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Bat-Species Diversity at an Urban–Rural Interface: Dominance by One Species in an Urban Area

Jason P. Damm, Dale W. Sparks, and John O. Whitaker Jr.

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Cover Photograph: Female Evening Bat (*Nycticeius humeralis*) captured at the Indianapolis International Airport Conservation Management Properties. Photograph © Jason Damm.

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Bat-Species Diversity at an Urban–Rural Interface: Dominance by One Species in an Urban Area

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Abstract - To investigate urbanization impacts on a midwestern bat community, we used 9 years of mist-net captures from 10 urban and rural sites on the southwestern edge of Indianapolis, IN, where the percentage of urbanized groundcover within 1.3 km of a net site ranged from 0% to 26%. We used Pearson correlation statistics to examine the effect of urban groundcover on each species' abundance, and the Shannon-Wiener diversity index to quantify species diversity at the study area. To test the effect of urbanization on diversity, we used the percentage of urban groundcover and year to construct linear mixed-models. *Eptesicus fuscus* (Big Brown Bat) was the dominant species at all sites, regardless of degree of urbanization. Percent of urban groundcover was negatively related to bat-species diversity, although 1 species, *Myotis septentrionalis* (Northern Long-eared Bat), showed a positive correlation with urban groundcover. *Perimyotis subflavus* (Tri-colored Bat) and *Myotis lucifugus* (Little Brown Bat) displayed significant negative correlations with the percentage of urban groundcover. *Myotis sodalis* (Indiana Bat) had a negative but statistically insignificant correlation. These data provide land managers with further insight when planning future bat-mitigation strategies.

Introduction

Urbanization has a variety of impacts on wildlife (Duchamp and Swihart 2008, McKinney 2002). Many organisms exhibit declines in abundance due to habitat loss, and overall species composition often trends toward homogeneity (Duchamp and Swihart 2008, Marchetti et al. 2006, McKinney 2006). Urban sprawl has been implicated as a likely factor in the decline of many taxa (Dickman 1987). These observations are concerning given the relatively long-term and potentially permanent effect of urbanization (McDonald et al. 2008, McKinney 2002). Some mammals, however, have demonstrated varying abilities to adapt to urban habitat alterations (Gehrt and Chelsvig 2004, Ordenana et al. 2010).

Bats often serve as reliable indicators of habitat quality and level of disturbance (Gehrt and Chelsvig 2004, Medellín et al. 2000, Sparks et al. 1998). Although some species, such as *Eptesicus fuscus* (Beauvois) (Big Brown Bat), are able to adapt and thrive in an anthropogenically disturbed environment (Gehrt and Chelsvig 2004, Jung and Kalko 2010, Oprea et al. 2009), other species of bats, such as members of the genus *Myotis*, are rarely found in association with humans. Many bat species occur in greater numbers in areas with a greater abundance of natural features. In

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Indiana, all species of bats are of management concern due to an overall decrease in abundance (Whitaker et al. 2002). Impacts of urbanization on bats indicate that species diversity declines as a function of urban area (Gehrt and Chelsvig 2004, Kurta and Teramino 1992, Sparks et al. 1998).

We used a long-term data set to study the impacts of urbanization on a community of bats located near the Indianapolis International Airport (IND) near Indianapolis, IN. Studies at this site (including regular monitoring of the site with mist-nets) began in 1991 as a direct result of expansion of IND, and these data provide a baseline for work that is still underway (Sparks et al. 2009). Protection and monitoring efforts targeted at the US federally endangered *Myotis sodalis* Miller & Allen (Indiana Bat) have resulted in the rare combination of a site that contains a strong urban–rural interface and long-term studies of the bat community. In general, the northern half of the site consists of isolated woodlands co-mingled with developed land-classes, while lands to the south of Interstate highway 70 include multiple woodlands in an agricultural matrix.

Within this community, regular mist-net sampling has been completed each year at 10 sites arranged along a medium-sized first-order perennial stream (the East Fork of White Lick Creek [WLC]). These netting data have provided comprehensive information about community structure and have greatly enhanced our understanding of the bat community at the site (Damm et al. 2011, 2014; Sparks et al. 1998; Ulrey et al. 2005; Whitaker et al. 2004), foraging ecology (Duchamp et al. 2004; Sparks et al. 2005a, 2005b; Walters et al. 2007), and roosting habits (Ritzi et al. 2005, Whitaker et al. 2006). Previous studies have indicated that the bat community at this location differs structurally from those at nearby rural sites (Sparks et al. 1998, Ulrey et al. 2005). The goal of our work was to compare the urban and rural portions of the study area to determine if this difference also occurs at a smaller spatial scale along a single stream.

Methods

Study area

The IND (39°42'57", 86°16'07") is situated on the southwestern edge of Indianapolis, a major US metropolis. The study area is located to the southwest of IND on lands purchased by the Indianapolis Airport Authority and bordered by US Highway 40 and Indiana Highway 67 to the north and south, respectively (Fig. 1). Indiana Highway 267 borders the study site to the west. Interstate Highway 70 (I-70) bisects the study site into northern and southern sections; the area north of I-70 is more developed due to a growing warehouse district. The southern half of the area is a matrix of agricultural and residential parcels with many small, scattered woodlots ranging from ~30 to 40 ha in area. All 10 of the net sites used in this study were located along the WLC, which runs north–south through the study area and crosses the site from the east side of Mooresville in the south to the west side of Indianapolis to the north. The banks of WLC are mostly wooded; the dominant species are: *Acer negundo* L. (Boxelder), *Populus deltoides* W. Bartram ex Marshall (Eastern Cottonwood), *Celtis occidentalis* L. (Hackberry), *Platanus occidentalis* L. (American

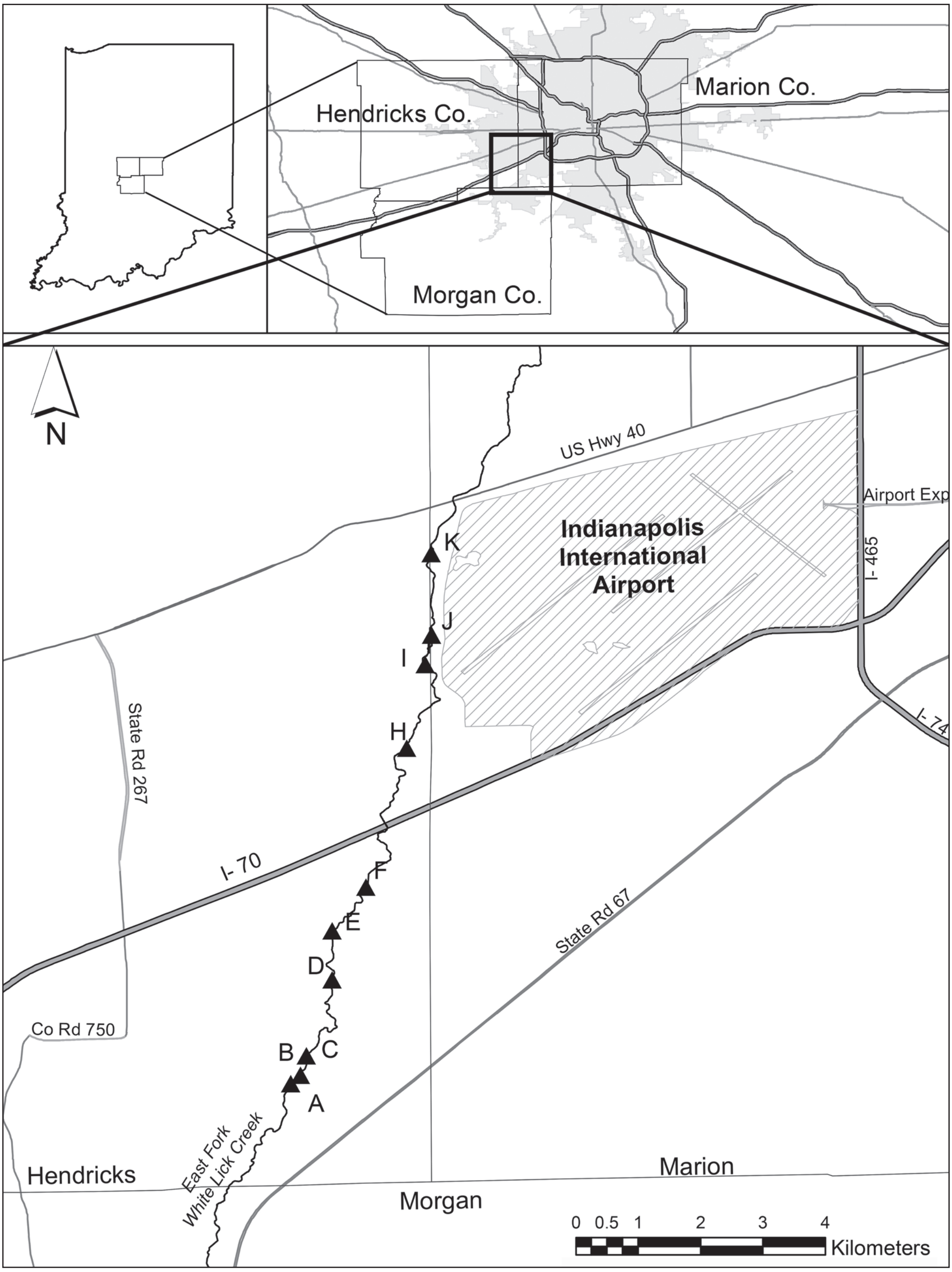

Figure 1. Location of the study area within the state of Indiana (top left) and greater Indianapolis Metroplex (top right). Bottom shows an overview of the study area, with major roads and the East Fork of White Lick Creek. Net sites are labeled and denoted by black triangles. Thatched area represents the Indianapolis International Airport (IND). Net sites A–F were located south of Interstate 70, and net sites H–K are to the north.

Sycamore), *Fraxinus pennsylvanica* Marshall (Green Ash), and *Juglans nigra* L. (Black Walnut). Most open areas are either cultivated or developed. The woodlots that are not adjacent to the WLC are dominated by Black Walnut, *Carya cordiformis* (Wangenh.) K.Koch (Bitternut Hickory), *Carya ovata* (Mill.) K. Koch (Shagbark Hickory), *Carya laciniosa* (Michx. F.) G. Don (Shellbark Hickory), *Quercus rubra* L. (Northern Red Oak), *Quercus alba* L. (White Oak), *Acer saccharum* Marshall (Sugar Maple), *Gleditsia triacanthos* L. (Honey Locust), and *Ulmus americana* (American Elm). A detailed description of WLC is provided in Ritzi et al. (2004). As part of the airport's mitigation procedures, they are purchasing adjacent properties and establishing small 4–10-ha (10–25-ac) woodlots along the WLC.

Mist-netting

The bat community was sampled annually from 15 May–15 August during the period 2002–2010. Mist-netting was conducted for 2 primary reasons: (1) to monitor and annually assess the overall bat community near the airport and (2) to radio-tag Indiana Bats to obtain roosting and foraging data. Standardized data taken from every bat included species and sex, age (adult or juvenile), reproductive status, length of right forearm (mm), and body mass (g). Each individual also received an individually numbered aluminum wing band (Porzana Ltd., East Sussex, UK) placed on the right or left forearm for male and female, respectively.

Netting sessions were conducted at 10 semi-permanent sites along WLC—4 north and 6 south of I-70. Each of these sites was sampled evenly. On each net night, 2 mist nets were placed in such a way as to funnel the bats along the flyway. All nets were set in place by dusk (~2100 h) and consisted of 2- and/or 3-tier 9 m x 2.6 m mist nets. Nets remained in place until at least 0115 h, unless adverse weather required them to be taken down earlier.

Habitat analysis

We created 1.3-km-diameter buffers around each net site using MapWindow v.4.8.4. open-source software. We used this buffer because it was the largest size that permitted us to retain independence of samples in the 6 sites—3 north and 3 south of I-70. We omitted from our analyses 3 of the southern sites (A, C, and E) and 1 northern site (J) to avoid overlap. Sites A, B, and C were all within 1 km from one another, so we retained site B a priori. Sites D and F were >1.3 km from one another; however, we removed site E due to overlap with sites D and F. Sites I and J were within 1.3 km of one another, so we retained site I a priori. Using habitat-class maps (updated from those used in Duchamp et al. [2004], Sparks et al. [2005a], and Walters et al. [2007]), we categorized the areas within each buffer as either rural or urban. Urban land-cover consisted of commercial, industrial, and high-density residential zones, as well as major transportation routes (i.e., I-70). We calculated the relative proportions of each of these habitat classes.

Data analysis

We employed the Shannon-Wiener diversity index (H'; Zar 1999) to quantify diversity by net site and by region (north and south of I-70). We report values for all

10 sites to provide data regarding bat captures along WLC, but we did not include sites A, B, D, and J in our statistical analyses. We derived relative evenness (J') by dividing H' by the natural log of the maximum number of species present ($H_{\max}$) to acquire a percentage. We calculated H' and J' in Microsoft Excel 2007.

We used Pearson's correlation statistic (Pearson's r) to test the hypothesis that abundance (the number of individuals for a given species) of each bat species was dependent on the proportion of urban groundcover within 1.3-km-diameter buffers centered on each net site ($n = 6$). We employed Student's t-tests to test the significance of correlations with urban groundcover. We ran the Pearson correlations in R v.2.13.1 (R Development Core Team, Vienna, Austria).

We tested differences in H' using linear mixed-models constructed in the program R v.2.13.1 with the package lme4 (Bates et al. 2008) with full maximum likelihood. We used year and percentage of urban groundcover as independent variables. We set year as a random factor and proportion of urban groundcover as a fixed independent factor; H' values were the dependent variable. We constructed 2 models, 1 including the proportion of urban groundcover and year, and another examining the effect of year with the intercept. We used a chi-square test to compare Akaike's information criterion (AIC) values to determine the model that best fit the data.

Results

One species, the Big Brown Bat, dominated the bat community in the urbanized northern regions surrounding WLC—it accounted for 65–82% of total captures at these sites (Table 1). Big Brown Bats were the most abundant ($n = 956$, 54.6%) bat species captured at the Indianapolis International Airport conservation properties from 2002 to 2010 (Table 1). It was also the most common species netted each year. Thirty-six percent of the total capture consisted of *Perimyotis subflavus* (F. Cuvier) (Tri-colored Bat; $n = 179$, 10.2%), *Lasiurus borealis* (Müller) (Eastern Red Bat; $n = 173$, 9.9%), Indiana Bat ($n = 163$, 9.3%), and *Myotis lucifugus* Le Conte (Little Brown Bat; $n = 115$, 6.6%). Other bats captured annually were *Nycticeius humeralis* (Rafinesque) (Evening Bat; $n = 71$; 4.1% of total captures) and Northern Long-eared Bat ($n = 83$; 4.7%). *Lasionycteris noctivagans* (LeConte) (Silver-haired Bat; $n = 6$), *Lasiurus cinereus* (Palisot de Beauvois) (Hoary Bat; $n = 4$), and *Myotis grisescens* A.H. Howell (Gray Bat; $n = 1$) together comprised only 0.6% of the captures and therefore were omitted from analyses.

The urbanized northern region had a much lower H' than the southern region (Table 2). Of all the bats found, a much higher percentage were Big Brown Bats in the north ($n = 457$; 75.8%) compared to the south ($n = 499$; 43.9%). The relative abundance correlation between this dominant species and urban groundcover was not statistically significant ($r = 0.54$, $P = 0.27$). Eastern Red Bat abundance showed no difference between the 2 regions ($n = 64$ and $n = 109$ in the north and south, respectively), representing 9.6% of all bats in the north and 10.6% in the south ($r = 0.20$, $P = 0.70$). The Evening Bat showed no difference between north and south ($n = 5$ and 66, respectively; $r = -0.023$; $P = 0.97$).

Table 1. Total number of each bat species captured in all years (2002–2010), listed by net site. Net sites A–F were located to the rural south of Interstate 70, and sites H–K were located to the urbanized north. All net sites were located along the East Fork of White Lick Creek in Hendricks County, IN.

	Net Site											
	Southern, rural sites						Northern, urbanized sites					
	A	B	C	D	E	F	H	I	J	K	Total south	Total north
Percentage urban groundcover within 1.3 km	2.0	0.0	0.0	0.0	0.0	5.6	21.3	18.1	21.1	26.4		
Big Brown Bat	18	105	96	32	226	22	118	130	122	87	499	457
Tri-colored Bat	23	19	20	25	56	18	5	2	10	1	161	18
Eastern Red Bat	6	17	20	16	38	12	14	13	17	20	109	64
Indiana Bat	82	12	28	7	18	7	3	0	2	4	154	9
Little Brown Bat	34	8	26	18	13	8	3	3	1	1	107	8
Northern Long-eared Bat	16	2	7	5	7	4	10	8	6	18	41	42
Evening Bat	0	1	1	0	60	4	0	1	2	2	66	5
Silver-haired Bat	1	1	1	0	1	1	1	0	0	0	5	1
Hoary Bat	0	1	0	0	0	2	0	1	0	0	3	1
Gray Bat	0	0	0	0	0	0	0	0	0	1	0	1
Total	180	166	199	103	419	78	154	158	160	134	1145	606

Indiana Bat abundance showed a marginal negative correlation with urban groundcover between north and south (n = 9 and 154, respectivley; r = -0.78, P = 0.070). This species represented 1.5% of captures in the urbanized north and 13.4% in the south. Tri-colored Bat (n = 18 and 161) and the Little Brown Bat (n = 8 and 107) both showed a significant decrease as urban groundcover increased in the north (r = -0.96, P = 0.0025 and r = -0.84, P = 0.036, respectively). Tri-colored Bats represented 3.0% of captures in the north, and 14.1% in the south, while the Little Brown Bat represented 1.3% in the urbanized north and 9.3% in the south.

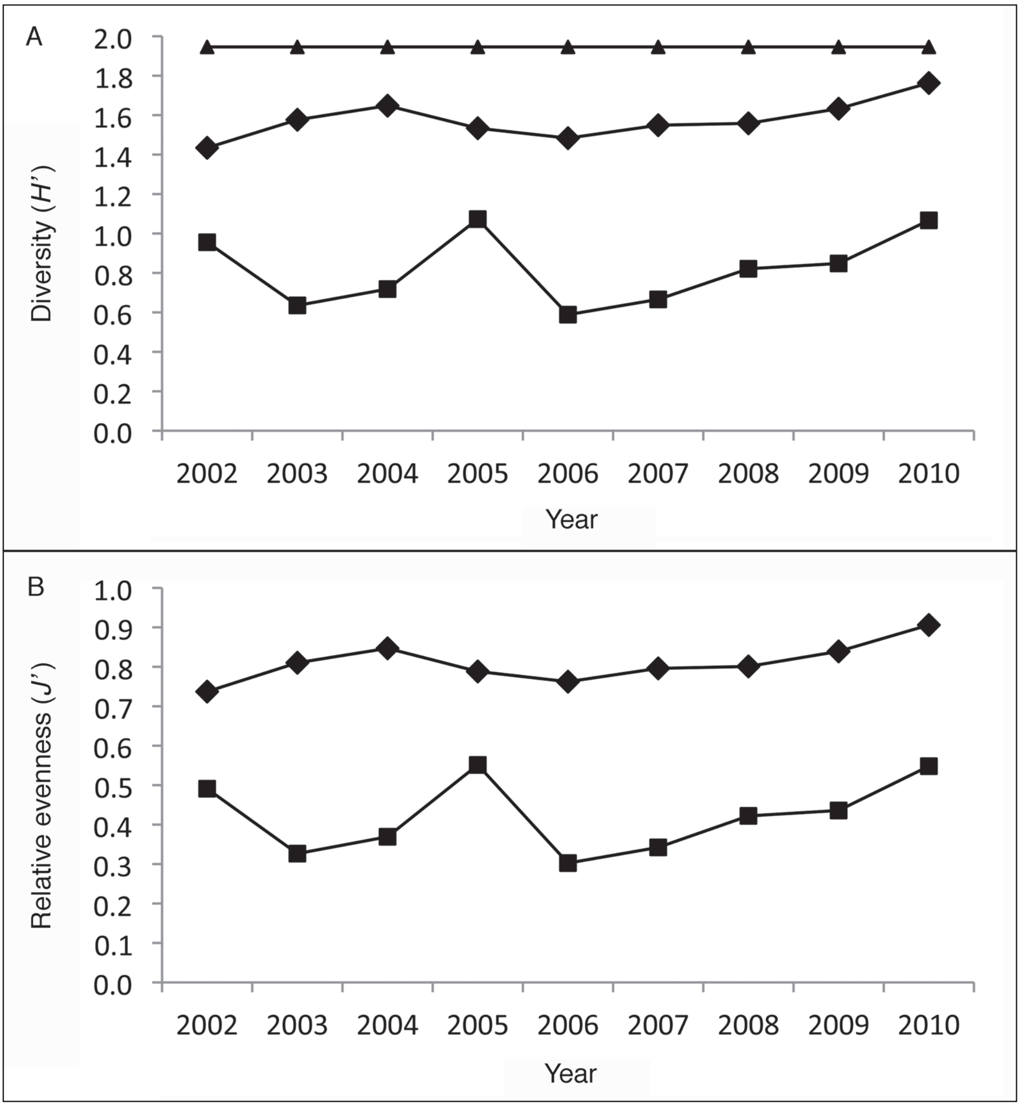

Figure 2. (A) The Shannon-Wiener diversity values (H') by year for the northern urbanized (squares) and southern rural (diamonds) regions of the Indianapolis International Airport conservation properties, Hendricks County, IN. The maximum attainable diversity ($H_{\max}$ = 1.946) is represented by triangles. (B) The relative evenness (J') for the northern (squares) and southern (diamonds) regions.

In contrast, Northern Long-eared Bat abundance was positively and significantly correlated with urban groundcover in the north ($r = 0.90$, $P = 0.015$). The Northern Bat made up 6.9% of captures in the urbanized north ($n = 42$) and 3.6% in the south ($n = 41$).

At our study site, bat diversity was consistently greater in the southern than the northern section (Fig. 2 , Table 2). In all years, southern sites had higher H'-values (range = 1.434–1.763), whereas the northern sites had lower H'-values (range = 0.589–1.073). Overall diversity for all years studied was also greater in the south than the north ($H'_s = 1.641$; $H'_n = 0.898$). J' ranged from 0.737 to 0.906 in the southern region and from 0.302 to 0.551 in the northern region (Fig. 2).

The model that explained the most variance in H' included the percent of urban groundcover and year as opposed to the model that included year alone with the intercept (Table 3). This model had an AIC value of 51.56 and a relative weight of 99.78% (0.9978). The model with urban ground cover removed had an AIC weight of 0.22% (0.00219), and a ΔAIC equal to 12.24. A comparison of the 2 models using a chi-square test showed that the model with urban groundcover was significantly better at explaining the data ($P = 0.0002$).

Table 2. Yearly number of captures and Shannon-Wiener diversity index values (H') for bat netting to the south and north of Interstate 70 at the Indianapolis International Airport. Relative evenness (J') is the value of H' divided by the maximum attainable diversity (H_{max}), measured as the natural log of the species richness (S). Bats captured = the total number of bats captured per year. Seven species were captured annually. We omitted from our analyses the 3 species that were rarely captured: Silver-haired, Hoary, and Gray Bats.

	Region							
	South, rural				North, urbanized			
Year	Bats captured	S	H'	J'	Bats captured	S	H'	J'
2002	130	7	1.434	0.737	42	6	0.955	0.491
2003	121	7	1.577	0.810	62	6	0.635	0.326
2004	114	7	1.648	0.847	62	6	0.718	0.369
2005	113	7	1.534	0.788	85	7	1.072	0.551
2006	126	7	1.483	0.762	56	3	0.589	0.302
2007	111	7	1.549	0.796	60	5	0.666	0.342
2008	116	7	1.558	0.801	79	5	0.821	0.422
2009	127	7	1.633	0.839	69	4	0.848	0.436
2010	179	7	1.763	0.906	88	5	1.066	0.548
Total	1137		1.641	0.843	603		0.898	0.462

Table 3. Models used to explain species diversity relative to year and percentage of urban groundcover from the 9 years studied, 2002–2010. Urban groundcover was derived from 1.3-km buffers around 3 net sites in each region north and south of I-70. Urban groundcover was a fixed factor and year was a random factor in our analysis. The first model contained both percentage urban groundcover within 1.3-km buffers and year. The second model tested the effect of year alone. * denotes the model that explained a significant amount of variation.

Model	AIC	ΔAIC	Relative likelihood	AIC_w
Urban groundcover, Year	51.56	0.00	1	0.997806*
Year	63.80	12.24	0.002198	0.002194

Discussion

Previous studies of the effects of urbanization have shown that some species decline and others thrive in an increasingly urban setting (Marchetti et al. 2006, Ordenana et al. 2010). Marchetti et al. (2006) found that urbanization caused declines in many native fishes in California, while also facilitating the spread of non-native fishes. At the IND, Ritzi et al. (2004) found that fish diversity in the WLC positively increased with distance from urban areas. Ordenana et al. (2010) showed that as proximity to urban areas increased, many species of carnivores declined. Our results coincide with previous reports on the effects of urban landscapes on wildlife (Duchamp and Swihart 2008, Fitzsimons et al. 2011, Marchetti et al. 2006, McKinney 2006, Ordenana et al. 2010). These data show that urbanization likely contributes to the decline of overall diversity, while benefiting a minority of species.

We expected that Big Brown Bats would be abundant relative to other species because this species is often captured and is believed to be the most common bat in Indiana (Whitaker and Mumford 2009). The relative abundance of the Eastern Red Bat was similar in the 2 areas. Relative abundance refers to how evenly a species is spread across the community. Gehrt and Chelsvig (2004) found the Eastern Red Bat had a positive response to nearby industrial and commercial areas. The primary use of foliage for roosting by the Eastern Red Bat could be a reason for no change in abundance between northern and southern regions in this study area as there were plenty of trees in both regions. Eastern Red Bats rarely use man-made structures as roosts; however, they are known to forage near street lamps (Duchamp et al. 2004, Fitzsimons et al. 2011, Geggie and Fenton 1985, Hickey et al. 1996). Northern Long-eared Bat showed a strong positive correlation with urban groundcover. This result could be due to roosting requirements because many Northern Long-eared Bats have been radio-tracked to woodlots in the northern region of the study area where the species extensively roosts in artificial roosts that were placed to provide habitat for Indiana Bats (Sparks et al. 2009). At our study site, this species apparently occupies very small home ranges (Sparks et al. 1998, Whitaker and Sparks 2008), and thus, may be able to survive in small areas of appropriate habitat.

The Indiana Bat, Little Brown Bat, and Tri-colored Bat all showed either a significant decline in abundance relative to urban groundcover or a trend toward significance. Evening Bats were regularly captured at 1 site along a corridor to a known roosting location, so it is likely that the greater southern abundance of this species was not related to urbanization, but to proximity to the roost site (Duchamp et al. 2004).

The Big Brown Bats ability to successfully thrive in both urban and rural environments has been well documented. Menzel et al. (2001) reported preference of rural areas for foraging by the Big Brown Bat in Georgia, but also noted that the species may use intermediately-developed urban landscapes as well. Neubaum et al. (2007) examined characteristics of urban roosts used by Big Brown Bats in Colorado and found that bats were selectively choosing urban roosts based on openings and level of disturbance, and urban roost selection seemed to be analogous to natural roost selection (i.e. trees). Williams and Brittingham (1997) studied urban roosting trends in Pennsylvania and also reported similarities in urban selection to natural. The urban areas surrounding IND have many old homes and buildings that could be used by Big Brown Bats (personal observation), however these areas have not been sampled. In Indiana, Big Brown Bats have been reported as hibernating in heated buildings (Whitaker and Gummer 2000, Whitaker and Gummer 1992, Whitaker 1997). Damm et al. (2014) found female Big Brown Bat capture rates to be similar between urban and rural areas.Thus, it is not surprising that I found no correlation between abundance of that species and urban groundcover in this study.

These results suggest that some bat species seem to be more able to cope with a heavily modified anthropogenic landscape and occur in a greater abundance in these sites, while other species show declines in numbers relative to urbanization. In all years examined, the more urbanized northern region was consistently dominated by the Big Brown Bat. Jung and Kalko (2010) found that species of bats in Panama also showed species-specific land use with respect to urban–forest interface. Duchamp et al. (2004) examined foraging areas used by the Big Brown Bat and Evening Bat at this site in Indianapolis. They found that the Evening Bat showed more fidelity to a foraging patch than the Big Brown Bat. Perhaps of greater importance in this study was their finding that the Big Brown Bat used some low-density residential areas for foraging. Additionally, Duchamp and Swihart (2008) found greater bat diversity as urban area decreased and the total forested area increased in north-central Indiana along the Upper Wabash River Basin (~100 km to the north of our study site).

Although our results suggest that urbanization plays a role in bat-species diversity, richness, and abundance at this study site, urban groundcover alone is probably not the only factor involved. Much of the difference in bat-species richness (the number of species in an area) can likely be attributed to specific roosting and foraging requirements. Many of the bat species in this study roost in natural situations (i.e., trees); however, the Big Brown Bat is well known to use anthropogenic roosts such as warehouses and residential buildings (Duchamp et al. 2004, Neubaum et al. 2007, Whitaker and Gummer 1992, Whitaker et al. 2006, Williams and Brittingham 1997) and is best described as an urban exploiter. Ordenana et al. (2010) found similar trends in carnivore-species richness using areas described as urban edge in southern California. They found that certain species, such as *Procyon lotor* (L.) (Raccoon) and *Canis latrans* Say (Coyote), were more likely to occur as the percentage of urban cover increased, whereas species that are more sensitive to anthropogenic impacts, such as the *Mephitis mephitis* (Schreber) (Striped Skunk) and *Urocyon cinereoargenteus* (Schreber) (Gray Fox), were shown to decrease with increased urbanization.

Another possible factor involved in the lower diversity of wildlife in urban areas is the relatively heavy use of roads. Oprea et al. (2009) found urban parks, which represent fragments of forested habitat within an urban matrix, had much greater bat diversity than wooded and non-wooded streets in Brazil. This result implies that, even with tree cover, many species are absent or rare in urban and suburban areas. Zurcher et al. (2010) found bats at the IND study area were significantly averse to road traffic, and this behavior could help explain avoidance of urban areas by some species of bats. An examination of individual recaptures between the north and south regions at our site could give more insight into the effects of roadways, especially major high-traffic ones such as I-70.

Although our data agree with the findings of other studies regarding the effects of urbanization on species diversity (Gehrt and Chelsvig 2004, Kurta and Teramino 1992, Marchetti et al. 2006, Ordenana et al. 2010), much more research is warranted in this field. The lands that have been studied at this urban–rural interface were purchased to mitigate for habitat loss due to airport expansion, as well as to provide a noise buffer for airport traffic. Further, the continued use of bat-boxes in remnant forests by the Northern Long-eared Bat suggests that this is a viable mitigation strategy for the species. In addition to White-nose Syndrome (WNS; Blehart et al. 2009), habitat loss has been implicated as a contributing factor in the population decline of this species. However, our results suggest that the Northern Long-eared Bat can make use of small wooded areas. Further research is warranted in this area. Studies focusing on how urbanization affects individuals at the species level, both positively and negatively, can provide beneficial knowledge into the adaptive thresholds of species.

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