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ORIGINAL PAPER

# Factors influencing winter home ranges and activity patterns of raccoon dogs *Nyctereutes procyonoides* in a high-altitude area of Japan

**Yoshikazu Seki · Masaaki Koganezawa**

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**Abstract** Between October 2006 and June 2007, we radio-tracked six adult raccoon dogs *Nyctereutes procyonoides* (Gray, 1834) in a high-altitude area of Japan to determine which factors influenced home ranges, daily movements, and activity patterns of Japanese raccoon dogs, with an emphasis on the winter season. The home-range sizes for the six individuals were smaller in winter than in autumn. In winter, the daily movement distances significantly decreased in response to decreasing temperature and increasing snow depth, suggesting these environmental factors contributed to a decrease in the home-range sizes during this period. Moreover, during daytime, raccoon dogs were more active in winter than in the snow-free periods (autumn and spring), and the proportion of the daytime movement distances to the total daily movement distances significantly increased as the mean daily air temperatures decreased. Therefore, it appears that the raccoon dogs in our study area passed the winter by minimizing their energy expenditure by restricting their movements when temperatures were at their lowest and snow depth was highest, and by moving more during the daytime when temperatures were higher.

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Y. Seki (✉)
United Graduate School of Agricultural Science,
Tokyo University of Agriculture and Technology,
3-5-8 Saiwai-cho,
Fuchu-City, Tokyo, Japan
e-mail: yoshikazuseki@hotmail.com

M. Koganezawa
Utsunomiya University Forests,
Faculty of Agriculture, Utsunomiya University,
7556 Funyu, Shioya-machi, Shioya-gun,
Tochigi Prefecture, Japan

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## Introduction

Interspecific variation in the home-range size of carnivores can be explained to a certain extent by body size and diet type (e.g., McNab 1963; Clutton-Brock and Harvey 1978; Harestad and Bunnell 1979; Gittleman and Harvey 1982). Similarly, intraspecific variation in home-range size has been demonstrated to be influenced by the distribution and abundance of resources (e.g., Macdonald 1983; Sandell 1989; Herfindal et al. 2005; Imaizumi 2007), and social factors (e.g., Grigione et al. 2002; Boydston et al. 2003).

The raccoon dog *Nyctereutes procyonoides* (Gray, 1834) is a medium-sized canid endemic to eastern Asia. In Japan, the subspecies *Nyctereutes procyonoides viverrinus* (Temminck, 1844) on the islands of Honshu, Shikoku, and Kyushu inhabits various environments, including forest and urban areas (Imaizumi 1960; Abe et al. 2005). Previous studies have demonstrated variations in the home-range sizes of raccoon dogs, with home ranges being smaller in temperate forest zones, islets, and urban areas than in the subalpine zone (Ikeda et al. 1979; Ikeda 1985; Ward and Wurster-Hill 1989; Yamamoto 1993; Yamamoto et al. 1994; Yamamoto et al. 1996; Saeki et al. 2007). Whereas the small home ranges reported previously can be explained by the richness of food supplies (Saeki et al. 2007), less is known about factors influencing the seasonal changes in home ranges of raccoon dogs. For example, although raccoon dogs show winter lethargy in areas where winters are harsh, such as Finland, they remain active in areas with milder winters, such as Japan (Kauhala and Saeki 2004a, b). Even in Japan, however, the home-range sizes of raccoon dogs are smaller in winter compared with those in other seasons (Saeki et al. 2007), although the factors underlying this variation have not been thoroughly studied. Even though the subspecies *N. procyonoides ussuriensis* (Matschie, 1907) hibernates during harsh winters in Finland (Kauhala and Saeki 2004a, b), the animals are often active during mild winters (Kauhala et al. 1993, 2007). Because the behavior of Finnish raccoon dogs in winter has been reported to be influenced by environmental factors, such as air temperature and snow depth (Kauhala et al. 2007), one would expect Japanese raccoon dogs' behavior in winter to be also influenced by these factors.

Moreover, although differences in adaptation to cold weather between Japanese and Finnish raccoon dogs have been reported (Kauhala and Saeki 2004a), the activity patterns of raccoon dogs in the cold regions of Japan have not yet been studied. It has been also reported that in Finland, raccoon dogs pass the winter in good condition by sleeping during the winter (Kauhala 1993). One of our concerns is how Japanese raccoon dogs pass the winter in the cold regions.

The purpose of this study was to identify the home ranges and activity patterns of raccoon dogs in Oku-Nikko, a high-altitude area of Japan. In this paper, we discuss the factors influencing winter home ranges and activity patterns of this species and how they pass the winter.

## Study area

The fieldwork was conducted in Nikko National Park, Tochigi Prefecture, Japan, located in the cool temperate zone (36°45′N, 139°25′E; Fig. 1). The study area encompassed approximately 1,000 ha and the altitude ranged from approximately 1,300 to 1,700 m (montane to subalpine zone). According to the data collected by the Nikko Weather Station (1,292 m) between 1971 and 2000, the mean annual temperature and mean annual precipitation were 6.7°C and 2,103 mm, respectively. The ground was covered with snow from late December until late March during the study periods. The vegetative canopy of the study area is dominated by deciduous broad-leaved trees. The understorey is dominated by *Aster ageratoides leiophyllus*, *Cynanchum caudatum*, and *Senecio nemorensis*. Other carnivores inhabiting this area are red foxes *Vulpes vulpes* (Linnaeus, 1758); feral dogs *Canis familiaris* (Linnaeus, 1758); Japanese martens *Martes melampus* (Wagner, 1840); Japanese badgers *Meles anakuma* (Temminck, 1844); feral cats *Felis catus* (Linnaeus, 1758); masked palm civets *Paguma larvata* (Smith, 1827); and Asiatic black bears *Ursus thibetanus* (G. Cuvier, 1823).

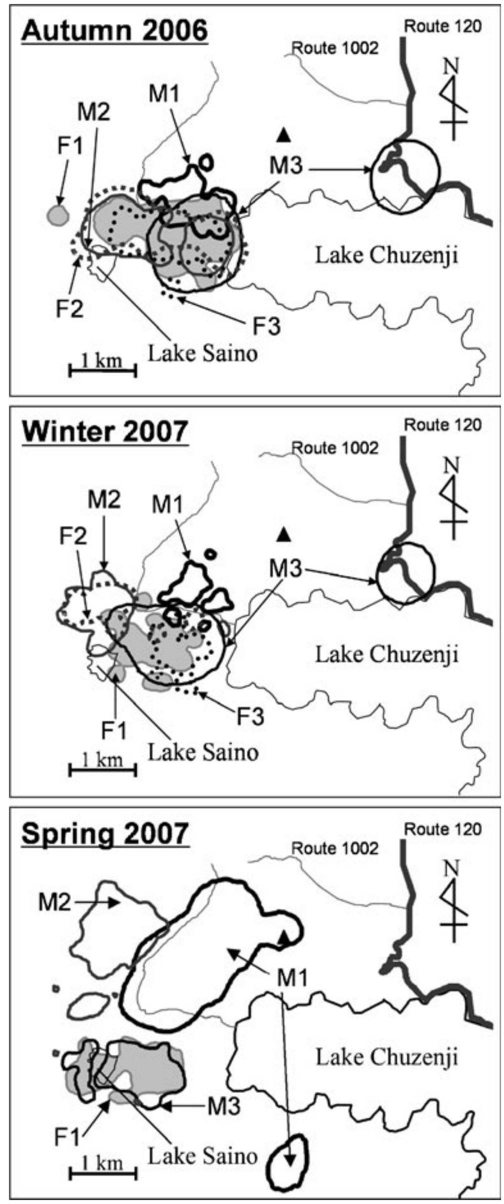


**Fig. 1** The study area and the spacing patterns of six raccoon dogs estimated by the 95% fixed-kernel method during each season in 2006–2007 in Oku-Nikko, Tochigi Prefecture, Japan

## Material and methods

### Trapping and radio tracking

Between August and December 2006, trapping of raccoon dogs was conducted in the region around Senjugahara and along route 1002 and a maximum of 19 Havahart live traps (26.5-cm width × 31.5-cm height × 81.5-cm length; Woodstream Co., USA) were used, baited with fried chicken and sausages. There were 40 trap sites, covering an area of approximately 200 ha. The traps were checked at dawn, and captured animals were immobilized with ketamine hydrochloride (10–20 mg/kg) at the trap sites. The sex, weight, and body size of each individual was recorded. We classified each individual as a juvenile (0 year) or an adult (>1 year) by the degree of wear on the incisors (Hata 1973). Radio collars (Advanced Telemetry System, Inc., USA) weighing 50–120 g, which represented about 1–2% of body weight, were attached, and the animals were released at the trapping sites after they had recovered from anesthesia. During handling, the raccoon dogs were kept warm using quilts and rags to prevent hypothermia. Capture and handling were carried out to minimize stress of the animals, according to the approved guidelines (Japan Ethological Society 2002).

Eleven raccoon dogs (seven adults and four juveniles) were captured between August and November 2006. Of these 11 individuals, we succeeded in estimating the home-range sizes of three adult males and three adult females for more than one period. In analysis, we used three periods corresponding to the seasons: October–December (autumn), January–March (winter), and April–June (spring).

We located collared raccoon dogs using a portable receiver (FT-290mkII, Yaesu Radio Co. Ltd., Japan) and a hand-held four-element Yagi antenna (H-4EL, Ham Center Sapporo, Japan). Locations of animals (hereafter referred to as fixes) were estimated by triangulating compass bearings taken from a minimum of two separate locations. The mean location error was 30 m (SE=7, range 5–60 m), calculated from a dead individual, a dropped radio collar, and seven

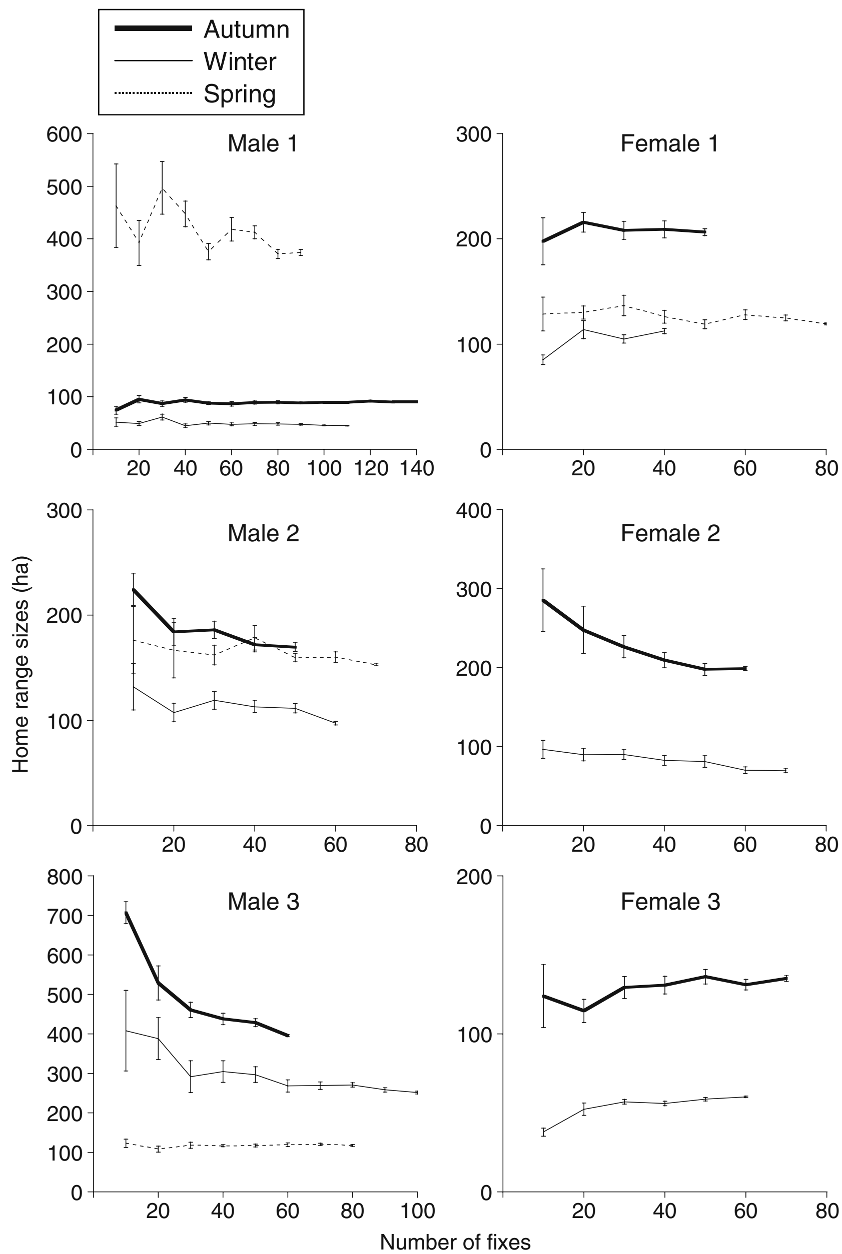


**Fig. 2** The home-range sizes (hectares) of six raccoon dogs for three seasons in 2006–2007 in Oku-Nikko, calculated using the 95% fixed-kernel method for different numbers of location fixes. The values for each set of fixes are the mean ± SE of 10 randomized replicates

den sites that were utilized by raccoon dogs. However, location error may be greater for moving animals (e.g., Kauhala and Tiilikainen 2002). Therefore, to minimize errors, we took the bearings as quickly as possible, usually within 2 min each. Each raccoon dog was located 1–24 times during each day of tracking and was tracked for at least 7 days during each period. The time interval between successive fixes was ≥1 h.

Data analysis

We used the Geographic Information System software (ArcView version 3.2, ESRI, USA) with an animal movement extension tool to analyze the home-range size (Hooge and Eichenlaub 1997). The home-range size was estimated by using the 95% fixed-kernel (FK; Worton 1989) method with bandwidth selected by least squares cross validation (LSCV), which provides the least-biased estimates of home-range size (Ozaki and Kudo 2002). We did not use some fixes for home-range calculations. According to Yamamoto (1993), resting sites were identified as those points in which the raccoon dogs did not move for ≥2.5 h and for which there was no signal variability. In such cases, we used only one fix for home-range calculations even if we recorded multiple fixes for the same point. Since spatial autocorrelation between successive locations has a low influence on home-range estimates (Ozaki and Kudo 2002), we used all the other fixes with the time interval between successive fixes of ≥1 h for estimating the home ranges. Seaman et al. (1999) indicated that ≥30 locations are needed for home-range estimation using FK with LSCV. To assess whether the home-range sizes of six raccoon dogs reached a stable asymptote, we constructed area–observation curves on the 95% FK by randomizing the order of fixes for each raccoon dog with ≥30 fixes in each season. Starting with 10 fixes for each raccoon dog, the number of fixes was increased in increments of 10 until all fixes within a set were assessed. We conducted 10 randomized replicates of each sample size. The results confirmed that our sample size was adequate (Fig. 2). The Wilcoxon signed-rank test was used to determine whether the home-range sizes of each individual decreased in winter compared with autumn.

We computed the daily movement distances in winter as the sum of the straight line distances between consecutive fixes taken at 1-h intervals for a 24-h radio tracking session ($n$=18) and the proportion of daytime movements as the proportion of the daytime (from 0600 to 1759 hours) movement distances to the total daily movement distances. Because the area in Senjugahara that was utilized by raccoon dogs is only slightly inclined and approximately 80% fixes in winter were located in flat areas, we did not consider the altitude differences between fixes when calculating the distances. We obtained one to six data sets for the daily movement distances for six raccoon dogs in winter. Because paired mates share the same home range and roam together or close to each other (Kauhala et al. 1993; Drygala et al. 2008a, b), we treated the data of four individuals as those of two pairs (M2–F2 pair and M3–F1 pair, as determined by means of intensive radio tracking and home-range overlap; Fig. 1). However, we used both the data of males and females within pairs because we radio-tracked them on different days. Thus, the number of distance data sets finally ranged from three to six for two individuals and two pairs. We examined the relationship between the distance data with the repeated observations and environmental factors (air temperature and snow depth) by performing multiple regression analysis with dummy variables according to the method of Bland and Altman (1995). This method allows us to examine whether a change in a movement distance within an individual is associated with a change in an environmental factor by removing the differences between individuals and looking only at changes within. We used the daily movement distances and the proportion of daytime movements as outcome variables and the mean air temperature calculated

**Table 1** Body measurement of the raccoon dogs captured in 2006 and the home-range sizes (hectares) of each individual in Oku-Nikko from October 2006 to July 2007

| Raccoon dog number | Date of capture | Body weight (kg) | Head and body length (mm) | Home-range sizes (ha) (fixes) | | |
|---|---|---|---|---|---|---|
| | | | | Autumn (Oct–Dec) | Winter (Jan–Mar) | Spring (Apr–Jun) |
| Adult male | | | | | | |
| 1 | 8/22 | 5.2 | 545 | 91 (145) | 45 (116) | 379 (95) |
| 2 | 10/26 | 5.6 | 550 | 165 (58) | 95 (63) | 151 (72) |
| 3 | 11/2 | 4.7 | 520 | 386 (67) | 239 (110) | 121 (90) |
| Adult female | | | | | | |
| 1 | 10/26 | 5.6 | 510 | 207 (57) | 116 (44) | 122 (83) |
| 2 | 11/16 | 5.2 | 515 | 193 (68) | 70 (79) | – |
| 3 | 11/17 | 5.9 | 540 | 134 (57) | 60 (61) | – |

Home-range sizes were estimated using the 95% fixed-kernel method. Numbers in parentheses show the number of fixes obtained in each period

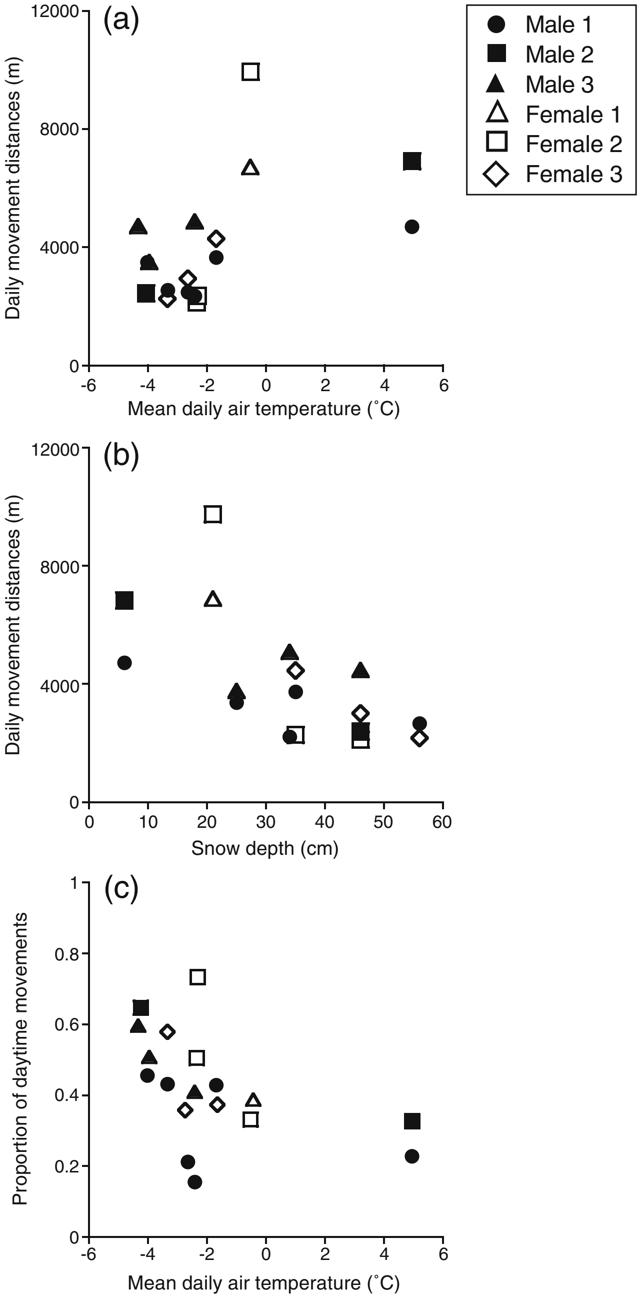


**Fig. 3** The relationship between the movement distances of raccoon dogs and temperature and snow depth in Oku-Nikko in January–March (winter) 2007. The correlation between **a** mean daily air temperature and daily movement distances, **b** snow depth and daily movement distances, and **c** mean daily air temperature and proportion of the daytime (from 0600 to 1759 hours) movement distances to the daily movement distances (i.e., proportion of daytime movements). Individuals with the same markings are in pairs

from the data provided by the Nikko Weather Station, snow depth measured at a point in Senjugahara (Fig. 1), and individual raccoon dogs (pairs) as predictor variables. The individual animals were treated as categorical factors by using dummy variables with 3° of freedom. The *p* value from the *t* test for the regression slopes of each environmental factor was used to determine the probability of the analyses. The magnitude of the within-individual correlation coefficients between each environmental factor, daily movement distance, and proportion of daytime movements were calculated as the square root of (sum of squares for each environmental factor)/(sum of squares for each environmental factor+residual sum of squares). The sign of the correlation coefficient was derived from that of the regression coefficient for each environmental factor.

Furthermore, we compared the raccoon dogs' daytime (from 0600 to 1759 hours) and nighttime (from 1800 to 0559 hours) activity levels in winter with those in the snow-free periods (autumn and spring). The activity levels were estimated using the frequencies of movement and non-movement of the animals that were obtained by analyzing 24-h successive location data. Significant differences were determined using the $\chi^2$ test.

All statistical analyses were performed using R version 2.8.1 software (R Development Core Team 2008). The significance was set at $p<0.05$ for all statistical analyses.

## Results

We succeeded in estimating the home-range sizes of three adult males and three adult females (hereafter referred to as M1–3 and F1–3, respectively) for more than one period (Table 1). The home-range sizes of each individual significantly decreased from autumn to winter (Wilcoxon signed-rank test, $V=0$, $p<0.05$).

The multiple regression yielded the following equation: daily movement distances ($m$)=3,861+439×air temperature+

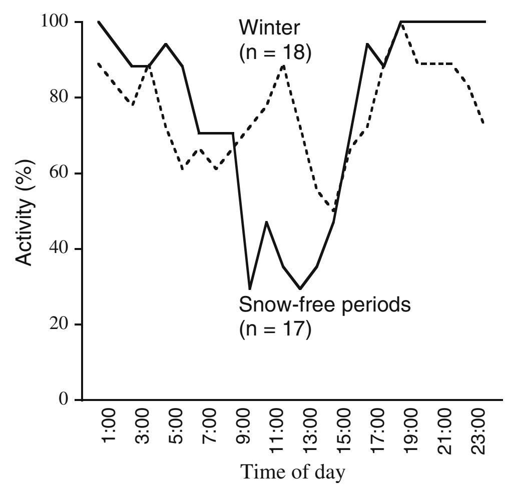


**Fig. 4** The activity (percent) of raccoon dogs in Oku-Nikko in winter and snow-free periods (autumn and spring). The activities were calculated using the frequencies of movement and non-movement of the animals obtained from 24-h successive location data. The numbers in parentheses show the total number of 24-h successive tracking of six raccoon dogs

1,202×M2–F2 pair+2,409×M3–F1 pair+476×F3 (Fig. 3a), and 6,218−90×snow depth+1,222×M2–F2 pair+1,664×M3–F1 pair+1,096×F3 (Fig. 3b); proportion of daytime movements=0.28−0.03×air temperature+0.20×M2–F2 pair+0.11×M3–F1 pair+0.08×F3 (Fig. 3c). With regard to the within-individual variations, positive correlation (correlation coefficient, 0.60) was observed between the mean daily air temperature and daily movement distance ($t$=2.72, df=13, $p$<0.05; Fig. 3a); negative correlation was observed between snow depth and daily movement distance (correlation coefficient, −0.66) ($t$=−3.19, df=13, $p$<0.05; Fig. 3b) and between the mean daily air temperature and the proportion of daytime movements (correlation coefficient, −0.60) ($t$=−2.72, df=13, $p$<0.05; Fig. 3c).

The activity levels for six raccoon dogs during the daytime were higher in winter than in other periods ($\chi^2$=4.64, df=1, $p$<0.05; Fig. 4).

## Discussion

The home-range size (95% FK) of each individual was smaller in winter than in autumn (Table 1), and the behavior of the animals was influenced by air temperature and snow depth (Fig. 3). In Finland, the behavior of subspecies *N. procyonoides ussuriensis* was also influenced by air temperature and snow depth. For example, the animals were usually inactive when temperature fell below −10°C and the snow depth was greater than 35 cm (Kauhala et al. 2007). Although the activity of raccoon dogs was lower in winter compared to the other seasons, even in an area with almost no snow in Japan, the interfix speeds were lower in colder ambient temperatures (Saeki 2001; Saeki et al. 2007). Therefore, we infer that low temperature is the primary factor contributing to the decrease in the home-range size of raccoon dogs in winter. In snowy areas, snow would also be a factor contributing to the decrease in home-range size because soft, deep snow impedes the raccoon dogs' movements (Kauhala and Saeki 2004a). Further, besides the fact that there is less food available in winter, an increase in snow depth would decrease the feeding efficiency of raccoon dogs since these animals primarily collect food from the ground (Ikeda et al. 1979; Sasaki and Kawabata 1994). It is likely that raccoon dogs restrict their movements in low air temperatures and heavy snow to minimize their energy expenditure.

Moreover, in this study area in winter the raccoon dogs were more active during the daytime (Fig. 4), and the proportion of daytime movements increased as the mean daily air temperatures decreased in winter (Fig. 3c). Therefore, it appears that raccoon dogs in the study area passed the winter by minimizing their energy expenditure by restricting their movements when temperatures were at their lowest and by moving more during the daytime when temperatures were higher. In farms in Finland, raccoon dogs have been observed to sit with their dark chest towards the sun during the spring to warm their body and save energy; this basking behavior has been observed particularly in the morning when the animals have experienced the dark and usually very cold spring night (Harri and Korhonen 1988). The daytime activity of raccoon dogs may be a behavioral adaptation to the cold weather. However, Kauhala et al. (2007) reported that Finnish raccoon dogs were often more active at night than in the daytime in each season, and their activity levels during the daytime (particularly between 1000 and 1400 hours) were lower in winter than in the snow-free seasons. These differences in activity patterns might reflect differences in adaptation to the cold weather between Japanese and Finnish raccoon dogs. Of these two subspecies, the Finnish raccoon dogs have a larger stomach volume and are better insulated than Japanese raccoon dogs, as the former have thicker fur (Korhonen et al. 1991). In addition, Finnish raccoon dogs can accumulate large fat reserves as adult raccoon dogs almost double their weight between early summer and late autumn (Kauhala 1993; Kauhala and Saeki 2004a). Because this species is chiefly nocturnal (Novikov 1956; Imaizumi 2007), the adaptability of Finnish raccoon dogs to the cold weather may enable them to be more active during the nighttime even in winter. Therefore, to compensate for the relatively low adaptability of Japanese raccoon dogs to the cold weather during winter, raccoon dogs in our study area might have restricted their movements at night, especially in colder weather. Kauhala and Saeki (2004a) pointed out that Japanese raccoon dogs could be on the road to speciation because of several differences found between Japanese and Finnish raccoon dogs. Further studies on the activity patterns of raccoon dogs in various environments in Japan should help us to understand different behaviors of this species.

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