

Gliding ability of the Siberian flying squirrel *Pteromys volans orii*

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Abstract. Forest fragmentation is a threat to flying squirrel population due to dependence on gliding locomotion in forests. Therefore, it is essential to understand their gliding ability. The gliding locomotion of *Pteromys volans orii*, were observed from July 2003 to June 2005, in Obihiro, Hokkaido, Japan. The horizontal distance and glide ratio obtained from 31 glides were employed as indicators to know their gliding ability. The gliding ability was not affected by weight and sex in the Siberian flying squirrel. Mean horizontal distance and glide ratio were 18.90 m and 1.70 with great variation. Although maximum values were 49.40 m (horizontal distance) and 3.31 (glide ratio), most of the horizontal distance and glide ratio were in the '10–20 m' and '1.0–1.5', respectively. Therefore, to retain the flying squirrel populations, forest gaps should not exceed the distance traversable with a glide ratio of 1.0 (distance between forests/tree height at the forest edge).

Key words: gliding ability, gliding ratio, horizontal distance, *Pteromys volans orii*.

The Siberian flying squirrel, *Pteromys volans*, ranges over northern parts of the Eurasia, and from Korea to Hokkaido, Japan. This species is a nocturnal gliding mammal. The flying squirrel population in Finland has declined due to a shrinkage of the area of its optimal habitat, which comprises stands of mature spruce and broadleaved trees (Hokkanen et al. 1982). *P. volans orii* which is endemic subspecies to Hokkaido is widely distributed in the lowlands and mountains. Therefore, it is not listed as a threatened species in Japan (Ministry of the Environment 2002). However, its forest habitats are shrinking due to land development. Residential areas and road construction have reduced or fragmented the forests.

Unlike terrestrial mammals, flying squirrels depend on gliding locomotion. Although gliding is an effective locomotion mode in forests, it would be difficult for them to travel across wide-open area. Thus, forest fragmentation could be a threat to populations of *P. volans orii*. Yanagawa et al. (2004) constructed a structure to cross roads to mitigate the problems caused by forest fragmentation in Hokkaido. Although there has been some action to conserve *P. volans orii*, its biological traits are not fully understood.

The key purposes of gliding may be to avoid predators or to minimize the energy costs of moving (Goldingay 2000). Gliding locomotion has been investigated in some mammalian species (Ando and Shiraishi 1993; Jackson 1999; Vernes 2001). Flying squirrels are occasionally exposed to high risks such as strong wind and predators, when they travel across wide gaps between fragmented forests. It is of particular importance to identify what is the secure gliding environment for flying squirrels in forests. Therefore, we observed the gliding locomotion of *P. volans orii*, and estimated their gliding abilities.

Materials and methods

Study area

The study was conducted in Obihiro, Hokkaido, Japan (42°51'–53°N, 143°9'–11°E). This city has a large residential area and extensive agricultural land which provides habitats for flying squirrels. Some habitats are fragmented and isolated, without tree connectivity. Our study areas of eight forests (1.7–3.1 ha) were located near the town, in strips along riverbanks, and in built-up areas and meadows (Fig. 1). These areas are flat and

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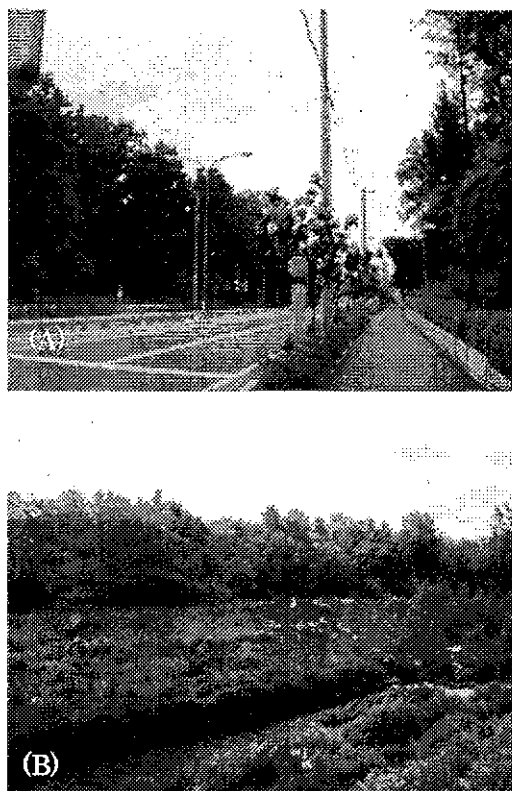


Fig. 1. Landscapes of our study area. (A) shows a small forest adjacent to roads, (B) shows a forest on the bank of a river.

approachable, and are occupied by broadleaf trees such as *Betula platyphylla* var. *japonica*, *Alnus japonica*, and *Quercus dentata*, and conifers such as *Abies sachalinensis* and *Larix leptolepis*. The mean tree height in the forests was 11.5 to 19.1 m, and the mean density was 116.7 to 908.3 trees/ha. There were sparse branches in the mid-story and shrubs in the understory, therefore it was considered as the environment with few obstructions for gliding by flying squirrels.

Field observations

More than 100 nest boxes were spread throughout the study areas at 2 to 5 m height, as reported by Yanagawa (1994). From July 2003 to June 2005, 64 nest boxes were checked more than twice a month (excluding December to February) in the daytime. When the resting flying squirrels were found, these boxes were collected to capture them. Body mass, sex, reproductive condition, and age class were recorded for all captured flying squirrels. All animals were marked with numbered metal ear tags. Nest boxes with marked individuals were returned to the capture point before sunset. After sunset,

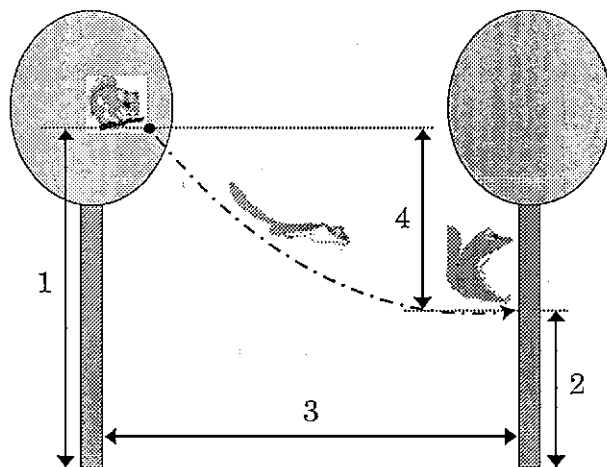


Fig. 2. Gliding path of the flying squirrel and four measurements: 1) height of launch, 2) height of landing, 3) horizontal distance, and 4) vertical drop.

we observed their gliding behavior. Most animals first climbed the tree in which the nest box was installed, then glided from a high point of this tree to a lower point of another tree. To avoid disturbing them, we observed their gliding locomotion without the use of artificial light when possible. Observations were not carried out on gusty or rainy days due to the impact of these conditions on the glide path.

Measurement of glides

Based on the observations of gliding locomotion, the height from ground to launch point, height from ground to landing point, and horizontal distance between launch and landing trees were recorded. Vertical drop was calculated as the difference between height of launch and height of landing (Vernes 2001) (Fig. 2). Each was measured by laser rangefinder (Opti-Logic Corporation) to the nearest 0.1 m. Horizontal distance and glide ratio (horizontal distance/vertical drop) were employed as indicators of gliding ability (Ando and Shiraishi 1993).

Results

A total of 69 flying squirrels (35 males and 34 females) were captured using the nest boxes. Excluding young flying squirrels, 31 glides (18 males and 13 females) were recorded. Same individuals were included in all 31 glides. Most observed glides were the first glides after leaving the nest box, but 9 glides were made by four squirrels on successive travels. Glides were measured easily, since most flying squirrels traveled in a

Table 1. Parameters of gliding and weight for males and females

Parameters	Males (n = 18)				Females (n = 13)				Statistic	
	Mean	SD	Min	Max	Mean	SD	Min	Max	U	P
Height of launch (m)	15.71	4.32	8.50	23.80	13.45	5.44	5.60	24.00	86.50	ns
Height of landing (m)	3.78	2.29	1.00	8.60	2.67	1.67	0.80	6.70	81.00	ns
Vertical drop (m)	11.92	3.97	6.70	18.60	10.78	5.49	3.80	22.20	95.50	ns
Horizontal distance (m)	20.62	11.82	4.30	49.40	16.52	9.45	5.70	39.00	90.50	ns
Glide ratio	1.70	0.75	0.61	3.31	1.69	0.75	0.48	2.97	115.00	ns
Weight (g)	110.20	10.79	91.30	123.30	132.18	28.67	73.70	161.40	47.00	<0.01

Table 2. Mean and range of the gliding performance for all glides

Parameters	All glides (n = 31)			
	Mean	SD	Min	Max
Height of launch (m)	14.76	4.87	5.60	24.00
Height of landing (m)	3.32	2.10	0.80	8.60
Vertical drop (m)	11.44	4.62	3.80	22.20
Horizontal distance (m)	18.90	3.97	4.30	49.40
Glide ratio	1.70	0.74	0.48	3.31

straight line, without turning, and the topography was flat. There were no significant differences in the gliding parameters between male and female (*t*-test, $P > 0.05$; Table 1), although females (mean \pm SD; 132.18 ± 28.67 g) were significantly heavier than males (110.20 ± 10.79 g; $P < 0.01$). The data for males and females were therefore pooled in the following analysis. Moreover, body weight did not correlate with either horizontal distance or glide ratio (Pearson's correlation coefficient; $P > 0.05$).

The mean horizontal distance and glide ratio were 18.90 m and 1.70, respectively (Table 2). However, there was a wide range of horizontal distances (4.30–49.40 m) and of glide ratios (0.48–3.31). The various glides we observed allowed us to identify the most commonly used type of glide. To determine the frequency distribution of the glides, we categorized them into 4 classes of horizontal distance and 6 classes of glide ratio. The most frequently traveled distance was 10 to 20 m (17 cases). The other distance classes were rarely observed (Fig. 3). The most frequent glide ratio was in the '1.0–1.5' class (10 cases) (Fig. 4). The '≥3.0' class had only one case, but the other classes had five cases each. In addition, horizontal distance was significantly positively correlated with glide ratio ($r = 0.63$, $P < 0.0001$).

Discussion

In Siberian flying squirrels, there were no significant

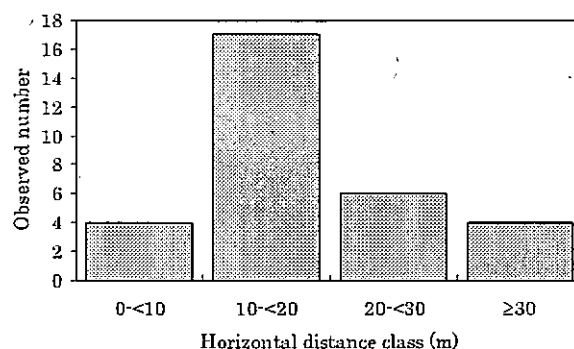


Fig. 3. Observed numbers of horizontal distance divided by four classes.

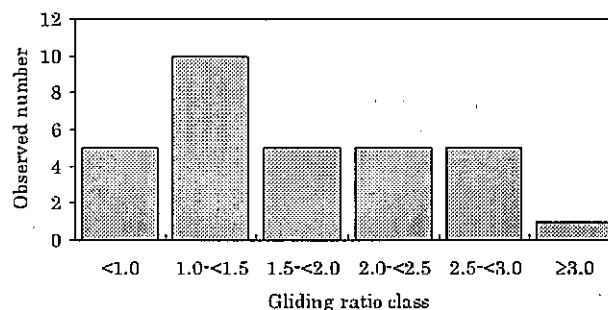


Fig. 4. Observed numbers of gliding ratio divided by six classes.

differences in gliding indicators between male and female. They had excellent gliding ability; that was 50 m for horizontal distance and 3.3 for glide ratio in maximum. However, the most observed glides of this species were 10 to 20 m for their horizontal distance and 1.0–1.5 for glide ratio. This may be to avoid high risks such as a strong wind and avian predators in crossing wide gaps.

The mean horizontal distance of the Siberian flying squirrel was similar to that of the northern flying squirrel, *Glaucomys sabrinus* (14.2–19.0 m; Vernes 2001), which has a similar weight (Goldingay 2000). Similarly, there was little difference in the mean glide ratios

between Siberian flying squirrels and northern flying squirrels (1.98; Vernes 2001). Also, the sugar glider, *Petaurus breviceps*, which has the same body size as the Siberian flying squirrel, glides as flying squirrels (20.42 m; Jackson 1999). The southern flying squirrel, *G. volans*, which is smaller than the Siberian flying squirrel, has a mean glide ratio of 1.53 (Scheibe and Robins 1998), but a larger species, Japanese giant flying squirrel (*Petaurista leucogenys*), has glide ratios of 1 to 3 (Ando and Shiraishi 1993). It would appear that smaller species have lower glide ratios. Our data show, however, that there was no significant difference between squirrels of different weights in a same species. Gliding ability of the Siberian flying squirrel was also unaffected by their weights.

The Siberian flying squirrel showed a wide range of horizontal distances and glide ratios, with the maximum for both being somewhat higher than that seen in other gliding mammals (*G. sabrinus*, Vernes 2001; *Petaurus breviceps*, Jackson 1999; *Petaurista leucogenys*, Ando and Shiraishi 1993). We therefore suggest that the Siberian flying squirrel also has a high gliding ability, matching that of other gliding mammals. This higher gliding ability could often be observed at widely fragmented forest edges, where the gliding ratio was positively correlated with horizontal distance. In general, however, flying squirrels would be prevented from traveling among fragmented forests without an intermediate tree due to the limits on their practicable gliding distance.

The maximum horizontal distance of the Siberian flying squirrel may be 50 m with a glide ratio of 3.3. Nevertheless, most of its horizontal distances and glide ratios were up to 20 m and 3.0, respectively. In addition, most glides were in the '10–20 m' and '1.0–1.5' classes. Although they have a comparatively high gliding ability, they generally travel shorter distances. The reason for this conservatism might be the psychological and technical difficulties seen in *Petaurista leucogenys* (Ando and Shiraishi 1993). Therefore, when their forest habitat is fragmented by development, the gaps between forests should be less than the distance traversable with a glide ratio of at least 1.0 (= distance between forests/tree height at the forest edge) by adult flying squirrels. On account of the reduced abilities of young flying squirrels, lower distances and glide ratios should be considered.

In Finland, Selonen and Hanski (2004) showed that wide open areas prevent the straight movement of young Siberian flying squirrels. Also, the density of southern

flying squirrels may be high in areas where distances between patches is <500 m (Woodworth et al. 2000). The effects of clear-cuttings negatively affect the biology and occurrence of the flying squirrels, so the squirrel's need to glide should be supported. If clearings exceed the gliding ability of flying squirrels, developments must include measures to permit movement among forests (e.g., Eco-bridge for flying squirrels, Yanagawa et al. 2004).

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