Journal of Mammalogy, xx(x):1–9, 2018
DOI:10.1093/jmammal/gyy033

Home range of raccoon dogs in an urban green area of Tokyo, Japan

Ibuki Mitsuhashi, Takako Sako, Makito Teduka, Ririko Koizumi, Masayuki U. Saito, and Yayoi Kaneko*

Carnivore Ecology and Conservation Research Group, Tokyo University of Agriculture and Technology, Saiwaicho 3-5-8, Fuchu City, Tokyo 183-0054, Japan (IM, RK, MUS, YK)
Imperial Household Agency, Chiyoda 1-1, Chiyoda-ku, Tokyo 100-8111, Japan (TS)
Fieldwork Office, Asahicho 4-29-2, Akishima City, Tokyo 196-0025, Japan (MT)

* *Correspondent: ykaneko7946@gmail.com*

The raccoon dog (*Nyctereutes procyonoides viverrinus*) has recently become common in urban environments in Japan. We predicted that, like other carnivores adapted to urban environments, raccoon dogs in urban areas should have smaller home ranges than those in rural areas. We investigated the size of home ranges of raccoon dogs in the Akasaka Imperial Grounds, a 51-ha green area in central Tokyo. Between August 2012 and August 2014, 7 adult males and 4 adult females were radiotracked. Mean (± *SD*) home range size of these 11 raccoon dogs (100% minimum convex polygon = 17.6 ± 13.0 ha; 95% fixed kernel = 8.3 ± 5.7 ha) was smaller than that of raccoon dogs in rural areas obtained in previous studies, and core areas (75% local convex hull) averaged 3.7 ± 4.1 (*SD*) ha. We detected no seasonal changes in home range size. These results were consistent with the notion that urban carnivores typically have small home ranges. The small home range size seems to be explained by abundance of food resources, restricted environment, and the high population density of raccoon dogs in the urban green area.

Key words: home range, *Nyctereutes procyonoides*, raccoon dog, radiotelemetry, urban wildlife

Urbanization is one of the major drivers of biodiversity loss (McKinney 2006), and its progress has reduced the range of many species, particularly carnivores (Cardillo et al. 2004; Bateman and Fleming 2012). The urban area is a challenging environment for many terrestrial mammals, especially carnivores, because natural resources (e.g., vegetation) are scarce, habitats are fragmented, and phenomena such as light pollution and heat islands occur (Bateman and Fleming 2012). However, carnivores such as the common raccoon (*Procyon lotor*), European badger (*Meles meles*), feral cat (*Felis catus*), and red fox (*Vulpes vulpes*) have adapted and colonized the urban environment, where their population densities are higher and home ranges are smaller than in rural and forest areas. These differences seem to be influenced by the abundance of artificial food resources in urban areas (e.g., Prange et al. 2004; Tennent and Downs 2008; Davison et al. 2009; Rosatte and Allan 2009).

The relationship between home range size and urban development is sometimes paradoxical. Coyotes (*Canis latrans*), for example, typically avoid land-use types associated with human activity (e.g., residential areas, urban grassland), and the size of their home ranges is positively associated with the amount of human-related development (Gehrt et al. 2009). Sizes of home ranges of carnivores are influenced by many factors, including distribution and amount of food resources (Prange et al. 2004; Wehtje and Gompper 2011), body size (Harestad and Bunnel 1979), sex (Kaneko et al. 2014), season (Bixler and Gittleman 2000), and population density (Bjornlie et al. 2014), and the effects of urbanization vary among species and even among different populations of the same species (Davison et al. 2009; Herr et al. 2009; Bateman and Fleming 2012). Thus, conservation and management decisions involving urban carnivores should be based on detailed behavioral studies of local populations (Davison et al. 2009).

In the special wards of Tokyo, one of the most urbanized areas of Japan, 19 mammalian species occur, including the Japanese red fox (*V. v. japonica*), the Japanese badger (*Meles anakuma*), and the Japanese marten (*Martes melampus*). Each of these species of carnivore has become locally extinct with the progress of urbanization (Bureau of Environment, Tokyo Metropolitan Government 2010). Based on the "plan for the 2020 Tokyo," the Tokyo Metropolitan Government has been promoting the preservation of urban green areas and establishment of an ecological network.

The raccoon dog (*Nyctereutes procyonoides*) is a medium-sized (3–10 kg) canid endemic to far eastern Asia (Kauhala and Saeki 2004) and it is considered an invasive species in Europe (Mulder 2012). The Japanese subspecies *N. p. viverrinus* and *N. p. albus* are morphologically and genetically different from mainland populations and thus might be distinct from continental subspecies (Kim et al. 2013, 2015). In Japan, raccoon dogs occur in various landscape types, including forests, subalpine areas, agricultural landscapes, and urban areas (Saeki 2009). *Nyctereutes p. viverrinus* is the only native carnivore successfully inhabiting the special wards of Tokyo Metropolis (Teduka and Endo 2005; Sako et al. 2008; Tsuriya 2013; Kawada et al. 2014). Historically, with the increase in urbanization, raccoon dogs became locally extinct in the special wards of Tokyo in the 1950s (Obara 1982). Their re-colonization was confirmed in the late 1990s, and it is considered a reintroduced population (Endo et al. 2000). The number of raccoon dogs observed in the special wards has recently been increasing (Sako et al. 2008) and raccoon dogs have been observed in the study area since the early 1990s (Teduka and Endo 2005; Sako et al. 2008).

The home range size of raccoon dogs in Japan varied from 10 ha on an islet (Ikeda 1982) to 610 ha in the subalpine zone (Yamamoto et al. 1994), and in the typical landscapes of *satoyama* (a mosaic of forest and agricultural landscapes maintained through traditional use by local people) it averaged 111 ha (Saeki et al. 2007). In an urban habitat, Kawada et al. (2014) reported that home ranges of raccoon dogs were almost completely encompassed within a 115-ha green area, and monthly home range sizes varied from 5 to 30 ha. In addition, in Akasaka Imperial Grounds (AIG), Koizumi et al. (2017) reported that home ranges of raccoon dogs in summer–autumn varied from 7 to 37 ha. To understand the amount of habitat necessary to maintain urban raccoon dog populations, it is paramount to clarify annual, seasonal, and sexual variation in home range sizes of raccoon dogs in urban environments. If an urban green area is a suitable habitat for raccoon dogs, their home range sizes should be smaller than those of raccoon dogs in rural areas.

We examined the sizes of raccoon dog home ranges in an urban green area to determine if raccoon dogs in urban populations have smaller home ranges than those in rural populations as reported for other species, and to explore seasonal variation in home range size.

Materials and Methods

Study area.—The study was conducted in the AIG, a 51-ha green area in the urban core of Minato-ku, Tokyo (43,568 people/km^2 during the day and 10,085 people/km^2 during the night), which is on the edge of the distributional range of the raccoon dog in Tokyo urban areas (Fig. 1). The urban core of Tokyo has a warm-temperate humid climate, and its mean annual rainfall and average temperature from 2012 to 2014 were 1,664 mm and 16.7°C, respectively (Japan Meteorological Agency 2015). The State Guest House (12 ha) is adjacent to the north side of the AIG and both areas are surrounded by 1–4 lanes of high traffic flow (some sections have over 50,000 vehicles/day—Ministry of Land, Infrastructure, Transport and Tourism 2011). In the vicinity are offices, commercial facilities, and densely populated residential areas where development is substantial. The main land uses of the AIG and State Guest House are forest (34 ha; 52%), developed areas such as buildings and roads (15 ha; 24%), open grassland (11 ha; 18%), and aquatic areas such as ponds (2 ha; 4%; Fig. 2). Entry of the general public into the AIG and State Guest House is restricted; garden managers and business operators can only enter during the day, and only a few people and security guards can enter at night.

Live captures.—Due to restricted access to the study area, the trapping period was limited. During the 5 one-night trapping sessions conducted between August 2012 and March 2014, 11 adult raccoon dogs (7 males and 4 females; Table 1) were captured, using 2 trapping methods: iron-mesh wire box traps (32 × 26 × 82 cm, SMC animal trap, Surge Miyawaki, Co., Ltd., Tokyo, Japan; 31 × 25 × 81 cm, Havahart, Woodstream Corporation, Lititz, Pennsylvania) and padded food-hold traps (Soft Catch, Woodstream Corporation). The traps were checked twice during the night and closed during the day. Captured individuals were immobilized with an injection of 0.2–0.3 ml/kg ketamine hydrochloride (Ketalar, Daiichi Sankyo, Tokyo, Japan), 0.1 ml/kg atropine sulfate (Mitsubishi Tanabe Pharma, Osaka, Japan), and 0.1 ml/kg medetomidine chloride (Domitor, Nippon Zenyaku Kogyo Co., Ltd., Tokyo, Japan). Each individual was weighed and measured, its sex and age class were determined (via tooth wear and reproductive condition), and VHF radiocollars were fitted to their necks (≤75 g, under 3% body mass; Biotrack, Dorset, United Kingdom). After recovering from immobilization, individuals were released at the capture site. Trapping and handling animals followed the guidelines of the American Society of Mammalogists (Sikes et al. 2016).

Radiotelemetry.—Locations of raccoon dogs were obtained using FT-290mk-II/AR receivers (Yaesu Musen, Tokyo, Japan) and hand-held Yagi antennas or by visual observation. Radiotracking was conducted 1–3 nights per month, typically from 1600–2100 h or 1600–0800 h, and all the tracking surveys were performed from the AIG area, even when raccoon dogs entered the State Guest House area. To minimize telemetry error, 2 or 3 locations were obtained as close to monitored individuals as possible. Due to the extensive network of human paths within the AIG, it was frequently possible to locate individuals at the maximum signal level. Azimuths for a single location were recorded within a 10-min interval; however, most (80.6%) consecutive azimuths were recorded within 3 min. Sequential locations obtained for the same individual in less than 15-min intervals were excluded from the analyses.

Home range estimation.—Home range size was estimated using 100% and 95% minimum convex polygons (MCP100 and MCP95, respectively). Because MCP is the most widely used method for estimating animal home ranges (Powell 2000), it was used here for comparison purposes despite its sensitivity to extreme data points and tendency to overestimate home range sizes (Harris et al. 1990; Powell 2000). Thus, 95% fixed kernel methods (FK95) with least squares cross-validation (Seaman

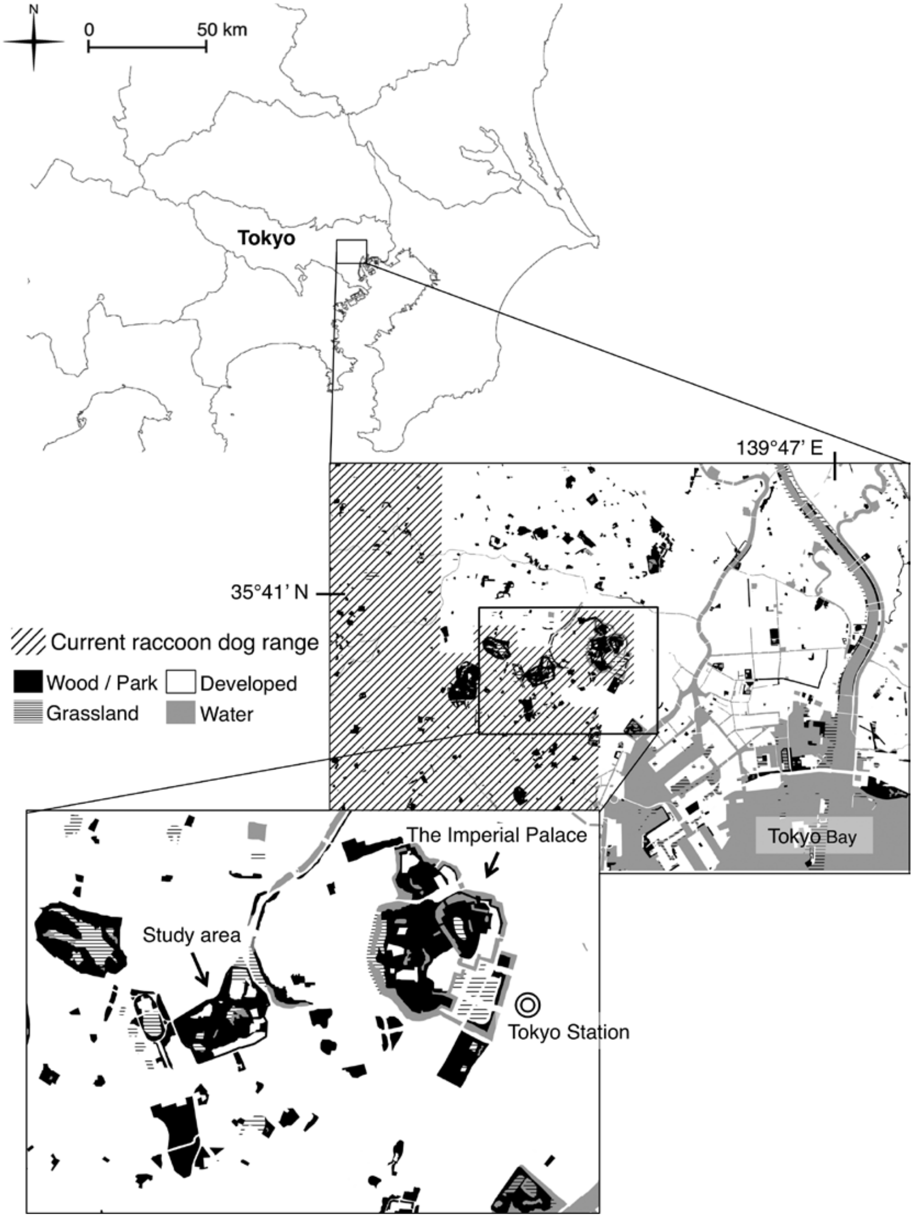

Fig. 1.—Location of study area, raccoon dog (*Nyctereutes procyonoides*) distribution, and land use within central Tokyo, Japan. The raccoon dog range was mapped based on mammal distribution survey data by the Biodiversity Center of Japan (2004), Kawada et al. (2014), Sako et al. (2008), Teduka and Endo (2005), and Tsuriya (2013), representing the period of 2000–2012.

and Powell 1996; Seaman et al. 1999) and 95% local convex hull (LCH95—Getz and Wilmers 2004; Getz et al. 2007) were also used. Although FK95 was used to facilitate comparisons to other studies, including those conducted in Japan (Saeki et al. 2007), LCH95 had the advantage of effectively excluding the areas not used by the animals (e.g., ponds, buildings) (Getz et al. 2007), which is important for accurate home range estimation in fragmented landscapes such as urban areas. The adaptive LCH method (the most robust LCH estimator—Getz et al. 2007) was selected and, as suggested by Getz et al. (2007), the *a*-value was parameterized as the greatest distance between all locations obtained for each individual.

Home range was calculated based on a minimum of 30 locations (Seaman et al. 1999), at least 5 tracked nights, and at least 3 months tracking period per individual per season. Swihart and Slade (1985b) suggested that data with independent sampling intervals were necessary for home range estimations. However, continuous tracking locations were used for home range estimations in the present study for the following reasons. First, there is a trade-off between "independence" and data size, with small data sets reducing the accuracy of home range estimates and disregarding biologically relevant information (De Solla et al. 1999). These authors also found that the accuracy of FK estimates improved at shorter time intervals despite the increase in autocorrelation among locations. In addition, the accuracy of LCH estimates increase as sample size increases (Getz and Wilmers 2004). Second, the use of MCP and LCH reduces the sensitivity to autocorrelation of successive locations, because these methods do

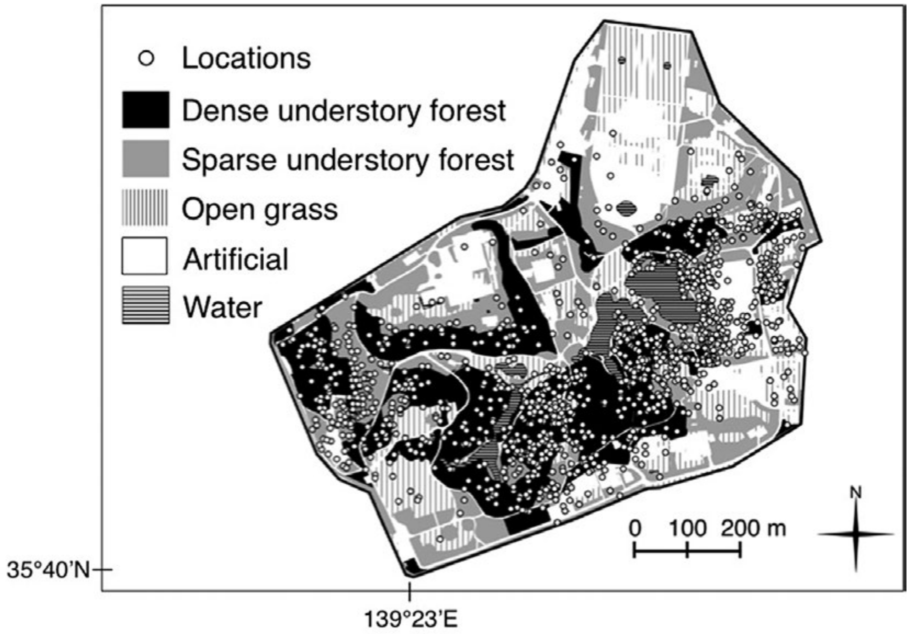

Fig. 2.—Land use in the Akasaka Imperial Grounds (AIG) and the State Guest House, and locations of 11 raccoon dogs (*Nyctereutes procyonoides*) radiotracked between 2012 and 2014, in central Tokyo, Japan. Tracking surveys were only performed from the AIG.

Table 1.—Summary of telemetry data and home range sizes (ha) for 11 radiocollared adult raccoon dogs (*Nyctereutes procyonoides*) in the urban green area of the Akasaka Imperial Grounds (AIG), central Tokyo, Japan. FK = fixed kernel; LCH = local convex hull home ranges; MCP = minimum convex polygon.

Raccoon dog ID	Weight[a] (kg)	*N* of fixes	Tracking period	Tracking period (days)	Reason for the end of tracking	MCP100	MCP95	FK95	LCH95	LCH75
Female										
F1	3.5	110	Aug. 2012–June 2013	303	Missing	31.9	30.7	12.2	12.4	5.8
F2	5.1	90	Apr.–Aug. 2014	140	End of study	9.8	6.2	5.8	4.7	1.9
F3	2.8	88	Apr.–Aug. 2014	140	End of study	5.9	4.5	2.9	3.3	1.2
F4	3.3	78	Apr.–Aug. 2014	140	End of study	5.9	3.9	6.0	2.5	1.3
					Mean ± *SD*	13.4 ± 12.5	11.3 ± 12.9	6.7 ± 3.9	5.7 ± 4.5	2.5 ± 2.2
Male										
M1	3.7	155	Aug. 2012–Aug. 2013	366	Missing	49.2	44.7	22.7	32.8	15.4
M2	4.2	245	Aug. 2012–Jan. 2014	514	Dead	18.5	11.3	8.4	7.7	2.8
M3	3.9	286	Aug. 2012–Mar. 2014	583	Battery exhaustion	7.4	5.8	6.9	4.9	2.6
M4	3.9	160	Aug. 2012–July 2013, Apr.–July 2014	346, 89	Trouble with transmitter/collar dropped off	20.9	8.9	5.4	5.8	2.4
M5	3.2	80	Apr.–Aug. 2014	140	End of study	14.9	5.9	2.2	5.4	2.3
M6	3.6	79	Apr.–Aug. 2014	140	End of study	14.3	3.2	6.2	3.4	1.9
M7	3.5	83	Apr.–Aug. 2014	140	End of study	14.8	11.3	12.4	5.7	2.8
					Mean ± *SD*	20.0 ± 13.6	13.0 ± 14.3	9.2 ± 6.7	9.4 ± 10.4	4.3 ± 4.9

[a] Data on the first capture.

not adhere to the assumption that data points are independent (Swihart and Slade 1985a; Getz and Wilmers 2004). In the present study, an increasing number of locations had no effect on home range size, but the relationship between sample size and home range size was stronger for FK95 and LCH95 estimates than for MCP95 (Table 2), and FK95 and LCH95 estimates were correlated with MCP95 estimates (Pearson's correlation; FK95: $r = 0.78$, $P < 0.01$, $n = 11$; LCH95: $r = 0.95$, $P < 0.01$). Therefore, FK and LCH methods were only used for estimates of home range size and excluded from subsequent analyses.

Table 2.—Pearson's correlation coefficient (*r*), *P*-, and *t*-values between the number of locations and home range sizes for 11 raccoon dogs (*Nyctereutes procyonoides*) radiotracked between August 2012 and August 2014 in the Akasaka Imprial Grounds (AIG), central Tokyo, Japan. FK = fixed kernel; LCH = local convex hull home ranges; MCP = minimum convex polygon.

	MCP100	MCP95	FK95	LCH95
P	0.78	0.54	0.31	0.42
r	0.10	0.21	0.34	0.27
t	0.29	0.63	1.08	0.84

Core areas were estimated using LCH, because this method incorporates the frequency of space utilization and is robust to temporal changes of space use patterns (Getz et al. 2007). The number of locations used for estimates of core areas was determined by plotting utilization distribution graphs in which the X-axis was the percent of locations used by each animal and the Y-axis was the percent of home range sizes (Kauhala et al. 1993); slope discontinuity was used as an indicator of how many locations constituted the core. The 75% distribution area was used as the core area because in most (81.8%) cases, the slope discontinuity appeared in the 70–80% range. Seasons were defined as mating-gestation (December–next April), pup-rearing (May–August), and autumn (fat accumulation and dispersal; September–November) to reflect the life cycle of the raccoon dog (Ikeda 1983; Saeki 2009). All statistical analyses were performed in R 3.0.1 (R Development Core Team 2013): MCP and FK estimates were performed in the adehabitatHR package (Calenge 2006) and LCH estimates in the tlocoh package (Lyons et al. 2013); home range and core area size differences between sexes and seasons were evaluated using the Wilcoxon rank sum test at the 0.05 level of significance.

RESULTS

Home range.—All locations obtained for the 11 tracked raccoon dogs were within the AIG and the State Guest House (Fig. 2). According to MCP100, home range sizes varied from 5.9 to 49.2 ha (Table 1) and the mean home range size was 17.6 ha ($SD = 13.0$) for 100% and 12.4 ha ($SD = 13.2$) for 95% of the locations. According to FK95 and LCH95, mean home range sizes were 8.3 ha ($SD = 5.7$) and 8.0 ha ($SD = 8.2$), respectively. For total home ranges, there were no significant differences between males and females, regardless of the home range estimator used (Wilcoxon rank sum test, $7 \le W \le 11$, $n_1 = 4$, $n_2 = 7$, $0.23 \le P \le 0.65$; Table 1). The size of home ranges during the pup-rearing and autumn seasons were not significantly different (Wilcoxon rank sum test, $22 \le W \le 40$, $n_1 = 10$, $n_2 = 7$, $0.23 \le P \le 0.67$; Table 3). Although statistical tests could not be performed for the mating-gestation season due to its small sample size, home range sizes during this season were similar to those during other seasons (Table 3).

Considering individuals, male M1 had the largest home range, as he used almost the entire study area. The next largest home range belonged to female F1. The home range size of F1 was stable from August 2012 to February 2013 but increased after March 2013. This was likely influenced by her reproductive condition because she was parous in the summer of 2012 but we had no evidence of breeding in 2013. Signals from M1 and F1 stopped being received during the study and, despite several searches around the study area, they were not found.

Core area.—The mean size of core areas of raccoon dogs was 3.7 ha ($SD = 4.1$) and core areas covered 20.0% ($SD = 0.07$) of their MCP100 home ranges (Table 3). As with the home ranges, size of core areas did not differ between the sexes (Wilcoxon rank sum test, $W = 6$, $n_1 = 4$, $n_2 = 7$, $P = 0.16$) or between pup-rearing and autumn seasons (Wilcoxon rank sum test, $W = 38$, $n_1 = 10$, $n_2 = 7$, $P = 0.81$).

DISCUSSION

The average home range size of adult raccoon dogs in the AIG was smaller than estimates from more natural study areas, including forest, subalpine, rural, or suburban (Ikeda 1982; Ward and Wurster-Hill 1989; Yamamoto 1993; Yamamoto et al. 1994; Sonoda and Kuramoto 2004; Saeki et al. 2007; Seki and Koganezawa 2011). The home ranges reported here also seem to be smaller than those estimated for one other urban area in Tokyo (Kaneko et al. 2008) but larger than another (Kawada et al. 2014). Although method of calculation may confound comparisons, we believe that the home ranges used by raccoon dogs reported here are among the smallest reported in Japan and elsewhere (Table 4).

Reduction in home range size has been reported for several species of carnivores inhabiting cities, including common raccoons, European badgers, and red foxes, which was attributed to high food availability, such as scavenged food or food provided by local people (e.g., Prange et al. 2004; Davison et al. 2009; Rosatte and Allan 2009). However, raccoon dogs in AIG make little use of human garbage (Teduka and Endo 2005), and, therefore, anthropogenically derived food distribution and availability does not seem likely to have influenced the small home range sizes reported here.

According to Kauhala et al. (2010), the home range size of *N. p. ussuriensis* tends to be smaller when it includes grassland and garden habitats, and many habitat types per unit area. Although the habitat types in the AIG differed from rural areas or mountains, habitats of the AIG included man-made ponds, lawns, planted small forests, and residential buildings, which were arranged in a mosaic pattern. Forests, in particular, were managed differently in the AIG compared to in rural areas

Table 3.—Mean seasonal home range and core area sizes (ha) for 11 adult raccoon dogs (*Nyctereutes procyonoides*) radiotracked between August 2012 and August 2014 in the Akasaka Imperial Grounds (AIG), central Tokyo, Japan. Two numbers divided by the forward slash represent the 2 home range or core area sizes estimated for the mating-gestation season. FK = fixed kernel; LCH = local convex hull home ranges; MCP = minimum convex polygon.

Season	*N* of seasonal home ranges	Home range			Core area
		MCP95	FK95	LCH95	LCH75
Mating-gestation	2	3.6/3.6	8.0/4.1	2.8/2.1	1.2 / 1.4
Pup-rearing	10	8.6 ± 12.1	2.5 ± 1.7	5.0 ± 3.6	1.1 ± 0.6
Autumn	7	5.8 ± 5.2	7.4 ± 4.9	3.6 ± 3.7	2.2 ± 2.2

Table 4.—Comparison of home range sizes (ha), locations, habitats, and tracking characteristics among all studies of raccoon dogs (*Nyctereutes procyonoides*) based on radiotracking method, conducted between 1977 and 2014. FK = fixed kernel home ranges; MCP = minimum convex polygon; na = not available.

Study	Country	Location	Habitat	*N* of estimated home ranges	Tracking period	Mean home range size ± *SD* (range)	
						100% MCP	95% FK
Ikeda (1982)	Japan	33°08′N 129°40′E	Islet	3	4–12 days	10 (8–12)	na
Present study	Japan	35°40′N 139°43′E	Urban	11	5–20 months (Aug. 2012–Aug. 2014)	18 ± 13 (6–49)	8 ± 6 (2–23)
Kawada et al. (2014)	Japan	35°41′N 139°45′E	Urban	6 (mean of monthly home ranges for 6 raccoon dog each)	3–25 months (Dec. 2007–Dec. 2009)	No mean value (5–30)	na
Kaneko et al. (2008)	Japan	35°42′N 139°23′E	Urban	14	1–9 months (Oct. 2004–June 2007)	73	na
Yamamoto (1993)	Japan	35°36′N 139°33′E	Suburban	5	9–37 days (Aug. 1992–Jan. 1993)	31 (15–44)	na
Sonoda and Kuramoto (2004)	Japan	35°35′N 139°25′E 35°36′N 139°33′E	Suburban	6	2–10 days (Dec. 2001–Jan. 2004)	53 ± 32 (17–84)	na
Saeki (2001); Saeki et al. (2007)	Japan	35°22′N 140°18′E	Rural	17	2–38 months	278 (29–1,252)	111 (23–228)
Ward and Wurster-Hill (1989)	Japan	39°48′N 140°13′E	Forest	5	5–20 days (Nov.–Dec. 1987)	59 (47–81)	na
Ikeda (1982)	Japan	31°41′N 130°51′E	Plateau	5 (fixes >30)	4–12 days	30 (13–51)	na
Ward and Wurster-Hill (1989)	Japan	31°41′N 130°51′E	Plateau	4	5–20 days (Nov.–Dec. 1987)	49 (31–63)	na
Seki and Koganezawa (2011)	Japan	36°45′N 139°25′E	Subalpine	16 seasonal home ranges (6 raccoon dogs)	Oct. 2006–June 2007	na	(45–386)
Yamamoto et al. (1994)	Japan	35°53′N 138°10′E	Subalpine	12	3–8 months	610	na
Choi and Park (2006)	South Korea	35°21′N 127°28′E	Rural	9	61–331 days	80 ± 53 (35–202)	na
Kauhala et al. (2010)	Finland	60°26′N 22°10′E	Periurban	16	May–Aug. (2005–2007)	130 ± 46	107 ± 31
Kauhala and Auttila (2010)	Finland	60°26′N 22°10′E	Periurban	19	May–Aug. (2005–2008)	na	104 ± 30
Kauhala et al. (2010)	Finland	61°10′N 24°50′E	Rural	14	May–Aug. (2005–2007)	118 ± 61	93 ± 31
Kauhala and Auttila (2010)	Finland	61°10′N 24°50′E	Rural	17	May–Aug. (2005–2008)	na	99 ± 40
Kauhala et al. (2006)	Finland	60°32′N 27°41′E	Rural	17	Autumn 2000–Summer 2004	570 ± 256	390 ± 142
Kauhala et al. (1993)	Finland	61°14′N 25°10′E	Forest	37 seasonal home ranges (23 raccoon dogs)	Spring 1989–Autumn 1991	700	na
Drygala et al. (2000)	Germany	53°34′N 13°07′E	Rural	4 (adults)	June 1999–Oct. 1999	390 ± 261 *SE*	na
Drygala et al. (2008)	Germany	53°36′N 13°14′E	Rural	62 seasonal home ranges (females 28; males 33, 26 raccoon dogs)	Oct. 1999–Oct. 2003	551 ± 418 (male), 583 ± 398 (female)	352 ± 313 (male), 382 ± 297 (female)
Sutor and Schwarz (2012)	Germany	51°37′N 13°56′E	Rural	9	Feb. 2001–July 2004	313 ± 53	183 ± 154
Drygala and Zoller (2013)	Germany	53°55′N 11°56′E	Rural	13	July 2004–Dec. 2006	na	161 ± 75
Süld et al. (2017)	Estonia	58°24′N 26°32′E	Rural	2	Mar. 2012–Nov. 2013	232 (207–257)	na
Süld et al. (2017)	Estonia	58°25′N 25°01′E	Forest	3	May 2012–Nov. 2013	193 (167–236)	126 (112–155)

in that understory areas were mowed 2–4 times per year and these managed forests were interspersed with areas usually not maintained by humans. In addition, berry fruits like bayberry (*Morella rubra*) and ginkgo (*Ginkgo biloba*) were planted, and *Rubus hirsutus* grows naturally in forests. In the AIG, the raccoon dog was reported to mainly feed on insects, fruits, myriapods (*Myriapoda*), and birds throughout the year (Teduka and Endo 2005). Thus, the raccoon dog has access to and can switch among a variety of food items in the AIG, which would appear to make AIG suitable annual habitat.

The small home range sizes observed in the present study also might be because the AIG is a semi-closed environment, surrounded by heavy-trafficked roads. Raccoon dog individuals inhabiting green areas in the suburbs were reported to visit dumping grounds or private houses where food resources are provided and to use them as feeding areas (Yamamoto 1993). None of the individuals we tracked regularly crossed roads to use other adjacent green areas. Previous work reported raccoon dogs avoiding roads in a suburban setting in Japan (Kaneko et al. 2008) and in the Imperial Garden (Kawada et al. 2014). Roads and developed urban environments affected the dispersion of other medium-sized carnivores such as the common raccoon and bobcat (*Lynx rufus*—Prange et al. 2004; Riley et al. 2006). It is likely that heavily used roads or urban business districts affect the pattern of distribution, configuration, and size of home ranges of the raccoon dog.

In the AIG, seasonal changes of home range size were small: there was no significant difference in sizes of home ranges and core areas between summer (pup-rearing) and autumn (dispersal). In addition, home range size during the mating-gestation season did not differ from that in other seasons such as summer and autumn. Previously reported estimates of home range size of the raccoon dog found it varies seasonally and it is generally largest in autumn in mountainous or rural areas (Kauhala et al. 1993; Saeki et al. 2007; Drygala et al. 2008; Seki and Koganezawa 2011; Sutor and Schwarz 2012; Table 4). In rural areas of Japan, the home range size was larger in summer and autumn and smallest in winter and spring (Saeki et al. 2007; Saeki 2008). This is explained by assuming that a greater area is necessary when increasing food intake to accumulate fat in preparation for winter. Furthermore, reduction in home range size in winter is related to a decline in activity due to low temperature and snowfall (Kauhala et al. 2006; Saeki et al., 2007; Seki and Koganezawa 2011).

Temperature and precipitation vary seasonally and this variation has been related to the activity of raccoon dogs. Kauhala and Saeki (2004) reported that raccoon dogs inhabiting continental areas den during the coldest days of winter but become active when the temperature exceeds 0°C. In Japan, the raccoon dog does not hibernate but reduces its activity during winter (Seki and Koganezawa 2011). The present study area is warmer during winter than other places where raccoon dogs have been studied (Saeki et al. 2007; Seki and Koganezawa 2011), and the minimum temperatures were below 0°C only for 4 and 6 days in 2013 and in 2014, respectively (Japan Meteorological Agency 2015). Therefore, decreases in raccoon dog activity during winter might be rare in the AIG, which might explain the small seasonal changes of home range sizes that we observed.

Density may affect the socio-spatial relationship among carnivores that inhabit urban areas. Iwasaki et al. (2017) estimated that the population density of raccoon dogs in the AIG was 0.52 individuals/ha from 2012 to 2013. Although the population density of raccoon dogs in Japanese forests and rural areas is not known, the estimated density for forest areas in Finland (0.004–0.008 individuals/ha—Kauhala et al. 2006) and rural areas in Germany (0.010 individuals/ha—Drygala et al. 2008), both of which are introduced populations, is much lower than that found in the AIG. The density estimated in the AIG is comparable to the density reported for insular populations: 0.46–0.86 individuals/ha in Takashima islet (18.7 ha—Ikeda et al. 1979) and 0.40–1.00 individuals/ha in Matsuura island (26.6 ha—Ikeda 1982) in the Kyushu region. In an urban area in London, United Kingdom, home range sizes of red foxes increased when their density decreased due to the spread of a disease (mange). This occurred in the absence of change in the amount of food resources available (Baker et al. 2000). Similarly, the small home range sizes of raccoon dogs in the AIG might be the result of its high population density during this study. A high frequency of direct (encounters) or indirect (scent at shared latrines) communication (Koizumi et al. 2017) among raccoon dogs that signals density also may affect home range size.

Our results demonstrated that the home range sizes of raccoon dogs are small in an urban green area. Because the use of space by raccoon dogs is not likely affected by anthropogenically derived food in the AIG, their small home range size might be explained by habitat interspersion formed by garden elements and planted fruit trees, which may produce rich food resources for raccoon dogs, low human disturbance, and the somewhat insular nature of the study area. Furthermore, warmer weather in winter, and behavioral mechanisms (e.g., information exchange at latrines) at high population density might also influence home range size and stability over time. Our study had a small sample, but provided information that can help conserve this population of raccoon dogs. Small home range size in the AIG suggests that once the key habitat associations are identified, we can identify features that permit raccoon dogs to occur in an isolated green area, even in a highly urbanized landscape.

ACKNOWLEDGMENTS

We are particularly indebted to His Majesty Emperor Akihito and His Highness Prince Akishino for allowing this study, and we are grateful to Dr. S. Kawada, National Museum of Nature and Science, for enabling access to the Akasaka Imperial Grounds. We also specially thank the staff of the Gardens Division, Imperial Household Agency for their support during raccoon dogs' tracking. This study was partially supported by a Grant-in-Aid for Scientific Research (No. 26257404, 16H02996) from the Japan Society for the Promotion of Science, and a grant from the National Museum of Nature and Science.

Literature Cited

Baker, P. J., S. M. Funk, S. Harris, and P. C. L. White. 2000. Flexible spatial organization of urban foxes, *Vulpes vulpes*, before and during an outbreak of sarcoptic mange. Animal Behaviour 59:127–146.

Bateman, P. W., and P. A. Fleming. 2012. Big city life: carnivores in urban environments. Journal of Zoology 287:1–23.

Biodiversity Center of Japan. 2004. The National Survey on the Natural Environment report of the distributional survey of Japanese animals (mammals). Biodiversity Center of Japan, Tokyo, Japan (in Japanese).

Bixler, A., and J. Gittleman. 2000. Variation in home range and use of habitat in the striped skunk (*Mephitis mephitis*). Journal Zoology of London 251:525–533.

Bjornlie, D. D., F. T. Van Manen, M. R. Ebinger, M. A. Haroldson, D. J. Thompson, and C. M. Costello. 2014. Whitebark pine, population density, and home-range size of grizzly bears in the Greater Yellowstone Ecosystem. PLoS ONE 9:e88160.

Bureau of Environment, Tokyo Metropolitan Government. 2010. Red List of Threatened Species in Tokyo. Bureau of Environment, Tokyo Metropolitan Government, Tokyo, Japan (in Japanese).

Calenge, C. 2006. The package "adehabitat" for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modelling 197:516–519.

Cardillo, M., A. Purvis, W. Sechrest, J. L. Gittleman, J. Bielby, and G. M. Mace. 2004. Human population density and extinction risk in the world's carnivores. PLoS Biology 2:909–914.

Choi, T.-Y., and C.-H. Park. 2006. Home-range of raccoon dog *Nyctereutes procyonoides* living in the rural area of Korea. Journal of Ecology and Field Biology 29:259–263 (in Korean with English summary).

Davison, J., M. Huck, R. J. Delahay, and T. J. Roper. 2009. Restricted ranging behaviour in a high-density population of urban badgers. Journal of Zoology 277:45–53.

De Solla, S. R., R. Bonduriansky, and R. J. Brooks. 1999. Eliminating autocorrelation reduces biological relevance of home range estimates. Journal of Animal Ecology 68:221–234.

Drygala, F., H. M. Mix, N. Stier, and M. Roth. 2000. Preliminary findings from ecological studies of the raccoon dogs (*Nyctereutes procyonoides*) in eastern Germany. Zeitschrift für Ökologie und Naturschutz 9:147–152.

Drygala, F., N. Stier, H. Zoller, H. M. Mix, K. Bogelsack, and M. Roth. 2008. Spatial organisation and intra-specific relationship of the raccoon dog *Nyctereutes procyonoides* in Central Europe. Wildlife Biology 14:457–466.

Drygala, F., and H. Zoller. 2013. Spatial use and interaction of the invasive raccoon dog and the native red fox in Central Europe: competition or coexistence? European Journal of Wildlife Research 59:683–691.

Endo, H., T. Kuramochi, S. Kawashima, and M. Yoshiyuki. 2000. On the masked palm civet and the raccoon dog introduced to the Imperial Palace, Tokyo, Japan. Memoirs of the National Museum of Nature and Science 35:29–33.

Gehrt, S. D., C. Anchor, and L. A. White. 2009. Home range and landscape use of coyotes in a metropolitan landscape: conflict or coexistence? Journal of Mammalogy 90:1045–1057.

Getz, W. M., S. Fortmann-Roe, P. C. Cross, A. J. Lyons, S. J. Ryan, and C. C. Wilmers. 2007. LoCoH: nonparameteric kernel methods for constructing home ranges and utilization distributions. PLoS ONE 2:e207.

Getz, W. M., and C. C. Wilmers. 2004. A local nearest-neighbor convex-hull construction of home ranges and utilization distributions. Ecography 27:489–505.

Harestad, A. S., and F. L. Bunnel. 1979. Home range and body weight—a reevaluation. Ecology 60:389–402.

Harris, S., W. J. Cresswell, P. G. Forde, W. J. Trewhella, T. Woollard, and S. Wray. 1990. Home-range analysis using radio-tracking data—a review of problems and techniques particularly as applied to the study of mammals. Mammal Review 20:97–123.

Herr, J., L. Schley, and T. J. Roper. 2009. Socio-spatial organization of urban stone martens. Journal of Zoology 277:54–62.

Ikeda, H. 1982. Socio-ecological study on the raccoon dog, *Nyctereutes procyonoides viverrinus*, with reference to the habitat utilization pattern. Ph.D. dissertation, Kyushu University, Fukuoka, Japan.

Ikeda, H. 1983. Development of young and parental care of the raccoon dog, *Nyctereutes procyonoides viverrinus* TEMMINCK, in captivity. The Journal of the Mammalogical Society of Japan 9:229–236.

Ikeda, H., K. Eguchi, and Y. Ono. 1979. Home range utilization of a raccoon dog, *Nyctereutes procyonoides viverrinus*, TEMMINCK in a small islet in Western Kyushu. The Ecological Society of Japan 29:35–48.

Iwasaki, K., M. U. Saito, T. Sako, R. Koizumi, M. Teduka, and Y. Kaneko. 2017. Population estimation of raccoon dogs in the Akasaka Imperial Grounds using camera trap. Journal of Field Science 15:49–55 (in Japanese with English summary).

Japan Meteorological Agency. 2015. Past weather retrieving service. http://www.data.jma.go.jp/obd/stats/etrn/index.php. Accessed 7 November 2015.

Kaneko, Y., E. Kanda, S. Tashima, R. Masuda, C. Newman, and D. W. Macdonald. 2014. The socio-spatial dynamics of the Japanese badger (*Meles anakuma*). Journal of Mammalogy 95:290–300.

Kaneko, K., S. Maruyama, and O. Nagano. 2008. Habitat use of raccoon dogs (*Nyctereutes procyonoides*) in and around Showa Kinen National Government Park, Tokyo. Journal of the Japanese Institute of Landscape Architecture 71:859–864 (in Japanese with English summary).

Kauhala, K., and M. Auttila. 2010. Habitat preferences of the native badger and the invasive raccoon dog in southern Finland. Acta Theriologica 55:231–240.

Kauhala, K., E. Helle, and K. Taskinen. 1993. Home-range of the raccoon dog (*Nyctereutes procyonoides*) in southern Finland. Journal of Zoology 231:95–106.

Kauhala, K., K. Holmala, W. Lammers, and J. Schregel. 2006. Home ranges and densities of medium-sized carnivores in south-east Finland, with special reference to rabies spread. Acta Theriologica 51:1–13.

Kauhala, K., and M. Saeki. 2004. Raccoon dog. Pp. 136–142 in Canids: foxes, wolves, jackals and dogs. Status survey and conservation action plan (C. Sillero-Zubiri, M. Hoffmann, and D. W. Macdonald, eds.). IUCN/SSC Canid Specialist Group, Gland, Switzerland.

Kauhala, K., J. Schregel, and M. Auttila. 2010. Habitat impact on raccoon dog *Nyctereutes procyonoides* home range size in southern Finland. Acta Theriologica 55:371–380.

Kawada, S., M. Teduka, and T. Sako. 2014. Home ranges of the raccoon dog, *Nyctereutes procyonoides*, in the Imperial Palace estimated by radiotelemetry. Memoirs of the National Museum of Nature and Science 50:565–574 (in Japanese with English summary).

Kim, S. I., T. Oshida, H. Lee, M. S. Min, and J. Kimura. 2015. Evolutionary and biogeographical implications of variation in skull morphology of raccoon dogs (*Nyctereutes procyonoides*, Mammalia: Carnivora). Biological Journal of the Linnean Society 116:856–872.

Kim, S. I., et al. 2013. Phylogeography of Korean raccoon dogs: implications of peripheral isolation of a forest mammal in East Asia. Journal of Zoology 290:225–235.

Koizumi, R., T. Sako, M. Teduka, M. Kobori, M. U. Saito, and Y. Kaneko. 2017. Individual interaction at latrine sites of raccoon dogs in the Akasaka Imperial Grounds, central Tokyo. Journal of Field Science 15:7–13 (in Japanese with English summary).

Lyons, A., W. Turner, and W. Getz. 2013. Home range plus: a space-time characterization of movement over real landscapes. Movement Ecology 1:2.

McKinney, M. L. 2006. Urbanization as a major cause of biotic homogenization. Biological Conservation 127:247–260.

Ministry of Land, Infrastructure, Transport and Tourism. 2011. Road traffic census 2010. http://www.mlit.go.jp/road/census/h22-1/index.html. Accessed 7 November 2015.

Mulder, J. L. 2012. A review of the ecology of the raccoon dog (*Nyctereutes procyonoides*) in Europe. Lutra 55:101–127.

Obara, H. 1982. Mammals in Tokyo. Pp. 65–73 in Biohistory of Tokyo (M. Numata and H. Obara, eds.). Books Kinokuniya, Tokyo, Japan (in Japanese).

Powell, R. A. 2000. Animal home ranges and territories and home range estimators. Pp. 65–110 in Research techniques in animal ecology: controversies and consequences (L. Boitani and T. K. Fuller, eds.). Columbia University Press, New York.

Prange, S., S. D. Gehrt, and E. P. Wiggers. 2004. Influences of anthropogenic resources on raccoon (*Procyon lotor*) movements and spatial distribution. Journal of Mammalogy 85:483–490.

R Development Core Team. 2013. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. www.R-project.org/. Accessed 7 November 2015.

Riley, S. P. D., et al. 2006. A southern California freeway is a physical and social barrier to gene flow in carnivores. Molecular Ecology 15:1733–1741.

Rosatte, R., and M. Allan. 2009. The ecology of red foxes, *Vulpes vulpes*, in Metropolitan Toronto, Ontario: disease management implications. Canadian Field-Naturalist 123:215–220.

Saeki, M. 2001. Ecology and conservation of the raccoon dog (*Nyctereutes procyonoides*) in Japan. Ph.D. dissertation, University of Oxford, Oxford, United Kingdom.

Saeki, M. 2008. Ecology of animals inhabiting a "satoyama" landscape—raccoon dogs. Pp. 321–345 in Mammalogy in Japan II—medium- and large-sized mammals and primates (S. Takatsuki and J. Yamagiwa, eds.). University of Tokyo Press, Tokyo, Japan (in Japanese).

Saeki, M. 2009. Carnivora Canidae *Nyctereutes procyonoides viverrinus* (Gray, 1834). Pp. 216–217 in The wild mammals of Japan (S. D. Ohdachi, Y. Ishibashi, M. A. Iwasa, and T. Saitoh, eds.). Shokadoh Book Sellers, Kyoto, Japan.

Saeki, M., P. J. Johnson, and D. W. Macdonald. 2007. Movements and habitat selection of raccoon dogs (*Nyctereutes procyonoides*) in a mosaic landscape. Journal of Mammalogy 88:1098–1111.

Sako, T., S. I. Kawada, M. Teduka, and T. Uesugi. 2008. Seasonal food habits of the raccoon dog, *Nyctereutes procyonoides*, in the Imperial Palace, Tokyo, Japan. Bulletin of the National Museum of Nature and Science, Series A: Zoology 34:63–75 (in Japanese with English summary).

Seaman, D. E., J. J. Millspaugh, B. J. Kernohan, G. C. Brundige, K. J. Raedeke, and R. A. Gitzen. 1999. Effects of sample size on kernel home range estimates. Journal of Wildlife Management 63:739–747.

Seaman, D. E., and R. A. Powell. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology 77:2075–2085.

Seki, Y., and M. Koganezawa. 2011. Factors influencing winter home ranges and activity patterns of raccoon dogs *Nyctereutes procyonoides* in a high-altitude area of Japan. Acta Theriologica 56:171–177.

Sikes, R. S., and The Animal Care and Use Committee of the American Society of Mammalogists. 2016. 2016 Guidelines of the American Society of Mammalogists for the use of wild mammals in research and education. Journal of Mammalogy 97:663–688.

Sonoda, Y., and N. Kuramoto. 2004. Environmental selectivity to the lower-layer vegetative structure by raccoon dogs at Tama hill. Environmental Systems Research 32:335–342 (in Japanese with English summary).

Süld, K., U. Saarma, and H. Valdmann. 2017. Home ranges of raccoon dogs in managed and natural areas. PLoS ONE 12:e0171805.

Sutor, A., and S. Schwarz. 2012. Home ranges of raccoon dogs (*Nyctereutes procyonoides*, Gray, 1834) in Southern Brandenburg, Germany. European Journal of Wildlife Research 58:85–97.

Swihart, R. K., and N. A. Slade. 1985a. Influence of sampling interval on estimates of home-range size. Journal of Wildlife Management 49:1019–1025.

Swihart, R. K., and N. A. Slade. 1985b. Testing for independence of observations in animal movements. Ecology 66:1176–1184.

Teduka, M., and H. Endo. 2005. Utilization of fecal pile sites, and food habit of the raccoon dog (*Nyctereutes procyonoides*) in the Akasaka Imperial Gardens, Tokyo. Memoirs of the National Museum of Nature and Science 39:35–46 (in Japanese with English summary).

Tennent, J., and C. T. Downs. 2008. Abundance and home ranges of feral cats in an urban conservancy where there is supplemental feeding: a case study from South Africa. African Zoology 43:218–229.

Tsuriya, Y. 2013. The mammals found from Meiji Jingu. Pp. 161–165 in Report of the second general survey on the shrine precincts of Meiji Jingu on the occasion of 100th anniversary after the enshrinement (Committee of the Second General Survey on the Shrine Precincts of Meiji Jingu on the Occasion of 100th Anniversary after the Enshrinement, ed.). Shrine Office of Meiji Jingu, Tokyo, Japan (in Japanese with English summary).

Ward, O. G., and D. H. Wurster-Hill. 1989. Ecological studies of Japanese raccoon dogs, *Nyctereutes procyonoides viverrinus*. Journal of Mammalogy 70:330–334.

Wehtje, M., and M. E. Gompper. 2011. Effects of an experimentally clumped food resource on raccoon *Procyon lotor* home-range use. Wildlife Biology 17:25–32.

Yamamoto, Y. 1993. Home range and diel activity pattern of the raccoon dog, *Nyctereutes procyonoides viverrinus* in Kawasaki. Bulletin of the Kawasaki Municipal Science Museum for Youth 4:7–12 (in Japanese with English summary).

Yamamoto, Y., K. Terao, T. Horiguchi, M. Morita, and S. Yachimori. 1994. Home range and dispersal of the raccoon dog (*Nyctereutes procyonoides viverrinus*) in Mt. Nyugasa, Nagano Prefecture, Japan. Natural Environmental Science Research 7:53–61.

Submitted 14 August 2017. Accepted 11 March 2018.

Associate Editor was Bill Zielinski.