# Habitat Use of the Southern Flying Squirrel (*Glaucomys volans*) in Bluff Forests of Southwestern Illinois

by Loren N. Dunham, Bachelor of Science

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# ABSTRACT

## HABITAT USE OF THE SOUTHERN FLYING SQUIRREL (*Glaucomys volans*) IN BLUFF FORESTS OF SOUTHWESTERN ILLINOIS

by

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Chairperson: Professor Richard L. Essner, Jr.

Increased agriculture and urbanization in southwestern Illinois have severely fragmented the forests of the region. Habitat fragmentation may cause lower species richness, population declines, or extirpation due to phenomena such as edge effects, inbreeding depression, and stochasticity. The effects of habitat fragmentation on suburban wildlife are poorly understood, especially for small mammals such as the Southern Flying Squirrel (*Glaucomys volans*). Flying squirrels are arboreal rodents whose presence in a forest is indicative of habitat quality, as this species prefers mature and relatively open forest stands. Flying squirrels can be found in the forested areas of the Southern Illinois University Edwardsville (SIUE) campus. Demographic features of this population and habitat use among forest patches were unknown. Artificial nest boxes were utilized to perform a mark-recapture study of the flying squirrel population as well as examine habitat use. Objectives were to obtain demographic information, and to create a predictive habitat model relating habitat characteristics to presence or absence of nest box materials using logistic regression. Study sites consisted of 145 randomized plots in three forest patches located within the SIUE campus, which were monitored November 2013 through October 2014. A model was generated for combined activity (nesting or feeding materials were present) at plots, which contained forest age, dominance of hard mast at a plot, tree density, topographic position, richness of the shrub layer, and the 90th percentile diameter at breast height. Habitat models were also generated for specified response variables of feeding material presence and nesting material presence. The top model for predicting feeding material presence in a nest box contained dominance of hard mast on a plot, richness of the shrub layer, and basal area of logs. The top model for predicting nesting material presence in a nest box contained the shrub layer stem count, roughness of the nest box tree bark, proximity to edge, cavity count, and the average hard mast dominance in the area surrounding the plot. Models tended to include characteristics regarding hard mast dominance and refugia, suggesting nest box use was influenced by avoidance of predation and food resource availability.

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# CHAPTER I
# INTRODUCTION

## Overview

Humans have drastically changed the landscape of the Midwestern region through agriculture and urbanization (Iverson and Oliver 1989; Nupp and Swihart 2000). In 1820, the state of Illinois had over 5.5 million hectares of forest, comprising nearly 38% of the state (Iverson 1988). By 1980 only about one million hectares of forest remained in the state, and nearly 80% of Illinois' land area was being used for agriculture (Iverson 1988; Iverson and Oliver 1989; Rosenblatt et al. 1999). As forested areas are removed for human land uses, habitat can be affected in many ways. It can be reduced in area, islands can become more isolated as distance between patches increases, the original species composition of the community can be greatly altered, and suitable habitat can be lost by severe changes or total removal (Prugh et al. 2008). As humans modify the landscape, forest patches often become isolated and are completely surrounded by a matrix of human-developed land, which is unsuitable for occupation by many species and often prevents movement between patches (Rosenblatt et al. 1999; Nupp and Swihart 2000). Detrimental effects of habitat fragmentation have been seen in many taxa, including invertebrates, vertebrates, and plants (Prugh et al. 2008). Habitat fragmentation is known to cause lower species richness, changes in communities, population declines, or extirpation through phenomena such as edge effects, inbreeding depression, and stochasticity (Rosenblatt et al. 1999; Nupp and Swihart 2000; Prugh et al. 2008). The effects of habitat fragmentation on wildlife found in suburban areas are poorly understood, especially for small mammals such as the Southern Flying Squirrel (*Glaucomys volans*).

## Behavior and Species Interactions

The Southern Flying Squirrel is an arboreal small mammal which glides through the forest using a patagium, a specialized area of skin, muscle, and connective tissue found between the wrist and ankle. Southern Flying Squirrels can be found throughout the eastern United States and some areas of Central America (Dolan and Carter 1977). They remain active year-round and are nocturnal, becoming active within an hour of sundown and ceasing activity within an hour of sunrise (Bendel and Gates 1987; Stone et al. 1997). Flying squirrels have an important role within their community, interacting with numerous species as both predator and prey. The majority of their diet consists of items such as acorns, seeds, fruits, mosses, and fungi; however, they are also known to feed on insects, bird eggs, and hatchlings (Harlow and Doyle 1990; Schwartz and Schwartz 2002; Mitchell et al. 2005). Flying squirrels serve as prey for owls, domestic cats, weasels, snakes, raccoons, and hawks (Dolan and Carter 1977; Bendel and Gates 1987; Harlow and Doyle 1990).

## Habitat Preferences

Southern Flying Squirrels are found in hardwood and mixed deciduous/coniferous forests across a large portion of the eastern United States (Dolan and Carter 1977; Forsyth 1999), and are not exclusive to one habitat type  (Muul 1974; Bendel and Gates 1987). When establishing home ranges, flying squirrels tend towards mature forest stands with large-diameter trees, open spaces for gliding, hard mast food sources, and cavities available for nesting (Muul 1974; Bendel and Gates 1987; Harlow and Doyle 1990). Therefore presence of flying squirrels within an area may serve as an indicator of forest quality. When flying squirrels occupy lower-quality forest it requires increased movement to gather sufficient resources and these areas cannot support as high a density of squirrels (Bendel and Gates 1987). Therefore higher densities of flying squirrels are expected in higher-quality areas with older-growth trees and higher proportions of hard mast. Habitat preferences of flying squirrels may relate to predator avoidance, as mature forests offer clear gliding paths for escape and more numerous cavities for avoidance, and certain amounts of understory and shrub cover offer concealment from predators when foraging on the ground (Bendel and Gates 1987).

Southern Flying Squirrels are secondary cavity nesters, meaning they use cavities previously created by woodpeckers or through decomposition (Muul 1968). Southern Flying Squirrels use cavities for a variety of functions including nesting sites, feeding stations, refugia, and defecatoria. Nesting cavities play an important role because flying squirrels nest communally in winter, and for this reason the survival rate within a population may have a positive density dependence (Nupp and Swihart 2000). Since flying squirrels do not excavate their own cavities, cavity availability may act as a limiting factor, especially in human-altered areas. Cavity-nesting species living near developed areas not only decline due to reduction of natural habitat, but often because snags are eliminated for safety or cosmetic reasons (Blewett and Marzluff 2005). Previous studies have found the frequency of nest box use was higher in areas with fewer snags, and snags are typically where woodpecker holes and other cavities are found (Muul 1968; Gilmore and Gates 1985; Bendel and Gates 1987; Woodworth et al. 2000).

Another factor affecting flying squirrel use in an area may be the presence of ground refugia. Since flying squirrels cannot move quickly on the ground and would easily be overtaken by many predators, they avoid moving on the ground in vulnerable situations and will take to refugia if threatened (Bendel and Gates 1987). Southern Flying Squirrels have been known to take refuge under root systems and fallen trees, or occasionally in subterranean cavities left behind by decomposing root systems. Therefore lower availability of these refugia may lead to a decrease of use in an area (Gilmore and Gates 1985; Woodworth et al. 2000). Previous literature is conflicting on whether summer ground cover leads to greater or lesser use, as increased ground cover leads to greater concealment from predators but may decrease ease of locomotion or conceal a predator's approach (Sonenshine and Levy 1981; Bendel and Gates 1987; Boardman 1991; Woodworth et al. 2000).

## Habitat Loss and Dispersal

Habitat loss can occur through the disruption or removal of natural habitat as a result of road construction, creation of residential areas, conversion to agriculture, or expansion of municipalities. Over the past two centuries in Illinois, forested areas have decreased from 38.2% to approximately 12% due to agricultural use and urbanization (Iverson and Oliver 1989). This has fragmented habitat, increased edge effects, and surrounded habitat with typically inhospitable matrix (Heske 1995; Rosenblatt et al. 1999; Woodworth et al. 2000). Patches are not true islands so the effects of isolation are not always severe, and while surrounding matrix may be unsuitable habitat, it is potentially navigable in some cases (Prugh et al. 2008). The type of matrix surrounding a habitat patch may have an effect on isolation sensitivity, as a surrounding natural matrix does not affect isolation sensitivity as strongly as a human-dominated surrounding matrix (Prugh et al. 2008). Agricultural fields tend to be sprawling monocultures, and fields typically do not contain vertical structures from which to glide. Due to the habitat preferences of Southern Flying Squirrels, and due to their mode of locomotion, surrounding agricultural matrix in much of the Midwest likely increases sensitivity to habitat fragmentation (Rosenblatt et al. 1999; Nupp and Swihart 2000; Rizkalla and Swihart 2007).

The ability of Southern Flying Squirrels to disperse between forest patches disturbed by human activity is uncertain due to a general reluctance to locomote on the ground and a lack of vertical structures from which to glide (Rosenblatt et al. 1999; Woodworth et al. 2000). In an Illinois study, Southern Flying Squirrels were found to be absent from forest patches isolated by more than 0.5 km, likely due to the presence of open habitats (Rosenblatt et al. 1999). Another study found Southern Flying Squirrels to be present in larger, well-connected patches of habitat and noted absence in areas that were small and isolated (Walpole and Bowman 2011). The north and central portions of Illinois are less-forested landscapes as compared to the southern portion of the state. Madison County, Illinois, historically lost vast tracts of forest to logging, agriculture, and urbanization. Today some of the largest remaining tracts of forest are found within the Bohm Woods State Nature Preserve and the Southern Illinois University Edwardsville Nature Preserve (Richter et al. 2010), though they are mostly surrounded by agricultural and suburban matrices. While interpatch dispersal may seem unlikely due to isolation, Southern Flying Squirrels have been shown to glide up to 75 m across an open area in a single flight (Bendel and Gates 1987). This means there is potential to disperse across an area such as a campus, where there is a variety of trees interspersed across open areas.

## Objectives of the Study

The population of flying squirrels in this area has not been previously described in detail. Little is known about habitat use or the ability to disperse within an urban landscape such as the Southern Illinois University Edwardsville (SIUE) campus. One objective of this study is to capture and mark Southern Flying Squirrels to obtain information about population demography, dispersal ability, and home ranges on and around the campus of SIUE. A second objective of this study is to identify influential habitat predictors for Southern Flying Squirrels by creating habitat models relating habitat characteristics to presence or absence of materials within nest boxes. Habitat models are useful for many species which are difficult to sample due to low density, irregular distribution, or a secretive nature, and can also be useful for identifying areas of suitable habitat by measuring characteristics indicative of quality (Odom et al. 2001; Menzel et al. 2006). I aimed to gain an understanding of the relationship between variables indicative of forest quality and the suitability of habitat for flying squirrels. This should provide insight into the effects of habitat disturbance in human-altered suburban areas similar to those found in southwestern Illinois, which may be helpful in future land-use planning decisions.

I hypothesize that habitat available on SIUE's campus is suitable for Southern Flying Squirrels, and there will be a distinction in vegetation characteristics between areas where boxes are and are not used. My predictions included 1) areas of older forest are more likely to be utilized by flying squirrels, 2) flying squirrels are less likely to utilize a nest box for nesting or feeding if cavities and snags are abundant, and 3) a nest box is more likely to be used if there is an abundance of food resources and cover from predators nearby.

# CHAPTER II
# METHODOLOGY

## Study Sites

The study sites for this project consisted of three forest patches located on the Southern Illinois University Edwardsville (SIUE) campus, which is located about 35 km northwest of downtown St. Louis, Missouri (Figure 1). These forest patches were located on loess bluffs along the edge of the American Bottoms, and the majority of the land was previously used for agriculture before the inception of campus in 1963. Forest age was not uniform throughout the forest patches. In some areas regrowth has taken place within the past decade, while trees have been present for at least 150 years in areas along ravines where cultivation was not historically possible. The matrices surrounding forest patches varies between paved bike trails, roads, parking lots, mown fields, recreational complexes, residential areas, and restored prairie. Forest patch areas ranged from 44.5 to 69.7 hectares. The distance from forest patches to the nearest forested area range from about 50 to 100 m, although solitary trees are interspersed in some parts of the surrounding matrix. Two neighboring forest patches, Sweet William Woods and the Western Corridor, have been included in the Southern Illinois University Edwardsville Nature Preserve (est. 2010), while Bluebell Woods and its neighboring areas are not (Figure 2 and Table 1).

Figure 1. Map of the St. Louis area. Includes Edwardsville, IL, in relation to St. Louis, MO

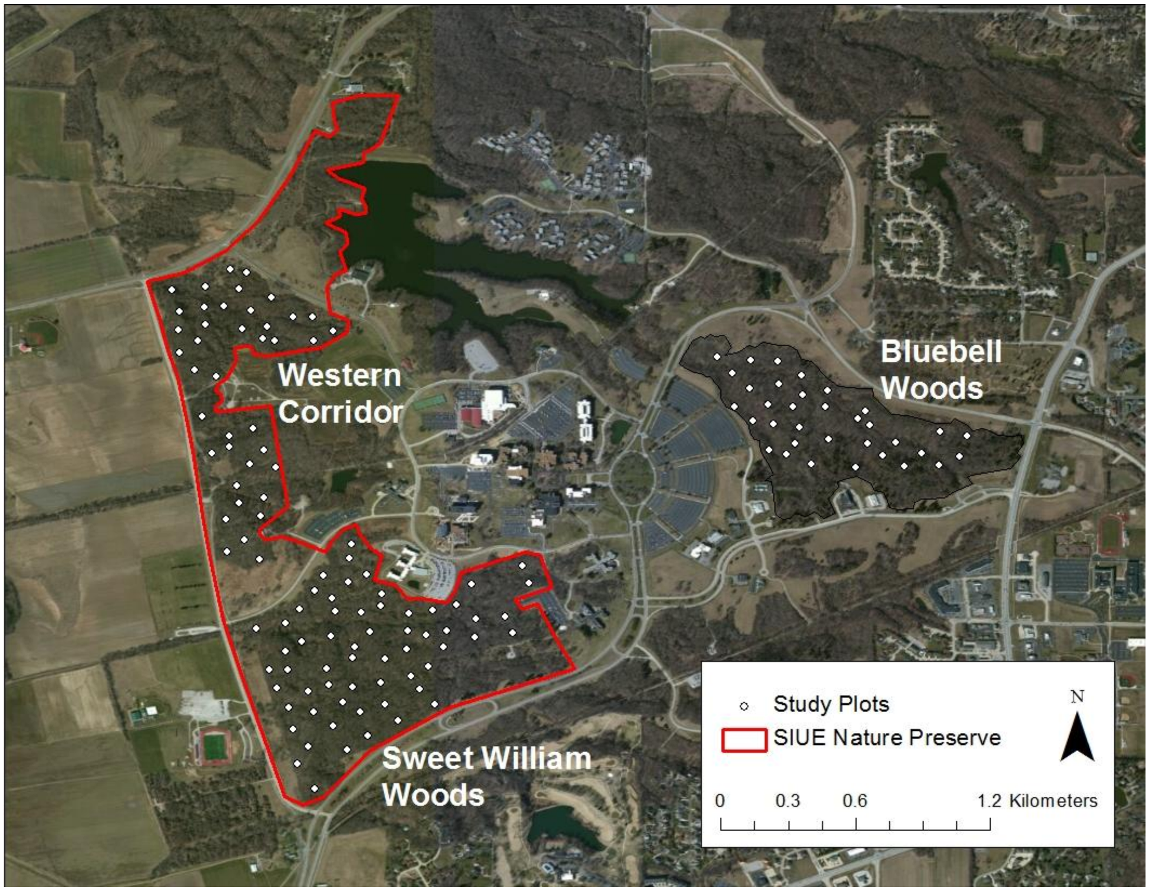


Figure 2. Map of the study areas. Bluebell Woods, Sweet William Woods, and the Western Corridor are three separate forest patches located on the campus of SIUE. Sweet William Woods and the Western Corridor, located along the western portion of campus, are within the SIUE Nature Preserve (denoted in red).

Table 1. Study sites for the project

| **Forest Patch** | **Area (ha)** | **Perimeter (m)** | **Number of Plots** | **Nature Preserve?** |
|---|---|---|---|---|
| Bluebell | 44.5 | 3817.8 | 34 | no |
| Sweet William | 69.7 | 5626.8 | 66 | yes |
| Western Corridor | 57.0 | 5722.2 | 42 | yes |

## Layout and Techniques

Plot centers were randomly selected using ArcGIS 10. A GPS unit was used to navigate to the random coordinates, and if the location was suitable the center was permanently marked, with new coordinates being recorded if the center was moved. Plot center locations were determined unsuitable if they were in open fields, along edges of two distinctly different-aged forest boundaries (as determined by historical aerial maps), within 20 m of human-disturbed edges, or if plot centers were separated by less than 80 m. Existing plots were established in Bluebell Woods and Sweet William Woods in 2007, and new plots were established in the Western Corridor in 2013. Before taking vegetation data, it was ensured that erosion had not rendered previously existing plots too close to a ravine, and that plots met the aforementioned criteria. If a plot did not, it was relocated to meet these requirements. If a plot could not be relocated, it was considered for decommission.

Plots in appropriate locations had one flying squirrel nest box positioned on the nearest suitable tree to the existing marked center. Suitable trees were living, nearly upright, and had a diameter of at least 20 cm at breast height. Nest boxes (16 cm x 16 cm x 35 cm) were constructed of untreated cedar boards, with a circular opening (3.8-cm diameter) located on one side near the top. Openings were surrounded by hardware cloth to discourage enlargement by animals. Each box had a latching hinged lid which allowed for inspection of box contents (Figure 3). Nest boxes were attached approximately 3 m above the ground on the southern- or eastern-facing side of the tree trunk (Figure 4).

Figure 3. Nest box design

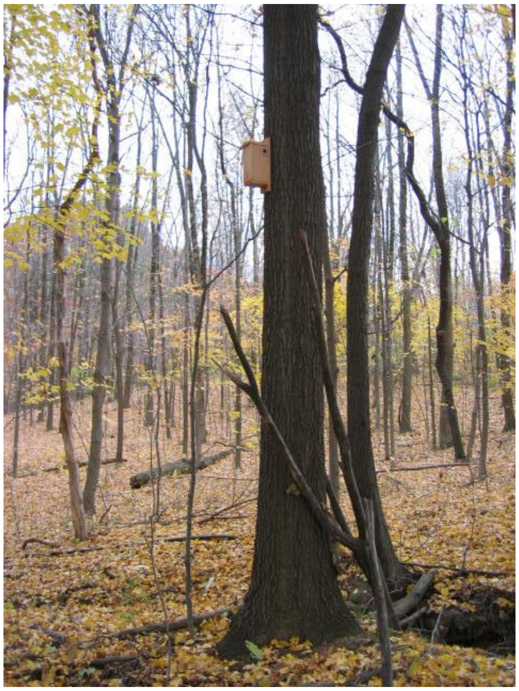


Figure 4. Nest box mounted on a plot in Sweet William Woods

Nest box use was monitored November 2013 through October 2014. Boxes were not checked in June, July, or August because rates of nest box occupancy are lower during the warmest summer months (Stone et al. 1996; Brady et al. 2000; Woodworth et al. 2000; Althoff and Althoff 2001; Reynolds et al. 2009). Each plot was visited five times, for a total of 725 inspections. As flying squirrels are nocturnal, nest boxes were checked during the daytime. Boxes were checked by climbing a 3-m aluminum Swedish sectional ladder, blocking the hole with a rag, opening the lid, and gently tapping the box to check for squirrel presence. For each visit, contents of the nest box (e.g. squirrels, nesting materials, signs of feeding, other vertebrate or invertebrate occupants) were recorded (Figure 5). Southern Flying Squirrel nests typically consist of finely shredded inner bark, occasionally also containing moss, lichens, leaves, or feathers (Dolan and Carter 1977), all of which were observed in nest boxes during the study. Feeding stations typically contained caches of acorns or hickory nuts. Notes were taken regarding the amount and condition of the contents, and if any determinately flying squirrel feces or feeding materials were found on top of the box they were recorded as sign of a visit since the last nest box check.

Figure 5. Characteristic feeding materials (left) and nesting materials (right)

If a flying squirrel was found inside a nest box the lid was closed, a jar was placed covering the entrance hole, and the box was tapped until the animal exited the box and entered the jar. The hole was then re-plugged until it was verified no more flying squirrels were in the box. The captured animal was transferred from the jar to a clear plastic bag to make handling and data collection easier. The mass, sex, age, breeding status, and location of the individual were recorded. Captured individuals were ear-tagged with a Monel #1005-1 stainless steel ear tag (National Band and Tag Co., Newport, KY) which had a unique stamped number to allow for future recapture identification. Mass was measured with a 50- or 100-gram Pesola™ spring scale and recorded to the nearest 0.1 grams. Sex was classified as male or female, and breeding status was classified as perforate vagina, pregnant, or lactating (for females), and scrotal or nonscrotal (for males). Age classifications were broken into three categories determined by mass: nestlings weighed less than 25.0 grams, sub-adults weighed between 25.0 and 50.0 grams, and adults weighed over 50.0 grams (Woodworth et al. 2000; Reynolds et al. 2009). After processing, individuals were released on the tree on which they were captured. If an animal escaped before complete processing, as much known information was recorded as possible and it received “unknown” labels for the other data. All procedures were reviewed and approved by the Southern Illinois University Edwardsville Institutional Animal Care and Use Committee (Protocol I.D. #06-08-09-RLE-04).

Vegetation data were collected on plots from June to November 2013 and July through October 2014 by undergraduate researchers in another SIUE lab. At each plot, the vegetation survey plot extended around the center marker (Figure 6). Existing plots originally had a 15 m radius, and during data collection in 2013 and 2014 the plot radius was extended to 17.84 m to increase the plot area from 0.075 ha to 0.1 ha. Within the 17.84-m radius all trees larger than 5 cm diameter at breast height (DBH) had the species, height, and DBH recorded, with a total sampling area of 1000 $m^2$. Each plot had four shrub belts (1.56 m x 16.0 m) extending from the center for a sampling area of 100 $m^2$, where shrub and tree sapling stems over 1 m in height but <5 cm DBH were counted. From these data the richness of tree species on the plot, 90th percentile DBH, total basal area, basal area of hard mast species, and density of trees per hectare were calculated. From the shrub layer data the density of stems per hectare and richness of species on the plot were calculated.

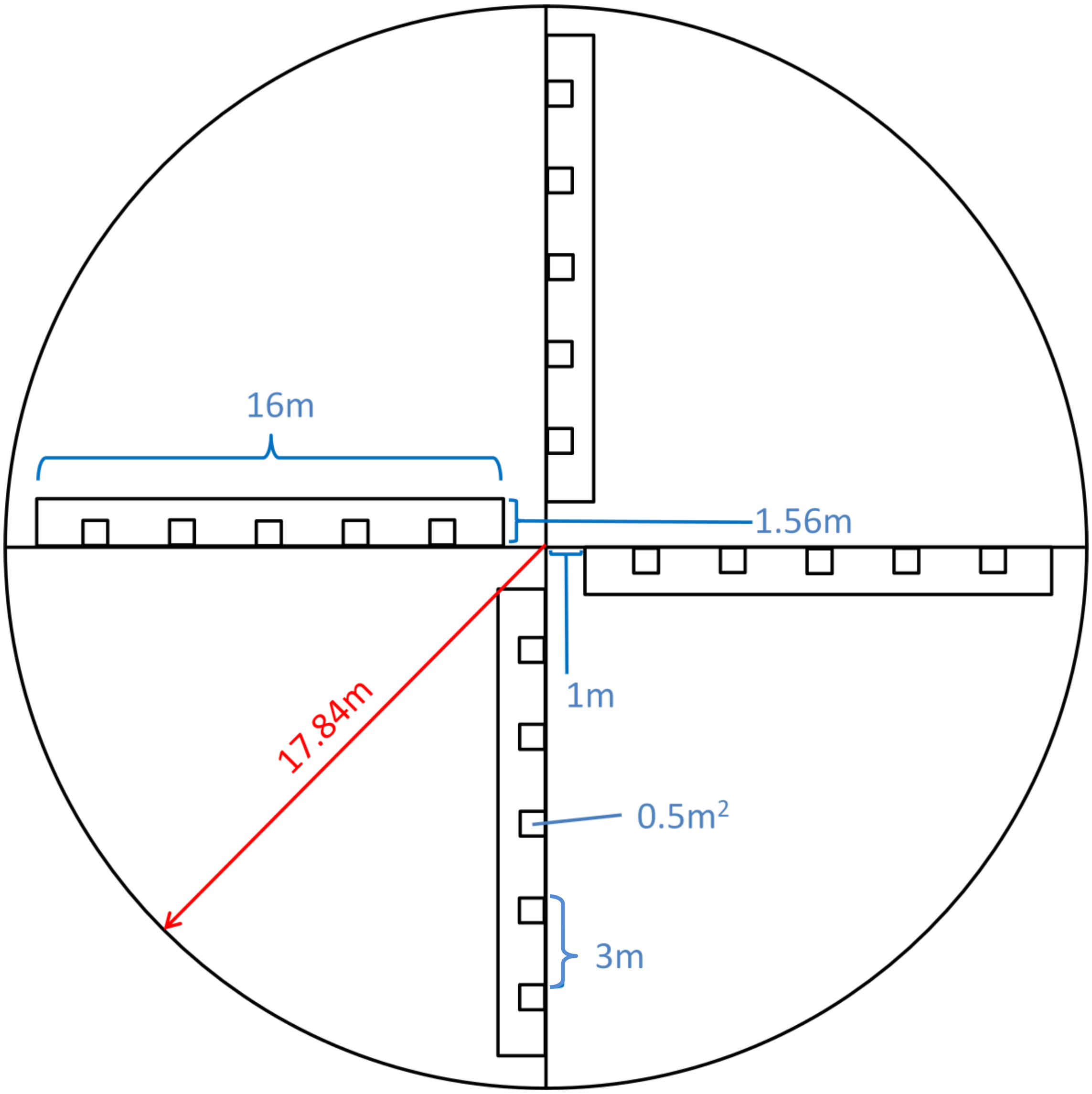


Figure 6. Setup of vegetation plots. The plot marker is located in the center at the transect intersection. Along the four perpendicular transects lie 1.56 m by 16 m shrub belts where shrub layer sampling occurred, and tree sampling occurred within the entire 17.84 m radius.

Additionally, the dominance of hard mast surrounding each plot was calculated by determining neighboring plots through Delaunay triangulations and averaging hard mast dominance of the plot and its neighbors. Delaunay triangulations connect each plot to its nearest neighbors by a straight line, and neighbors are maintained as long as a circle passing through the three points does not contain any other points (Getis and Boots 1978). Once neighbors were identified, plot locations were examined on a map. Any neighbors were removed if a straight line between plots crossed open fields and/or plots were in different forest patches. Once appropriate neighbors were identified, the average hard mast of the plot and its neighbors was calculated. This calculation was done to consider effects of food abundance at neighboring plots since flying squirrels should be able to quickly traverse distances between plot centers.

The presence of snags was assessed on each plot by counting the number of standing snags and measuring the DBH of each. Snags were assigned a decomposition class between two and nine (Thomas 1979), where Class 2 was a tree visibly declining in health and Class 9 was a decomposed, broken-off stump. Basal area of fallen logs was measured as well, and classes one to five were assigned to quantify decomposition (Thomas 1979), where Class 1 was a freshly fallen tree and Class 5 was near complete decomposition. For this assessment fallen limbs were not counted unless the main branch was greater than 10 cm, and limbs and logs must have been in contact with the substrate to be counted. Visual scans were performed periodically on the plot and any visible natural cavities on the plot were counted. Bark roughness for each nest box tree was assigned a category from one to three, with Category 1 being mostly smooth and Category 3 being rough or deeply furrowed. The topographic position of a plot was categorized as being flat/no slope, ridge, upper third of slope, middle third of slope, lower third of slope, or valley/ravine. The distance of each plot to the closest forest edge and closest ravine was estimated using ArcGIS 10 software. Each plot was assigned a binary response to whether or not it was within 50 m of an edge or ravine to avoid biases against plots on the peripheries of oddly-shaped forest patches.

Successional age of the forest at a plot was estimated by researchers in another SIUE research lab. ArcGIS 10 was used to determine historical forest boundaries in a series of aerial images of campus and compare them to current plot coordinates.

A summary of the habitat covariates generated from these data is found in Table 2.

Table 2. List of habitat model variables

| **Variable Nickname** | **Description of Variable** |
|---|---|
| LogBasal | Basal area of logs |
| SnagBasal | Basal area of snags |
| CavityCt | Number of natural cavities visible on plot |
| FeedDom | Dominance of oaks, hickories, and walnuts on plot |
| AVGFeedDom | Average dominance of hard mast (plot and neighbors) |
| TreeRich | Richness of tree species on plot |
| 90thDBH | 90th percentile tree DBH on plot |
| TreeBasal | Total basal area of trees on plot |
| TreeDens | Density in trees/ha |
| TotShrub | Number of shrub stems on plot |
| ShrubRich | Richness of shrub layer (shrubs and saplings) on plot |
| BoxTreeDBH | Nest box tree DBH |
| BoxTreeBark | Nest box tree bark roughness |
| ForestAge | Successional age of the forest |
| TopoPos | Topographical position of plot |
| NearEdge | Is plot within 50m of forest edge? |
| NearRav | Is plot within 50m of ravine? |
| NMpres | Nesting material presence/absence |
| FMpres | Feeding material presence/absence |
| AnyAct | Presence/absence of nesting or feeding materials |

Upon completion of data collection, the nest box content records were used to assess activity or non-activity of flying squirrels at a plot. Nest boxes were emptied of contents in 2010 and any materials found inside were assumed to have been brought in relatively recently.

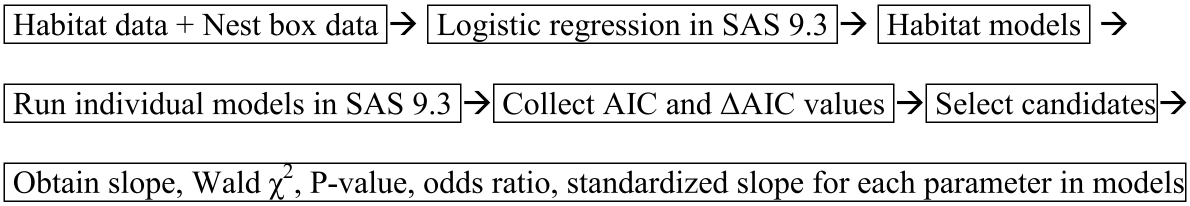
If a vegetation plot was unable to be set up at a plot and the plot could not be relocated, it was considered for decommission and nest box data were excluded. If a nest box became damaged or destroyed, the plot was still used as long as data were collected before damage or after repair. For generation of models, plots from Bluebell Woods were not used. Vegetation plots in Bluebell Woods have not been relocated from borderline locations of different-aged forests, and the existing vegetation data were measured on older 0.075 ha plots rather than updated 0.1 ha plots. A summary of plot exclusions is available in Table 3.

Table 3. Summary of plot exclusions

| **Plot Number** | **Reason for Exclusion** |
|---|---|
| 1-34 | Incomplete data set |
| 35 | Plot decommissioned |
| 49 | Plot decommissioned |
| 52 | Plot decommissioned |
| 55 | Plot decommissioned |
| 69 | Plot decommissioned |
| 97 | Box destroyed; Plot decommissioned |
| 139 | Plot decommissioned |
| 141 | Plot not established |
| 146 | Plot decommissioned |
| 150 | Plot decommissioned |
| 155 | Box destroyed; Plot decommissioned |

## Data Analyses

Vegetation data for plots (Table 2) were used along with nest box content data in order to relate habitat variables to the presence or absence of flying squirrel materials in a predictive manner through logistic regression (Pearce and Ferrier 2000; Odom et al. 2001; Keating and Cherry 2004; Smith et al. 2004; Mackenzie and Royle 2005; Mitchell et al. 2005). Data analyses were performed using SAS 9.3. Before creating models, a data correlation matrix was generated to examine correlations and check for colinearity between predictors. As a result, the total tree basal area on a plot was removed from consideration. Models were found for three response variables: nesting material presence, feeding material presence, and combined (feeding or nesting material) activity. For each response variable, the top three best-fitting models were generated for each possible number of variables (i.e. best three one-variable models, best three two-variable models, etc.). Each of the obtained models was individually run to obtain the p-value, Akaike's Information Criteria (AIC) value, corrected AIC (AICc) value, and model Akaike weight ($w_i$). Model AIC values are affected by the goodness-of-fit and the number of parameters in the model, and assess the quality of a model relative to other comparable models. AICc values adjust for small sample size, and sample size is considered small if the ratio between the number of observations and the number of parameters is less than 40 (Burnham and Anderson 2002); the ratio in this study was approximately ten. The AICc values for each set of models were compared to select the top model (lowest AICc value) for each of the response variables, as well as identify additional candidate models (those with a ΔAICc <2 units from the top model; Burnham and Anderson 2002).



Once candidate models were identified the top three models were examined and for each parameter appearing in the models the slope, Wald chi-squared value, P-value, and odds ratio estimate were collected. For each parameter a standardized slope was also calculated (Menard 2004), in order to compare the influences of parameters on the response variable. The habitat data from plots in the Western Corridor and Sweet William Woods were then put into the equation for the top model for each response variable in order to calculate a probability of finding materials. Plots were then broken into three groups based on probability: the lowest third, middle third, and highest third. These groups were mapped using ArcMap 10 software to examine which plots/areas were most likely to experience any use by Southern Flying Squirrels, which areas were likely to be used for nesting, and which areas were likely to be used for feeding.

# CHAPTER III
# RESULTS

## Demographics and Box Use

A total of 102 nest boxes (70.8%) showed some evidence of flying squirrel use during the study: 58 nest boxes (39.6%) contained nesting materials, 45 nest boxes (31.3%) contained feeding materials, and 11 nest boxes had animals present (

Figure 7). Southern Flying Squirrels were found to be present in all three forest patches. In 725 trap night efforts, 24 capture and recapture events took place for a success rate of 3.3%. Captured individuals consisted of 3 adult males, 6 adult females, and 5 neonates of unknown sex. The sex ratio based on captures did not differ significantly from 1:1 ($x^2$=0.371, df=1, P=0.05).

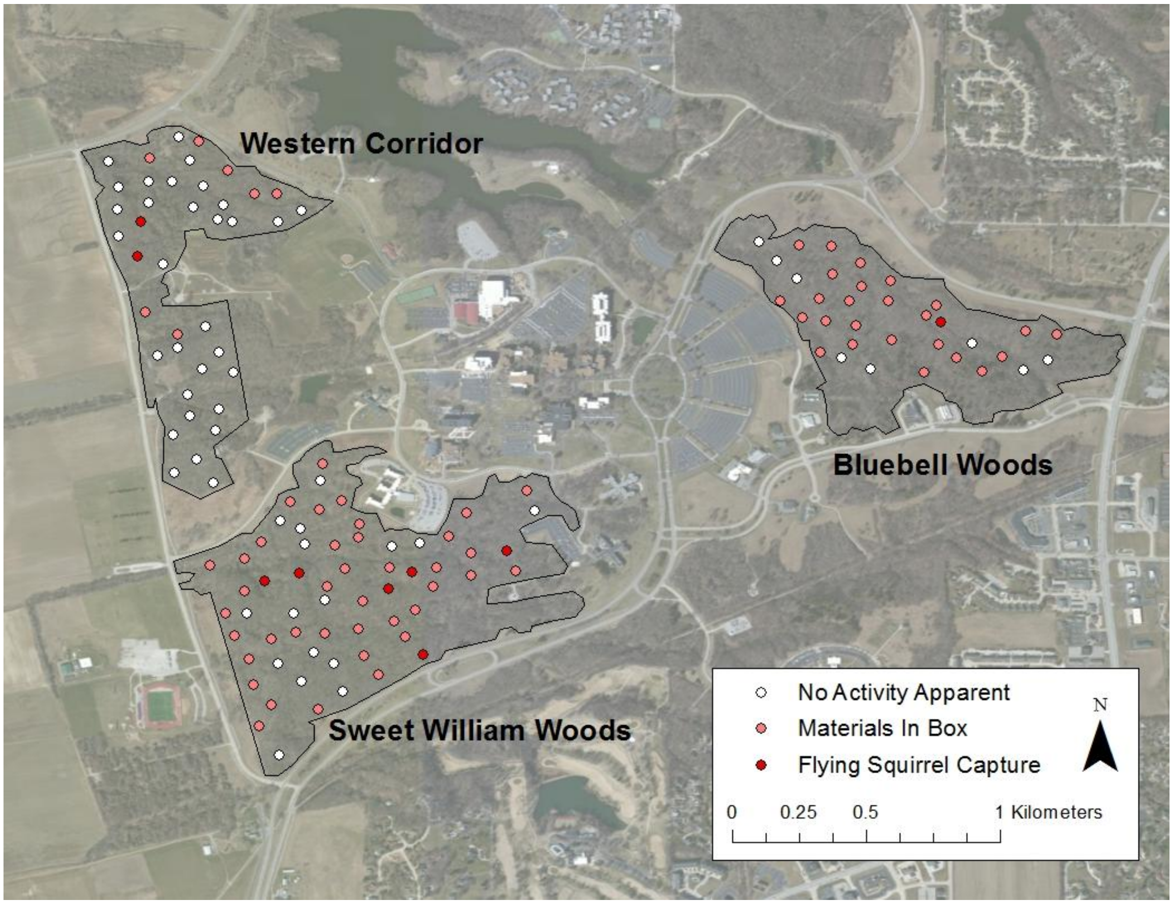


Figure 7. Map depicting Southern Flying Squirrel capture and activity sites. Southern Flying Squirrels were captured in all three forest patches, and a pattern of captures appeared along large ravines.

## Habitat Models

Significant models were developed predicting presence of nesting materials (Table 4), feeding materials (Table 5), and combined activity (nesting or feeding materials) at plots (Table 6). Results displayed in tables include the three most highly ranked models for each response variable. A summary of the influences of parameters on response variables within models is available in Table 7.

The best-fit model predicting presence of nesting materials in a nest box (Table 4) was a five-variable model containing shrub layer stem count, roughness of box tree bark, proximity to edge, average dominance of hard mast in an area, and cavity count ($p=0.0017$). In candidate models, the presence of nesting materials in a box had a positive association with average dominance of hard mast in an area, richness of the shrub layer, basal area of snags, and cavity count. Presence of nesting materials had negative associations with plot proximity to an edge, the 90th percentile tree DBH, shrub layer stem count, and bark roughness of the nest box tree (Table 7). The equation generated from the top-fitting model was used to calculate the probability of nesting material presence at each plot, a map of which can be seen in Figure 8.

The best-fit model for predicting presence of feeding materials in a nest box (Table 5) was a three-variable model containing the dominance of hard mast species on a plot, the richness of shrub species on the plot, and the basal area of logs ($p=0.0019$). Across candidate models, the presence of feeding materials in a nest box had positive associations with the dominance of hard mast on a plot, the shrub layer stem count, richness of the shrub layer, basal area of logs, and roughness of the box tree bark. Presence of feeding materials had negative associations with tree species richness and the basal area of snags (Table 7). The equation generated from the top-fitting model was used to calculate the probability of feeding material presence at each plot, a map of which can be seen in Figure 9.

The best-fit model for predicting any material presence in a nest box (Table 6) was a six-variable model containing forest age, dominance of hard mast on a plot, the density of trees, topographic position, richness of the shrub layer, and the 90th percentile DBH of trees on the plot (p=0.0057). Combined activity (feeding or nesting materials present) had positive associations with dominance of hard mast on a plot, average dominance of hard mast in the area surrounding the plot, species richness of the shrub layer, basal area of logs, and forest age. There were negative associations with proximity to edge, the 90th percentile tree DBH, tree richness, tree density, and basal area of snags (Table 7). The equation generated from the top-fitting model was used to calculate the probability of nesting material presence at each plot, a map of which can be seen in Figure 10.

Table 4. Habitat models for response variable: nesting material presence. Displayed are the top three models. Each model's number of variables (K), corrected Akaike Information Criteria value (AICc), difference between the candidate model and top model (ΔAICc), and Akaike model weight (*w*) are included. Each predictor is listed with its slope, Wald Chi-square value, P-value, Odds Ratio Estimate, and standardized estimated slope.

| **Parameter** | **Wald** | **P** | **Odds Ratio** | **Standardized Slope** | **K** | **AICc** | **ΔAICc** | ***w*** |
|---|---|---|---|---|---|---|---|---|
| 1.4809 (intercept) | 2.043 | 0.153 | | | 5 | 113.233 | 0.000 | 0.116 |
| -0.00368*TotShrub | 7.436 | 0.006 | 0.996 | -0.443 | | | | |
| -1.0435*BoxTreeBark | 6.718 | 0.010 | 0.352 | -0.389 | | | | |
| 0.9881*NearEdge | 3.373 | 0.066 | 2.686 | 0.249 | | | | |
| 0.181*AVGFeedDom | 2.943 | 0.086 | 1.198 | 0.233 | | | | |
| 0.1899*CavityCt | 2.450 | 0.118 | 1.209 | 0.220 | | | | |
| 1.7993 (intercept) | 3.037 | 0.081 | | | 4 | 113.458 | 0.225 | 0.103 |
| -0.00342*TotShrub | 6.965 | 0.008 | 0.997 | -0.412 | | | | |
| -1.0029*BoxTreeBark | 6.289 | 0.012 | 0.367 | -0.374 | | | | |
| 0.1776*AVGFeedDom | 2.991 | 0.084 | 1.194 | 0.229 | | | | |
| 0.7606*NearEdge | 2.186 | 0.139 | 2.139 | 0.192 | | | | |
| 1.9706 (intercept) | 3.720 | 0.054 | | | 3 | 113.464 | 0.231 | 0.103 |
| -0.00341*TotShrub | 7.056 | 0.008 | 0.997 | -0.411 | | | | |
| -0.9994*BoxTreeBark | 6.410 | 0.011 | 0.368 | -0.373 | | | | |
| 0.1924*AVGFeedDom | 3.623 | 0.057 | 1.212 | 0.248 | | | | |

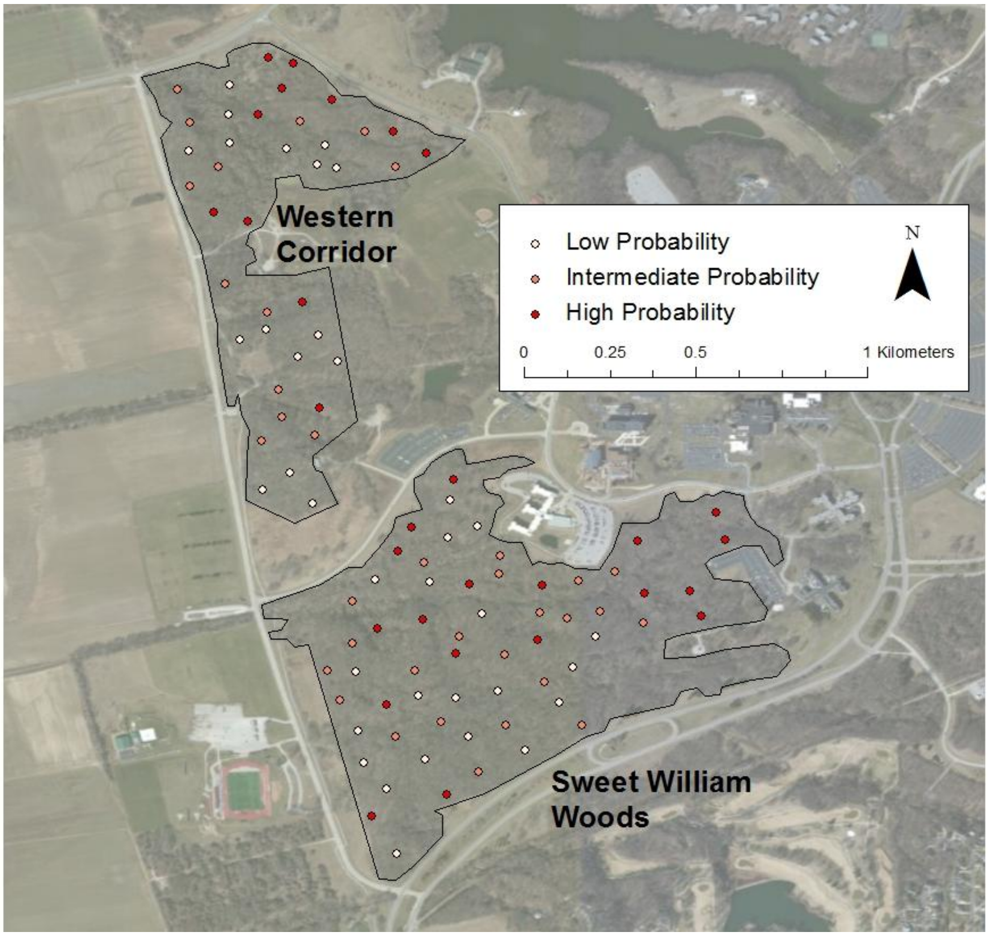


Figure 8. Map depicting probability of nesting material presence. This map depicts the probability of nesting materials being found inside a box. Probability was calculated by entering habitat variable measurements at each plot into the top model equation. Plots are broken into three equal groups based on calculated probabilities to contain materials: boxes in the lowest third, middle third, and highest third of probability (relative to other plots).

Table 5. Habitat models for response variable: feeding material presence. Displayed are the top three models. Each model's number of variables (K), corrected Akaike Information Criteria value (AICc), difference between the candidate model and top model (ΔAICc), and Akaike model weight (*w*) are included. Each predictor is listed with its slope, Wald Chi-square value, P-value, Odds Ratio Estimate, and standardized estimated slope.

| **Parameter** | **Wald** | **P** | **Odds Ratio** | **Standardized Slope** | **K** | **AICc** | **ΔAICc** | ***w*** |
|---|---|---|---|---|---|---|---|---|
| -3.1534 (intercept) | 13.457 | 0.000 | | | 3 | 115.237 | 0.000 | 0.125 |
| 0.1352*FeedDom | 7.031 | 0.008 | 1.145 | 0.385 | | | | |
| 0.1286*LogBasal | 7.281 | 0.007 | 1.137 | 0.373 | | | | |
| 0.2382*ShrubRich | 2.711 | 0.100 | 1.269 | 0.215 | | | | |
| -1.5183 (intercept) | 1.925 | 0.165 | | | 5 | 115.736 | 0.499 | 0.098 |
| 0.1587*LogBasal | 8.222 | 0.004 | 1.172 | 0.460 | | | | |
| 0.1191*FeedDom | 4.856 | 0.028 | 1.127 | 0.340 | | | | |
| -0.2165*SnagBasal | 2.950 | 0.086 | 0.805 | -0.281 | | | | |
| 0.00231*TotShrub | 3.924 | 0.048 | 1.002 | 0.279 | | | | |
| -0.1362*TreeRich | 2.359 | 0.125 | 0.873 | -0.220 | | | | |
| -2.981 (intercept) | 11.977 | 0.001 | | | 4 | 115.910 | 0.673 | 0.089 |
| 0.1552*LogBasal | 8.347 | 0.004 | 1.168 | 0.450 | | | | |
| 0.1308*FeedDom | 6.655 | 0.010 | 1.140 | 0.373 | | | | |
| 0.2415*ShrubRich | 2.803 | 0.094 | 1.273 | 0.218 | | | | |
| -0.1402*SnagBasal | 1.421 | 0.233 | 0.869 | -0.182 | | | | |

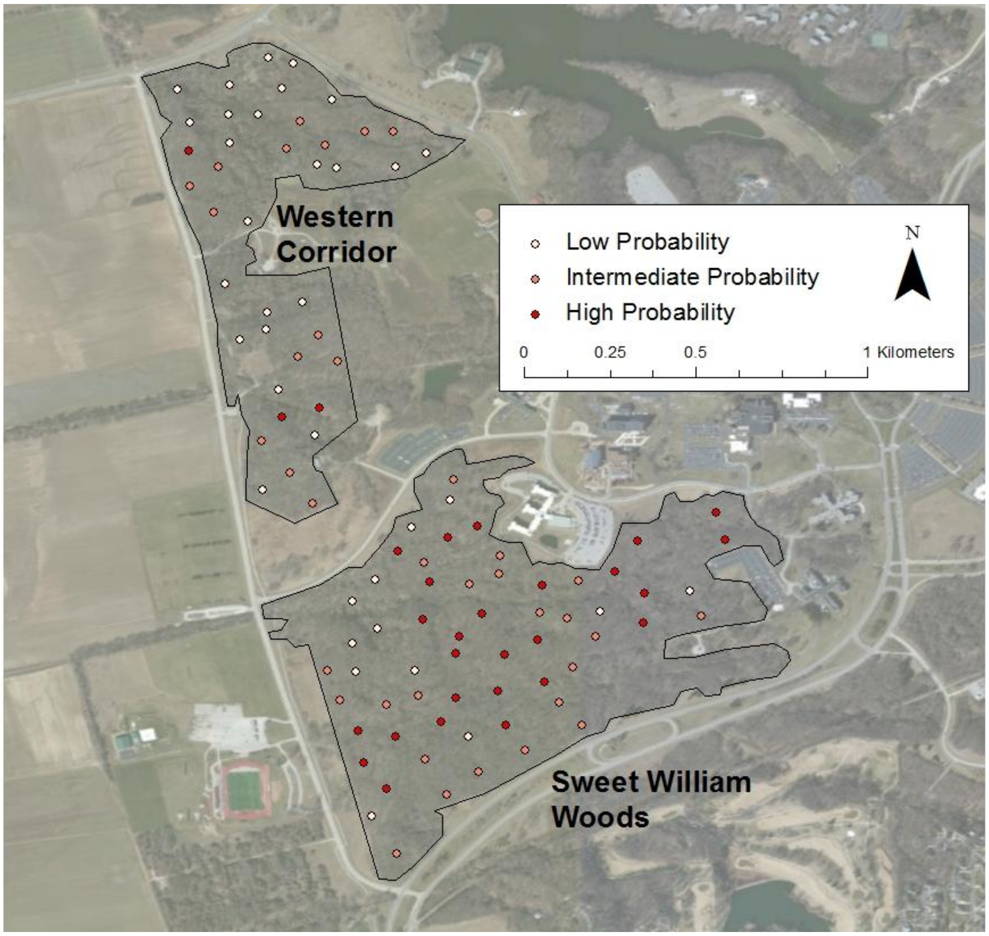


Figure 9. Map depicting probability of feeding material presence. This map depicts the probability of feeding materials being found inside a box. Probability was calculated by entering habitat variable measurements at each plot into the top model equation. Plots are broken into three equal groups based on calculated probabilities to contain materials: boxes in the lowest third, middle third, and highest third of probability (relative to other plots).

Table 6. Habitat models for response variable: combined material presence. Displayed are the top three models. Each model's number of variables (K), corrected Akaike Information Criteria value (AICc), difference between the candidate model and top model (ΔAICc), and Akaike model weight (*w*) are included. Each predictor is listed with its slope, Wald Chi-square value, P-value, Odds Ratio Estimate, and standardized estimated slope.

| **Parameter** | **Wald** | **P** | **Odds Ratio** | **Standardized Slope** | **K** | **AICc** | **ΔAICc** | ***w*** |
|---|---|---|---|---|---|---|---|---|
| 1.6255 (intercept) | 0.998 | 0.318 | | | 6 | 125.927 | 0.000 | 0.094 |
| 0.0314*ForestAge | 6.778 | 0.009 | 1.032 | 0.461 | | | | |
| 0.1170*FeedDom | 3.654 | 0.056 | 1.124 | 0.334 | | | | |
| -0.00291*TreeDens | 4.381 | 0.036 | 0.997 | -0.294 | | | | |
| -0.3199*TopoPos | 3.813 | 0.051 | 0.726 | -0.272 | | | | |
| 0.2726*ShrubRich | 3.341 | 0.068 | 1.313 | 0.246 | | | | |
| -0.0483*90thDBH | 2.363 | 0.124 | 0.953 | -0.230 | | | | |
| 1.4899 (intercept) | 0.812 | 0.368 | | | 7 | 125.991 | 0.064 | 0.091 |
| 0.1522*FeedDom | 4.864 | 0.027 | 1.164 | 0.434 | | | | |
| 0.0290*ForestAge | 5.711 | 0.017 | 1.029 | 0.427 | | | | |
| -0.3493*TopoPos | 4.323 | 0.038 | 0.705 | -0.297 | | | | |
| -0.00290*TreeDens | 4.286 | 0.038 | 0.997 | -0.293 | | | | |
| -0.0552*90thDBH | 2.877 | 0.090 | 0.946 | -0.263 | | | | |
| 0.2774*ShrubRich | 3.338 | 0.068 | 1.320 | 0.250 | | | | |
| 0.0727*LogBasal | 2.186 | 0.139 | 1.075 | 0.211 | | | | |
| 0.0281 (intercept) | 0.001 | 0.982 | | | 5 | 126.089 | 0.162 | 0.087 |
| 0.0232*ForestAge | 4.981 | 0.026 | 1.023 | 0.341 | | | | |
| 0.115*FeedDom | 3.756 | 0.053 | 1.122 | 0.328 | | | | |
| -0.3224*TopoPos | 4.017 | 0.045 | 0.724 | -0.275 | | | | |
| -0.00237*TreeDens | 3.282 | 0.070 | 0.998 | -0.239 | | | | |
| 0.256*ShrubRich | 3.005 | 0.083 | 1.292 | 0.231 | | | | |

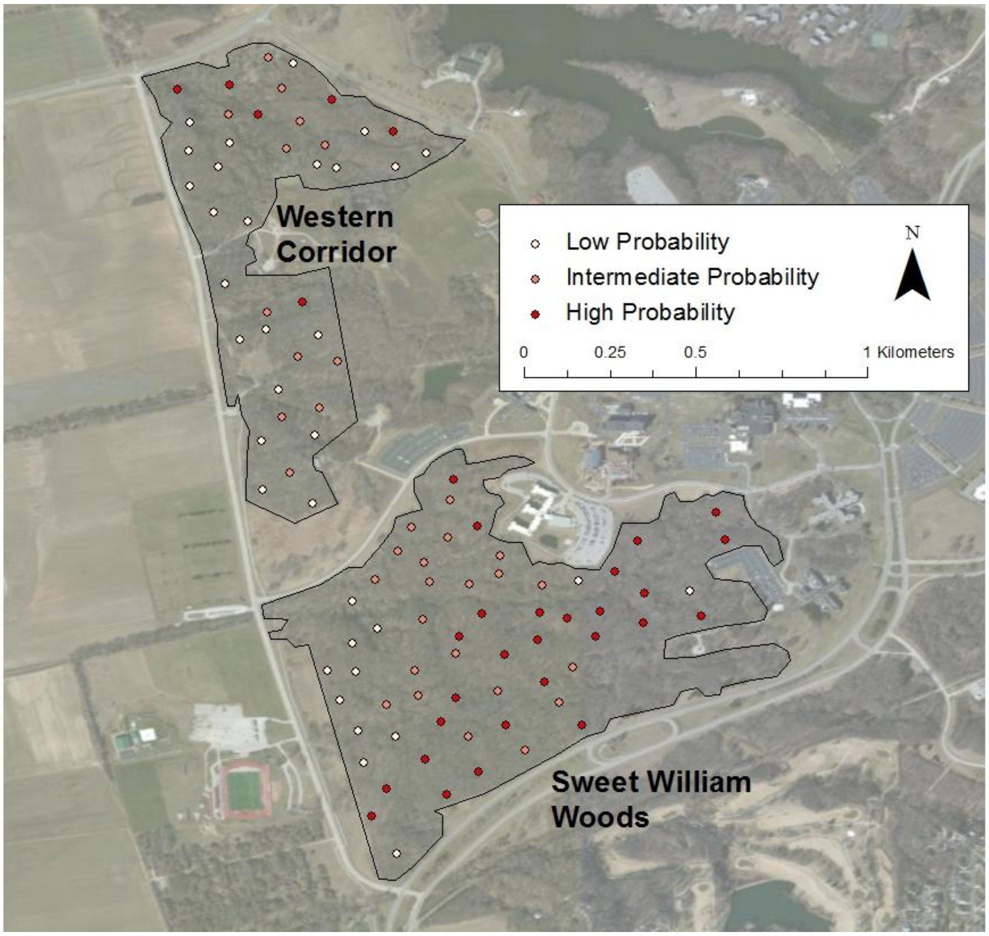


Figure 10. Map depicting probability of Southern Flying Squirrel activity. This map depicts the probability of either type of materials being found inside a box. Probability was calculated by entering habitat variable measurements at each plot into the top model equation. Plots are broken into three equal groups based on calculated probabilities to contain materials: boxes in the lowest third, middle third, and highest third of probability (relative to other plots).

Table 7. Summary of parameter influences for response variables. Positive associations are represented as (+), negative associations are represented as (-), and no significant associations are represented as (0). Parameters which are significant at alpha=0.05 within the top three candidate models are denoted with an asterisk. For the strength of parameter influences within models, see the standardized slopes included in Tables 4-6.

| **Variable** | **Nesting Materials** | **Feeding Materials** | **Combined Activity** |
|---|---|---|---|
| NearEdge | - | 0 | - |
| NearRav | 0 | 0 | 0 |
| 90thDBH | - | 0 | - |
| TreeRich | 0 | - | - |
| TreeDens | 0 | 0 | -* |
| FeedDom | 0 | +* | +* |
| AVGFeedDom | + | 0 | + |
| TotShrub | -* | +* | 0 |
| ShrubRich | + | + | + |
| CavityCt | + | 0 | 0 |
| SnagBasal | + | - | - |
| LogBasal | 0 | +* | + |
| ForestAge | 0 | 0 | +* |
| BoxTreeBark | -* | + | 0 |
| BoxTreeDBH | 0 | 0 | 0 |

# CHAPTER IV
# DISCUSSION

## Box Use and Capture Rate

A high rate of overall nest box use was observed (70.8%), which was comparable to the 78% occupancy found by Woodworth *et al*. (2000). Over a third of boxes contained nesting materials (39.6%) and another third were used for caching feeding materials (31.3%). The capture rate was 3.3%, which is within literature values. Capture rates of flying squirrels have been as low as 1-2% (Adams and Campbell 1996) and as high as 24% (Layne and Raymond 1994), but can be affected by many factors such as the number or frequency of checks, duration of study, or year-to-year population fluctuations. This study did not find a male- or female-biased sex ratio. Some studies also did not find a sex ratio significantly different from 1:1 (Taulman et al. 1998; Reynolds et al. 2009), however others found male-biased ratios in nest boxes (Gilmore and Gates 1985; Layne and Raymond 1994).

Results predicting nest box uses within forest patches showed interesting patterns. When mapping, the plots were broken into three equal groups of lowest probability, intermediate probability, and higher probability. Nest boxes identified by the predictive model to have higher probability of containing nesting materials were interspersed through the Western Corridor and Sweet William Woods (Figure 8). Many plots were located in proximity to the large ravine which runs east-west through Sweet William Woods, but there were also several plots along the peripheries of both forest patches. Nest boxes identified by the predictive model to have higher probability of containing feeding materials had a higher concentration within Sweet William Woods (Figure 9). Western Corridor had few plots in the highest third. For the model for combined activity once, nest boxes identified in the highest third of probability to contain materials were once again concentrated in Sweet William Woods, with the northern end of the Western Corridor also having several intermediate and higher probability plots (Figure 10). In all three maps, the southern half of the Western Corridor had the fewest number of higher probability boxes, indicating this region may contain less ideal habitat. When checking plots in this area, little Southern Flying Squirrel activity was observed within nest boxes during the study (Figure 7), although one box contained materials thought to belong to *Peromyscus leucopus*.

### Factors Influencing Nest Box Use

Plot proximity to forest edge appeared in models for nesting material presence (Table 4) and combined activity (Table 6). Being in the forest interior increased the likelihood a box would be used. In one study, only 16.2% of den sites were within 20 m of the forest edge, while 83.8% were located in the interior forest (Bendel and Gates 1987), and nearly all tagged individuals avoided clear-cut areas. Another study found an apparent edge effect, but were unsure whether it was due to an increased presence of invasive species at the edge or increased predation pressure (Cannan et al. 2011). These patterns could reflect a preference for interior forest, avoidance of invasive species, or increased predation risks at the periphery of the forest. Human fragmentation of flying squirrel habitat likely means an increase in predation pressures, which has been observed along forest edges and in seed-tree harvest areas (Taulman et al. 1998; Taulman and Smith 2004). Predation risk could be increased in forest patches with a high edge-to-interior ratio, and declining patch sizes could also yield repercussions for pioneer individuals attempting to disperse across open distances (Taulman et al. 1998). Studies have found habitat area, connectivity, and the amount of edge versus interior habitat were significant predictors of Southern Flying Squirrel presence (Rosenblatt et al. 1999; Woodworth et al. 2000; Walpole and Bowman 2011), which should be a consideration in suburban areas. This study did not have focal areas differing on landscape-level factors such as size and isolation, however these factors could have effects on populations, especially as human development continues.

Forest age appeared as the most influential variable in the top model for combined activity (Table 6), and had a positive association (Table 7) indicating a preference for more mature forest. In a study of Southern Flying Squirrels in fragmented forests, Taulman and Smith (2004) found squirrels often used mature forest corridors along intermittent creeks to travel and avoid lower-quality forests. Another study found that retention of mature forest stands near harvested areas greatly reduced impacts of logging on Southern Flying Squirrels (Taulman et al. 1998). Tree richness appeared in models for feeding material presence and combined activity (Table 5, Table 6) with a negative association (Table 7). This pattern may relate to forest age, as forests in later successional stages are expected to have lower species richness than forests in mid-successional stages. There was an apparent pattern of captures along areas with ravines (Figure 7). Out of the nine boxes indicating Southern Flying Squirrel captures on the map, seven of those are located near a large ravine. Ravines within these forested areas may act as open avenues for movement across forest patches to gather resources, or could also offer quick escape routes when avoiding predators. Areas near ravines also tend to be older-growth forest, due to the farming history of the region. If an area was able to be plowed, forests were removed and the area was farmed. For this reason, older trees tend to be found in the areas that were not suitable for plowing.

The forest patches on campus have regrown from pastures and farmed fields over time, leading to a general trend of younger forest near the peripheries as patches expand. Many edges are overgrown with vines, have invasive species such as tree of heaven (*Ailanthus altissima*) or Japanese honeysuckle (*Lonicera japonica*), or have black locust trees (*Robinia pseudoacacia*) which are nearing the end of their lifespan. In this study there were two observations of pregnant/nursing females in nest boxes located in areas which appeared to be lower-quality habitat at forest peripheries. Home range studies have found that observed female home ranges showed little, if any, overlap with one another, while male home ranges show much more overlap with one another as well as female home ranges (Bendel and Gates 1987; Taulman and Smith 2004). It is possible that pregnant females may seek out what appears to be lower-quality habitat in order to reduce competition or home range overlap with conspecifics.

In this study, cavity count appeared in models for nesting material presence (Table 4). There was a positive association with the number of cavities and presence (Table 7), which did not follow predictions. Cavity availability has been thought to act as a limiting resource for populations of Southern Flying Squirrels, and it is expected estimates will be low if there are large numbers of natural cavities available. Natural cavities are chosen preferentially over artificial nest boxes due to superior insulation from cold and protection from the elements (Gilmore and Gates 1985; Althoff and Althoff 2001). An increased abundance of natural cavities in an area will likely decrease probability of nest box use, which will also decrease detection (Gu and Swihart 2004). In a telemetry study, the core activity areas of focal animals had significantly more available cavities (Bendel and Gates 1987). In a study of habitat selection of flying squirrels being removed from red-cockaded woodpecker nests, Mitchell *et al*. (2005) did not find vegetation characteristics to be related to flying squirrel presence or absence. This led them to hypothesize that flying squirrels choose nest site locations due to cavity availability and not specific vegetation structures (Mitchell et al. 2005).

If cavities were a limiting factor, one would expect to find higher rates of nest box use in areas with lower cavity counts because the nest boxes would have increased availability of a limiting resource. This was experienced by a study in northern Louisiana, where a larger proportion of boxes were used in areas with fewer cavities (Goertz et al. 1975). One study did not observe a significant increase in population size after adding nest boxes, concluding nesting sites were not a limiting factor for flying squirrels in that area (Brady et al. 2000). Additionally, the effects of cavity abundance can fluctuate from year to year due to temperature or precipitation differences. This may lead to abundance overestimates if cavity use is higher or underestimates if cavity use is lower in a year due to climatic effects (Laves and Loeb 2006). It is possible that in the forests on campus cavities do not act as a limiting resources, and a higher cavity count may rather indicate more places to establish den sites and take refuge when avoiding predators. With higher cavity counts in some areas, there could therefore be a higher density of Southern Flying Squirrels. The more individuals found in an area, each individual maintaining multiple den sites, the higher the probability a nest box would be filled with nesting materials.

Snag basal area appeared in candidate models for all three response variables, however only appeared in the top three models for feeding material presence (Table 4Table 5). Snag basal area had a positive association with nesting materials and a negative association with feeding materials and combined activity (Table 7). This positive association with nesting materials lies in agreement with the appearance of cavity count in that model set, however the negative association with feeding materials and combined activity follows my predictions. Flying squirrels previously have been shown less likely to utilize nest boxes in areas where snags are more abundant (Gilmore and Gates 1985; Bendel and Gates 1987), and the number of snags likely reflects the number of natural cavities which will be available. In  a study examining the effects of logging on Southern Flying Squirrels, the retention of snags in harvested areas reduced negative effects on flying squirrel populations (Taulman et al. 1998). Studies have found Southern Flying Squirrels nest preferentially in snags versus live trees, which could explain why they were observed to visit plots in areas with a higher number of snags more frequently during activity periods (Bendel and Gates 1987; Cannan et al. 2011). Snag density had a positive effect on Southern Flying Squirrel density in study areas in one study (Taulman and Smith 2004), and other studies have found the number of snags was lower surrounding used nest boxes versus unused boxes (Gilmore and Gates 1985; Woodworth et al. 2000). The negative association with snag basal area seen in this study followed predictions that nest boxes were more likely to be used in areas where the preferred resource was in lower abundance.

Variables relating to the shrub layer appeared in many predictive models. Total shrub layer stem count appeared in models for nesting and feeding material presence (Table 4,

Table 5), while the richness of the shrub layer appeared in models for all three response variables (Table 4, Table 5, Table 6). Higher shrub richness on a plot increased likelihood of materials being present in the nest box. Many areas in the forests on campus have experienced invasion by Japanese honeysuckle (*Lonicera japonica*), and in areas where honeysuckle dominates one would expect a lower species count. The shrub layer richness also includes tree saplings, so a higher richness could reflect recruitment of tree saplings as well. A difference in the association with shrub stem count was seen between plots with nesting and feeding materials in boxes. Plots with nesting materials in the box showed a negative association with shrub layer stem count, while boxes with feeding materials showed a positive association. Several studies have found higher shrub layer stem counts to have a positive influence on activity in an area (Sonenshine and Levy 1981; Gilmore and Gates 1985; Bendel and Gates 1987). My study supports these findings, and these patterns may relate to available cover when foraging. A higher density of shrub stems would help conceal flying squirrels from predators when they are active on or near the ground (Bendel and Gates 1987). Similar to shrub stem count, there was a positive association of log basal area on plots with feeding materials in boxes. Gilmore and Gates (1985) found a higher proportion of logs in areas that were used for feeding during activity periods. Logs may offer additional cover or concealment from predators when individuals are on or near the ground, with hollow portions offering refugia. A log lying on the forest floor could also offer a more even surface to quickly move across the ground.

The dominance of hard mast on a plot appeared in the top model for feeding material presence (Table 5) and combined activity (Table 6). Additionally, the average dominance of hard mast on a plot and its neighbors appeared in the top model for nesting material presence (Table 4). Both predictors had positive influences on the response variables when they appeared in models (Table 7). It has been suggested one of the main factors affecting home range sizes of Southern Flying Squirrels is the availability and distribution of food resources (Taulman and Smith 2004). It is noteworthy that the abundance of food resources on the plot immediately surrounding the nest box appeared in candidate models for feeding material presence, while the average food availability in the area surrounding the plot appeared in many models for nesting material presence. This could reflect the ability of Southern Flying Squirrels to quickly travel across the distances between study plots, which are on average approximately 100 m. While they are likely to cache in a box immediately surrounded by hard mast, they are likely to nest in an area with food resources at neighboring plots.

Characteristics of the nest box tree may influence whether a nest box is likely to be used. The roughness of the nest box tree's bark appeared in models for nesting material presence (Table 4) with a negative association (preferred smoother bark), and with a positive association in models for feeding material presence (Table 5). Sonenshine and Levy (1981) found a higher capture frequency in nest boxes on trees with increased bark textures. Relationships with tree bark roughness and diameter could relate to ease of locomotion, as smoother bark would allow for easier locomotion, as would a smaller tree diameter (Cartmill 1985). Nesting in trees which have smoother bark has been shown to add protection from predators such as arboreal snakes. Bird nests located in trees with smoother bark, or in snags with no bark, experienced lower rates of predation by arboreal snakes (Mullin and Cooper

2002; Leonard 2009), and secondary cavity nesters which later inhabit those cavities would also experience the same benefits of smoother bark.

A noteworthy consideration is that several forest patches found on campus are larger and have higher connectivity now than they did before campus was made, and many areas are still undergoing succession. As the fields and pastures have been allowed to reforest, the area usable by flying squirrels has likely increased and the near ubiquitous use observed across forest patches relates to their generalist nature. However, as areas on and around campus continue to undergo urbanization, unprotected forest patches will continue to become smaller and more isolated. Open areas are problematic for flying squirrels and limit their ability to disperse to new forest or recolonize areas from which they have been extirpated. Incorporation of trees which can act as gliding structures and corridors across these open areas will be beneficial to animals such as Southern Flying Squirrels in the future as urbanization continues.

## Conclusions

This study found different influential habitat parameters between plots where the boxes contained nesting or feeding materials, particularly those reflecting food availability and the shrub layer. Among the variables found in models, significant factors included forest age, shrub layer stem counts, log basal areas, and dominance of hard mast on a plot. Higher cavity counts in areas with nesting activity in boxes would suggest the cavities are not acting as a limiting resource, but instead may allow a greater number of flying squirrels to inhabit an area, therefore increasing likelihood a nest box would be used as a den site. The Southern Flying Squirrels on campus appear to be influenced by a higher availability of food sources and by vegetation characteristics which provide sufficient concealment and refugia from predators. It has been suggested that den site selection may be driven by predator avoidance and interspecific competition, and in the case of a high population density, intraspecific competition as well (Muul 1968; Bendel and Gates 1987; Borgo et al. 2006). Therefore competition for limiting resources and avoidance of predators likely influences den site selection to a higher degree than does vegetation characteristics in the microhabitat.

## Limitations

A limitation to this study is the cryptic nature of Southern Flying Squirrels. Detection is affected by density and behavior of the focal species, as well as the efficiency of sampling. For a species with a low density, which are also cryptic and den at multiple sites, there may be a very low detection rate for a sampling method such as the one in this study (Gu and Swihart 2004). One way to reduce false absences is to conduct multiple surveys within a short amount of time (Mackenzie and Royle 2005); however, efficiency of sampling was limited due to the large number of plots and the time it took to locate and check each plot. Additionally, population estimates are less precise when occupancy rates are less than 10% (Althoff and Althoff 2001). Limitations on sampling and climactic factors likely contributed to the low rate of animal captures. It was for this reason material presence inside nest boxes were taken into account when generating predictive models.

Another limitation may be utilizing one sampling style and duration. Laves and Loeb (2006) suggested that utilizing only one trapping method may yield estimates which do not accurately represent true population size or structure for Southern Flying Squirrels. This is because captures from nest boxes represent den site use while captures from Sherman live trapping represent habitat use during nightly foraging and movement. These two different methods might represent different population segments or yield data about two different types of habitat usage (Laves and Loeb 2006). Sherman live trapping would likely have led to a larger number of captures, allowing demography estimates. The number of flying squirrels found in the population can vary throughout the year, and fluctuates greatly between years (Althoff and Althoff 2001), which can largely affect occupancy of nest boxes. Long-term data collection would be beneficial, and nest boxes should be emptied periodically to assess which areas experience recent activity. Another potential limitation of this study was the mounting height of nest boxes. When live trapping flying squirrels, medium to high traps captured similar percentages of flying squirrels while low traps were half as successful, therefore a trap height of 4.5-5 m was recommended (Risch and Brady 1996). Nest boxes are currently mounted at a height of approximately 3 m. A higher capture rate may have been experienced if nest boxes were attached higher.

Heterogeneity of the environment can have effects on habitat use estimates. It is possible to have an overrepresentation of habitat use in a specific area if the study is structured in a way which may artificially lead to use—for example, placing nest boxes in areas of less suitable habitat may provide a limiting resource in an area where it may not be otherwise available. This would increase use of the area and potentially cause a habitat model to be misleading (Menzel et al. 2006). For example, there could be an area with a large number of flying squirrels due to an abundance of resources, whereas another area could have a very low population of flying squirrels due to unsuitable resources. Once artificial nest boxes are in place, a high rate of nest box use might be observed in the high-quality area due to the high flying squirrel density, while a high rate of occupancy could be observed in the lower-quality area due to the new availability of a limiting resource. The potentially comparable occupancy rates between the two areas would be misleading.

## Recommendations for Future Research

Bohm Woods has previously been identified as valuable for conservation purposes, as it is relatively undisturbed mature-growth forest containing tracts of upland forest and wet bottomland forest and supports higher numbers of forest interior avian species than surrounding areas (Richter et al. 2010). As a continuation of this project, it is recommended to install artificial nest boxes in Bohm Woods, in order to assess population demography and habitat use and determine if the supposed higher-quality habitat is able to support a higher density of Southern Flying Squirrels. It would be interesting to see if flying squirrel use of Bohm Woods is as ubiquitous as it was in the other forest patches, and if the predictive variables within habitat models would change based on the larger data set. It would also be interesting to expand into other forest patches to further investigate how Southern Flying Squirrel populations have responded to the urbanized landscape in this area. Incorporating the amount of materials inside nest boxes would also be useful, to quantify which plots receive the most use.

Radio-collaring and tracking individual flying squirrels would yield information on core activity areas, home range sizes, natural den site locations, and potentially dispersal ability between forest patches. It may make it possible to identify areas being used as corridors between forest patches and perhaps be useful in planning tree plantings on campus to increase dispersal potential. Radio collaring would also allow for comparisons to literature values of home ranges and perhaps yield information about resource availability (large home ranges may indicate lower abundance of resources, while small home ranges would suggest higher resource availability).

Another consideration is the retention of markings. Ear tags may potentially be ripped out during travel through vegetation; however, flying squirrels are gregarious in nature and tags will more likely be lost during grooming between individuals. After one year, Southern Flying Squirrels which were double ear-tagged had an 80.9% retention rate of both tags, while 23.9% lost one and 4.7% lost both (Fokidis et al. 2006). Ear tags had approximately a 50% survival probability after two years (Fokidis et al. 2006). In this study, captured animals were examined for signs of tag loss and none were found to show signs of a recently lost marking.  However, as time goes on it will become more and more unlikely to identify individuals tagged during this study. Considering an alternate form of marking individuals may also be beneficial, in particular Passive Integrated Transponder (PIT) tags. Southern Flying Squirrels had a 91.6% retention rate of PIT tags in the study by Fokidis *et al*. (2006). Animals would be more likely to reliably retain PIT tags over time, and a greater amount of information on movement and nest box use could be obtained by placing readers at the entrances of the most active nest boxes and recording visits over long periods of time.

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