

Home Range Size and Overlap of the Small Nocturnal Schlegel's Japanese Gecko (*Gekko japonicus*), Introduced into a City Park in Korea

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Abstract Studying the home range of an organism is important in understanding its ecology. Due to being cryptic, few studies have been conducted on the home range studies of small, nocturnal geckos. We conducted radio-tracking surveys for 23 individuals to estimate the home range size and home range overlap of the Schlegel's Japanese gecko (*Gekko japonicus*) previously introduced into a suburban city park. Individuals were commonly found in artificial structures (buildings and accessory structures) and on nearby natural trees. Daily moved distance was positively correlated with home range size. Minimum convex polygon (MCP) home range was 97.8 m² for females and 99.5 m² for males, on average. *Gekko japonicus* moved farther daily distances and used wider MCP and Kernel 95 home ranges in breeding season compared to non-breeding season, while the size of Kernel 50 home range did not differ between seasons. Both daily moved distance and home range size were not significantly different between sexes. In the breeding season, MCP and Kernel 50 home ranges of each gecko overlapped with 32.4% and 13.8% of remaining geckos, respectively. Our results not only show that 1) *G. japonicus* uses both artificial structures and adjacent natural trees as microhabitat, but also suggest that 2) *G. japonicus* is non-territorial, but has a core habitat that is shared with few other individuals, and 3) the reproductive system of *G. japonicus* is polygamous.

Keywords radio telemetry, invasive species, territory, lizard, Korea

1. Introduction

Home range is defined as the area regularly used by an animal for foraging, avoiding predators, and reproduction (Burt, 1943). Home range provides information on habitat range, available resources, and dispersal potential to nearby areas (Locey and Stone, 2006; Perry and Garland, 2002; Rose, 1982). In addition, comparison of home range size and overlap among individuals provides information on resource competition, interaction between sexes, and breeding system (Ferner, 1974; Kerr and Bull, 2006; Stamps, 1977). Thus, determining home range is

important in understanding the ecology of a species.

In lizards, studies on home range have focused on invasive, endangered, or relatively large species (Gerner, 2008; Gomez Zlatar, 2003; Kim *et al.*, 2012). This is largely due to logistic difficulties in studying small, cryptic, nocturnal species (Kalwinski, 1991; McIvor, 1972; Rose and Barbour, 1968). Traditionally, the mark-recapture method has been used to study lizard home range (Klawinski, 1991; McIvor, 1972; Stamps, 1977). However, radio telemetry has recently been used, which can give more precise information on home range and movement patterns (Gerner, 2008; Kerr and Bull, 2006; Kim *et al.*, 2012; Stellatelli *et al.*, 2016). Due to the difficulty in observing of nocturnal geckos living in forests, few of such studies have been conducted. Particularly, home range determination by radio telemetry has not been conducted on any nocturnal geckos.

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Received: 29 January 2019 Accepted: 2 April 2019

Schlegel's Japanese gecko (*Gekko japonicus*) is a small, nocturnal gecko, distributed in China, most main islands of Japan, and southern parts of the Korean Peninsula (Lee *et al.*, 2004; Wada, 2003; Zhao and Adler, 1993). Populations of *G. japonicus* in Japan and Korea are considered introduced (Lee *et al.*, 2004; Toda and Yoshida, 2005). This species mainly inhabits urban residential areas and city parks in Korea and Japan, but is also found in forests in China (Lee *et al.*, 2004; Ota and Tanaka, 1996; Zhang *et al.*, 2016). *Gekko japonicus* consumes insects and other arthropods that are attracted to city lights in urban environments (Ota and Tanaka, 1996; Werner *et al.*, 1997). Despite various behavioral, ecological, and genetic studies on *G. japonicus* (Kim *et al.*, 2018, 2019; Park *et al.*, 2018; Tawa *et al.*, 2014; Toda *et al.*, 2003; Zhang *et al.*, 2009), we do not have any data on home range of this species. Considering that *G. japonicus* occupies an important ecological niche in urban ecosystems (Brooke Stabler *et al.*, 2012; Lee *et al.*, 2004) and additional dispersal/introduction of *G. japonicus* is expected in Korea and Japan, it is necessary to determine its home range.

In this study, we used radio telemetry to understand the home range of *G. japonicus* in a suburban city park.

We had three specific questions to investigate: 1) if *G. japonicus* are found on both artificial structures and natural trees in nearby forest, 2) if home range varies between season and sex, and 3) if the home range of individuals overlap.

2. Materials and Methods

2.1. Study site and gecko collection As a study site, we selected parts of a suburban city park in Busan, Korea (N 35°13', E 129°04', 70 m × 70 m), where we could freely approach the various habitats at night. A schematic of the site is in Figure 1. The site contained a two-story cable-car building (31 m long × 13 m wide × 12 m high), a toilet building (8 m long × 6 m wide × 4 m high), and adjacent pine forest surrounding these buildings. The first floor of the cable-car building has a small convenience store and a daycare center. On the northeast side of the cable-car building, there were three wooden paths (2.8–5.2 m wide × 1.5–2.8 m long) and a artificial rock wall (0.5 m wide × 35 m long) between the building and park walkway. In the forest, the upper layer was comprised of *Pinus densiflora* and *Chamaecyparis pisifera*, while the lower layer was comprised of *Rhododendron schlippenbachii*, *Camellia*

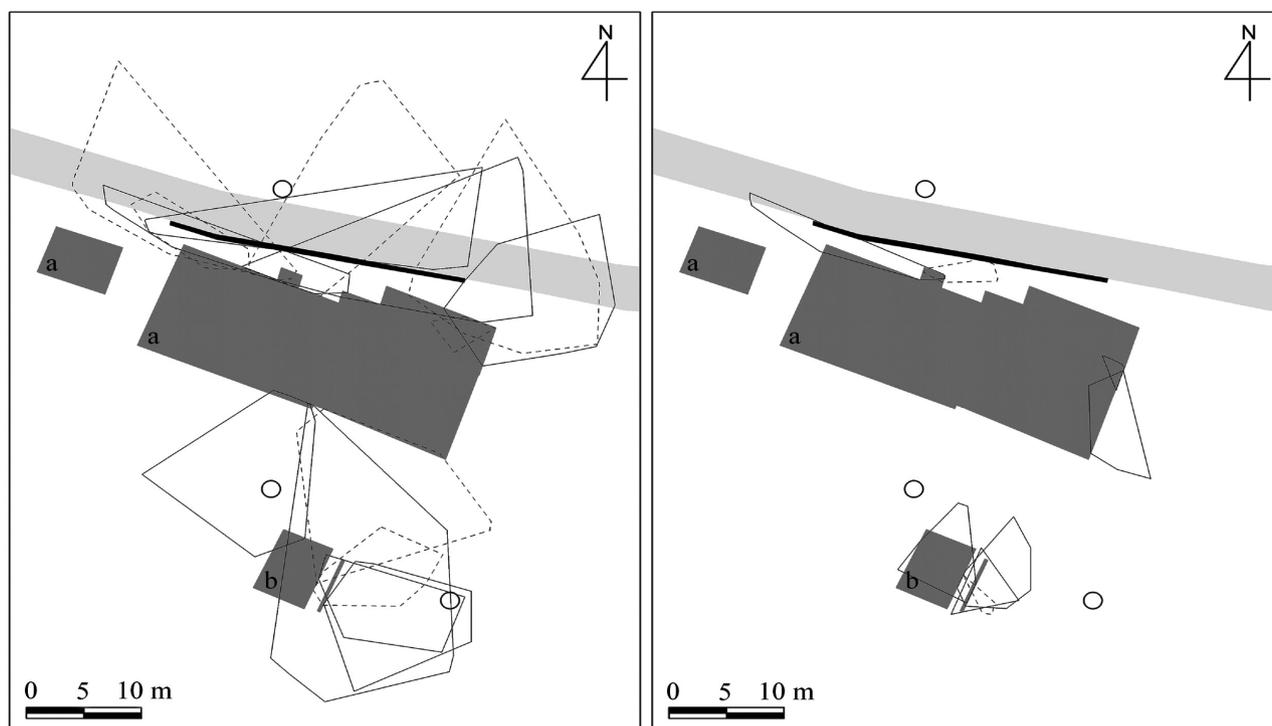


Figure 1 Schematic diagram of the study site and the minimum convex polygon (MCP) home range of female (solid line) and male (dotted line) *Gekko japonicus*, which radio-tracked in a suburban city park during (A) breeding (June 8–July 10) and (B) non-breeding (October 2–24, 2018) season. a, cable-car building; b, toilet building; O, street lights. Black and light gray bars at the north-east side of the cable-car building indicate artificial rock wall and park walkway, respectively. Three wooden paths exist between the rock wall and the cable-car building and the pine forest surrounds the buildings (not shown for clarity).

japonica, and *Cornus controversa*. Some pine tree branches touched or extended over the cable-car and toilet buildings. There were three street lights: one at north-east side of cable-car building and two at near toilet building, approximately 3.2–14 m away from the buildings. These street lights automatically turned on at 1800 and off at 2330. Lights in the convenience store irregularly turned on and off. In addition, the site was illuminated by dim city lights at night.

We captured geckos on the walls of cable-car and toilet buildings by hand or using insect nets. Considering the weight of the radio transmitter, we only collected adult geckos whose body weight was over 4 g. After recording the exact capture location on the mimetic diagram of the study site (Figure 1), geckos were individually marked with a small paint dot (Paint marker, Munwha, Seoul), kept in a collecting box (19 cm long × 12 cm wide × 13 cm high), and transported to the field station approximately 650 m from the study site.

2.2. Attaching transmitters and conducting radio-tracking The radio transmitters we used were PicoPip (173 MHz, size 12 mm long × 7 mm wide × 4 mm high, battery life 21 days, weight 0.35 g; Biotrack, Wareham, UK). We constructed a transmitter package by first attaching the transmitter to prepared 'X' shaped sport tape (5 mm wide, Nasara, Paju, South Korea) using power epoxy steel (Locstar, Warwickshire, UK) following previous studies (Kim *et al.*, 2012; Winkel and Ji, 2014). The weight of the prepared package was 0.42 ± 0.01 g ($n = 23$). After measuring snout-vent length (SVL) and body weight (BW) of each individual using electronic calipers (nearest 0.1 mm; CD-15CPX, Mitutoyo-Korea, Seoul) and a digital balance (nearest 0.01 g; MH-200, Sellbuy, China), we attached the transmitter package to the individual by applying small amount of super glue (Loctite-401, Henkel, Germany). The ratio of transmitter to body weight of individuals was $8.3\% \pm 0.3\%$ (5.2–10.0, $n = 23$). Individuals wearing the transmitter package were kept in a box (19 cm long × 12 cm wide × 13 cm high) for more than one hour to confirm that the package was stable and did not disturb activity. All geckos were released at the collection site within 12 hours of its initial capture.

We conducted radio-tracking during both the breeding (June 8 to July 10, 2018; 33 days) and non-breeding season (October 2 to 24, 2018; 23 days) using an IC-R20 receiver (Icom, Osaka, Japan) connected to a 3-element Yagi antenna (173 MHz, Biotrack, Wareham, UK). In this study, we defined the breeding and non-breeding season based on if females have visible eggs in their abdomen,

considering previous results on the reproductive biology of this species (Ikeuchi, 2004; Ji *et al.*, 1991). In the non-breeding season, all females did not have visible eggs, but in the breeding season, 6 out of 7 females had visible eggs. To increase the number of detections while not excessively disturbing geckos, we determined the location of individuals twice each day, once between 09:30–14:00 and once between 21:00–02:00. When we were unable to directly observe individuals (e.g., inside structures or high on trees), we determined location using a trigonometry (Kim *et al.*, 2012; Ra *et al.*, 2008).

We determined geckos' location and classified as either artificial structures (i.e., building, wooden path, artificial rock wall, and electric pole) or natural structures (i.e., tree, natural rock, and forest floor). In this study, when presenting the pooled artificial and natural structures as different microhabitats, we used words of "building microhabitat" and "tree microhabitat" for each structure group. The location was recorded on a map, and we noted two reference distances from the building at 0.1 cm unit. We measured these two distances using a laser distance meter (Fluke-414D, Fluke, Everett, USA). We did not record locations using GPS coordinates due to their inaccuracy at such a small spatial scale. We measured the moved distance of an individual by measuring the shortest distance between the current and previous location using the laser distance meter.

When a gecko was directly observed, we recorded the locating time as the time after sunset and measured body surface temperature to the nearest 0.1°C within 2 m from the gecko using an infrared digital thermometer (D/S Ratio: 12:1, Fluke-AR330, Fluke, Everett, USA). To record daily temperature (0.1°C) and humidity (0.1%) every 30 min during the study period, we placed three EasyLog data loggers (Lascar, Whiteparish, UK) on the outer wall of the cable-car building approximately 2 m high from the ground.

2.3. Handling data Variables analyzed in this study consisted of 2 capture-, 4 day-, and 14 individual-based variables (Table S1). We generally compared these variables between seasons and sexes. Capture-based data were the body surface temperature of an individual when located and the locating time of each gecko. Day-based data consisted of mean air temperature and humidity, precipitation, and mean moved distance. The temperature and humidity were daily means from the three EasyLog data loggers. Daily precipitation data were obtained from Busan meteorological station (<https://data.kma.go.kr>), which was 13 km away from the study site. Mean daily moved distance was calculated as the mean value of

collected daily distances of all individuals for a particular date.

Individual-based data consisted of the number of detections, detection ratio in building microhabitat or tree microhabitat, farthest moved distance from the building to the forest, mean daily moved distance, home range size, and home range overlap ratio. The detection ratio in building (or tree) microhabitat was calculated as the number of detections in building (or tree) microhabitat divided by total number of detections. The farthest moved distance from the building was the distance between the furthest location into forest and the edge of the building. The mean daily moved distance was the mean of all collected daily moved distances of an individual during the radio-tracking period. A daily moved distance was only obtained when a gecko was detected over three consecutive times (i.e., day-night-day) so that the distance included both one day-time and one night-time moved distance. The mean daily moved distance was also calculated separately for each building and tree microhabitat.

For home range, we calculated minimum convex polygon (MCP), Kernel 50, and Kernel 95 home range using a batch home range processing tool in QGIS v3.4 (<https://www.qgis.org/en/site/>). We selected the three different home range estimators in order to compare with previous results on the home range size and overlap of other lizards and geckos. MCP and Kernel 95 represent meaningful maximum home range, while Kernel 50 represents core home range (Börger *et al.*, 2006; Robles and Halloy, 2010). Individual and area overlap ratios were calculated using MCP and Kernel 50 home ranges (Diego-Rasilla and Pérez-Mellado, 2003; Kerr and Bull, 2006; Robles and Halloy, 2010). The individual overlap ratio was calculated as the number of individuals of which home range overlapped with the target individual, divided by the number of all remaining individuals being radio-tracked during the period. The area overlap ratio was calculated following the Cooper (1978)'s method. In detail, we first calculated the overlap area ratio of each individual whose home range overlapped with a target individual by dividing the overlapping area between the two individuals by the smaller home range of the two individuals. Then, we calculated the mean value of the obtained area overlap ratio of the all geckos, of which home range overlapped with the target individual.

2.4. Statistical analyses All analyses were done in SPSS v. 24.0 (SPSS Inc., Chicago, USA). Numeric data were presented as mean \pm 1 standard error if not specifically mentioned.

Seven out of 23 variables (including SVL and BW) were not normally distributed (Kolmogorov-Smirnov, P s < 0.05). First, we used a Spearman correlation test to know relationships among day-based data of mean daily air temperature and humidity, precipitation, and pooled daily moved distance. If the certain pooled data showed significance, we subsequently analyzed the relationship separately for breeding and non-breeding season. We used the same test to analyze relationships among individual-based data of the number of detections, SVL, BW, detection ratio in building microhabitat, farthest distance from the building, daily moved distance (for building microhabitat, tree microhabitat, and pooled data), home range size (MCP, Kernel 50, and Kernel 95), and home range individual and area overlap ratio (MCP and Kernel 50).

To know if the body surface temperature of geckos differed between seasons and sexes, we analyzed the data using a univariate general linear model (UGLM). In the analysis, the locating time was used as a covariate. For individual-based data, we used a multivariate general linear model to test for differences based on seasons and sexes in detection ratio in building microhabitat, mean daily moved distance (for building microhabitat, tree microhabitat, and pooled data), farthest distance from the building, and home range size (MCP, Kernel 50, and Kernel 95). In this analysis, the number of detections, SVL, and BW were used as covariates. We also used the UGLM to test for difference in home range overlap individual and area ratio between seasons and between sexes. In addition, difference in daily moved distance between building and tree microhabitats with regard to seasons and sexes was tested by the paired *t*-tests. Finally, we used an independent sample *t*-test to test if mean daily air temperature, humidity, and precipitation were different between seasons.

3. Results

3.1. General trends We radio-tracked 15 geckos (7 females and 8 males) in breeding season and 8 (2 females and 6 males) in non-breeding season (Table S2). The mean number of detections was 38.4 (\pm 11.8 SD, n = 23). We directly observed geckos in 254 out of 882 total detections (31.5% \pm 25.6% SD, n = 23). The number of detections did not differ both between seasons and between sexes (P s > 0.05). The size of females (SVL, 66.2 \pm 1.4; BW, 5.9 \pm 0.2, n = 9) was larger than males (SVL, 62.0 \pm 0.4; BW, 4.7 \pm 0.1, n = 14; P = 0.003 for SVL and P < 0.001 for BW), but the SVL and BW did not

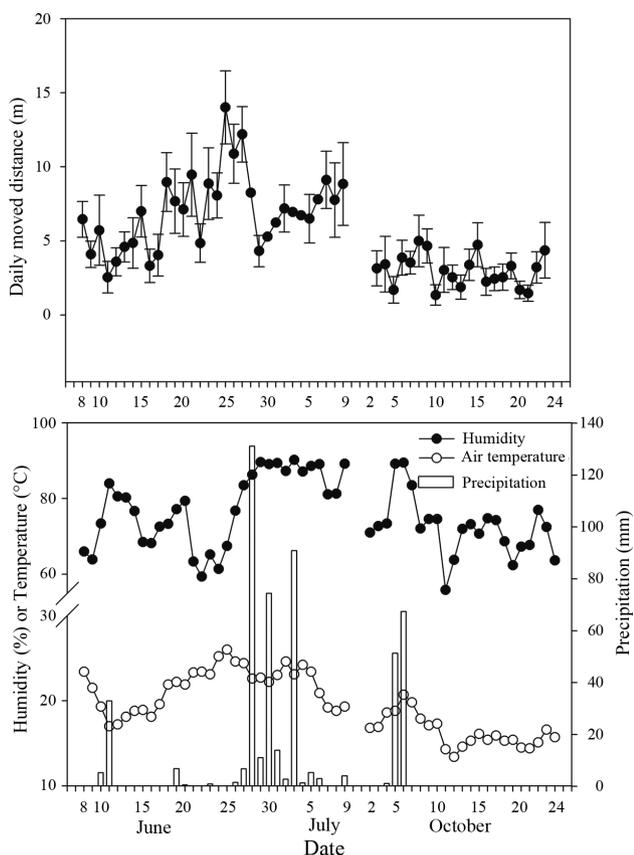


Figure 2 Mean daily moved distance (A) of *Gekko japonicus* along local climate (air temperature, humidity, and precipitation, B) conditions during breeding season (June 8–July 10, 2018), and non-breeding season (October 2–24, 2018).

differ between seasons ($P_s > 0.05$).

Mean daily air temperature was higher in the breeding season (21.5 ± 0.5 , $n = 27$ days) compared to the non-

breeding season (6.3 ± 0.4 , $n = 23$ days; $t = 7.9$, $df = 48$, $P < 0.001$), but mean humidity and precipitation did not differ ($P_s > 0.05$). Overall mean daily moved distance was positively correlated with only mean daily air temperature ($r = 0.788$, $n = 47$, $P < 0.01$, Figure 2). In separate analyses, the relationship was seen in breeding season ($r = 0.593$, $n = 26$, $P < 0.01$), but not in non-breeding season ($P > 0.05$). Body surface temperature of geckos was higher in the breeding season (corrected mean \pm SE, 24.0 ± 0.3 , $n = 141$) compared to non-breeding season (18.0 ± 0.5 , $n = 113$; $F_{1, 254} = 75.82$, $P < 0.01$), but the body surface temperature did not differ between females (21.0 ± 0.5 , $n = 114$) and males (21.3 ± 0.3 , $n = 140$; $P > 0.05$).

3.2. Daily moved distance In individual-based analyses, mean daily moved distance in building microhabitat was positively related with the number of detections ($r = 0.439$, $n = 22$, $P = 0.041$). The remaining relationships were not significant ($P_s > 0.05$).

We detected geckos in both building microhabitat ($54.9\% \pm 5.9\%$, $n = 23$) and tree microhabitat ($45.1\% \pm 5.9\%$, $n = 23$, Table 1). In building microhabitat, we detected 74.8% (357 out of 477 detections) of geckos on walls or inside building structure, 17.0% (81 detections) on/in the wooden path structure, and 4.8% (23 detections) on/in the rock wall structure, and 3.4% (16 detections) in other structures (e.g., on electric poles). In tree microhabitat, 98.5% (399 out of 405 cases) of detections were on branches and bark of tree trunks, and only six times were on the forest floor structure. The detection ratio in building and tree microhabitat was not different between seasons, between day-time and night-time, and

Table 1 Detection ratio in building microhabitat, daily moved distance, farthest distance moved toward the forest, and home range size of *Gekko japonicus*.

Season	Sex	Detection in building microhabitat (%) (range)	Daily moved distance (m) (building/ tree microhabitat)	Farthest distance to forest (m) (range)	Home range (m ²)		
					MCP (range)	Kernel 50 (range)	Kernel 95 (range)
Breeding season	Female	63.3 ± 9.6 (25.0–100)	6.0 ± 1.2 (3.9/ 9.1)	12.5 ± 3.0 (0–20.5)	123.8 ± 32.9 (10.0–224.2)	20.5 ± 6.7 (2.6–41.5)	130.7 ± 38.7 (24.5–262.5)
	Male	48.5 ± 9.6 (5.0–86.1)	8.0 ± 1.0 (4.8/ 10.6)	15.0 ± 0.7 (10.9–17.3)	154.0 ± 28.5 (64.7–309.4)	32.7 ± 11.5 (6.1–109.6)	204.9 ± 46.1 (54.5–468.7)
	Total	55.4 ± 6.8	7.1 ± 0.8 (4.4/ 10.0)	13.8 ± 1.4	139.9 ± 21.2	27.0 ± 6.9	170.2 ± 31.1
Non-breeding season	Female	12.3 ± 6.0 (6.3–18.2)	1.9 ± 0.2 (0.7/ 0.9)	3.1 ± 1.0 (2.1–4.2)	6.8 ± 3.5 (3.3, 10.2)	1.2 ± 0.1 (1.1, 1.2)	5.8 ± 1.7 (4.1, 7.4)
	Male	67.9 ± 10.0 (34.1–100)	3.3 ± 0.4 (1.3/ 2.8)	5.3 ± 1.7 (0.0–10.1)	26.8 ± 5.6 (2.8–36.3)	7.2 ± 1.8 (0.5–12.4)	39.8 ± 9.0 (2.9–67.8)
	Total	54.0 ± 11.8	2.9 ± 0.4 (1.2/ 2.2)	4.7 ± 1.1	21.8 ± 5.3	5.7 ± 1.7	31.3 ± 8.6

between sexes ($P_s > 0.05$). However, detailed use of different structure types was different between sexes and between seasons, but not between day- and night-time (Table S3).

Mean pooled daily moved distance was not different between seasons ($P > 0.05$), but the daily moved distance in building microhabitat ($F_{1,20} = 5.02$, $P = 0.045$) and tree microhabitat ($F_{1,20} = 12.93$, $P = 0.004$) were different between seasons (Table 1). Any of the daily moved individual distances were not different between sexes ($P_s > 0.05$). Daily movement was farther in tree microhabitat than in building microhabitat (paired $t = 5.19$, $df = 19$, $P < 0.01$, Table 1). This trend was seen in breeding season ($t = 5.19$, $df = 19$, $P < 0.01$), but not in non-breeding season ($P > 0.05$). Further daily movement in tree microhabitat was also indicated when the data for males and females were analyzed separately (female, $t = 2.93$, $df = 7$, $P = 0.022$; male, $t = 4.15$, $df = 11$, $P = 0.002$).

Individuals moved farther distance from the building toward the forest during breeding season (13.8 ± 1.4 m, $n = 15$) compared to non-breeding season (4.7 ± 1.1 m, $n = 8$), but the distance was not significant different between sexes ($P > 0.05$, Table 1).

3.3. Size and overlap of home range MCP home range was positively correlated with the number of detections ($r = 0.488$, $n = 23$, $P = 0.018$), while the SVL of geckos was negatively correlated with Kernel 50 home range ($r = -0.485$, $n = 23$, $P = 0.019$). The remaining relationships were not significant different ($P_s > 0.05$). In addition, the individual- and area-based overlap ratios of home range were not related with any tested variables ($P_s > 0.05$).

MCP (139.9 ± 21.2 m² for breeding and 21.8 ± 5.3

m² for non-breeding season; $F_{1,23} = 8.98$, $P = 0.009$) and Kernel 95 (170.2 ± 31.1 m² for breeding and 31.3 ± 8.6 m² for non-breeding season; $F_{1,23} = 5.43$, $P = 0.033$, Table 1) home ranges were greater in the breeding season compared to non-breeding season, but Kernel 50 home range was not different between the seasons (27.0 ± 6.9 m² for breeding and 5.7 ± 1.7 m² for non-breeding season; $P > 0.05$, Table 1). The size of any of home range types was not different between sexes ($P_s > 0.772$).

The overlap ratio of MCP and Kernel 50 home range individual (MCP, $F_{1,23} = 10.0$, $P = 0.005$; Kernel 50, $F_{1,23} = 7.3$, $P = 0.014$) and area (MCP, $F_{1,23} = 7.4$, $P = 0.014$; Kernel 50, $F_{1,23} = 17.9$, $P < 0.01$) was greater in the breeding season than non-breeding season (Table 2). MCP individual ($F_{1,23} = 7.0$, $P = 0.016$) and area ($F_{1,23} = 4.6$, $P = 0.046$) overlap ratios of males were bigger than those of females, but the ratios of Kernel 50 were not different between sexes ($P_s > 0.500$, Table 2). In addition, we provide the results of individual and area overlap ratio of MCP and Kernel 50 home ranges between intra-sexual and inter-sexual individuals as supplementary materials (Table S2, Figure S1), considering relatively small sample cases of intra-sexual and inter-sexual overlaps, particularly in non-breeding season.

4. Discussion

To estimate the home range size and overlap of *G. japonicus*, we radio-tracked individuals during both breeding and non-breeding season. *Gekko japonicus* used both artificial structures and adjacent natural trees as microhabitat and its MCP home range was 97.8 m² for females and 99.5 m² for males, on average. Considering

Table 2 Individual and area overlap ratio of the MCP and Kernel 50 home range of *Gekko japonicus*. No., number; Ind., individual; intra, intra-sexual; inter, inter-sexual.

Season	Sex	MCP			Kernel 50		
		No. ind. (range)	Ind. ratio (%) (range)	Area ratio (%) (range)	No. ind. (range)	Ind. ratio (%) (range)	Area ratio (%) (range)
Breeding season	Female ($n = 7$)	4.4 (3–5)	31.6 ± 2.1 (21.4–35.7)	40.1 ± 5.4 (23.0–57.9)	1.9 (1–4)	13.3 ± 3.3 (7.1–28.5)	53.8 ± 9.5 (7.8–92.3)
	Male ($n = 8$)	4.6 (2–8)	33.0 ± 4.7 (14.3–57.1)	44.9 ± 7.7 (7.6–72.9)	2 (1–5)	14.3 ± 3.6 (7.1–35.7)	38.1 ± 9.1 (7.8–78.6)
	Total	4.5 (2–8)	32.4 ± 2.6	42.6 ± 4.7	1.9 (1–5)	13.8 ± 2.4	45.4 ± 6.6
	Female ($n = 2$)	0	0	0	0	0	0
Non-breeding season	Male ($n = 6$)	2 (1–3)	28.6 ± 6.4 (14.2–42.9)	34.8 ± 9.0 (9.8–60.9)	0.3 (0–1)	4.8 ± 3.0 (0–14.3)	4.8 ± 3.1 (0.0–14.5)
	Total	1.5 (1–3)	21.5 ± 6.6	26.1 ± 8.7	0.3 (0–1)	3.6 ± 2.3	3.6 ± 2.4

individual and area overlap ratio of MCP and Kernel 50 home range among geckos, *G. japonicus* is likely non-territorial and its reproductive system is likely polygamous.

Regardless of season and sex, *G. japonicus* used both building and tree microhabitats. In the artificial or urban habitats, introduced animals including nocturnal geckos often find refuge in various crevices in man-made structures and efficiently feed on abundant insects (Francis and Chadwick, 2012; Saenz, 1996; Williams and McBrayer, 2007). In particular, when geckos are introduced into cooler areas compared to their original habitat, building or house habitat can provide a suitable hibernaculum with stable temperature (Brooke Stabler *et al.*, 2012; Locey and Stone, 2006; Norden and Norden, 1991). In the study site, *G. japonicus* used both artificial structures and adjacent natural trees as microhabitat although they often moved farther in tree microhabitat. Despite some potential bias in our observations because we initially captured all geckos from the buildings, our results have two important implications in the understanding the habitat use of nocturnal geckos. First, ecological field data of nocturnal geckos may be biased, as observations in previous studies are often from individuals, which gathered at light sources on various walls (Eifler *et al.*, 2017; Gomez-Zlatar, 2003; Park *et al.*, 2018). To get a complete view of nocturnal gecko ecology, adjacent natural microhabitat such as trees and plants needs to also be considered. Second, our study reveals that nocturnal geckos living in residential areas or city parks would also use plants and trees as the components of its microhabitat. When managing an area for gecko conservation, these vegetation need to be included into the management plan.

The home range size of a species generally depends on habitat structure, distribution of prey and refuges, and body size and reproductive system of the species (Perry and Garland, 2002; Stelatelli *et al.*, 2016). MCP home range of the Pacific gecko (*Hoplodactylus pacificus*; McIvor, 1972) and Mediterranean gecko (*Hemidactylus turcicus*; Klawinski, 1991; Rose and Barbour, 1968), which are small nocturnal species, was approximately 2.2 m² and 4.1 m², respectively. In this study, *G. japonicus* had much bigger MCP home range as about 99 m² for both females and males. Two factors might be responsible for this result. First, compared to traditional capture-recapture methods, using the radio-tracking method allow for easier detection of cryptic species, likely resulting in a much larger home range. Second, during the study period, *H. pacificus* and *H. turcicus* used single

microhabitat types, such as buildings or small mountain hill (Klawinski, 1991; McIvor, 1972). Unlike them, *G. japonicus* used two different microhabitat types of both building and trees in this study, resulting in a bigger home range.

In the breeding season, *G. japonicus* used a larger MCP and Kernel 95 home range than in non-breeding season. To meet increased energy requirements during the breeding season, a large home range is necessary (Perry and Garland, 2002). The result that *G. japonicus* increased its daily moved distance and travelled farther distance to the forest in breeding season could be responsible for a home range expansion during the breeding season. As we found a positive correlation between daily moved distance and mean air temperature in this study, increased air temperature in breeding season could also facilitate increased moved distance and home range through higher body temperature (Hu and Du, 2007; Huey *et al.*, 1989). On the other hand, the size of Kernel 50 home range was not different between seasons. This result might be a result of female and male *G. japonicus* having a core habitat, regardless of season. We discuss this in further detail below.

All home range coefficients evaluated in this study did not differ between sexes. In general, home range of females is determined based on the distribution of essential resources, while that of males based on the female distribution and additional resources (Perry and Garland, 2002). So, males generally have larger home range than females (Ikeuchi *et al.*, 2005; McIvor, 1972; Stelatelli *et al.*, 2016). Indifferent home range size between female and male *G. japonicus* might be explained by two factors. First, relatively indistinctive sexual dimorphism of *G. japonicus* might be involved in the result (Zhang *et al.*, 2009). In lizards, small sexual size dimorphism is generally related to small differences in home range size between sexes (Cox *et al.*, 2003). Second, reduced home range size of both males and females in introduced area might be in part responsible for the result. In Korea, as *G. japonicus* is likely an invasive species (Lee *et al.*, 2004), so its microhabitat use might be restricted by local climate conditions. Comparative studies in China or Japan, a potential original habitat, may further clarify nature of home range differences between female and male *G. japonicus*.

There was less overlap in Kernel 50 home range compared to MCP home range. In the breeding season, home range of an individual overlapped with 32.4% (MCP) or 13.8% (Kernel 50) of remaining individuals. In previous studies of lizards, a home range overlap

of greater than 25% categorized a species to be non-territorial (Manteuffel and Eiblmaier, 2008; Robles and Halloy, 2010). Based on this criterion, *G. japonicus* is non-territorial based on MCP home range, but tends to have core habitat based on Kernel 50 home range, although it might be shared with few others. This pattern has been observed in other gecko species (Kerr and Bull, 2006; Stamps, 1977), not protecting whole home ranges, but having core area. This result is also consistent with results of previous *G. japonicus* studies. In indoor vivaria, *G. japonicus* shared refuges with a few individuals, but excluded juveniles from the areas (Park *et al.*, 2018). Also, *G. japonicus* in refuges produced alarm calls only when other geckos closely approached (Jono and Inui, 2012), showing exclusively use core habitat at least for a time.

On the other hand, the individual and area overlap ratio of both MCP and Kernel 50 home range was greater in the breeding season, and the ratios of males were greater than those of females. Furthermore, inter-sexual ratios of MCP home range individual overlap tended to be greater than intra-sexual overlap ratios during breeding season ($P = 0.013$, Table S2, Figure S1) although such a trend was not seen during non-breeding season. These results suggest that females and males meet multiple individuals of opposite sex, and that males or females actively seek multiple mates during the breeding season. These results imply that the reproductive system of *G. japonicus* is likely polygamous, as found in other lizard species (Stamps, 1977). Nevertheless, overall verification of reproductive system can be done by analyzing multiple paternity in offspring using appropriate molecular markers (Cho *et al.*, 2018).

In conclusion, *G. japonicus* were commonly found in both artificial structures and adjacent natural trees as microhabitat. In the breeding season, *G. japonicus* moved farther distances and used wider home ranges. The daily moved distance and home range were not different between sexes. In breeding season, individual MCP home range overlapped with 32% of remaining individuals, but the overlap ratio of the core home range (Kernel 50) was relatively low as 14%, indicating that *G. japonicus* is likely non-territorial, and has a core habitat that is shared with few geckos. Considering home range overlap between sexes in breeding season, the reproductive system of *G. japonicus* is likely polygamous.

Acknowledgements We thank J. Y. SONG in Korea National Park Service for providing the receiver during the study. This study was supported by the Basic Science Research Program through the National Research

Foundation of Korea (NRF) funded by the Ministry of Education (2016R1D1A1B03931085) and has been worked with the support of a research grant of Kangwon National University in 2018. This research was conducted within the guidelines and approval of the Institutional Animal Care and Use Committee of Kangwon National University (KW-161128-2).

Reference

- Börger L., Franconi N., de Michele G., Gantz A., Meschi F., Manica A., Lovar S., Coulson T.** 2006. Effects of sampling regime on the mean and variance of home range size estimates. *J Anim Ecol*, 75: 1393–1405
- Brooke Stabler L., Johnson W. L., Locey K. J., Stone P. A.** 2012. A comparison of Mediterranean gecko (*Hemidactylus turcicus*) populations in two temperate zone urban habitats. *Urban Ecosyst*, 15: 653–666
- Burt W. H.** 1943. Territoriality and home range concepts as applied to mammals. *J Mammal*, 24: 346–352
- Cho H., Park J., Choi W., Struijk R. P. J. H., Park D.** 2018. Multiple paternity in the endangered Amur ratsnake (*Elaphe schrenckii*). *Russian J Herpetol*, 25: 61–70
- Cooper W. E. Jr.** 1978. Home range criteria based on temporal stability of areal occupation. *J Theor Biol*, 73: 687–206
- Cox R. M., Skelly S. L., John-Alder H. B.** 2003. A comparative test of adaptive hypotheses for sexual size dimorphism in lizards. *Evolution*, 57: 1653–1669
- Diego-Rasilla F. J., Pérez-Mellado V.** 2003. Home range and habitat selection by *Podarcis hispanica* (Squamata, Lacertidae) in Western Spain. *Folia Zool*, 52: 87–98
- Eifler M. A., Marchand R., Eifler D. A., Malela K.** 2017. Habitat use and activity patterns in the nocturnal gecko, *Chondrodactylus turneri*. *Herpetologica*, 73: 43–37
- Ferner J. W.** 1974. Home range size and overlap in *Scetoporus undulatus erythrocheilus* (Reptilia: Iguanidae). *Copeia*, 1974: 332–337
- Francis R. A., Chadwick M. A.** 2012. What makes a species synurbic? *Appl Geogr*, 32: 514–521
- Gerner T.** 2008. Home range, habitat use and social behavior of the endangered Mauritian gecko *Phelsuma guentheri*. MS Thesis. University of Zurich
- Gomez Zlatař P. A.** 2003. Microhabitat preference of the introduced gecko *Hemidactylus turcicus* in an urban environment. MS Thesis, University of Florida
- Hu L., Du W.** 2007. Thermoregulation and thermal dependence of locomotor performance in the gecko *Gekko japonicus*. *Acta Zool Sinica*, 53: 227–232
- Huey R. B., Niewiarowski P. H., Kaufmann J., Herron J. C.** 1989. Thermal biology of nocturnal ectotherms: is sprint performance of geckos maximal at low body temperatures? *Physiol Zool*, 62: 488–504
- Ikeuchi I.** 2004. Male and female reproductive cycles of the Japanese gecko, *Gekko japonicus*, in Kyoto, Japan. *J Herpetol*, 38: 269–274
- Ikeuchi I., Mori A., Hasegawa M.** 2005. Natural history of

- Phelsuma madagascariensis kochi* from a dry forest in Madagascar. *Amphibia-Reptilia*, 26: 475–483
- Ji X., Wang P. C., Hong W. X.** 1991. The reproductive ecology of the gecko *Gekko japonicus*. *Acta Zool Sinica*, 37: 185–192
- Jono T., Inui Y.** 2012. Secret calls from under the eaves: acoustic behavior of the Japanese house gecko, *Gekko japonicus*. *Copeia*, 2012: 145–149
- Kerr G. D., Bull C. M.** 2006. Exclusive core areas in overlapping ranges of the sleepy lizard, *Tiliqua rugosa*. *Behav Ecol*, 17: 380–391
- Kim D. I., Choi W. J., Park I. K., Kim J. S., Kim I. H., Park D.** 2018. Comparisons of microhabitat use of Schlegel's Japanese gecko (*Gekko japonicus*) among three populations and four land cover types. *J Ecol Environ*, 42: 198–204
- Kim D. I., Park I. K., Kim J. S., Ota H., Choi W. J., Kim I. H., Park D.** 2019. Spring and summer microhabitat use by Schlegel's Japanese gecko (*Gekko japonicus*), in urban areas. *Anim Cells Syst*, 23: 64–70
- Kim I. H., Ra N. Y., Park D.** 2012. Habitat use, home range, and hibernaculum of the Mongolian racerunner, *Eremias argus* (Lacertidae, Reptilia) in a coastal sand dune in South Korea. *Asian Herpetol Res*, 3: 133–140
- Klawinski P. D.** 1991. Home range, activity and spatial distribution of the Mediterranean gecko, *Hemidactylus turcicus*. MS Thesis, Stephen F. Austin State University
- Lee J. N., Kang S. G., Lee I. S.** 2004. The study on the *Gekko japonicus* in Korea. *Bull Basic Sci Res Inst Kyeongsung Univ*, 16: 57–63
- Locey K. J., Stone P. A.** 2006. Factors affecting range expansion in the introduced Mediterranean gecko, *Hemidactylus turcicus*. *J Herpetol*, 40: 526–530
- Manteuffel V. M., Eiblmaier M.** 2008. The influence of competitor density on space use in juvenile striped plateau lizards (*Sceloporus virgatus*). *Acta Oecol*, 33: 365–371
- McIvor I. R.** 1972. Ecology of a population of *Hoplodactylus pacificus*, the common New Zealand gecko (Reptilia: Gekkonidae). MS Thesis, University of Canterbury
- Norden A. W., Norden B. B.** 1991. The Mediterranean gecko (*Hemidactylus turcicus*) in Baltimore, Maryland. *Maryland Nat*, 33: 57–58
- Ota H., Tanaka S.** 1996. Gekkonidae and Eublepharidae. In Sengoku S., Hikida T., Matsui M., Nakaya K. (Eds.), *The Encyclopedia of Animals in Japan 5, Amphibians, Reptiles, Chondrichthyes*. Tokyo, Japan: Heibonsha Ltd. Publishers
- Park I. K., Kim D. I., Jang S. Y., Kim D. Y., Choi W. J., Kim J. S., Koo K. S., Park D.** 2018. Preference and competition for shelters at day and night between adult and juvenile Schlegel's Japanese gecko (*Gekko japonicus*) in an indoor vivarium. *Korean J Environ Ecol*, 32: 373–380
- Perry G., Garland T.** 2002. Lizard home ranges revised: effects of sex, body size, diet, habitat, and phylogeny. *Ecology*, 83: 1870–1885
- Ra N. Y., Sung H. C., Cheong S. K., Lee J. H., Eom J., Park D.** 2008. Habitat use and home range of the endangered Gold-spotted pond frog (*Rana chosenica*). *Zool Sci*, 25: 894–903
- Robles C. I., Halloy M.** 2010. Core area overlap in a neotropical lizard, *Liolaemus quilmes*: relationship with territoriality and reproductive strategy. *Herpetol J*, 20: 243–248
- Rose B.** 1982. Lizard home range: methodology and functions. *J Herpetol*, 16: 253–269
- Rose F. L., Barbour C. D.** 1968. Ecology and reproductive cycles of the introduced gecko, *Hemidactylus turcicus*, in the Southern United States. *Am Midl Nat*, 79: 159–168
- Saenz D.** 1996. Dietary overview of *Hemidactylus turcicus* with possible implications of food partitioning. *J Herpetol*, 30: 461–466
- Stamps J. A.** 1977. Social behavior and spacing patterns in lizards. In Gans C. G., Tinkle D. W. (Eds.), *Biology of the Reptilia*, Vol. 7. Ecology and Behavior. New York, USA: Academic Press, 265–332
- Stellatelli O. A., Block C., Moreno-Azócar D. L., Vega L. E., Isacch J. P., Cruz F. B.** 2016. Scale dependency of *Liolaemus* lizards' home range in response to different environmental variables. *Curr Zool*, 62: 521–530
- Tawa Y., Jono T., Numata H.** 2014. Circadian and temperature control of activity in Schlegel's Japanese gecko, *Gekko japonicus* (Reptilia: Squamata: Gekkonidae). *Curr Herpetol*, 33: 121–128
- Toda M., Hikida T., Okada S., Ota H.** 2003. Contrasting patterns of genetic variation in the two sympatric geckos *Gekko tawaensis* and *G. japonicus* (Reptilia: Squamata) from western Japan, as revealed by allozyme analyses. *Heredity*, 90: 90–97
- Toda M., Yoshida T.** 2005. Issues and perspectives regarding invasive alien species of amphibians and reptiles in Japan. *Bull Herpetol Soc Jpn*, 2005: 139–149
- Wada T.** 2003. Distribution of house-dwelling geckos in Japan, based on a research using questionnaire. *Shizenshi-Kenkyu*, 3: 2–19
- Werner Y. L., Okada S., Ota H., Perry G., Tokunaga S.** 1997. Varied and fluctuating foraging modes in nocturnal lizards of the family Gekkonidae. *Asiatic Herpetol Res*, 7: 153–165
- Williams S. C., McBrayer L. D.** 2007. Selection of microhabitat by the introduced Mediterranean gecko, *Hemidactylus turcicus*: influence of ambient light and distance to refuge. *Southwest Nat*, 52: 578–585
- Winkel D., Ji W.** 2014. Attaching radio-transmitters to geckos: trials and tribulations. *Herpetol Rev*, 45: 13–17
- Zhang Y. P., Du W. G., Zhu L. J.** 2009. Differences in body size and female reproductive traits between two sympatric geckos, *Gekko japonicus* and *Gekko hokouensis*. *Folia Zool*, 58: 113–122
- Zhang Y. P., Ping J., Li Hao S., Zhou H. B.** 2016. Temporal and spatial variation in life history traits of the Japanese gecko, *Gekko japonicus*. *Herpetol J*, 26: 305–311
- Zhao E. M., Adler K.** 1993. *Herpetology of China*. Oxford, Ohio, USA: Society for the Study of Amphibians and Reptiles

Appendix

Table S1 Variables which used and analyzed in the study.

Category (No. of variables)	Variables
Capture-based variable (2)	Body surface temperature upon locating individual
	Time after sunset upon locating individual
Day-based variable (4)	Mean air temperature
	Mean humidity
	Precipitation
	Mean moved distance of the individuals
Individual-based variable (14)	Number of detections
	Detection ratio in building and tree microhabitats
	Farthest distance moved from the building (cable-car or toilet building) to the surrounding forest
	Mean daily moved distance throughout the study period (for building microhabitat, tree microhabitat, and pooled data)
	Home range (MCP, Kernel 50, and Kernel 95)
Home range overlap ratio (individual and area overlap ratio \times MCP and Kernel 50)	

Table S2 Summary of Schlegel's Japanese gecko (*Gekko japonicus*) radio-tracking results in a suburban city park between June 8 and July 10 and between Oct. 2 and Oct. 24, 2018. Abbreviations follow: SVL, snout-vent length; BW, body weight; No., number; art., artificial; nat., natural; ind., individual; intra, intra-sexual; inter, inter-sexual.

Sex	SVL (cm)	BW (g)	No. detection	Detection in building (%)	Daily moved distance (m)			Farthest distance to forest (m)	Home range (m ²)			Home range individual and area overlap					
					Building	Tree	Pooled		MCP	Kernel 50	Kernel 95	No. ind (intra/inter)	Ind. ratio (%) (intra/inter)	Area ratio (%) (intra/inter)	No. ind (intra/inter)	Ind. ratio (%) (intra/inter)	Area ratio (%) (intra/inter)
F	68.4	7.1	53	67.9	5.4	4.6	5.1	8.8	175.5	12.9	95	5(1/4)	35.7 (16.7/57.1)	23.0 (34.7/20.0)	1 (0/1)	7.1 (0/7.1)	7.8 (0/7.8)
F	66.7	6.4	52	25.0	4.3	13.2	11.1	20.5	224.2	34.7	262.5	4(1/3)	28.6 (16.7/42.9)	48.8 (46.0/49.8)	1 (1/0)	7.1 (7.1/0)	51.9 (51.9/0)
F	66.5	5.7	52	42.3	5.9	11.3	8.9	20.0	190.4	41.5	251	5(2/3)	35.7 (33.3/42.9)	23.2 (3.0/36.7)	2 (0/2)	14.3 (0/14.3)	60.7 (0/60.7)
F	71.3	5.0	45	84.4	5.9	11.0	7.1	6.4	35.6	2.6	31.7	5(2/3)	35.7 (33.3/42.9)	54.2 (48.9/59.8)	1 (1/0)	7.1 (7.1/0)	92.3 (92.3/0)
F	61.4	5.3	17	100.0	2.1	-	2.1	0.0	10.0	5.4	24.5	3(1/2)	21.4 (16.7/28.6)	33.3 (46.0/27.0)	3 (1/2)	21.4 (7.1/14.3)	46.9 (51.9/44.4)
F	58.8	5.2	47	53.2	2.4	5.8	4.1	20.0	176.1	41.1	190.3	5(2/3)	35.7 (33.3/42.9)	40.2 (51.5/32.7)	4 (1/3)	28.6 (7.1/21.4)	55.3 (92.3/43.0)
F	66.9	5.8	30	70.0	1.6	8.4	3.6	12.1	55.1	5.0	59.9	4(1/3)	28.6 (16.7/42.9)	57.9 (34.7/65.6)	1 (0/1)	7.1 (0/7.1)	62.0 (0/62.0)
Breeding season	M	61.0	4.4	45	31.1	5.9	16.6	13.2	15.5	309.4	27.7	5(3/2)	35.7 (50.0/28.6)	72.9 (66.1/83.2)	1 (1/0)	7.1 (7.1/0)	68.9 (68.9/0)
M	60.3	4.4	36	66.7	2.9	10.8	5.6	17.3	221.3	40.5	292	8(3/5)	57.1 (50.0/71.4)	24.6 (36.2/17.7)	5 (2/3)	35.7 (14.3/21.4)	45.8 (50.0/43.0)
M	61.9	5.2	54	44.4	7.4	12.8	10.4	16.5	148.0	19.2	159.9	3(1/2)	21.4 (16.7/28.6)	53.6 (28.1/66.3)	2 (1/1)	14.3 (7.1/7.13)	27.7 (14.6/40.7)
M	62.5	4.5	36	86.1	4.5	11.4	6.2	10.9	64.7	21.3	152.9	5(2/3)	35.7 (33.3/42.9)	50.1 (28.1/66.3)	3 (1/2)	21.4 (7.1/14.3)	78.6 (85.4/75.1)
M	61.9	4.3	47	61.7	3.6	8.8	5.5	12.9	143.7	22.7	125.3	2(1/1)	14.3 (16.7/14.3)	7.6 (10.2/5.1)	1 (0/1)	7.1 (0/7.1)	7.8 (0/7.8)
M	62.8	5.2	37	24.3	2.2	7.5	6.1	15.3	73.8	6.1	54.5	4(2/2)	28.6 (33.3/28.6)	61.4 (93.9/28.9)	2 (2/0)	14.3 (14.3/0)	41.8 (41.8/0)
M	63.9	5.8	20	5.0	-	9.8	9.8	16.3	106.5	14.1	129.1	4(2/2)	28.6 (33.3/28.6)	57.5 (90.9/24.0)	1 (1/0)	7.1 (7.1/0)	14.8 (14.8/0)
Non-breeding season	M	58.7	5.2	19	68.4	7.0	7.5	7.1	15.0	164.3	109.6	6(2/4)	42.9 (33.3/57.1)	31.4 (36.5/28.9)	1 (0/1)	7.1 (0/7.1)	19.2 (0/19.2)
F	64.5	6.0	16	6.3	0.3	1.0	2.1	2.1	3.3	1.1	4.1	0 (0/0)	0.0 (0/0)	0.0 (0/0)	0 (0/0)	0.0 (0/0)	0.0 (0/0)
F	71.2	6.6	44	18.2	1.2	0.8	1.7	4.2	10.2	1.2	7.4	0 (0/0)	0.0 (0/0)	0.0 (0/0)	0 (0/0)	0.0 (0/0)	0.0 (0/0)
M	62.6	4.5	40	100.0	0.7	-	1.4	0.0	2.8	0.5	2.9	1 (1/0)	14.3 (20.0/0)	32.1 (32.1/0)	0 (0/0)	0.0 (0/0)	0.0 (0/0)
M	61.6	4.3	44	34.1	1.5	2.5	4.4	5.6	36.0	12.2	50.5	3 (2/1)	42.9 (40.0/16.7)	60.5 (49.8/81.8)	1 (1/0)	14.3 (14.3/0)	14.5 (14.5/0)
M	60.3	4.0	42	81.0	1.3	3.3	3.4	10.1	32.9	12.4	67.8	1 (0/1)	14.3 (0/16.7)	9.8 (0/9.8)	0 (0/0)	0.0 (0/0)	0.0 (0/0)
M	62.4	5.2	42	54.8	1.3	2.1	3.8	3.8	36.3	6.2	45.6	3 (2/1)	42.9 (40.0/16.7)	13.2 (12.2/15.2)	0 (0/0)	0.0 (0/0)	0.0 (0/0)
M	63.4	4.5	38	52.6	1.5	1.5	3.1	7.3	35.4	6.4	42.3	1 (1/0)	14.3 (20.0/0)	32.1 (32.1/0)	0 (0/0)	0.0 (0/0)	0.0 (0/0)
M	64.4	4.6	26	84.6	1.5	4.6	3.6	4.6	17.3	5.5	29.6	3 (2/1)	42.9 (40.0/16.7)	60.9 (52.0/78.8)	1 (1/0)	14.3 (14.3/0)	14.5 (14.5/0)

Table S3 Summary of the use of different structure types (the number of cases) by the Schlegel's Japanese gecko (*Gekko japonicus*), which introduced into a suburban city park based on different sex, time of day, and season.

Category Structure	Pooled	Sex		Time of day		Season	
		Male	Female	Day	Night	Breeding	Non-breeding
In/on building	357	224	133	171	186	237	120
In/on wooden path	81	42	39	38	43	49	32
In/on rock wall	23	16	7	14	9	21	2
Others (pole, iron)	16	14	2	8	8	7	9
On tree	399	226	173	184	215	270	129
On forest floor	6	4	2	1	5	6	0
Total	882	526	356	416	466	590	292
Chi-square test		$\chi^2 = 11.2, df = 5, P = 0.05$		$\chi^2 = 4.3, df = 5, P = 0.51$		$\chi^2 = 14.7, df = 5, P < 0.01$	

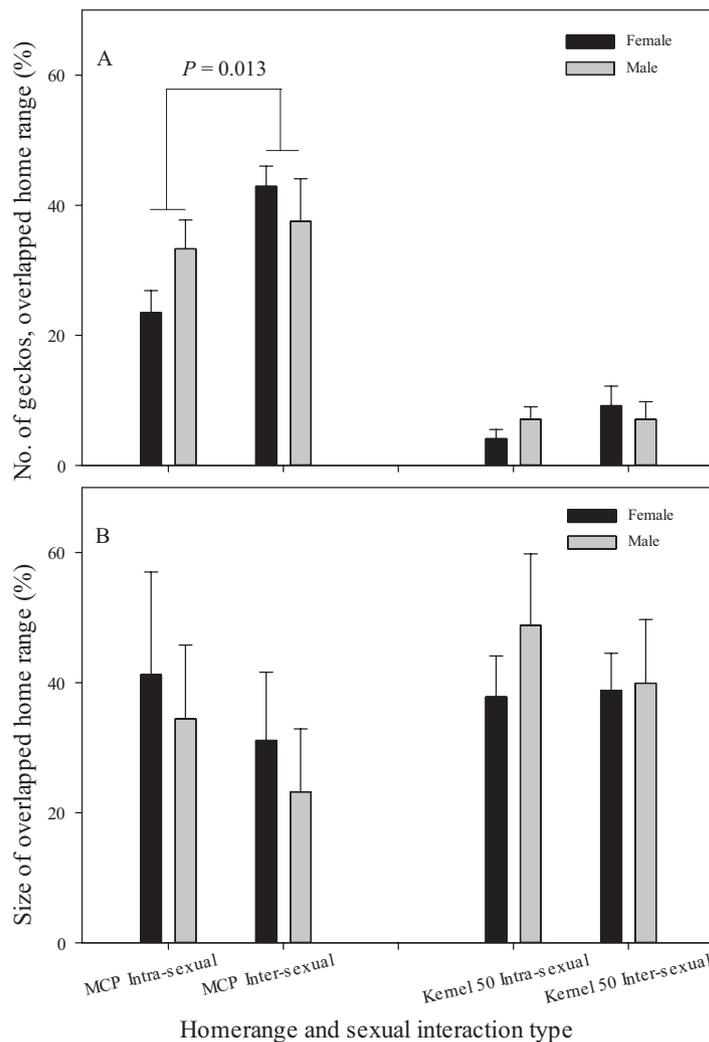


Figure S1 The individual (pooled) overlap ratio of MCP home range between inter-sexual individuals was significantly greater than the ratio between intra-sexual individuals in breeding season ($Z = 2.48, n = 15, P = 0.013$). Except that, other remaining comparisons between intra- and inter-sexual individuals and between males and females were not significant ($P_s > 0.05$). Due to small sample cases, we did not analyze the relationships in non-breeding season. For detailed data, see Supplementary Table S2.