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Home Range Analysis of *Teratoscincus roborowskii* in the Turpan Basin, Northwestern China: Insights from VHF Tagging Technology

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Abstract. The home range of an animal encompasses the area utilized during activities such as foraging, mating, and other routine behaviors, with its size reflecting behavioral patterns and ecological niche. Factors influencing home range size include sex, body size, and diet, with sex and body size being the most significant determinants. The *Teratoscincus roborowskii*, or Turpan Wonder Gecko, is endemic to the Turpan Basin of Xinjiang, northwestern China, yet its home range during the breeding period remains understudied. This research employed radio-tracking methods to evaluate the home range of *T. roborowskii* during the breeding season, focusing on influences from sex and body size. Our study involved radio telemetry of 11 individuals from June to July in 2020 and 2021. We quantified total and core home range sizes using the minimum convex polygon (MCP) and kernel density estimation (KDE) methods. Results via MCP revealed total and core home range sizes of $7894.06 \pm 2672.87\ m^2$ and $4852.41 \pm 2045.55\ m^2$, respectively. Males exhibited larger home ranges than females; however, the difference was not statistically significant. A significant correlation was found between snout-vent length (SVL) and home range size, indicating that lizards with larger SVLs occupied larger home ranges, regardless of sex. This study provides critical insights into the activity range and influencing factors of *T. roborowskii* during the breeding period, contributing essential data for its conservation efforts.

Keywords. Kernel density estimation method, Minimum convex polygon, Radio-tracking, Movement ecology, Reproduction period

INTRODUCTION

Home range refers to the area traversed by an animal during natural activities such as foraging, mating, nurturing young, and other routine behaviors (Burt, 1943; Powell and Mitchell, 2012). It constitutes a critical habitat that offers essential shelter and food resources, with environmental conditions and potential mates being the primary resources of interest in most ecological studies (Kearney et al., 2018; Ryberg et al., 2019; Ariano-Sánchez et al., 2020; Renet et al., 2022; Ventura et al., 2022; Clement et al., 2022; Balouch et al., 2022). The size of the home range is often viewed as an indicator of the energetic and physiological needs or ecological niche of a species (Huey et al., 1989; Verwaijen and Van Darnme, 2008; Warner and Shine, 2008; Sillero et al., 2021; Kusaka and Valdivia, 2021; Zhong et al., 2021). Consequently, researchers have extensively investigated the relationships between various ecological factors and home range size across different lizard species (Huey et al., 1989; Perry and Garland, 2002; Salido and Vicente, 2019). However, to date, the home range characteristics of certain lizard species, such as *T. roborowskii*, remain poorly understood. This knowledge gap underscores the necessity for further comprehensive studies to elucidate the ecological, behavioral, and environmental factors influencing home range dynamics in these understudied species. Investigating *T. roborowskii* in particular could provide valuable insights into the adaptive strategies and spatial ecology of lizards inhabiting unique or extreme environments.

Several factors may influence the size of a lizard's home range. Larger-bodied lizards typically require greater distances to satisfy their energetic needs, thereby necessitating larger home ranges for effective foraging (Armstrong, 1965; Schoener, 1968; Turner et al., 1969; Perry and Garland, 2002; Garcia-Rosales et al., 2021; Zhao et al., 2022). Additionally, home range size can be influenced by foraging strategies and the specific types of prey available within the ecological hierarchy (Nunn and Barton, 2000; Mysterud et al., 2001). Furthermore, studies indicate that male lizards often exhibit larger home ranges than females during the breeding season, a phenomenon attributed to differences in mating behaviors (Mysterud et al., 2001; Aragon et al., 2001; Li et al., 2013; Ventura et al., 2022).

Two primary methods are employed to calculate home range: the Minimum Convex Polygon (MCP) method and Kernel Density Estimation (KDE). The MCP method is widely recognized for its ease of use and comparability across studies (anderson, 1982; Laver and Kelly, 2008). While it does not appropriately account for the unique distribution patterns of observations, it provides a straightforward description of the home range (Seaman and Powell, 1996). Conversely, the KDE method has gained favor for its ability to generate utilization distributions (UD) and assess the degree of home range overlap among individuals (Worton, 1995; Mitchell and Powell, 2004; Gitzen et al., 2006). This technique requires the careful selection of an appropriate bandwidth for calculating UD, with least squares cross-validation (hLSCV) and reference bandwidth (href) methods being common choices. The hLSCV method is often recommended due to its capacity for smoothness and fit, rendering it more suitable than the href approach (Powell, 2000; Gitzen et al., 2006).

Over the years, methodologies for recording animal occurrence locations have transitioned from labor-intensive techniques to automated systems (Harris et al., 1990; Kie et al., 2010; Cagnacci et al., 2010). Very High-Frequency (VHF) radio telemetry devices enable the real-time monitoring and recording of an animal's sequential locations (Harris et al., 1990; Mitchell and Powell, 2004; Marzluff et al., 2004; Moorcroft and Barnett, 2008; Williams et al., 2020). These devices incorporate transmitters that emit signals at specific radio frequencies, allowing tracking by nearby radio receivers. However, the use of VHF technology necessitates close proximity to the studied animals, which can interfere with their natural behavior and habitat use.

In this study, we aim to investigate the home range of *T. roborowskii* using Very High Frequency (VHF) telemetry. Additionally, we seek to examine whether sex and body size have a significant influence on the home range size of *T. roborowski*i. This research will contribute to a deeper understanding of the spatial ecology and behavioral patterns of this species, providing insights into the factors that may shape its habitat use and movement dynamics.

MATERIALS AND METHODS

Study site

The Turpan Eremophyte Botanical Garden (TEBG) is located in the southeastern part of the Turpan Basin in Xinjiang, China (89°11’ E, 42°51’ N). This garden is unique as the only botanical garden globally dedicated to the Asian desert plant subregion, situated at altitudes ranging from -105 to -76 meters. The TEBG experiences an arid continental climate, characterized by an annual minimum temperature of -9.5 °C and a maximum temperature of 49.6 °C. The annual effective accumulated temperature is 5454.5 °C, with approximately 3000 hours of sunshine per year. Annually, the area receives an average precipitation of 16.4 mm and maintains an average humidity of 41.0% (Yin, 2004). The garden is home to a diverse array of flora, encompassing over 200 plant genera and 60 families, including species such as *Tamarix spp*., *Calligonum spp*., *Capparis spinosa*, *Ammopiptanthus spp*., and various insect families including Formicidae, Carabidae, and Tenebrionidae. Additionally, notable populations of reptiles, mammals and birds inhabit the garden, such as *Phrynocephalus axillaris*, *Eremias velox*, *Eryx tataricus, Vulpes vulpes*, *Lepus tolai,,Hemiechinus auritus, Streptopelia decaocto*, and *Asio otus*..

Data collection using radio telemetry

June to July are the breeding periods of *T. roborowskii* (Li et al., 2013). The study was conducted during the of June to July in 2020 and 2021, a radio-telemetry survey was conducted to track a total of 13 individuals of the target lizard species, comprising 5 females, 7 males, and 1 juvenile. In 2020, 7 lizards (3 females and 4 males) were monitored, while 6 lizards (2 females, 3 males, and 1 juvenile) were observed in 2021. The lizards were manually captured and equipped with VHF transmitters (model: Lotek's CTx Connectivity VHF tags) weighing 0.9 g, representing less than 1% of the minimum body mass of the lizards. The transmitters were affixed to the lizards' dorsum using a back-loading method. The snout-to-vent length (SVL) of all captured individuals was measured using a vernier caliper, and sex was recorded.

Following their release, the lizards' positions (longitude and latitude) were tracked using a Lotek VHF biotracker equipped with a three-element BNC antenna. To mitigate the effects of temporal autocorrelation on home range estimations, a tracking schedule was established to record one GPS location within a 60-minute interval each day from 00:00 to 05:00 h, aligning with the active foraging period of the species during the night. Telemetry individuals were designated as F1-F6 for females, M1-M6 for males, and J1 for the juvenile. During the study, 230 effective location points for the lizards were recorded; however, less than five location points for individuals M5 and M6 could not be included in the home range model analysis (Fig. 1). Consequently, only 11 individuals were analyzed for home range results.

Data analyses

To determine the home ranges of the 11 individuals, we employed two methods: the Minimum Convex Polygon (MCP) and Kernel Density Estimation (KDE), utilizing the adehabitatHR package in R version 4.1.2 (R Core Team, 2019). The KDE method was selected due to its widespread application among researchers for home range estimation (Worton, 1995; Silverman, 1986). The 95% home ranges of the lizards were calculated using both the MCP and KDE methods, while the 50% home ranges were specifically derived from the KDE method. The 95% MCP and KDE probability contours represent the overall home range of the lizards, whereas the 50% MCP and KDE probability contours delineate the core area within their home range (Powell, 2000).

$$h_{(\mathrm{epa})} = 1.77\sigma n^{-\frac{1}{6}}$$

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

The KDE method for calculating the home ranges of the lizards relies on the bandwidth (h), the number of locations (n), and a unimodal bivariate probability density function (K) as described by Silverman (1986).

Seaman et al. (1999) recommended the least-squares cross-validation (LSCV) method for bandwidth selection in KDE. However, recent studies have indicated that the LSCV bandwidth may not be suitable for many lizard species. Consequently, we opted for the reference bandwidth (href), which offers improved fitting performance for small sample sizes. For the kernel function, we selected the Epanechnikov (epa) method, known for its ability to accurately fit multiple central areas and produce reliable results (Silverman, 1986). To facilitate comparisons with other studies, we also employed the MCP model. Additionally, we identified the activity centers for each individual using the KDE method (Bertrand et al., 1996).

Statistical analysis involved assessing the normality of the home range size and snout-vent length (SVL) variables using the Shapiro-Wilk normality test. The results indicated that home range size was not normally distributed ($W = 0.808$, $p = 0.018$). Consequently, we log-transformed the home range size and employed Fisher's F test to evaluate variance homogeneity. After confirming the normality and homogeneity of variance of the data, we utilized the Student's t-test to compare home range sizes and SVL between sexes. In cases where no significant difference in SVL was observed between the sexes, SVL data were combined to analyze the effect of gender on home range size. To assess the correlation between home range size and SVL, we calculated Pearson's correlation coefficient. It is important to note that for juvenile individual J1, we performed home range calculations without conducting further statistical analyses. All statistical analyses were conducted using R (R Core Team, 2019), and data are presented as Mean ± standard error (Mean ± SE). The significance level was set at $p \leq 0.05$.

RESULTS

During the survey period, we collected a total of 230 location points for the 11 lizards, yielding an average of 20.91 ± 2.36 points per individual. The 95% home range sizes for each lizard were calculated using both the Minimum Convex Polygon

(MCP) and Kernel Density Estimation (KDE) methods. The areas ranged from a minimum of 1182.72 m² to a maximum of 25669.02 m² for the MCP method, and from 4120.18 m² to 85977.76 m² for the KDE method. The mean total home range size for the lizards was 8567.79 ± 2859.55 m² as determined by the 95% MCP method and 28006.87 ± 8455.75 m² as calculated using the 95% KDE method. Furthermore, we identified the core area within the home range for each individual, finding mean core sizes of 927.80 ± 366.68 m² (50% MCP) and 4970.70 ± 1856.47 m² (50% KDE).

The results of the Student's t-tests indicated that male lizards exhibited larger home range sizes compared to female lizards. However, there were no significant differences in snout-vent length (SVL) between adult male and female lizards ($t = -0.858$, $df = 7.519$, $p = 0.418$). When different SVL categories were combined and sex was the sole consideration, no significant differences were observed between male and female lizards regarding total home range size as assessed by both the 95% Minimum Convex Polygon (MCP) method ($t = 1.410$, $df = 7.999$, $p = 0.1962$) and the 95% Kernel Density Estimation (KDE) method ($t = 0.344$, $df = 7.778$, $p = 0.740$). Similarly, for core home range size, no significant differences were found using the 50% MCP method ($t = 0.795$, $df = 7.128$, $p = 0.452$) or the 50% KDE method ($t = 0.1495$, $df = 7.577$, $p = 0.885$) (Fig. 2). Furthermore, all variables met the assumptions of normality and homogeneity of variance.

A correlation analysis was performed to investigate the relationship between snout-vent length (SVL) and home range size among individuals. The analysis revealed a significant positive correlation between the 50% Minimum Convex

Polygon (MCP) core areas and SVL, suggesting that individuals with greater SVL tend to occupy larger home ranges. In contrast, the results obtained from the Kernel Density Estimation (KDE) method did not demonstrate a strong correlation trend. This discrepancy may be attributed to the inherent variability associated with the KDE method, which can lead to fluctuations in the estimated home range sizes.

DISCUSSION

Our study revealed that the minimum home range of *T. roborowskii*, estimated using the Minimum Convex Polygon (MCP) method, was 1182.72 m^2, while the Kernel Density Estimation (KDE) method yielded a significantly larger estimate of 4120.18 m^2. These results are substantially greater than those previously reported using the mark-recapture method. For instance, Li et al. (2013) documented home range sizes of *T. roborowskii* as 337.37 $\pm$ 185.95 m^2 for males, 187.80 $\pm$ 90.09 m^2 for females, and 191.57 $\pm$ 52.4 m^2 for juveniles using mark-recapture. Such discrepancies between home range estimates derived from Very High Frequency (VHF) telemetry and mark-recapture methods are well-documented in ecological studies. The mark-recapture method is highly sensitive to the spatial configuration of the capture grid and the distance between capture points, which can lead to significant underestimation of home range sizes (Lira and dos Santos Fernandez, 2009). Additionally, repeated handling and tagging during mark-recapture studies may alter the natural behavior of the study animals, further biasing the results (Gurnell et al., 1989).

This methodological limitation has been consistently highlighted in previous research, with radio telemetry generally producing larger home range estimates compared to mark-recapture. For example, Sunquist (1987) and Bradshaw (2002) reported that radio telemetry yielded significantly larger home ranges for *Didelphis marsupialis* and *Tarsipes rostratus*, respectively. Similarly, Bergstrom et al. (1988) found that radio telemetry estimates for chipmunks' home ranges were six times greater than those obtained through mark-recapture. Comparable patterns have been observed in studies of lizards, where radio telemetry generated home range sizes four to five times larger than those estimated via mark-recapture (Tisell et al., 2019). These findings underscore the importance of methodological considerations in home range studies and suggest that VHF telemetry provides a more accurate representation of spatial ecology, particularly for species with wide-ranging movements or complex habitat use patterns.

Adult sexual dimorphism in lizards is categorized into three types: (1) males larger than females, (2) females larger than males, and (3) no significant size difference between sexes (Powell and Russell, 1985). Generally, larger lizards require more extensive home ranges to meet their energy demands, thereby securing food resources and obtaining a competitive edge in mating scenarios. T. roborowskii falls into the third category, exhibiting no substantial size disparity between sexes, aside from males having a significantly broader head width than females (Harestad and Bunnell, 1979; Liu et al., 2010). The absence of a significant difference in home range size between sexes may stem from the negligible differences in body size and reproductive investment. Male lizards often overlap their home ranges with multiple females as a strategy to maximize reproductive success. During the breeding season, increased territoriality in males, coupled with the reproductive behaviors that elevate movement and survival costs for females, further complicates home range dynamics (Utsumi et al., 2022; Payne et al., 2022; Zhao et al., 2022). This study found that larger individuals of *T. roborowskii* tended to occupy more expansive home ranges, with males exhibiting larger home ranges than females, likely attributable to the inconsequential differences in body size and reproductive effort between the sexes (Liu, 2010). Previous research corroborates these findings; for instance, male *Leiolepis reevesii* displayed significantly larger home ranges than females, and a positive correlation was noted between home range size and snout-vent length (SVL) ($n=10$, $r=0.815$, $P=0.004$). Although both males and females displayed intrasexual territoriality, females exhibited significantly higher territoriality than males (Yang et al., 2019). In another study, the home range of male *Phrynocephalus vlangalii* was reported to be 7.6 times larger than that of females, independent of SVL (Wang et al., 2004). Similarly, male *S. crocodilurus* demonstrated a significantly larger linear home range compared to females, with no apparent influence from body weight. Gender and age emerge as significant factors influencing home range dynamics, as both sexes display territorial behaviors (Qing, 2019). Furthermore, artificially elevated testosterone levels in *Uta stansburiana* have been shown to significantly increase home range size and territoriality (Denardo et al., 1994).

Silverman et al. (1986) assert that bandwidth selection considerably impacts the

KDE method's outcomes. Seaman and Powell (1996) recommend utilizing least squares cross-validation (hLSCV) as the bandwidth selection technique for KDE fitting. However, our findings indicated that employing hLSCV with small sample sizes resulted in excessive smoothness and overestimation of home range sizes, leading to fragmented home range representations, particularly in individuals with multiple activity centers and clustered distributions. For example, the smoothing value for individuals M1 (Loci=26) and A1 (Loci=27) was inadequate, making the hLSCV bandwidth non-nested and introducing considerable bias (Seaman et al., 1998). In contrast, the href method is generally viewed as appropriate for Gaussian-distributed sites and may offer advantages for estimating home range sizes (Bowman et al., 1999).

Conclusion Our study demonstrates that male *T. roborowskii* have larger home range sizes than females during the breeding period, with larger individuals occupying more extensive home ranges. Additionally, we found that the radio tracking method produced larger home range estimates compared to the mark-recapture method, thereby providing a valuable reference for method selection in future research.

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Tables

Table 1. Results of individual home range analysis using MCP and KDE methods.

ID	95%MCP/m^2	95%KDE/m^2	50%MCP/m^2	50%KDE/m^2
M1	4175.48	10700.52	198.07	2393.54
M2	7915.51	22711.50	781.09	5402.25
M3	20717.65	40166.70	532.41	1673.613
M4	1747.42	4120.18	458.73	682.32
M6	25669.02	85977.76	3374.15	19050.47
M1-M6 Mean±SE	12045.02±4721.50	32735.33±14654.04	786.7±504.30	5840.44±3395.19
F1	4778.08	11958.08	597.44	1839.71
F2	1182.72	30242.78	45.08	3636.23
F4	1194.22	4479.96	277.13	762.55
F5	1879.77	11207.34	241.35	2819.91
F6	16418.05	58503.87	2772.50	11446.41

F1-F6 Mean±SE	5090.57±2908.36	23278.41±9789.22	1068.89±583.76	4100.96±1898.30
Mean±SE	8567.79±2859.55	28006.87±8455.754	927.80±366.68	4970.7±1856.47
J1	1156.75	4449.44	29.84	458.03

Figures

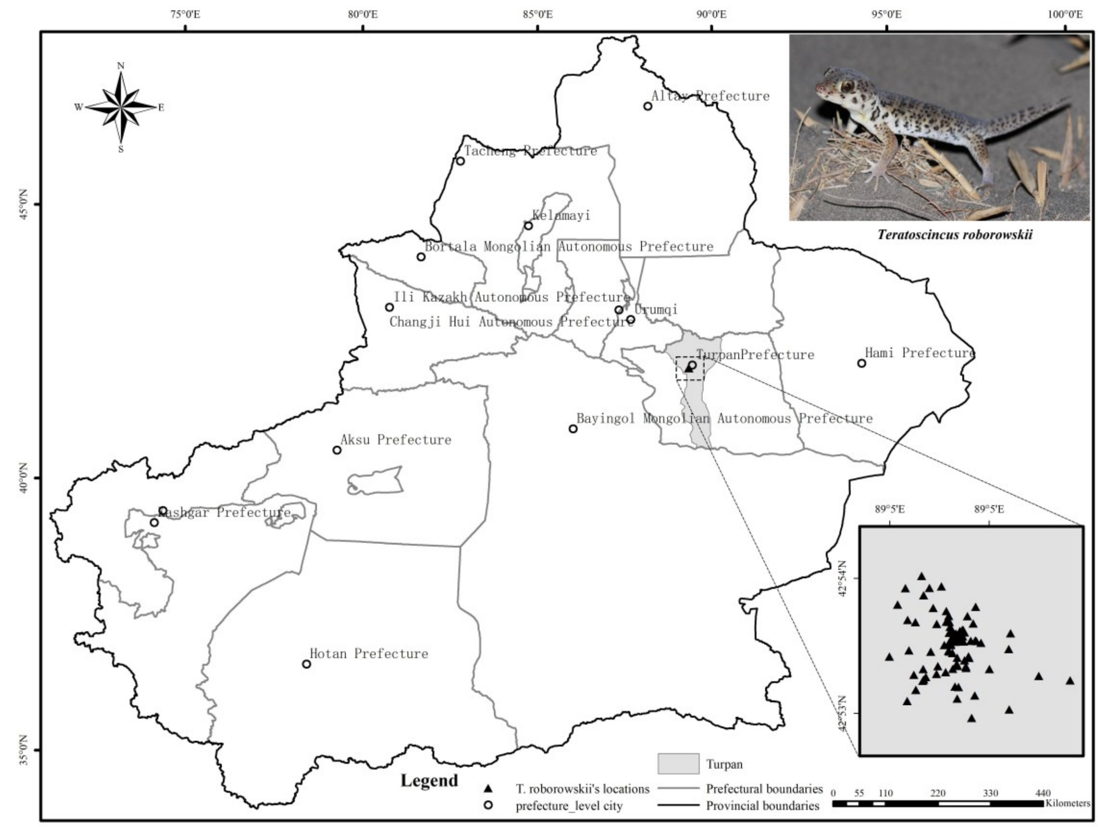


Fig 1. Map showing the locations of *T. roborowskii*.

Fig 2. Home range estimation of *T. roborowskii* using Minimum Convex Polygon (MCP) and Kernel Density Estimation (KDE) methods.

(A) MCP at 95% inclusion level, (B) MCP at 50% inclusion level, (C) KDE at 95% utilization distribution, and (D) KDE at 50% utilization distribution.

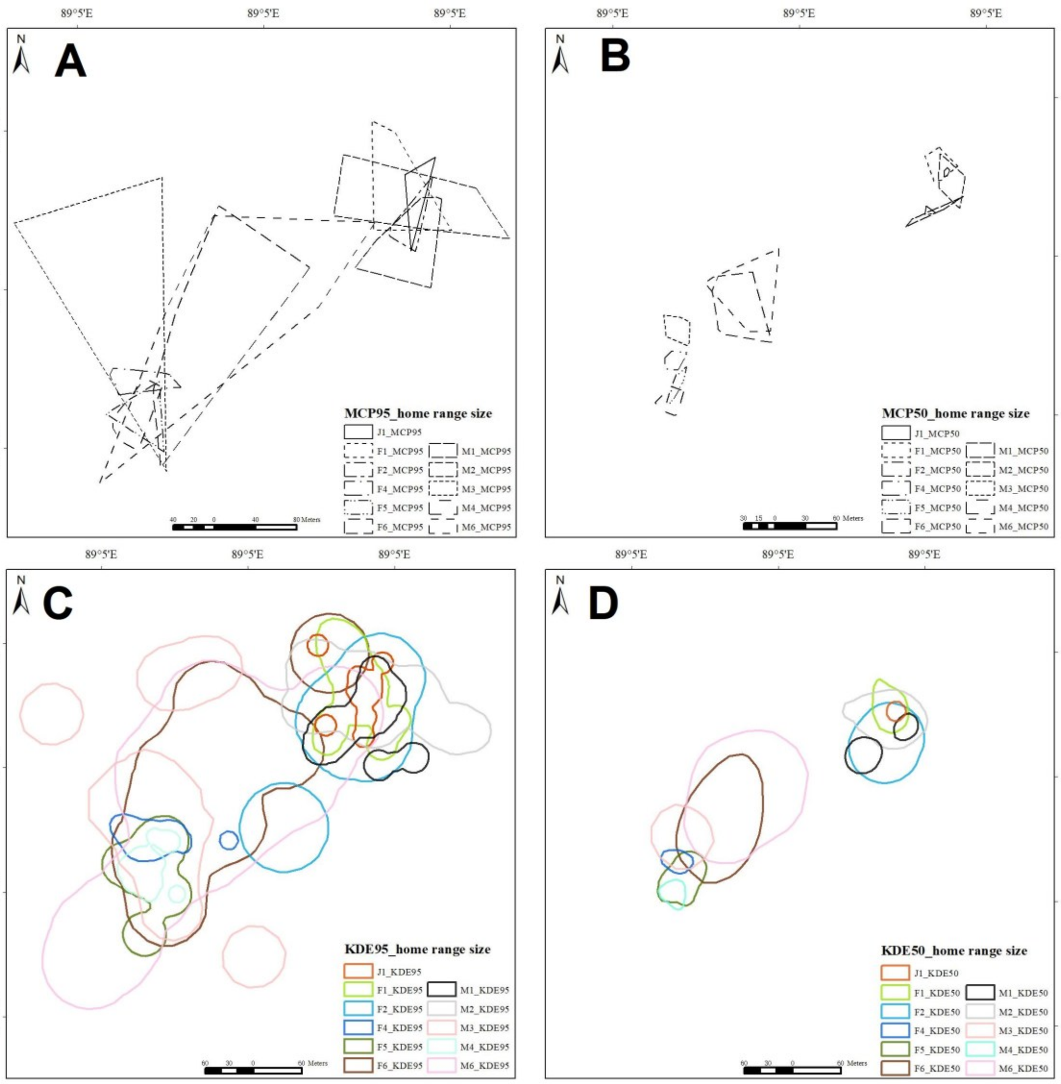
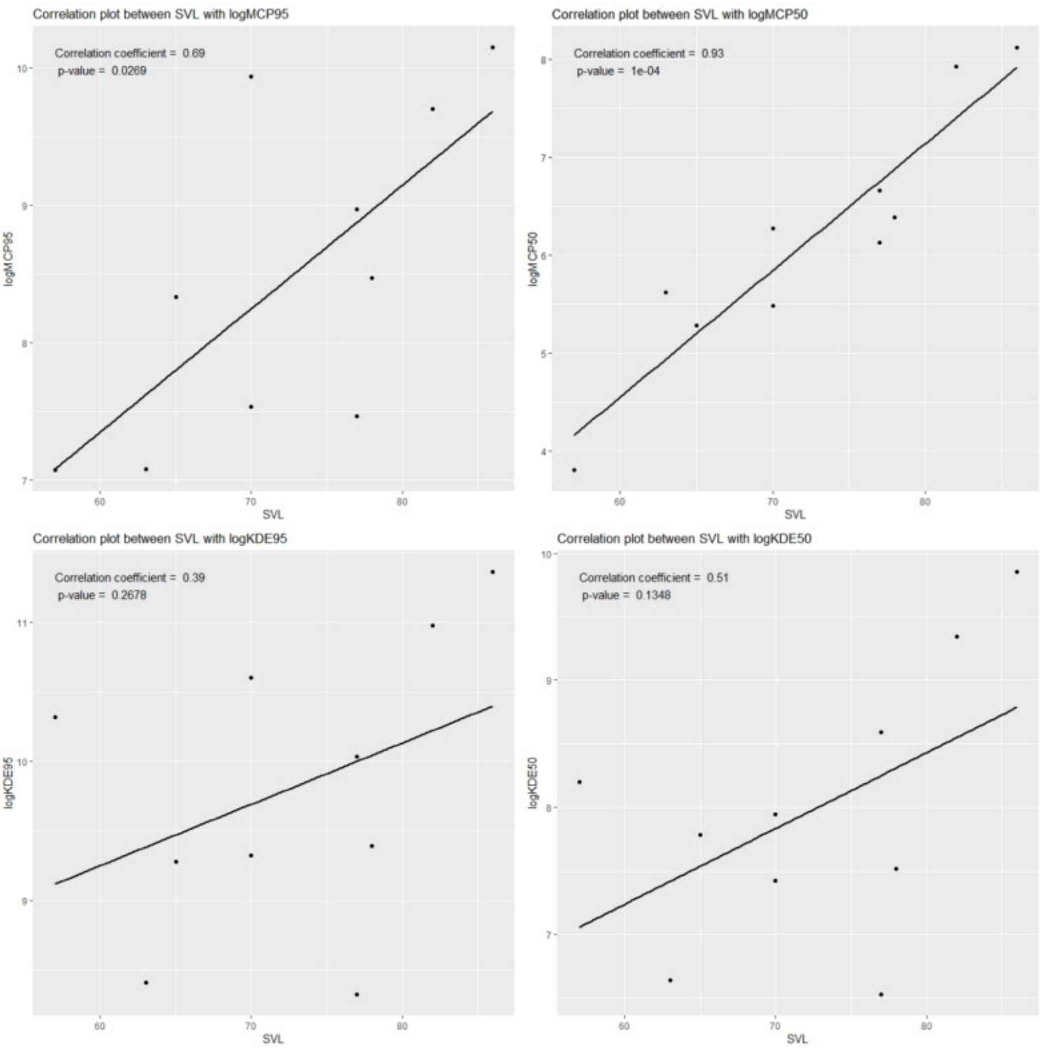


Fig 3. Correlation between SVL and home range size.



Correlation plot between SVL with logMCP95
Correlation coefficient = 0.69
p-value = 0.0269
logMCP95
SVL
Correlation plot between SVL with logMCP50
Correlation coefficient = 0.93
p-value = 1e-04
logMCP50
SVL
Correlation plot between SVL with logKDE95
Correlation coefficient = 0.39
p-value = 0.2678
logKDE95
SVL
Correlation plot between SVL with logKDE50
Correlation coefficient = 0.51
p-value = 0.1348
logKDE50
SVL