HOME RANGE EXPANSION BY EVENING BATS (*NYCTICEIUS HUMERALIS*) IN AN URBAN ENVIRONMENT

by

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Introduction

Bats are critical to their surrounding environment, providing a number of ecosystem services, such as pollination (Borbon-Palomares et al. 2018), seed dispersal (Sugiyama et al. 2018), and pest control (Olimpi & Philpott 2018; Russo et al. 2018). In the United States, bats have been estimated to save the agricultural industry >$3.7 billion in pesticides and crop damages annually (Boyles et al. 2011). Despite their benefits, bat populations are being threatened by the cumulative impacts of habitat loss, disease, and land-use change (Frick et al. 2017). For instance, since 2006 white-nose syndrome, a disease caused by a fungal pathogen (*Pseudogymnoascus destructans*), has spread across the United States and Canada, resulting in the deaths of >6 million bats (Rhodes & Fisher 2018). Comparatively, the fatalities of large numbers of tree-dwelling migratory bats (>500,000 annually) have been reported at wind energy resources throughout North America (Arnett & Baerwald 2013; Frick et al. 2017). However, while white-nose syndrome and the installation of wind turbines have only impacted bats in the last decade, habitat loss has led to the decline of bat populations globally for at least the last 50 years (McAney 1994; Robinson & Stebbings 1994; Scanes et al. 2018). For example, the Indiana bat (*Myotis sodalis*) was registered under the Endangered Species Act in 1967 due to the loss of roosting and foraging habitat (Bergeson et al. 2018; FWS 2018). The majority of habitat loss affecting bats has been a result of intensive farming (Olimpi & Philpott 2018), industrial forestry practices (Bergeson et al. 2018) , and urbanization (Beninde et al. 2015; MacGregor-Fors et al. 2016; Scanes et al. 2018). This loss of habitat and critical resources has resulted in reports of altered bat activity (Uhrin et al. 2017), abundance (Krauel & LeBuhn 2016), and species diversity (Threlfall et al. 2012; Kahnonitch et al. 2018). However, to some extent the effects of agriculture and forestry practices can be alleviated through appropriate management (Olimpi & Philpott 2018). For example, in studies evaluating the impacts of forestry management on Indiana bats, prescribed burns established greater foraging opportunities and created desirable roosting habitat in the form of hollow trees (Bergeson et al. 2018). In contrast, it is more of a challenge to manage urban areas, as they represent highly modified environments with a concrete infrastructure and impervious surfaces that appear to offer little or no resources for bats (Gallo et al. 2018). Thus, the continued expansion of urban areas is anticipated to further impact bat populations, which may increase their risk of extinction (Luck et al. 2013; Krauel & LeBuhn 2016; Scanes et al. 2018).

Despite these negative connotations, emerging studies suggest that urban areas have the potential to provide resources necessary to sustain healthy bat populations (Gehrt & Chelsvig 2003; Krauel & LeBuhn 2016). In an urban environment, these resources may be available in fragmented green spaces, such as parks, cemeteries, and golf courses (Kurta & Teramino 1992; Kowarik et al. 2016). A number of studies have shown bat activity to be higher in these green spaces than in the surrounding urban areas (Basham et al. 2011; Verissimo Silva de Araujo & Bernard 2016). Nevertheless, for such green remnants to support bats, they need to provide suitable and readily available resources. Moreover, 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 movement corridors to access these other resources (Li & Wilkins 2014; Beninde et al. 2015; Krauel & LeBuhn 2016). For example, the tree-dwelling silver-haired bat (*Lasionycteris noctivagans*) prefers to roost in the hollows of trees, underneath loose bark, and in woodpecker holes (Ammerman et al. 2012).

While urban areas may not have ‘classic’ resources (defined here as widely acknowledged or preferred), it is becoming more evident that bat species have been able to behaviorally adapt to using unconventional, often anthropogenic alternatives. For instance, Australian fruit bats (*Pteropus* spp.) have been observed utilizing non-native food sources in an urban environment (Paez et al. 2018). Similarly, bats known to roost in caves, crevices, and trees have been able to take advantage of anthropogenic structures, such as wine cellars, buildings, and bridges as alternative roosting sites (Li & Wilkins 2015). For example, tri-colored bats (*Perimyotis subflavus*) have been found using box culverts along Texas highways as winter hibernacula sites (Sandel et al. 2001). Furthermore, tree-lined streets and hedgerows in urban areas can offer foraging opportunities and commuting routes equivalent to woodland edges that provide bats protection from predators (Oprea et al. 2009; Kelm et al. 2014). Finally, water sources in an urban environment can often be found in the form of ornamental ponds or lakes, retention ponds, streams, and drainage ditches (Bowles et al. 1990; Nystrom & Bennett 2019). Such water resources, however, may be ephemeral when subjected to prolonged high temperatures (Wallace et al. 2005; Goodrich et al. 2018). Thus, in areas where water sources become scarce, bats must either leave an area or seek an alternative to persist.

One alternative water source may include residential swimming pools. A study revealed that bats readily drank at swimming pools in an urban area when access to more conventional water sources became restricted (Nystrom & Bennett 2019). Furthermore, this study noted that the frequency at which bats drank at swimming pools increased with higher temperatures. 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, we predict when resources, such as water, become limited in green spaces, resident bats would expand or shift their home ranges to access alternative sources of water, in the form of residential swimming pools, in the surrounding neighborhoods.

To explore whether bats expand or shift their ranges to encompass residential swimming pools, we conducted a telemetry study in which we tracked resident evening bats (*Nycticeius humeralis*) in local parks across their summer activity period in Fort Worth, Texas, USA. By identifying periodic shifts in their range sizes, we may be able to determine the importance of such alternative water sources, which may in turn provide insights into how we can effectively improve urban habitat for bats.

Methods

Study Site

We conducted our study at two connected parks in Fort Worth, Texas, USA: Foster Park and Overton Park (32°41’21.17” N, 97°22’46.75” W; Fig. 1). These parks are owned and operated by the City of Fort Worth Park and Recreation Department. Combined, the parks cover a 24.5 ha linear tree-lined green space centered around a drainage ditch and a ~60 m by 20 m retention pond when at capacity. Both the pond and drainage ditch are ephemeral; in particular, the drainage ditch tends to only contain water immediately after heavy rains. The site is also heavily manicured with little or no understory vegetation, and the majority of trees are mature, exceeding >6 m in height. Tree species include bur oaks (*Quercus macrocarpa*), cedar elms (*Ulmus crassifolia*), American elms (*Ulmus americana*), common hackberries (*Celtis occidetalis*), and Texas ashes (*Fraxinus texensis*; FWPR Undated).

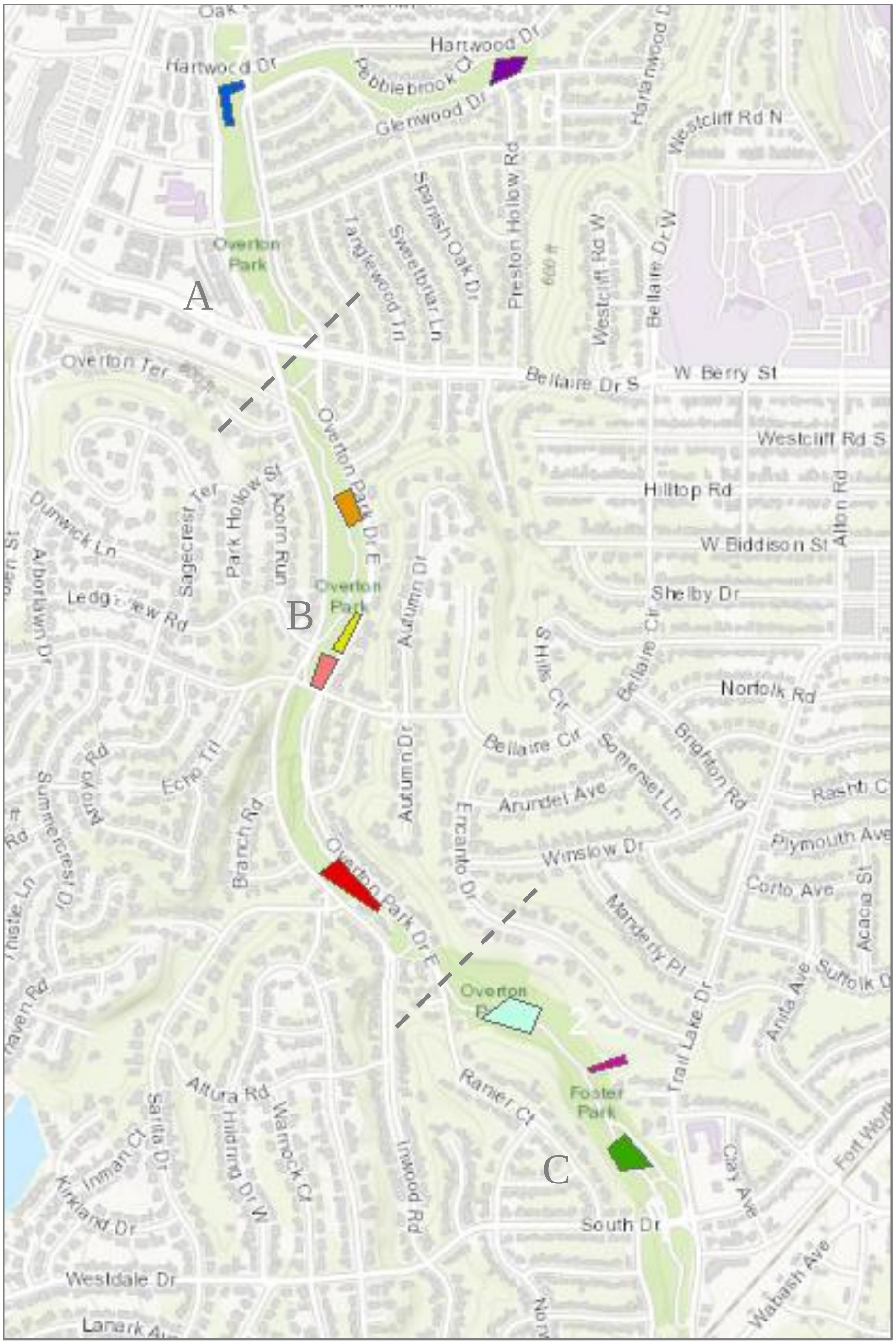


Figure 1: Map of study site including Foster and Overton Park in Fort Worth, Texas, USA. Colored polygons indicate mist netting sites. Sections A to C delineate the mist netting survey rotation.

Mist Netting

From previous acoustic monitoring and mist netting surveys undertaken from 2013-2016, the study site contained an abundance and diversity of bats (Bienz 2016; Smith 2019; unpublished data). From these surveys, seven species were recorded: eastern red (*Lasiurus borealis*), hoary (*Lasiurus cinereus*), silver-haired, canyon (*Parastrellus hesperus*), tri-colored, evening, and Mexican free-tailed (*Tadarida brasiliensis*) bats. Of these species, the evening bat has been acoustically recorded and captured most frequently and resides in the area year-round (unpublished data). As a result, we selected the evening bat as our study species. To increase capture success, we used the aforementioned acoustic surveys to identify 9 survey sites where evening bat activity was concentrated within the parks (unpublished data; Fig. 1). We divided the study site into 3 sections (see Fig. 1) and conducted mist netting surveys at a selected survey site within each section. We then rotated among the 3 sections and survey site from March to September (representing the seasonal activity period of evening bats; Ammerman et al. 2012).

To capture bats at each survey site, we used triple, double, and single-high 6-18 m length monofilament mist nets from Avinet Research Supplies (Fig. 2). The nets were opened ~10 mins before dusk and remained open 1-3 hrs to encapsulate the evening bat primary activity period, weather permitting (Baerwald & Barclay 2011; McAlexander 2013; unpublished data). Prior to the start of each survey night, we recorded the date, site, start time, temperature (°C), cloud cover (full, partial and clear), average wind speed and wind gusts (kph), dew point (°C), humidity (%), pressure (inHg), moon phase, moon illumination (%), and whether the moon was visible. We recorded these variables as they are known to potentially influence bat activity (Appel et al. 2017; Pettit & O'Keefe 2017). We did not conduct mist netting surveys when there was lightning in the immediate area, precipitation, average winds ≥24 kph, gusts ≥40 kph or temperatures <5°C. We then opened the nets, moved ~20 m away, and returned every 10 mins to check for bats. Once a bat was captured in a net, we removed the bat by hand within 5 mins, or else it was cut out using curved embroidery scissors to minimize further stress (Fig. 3).

Figure 2: Triple-high mist netting set up in Overton Park, Texas.

Figure 3: Picture of bat being removed from a mist net.

After removal, we immediately released bats that were identified as pregnant, lactating, carrying young, or any other species (i.e., not evening bats). We placed all remaining bats in cloth bags and hung the bags on the side of the mist nets until the survey was completed. Once nets were closed and disassembled, we noted the survey end time and processed all captured bats by recording their weight (g), forearm length (mm), sex, age (juvenile or adult), condition (pregnant, lactating, non-breeding, or descended testicles), and assigning them a unique ID (e.g., 1Nyhu23Apr19, including the numerical order the bat was caught, species, and date). We then selected an individual that weighed >9 g to ensure the transmitter did not exceed 5% its body weight (Sikes et al. 2016), and appeared to be visibly in good condition (i.e., little or no parasite load, no bald patches, and no current injuries, such as holes in wings). Where possible, we tried to alternate the selection of males and females over the survey period. Once an individual was selected, we released all remaining bats and transported the selected bat to a customized flight facility (described in Bienz 2016). This open-air facility was kept as close to natural conditions as possible and contained a 1 m by 2 m water tray, an abundance of aerial prey, and roosting opportunities in the form of puppy carriers and carpeted cat houses. We kept the bat in this facility until ~30 mins before dusk the following day. At this time, we attached a SOM-2007 transmitter from Wildlife Materials, Inc. For this process, we trimmed the fur from the mid-dorsal back of the bat and then used Perma-type surgical cement to adhere the transmitter to this area (Fig. 4). Once the transmitter was secure, we placed the bat into a cloth bag and transported it back to its site of capture. We then released the bat either on a tree or by hand at dusk.

Figure 4: Evening bat with an attached with SOM-2007 transmitter from Wildlife Materials, Inc.

Note that all technicians handling bats had rabies pre-exposure vaccinations and wore bite-resistant gloves. Furthermore, an Institutional Animal Care and Use Protocol (IACUC permit #16-09-01) was in place for these procedures, which followed guidelines provided by Sikes et al. (2016). We did not require permits from state or federal agencies, as north central Texas does not currently have any registered threatened or endangered bat species. Nevertheless, we did have permits to conduct surveys within the park system from the Fort Worth Park and Recreation Department. Our methods and capture data were also annually inspected and reviewed by the animal and plant health inspection services of the United States Department of Agriculture.

Telemetry Surveys

To determine the home range of bats within our study site and the surrounding neighborhood, we conducted radio-tracking telemetry surveys. For this, we coordinated a team of 3-4 technicians to biangulate, triangulate, or quadrangulate (where possible) the position of a bat with an attached transmitter based on the signal strength (Ryan 2011). Thus, we used the Global Positioning System (GPS) location of each technician and the azimuth bearing of the signal from that technician to determine the location of the bat (i.e., the intersection of the 2-4 bearings; Fig. 5). By taking bearings and locations simultaneously at regular intervals (i.e., every minute), we were then able to generate the area flown by a bat. We used TRX-48 16 channel receivers with 3-element lightweight folding antennas from Wildlife Materials to determine the bearing of the strongest signal from the radio-transmitter (Fig. 6A). We also used Samsung Galaxy S5 and S7 mobile phones with two Android compatible apps installed: 1) Locus Map Pro, to record GPS locations of the technicians and signal bearing, and 2) Seconds, a circuit trainer app used to ensure that all technicians recorded GPS locations and bearings within a set timeframe (i.e., serving as a timer).

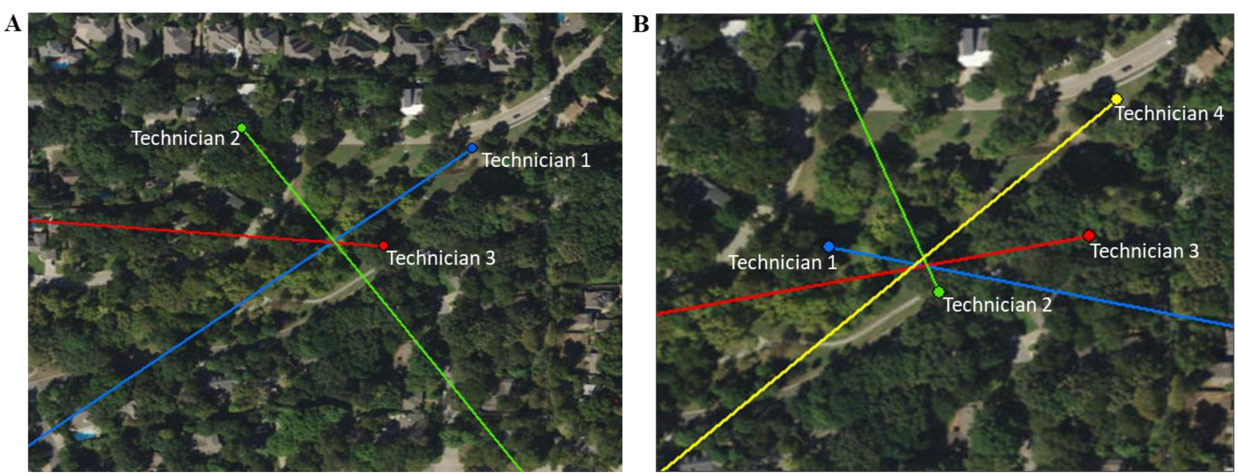


Figure 5: Example of (**A**) triangulation and (**B**) quadrangulation of the location of a bat determined from intersecting bearing lines from technicians.

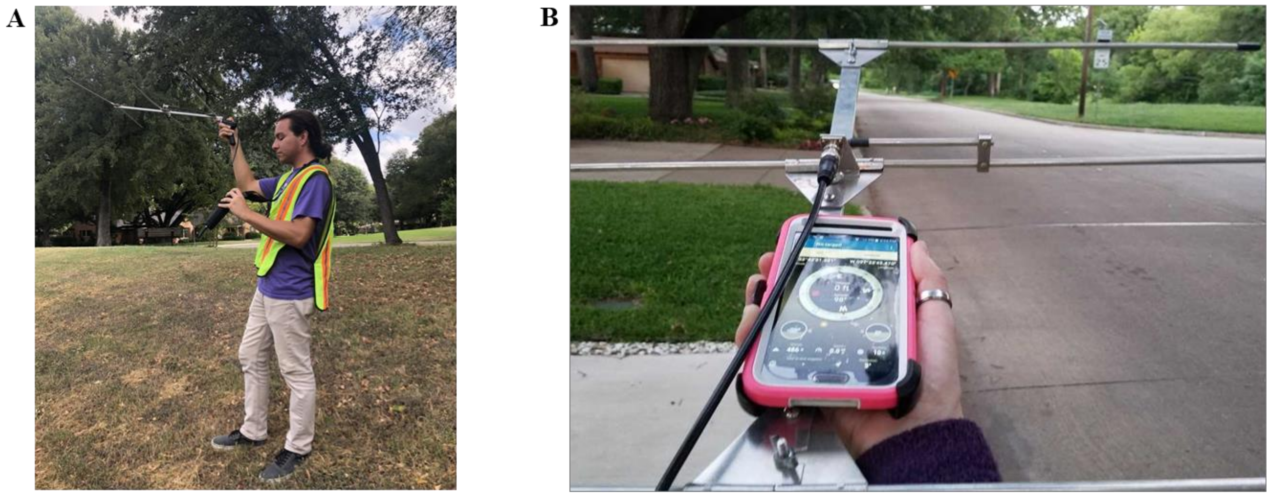


Figure 6: Telemetry equipment used in surveys. (**A**) shows a technician with a TRX-48 receiver and 3-element antenna from Wildlife Materials and (**B**) shows a Samsung mobile phone held atop an antenna open to the compass display of Locus Map Pro app.

Prior to the release of the bat with the transmitter attached at dusk, we calibrated the aforementioned equipment for each technician, ensuring that all receivers were set to the correct transmitter frequency (e.g., ranging from 150.000 to 150.160 MHz) and that the signal strength was strong and clear (i.e., confirming that all equipment was working correctly). We also made certain that GPS and compass displays on the mobile phones were as accurate as possible. For this, we confirmed that all the phones displayed GPS coordinates that were within 1 m of the actual location of the technician and the direction (i.e., azimuth) displayed was ≤2° from the azimuth shown on a standard handheld compass (Fig. 7). We then synchronized the Seconds app between all the mobile phones. This app was used to emit a warning beep 10 secs prior to the turn of each minute, then a 3-sec countdown occurred (i.e., 3 beeps) up to the turn of a minute, and finally a second 3-sec countdown to the end of a 10-sec period directly after the turn of the minute. Thus, once a bat started flying, technicians would record their GPS location and bearing, where possible, in this 10-sec period following the turn of every minute. Lastly, a 3- to 4-way phone call between technicians was set up to ensure prompt communication, which enabled the technicians to coordinate and reposition themselves, when necessary, to better triangulate the bat throughout the survey.

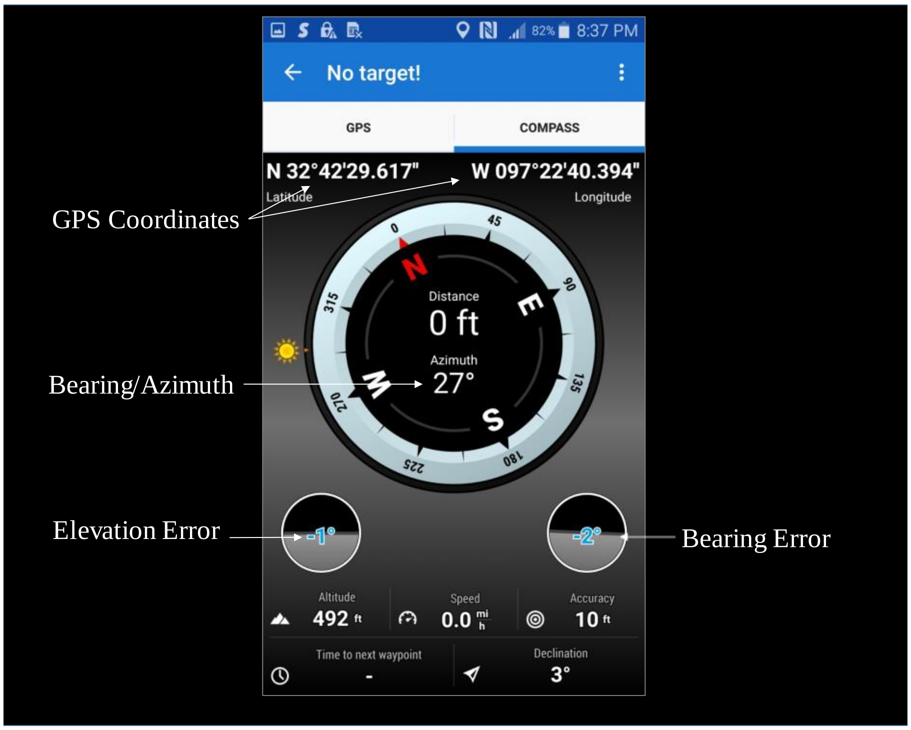


Figure 7: Screenshot of the compass screen in the Locus Map Pro app.

Technicians spaced themselves evenly apart >500 m away from where the bat was released (i.e., in a triangular or quadrangular formation). At the start of the survey, we recorded survey information (date, bat ID, start time, and technicians present) and environmental data (refer to mist netting surveys above), as well as the starting location and initial bearing of each technician. For the latter, we held the mobile phones, displaying the Locus Map Pro app compass, on top of the antenna (Fig. 6B). As technicians angled their antennas in the direction of the strongest signal from the transmitter, their GPS location and the associated bearing were displayed on the mobile phones (Fig. 7). In addition, to improve bearing accuracy, technicians minimized altitude and bearing errors (i.e., below 10°; Fig. 5B) that occurred by holding the antenna parallel to the ground (i.e., the vertical plane was adjusted not the horizontal plane). The bearing and GPS location were then recorded by taking a screenshot of the phone display (Fig. 7).

Once the bat was released, technicians took screenshots at the turn of every minute, but only when they had determined the direction of the strongest signal. Technicians then moved and reoriented themselves (on foot or by vehicle) to ensure they remained in a triangular or quadrangular formation surrounding the bat. Screenshots were taken until the bat remained sedentary at a roost site for >15 mins, at which point we considered it to be roosting. As the objective of this study was to determine area usage associated with drinking activity, we focused our survey effort on a 1-3 hr period after dusk when this activity would primarily be undertaken (McAlexander 2013). Furthermore, preliminary surveys revealed that when bats returned to roost after their first flying bout they would remain there for 2 or more hours. Thus, we only tracked bats during this first bout of activity.

The following day, we confirmed whether the bat was still located at the roost identified from the previous night. Based on the location of the bat, we proceeded as follows: 1) if the bat was present, a screenshot was taken to record the location of the roost site and surveys started at this location that night, 2) if the bat was not present, we searched a 2.5-km radius surrounding the park system until a new roost site was located, from which surveys were started that night, and 3) if we were unable to find the bat within this 2.5-km radius during the day, we started surveys with technicians distributed across the study site at locations with high elevation (identified in Appendix A; Ryan 2011), attempting to detect the bat in flight at dusk onwards. We then searched for a transmitter signal at these locations, and if found we proceeded to track the bat as previously detailed above. If a signal was not located during a 1-hr period, we repeated searches for 2 more consecutive nights to confirm that the bat had left the area. For those bats that remained in the area, nightly surveys (weather dependent) were undertaken for ~10 days, or until the transponder was damaged, groomed off, or its battery died. Note that for safety purposes, technicians wore high visibility vests and any vehicles used had magnetic signs with “Bat Research in Progress” and their hazard warning lights on during surveys.

Data Processing

After each survey, we extracted the following information from each screenshot: time, GPS location (converted from Degrees Minutes Seconds to Decimal Degrees), bearing, and bearing error (Fig. 7). Using ArcMap version 10.6 (ESRI Inc., Redlands, CA), we input the coordinates and associated attributes to create a point-based shapefile for each technician every survey night. We then used the ‘Bearing Distance to Line’ tool (found in the Data Management toolbox) to create a line extending up to 2.5 km from each point location (i.e., the location of a technician) in the direction of each corresponding bearing (hereafter called a bearing line). We created a point at each intersect where 2 or more bearing lines overlapped within a given minute. These point locations were then saved to a shapefile with their associated bat ID, date, and confidence value. The latter value was a measure of our confidence in pinpointing the location of the bat, where higher values were given to points representing the highest confidence. For example, when two or more bearing lines intersected, we allocated a value of 12. Where bearing lines did not intersect, we created 2 additional bearing lines based on the bearing error. Where a bearing error line intersected an original bearing line, we created a point which we allocated a confidence value of 9. If only bearing error lines intersected, we extracted the area between these lines and created a polygon to represent the intersection (Fig. 8). We then converted the polygon into a series of points using the 'Create Fishnet' tool (found in the Data Management toolbox). This tool generated a single point in each 10 m by 10 m cell within the polygon. These points were saved to the point location shapefile and given a value of 6. Next, if there were instances where areas still did not intersect, we created a further 2 user-based bearing error lines on either side of the bearing error lines. These secondary bearing error lines represented a user error ±5% of the bearing error. Again, we created a polygon where the area within 2 or more of the user-based bearing error lines intersected. The area within these polygons was then converted to points (as above) and saved to the point location shapefile with a confidence value of 3. Finally, where only one technician had the direction of the bat for >5 consecutive screenshots, we created a polygon that encapsulated the maximum lateral range of their bearing lines extending 2.5 km from the technician. In instances when landscape features (such as high ground and buildings) were known to block the transmitter signal, the extent of the polygon was adjusted accordingly (i.e., resized to <2.5 km). The polygon was then converted to points with a confidence value of 1.

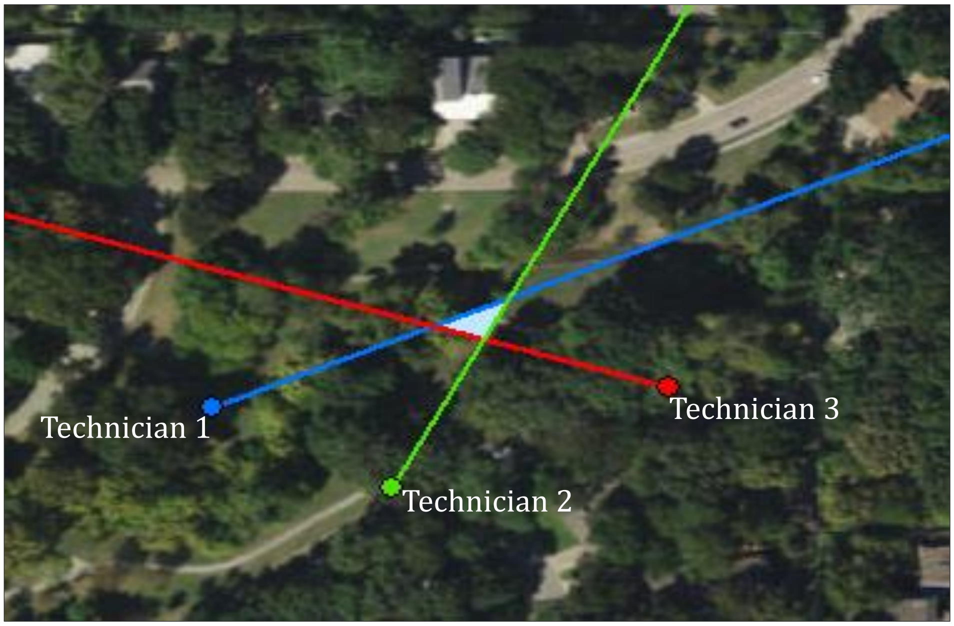


Figure 8: Example of polygon (shaded region) created when secondary bearing error lines intersected.

To determine home range size of the 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 (Getz et al. 2007). This method, which associates point locations with their nearest neighbor (k-1) as a series of convex hulls, was selected as it effectively excluded areas that were not used by bats. When creating these LoCoHs, we set ‘k’ values as the square root of the total number of point locations recorded for each bat. 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 that were within 1 standard deviation of their distribution (hereafter referred to as the core area), 2) 95% of the points equivalent to 2 standard deviations (secondary area), and 3) 99.7% of the points the equivalent to 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 these 3 areas that fell within the surrounding neighborhood. In addition, nightly foraging activities of bats primarily using parks may not have been strictly limited to the confines of that park. For example, depending on species-specific perceptions of risk, different species may forage or commute within a range of distances from linear features or habitat edges (Bennett & Hale 2018). We considered that this additional foraging extent may have influenced the percentage of the home range that fell within the surrounding neighborhood. Thus, we included 2 buffers (20 m and 40 m distances from the park edges), as these represented the extent evening bats were likely to forage from the edges of tree canopies and tree lines, and therefore could be considered part of the park system (Morris et al. 2011; Ammerman et al. 2012; Bennett & Hale 2018). Subsequently, we identified 3 different variants for the park system: 1) the total area of the park with no buffer around the park edge, 2) the total area of the park with a 20 m buffer around the park edge, and 3) the total area of the park with a 40 m buffer around the park edge. Note that for this and the below analysis, we did not include any bats that were tracked for <3 days, as we were not confident that there was enough data to effectively establish home range sizes.

To determine area usage by bats, we conducted a hotspot mapping exercise based on the confidence values allocated to each bat point location. For this exercise, we used the ‘Point Statistics’ tool in the Spatial Analyst Tools toolbox. This tool sums the confidence values within each 10 m^2 cell to form an output raster map delineating the variations in concentration of activity within the total area each bat flew. From these maps, we identified areas with the highest concentration of activity and determined the proportion of these areas that fell within the surrounding neighborhood (as described above). We also determined how far the edge of these hotspots were from the edge of the park system. As multiple hotspots could potentially occur, we determined both a maximum and a minimum distance. Note that if a hotspot fell within or abutted the park system, we designated a distance of 0 m.

Finally, we determined the number of residential swimming pools within each core, secondary, and tertiary area using a remote sensing technique. We acquired a Landsat 8 OLI sensor image and adjusted the spectral resolution to incorporate bands 5 (Near Infrared), 4 (Red), and 3 (Green) to highlight all water bodies (e.g., it makes water more distinguishable from features such as vegetation or impervious surfaces). We then converted the raster map to polygons based on raster cell values using the ‘Raster to Polygon’ tool from the Raster toolset. Next, we used ‘Select by Attributes’ tool in the Data Management toolbox to exclude any objects that were <20 m^2, which we established to be the minimum size of a residential swimming pool. We also manually excluded any natural or semi-natural water bodies included within the area and used Google Earth freeware (Keyhole Inc.) and Zillow (Zillow Group, Inc. Seattle, WA), an online real estate database, to confirm that the remaining water bodies were swimming pools. Finally, we determined the number of pools within each home range of a bat using the ‘Select by Location’ tool to extract all residential swimming pools that fell within (entirely or partially) each core, secondary, and tertiary area.

Data Analysis

From the above, we generated 21 dependent variables for each bat: the size of each core, secondary, and tertiary area (km^2), the percentage of the core, secondary, and tertiary areas (km^2) that fell within the surrounding neighborhood with no buffer, a 20 m buffer, and a 40 m buffer around the park, the percentage of a hotspot(s) that fell within the surrounding neighborhood with no buffer, a 20 m buffer, and a 40 m buffer around the park, and the minimum and maximum distance (m) of a hotspot(s) from the park system edge with no buffer, a 20 m buffer, and a 40 m buffer. We then identified 3 independent variables that we predicted would impact the home range size of bats: temperature, precipitation, and number of residential swimming pools. For temperature, we calculated an average of the temperatures (°C) recorded across the nights an individual bat was successfully tracked. Note that the temperature used was recorded at the start of each survey night. For precipitation, we first estimated the total amount of rainfall (mm) that occurred across the tracking period of an individual bat (hereafter referred to as the first precipitation variant). As the extent of precipitation that occurred prior to tracking a bat may have influenced water availability during the tracking period, we also estimated 2 other rainfall values: 1) the total amount of rainfall that occurred across the tracking period along with a 7-day period prior to the surveys (second precipitation variant) and 2) the total amount of rainfall that occurred across the tracking period along with a 30-day period prior to the surveys (third precipitation variant; www.usclimatedata.com). Note that these additional variables were related (collinearity) and were therefore variants of precipitation that we considered separately in the analysis. Thus, to determine whether our 3 independent variables correlated alone or in combination to each of the 21 dependent variables, we conducted a series of regression analyses (linear, non-linear, and stepwise) where possible (e.g., only area-related variables could be compared with the number of swimming pools). For these analyses, there were 2 assumptions: 1) that the data were normally distributed and 2) that there was no collinearity among the independent variables. To avoid violating the assumptions, we tested for normality and separately repeated the analysis for each of the precipitation variants. All statistical analyses were conducted using IBM SPSS Statistics (IBM 2017) where α=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. In summary, a total of 97 evening bats were captured in mist nets, and of these, we attached transponders to 36 bats (Table 1). Six of the 36 bats were tracked for <3 days, and therefore were not included in the following analysis. We tracked the remaining 30 bats on average 68 mins per night (ranging from 4-182 mins) for 7 days on average (ranging from 3-16 days). Note that the maximum time spent tracking a bat per night did not exceed the 3-hr bat activity period after dusk.

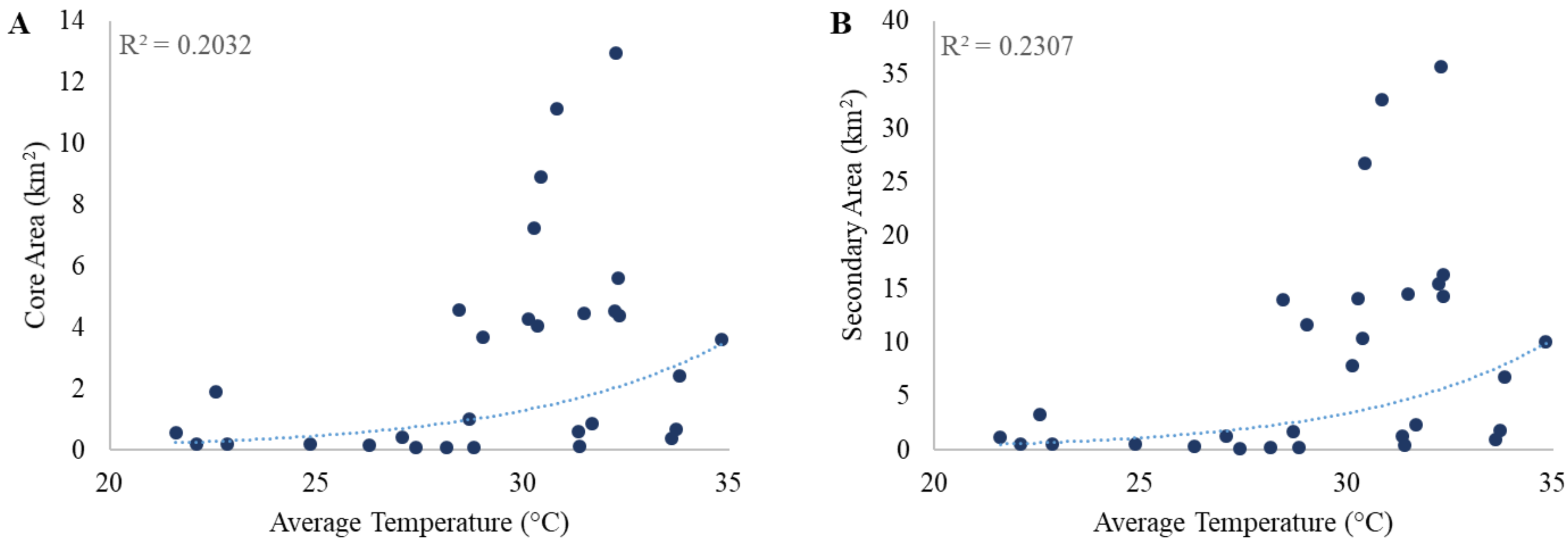
Table 1: Total number of evening bats (*Nycticeius humeralis*) captured and tracked from March 2017-September 2019. Note that **M** refers to males and **F** refers to females. Section refers to areas in which mist netting surveys were rotated (see Fig. 1).

	2017		2018		2019	
Section	***Caught***	***Tracked***	***Caught***	***Tracked***	***Caught***	***Tracked***
A	8 (4M/4F)	2 (1M/1F)	6 (6M/0F)	3 (3M/0F)	6 (4M/2F)	3 (3M/0F)
B	20 (8M/12F)	5 (3M/2F)	23 (9M/14F)	5 (1M/4F)	8 (8M/0F)	5 (5M/0F)
C	6 (4M/2F)	3 (3M/0F)	8 (5M/3F)	3 (1M/2F)	12 (11M/1F)	7 (7M/0F)
Total	**34 (16M/18F)**	**10 (7M/3F)**	**37 (20M/17F)**	**11 (5M/6F)**	**26 (23M/3F)**	**15 (15M/0F)**

After processing the tracking data, we generated a total of 32,790 bat point locations (9,451 with a confidence value of 12, 31 with a value of 9, 944 points with a value of 6, 1,696 with a value of 3, and 20,468 with a value of 1). For home range sizes, we found that the core areas averaged 2.97 km^2 ± 3.44 SD (ranging 0.06-12.94 km^2), secondary areas averaged 8.24 km^2 ± 9.85 SD (ranging 0.16-35.73 km^2), and tertiary areas averaged 15.93 km^2 ± 20.99 SD (ranging 0.16-93.19 km^2; see Appendix B for individual bat home ranges). 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 increase in temperature and we found this positive correlation to be significant, best fit with an exponential regression (Table 2; Fig. 9). Comparing the core, secondary, and tertiary areas with each of the 3 precipitation variants, we saw no apparent significant correlation between precipitation and the size of these areas (Tables 3-5; Fig. 10). Upon further investigation, we found that precipitation appeared to be independent of range expansion and was not an effective measure of water availability within the park system as hypothesized (see discussion for further details). Consequently, we did not include precipitation as an independent variable for the remaining analyses. Finally, when we compared the core, secondary, and tertiary areas for each bat with the average number of swimming pools within these areas, we observed an increase in area with a higher number of swimming pools and found this positive correlation to be significant and best fit a linear regression (Table 6; Fig. 11). Further to these results, the stepwise regression with temperature and the number of swimming pools revealed a positive relationship between the dependent variables (core, secondary, and tertiary area size) and one independent variable, number of swimming pools (Core: R= 0.692, F = 25.737, df = 29, P<0.01; Secondary: R= 0.731, F = 32.1, df = 29, P<0.01 Tertiary: R= 0.819, F = 57.052, df = 29, P<0.01). Despite temperature being an influencing factor by itself, when combined with swimming pools in this analysis the strong positive correlation between home range size and the number of swimming pools excluded temperature. However, we acknowledged that the increase in range size with swimming pools was likely a result of autocorrelation. Thus, while an increase in swimming pools demonstrated that bats were expanding their ranges into the surrounding urban environment, we cannot assume these alternative resources were driving the expansion. Subsequently, we did not consider interactions between temperature and the number of swimming pools in the following analyses.

Table 2: 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.

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



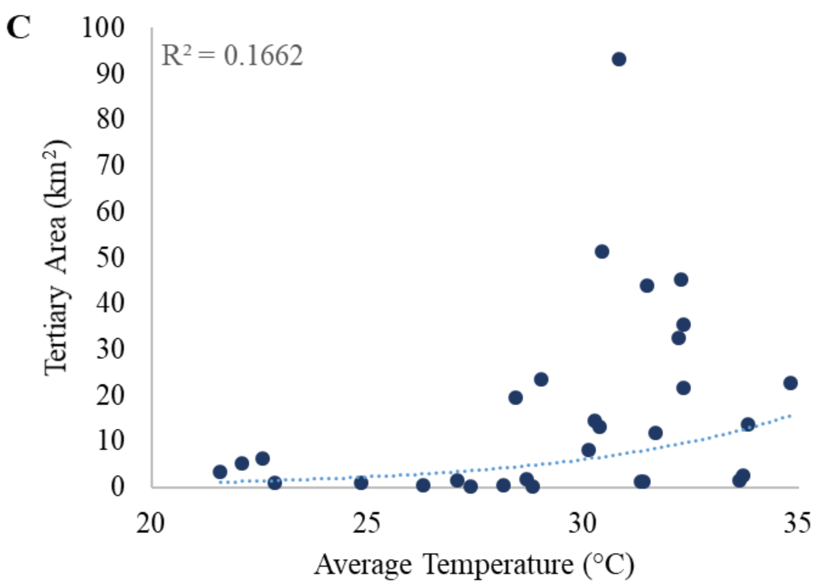


Figure 9: Relationship between (**A**) core, (**B**) secondary, and (**C**) tertiary areas (km^2) of each bat and average temperatures (°C) recorded across the nights an individual evening bat (*Nycticeius humeralis*) was successfully tracked. Each point on the scatter plot represents the home range area of an individual bat. Dotted lines and R^2 value represent exponential regression fit.

Table 3: Summary of the linear regressions for first, second, and third precipitation variants with the core, secondary, and tertiary areas (km^2) within the home range of each evening bat (*Nycticeius humeralis*).

		1st Precipitation Variant	**2nd Precipitation Variant**	**3rd Precipitation Variant**
Core	*R*	0.091	0.270	0.012
	df	29	29	29
	F	0.235	2.205	0.004
	P	0.632	0.149	0.948
Secondary	*R*	0.057	0.212	0.056
	df	29	29	29
	F	0.90	1.318	0.087
	P	0.767	0.261	0.770
Tertiary	*R*	0.046	0.020	0
	df	29	29	29
	F	0.060	0.011	0.850
	P	0.809	0.917	0.364

Table 4: Summary of the exponential regressions for first, second, and third precipitation variants with the core, secondary, and tertiary areas (km^2) within the home range of each evening bat (*Nycticeius humeralis*).

		1st Precipitation Variant	**2nd Precipitation Variant**	**3rd Precipitation Variant**
Core	*R*	0.300	0.201	0.003
	df	29	29	29
	F	2.765	1.173	0.000
	P	0.107	0.288	0.989
Secondary	*R*	0.245	0.168	0.020
	df	29	29	29
	F	1.783	0.818	0.011
	P	0.192	0.374	0.917
Tertiary	*R*	0.217	0.088	0.095
	df	29	29	29
	F	1.380	0.219	0.254
	P	0.250	0.643	0.618

Table 5: Summary of the logistic regressions for first, second, and third precipitation variants with the core, secondary, and tertiary areas (km^2) within the home range of each evening bat (*Nycticeius humeralis*).

		1^{st} Precipitation Variant	**2^{nd} Precipitation Variant**	**3^{rd} Precipitation Variant**
Core	*R*	0.300	0.201	0.003
	df	29	29	29
	F	2.765	1.173	0.000
	P	0.107	0.288	0.989
Secondary	*R*	0.245	0.168	0.020
	df	29	29	29
	F	1.783	0.818	0.011
	P	0.192	0.374	0.917
Tertiary	*R*	0.217	0.088	0.095
	df	29	29	29
	F	1.380	0.219	0.254
	P	0.250	0.643	0.618

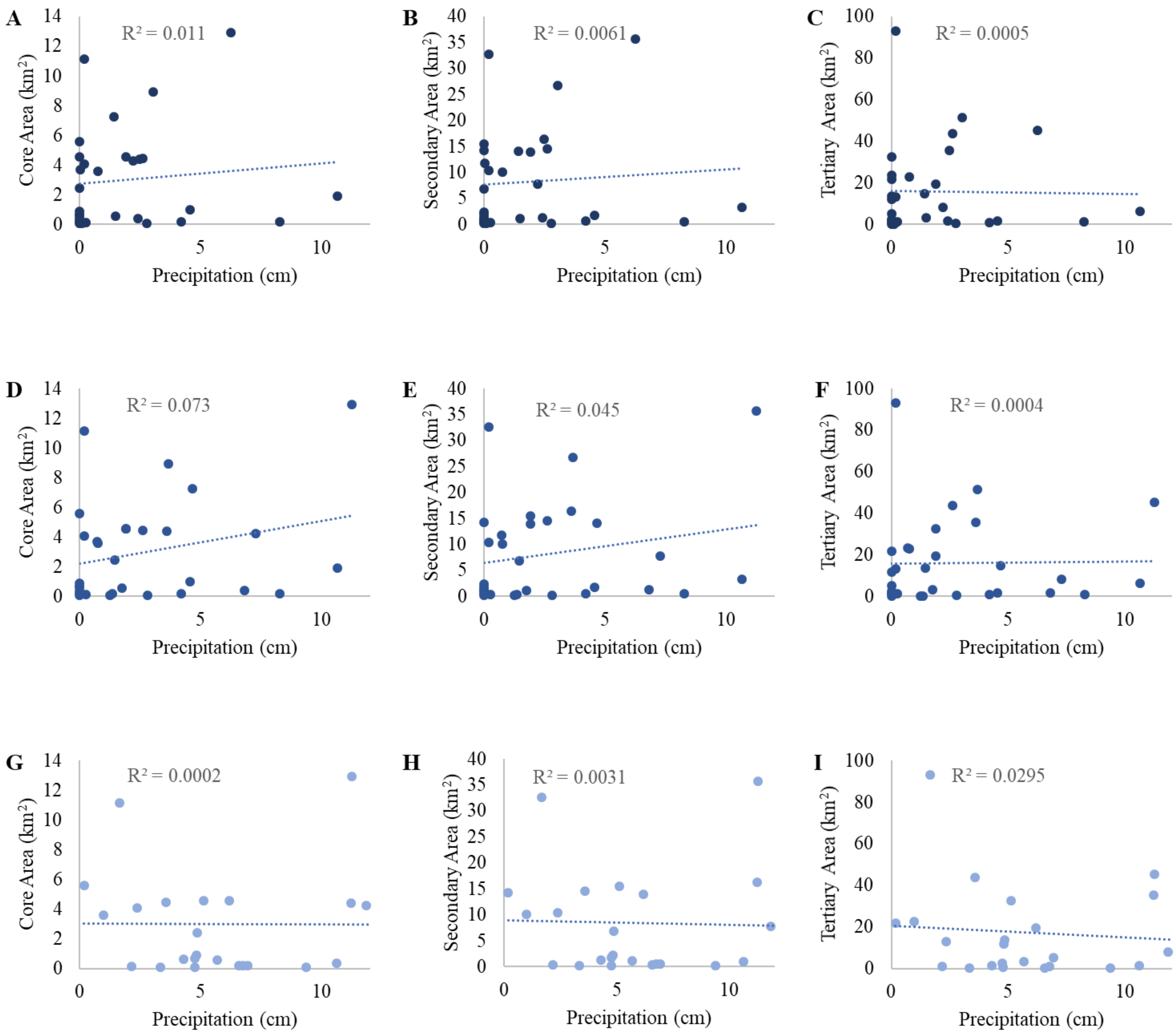
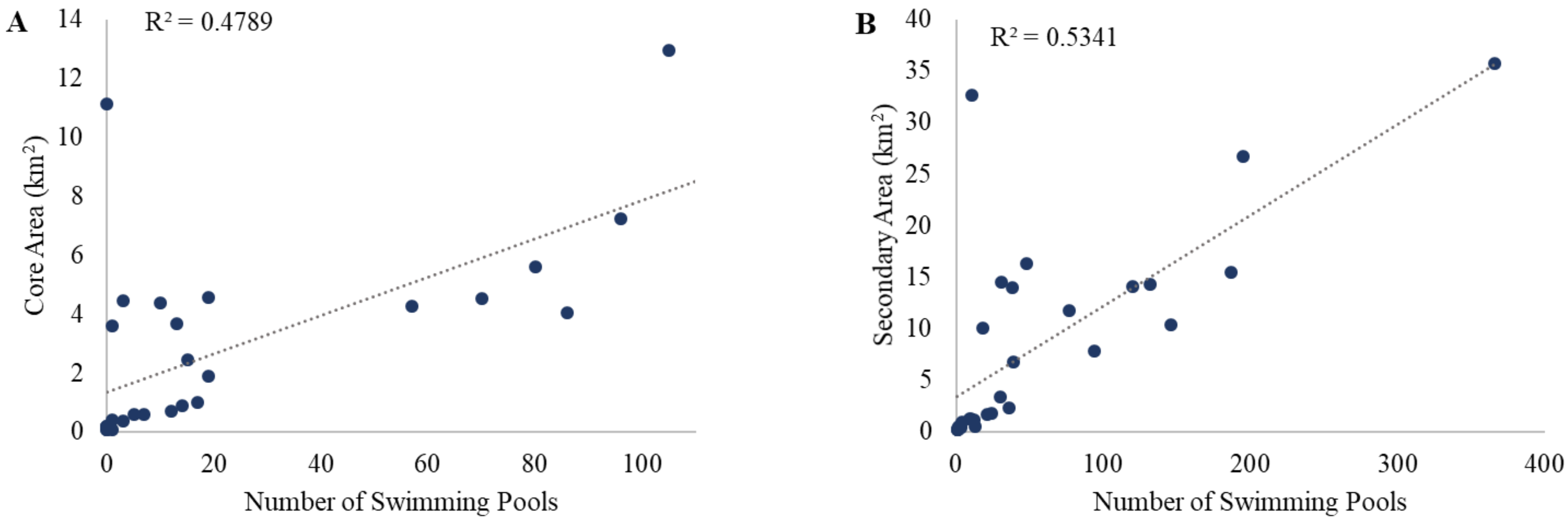


Figure 10: Relationship between core (**A**, **D**, **G**), secondary (**B**, **E**, **H**), and tertiary areas (**C**, **F**, **I**) of each bat and the 3 precipitation variants: 1) the total amount of rainfall (cm) that occurred across the survey period of an individual evening bat (*Nycticeius humeralis*; dark blue), 2) the total amount of rainfall that occurred across the tracking period along with a 7-day period prior to the surveys (medium blue), and 3) the total amount of rainfall that occurred across the tracking period along with a 30-day period prior to the surveys (light blue). Each point on the scatter plot represents the home range area of an individual bat. Dotted lines and R^2 value represent linear regression fit.

Table 6: Summary of the linear and non-linear regressions for the number of swimming pools within each home range compared to the core, secondary, and tertiary areas (km^2) within the home range of each evening bat (*Nycticeius humeralis*). * represents significant *P* values.

		Linear	**Exponential**	**Logistic**
Core	*R*	**0.692**	0.645	0.645
	df	29	29	29
	F	25.737	19.961	19.961
	P	<0.001*	<0.001*	<0.001*
Secondary	*R*	**0.731**	0.649	0.649
	df	29	29	29
	F	32.1	20.334	20.334
	P	<0.001*	<0.001*	<0.001*
Tertiary	*R*	**0.819**	0.767	0.767
	df	29	29	29
	F	57.052	40.066	40.066
	P	<0.001*	<0.001*	<0.001*



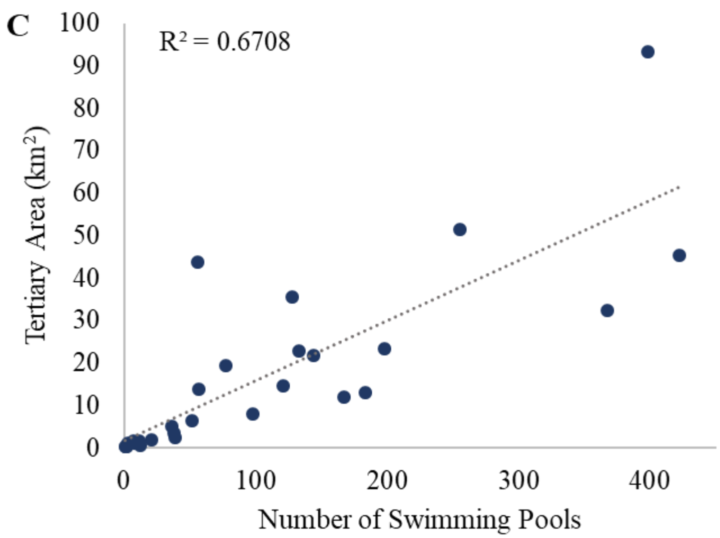


Figure 11: Relationship between **A** core, **B** secondary, and **C** tertiary core areas (km^2) of each bat and the number of swimming pools within the core, secondary, and tertiary areas of the home range of each evening bat (*Nycticeius humeralis*). Each point on the scatter plot represents the home range area of an individual bat. Dotted lines and R^2 value represent linear regression fit.

Table 7 summarizes the percentage of the home range that fell within the surrounding residential neighborhoods for each bat. Comparing the percentage of core area with the average temperature, we observed a positive correlation between the percentage of this area and temperature with no buffer, a 20 m buffer, and a 40 m buffer around the park system and this relationship was significant and best-fit with a linear regression (Table 8-10; Fig. 12A). For the percentage of secondary area in the surrounding neighborhood, we found no apparent correlation between the percentage of area and temperature with no buffer and a 20 m buffer around the park system. In contrast, we observed a significant positive correlation with a 40 m buffer which best fit a linear regression (Tables 8-10; Fig. 12B). For the percentage of tertiary area in the surrounding neighborhood, we found no apparent correlation between the percentage of area and temperature with no buffer, a 20 m buffer, and a 40 m buffer around the park system (Tables 8-10; Fig. 12C). Finally, when we compared the percentage of the core, secondary, and tertiary areas for each bat that fell within the surrounding neighborhood with the number of swimming pools present, we observed an increase in percentage area with an increase in the number of swimming pools (Tables 11-13; Fig. 13).

Table 7: Percentage of the core, secondary, and tertiary areas within the home range of each evening bat (*Nycticeius humeralis*) that fell within the surrounding neighborhood with no buffer, a 20 m buffer, and 40 m buffer around the park.

		No Buffer	**20 m Buffer**	**40 m Buffer**
Core	***Mean***	70.5%	61.1%	54.5%
	SD	32.1%	34.1%	36.5%
	Range	0-100%	0-99.8%	0-98%
Secondary	***Mean***	75%	66.9%	60.4%
	SD	25.8%	29.2%	31.2%
	Range	0-99.9%	0-98.7%	0-96.7%
Tertiary	***Mean***	81.8%	75%	69.6%
	SD	19.7%	24.4%	27.2%
	Range	15.5-99.9%	1.5-98.7%	0-97.9%

Table 8: Summary of the 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 with no buffer, a 20 m buffer, and a 40 m buffer around the park. This analysis did not work for exponential and logistic regressions as a Log transformation could not be performed. * represents significant *P* values.

		No Buffer	**20 m Buffer**	**40 m Buffer**
Core Area	*R*	0.398	0.427	0.455
	df	29	29	29
	F	5.277	6.229	7.304
	P	0.029*	0.019*	0.012*
Secondary Area	*R*	0.296	0.343	0.361
	df	29	29	29
	F	2.668	3.722	4.196
	P	0.112	0.064	0.05*
Tertiary Area	*R*	0.338	0.455	0.344
	df	29	29	29
	F	3.606	7.304	3.759
	P	0.068	0.063	0.063

Table 9: Summary of the exponential 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 with no buffer, a 20 m buffer, and a 40 m buffer around the park. This analysis did not work for the core areas as a Log transformation could not be performed. * represents significant *P* values. - indicates that an analysis could not be performed.

		No Buffer	**20 m Buffer**	**40 m Buffer**
Core Area	*R*	-	-	-
	df	-	-	-
	F	-	-	-
	P	-	-	-
Secondary Area	*R*	-	-	-
	df	-	-	-
	F	-	-	-
	P	-	-	-
Tertiary Area	*R*	0.297	0.248	-
	df	29	29	-
	F	2.702	1.843	-
	P	0.111	0.185	-

Table 10: Summary of the logistic 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 with no buffer, a 20 m buffer, and a 40 m buffer around the park. This analysis did not work for the core areas as a Log transformation could not be performed. * represents significant *P* values. - indicates that an analysis could not be performed.

		No Buffer	**20 m Buffer**	**40 m Buffer**
Core Area	*R*	-	-	-
	df	-	-	-
	F	-	-	-
	P	-	-	-
Secondary Area	*R*	-	-	-
	df	-	-	-
	F	-	-	-
	P	-	-	-
Tertiary Area	*R*	0.297	0.248	-
	df	29	29	-
	F	2.702	1.843	-
	P	0.111	0.185	-

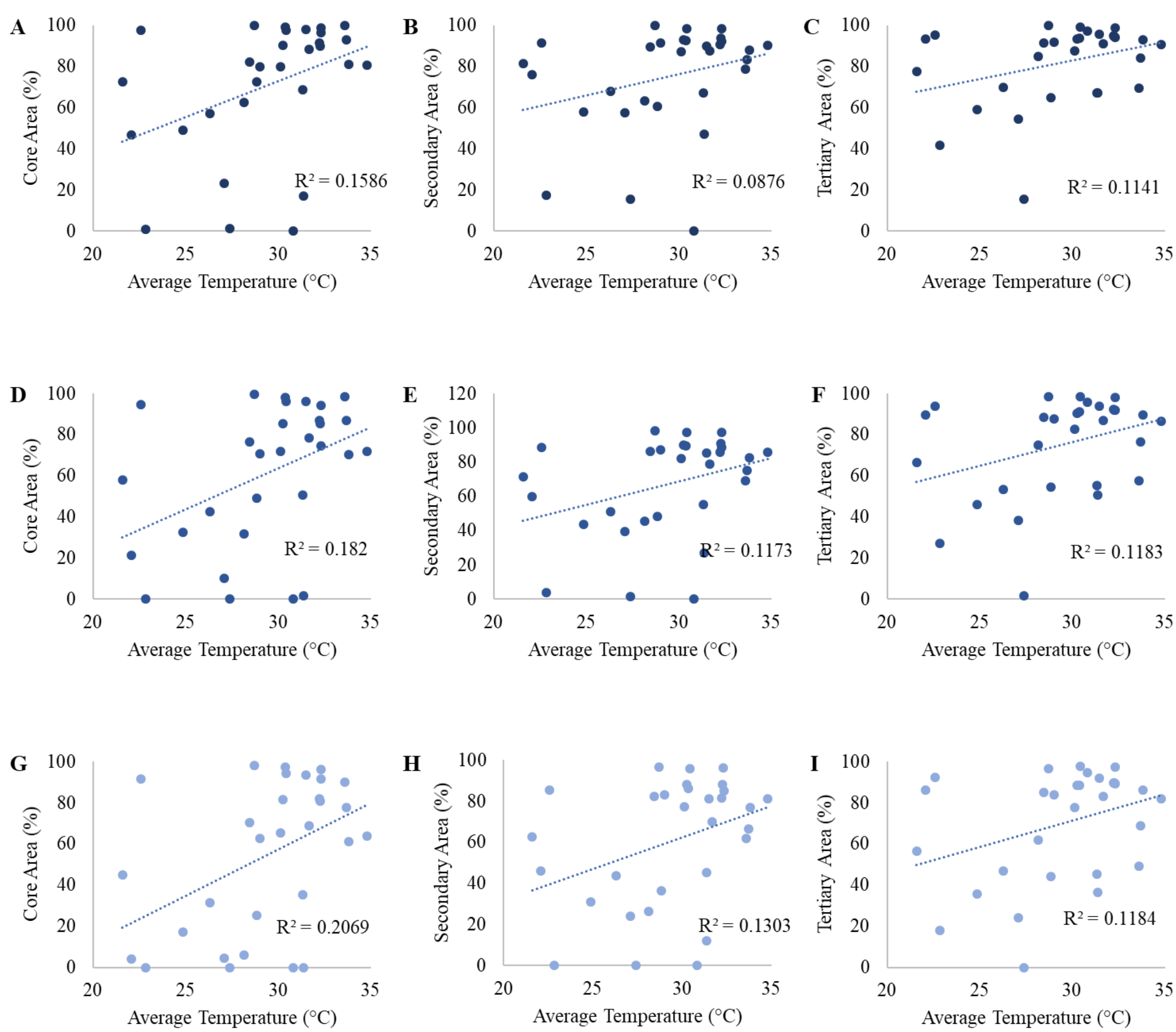


Figure 12: Relationship between the percentage of (**A**, **D**, **G**) core, (**B**, **E**, **H**)secondary, and (**C**, **F**, **I)** tertiary areas (km^2) of each evening bat (*Nycticeius humeralis*) that fell within the surrounding residential neighborhood and average temperatures (°C) recorded across the nights an individual bat was successfully tracked with no buffer (dark blue), a 20 m buffer (medium blue), and a 40 m buffer (dark blue) on the park system. 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.

Table 11: Summary of the linear regressions for the number of swimming pools within each home range compared to the core, secondary, and tertiary areas (km^2) within the home range of each evening bat (*Nycticeius humeralis*) with no buffer, a 20 m buffer, and a 40 m buffer around the park system. * represents significant *P* values.

		No Buffer	**20 m Buffer**	**40 m Buffer**
Core Area	*R*	0.472	0.546	0.568
	df	29	29	29
	F	8.045	11.881	13.332
	P	0.008*	0.002*	0.001*
Secondary Area	*R*	0.508	0.56	0.587
	df	29	29	29
	F	9.756	12.77	14.705
	P	0.004*	0.001*	0.001*
Tertiary Area	*R*	0.526	0.56	0.587
	df	29	29	29
	F	10.715	12.77	14.705
	P	0.003*	0.001*	0.001*

Table 12: Summary of the exponential regressions for the number of swimming pools within each home range compared to the core, secondary, and tertiary areas (km^2) within the home range of each evening bat (*Nycticeius humeralis*) with no buffer, a 20 m buffer, and a 40 m buffer around the park system. This analysis did not work for the core areas as a Log transformation could not be performed. * represents significant *P* values. - indicates that an analysis could not be performed.

		No Buffer	**20 m Buffer**	**40 m Buffer**
Core Area	*R*	-	-	-
	df	-	-	-
	F	-	-	-
	P	-	-	-
Secondary Area	*R*	-	-	-
	df	-	-	-
	F	-	-	-
	P	-	-	-
Tertiary Area	*R*	0.427	0.364	-
	df	29	29	-
	F	6.229	4.726	-
	P	0.019*	0.048*	-

Table 13: Summary of the logistic regressions for the number of swimming pools within each home range compared to the core, secondary, and tertiary areas (km^2) within the home range of each evening bat (*Nycticeius humeralis*) with no buffer, a 20 m buffer, and a 40 m buffer around the park system. This analysis did not work for the core areas as a Log transformation could not be performed. * represents significant *P* values. - indicates that an analysis could not be performed.

		No Buffer	**20 m Buffer**	**40 m Buffer**
Core Area	*R*	-	-	-
	df	-	-	-
	F	-	-	-
	P	-	-	-
Secondary Area	*R*	-	-	-
	df	-	-	-
	F	-	-	-
	P	-	-	-
Tertiary Area	*R*	0.427	0.364	-
	df	29	29	-
	F	6.229	4.726	-
	P	0.019*	0.048*	-

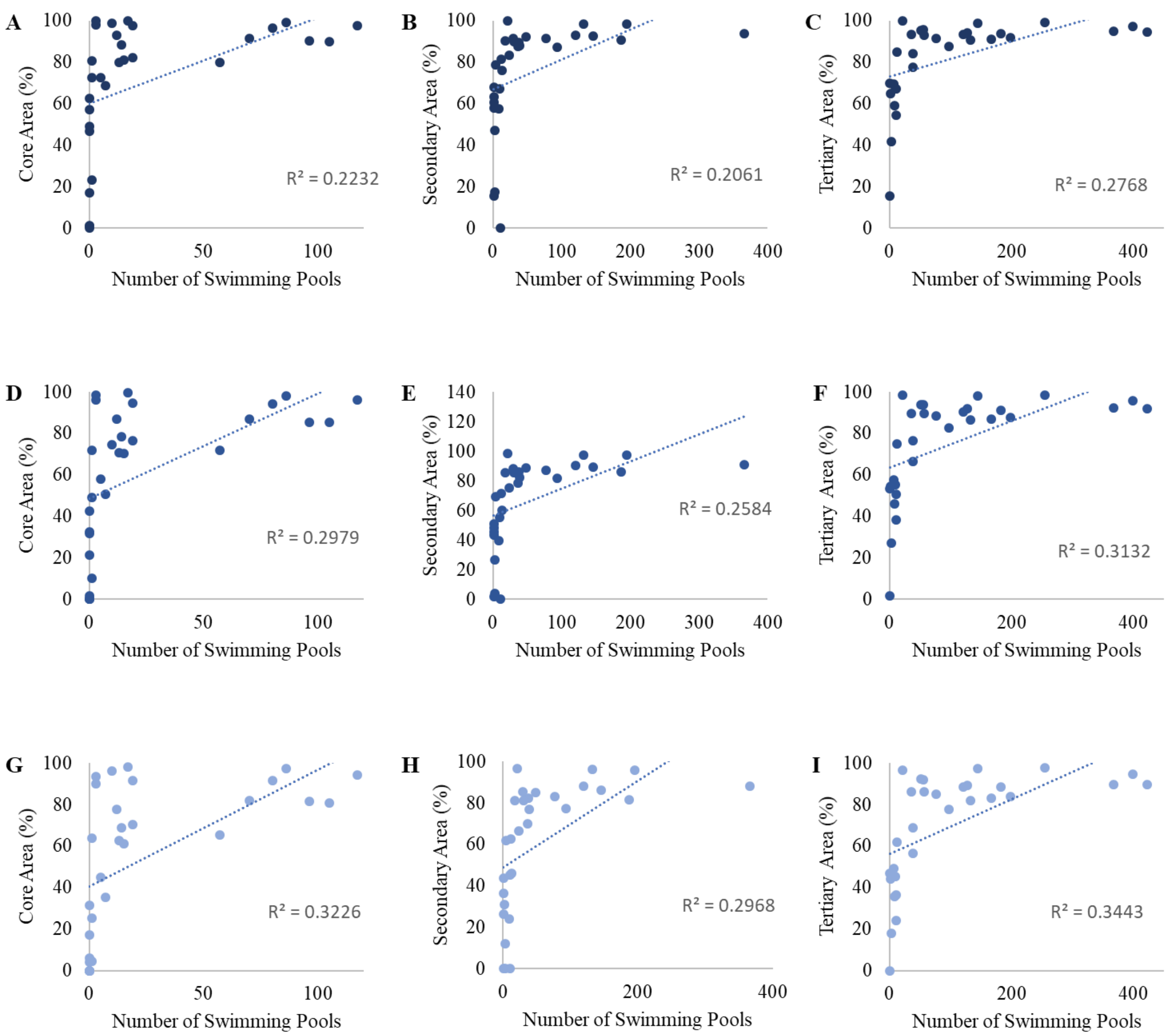
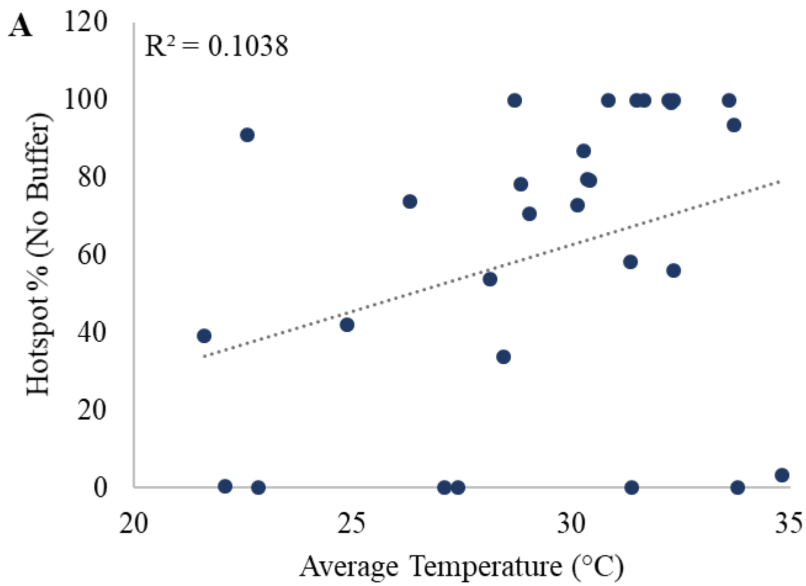


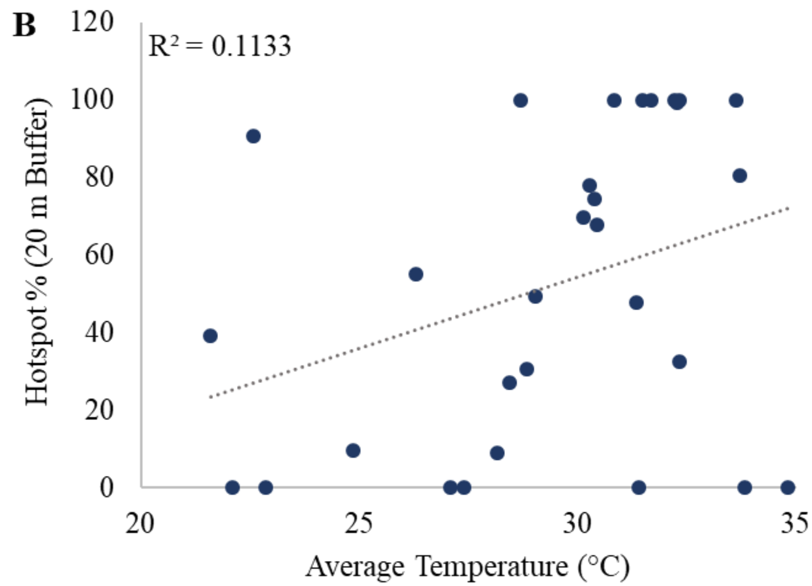
Figure 13: Relationship between the percentage of the (**A**, **D**, **G**) core, (**B**, **E**, **H**) secondary, and (**C**, **F**, **I**) tertiary core areas (km^2) of each evening bat (*Nycticeius humeralis*) within the surrounding residential neighborhood with no buffer (dark blue), a 20 m buffer (medium blue), and a 40 m buffer (light blue) around the park system and the number of swimming pools within the core, secondary, and tertiary areas of the home range of a bat. 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.

For the percentage of the hotspots that fell within the surrounding residential neighborhoods for each bat with no buffer on the park system, we determined that 60.3% ± 38.7 SD of these hotspots fell within this area (ranging from 0-100%; see Appendix C for hotspot maps for each individual bat). For the percentage of hotspots with a 20 m buffer on the park system, we determined that 50.4% ± 40.1 SD of these hotspots fell within this area (ranging from 0-100%). For the percentage of the hotspots that fell within the surrounding residential neighborhoods for each bat with a 40 m buffer on the park system, we determined that 45.8% ± 41.3 SD of these hotspots fell within this area (ranging from 0-100%). Comparing these percentages with the average temperature, we observed no apparent increase in the percentage and associated temperature (Table 14; Fig. 14).

Table 14: Summary of the linear regressions for the average temperature compared to the percentage of hotspots for each evening bat (*Nycticeius humeralis*) that fell within the surrounding neighborhood with no buffer, a 20 m buffer, and a 40 m buffer around the park system. This analysis did not work for exponential and logistic regressions as a Log transformation could not be performed.

		No Buffer	**20 m Buffer**	**40 m Buffer**
Hotspot Percentage	*R*	0.322	0.337	0.311
	df	29	29	29
	F	3.241	3.557	2.998
	P	0.083	0.069	0.094





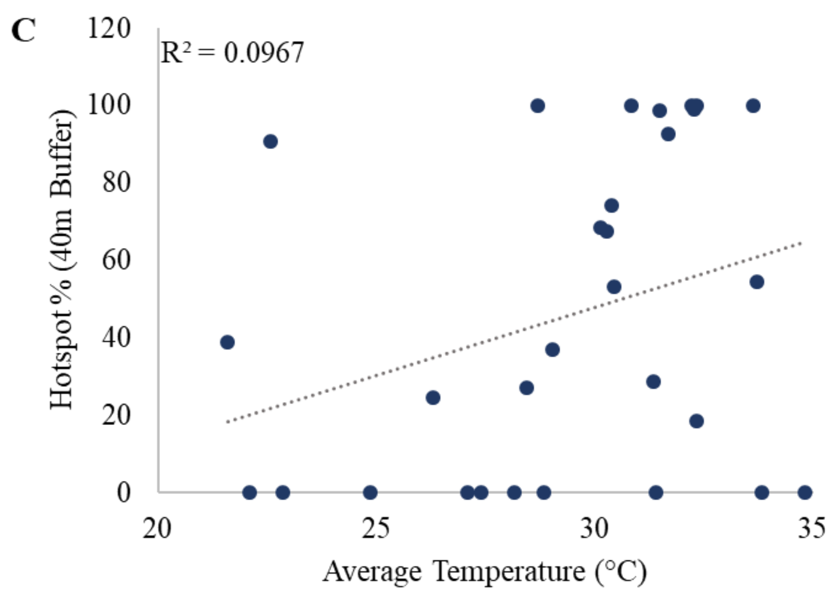


Figure 14: Relationship between the percentage hotspots of each evening bat (*Nycticeius humeralis*) that fell within the surrounding residential neighborhood with no buffer, a 20 m buffer, and a 40 m buffer around the park system and average temperatures (°C) recorded across the nights an individual bat was successfully tracked. Each point on the scatter plot represents the percentage of a hotspot that falls within the neighborhood for an individual bat. Dotted lines and R^2 values represent linear fit.

Table 15 summarizes the minimum and maximum distance of a hotspot from the nearest edge of the park system for each bat. Comparing these distances with the average temperature, we observed no apparent increase in distance from the park system with an increasing temperature (Table 16; Fig. 15).

Table 15: Summary of the minimum and maximum distances of hotspots for each evening bat (*Nycticeius humeralis*) from the nearest edge of the park system with no buffer, a 20 m buffer, and a 40 m buffer around the park edge.

		No Buffer	**20 m Buffer**	**40 m Buffer**
Minimum Distance	**Mean**	0.086 km	0.083 km	0.080 km
	SD	0.350 km	0.346 km	0.342 km
	Range	0-1.89 km	0-1.87 km	0-1.85 km
Maximum Distance	**Mean**	0.219 km	0.207 km	0.195 km
	SD	0.376 km	0.371 km	0.367 km
	Range	0-1.89 km	0-1.87 km	0-1.85 km

Table 16: Summary of the linear regressions for the average temperature compared to the minimum and maximum distances of hotspots from the park system for each evening bat (*Nycticeius humeralis*) with no buffer, a 20 m buffer, and a 40 m buffer on the park system. This analysis did not work for exponential and logistic regressions as a Log transformation could not be performed.

		No Buffer	**20 m Buffer**	**40 m Buffer**
Minimum Distance	*R*	0.123	0.122	0.117
	df	29	29	29
	F	0.431	0.424	0.391
	P	0.517	0.52	0.537
Maximum Distance	*R*	0.194	0.19	0.185
	df	29	29	29
	F	1.095	1.043	0.988
	P	0.304	0.316	0.329

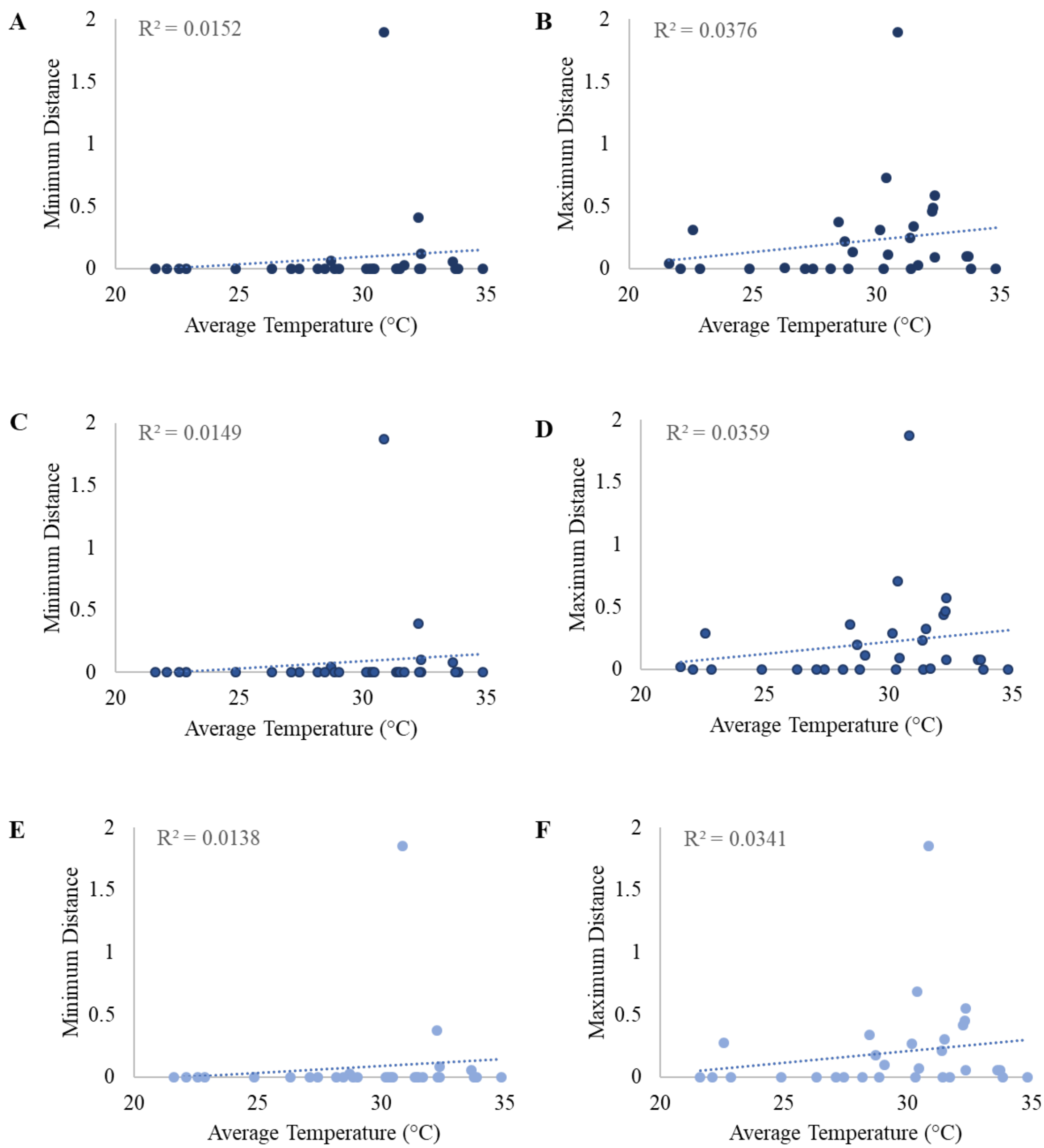


Figure 15: Scatter plot delineating the relationship between the minimum and maximum distance of hotspots for each evening bat (*Nycticeius humeralis*) from the park system edge to the average of the temperatures (°C) recorded across the nights an individual bat was successfully tracked with no buffer (dark blue), a 20 m buffer (medium blue), and a 40 m buffer (light blue) on the park system. Each point on the scatter plot represents the distance of a hotspot from the park system for an individual bat. Dotted lines and R^2 value represent linear best fit.

Discussion

In this study, we determined that evening bats expanded and/or shifted their home ranges into the surrounding neighborhood during their summer activity period when temperatures increased to access areas with a greater number of swimming pools. More specifically, we recorded home ranges to vary in size from 0.16 km^2 to 93.18 km^2, representing a 6-fold difference in size. The smaller ranges occurred at the beginning and end of the summer activity period, while the larger ranges occurred toward the middle of the season (Fig. 16). This change in range size shows that during the middle of the summer activity period these bats are either expanding and/or shifting their home ranges to incorporate the surrounding neighborhoods.

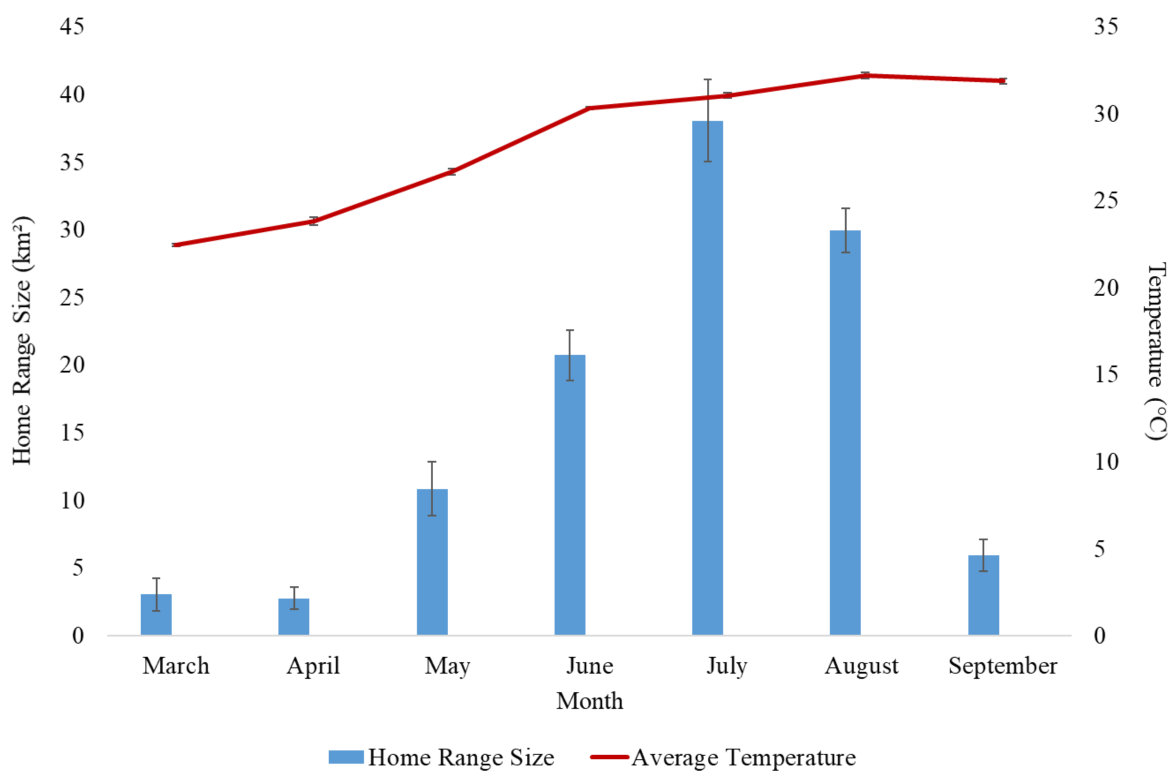


Figure 16: Average monthly home range expansion by evening bats (*Nycticeius humeralis*) from March to September 2017-2019.

The expansion of home ranges into the surrounding neighborhood provides evidence that these areas offer important resources for bats. Thus, even though green spaces are generally perceived to be the only suitable habitat for bats in an urban or suburban environment (Kurta & Teramino 1992; MacGregor-Fors et al. 2016; Verissimo Silva de Araujo & Bernard 2016), our results suggest that this entire area is potentially suitable for evening bats. Moreover, such expansions in evening bat home range size have been previously reported in a study conducted in southwestern Georgia (Morris et al. 2011). However, the increase reported in this aforementioned study did not occur to the same extent, which may have been due to 2 potential reasons: 1) timing of the study and 2) location. 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 ranges (2011). In addition, as the study was conducted in Georgia, there were most likely variations in resource availability and environmental differences that could have influenced range sizes.

To explore the factors driving this expansion and/or shift in home ranges of evening bats, we originally predicted that 3 variables could be influential: temperature, precipitation, and number of swimming pools. Our study revealed that temperature and the number of swimming pools were significantly correlated to home range size. This correlation demonstrated that as the temperature increased, bats extended their home ranges into areas with a higher number of swimming pools. We cannot confirm whether this expansion was to access alternative water sources. However, a previous study by Nystrom and Bennett (2019) proposed that as temperatures exceeded a certain threshold bats would utilize residential swimming pools as an alternative resource. Furthermore, in our study we found that the temperature was positively correlated with the percentage of the core area that fell within the surrounding neighborhood. As bats tend to access water to drink upon emerging from their roosts (McAlexander 2013), we would therefore expect to observe an expansion in their core areas as they travel further distances to access alternative water sources. We also noted that during our study water that was initially available in the park system at the beginning of the activity season became limited later in the season, which coincided with the bat range expansion. For example, the majority of the drainage ditch running through the park system was dry and any areas of water that remained were either small or covered with algae and aquatic vegetation, restricting the ability of bats to drink from them (Fig. 17A-C). Even larger water bodies within the study area, such as the Trinity River, had receded, exposing rocks and other debris, which in turn created clutter that prevented bats from using them as a water source (Fig. 17D; Todd & Williamson 2019). Subsequently, for bats to remain in the area, they would have to seek water from alternative sources on occasions when natural resources were limited. As there were little or no water resources available in the park system when we recorded bats expanding their ranges and accessing areas with higher numbers of residential swimming pools, this provided support for the use of the pools as an alternative water source for bats.

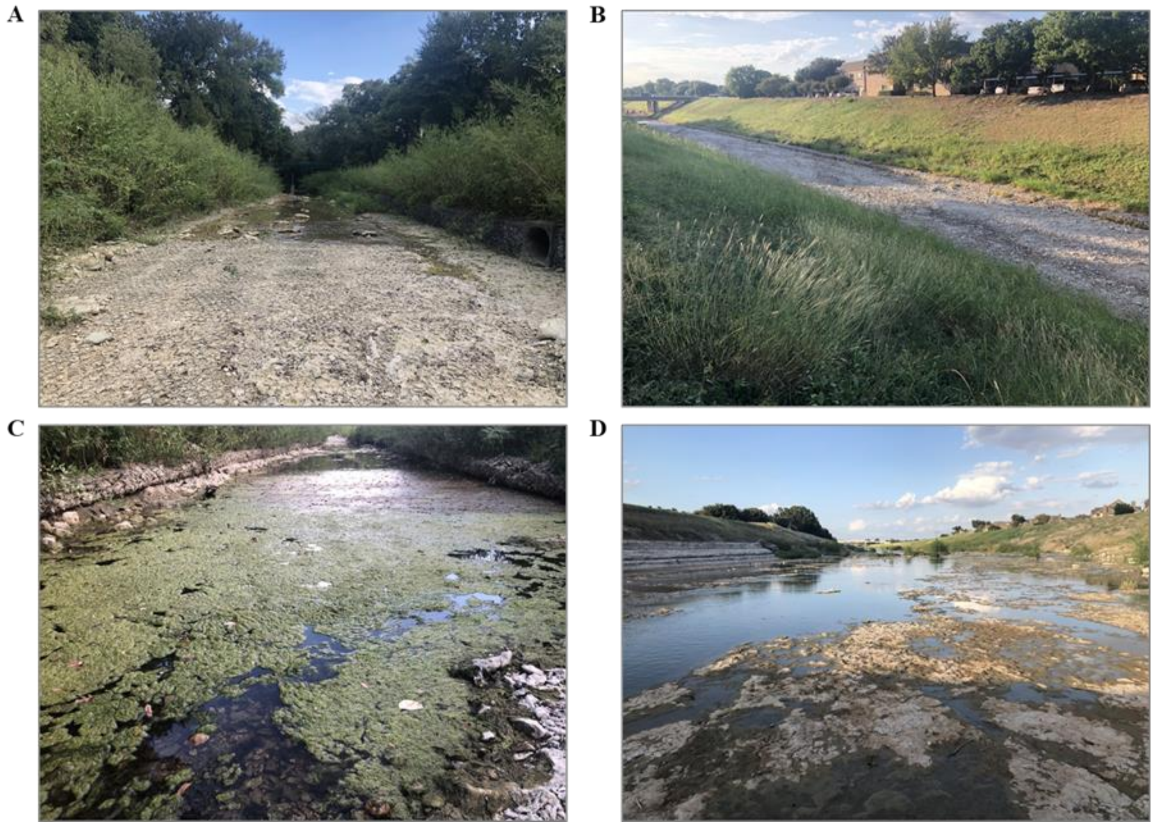


Figure 17: (**A**) and (**B**) show the depleted water within the drainage ditch system from a period of high temperatures and low precipitation in Overton Park, Fort Worth, Texas. (**C**) depicts algae growth in the drainage ditch system of Overton Park, while (**D**) shows the decreased water levels in the Trinity River in August 2019.

While we expected precipitation to be directly linked with water availability and, therefore, home range expansion, there was no significant correlation between precipitation and home range size. This result may be because our measure of precipitation was not an accurate estimate of water availability. For example, although it did rain during the hotter months, the resulting rainfall was insufficient to influence water levels or wash away algae in the natural or semi-natural water bodies within the park system (Fig. 18). Furthermore, despite abnormally high precipitation throughout the summer in the study by Nystrom and Bennett (2019) within the same study site, algae and vegetation continued to create clutter in these water bodies. Thus, perhaps a better measure of water availability would be surface area, or in other words, the amount of area that remained uncluttered and was subsequently available for bats.

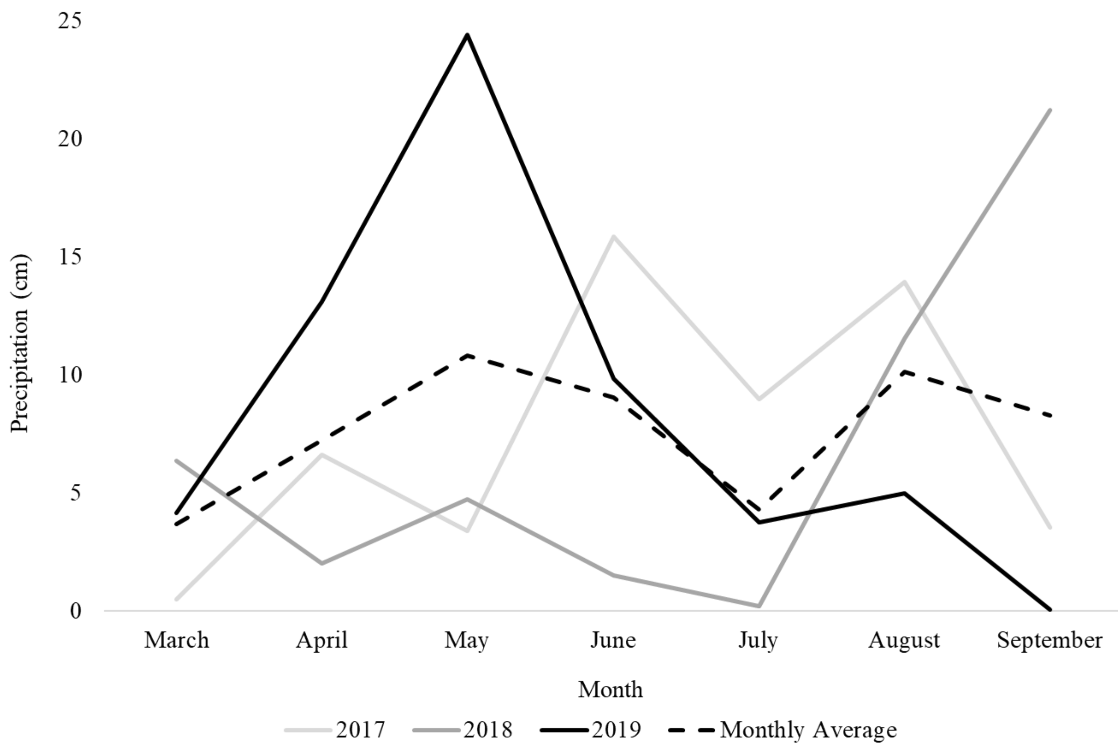


Figure 18: Graph showing the total monthly precipitation levels from March to September 2017-2019 and the average monthly precipitation levels from all 3 years.

We acknowledge that bats could have been expanding their range to increase foraging opportunities (McGlynn et al. 2019; Urcola & Fischer 2019). For example, the backyard or the space above pools might provide foraging opportunities. While our study does not identify specific resources used by the bats, the fact that we recorded expansions and/or shifts in ranges shows that these bats might be changing their area usage as a result of reduction in available resources. 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 areas, such as Texas (e.g., studies such as Salsamendi et al. 2012 and Straka et al. 2019).

We also acknowledge that our surveys only focus on the species-specific behavior and habitat use of evening bats. Nevertheless, Nystrom and Bennett (2019) recorded 4 of the 7 local bat species drinking at swimming pools, including: evening, eastern red, hoary, and silver-haired bats. These results suggest that other species rely on residential swimming pools as an alternative resource. Additionally, other studies have also observed multiple species utilizing the same water source (Adams & Simmons 2002; Adams & Thibault 2006). Thus, we recommend that future studies be conducted to determine if other species demonstrate an equivalent range expansion and/or shift. Similarly, it should be noted that we did not find any sex-specific differences in range expansion. When temperatures were below the 30°C threshold, female home range size averaged 6.37 km^2 (ranging 0.94-19.46 km^2) while the home range size for males averaged 4.32 km^2 (ranging 0.16-23.42 km^2). When temperatures exceeded the 30°C threshold, female home range size averaged 20.10 km^2 (ranging 1.25-45.2 km^2) while home range size for males averaged 25.63 km^2 (ranging 1.13-93.18 km^2).

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; Li & Kalcounis-Rueppell 2018; Straka et al. 2019). 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?”

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 (MacGregor-Fors et al. 2016; Verissimo Silva de Araujo & Bernard 2016). Thus, understanding resource use in urban environments would help inform wildlife practitioners on how to enhance these areas for bats. For example, by making 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 (Lison & Calvo 2011; Gallo et al. 2018).

Appendix A

We used ArcGIS Pro 2.2 to analyze the high elevation points of our study site. First, using Lidar data of the study site we created a Digital Elevation Model (DEM) and Digital Surface Model (DSM) rasters to indicate the bare ground and surface height of tall objects, such as trees and houses. To get the height (Z-value) of these objects, we used the minus raster tool to subtract the DEM elevation from the DSM elevation. We joined the maximum Z-value recorded for each building to a building footprint map from the City of Fort Worth. We then extruded these buildings to the extent of this Z-value, creating a 3-D model of the buildings surrounding our study site. Next, we ran a Radial Line of Sight analysis using Military Tools for ArcGIS to analyze the line of sight from 18 high elevation points throughout the study site from a person standing on the ground holding an antenna (2 m off the ground) to the average height of a flying bat (8 m off the ground). This analysis allowed us to observe where the transmitter signal from a bat would be strongest (i.e., the bat was within the line of sight) and where the signal would be weaker. Of the 18 elevation points, we found locations 1, 7, 13, 14, and 18 to be the most effective for radio-tracking bats throughout the study site and therefore used these locations during surveys.

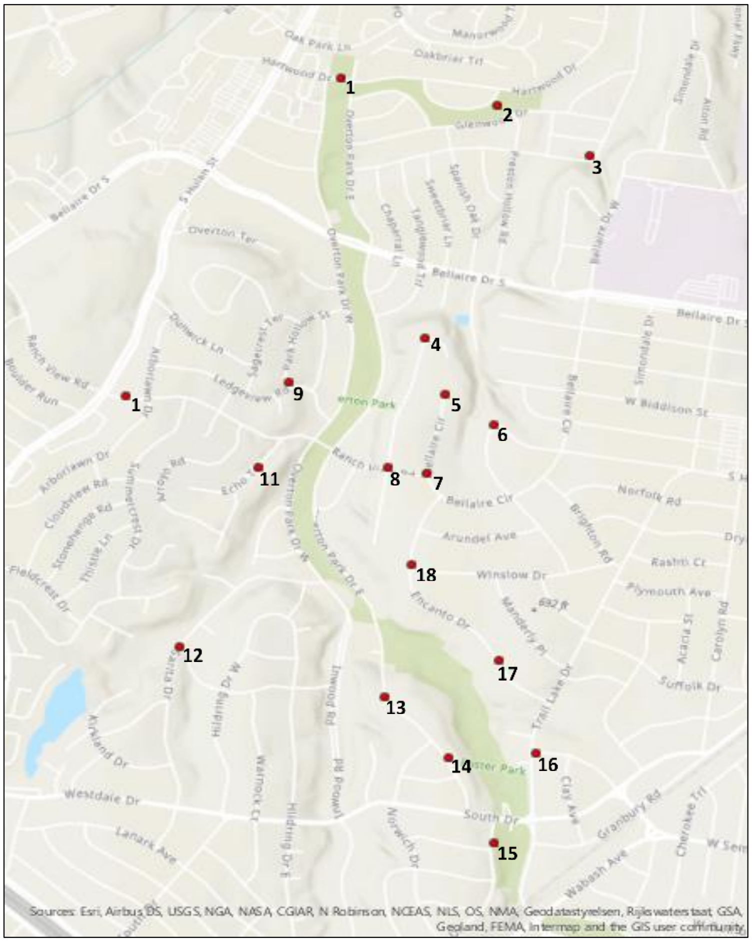


Figure A1: The locations of 18 high elevation points throughout the study site.

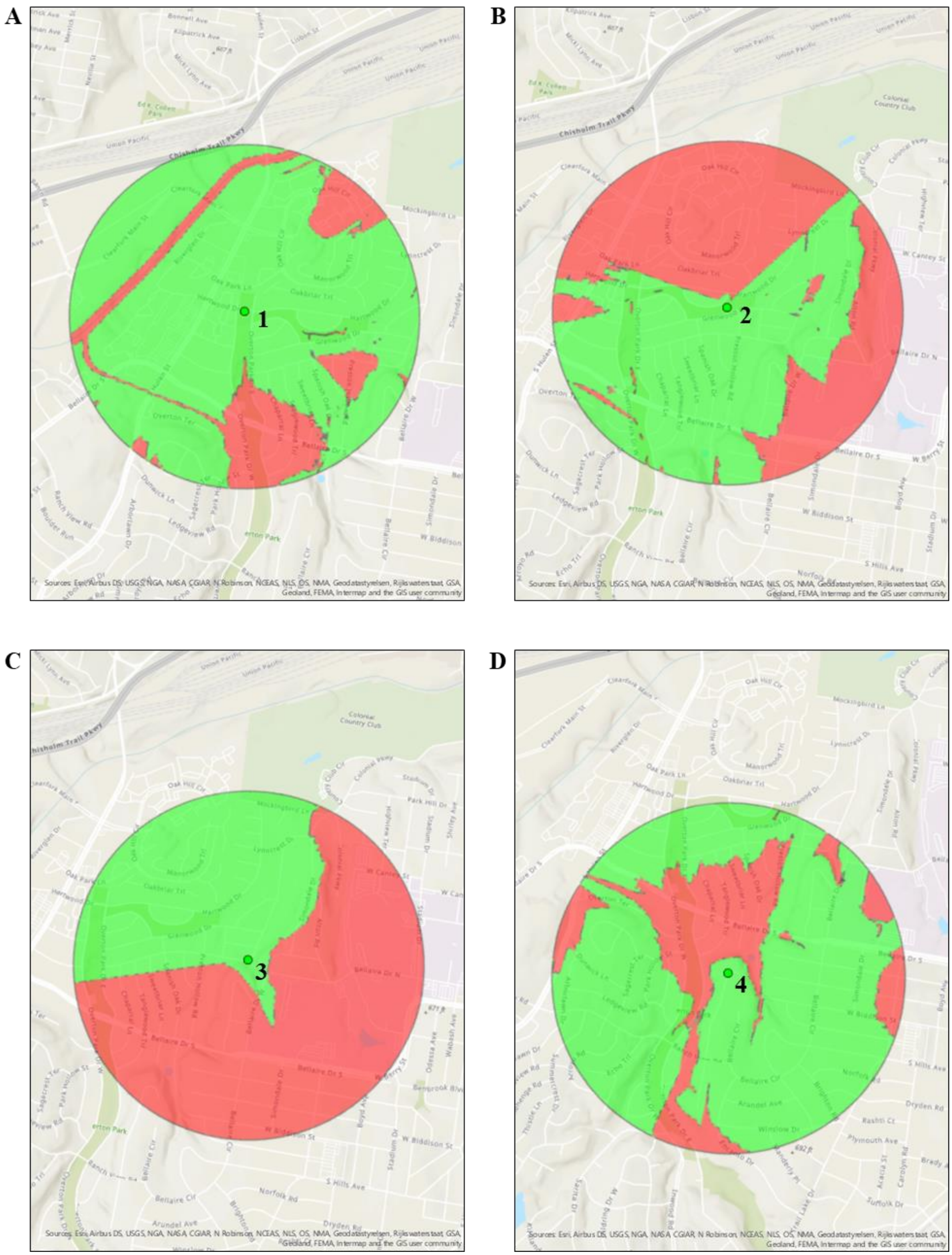


Figure A2: (**A-D**) depict a line of sight analysis of locations 1-4.

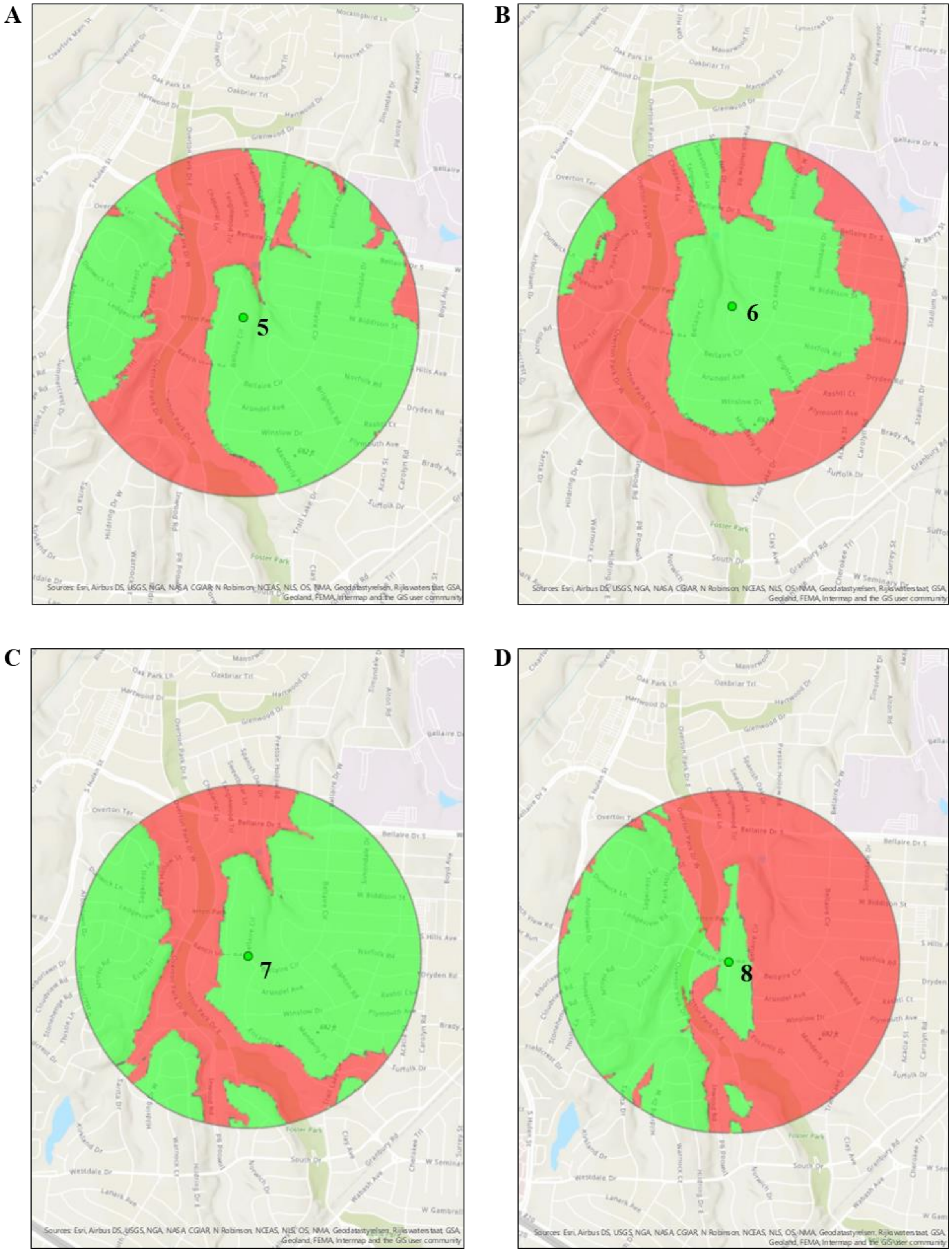


Figure A3: (**A-D**) depict a line of sight analysis of locations 5-8.

Figure A4: (**A-D**) depict a line of sight analysis of locations 9-12.

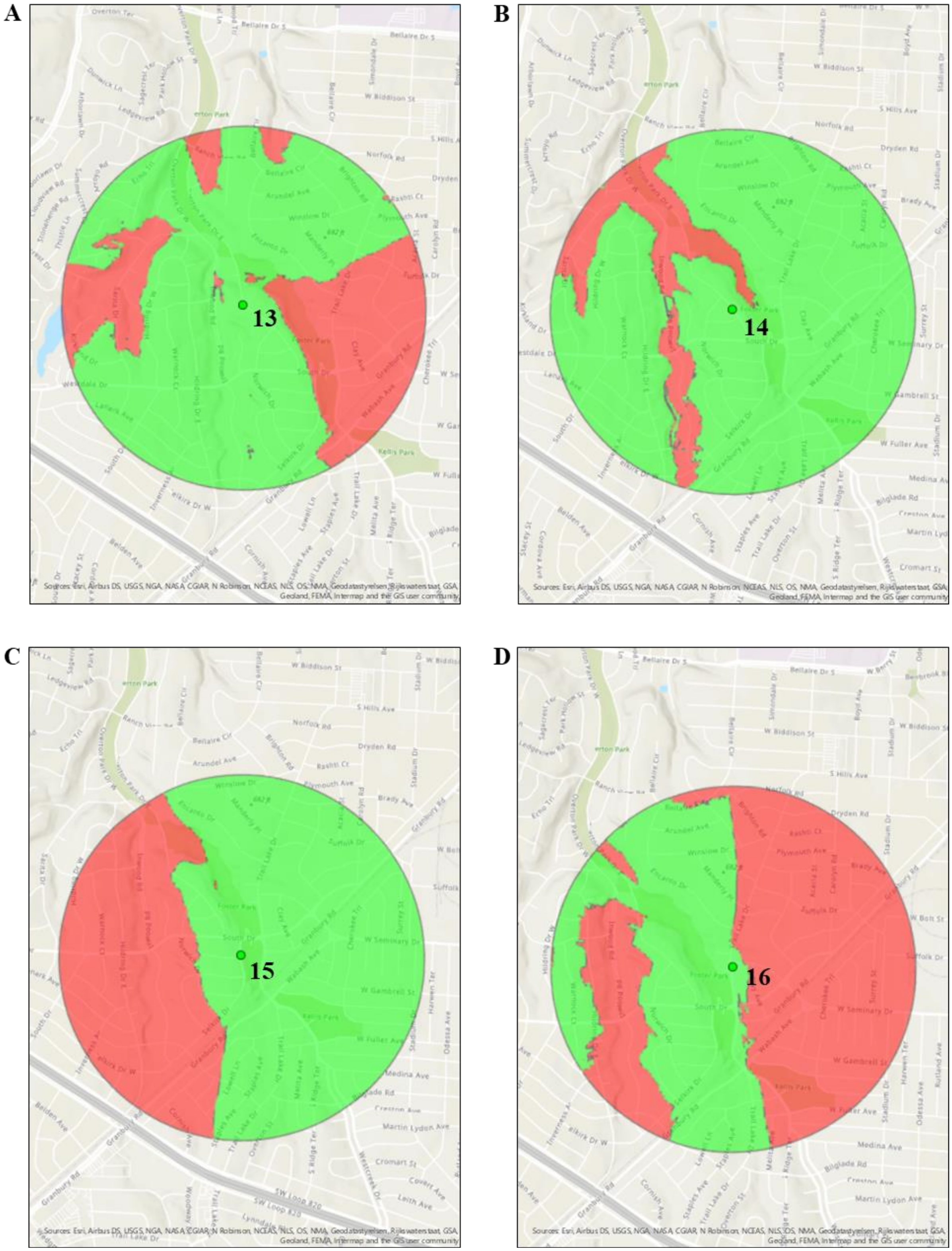


Figure A5: (**A-D**) depict a line of sight analysis of locations 13-16.

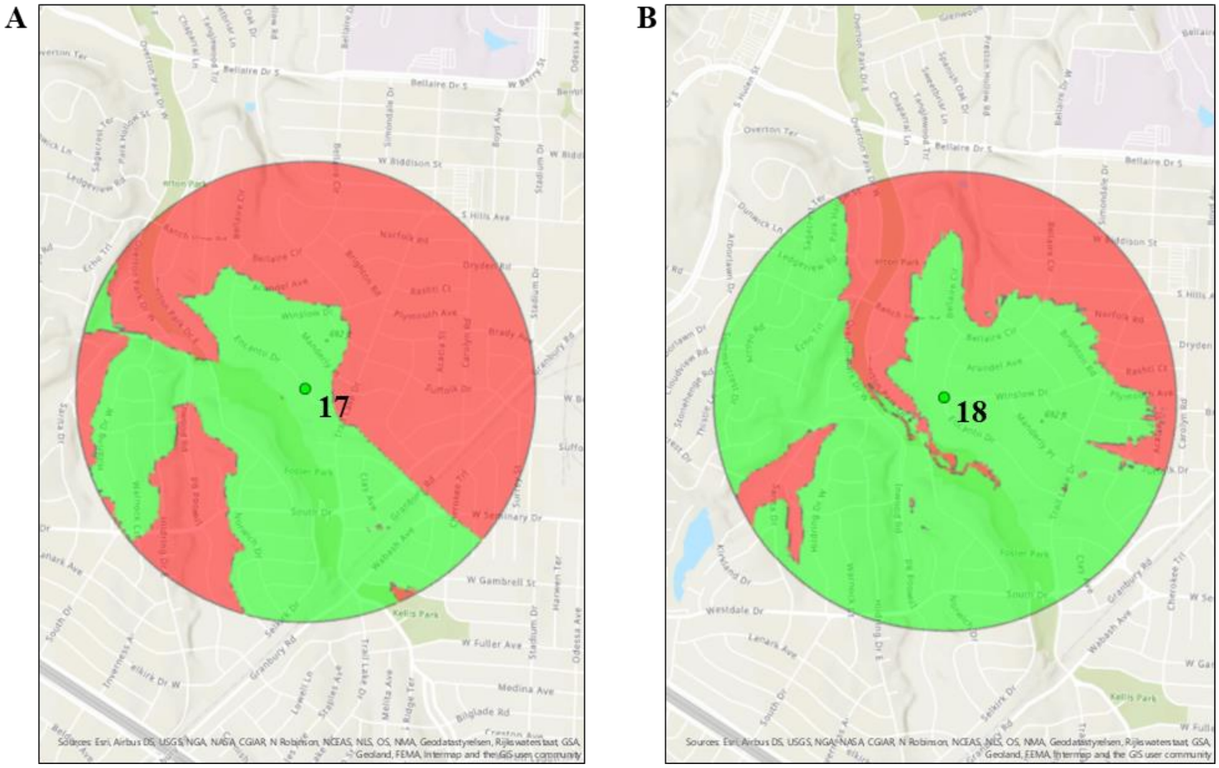


Figure A6: (**A-B**) depict a line of sight analysis of locations 17 and 18.

Appendix B

A

B

C

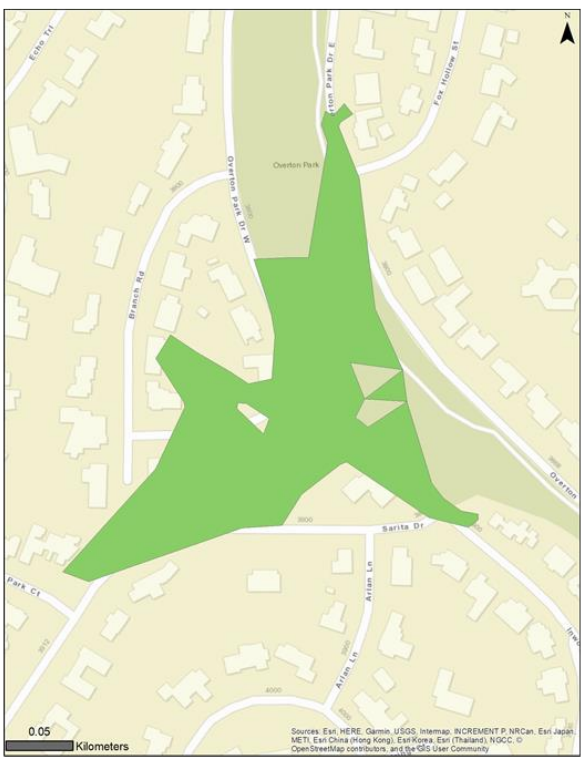


Figure B1: (**A**) shows the core (17 km^2), (**B**) the secondary (32 km^2), and (**C**) the tertiary (33 km^2) areas for evening bat "3Nyhu20Apr17" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

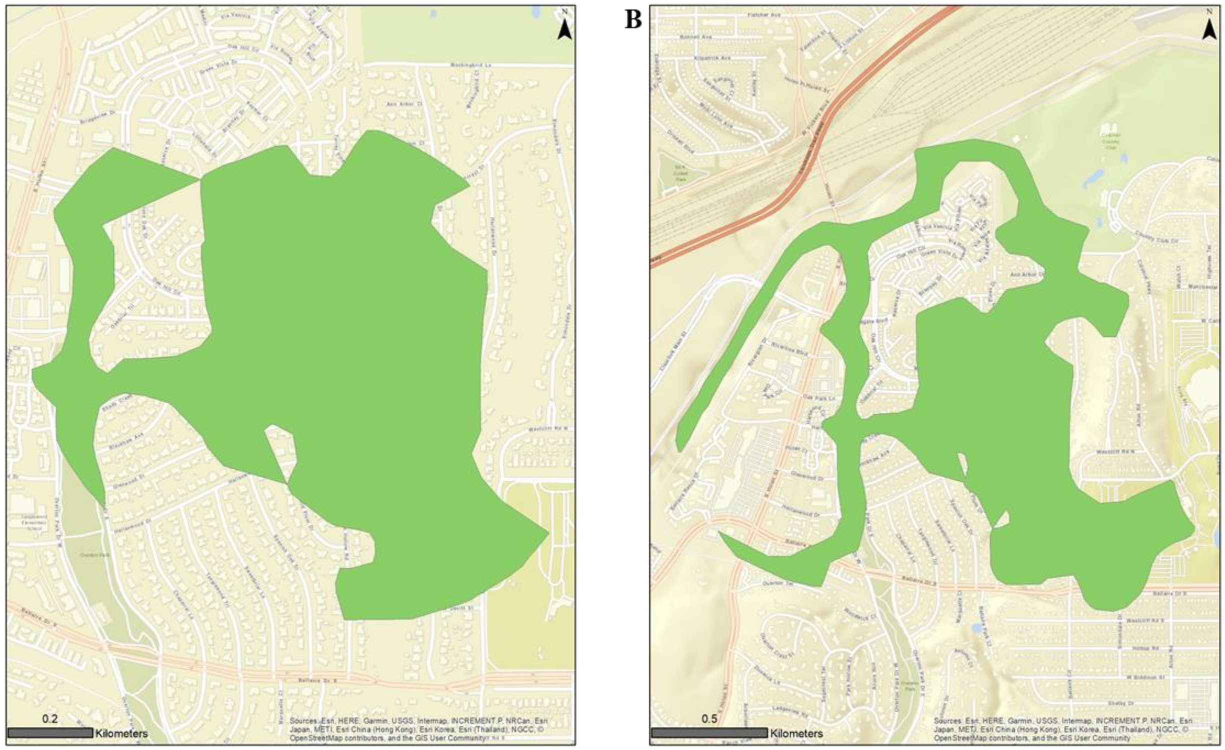
A

B

C

Figure B2: (**A**) shows the core (6 km^2), (**B**) the secondary (16 km^2), and (**C**) the tertiary (16 km^2) areas for evening bat "3Nyhu26May17" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A B



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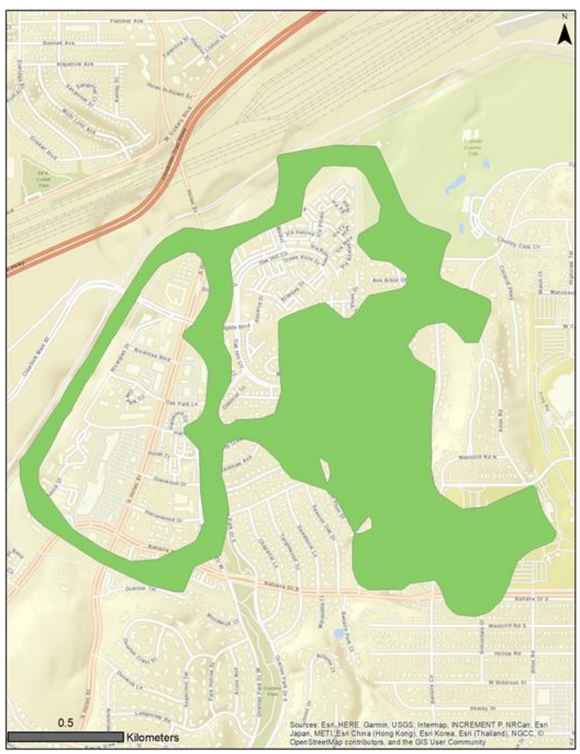


Figure B3: (**A**) shows the core (723 km^2), (**B**) the secondary (1,408 km^2), and (**C**) the tertiary (1,460 km^2) areas for evening bat "1Nyhu13Jun17" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A

B

C

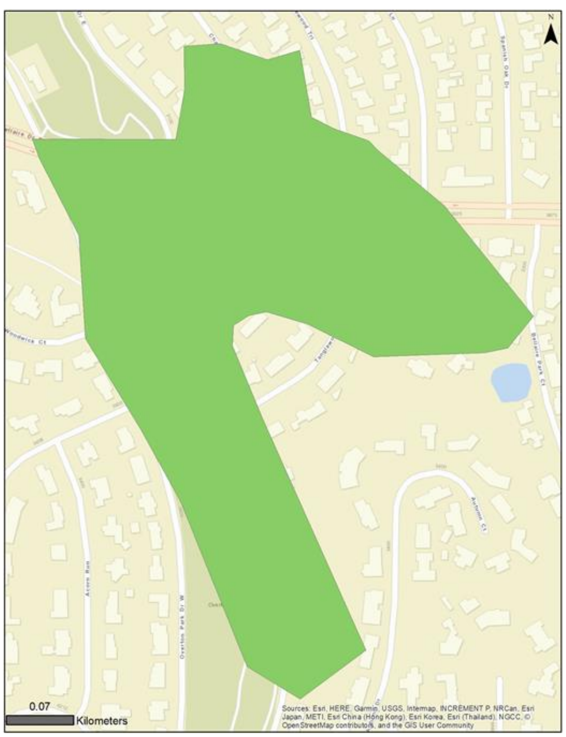


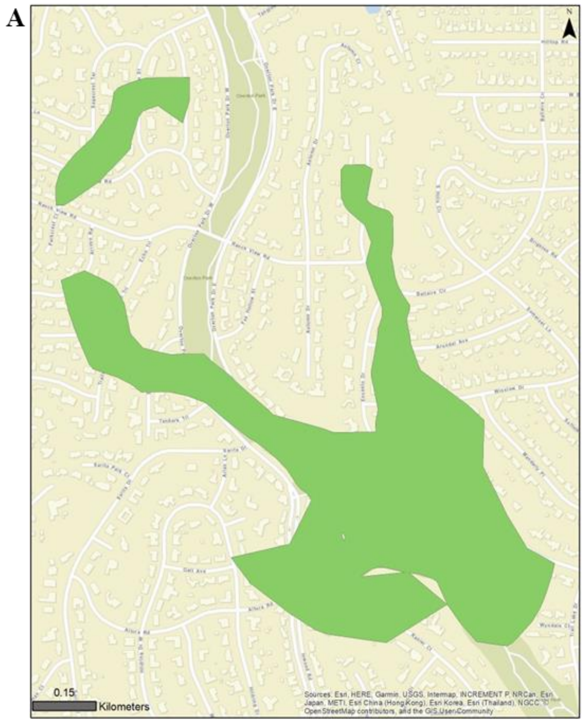
Figure B4: (**A**) shows the core (37 km^2), (**B**) the secondary (97 km^2), and (**C**) the tertiary (146 km^2) areas for evening bat "1Nyhu16Jul17" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

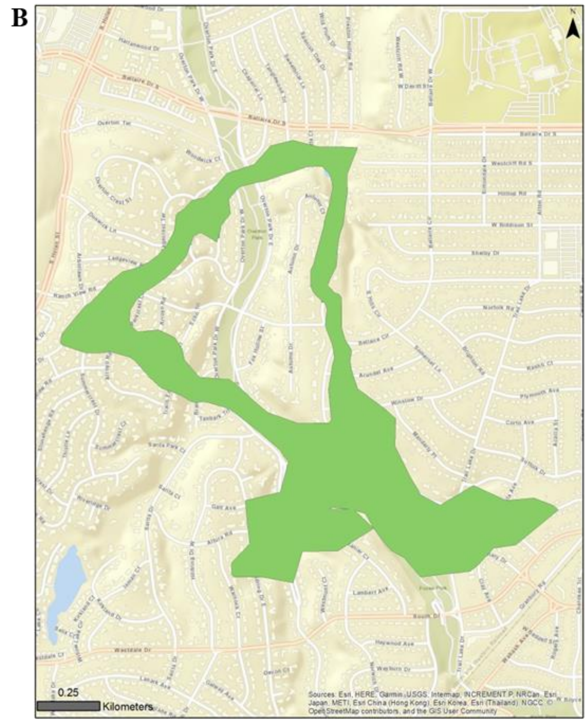
A

B

C

Figure B5: (**A**) shows the core (99 km^2), (**B**) the secondary (173 km^2), and (**C**) the tertiary (173 km^2) areas for evening bat "3Nyhu31Jul17" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.





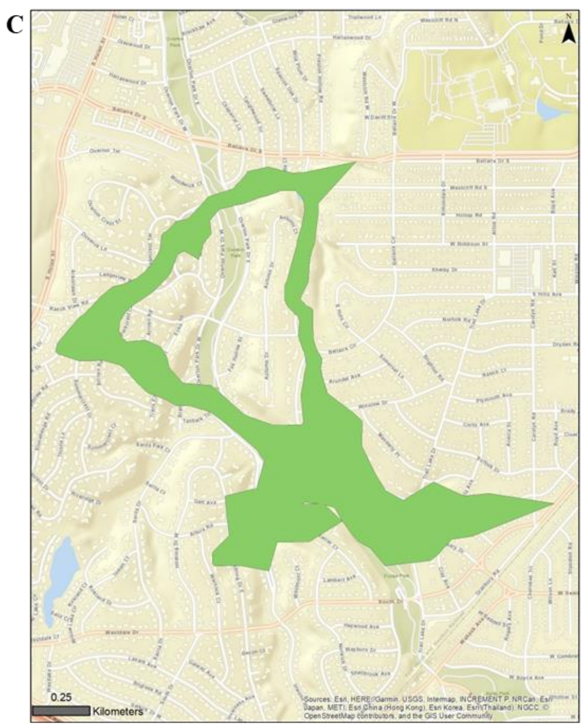


Figure B6: (**A**) shows the core (426 km^2), (**B**) the secondary (780 km^2), and (**C**) the tertiary (807 km^2) areas for evening bat "1Nyhu18Aug17" (*Nycticeius humeralis*) in a suburban neighborhood in Fort Worth, Texas, USA.

A

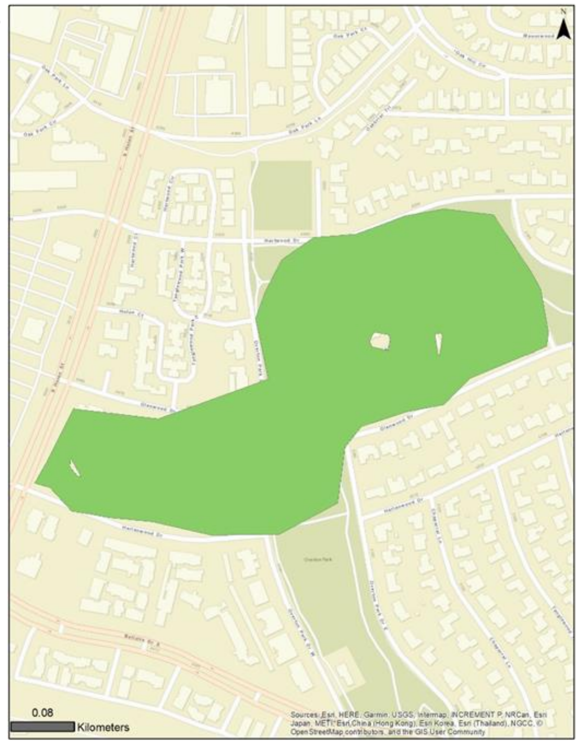
B

C

Figure B7: (**A**) shows the core (8 km^2), (**B**) the secondary (21 km^2), and (**C**) the tertiary (25 km^2) areas for evening bat "1Nyhu5Sep17" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A

B



C

Figure B8: (**A**) shows the core (60 km^2), (**B**) the secondary (126 km^2), and (**C**) the tertiary (126 km^2) areas for evening bat “3Nyhu15Sep17” (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A

B

C

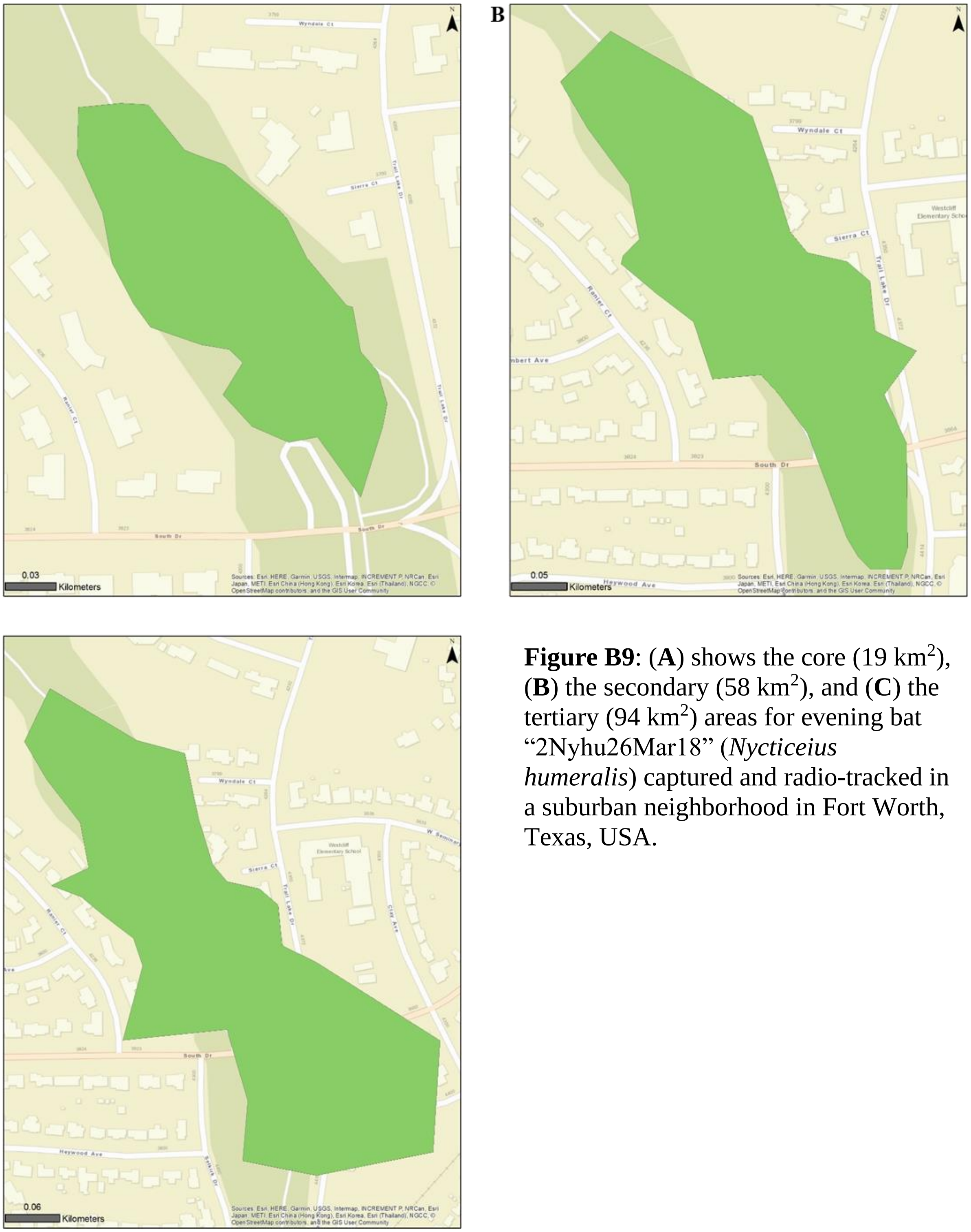
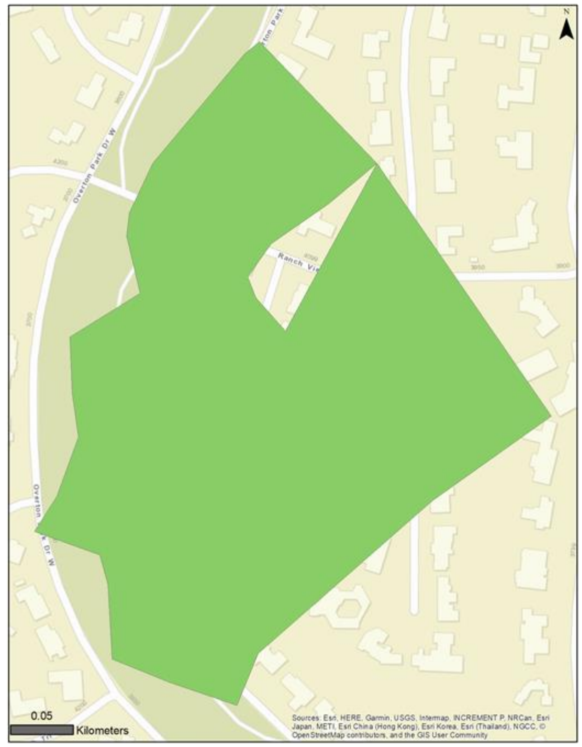


Figure B9: (**A**) shows the core (19 km^2), (**B**) the secondary (58 km^2), and (**C**) the tertiary (94 km^2) areas for evening bat "2Nyhu26Mar18" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A

B



C

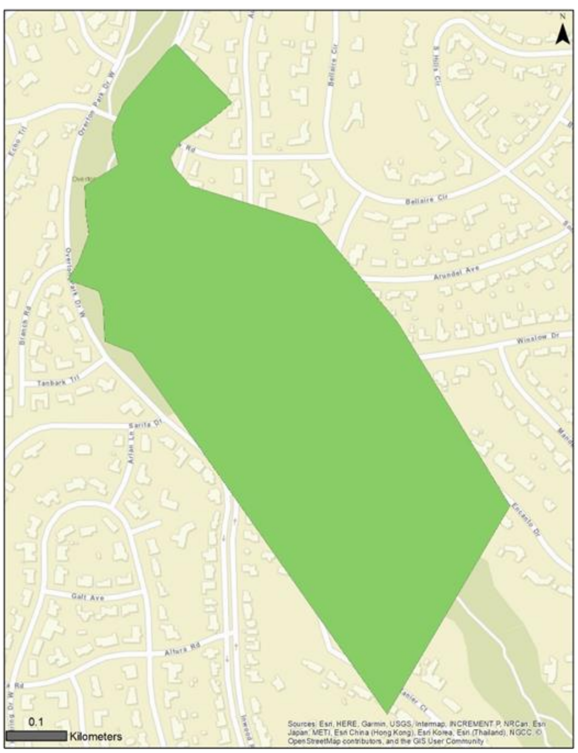


Figure B10: (**A**) shows the core (57 km^2), (**B**) the secondary (112 km^2), and (**C**) the tertiary (334 km^2) areas for evening bat "1Nyhu19Apr18" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

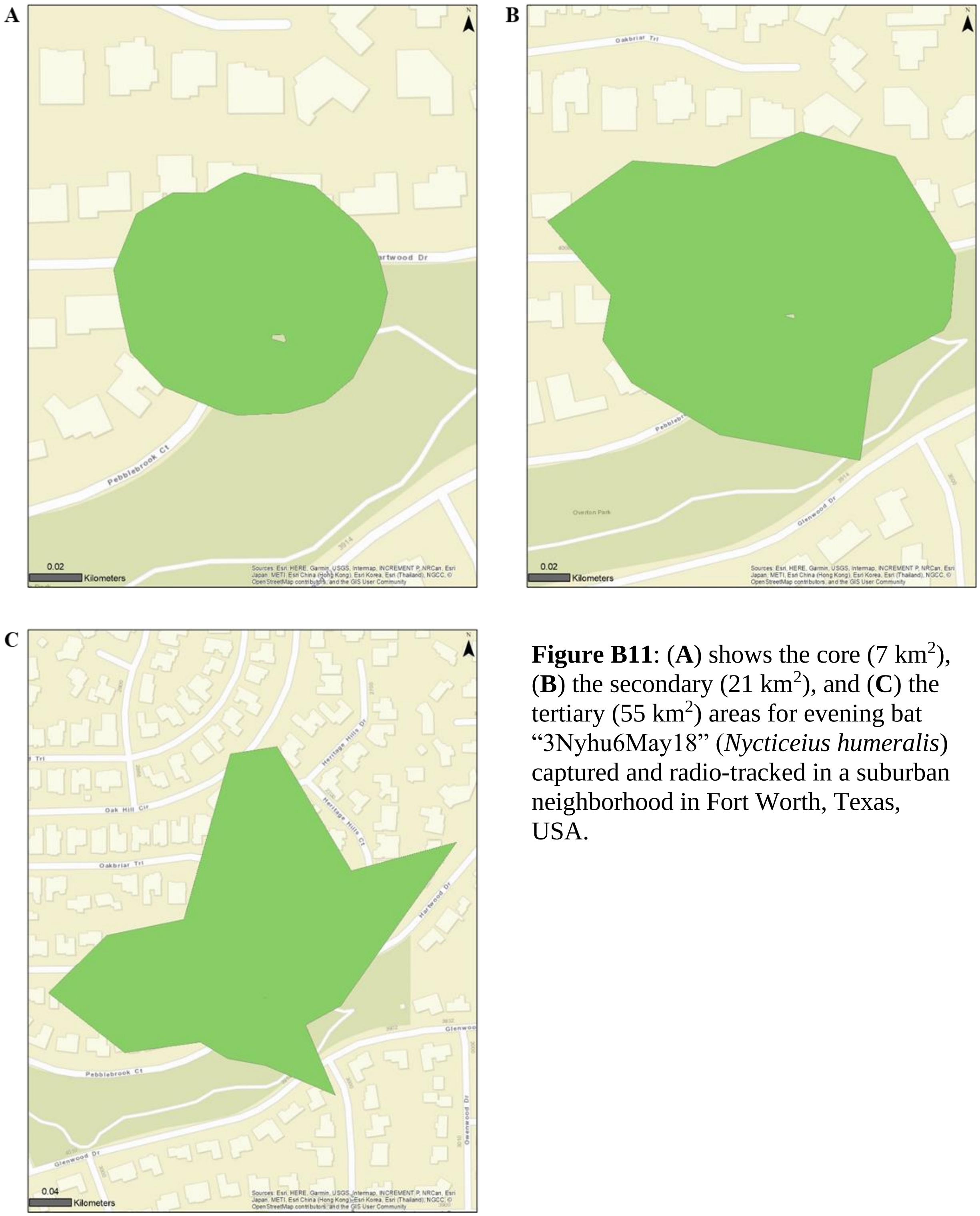


Figure B11: (**A**) shows the core (7 km^2), (**B**) the secondary (21 km^2), and (**C**) the tertiary (55 km^2) areas for evening bat "3Nyhu6May18" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

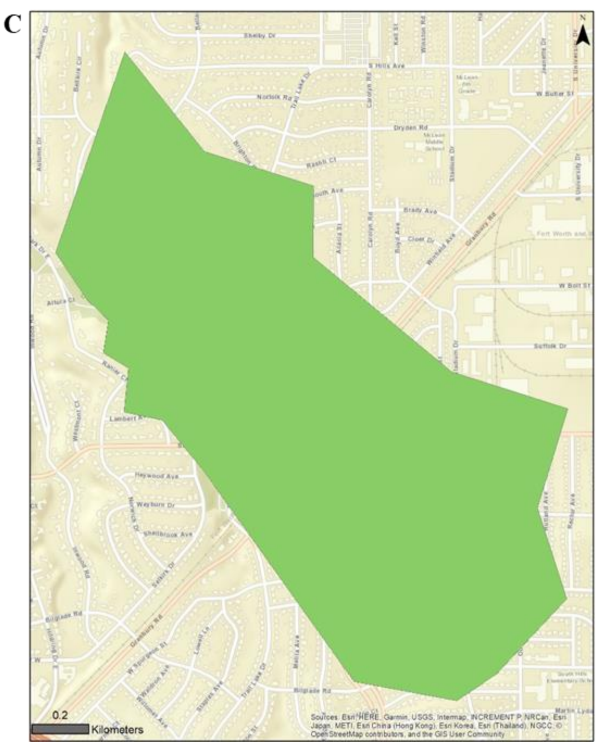
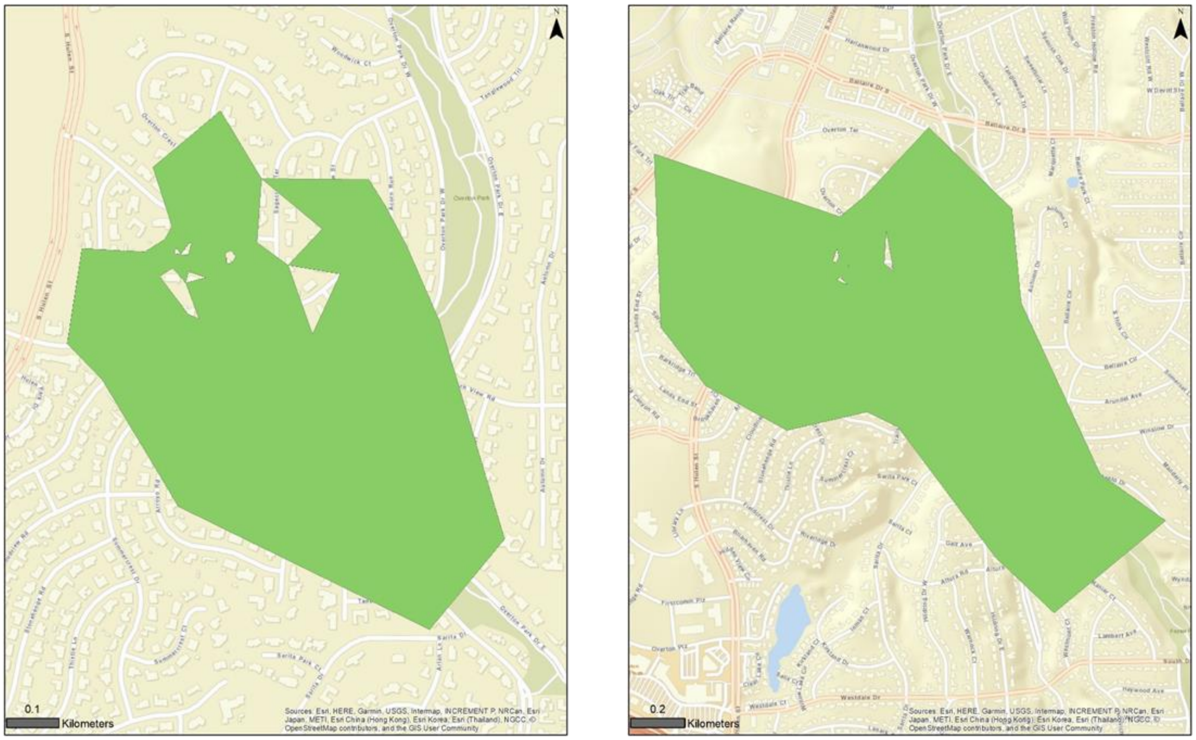


Figure B12: (**A**) shows the core (456 km^2), (**B**) the secondary (1,398 km^2), and (**C**) the tertiary (1,946 km^2) areas for evening bat "1Nyhu16May18" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.



C

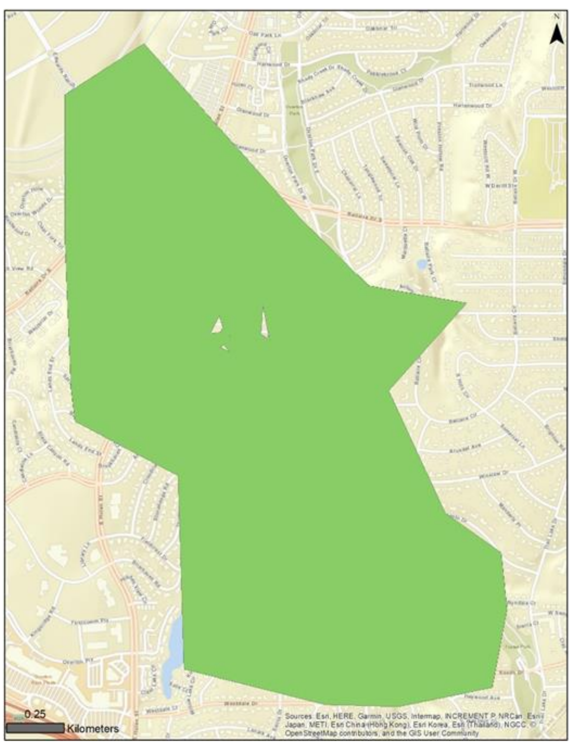


Figure B13: (**A**) shows the core (454 km^2), (**B**) the secondary (1,545 km^2), and (**C**) the tertiary (3,244 km^2) areas for evening bat "5Nyhu25May18" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A

B

C

Figure B14: (**A**) shows the core (11 km^2), (**B**) the secondary (41 km^2), and (**C**) the tertiary (113 km^2) areas for evening bat "2Nyhu5Jun18" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

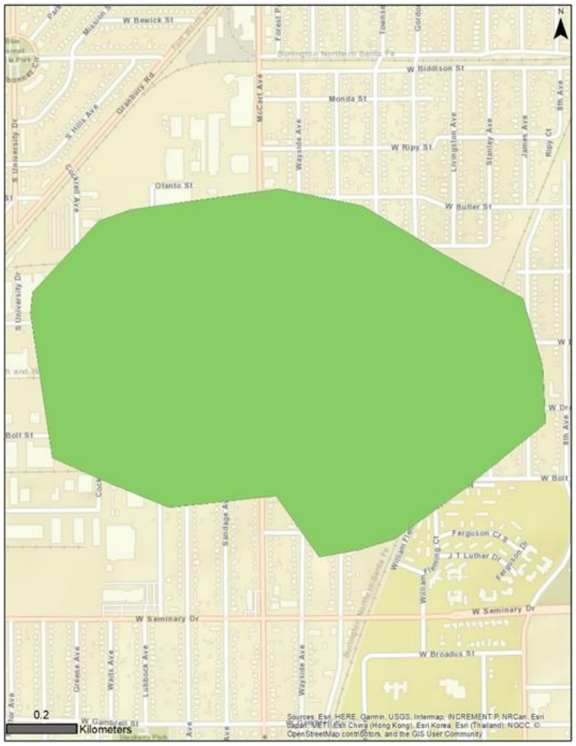
A

B

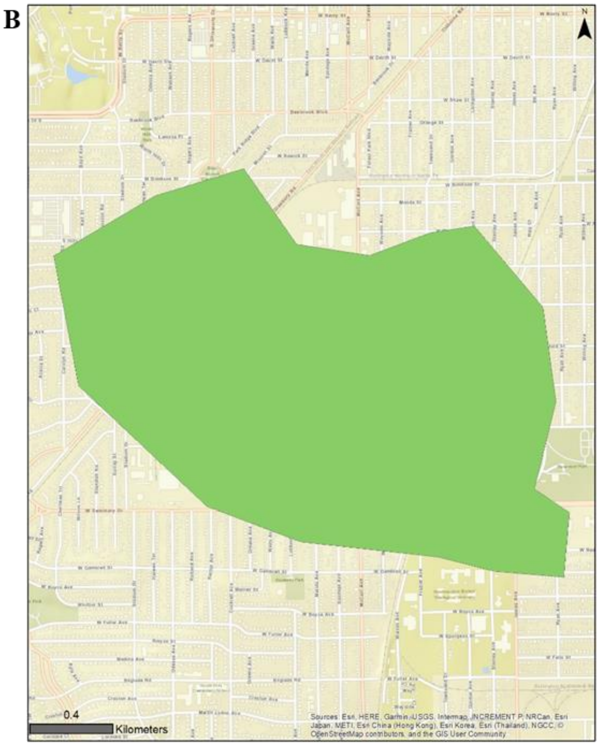
C

Figure B15: (**A**) shows the core (406 km^2), (**B**) the secondary (1,034 km^2), and (**C**) the tertiary (1,310 km^2) areas for evening bat “1Nyhu18Jun18” (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A



B



C

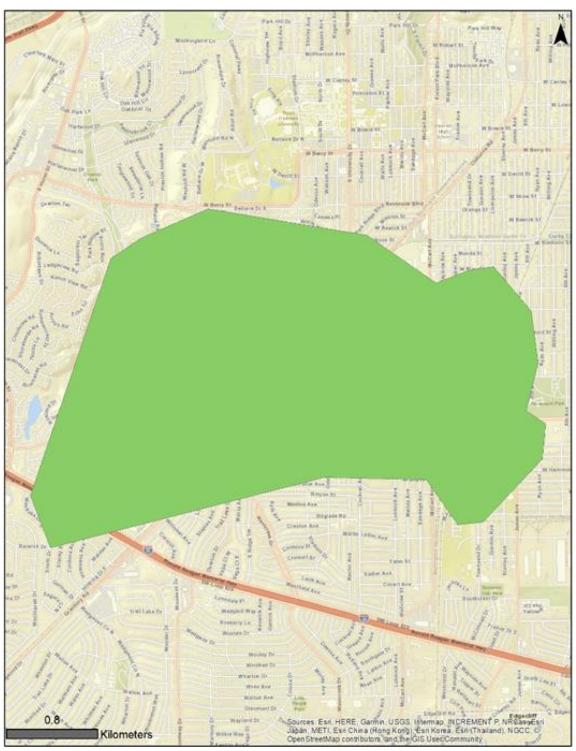
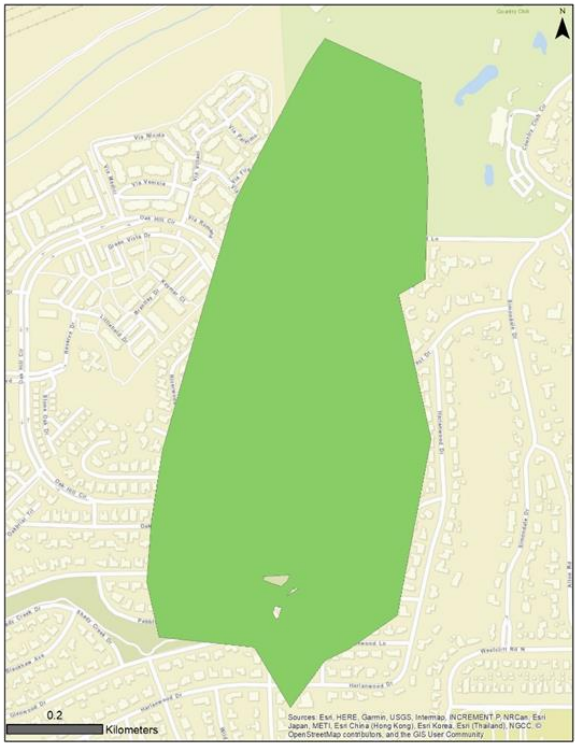
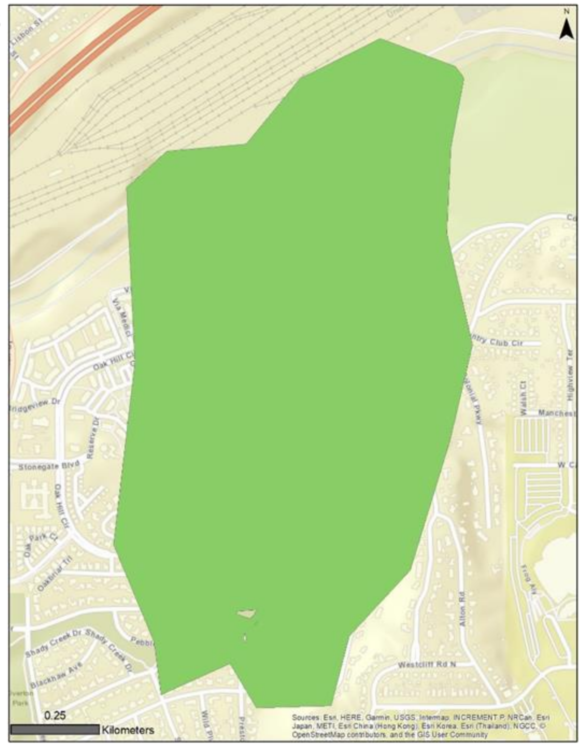


Figure B16: (**A**) shows the core (1,112 km^2), (**B**) the secondary (3,268 km^2), and (**C**) the tertiary (9,318 km^2) areas for evening bat "2Nyhu2Jul18" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A



B



C

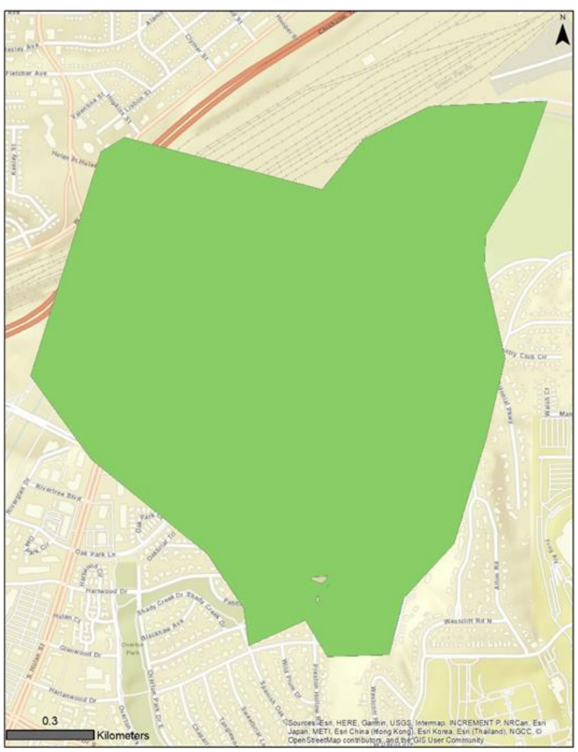


Figure B17: (**A**) shows the core (559 km^2), (**B**) the secondary (1,426 km^2), and (**C**) the tertiary (2,170 km^2) areas for evening bat "1Nyhu29Jul18" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

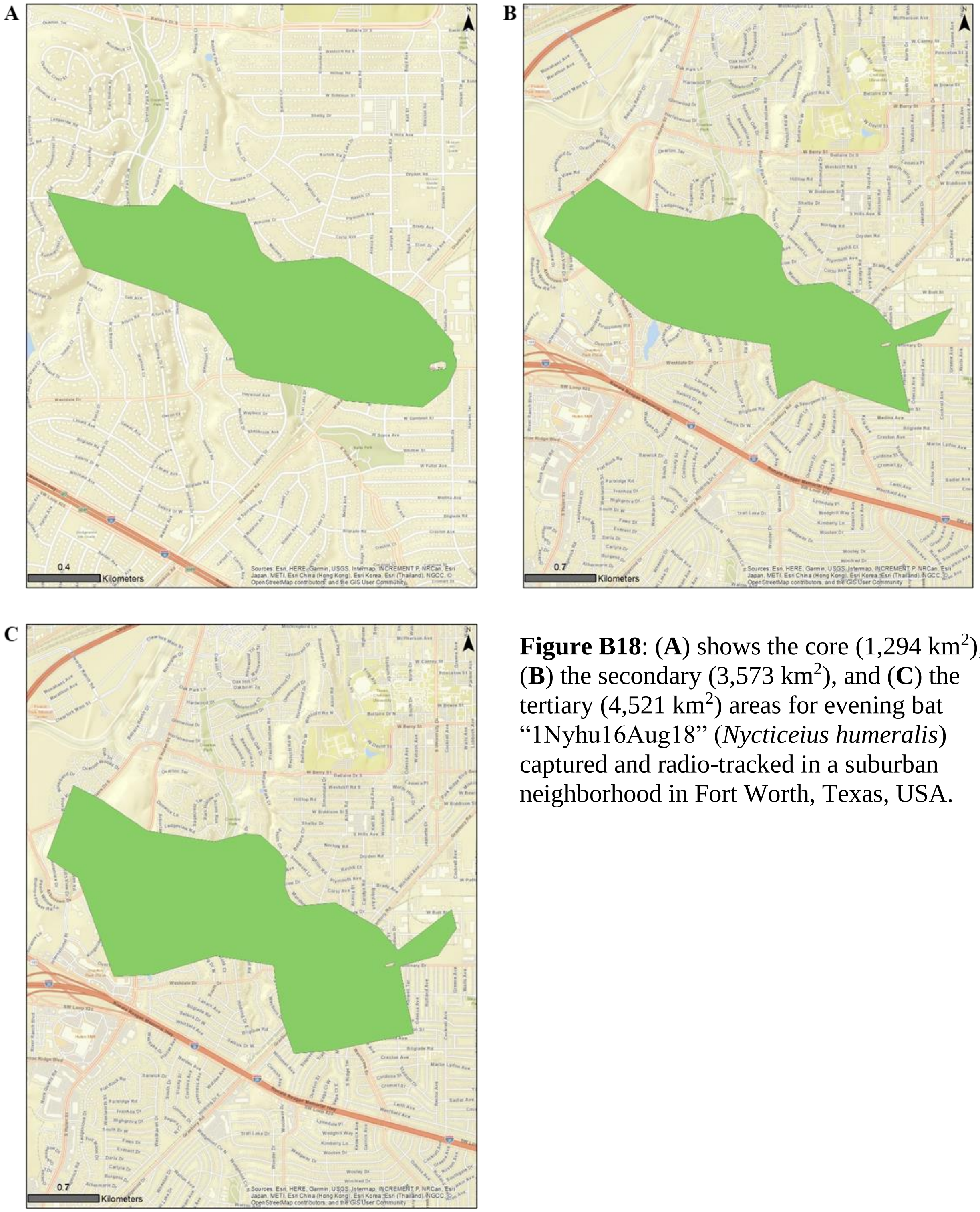
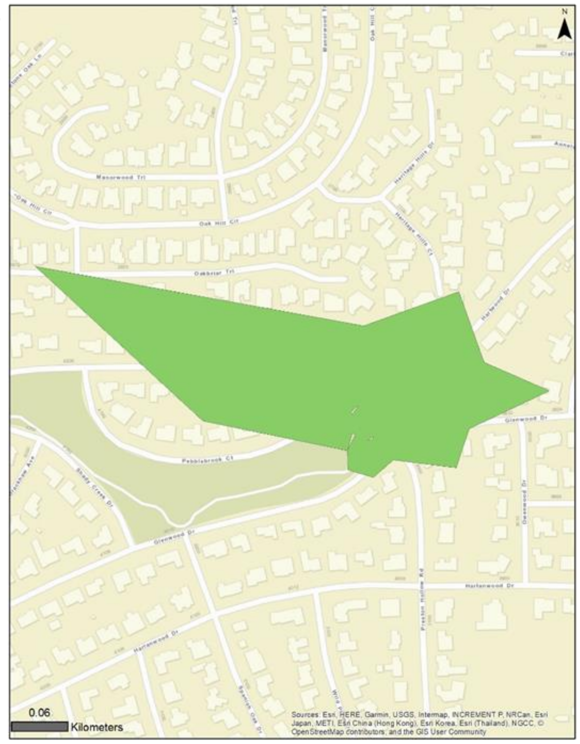


Figure B18: (**A**) shows the core (1,294 km^2), (**B**) the secondary (3,573 km^2), and (**C**) the tertiary (4,521 km^2) areas for evening bat “1Nyhu16Aug18” (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A

B



C

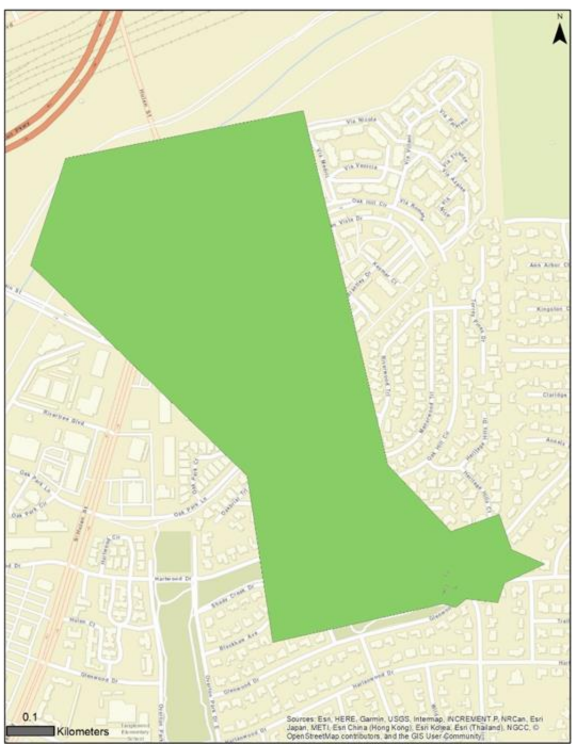
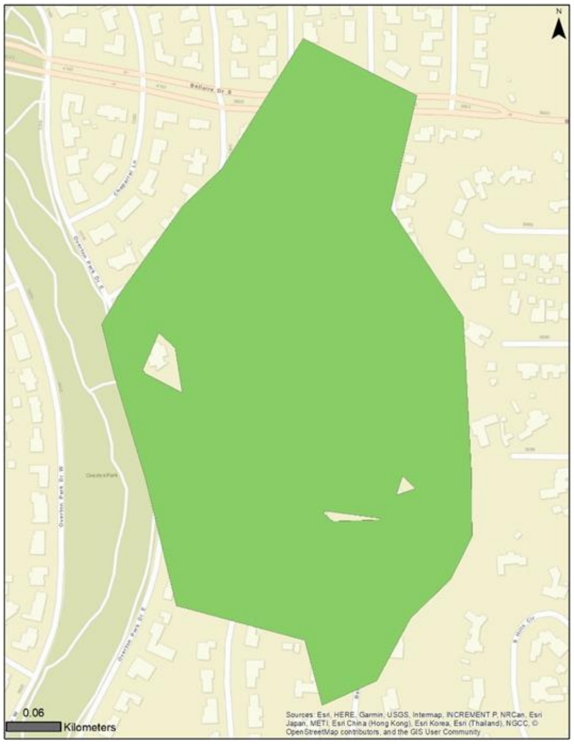
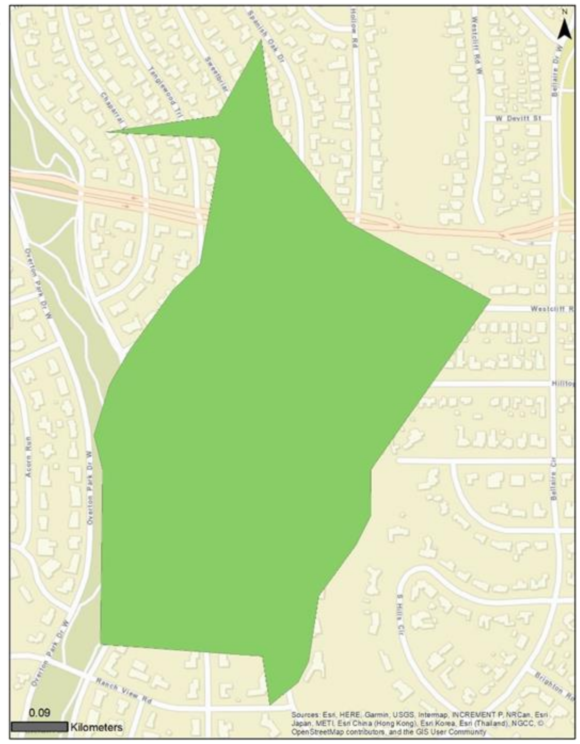


Figure B19: (**A**) shows the core (19 km^2), (**B**) the secondary (57 km^2), and (**C**) the tertiary (515 km^2) areas for evening bat "1Nyhu21Mar19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A


B


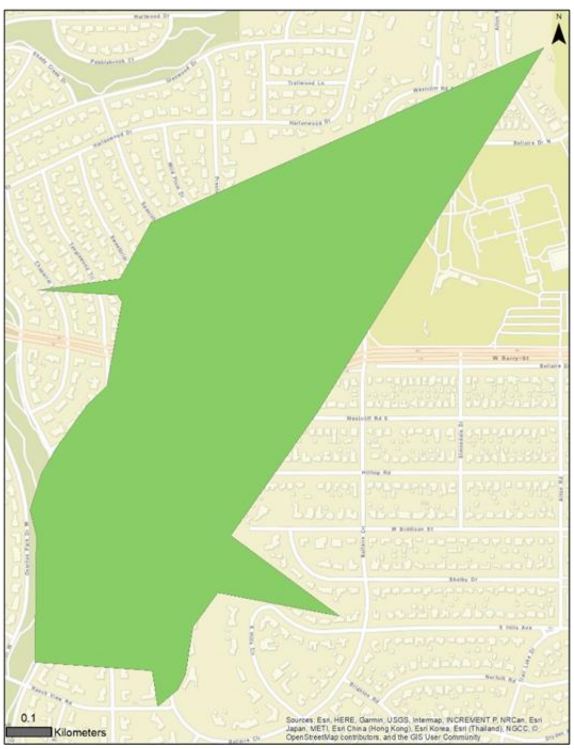
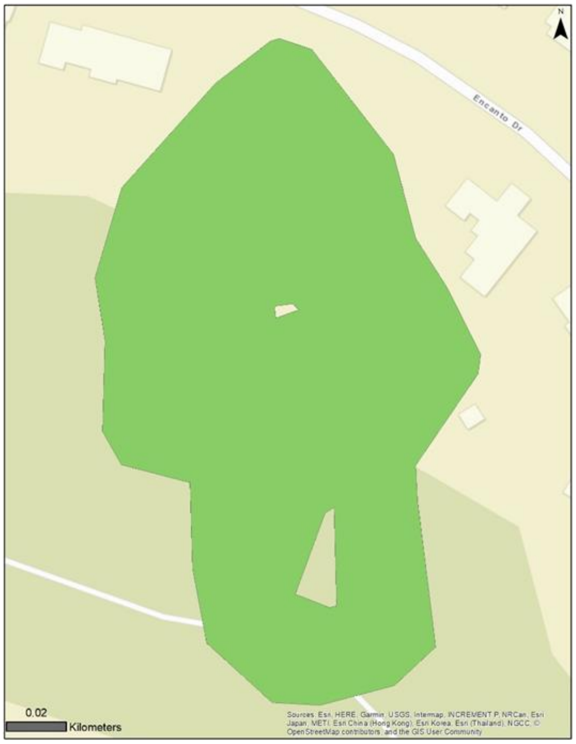
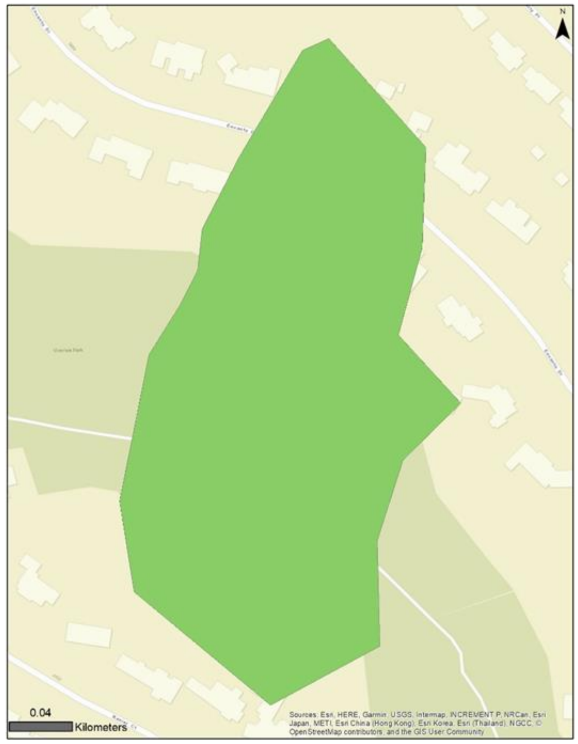
C


Figure B20: (**A**) shows the core (189 km^2), (**B**) the secondary (334 km^2), and (**C**) the tertiary (636 km^2) areas for evening bat "1Nyhu5Apr19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A



B

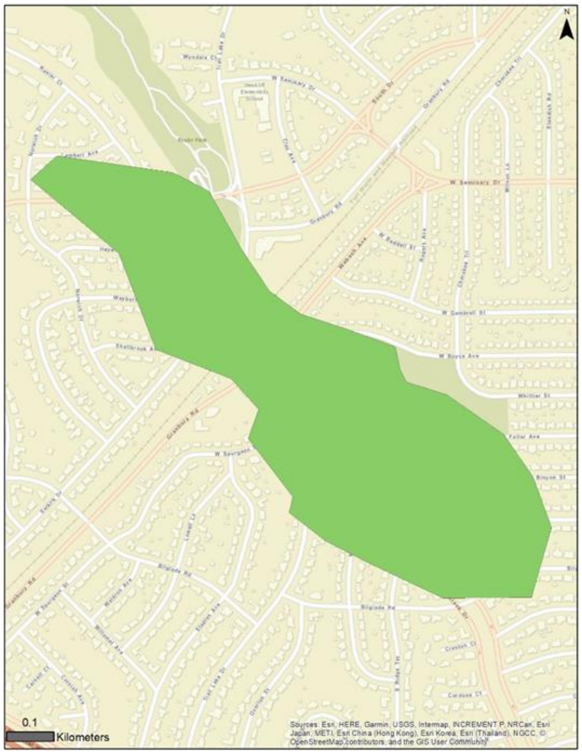


C

Figure B21: (**A**) shows the core (19 km^2), (**B**) the secondary (56 km^2), and (**C**) the tertiary (104 km^2) areas for evening bat "8Nyhu25Apr19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

Figure B22: (**A**) shows the core (41 km^2), (**B**) the secondary (125 km^2), and (**C**) the tertiary (161 km^2) areas for evening bat "1Nyhu13May19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A



B

C

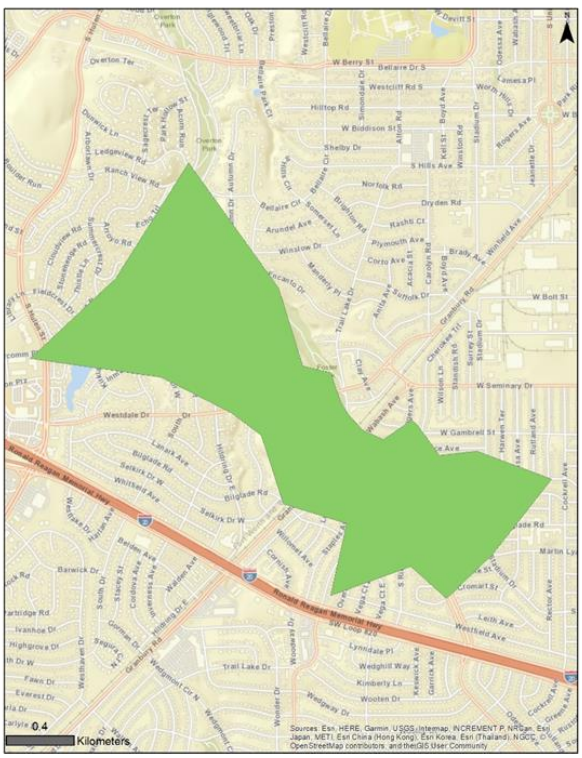
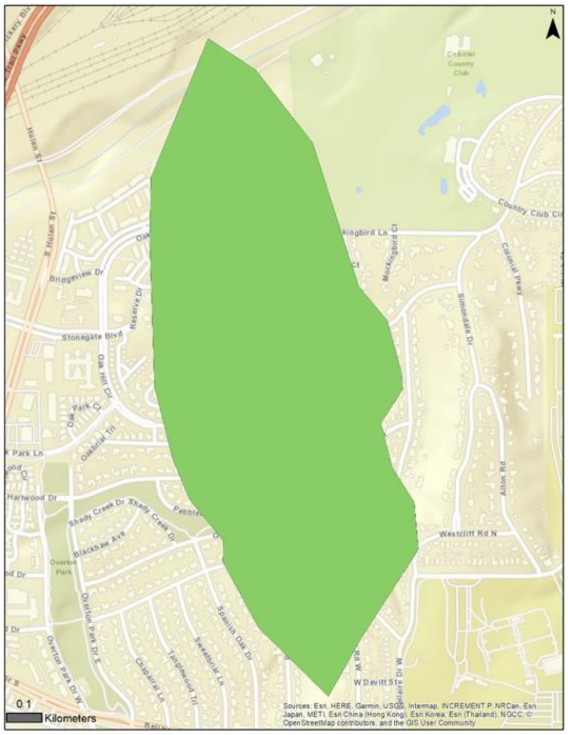
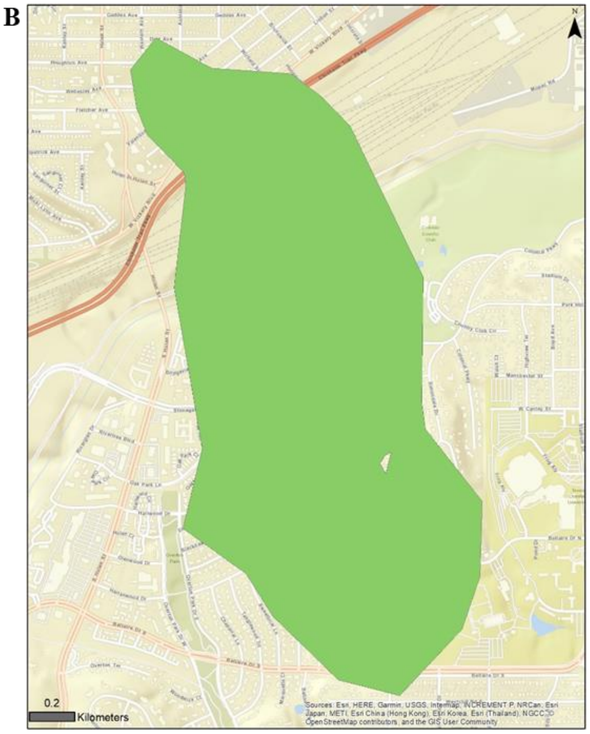


Figure B23: (**A**) shows the core (368 km^2), (**B**) the secondary (1,171 km^2), and (**C**) the tertiary (2,342 km^2) areas for evening bat "1Nyhu11Jun19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A



B



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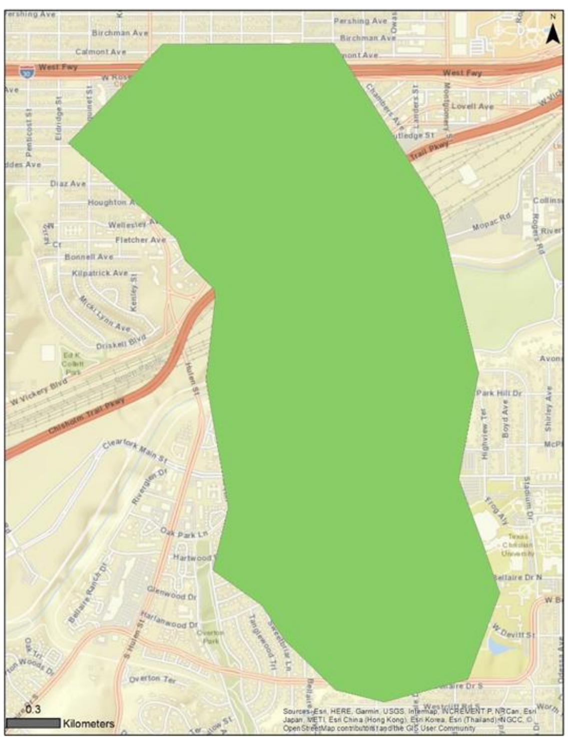
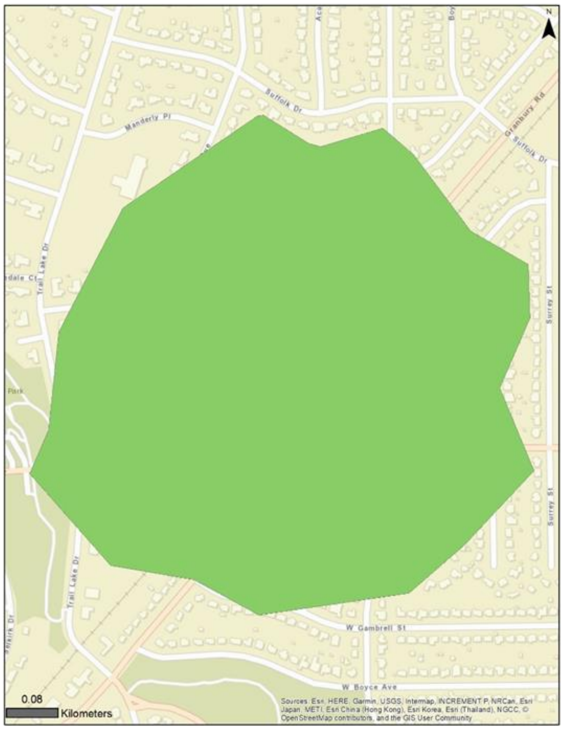
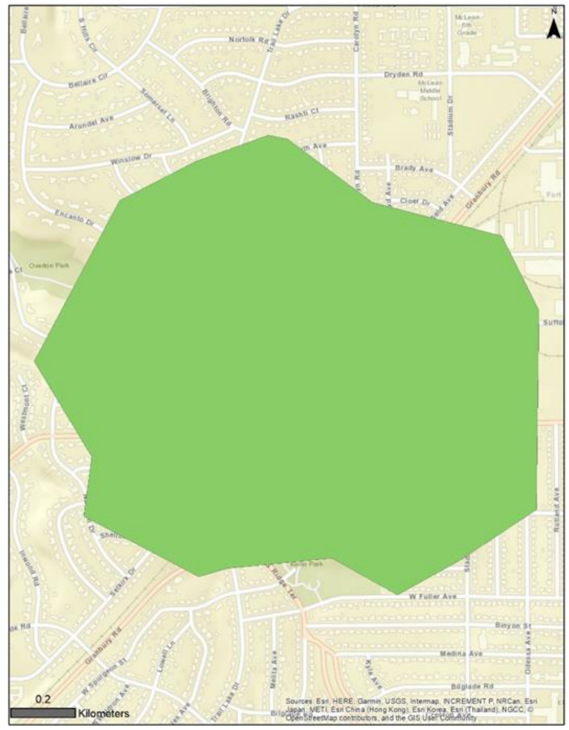


Figure B24: (**A**) shows the core (891 km^2), (**B**) the secondary (2,672 km^2), and (**C**) the tertiary (5,140 km^2) areas for evening bat "3Nyhu25Jun19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A



B



C

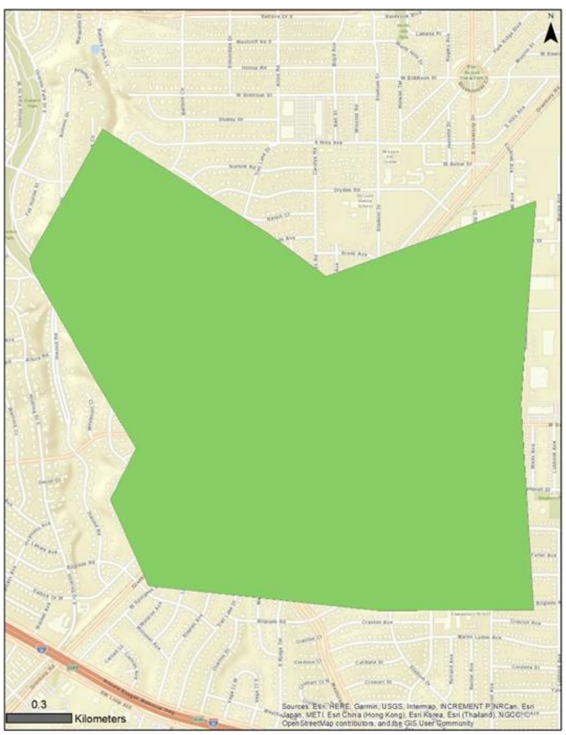


Figure B25: (**A**) shows the core (439 km^2), (**B**) the secondary (1,633 km^2), and (**C**) the tertiary (3,548 km^2) areas for evening bat "2Nyhu9Jul19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A

B

C

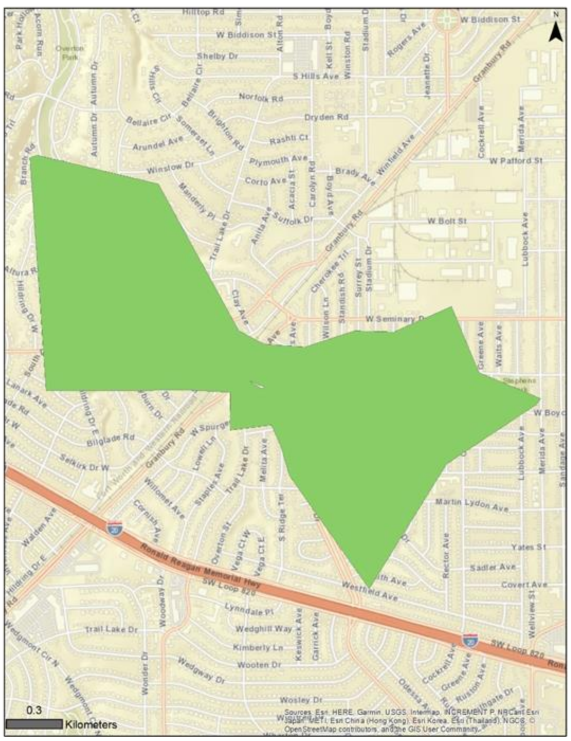
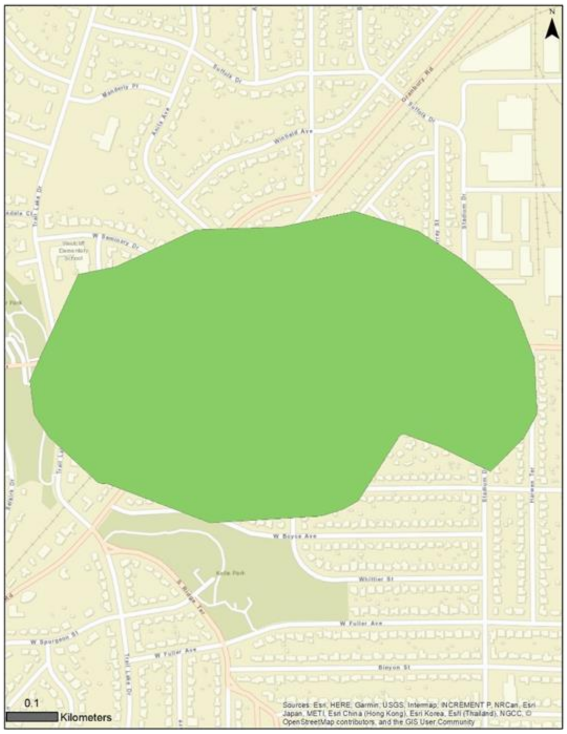


Figure B26: (**A**) shows the core (359 km^2), (**B**) the secondary (1,009 km^2), and (**C**) the tertiary (2,271 km^2) areas for evening bat "1Nyhu14Aug19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A

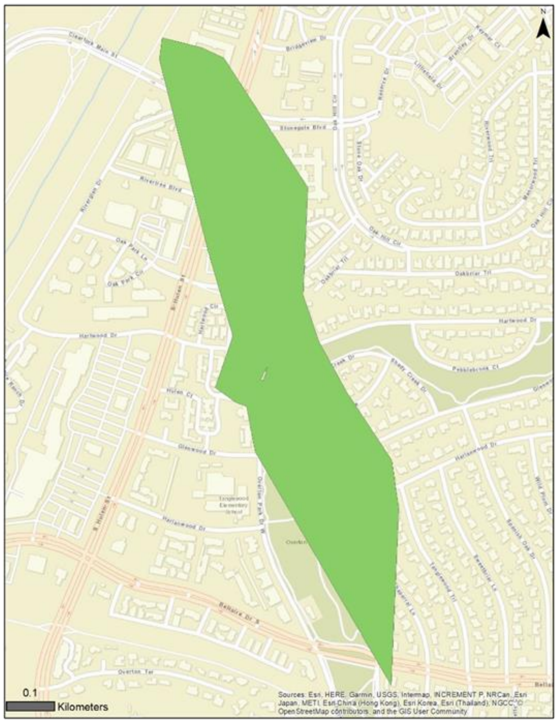


B

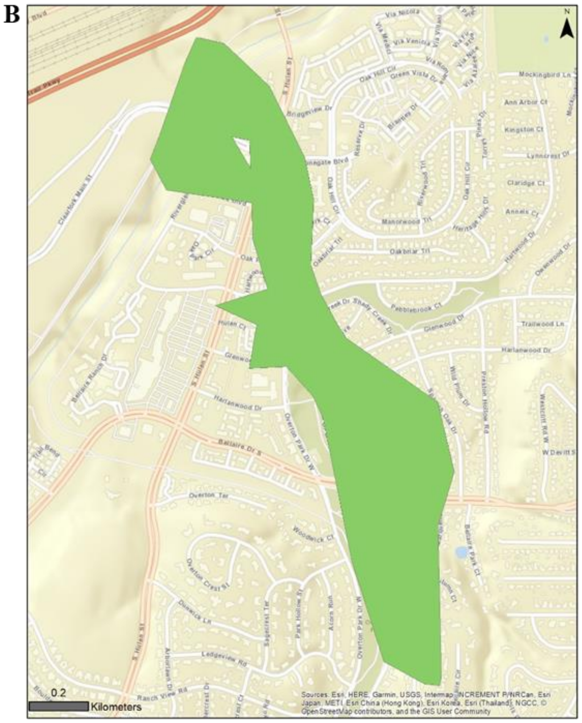
C

Figure B27: (**A**) shows the core (446 km^2), (**B**) the secondary (1,451 km^2), and (**C**) the tertiary (4,378 km^2) areas for evening bat “1Nyhu25Aug19” (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A



B



C

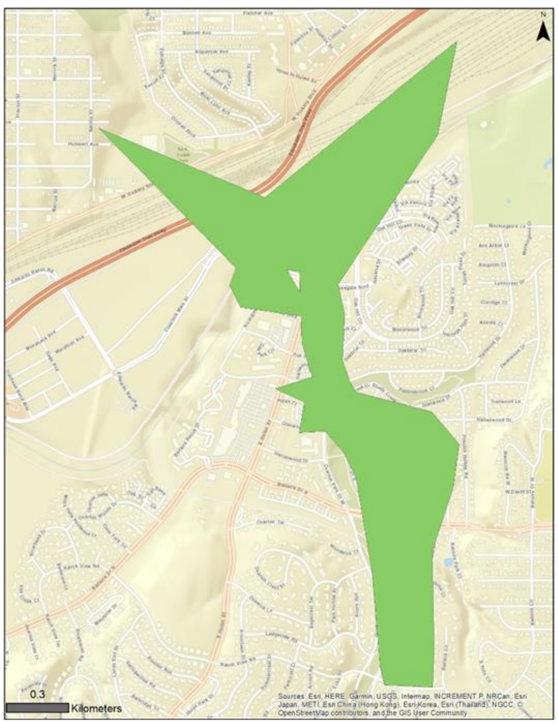
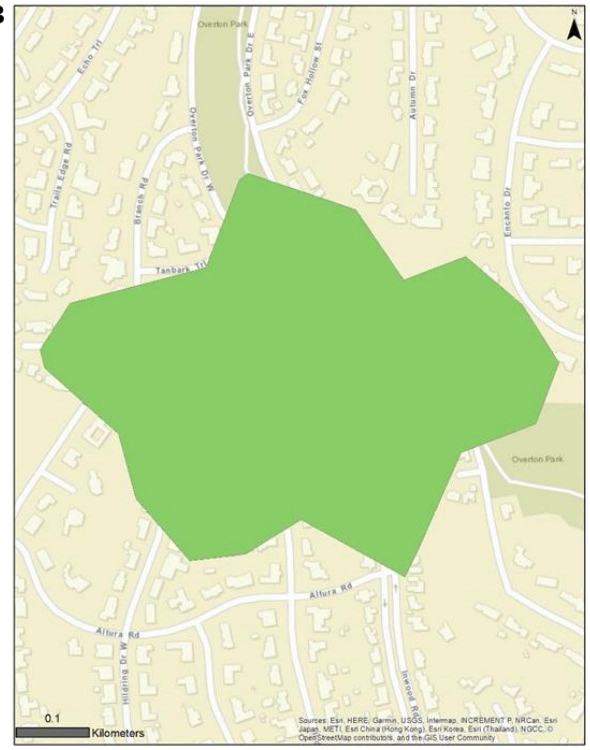


Figure B28: (**A**) shows the core (243 km^2), (**B**) the secondary (683 km^2), and (**C**) the tertiary (1,368 km^2) areas for evening bat "1Nyhu5Sep19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A

B



C

Figure B29: (**A**) shows the core (87 km^2), (**B**) the secondary (229 km^2), and (**C**) the tertiary (1,187 km^2) areas for evening bat "3Nyhu12Sep19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

A

B

C

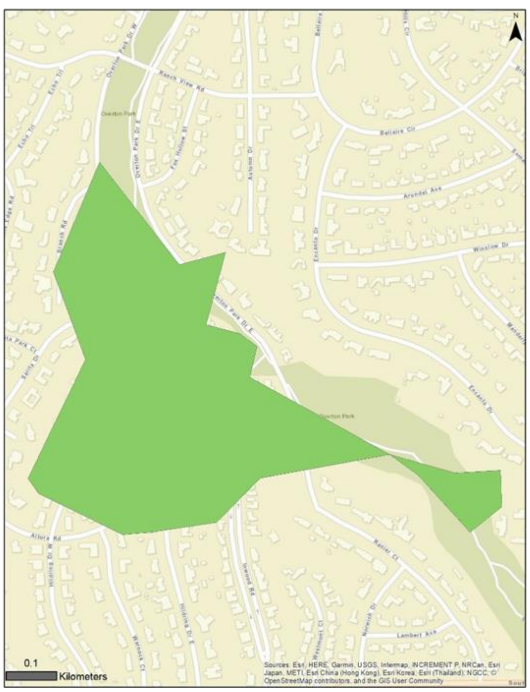


Figure B30: (**A**) shows the core (67 km^2), (**B**) the secondary (180 km^2), and (**C**) the tertiary (250 km^2) areas for evening bat "1Nyhu21Sep19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

Appendix C

Least Activity

Most Activity

Key for the following hotspots demonstrating activity levels within the home range of an evening bat (*Nycticeius humeralis*) captured and radio-tracked in Fort Worth, Texas, USA.

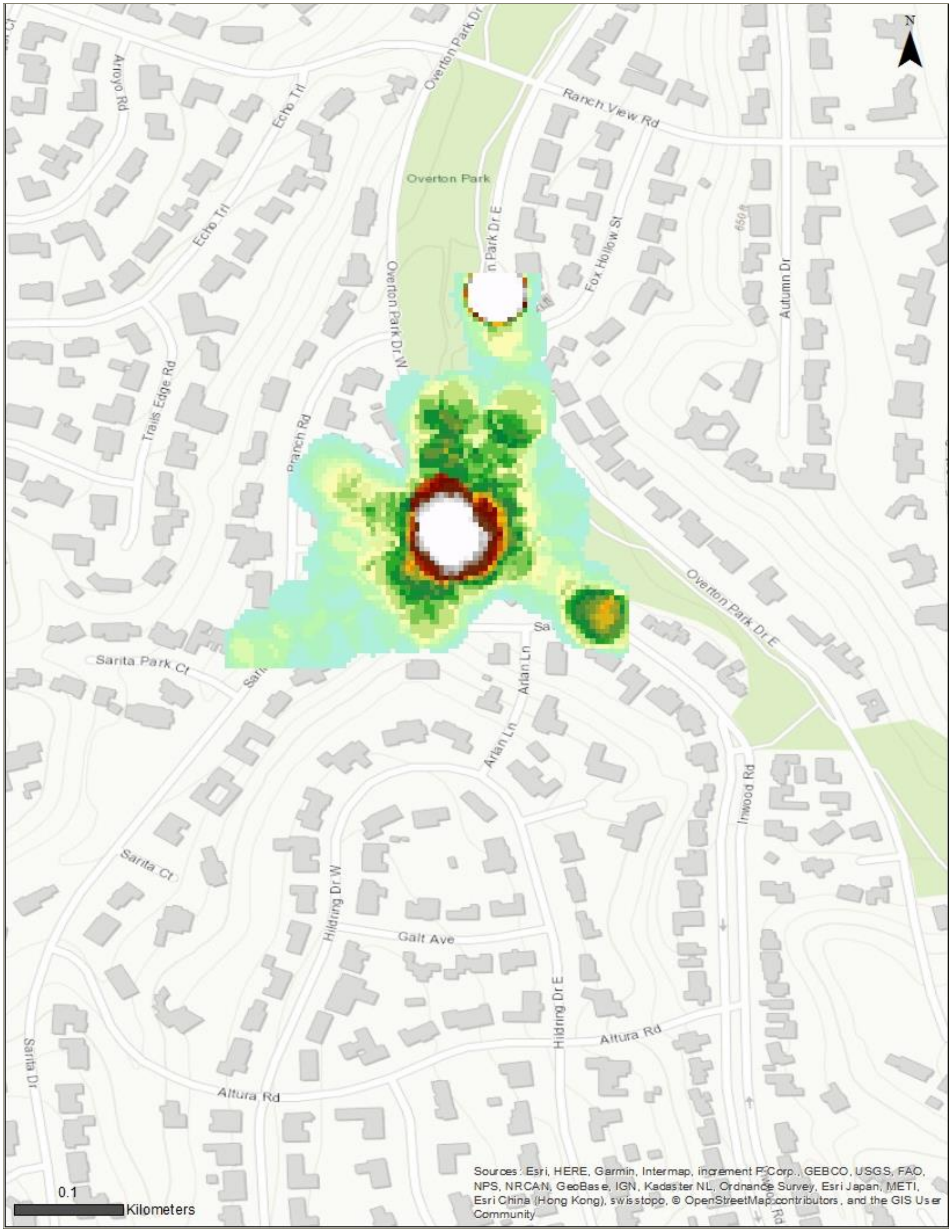


Figure C1: Hotspot map demonstrating activity levels within the home range of an evening bat "3Nyhu20Apr17" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

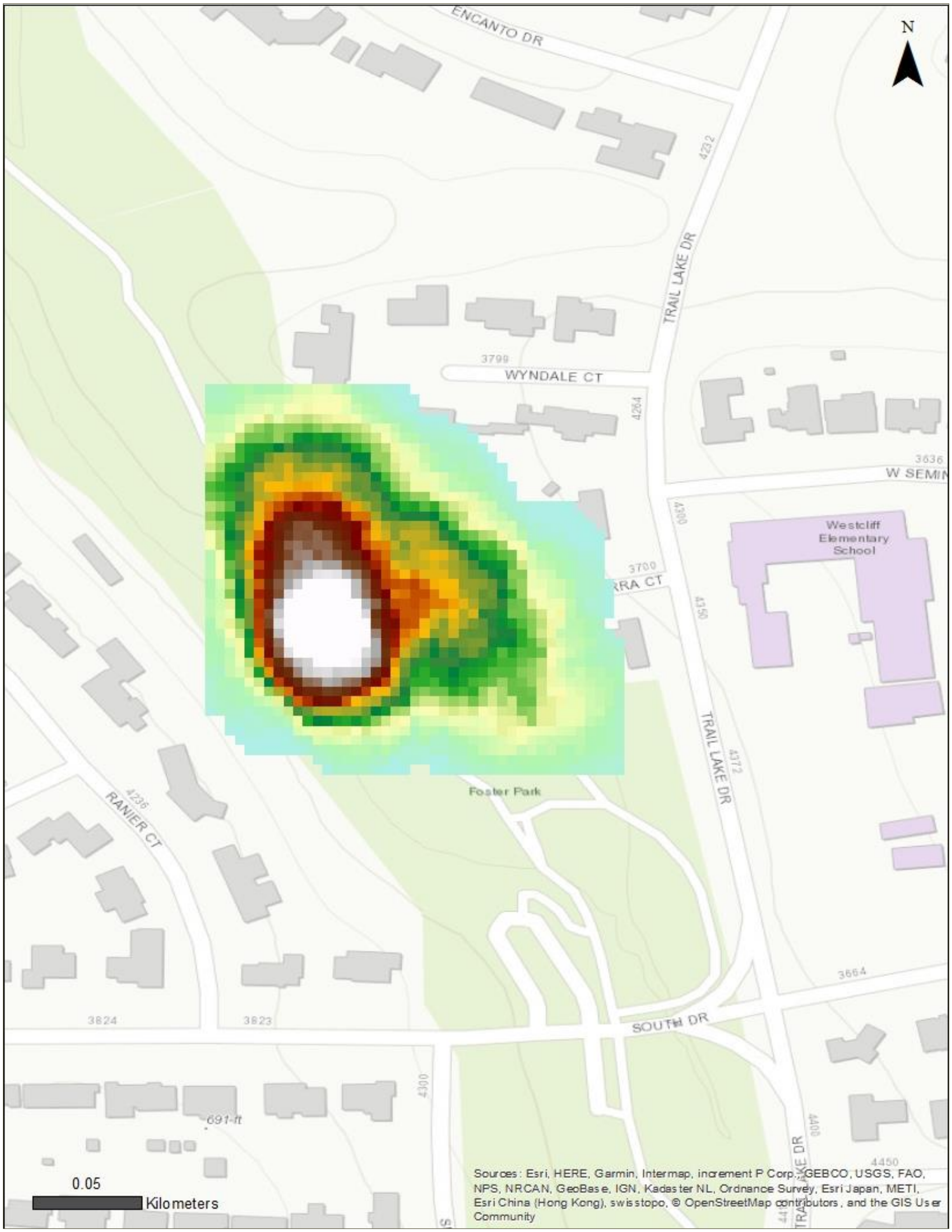


Figure C2: Hotspot map demonstrating activity levels within the home range of an evening bat "3Nyhu26May17" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

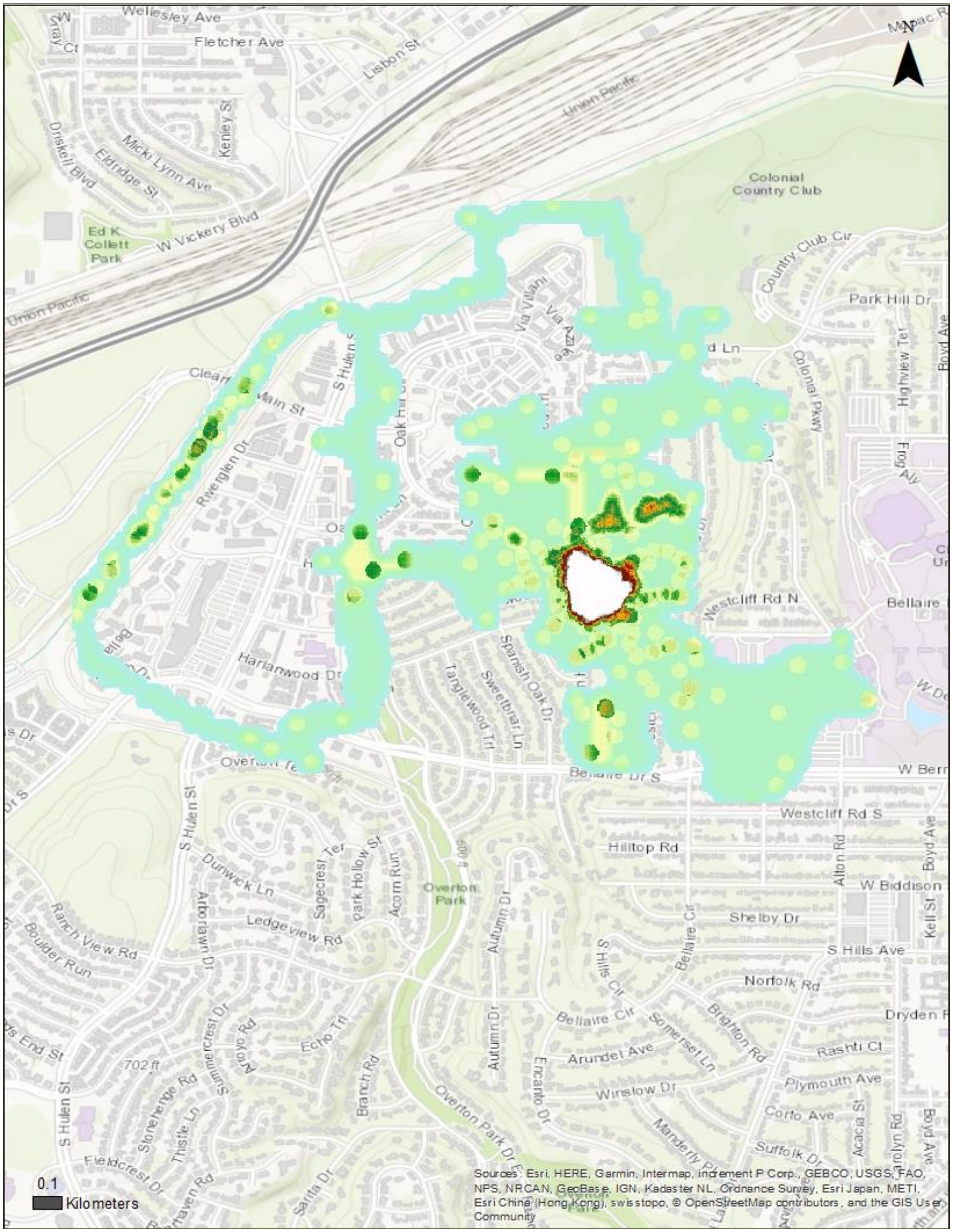


Figure C3: Hotspot map demonstrating activity levels within the home range of an evening bat "1Nyhu13Jun17" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

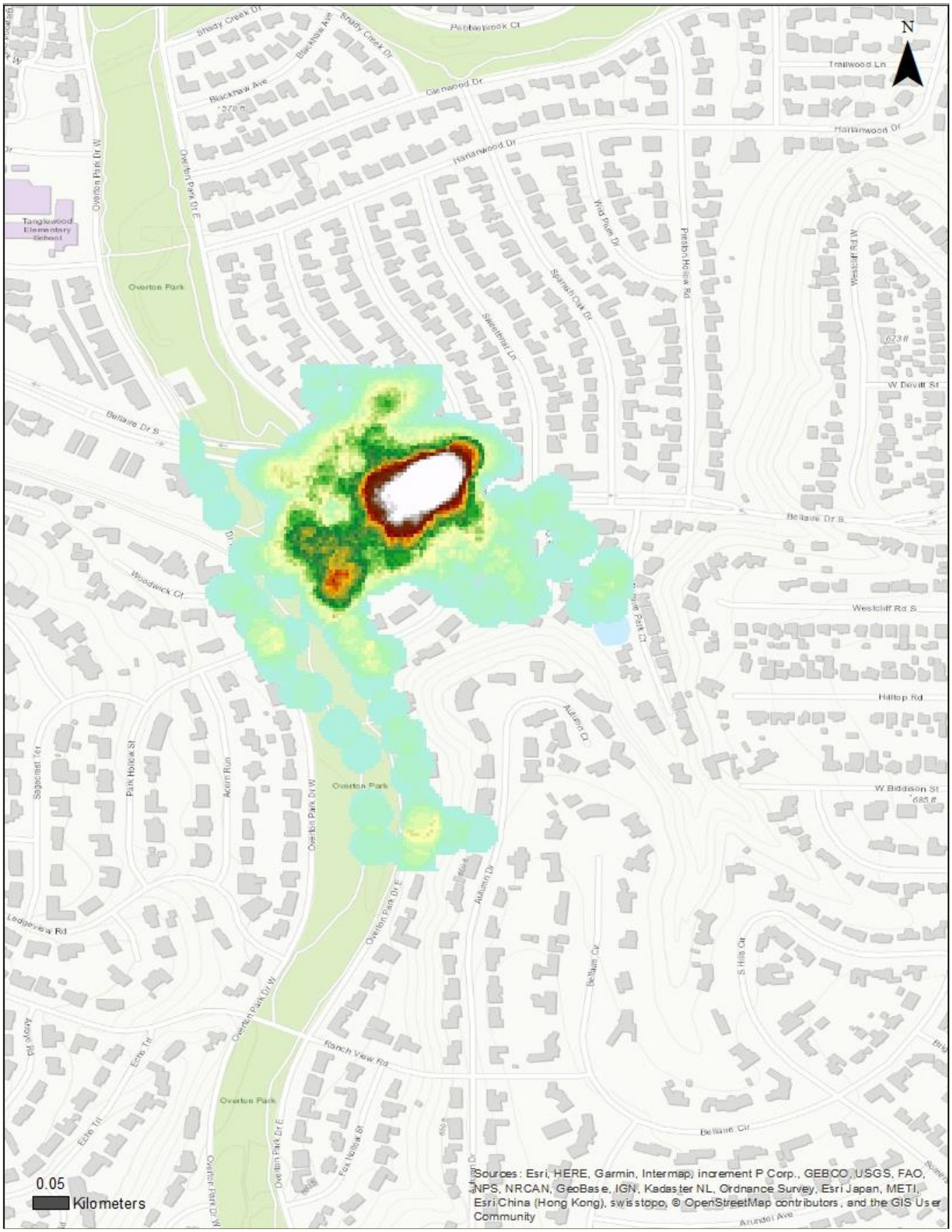


Figure C4: Hotspot map demonstrating activity levels within the home range of an evening bat "1Nyhu16Jul17" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

Figure C5: Hotspot map demonstrating activity levels within the home range of an evening bat "3Nyhu31Jul17" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

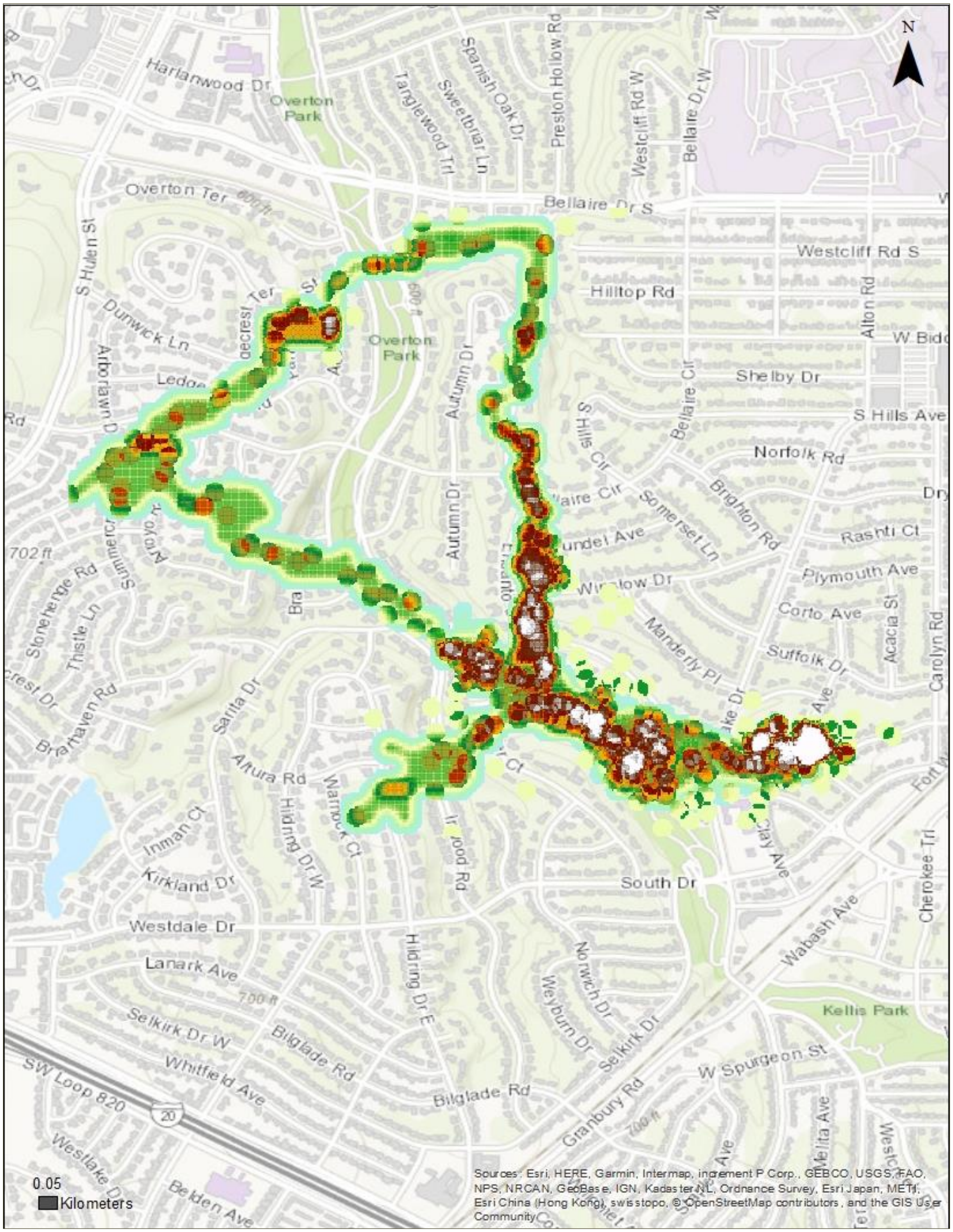


Figure C6: Hotspot map demonstrating activity levels within the home range of an evening bat "1Nyhu18Aug17" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

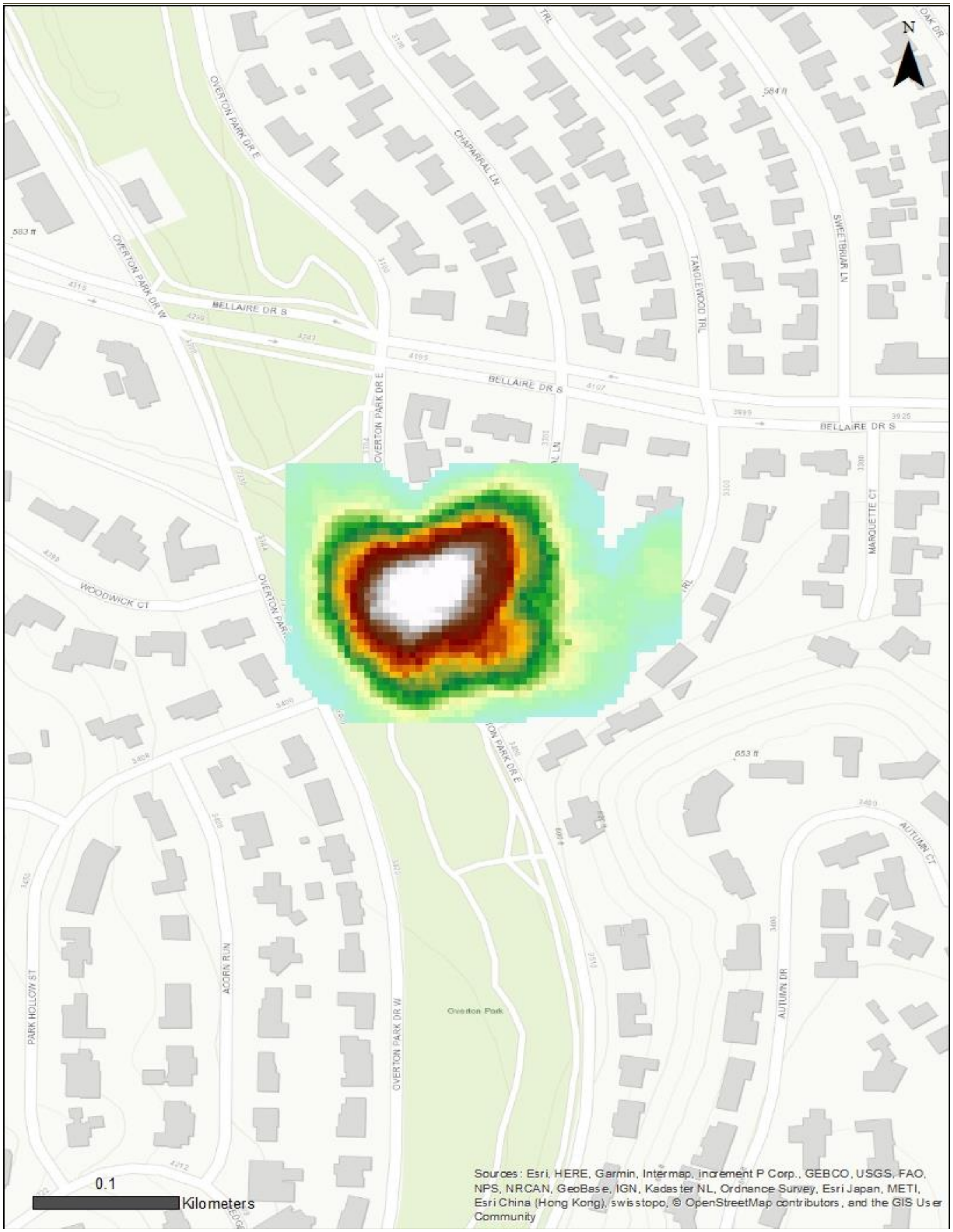


Figure C7: Hotspot map demonstrating activity levels within the home range of an evening bat "1Nyhu5Sep17" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

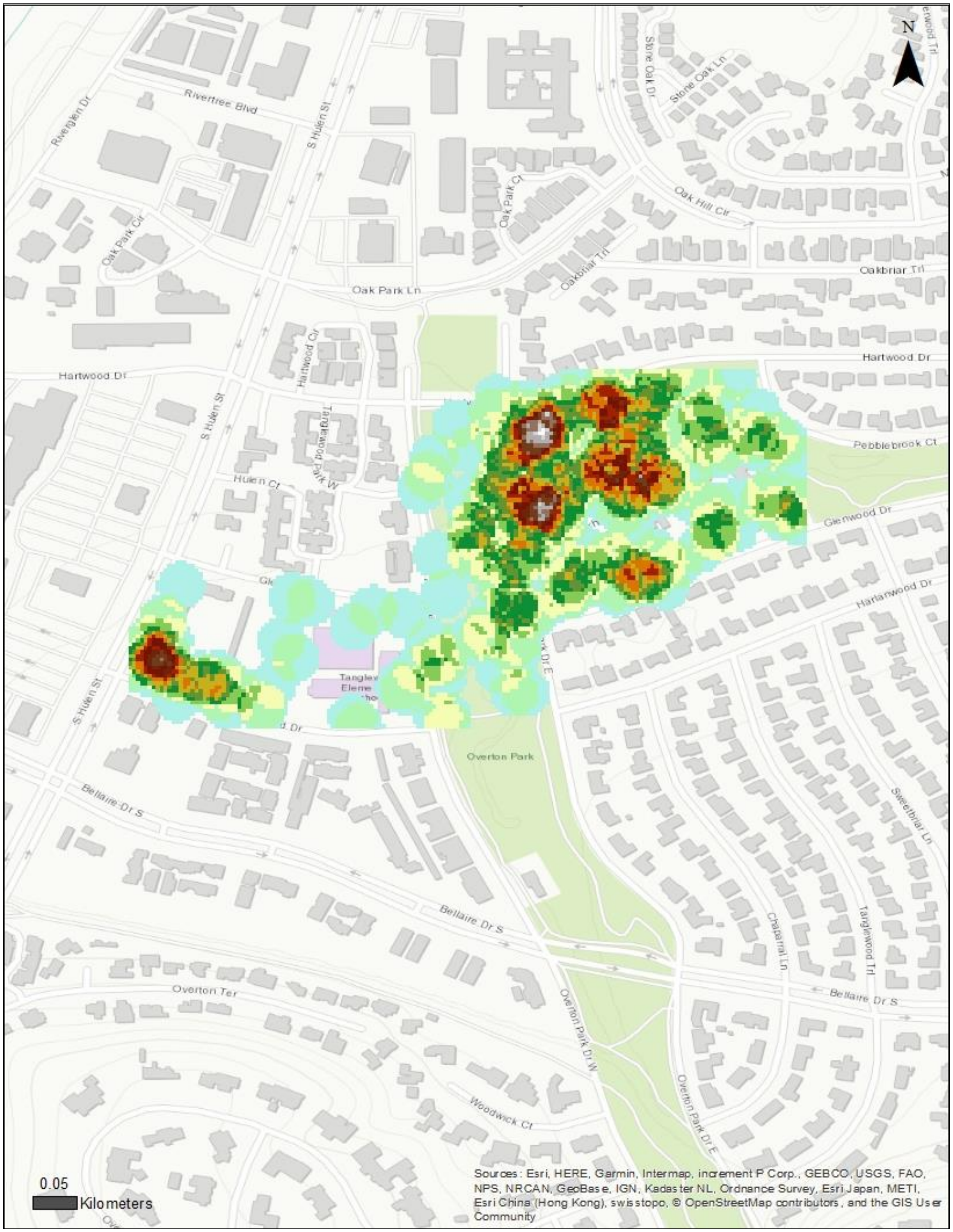


Figure C8: Hotspot map demonstrating activity levels within the home range of an evening bat “3Nyhu15Sep17” (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

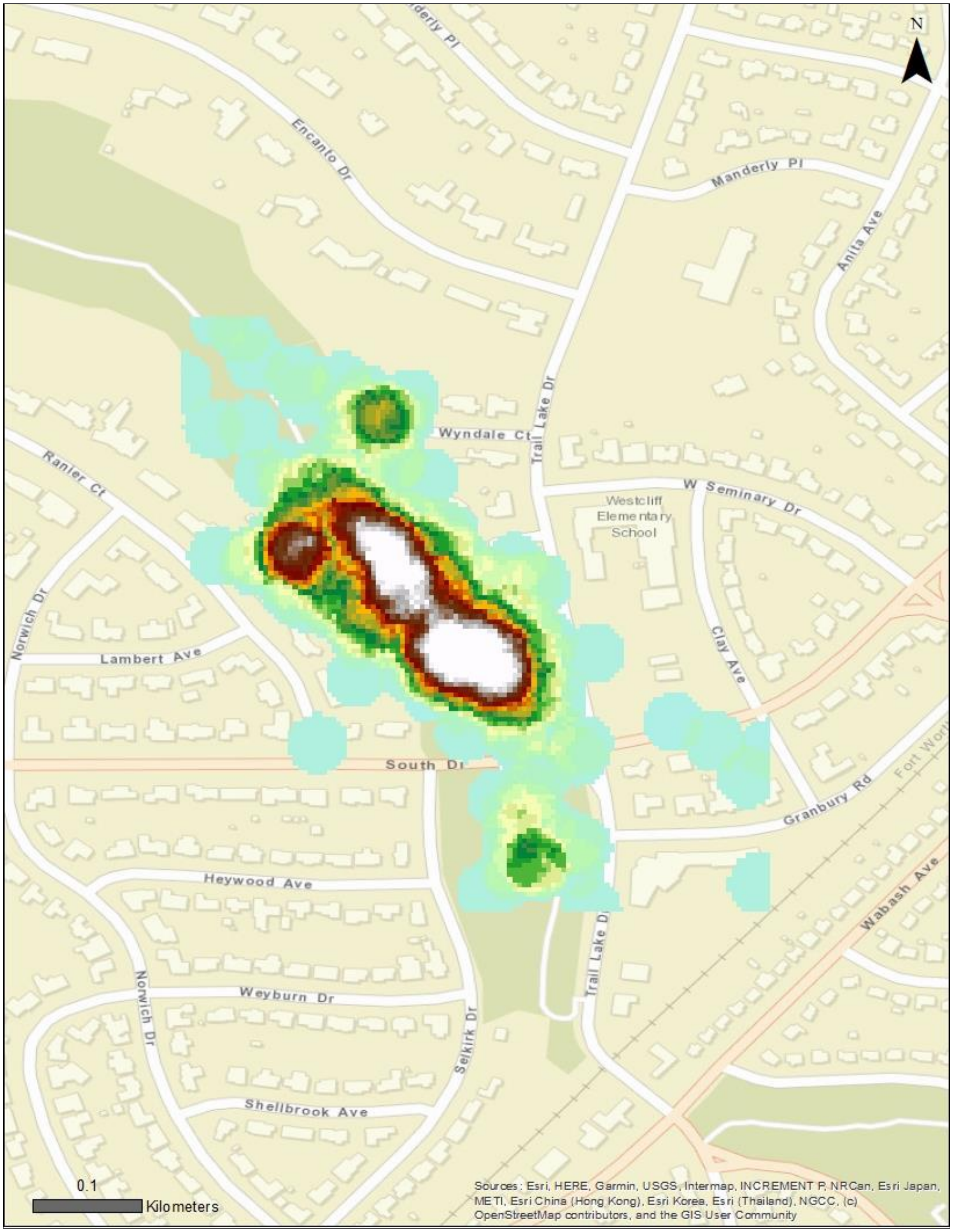


Figure C9: Hotspot map demonstrating activity levels within the home range of an evening bat "2Nyhu26Mar18" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

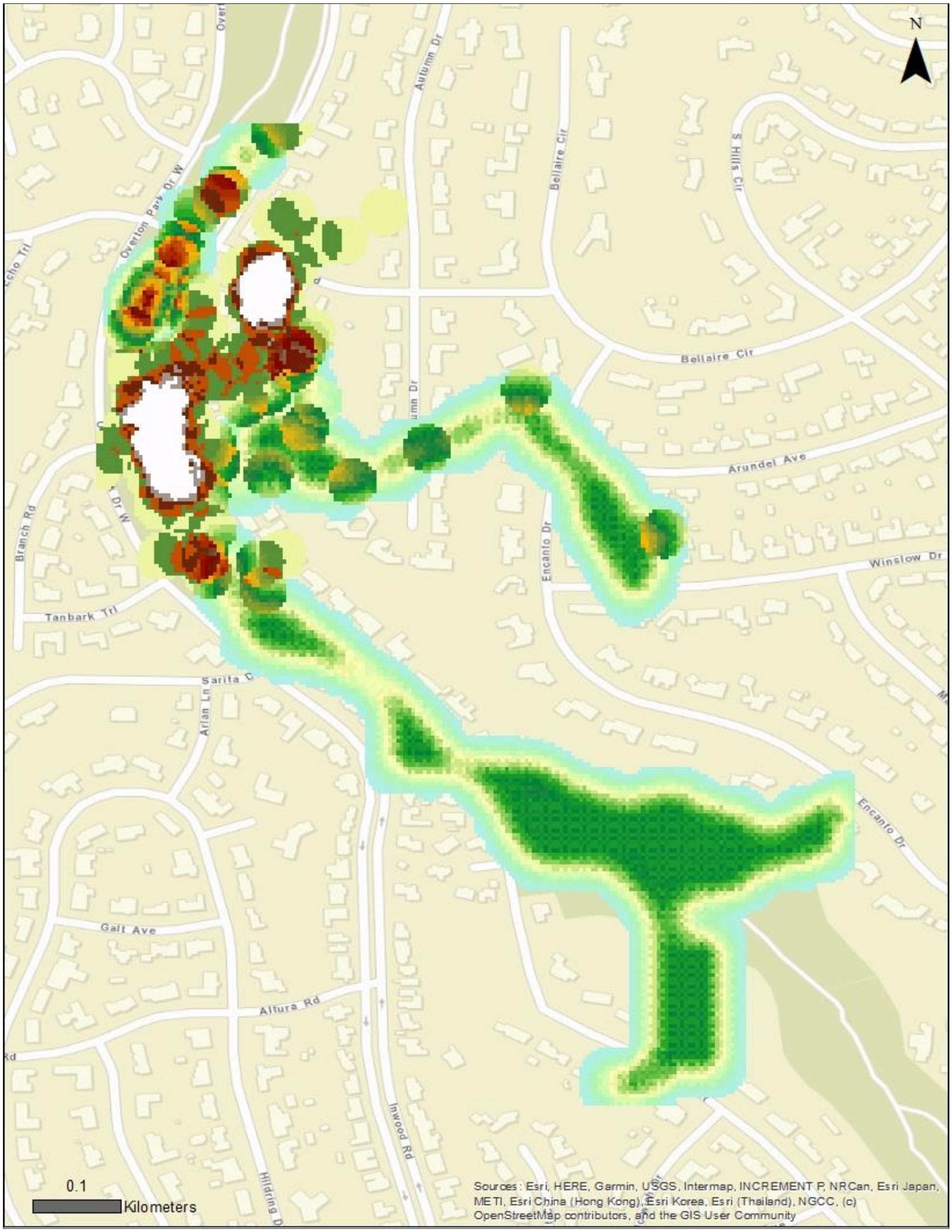


Figure C10: Hotspot map demonstrating activity levels within the home range of an evening bat “1Nyhu19Apr18” (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

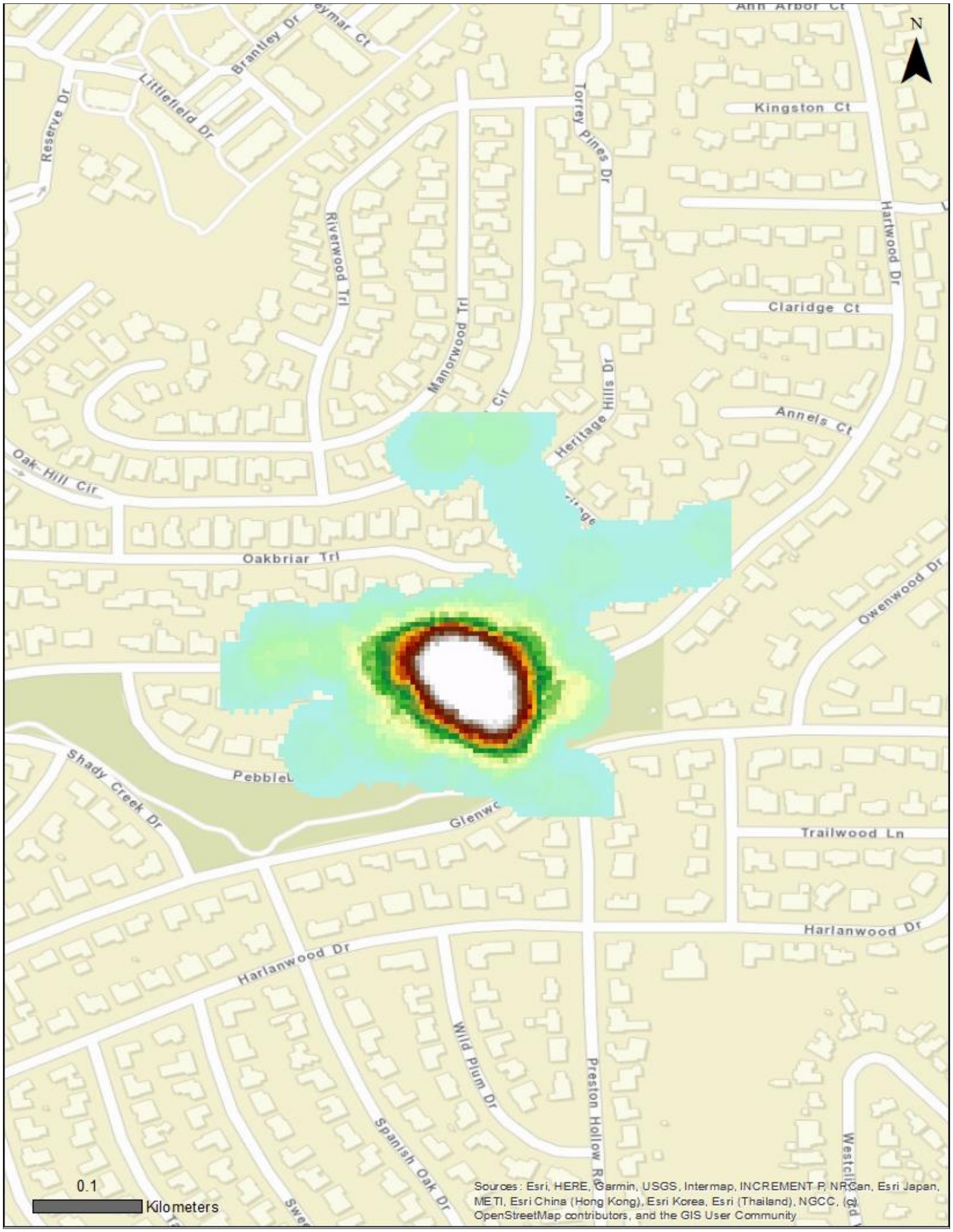


Figure C11: Hotspot map demonstrating activity levels within the home range of an evening bat "3Nyhu6May18" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

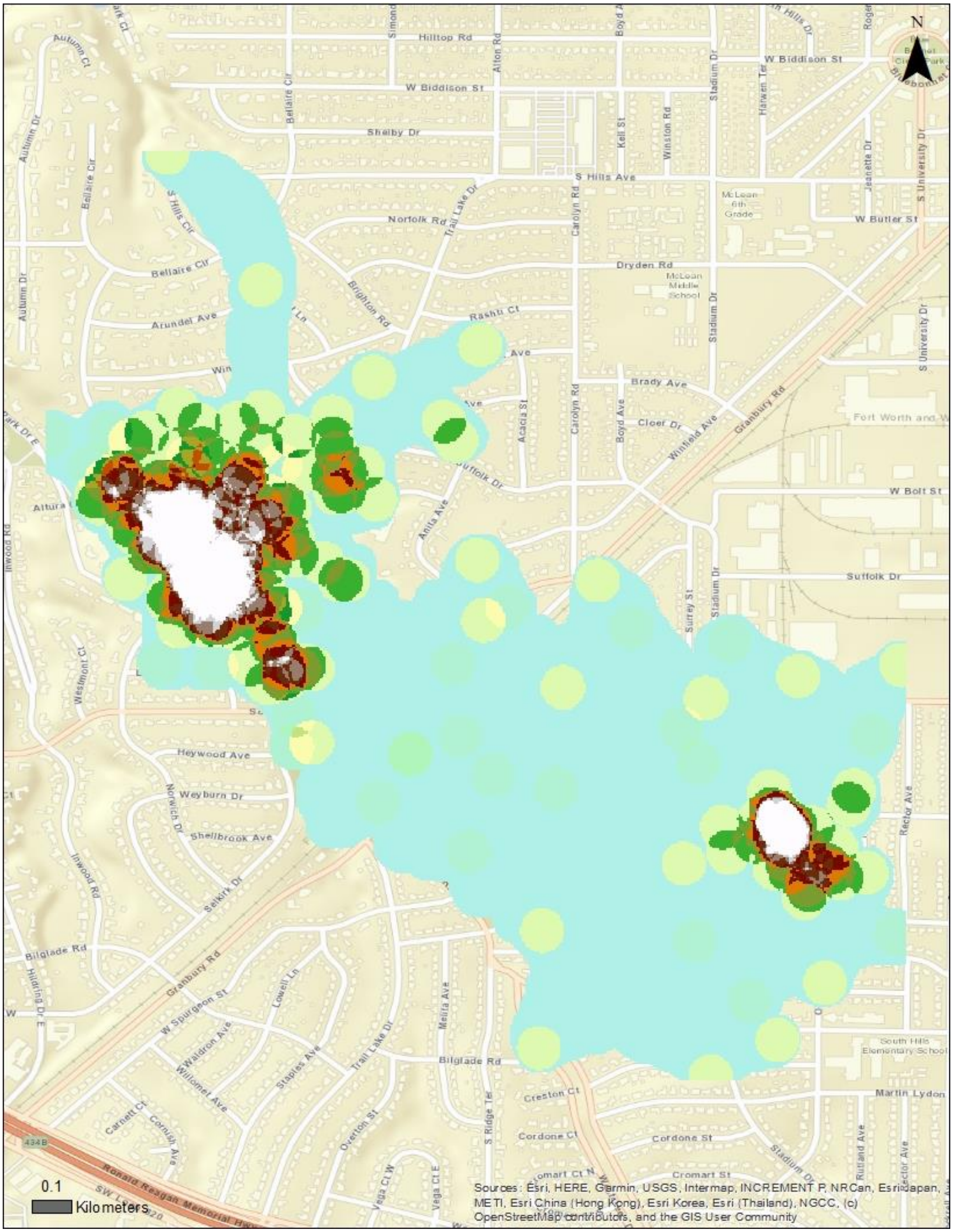


Figure C12: Hotspot map demonstrating activity levels within the home range of an evening bat “1Nyhu16May18” (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

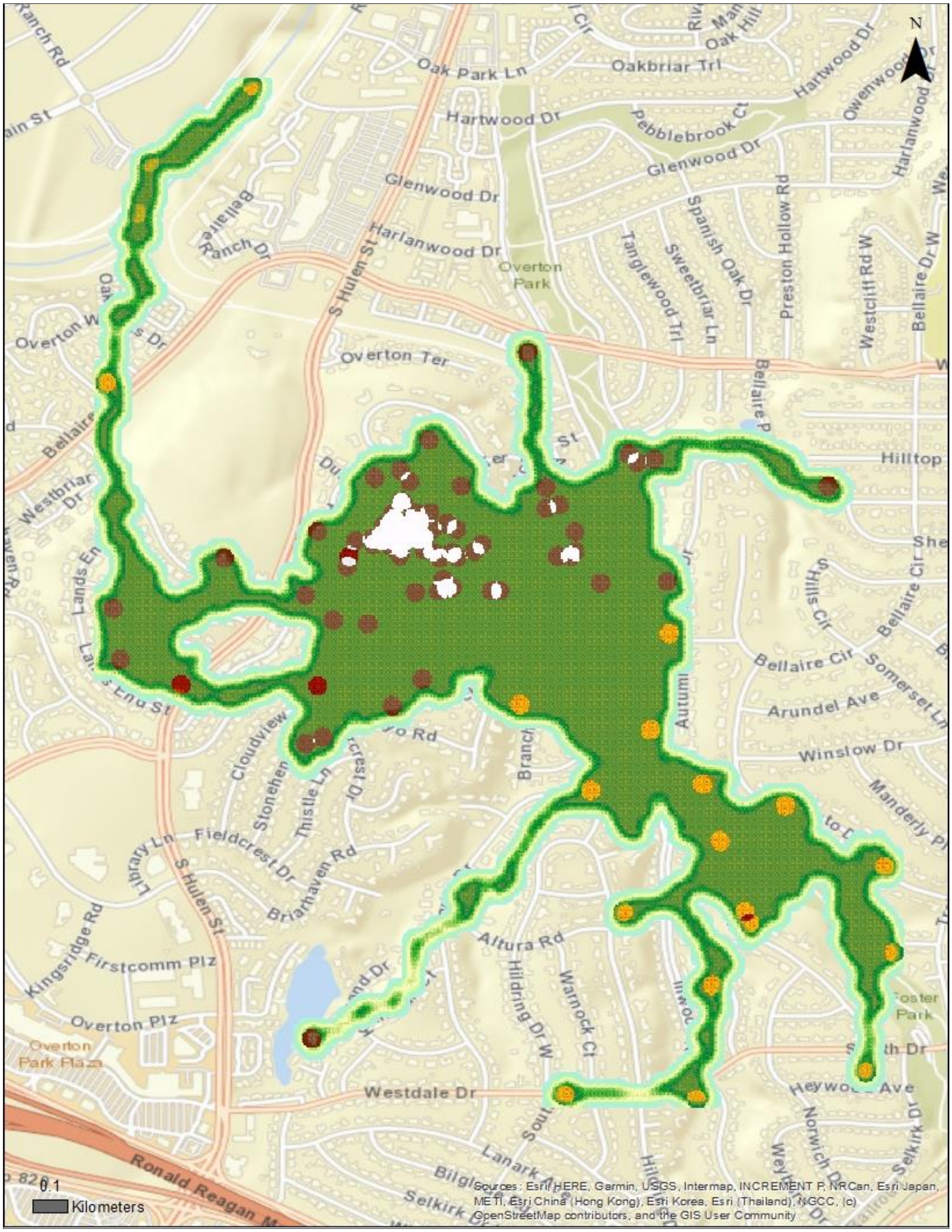


Figure C13: Hotspot map demonstrating activity levels within the home range of an evening bat “5Nyhu25May18” (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

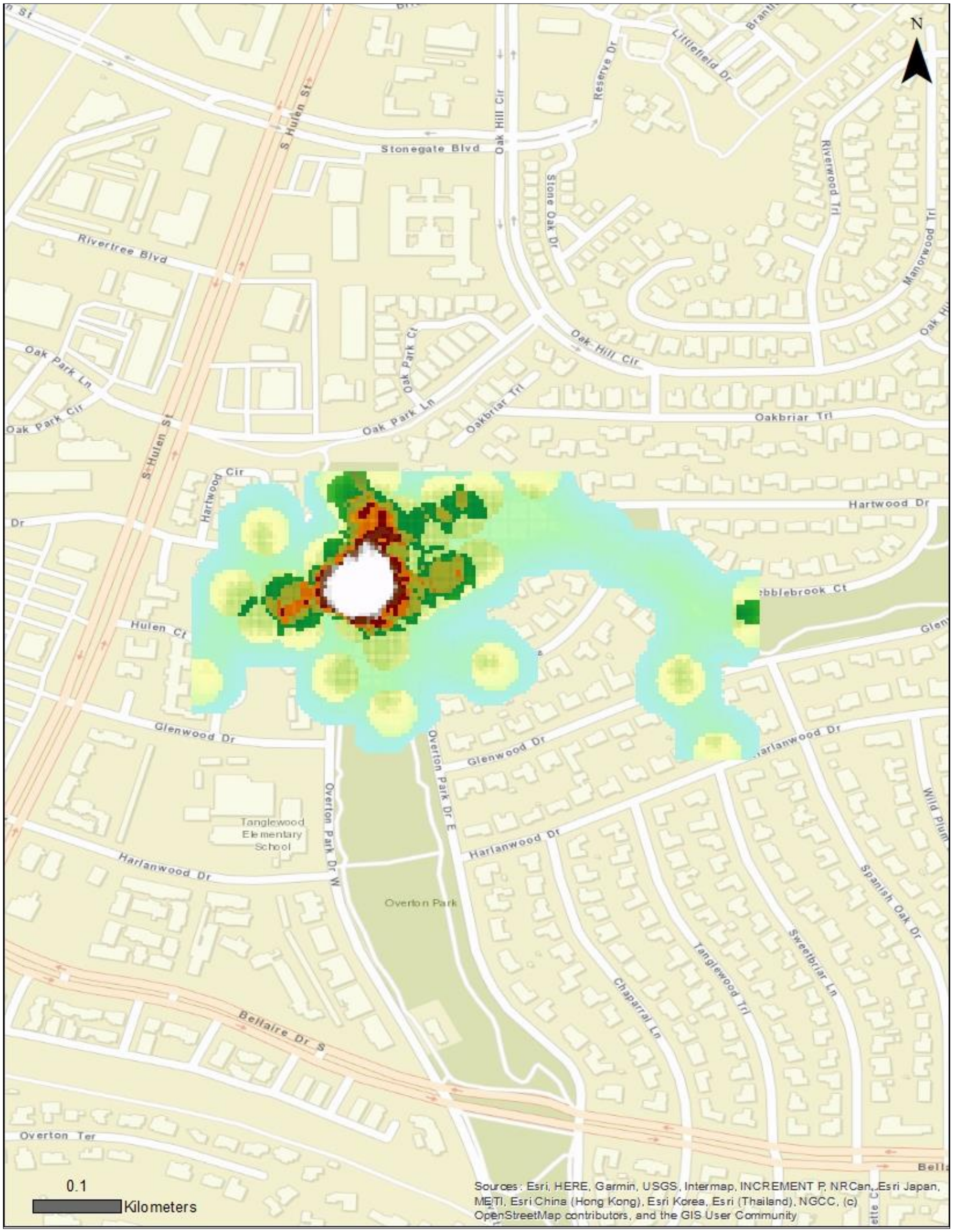


Figure C14: Hotspot map demonstrating activity levels within the home range of an evening bat "2Nyhu5Jun18" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

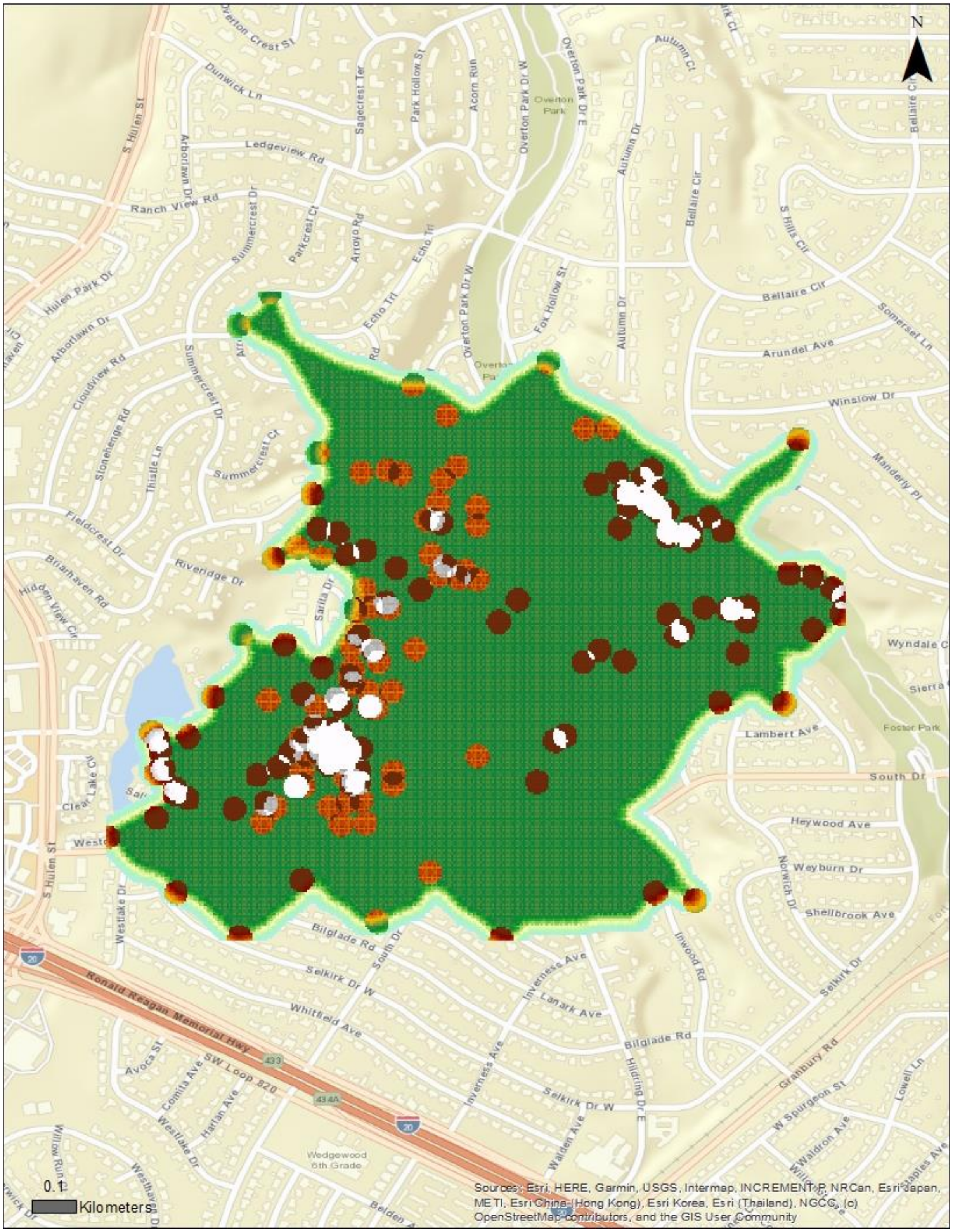


Figure C15: Hotspot map demonstrating activity levels within the home range of an evening bat "1Nyhu18Jun18" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

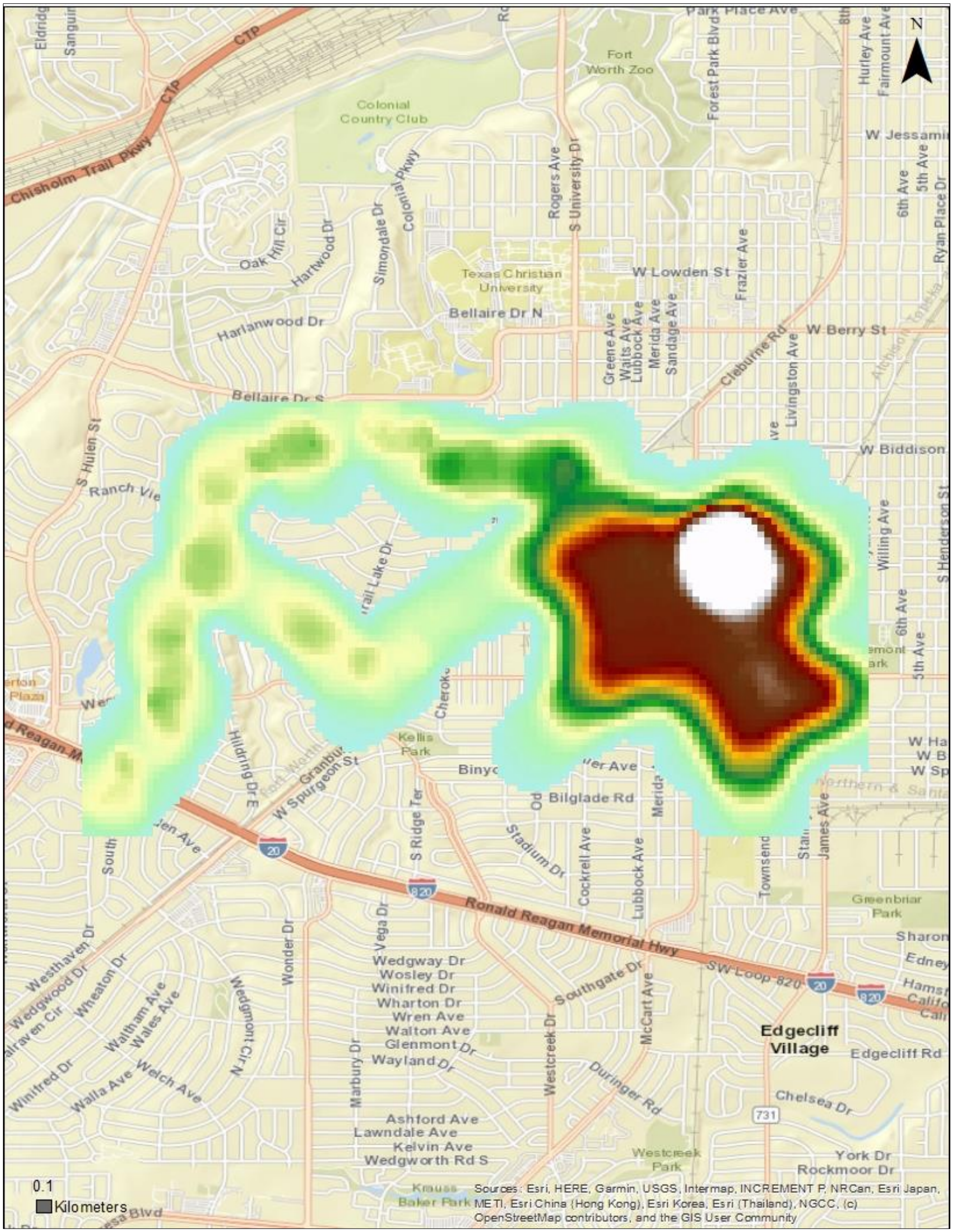


Figure C16: Hotspot map demonstrating activity levels within the home range of an evening bat "2Nyhu2Jul18" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

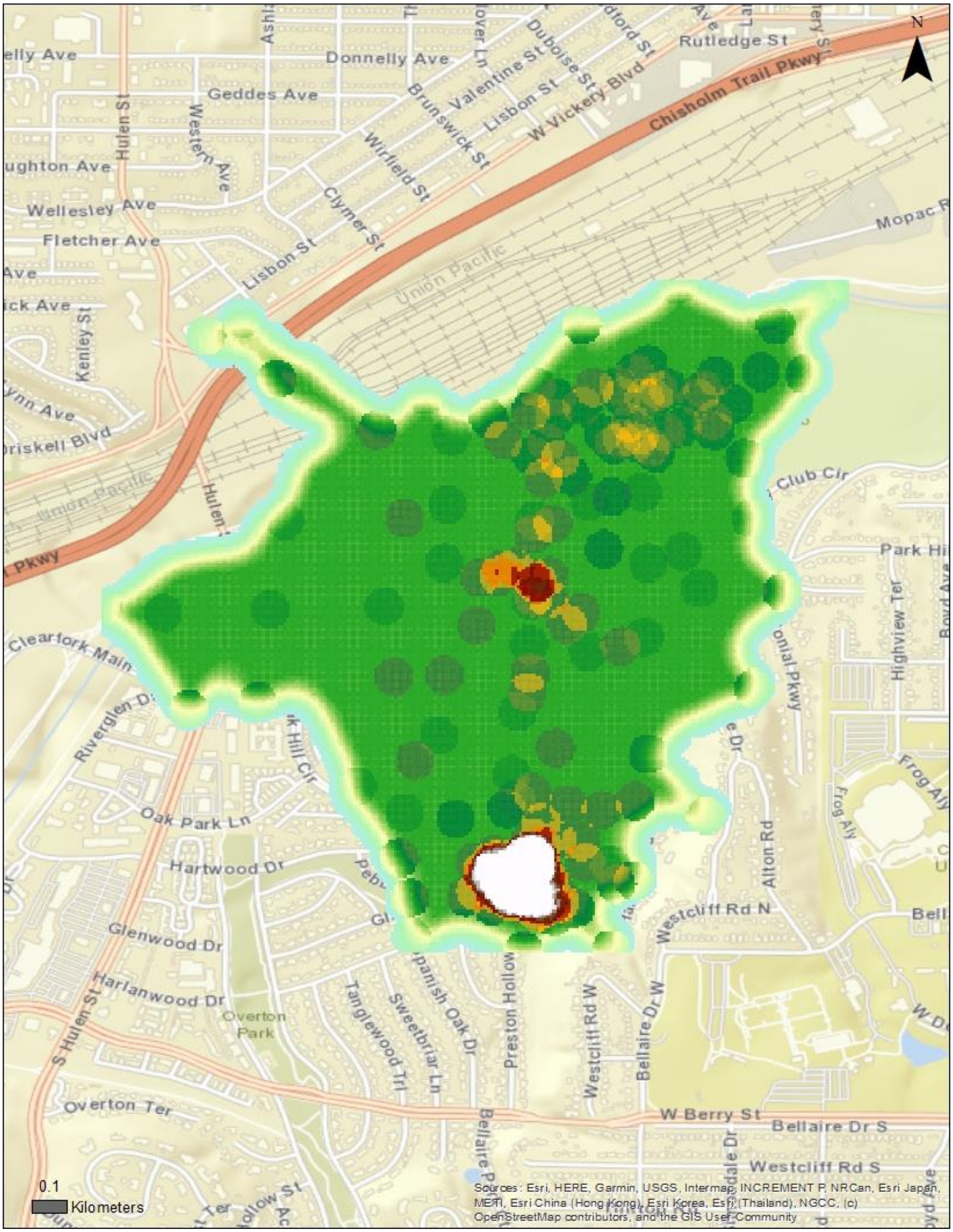


Figure C17: Hotspot map demonstrating activity levels within the home range of an evening bat “1Nyhu29Jul18” (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

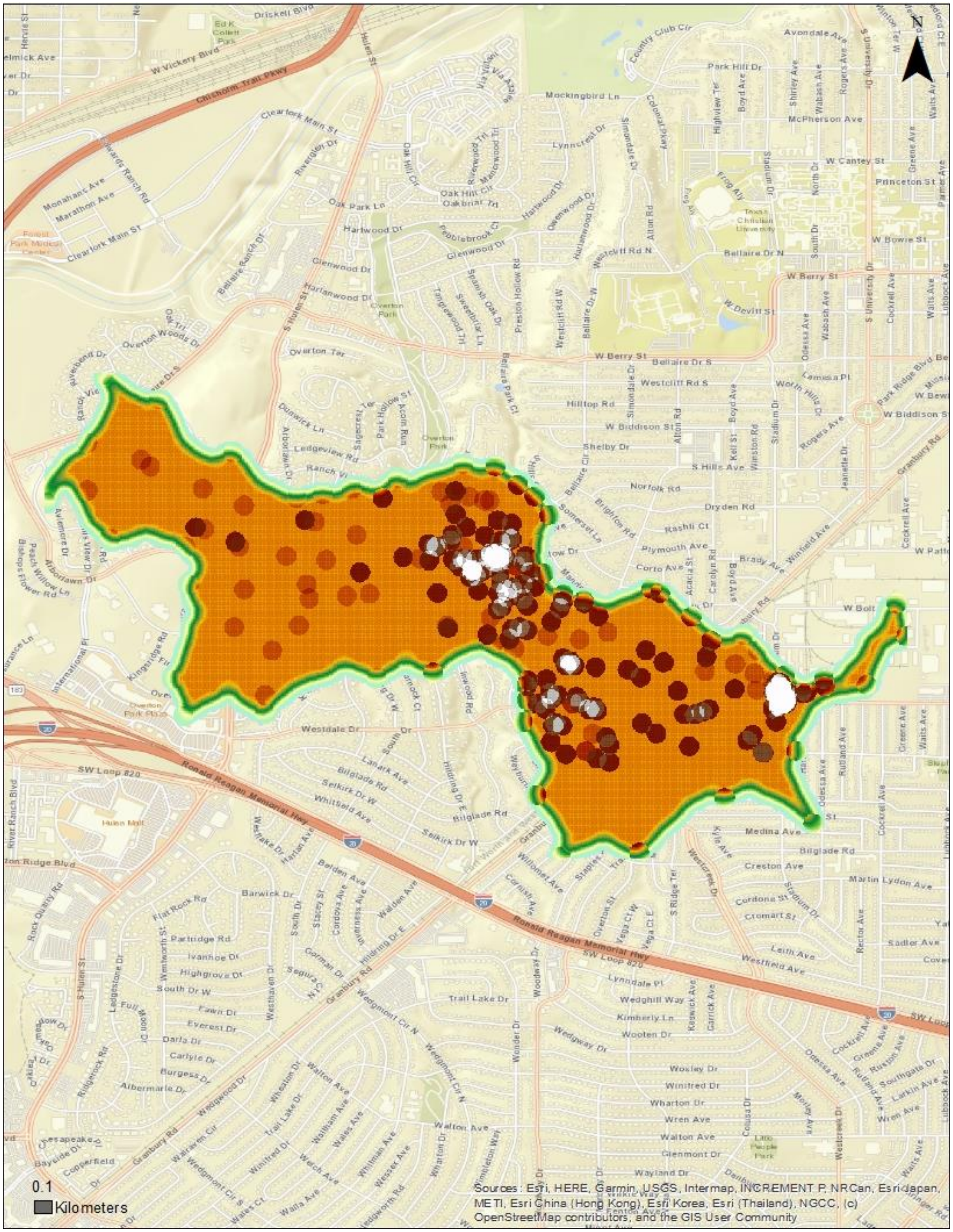


Figure C18: Hotspot map demonstrating activity levels within the home range of an evening bat "1Nyhu16Aug18" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

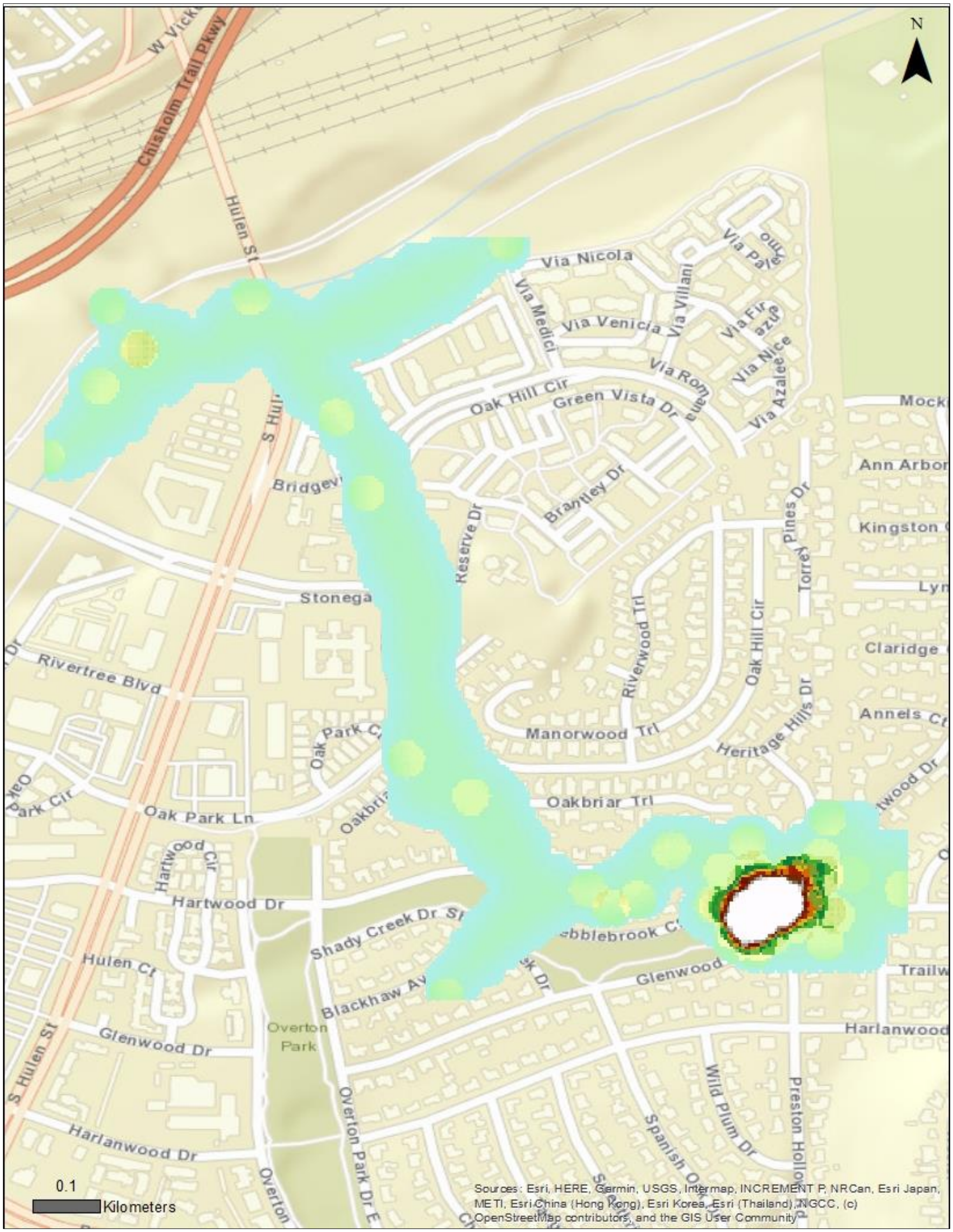


Figure C19: Hotspot map demonstrating activity levels within the home range of an evening bat "1Nyhu21Mar19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

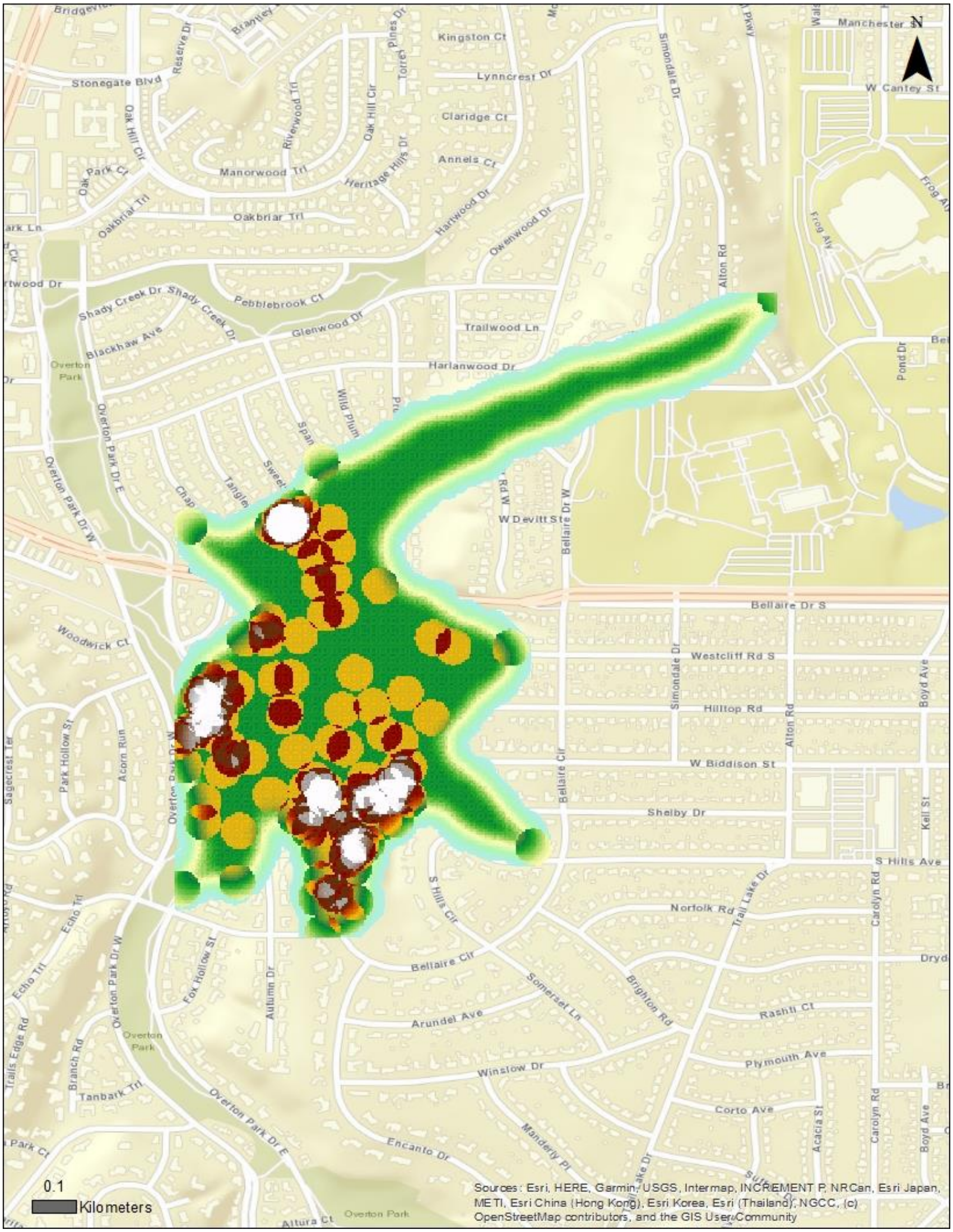


Figure C20: Hotspot map demonstrating activity levels within the home range of an evening bat "1Nyhu5Apr19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

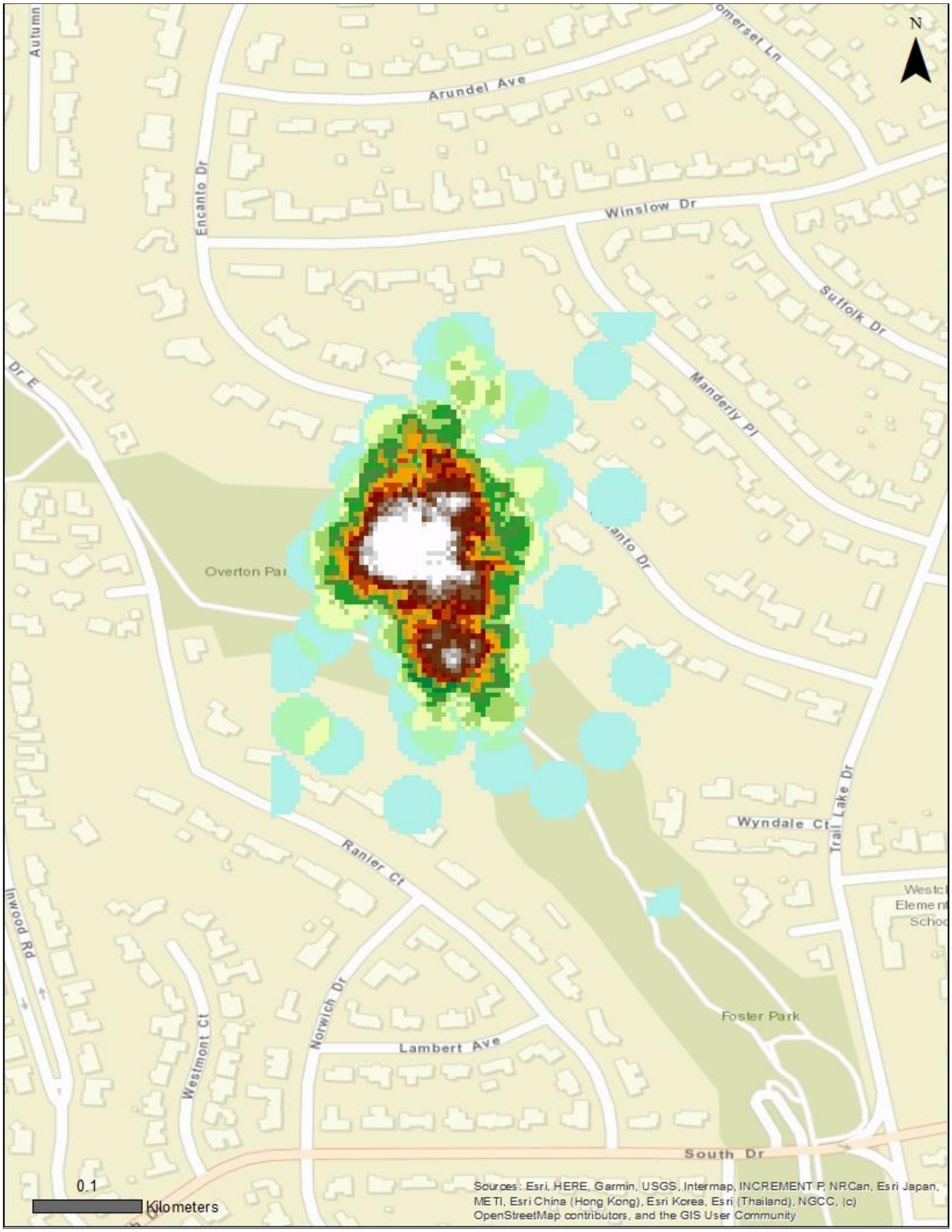


Figure C21: Hotspot map demonstrating activity levels within the home range of an evening bat "8Nyhu25Apr19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

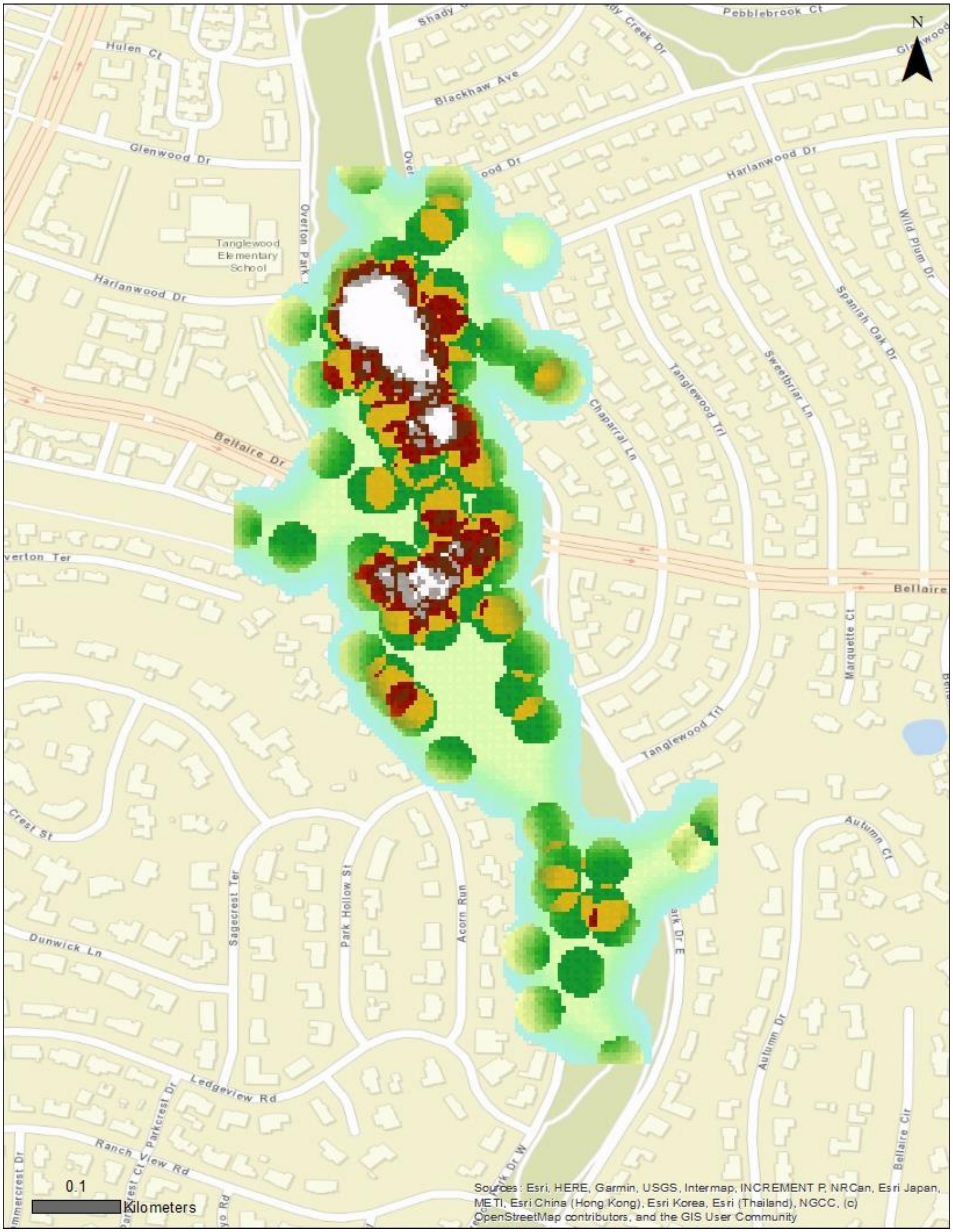


Figure C22: Hotspot map demonstrating activity levels within the home range of an evening bat "1Nyhu13May19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

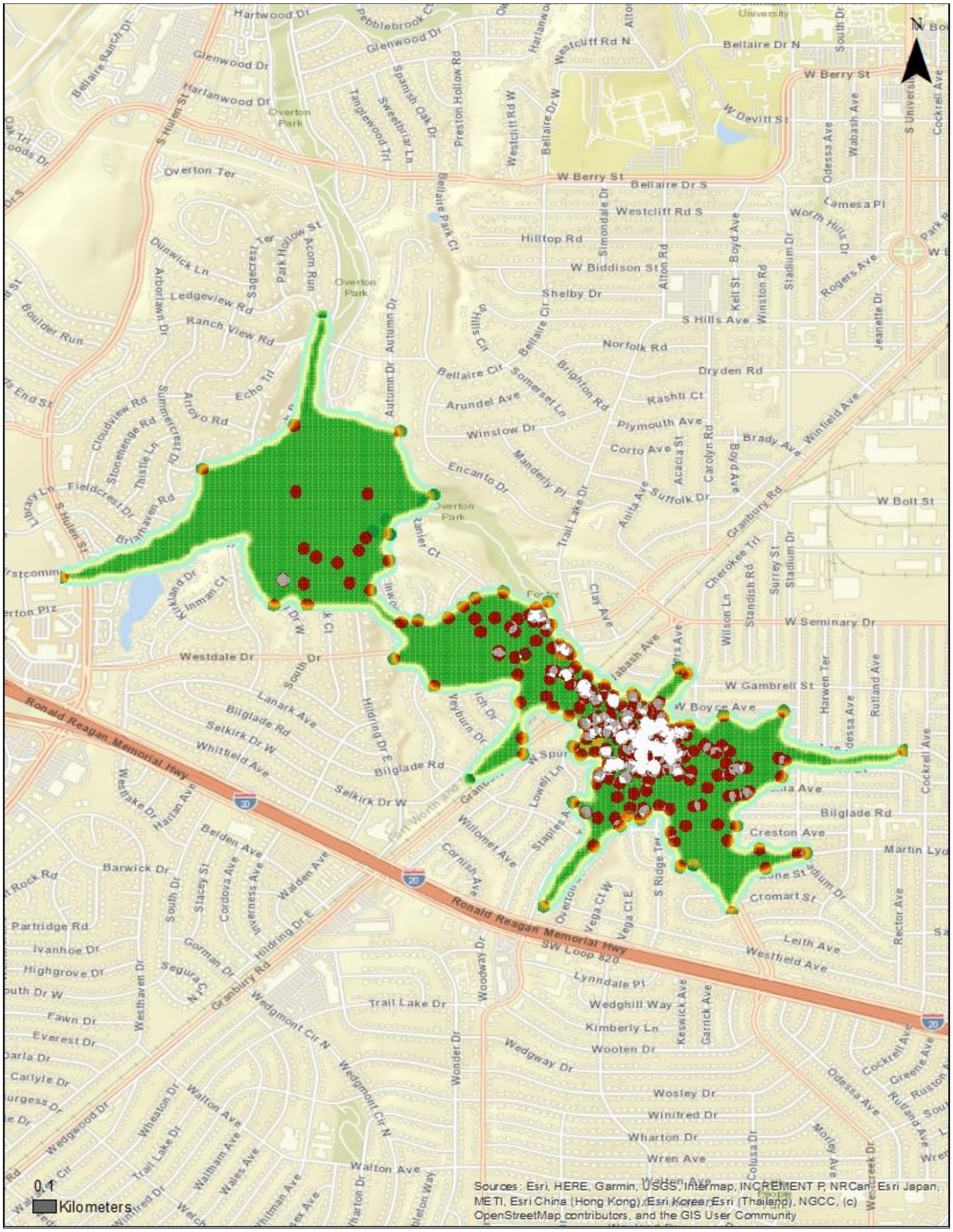


Figure C23: Hotspot map demonstrating activity levels within the home range of an evening bat “1Nyhu11Jun19” (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

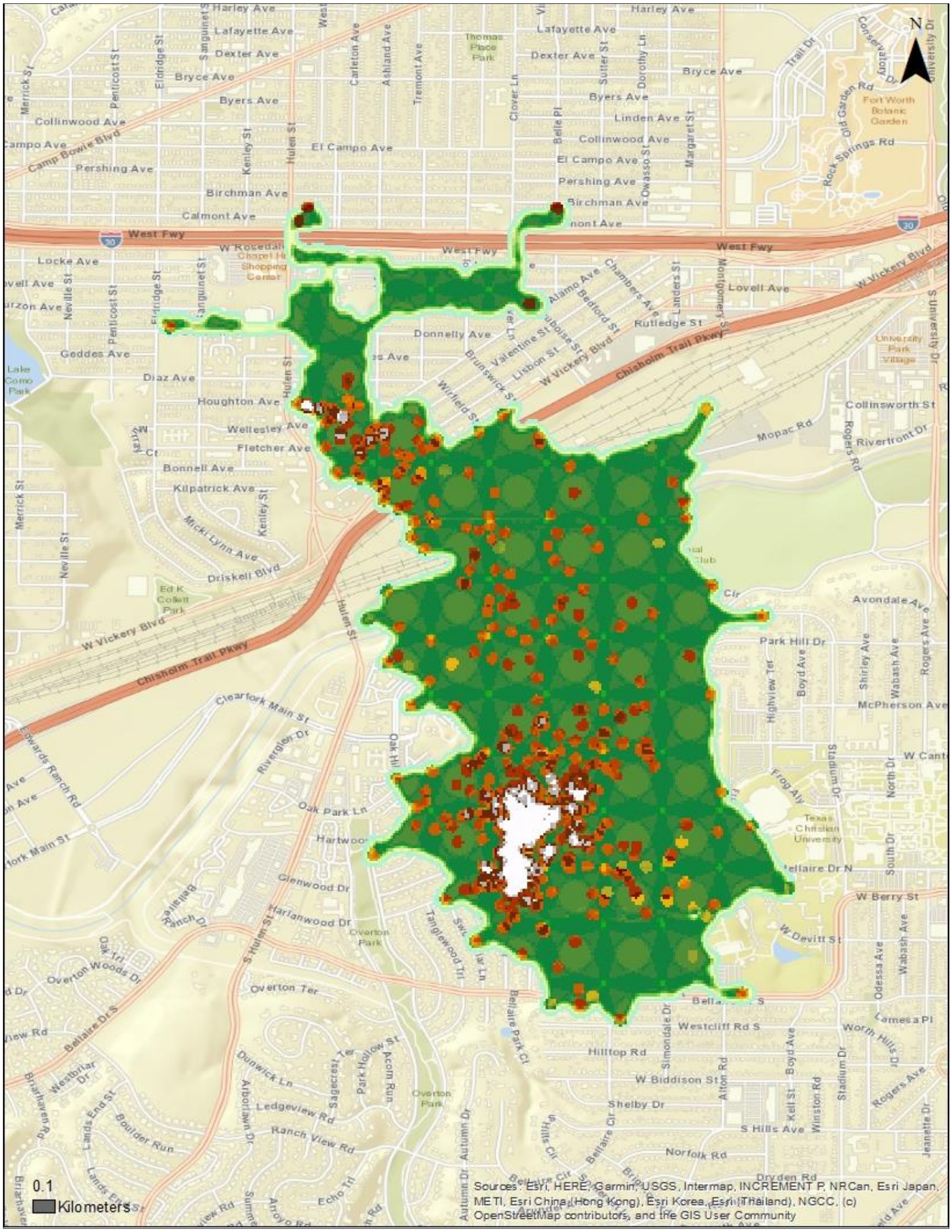


Figure C24: Hotspot map demonstrating activity levels within the home range of an evening bat "3Nyhu25Jun19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

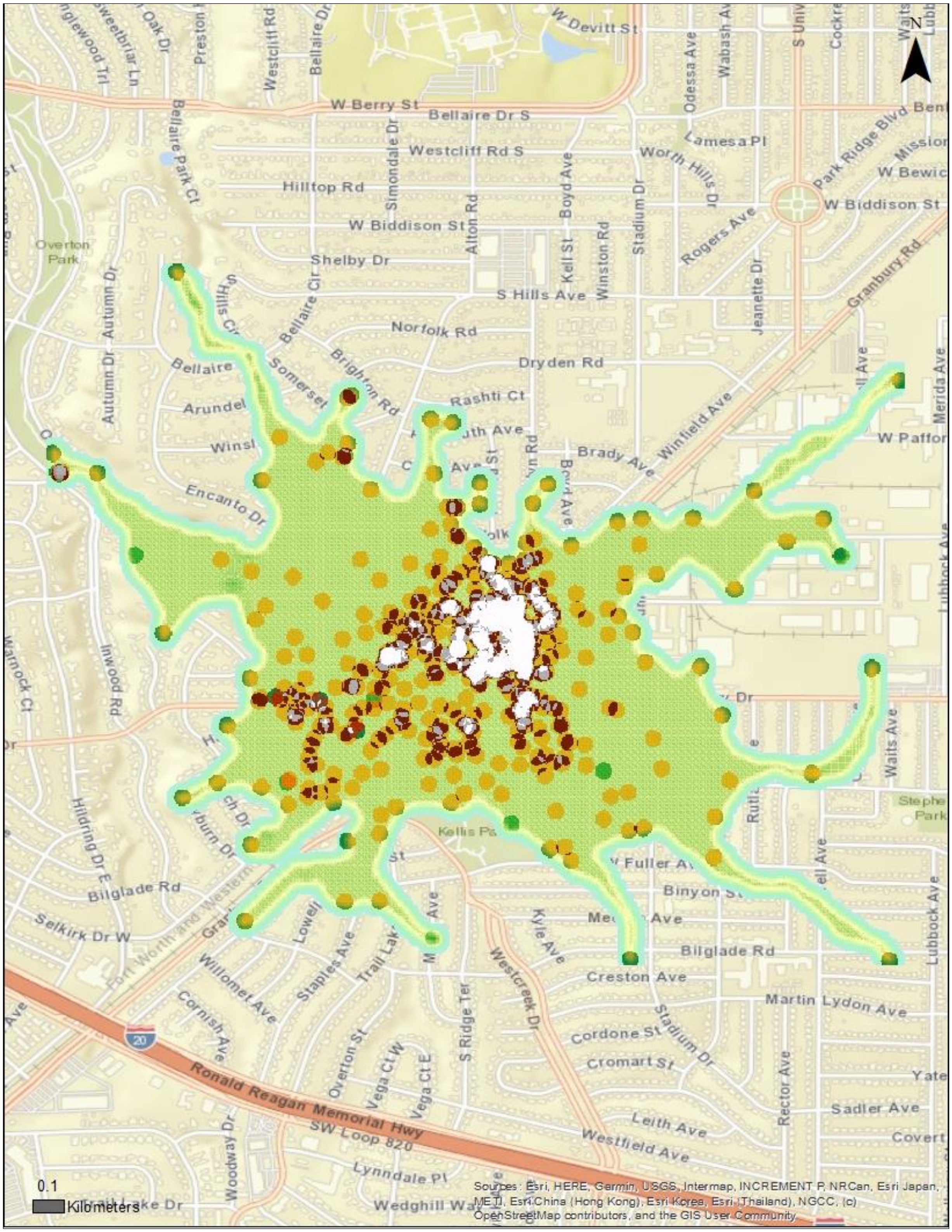


Figure C25: Hotspot map demonstrating activity levels within the home range of an evening bat “2Nyhu9Jul19” (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

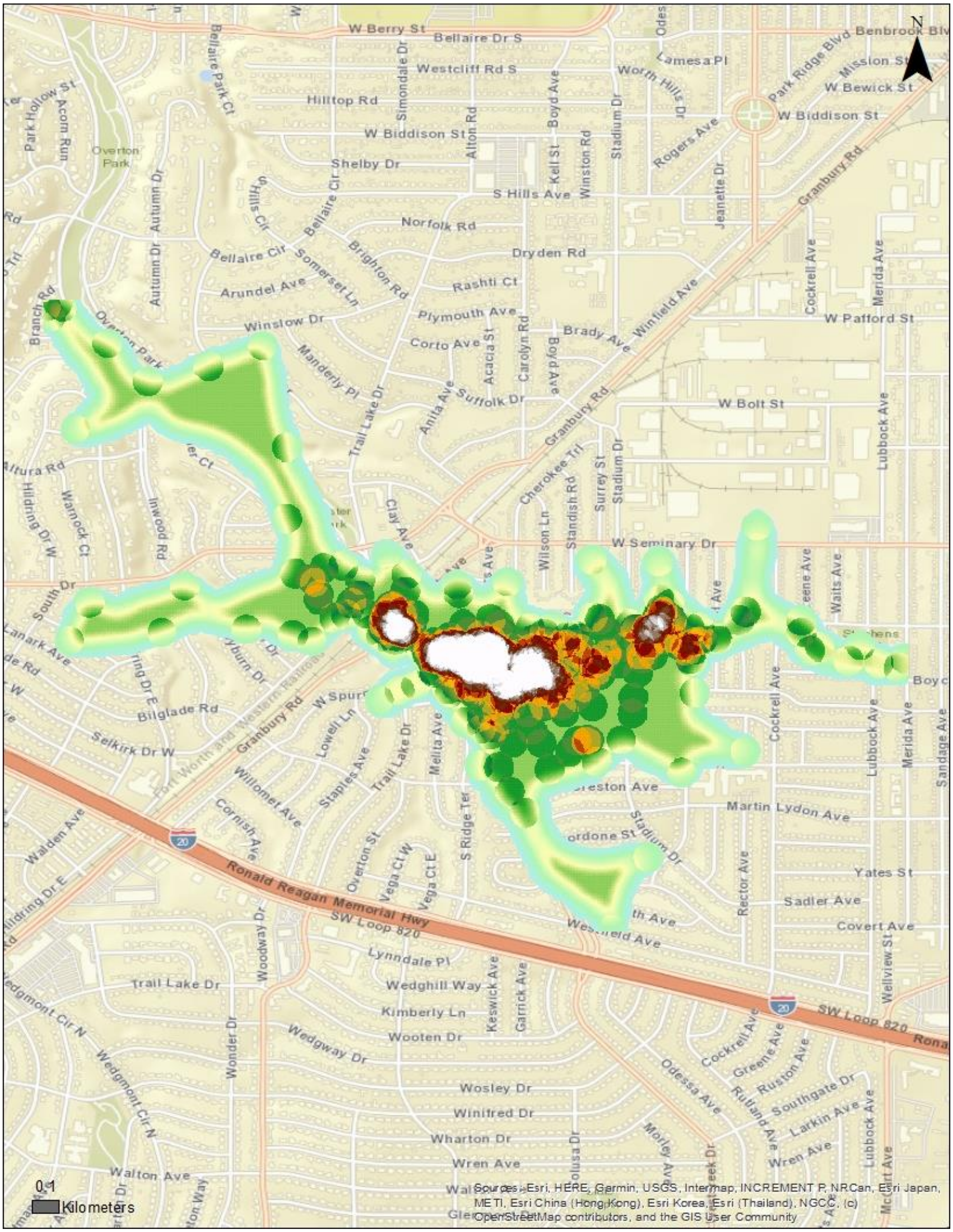


Figure C26: Hotspot map demonstrating activity levels within the home range of an evening bat “1Nyhu14Aug19” (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

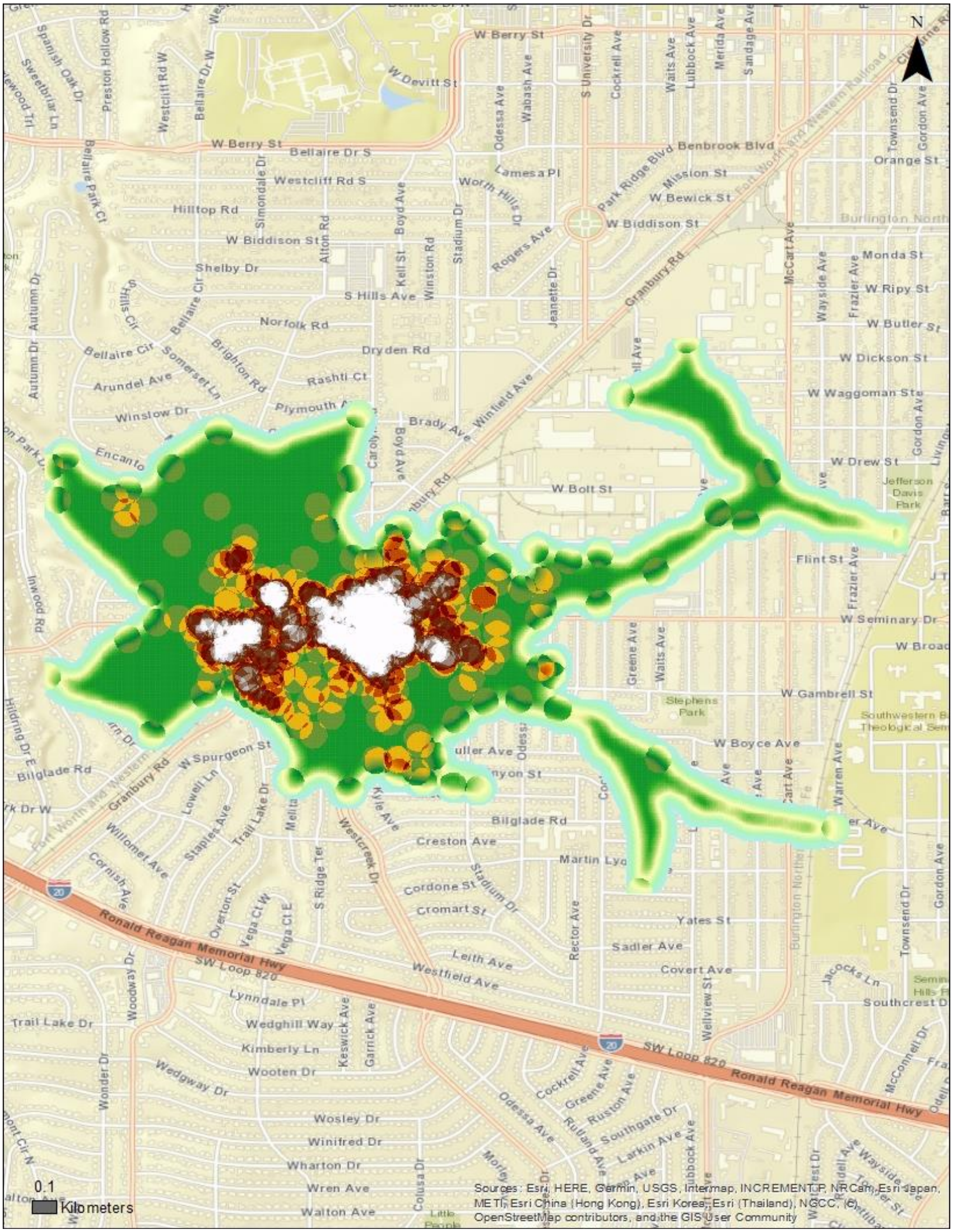


Figure C27: Hotspot map demonstrating activity levels within the home range of an evening bat “1Nyhu25Aug19” (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

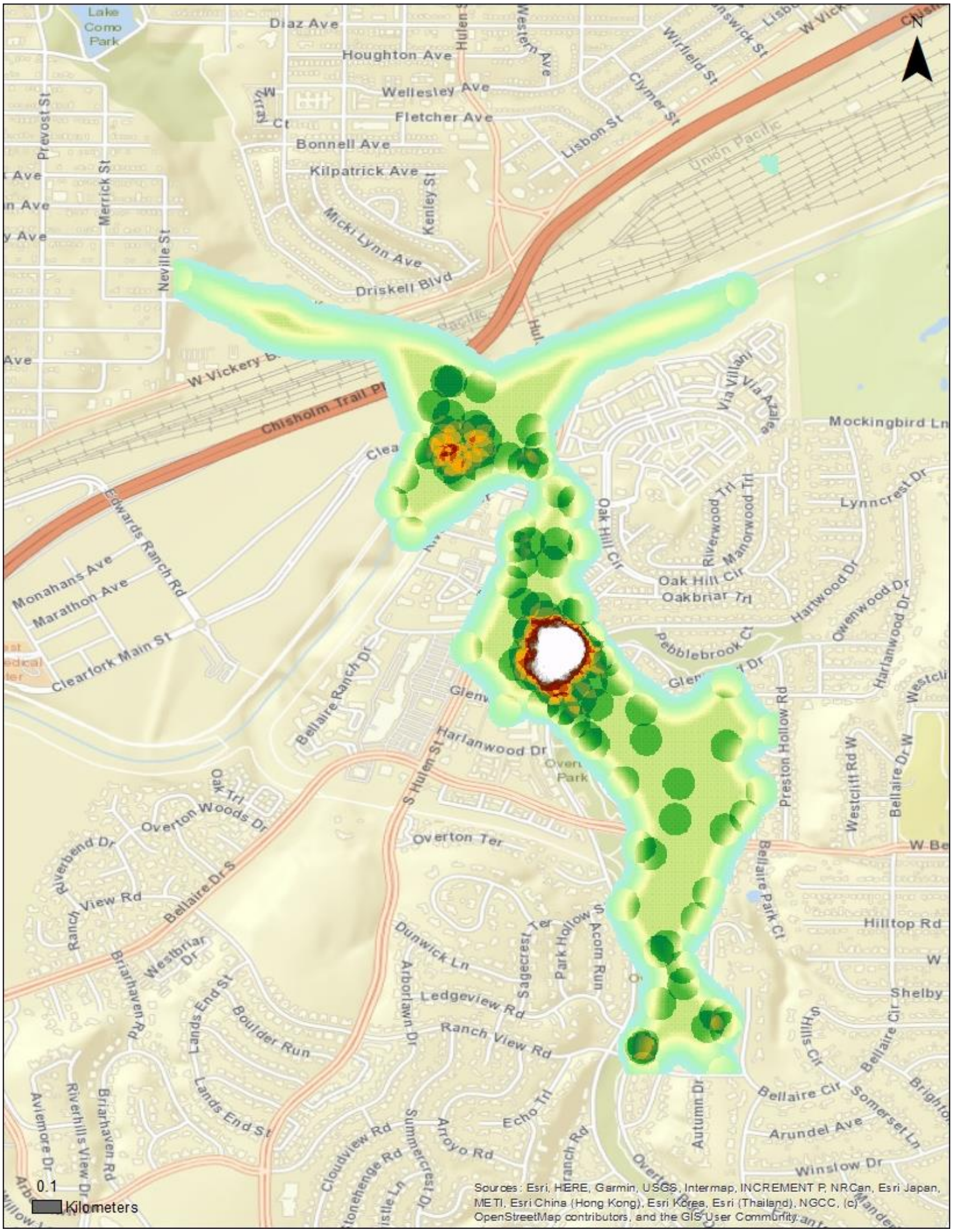


Figure C28: Hotspot map demonstrating activity levels within the home range of an evening bat “1Nyhu5Sep19” (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

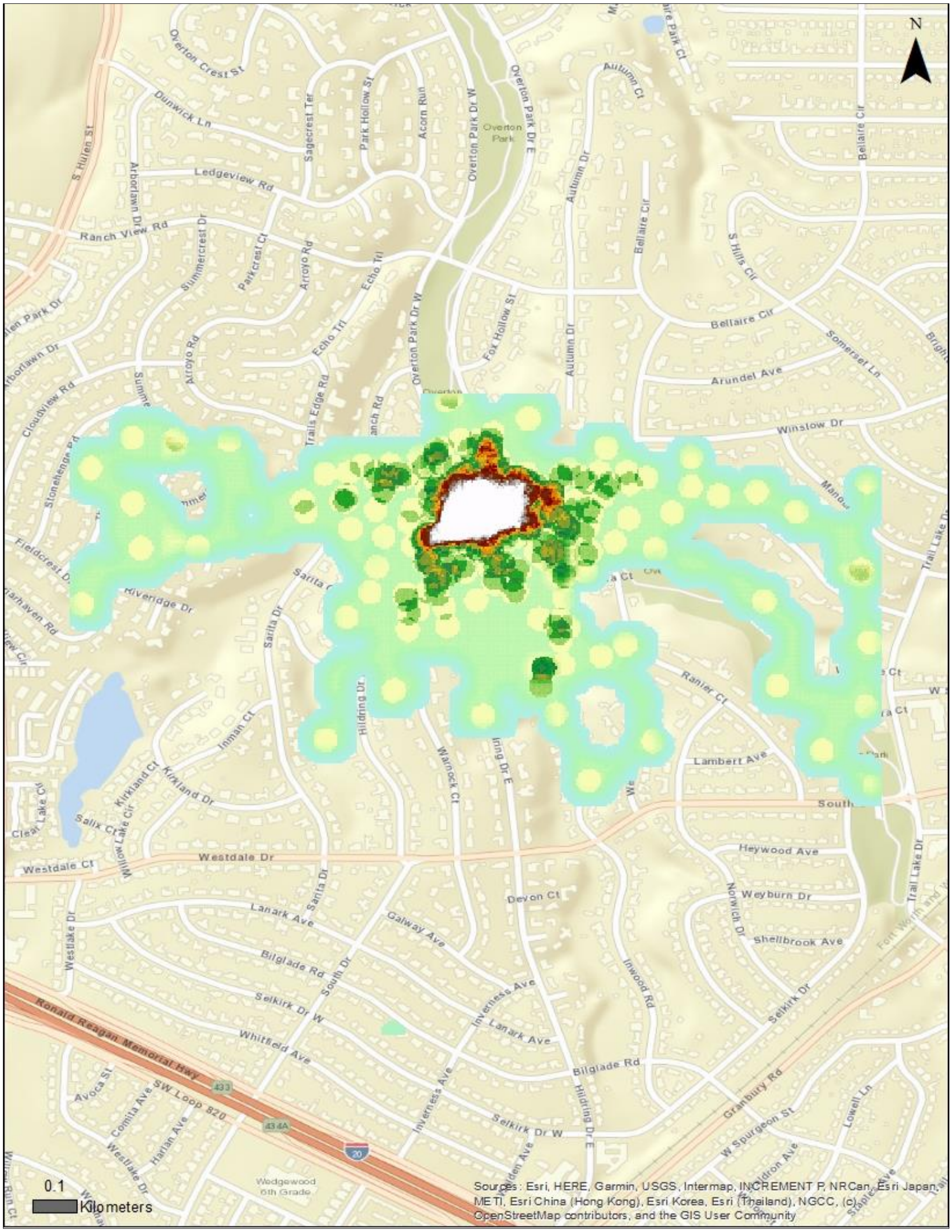


Figure C29: Hotspot map demonstrating activity levels within the home range of an evening bat "3Nyhu12Sep19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

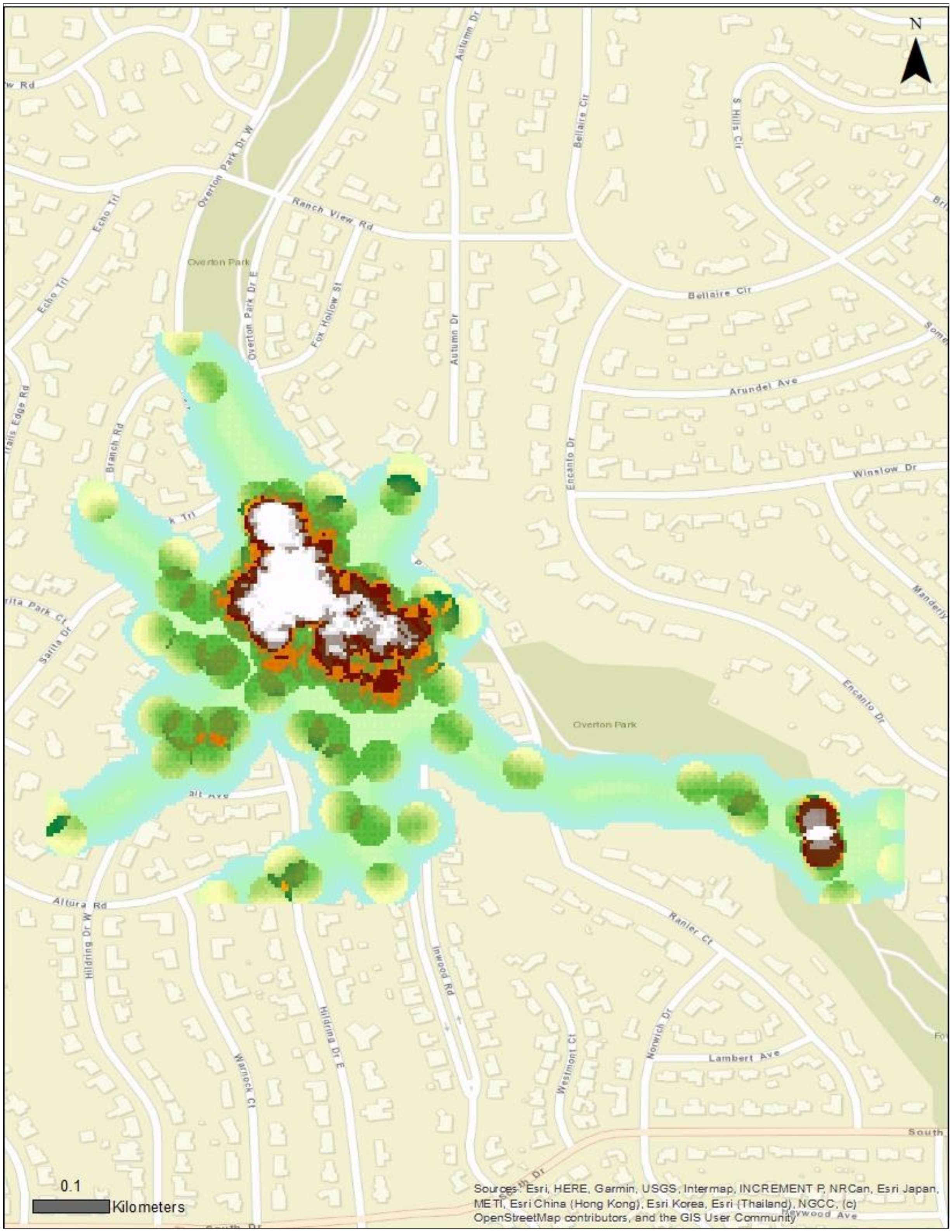


Figure C30: Hotspot map demonstrating activity levels within the home range of an evening bat "1Nyhu21Sep19" (*Nycticeius humeralis*) captured and radio-tracked in a suburban neighborhood in Fort Worth, Texas, USA.

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Vita

Personal Background

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Education

2014	Diploma, The Woodlands High School, The Woodlands, TX
2017	Bachelor of Science, Environmental Sciences, Texas Christian University
2017	Bachelor of Arts, English, Texas Christian University
2020	Master of Science, Environmental Science, Texas Christian University

Experience

2020	Teaching Assistant, Texas Christian University
2017-2019	Research Coordinator, Texas Christian University
2019	Intern, Friends of the Fort Worth Nature Center
2018	Equestrian Instructor and Camp Counselor, Trinity River Farms & Equestrian Center
2015-2017	Research Technician, Texas Christian University
2014	Kennel Technician, Forest Shadows Pet Resort

Presentations

Hall, EM, Bennett, VJ. Weather-dependent home range expansion by *Nycticeius humeralis* in an urban environment. 49th North American Bat Society for Research. Kalamazoo, MI.

Hall, EM, Bennett, VJ. Elevation analysis of Foster and Overton parks for radio-tracking bats. Michael and Sally McCracken Student Research Symposium. Texas Christian University. Fort Worth, TX.

Hall, EM, Puett, RW, Bennett, VJ. If it weren't for the neighbors! – Urban habitats can benefit bats. Michael and Sally McCracken Student Research Symposium. Texas Christian University. Fort Worth, TX.

Awards

2019	\$3,000- Environmental Science Graduate Research Fund
2019	\$400- TCU Graduate Student Travel Grant
2019	\$1,999- Graduate Science and Engineering Research Center (SERC) Grant
2017	\$1,446- Undergraduate Science and Engineering Research Center (SERC) Grant

Abstract

HOME RANGE EXPANSION BY EVENING BATS (*NYCTICEIUS HUMERALIS*) IN AN URBAN ENVIRONMENT

by Ellen Hall, M.S., 2020
Department of Environmental Sciences
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Despite the negative connotation of urban sprawl for bat populations, fragmented green spaces, such as parks, have the potential to provide necessary resources for bats. Certain resources, such as water sources, however, can be ephemeral when subject to prolonged periods of high temperatures and low precipitation. Thus, for those bats utilizing urban green spaces, we hypothesized that they would expand or shift their home ranges to access alternative resources in the surrounding neighborhoods. We conducted a telemetry study tracking resident evening bats (*Nycticeius humeralis*) caught in a local park system across their summer activity period from 2017-2019. Our results supported our hypothesis, demonstrating that bats expanded their home ranges from the park system into the surrounding neighborhoods when average nightly temperatures increased. Thus, our study highlights the importance of the surrounding urban neighborhood for bats, and if managed appropriately could potentially contribute to and encourage healthy, stable bat populations.