Occurrence of a forest-dwelling bat, northern myotis (Myotis septentrionalis), within Canada’s largest conurbation

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Abstract

While some species thrive in urban areas, many are absent from such environments. Those that are successful often have high behavioural flexibility that allows them to exploit new niches in a human-modified landscape. Northern myotis (Myotis septentrionalis) is an endangered bat species rarely identified in urban areas, though it is unclear whether this is due to absence or difficulties in surveying. We investigated the ecology of a population of northern myotis within Canada’s largest conurbation, including reproductive status, roosting preference, and movements. Using capture surveys, we confirmed the presence of reproductive females and healthy juveniles over two seasons. Using radio telemetry and acoustic surveys, we identified a cluster of tree roosts in the centre of the forest, and foraging areas concentrated around waterways within the bounds of the forest. These observations suggest the roosting and movement ecology of this population is similar to that observed for this species in rural environments, despite the urban surroundings. Our results suggest that northern myotis is not a synurbic species but can occur within urbanized environments when suitable habitat is available. We suggest that large forest patches with mature, interior forest cover are likely to be an important resource for northern myotis, and they will be vulnerable to the loss or fragmentation of these features in rapidly urbanizing landscapes. These findings are highly relevant to the ecology and preservation of northern myotis and present a case for greater consideration of this species in urban forests.

Key words: bats, urbanization, urban ecology, radio telemetry, acoustic monitoring

Introduction

Environmental changes associated with urbanization affect all local species and ecosystems (Soulsbury and White 2015). Common negative impacts include the loss and fragmentation of natural land cover, increased light and noise pollution, and changes in available food resources, all of which can cause declines in population size and health, or even extirpation of certain species (McKinney 2002). In contrast, other species can tolerate or even benefit from such changes. The ability of some species to adapt to urban environments is associated with high behavioural plasticity (Lowry, Lill, and Wong 2013). Associated behaviour changes include smaller territories, prolonged breeding seasons and changes in diet and foraging habits; such species are increasingly referred to as ‘synurbic’ (Luniak 2004).

Some bat species occur frequently in urban areas. For example, in North America, big brown bats (Eptesicus fuscus) and—prior to white-nose syndrome related declines—little brown myotis (Myotis lucifugus) are common in urban areas (Barclay and Cash 1985; Geggie and Fenton 1985; Duchamp, Sparks, and Whitaker 2004; Neubaum, Wilson, and O’shea 2007; Coleman and Barclay 2011). These species readily roost in human-built...
structures and forage in city parks and gardens. Species that change their behaviour to roost in anthropogenic structures may benefit from roosting opportunities provided by human development (Thomas and Jung 2019); however, such benefits appear to exist even at relatively low levels of development (Thomas et al. 2021). While some studies have compared such species’ success in urban versus natural landscapes (Geggie and Fenton 1985; Coleman and Barclay 2011), and identified neutral or negative responses, the occurrence of certain bat species in urban areas indicates that they can adapt to such environments. However, most bat species are rarely observed in urban areas, suggesting little tolerance for, or proclivity to take advantage of, the human environment. These inter-species differences in urban adaptability reflect behavioural differences among bat species, and highlight a significant conservation concern for species less able to adapt to the impact of today’s unprecedented global urbanization (Seto et al., 2011) and the potential negative effects on their populations (Jung and Threlfall 2016).

Northern myotis (Myotis septentrionalis) is a 5–8 g species that occurs throughout North America (Simmons 2015), but is not commonly reported in urban environments. Northern myotis is a gleaning bat associated with forest landscapes (Caceres and Barclay 2000) where it prefers to roost in tall trees with mild decay (Sasse and Pekins 1996; Caceres 1998; Jung, Thompson, and Titman 2004). While the species is commonly reported and studied in forest-dominated landscapes (Caceres 1998; Owen et al. 2003; Broders et al. 2006; Henderson and Broders 2008), its occurrence in urban environments has not yet been reported. Northern myotis are an endangered species in Canada (Species at Risk Act, SC 2002, c 29 2002), and have declined in Ontario in recent years (Humphrey and Fotherby 2019).

We investigated the occurrence, roosting preferences and movement of northern myotis in an urban park within Canada’s largest urban area. We aim to address whether northern myotis avoid urban areas, or whether the absence of published observations can be attributed to the difficulty of surveying this species in such environments and low survey effort to date. We used capture and acoustic surveys to investigate the occurrence and demographics of the population within a forest patch, and radio telemetry to identify day roosts and night-time movements of individual bats.

Materials and methods

Study area

Glen Rouge Forest is a 348-ha forest (Toronto and Region Conservation Authority 2015) located in the Rouge River watershed. The forest is within the Greater Toronto Area (GTA), Canada’s largest metropolitan area (2016 population: 5 928 040; Statistics Canada 2017). It contains mature and sizable interior forest landcover, defined as being at least 100 m from the forest edge, which is uncommon in the GTA. Glen Rouge Forest is one of only two patches in the south of the Rouge River watershed to have interior forest cover beyond 200 m from an edge (Toronto and Region Conservation Authority 2015). The forest contains patches of deciduous, coniferous and mixed forest cover, along with swamp close to the waterways (The Ontario Ministry of Natural Resources 2019) (Fig. 1). Most of the forest is dominated by red maple (Acer rubrum), sugar maple (Acer saccharum) and eastern hemlock (Tsuga canadensis), with some red oak (Quercus rubra) and white pine (Pinus strobus) (Toronto and Region Conservation Authority 2015). There is little understory in the forest, the ground cover is limited and highly disturbed and the forest contains a high density of trails in all areas.

The forest is protected from development by steep ravine slopes; it is bordered by subdivisions to the east and west, and a 14-lane highway to the south. The northern edge of the forest is a clear cut hydro corridor. Two waterways pass through Glen Rouge Forest: Rouge River and Little Rouge Creek. The forest incorporates large changes in topography, with up to 25 m change in elevation between river valleys and peaks. Glen Rouge Forest is located in the south of Rouge National Urban Park, which is approximately 80 km² and extends north from Lake Ontario. The wider Rouge River watershed contains ~22% natural cover, including 12% forest, 9% meadow and <1% wetland (Toronto and Region Conservation Authority 2015).

Capture surveys

We undertook 23 trapping surveys within Glen Rouge Forest between 30 May 2019 and 14 August 2019, catching bats with mist nets (Avinet, Portland, Maine, United States). We placed nets on flyways, forest edges and the tops of slopes. Nets were open for ~3 h per night beginning at sunset, and were checked every 15 min. Bats were restrained in cloth bags, which were sterilized in an autoclave between uses, and handled with a new pair of disposable nitrile gloves for each bat.

Captured bats were identified to species using appropriate field guides (Reid 2006; Thorne 2017). Sex, approximate age, weight, forearm length and reproductive status were recorded for each bat (Haarsma 2000) along with a visual inspection of the wings for signs of white-nose syndrome scarring (Reichard and Kunz 2009). We applied a lipped aluminium wing band (Porzana, UK) to each adult northern myotis. We released all bats near the site of capture within 45 min of their removal from the net. We conducted all animal captures and handling in accordance with a detailed animal care protocol, approved by the Toronto Zoo Animal Care and Research Committee. All animal captures took place under the following authorisations: Wildlife Scientific Collectors Permit (1087364), Ontario Endangered Species Act permit (AU-B-013-17) and Parks Canada Research and Collectors and federal Species at Risk Act permits (2019-33239).

Radio telemetry

We used radio telemetry to follow the movements of northern myotis in our study, to identify daily roost locations and areas of forest visited by the bats during the night. In July 2019, we attached 0.29 g coded NanoTag radio transmitters (Lotek, Newmarket, Canada) to five adult northern myotis: one male and four females. Only bats weighing >6 g were selected for tracking, to ensure the mass of the transmitter and glue was <5% of their bodyweight (Aldridge and Brigham, 1988). We attached transmitters using Perma-Type Surgical Cement (Perma-Type Company Inc., Plainville, USA) following the method described by Carter (2009).

We located transmitters using SRX800 receivers with three-element Yagi antennae (Lotek, Canada). Tagged bats were tracked during daytime using homing (Kenward 2001) to identify trees used as roosts, or the approximate location in cases where it was not possible to identify the specific roost tree. To track nocturnal movements, surveyors stayed in close proximity to the bats and estimated their positions using signal strength and bearing measurements. Signal strength varies linearly with the distance between the transmitter and the
receiver. However, signal strength and bearing angles are also affected by local topography, vegetation and the relative position of the transmitting and receiving antennae. To account for this variation, we moved an additional transmitter among known positions in the area of the forest used by foraging bats, while bearings and signal strengths were recorded by a receiver operator who did not know the transmitter’s precise location. We used these measurements to calculate a range of error for distance estimations derived from signal strength, and angle measurements. We plotted the bats’ location during each observation as polygons delimited by the minimum and maximum estimated distance for the recorded signal strength, and the average bearing error using QGIS (QGIS Development Team 2019). We combined these polygons to create a total polygon for all observations to estimate the individual bats’ total range. We did not calculate specific home-range estimates (Kenward 2001) due to the limited scope of our study and size of the dataset.

When we could not locate a tagged bat’s signal, we searched throughout Glen Rouge Forest on foot. For bats that were not located in the forest, we conducted driving transects using an omnidirectional car antenna (Lotek, Canada) in the surrounding areas, searching within a 6 km radius of Glen Rouge Forest that exceeds the likely home-range size for northern myotis (Owen et al. 2003). We also searched suburban neighbourhood parks and trails within this range on foot if vehicle access was not possible. If these searches did not yield a signal, we concluded that the transmitters were either damaged or out of range.

**Acoustic surveys**

To understand how activity of northern myotis varied within Glen Rouge Forest, we conducted acoustic surveys to collect observations throughout the study area. We used QGIS (QGIS Development Team 2019) to overlay a 500 m grid on Glen Rouge Forest, aligned with the hydro corridor at the northern boundary, and sampled bats acoustically in each cell that fully or partially overlapped the site. Data were collected within each grid cell (n = 21) for 10 consecutive nights to account for nights with sub-optimal weather conditions. The distances between sample locations varied depending on the availability of suitable acoustic surveying locations. We collected data concurrently in three plots at a time during a total of seven monitoring periods between 14 May 2019 and 23 July 2019. The sampling order was determined using a random number generator.

Acoustic data were collected using Anabat Swift full spectrum acoustic recorders with omnidirectional microphones (Titley Scientific, Brendale, Australia) installed on forest edges and flyways. Recorders were programmed to monitor from 30 min prior to sunset until 30 min after sunrise, and to trigger and record sounds using the following parameters: firmware version = 1.0, sensitivity = 15, minimum frequency = 10 kHz, maximum frequency = 250 kHz, minimum event = 2 ms, trigger window = 2 s, sample rate = 320 kHz, analogue high pass filter = on, maximum file length = 8 s. Microphones were installed approximately 3 m above ground level on tree trunks, with a pole.
to hold the microphones 0.5 m away from the tree in an area free from obstructions to maximize acoustic detection.

Acoustic data were analysed using the SonoBat suite of automated processing tools (Szewczak 2019). We used the SonoBat noise scrubber to filter files that did not contain bat tonal features (settings: high grade, 20 kHz and above), then used the ‘northnortheastern US and southern Ontario’ classifier in SonoBat to assign species identifications to each remaining file (settings: acceptable call quality: 0.6, sequence decision threshold: 0.9, maximum number of calls to consider: 32, automatic filtering). To remove false positives, we reviewed all files identified as containing northern myotis calls and manually vetted identifications. There is high overlap between the call characteristics of bat species within the Myotis genus, including between northern myotis and little brown myotis, which is also present in Glen Rouge Forest (Thorne, unpublished data 2018). We distinguished northern myotis through the presence of a higher start frequency, steeper upper and lower slopes, and shorter duration (Humboldt State University Bat Lab 2011). Where we could not confidently distinguish between northern myotis and little brown myotis, we labelled the observation as Myotis spp.

We used a custom package ‘batr’ (Thorne 2021) in R (R Core Team 2019) to extract GUANO metadata from processed files, and calculate species activity at each site. We measured species activity as the number of distinct acoustic observations that occurred throughout the monitoring period, with an observation defined as a sound file containing a sequence of at least three identifiable bat calls. We used QGIS (QGIS Development Team 2019) to generate heat maps with a radius of 500 m to match the resolution of our sampling grid.

## Results

### Trapping survey

We captured seven northern myotis in 2018 and nine in 2019, including all sex and age classes, and 10 reproductive adult females (Table 1). None of the captured bats displayed any detectable wing-scarring that could result from white-nose syndrome.

### Acoustic monitoring

We collected acoustic data in a total of 20 grid cells (data from one cell were lost due to equipment failure). We recorded a total of 329 acoustic observations of northern myotis between 14 May 2019 and 23 July 2019. The species occurred in all 20 grid cells, with limited areas of damage or decay, except for one roost in a pine. Roosts appeared to occur primarily in living, healthy trees.

| Date          | Age Class | Sex | Reproductive Status | Weight (g) | Radio-Tracked? | Transmitter No. |
|---------------|-----------|-----|---------------------|------------|----------------|-----------------|
| 10 July 2018  | A         | F   | Post-lactating      | 6.5        | Yes—roosts only |                 |
| 10 July 2018  | A         | F   | Post-lactating      | 6          |                 |                 |
| 12 July 2018  | J         | F   | –                   | 4.5        |                 |                 |
| 13 July 2018  | J         | M   | –                   | 5          |                 |                 |
| 13 July 2018  | J         | M   | –                   | 7.5        |                 |                 |
| 17 July 2018  | A         | F   | Post-lactating      | 7          | Yes—roosts only |                 |
| 17 July 2018  | A         | F   | Post-lactating      | 6.5        | Yes—roosts only |                 |
| 18 June 2019  | A         | F   | Pregnant            | 8          |                 |                 |
| 21 June 2019  | A         | F   | Pregnant            | 8.5        |                 |                 |
| 9 July 2019   | A         | F   | Post-lactating      | 8          | Yes—roosts and foraging | 3 |
| 9 July 2019   | A         | M   | Active              | 7.5        | Yes—roosts and foraging | 4 |
| 11 July 2019  | A         | F   | Post-lactating      | 8          | Yes—roosts and foraging | 2 |
| 15 July 2019  | A         | F   | Post-lactating      | 8          | Yes—roosts and foraging | 1 |
| 15 July 2019  | A         | F   | Post-lactating      | 8          |                 |                 |
| 30 July 2019  | A         | M   | Active              | 7          |                 |                 |
| 31 July 2019  | A         | F   | Undetermined, had previously bred | 8.5 |                 | 1 |

*Table 1: Select biometric data for individual northern myotis captured in Glen Rouge Forest in 2018 and 2019*
though the number of observations in each cell varied from 1 to 54 (mean: 16.45, SD: 14.45) (Fig. 4). Activity was highest in the meadow surrounding the Rouge River in the southwest of Glen Rouge Forest. Higher acoustic activity also occurred in close proximity to the roosts, along Little Rouge Creek on the northeast of the forest, and at recorders in the southeast extent of our sample grid, the other side of Highway 401, which has 14 lanes of traffic in this section.

During our acoustic monitoring, we also collected the following acoustic data for other bat species (numbers given as total acoustic observations throughout all study periods): 9219 big brown bat ($E. fuscus$), 111 eastern red bat ($Lasiurus borealis$), 1552 hoary bat ($Lasiurus cinereus$), 1274 silver-haired bat ($Lasionycteris noctivagans$), 54 little brown myotis ($M. lucifugus$), 6 tri-coloured bat ($Perimyotis subflavus$) and 878 classified as unidentified Myotis.

### Discussion

Our investigation describes the ecology of northern myotis in a forest patch that is highly disturbed by human visitation and located within a densely developed part of Canada’s largest urban area. The northern myotis population appears to be healthy and reproductively active. However, despite the proximity of the urban landscape, our observations suggest the population does not exploit the anthropogenic environment, e.g. by roosting in human-built structures or foraging within the urban development beyond the forest boundaries. In contrast, multiple big brown bat and at least one little brown myotis colonies have been recorded in buildings within the park (Parks Canada, unpublished data 2019). We found that while roost switching occurred frequently, northern myotis repeatedly chose to roost in tree roosts in the forest interior. Similarly, the bats in our
study travelled short distances through the forest to fly over rivers and meadows but did not enter the wider urban area.

The data presented in this investigation are relatively narrow in scope. Our radio telemetry data presents a snapshot of activity by a small number of individuals during a single period of their annual cycle: the post maternity period. The population’s spatial ecology could vary outside of this period, and additional telemetry or acoustic data collection would aid in understanding any seasonal changes. Our acoustic data collection was limited to the forest itself by practical constraints, and acoustic sampling is further limited by the challenges of attaining conclusive recordings of this quiet, high-frequency species. The numbers of acoustic observations of northern myotis we recorded were low, even from a recorder located < 100 m from several known roosts. This, combined with the large proportion of myotis observations that could not be identified beyond genus, suggests that acoustic monitoring alone is insufficient for this species.

Despite these limitations, our data conclusively show that northern myotis can occur in a disturbed forest near intensive urban development, despite the lack of reported observations in such environments. However, the population in Glen Rouge Forest is inevitably exposed to multiple anthropogenic stressors not experienced by their rural conspecifics. The dense suburban development, the road network surrounding the forest and the neighbouring 14-lane highway are all sources of stimuli known to disturb other bat species, such as traffic noise (Jones 2008; Siemers and Schaub 2011) and light pollution (Rowse et al. 2016). Within Glen Rouge Forest itself, recreational use is extensive causing disturbance including: a high density of trails, extensive trampling that suppresses forest understory and ground cover, and introductions of invasive species. While our investigation did not seek to quantify the impact of these urban stressors on northern myotis at Glen Rouge Forest, all captured individuals fell within normal weight and size parameters for the species, had no wing scarring suggestive of recent recovery from white-nose syndrome and most adults were reproduc tively active.

The ability of northern myotis in our study to tolerate anthropogenic disturbance within and around the forest suggests these factors alone are not the reason that this species is infrequently observed in urban environments; instead, it may be specific characteristics of Glen Rouge Forest that make it habitable. We did not observe any direct exploitation of the urban environment by northern myotis, which did not appear to behave like 'synuric' species that respond to urban environments through behavioural plasticity (Luniak 2004; Thomas and Jung 2019; Thomas et al. 2021). Instead, the bats appear to depend on features of the forest itself. For example, despite the availability of a wide range of anthropogenic structures, bats in our study roosted exclusively in trees, consistent with behaviour reported in other populations (Caceres and Barclay 2000; Owen et al. 2003; Broders and Forbes 2004; Jung, Thompson, and Titman 2004; Wisconsin Department of Natural Resources 2013).

Figure 3: Foraging areas of three female (transmitters 1-3) and one male (transmitter 4) northern myotis radio-tracked between 10 July 2019 and 21 July 2019 (purple-shaded areas) within Glen Rouge Forest in Rouge National Urban Park (boundary in black), polygons incorporate all location estimates with error during foraging periods. Map data: © OpenStreetMap contributors, SRTM | Map display: © OpenTopoMap (CC-BY-SA)
Northern myotis have been observed roosting in artificial structures (e.g., Sasse and Pekins 1996; Foster and Kurta 1999; Cruz, Ward, and Schroder 2018); however, such behaviour remains rare for maternity colonies. Similarly, radio telemetry data suggest that bats in our study remained within the forest boundaries during the night. Individuals travelled approximately 500–800 m from their roost trees to visit areas over the Rouge River or Little Rouge Creek. This behaviour closely parallels that observed in studies of rural populations (e.g., Caceres and Barclay 2000; Henderson and Broders 2008).

Beyond choosing natural roosts, northern myotis in our study exclusively selected roost locations near the centre of the forest and away from forest edges: this, combined with their apparent reluctance to leave the forest during the night, suggests that patch size could be important to the population’s success. Interior forest offers a refuge from anthropogenic stressors in the urban environment that surrounds Glen Rouge Forest, such as light and noise pollution. Mature interior forest is also likely to contain trees in a range of decay states, offering a wide choice of roosts to a cavity roosting species (Jung, Thompson, and Titman 2004). A study by Henderson and Broders (2008) identified patch size as the strongest factor affecting the distribution of female northern myotis in the forest-agricultural landscape of Prince Edward Island, Canada.

If large forest patches, incorporating interior forest well away from edges, is required by northern myotis, this has strong implications for the conservation of the species in a rapidly changing landscape such as that surrounding Toronto. Large areas of continuous forest, and interior forest, are already rare in this region and are likely to become rarer and more fragmented as the human population grows and urbanization continues. Species such as the Acadian flycatcher, which specialize on interior forest, are expected to decline as habitats become more fragmented (e.g., Bender, Contreras, and Fahrig 1998; Hoover, Tear, and Baltz 2006). A similar requirement for northern myotis would mean its long-term survival is dependent on the preservation of suitable areas of habitat for it to occupy. This is particularly important following the national decline of this species due to white-nose syndrome (Canadian Wildlife Health Cooperative 2015): if northern myotis can recover from this disease, it needs habitat to recover into.

Further study is necessary to refine our understanding of these bats’ interactions with their urban surroundings and the importance of factors such as patch size and interior forest. While acoustic surveys have limitations, it is an easy and non-invasive method to collect preliminary data and direct more intensive survey efforts. Acoustic surveys beyond the boundaries of Glen Rouge Forest would test the implication of our radio telemetry data that suggest northern myotis do not travel outside of the forest during the summer. Acoustic data could also be collected over a longer time to test whether the bats’ spatial ecology varies throughout their active season. These data could also give insight into the relative impact of urban stressors on this species and help to identify priorities for management and conservation actions. Monitoring in other urban forest patches within the range of northern myotis would help to understand the frequency at which this species occurs in urban areas, and further refine factors such as minimum patch size to support its presence. Finally, investigating the population genetics of northern myotis in Glen Rouge Forest would be valuable to assess the population’s genetic health and to better understand any long-term impacts of potential population decline and isolation.
Our study describes a reproductively active population of northern myotis in an urbanized landscape. We suggest that the occurrence of this species, which is not widely reported in urban environments, is related to the presence of suitable habitat such as sufficiently sized patches of mature interior forest, and natural roosting opportunities. We identify several directions for future investigation and conservation of this species: where interior forest has greatly declined in southern Ontario, a better understanding of their population genetics and characterizing their specific habitat requirements can contribute to species conservation and land conservation efforts, particularly in landscapes that are becoming increasingly urbanized.

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Data availability

No data suitable for deposit in a repository were generated during this study. Specific locations of species captures and roosts cannot be shared due to the species status as data-sensitive in Ontario.

Conflict of interest statement: None declared.

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