Transactions of the Illinois State Academy of Science
(2020) Volume 113, pp. 23-26

received 11/9/19
accepted 7/1/20

Gap Crossing Event in the Southern Flying Squirrel (*Glaucomys volans*) in Fragmented Urbanized Forest Habitat

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ABSTRACT

During a radio-telemetry study in 2018 in southern Illinois, an adult male southern flying squirrel (*Glaucomys volans*) was tracked between two forest patches on the campus of Southern Illinois University Edwardsville (SIUE), named the Western Corridor and Sweet William Woods. Based on GPS coordinates of the tracked squirrel, we determined that the squirrel most likely crossed a gap between forest patches via a gliding route. We identified putative launch and landing trees that would maximize glide distance while minimizing the ground needed to be covered. Based upon glide ratios from the literature, we estimated minimum, average, and maximum glide angles along with corresponding glide distances. Glide distances were calculated for each angle across a range of potential launch branch heights for the launch tree. From the calculations, it was determined that squirrels were able to cross the gap from branches that were at least 6 m in height, utilizing a minimum glide angle of 8.21°. While flying squirrels are highly agile gliders, gap crossing presents a significant problem moving between forest patches. Tree planting near forest edges may offer a feasible solution to reestablish connectivity and alleviate potential inbreeding depression.

Keywords: southern flying squirrel, *Glaucomys volans*, urbanization, fragmentation, radio-telemetry

INTRODUCTION

In 2018, we conducted a radio-telemetry study examining movement patterns and microhabitat selection in the southern flying squirrel (*Glaucomys volans*) at four study sites. One of the four sites was wooded private property, north of Edwardsville, IL (474 hectares; N 38° 54′ 42.6″, W 089° 53′ 19.1″). The other three study sites were urbanized forested habitat fragments on the Southern Illinois University Edwardsville (SIUE) campus-Western Corridor (79 hectares; N 38° 47′ 49.2″, W 90° 00′ 43.2″), Sweet William Woods (84 hectares; N 38° 47′ 9.6″, W 90° 00′ 18″), and Bluebell Woods (44 hectares; N 38° 47′ 42″, W 089° 59′ 9.6″; Fig. 1). Each of the three forest fragments on the SIUE campus was separated from one another by fields, moderate traffic two-laned roads, and campus infrastructure.

Studies of gap crossing in southern flying squirrels are limited. Only one other study has examined this phenomenon in this species (Rizkalla and Swihart, 2007). In contrast, several studies have examined gap crossing in their sister species, the northern flying squirrel (*G. sabrinus*; Findley, 1946; Smith et. al, 2013), as well various Australian gliders (Ball and Goldingay, 2008; Goldingay et al., 2011; Asari et al., 2010; Taylor and Goldingay, 2013; Goldingay et al., 2013). Southern flying squirrels are suspected to avoid crossing gaps, as in many instances this would require ground traversal. Flying squirrel morphology makes running along the ground inefficient and energetically expensive, and such a mode of transportation makes squirrels more susceptible to predation from species like owls (Flaherty et al. 2010). For our study, we predicted that the tracked southern flying squirrels would be unlikely to cross between any of the sites on the SIUE campus, due to travel distance, with roads and fields acting as barriers.

Contrary to our predictions, we documented a dispersal event between the Western Corridor and Sweet William Woods in April 2018 (Fig. 1). A 60 g reproductive adult male moved from the Western Corridor to Sweet William Woods. The shortest aerial pathway was from a sugar maple (*Acer saccharum*) at the edge of a peninsula of trees in the Western Corridor, across a road to an elm tree (*Ulmus* spp.) at the edge of Sweet William Woods. The gap itself contained a two-laned road with mowed strips of grass immediately on either side (Fig. 2). Traffic for this road was considered moderate as it passed the threshold for low volume traffic for a local road (>400 cars per day; Federal Highway Administration, 2012), averaging at about 2200 vehicles per day (Illinois Department of Transportation, 2020). While southern flying squirrels descend from trees to forage, they rarely travel long distances by ground (Schwartz and Schwartz, 2001). In addition, there is a restored prairie present that leads up to the putative launch tree (prairie behind the launch tree in Fig. 2). The prairie contains dense grasses and forbes, which forces the flying squirrel to travel by a peninsula of trees extending off the corridor (Fig. 1). This pathway circumvents the prairie altogether while reaching the narrowest gap between the two forest patches, making the gliding route seem more plausible. The objective of this paper was to use gliding performance data from the literature to determine if the squirrel was capable of crossing the gap via gliding.

MATERIALS AND METHODS

The campus of Southern Illinois University Edwardsville (SIUE) is located in the greater St. Louis Metropolitan

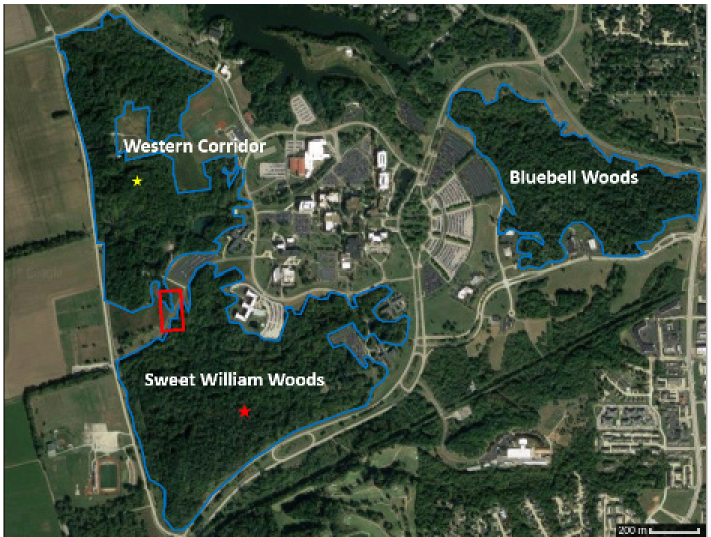

Figure 1. Aerial map of the forest sites surrounding the gap crossed on SIUE campus: Sweet William Woods and the Western Corridor. Bluebell Woods is the large forest patch on the eastern side of campus behind the fan parking lot. Shortest possible gap highlighted with a red box. Location of southern flying squirrel on April 2nd represented with a yellow star in the Western Corridor. Location of the relocated southern flying squirrel on April 25th represented with a red star in Sweet William Woods.

Figure 2. Photo of the gap with putative glide pathway (red dotted line) between the peninsula off the Western Corridor (right) and Sweet William Woods (left).

area. The campus includes three large forest patches: Sweet William Woods (84 ha), the Western Corridor (79 ha), and Bluebell Woods (44 ha; Fig. 1). Between Sweet William Woods and the Western Corridor lies a two-lane road with medium traffic. This road has mowed strips of grass on both sides (Fig. 2).

Capture methods for southern flying squirrels, radio-collars used, and tracking procedures followed Howard et al. (2020). During the radio-telemetry field season, a male flying squirrel was recorded in a snag in the Western Corridor on April 2nd, 2018 via radio telemetry. The squirrel was not relocated until April 25th, 2018, where the radio collar signal was determined to be in a small cavity high in a tree within Sweet William Woods. While it is possible that the squirrel was predated upon, radio collars were found to be shed by squirrels within tree cavities often throughout the study, suggesting the squirrel moved there on its own accord. To determine the putative pathway, the shortest gap distance between trees from the two forests was identified. This route extended from a peninsula of trees on the southern edge of the Western Corridor to the tree line along the northern edge of Sweet William Woods (Fig. 2). To verify that the squirrel was capable of crossing the pathway by gliding, we calculated glide distance using three components: (1) a range of launch heights, (2) gap distance, and (3) pre-determined glide ratios from the literature.

Total tree height was measured with a hypsometer (OPTi-LOGIC Laser RangeFinder, model 400LH). With the known height of the launch tree, a range of possible tree branch launch heights were determined using Google Earth Pro (Version 9.3.106.3). The gap distance between the Western Corridor and Sweet William Woods was measured using Google Maps (resolution = 15 m/pixel). Scheibe and Robins (1998) examined southern flying squirrel gliding performance to determine glide ratios, represented as the horizontal distance travelled relative to vertical distance travelled during a glide. Minimum glide ratio was estimated as 0.36, mean glide ratio was 1.53, and maximum glide ratio was 6.93.

To find the potential distance glided by the southern flying squirrel based on launch height, we first found the minimum, average, and maximum glide angles a southern flying squirrel could utilize via trigonometry. Glide angle (θ) is defined as the arctangent of the opposite side of the triangle (vertical distance) divided by the adjacent side of the triangle (horizontal distance), or $\theta = \arctan$ (opposite/adjacent; Fig. 3). We incorporated values from each glide ratio into the formula $\theta = \arctan$ (opposite/adjacent), and solved for θ to get minimum, average, and maximum glide angles.

After identifying the minimum, average, and maximum glide angles, we then estimated the horizontal glide distance ranges for each angle across a range actual of tree branch heights from the putative launch tree. We used the formula $\theta_{glide} = \arctan (h/d_{glide})$, where θ_{glide} is the known glide angles previously calculated, h is the known height of the launch branch, and d_{glide} is the horizontal glide distance. Solving for d_{glide} using the minimum glide angle provided an estimate of horizontal glide distance, and likewise with the average and maximum glide angles, based on a given tree branch height.

RESULTS

The height of the putative launch tree was 23.8 m and the horizontal gap distance was 38.9 m. Flying squirrels normally launch from horizontal branches to maximize take-off forces for the glide (Paskins et al., 2007) and tend to land on vertical tree trunks (Caple et al., 1983). From the trigonometric calculations utilizing glide ratios from Scheibe and Robins (1998), the minimum, average, and maximum distance glide angles were 8.21°, 33.2°, and 70.2° respectively. With the minimum glide angle, we estimated squirrels could glide between 11.9 m and 110.8 m when launching from tree branches 1.72 m to 17.78 m. Average glide angle allowed a squirrel to glide between 2.62 m to 27.2 m. Maximum glide angle limited a squirrel to glide from 0.62 m to 6.4 m (Fig. 4). Thus, the male flying squirrel was able to cross the 38.91 m gap between the Western Corridor to Sweet William Woods aerially if it utilized a launch branch greater than 6 m if it had utilized a glide angle near the minimum glide angle of 8.21°. Wind conditions may have impacted this aerial crossing; however, with headwinds assisting glides and tailwinds impeding glides.

DISCUSSION

Any prior evidence of gap crossing behavior in southern flying squirrels under natural conditions is undocumented. Rizkalla and Swihart (2007) performed translocation experiments and found that flying squirrels were more effective at crossing agricultural habitat to reach large forest patches than either white-footed mice (*Peromyscus leucopus*) or eastern chipmunks (*Tamias striatus*). Thus, southern flying squirrels appear able to cross relatively open ground such as between or under rows of crops. However, the dense matrix of prairie grasses and forbs located between the forest patches at SIUE makes up a bulk of the gap. This would have made such an over-ground crossing extremely difficult and potentially risky compared with the aerial route.

In another study of the closely related northern flying squirrels, the pathway used to return home was examined by translocated squirrels. Northern flying squirrels were found to consistently avoid gaps regardless of the length of distance to move around the gap. The direct route across a gap could be up to ~7 times shorter than moving around through forest cover, yet northern flying squirrels still would opt for the longer route (Smith et al., 2013). This decision to spend the energy to travel longer distances highlights flying squirrels' need for cover when moving to avoid predation.

Other gap crossing studies, performed on Australian gliding mammals, have examined the efficacy of man-made structures in fragmented environments. Squirrel gliders (*Petaurus norfolcensis*) successfully crossed gaps using wooden poles placed next to roads between forest stands (Ball and Goldingay, 2008; Goldingay et. al, 2011; Taylor and Goldingay, 2013). Rope bridges have also facilitated travel in squirrel gliders, sugar gliders (*P. breviceps*), and feathertail gliders (*Acrobates pygmaeus*) (Goldingay et al., 2013). Additionally, the mahogany glider (*P. gracilis*) has utilized power line poles to cross gaps (Asari et al., 2010). These gliding mammals have found success using an array of non-natural structures when taller trees are unavailable.

Illinois has been subject to massive deforestation over the centuries, with forested area declining from 5.58 million hectares in 1820 to 1.73 million hectares in 1985 (Iverson, 1991). Such deforestation has contributed to massive fragmentation and secondary forest

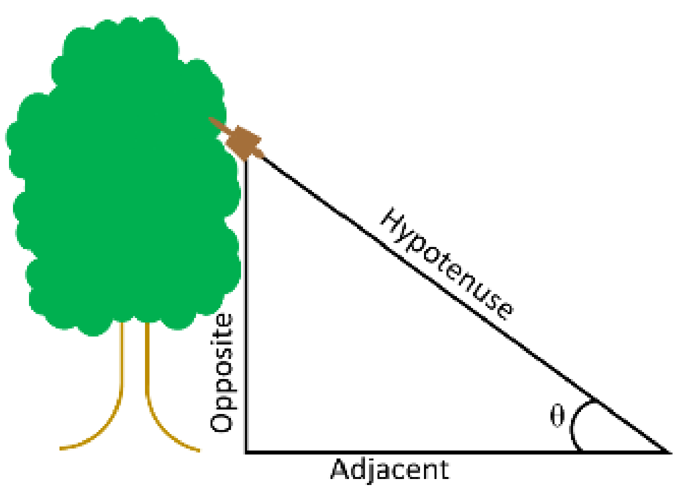

Figure 3. Diagram showing the opposite, adjacent, and hypotenuse sides of the triangle, in reference to the glide angle (θ), used for calculation of glide ratios of the southern flying squirrel.

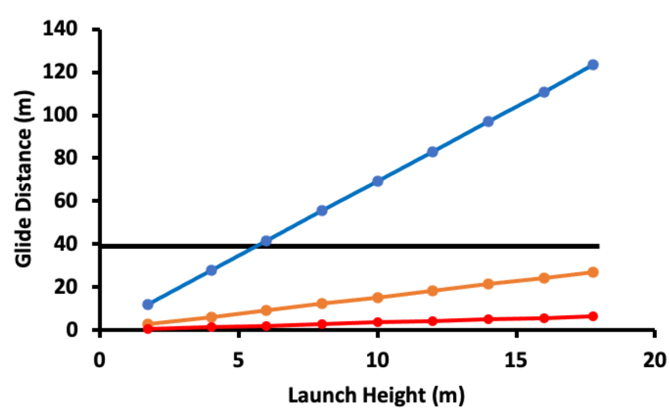

Figure 4. Graph of glide distance (m) vs. launch height (m) at the minimum, average, and maximum glide angles for southern flying squirrels traveling from the Western Corridor to Sweet William Woods across a range of launch heights. Launch heights range from 1.72 m to 17.78 m. Gap distance was 38.9 m. Blue = minimum glide angle of 8.21°. Orange = average glide angle of 33.2°. Red = maximum glide angle of 70.2°. The black line represents the gap distance of 38.9 m between Sweet William Woods and Western Corridor.

throughout the state (Iverson, 1991). Because much of Illinois is composed of fragmented forest, maintaining connectivity between patches through corridors is critical for continued southern flying squirrel survival. Corridors could be designed to extend towards forest gaps in order to facilitate crossing by southern flying squirrels. Such corridors would not necessarily need to be extensive in order to be effective. For example, the corridor of trees the flying squirrel used to approach the gap in this study for crossing the Western Corridor to Sweet William Woods narrowed from a width of 5-10 trees at the base to 1-2 trees as it approached the road. Corridors could be created relatively quickly (< 10 years) by planting fast growing native Illinois trees such as tulip poplars (*Liriodendron tulipifera*) or eastern cottonwoods (*Populus deltoides*; Mohlenbrook, 2009). Planting these trees strategically in gaps between large forest patches throughout rural and urban Illinois could reestablish connectivity in a short period of time, thus alleviating possible inbreeding depression caused by geographic isolation (Yale and Mills, 2001).

ACKNOWLEDGEMENTS

Funding for this study was provided by Southern Illinois University Edwardsville and the Webster Groves Nature Study Society. We thank the undergraduate and graduate students from Southern Illinois University Edwardsville who assisted with fieldwork efforts on this project. Special thanks to Mile Gossett for assistance with tree identification, as well as SIUE physics instructor Catherine Williams for her insight with performing trigonometric calculations. Research was conducted in compliance with SIUE Institutional Animal Care and Use Committee (IACUC) protocols.

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