Spatial Ecology of Black Rat Snakes (*Pantherophis obsoletus*) at the Oklahoma City Zoo and Botanical Gardens, Oklahoma City, Oklahoma

By

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Spatial Ecology of Translocated Black Rat Snakes (*Pantherophis obsoletus*) at the Oklahoma Zoo and Botanical Gardens, Oklahoma City, Oklahoma.

Understanding movement and activity patterns are key to implementing relocation strategies for black rat snakes (*Pantherophis obsoletus*) in areas where they are considered pests. By monitoring how translocated black rat snakes move, management plans can be constructed to include spatial displacement options rather than euthanization. Translocation may affect snake survival negatively, so we compared home range and activity patterns in 3 groups of snakes. These groups consist of 1.) snakes that were captured near aviaries and released at a different location, 2.) snakes captured away from aviaries and released at a different location and 3.) snakes captured away from aviaries and released at the point of capture. Black rat snakes were surgically implanted with a transmitter (R1100 series) by hospital zoo staff. Snakes were translocated across a pond to an adjacent property from the zoo. Tracking occurred from June 1, 2020 to October 1, 2020. Snakes were located twice a day for 72 hours after release, then every day for a week. Afterwards, they were then tracked 3 times a week until the end of tracking season. Initial t-test showed no significance differences between sexes for home range or movement. ANOVA results showed no significant differences in home range for MCP 50%, MCP 95%, or KDE 50%, but did find significant differences in group home ranges for KDE 95%. A post hoc Tukey test determined that significant differences were detected between treatment groups 1 and 3 ($p = 0.043$) for KDE 95%. Movement among groups did not differ significantly. Results from this study suggest that translocation does not negatively impact black rat snake survival. However, return of translocated snakes also suggests that snakes must be moved greater than ~250 m in order to effectively re-locate nuisance snakes.

INTRODUCTION

Black rat snakes (*Pantherophis obsoletus*) are a widespread species that inhabit various habitats and are common in central and southeastern United States ranging to southern Canada (Mullin et al. 2000, Weatherhead and Blouin-Demers 2004). The IUCN (International Union for Conservation of Nature) lists them as a Species of Least Concern and their population is stable but fragmented (Hammerson 2019). Although they do not specialize on one specific type of prey, they have been documented to predate on birds and nested eggs (Weatherhead et al. 2003, Stakes et al. 2005). They are remarkable climbers and can devour entire egg clutches in a single nest visit (Stakes et al. 2005), making them highly important management priorities for zoos and aviaries. Stakes et al. (2005) also mentions that most snake predation on nesting birds occurred at night, increasing their potential threat to captive birds in the absence of zoo staff.

Strategies for managing pest species usually incorporate euthanasia; however other alternative approaches, like translocation, are being tested to determine their effectiveness (Butler et al. 2005; Harvey et al. 2014; DeGregorio et al. 2017). Most research on translocation focuses on activity patterns, movements, and home ranges, as well as estimating hibernacula sizes (Weatherhead and Hoysak, 1989; Mullin et al., 2000; Weatherhead and Blouin Demers, 2004). Use of transmitters allows researchers to estimate distances traveled and home range size. Klug et al. (2011) reported that eastern yellow-bellied racers (*Coluber constrictor flaviventris*) and Great Plains rat snakes (*Pantherophis emoryi*) exhibited a difference in movement and activity patterns from each other. While both species had similar sized home ranges, distance traveled varied, averaging 67.3 m for yellow-bellied racers and 41.3 m for Great Plains rat snakes. Home range sizes of black rat snakes and distances travelled by black rat snakes vary between sexes. Weatherhead and Hoysak (1989) reported an average home range of 1.4 ha for females and 7.57 ha home ranges for males in Ontario, Canada. Mullin et al. (2000) reported home range sizes of grey rat snakes (*Pantherophis spiloides*) at 6.3 ha for males and 3.3 ha for females in a study conducted in Tennessee and Arkansas.

Additionally, radio-tracking allows researchers to detect how snake behavior is impacted by transmitter implantation. Fitch and Shirer (1971) used a force-feeding technique to implant transmitters into several species of snakes, including black rat snakes, pine snakes (*Pituophis melanoleucus*), timber rattlesnakes (*Crotalus horridus*), black racers (*Coluber constrictor*), gartersnakes (*Thamnophis sirtalis*), copperheads (*Agkistrodon contortrix*), prairie kingsnakes (*Lampropeltis calligaster*), and northern watersnakes (*Nerodia sipedon*). Most snakes that were force-fed transmitters moved slower than snakes without transmitters. Force-feeding methods affect movement, as snakes that finish a meal tend to move more slowly than empty bellied snakes. Additionally, most transmitted snakes disgorged their transmitters during the study. There are also some inconsistencies among literature on the implications of surgically implanted transmitters. A study by Hale et al. (2017) suggested that surgically implanted transmitters do not impede movement of tracked timber rattlesnakes, however, Weatherhead and Blouin-Demers (2004) found that over 6 years, transmitted individuals experienced less growth in mass in males and females laid smaller egg clutches. Furthermore, they found that the direct and indirect effects of the transmitters were magnified by the colder climate in which the snakes inhabited (Weatherhead and Blouin-Demers, 2004). Despite these findings, they stressed the importance of continued telemetry studies due to benefits largely outweighing the costs.

I investigated the effects of translocation on rat snakes due to issues with depredation on eggs in aviaries. Translocated snakes tend to have larger home ranges and longer bouts of travel than resident snakes (Butler et al. 2005, Lee and Park 2011). A study by Fitch and Shirer (1971) investigated snakes that were released several kilometers from their points of capture. Results suggested that radio tracked snakes seemed to lack homing ability; only two snakes returned to specific points, one timber rattlesnake and one gravid gartersnake. Six out of eleven timber rattlesnakes died in a translocation study by Reinert and Rupert Jr. (1999). Vehicle collisions, disease, predators, and low temperature exposure in winter were listed as primary causes of death. Translocated snakes also exhibited abnormal movement patterns in a study by Reinert and Rupert Jr. 1999. To better understand the effect translocation has on black rat snakes and whether translocation is an effective means of removal, movement and activity patterns were compared between three groups: 1.) translocated snakes captured near aviaries, 2.) translocated snakes captured away from aviaries, and 3.) snakes found away from aviaries and released at the original point of capture. According to relevant literature, translocated snakes are expected to have larger home ranges and bouts of movement than snakes returned to their original point of capture.

STUDY SITE

The study area was located in Oklahoma County, OK. The OKCZ (35.52391, -97.47249) and Camp Trivera (35.51692, -9746787) served as the primary areas where snakes were captured and released (Fig. 1 and Fig. 2). Camp Trivera, an adjacent property owned by OKCZ, was the designated release site for translocated snakes. Construction for Camp Trivera began in the summer of 2020 and was finished in summer 2021. Camp Trivera acts as a STEM Camp for the

Girl Scouts of America. Northeast Lake separates OKCZ from Camp Trivera, and has an area of approximately 12.43 ha with the greatest distance of length from shorelines at roughly 254.16 m and shortest distance at 32.07 m. The total area for OKCZ and Camp Trivera are 32.62 ha and 14.69 ha, respectively. According to Mesonet (accessed May 15, 2022), average highs and lows for Oklahoma County in 2020 were 22.4 ℃ and 10.1 ℃, respectively. In 2021, the average highs for Oklahoma County were 22.2 ℃ and the average lows were 10.3 ℃. Average precipitation for Oklahoma County in 2020 was 8.76 cm. Average precipitation for Oklahoma County in 2021 was 7.62 cm (Brock et al. 1995, McPherson et al. 2007).

Surrounding vegetation at Camp Trivera and OKCZ consisted of post oak (*Quercus stellata*), persimmons (*Diospyros virginiana*), red mulberry (*Morus rubra*), Chinese privet (*Ligustrum sinense*), Japanese honeysuckle (*Lonicera japonica*), sycamore (*Platanus occidentalis*), eastern red cedar (*Juniperus virginana*), eastern red bud (*Cercis canadensis*), trumpet creeper (*Campsis radicans*), buttonbush (*Cephalanthus occidentalis*), Arkansas yucca (*Yucca arkansana*), hackberry (*Celtis occidentalis*), poison ivy (*Toxicodendron radicans*), and loblolly pine (*Pinus taeda*). Local fauna occasionally spotted at both Camp Trivera and OKCZ consisted of red eared slider (*Trachemys scripta*), three toed box turtle (*Terrapene carolina triunguis*), prairie lizard (*Sceloporus consobrinus*), yellow orbweaver (*Argiope aurantia*), great tailed grackle (*Quiscalus mexicanus*), dekay's brownsnake (*Storeria dekayi*), Woodhouse's toad (*Anaxyrus woodhousii*), ring-necked snake (*Diadophis punctatus*), garter snake (*Thamnophis sirtalis*) Little brown skink (*Scincella lateralis*), Canada geese (*Branta canadensis*), and other waterfowl species. Both sites are park-like with abundant hard surfaces interspersed with grassy areas and natural plots.

One snake in this study (#141) had to be re-located to Arcadia Lake due to repeated predation on avian exhibits at the zoo. Arcadia Lake (35.64810, -97.37552) is 1,545 ha area in total, however, only 74.35 ha was used as the study site for the translocated snake. Arcadia Lake is located in both Edmond and Oklahoma City, which reside within Oklahoma County. Common flora and fauna encountered at Arcadia Lake during this project included red cedar, red bud, Chinese privet, American elm (*Ulmus americana*), prickly pear (*Opuntia macrorhiza*), callary pear (*Pyrus calleryana*), southern red oak (*Quercus falcata*), post oak (*Quercus stellata*), black jack oak (*Quercus marilandica*), honey locust (*Gleditsia triacanthos*), buttonbush (*Cephalanthus occidentalis*), greenbriar (*Smilax spp*.), blue heron (*Ardea herodias*), turkey vulture (*Cathartes aura*), red tailed hawk (*Buteo jamaicensis*), Canada geese, and other waterfowl species.

MATERIALS AND METHODS

Data Collection and Transmitter Implantation

Field seasons ran from June 1, 2020 through October 31, 2021, with an emphasis on data collection from March through October. Additional tracking sessions occurred at least once a month during the dormant season (November to February) to maintain locations of snakes during the winter months. Snakes were captured on site at the OKCZ either opportunistically by Oklahoma City Zoo staff and myself or by use of cover boards (Halliday and Blouin-Demers 2015). Large wooden boards were utilized for coverboard capture methods. They were placed in inconspicuous places away from foot traffic trails so that snake movement would not be influenced. Coverboards were checked three times a week during tracking days (Halliday and Blouin-Demers, 2015). Following capture, zoo veterinary hospital staff determined the sex of the snakes, assessed their health, weighed and measured each individual, and then surgically implanted radio transmitters (ATS 4g R1170 series; Advanced Telemetry Systems, Isanti, MN) into individuals of approximately 1 m length or greater. Transmitters couldn't exceed 3% of the snakes body weight. This criteria for length helped maintain the optimal transmitter-to-snake weight ratio. OKCZ veterinary staff followed procedures found in Reinert and Cundall (1982), where anesthesia was maintained through an inhalation chamber in which the snake's head rested. Meanwhile, incisions were made in the peritoneal cavity where the transmitter can sit safely without coming into contact with internal organs. Transmitters weighed less than 3% of the snakes' body weight in order to decrease potential impacts on health and movement (Reinert and Cundall 1982, Weatherhead and Anderka 1984, Marshall et al. 2006, Lentini et al. 2011). Snakes were allowed to recover for 1-2 days post-surgery before being released (Hale et al. 2017). This time frame allowed for recovery after surgery, as instructed through IACUC protocols and methodologies found in current literature (Lentini et al. 2011, Hale et al. 2017). Studies have shown that prolonged exposure to captive environments can negatively influence survival of snakes once released (Harvey et al. 2014, DeGregorio et al. 2017) thus, all individuals were released as quickly as possible after recovery time

After release, snakes were tracked twice a day for 72 hours. Four to 11 days after release, they were tracked once daily and then tracked 3 times a week until the end of the field season. Bearings and locations were recorded using a handheld Garmin GPS 64s (Garmin Ltd., Olathe, KS). Locations were triangulated using Location of a Signal (LOAS, Version 4), and home ranges were estimated using BIOTAS (Version 2) (Ecological Software Solutions LLC, FL). Locations of each capture, release sites, and all subsequent snake locations were entered into a GIS database (ArcGIS Version 10.8, ESRI Redlands, CA) for further analyses. At the end of field season 2021, snakes were tracked and located to have the transmitters removed by zoo veterinary staff. Prolonged exposure to transmitters has been documented to have adverse effects on survivability (Weatherhead and Blouin-Demers 2004, Lentini et al. 2011, Harvey et al. 2014, DeGregorio et al. 2017, Hale et al. 2017). Each snake was released afterwards at the designated release site. The protocols for this study were approved by UCO IACUC (protocol #20012) and necessary permissions were granted by the Oklahoma City Zoo and Botanical Gardens' Scientific Review Committee, as well as capturing permits from the Oklahoma Department of Wildlife Conservation (ODWC).

Home Range

Black rat snake home ranges were measured by using adaptive kernel estimators (KDEs) and minimum convex polygons (MCPs) in BIOTAS home range estimation software, in order to compare results to previous research (Weatherhead and Hoysak 1989; Row and Blouin-Demers 2006; and Allen and Singh 2016). MCPs are home ranges indicated by a unique polygon whose outermost location data outline the polygon's area (Weatherhead and Hoysak, 1989; Hart et al., 2015). For this reason, MCPs are considered to overestimate home ranges.Although they may not be the best indicators of home range, it is necessary to compute them in order to compare results to previous research.. Further, different home range estimation software can vary outputs created by MCPs (Lawson and Rodgers 1997). Minimum convex polygons are commonly used in various home range studies and do not rely on statistical distribution to calculate home range (Buchanan et al. 2017). A 95% MCP was used to estimate home range in tracking and locating areas. A 50% MCP was also used to look at where snakes are likely to be found (Hart et al. 2015).

Kernel Density Estimators (KDEs) are defined by Seaman and Powell (1996) as a probability density placed over a single sampling point. Using an intersecting grid, densities are averaged from the re-occurring overlap within the kernel, resulting in an estimated density likelihood for home range. The formula given to calculate KDEs are as follows:

$$\hat{f}(x) = [1/(nh^2)] \sum_{i=1}^{n} K \left\{ \frac{(x - X_i}{h} \right\}$$

Where n represents the number of data points; h is the bandwidth, or smoothing factor value; and K is a density of the kernel. The x represents the values of the axis from the x, y coordinates and X_i is a continued series of individually observed x vectors (Seaman and Powell 1996). Least squares cross-validation (LSCV) is the standard way to determine smoothing factor values when using KDEs (Buchanan et al. 2017). Kernel density is a non-parametric technique that detects disproportionately used areas within an animal's home range (Hart et al. 2015). Fixed and adaptive kernels have been applied to many studies spanning different topics such as ecology, epidemiology, and crime maps. Fixed kernels have a fixed radius across a map, where adaptive kernels offer size variability across a map to independent plotted points.

I used adaptive kernels instead of fixed kernels because of their high sensitivity and specificity. Further, fixed kernels were found to underestimate home range values. Lemke et al. (2015) concluded that fixed kernel density estimators yielded more conservative values when delineating at-risk cancer areas for rural and urban settlements. Fixed kernel density estimators did have a reduced sensitivity but made up for this by a reoccurring oversmoothing factor when estimating at-risk areas. This allowed for higher specificity. Conversely, adaptive kernel density estimators tended to have higher variability, but maintained higher sensitivity and levels of specificity on par with fixed kernel estimates (Lemke et al. 2015).

Kernels are a widely used tool for quantifying home range estimates. The most important part of creating kernels is choosing a smoothing factor (h). The recommended method for selecting the h-value is by using the least squared cross validation (LSCV). The smoothing factor was set to 0.50 to better balance small- and large-scale home range estimates, which followed protocols described by Row and Blouin-Demers (2006) in their work investigating the reliability of KDEs of milksnakes (*Lampropeltis triangulatum*). The lower the value of the smoothing factor, the more detail (shape, size, location, area) is provided about a small-scale polygon. Larger smoothing factor values tend to be better suited for larger generalized areas. Row and Blouin-Demers (2006) also reported that measurements using kernels can be unevenly distributed when using LSCV to select for the smoothing factor. Further, their results illustrated that kernel home range estimates vary significantly when used as estimators for milksnake movements when compared to MCPs. The kernel values tended to have larger, differing values whereas MCP values were smaller and more stable. This was likely due to site fidelity leading to autocorrelation, which can occur when an animal is recorded as using the same site multiple times. Row and Blouin-Demers (2006) used MCPs for initial home range estimates for herpetofauna, except for autocorrelation occurrences. To correct for autocorrelation, KDEs were adjusted until they matched approximately the sizes of MCPs. For this study, I used Moran's I to test for for spatial autocorrelation in black rat snake home range, but KDEs were not used to correct for any occurring autocorrelation.

Movement

I estimated black rat snake movement using LOAS and BIOTAS software using a Maximum Likelihood Estimator. Both programs utilize Rao's Spacing Test, Runs Direction of Change, and Rayleigh's Mean Directionality Test and give identical results when running tests. However, LOAS had stronger triangulation and bearing calculating capabilities, where BIOTAS was capable of only measuring movement. This allowed for cross referencing results when comparing test and movement analyses. Straight-line movements were assumed to better visualize daily/nightly travel (Hart et al. 2015). Connecting successive movement tracks in LOAS allowed the assumption of straight-line movements, which in turn, allowed estimates of average daily movements (Hart et al. 2015). Both Rayleigh's and Rao's tests incorporate circular statistics. Random data distribution, or non-uniform data distribution, were assumed for Rayleigh's Test. Similarly, Rao's Spacing test assumes that if the data is uniform, then consecutive observations should be evenly spaced around a 360-degree arc. Because of the moderately reliable strength of Rayleigh's and Rao's Tests, they are amongst the most commonly used movement calculations in biology and ecology studies (Landler et al. 2018). Statistical power from the tests often leads to correct and successful rejection of the null hypothesis, where type 1 errors may occur.

Runs test is strictly linear, where change in direction is considered a "left turn" versus a "right turn". Runs test also provides an average movement. This test is most powerful when considering movement activity within a small-scale area such as a home range.

Effects of Translocation

Effects of translocation were investigated to determine whether translocation is an effective tool for removing nuisance species. This study investigated translocation effects, movement, and home range sizes by following methodologies of Weatherhead and Anderka (1984), Weatherhead and Blouin-Demers (2004), and Allen and Singh (2016). Survival of snakes and rate of return to the original point of capture were used for this purpose. By using the framework suggested by Allen and Singh (2016), life history traits and potential impacts of black rat snakes on the environment can be used to evaluate the efficiency of management practices. Weatherhead and Blouin-Demers (2004) suggested that transportation and repeated disturbances by researchers could increase risk of negative impacts on radio-transmitted snakes. To help decrease the risk of potential mortality, contact with snakes was mitigated as much as possible while tracking and locating.

RESULTS

Fifteen snakes were tracked during the field season and dormant season of 2020 and 2021. Snakes were weighed, length measured, and sex was determined before surgical insertion of transmitters and subsequent release. Snake weight before release ranged from 165 g to 780 g with a mean weight of 463.73 g. Individuals ranged in size from 0.81 m to 1.30 m with a mean size of 1.12 m. Of the sample collected, 6 were male (including the individual tagged twice) and 9 were female.

Total tracking days for 2020 to 2021 were 181 days with a mean of 90.5 tracking days for both seasons. Total tracking days includes each day throughout the field and winter seasons that snakes were located. Tracking days for 2020 and 2021 ranged from 1 to 31 days, and 1 to 24 days, respectively for all animals. Movement and home range did not seem to be affected as the snake's activity patterns did not change between the separate transmitter implantations. Furthermore, Hart et al. (2015) assigned two transmitters per python in the event that one of the transmitters failed. Two snakes (#202 and #062) went missing during the study, therefore home range and movement data were limited. Snake #202 was released July 8^{th} 2020 and was last detected August 10^{th} 2020, resulting in 63 locations. Snake #062 was released May 16^{th} 2021 and was last detected June 23^{rd} 2021, resulting in 90 locations.

Three treatment groups were established to compare movements, home range sizes, and translocation effects. I compared movements and home range sizes between male and females and among the 3 treatments. The first group consisted of 4 snakes that were captured in or around aviaries and translocated away from the zoo, which included 2 males and 2 females. The second group had 6 snakes that were captured away from aviaries and were also translocated. In this group, there were 4 females and 2 males. The third group consisted of snakes captured away from aviaries and returned to the point of original capture, which included 3 males and 3 females. An independent t-test was used first to determine any differences between males and females, and then again to detect differences between treatment groups.

All translocated snakes were moved to Camp Trivera. Treatment categories, sex, and corresponding tag number are summarized in Table 1, as well as results of home range estimates and movement tests. A Levene's test of normality among variance was used to test for homoscedasticity. Data met the assumption for use of individual t-tests.

Home Range

Home range was estimated using MCPs at 95% and 50% with kernel density estimators at 95% and 50%. Kernel density estimators yielded significantly smaller home range values than MCPs. Moran's I Test was used to identify any spatial autocorrelation. Spatial correlation was detected in the dataset of eight individuals. This was most likely due to the fact that a large number of individuals returned to a core use area more than once. Returning to core use areas inflated home range estimates and thus, led to spatial autocorrelation as stated by Row and Blouin-Demers (2006) and Hart et al. (2015). Results show there was no difference in home range between males and females for MCP 95% and MCP 50% (ANOVA, p = 0.618; ANOVA, p = 0.064) or KDE 95% and KDE 50% (ANOVA, p = 0.899; ANOVA, p = 0.073) (Figure 3). Additionally, there were no significant differences in home ranges between treatment groups for MCP 95% (ANOVA, p = 0.121), MCP 50% (ANOVA, p = 0.107), or KDE 50% (ANOVA, p = 0.223). However, a significant difference was detected among group home ranges for KDE 95% (ANOVA, p = 0.049) (Figure 4).

A Tukey post hoc detected there was a significant difference in home ranges between snakes that were translocated from aviaries and snakes that were returned to original point of capture for KDE 95%. (Tukey, p = 0.043) (Figure 4). Comparison maps of group home ranges were made for visual comparison (Figure 5) as well as individual home range maps that include MCPs and KDEs (Figure 6).

Movement

Rayleigh's test determined that all but one snake's (#260) movements were random, or non-uniform (Table 1). Rao's Spacing test determined that all snake movements were not uniform, with the exception of #141, whose movement behavior at Arcadia Lake displayed non-random, or uniform data and differed from that observed at the Oklahoma City Zoo and Camp Trivera. Total movements ranged from 1345.41 m to 15,326.51 m. No differences were detected in total movements (ANOVA, p = 0.355) or average daily movements (ANOVA, p = 0.886) between sexes (Figure 7). No significant differences were detected in total movement (ANOVA, $p = 0.283$) or average daily movements (ANOVA, $p = 0.329$) (Figure 8) among the 3 treatment groups. Movements of individuals were also recorded and mapped for visual reference (Figure 9).

Effects of Translocation

Translocation effects were minimal as most snakes (excluding #062 and #202) were successfully located with each tracking event and were shown to survive overwintering. Most snakes (excluding #062 and #202) returned to the zoo and established a home range within the zoo. Snakes that established home ranges outside of the zoo also survived translocation events and overwintering. This suggests that there were minimal, if any, adverse effects of translocation on radio transmittered black rat snakes.

DISCUSSION

Home Range

Over half of the sample for this study returned to the zoo shortly after being translocated and also retained smaller home ranges. Snakes that didn’t return to the zoo included individuals #062, #020, #202 and #340. These results contradict the findings of Butler et al. (2005) and Lee and Park (2011), where translocated snakes exhibited roughly 6 times the home range size of resident snakes. Sex and treatment also did not seem to have a significant effect on home range or movement. These results contradict findings from Weatherhead and Hoysak (1988) where males tended to move farther and had larger home ranges than females. Duration of study, geographical location, and sample size differences among the studies may have been an underlying cause to the contrasting results.

Kernel density estimators and MCP's were used to approximate the size of home ranges in black rat snakes. Both KDEs and MCPs were used to estimate black rat snake home ranges, which resulted in inflated home ranges in some cases due to snakes revisiting several core-use areas. Additionally, this study's home ranges of male black rat snakes were smaller than those of females, which differs from the findings of Weatherhead and Hoysak (1989) and Klug et al. (2011). However, these results were consistent with findings of Johnson (2000), where non-gravid females had significantly larger home ranges than males. Row and Blouin-Demers (2006) reported that measurements using kernels can be unevenly distributed when using LSCV to select for the smoothing factor. Their results suggested that site fidelity induced autocorrelation influenced KDE size, with KDEs being drastically larger and more variable than MCP values. Conversely, results from my study had smaller KDE values when compared to MCP values.

There was a significant difference between treatment group 1 (snakes that were translocated from aviaries) and treatment group 3 (snakes that were returned to original point of capture). Three individuals (#020, #181, and #202) belonging to group 1 had larger home ranges, thus increasing overall home range size for that treatment. Food resources and hibernacula outside of the zoo may have been more widely dispersed which may have contributed to larger home range estimates. The larger spatial scale outside of the zoo may have influenced the sparsity of prey items, also contributing to larger home ranges as well. For example, food resources for the snakes will be more concentrated within the zoo grounds. All individuals that returned to the zoo had smaller home ranges, regardless of group. One explanation to this is that there are numerous artificial structures as well as high vegetation that can be used for cover at the zoo. Additionally, food resources are plentiful, suggesting that snakes within the zoo need not utilize larger home ranges to thrive.

Movements

Despite having a moderate power capable of rejecting the null hypotheses (which indicate random movement and non-uniform distribution), Rayleigh's and Rao's movement tests mostly failed to reject the null hypotheses. This might be because of the small sample size of black rat snakes captured. All movements except one snake (#260) were considered random by Rayleigh's test. Rao's Spacing test determined that all snake movements were random with the exception of #141. These findings reflect the fact that #141 was able to cross the lake twice and preyed on the same aviary twice. Movement data was still being collected during this event, which may have influenced movement results. Although not significant, females moved more than males, both for total movements and for average daily movements. In some cases, it was clear that foot traffic played a role in influencing the movement of black rat snakes. Construction zones within OKCZ produced heavy human activity, suggesting that anthropogenic activity was the cause for snakes moving that had resided in that area for weeks prior. Conversely, new installments of exhibit structures provided excellent cover and hibernacula for some, suggesting that construction didn't deter them. Zoo grounds may have high concentrated prey resources, negating the need for long bouts of travel for food, whereas, food resources outside of the zoo grounds should have less concentrated prey items, encouraging longer bouts of travel.

Effects of Translocation

Out of 15 snakes that were tracked, 3 are believed to have disappeared or have died. There was no movement recorded for almost a year for #260, whose last location was near a drain in the rhino exhibit. This may indicate that the cause of death may be structurally related and not necessarily related to translocation. Two other snakes (#202 and #062) were not located since August 10, 2020 and May 16, 2021, respectively. All other snakes were continuously tracked through winter seasons and left no indication of mortality or changes in behavior. Because of the short-term nature of this study, it is believed that no mortality would occur from translocation alone, especially since most translocated snakes were able to navigate their way back to the zoo. One individual (#141) had to be translocated further to Arcadia Lake due to repeated predation on aviaries. Over winter tracking determined that she was still moving and utilized resources found within her new home range at the lake. All snakes, except for two missing individuals, were located, retrieved, and had the transmitters removed. Following the 2 day recovery period, they were released back at Camp Trivera and Arcadia Lake.

Two individuals, # 202 and # 062 disappeared shortly after being released. Black rat snakes are generalist species, which display behavior that enabled them to survive past the 2021 tracking season. However, results from a 6-year study by Weatherhead and Blouin-Demers (2004) suggested that transportation, risk of infections, and disturbances by researchers may have negative impacts on survival of radio transmitted snakes. Snakes in this study were only tracked for two years, possibly reducing risks of negative impacts by reducing the time that snakes were exposed to the transmitters. Additionally, this study’s results contradict findings by that of Lee and Park (2011), and Butler et al (2005) which found that translocated snakes increased both movements and home ranges after initial translocation.

This study's results suggest that translocation doesn't seem to be effective unless snakes are moved distances greater than 260 m. The individual with the tag ID #141 had to be translocated further away due to repeated predation on aviaries, despite being initially translocated away from the zoo. At the time of retrieving snakes for transmitter removal, #141 hadn't returned to the zoo. However, she was found in good condition, further supporting the notion that translocation may not harm this species of snake.

Limitations

Foot traffic and heavy construction at OKCZ and at Camp Trivera may have influenced the movements of black rat snakes during the study making them more difficult to track and locate. There were instances where snakes had found paths beyond construction zones where access wasn't possible. Additionally, days of adverse weather such as thunderstorm and heavy rains also limited time spent in the field.

Some other factors also made retrieval of snakes difficult. During the summer of 2022, snakes took refuge deep within crevices of rocks, foundational structures, and in the canopies of trees within the OKCZ. Activity patterns had become more nocturnal, a means of avoiding exceptionally hot temperatures of the day. Tracking continued until the weather cooled down. Cover boards were laid down that following fall to increase chances of recapture for transmitter removal.

Conclusion

In sum, home ranges differed neither between sex or among treatments, with the exception of home range estimates between snakes translocated away from aviaries and snakes returned to original point of capture for KDE 95%. Movement also did not differ significantly between treatments or sex. Black rat snakes seem largely unaffected by translocation, as most returned to familiar areas within the zoo. Being generalists, radio tagged black rat snakes were found to thrive in translocated areas prior to returning to the zoo. Additionally, the individual translocated to Arcadia Lake also survived overwintering and was successfully returned to the new home range after transmitter removal. Prolonged use of transmitters was not evaluated but have been known to have adverse effects on black rat snakes (Weatherhead and Blouin-Demers 2004). With the relatively short duration of this study, coupled with minimizing disturbances upon locating the snakes, adverse transmitter effects were believed to be avoided or at least drastically reduced. Snakes returning to the zoo were last located at Camp Trivera approximately 2-3 days before being located again on zoo grounds. It is difficult to pinpoint when snakes moved or which path was taken to reach the zoo. Translocation distances of 260 m or less are not sufficient for keeping black rat snakes away.

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APPENDIX

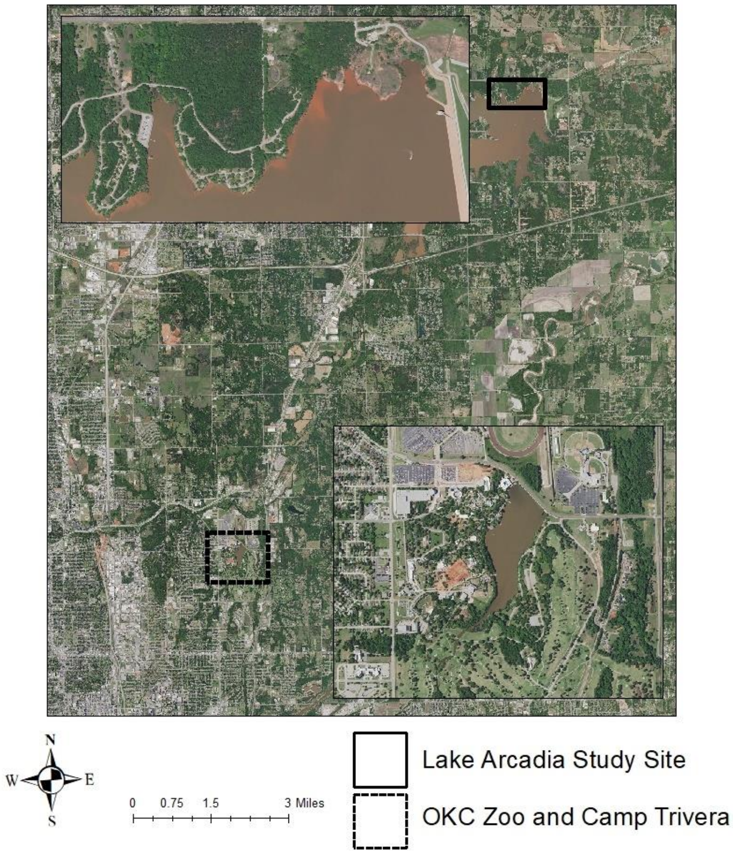


Figure 1. Map of study sites within Oklahoma County where snakes were captured, released, and monitored from June 1, 2020 to October 1, 2021. The solid box indicates the portion of Arcadia Lake that served as the study site. The dashed box encompasses the Oklahoma City Zoo and Camp Trivera properties, where snakes were captured and released.

Figure 2. Oklahoma City Zoo (outlined in red to the left) and Camp Trivera (outlined in green to the right) were the primary sites for black rat snake capture and release from June 1, 2020 to October 1, 2021.

Tag	Sex	Treatment	Rayleigh's Mean Directionality Test	Rao's Spacing Test	Run's Test on Directional Change	Total Line Length (m)	Average Movement Length (m)	MCP 95%	MCP 50%	KDE 95%	KDE 50%	Autocorrelation
20	male	1	random	random	not random	15326.5	31.40	21.93	5.83	2.57	0.14	yes
40	female	2	random	random	not random	8233.74	21.73	2.84	0.32	0.32	0.007	yes
62	male	3	random	random	random	2205.09	24.77	3.27	0.23	0.12	0.005	no
82	male	2	random	random	random	4708.26	16.35	9.71	0.092	0.45	0.06	yes
121	male	3	random	random	not random	2650.99	15.68	5.19	0.2	0.29	0.01	no
161	female	3	random	random	random	3469.18	12.754	2.11	0.15	0.17	0.007	yes
181	female	1	random	random	not random	9011.47	25.10	13.72	1.77	2.83	0.04	yes
202	female	1	random	random	random	1345.41	21.70	3.72	0.28	0.17	0.003	no
221	female	2	random	random	not random	3956.16	31.94	6.77	0.33	0.67	0.02	yes
240	female	3	random	random	not random	5115.42	20.96	7.65	0.6	0.36	0.01	no
260	female	3	not random	random	random	3411.31	17.95	4.19	1.09	0.09	0.002	no
300	male	2	random	random	not random	2878.29	13.77	11.08	0.59	0.31	0.01	no
320	female	2	random	random	not random	3863.85	21.71	8	0.72	0.25	0.004	no
340	male	1	random	random	random	2802.51	22.60	5.71	0.57	0.2	0.004	no
379	male	3	random	random	not random	5214.66	25.19	3.15	0.4	0.29	0.01	yes
141arc	female	2	random	not random	random	2314.00	37.93	26.05	0.69	1.01	0.06	no
141zoo	female	2	random	random	not random	4922.15	28.95	17.75	1.19	0.75	0.05	yes

Table 1. Identification and sex have been listed above, as well as the treatment assigned to the corresponding individual snake. Three tests (Rayleigh's, Rao's, and Runs) were used to detect non-uniform or randomness of the movement data (Table 1). Rayleigh's test and Rao's test indicated all but one snake showed random, or non-uniform data distribution. Runs test showed that 8 individuals exhibited uniform changes in directionality and 5 individuals exhibited non-uniform changes in directionality during movements. Both uniform and non-uniform data was collected for individuals #141 and #082/#121. Total movement and average daily movement were also recorded. Home range estimates for KDEs and MCPs are listed for individual snakes. Home range estimates include values for MCP 95%, MCP 50%, KDE 95%, and KDE 50%. Instances of spatial autocorrelation for each snake was also recorded.

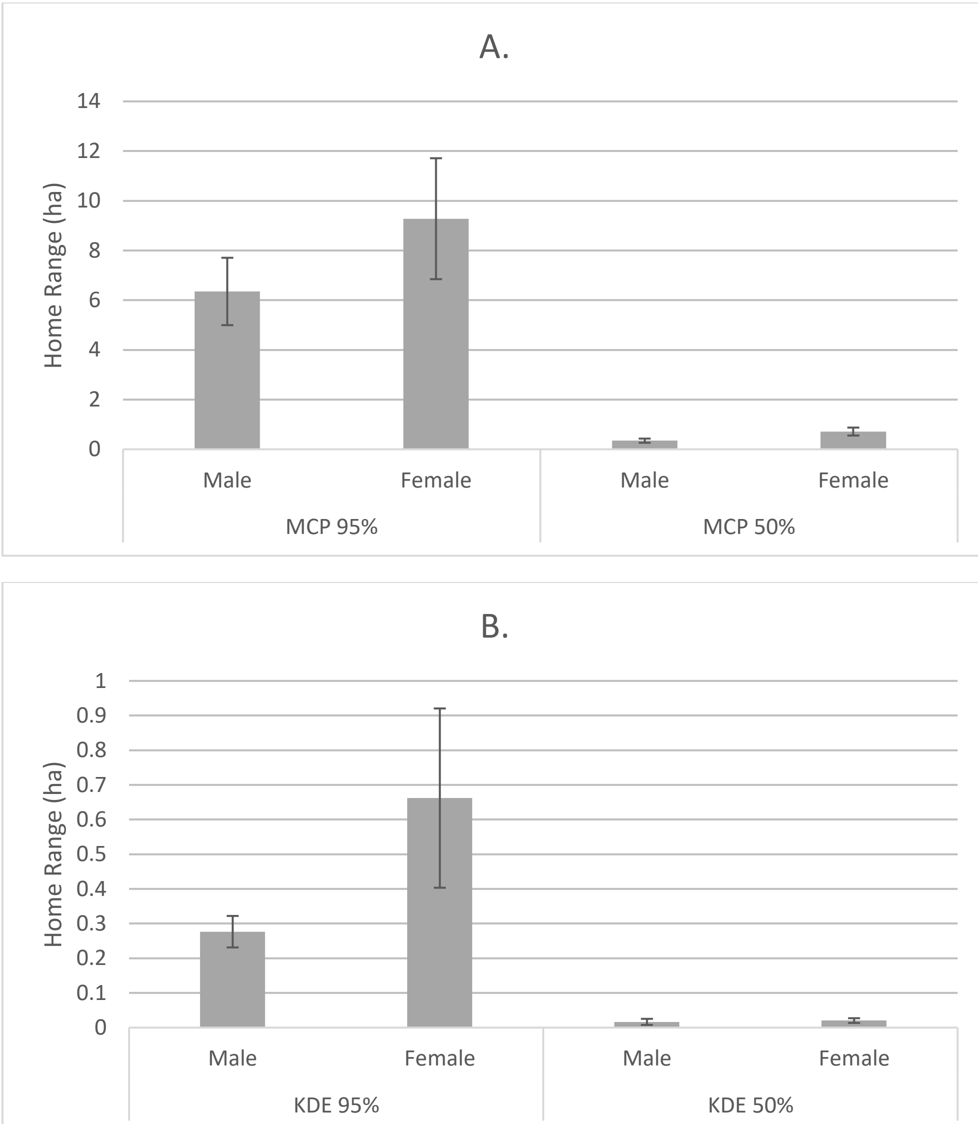


Figure 3. Figure 3 shows interactions between sex and home ranges: A.) MCP 95% and 50% home range sizes for male (+- 1.35 SE, 0.084 SE) and female (+-2.43 SE, +- 0.16 SE) black rat snakes are reported. B.) Mean KDE 95% and 50% home range sizes for male (+- 0.045 SE, +- 0.0087 SE) and female (+- 0.25 SE, +- 0.0068 SE) black rat snakes are also reported.

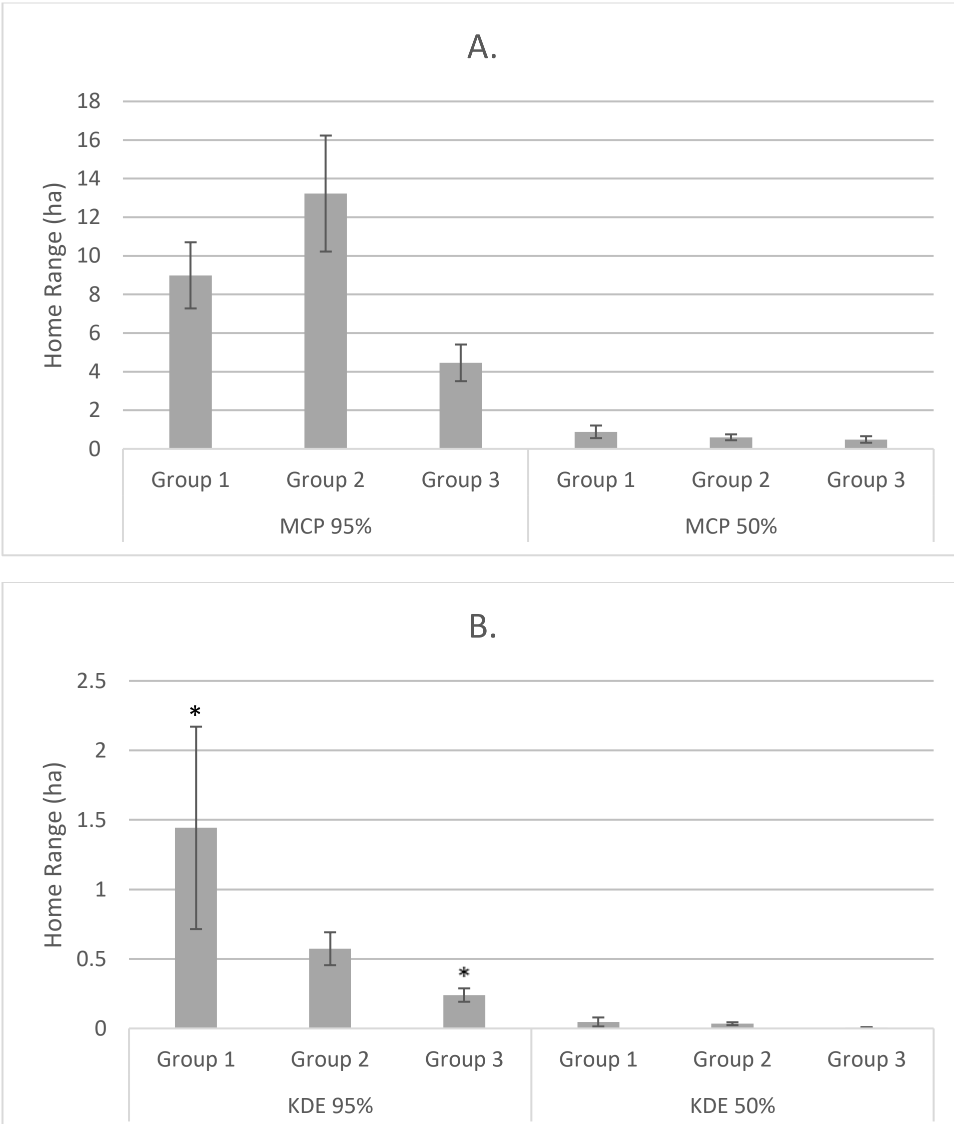


Figure 4. A.) No statistical differences were detected in home ranges among all three groups for MCP 95% (ANOVA, $p = 0.121$) and MCP 50% (ANOVA, $p = 0.107$). B.) There was no significant differences between home ranges among groups at KDE 50% (ANOVA, $p = 0.223$). There was, however, significant differences in home ranges between snakes translocated from aviaries (group 1) and snakes released at the original point of capture (group 3) for KDE 95% (ANOVA, $p = 0.49$; Tukey, $p = 0.043$). Asterisks denote the significant differences in groups for KDE 95%.

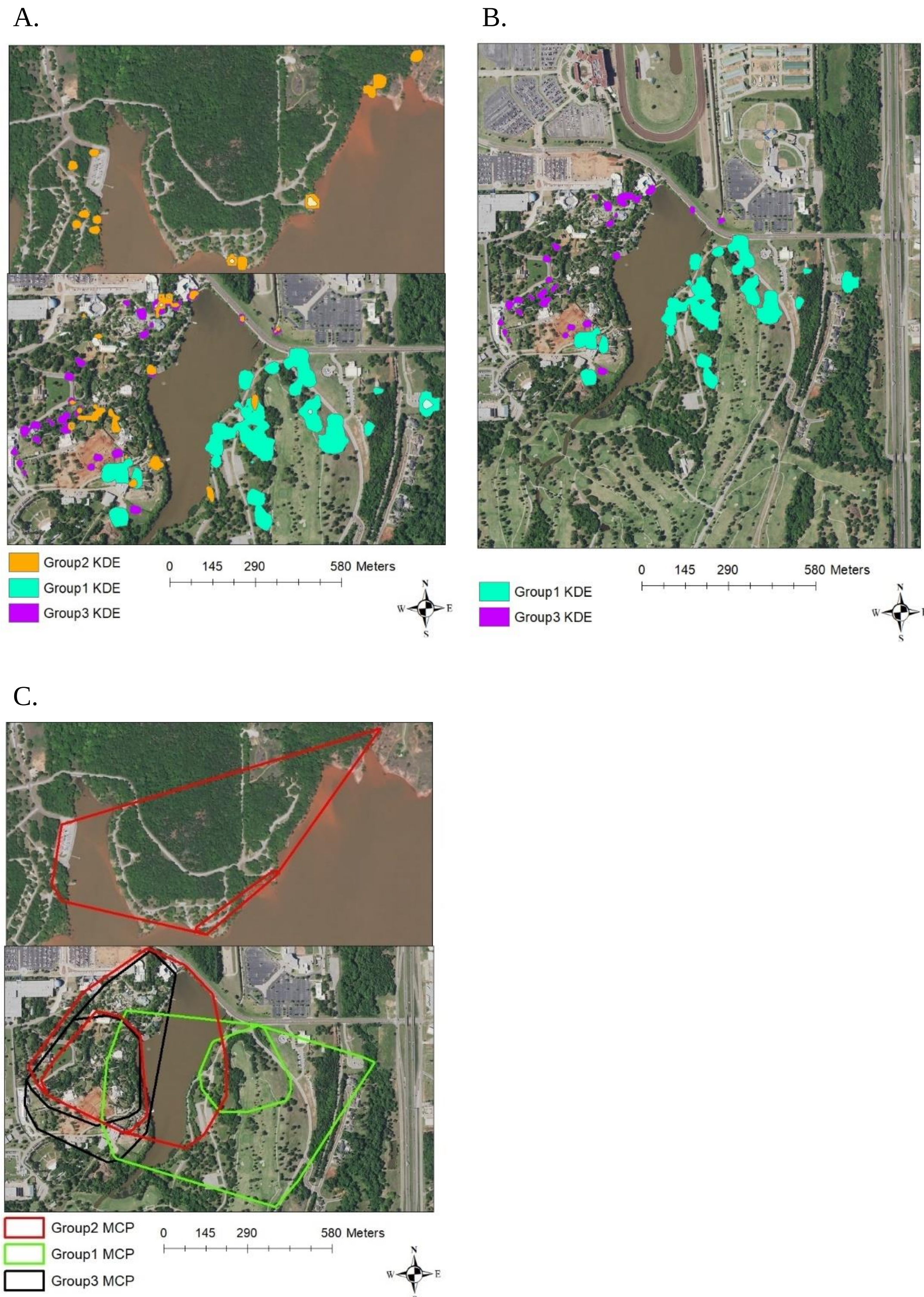
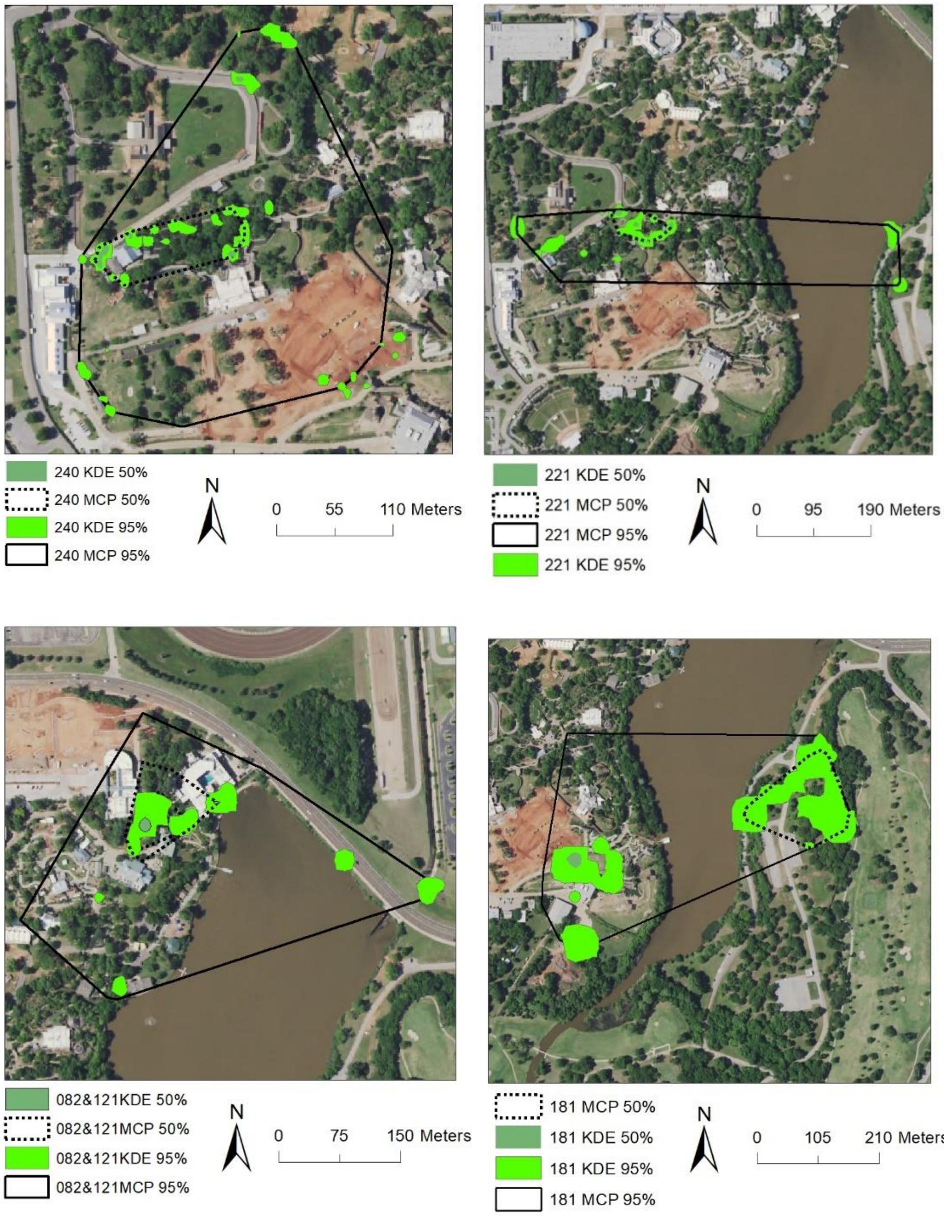
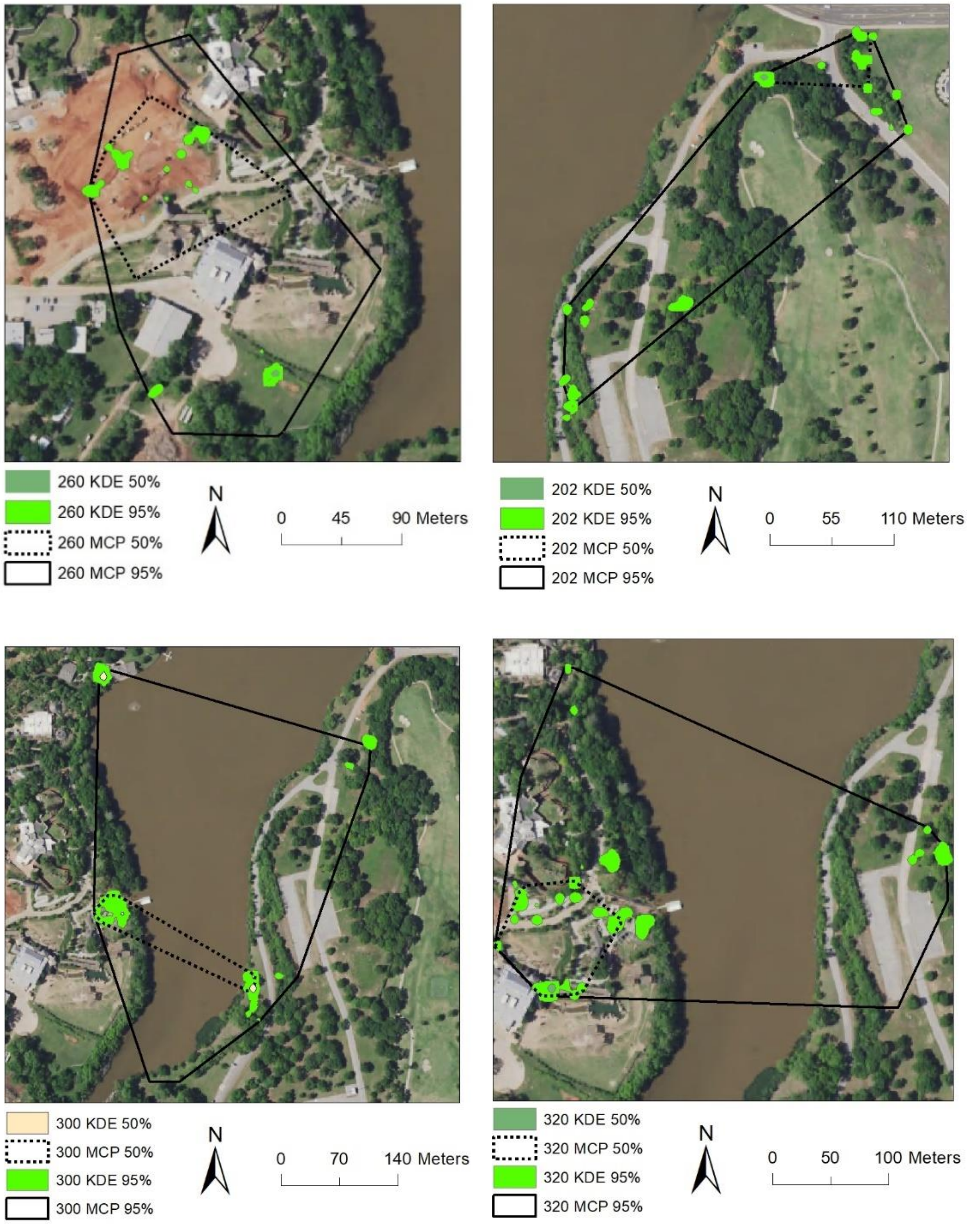
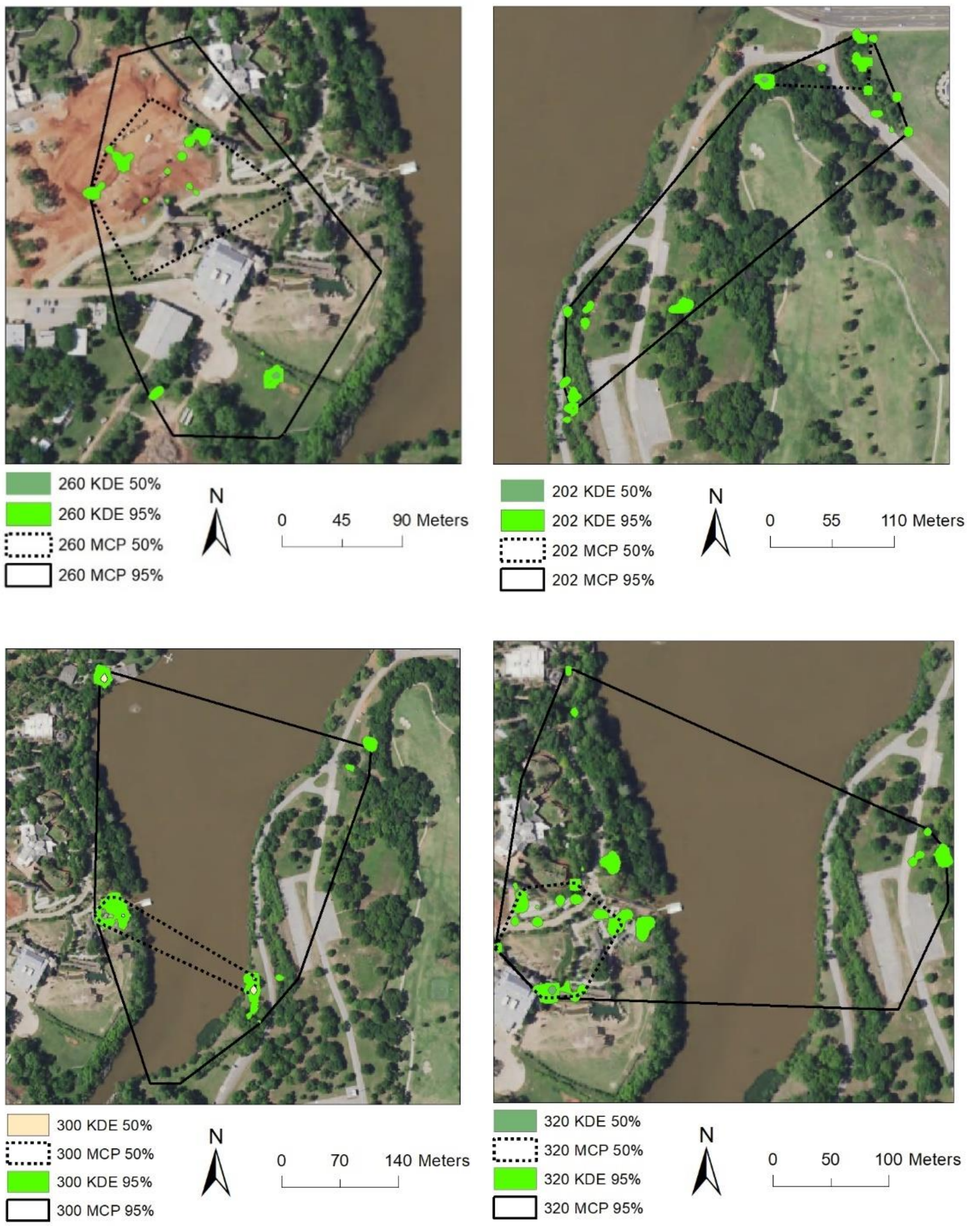


Figure 5. Figure five lists three maps where group home ranges are compared and expressed as both KDEs and MCPs: A.) all kernel density home ranges are expressed. It features both KDE 95% and 50% (ANOVA, p = 0.49; ANOVA, p = 0.223) for home ranges found at the Arcadia Lake, Camp Trivera, and OKCZ. B.) Comparison of group home ranges for KDE 95% are visualized where significant differences between translocated snakes and snakes returned to

point of capture were detected (Tukey, p = 0.043). C.) A visual representation of the different groups using MCPs. Both larger and core home range uses are interpreted. There was no significant difference in home range sizes detected among groups for MCP 95% or MCP 50% (ANOVA, p = 0.121, ANOVA, p = 0.107).


240 KDE 50%
240 MCP 50%
240 KDE 95%
240 MCP 95%
N
0 55 110 Meters
221 KDE 50%
221 MCP 50%
221 MCP 95%
221 KDE 95%
N
0 95 190 Meters
082&121KDE 50%
082&121MCP 50%
082&121KDE 95%
082&121MCP 95%
N
0 75 150 Meters
181 MCP 50%
181 KDE 50%
181 KDE 95%
181 MCP 95%
N
0 105 210 Meters


260 KDE 50%
260 KDE 95%
260 MCP 50%
260 MCP 95%
N
0 45 90 Meters
202 KDE 50%
202 KDE 95%
202 MCP 50%
202 MCP 95%
N
0 55 110 Meters
300 KDE 50%
300 MCP 50%
300 KDE 95%
300 MCP 95%
N
0 70 140 Meters
320 KDE 50%
320 MCP 50%
320 KDE 95%
320 MCP 95%
N
0 50 100 Meters


260 KDE 50%
260 KDE 95%
260 MCP 50%
260 MCP 95%
N
0 45 90 Meters
202 KDE 50%
202 KDE 95%
202 MCP 50%
202 MCP 95%
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0 55 110 Meters
300 KDE 50%
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320 KDE 95%
320 MCP 95%
N
0 50 100 Meters

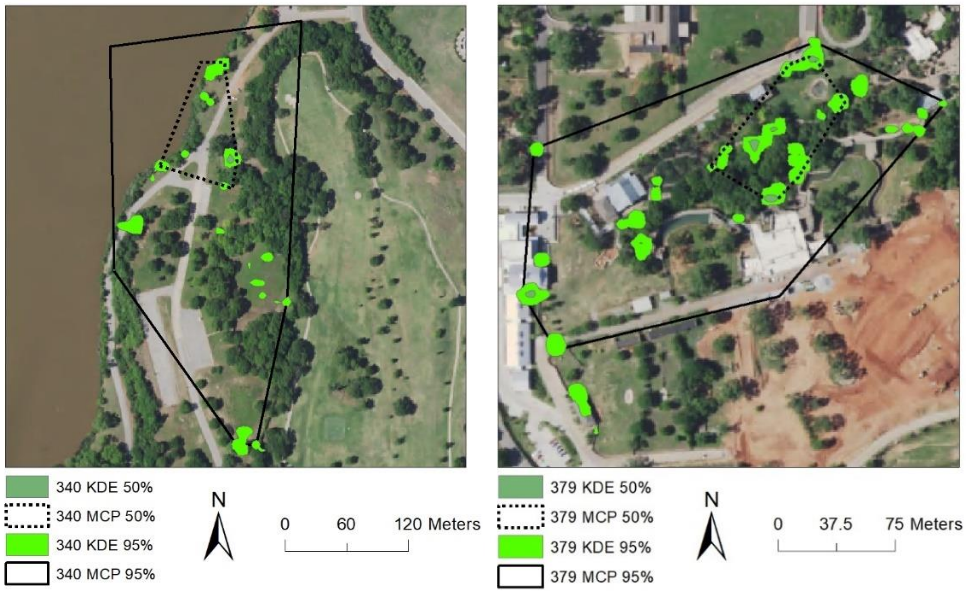


Figure 6. Individual home range maps for black rat snakes consisting of both KDEs and MCPs were created for visual comparisons. An additional map was made for #141 because it was moved from the OKCZ to Arcadia Lake. Tag identification for individuals were included for convenience.

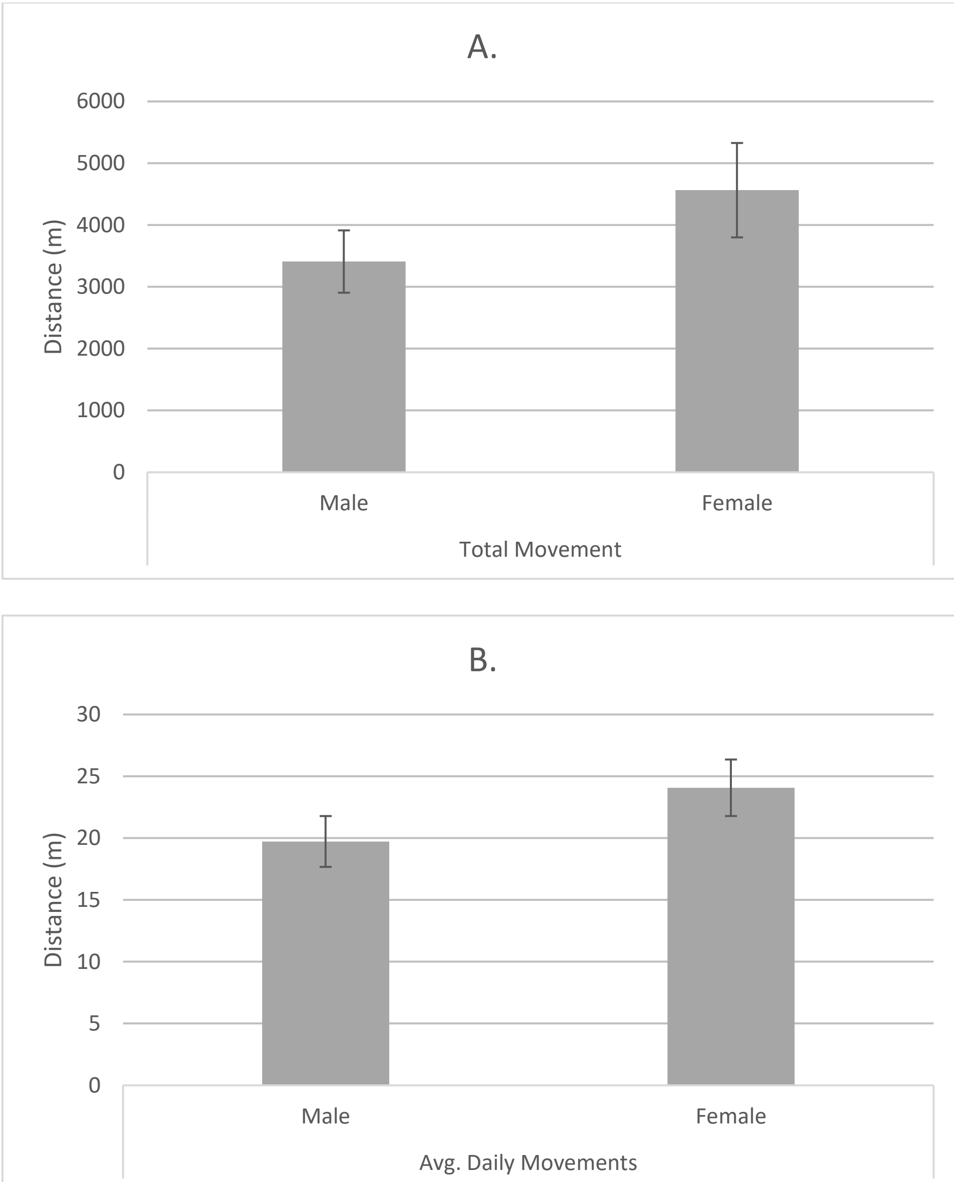


Figure 7. Both total movements and average daily movements were compared across sexes. A.) There was no significant differences between males and females for total movement (ANOVA, $p = 0.355$). B.) There were no significant differences detected between male and female for average daily movements (ANOVA, $p = 0.886$).

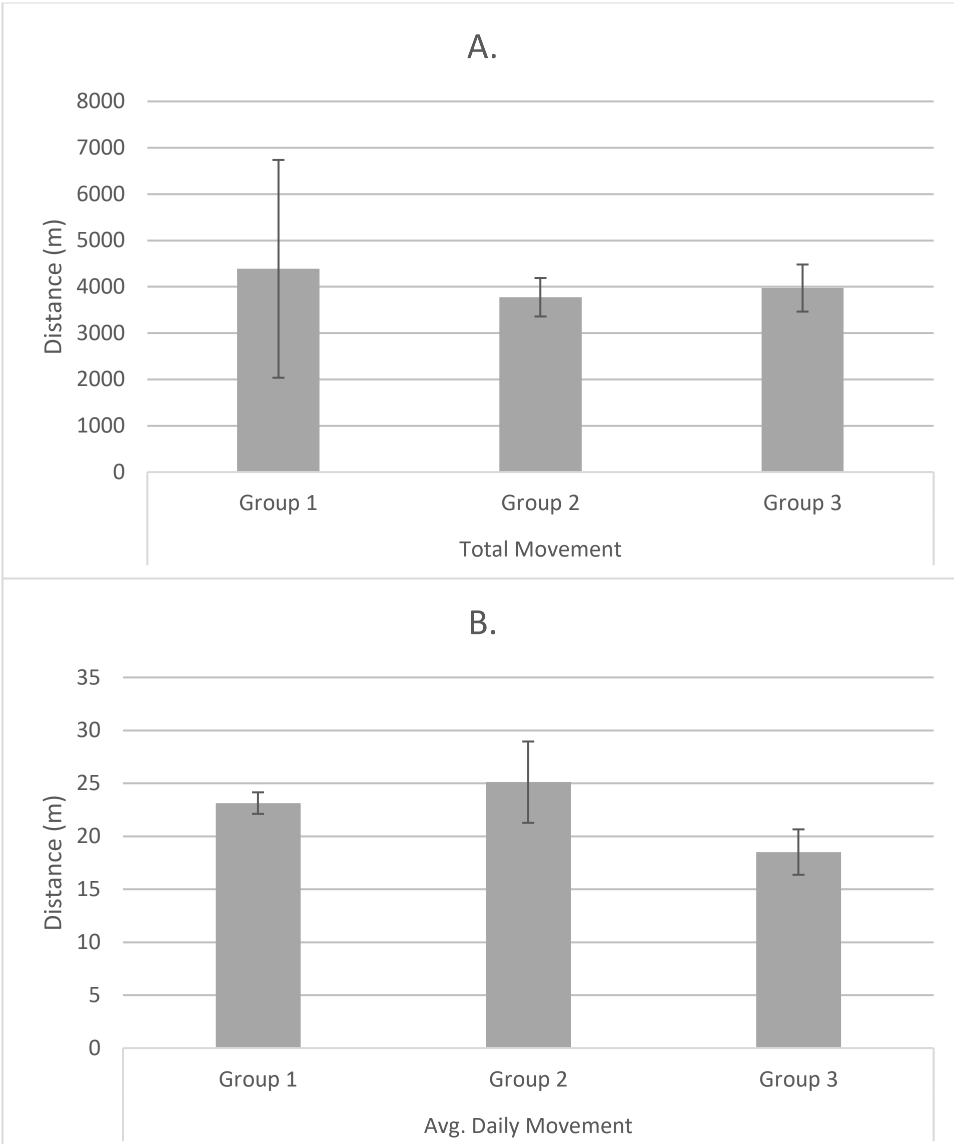
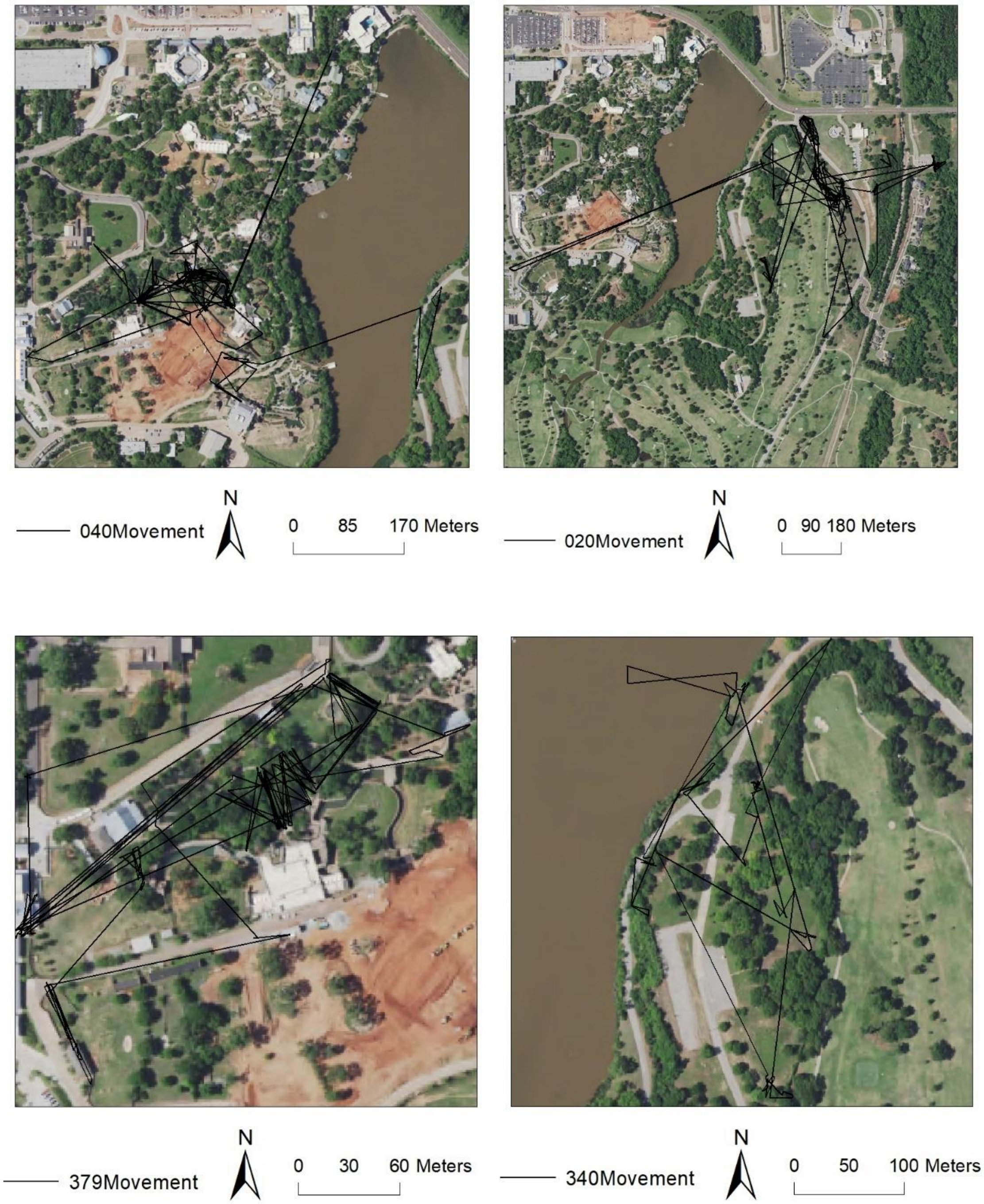
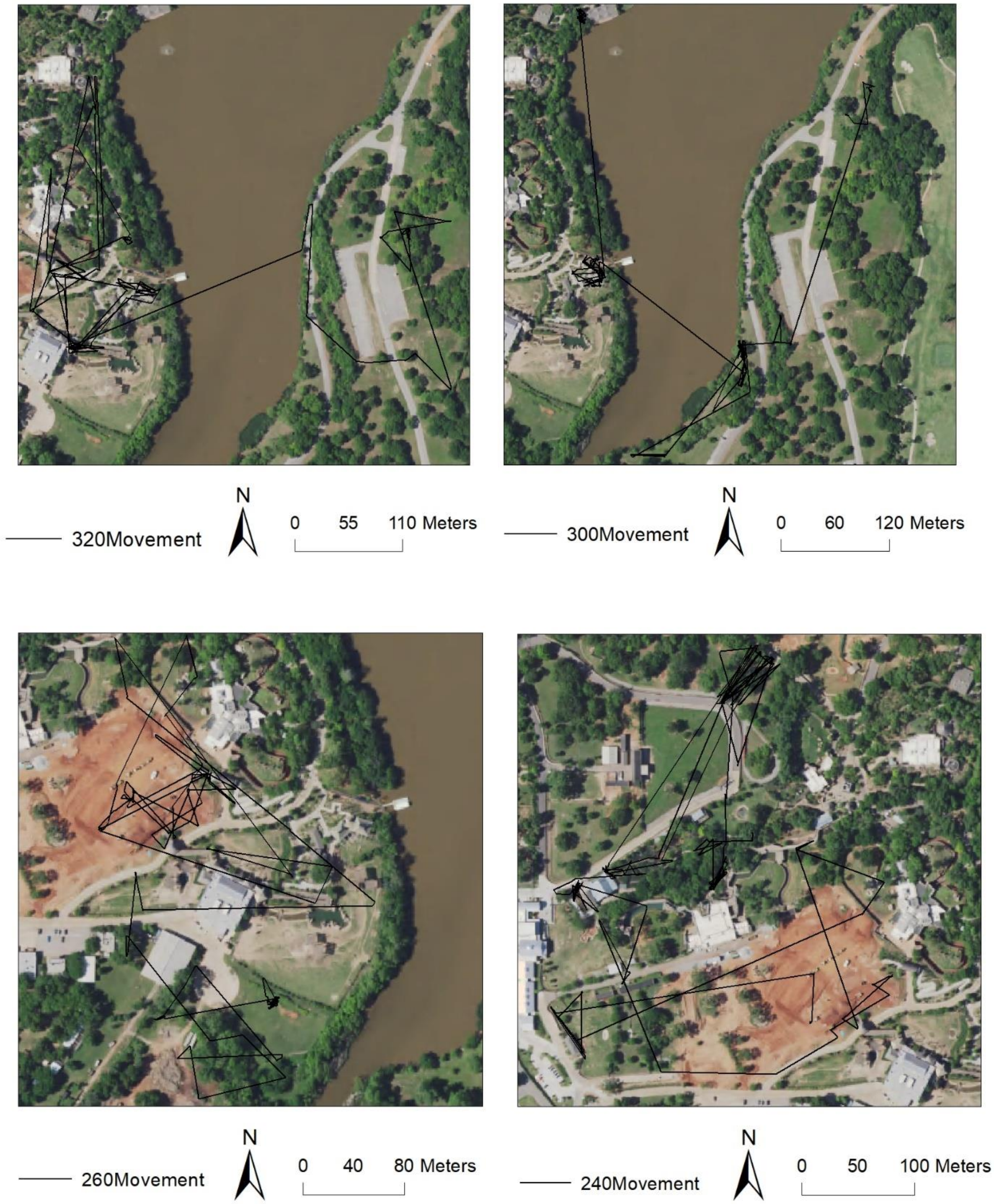
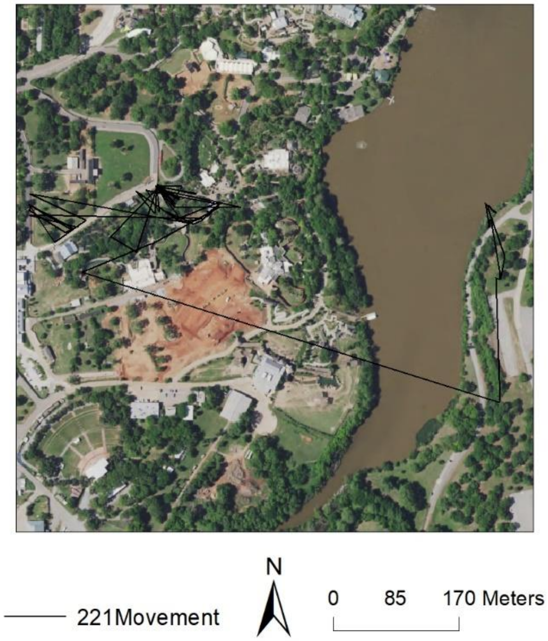


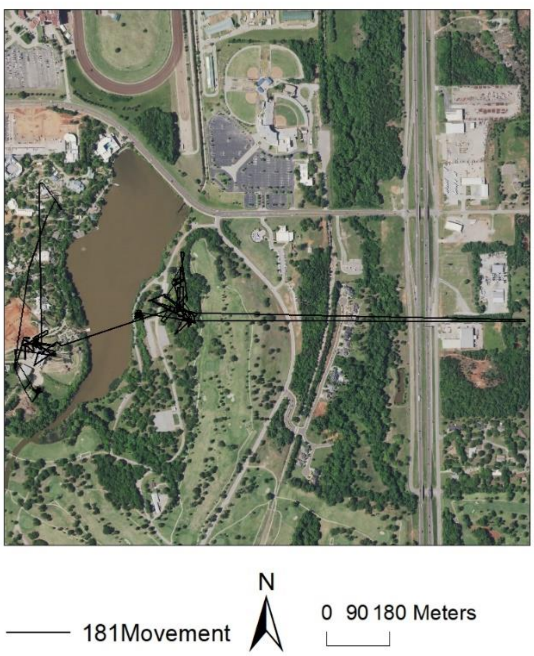
Figure 8. Movements were compared among the three groups. A.) There was no significant difference detected in total movements among the three groups (ANOVA, p = 0.283). B.) Additionally, no significant differences were detected among groups for average daily movements (ANOVA, p = 0.329).

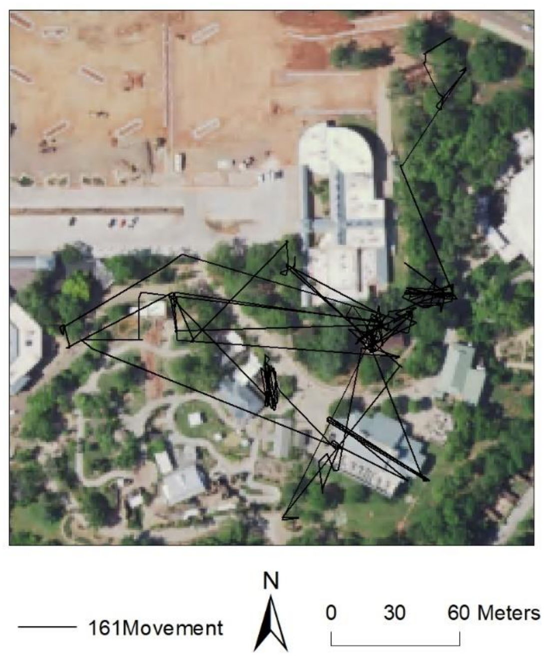

040Movement
N
0 85 170 Meters
020Movement
N
0 90 180 Meters
379Movement
N
0 30 60 Meters
340Movement
N
0 50 100 Meters

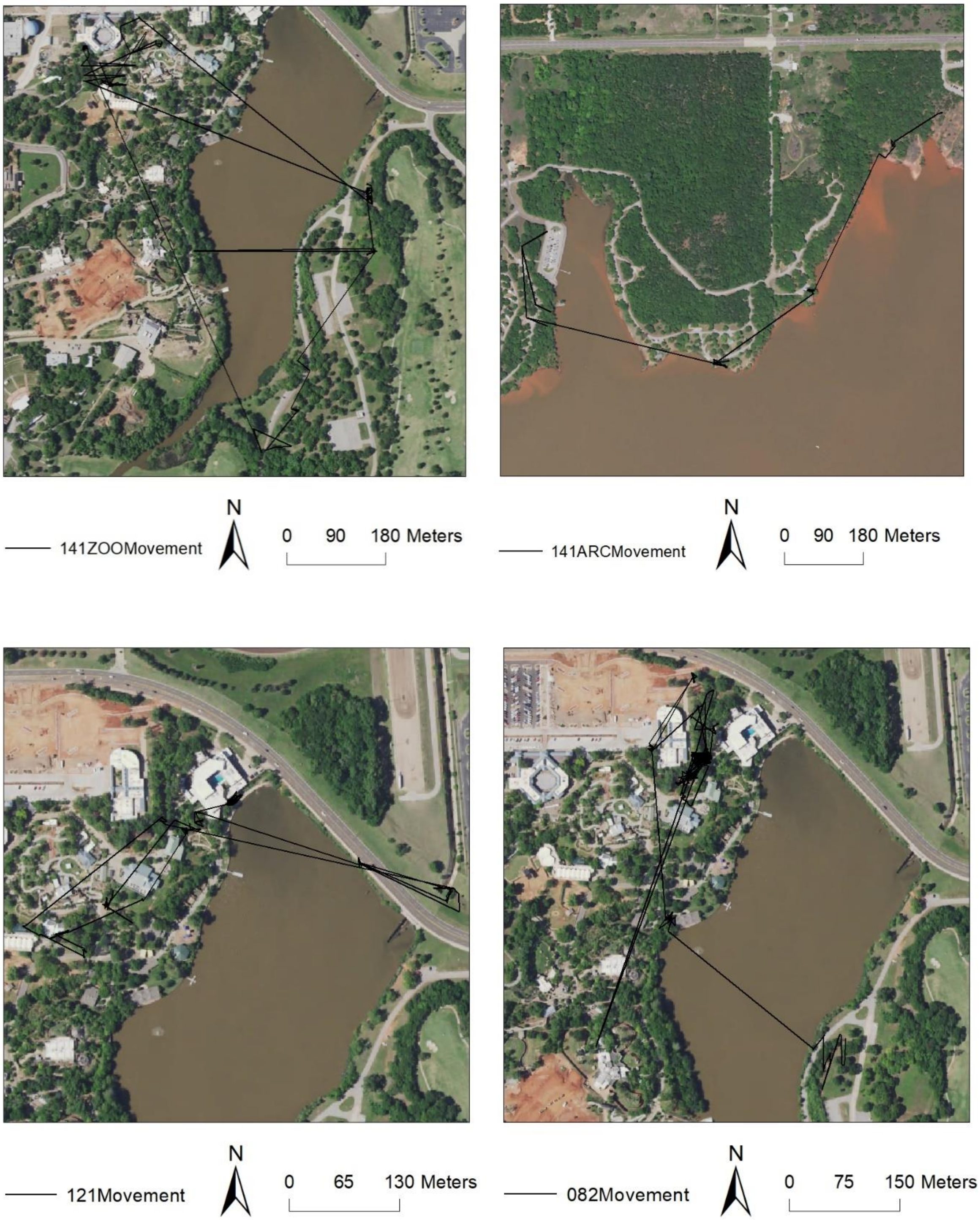

320Movement
N
0 55 110 Meters
300Movement
N
0 60 120 Meters
260Movement
N
0 40 80 Meters
240Movement
N
0 50 100 Meters


221Movement
N
0 85 170 Meters


202Movement
N
0 45 90 Meters


181Movement
N
0 90 180 Meters


161Movement
N
0 30 60 Meters


141ZOOMovement
N
0 90 180 Meters
141ARCMovement
N
0 90 180 Meters
121Movement
N
0 65 130 Meters
082Movement
N
0 75 150 Meters

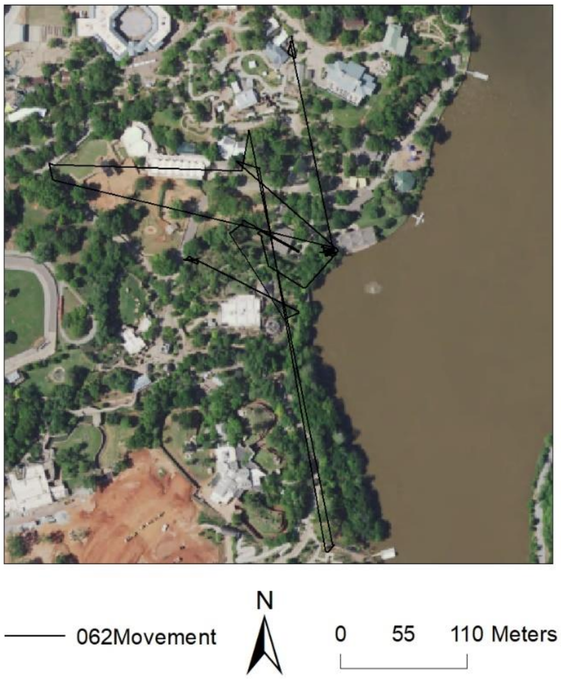


Figure 9. These maps mark the movements of individual black rat snakes tracked from June 1, 2020 through October 1, 2021 at OKCZ, Camp Trivera, and Arcadia Lake.