Home range expansion in response to temperature by evening bats (Nycticeius humeralis) in an urban environment

Ellen Hall (ellen.m.hall@tcu.edu)
Texas Christian University
Victoria Bennett
Texas Christian University

Research

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Home range expansion in response to temperature by evening bats (*Nycticeius humeralis*) in an urban environment

Ellen M. Hall* and Victoria J. Bennett

Department of Environmental Science, Texas Christian University, Fort Worth, TX, USA 76129

*Correspondence: ellen.m.hall@tcu.edu

Abstract

Background: Despite the negative connotation of urban sprawl for bat populations, fragmented green spaces such as parks, cemeteries, and golf courses have the potential to provide necessary resources for bats. For example, water resources in these areas can include natural or semi-natural lakes, ponds, streams, and drainage ditches. Such water resources, however, are frequently ephemeral when subject to prolonged periods of high temperatures. We, therefore, hypothesize that bats will expand or shift their home ranges from these urban green spaces into the surrounding neighborhoods to access alternative resources, such as residential swimming pools.

Methods: To explore whether bats expand their ranges from urban green spaces, we conducted a telemetry study in which we radio-tracked resident evening bats (*Nycticeius humeralis*) in a local park system during their summer activity period from 2017-2019 in Fort Worth, Texas, USA. From radio-tracking surveys, we measured home range size using a k-LoCoH method and the percentage of these home ranges that fell within the park system. We compared these variables using linear and non-linear regressions with temperature.

Results: We successfully tracked a total of 30 bats over the 3-year period and found a positive correlation between home range size and temperature. Furthermore, we observed that home ranges increased 6 times in size when temperatures exceeded 30ºC.

Conclusions: Our study indicates the importance of urban neighborhoods surrounding green spaces in providing alternative resources, such as water, for bats. If managed appropriately, these urban areas have the potential to act as urban oases for bat populations, which in turn can contribute to their conservation.

Keywords: Area usage, Bat activity, Chiroptera, Green spaces, Local Convex Hulls, Radio-telemetry, Resource use, Suburban neighborhoods

Background

The continued expansion of urban areas is anticipated to be a major threat to bat populations [1-3]. These areas in particular represent highly modified environments with concrete structures and impervious surfaces that appear to offer little or no resources for bats [4]. Thus, many studies have shown that urbanization adversely alters bat activity [5], abundance [1], and species diversity [6, 7]. Yet, despite the negative connotations of urbanization, studies suggest that urban areas have the potential to provide resources necessary to sustain healthy bat populations in the form of fragmented green spaces, such as parks, cemeteries, and golf courses [8, 9]. Nevertheless, for such areas to support bats, they need to provide suitable and readily available resources. More importantly, for these areas to support an abundant and diverse bat community, they must provide species-specific resources, such as roosting sites, foraging opportunities, water sources, and commuting routes [1, 10, 11].

While urban areas may not have ‘classic’ resources (defined here as typically used or preferred), it is becoming more evident that bat species have or may be able to adapt to using semi-natural or anthropogenic alternatives [12]. For example, water sources in an urban environment can often be found in the form of ornamental ponds or lakes, retention ponds, streams, and drainage ditches. Though these water sources may not be completely natural, they are used by bats [13, 14]. These semi-natural resources, however, may be ephemeral when subjected to prolonged periods of high temperatures [15, 16]. Thus, in areas where water resources become scarce, bats may have to relocate or seek more unconventional alternatives. One such alternative may include residential swimming pools. A recent study revealed that bats readily drank at swimming pools in an urban area when access to more conventional water sources became restricted [14]. Furthermore, this study noted that the frequency at which bats drank at swimming pools increased with higher temperatures throughout the summer months. We, therefore, hypothesized that resident bats in urban environments would concentrate their home ranges (defined here as an area a bat travels nightly in search of food and water) to green spaces when resources were available. Yet, when resources, such as water, become limited due to increased temperatures we predict that bats will expand their home ranges from these urban green spaces into the surrounding neighborhoods to access alternatives, such as residential swimming pools. To explore whether bats expand or shift their ranges, we conducted a telemetry study in which we radio-tracked resident evening bats (*Nycticeius humeralis*) in local parks across their summer activity period in Fort Worth, Texas, USA. Given that urban expansion will inevitably continue, gaining a better understanding as to how bats interact and potentially thrive in such environments may provide much needed insights into how urban habitats can be improved for bats.

Methods

Study Site

We conducted our study at 3 connected public parks in Fort Worth, Texas, USA: Kellis, Foster, and Overton Parks (32°41’21.17” N, 97°22’46.75” W; Fig. 1). Combined, the parks cover an ~420 km^2 linear tree-lined green space centered around a drainage ditch and an ~60 m by 20 m retention pond when at capacity. Both the pond and drainage ditch were ephemeral; in particular, the drainage ditch tended to only contain water immediately after heavy rains. The surrounding area extending up to 2.5 km around this park system consisted of suburban neighborhoods, residential roadways, and predominantly single-story ranch houses with >1,000 residential swimming pools. Additional natural water sources within this area included the Trinity River, Willow Creek Lake, and <5 ornamental ponds (Fig. 1).

To determine the home range of evening bats, we conducted radio-telemetry surveys from March to September 2017-2019, incorporating the summer activity period of this species. We captured bats from 9 survey sites where frequent evening bat activity was recorded in preliminary acoustic monitoring surveys. For the telemetry surveys, we selected individual bats that weighed >9 g as recommended by Sikes et al. [17], were in good condition, and were not pregnant or lactating. We then attached an ~0.45 g SOM-2007 transmitter (frequency ranging from 150.000 to 150.160 MHz) from Wildlife Materials, Inc., using a Perma-type surgical cement. After the transmitter application, we released bats at the site of capture. Note that we tracked 1 bat at a time.

To track each bat, we coordinated a team of 3-4 technicians to triangulate the position of the bat using TRX-48 16 channel receivers with 3-element lightweight folding antennas from

Wildlife Materials. We collected the following data at 1-min intervals until the bat remained sedentary at a roost site for >15 mins: 1) the GPS location of each technician, 2) the azimuth bearing of the transmitter signal from that technician, and 3) the associated bearing errors. Preliminary surveys revealed that bats returned to roost after their first flying bout and would remain there for ≥2 hrs before foraging again. As water resources were more likely to be accessed during the first activity bout, we only tracked bats in this initial period [18]. Nightly surveys (weather dependent) were undertaken for <24 days, or until the transponder was damaged, groomed off, or its battery died. Note that an Institutional Animal Care and Use Protocol (IACUC permit #16-09-01) was in place for these procedures and followed the capture and handling recommendations of Sikes et al. [17].

We then used the GPS locations and the azimuth bearings to determine the location of the bat each minute. For this, we used ArcMap version 10.6 (ESRI Inc., Redlands, CA) to identify where bearing lines intersected (i.e., the intersection of the 3-4 bearings). To determine the home range size of tracked bats, we used the Home Range Analysis and Estimation toolbox (a non-parametric kernel estimator) within OpenJUMP version 1.14.1 (an open source GIS software) to create local convex hulls (LoCoH) for each bat. This method, which associates point locations with their nearest neighbor (k-1) as a series of convex hulls, was selected as it excluded areas that were not used by bats when estimating home range size [19]. As part of this exercise, we also generated 3 different home range sizes based on the distribution of points, including 1) 68% of the points representing 1 standard deviation of their distribution (hereafter referred to as the core area), 2) 95% of the points, which was equivalent to 2 standard deviations (secondary area), and 3) 99.7% of the points representing 3 standard deviations (tertiary area). For each core, secondary, and tertiary area generated, we extracted the total area (km^2) used by each bat. We also determined the percentage of each area that fell within the surrounding neighborhood. For this, we extracted the park system area. Note that these analyses, we did not include bats that were tracked for <3 days, as there was not enough data to confidently establish a home range.

In total, we generated 6 different dependent variables for each bat: the core, secondary, and tertiary areas (km^2) and the percentage of the core, secondary, and tertiary areas (km^2) that fell within the surrounding neighborhood. We used temperature as an independent variable as we hypothesized that it would impact the home range size of bats. For this variable, we calculated an average of the temperatures (°C) recorded across the nights an individual bat was successfully tracked (hereafter referred to as average temperature). Note that the temperature for each survey night was taken to be the temperature recorded at the start of each survey. To determine whether temperature was correlated with any of the 6 dependent variables, we conducted a series of linear and non-linear regression analyses. We also tested all dependent variables for normality. All statistical analyses were conducted using IBM SPSS Statistics (IBM Corp., Armonk, NY) where $\alpha=0.05$.

Results

We conducted surveys from 30 March to 28 September 2017, 22 March to 27 August 2018, and 21 March to 25 September 2019. A total of 36 bats (7 males and 3 females 2017, 5 males and 6 females 2018, 15 males and 0 females 2019) were tracked. Six bats were tracked for <3 days and were, therefore, not included in the following analyses. We tracked the 30 remaining bats on average for 68 mins each night (ranging from 4-182 mins) and an average of 7 days (ranging from 3-16 days).

After processing the data, we generated a total of 32,790 bat point locations. For the home range size, we found that the core areas averaged 2.97 km^2 (ranging 0.06-12.94 km^2), secondary areas averaged 8.24 km^2 (ranging 0.16-35.73 km^2), and tertiary areas averaged 15.93 km^2 (ranging 0.16-93.19 km^2). When we compared the core, secondary, and tertiary areas for each bat with the average temperature, we observed an increase in the size of these areas with an increasing temperature and found this positive correlation to be significant, best fit with an exponential regression (Table 1; Fig. 2).

Table 1: Summary of the linear and non-linear regressions for the average temperature compared to the core, secondary, and tertiary areas (km^2) within the home range of each evening bat (*Nycticeius humeralis*). * represents significant *P* values. The logistic analysis did not work for the core and secondary areas as a Log transformation could not be performed. - indicates that an analysis could not be performed.

		Linear	Exponential	Logistic
Core	*R*	0.381	**0.451**	-
	df	29	29	-
	F	4.767	7.14	-
	P	0.038*	0.012*	-
Secondary	*R*	0.399	**0.48**	-
	df	29	29	-
	F	5.299	8.396	-
	P	0.029*	0.007*	-
Tertiary	*R*	0.357	**0.408**	0.297
	df	29	29	29
	F	4.087	5.581	2.702
	P	0.053	0.025*	0.111

For the percentage of the home range that fell within the surrounding residential neighborhoods for each bat, we determined an average of 70.5% (ranging from 0-100%) of core areas, an average of 75% (ranging from 0-99.9%) of secondary areas, and an average of 81.8% (ranging from 15.5-99.9%) of tertiary areas fell within the neighborhood. Comparing the percentage of core, secondary, and tertiary areas for each bat with the average temperature, we observed an apparent increase in the percentages of core areas that fell within the surrounding neighborhood with an increasing temperature and this best fit a linear regression (Table 2; Fig. 3A). For the percentage of secondary and tertiary areas in the surrounding neighborhood, we observed no apparent correlation between the percentage of area and temperature (Table 2; Fig. 3B-C).

Table 2: Summary of the linear and non-linear regressions for the average temperature compared to the percentage of the core, secondary, and tertiary areas (km^2) of the home range of each evening bat (*Nycticeius humeralis*) that fell within the surrounding neighborhood. The exponential and logistic analyses did not work for the core and secondary areas as a Log transformation could not be performed. * represents significant P values. - indicates that an analysis could not be performed.

		Linear	Exponential	Logistic
Core	*R*	0.398	-	-
	df	29	-	-
	F	5.277	-	-
	P	0.029*	-	-
Secondary	*R*	0.296	-	-
	df	29	-	-
	F	2.668	-	-
	P	0.112	-	-
Tertiary	*R*	0.338	0.297	0.297
	df	29	29	29
	F	3.606	2.702	2.702
	P	0.068	0.111	0.111

Discussion

In this study, we determined that evening bats expanded their home ranges into the surrounding neighborhood during their summer activity period when temperatures increased. Across this period, we recorded home ranges to vary in size from 0.16 km^2 to 93.18 km^2. Moreover, the smaller ranges occurred at the beginning and end of this period, while the larger ranges occurred toward the middle of the summer (Fig. 4). Such expansions in evening bat home range size have been previously reported in a study conducted in southwestern Georgia [20]. However, the increase reported in this aforementioned study did not occur to the same extent, which may have been due to a number of reasons, including timing of the study, location, resource availability, and environmental variations. Note that in our study bats were tracked from March to September, while Morris et al. tracked bats from June to August, the months in which we recorded the largest home range sizes [20].

Furthermore, we found that the larger home range sizes occurred during the middle of the summer activity period, coinciding with the highest recorded temperatures. More specifically, we found that when temperatures exceeded a 30°C threshold, we saw a 6-fold increase in home range size. This correlation demonstrated that as the temperature increased, bats increased the size of their home ranges to incorporate a greater proportion of the surrounding neighborhood. These results therefore support the hypothesis that bats expanded their home ranges from urban green spaces to access available resources in the surrounding neighborhoods as temperatures increased. While our study did not directly explore resource availability, the specifics of our results indicate that home ranges expanded in response to limited resources.

Firstly, water availability in the park system was limited at the time of expansion, with the water in the drainage ditch drying up or receding to small pools covered in algae and aquatic vegetation (Fig. 5 A-C). Similarly, larger water bodies, such as the Trinity River, receded, exposing rocks and other debris (Fig. 5D). Subsequently, with increased clutter on these water surfaces, bats were prevented from accessing them and would have to seek water from alternative sources to persist in the area [21]. As proposed in the study by Nystrom and Bennett [14], when temperatures exceeded a certain threshold bats would utilize residential swimming pools as an alternative resource. Moreover, this study recorded a higher frequency of bats drinking at swimming pools with higher temperatures.

With this in mind, we explored whether there was a positive relationship between the presence of swimming pools and range expansion into the surrounding neighborhood. Post factum, we determined the number of residential swimming pools within each home range using a remote sensing technique to distinguish swimming pools from features such as vegetation and impervious surfaces. We observed a positive correlation between size and the proportion of home range that fell within the surrounding neighborhood and the number of swimming pools (Size: $R = 0.819$, $F = 57.052$, df = 29, $P<0.001$; Proportion: $R = 0.526$, $F = 10.715$, df = 29, $P = 0.003$). We acknowledged that the increase in range size with swimming pools was likely a result of autocorrelation; however, we might not have observed such as strong positive correlation if bats were equally utilizing areas with and without swimming pools. We also acknowledge that bats could have been expanding their ranges to increase foraging opportunities [22, 23]. As water sources become limited, there may be a similar trend in prey distribution and abundance. Subsequently, bats may forage further distances in search of prey. It is possible that the surrounding neighborhood may offer foraging opportunities along tree-lined streets, backyards, and even above swimming pools [24-27].Thus, even though green spaces are generally perceived to be the only suitable habitat for bats in an urban or suburban environment [9, 28, 29], our results suggest that this entire area is potentially suitable for evening bats. Therefore, to fully understand the importance of urban habitat and the quality and availability of resources, we recommend further research be conducted to identify the specific resources that bats are using in urban areas [30-32]. We also recommend an appropriate measure of water availability would be surface area, or in other words, the amount of area that remained uncluttered and subsequently available.

Another consideration in regard to our study is that the number of swimming pools in the home range may not directly relate to pool use by bats. Not all swimming pools may be suitable or accessible for bats (e.g., water quality, lighting, size of pool, canopy cover) [31, 33]. The expansion of home ranges with increasing temperatures clearly indicates that bats were selecting to use swimming pools when their preferred water resources, natural and semi-natural sources, were no longer available. This result poses the question “is there a way we can make residential swimming pools a preferred water resource?”

Furthermore, our surveys only focus on the species-specific behavior and habitat use of evening bats. Nystrom and Bennett [14] recorded 4 of the 7 local bat species drinking at swimming pools, which suggests that other species are utilizing this urban resource. Thus, we recommend that future studies be conducted to determine if other species demonstrate an equivalent range expansion.

Conclusions

Our study highlights the importance of the surrounding neighborhood adjacent to green spaces in providing resources, such as water, for bats. Any use of the surrounding neighborhood further indicates that urban habitat can potentially support an abundant and diverse bat population [28, 29]. Thus, understanding resource use in urban environments would help inform wildlife practitioners on how to enhance these areas for bats. For example, by making residential swimming pools readily available for bats, urban environments may become more suitable and accessible for bats throughout their activity period. Thus, improving these urban areas may contribute to the conservation of bats and help mitigate the impacts of urbanization [4, 34].

List of abbreviations

LoCoH: Local Convex Hull

Ethics approval and consent to participate

For all surveys we had an Institutional Animal Care and Use Protocol (IACUC permit #16-09-01) in effect and all protocols followed guidelines set out in Sikes et al. [15].

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare they have no competing interests.

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Authors' contributions

EH and TB gained funding, organized the project, collected the data, analyzed the data, and were involved in the production of the journal manuscript.

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Figure Legend

Fig. 1 Map of study site including Kellis, Foster, and Overton Park in Fort Worth, Texas, USA. The red points indicate mist netting sites while natural and semi-natural water resources are outlined in blue.

Fig. 2 Relationship between (**A**) core, (**B**) secondary, and (**C**) tertiary areas (km2) of each bat and average temperatures (°C) recorded across the nights an individual evening bat (*Nycticeius humeralis*) was successfully tracked. Each point on the scatter plot represents the home range area of an individual bat. Dotted lines and R^2 value represent exponential regression fit.

Fig. 3 Relationship between the percentage of (**A**) core, (**B**) secondary, and (**C**) tertiary areas (km^2) of each evening bat (*Nycticeius humeralis*) that fell within the surrounding residential neighborhood and average temperatures (°C) recorded across the nights an individual bat was successfully tracked. Each point on the scatter plot represents the percentage of a home range area for an individual bat. Dotted lines and R^2 values represent linear regression best fit.

Fig. 4 Average monthly home range expansion by evening bats (*Nycticeius humeralis*) from March to September 2017-2019.

Fig. 5 A shows the drainage ditch system at the beginning of the summer activity period and **B** shows the depleted water at the same site in the middle of the summer during a period of high temperatures in Overton Park, Fort Worth, Texas. **C** depicts the drainage ditch at the beginning of the summer activity period while **D** shows algae growth in the system of Overton Park in the middle of the summer. **E** shows the Trinity River at the beginning of the summer activity period and **F** shows the decreased water levels in the river in the middle of the summer.

Figures

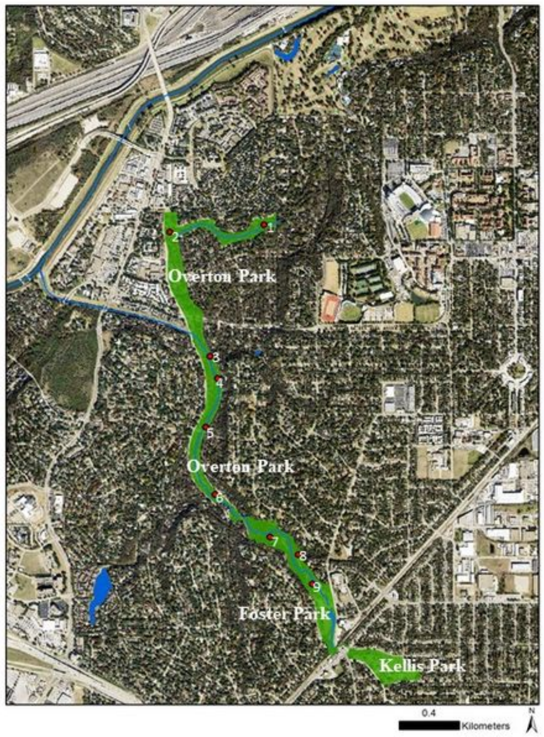

Figure 1

Map of study site including Kellis, Foster, and Overton Park in Fort Worth, Texas, USA. The red points indicate mist netting sites while natural and semi-natural water resources are outlined in blue.

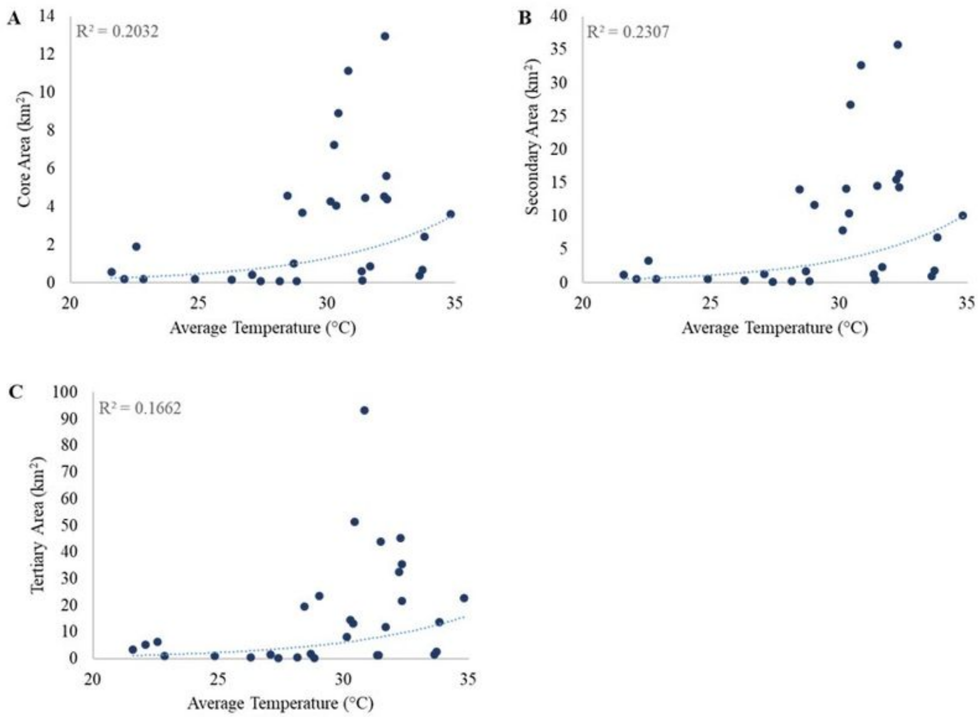

Figure 2

Relationship between (A) core, (B) secondary, and (C) tertiary areas (km2) of each bat and average temperatures (°C) recorded across the nights an individual evening bat (Nycticeius humeralis) was successfully tracked. Each point on the scatter plot represents the home range area of an individual bat. Dotted lines and R2 value represent exponential regression fit.

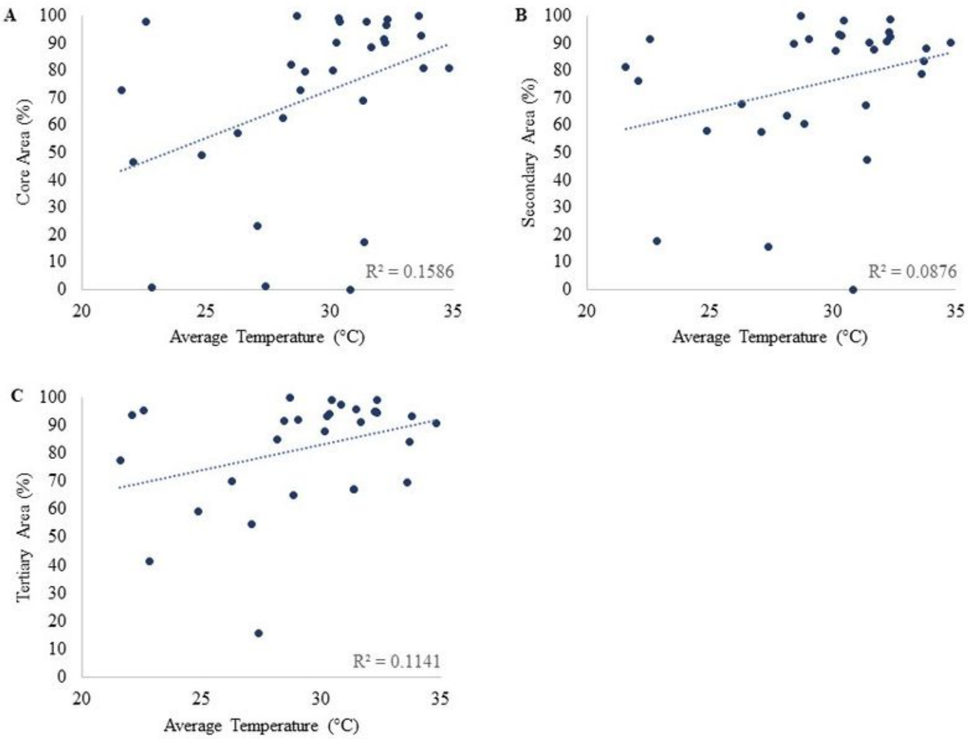

Figure 3

Relationship between the percentage of (A) core, (B) secondary, and (C) tertiary areas (km2) of each evening bat (Nycticeius humeralis) that fell within the surrounding residential neighborhood and average temperatures (°C) recorded across the nights an individual bat was successfully tracked. Each point on the scatter plot represents the percentage of a home range area for an individual bat. Dotted lines and R2 values represent linear regression best fit.

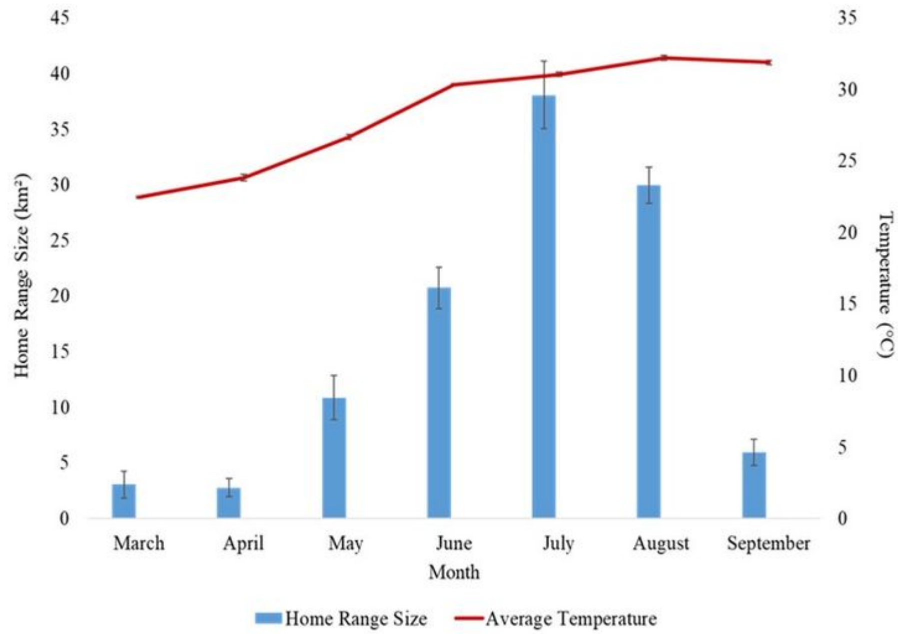

Figure 4

Average monthly home range expansion by evening bats (Nycticeius humeralis) from March to September 2017-2019.

Figure 5

A shows the drainage ditch system at the beginning of the summer activity period and B shows the depleted water at the same site in the middle of the summer during a period of high temperatures in Overton Park, Fort Worth, Texas. C depicts the drainage ditch at the beginning of the summer activity period while D shows algae growth in the system of Overton Park in the middle of the summer. E shows the Trinity River at the beginning of the summer activity period and F shows the decreased water levels in the river in the middle of the summer.