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Distribution and habitat use of the endangered Siberian flying squirrel *Pteromys volans* (Rodentia: Sciuridae)

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Abstract

Background: Understanding the habitat characteristics of the endangered Siberian flying squirrel *Pteromys volans* is the first step in conserving and managing the forests it requires for nesting, gliding, and feeding. Therefore, in the present study, we characterized the habitats of *P. volans* using GIS analysis of 411 forest sites in South Korea where fecal droppings were found.

Results: Fecal signs of *P. volans* were found in various regions in South Korea, including the Baekdudaegan Mountains. GIS analysis with six environmental layers (vegetation type, wood-age class, diameter at breast height [DBH], crown density, elevation, and distance from stream) revealed that fecal signs of *P. volans* were more frequently found in broad-leaved deciduous forests (42%) located 200–399 m above sea level (43.1%) and 0–199 m from the nearest stream (53%), with 5th class wood-age (35.3%), middle size class DBH (51.1%), and high crown density (71%).

Conclusions: The present study provides information on the biotic and abiotic characteristics of *P. volans* habitats. In South Korea, the fecal droppings of *P. volans* were found predominantly old deciduous broadleaf forests. Further studies are needed to reveal whether the more frequent occurrence of *P. volans* dropping in broadleaf forests may be due to a particular preference of this species for the forests or to a simple reflection of the area of the broadleaf forests occupying a much larger area than other forest types in Korea.

Keywords: Habitat use, *Pteromys volans*, Siberian flying squirrel, GPS coordinates

Background

Siberian flying squirrels (*Pteromys volans*) (Sciuridae) are distributed from Finland and the Baltic Sea in the west to eastern Siberia and the Pacific Coast in the east, and their range includes the Korean Peninsula, Sakhalin Island in Russia, Northeast China, and Hokkaido in Japan (Cobet and Hill 1991; Nowak 1999; Won and Smith 1999; Hanski et al. 2000; Shar et al. 2016; Jo et al. 2018). Although *P. volans* is classified as a species of “Least Concern (LC)” in the IUCN Red List (Shar et al. 2016), it is classified as threatened at the national level

in some countries. The species is nearly extinct in Latvia (Shar et al. 2016) and is classified as “Nearly Threatened” in Finland (Liukko et al. 2016) and “Vulnerable (VU)” in both Estonia and China (Red Data Book of Estonia 2008; Jiang et al. 2016).

In South Korea, *P. volans* is the only flying rodent that ranges from the northeastern boreal forests of the Peninsula to the Taebaek Mountains in the south (Won and Smith 1999; Jo et al. 2018). Due to population decline, the species was listed as a natural monument by the Cultural Heritage Administration in 1982 and an endangered species by the Ministry of Environment in South Korea in 1998 (Won and Smith 1999; Jo et al. 2018).

As is often the case among wildlife (Andrén 1994; Baillie et al. 2004), changes in forest structure and composition,

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as well as habitat loss (e.g., logging), may be directly linked to the population decline of *P. volans* (Hokkanen et al. 1982; Lampila et al. 2009). Therefore, understanding their habitat characteristics is the first step in conserving and managing the forests that this endangered species requires for nest cavities, winter food, and gliding.

Although the habitat characteristics of *P. volans* have been relatively well studied in other countries, particularly Finland (Hanski 1998; Hanski et al. 2000; Timm and Kiristaja 2002; Airapetyants and Fokin 2003; Hurme et al. 2007; Selonen and Mäkeläinen 2017), they have not been adequately studied in South Korea, and the areas that have been studied are restricted to local habitat ranges (Cho et al. 2013; Kim et al. 2020). In the present study, we provide information on habitat characteristics of *P. volans* in South Korea using GIS analysis of locations in various forest regions where fecal droppings were found.

Materials and methods

The GPS coordinates of 411 fecal signs of *P. volans* were extracted from wildlife signs collected through the National Park Natural Resources Survey and National Natural Environment Survey, which were conducted in South Korea from July 2011 to November 2017. Surveys of wildlife were conducted according to the Guidelines for the 3rd and 4th National Natural Environment Surveys (Jeong et al. 2006; Hyeon et al. 2012). The droppings of *P. volans* were identified according to the morphological characteristics described in the previous papers (Woo et al. 2013; Han et al. 2018).

Biotic (vegetation, wood-age class, diameter at breast height [DBH], and crown density) and abiotic (elevation and distance from stream) components of the areas where *P. volans* droppings occurred were selected for GIS-based habitat analysis (Lim et al. 2015a, 2015b). Information on vegetation, wood-age class, DBH, and crown density was obtained from the 5th Digital Forest Cover Type map (Forest Service, South Korea). Elevation information was collected from a digital elevation model (Aster GDEM, NASA), which was constructed by extracting the contour layer from a digital topographic map of 1:5000 accumulation. Information on the distance from the nearest stream was obtained from the Water Resources Management Information System of the Ministry of Environment, South Korea. Spatial analysis of the habitat components was conducted using ArcGIS 10.1 (ESRI Inc., Redlands, CA, USA), with a spatial resolution of 30 m for all layers.

Results and discussion

Many fecal signs of *P. volans* were found in the Baekdudaegan and its surrounding region, an elongated mountain ridge that runs almost the entire length of the

Korean Peninsula from Mt. Baekdusan in the north to Jirisan National Park in the south (Fig. 1). Of the 411 fecal signs, 38 signs were found within the Baekdudaegan Protected Area. According to GIS analysis of the fecal sign locations ($n=411$) with the environmental GIS layers (Fig. 2), the fecal signs of *P. volans* were more often found in broadleaf deciduous forests (42%) (Fig. 3A), with 5th class wood-age (35.3%) (Fig. 3B), middle size class DBH (51.1%) (Fig. 3C), and high crown density (71%) (Fig. 3D). The signs ($n=411$) were primarily found at 200–399 m above sea level (43.1%; mean 483 ± 296 m; range 36–1496 m) (Fig. 3E) and 0–199 m from the nearest stream (53%; mean 236 ± 205 m; range 0–1060 m) (Fig. 3F).

A recent habitat study conducted in South Korea (see Table 5 in Kim et al. 2020) indicated that *P. volans* preferred deciduous forests (54%) with DBH of 18–30 cm and high crown density rather than coniferous (30%) or mixed forests (16%), despite the fact that available habitats consisted of primarily coniferous forests (48%). These results are similar to those in the present study (Fig. 3), except that our results indicated a preference for the 5th wood age class, whereas the 4th age class was preferred in the previous study. Another earlier study also revealed that 63.3% of 30 *P. volans* signs, including 15 nests and 15 droppings, were found in deciduous trees in mixed forests (Cho et al. 2013).

According to our study and the other studies previously conducted in South Korea, the Korean *P. volans* appears to prefer deciduous forests than coniferous forests. However, it cannot also be ruled out that more findings of *P. volans* droppings in broadleaf deciduous forests may be related to the type of the vegetation that dominates in South Korea rather than to a greater preference of *P. volans* for broadleaf forests. The most common forest type in South Korea is deciduous broadleaf forests in warm-temperate zone, whereas coniferous or mixed forests are restricted to only small areas of high mountains (Figs. 2A, E). This may explain why the fecal droppings are more common in deciduous broadleaf forests than coniferous forests in South Korea.

There are previous studies that can correlate the distribution of *P. volans* with dominant vegetation of habitats (Hanski 1998; Reunanen et al. 2002; Timm and Kiristaja 2002; Airapetyants and Fokin 2003; Santangeli et al. 2013). Forests in the boreal regions of Finland, Russia, and Estonia are dominated over most of their range by coniferous trees, especially species of spruce, pine, larch, and fir, with some broadleaf species of aspen, birch, poplar, alder, and willow (Freedman 1999). In these boreal countries, *P. volans* inhabits mature conifer-dominated forests with a mixture of deciduous trees, such as birch, alder, and aspen (Hanski 1998; Reunanen et al. 2002; Timm and Kiristaja 2002; Airapetyants and Fokin 2003;

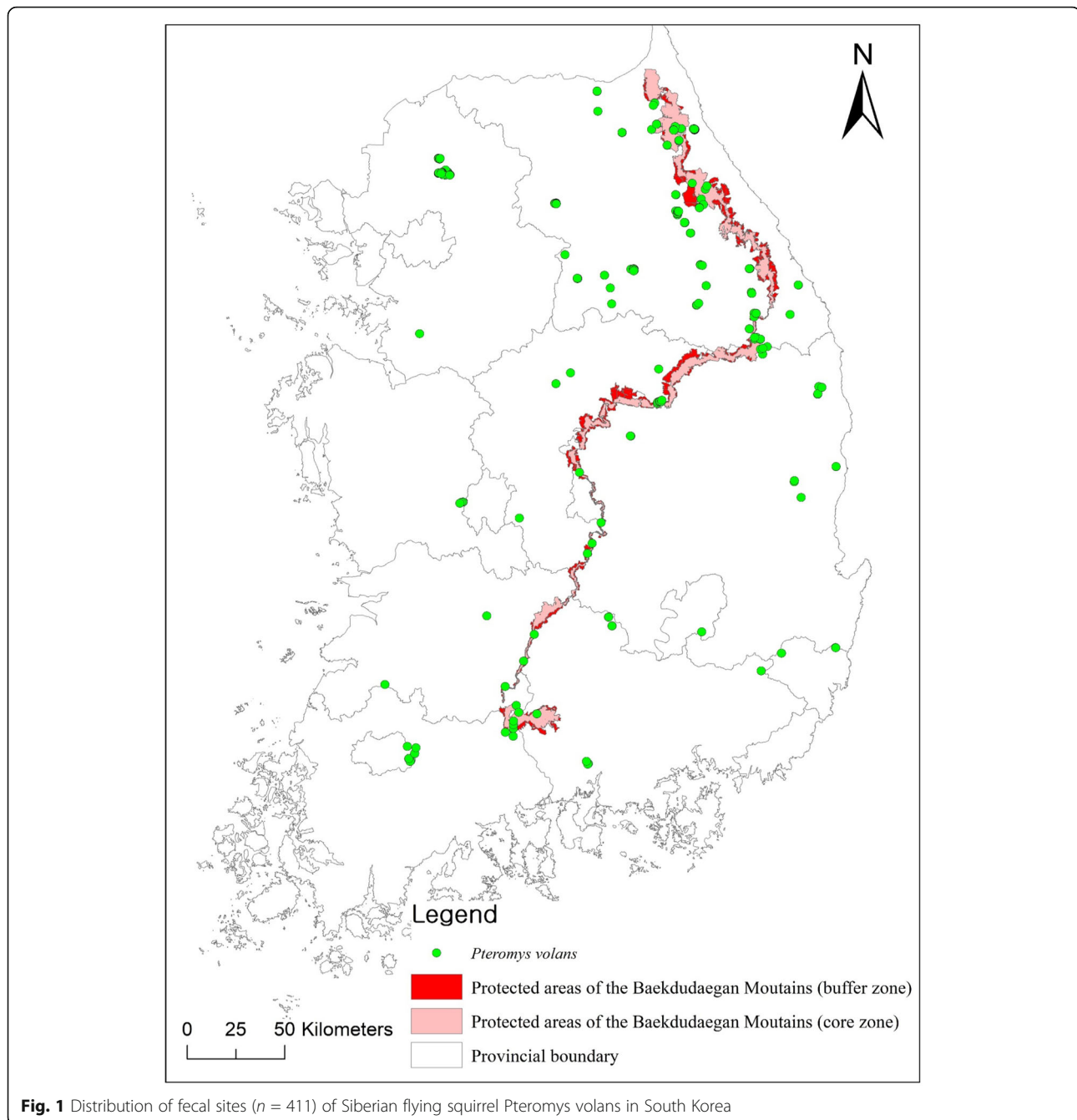
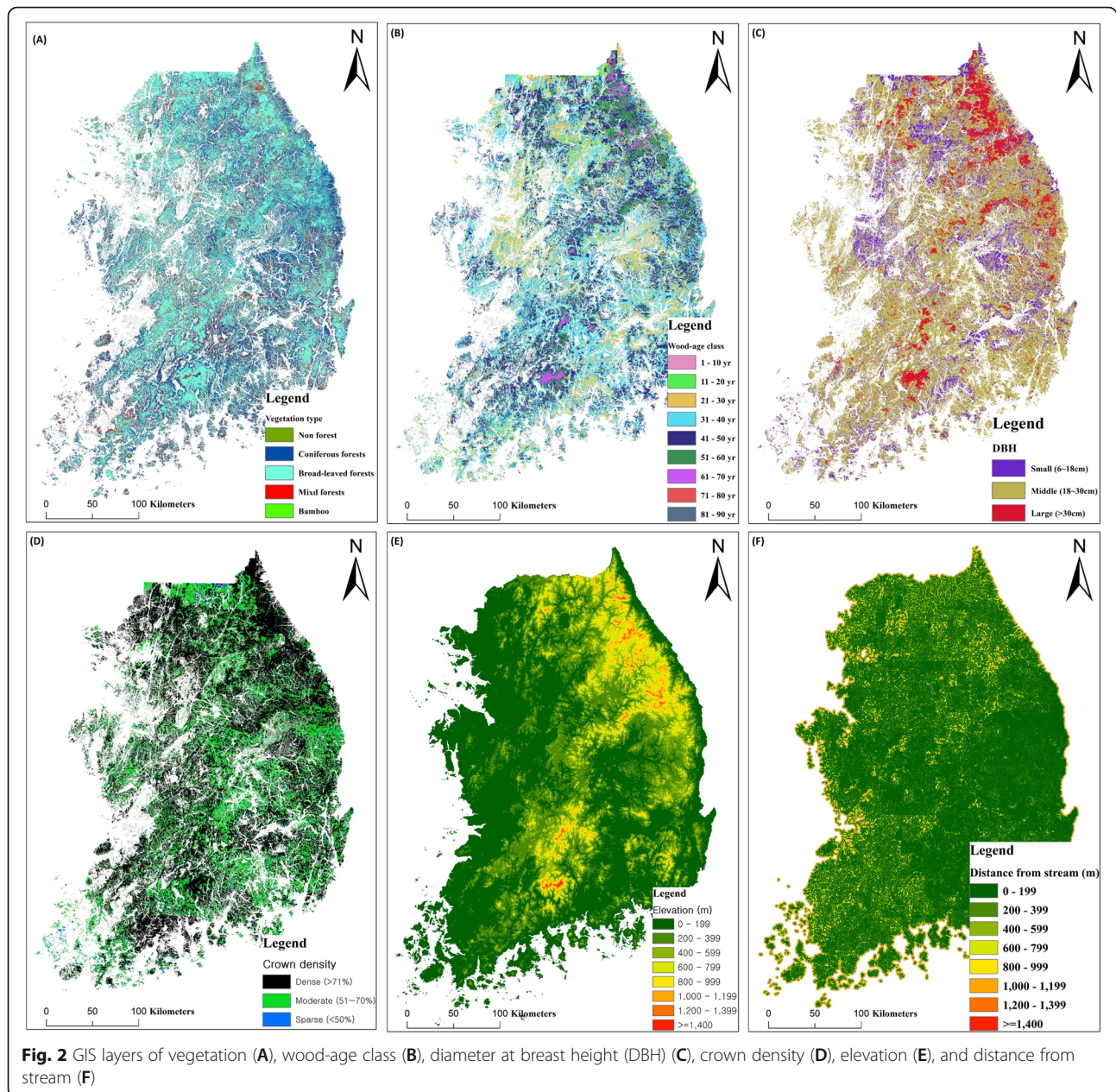


Fig. 1 Distribution of fecal sites ($n = 411$) of Siberian flying squirrel *Pteromys volans* in South Korea

Santangeli et al. 2013). *Pteromys volans* feeds mainly on the leaves of deciduous trees in summer (Mäkelä 1996), while catkins of birch and alder, as well as buds of both coniferous and deciduous trees, are used as food in winter and early spring (Mäkelä 1996; Hanski 1998; Selonen and Mäkeläinen 2017). In those boreal countries, therefore, the frequent use of coniferous forests as the species' primary habitat may have more to do with the broader dominance of coniferous forests in boreal regions rather than because of a greater preference for conifers.

In this study, the droppings of the Korean *P. volans* were found more frequently in broadleaf forests. However, the data used for GIS analysis of forest types was restricted to the sites where *P. volans* droppings were found within the surveyed areas, whereas those where the droppings were not found were not included. Therefore, through this study, it cannot be confirmed whether the more frequent finding of their droppings in broadleaf forests is due to the greater preference of *P. volans* for broadleaf forests or to the broader occupation of broadleaf forests in South Korea.



To confirm the forest types (deciduous, coniferous, or mixed trees) preferred by *P. volans*, in future research, the overall forest types within the entire survey area should be compared with the forest type of the area where *P. volans* droppings were found within the survey area. In addition, it is necessary to investigate the forest types of not only the areas where the droppings were found within the survey area, but also the areas where they were not found.

Conclusions

The present study provides information on biotic (vegetation type, wood-age class, DBH, and crown density)

and abiotic (elevation and distance from stream) habitats of the endangered *P. volans* in South Korea. The fecal signs of *P. volans* were more often found in old deciduous broadleaf forests in South Korea, in contrast to other countries such as Finland, Russia, and Estonia, in which they were mainly found in conifer-dominated forests. The results of our study are in good agreement with those of the previous studies conducted in South Korea on the forest types preferred by *P. volans* (Cho et al. 2013; Kim et al. 2020). The more frequent occurrence of *P. volans* droppings in broadleaf forests may be because this species prefers the forests than other forest types. Another possibility may be because broadleaf forests are spread

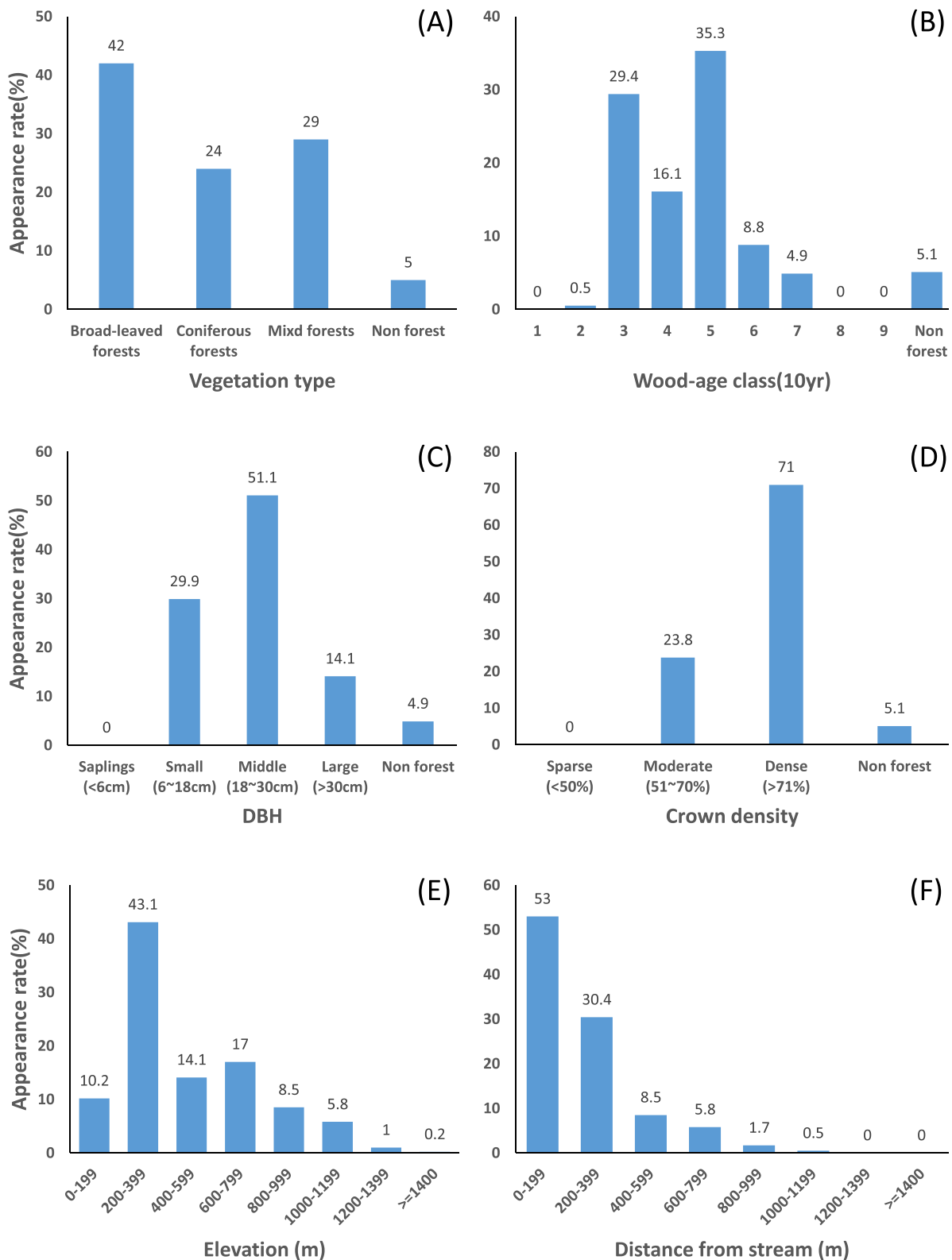


Fig. 3 Appearance percentage of *Pteromys volans* signs (n=411) by vegetation type (A), wood-age class (B), diameter at breast height (DBH) (C), crown density (D), elevation (E), and distance from stream (F)

over a much larger area than other forest types in South Korea, rather than a particular preference of this species for broadleaf forests. In further studies, the forest types in the dropping-discovered and non-discovered sites in the survey area should be compared to identify the forest type favored by *P. volans*. Our results can benefit wildlife ecologists working on the conservation and habitat management of the Siberian flying squirrel and related species.

Abbreviations

DBH: Diameter at breast height; DEM: Digital elevation model

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Authors' contributions

LSJ: Data collection, writing—original draft, and GIS analysis; KKY: Data collection; KEK: Data collection; HCW: Data collection; PYC: Data collection, research grant acquisition, research design, and writing—review and editing. The author(s) read and approved the final manuscript.

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Availability of data and materials

The datasets collected during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing financial interests or personal relationships that influenced or could be perceived to have influenced the work reported in this article.

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