative loadings for racial diversity index and HOLC ratings, indicating separation of sites by more diverse areas that had relatively good historical ratings from HOLC (Figure 4). Percent Black residents, high school degree educated residents, and single-female headed households with children had a strong positive correlation with each other, as did vacant housing and older housing (Table 4); Black residents and older housing were retained for use in the models.

Because BCPO distributes sites by the bat community present, it has the same appearance as the BCPO used for environmental variables (see Chapter 2, Figure 4). Bray-Curtis Polar Ordination arranged sites primarily by the amount of big brown, red, and evening bat detections. For variable correlation, no socioeconomic variables were strongly correlated with the first axis (Table 5). The second axis had a weak positive correlation with female householders, and black residents and a weak negative correlation with income. Thus, no ordination-based models were created. *L. cinereus*, and *Lasionycteris noctivagans* were only correlated to a third (discarded) axis, so models were not created for these.

Legacy effects

Slightly less than half of sites were in located in neighborhoods that were historically rated by HOLC as declining (C), followed by neighborhoods rated as hazardous (D) and still desirable (B), with only one site located in a HOLC-categorized

“best” (A) neighborhood; several sites were located in areas that were never given a rating (Figure 5). Species activity levels in different rated neighborhoods varied as well. *E. fuscus* had consistently higher activity in neighborhoods that were once B rated and areas that had no rating; there was more variation in activity levels in neighborhood rated C and D (Figure 6). Activity levels of *L. cinereus* and *L. noctivagans* increased as neighborhood rating decreased (Figures 7 and 8), while it decreased for *N. humeralis*. (Figure 9). Activity varied for *L. borealis*. (Figure 10).

Socioeconomic Models

There were no significant models for species richness; the best candidate was the null model, followed closely by the income model (Table 6). For individual species activity, the combination models were best which incorporated income, housing, and residents (Tables 7 -9). There was more *E. fuscus* detections in census block groups that had more Black residents and less old and rental housing present. Vacant lots with more *L. borealis* detections were in block groups that had less Black residents, less older housing, more rental housing, and higher income. N. humeralis was detected more in vacant lots that had more Black residents, with higher income, in neighborhoods that had less old housing, more rentals, and were more diverse (Table 10).

Discussion

Although many socioeconomic studies of ecology focus solely on income and race, including additional variables helped uncover the more subtle complexity of neighborhoods in Baltimore. Bat activity was shaped by neighborhood structure, income, and race (which was also correlated to residential structure). Each of the three species analyzed had different relationships to these predictors, suggesting they are more active in different types of neighborhoods. *E. fuscus* was detected more in neighborhoods that had more Black residents, and less housing that was over 80 years old, vacant, or rented. This describes neighborhoods located between the inner city and periphery of the city, which are predominantly black and contain housing of an intermediate age that are still mostly owned and not rented.

L. borealis was detected more in neighborhoods that had less Black residents, higher income residents, less older and vacant housing but more rentals. This describes neighborhoods located in north and south central Baltimore that have more white residents with higher income that also have rental housing available. The top model for *N. humeralis* was very similar, but was instead detected more in neighborhoods with more Black residents but that were also more diverse. Neighborhoods like these would be adjacent to the predominantly white neighborhoods of central Baltimore.

Results supported my hypotheses regarding income and housing age. Income results may be skewed however, as only two sites were located in areas where median income was above $90,000 and most sites were located in low income areas. Baltimore

City's map of vacant lots sites included lots in high-income areas (COB 2017) but these lots were privately owned and managed by surrounding neighborhood associations so they were not included in the study. I hypothesized that housing age in neighborhoods could possibly be associated with age of street trees in those areas; on the other hand, it may be possible that older areas may *not* have trees present, as street trees tend not to have long lifespans. A study on tree mortality (Nowak et al 2004) found on average street trees have a life span of 15- 30 years, though this depended on the species, surrounding landcover, and diameter.

Results were similar to those seen in other socioeconomic studies in Baltimore. . Percent Black residents and amount of older housing were two other common predictors of bat activity which were also predictors of European starling abundance in a study also conducted in Baltimore (Denison 2010). Rega-Brodsky (2016) noted that neighborhoods that were mostly black and had high amounts of female-headed households with children tended to contain vacant lots with fewer, smaller trees (many of which were the same ones used for this study). Rega-Brodsky (2016) found neighborhoods that had more owned homes (and thus fewer rental homes) tended to have vacant lots with larger (perhaps older) trees.

There were no socioeconomic predictors for bat species richness; the same result was seen for bird species richness in Rega-Brodsky (2016). A tally of the total number of species observed in an area may not be the most effective measure for volant taxa; their presence in and around a vacant lot doesn't indicate use, and in some cases may be documentation of individuals simply passing by lots as they travel other habitat (Denison

2010). This was noticeable in the summary of species calls at each site (Appendix 2) where some bat species were recorded only once or twice at a site.

Detections of species based on the area's past HOLC rating varied; there appeared to be a positive association with *N. humeralis* and good ratings, whereas a negative association was seen for *L. cinereus,* and *L. noctivagans*, and mixed results were seen for *E. fuscus L. borealis*. These results are likely skewed, as vacant lot sites were predominantly located in areas that were once rating as declining or hazardous, providing little data on vacant lots that had historically good or desirable ratings.

These lending risk ratings given by HOLC were based on housing age, condition, and residential race, immigration status, and occupation. This led to a pattern of disinvestment in those neighborhoods (Grove et al 2015, Brown 2016), which resulted in more vacant housing and less street trees and canopy cover in these areas (Grove et al 2018). While this one measure of legacy effect was included as a random effect, additional quantifiable measure of legacy effects (e.g. census variables from 1940s when HOLC ratings were being used) may have documented a stronger legacy effect on current species' detections.

Literature Cited

Boone, C. G., Buckley, G. L., Grove, J. M., and C. Sister. 2009. Parks and people: An environmental justice inquiry in Baltimore, Maryland. Annals of the Association of American Geographers, 99(4): 767–787.

Boone, C. G., Cadenasso, M. L., Grove, J. M., Schwarz, K., and G.L. Buckley. 2010. Landscape, vegetation characteristics, and group identity in an urban and suburban watershed: why the 60s matter. Urban Ecosystems, 13: 255–271.

Brown, L. 2016. Two Baltimores: The White L versus the Black Butterfly. *City Paper*. http://www.citypaper.com/bcpnews-two-baltimores-the-white-l-vs-the-black-butterfly-20160628-htmlstory.html.

City of Baltimore (COB). 2018. Open Baltimore Database. https://data.baltimorecity.gov/

Corben, C. 2018. AnalookW for Bat Call Analysis Using ZCA, Version 4.3I. http://users.lmi.net/corben/Beta/AnalookW.zip

Davis, A. Y., Belaire, J. A., Farfan, M. A., Milz, D., Sweeney, E. R., Loss, S. R., and E.S. Minor. 2012. Green infrastructure and bird diversity across an urban socioeconomic gradient. Ecosphere, 3(11): 1–18.

Denison, C. 2010. Effects of Socioeconomics on European Starlings (*Sturnus vulgaris*) abundance in Baltimore, Maryland. Thesis.

Gerrish, E., and S.L. Watkins, S. L. 2018. The relationship between urban forests and income: A meta-analysis. Landscape and Urban Planning, 170: 293–308.

Grove, M., Ogden, L., Pickett, S., Boone, C., Buckley, G., Locke, D. H., Lord, C., and B. Hall. 2018. The Legacy Effect: Understanding How Segregation and Environmental Injustice Unfold over Time in Baltimore. Annals of the American Association of Geographers, 108(2): 524–527.

Grove, M., Cadenasso, M., Pickett, S.T.A., Machlis, G., and W. Burch Jr. 2015. The Baltimore School of Urban Ecology: Space, Scale and Time for the Study of Cities. New Haven: Yale University Press. 217 pp.

Hope, D., Gries, C., Zhu, W., Fagan, W. F., Redman, C. L., Grimm, N. B., Nelson, A.L., Martin, C., and A. Kinzig. 2003. Socioeconomics drive urban plant diversity. PNAS, 100(15): 8788–8792.

Kinzig, A. P., Warren, P., Martin, C., Hope, D., and M. Katti, M. 2005. The Effects of Human Socioeconomic Status and Cultural Characteristics on Urban Patterns of Biodiversity. Ecology and Society, 10(1): 23.

LaDeau, S. L., Leisnham, P. T., Biehler, D., and D. Bodner. 2013. Higher mosquito production in low-income neighborhoods of Baltimore and Washington, DC: Understanding ecological drivers and mosquito-borne disease risk in temperate cities. International Journal of Environmental Research and Public Health, 10(4): 1505–1526.

Leong, M., Dunn, R. R., and M.D. Trautwein. 2018. Biodiversity and socioeconomics in the city: a review of the luxury effect. Biology Letters, 14: 1–6.

Lerman, S. B., and P.S. Warren, P. S. 2011. The conservation value of residential yards: Linking birds and people. Ecological Applications, 21(4): 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.

Lubbe, C. S., Siebert, S. J., and S.S. Cilliers. 2010. Political legacy of South Africa affects the plant diversity patterns of urban domestic gardens along a socio-economic gradient. Scientific Research and Essays, 5(19): 2900–2910.

Maloney, M., and C. Auffrey. 2013. The Social Areas of Cincinnati: An Analysis of Social Needs. www.socialareasofcincinnati.org.

Nelson, R. K., Winling, L., Marciano, R., and N. Connolly. 2019. Mapping Inequality: Redlining in New Deal America. https://dsl.richmond.edu/panorama/redlining/#loc=11/39.2599/-76.6406&opacity=0.8&city=baltimore-md.

Nilon, C. H. 2014. The Urban System: Social Drivers. In McCleery, R., Moorman, C., and Peterson, M.N. [eds.]. Urban Wildlife Conservation: Theory and Practice. New York: Springer. 406 pp.

Nowak, D. J., Kuroda, M., and D.E. Crane. 2004. Tree mortality rates and tree population projections in Baltimore, Maryland, USA. Urban Forestry and Urban Greening, 2: 139–147.

Rega-Brodsky, C. C. 2016. Urban Vacant Lots: Ecological Quality and Social Opportunities in Baltimore, Maryland. Dissertation.

Roman, L. A., Pearsall, H., Eisenman, T. S., Conway, T. M., Fahey, R. T., Landry, S, Vogt, J., van Doorn, N.S., Grove, J. M., Locke, D. H., Bardekjian, A.C., Battles, J.J., Cadenasso, M. L., Konijnendijk van den Bosch, C.C., Avolio, M., Berland, A., Jenerette, G. D., Mincey, S. K., Pataki, D. E., and C. Staudhammer. 2018. Human and biophysical legacies shape contemporary urban forests: A literature synthesis. Urban Forestry & Urban Greening, 31: 157–168.

Troy, A. R., Grove, J. M., O'Neil-Dunne, J. P., Pickett, S. T. A., and M.L. Cadenasso. 2007. Predicting Opportunities for Greening and Patterns of Vegetation on Private Urban Lands. Journal of Environmental Management, 40: 394–412.

Watkins, S. L., and E. Gerrish. 2018. The relationship between urban forests and race: A meta-analysis. Journal of Environmental Management, 209: 152–168.

Zivanovic, A. J., and G.W. Luck. 2016. Social and environmental factors drive variation in plant and bird communities across urban greenspace in Sydney, Australia. Journal of Environmental Management, 169: 210–222.

United States Census Bureau (USCB). 2019. American FactFinder. https://factfinder.census.gov.

Tables and Figures

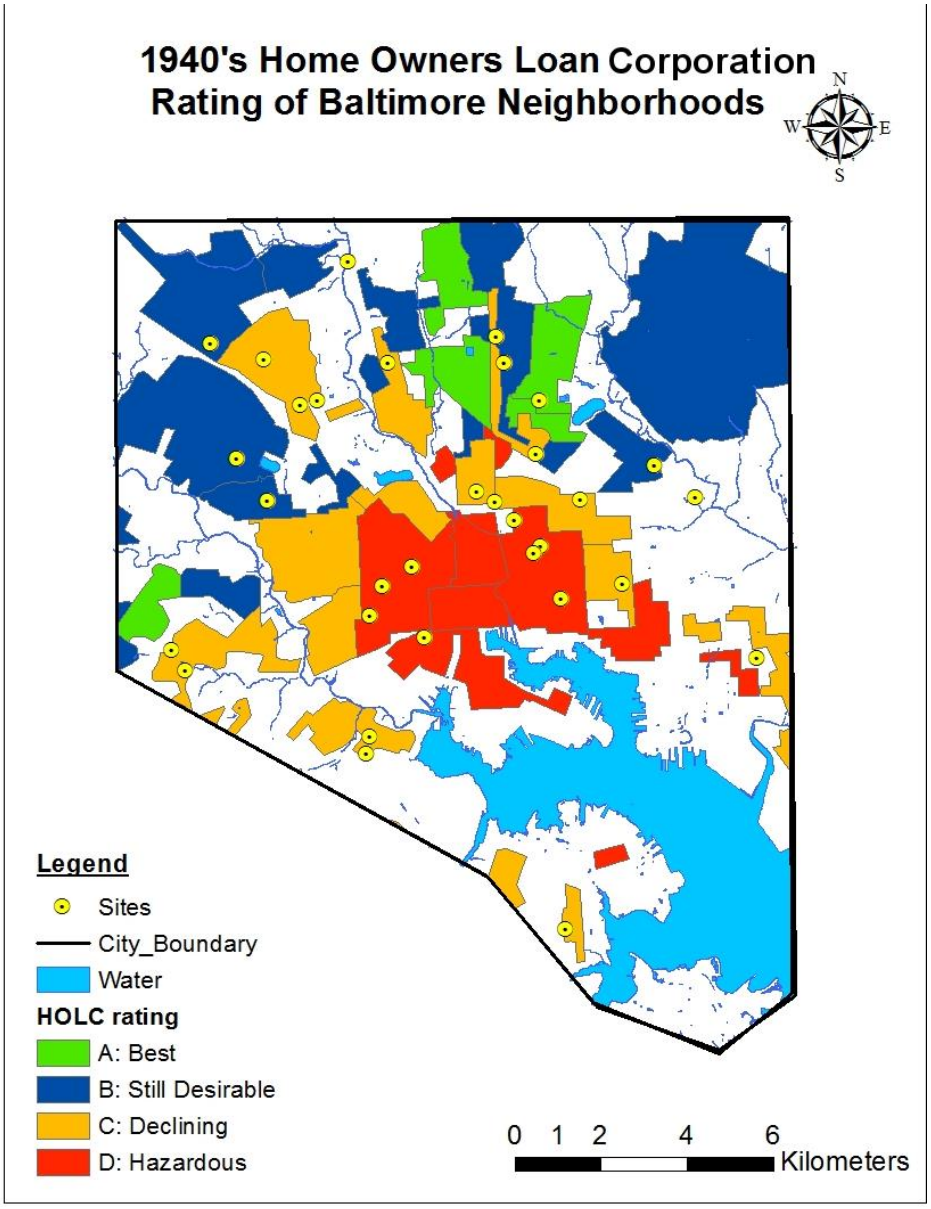


Figure 1. Location of research sites based on 1940's Home Owner Loan Corporation ratings for neighborhoods.

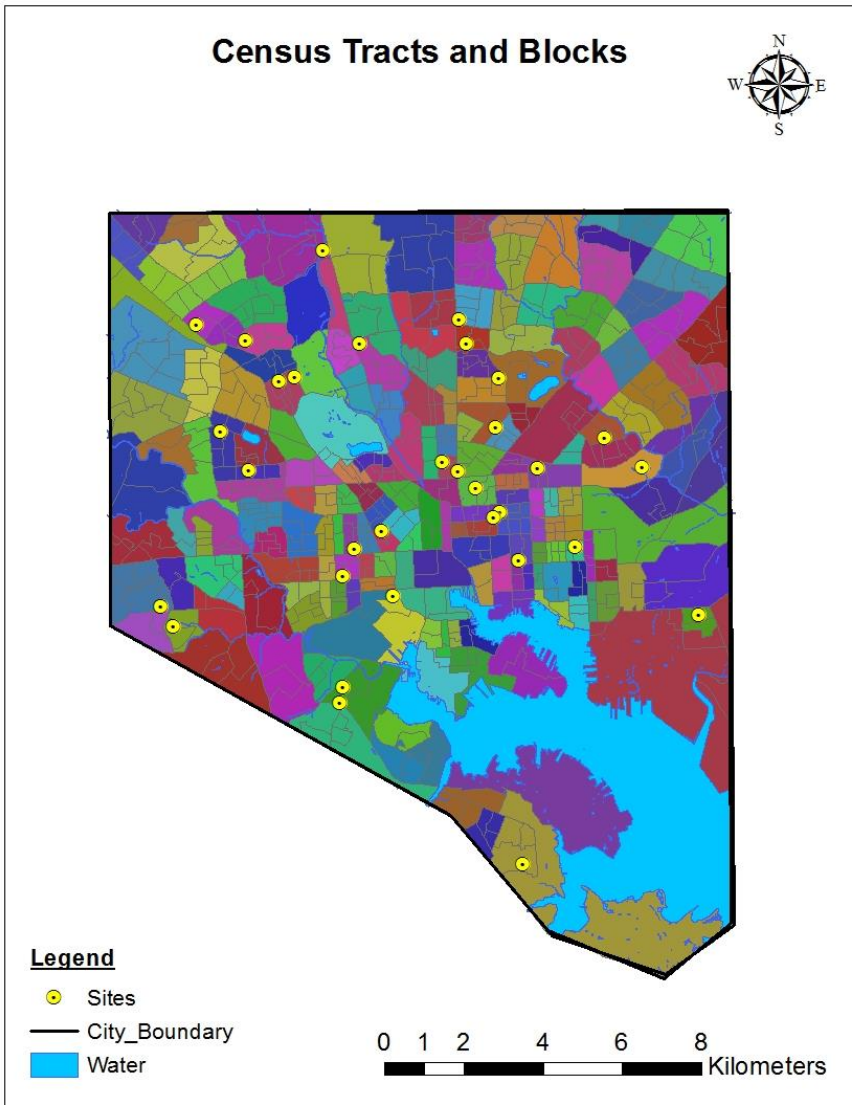


Figure 2. Location of sites within census tracts and census block groups. Colors denote the larger census tracts, and lines within each tract delineate the block groups used for this study.

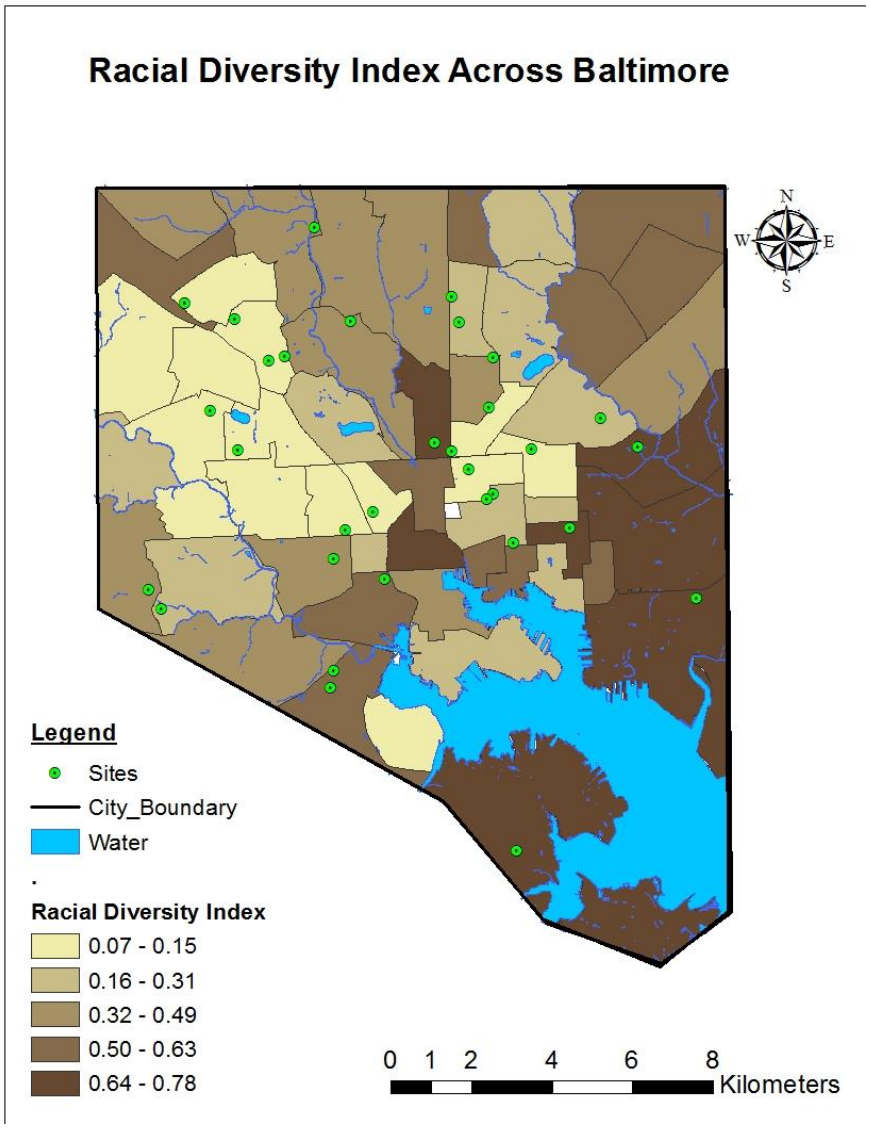


Figure 3. Location of sites and the Racial Diversity Index of neighborhoods in Baltimore City.

Table 1. Socioeconomic predictors and abbreviated names.

Socioeconomic Variable	**Abbreviation**
%Vacant housing	hvac
% Rental housing	hrent
Median household income	mhhi
% Housing built before 1939	hold
% of residents w/only HS diploma	Hsed
% of female householders w/ children	fhhk
% Black residents	aa
Racial Diversity Index	RDI N
Home Owner Loan Corportation 1940's rating	HOLC N

Table 2. Summary of socioeconomic measures.

	Mean	**Standard deviation**	**Minimum**	**Maximum**
hvac	0.23	0.17	0.00	0.55
hrent	0.55	0.22	0.02	0.92
mhhi	41,973.91	25,512.99	14,107.00	131,705.00
hold	0.45	0.20	0.04	0.77
HSed	0.32	0.12	0.05	0.57
fhhk	0.22	0.11	0.01	0.44
aa	0.78	0.29	0.08	0.98
RDI-N	0.35	0.25	0.07	0.91

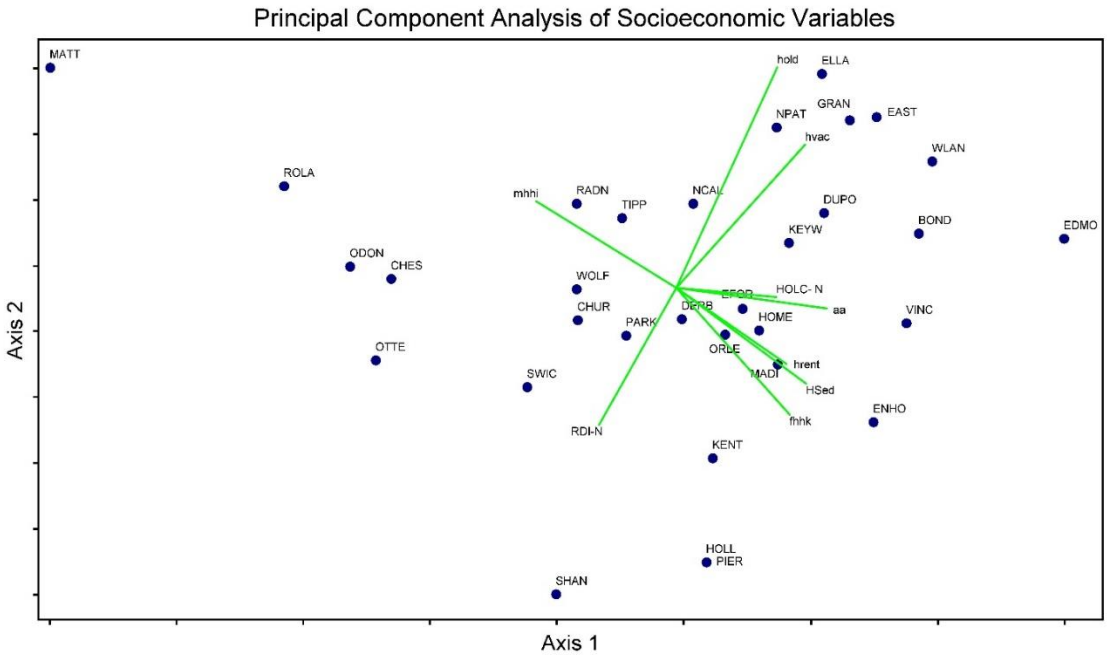


Figure 4. Principle Component Analysis of sites depicting similarity of sites based on the socioeconomic variables of the census block groups in which they are located.

Table 3. Principle component loadings and eigenvalues for socioeconomic Principal Component Analysis (PCA).

Variables	**PC 1**	**PC 2**	**PC 3**
hvac	0.6959	0.4851	-0.2358
hrent	0.5974	-0.2576	-0.3285
mhhi	-0.7569	0.2929	-0.1864
hold	0.5452	0.7434	-0.1956
HSed	0.7004	-0.3234	-0.0518
fhhk	0.6107	-0.4275	0.108
aa	0.8099	-0.0699	0.433
RDI-N	-0.4186	-0.4628	-0.5879
HOLC- N	0.5384	-0.0311	-0.5581
Eigenvalue	3.696	1.447	1.095
% of Variance	41.062	16.083	12.172
Cumulative Variance	41.062	57.145	69.317

Table 4. Correlation Table of socioeconomic variables.

	hvac	**hrent**	**mhhi**	**hold**	**Hsed**	**fhhk**	**aa**	**RDI-N**
hrent	0.25	x	x	x	X	x	x	x
mhhi	-0.33	-0.57	x	x	X	x	x	x
hold	0.77	0.20	-0.19	x	X	x	x	x
Hsed	0.36	0.37	-0.44	0.12	X	x	x	x
fhhk	0.31	0.26	-0.50	0.09	0.44	x	x	x
aa	0.43	0.27	-0.62	0.29	0.59	0.55	x	x
RDI-N	-0.21	-0.10	0.27	-0.37	-0.12	0.02	-0.49	x
HOLC-N	0.32	0.40	-0.25	0.28	0.40	0.20	0.26	-0.08

Table 5. Bray-Curtis Polar Ordination correlation (r) of species' activity levels and socioeconomic variables. This was used to create the preliminary models for each species.

	1	**2**
E. fuscus	**0.699**	**0.62**
L. borealis	**0.741**	-0.397
L. cinereus	0.246	0.268
L. noctivagans	-0.247	0.319
N. humeralis	**0.564**	0.223
hvac	-0.044	0.171
hrent	-0.058	0.06
mhhi	0.021	-0.351
hold	-0.017	-0.062
Hsed	0.058	0.224
fhhk	-0.043	0.342
aa	-0.056	0.295
RDI	-0.003	0.086

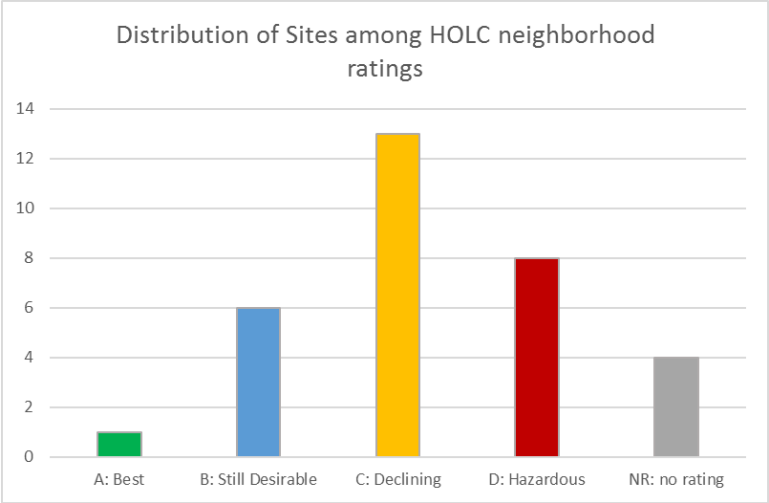


Figure 5. Summary of vacant lot sites based on the 1940 HOLC rating.

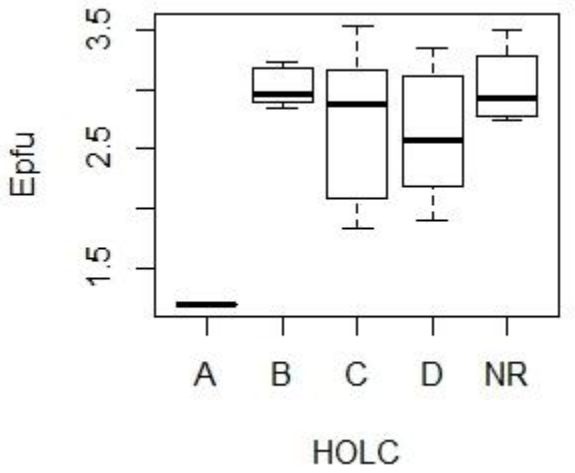


Figure 6. Comparison of *E. fuscus* activity at sites based on HOLC rating.

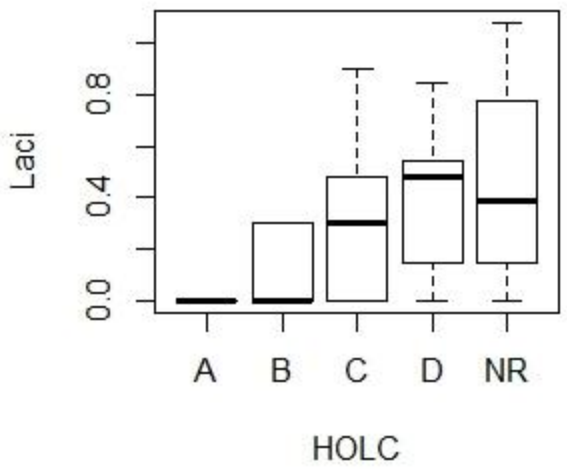


Figure 7. Comparison of *L. cinereus* activity at sites based based on HOLC rating.

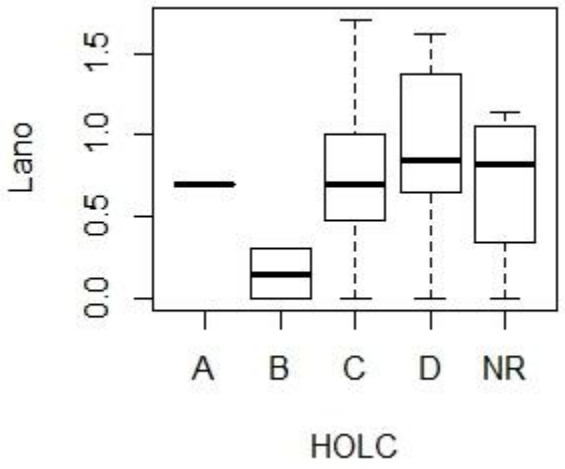


Figure 8. Comparison of *L. noctivagans* activity at sites based on HOLC rating.

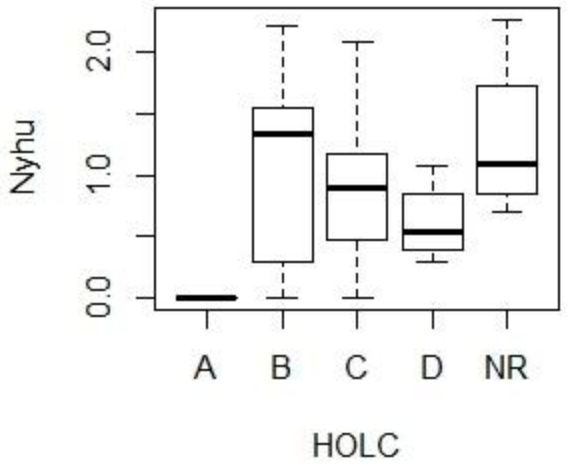


Figure 9. Comparison of *N. humeralis* activity at sites based on HOLC rating.

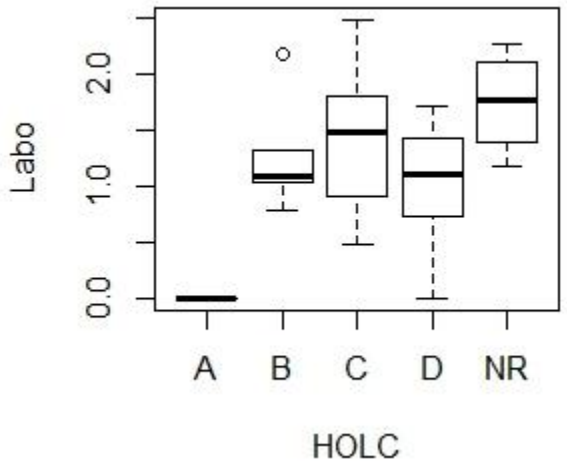


Figure 10. Comparison of *L. borealis* activity at sites based on HOLC rating.

Table 6. Candidate models for species richness.

	K	AICc	Delta AICc	AICc Wt	Cum. Wt	LL
Null	3	119.16	0	0.59	0.59	-56.15
Luxury effect	4	120.97	1.81	0.24	0.83	-55.74
Race + income	5	123.18	4.01	0.08	0.91	-55.43
Neighborhood structure	5	124.21	5.05	0.05	0.96	-55.95
Residential structure	5	124.51	5.35	0.04	1	-56.1
Combined SE	8	133.06	13.9	0	1	-55.4

Table 7. Candidate models for *E. fuscus*.

	K	AICc	Delta AICc	AICc Wt	Cum. Wt	LL
Combined SE	8	15854.15	0	1	1	-7915.94
Race + income	5	16953.18	1099.03	0	1	-8470.44
Residential structure	5	17226.22	1372.08	0	1	-8606.96
Neighborhood structure	5	19988.72	4134.57	0	1	-9988.21
Luxury effect	4	19531.55	3677.4	0	1	-9761.03
Null	3	20178.88	4324.73	0	1	-10086

Table 8. Candidate models for *L. borealis*.

	K	AICc	Delta AICc	AICc Wt	Cum. Wt	LL
Combined SE	8	1492.61	0	1	1	-735.18
Race + income	5	1656.5	163.88	0	1	-822.1
Neighborhood structure	5	1658.56	165.94	0	1	-823.12
Residential structure	5	1660.13	167.51	0	1	-823.91
Luxury effect	4	1679.01	186.4	0	1	-834.77
Null	3	1786.21	293.59	0	1	-889.68

Table 9. Candidate models for *N. humeralis*.

	K	AICc	Delta AICc	AICc Wt	Cum. Wt	LL
Combined SE	8	749.31	0	1	1	-363.53
Residential structure	5	858.05	108.74	0	1	-422.87
Race + income	5	1011.16	261.85	0	1	-499.43
Neighborhood structure	5	1186.55	437.23	0	1	-587.12
Luxury effect	4	1331.47	582.16	0	1	-660.99
Null	3	1512.17	762.86	0	1	-752.66

Table 10. Coefficients and P values for predictors in top model for species richness and individual species Parentheses indicate P value. Models with < 2 difference in AIC_c ranking from the top model were included.

	aa	Hold	hrent	mhhi	RDI
E. fuscus	1.799 (< 0.01)	-0.225 (< 0.01)	-1.190 (< 0.01)	-0.013 (0.21)	-0.019 (0.52)
L. borealis	-0.630 (< 0.01)	-1.649 (< 0.01)	1.269 (< 0.01)	0.279 (< 0.01)	-0.166 (0.29)
N. humeralis	9.702 (< 0.01)	-1.007 (< 0.01)	3.100 (< 0.01)	0.796 (< 0.01)	2.362 (< 0.01)
Species Richness				-0.082 (0.38)	

Conclusion

This research has begun to provide insight into what factors may be important for urban bats' foraging habitat. Attempting to use active acoustic monitoring to document bat community composition along both a direct and indirect urbanization gradient didn't reveal a pattern. When multiple environmental and socioeconomic measures were incorporated and monitoring switched from active to passive, the amount of acoustic activity of bat species could be better predicted. Canopy-associated measures at both the site and neighborhood scale, streetlights, site distance from water and the urban core, residential race and income, old housing, and rental housing were all common predictors of bat species' activity levels. Species relationships with these predictors varied and some species had additional predictors, resulting in a unique mix of predictors for each species. Overall species richness could not be predicted with environmental nor socioeconomic measures.

This first look into the bat community in Baltimore resulted in over 33,000 sequences being recorded from six species, half of the total number of bat species present in Maryland. The bat community present in Baltimore was shaped primarily by the big brown bat (*E. fuscus)*, red bat (*L. borealis*), and evening bat (*N. humeralis*), the most commonly detected species. Hoary (*L. cinereus*) and silver-haired bats (*L. noctivagans*), were present a low frequencies at many sites, and the tricolor bat (*P. subflavus*) was rare at sites within Baltimore City.

Some larger lots could potentially be managed to have vegetation structural complexity (allowing both canopy cover and open space to accommodate bat species with different), but many lots are too small to do this. Vacant lots closer to water and surrounded by areas of high canopy cover and/or forested land have the most potential to be managed for bats. Regardless of size, these lots should be managed in a way that supports residential preferences while also supporting wildlife.

Appendices

Appendix 1. Total number of sequences recorded at GFW sites, summer 2016.

Site	***E. fuscus***	***L. borealis***	***L. cinereus***	***L. noctivagans***	***N. humeralis***	***P. subflavus***	**Unknown**	Total
GL	17	37	0	0	0	0	0	**54**
DE	140	137	0	2	13	10	13	**315**
MD	44	15	9	3	4	0	6	**81**
SL	124	1	0	3	0	0	5	**133**
VN	104	7	0	1	0	33	5	**150**
PM	229	24	3	0	5	0	10	**272**
DR	37	5	0	0	1	0	2	**45**
RH	209	35	1	4	8	1	23	**281**
WB	160	69	0	0	12	0	12	**253**

Appendix 2. Total number of detections at vacant lot sites, 2017-2018. Epfu = *E. fuscus*, Labo = *L. borealis*, Laci = *L. cinereus*, Lano = *L. noctivagans*, Nyhu = *N. humeralis*, Pesu = *P. subflavus*. "Q" indicates sequences that could not be identified to species, and the number corresponds to the frequency level of the call in kHz.

Site	**Epfu**	**Labo**	**Laci**	**Lano**	**Nyhu**	**Pesu**	**Q25**	**Q35**	**Q40**	***Site total***
DUPO	1044	2	2	4	2	0	12	4	0	***1,070***
TIPP	899	5	1	0	0	0	4	1	0	***910***
DERB	3167	84	11	4	185	0	146	19	0	***3,616***
ROLA	102	147	0	0	0	0	6	2	20	***277***
EDMO	1596	11	0	4	5	0	70	9	2	***1,697***
VINC	1022	0	1	3	2	0	28	13	2	***1,071***
HOLL	271	17	1	24	96	0	14	2	2	***427***
PARK	1765	19	2	29	14	0	53	10	1	***1,893***
RADN	1715	13	0	0	19	0	5	22	3	***1,777***
SHAN	560	40	0	8	14	5	21	11	8	***667***
EAST	120	7	0	2	0	0	3	0	0	***132***
KENT	1517	10	0	1	34	0	11	7	0	***1,580***
CHUR	997	130	1	4	12	0	35	17	12	***1,208***
MADI	2233	9	0	29	3	0	133	5	0	***2,412***
ODON	636	14	2	13	4	0	8	1	3	***681***
WOLF	217	50	2	0	1	0	20	7	1	***298***
ELLA	697	20	1	1	22	0	14	16	1	***772***
GRAN	775	150	0	1	162	0	8	12	2	***1,110***

Site	Epfu	Labo	Laci	Lano	Nyhu	Pesu	Q25	Q35	Q40	*Site total*
KEYW	3396	29	2	2	3	0	10	32	1	***3,475***
MATT	1130	185	1	0	9	1	4	11	4	***1,345***
CHES	15	0	0	4	0	0	4	0	0	***23***
EFOR	906	10	0	0	1	0	31	2	0	***950***
HOME	100	33	0	4	11	0	8	6	0	***162***
NPAT	68	5	0	6	1	0	7	1	0	***88***
BOND	624	13	2	18	7	0	13	2	0	***679***
ENHO	188	22	2	41	2	0	20	0	0	***275***
NCAL	736	62	1	0	19	0	4	10	1	***833***
ORLE	398	6	0	7	2	0	5	1	0	***419***
OTTE	122	2	3	6	1	0	3	7	1	***145***
PIER	1557	303	4	9	121	0	25	38	7	***2,064***
SWIC	1430	63	7	50	7	0	15	10	0	***1,582***
WLAN	79	30	6	6	11	0	2	3	2	***139***
Species total	*30,082*	*1,491*	*52*	*280*	*770*	*6*	*742*	*281*	*73*	***33,777***

Appendix 3. Socioeconomic Measures of the census block groups used in this study.

Site	Neighborhood	Census Tract	Census Block	hvac	hrent	mhhi	hold	HSed	fhhk	aa	RDI-N	HOLC-N
ORLE	Patterson Park North & East	601	1	0.362	0.683	60625	0.607	0.296	0.439	0.623	0.77	C
WOLF	Oldtown/ Middle East	604	1	0.143	0.665	61563	0.274	0.270	0.112	0.617	0.208	D
NPAT	Clifton/ Berea	802	3	0.219	0.558	23942	0.768	0.222	0.200	0.954	0.079	C
BOND	Oldtown/ Middle East	808	2	0.412	0.746	39375	0.660	0.340	0.368	0.971	0.208	D
CHES	The Waverlies	903	1	0.082	0.308	82903	0.232	0.223	0.130	0.794	0.375	A
HOME	The Waverlies	905	1	0.212	0.406	41667	0.505	0.423	0.316	0.959	0.375	C
EAST	Midway/ Coldstream	908	5	0.476	0.618	36184	0.733	0.349	0.248	0.937	0.096	C
ENHO	Greenmount East	909	4	0.093	0.866	19438	0.382	0.499	0.233	0.968	0.091	D
MADI	Greenmount East	1001	3	0.445	0.349	54091	0.458	0.573	0.225	0.984	0.91	D
NCAL	Greater Charles Village/Barclay	1204	2	0.310	0.745	45333	0.719	0.271	0.135	0.779	0.678	C

Appendix 3 (continued). Socioeconomic Measures of the census block groups used in this study.

Site	Neighborhood	Census Tract	Census Block	hvac	hrent	mhhi	hold	HSed	fhhk	aa	RDI-N	HOLC-N
ROLA	Medfield/ Hampden/ Woodberry/ Remington	1307	5	0.000	0.400	90913	0.404	0.145	0.046	0.135	0.404	C
ELLA	Greater Mondawmin	1507.02	3	0.519	0.521	23309	0.709	0.249	0.211	0.955	0.082	B
GRAN	Forest Park/ Walbrook	1508	6	0.498	0.683	50461	0.679	0.462	0.162	0.970	0.108	B
DERB	Southern Park Heights	1512	1	0.065	0.763	18654	0.440	0.395	0.113	0.938	0.093	NR
KEYW	Southern Park Heights	1512	5	0.216	0.418	14107	0.573	0.280	0.292	0.956	0.093	C
EDMO	Sandtown-Winchester/ Harlem Park	1602	3	0.554	0.915	16845	0.657	0.478	0.336	0.945	0.073	D
WLAN	Upton/Druid Heights	1703	1	0.483	0.780	16017	0.678	0.343	0.183	0.976	0.154	D
VINC	Southwest Baltimore	1901	3	0.384	0.912	15426	0.556	0.345	0.270	0.939	0.431	D
OTTE	Washington Village/ Pigtown	2201	2	0.048	0.652	50428	0.174	0.190	0.010	0.132	0.612	D

Appendix 3 (continued). Socioeconomic Measures of the census block groups used in this study.

Site	Neighborhood	Census Tract	Census Block	Hvac	hrent	mhhi	hold	HSed	fhhk	aa	RDI-N	HOLC-N
PARK	Allendale/ Irvington/ S Hilton	2501.02	2	0.039	0.480	40766	0.369	0.267	0.230	0.877	0.229	C
HOLL	Westport/Mount Winans/ Lakeland	2503.01	2	0.090	0.584	21554	0.174	0.339	0.379	0.961	0.62	C
PIER	Westport/ Mount Winans/ Lakeland	2503.01	2	0.090	0.584	21554	0.174	0.339	0.379	0.961	0.62	C
CHUR	Brooklyn/ Curtis Bay/ Hawkins Point	2505	3	0.195	0.511	50250	0.521	0.470	0.161	0.224	0.667	C
KENT	Belair/ Edison	2603.01	3	0.121	0.487	45329	0.248	0.450	0.391	0.893	0.246	B
SHAN	Claremont	2603.03	1	0.093	0.722	17898	0.041	0.321	0.321	0.632	0.667	NR
ODON	Southeastern	2606.04	2	0.203	0.389	36136	0.392	0.088	0.148	0.249	0.734	NR
EFOR	Greater Govans	2710.01	3	0.188	0.742	30385	0.462	0.306	0.245	0.933	0.186	B
RADN	Greater Govans	2710.02	3	0.258	0.050	43286	0.359	0.291	0.160	0.912	0.186	B

Appendix 3 (continued). Socioeconomic Measures of the census block groups used in this study.

Site	Neighborhood	Census Tract	Census Block	Hvac	hrent	mhhi	hold	HSed	fhhk	aa	RDI-N	HOLC-N
MATT	Mt Washington/ Coldspring	2715.01	1	0.060	0.020	131705	0.414	0.047	0.058	0.085	0.492	NR
DUPO	Southern Park Heights	2716	4	0.346	0.326	26250	0.580	0.383	0.302	0.952	0.093	C
TIPP	Pimlico/ Arlington/ Hilltop	2718.01	3	0.229	0.247	55208	0.393	0.324	0.192	0.962	0.12	B
SWIC	Beechfield/ Ten Hills/ West Hills	2804.03	2	0.000	0.596	61563	0.202	0.349	0.095	0.767	0.362	C

Vita

Ela- Sita Carpenter was born and raised in Baltimore, Maryland. She graduated from Baltimore Polytechnic Institute in 2001. She attended Hampton University in Hampton, Virginia, and received her Bachelors of Science degree in Biological Science in 2005. Shortly after, she began her Master's degree in Environmental Science at Christopher Newport University in nearby Newport News. Her thesis research focused on the roosting affinities of Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) in abandoned building roosts in southeast Virginia; this work resulted in documenting the first hibernacula for this species in Virginia and locating funding to stabilize two building roosts home to unusually large maternity colonies. She received her M.S. in Environmental Science in 2008. For the next several years, she alternated between certificate programs, seasonal wildlife positions, and nature photography. She obtained certificates in Species Monitoring and Conservation of Terrestrial Mammals from the Smithsonian-Mason School of Conservation in 2013 and Urban Environmental Education from Cornell University in 2015. Seasonal wildlife work included bat monitoring in Nevada, shorebird telemetry in Virginia, and urban songbird surveys back in Baltimore. She also worked briefly at the Maryland Science Center as an educator. She moved to Columbia, Missouri in 2015 to begin her PhD in Natural Resources (with an emphasis in Fisheries and Wildlife Science) at the University of Missouri-Columbia. In May 2019, she received a PhD in Natural Resources and a graduate certificate in Science Outreach from the University of Missouri-Columbia.