The enhanced retreating trend reveals that many glaciers in the Baspa Valley show their individual limbs exposed, which were initially flowing as a single glacier. The present-day Baspa Valley reflects increase in the number of glaciers with a decrease in their size on account of fragmentation.

Other than global warming, factors like size of accumulation and ablation zone, slope of ablation zone, amount of moraine cover on ablation zone and orientation of the glaciers, are intimately related with each other and are important local controlling factors of glacial retreat for the Baspa Valley. It is difficult to correlate the retreat of the glaciers simply on the basis of a single parameter. However, the retreat of glaciers of the Baspa Valley is found to be inversely proportional to the size of the accumulation zone and the Mcab/Exab ratio. The slope of the ablation zone is directly proportional to the glacier retreat.

The direction of the glaciers is important, since it provides information about the period of solar radiation. The south-facing glaciers are exposed to solar radiation for longer time compared to north-facing glaciers. The longer time of exposure to solar radiation increases the rate of melting for south-facing glaciers than the north-facing glaciers.

In the past, the extensions of glaciers were at much lower altitude, i.e. at least 950 m below the present-day extent of the glaciers. The maximum lengthwise retreat in the case of south-facing glacier is 4670 m, whereas in the case of the north-facing glaciers, it is 3880 m. The present glacial geomorphic studies of the Baspa Valley suggest that the south-facing glaciers are retreating faster (24.85%) than the north-facing glaciers (17.97%).

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Gliding behaviour of Indian Giant Flying Squirrel *Petaurista philippensis* Elliot

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Gliding behaviour of Indian Giant Flying Squirrel (*Petaurista philippensis*) was observed from March 2009 to February 2010, at Sitamata Wildlife Sanctuary, Rajasthan, India. A total of 1203 glides were observed. One hundred glides were recorded for assessment of gliding behaviour and 32 glides were recorded for analysing gliding speed. The mean glide ratio (2.32) was found to be higher than that of *Petaurista leucogenys* (1.87), *Glaucomys sabrinus* (1.98), *Pteromys volans orii* (1.70), and lower than that of *Glaucomys volans* (2.8). Ground speed (6.96 m/s), air speed (7.51 m/s) and gliding angle (25.53) were similar to other studies. Mean horizontal distance and air distance were 16.28 and 20.08 m respectively. Short glides were preferred by *P. philippensis* in comparison to long glides.

Keywords: Air speed, air distance, glide ratio, ground speed, glide angle, *Petaurista philippensis*.

THE ability of arboreal forms to leap from great heights without harm is a valuable adaptation to life high above the surface of the ground. This ability reaches its maxi-

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mum development among non-flying animals that have developed some form of a patagium and that are capable of gliding[1].

'Gliding' is aerial locomotion without any 'motor' propulsion (i.e. beating of wings), wherein the animal loses altitude in order to maintain forward motion[2]. Gliding evolved as an energy cost-effective mode of locomotion in arboreal animals because gliding between trees consumes less energy and time compared to running and flying[1]. It has evolved independently in at least six groups of mammals. The most diverse and widespread of these groups are flying squirrels (15 genera, 44 species)[3]. There have been numerous studies of different species of flying squirrel in the context to gliding[4–12].

Eleven species of flying squirrels are found in India, most of which are concentrated in the Himalayan and North East regions, whereas the Western Ghats remains depauperate with only two species found along its stretch[13–15]. *Petaurista philippensis* contains broader distribution in comparison to other species, which are commonly present in peninsular South India and some western states of the country[16]. Many aspects of flying squirrels were explored in India but no work has been carried out on their gliding behaviour[14–22].

In this communication we analyse the gliding behaviour of *P. philippensis* and compare with other flying squirrels.

The Sitamata Wildlife Sanctuary (74°25′–40′E and 24°04′–23′N), established in 1979, is located in the Southern Aravallis of Rajasthan. It covers an area of 423 sq. km, in which the total reserve forest area is 345.37 sq. km and protected forest area is 77.57 sq. km. The configuration of the land is hilly and rugged with high altitude variation ranging from 280 to 600 m. The general slope of the land is from northwest to southeast. The sanctuary falls under the sub-tropical humid climatic region, characterized by distinct winter (November–February), summer (March–June) and monsoon (June–October) seasons. Average rainfall is 756 mm and mercury seldom falls below 6°C in winter and never rises above 45°C in summer. According to Champion and Seth[23], forest of the sanctuary is deciduous type with *Tectona grandis*, *Terminalia tomentosa*, *Terminalia arjuna*, *Boswellia serrata*, *Madhuca indica*, *Erahatia levis*, *Diospyros melanoxylon*, *Soymida febrifuga*, *Ficus religiosa*, *Ficus cordifolia*, *Cordia dichotoma*, *Aegle marmelos*, *Mangifera indica* and *Amlica officinalis* being the predominant tree species.

The study was conducted from March 2009 to February 2010. The protocol for field visits was fortnightly in fifteen days through each month. Animals were observed visually, using binoculars and spotlight (NS-8300DX) with Swiss handle, continuously from 1900 to 0600 h. *P. philippensis* is a nocturnal and arboreal animal. It was detected by eye-shine, calls and movement in or between the trees.

For analysis of gliding behaviour, different parameters were used, such as height of launch (m), height of landing (m), vertical drop (m), horizontal distance (m), air distance (m), glide ratio, ground speed (m/s), air speed (m/s), gliding angle (°) and girth at breast height (GBH) of landing tree (cm) (Figure 1).

Heights of launch, landing and horizontal distance were measured using a measuring tape. A stopwatch was used to record the time of gliding. Vertical drop was calculated as the difference between height of launch and height of landing. Glide ratio was calculated as horizontal distance divided by vertical drop. Direct glide distance and gliding angle were measured by plotting starting, landing and horizontal distance on a graph paper. Direct glide distance was used to calculate air speed (direct glide distance/time) and horizontal distance was used to calculate ground speed (horizontal distance/time).

Pearson's product moment correlation (r) was used to estimate correlation between different parameters. Linear regression (r^2) was used to assess the relationship of horizontal distance to vertical drop and gliding speed. Chi

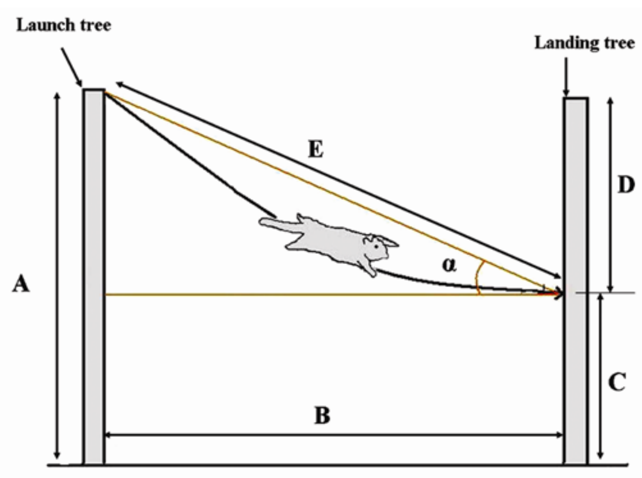

Figure 1. A model of gliding trajectory of flying squirrel and measurements: launching height (A), horizontal distance (B), landing height (C), vertical drop (D), air or direct distance (E) and gliding angle (α).

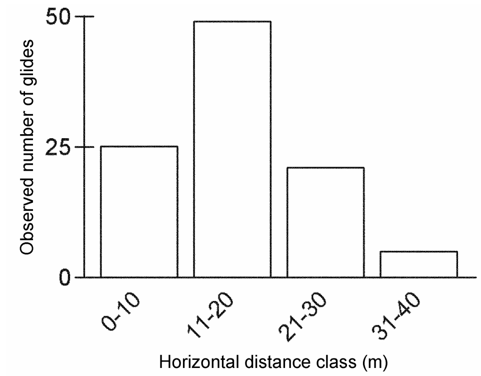

Figure 2. Observed number of glides in horizontal distance divided into four classes.

Table 1. Mean and range of different parameters for gliding behaviour of *Petaurista philippensis*

Parameter	*n*	Mean	SD	Minimum	Maximum
Height of launch (m)	100	19.42	4.58	8	28
Height of landing (m)	100	11.91	3.97	4.5	22
Vertical drop (m)	100	7.51	3.72	2	17
Horizontal distance (m)	100	16.28	7.70	4	35
Air distance (m)	100	18.06	8.27	4.47	38.48
Glide ratio	100	2.32	0.96	1.15	6
Ground speed (m/s)	32	6.96	1.94	3.75	10.39
Air speed (m/s)	32	7.51	2.04	4.18	11.36
Gliding angle (°)	100	25.53	7.80	8	45
GBH of landing tree (cm)	100	224.4	77.86	80	435

Table 2. Mean gliding angle and girth at breast height (GBH) of landing tree in different horizontal distance classes of *P. philippensis*

Horizontal distance class (m)	*n*	Gliding angle (°) Mean ± SD	GBH of landing tree (cm) Mean ± SD
0–10	25	29.0 ± 8.90	226.6 ± 85.81
11–20	49	24.5 ± 7.70	220.8 ± 74.92
21–30	21	23.6 ± 5.80	216.7 ± 76.35
31–40	5	24.0 ± 3.50	223.5 ± 74.82

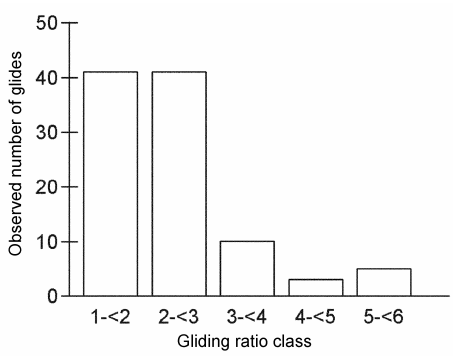

Figure 3. Observed number of glide ratios divided into five classes.

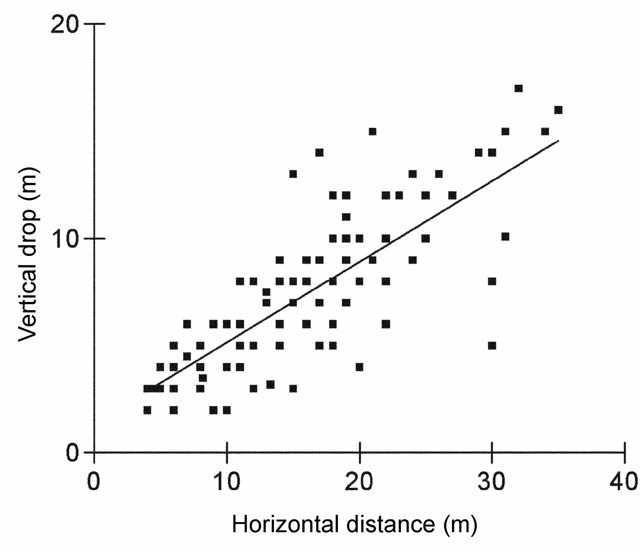

Figure 4. Relationship between vertical drop and horizontal distance ($r^2 = 0.60$, $n = 100$, $P < 0.001$) of *Petaurista philippensis*.

square test (χ^2) was applied for comparing seasonal variation in gliding number.

A total of 1203 glides were observed during the study period but due to the quick movement of the animal we were able to record the speed for only 32 glides. One hundred glides were recorded for assessment of gliding behaviour (Table 1). These were divided into four categories according to their horizontal distance (Figure 2) and five categories according to their glide ratio (Figure 3). *P. philippensis* preferred a horizontal distance class of 11–20 m, and the least preferred distance class was 31–40 m. Gliding always started from the upper canopy area of the launching tree. No glide was observed that initiated from the middle or lower canopy area. Launching height did not correlate with horizontal distance ($r = 0.24$, $n = 100$, $P > 0.0001$).

Glide ratio ranged from 1.15 to 6.00. The most frequent glide ratio class was 1–<2 and 2–<3 (41 cases; Figure 3). The 0–10 m horizontal distance class contained mean glide ratio of 2.01 ± 0.96 SD, the 11–20 m class 2.40 ± 0.96, the 21–30 m class 2.52 ± 1.02 and the 31–40 m class 2.28 ± 0.45. No correlation was found between glide ratio and horizontal distance ($r = 0.25$, $n = 100$, $P > 0.0001$), air speed ($r = 0.13$, $n = 32$, $P > 0.0001$) and air distance ($r = 0.08$, $n = 32$, $P > 0.0001$).

Figure 4 shows the relationship between horizontal distance and vertical drop. Vertical drop was significantly correlated with horizontal distance ($r = 0.77$, $n = 100$, $P < 0.0001$). Highest vertical drops were recorded in the 30–40 m class and lowest in the 0–10 m horizontal distance class. Gliding speed increased with increasing horizontal distance (Figure 5). Air speed and ground speed showed significant correlation ($r = 0.98$, $n = 32$, $P < 0.0001$). Air speed was slightly higher than ground speed (Figure 5).

The highest mean GBH value of landing trees was related to the 0–10 m horizontal distance class and lowest mean value to the 21–30 m class (Table 2). There was no correlation between GBH of landing tree and horizontal distance (r = –0.01, n = 100, P > 0.001).

Gliding angle is an important factor in gliding behaviour of *P. philippensis*. Table 2 shows that a higher gliding angle was found in smaller gliding distance, and gliding angle decreased with increasing gliding distance. Correlation between gliding angle and horizontal distance was found to be significant (r = –0.31, n = 100, P < 0.0001).

Gliding behaviour was affected by seasonal variation. During the study period, 1203 glides were observed with monthly fluctuations (Table 3). Higher number of glides was observed in summer season followed by monsoon and winter. The number of glides between two successive seasons was insignificant; summer–monsoon (χ^2 = 72.56, df = 3, P > 0.0001), monsoon–winter (χ^2 = 41.75, df = 3, P > 0.0001) and winter–summer (χ^2 = 123.5, df = 3, P > 0.0001).

Gliding activity of *P. philippensis* was initiated from 1930 h during their active period (Figure 6). This activity decreased till 0130 h, after which it again increased slightly and totally ceased at 0530 h, with the flying squirrels entering their dens. Early night period (1930–2330 h) was the most active time for gliding, middle night period (2330–0230 h) was the dormant time and late falling time (0230–0530 h) was the less active period of *P. philippensis* for their gliding activity.

Table 3. Seasonal variation in the number of glides of *P. philippensis* at the Sitamata Wildlife Sanctuary from March 2009 to February 2010

	Summer	Monsoon	Winter
Total number	537	385	281
Mean ± SD	134.3 ± 18.89	96.25 ± 13.70	70.25 ± 5.05

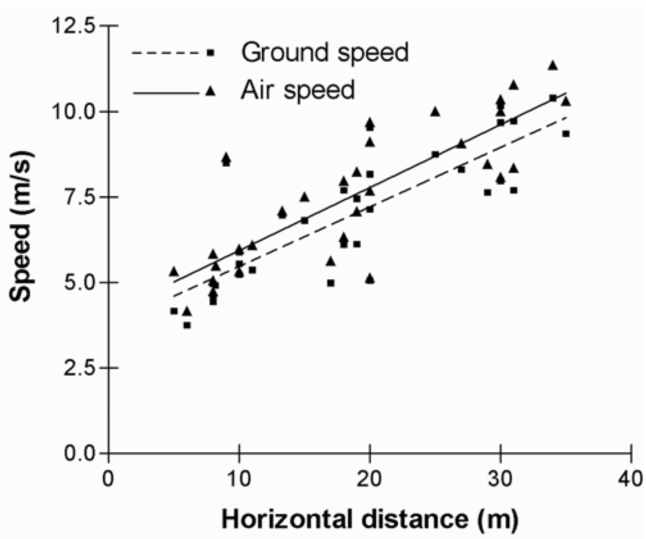

Figure 5. Relationship of horizontal distance to air speed (r^2 = 0.69, n = 32, P < 0.001) and ground speed (r^2 = 0.67, n = 32, P < 0.001).

In the present study, *P. philippensis* preferred short glides (11–20 m horizontal distance class), which is similar to *Glaucomys* sp.[24], *Pteromys volans orii*[10] and *Petaurista leucogenys*[7]. Long glides require a broad platform for landing, which is not always available on its gliding route. Many intervening trees also restrict its long-distance gliding. Another reason is the flying squirrels have limited home range of a few hectare area and long distance gliding would be unnecessary in such small home ranges with continuous vegetation[7]. *Glaucomys* sp. glides were found to be within the range of 6–20 m, although they are capable of gliding for more than 90 m (ref. 24). Ando and Shiraishi[7] observed that long-distance glides exceeding 50 m accounted for only 7.4% of total glides for *P. leucogenys* and longest glide of 115 m was recorded only once. Over short distances, *P. leucogenys* was found to prefer non-gliding locomotion to gliding. This could be because short-distance glides do not allow enough time to attain the optimal glide ratio for a constant glide. Gliding with a very low glide ratio, as happens in a parachute descent, lacks stability in the air and does not fully permit manoeuvrability in the air[7].

The mean glide ratio of *P. philippensis* was 2.32 ± 0.96, with great variability in their range 1.15–6.00. Glide ratio for *P. leucogenys* was recorded in two studies and found to be 3.5 (range 1–3) and 1.87 (range 3–3.5) respectively[6,7]. The present mean glide ratio (2.32) was also found to be higher than that of *Glaucomys sabrinus* (1.98)[3] and *P. volans orii* (1.70)[10], but lower than that of *Glaucomys volans* (2.8)[25]. Flying squirrels had higher glide ratios when there were no environmental obstacles that prevented animals from gliding[6]. Lower glide ratios avoid high risks such as a strong wind and avian predators in crossing wide gaps[10].

Air speed of *P. philippensis* (4.18–11.36 m/s) was slightly higher than its ground speed (3.75–10.39 m/s). Scheibe and Robins[26] measured gliding speed of *G. volans* which varied between 4.12 and 8.85 m/s. Ando and Shiraishi[7] recorded variations in ground speed of *P. leucogenys* in the field between 7 and 15.1 m/s. Stafford *et al.*[6] also calculated a ground speed of 3.03–8.89 m/s for the same species. Scholey[27] reported mean air speed (15.1 ± 3.2) for *P. petaurista* that was higher than that observed in the present study (7.51 ± 2.04). All of these studies, including the present one, are based on the assumption that launch and landing phases of the glides are of equal duration on short and long glides, and that there is no consistent difference in mid-glide speeds between short and long glides. Flying squirrels may have increased their gliding speed by increasing their gliding angle, which in turn would reduce the glide ratio. Localized variation in wind speed and direction might also affect the optimal speed[3].

Vertical drop of *P. petaurista* (7.45 m)[27], *G. sabrinus* (1.91)[3] and *G. volans* (1.85)[26] was lower compared to that of *P. philippensis* (7.51 m). Vertical drop could be

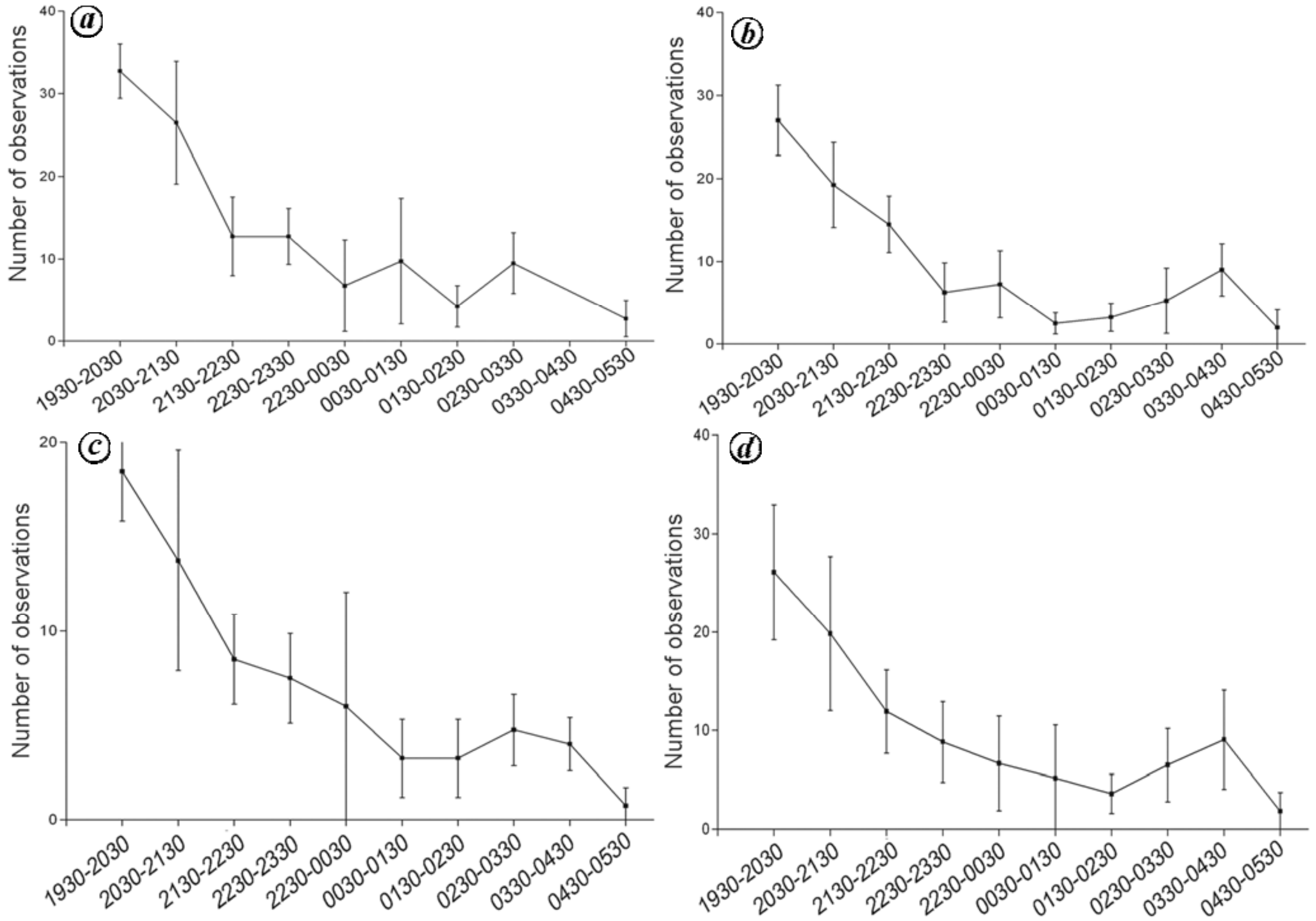

Figure 6. Seasonal and yearly variation of gliding number during active period (1930–0530 h) of *P. philippensis*. ***a***, Summer season; ***b***, Monsoon season; ***c***, Winter season and ***d***, Yearly.

influenced by desired gliding speed, intended gliding distance or individual variations in body mass, or patagium area[3]. Vernes[3] stated that members of the genus *Petaurista* weigh 1–2.5 kg and require a greater vertical drop at the beginning of a glide in comparison to the smaller *Glaucomys* (about 45–1.20 g).

Vertical drop is directly related to gliding angle. In the present study, the mean gliding angle was 25.53°. Vernes[3] recorded mean gliding angle (26.8°) of *G. sabrinus*. Glides typically began with a high gliding angle, which was reduced with a gain in speed[28].

Stafford *et al*.[6] defined five separate glide phases in *P. leucogenys*. These are launch, glide, transition, braking and landing. During launch the animal leaves the support and deploys the patagium. Until the patagium is deployed and begins generating aerodynamic forces, the animal is subject largely to ballistic forces. Patagium deployment signals the start of the gliding phase, where aerodynamic forces determine the glide path. In the glide phase, the angle of attack is relatively low (between 10° and 45°). In the transition phase, gliding angle is higher (30°–60°), and during the braking phase it increases to almost 90°. During the landing phase, the animal begins to adduct the limbs ventrally, furl the patagium, and is again in the realm of ballistic forces. Similar glide phases were observed in the present study also.

For longer glides, gliding mammals usually select vertical trunk[29]. *P. leucogenys* preferred landing on trees with a trunk diameter of more than 20 cm, and trunks of less than 10 cm were seldom used for landing. They also used vertical trunks as landing sites, but occasionally landings were made on leaning trunks. Sometimes, the squirrels glided toward slender horizontal branches, although landing on such branches was usually observed after short glides[7]. *P. philippensis* always landed on the vertical trunk of a landing tree, with mean GBH being 224.4 ± 77.86 cm in the present study. No case of falling to the ground due to failure in landing was observed in the present study.

Higher number of glides was observed during summer because probably early summer is the breeding season of *P. philippensis*. The number decreased from monsoon to winter (Table 3). The number of glides may depend on seasonal distribution of food resources. Early night period (1930–2330 h) was most active time for gliding activity in the present study. This was possibly related to their feeding habit and foraging behaviour. Gliding allows squirrels to forage more efficiently by reducing travel time[30,31]. Middle night period (2330–0230 h) was devoted to sleeping and resting, with less feeding activity.

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