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**Cover Photograph:** The Boils at McConnell Springs, Fayette County, KY, USA. This artesian spring characterizes the unique karst topography at McConnell Springs, and is one of the hydric habitats assessed for bat activity in the study. Photograph © Keith Harding.
Hydric Habitats are Important to Foraging Bats in the Bluegrass Region’s Urban Parks

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Abstract - Hydric habitats such as riparian areas and wetlands can be valuable resources for bats. These habitats provide corridors for movement, support a rich prey base, and may provide valuable roost locations. In order to better understand the importance of these habitats in urban ecosystems, bat activity was assessed across five sampling locations at two study sites in the Inner Bluegrass region of Fayette County, KY. The hydric habitats assessed included artesian springs and a human-made stormwater wetland at McConnell Springs Natural Area, as well as West Hickman Creek at Veteran’s Park. Activity levels of bats in these habitats were then compared to the surrounding forest habitats by conducting acoustic surveys over 29 nights from May to September of 2012 and 2013. Black-light traps were concurrently deployed on 11 of these nights to assess the abundance and diversity of phototaxic prey. Bats were more active in hydric habitats than in the surrounding forest (P < 0.01). While overall insect abundance was consistent between hydric and forest habitats (P > 0.05), an abundance of Coleoptera and Diptera were observed at the wetland versus other hydric habitats. In addition to structural differences in habitat, availability of these insect prey may have also contributed to the increased activity of bats in the mid-frequency phonic group observed at the wetland. With continued threats of habitat fragmentation, bats may become increasingly dependent upon resources and corridors afforded by hydric areas in urban landscapes. These results underscore the need for management of these habitats as a resource for bats in eastern North America.

Introduction

Riparian areas and other hydric habitats are critical to North American bats. These habitats can be important foraging locations for many species, such as Myotis lucifugus (Le Conte) (Little Brown Bat), Perimyotis subflavus (Cuvier) (Tri-Colored Bat), Eptesicus fuscus (Beauvois) (Big Brown Bat), Lasiurus borealis Gray (Eastern Red Bat), Myotis septentrionalis (Trouessart) (Northern Long-eared Bat), Myotis sodalis Miller and Allen (Indiana Bat), and Nycticeius humeralis Rafinesque (Evening Bat) (Kniowski and Gehrt 2014, Kurta et al. 2005, Schirmacher et al. 2007). Of these, the Indiana Bat is federally endangered (USFWS 2009), and the Northern Long-eared Bat is currently being considered for endangered status (USFWS 2013). Further, hydric habitats have been shown or speculated to be preferred roosting habitats for maternity colonies of Indiana Bats, Evening Bats, and Big Brown Bats in both the Midwest and Appalachian regions of North America (Carter 2006, Kurta et al. 2005, Neubaum et al. 2007). The species known to use

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Manuscript Editor: Brooke Maslo
these habitats for foraging and roosting are found across a wide range of genera, which highlights the importance of these habitats to a variety of insectivorous bats.

Maintaining high-quality aquatic habitat is a concern across much of the urban landscape of North America (Paul and Meyer 2001, Walsh et al. 2005) and is of particular importance to North American bats that may rely upon aquatic habitats for insect prey (Kalcounis-Rüppell et al. 2007). While urbanization may correlate with increased bat presence by providing forested habitat within broader arable landscapes (Gehrt and Chelsvig 2004), urban sprawl is nonetheless a threat to existing forested foraging and roosting habitats used by bats. Development may have positive (or little) effects on individual bat species with varied diets (e.g., Coleman and Barclay 2012, Rollinson et al. 2013), but more generally, richness and diversity of insectivorous assemblages can be reduced in urban systems, and accumulating data demonstrate varied species-level impacts in urban ecosystems (Coleman and Barclay 2012, Dixon 2012, Smith and Gehrt 2010, Threlfall et al. 2012a). Considering this reduction, management initiatives are likely needed both to protect natural areas as resources for bats as well as to mitigate adverse impacts on biodiversity across the globe (Duchamp and Swihart 2008, Threlfall et al. 2012b).

Our objective is to investigate the relationship between bats and hydric habitats in an urban landscape. Our study took place in the Bluegrass Region of Kentucky, where urbanization is known to induce channel instability and lead to watershed degradation (Hawley 2013). Urban development continues to expand across the Bluegrass Region (Price 2011). As such, this study lays a foundation for assessing the impacts of urbanization on bats in the Interior Low Plateau of North America. These data are valuable not only for bat conservation, but also more generally for understanding the importance of urban natural areas for maintaining biodiversity. We expect bats to consistently use hydric habitats more than the surrounding forest habitat and, following expectations of ecomorphology (Lacki et al. 2007, Smith and Gehrt 2010), we hypothesize the greatest detection of low- and mid-frequency echolocators will be in the open-canopy habitat of a wetland and that greater detection of higher-frequency echolocators (Myotis spp.) will be in closed-canopy habitats (including an artesian spring and stream corridor). We expect activity patterns for all bats to positively relate to a presumably higher abundance of insect prey found in hydric habitats.

Field-site Description

The study was conducted in Fayette County, located in the Inner Bluegrass of Kentucky (Level IV Ecoregion). The area is known for its limestone bedrock, fertile soils, and relatively flat landscape with typical topographic relief of 15–46 m. Originally characterized by savanna woodlands, much of this region has been converted to agricultural and industrial use, with most remaining deciduous forest occurring in or near riparian zones (Woods et al. 2002).

Sampling took place at two study sites managed by the Lexington-Fayette Urban County Government. McConnell Springs Nature Park (38°03'17.9"N, 84°31'40.1"W) is a ~11-ha natural area surrounded by urban development (LFUCG...
Parks and Recreation 2014b) and bordered by railroad tracks and an industrial park. While several previous owners used the land primarily for agriculture, McConnell Springs became protected as a city park in 1994 for the purposes of education and recreation. Since that time, restoration efforts have been undertaken to restore the integrity of McConnell Springs’ natural and cultural features (O’Malley 2007). The specific habitats sampled at McConnell Springs included: two locations along a human-made stormwater wetland (0.40 ha in size with a basal area [BA] of 18.9 ± 6.3 m²/ha, completed in winter 2009–2010), two artesian springs (BA of 20.6 ± 5.7 m²/ha), and two trailside locations within the forested interior of the park (BA of 21.8 ± 1.1 m²/ha at survey points). Veteran’s Park (37°57’23.2”N, 84°30’22.2”W ) is a 95.3-ha suburban park with 2.25 km of paved walking trails, numerous mountain biking trails, four picnic shelters, and numerous sports fields (LFUCG Parks and Recreation 2014a, Pinnacle Homeowners Association 2014). The specific habitats sampled at Veteran’s Park included two trailside locations within the forested interior of the park (BA of 21.8 ± 2.3 m²/ha) and two locations along West Hickman Creek, which runs ~1.25 km through the park (BA of 32.7 ± 4.0 m²/ha).

Methods

We conducted acoustic assessments of bat activity and black-light insect trapping concurrently on a monthly schedule from June–August of 2012 and June–October of 2013. While surveys in 2012 were limited to McConnell Springs, efforts were expanded in 2013 to include both McConnell Springs and Veteran’s Park, which were sampled on separate occasions within the same month. In 2012, weekly temperature lows during survey weeks ranged from 11.7 to 17.8 °C with rainfall ranging between 0.00 and 91.7 mm. In 2013, temperatures ranged from -1.67 to 17.2 °C with rainfall ranging between 0.00 and 91.4 mm (University of Kentucky Agricultural Weather Center 2014).

A Song Meter 2 (“Bat+” option, Wildlife Acoustics, Maynard, MA) was used to record echolocation calls of bats from sunset to sunrise over ≥2 consecutive nights at each study site within a month. For a survey, we placed detection systems at single, fixed points at each selected habitat at a study site (n = 3 for McConnell Springs, n = 2 for Veteran’s Park). Detection systems were placed at the edge of hydric habitats, and forest sampling locations were ≥ 50 m from the forest edge (Dodd et al. 2012). Microphones were attached to a 3-m cable and fixed at ~1.5 m in the direction of an open corridor to optimally record an area likely be used by bats. In the case of hydric habitats, we placed microphones so that the zone of detection covered as much of the air space above the water as was possible. We collected full-spectrum data for these surveys using the default settings and a rate of 16,000 samples/second. Data were downloaded and converted to zero-crossing format using Kaleidoscope v.1.2 (Wildlife Acoustics, Maynard, MA). These data were then analyzed using Bat Call Identification v. 2.6a (BCID; Kansas City, MO; Allen et al. 2011, Romeling et al. 2012). Using the software’s reference library for species in Kentucky, we analyzed files containing ≥5 echolocation pulses. This identification procedure yielded total numbers of echolocation pulses and “passes”
(discrete strings of pulses in a recording) for overall bat activity and phonic groups (low, mid-, and high, or “Myotis” frequencies as defined by BCID). A 70% confidence level was used for identification of phonic groups. To maximize autocalibrator accuracy, we additionally examined acoustic data using Kaleidoscope Pro v. 2.1.0 (hereafter Kaleidoscope; Wildlife Acoustics, Maynard, MA), similarly basing analyses on files containing ≥5 echolocation pulses and using the software’s reference library for species in Kentucky. We then assigned the resulting species identifications (based on a “0”-setting for sensitivity and accuracy) to the same phonic groups generated by BCID. For both identification programs, the numbers of passes recorded per night within phonic groups were considered for subsequent statistical analysis.

Concurrent with acoustic surveys, we used black-light traps (10-watt Universal Light Trap, Bioquip Products, Gardena, CA) to assess the relative diversity and abundance of nocturnal insects. Similar to the placement of acoustic detection systems, black-light traps were simultaneously placed at single, fixed points for each selected habitat on the same night at a study site. We placed traps at the edge of hydric habitats, and forest sampling locations were ≥50 m from the forest edge (Dodd et al. 2012). All traps were located ≥50 m away from acoustic survey points (Dodd et al. 2012), suspended at 2.5 m, and operated from sunset to sunrise using digital timers (Flexcharge Programmable Timer, Northern Arizona Wind and Sun, Inc., Flagstaff, AZ). We captured insects on a single night during each survey interval for acoustic surveys. A dichlorvos-based insecticide strip killed trapped insects. While black-light traps preferentially sample phototaxic insects (Fayle et al. 2007), these traps are the standard technique for surveying assemblages of nocturnal insects (Southwood 1978) and offer a useful approach for comparing the relative abundance of bat prey items across habitat types (Lacki et al. 2007). Following a trap night, specimens were sorted and placed in cold storage (4 °C) for later identification in the laboratory. We identified insects to order using reference keys (Triplehorn and Johnson 2005) and enumerated them to estimate relative abundance of prey across habitats.

Response variables for bat activity included the passes per detector-night for low-, mid-, and Myotis-frequency phonic groups identified using both BCID and Kaleidoscope. Response variables for insect occurrence included the abundance per trap-night for Coleoptera, Diptera, Lepidoptera, and an “other” category for less numerous insects. We tested response variables for homogeneity of variance using Variance Ratio $F_{\text{MAX}}$ tests, and conducted analyses on log-transformed values when variances were heterogeneous (Sokal and Rohlf 1969). We assessed annual variation and variation between sites using one-way analyses of variance (ANO-VAs) for all response variables. If data varied between years or site, this variation was partitioned out in subsequent analysis as a covariate. If not, data for both years were pooled (Dodd et al. 2012). We then performed ANOVAs for our suite of response variables for acoustic activity and insect occurrence. Main effects in this model included seasonality (by month) and habitat (hydric versus surrounding forest). When models were significant, we used the Fisher’s least significant difference
means-separation procedure to evaluate effects (SAS 2002). The means-separation procedure was considered significant when the α-level was \( P \leq 0.05 \); summary statistics are presented as mean ± standard error.

**Results**

Acoustic surveys spanned 29 nights from June to October, resulting in 48 detector-nights (excluding equipment malfunctions). No differences were observed between years or sites for any phonic grouping (\( P > 0.05 \)), save an annual effect observed for the low-frequency phonic group identified using Kaleidoscope (\( F_{1.46} = 6.5, P = 0.01 \)). In this case, fewer low-frequency bat passes per night were recorded in 2012 (31.4 ± 12.5 passes/night) versus 2013 (77.2 ± 21.3 passes/night). The model for the mean passes per night of the low-frequency phonic group was significant using both BCID (\( F_{9,38} = 7.11, P < 0.01 \)) and Kaleidoscope (\( F_{9,38} = 5.95, P < 0.01 \)). For both models, habitat and seasonality were significant but the interaction between these main effects was not (Fig. 1). Models for the mean passes per night of the mid-frequency phonic group were significant using both BCID (\( F_{9,38} = 5.41 \),

![Figure 1. Variation in the activity of bats in the low-frequency phonic group. Different letters within a data series indicates significance (\( P \leq 0.05 \)).](image-url)
$P < 0.01$) and Kaleidoscope ($F_{9,38} = 6.38, P < 0.01$), but only for a habitat effect (Fig. 2). Finally, models for the mean passes per night of the *Myotis* phonic group were significant for both BCID ($F_{9,38} = 15.01, P < 0.01$) and Kaleidoscope ($F_{9,38} = 11.35, P < 0.01$), with habitat, seasonality, and the interaction between these main effects being significant (Fig. 3). Across all phonic groups, bat activity was significantly higher in hydric habitats than in non-hydric habitats, and bat activity peaked during the middle months of our surveys (Figs. 1–3). Activity patterns for the varied phonic groups appeared to differ across hydric habitats when comparing BCID and Kaleidoscope (Fig. 4). Even so, both BCID and Kaleidoscope analyses indicated a consistent general trend of heightened activity of the mid-frequency phonic group at the wetland versus other hydric habitats.

Black-light surveys for nocturnal insects spanned a total of 11 nights ($n = 30$ trap-nights). Over two-thirds of the 19,458 insects captured consisted of Coleoptera, Diptera, and Lepidoptera. There were no differences between sites, habitats, and seasons ($P > 0.05$), but more insects were captured per night in 2012 than in 2013 ($1145 \pm 294$ versus $318 \pm 52$ insects / trap, $F_{1,25} = 9.45, P < 0.01$). Within

![Figure 2. Variation in the activity of bats in the mid-frequency phonic group. Different letters within a data series indicates significance ($P \leq 0.05$).](image-url)
the hydric habitats surveyed, however, variation was observed for common insect orders (Fig. 5). While Lepidopteran abundance was similar across these habitats, Coleoptera and Diptera appeared to be more abundant at the wetland habitat.

**Discussion**

Numerous studies have linked forested riparian habitats to bat foraging and roosting in eastern North America (Carter 2006, Dodd et al. 2008, Kniowski and Gehrt 2014, Kurta et al. 2005, Neubaum et al. 2007, Schirmacher 2007), and we found the positive association between hydric habitats and heightened bat activity extends to an urban landscape. Our results demonstrate greater activity of bats across all phonic groups in hydric habitats versus surrounding urban forest. These results underscore data collected elsewhere around the globe (Threlfell et al. 2012a, b) and stress the importance of management efforts to protect such habitats for the purposes of bat conservation. While forest patches are important habitats for bats in urban landscapes (Johnson et al. 2008), our data further suggest that hydric habitats in these forest patches are particularly

![Figure 3. Variation in the activity of bats in the Myotis phonic group. Different letters within a data series indicates significance ($P \leq 0.05$).](image)
Figure 4. Variation in activity of bats recorded across hydric habitats.

Figure 5. Variation in abundance of insects captured across hydric habitats.
important for foraging bats.

Our results also suggest a trend in the activity of mid-frequency echolocators across hydric habitats, with results from BCID and Kaleidoscope consistently estimating the activity of this phonic group to be concentrated at the stormwater wetland at McConnell Springs. This habitat provided a sizeable canopy gap (0.4 ha) and abundance of forest edge (LFUCG Division of Water Quality 2014). Mid-frequency echolocators (a phonic group including the Eastern Red Bat, Evening Bat, and Tri-Colored Bat) are known to utilize such canopy edges and gaps (Lacki et al. 2007), and dietary preferences of this phonic group also support our observations of high activity at the wetland habitat. Tri-Colored Bats have a preference for Dipteran prey, which would likely be abundant by the stagnant waters of an urban wetland (Carter et al. 2003, Yadav et al. 2012). And, while our spatial replication was limited to only a single survey location per hydric habitat for placement of acoustic detectors and black-light traps, our observations for prey abundance corroborate this. Further, both the Eastern Red Bat and Evening Bat in the region are known to prey heavily on hard-bodied insects, such as Coleoptera and Hemiptera (Dodd 2010, Feldhammer et al. 2009, Whitaker and Clem 1992). Trends for Coleoptera in our study suggest this prey group was also highly abundant at the wetland survey location, which could further contribute to our observations for activity of mid-frequency echolocators.

Activity in the low-frequency phonic group (including Lasionycteris noctivagans Peters [Silver-haired Bat], Lasiurus cinereus [Beauvois] [Hoary Bat], and the Big Brown Bat) were inconsistently reported across hydric habitats by BCID and Kaleidoscope. These results are valuable as an illustration of the ongoing concerns associated with using automated software programs to identify the echolocation calls of bats (Janos 2013), and likely also reflect limitations in our study design (i.e., the need for spatial replication across the types of hydric habitat). While results from BCID suggested relatively similar levels of activity of low-frequency echolocators across hydric habitats, results from Kaleidoscope suggested heightened activity of this phonic group at the streamside survey location. Thus, despite low-frequency echolocators being widely reported to forage in open, uncluttered habitats (Lacki et al. 2007), we found only limited support for this suspicion. However, members of the low-frequency phonic group (i.e., Big Brown Bat and Silver-haired Bat) are among the most common bats recorded in urban environments (Gehrt and Chelsvig 2004, Johnson et al. 2008). Further, Smith and Gehrt (2010) noted that activity of Big Brown Bats was not predictable in regard to microhabitat parameters measured at parks in the Chicago metropolitan area. As such, it is possible that the commonality of these bats may have contributed to our ubiquitous observations across hydric habitats.

Similar to results for low-frequency echolocators, we found varied, albeit reduced, estimates of activity of the Myotis phonic group between the two acoustic software programs considered in our study. However, species within this genera are known to use a variety of forest habitats (Lacki et al. 2007), and while we expected to find a greater general affiliation of this species group with closed-canopy
forested and hydric habitats, this suspicion was not confirmed.

Our study is not exhaustive, and our design possesses the biases associated with acoustic monitoring for bats and with using only a single approach to index prey availability (Lacki et al. 2007). However, our study provides clear evidence that hydric habitats are important to insectivorous bats in the Bluegrass Region throughout their active period. This study provides a benchmark for subsequent research which should further investigate how different types of hydric features may impact bat activity, as well as how the size and shape of hydric habitats in urban environments may influence their use by foraging bats.

Acknowledgments

This project was funded by the Lexington-Fayette Urban County Government and was made possible by the support of the University of Kentucky’s Forestry Department. The authors thank T. Culbertson for technical assistance, as well as numerous employees at McConnell Springs Natural Area. The authors are particular indebted to Laurie Thomas; without her assistance this project would not have possible. This study is published as Kentucky Agricultural Experiment Station publication number 14-08-033.

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