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ORIGINAL PAPER

The use of artificial nest boxes by Siberian flying squirrels (*Pteromys volans*) in South Korea

Jong-U Kim[1] · Woo-shin Lee[1] · Eun-Jae Lee[2]

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Abstract In this study, we examined the use of artificial nest boxes by Siberian flying squirrels (*Pteromys volans*) in three coniferous and mixed forests in Gangwon Province, South Korea. Six hundred and twelve boxes with different sized entry holes (ranging from 3 to 7 cm in diameter) were placed in the forests between 2004 and 2009. *Pteromys volans* used nine boxes in the coniferous forests and two boxes in the mixed forests. The squirrels only used boxes with entrance holes measuring 3.5, 4, and 5 cm in diameter, showing a strong and moderate preference for boxes with 5 and 4-cm holes, respectively, and a strong avoidance for boxes with 3- and 7-cm holes. Therefore, we suggest placing artificial nest boxes with entrance holes 5 cm in diameter to encourage breeding activity. Most nests made in the artificial boxes were composed of fibrous materials from woody vines. We recommend placing artificial nest boxes with holes of 5-cm diameter in coniferous forests, which support dense populations of *P. volans*, to survey whether this approach would positively affect the breeding habits and population maintenance of this species.

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✉ Eun-Jae Lee
wildlife@dsi.re.kr

[1] Department of Forest Sciences, Seoul National University, Seoul 08826, Republic of Korea

[2] Urban Planning Research Division, Daejeon Sejong Research Institute, Daejeon 34863, Republic of Korea

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Introduction

Natural tree cavities are used as nesting, resting or feeding sites by many terrestrial vertebrate species. However, forests are being more intensively managed for timber production, so the availability of natural cavities to wildlife is decreasing over the world (McComb and Noble 1981). Artificial nest boxes can substitute for natural cavities for many cavity-dependent species (Bellrose et al. 1964; McComb 1979; Nixon and Donohoe 1979). Artificial nest boxes have been placed in forests mainly to support the breeding of tits and sometimes that of the scops owl (*Otus* spp.) in South Korea, but some mammal species such as the Siberian flying squirrel (*Pteromys Volans*) and the Siberian chipmunk (*Tamias sibiricus*) also use the nest boxes for nesting, roosting and feeding.

The size of an entrance hole affects exposure to sunlight and wind, as well as access by large predators and competitors. The size of the entrance hole, the age of the adults, and the height and placement of nest boxes can all affect the rate of successful breeding in nest boxes (Purcell et al. 1997; Wiebe and Swift 2001). Because cavity size is an important variable that affects occupancy by a species (Evan et al. 2002), the size of the entrance holes in artificial nest boxes might also influence the preference of nest boxes by secondary cavity-nesters (Choi et al. 2007).

Pteromys volans belongs to the Siberian fauna. This species has a wide geographical distribution in the Eurasian taiga, ranging from Finland in the west to Russia (Chukotka, Sakhalin Island), Japan (Hokkaido) and the Korea peninsula in the east (Haukisalmi and Hanski 2007). The

flying squirrel is a nocturnal, arboreal rodent which nests in tree cavities, twig dreys and nest boxes. Studies in Finland suggest that flying squirrels prefer sheltered, spruce-dominated (*Picea abies*) mixed forests that contain a distinct deciduous tree component for food, as well as large aspens (*Populus tremula*) that contain nesting cavities (Hanski 1998; Reunanen et al. 2002). The westernmost populations in Finland (Hokkanen et al. 1982), Estonia (Timm and Kristaja 2002) and Latvia have declined severely during the 20th century because of habitat loss.

Small populations of *P. volans* occur in the mature forests of South Korea. However, their populations have recently declined because of habitat fragmentation and loss, as well as poor forest management practices and urban development (Yoon et al. 2004). The flying squirrel is now designated a natural monument by the Cultural Heritage Administration of Korea and as an endangered species by the Ministry of Environment of the Republic of Korea.

Studies on the use of artificial nest boxes have focused on secondary cavity-nesting birds, such as tits, with few studies focusing on the use of artificial nest boxes by mammals. Various aspects of the ecology of *P. volans* have been examined, including their movement patterns (Hanski et al. 2000; Selonen and Hanski 2003), habitat use (Reunanen et al. 2004; Selonen and Hanski 2006), dispersal of young individuals (Selonen and Hanski 2003, 2006; Selonen et al. 2007), and survival and population growth (Lampila et al. 2009), with most studies being conducted in Finland. However, few studies have examined the use of artificial nest boxes by *P. volans*. Moreover, the ecological characteristics and other basic information about the species remain poorly understood in South Korea.

Therefore, this study aimed to examine the use of artificial nest boxes by *P. volans* in South Korea. Our study objective was to develop guidelines for how to manage and sustain populations of cavity breeding mammals, such as *P. volans*, to preserve important resources for survival in depleted forests.

Methods

This study was conducted in three mountainous forests: Mt. Chungtae (37°31′N, 128°17′E), Mt. Jaewang (37°44′N, 128°43′E) and Mt. Baekwoon (37°19′N, 127°57′E). All three sites are located in Gangwon Province, South Korea (Fig. 1). The mean annual temperatures at Mt. Chungtae, Mt. Jaewang and Mt. Baekwoon are 11.3 °C, 7.6 °C, and 12.4 °C, respectively. The mean annual precipitation is 1308 mm, 1401 mm, and 1568 mm, respectively. The dominant tree species was the Korean pine (*Pinus koraiensis*) at Mt. Chungtae, the Japanese red pine (*Pinus densiflora*) at Mt. Jaewang and the bald cypress (*Taxodium distichum*) at

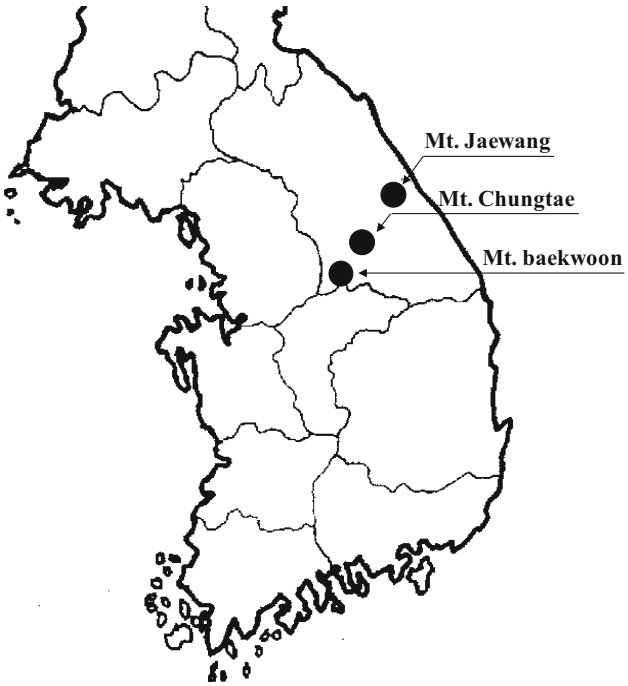

Fig. 1 Location of the three study sites in Gangwon Province, South Korea

Fig. 2 Placed artificial nest box at study site

Mt. Baekwoon. Coniferous trees with wide trunks were relatively well preserved at all three study sites.

We placed and monitored 612 artificial nest boxes (width: 16 cm, length: 15 cm, height: 30 cm) at the three study sites between 2003 and 2009 (Fig. 2). We placed 262 boxes at the Mt. Chungtae site in 2003, and 200 and 150 boxes at the Mt. Jaewang and Mt. Baekwoon sites, respectively, in 2007. The artificial nest boxes had entrance holes of five diameters: 3, 3.5, 4, 5, and 7 cm. We distributed the nest boxes with 3, 3.5, and 4-cm holes evenly at each study site. In addition, we placed 33 nest boxes with 5-cm holes and 15 boxes with 7-cm holes at the Mt. Chungtae site (Table 1). All entrance holes of nest boxes were placed at heights from 2 to 3 m above the ground, with a distance of 30 m between each nest box.

We checked all boxes each breeding season (between March and July) from 2004 to 2009. When flying squirrels were detected using the boxes, we only checked the boxes to determine the litter size, with no further interference. When all of the young had fledged from the nests, we identified the nest material and recorded the shapes of the nests in the boxes. We also weighed the nest material.

We recorded the size of entrance hole in the boxes that had been used by *P. volans* and tits. We used Jacobs' index of preference (Jacobs 1974) to calculate the preference index (PI) for each nest box type, and categorized the PI results into five groups, following Choi et al. 2007; strong preference ($1.00 \geq PI > 0.60$), moderate preference ($0.60 \geq PI > 0.20$), no preference ($0.20 \geq PI > -0.20$), moderate avoidance ($-0.20 \geq PI > -0.60$), and strong avoidance ($-0.60 \geq PI > -1.00$).

Results

Pteromys volans used 11 nest boxes (use rate: 1.11%) at all sites between 2004 and 2009 (Table 2). The mean litter size was 2.64 ± 0.50 (n = 11), with a maximum litter size of three.

Between 2005 and 2009, we checked four boxes used by flying squirrels at Mt. Chungtae in 2004. Two boxes at Mt. Jaewang and one box at Mt. Baekwoon used by squirrels in 2008. Two boxes were used by squirrels at each of Mt. Jaewang and Mt. Baekwoon in 2009. Nine of the used boxes were in coniferous forests, whereas two were in mixed forests.

Flying squirrels only used the boxes with holes measuring 3.5, 4 and 5 cm in diameter. At Mt. Chungtae, squirrels only used boxes with 5 cm diameter entrance holes. In comparison, at Mt. Jaewang and Mt. Baekwoon, they only used boxes with entrance holes measuring 3.5 and 4 cm in diameter. Moreover, the squirrels had enlarged two of the 3.5-cm holes to 3.76 and 3.74 cm (Fig. 3). Boxes with 3 and 7-cm diameter entrance holes were not used. Squirrels showed a strong preference for nest boxes with 5-cm diameter holes (PI = 0.742), and a moderate preference for nest boxes with 4-cm diameter holes (PI = 0.233). In contrast, squirrels showed moderate avoidance of nest boxes with 3.5-cm diameter holes (PI = − 0.324) and a strong avoidance of nest boxes with 3 and 7-cm diameter holes (Fig. 4).

Also, tit species used 77 nest boxes at all sites (Table 3). We checked 22 boxes used by Marsh tits (*Parus palustris*). 29 boxes by Great tits (*Parus major*), 26 boxes were used by Varied tits (*Sittiparus varius*).

Different tit species differed significantly in the entrance hole preference of artificial nest boxes. For instance, Marsh tits showed a moderate preference (PI = 0.507) for nest boxes with 3-cm diameter holes (Fig. 5) and showed moderate avoidance (PI = − 0.446) of nest boxes with 3.5-cm diameter holes and strong avoidance of nest boxes with 4, 5, and 7-cm diameter holes (PI = − 1.000). Grest tits preferred 3.5-cm diameter holes (PI = 0.296), and showed moderate and strong avoidance for nest boxes with 3, 5, and 7-cm diameter holes (Fig. 6). Varied tits showed a moderate preference for nest boxes with 4-cm diameter holes (PI = 0.342) and strongly avoid nest boxes with 3 and 7-cm diameter holes (PI = − 1.000) (Fig. 7).

When the young squirrels had fledged from the nests, we collected the nest material and identified it in the laboratory. Nine nests (82%) were mostly composed of woody fibers derived from vines (Table 4). In all nine boxes, the squirrels had cut the woody vines thinly and made a nest with holes (Fig. 8). In seven boxes, woody vines were the

Table 1 Number of nest boxes with entrance hole in five different diameters at three study sites

Diameter of entrance holes (cm)	Study sites			Total
	Mt. Chungtae	Mt. Jaewang	Mt. Baekwoon	
3	63	60	50	173
3.5	88	80	50	218
4	63	60	50	173
5	33	–	–	33
7	15	–	–	15
Total	262	200	150	612

Table 2 Number and percentage of nest box use with different entrance hole in diameters by Siberian flying squirrel at three study sites

Diameters of entrance hole (cm)	Study sites					Total
	Mt. Chungtae	Mt. Jaewang		Mt. Baekwoon		
	2004	2008 (%)	2009 (%)	2008 (%)	2009 (%)	
3	0	0	0	0	0	0
3.5	0	0	1 (1.25)	0	1 (2.00)	2 (0.65)
4	0	2 (3.33)	1 (1.67)	1 (2.00)	1 (2.00)	5 (1.80)
5	4 (12.12)[a]	–	–	–	–	4 (12.12)
7	0	–	–	–	–	0
Total	4 (1.53)	2 (1.00)	2 (1.00)	1 (0.67)	2 (1.33)	11 (1.11)

[a]Number (%)

Fig. 3 Expanded 3.5 cm diameter hole by Siberian flying squirrel

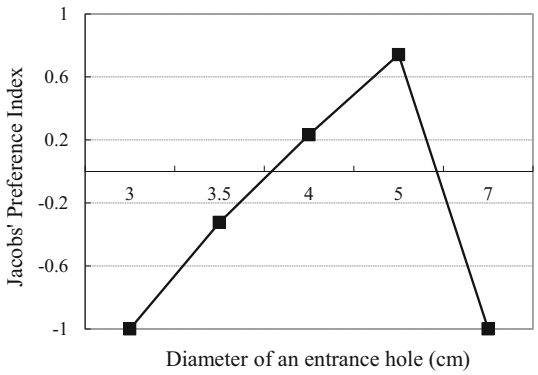

Fig. 4 Jacobs' preference indices for entrance hole sizes of nest boxes used by Siberian flying squirrel

only nest material present. In the other two boxes, fallen leaves, branches, and the bark of deciduous and coniferous trees were used instead. Two nests used by the species were concave and made mainly of the fallen leaves of deciduous species such as the Japanese spice bush (*Lindera obtusiloba*), Manchurian hazel (*Corylus mandshurica*), Castor aralia (*Kalopanax septemlobus*), and Korean ash (*Fraxinus rhynchophylla*). Small amounts of nest material were represented by coniferous leaves, such as Korean pine, Japanese red pine, and bald cypress. There were no woody vines in either of these nests.

Discussion

Our study sites were relatively well-managed forests in South Korea, in which many trees with wide trunks are present that are potentially suitable for use by primary and secondary cavity-nesters. However, the flying squirrels used very few nesting boxes. The fact that only small populations of squirrels were present in these forests might explain this disappointing result.

Many studies have shown that habitat quality influences litter size, leading to a trade-off between the number of offspring produced and the amount of parental care (Zang 1988; Badyaev and Ghalambor 2001). *Pteromys volans* give birth to litters containing an average of three young, and a maximum of six young (Yoon et al. 2004). The average litter size of squirrels in our study areas was similar to that previously reported, but our largest litter was three, half of the reported maximum litter size. This number might reflect habitat quality; however, additional studies, such as forest structure and nest tree characteristics are needed to explore this.

Of the boxes used, 82% were in coniferous forests. The flying squirrel mainly inhabits coniferous forests (Yu 2000), because these forests contain more trees with wide trunks and more cavities made by woodpeckers, which serve as nesting sites.

By installing nest boxes with entrance holes ranging from 3 to 7 cm in diameter we documented strong preference of the squirrels for 5 cm holes. Nest boxes with 3 and 3.5-cm diameter holes are too small for the flying squirrel. In contrast, a 7-cm diameter hole is large enough to permit attack by predators, such as *Otus* spp. Boxes with 3.5- and 4-cm diameter holes could also lead to inter-

Table 3 Number and percentage of nest box use with different entrance hole in diameters by tit species

Diameters of entrance hole (cm)	*Parus palustris*	*Parus major*	*Sittiparus varius*	Total
3	19 (10.98)[a]	3 (1.73)	0	22 (12.72)
3.5	3 (1.38)	19 (8.72)	10 (4.59)	32 (14.68)
4	0	7 (4.05)	15 (8.67)	22 (12.72)
5	0	0	1 (3.03)	1 (3.03)
7	0	0	0	0
Total	22 (3.59)	29 (4.74)	26 (4.25)	77 (12.58)

[a]Number (%)

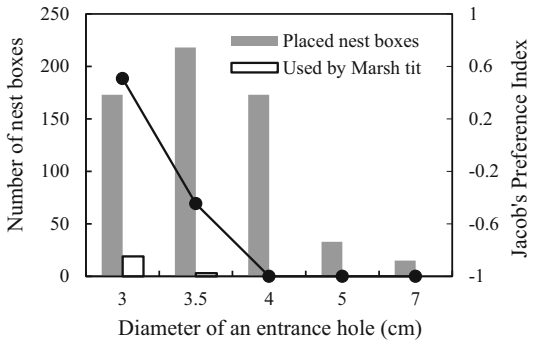

Fig. 5 Jacob's preference indices for entrance hole sizes of nest boxes used by Marsh tit

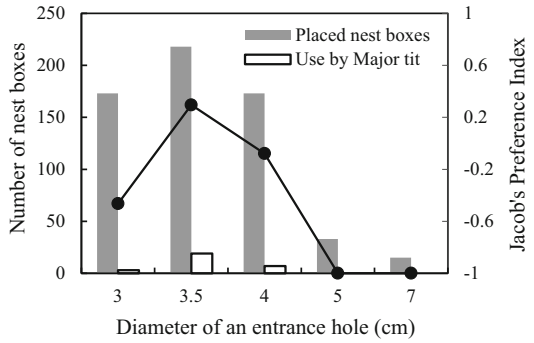

Fig. 6 Jacob's preference indices for entrance hole sizes of nest boxes used by Great tit

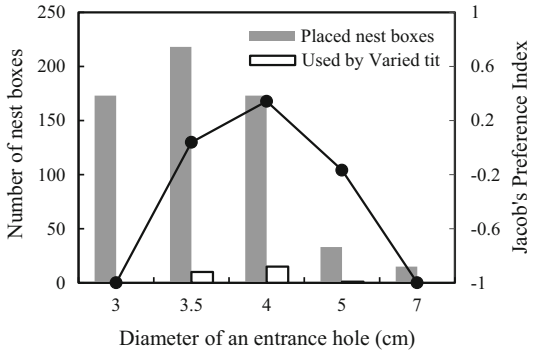

Fig. 7 Jacob's preference indices for entrance hole sizes of nest boxes used by Varied tit

Table 4 The nest materials used by Siberian flying squirrel at 11 boxes of 3 study sites

	N[a]	(%)	Mean weights (g)	(%)
Woody vines	9	82.00	30.21	50.96
Deciduous trees	4	36.36	13.64	23.01
Quercus spp.	4	36.36	7.14	12.04
Lindera obtusiloba	2	18.18	4.70	7.93
Corylus mandshurica	2	18.18	0.84	1.42
Kalopanax septemlobus	1	9.09	0.31	0.52
Morus alba	1	9.09	0.29	0.49
Stephanandra incisa	1	9.09	0.21	0.35
Fraxinus rhynchophylla	1	9.09	0.15	0.25
Coniferous trees	4	36.36	0.27	0.46
Pinus densiflora	3	27.27	0.08	0.13
Pinus koraiensis	2	18.18	0.07	0.12
Taxodium distichum	1	9.09	0.12	0.20
Unidentified	11	100	15.16	25.57
Total	11	100	59.28	100

[a]Number of nest used as nest materials of each plant species

specific competition for use with *Parus major* and *Sittiparus varius.*

They occupied 8.99% of boxes as compared to 1.11% occupied by flying squirrel. But tit species preferred boxes with entrance holes of diameters other than 5 cm, whereas flying squirrel preferred 5 cm entrance holes. Therefore, the optimum management strategy to minimize adverse effects of interspecific competition for nest sites is to install nest boxes with entrance holes measuring 5 cm in diameter.

The nests made by flying squirrels in the artificial nest boxes typically differed from those of the other nest box users, such as tits and *Tamias sibiricus*, in terms of shape and materials used. Bird species, such as *Parus* spp., mainly use bryophytes as nesting materials in artificial nest boxes, whereas *T. sibiricus* favor the broad leaves of deciduous trees. Bird species typically make concave nests in artificial nest boxes. However, most of the nests made by

Fig. 8 The shape of a nest made by the Siberian flying squirrel in artificial nest box

flying squirrels were consistently made of fibers from woody vines with holes. We could not identify exact species because of squirrels had cut and chewed the woody vines into fibrous materials. Common woody vine species in our study sites were wild kiwis (*Actinidia* sp.), grapes (*Vittis* sp.), and kudz vine (*Pueraria lobate*), thus flying squirrels may have used these materials in their nests. Our results indicate that woody vines are an extremely important nest material for the species. The flying squirrel is a sensitive nocturnal species. We suggest that the presence of vines in nest boxes represents an effort by squirrels to protect themselves from predators and excess light during the daytime. Additional surveys are needed to understand why squirrels consistently build nests made of woody vines. Such surveys should involve comparisons between artificial nests and natural cavity nests made by flying squirrels.

Management implications

Pteromys volans occurs in small populations that are widely distributed across South Korea. However, the preferred habitat of this species has diminished in recent years, mainly owing to forest management practices that call for removal of large, old trees, many of which might support cavities that could be used by flying squirrels. Furthermore, information about the current status and distribution of flying squirrels in South Korea remains limited. Nationwide survey is needed to compile such information and surveys should focus on well-managed coniferous forests in South Korea.

It is difficult to study the ecology of endangered species such as flying squirrels due to their small populations. However, studies using artificial nest boxes could help resolve this issue. Our study showed that for breeding, flying squirrels preferentially used artificial nest boxes, with entrance holes of 3.74- to 5-cm diameter, placed in coniferous forests. We recommend use of artificial nest boxes with 5-cm diameter entrance holes because they tend to minimize inter-specific competition and predation pressure.

Woody vines are usually removed by forest managers to promote the growth of dominant trees. However, we confirmed that woody vines are important nest materials for breeding flying squirrels. Therefore, forest managers should retain woody vines around major breeding areas of flying squirrels.

The placement of artificial nest boxes with holes measuring 5-cm diameter and the retention of woody vines in appropriate areas based on a nationwide survey might enhance prospects for the conservation of flying squirrel populations in South Korea.

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