

## Big city bats: Species-specific effects of the urban matrix on forearm length and fat stores of bats in the West Midlands, United Kingdom (Chiroptera: Vespertilionidae)

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received on 26 November 2022

**Abstract.** The effect of urbanisation on size and fat stores in bats has been poorly studied. We compare morphometric data in bats from two areas in the West Midlands, UK: one predominantly agricultural and one built-up. We examined forearm length and fat stores in 1,102 bats of five species (*Myotis daubentonii*, *M. nattereri*, *Pipistrellus pipistrellus*, *P. pygmaeus*, *Plecotus auritus*). All except *M. daubentonii* were significantly larger in the urban area; fat stores were greater in rural *M. nattereri* and *P. auritus*, and in urban *M. daubentonii* and *P. pygmaeus*. For *P. auritus*, the differences were only significant in males.

**Key words.** Chiroptera, urban ecology, morphometrics, urban-rural gradient.

### INTRODUCTION

Size and fitness have been found to decline towards the urban end of an urban-rural gradient in many organisms, including invertebrates (SADLER et al. 2006), birds (LIKER et al. 2008), and microorganisms (BRANS et al. 2017). In mammals, urbanisation often leads to individuals becoming larger, with the strength of that effect being greater in bigger, diurnal species, with nocturnal species tending to be smaller. This may be a consequence of some urban mammals exploiting anthropogenic food sources, utilising other resources (e.g., shelter, water) and benefiting from greater warmth and reduced predation risk (HANTAK et al. 2021).

Few studies have investigated the effects of urbanisation on bats. A study of *Eumops floridanus* in Florida, USA, found that body condition was lower in urban areas than in natural areas (WEBB et al. 2021), and a study of *Myotis lucifugus* in Alberta, Canada, found that animals in an urban landscape did not have greater body condition (COLEMAN & BARCLAY 2011). It has been suggested that effects on fitness in an urban-rural gradient are species-specific (RUSSO & ANCILLOTTO 2014), but where the fitness of urban bat populations has been studied the focus

doi: 10.37520/lynx.2023.005

has typically been on synanthropic species with no published studies on the effect of urban environments on the size or fitness of non-synurbic bats (COLEMAN & BARCLAY 2011, WEBB et al. 2021). Light, noise, and barriers to dispersal associated with the urban landscape are known to be deleterious to Chiroptera via a number of mechanisms including fragmentation, habitat loss (RUSSO & ANCILLOTTO 2014, ABBOTT et al. 2015), acoustic masking (BARBER et al. 2010, SIEMERS & SCHAUB 2011, ABBOTT et al. 2015), alterations in feeding behaviour (FINCH et al. 2020), and direct mortality (ABBOTT et al. 2015). Notwithstanding, several bat species thrive in anthropogenic habitats and these deleterious effects are therefore highly species-specific (RUSSO & ANCILLOTTO 2014).

Although bats are generally considered not to be significantly sexually dimorphic (MUÑOZ-ROMO et al. 2021), some dimorphism in body size exists in several Vespertilionidae, with females being 1–2% larger (RALLS 1976, MYERS 1978). Perhaps the most persuasive theory concerning the drivers of this dimorphism is the ‘big mother hypothesis’, which identifies various demands of motherhood (temperature, wing-loading to carry a foetus or pup, and competition with other females) as drivers of morphological adaptations (STEVENS et al. 2013). It has also been established that resource partitioning is utilised by some species, particularly at times of the year when such demands are highest, and it follows that any environmental influences on the calorific demands to which female bats in particular are susceptible would play out in overall fat stores (LINTOTT et al. 2014, PATRIQUIN et al. 2019). Following these observations, we hypothesised that there would be species-specific and sex-specific difference in sizes and fat stores between urban and rural bat populations. We compare morphometric measurements of five species of Vespertilionidae from two study areas within the wider West Midlands region, United Kingdom (one predominantly built-up and one largely agricultural).

## METHODS

### Data collection

Surveys were conducted in two study areas within the West Midlands, UK, between May 2013 and October 2021 under licence. The first area was Birmingham and the Black Country, comprising 62,533 ha

Table 1. Comparative median values for BCI and forearm length between urban and rural bats

	urban			rural			Mann-Whitney U
	med.	min.	max.	med.	min.	max.	
forearm (mm)							
<i>Myotis daubentonii</i>	37.3	34.2	40.9	37.4	34.9	39.8	W=7143, $p=0.850$
<i>Myotis nattereri</i>	40.0	37.0	41.8	39.1	36.5	41.0	W= 948, $p<0.001$
<i>Pipistrellus pipistrellus</i>	32.2	29.7	34.8	31.5	29.1	33.9	W=3895, $p<0.001$
<i>Pipistrellus pygmaeus</i>	31.8	29.1	34.3	31.2	29.1	33.9	W=5131, $p<0.001$
<i>Plecotus auritus</i>	38.6	35.7	41.6	38.2	36.0	41.4	W=3116, $p=0.011$
fat stores (BCI)							
<i>Myotis daubentonii</i>	0.229	0.163	0.322	0.208	0.157	0.309	W=4339, $p<0.001$
<i>Myotis nattereri</i>	0.186	0.161	0.224	0.197	0.166	0.225	W=1921, $p=0.022$
<i>Pipistrellus pipistrellus</i>	0.157	0.122	0.204	0.157	0.128	0.189	W=5947, $p=0.725$
<i>Pipistrellus pygmaeus</i>	0.169	0.132	0.228	0.155	0.117	0.217	W=4356, $p<0.001$
<i>Plecotus auritus</i>	0.191	0.151	0.241	0.196	0.149	0.251	W=4761, $p=0.028$

of which 52,671 ha (84.2%) is ‘built up’ (Office for National Statistics 2020). Birmingham and the Black Country (hereafter ‘urban area’) predominantly comprises industrial, commercial and residential areas with urban woodlands, parks and gardens, brownfield sites, canals and three major motorways. The second study area (hereafter ‘rural area’) is the county of Herefordshire (218,172 ha in area of which 4,713 ha (2.1%) is ‘built up’) and is predominantly agricultural with woodlands, grasslands, hedgerows and associated trees.

Data were generated from bats captured using mist nets and harp traps. Surveys adhered to UK (COLLINS 2016) or European (BATTERSBY 2010) guidelines utilising standard methodology (KUNZ & KURTA 1988, BARLOW 1999). Bats were identified, sexed and attributed to an age class based on evidence of sexual maturity as per DIETZ & KIEFER (2014). Weight was recorded ( $\pm 0.5$  g) using 20 g Pesola™ spring scales. We used forearm length (the radius with associated carpals) as a measure of size (following O’MARA et al. 2016) using Vernier callipers ( $\pm 0.1$  mm). Individuals were marked with non-toxic chalk paint to avoid duplicate data if re-captured on the same night. Body Condition Index (BCI) was calculated (body weight to forearm ratio) as a measure of fat stores as this is a standard (REYNOLDS & KORINE 2009), often-used metric for Chiroptera. Though the effectiveness of BCI for predicting fat stores is debated (McGUIRE et al. 2018), it has been shown to be the most important predictor of body composition compared to Total Body Electric Conductivity (PEARCE et al. 2008).

## Data handling

The study species (selected based on sufficient representation in both study areas) represented three feeding guilds: *Myotis daubentonii* (trawling), *Pipistrellus pipistrellus* and *P. pygmaeus* (hawking), and *Myotis nattereri* and *Plecotus auritus* (gleaning). Individuals with outlier measurements were removed from the dataset using rStatix package (KASSAMBARA 2021) in R (R Development Core Team 2014). As juveniles can reach 95% of adult size in 2–3 weeks (KUNZ 1982) before they are volant (ALTRINGHAM 2003) and our dataset showed no significant relationship between age and size ( $p=0.4925$ ), juveniles were included in analysis. Statistical analyses were undertaken using R (R Development Core Team 2014). As the datasets were not homogenous in size for landscape type or sex (Levine’s test for homogeneity of variance showed three of the five species having a significant value), we elected to use non-parametric Mann-Whitney U tests (wilcox.test function) of correlation to examine landscape type as a predictor of size and fat stores for each species, and then for each sex of each species.

## RESULTS

The final data comprised values for 1102 individual bats (813 female and 757 male, 537 rural and 565 urban) comprising five species: *Myotis daubentonii* (160 urban / 88 rural), *Myotis nattereri* (52 urban / 59 rural), *Pipistrellus pipistrellus* (201 urban / 61 rural), *Pipistrellus pygmaeus* (59 urban / 243 rural) and *Plecotus auritus* (93 urban / 86 rural).

Landscape type as a predictor of size (as forearm length) and fat stores (as BCI): The data (Table 1, Fig. 1) supported a significant difference in the median forearm lengths between urban and rural bats for *M. nattereri*, *P. pipistrellus*, and *P. pygmaeus* ( $p<0.001$  in each case) and *P. auritus* ( $W=3116$ ,  $p=0.0108$ ), with urban bats tending to have a greater median forearm length. *Myotis daubentonii* did not show a tendency towards greater median forearm length in either study area. Fat stores were significantly greater in rural bats in the gleaning species *M. nattereri* ( $W=1921$ ,  $p=0.02232$ ) and *P. auritus* ( $W=4761$ ,  $p=0.0279$ ), with greater fat stores in urban individuals of *M. daubentonii* and *P. pygmaeus* ( $p<0.001$ ). *Pipistrellus pipistrellus* showed no tendency to have a greater BCI in either area. In *P. auritus*, the significant differences for both values were sex-specific, with only male bats showing significant values when sexes were analysed separately (Table 2).

## DISCUSSION

Our data show that four out of the five study species (excluding *Myotis daubentonii*) were significantly larger in the urban area. Fat stores (as BCI) were significantly greater in individuals from the urban area for *Myotis daubentonii* and *Pipistrellus pygmaeus* and were significantly greater in the rural area for *Myotis nattereri* and *Plecotus auritus* (although for *P. auritus* significance for both values was evident only in males). The idea of some bats being significantly bigger or having greater fat stores in urban environments initially seems counter-intuitive because it is generally considered that insect diversity and abundance are lower in urban habitats (ANGOLD et al. 2006, JONES & LEATHER 2012). However, it can be argued that the comparatively low use of pesticides in urban areas (KHATRI & TYAGI 2015) and greater heterogeneity of habitat (JONES & LEATHER 2012) may increase insect diversity and abundance, somewhat mitigating other negative effects on insects. TEGLHØJ (2017) found that lower urban insect densities during the breeding season cause smaller nestling body mass in barn swallow (*Hirundo rustica*), but in mammals, it is the fitness of the mother and her ability to produce milk that determines the early fitness and growth of her offspring (RÖDEL et al. 2009, SKIBIEL & HOOD 2015). Thus, it

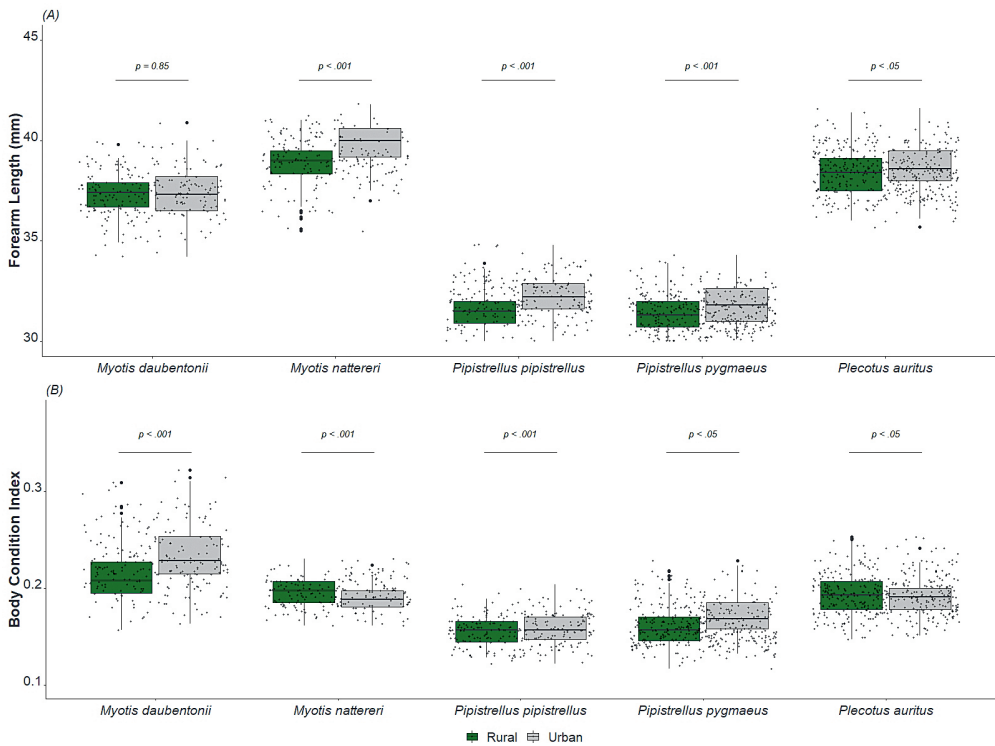


Fig. 1. Landscape type as a predictor of (A) body size (as forearm length) and (B) fat stores (as Body Condition Index).

Table 2. Species- and sex-specific results of Mann-Whitney U tests of landscape type as a predictor of body size (as forearm length) and fat stores (as BCI)

	all bats	males	females
size (forearm)			
<i>Myotis daubentonii</i>	W=7143, $p=0.850$	W=2552, $p=0.928$	W=1094, $p=0.988$
<i>Myotis nattereri</i>	W= 948, $p<0.001$	W= 428, $p<0.05$	W= 39, $p<0.001$
<i>Pipistrellus pipistrellus</i>	W=3895, $p<0.001$	W= 696, $p<0.001$	W=1308, $p<0.01$
<i>Pipistrellus pygmaeus</i>	W=5131, $p<0.001$	W=1424, $p<0.05$	W=1173, $p<0.05$
<i>Plecotus auritus</i>	W=3116, $p<0.05$	W= 995, $p<0.05$	W= 607, $p=0.222$
fat stores (BCI)			
<i>Myotis daubentonii</i>	W=4340, $p<0.001$	W=1250, $p<0.001$	W= 752, $p<0.05$
<i>Myotis nattereri</i>	W=1921, $p<0.05$	W= 645, $p=0.6169$	W= 156, $p=0.604$
<i>Pipistrellus pipistrellus</i>	W=5948, $p=0.7247$	W= 933, $p=0.1932$	W=2309, $p=0.154$
<i>Pipistrellus pygmaeus</i>	W=4356, $p<0.001$	W=1373, $p<0.05$	W= 785, $p<0.001$
<i>Plecotus auritus</i>	W=4761, $p<0.05$	W=1758, $p<0.01$	W= 774, $p=0.625$

may be the secondary effects resultant from a combination of other factors which influence the overall fitness of the mother and, in turn, her young:

1. Prey phenology: Urban insectivorous bats have access to prey items for a longer active season than their rural counterparts, through the urban heat island effect, which was demonstrated by MERCKX et al. (2021) to extend the flight period of Lepidoptera;
2. The urban trap: Urban barriers force roosting in greater proximity to feeding grounds, thus reducing nightly caloric burden (RUSSO & ANCILLOTTO 2014); and,
3. Urban waterways: The presence of a canal network provides an increased aquatic resource for drinking, foraging and commuting. *Myotis daubentonii* and *Pipistrellus pygmaeus*, which both have a documented affinity with riparian and lentic habitats, may benefit from the presence of the extensive canal network

In the case of the gleaning species *Plecotus auritus* and *Myotis nattereri*, increased light and noise in urban landscapes deleteriously affecting feeding efficacy through acoustic masking (BARBER et al. 2010) may explain their lower urban fat stores. Neither species has a known affinity with riparian habitats and, as gleaning species, they are not reliant on volant prey, meaning that they would not necessarily benefit from the urban heat island effect on prey phenology.

Whilst the datasets between bats in the two study areas were comparable in size and composition, were from the same broad UK region, utilised the same survey timings, season and methods, and were generally focused on woodland sites with water bodies, several variables may impact our results. Temporal weight fluctuations, both long-term (seasonally from pregnancy, birth, lactation, swarming and pre-hibernation periods) and short-term (nightly changes in weight before and after foraging; ŠUBA et al. 2011) can affect the weight of individual bats and, in turn, their BCI scores. In addition, the micro-habitat variables of our individual survey sites have not been quantified for the purposes of these analyses, and factors at a finer landscape scale may affect the feeding, drinking and roosting resources affecting a bat's size and fat stores.

Our results shed light on the vulnerability of gleaning species in urban environments, and we suggest that greater emphasis should be placed on the conservation of *Plecotus auritus* and *Myotis nattereri* living in urban landscapes as impacts of development on this guild may be greater due to their susceptibility to acoustic masking. Additionally, the importance of linear water networks for supporting urban bat assemblages, particularly those which rely on riparian and lentic habitats (e.g., *Myotis daubentonii*, *Pipistrellus pygmaeus*) should be considered. The retention of these features in a condition suitable for commuting, foraging and drinking bats should be a high priority in urban planning. Regarding monitoring urban bats, a greater emphasis on advanced survey techniques rather than acoustic monitoring may be an advantage, as demographic and body condition data would allow researchers to adequately monitor bat populations rather than simply recording their presence. Moreover, radio telemetry studies would show how individuals are moving through the urban matrix, how far they travel between roosts, what routes they adopt, and what barrier-crossing and perceived predation risks they take to meet their calorific needs.

#### Acknowledgements

The authors would like to thank Natural England for provision of survey licences, volunteers from the Herefordshire Mammal Group and the Birmingham and Black Country Bat Group's Urban Bat Project for assistance with fieldwork; Jon SADLER of the University of Birmingham and Ian DAVIDSON-WATTS for advice regarding interpretation of data; and Stefano KABURU from the University of Wolverhampton for statistical support.

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