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Source: Folia Zoologica, 65(2) : 101-106

Published By: Institute of Vertebrate Biology, Czech Academy of Sciences

URL: https://doi.org/10.25225/fozo.v65.i2.a5.2016

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Folia Zool. – 65 (2): 101–106 (2016)

Seasonal home ranges and activity of three rodent species in a post-fire planted stand

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Received 7 September 2015; Accepted 12 February 2016

Abstract. Movement patterns of three small rodent species (striped field mouse *Apodemus agrarius*, n = 18; Korean field mouse *A. peninsulae*, n = 21; and Korean red-backed vole *Myodes regulus*, n = 22) were tracked by radio-telemetry to determine seasonal variation in home range size, daily distance traveled, and number of daytime resting area in a post-fire planted stand of Japanese red pine *Pinus densiflora* in Mt. Gumbong, Samcheok, South Korea. Home range sizes and distances traveled did not differ among the species; however, significant differences were noted in the home range sizes (analysis of variance; $F = 9.24$, $df = 2, 6$, $p = 0.05$) and distances traveled (Kruskal-Wallis test; $H = 9.51\text{-}15.38$, $p = 0.05\text{-}0.01$) of each species across seasons. In winter, all three measures considerably decreased for all species examined. The home range sizes of male rodents of all species were 1.4-2.2 times larger than those of female rodents. All species were primarily nocturnal; in daytime, they remained confined to their resting areas. The durations of movement negatively correlated with daytime length (Spearman correlation analysis; $r = -0.41$, $p = 0.01$, $n = 2583$); no differences were observed in the number of daytime resting areas among species ($F = 0.81$, $df = 3, 6$, $p = 0.38$). However, the numbers of daytime resting areas of three small rodents were the smallest in winter. Thus, seasonal variation is an important factor affecting small rodent movement patterns. Further long-term ecological research would help elucidate how small rodents seasonally interact and share resources in the same habitat.

Key words: habitat, home range, movement, resting area, rodent

Introduction

Small rodents are important for ecosystem function as primary or secondary consumers (Stoddart 1979), prey (Dawson & Bortolotti 2000), and dispersers of plants and fungi (Murray 1986, Kirkland 1990). Moreover, small rodents have been considered indicator species of forest ecosystems (Lautenschlager et al. 1997, Rhim et al. 2012). Research on home range, habitat use patterns, and activity can provide valuable ecological information (Harris et al. 1990, Pires et al. 2010), needed for efficient conservation and management strategies (Macdonald et al. 1998, Buesching et al. 2007).

Movement and activity patterns of free-living small rodents are well studied. Aspects of the home range have been of particular interest, including its size, shape, and spatial or temporal distribution (Corp et al. 1997). Factors affecting space use, especially home range, include diet, climate, inter-specific competition, and predation (Rhim 2006a). In the home range, animals require food, water, cover, and space for their survival (Rhim 2006b, Lee et al. 2010). In general, home range size is determined by body size, energy requirements, habitat productivity, and sex (Swihart et al. 1988, Ostfeld 1990, Hanski et al. 2000). Additionally, home range size and boundaries may change depending on season, reproductive status, and estimation method (White & Garrot 1990). Diet, sex, body mass, reproductive status, productivity, and season, therefore, are expected to influence the resting area required by animals (Gompper & Gittleman 1991, Corp et al. 1997). The resting area is very important for small rodents as nesting, roosting, and escaping cover during daytime. Daytime resting areas, the places small rodents use between sunrise and sunset, were located by radio-tracking (Wolff & Hurlbutt 1982, Park et al. 2014). Knowledge of many aspects of home ranges, activities, and movements are therefore necessary to understand habitat use patterns (Lee 2011).

However, there is lack of information on movement of small rodents in planted stands in Korea. The information is fundamental to any consideration of conservation and management for the animals and

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their habitat. In this study, we used radio-telemetry to investigate seasonal variation in home range size, daily distance traveled, and number of daytime resting areas of small rodents in a post-fire Japanese red pine *Pinus densiflora* planted stand. The main objective was to investigate seasonal variation in movement patterns of three rodent species.

Material and Methods

This study was conducted in a post-fire Japanese red pine *Pinus densiflora* planted stand in Mt. Gumbong, Samchuk, Gangwon Province, South Korea (37°13′ N, 128°18′ E), between August 2008 and September 2009. The elevation range was 250-400 m a.s.l. Mean annual temperature was 11.8 °C (maximum: 35.0 °C, minimum: –10.5 °C). Mean annual precipitation was 1793 mm and mean snow depth was 57 cm (Lee et al. 2008, Lee et al. 2012). A fire occurred in April 2000 and burned thousands of hectares of Japanese red pine forest in the study area. All the trees were damaged and dead. Three study sites were selected in the post-fire Japanese red pine planted stands. Seedlings were seven years old during the study.

A square grid of 10 by 10 points with 10 m spacing was marked out in the study area. When trapping, one Sherman live-trap was placed at each point. A capture-mark-recapture technique was used to trap small rodents for three consecutive nights each month between August 2008 and May 2009. The traps were baited with fresh peanuts and checked every morning and evening thereafter until all available radio-collars, adjustable necklace transmitters (PIP 2 transmitters, 1.2 g, Biotrack Ltd., Wareham, Dorset, U.K.), had been fitted onto the rodents. The weight of collars was less than 4 % of body weight of small rodents used in this study. It is generally accepted that this does not pose a welfare problem for animals (Millspaugh & Marzluff 2001, Lee et al. 2010). For insulation, cotton and dry grass were provided inside the traps in winter. Upon capture, all individuals were identified at the species level, weighed, sexed, and assigned to an age class by tooth wear, sexual organs, pregnancy, and lactation (Gurnell & Flowerdew 2006, Lee et al. 2008, Lee et al. 2012).

Radio-collars were placed on individuals (n = 77) of three small rodent species: striped field mouse (*Apodemus agrarius*, Pallus, 1788, n = 26), Korean field mouse (*Apodemus peninsulae*, Thomas, 1907, n = 25), and Korean red-backed vole (*Myodes regulus*, Thomas, 1907, n = 26) (Table 1). These three species are the most common forest-floor small mammal species in the forests of South Korea (Rhim et al. 2007). The major predators of small rodents were raccoon dog *Nyctereutes procyonoides*, leopard cat *Prionailurus bengalensis*, Siberian weasel *Mustela sibirica*, Eurasian badger *Meles meles*, and yellow-throated marten *Martes flavigula* in our study area. Standard radio tracking methods were used, namely eye reflection, direct observation, and radio signals (White & Garrot 1990, Marby & Stamps 2008). Diurnal and nocturnal locations of the animals were determined by tracking the radio-collars' signals, using a directional three-element Yagi antenna and a hand-held GPS (Lee et al. 2012).

Radio tracking was carried out in 8-hours sessions (07:00-15:00, 15:00-23:00, and 23:00-07:00), separated by 8-hours intervals. Four radio-tracking periods were completed with 45 sessions in each season; fall (15 September-30 October), winter (27 November-12 January), spring (18 April-27 May), and summer (1 July-14 August). These dates did not include nights during the trapping. Each of the radio-tagged rodents was located 20 times per day throughout the study period. The home ranges of the three rodent species were calculated using the minimum convex polygon method (MCP; Samuel & Garton 1985, Harris et al. 1990) using 95 % MCP. MCP areas can be greatly influenced by outlaying locations and excluding the outer 5 % of locations helps take this into account. However, it is well known that MCPs range estimates often include areas that individuals little use.

Data were analyzed to estimate the distance traveled, as well as the size and spacing of the home ranges for each radio-tagged animal. Rate of movement (distance traveled per hour) was calculated. Distances traveled, seasonal home range sizes, and numbers of daytime resting areas were compared by species and season using ANOVA, because these data were normal and variances equal. Travel distances and home range sizes were compared among seasons and species by using a Kruskal-Wallis test (Zar 1999). In each season, home ranges were compared between sexes via a Mann-Whitney U-test. Pearson correlation analysis was also employed to evaluate the relationship between the daytime length and the duration of small rodents' movement in each season. Additionally, a Spearman correlation analysis was used to assess whether the number of daytime resting areas was related to the size of home range.

Results

Out of total of 77 radio-collared small rodents, 16 animals were excluded in the analysis because of

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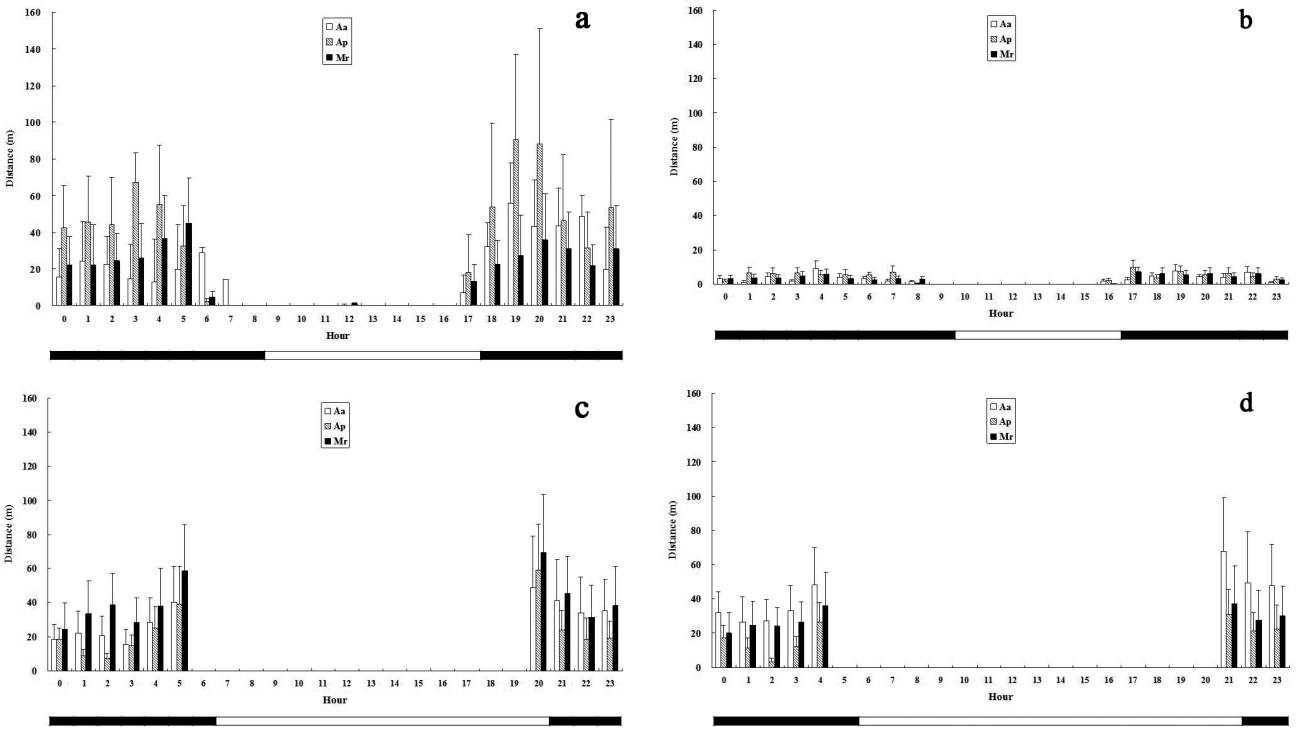


Fig. 1. Daily movements of three rodent species in (a) fall, (b) winter, (c) spring, and (d) summer (horizontal white bar, daytime; black bar, nighttime). Aa, *A. agrarius*; Ap, *A. peninsulae*; Mr, *M. regulus*.

Table 1. Seasonal number of tagged individuals and tracking success rate of three rodent species. Aa, *A. agrarius*; Ap, *A. peninsulae*; Mr, *M. regulus*. No. of tagged individuals means no. of individuals that were successfully tracked (total no. of individuals to which radio tags were attached).

Seasons	Species	No. of tagged individuals	Success rate (%)
Fall	Aa	3 (6)	50.0
	Ap	4 (5)	80.0
	Mr	6 (9)	66.7
	subtotal	13 (20)	65.0
Winter	Aa	5 (6)	83.3
	Ap	6 (7)	85.7
	Mr	6 (6)	100.0
	subtotal	17 (19)	89.5
Spring	Aa	5 (8)	62.5
	Ap	6 (7)	85.7
	Mr	6 (6)	100.0
	subtotal	17 (21)	81.0
Summer	Aa	5 (6)	83.3
	Ap	5 (6)	83.3
	Mr	4 (5)	80.0
	subtotal	14 (17)	82.4
Total	Aa	18 (26)	69.2
	Ap	21 (25)	84.0
	Mr	22 (26)	84.6
	total	61 (77)	79.2

transmitter failure. No animals lost collars or had sore necks when they were removed, and no collars got struck in the vegetation during the study. Each species was represented by 3-6 individuals in each season. Similar numbers of radio-collared and successfully tracked animals were recorded for each species (Table 1).

Home range sizes of small rodents (*A. agrarius* 7652 ± 987 m^2, *A. peninsulae* 6709 ± 735 m^2, and *Myodes regulus* 7859 ± 864 m^2) did not differ among species (ANOVA, F = 0.19, df = 2, 4, p = 0.82); however, significant differences were observed in home range sizes among seasons (F = 9.24, df = 2, 6, p = 0.05). There was also a significant interaction between species and season (F = 8.35, df = 2, 22, p = 0.05). Home range size of *A. agrarius* (13295 ± 1837 m^2) was the largest in summer, versus fall for *A. peninsulae* (4625 ± 315 m^2) and spring for *M. regulus* (5352 ± 614 m^2). In all three species, home range sizes were the smallest in winter (Table 2). Males' home range sizes were 1.4-2.2 times larger than those of females for each species (p = 0.01, Table 3).

No differences in distances traveled were observed among species (ANOVA, F = 0.13, df = 3, 6, p = 0.88). However, the travel distances significantly differed among seasons (Kruskal-Wallis test; *A. agrarius*, H = 15.38, p = 0.01; *A. peninsulae*, H = 9.51, p = 0.05; *M. regulus*, H = 13.62, p = 0.01). Travel distances were longer in the fall and spring, and considerably

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Table 2. Seasonal home range size of three rodent species estimated by 95 % minimum convex polygon. Values are mean ± SD, represented in m². Aa, *A. agrarius*; Ap, *A. peninsulae*; Mr, *M. regulus*.

Seasons	Species		
	Aa	Ap	Mr
Fall	10463 ± 1672 (n = 3)	10862 ± 865 (n = 4)	8343 ± 1012 (n = 6)
Winter	1743 ± 348 (n = 5)	1999 ± 956 (n = 6)	3168 ± 547 (n = 6)
Spring	5109 ± 491 (n = 5)	9318 ± 859 (n = 6)	14692 ± 1553 (n = 6)
Summer	13295 ± 1837 (n = 5)	4625 ± 315 (n = 5)	5352 ± 624 (n = 4)

Table 3. Sexual differences in home range size of three rodent species estimated by 95 % minimum convex polygon by Mann-Whitney U-test. Values are mean ± SD, represented in m². Aa, *A. agrarius*; Ap, *A. peninsulae*; Mr, *M. regulus*.

Species	Male	Female	Z-value	*p*-value
Aa	40588 ± 6832 (n = 10)	18073 ± 5411 (n = 8)	6.23	0.01
Ap	29662 ± 4679 (n = 9)	18809 ± 3041 (n = 12)	4.45	0.01
Mr	34577 ± 5420 (n = 13)	24871 ± 4664 (n = 9)	5.12	0.01

Table 4. Seasonal movement distance of three rodent species. Values are mean ± SD, represented in m/hr. Aa, *A. agrarius*; Ap, *A. peninsulae*; Mr, *M. regulus*.

Seasons	Species		
	Aa	Ap	Mr
Fall	16.77 ± 7.56 (n = 3)	27.21 ± 3.12 (n = 4)	15.21 ± 5.06 (n = 6)
Winter	2.66 ± 0.58 (n = 5)	3.63 ± 0.95 (n = 6)	2.99 ± 0.47 (n = 6)
Spring	12.07 ± 3.85 (n = 5)	9.75 ± 2.25 (n = 6)	12.51 ± 1.06 (n = 6)
Summer	13.82 ± 2.14 (n = 5)	6.03 ± 1.01 (n = 5)	9.44 ± 4.02 (n = 4)

Table 5. Seasonal observations of the number of daytime resting areas of three rodent species. Values are mean ± SD. Aa, *A. agrarius*; Ap, *A. peninsulae*; Mr, *M. regulus*.

Seasons	Species		
	Aa	Ap	Mr
Fall	1.67 ± 0.58	2.25 ± 0.19	2.17 ± 0.53
Winter	1.20 ± 0.43	1.13 ± 0.34	1.17 ± 0.41
Spring	2.00 ± 0.71	2.50 ± 0.57	3.33 ± 0.62
Summer	3.40 ± 0.52	2.40 ± 0.67	2.25 ± 0.50

decreased in winter (Table 4). Activity was the highest in the fall for *A. agrarius* and *M. regulus*, whereas *A. peninsulae* were most active in spring. Activity was the lowest in winter for all three species. The most active time was 19:00-21:00 in all seasons (Fig. 1). The three species were primarily nocturnal, emerging from daytime resting areas after sunset and coming back before sunrise. The durations of movement negatively correlated with daytime length (Spearman correlation analysis; r = –0.41, $p = 0.01$, n = 2583).

In daytime, they stayed in their resting areas. No differences in the number of daytime resting areas were observed among species (F = 0.81, df = 3, 6, $p = 0.38$). However, the numbers of daytime resting areas significantly differed among seasons (F = 6.18, df = 3, 6, $p = 0.05$). Numbers of daytime resting areas (2.00 ± 0.71-3.33 ± 0.62) were the lowest in winter (Table 5). Furthermore, no correlation was observed between the number of daytime resting areas and the size of home range (Spearman correlation analysis; *A. agrarius*, $p = 0.325$, n = 18; *A. peninsulae*, $p = 0.214$, n = 21; *M. regulus*, $p = 0.258$, n = 22).

Discussion

Ecological functions of small rodents are related to their activity and space use patterns, and these may show seasonal variation (Park et al. 2014). Because small rodents show lesser movement ability than do large animals, they must endure the changing conditions of their habitat (Schradin & Pillay 2006).

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In the present study, home range sizes of small rodents were considerably smaller in winter than in other seasons (Table 2). Survival in winter requires physiological and behavioural changes (Masaki et al. 2005). The cost of movement in winter may be very high because of low temperatures. Additionally, the lower abundance of food resources in winter can explain the smaller home ranges. Small rodents seem to minimize locomotion and spend more time in nests or resting areas for energy saving with the onset of winter (Halle & Stenseth 2000, Ortmann & Heldmaier 2000).

In winter, ambient temperature may be an essential contributor to decreases in home range size, distance traveled, nighttime activity, and number of daytime resting areas. Activity outside the nests decreased with decreasing ambient temperature in winter. This result suggests that energy expenditure was being minimized over the winter (Corp et al. 1997). To overwinter successfully, small rodents need to increase feeding activity, put on weight and store food during the fall (e.g. Vander Wall 1990). Therefore, they may have to cover a large home range area and use several daytime resting areas to maximize food encounters to prepare for the harsh winter (Park et al. 2014). Consistent with previous findings, males had larger home ranges than females (Tew & Macdonald 1994) (Table 3). Many small rodent species have promiscuous mating systems, in which males increase their chances of encountering receptive mates by having larger sized home ranges (Ostfeld 1990, Hanski et al. 2000, Park et al. 2014).

Seasonal and species-related differences were observed in travel distance (Table 4) and daytime nesting areas (Table 5). Light is considered a main controlling factor for activity in many small rodent species (Montgomery & Gurnell 1985). Temporal activity patterns of the species in this study were related to daytime length (Fig. 1). In summer, when nighttime was short, small rodents were active and outside the nests and daytime resting areas. However, they spent most of times in their nests and daytime resting areas in winter (Yletyinem & Norrdahl 2008, Lee et al. 2012). In longer daytime periods, almost the entire nighttime were used for foraging. The travel distance is a function of speed and duration of travel (Corp et al. 1997). Differences in home range size also attributed to seasonally different travel distances. Daytime resting areas were located underground and in cavities of dead or fallen trees. Most were covered with coarse woody debris, gravel, and rock (Park et al. 2014). Numbers of daytime resting areas were lower in winter than in other seasons. Moreover, larger spatial areas were used during the night, with bigger home ranges and higher number of daytime resting refuges. This results in lower resting area fidelity (Rosalino et al. 2011). Conversely, a higher resting area fidelity is found in winter.

Taken together, the results indicate that home range size, travel distance, and daytime nesting areas varied by season, with major decreases in winter for all three species, a time when food availability would also decrease. Additionally, duration of movement and number of resting areas of small rodents were found to be affected by daytime length, which is influenced by season.

Acknowledgements

This study was supported by the Forest Science and Technology Project (Grant No: S121315L140100) of the Korea Forest Service, Republic of Korea.

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