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Cover Photograph: Eastern Red Bat (*Lasiurus borealis*) spotted roosting at The High Line, a public park in New York City. Photograph © Ayinde Listhrop.

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Bats in the Bronx: Acoustic Monitoring of Bats in New York City

Kaitlyn L. Parkins[1,*], Michelle Mathios[1], Colleen McCann[2], and J. Alan Clark[1]

Abstract - Studies on urban bat ecology, mainly focusing on large-scale landscape features that affect biodiversity, have flourished in the last decade. In the present study, we investigated the presence of bats on a local scale in a highly urbanized area, Bronx Borough, in New York City (NYC), 1 of 2 North American megacities. We used passive and active monitoring of bat echolocation calls at 4 sites in the Bronx to determine which species were present and to examine seasonal variation in activity levels. We recorded 5 species of bats at our study sites: *Eptesicus fuscus* (Big Brown Bat), *Lasiurus borealis* (Eastern Red Bat), *L. cinereus* (Hoary Bat), *Lasionycteris noctivagans* (Silver-haired Bat), and *Perimyotis subflavus* (Tri-colored Bat). The majority of recorded activity was by Eastern Red Bat at all sites. Activity peaked in August and November during the migratory periods for Eastern Red Bat and Silver-haired Bat. During the winter months, we recorded activity by Eastern Red Bat, Silver-haired Bat, and Hoary Bat, and found that we detected greater bat activity on nights with higher maximum daily temperatures. Our study provides preliminary documentation of tree-bat migration through NYC and evidence of winter bat activity in NYC. Further acoustic and mist-net surveys will help us better understand the diversity and seasonal activity of bats in NYC.

Introduction

In recent years, the body of research on North American bats has grown substantially, and this interest in bat conservation is owed, in large part, to 2 major and relatively new causes of bat mortality: white-nose syndrome (WNS) and wind turbines. WNS has triggered mass mortality in some species of hibernating bats and continues to spread across North America (Cryan et al. 2013, Turner et al. 2011). Recent surveys of bat mortality due to collisions with turbines have raised concerns about wind development and its impact on migratory bat populations (Arnett and Baerwald 2013, Cryan and Barclay 2009). These increasing threats, often acting in concert with the pressures of habitat loss (Agosta 2002), roost disturbance (Agosta 2002), climate change (Sherwin et al. 2012), and urbanization (Weller 2009), have motivated efforts to understand their effect on bat populations. Here, we explore the basic ecology of urban bat populations.

Landscapes are becoming increasingly urbanized (United Nations 2012) and for most wildlife, urbanization results in negative overall effects on species richness and diversity (Czech et al. 2000; McKinney 2002, 2008). For insectivorous bat assemblages, urbanization tends to result in both a reduction of species diversity

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and dominance of a few, open-adapted, generalist species (Avila-Flores and Fenton 2005, Coleman and Barclay 2012, Duchamp and Swihart 2008, Loeb et al. 2008, Luck et al. 2013, Threlfall et al. 2011, Ulrey et al. 2005). In some cases, however, urbanization can provide a heterogeneous environment that is beneficial to particular species (Gehrt and Chelsvig 2003, 2004). Hence, the effects of urbanization on bats are largely species and context specific.

Because of the growing number of "megacities"—urban agglomerations with a population over 10 million—worldwide (United Nations 2014), a better understanding of the effects of various levels of urbanization on bat communities is needed. Most previous studies on this topic are broad-scale examinations of bats in an urbanized landscape. Here, we focus on local-scale recording of bats within New York City (NYC), the largest city in the US and second-largest in North America (US Census Bureau 2014). However, we are not aware of published studies of bats within NYC. Baseline data on bat activity and species occupancy is important, including data from a variety of locations, habitats, and seasons (Weller et al. 2009). Baseline surveys and monitoring of bats can also provide a basis for future research and are necessary for quantifying the impact of new threats as they arise. Before designing studies on the behavior and ecology of bats, species-occurrence data are needed.

One of the most common methods of determining bat species' distributions and activity patterns is acoustic monitoring. Insectivorous bats produce echolocation calls to navigate and locate prey. The ability to record and visualize those calls provides a non-intrusive method of monitoring bats. Bat species can generally be distinguished by their echolocation calls (O'Farrell 1997), and recordings of calls can be used to compare relative levels of bat activity (Hayes 2000). For this study, we used acoustic monitoring to gather baseline data on bat species presence and seasonal levels of activity at 4 relatively close sites in the Bronx, 1 of NYC's 5 boroughs.

We utilized range maps (Arnett and Baerwald 2013, Cryan and Barclay 2009, Harvey et al. 2011) and New York State Department of Environmental Conservation reports (Carl Herzog, New York State Department of Environmental Conservation, Albany, NY, pers. comm.) to predict presence of bat species in the Bronx. Based on these data, we determined that bat species possibly present in the Bronx included 9 species: *Eptesicus fuscus* (Beavois) (Big Brown Bat), *Lasiurus borealis* (Müller) (Eastern Red Bat), *L. cinereus* (Palisot de Beauvois) (Hoary Bat), *Lasionycteris noctivagans* (Le Conte) (Silver-haired Bat), *Perimyotis subflavus* F. Couvier (Tricolored Bat), *Myotis lucifugus* (Le Conte) (Little Brown Bat), *M. septentrionalis* (Trouessart) (Northern Long-eared Bat), *M. lebeii* (Audubon and Bachman) (Eastern Small-footed Bat), and *M. sodalis* Miller & Allen (Indiana Bat). Eastern Red Bat, Hoary Bat, and Silver-haired Bat are migratory, foliage-roosting species (tree bats). The 6 other species hibernate in caves during the winter and use tree cavities, buildings, or other structures as summer roosts (Harvey et al. 2011). We expected that Big Brown Bat would be the most commonly detected species, based on anecdotal reports and because, in many surveys, this species was the most common bat in North American urban centers (Agosta 2002, Damm et al. 2015, Duchamp and Swihart 2008, Everette et al. 2001, Loeb et al. 2008, Ulrey et al. 2005).

Most bat surveys are conducted during the summer; however, little is known about winter bat behavior even though this information could prove valuable in determining migration routes and overwintering strategies (Boyles et al. 2006). For this reason, we also explored bat activity in the Bronx during winter months, with the expectation of possibly detecting Eastern Red Bat. To date, Eastern Red Bat has not been detected in NYC in the winter months, but NYC is within the possible wintering range for this species (Cryan 2003, Sherwin et al. 2012), which is known to feed and switch roosts during winter and has been reported flying in locations with winter temperatures as low as -2 °C (Boyles et al. 2006, Jones et al. 2009).

Methods

Study site

We conducted this study within the Bronx borough of New York, NY. NYC has a population of ~8.4 million people within 487 km^2 (US Census Bureau 2014). We monitored 4 sites for bat activity: the Rose Hill Campus of Fordham University (Rose Hill), the New York Botanical Garden (NYBG), the Bronx Zoo, and Hughes Avenue, in the Belmont neighborhood of the Bronx (Fig. 1). The Fordham, NYBG,

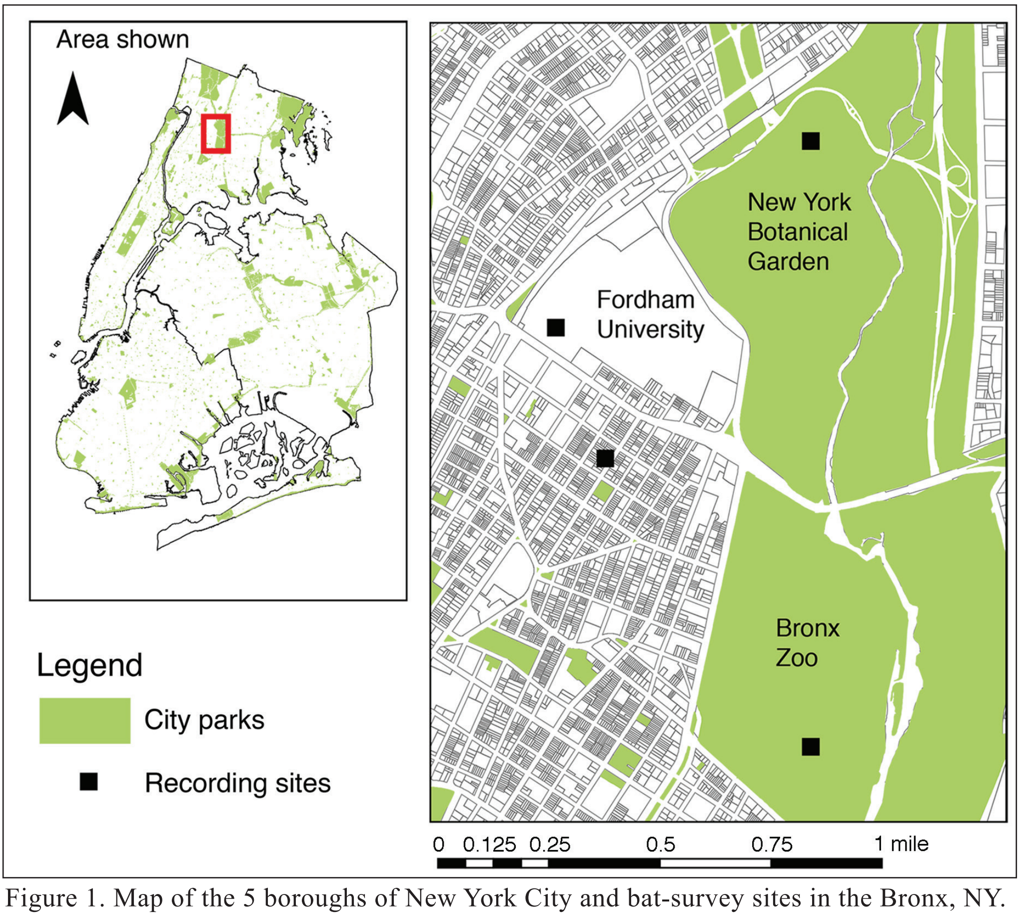

Figure 1. Map of the 5 boroughs of New York City and bat-survey sites in the Bronx, NY.

and Bronx Zoo sites were located within urban parks. These 3 parks are divided by 2 major thoroughfares, and NYBG and the Bronx Zoo are part of a larger contiguous green space called Bronx Park. The Hughes Avenue site is located near the parks but is in a commercial and residential area of dense buildings, high impervious surface, and little vegetation.

Passive acoustic monitoring

We recorded bat activity from 1 May 2012 to 15 February 2013 using stationary SongMeter SM2BAT+ (Wildlife Acoustics, Concord, MA) full-spectrum ultrasonic, acoustic-recording units (detectors) placed on the rooftop of buildings at each site. We placed detectors on rooftops to maximize their height and reduce the risk of vandalism. We used external SMX-US omni-directional microphones attached to the top of 2.7-m poles to minimize echolocation-bounce off hard surfaces and maximize the number and quality of calls recorded.

We set detectors to automatically record calls continuously throughout the night (from civil twilight to civil twilight), set at a 192-kHz sample rate, 12-kHz digital high-pass filter, 18-dB trigger level, 36-dB gain, and the microphone bias off. These settings were those recommended for the SongMeter SM2BAT+ with minor alterations for use in an urban environment (J. Tyburec, Janet Tyburec Consulting, Tucson, AZ; pers. comm). We used a 2.0-sec trigger-window minimum and 8.0-sec maximum file length so that calls would be an appropriate length for the call-analysis software. We recorded calls in .wav format onto SD data cards and copied them to hard drives for later analysis. We changed data cards and batteries approximately every 2 weeks.

Active acoustic monitoring

We also conducted bi-weekly active surveys at each site beginning the week of 25 June 2012 and ending the week of 27 August 2012. Active surveys consisted of walking a set transect using an Echometer 3 (EM3) ultrasonic recording unit (Wildlife Acoustics, Concord, MA). Each active survey began at sunset and lasted one hour. We recorded bat passes from the active surveys onto SD data cards and then copied to hard drives for later analysis.

Bat call analysis

We used the software's default settings and passed recordings from all sites through the SonoBat Batch Scrubber Utility 5.2 (DND Design, Arcata, CA) to remove the majority of files that did not contain bat passes. We defined a bat pass (or call) as a file with 2 or more pulses with each pass separated by 1 or more seconds (Kalcounis et al. 1999, Weller et al. 2009, White and Ghert 2001). Due to the large amount of high- and low-frequency ambient noise in our urban setting, we then visually inspected each file on a time-frequency spectrogram for the presence of bat echolocation calls in order to manually eliminate files that contained only non-bat noise.

We examined bat passes for quality before species analysis, and we used only regular, non-fragmented search-phase calls from a single echolocating bat for species analysis because low-quality, overlapping, and fragmented calls are likely to result in misidentification (Szewczak 2002, Weller et al. 2009). We used default settings in the SonoBat NNE 3.2.0 automated classifier to analyze passes. We set a required call quality of 0.80 and a decision threshold of 0.90, the default settings for Sonobat 3.2.0 (see Jameson and Willis 2014, Kalcounis-Ruppell et al. 2013). We considered a species confirmed when the Sonobat maximum-likelihood estimate was ≥0.90. A trained individual checked identifications using Sonobat NNE reference calls to confirm species presence at each site and to investigate any unusual identifications made by the automated classifier.

The use of acoustic recordings to make interspecific comparisons is limited due to differences in the ability to record and correctly identify passes from each species (Hayes 2000, O'Farrell and Gannon 1999). To account for these differences and to compare relative activity between species, we used the Miller activity index (Miller 2001), the number of 1-minute time blocks in which a species is present at each site.

We used all bat passes recorded, including those that we could not positively identify to the species level, to calculate an index of activity for each site and for each month. We quantified the activity index as the number of passes per recording night (Avila-Flores and Fenton 2005, Coleman and Barclay 2012, Duchamp and Swihart 2008, Gehrt and Chelsvig 2003, Loeb et al. 2008, Luck et al. 2013, Threlfall et al. 2011, Ulrey et al. 2005). The activity index does not provide an estimate of abundance of bats in an area (Gehrt and Chelsvig 2003, 2004; Hayes 2000) but is, instead, an estimate of the relative use of a site and can be used to make relative comparisons between sites (Hayes 2000, Parsons and Szewczak 2009). To compare activity levels on a temporal scale, we standardized the number of passes to recording hour, which controlled for the changes in nighttime length throughout the year. We obtained data on the duration of darkness in NYC on each recording night from the US Naval Observatory Astronomical Application Department online database (http://aa.usno.navy.mil/data/php).

We used only the data from active surveys for the confirmation of species' presence at each site. Because of time and personnel limitations, we could be present at only 1 site each night and, hence, we did not use the active-recording data to compare activity levels between sites. We examined activity levels using calendar months as divisions. This approach allowed us to examine seasonality of bat activity in the same manner as Cryan (2003).

We obtained daily minimum and maximum temperatures for the portion of the winter months during which we conducted surveys (1 December–15 February) from the National Oceanic and Atmospheric Administration Climate Data Online database (http://www.ncdc.noaa.gov/cdo-web/). We obtained temperature data recorded at Laguardia Airport, which is ~9.5 km from our survey sites. We expected that higher temperatures would be positively correlated with higher winter bat activity and that lower temperatures would be negatively correlated with lower winter bat activity; thus, we compared temperatures on days during which bat activity was and was not recorded using a one-tailed *t*-test.

Results

Species presence

We conducted passive acoustic surveys on 470 nights (5410 hours) between 1 May 2012 and 15 February 2013. The nights were not evenly distributed between the sites due to detector failures. We recorded for 59 nights at Hughes Avenue, 88 nights at the Bronx Zoo, 146 nights at NYBG, and 177 nights at Rose Hill. We conducted active acoustic surveys on 20 nights, 5 at each site, between 26 June and 1 September 2012.

We recorded >6000 bat passes among the 4 sites (5708 passive, 348 active). Of the recorded passes, we classified 57% (56% passive; 59% active) into the Sonobat-designated high-frequency call clade, which for the northeastern US includes: Eastern Red Bat, Tri-colored Bat, and *Myotis* spp. We classified the remaining 43% (44% passive; 41% active) into the low-frequency call clade comprised of Big Brown Bat, Silver-haired Bat, and Hoary Bat.

Species-level identification was possible for 49% of passes (49% of passive; 48% active). Overall, we confirmed 5 species: Eastern Red Bat, Silver-haired Bat, Big Brown Bat, Tri-colored Bat, and Hoary Bat. All species were present at all sites (Table 1). Sonobat analysis identified 2 passes as being from Little Brown Bat

Table 1. Bat species confirmed as present in the Bronx, NY, from 1 May 2012–15 February 2013, using passive and active acoustic monitoring techniques.

Site	Survey method	Species present
Bronx Zoo	Active	*Lasiurus borealis*
	Passive	*Perimyotis subflavus*
		L. borealis
		Eptesicus fuscus
		Lasionycteris noctivagans
		L. cinereus
New York Botanical Garden	Active	*L. borealis*
		E. fuscus
	Passive	*P. subflavus*
		L. borealis
		E. fuscus
		L. noctivagans
		L. cinereus
Fordham University, Rose Hill	Active	*L. borealis*
	Passive	*P. subflavus*
		L. borealis
		E. fuscus
		L. noctivagans
		L. cinereus
Hughes Avenue	Active	None
	Passive	*P. subflavus*
		L. borealis
		E. fuscus
		L. noctivagans
		L. cinereus

(1 each at the Bronx Zoo and NYBG); however, the Sonobat likelihood analysis for those recordings was 0.42, and we could not confirm using an acoustic key that either pass was from Little Brown Bat.

In general, active surveys recorded fewer species than passive surveys (Table 1). Only Eastern Red Bat and Big Brown Bat were recorded during active surveys. In no case did active surveys result in the confirmation of a species that was not also detected on a passive recorder. Eastern Red Bat made up 62% of identified passes from active surveys, and we classified the remaining 38% as Big Brown Bat. We classified 47% of passive recordings across all sites as Eastern Red Bat, 24% as Big Brown Bat, 21% as Sliver-haired Bat, 6% as Tri-colored Bat, and 2% as Hoary Bat. Miller indices showed the same trends—Eastern Red Bat had the highest overall value, followed by Big Brown Bat (Table 2).

Eastern Red Bat had the highest Miller index value at every site (Fig. 2). The highest relative Miller index value for Big Brown Bat occurred at NYBG. At the Bronx Zoo, Silver-haired Bat had nearly as high a Miller index value as Eastern Red Bat. Hoary Bat and Tri-colored Bat made up the smallest proportion of active minutes at all sites and were relatively evenly distributed across the four sites.

Activity levels

The sites averaged 12 passes per night (n = 4, SD = 8.8). The Bronx Zoo had the highest activity level overall with a mean of 22.9 passes per night, and Hughes Avenue had the lowest with a mean of 4.7 passes per night. Rose Hill and NYBG had means of 15.3 and 5.0 passes per night, respectively.

Bat activity peaked at all sites in August and October and was lowest in the winter months (Fig. 3); however, we recorded bat activity in all 9 months of this study. Species activity was not distributed evenly over the course of the sampling period (Fig. 4). From June through September, we recorded more activity by Eastern Red Bat than any other species, and activity for this species peaked in August.

Table 2. Count of passes, estimated likelihood of presence, and Miller activity index values (the number of 1-minute periods during which a species is present) for each bat species recorded in the Bronx, NY, 1 May 2012–15 February 2013. MYLU = *Myotis lucifugus*, PESU = *Perimyotis subflavus*, EPFU = *Eptesicus fuscus*, LANO = *Lasionycteris noctivagans*, LABO = *Lasiurus borealis*, and LACI = *Lasiurus cinereus*. Number of passes = total (and percent) of all passes identified to species level

Survey type	MYLU	PESU	EPFU	LANO	LABO	LACI	Number of passes
Passive							
Pass count	2	178	665	578	1318	62	2803 (49%)
Estimated likelihood	0.42	1.00	1.00	1.00	1.00	0.99	
Percent of total passes	0	6	24	21	47	2	
Miller Index	0	175	571	529	1261	60	
Active							
Pass count	0	5	102	5	166	0	278 (48%)
Estimated likelihood	0.00	0.44	1.00	0.18	1.00	0.00	
Percent of total passes	0	0	38	0	62	0	

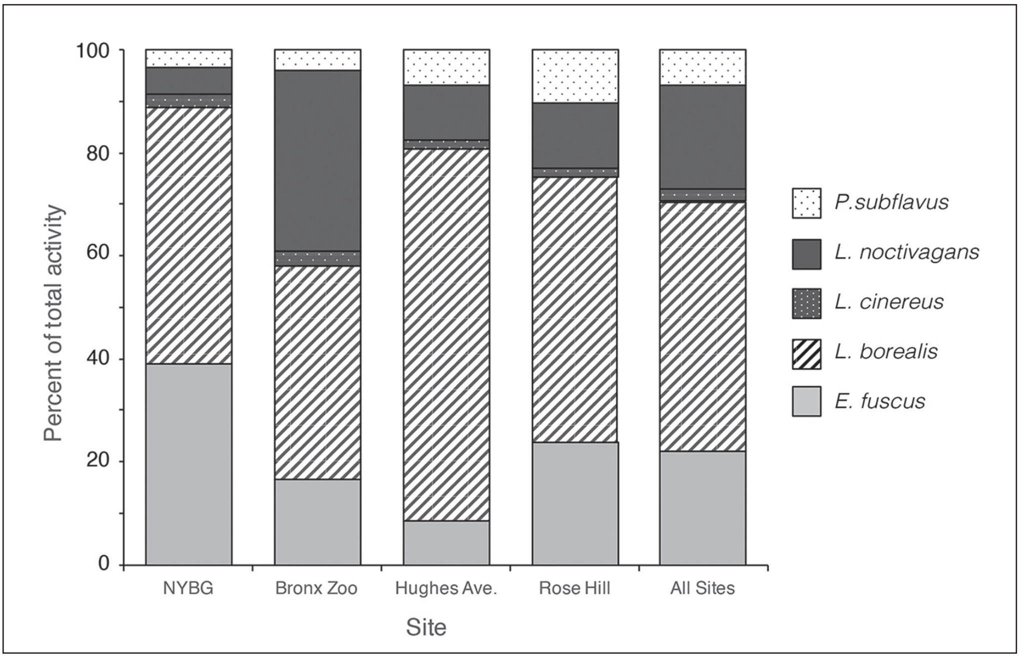

Figure 2. Proportion of total activity using the Miller activity index (the number of 1-minute periods in which a bat is present) recorded 1 May 2012–15 February 2013 for each bat species at 4 sites in the Bronx, NY.

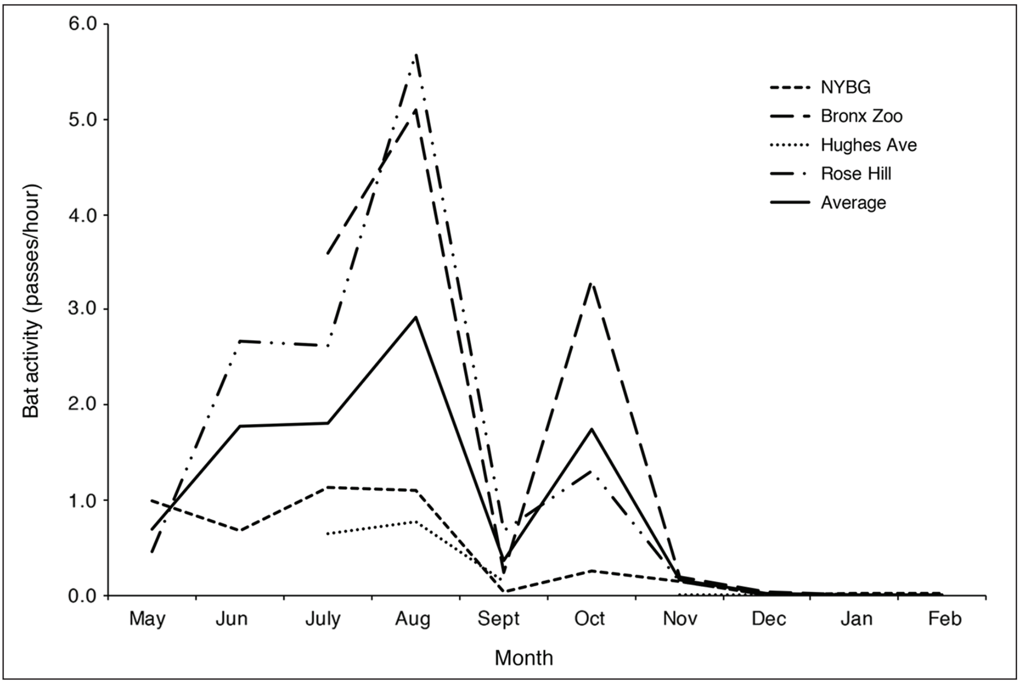

Figure 3. Average bat activity (passes/hour) from passive acoustic-recording devices at 4 sites in the Bronx, NY from 1 May 2012–15 February 2013. NYBG = New York Botanical Garden.

Big Brown Bat activity also peaked in August. In October, there was a substantial increase in activity by Silver-haired Bat, and this species had higher activity levels than any other species in October and November. Hoary Bat and Tri-colored Bat activity levels were low overall.

Winter activity

We followed Cryan (2003) and considered December, January, and February as the winter months for bats in the US and Canada. In December, we recorded 11 passes (1 at NYBG, 10 at the Bronx Zoo), 3 in January (all at NYBG), and 2 in February (both at NYBG). All identifiable winter bat activity was from tree bats; we recorded passes by Eastern Red Bat and Silver-haired Bat in December, and

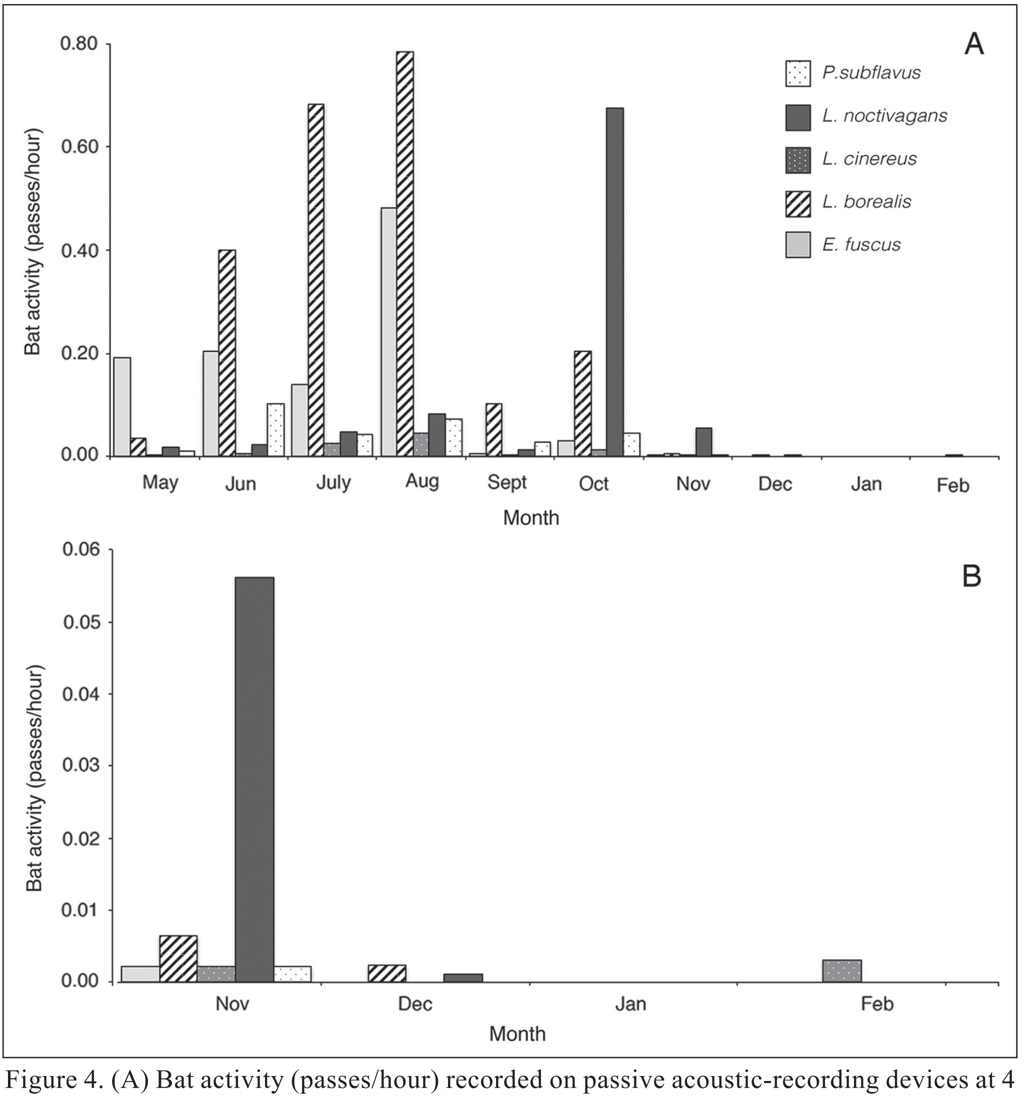

Figure 4. (A) Bat activity (passes/hour) recorded on passive acoustic-recording devices at 4 sites in the Bronx, NY from 1 May 2012–15 February 2013. (B) Subset of data: 1 December 2012–15 February 2013.

Hoary Bat in February. The December recordings fell into both the low- and high-frequency clades (5 and 6 passes, respectively), while all January and February recordings were classified in the low-frequency clade.

Daily high temperatures during the winter sampling dates ranged from -6.7 ºC to 16.1 ºC. The mean high temperature when bat activity was recorded (8.9 ºC) was higher than when bat activity was not recorded (5.6 ºC) (1-tailed *t*-test, $P = 0.03$). We found no relationship between bat activity and daily low temperature (1-tailed *t*-test, $P = 0.19$). Although the mean temperature was higher when bat activity was detected, we recorded bats on both high- and low-temperature days throughout the winter (Fig. 5).

Discussion

Species presence

Of the 9 species that are expected to occur in New York State, we detected the following 5 species in the Bronx during our sampling period: Eastern Red Bat, Silver-haired Bat, Big Brown Bat, Tri-colored Bat, and Hoary Bat. Our prediction that the majority of bat recordings would be from Big Brown Bat was not supported. The majority of the calls we recorded during both active and passive surveys were from Eastern Red Bat*,* and this species had the highest Miller Index at every site. In fact, tree bats—Eastern Red Bat, Silver-haired Bat, and Hoary Bat—made up 70% of all passively recorded calls in this study. This result may be partially explained by the natural history of the species detected and the fact that 3 of the 4 sites were in parks. However, passes from Eastern Red Bat made up the majority (71%) of recorded sequences even at the least vegetated site (Hughes Avenue), while the largest proportion of Big Brown Bats was at a highly vegetated site

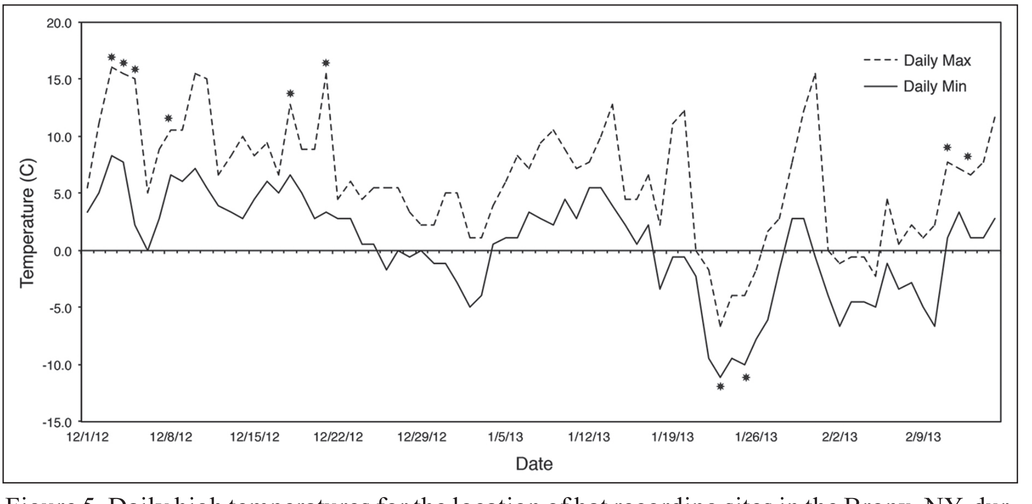

Figure 5. Daily high temperatures for the location of bat recording sites in the Bronx, NY, during winter months (1 Dec 2012–15 Feb 2013). Days on which bat activity was recorded are indicated by "*". The mean high temperature was higher when bat activity was recorded (8.9 ºC) than when bat activity was not recorded (5.6 ºC) (1-tailed *t*-test, $P = 0.03$). There was no relationship between bat activity and daily low temperature (1-tailed *t*-test: $P = 0.19$).

(NYBG). Our results are similar to those from surveys in locations with high densities of buildings in Manhattan, Queens, and the Bronx, where Eastern Red Bat comprised 66% of all passes recorded and tree bats compromised 95% of all passes recorded (Parkins and Clark 2015).

Although other studies have documented the dominance of Big Brown Bat in urban areas (e.g., Damm et al. 2015, Loeb et al. 2008, Ulrey et al. 2005), the landscape of NYC may be particularly well suited for tree bats. Eastern Red Bat is a generalist insectivore (Clare et al. 2009) and adapted to flight in open areas, 2 traits that make it more likely to thrive in cities (Duchamp and Swihart 2008). Other studies found a relationship between tree/vegetation cover and Eastern Red Bat activity in urban environments (Dixon 2011, Li and Wilkins 2014). Since 2007, hundreds of thousands of trees have been planted in NYC as part of the PlaNYC campaign. Twenty-one percent of NYC was covered with tree canopy as of 2010, with the goal of reaching 30% by 2030 (McPhearson 2011, McPhearson et al. 2013). The increasing tree cover in NYC may be conducive to the presence of tree bats. Additionally, the relatively low proportion of Big Brown Bat recordings at Hughes Avenue, compared to higher proportions at the 3 park sites, may be indicative of Big Brown Bat roosting in buildings and flying to parks to forage; this species is known to have a large home range and to fly long distances to feed in higher-quality habitat (Everette et al. 2001).

Little Brown Bat, which previously may have been common in NYC, was not documented in this study. White-nose syndrome (WNS) has greatly reduced northeastern Little Brown Bat populations (Turner et al. 2011); hence, it is not surprising that we did not record this species, particularly because NYC is close to the epicenter of the disease outbreak. Unfortunately, there are no published surveys of Little Brown Bat in NYC prior to the WNS outbreak to which we could compare activity patterns and species presence. Additionally, our lack of confirmation of Little Brown Bat at these 4 sites does not necessarily mean that the species was not present. Little Brown Bat is known to rely on water for foraging on aquatic insects, and only 1 of the 4 passive-recorder locations was near a source of non-moving water. In the future, recording near potential Little Brown Bat foraging habitat using both passive and active surveys to further explore this species' status in NYC would be beneficial.

Temporal activity

Each bat species exhibited distinctive changes in activity level over the course of the sampling period. Big Brown Bat is a common resident in the NYC region, and summer colonies often occur in close proximity to humans due to this species' habit of using buildings for roosting (Agosta 2002, Harvey et al. 2011). Our data also showed steady summer activity by this species. The peak in Big Brown Bat activity in August may indicate either increased foraging activity or movement prior to regional migration to winter hibernacula; this species is known to roost in buildings during the summer and migrate to less-developed areas for the winter (Neubaum et al. 2006). Tri-colored Bat activity was steady, but low, from June through October, suggesting that this species may be a low-density summer resident in NYC. Activity by Hoary Bat, a long distance migrant, was consistently very low, which suggests it may also be a low-density summer resident or migrant passing through NYC.

Hoary Bat was the only species recorded in February. Occurrence records and stable isotope analyses show a southern and coastal migration of this species during the autumn from inland summer ranges (Cryan 2003, Cryan et al. 2014). Most winter *Lasiurus* spp. (hairy-tailed bats) activity occurs below 40° N latitude in regions where winter temperatures do not often dip below freezing (Cryan and Veilleux 2007), and NYC is located on the northern edge of this region. Furthermore, Hoary Bats may be capable of roosting under leaves and surviving periods of freezing temperatures in the winter in a manner similar to Eastern Red Bat (Cryan et al. 2014); hence, we believe individuals of this species are wintering in NYC.

The peaks of bat activity in the late summer and fall, which are driven by increased activity by Eastern Red Bats and Silver-haired Bats, are particularly interesting. Eastern Red Bats disperse to wintering grounds south and east during the autumn, where they roost in trees and leaf litter (Cryan 2003, Cryan and Veilleux 2007) and remain somewhat active (see Boyles 2006). Summer activity by Eastern Red Bats is indicative of a potential summer population, but the increase in activity in July, with a peak in August and sharp decline in September, also suggests migratory movement through NYC. These data are consistent with similar patterns in Eastern Red Bat migratory activity found in other acoustic surveys conducted in the Midwest and East Coast (Johnson et al. 2010, Walters et al. 2006) and documented by Eastern Red Bat mortalities at wind farms (Arnett et al. 2008). A relatively large jump in Silver-haired Bat activity occurred later, in October, which is consistent with the timing of coastal migratory movement of these bats detected by Johnson et al. (2010) and, again, is suggestive of a pulse of bats migrating through NYC. The winter records of both of these species indicate that some individuals are likely also wintering in NYC.

As expected, the average temperature on days we detected bats was higher than days when we did not; however, individual records showed more variation. Two of the days on which we recorded bats were the coldest of the sampling period, at -3.9 ºC and -6.7 ºC. These occurrences were at NYBG, which is a public garden, so it is possible reason that this low-temperature activity resulted from human disturbance at their winter roosts.

Conclusions

This study is the first to document the migratory movement of Eastern Red Bats and Silver-haired Bats through NYC. These species are likely much more prevalent in NYC than previously thought, and Eastern Red Bat is possibly more common than Big Brown Bat, which is contrary to the generally accepted status of bats in NYC. Little is known about tree-bat migration ecology, and our study contributes to the understanding of migration timing and winter ranges for these species. Migration is a critical life stage, during which bats are susceptible to several threats (Cryan and Veilleux 2007). Results of further research on migratory movement of tree bats through urban landscapes should help inform management decisions and conservation planning for these species.

Although our survey added ecological information to our knowledge of bats in NYC, additional surveys are needed. Continued year-round recording should be combined with mist-net surveys, harp trapping, and active recording in a variety of landscapes to gain a fuller picture of the bat species assemblage in NYC. Also, surveys should be expanded to other boroughs and take place in areas of both high and low impervious-surface and building density, as well as in parks of various sizes in order to more thoroughly understand the habitat selection by bats in a North American megacity.

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