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# Gender Differences In Space-Use Patterns And Microhabitat Characteristics Of Southern Flying Squirrel (Glaucomys Volans) In Northeastern Iowa

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# GENDER DIFFERENCES IN SPACE-USE PATTERNS AND MICROHABITAT CHARACTERISTICS OF SOUTHERN FLYING SQUIRREL (*GLAUCOMYS VOLANS*) IN NORTHEASTERN IOWA

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# PREFACE

This thesis is written in the style of the Journal of Mammalogy, to which a portion will be submitted for publication.

# ABSTRACT


Southern flying squirrel (*Glaucomys volans*) is common throughout the eastern deciduous forests of the United States, southern Canada, Mexico, and Central America. However, within the state of Iowa *G. volans* currently is listed as a "species of special concern." This status is due to general loss of local habitat and lack of information about the species within the state.

The state of Iowa has lost a majority of its native land cover over the past century due to intensive agricultural practices. Most native forests have been reduced drastically. The majority of habitat that would be suitable for southern flying squirrel has been fragmented or destroyed. These combined factors have led to the current listing of southern flying squirrel as a species of special concern within the state of Iowa.

I studied southern flying squirrel at two sites in northeastern Iowa; the Mines of Spain State Recreational Area (MoSRA) and Wolter Property. The majority of my research was done at MoSRA. These sites were located in Dubuque and Clayton counties.

Beginning in the summer of 2012 and continuing in the summers of 2014 and 2015 male and female southern flying squirrel were fitted with radio transmitters. Both male and female southern flying squirrels were tracked subsequently by using radio telemetry techniques. During the course of this research 11 males and 15 females were fitted with radio transmitters. Tracking results were variable; while some individuals (1 male and 3 females) yielded only a few locations, others were successfully tracked for up to two months.

Home range area varied from 2.4 ha to 71.1 ha. Home ranges were larger for males than for females (*P*-value = 0.048). Males showed more variation in their range size as well. This variation possibly is due to the high degree of fragmentation within this habitat. Comparisons between my study home range sizes in other portions of southern flying squirrel range showed significant differences. Studies where southern flying squirrel home ranges were measured in contiguous forest habitat were smaller than those measured in my study.

Home ranges of southern flying were used to determine microhabitat selection. After determining home range boundaries habitat was sampled both habitat within home ranges (Used) and outside of home ranges (Available). These points were selected by using stratified random sampling design. These data were then used to determine if there is specific microhabitat selection by this species and if so what habitat variables they respond to most strongly. Habitat variables that were significant for explaining the presence of southern flying squirrel were distance-to-nearest-neighbor (distance between trees), tree height, litter depth, and forb cover. Tree species were not significant in explaining presence of southern flying squirrel. Forest structure, not forest community, appeared to be more critical in predicting the habitat of southern flying squirrel.
These data hopefully will yield a better understanding of space-use and ecology at a landscape level for the southern flying squirrel in northeastern Iowa. Currently, it is not understood how southern flying squirrel respond to forest characteristics in northeastern Iowa. Understanding movement patterns and habitat associations becomes vital should this species be listed as threatened or endangered within the state of Iowa.

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# INTRODUCTION

The increase of exploited land has led to native habitat composition and configuration change on a large scale (Nagendra et al. 2004). This has caused the reduction of forest tract sizes and general fragmentation throughout the world (Fahrig 2003). Midwestern states have been fragmented on a large scale due to agricultural practices over the last few centuries (Hart 1986) with Iowa among one of the most drastically altered states (Little and Harr 2005). Landscape changes especially have been intense due to industrialization practices, which have propagated in the Midwest since the end of World War II (Medley 1995). In the state of Iowa land cover has been altered extensively since the early 1800s (Fig. 1). Forests were once one of the most extensive types of land cover within the state but have now been reduced by more than 60% (Little and Harr 2005; Gallant et al. 2011). In the state of Iowa hardwood forests have been associated most closely with riparian areas in the northeastern and southern portions of the state (Little and Harr 2005).

Southern flying squirrel (*Glaucomys volans*) is widespread throughout the eastern deciduous forests of the eastern United States, southern Canada, as well as parts of Mexico and Central America (Fig. 2) (Muul 1968; Dolan and Carter 1977; Weigl, 1978; Sonenshine and Levy 1981). This range covers an area, which includes up to one third of the eastern United States (Braun 1988). Southern flying squirrel is not restricted to any particular forest type or by a specific mast-producing tree species (Muul 1974), however, hardwood forests provide critical food sources for southern flying squirrel. Rather, tree species selected for nesting sites reflects those available in the different geographic areas.

That is, southern flying squirrel use all available tree species in their habitat as nest sites (Sonenshine and Levy 1981; Bendel and Gates 1987; Fridell and Litvaitis 1991).

Members of the Genus *Glaucomys* are all nocturnal sciurids  with a dependence on mature tree stands for both nest sites and food resources (Sollberger 1940; Dolan and Carter 1977).  This genus belongs to the tribe Pteromyini, which is characterized by patagia, or stretched skin used for gliding over long distances (Dolan and Carter 1977). Southern flying squirrel is active throughout the night hours during warm months and also exhibits periods of nightly activity during colder months (Muul 1968).  Additionally, in the colder months, southern flying squirrel appears to form communal aggregations that are thought to confer thermal advantages (Muul 1968).  Its nocturnal activity patterns and seasonal changes in behavior likely reduce opportunities for human observation unless it is subject to directed study.

Flying squirrels are highly modified for an arboreal existence (Sollberger 1940). Climbing and gliding are a significant part of their locomotion (Dolan and Carter 1977). This means they are restricted to areas of appropriate forest tract size.  Without trees of sufficient height their unique locomotion to be a survival advantage (Dolan and Carter 1977).  Because of their many unique features as well as their nocturnal habits members of the genus *Glaucomys* are often understudied in terms of their basic ecology and distribution (Sollberger 1940; Lavers et al. 2006).  They are seldom detected in small mammal surveys (Legg 1981).  In Iowa, southern flying squirrel is listed as a Species of Special Concern (Little and Harr 2005), meaning their populations are declining or threatened within the state.  Although  the reported distribution of southern flying squirrel includes all but the extreme western corner of Iowa (Dolan and Carter 1977), there are relatively few records for the species within the state (Little and Harr 2005). The abundance of southern flying squirrel is officially “Uncommon” within Iowa and the population trend is “Unknown”. Possibly its listing in Iowa is due to a paucity of population and ecological information (Little and Harr 2005).

Despite the relatively high abundance of this species in most of its range there is little information available on the influence of vegetational structure on habitat use (Bendel and Gates 1987). Microhabitat characteristics affecting nest-box use have been examined (Gilmore and Gates 1985). Perhaps the most extensive microhabitat investigation (Sonenshine and Levy 1981) postulated that composite forest composite community, not just canopy species, appears to determine suitability of an area.

General habitat characteristics have been described in several studies (Sollberger1940; Jordan 1948; Madden 1974; Muul 1974; Goertz et al. 1975; Weigl 1978). These previous studies suggest southern flying squirrel prefers the hard mast produced by oak (northern red, *Quercus rubra*, white, *Q. Alba*) and hickory (shagbark, *Carya ovate*)( Ivan and Swihart 2000). These tree species also become the source for fungi that has been reported in southern flying squirrel diet (Harlow and Doyle 1990). Southern flying squirrel also is known to consume a variety of other food materials including eggs, nestlings, and adult birds, presumably from nest cavities (Dolan and Carter 1977). Other reports suggest that it also consumes small mammals as well (Sonenshine an Levy 1981).

Because hardwood forests, specifically old growth forests with mast producing trees such as oaks and hickories, are vital to the survival of southern flying squirrels, it is imperative to focus research efforts where forest structure is appropriate and might support southern flying squirrel populations. Northeastern Iowa historically was heavily forested, characterized by oak-hickory and oak savannah vegetation (Witzke et al. 1997; Gallant et al. 2011), which is thought to be ideal habitat for southern flying squirrel (Dolan and Carter 1977; Sonenshine and Levy 1981; Bendel and Gates 1987). However, these forests tracts have been reduced to a fraction of their former extent, due to increased agricultural practices in the region (Witzke et al. 1997; Little and Harr 2005; Gallant et al. 2011). Speculation suggests that there are now few areas of old-growth forest left in northeastern Iowa that can sustain breeding populations of southern flying squirrel (Little and Harr 2005).

One location in northeastern Iowa that lends itself to research effort on southern flying squirrels is the Mines of Spain Recreational Area (MoSRA), which is part of the State Park system. In 1981, southern flying squirrel was described as "Probably Relatively Common" within MoSRA due to a single observation. However, field work was done primarily during daylight hours in this study (Legg 1981). Until recently, the occurrence of southern flying squirrel had been determined solely through sporadic, anecdotal reports. Beginning in 2008, teams of University of Dubuque students have confirmed a population of southern flying squirrel at MoSRA (G. L. Zuercher, pers. comm.). Their success has led to interesting findings, including the appearance of strong male bias in trapping results. This might be due to real bias in the sex ratio or a function of different behavior between males and females.

Similarly, during the past two seasons, University of Dubuque students also have started conducting biological surveys at a private property, the Wolter Property, within northeastern Iowa. This land is on the boarders of Dubuque and Clayton counties. The Wolters have been working with Iowa DNR to restore property to its natural state. This includes a larger portion of hardwood forest thought to be currently supporting a population of southern flying squirrel. This is based on anecdotal sighting, as well as trapping surveys by the students (G. L. Zuercher, pers. comm.).

The purpose of my research was to study how male and female southern flying squirrel in northeastern Iowa use available habitat. Work was done in MoSRA as well as the Wolter Property. In addition, data from previous years was used to analyze the microhabitat and movement patterns at MoSRA in terms of distribution, abundance, and seasonal movements. Previous insights from this population suggest that male and female southern flying squirrel occupy very different home ranges (G. L. Zuercher, pers. comm.). Some studies suggest that male and female flying squirrel differ in their propensities to be captured in live traps (Laves and Loeb 2006). They reported that males are almost twice as likely to be captured as compared to females. It is not known whether this is a seasonal variation, or if it is a yearlong pattern. Females are thought to remain near their young when nursing, which could account for a smaller home range (Bendel and Gates 1987). Little is known about the breeding habits of female southern flying squirrel. Some evidence suggests that northern flying squirrel (*Glaucomys sabrinus*) has multiple litters per year (Smith et al. 2011), but it is unknown if the same is true for southern flying squirrel. Seasonally, this could impact the frequency with which female flying squirrels are trapped.

Home range size and use might vary considerably, depending on the habitat structure, the interactions among species, and the physiology and behavior of the individual (Bendel and Gates 1987). Most studies on home range of southern flying squirrel are conducted in contiguous forest habitat (Bendel and Gates 1987). Early studies using trapping techniques suggest that home-range estimates for adult southern flying squirrels range from 0.41 to 3.49 ha (Table 1; Madden, 1974; Gilmore and Gates, 1985). In some areas of the southeastern United States, home-range estimates for male southern flying squirrel are thought to be more variable than those of females (Stone et al. 1997). Other studies suggest that space use requirements between genders is approximately equivalent (Holloway and Malcom 2007). Flying squirrel home ranges appear to be larger in large harvested forests (Holloway and Malcom 2007). The largest home ranges reported for southern flying squirrels are reported in a landscape managed for logged timber (Taulman and Smith, 2004).

Understanding fine-scale habitat requirements of flying squirrels and use of space is crucial to ensure that populations are maintained in managed landscapes (Holloway and Malcom 2007). However, few studies have investigated flying squirrel microhabitat use (Fridell and Litvaitis, 1991). Some studies have suggested that habitat characteristics mimic those of woodpeckers (Picidae), because flying squirrels are not capable of excavating their own nest cavities (Sollberger 1940). Southern flying squirrel occur in areas where downy woodpecker (*Picoides pubescens*) excavations are in close proximity to nut-bearing trees (Sollberger 1940; Muul, 19474). This suggests that microhabitat characteristics could vary considerably depending on species composition and geographical location as well.

The main goal of my study was to investigate southern flying squirrel home ranges, movement patterns, and microhabitat use in a fragmented old growth forest in northeastern Iowa. The main goal of my research was to determine the extent of southern flying squirrel home ranges. During the course of my research both male and female southern flying squirrel were tracked.

I hypothesized that (1) southern flying squirrel home ranges were associated with specific microhabitat structures within the region, (2) males and females have different home range sizes in terms of area, and (3) the overall space use for both genders are than other studies due to the high degree of fragmentation. Microhabitat is thought to be a large factor in determining a viable population of southern flying squirrel as it requires specific conditions to form nest aggregations in the winter (Sonenshine and Levy, 1981). Therefore, determining space use characteristics and microhabitat use is essential to determine if conditions are right to maintain populations in northeastern Iowa.

METHODS

**Study Site**

Northeastern Iowa is part of the Paleozoic Plateau landform and is one of the most distinctive landforms in the state due to its abundant rock outcroppings and absence of glacial deposits (Little and Harr 2005). Because of its topography, relatively large areas of old-growth and secondary-growth forests have been left undisturbed from the advancement of agriculture (Gallent et. al 2011). These geologic features support rare and sensitive biological habitats in Iowa and remain ideal places for southern flying squirrel (Little and Harr 2005).

My research was conducted in two counties, Dubuque and Clayton, within this landform region of northeastern Iowa (Fig. 3). The primary research site for this project was is the Mines of Spain Recreational Area (MoSRA). Mines of Spain State Recreational Area is located directly southeast of the city of Dubuque in Dubuque County Iowa. Mines of Spain Recreation Area is approximately 527 ha in size and is managed by the Iowa Department of Natural Resources (IDNR)(Herzberg and Pearson 2001). It is a mosaic of several natural vegetation communities; oak-hickory, maple-basswood, and aspen-birch forests, juniper (*Juniperus spp.*) groves, bur oak (*Quercus macrocarpa*) groves, and hill prairies (Blewett et al. 1983). The management objectives for the MoSRA have included prevention of oak-hickory succession into maple-basswood forest (Legg 1981). This management objective should promote the persistence of southern flying squirrel within MoSRA (Fig. 4).

A secondary study site was on the Wolter Property located on the southern and northern borders of Clayton and Dubuque counties respectively. This site is located approximately 40 miles northwest of MoSRA. Landowners of this property have implemented similar conservation goals to those at the MoSRA. During the past several years landowners have worked with the Iowa DNR to begin restoring habitat to its historical condition. This includes oak-hickory forests that are thought to support southern flying squirrel in northeastern Iowa.

**Trapping**

My project was done in accordance with approval by the Fort Hays State University Institutional Animal Care and Use Committee protocol number 14-0003 (Appendix 1.). Trapping was done over three summers; 2012, 2014 and 2015. The Mines of Spain State Recreational area was trapped during the summer of 2012. During the summer of 2014 MoSRA and the Wolter property were trapped. In 2015 MoSRA was the only area trapped. Trapping efforts in 2012 were done in tandem with a population survey effort of students at the University of Dubuque. This was continued throughout the summer. In 2014 trapping at MoSRA was done between May 19th and June 5th and on the Wolter property between June 16th and June 21st. In 2015 trapping was carried out between May 27th and June 5th. Trapping efforts were not similar between years.

Four transects within MoSRA were sampled for southern flying squirrel. Each transect consisted of 30 trap stations, with stations being located 25 m apart. A single Ugglan Special No. 3 Multiple Capture Live Trap was placed at each station. Trap trees were selected by their diameter at breast height (DBH). Mast trees > 25 cm DBH are more likely to attract southern flying squirrel (Risch and Brady 1996). Traps were hung from a large galvanized nail attached directly to the tree between 4 and 5 m high. This height is more effective for the capture of southern flying squirrel than the easier to manage 1.5-2 m height used in other southern flying squirrel studies. However, it is considered to be no less effective than higher trap placements ($\geq$ 8 m; Risch and Brady 1996). Trapping on Wolter Property consisted of 30 trap stations equal to one transect. Due to the size of the private land (around 80 ha) only one transect was appropriate to use. Protocol for tree selection and trap placement was similar to that used for MoSRA.

Traps were baited with a mixture of peanut butter and oats. Trapping began during May in all field seasons and continued until the quota, or total number of individuals needed for the study, was met. Due to the amount of time required to check traps on each transect, transects were monitored on a rotating basis. The sequence was determined randomly at the start of the project and that sequence was maintained throughout so that equal amounts of time elapsed between trapping session for each transect. Traps were locked open when not in active use so as to prevent captures.

Upon capture, initial behavioral observations of all southern flying squirrel were made once traps were lowered to the ground. Any lethargic individuals were provided a 50% sugar and water solution via a dropper and allowed time to recover. Captured individuals were placed inside a canvas bag, allowed to calm if agitated, and ultimately transferred to a pre-weighed plastic bag in order to determine individual mass. Individual squirrels were then removed by gloved hand and restrained for measurements and tagging. For each capture, status (new capture or recapture), age (juvenile, sub-adult, adult), sex, and physical condition (scrotal or non-scrotal for males; lactating, pregnant, or inactive for females) were noted, mass (g), total length, tail length, and right hind foot length (all in mm) were measured. Mass was determined with a Pesola spring scale.

Body and tail length was measured with a field ruler. Foot length was measured with a digital caliper. Age was evaluated according to mass (Linzey and Linzey 1979, Laves and Loeb 2006): juveniles weighed $\leq 37$ g, sub-adults weighed 38-55 g, and adults weighed $\geq 56$ g. Reproductive condition of the females was assessed by examination of mammae and vulva; males were assessed by placement (ascended or descending) and size of testes.

All new individuals were marked with a Passive Integrated Transponder (PIT) tag. PIT tags provide a unique 10-digit-hexadecimal code. PIT tags were injected subcutaneously in the interscapular region (Boarman et al. 1998). Injection needles were sterilized with 70% alcohol and coated with an iodine solution prior to injection in order to prevent infection of injection sites. Needles were used on multiple individuals so precaution are taken to avoid contamination.

Non-target species captures were noted and released. Incidental mortalities (both target and non-target species) were stored at the University of Dubuque until processing occurred. A study skin and cleaned skeletal material was prepared for an incidental mortality and ultimately deposited within the University of Dubuque vertebrate teaching collection or at the Fort Hays State University Sternberg Museum of Natural History in Hays, KS.

**Telemetry**

Beginning in the summer of 2012 male and female southern flying squirrel were fitted with radio-telemetry units at MoSRA. During this time 4 transects were checked regularly as part of a continuing population survey of small mammals. A quota of 6 individuals was met (3 males and 3 females) after which no more individuals were fitted with transmitters. In 2014 trapping was conducted at both study sites (MoSRA and the Wolter property). During the 2014 field season 4 transects were checked regularly at the MoSRA and the Wolter property until a quota was met once again. Nine individuals (5 males and 4 females) were captured at MoSRA. Three females were captured at the Wolter property. During the 2015 field season 3 transects were checked regularly to meet a quota. Eight individuals (3 males and 5 females) were fitted with radio transmitters. Trapping was only carried out at the MoSRA.

I used Advanced Telemetry Systems (ATS; Insanti, MN) A2470 glue on transmitters. These transmitters have a battery life of up to 90 days and were deployed as early as possible to maximize data collection. Telemetry was done between May and September in all field seasons.

Radio-tracking was accomplished by using a Very High Frequency (VHF) receiver and Yagi antenna. Locations of individual squirrels were recorded daily, as long as the signal was detectable and weather was appropriate. A Garmin GPSMAP 64st Hiking GPS Navigator was used to record the coordinates of the observer. A handheld compass was used to determine the bearing from the observer to the individual southern flying squirrel. The location of each individual was determined through triangulation methods (Kenward 2001). A single observer recorded a minimum of three locations and bearings for individuals, typically within 15 min. Triangulations were conducted around sunset (30-60 min before or after sunset) when squirrels are thought to be the most active (Dolan and Carter 1977). I randomized the order in which locations were collected on individual animals from one night to the next throughout the study. I attempted to locate southern flying squirrels on a nightly basis to avoid excessive autocorrelation of points

(Ivan and Swihart 2000). This was not always possible as my ability to successfully track an individual depended on weather conditions. Additionally, in 2014 individuals were tracked on an hourly basis during one night a week in order to establish activity patterns. This was not done in other field seasons due to the availability of personal. Also in 2014 I attempted to locate diurnal nests for 6 individuals on a rotating basis.

**Microhabitat Sampling**

To quantify southern flying squirrel habitat use, I measured habitat characteristics of sites where flying squirrel were located by using radio telemetry (these are hereafter referred to as “Used” locations) and of random locations where southern flying squirrel were not detected (hereafter referred to as “Available” locations). I sampled 8 Used locations per individual on average for all squirrels. I was careful to select random sites within all home-ranges so as to avoid any overlap. All sites were at least 20 m apart to avoid excessive correlation. Available locations were selected in two ways: (1) stratified random sampling generator by using GIS tools both within and outside of home ranges and (2) selecting sites by walking a random distance (≥ 20 m) and bearing from a Used location.

I focused habitat measurements on trees, deadstands (dead trees), and ground cover, including forb populations. At each of the sites I recorded diameter at breast height (DBH) of trees and deadstands nearest to the predetermined GIS coordinates which were ≥ 10 cm DBH. The selected tree or deadstand was then used as the center for a quadrate sampling system (Fig. 5). Measurements were taken in each section of the quadrate, the condition of each tree was inspected for die-back or fungal growth. I inspected all trees and standing dead for the presence of cavities. From these data, I calculated basal area (BA) and average DBH (averDBH) of all trees. I calculated the average density of trees ≥ 10 cm DBH/ha and of large trees ≥ 25 cm DBH/ha. Vertical canopy cover was recorded in all quadrates using a densitometer.

I collected groundcover data by using a standardize Daubenmire frame method (Daubenmire 1959). This assesses vegetation structure based on percent within the area of ground where the frame was placed. I took measurements from one frame placed in each of the four sections on each quadrat. Percent coverage was determined in the field by using a 6 class system; 0-5 (1), 5-25 (2), 25-50 (3), 50-75 (4), 75-95 (5), 95-100 (6). Midpoints were then used to approximate the coverage for each variable (Daubenmire 1959). Groundcover variables included were forb, leaf, grass, soil, rock, fungus, nuts (commonly shells), and wood (smaller sticks and logs). Variables were chosen based on previous observation of common ground cover in the MoSRA.

To assess tree size two structural and four vegetational categories were used. I did this to determine if southern flying squirrel responded to tree size, which is thought to be indicative of tree maturity (Kozlowski 1992). Mast trees were considered separately as they are thought to be a critical food resource for southern flying squirrel (Dolan and Carter 1977). Maple trees currently are considered as part of the management plan for the MoSRA. The rest of the hardwoods were considered together. Categories were: hardwood trees (Hardwd, Hardwd > 25), maple trees (Maple, Maple > 25), mast trees (Mast, Mast > 25) standing dead (Stdead, Stdead > 25). Mast trees were those that produced nuts (bitternut hickory [*Carya cordiformis*], shagbark hickory [*Carya ovata*], mockernut hickory [*Carya tomentosa*], black walnut [*Juglans nigra*], white oak [*Quercus alba*], bur oak [*Quercus macrocarpa*], red oak [*Quercus rubra*], and black oak [*Quercus *velutina*]). Maple-basswood (boxelder [*Acer negundo*], black maple [*Acer nigrum*], sugar maple [*Acer saccharum*], silver maple [*Acer saccharinum*], American basswood [*Tilia americana*], little leaf linden [*Tilia cordata*]) were analyzed separately as they are considered in the management plan for the MoS region. I also calculated tree species richness of both use and available sites. A total of 8 habitat variables for southern flying squirrel were used for assessment.

A total of 96 locations were surveyed. This included 43 Used and 53 available sites. Trees also were inspected for obvious signs of cavities, which could be potential nest sites. Values from quadrates at each site were averaged. The southern flying squirrel was positively identified at both MoSRA and the Wolter Property. Both locations were surveyed for habitat characteristics. No comparisons were made between the two sampling locations.

**Home Range and Spatial Use**

Telemetric observations provided data for determinations of home-range and space-use patterns for both male and female southern flying squirrel. I estimated squirrel locations via maximum likelihood by using the LOAS 2.11 Software package from Ecological Software Solutions, LLC (Florida, USA). I used the kernel density estimation (KDE) and isopelth functions in Geospatial Modelling to calculate home ranges (95% fixed kernel estimates) and core areas (50% fixed kernel estimates) by use of the least squares cross validation (LSCV) technique (Fig. 6). Minimum convex polygon (MCP) ranges were built in Esri ArcGIS (A geographic information system; Kansas City, KS USA). Minimum convex polygons were used to compare to literature values (Fig. 7). Minimum sample sizes for kernel home range estimates are indicated at 24 locations per individual (Holloway and Malcom, 2007). Therefore, only home ranges with adequate sample sizes were included in overall home range determinations. Home ranges and core areas were considered separately to assess the complete space use (home range) as well as concentrated space use (core area) as animals use space disproportionately within their home ranges (Samuel et al 1985).

To look at use of space within the habitat I calculated the percentage of area overlap of home ranges and core areas. This was done for same-sex and different-sexed squirrels as well as individuals with all neighboring squirrels. I used and analysis of variance (ANOVA) to compare home ranges and core areas between male and female squirrels.

**Statistical Analyses**

*Home Range and Space Use* – To compare, MCP, home range, and core area central tendencies I conducted a student t-test. To determine if the data met assumptions of normality I first conducted a Shapiro-Wilks test. For data that met assumptions for normality I conducted a student t-test to compare the means. For data that did not meet assumptions for normality I applied a Mann-Whitney U test, which can hand non-normal data and is robust at comparing sizes of dependent variables.

I also looked at central tendencies of home range overlap for variables of percent male-male, females-male, and female-female pairs. These data were tested for normality prior to testing. I applied a one-way Analysis of Variance (ANOVA) to these data.

*Microhabitat Analysis* – Data were again tested for normality. I was interested in looking at three general types of microhabitat features; General habitat characteristics, tree size, and tree species. General habitat characteristics where primarily those collected from Daubenmire data (Table 2) and those dealing with overall habitat structure. All variables were averaged for each site. I included distance to nearest tree, height, DBH, and canopy cover. For habitat variables that were distributed normally I applied a discriminant function analysis (DFA) to compare Used and Available locations.

Tree size was categorized as above. To determine if southern flying squirrel responded to trees at different stages of development all categories of trees were grouped based on DBH size. These data were again tested for normality. Mann-Whitney U tests were used to determine significance based on various sample sizes for each categories between Used and Available treatments.

To determine if southern flying squirrel was responding to specific tree species I applied a Non-Metric Multidimensional Scaling (NMDS) test to the species within Used and Available area. This test was used to explore patterns in the data with regards to Used and Available sites and tree species.

# RESULTS

## Trapping assessment

*2012 sampling period.* Trapping was done in conjunction with a continuing population survey by University of Dubuque students. Non-target species included the white-footed mouse (*Peromyscus leucopus*), eastern chipmunk (*Tamias striatus*), eastern fox squirrel (*Sciurus niger*), and eastern gray squirrel (*Sciurus carolinensis*). The white-footed mouse was the most abundant non-target species observed followed by eastern chipmunk (Fig. 8).

*2014 sampling period*. This season consisted of 1,050 total trap nights over the course of two weeks. The success capture rate for capturing southern flying squirrel was 1.62%. Non- target species included the white-footed mouse, eastern chipmunk, fox squirrel, and eastern gray squirrel (Fig 8).

*2015 sampling period.* The season consisted of 600 trap nights over the course of ten days. The total capture rate for southern flying squirrel was 1.67%. Species richness for non-target species was much lower consisting of only white-footed mouse and eastern chipmunk (Fig 8).

## Telemetry assessment

*2012 sampling period.* An equal number of male and female individuals were tracked during this season (3 of each gender). One individual (819) male was only located once before the signal was lost and we were unable to recover it. Another male (843) was lost for a 5 days before the signal was acquired again in another portion of the park.

*2014 sampling period*. Twelve individuals were fitted with radio collars. Signals of 3 females on the Wolter Property were lost after recording only a few locations. These data are omitted from the spatial use assessment. Nine individuals, 5 males and 4 females, were tracked at MoSRA. All individuals captured at MoSRA were successfully tracked for up to two months.

*2015 sampling period*. All individuals were trapped at MoSRA during this season. Eight individuals were fitted with radio collars during this season. There were 5 females and 3 males. All individuals were successfully tracked up to a month.

**Spatial-use assessment**

*Home Range Size.* Home range sizes were calculated for all individuals with minimum sample size (n > 24). A total of 10 males and 11 females were used in space-use and habitat assessments. Two females were tracked during successive seasons (2014 and 2015). However, these data were treated as separate home ranges in my assessment, as squirrels re-disperse and occupy different home ranges from one year to the next (Bendel and Gates 1987).

I used Minimum Convex Polygons (MCPs), 95% fixed kernels (Home Ranges), and 50% fixed kernels (Core Areas) to determine spatial use patterns. Minimum convex polygons were calculated as they commonly are referenced in the literature (Bendel and Gates 1987; Fridel and Litvaitis 1991; Holloway and Malcom 2007). Therefore, MCPs were used for literature comparisons. Fixed kernel estimates are thought to be indicative overall habitat use while core areas are where animals concentrate their space use activities (Samuel et al 1985).

Mean MCP was 13.3 ha for all squirrels. Males averaged 21.5 ha and females averaged 7.4 ha (standard deviation = 19.6 and 6.1, respectively). Overall the average Home Range size was 30.5 ha. Males averaged 45.9 ha and females averaged 16.6 ha (standard deviation = 25.8 and 9.5, respectively). For Core Areas the average size for all individuals was 5.6 ha. Males averaged 8.5 ha and females averaged 3.0 ha (standard deviation = 5.9 and 1.5, respectively).

**Microhabitat Assessment**

*Structural Habitat Characteristics* – Structural habitat characteristics were those that determined the physical attributes of the habitat. These included those data collected from Daubenmire frames as well as forest density, tree size, height and distance between trees. Some Daubenmire variables, which were included in my survey based on literature, consisted of a low number of positive values. Ground cover for fungus, nuts, wood, and rocks all fit this description. I also did not survey many trees with obvious evidence of fungus growth externally. Positive identification of tree cavities was extremely low and could not be used in statistical testing.

*Tree Size.* Literature states that southern flying squirrel rely on old growth forests, specifically mast producing trees in order to survive (Dolan and Carter 1977). Therefore, I looked at variables dealing with tree size and maturity within Used and Available habitat. I used 8 habitat variables related to tree size, basal area, and tree density, and the relative abundance of each within Used and Available locations (Table 3). Because of the varying sample sizes I was unable to apply a DFA to these data. Instead I applied individual Mann-Whitney U tests to provide insights. These data were all non-significant for determining the habitat selection of southern flying squirrel in my study.

*Tree Species* – There were 25 tree species identified in my survey (Appendix 2). I identified mainly hardwoods with the exception of one conifer species (the eastern red cedar, *Juniperus virginiana*). The most common species in Used locations was the mockernut hickory making up 9.6% of trees measured. In Available locations rock elm was the most common. Both shagbark and bitternut hickory were more common in Used locations than in Available. Conversely, black walnut was more common in Available locations.

**Statistical Analysis**

*Space-use analysis*. The Shapiro-Wilks normality test indicated that for home ranges and core areas males and females (dependent variables) were distributed jointly as multivariate normal ($\alpha = 0.05$; Respectively: $W = 0.93$, $P$-value = 0.48; $W = 0.94$, $P$-value = 0.63). Therefore, I proceeded with student t-tests. However, Shapiro-Wilk for Minimum Convex Polygon indicated that dependent variables were not distributed normally ($W = 0.80$, P-value = 0.02). However, a Mann-Whitney U test of MCP areas between males and females was significant. This indicated that there was a significant difference ($W = 27$, P-value = 0.045) between males and females. Student paired t-tests also were significant for home ranges ($t(9) = -3.57$, $p = <0.01$) and core areas ($t(10.42) = -2.86$, $p=0.01$).

For all space use determinations (MCP, home range, and core areas) males occupied more space than females. That is, male occupied areas were larger in all space use determinations. Male space use was also more variable than female space use (Fig. 9 and 10).

*Home range overlap* - The ANOVA for range overlap was non-significant (F = 3.37, df = 2, p = 0.73). There were no differences between female-female, male-female, and male-male area overlaps (Table 4.). That is, variances were not statistically significant among groups.

*Microhabitat Analysis* – Canopy cover was distributed non-normally and I was unsuccessful at transforming the data. Therefore, I applied a Mann-Whitney U test to Canopy. Results were non-significant (W = 1035, p-value = 0.2217) between Used and Available locations (Table 5.).

Much of the data from the Daubenmire frame was not normally distributed. This is likely due to the fact that some of the data contained few positive results, including presence of grass, rocks, fungi, nuts, and wood (These were always entered as values of 0 if not present). Because the abundance of these variables were so low in both Used and Available sites it is unlikely that these data were significant to determine presence of southern flying squirrel. Therefore, these data were removed from the analyses.

*Structural Habitat Characteristics* – A discriminant function analysis was used to describe habitat characteristics (Fig 11), which were distributed normally (Table 6). To categorize general habitat characteristics I used distance-to-nearest-neighbor (DST), tree height (HGT), diameter at breast height (DBH), forb cover (FRB), litter depth (LIT), soil cover (SOL), and leaf cover (LEF). Diameter-at-breast-height and tree height were correlated linearly. However, because both of these variables likely are used by southern flying squirrel for habitat selection I included both data in the analysis. Some data were transformed to meet assumptions of normality (LIT, SOL, and LEF).

The sites had an unequal chance of membership (Used = 44%, Available = 55%). The first linear discriminant function was site = 2.741(*distance-to-nearest-tree*) + forb (*0.348*) + 0.156 (*DBH*) + 0.055(*Height*) – 3.746(*Soil Cover*) – 3.360(*Leaf Cover*) with 64% explained variance. The *height* variable had a lower mean for Used (12.698) treatments than Available (14.087). Means were higher for *forb, distance, DBH* in the Available (2.692, 0.623, 1.317 respectively) habitat than for Used (2.378, 0.538, 1.254) as well. For *soil cover* and *leaf cover* means were higher for Used (0.397, 0.504) habitat than for Available (0.372, 0.456). There was a classification accuracy of 65.9% for the two independent variables, which was statically significant ($\chi^2$ = 8.394, df = 1, p-value = 0.003). The classification between the two types of sites was verified based on the data collected.

*Tree Size* – For the 8 classes of tree size tested there were very different sample sizes. Therefore, I applied individual Mann-Whitney U tests to each variable. Treating data this way can inflate type I error, however, all tests were non-significant between Used and Available sites (Table 3).

*Tree Species.* The NMDS did not indicate specific trend in the species present between the two sites (Fig 12). The test did have a low stress (0.3), suggesting that the multiple dimensions do a good job of representing the data. However, looking at overall percentages (Table 5) it appeared that hickory (*Carya* spp) species were more common in Used habitats.

## DISCUSSION

I hypothesized that males and females would occupy different home ranges in terms of area. Home range areas were larger and more variable for males than for females in my study. Other telemetry studies on southern flying squirrels have noted similar differences in home range size (Sonenshine 1981; Bendel and Gates 1987; Fridell and Litvaitis 1999). However, many studies did not find a significant difference between genders and space use, most notably in areas of contiguous forest habitat (Bendel and Gates 1987; Holloway and Malcom 2007).

Other studies also have shown that females were more likely to overlap with male flying squirrels, which could be an indication of a promiscuous social system (Laves and Loeb 2006). However, my results were not significant for gender overlap. This does not mean southern flying squirrel are not promiscuous in this system. Probably, home ranges were more spread out in the available habitat, due to fragmentation of the forest, than in other studies based on resource availability. Also, sample size might have played a role in determining home range overlap. There were fewer males with overlapping home ranges than male-female overlap or female-female overlap in my study. This could have skewed results that were otherwise significant. Males could have larger home ranges as they appear to use more remote food resources (Taulman and Smith 2003). This could allow females to forage nearer nesting sites with reduced competition. Maturing young squirrels might benefit from their mother concentrating activities around local nesting and foraging sites (Taulman and Smith 2003).

Along with home range size, core area shapes also indicated much variation within my study. This could reflect the fragmented nature of old-growth hardwood forests in northeastern Iowa. Apparently, the southern flying squirrel in northeastern Iowa had specific spatial needs, likely which were due to the fragmented nature of this ecosystem. Several males had very large home ranges and core areas, and associated with larger forest tract size within the park (Fig. 7). This could be due to males moving to use remote food resources, as mentioned above. Some males were observed readily shifting home ranges in my study. Male signals were more likely to be lost than females as well as occupy greater spatial areas. Possibly, individuals are adjusting home ranges based on habitat disturbances or available mast selection (Taulman et al. 1998).

Males and females likely occupy very different home ranges due to resource needs and availability. These needs likely change throughout the year. In the summer females are thought to be restricted to a localized area when suckling young (Linzey and Linzey 1979). Most females in my study were either pregnant or at some state of lactation (pre, present, or post). This could explain why female focused on much smaller core areas. Probably, pregnant females captured in my study shifted their home range characteristics upon parturition to rear the young (Ransome and Sullivan 1997).

I was only able to capture females on the Wolter Property in my study. The property is approximately 80 ha in size; less than 10 ha larger than the largest male home range. Possibly, females were only found in this area due to the transient nature of male behavior. This area was not trapped until later in the season when females likely already had a litter of young.

I hypothesized that southern flying squirrel would respond to specific habitat variables, particularly forest structure, tree species, and tree size. While southern flying squirrel did not respond to a number of habitat variables that I had expected, it does seem that they responded to forest structure. For instance, tree species and tree size (DBH) were both had a negative influence in explaining the presence of southern flying squirrel. This suggested that southern flying squirrel might not select tree species as suggested by much of the literature (Dolan and Carter 1977; Bendel and Gates 1987; Taulman and Smith 2003). Many sources suggest that oak-hickory associations are associated positively with the presence of southern flying squirrel (Dolan and Carter 1977; Taulman and Smith 2003). It did seem that the presence of hickory (*Carya* spp) was possibly more likely to explain where southern flying squirrel was found in my study, however this was not statistically significant. This could be partly due to the time of year sampled. Hickory and oak produce nuts and acorns at different times of the year.

Possibly, southern flying squirrel adjusted its home range in my study to take advantage of mast production by different tree species at different times of the year (Kozlowski 1992). Apparently, *Carya* species were more prevalent in southern flying squirrel habitat. Oaks produce acorns later in the year (Goodrum et al. 1971), while some hickories produced early crops during the sampling period of my study.

Probably, southern flying squirrel responded most readily to distance between trees and amount of understory cover. Distance between trees was significantly shorter in Used habitat than in Available. This suggested that tree density could be significant for successful glides. Litter depth was higher in Used habitat than Available. Forb cover was lower in Used habitat. I think it is unlikely that southern flying squirrel responded directly to these variables. Rather, it is more likely that fewer forbs are associated with a more open understory, which is conducive to locomotion needs of the species. Greater litter depth could suggest the same, or could be more conducive to finding edible fungi, which make up a portion of their diet (Dolan and Carter 1977). Average tree height was shorter in Used habitat, and was also significant in explaining presence of southern flying squirrel.

Southern flying squirrel did not respond to specific categories of tree size or tree species in my study. These results could be partially due to sample size bias with regards to tree size. I did not have equal sample effort for all categories of tree size. However, other studies have shown that overall habitat structure is more critical to habitat selection than specific species, which supported my data (Bendel and Gates 1987; Sonenshine and Levy 1981).

Home range characteristics in my study varied considerably from many other studies. Measurements for 95% Minimum Convex Polygons (MCP), Home Ranges (95% Kernel estimations), and Core Use Areas (50% Kernel estimations) where all larger than those found in other studies (Holloway and Malcolm 2007; Bendel and Gates 1987; Taulman and Smith 2003; Stolberger 1940).

Possibly, population dynamics played a large role in driving the spatial use characteristics of the individuals in my study. When population levels are low males will occupy much larger home ranges and territories (Laves and Loeb 2006). This is thought to be because there is more competition for resources, most notably potential mates. This trend could be indicative of small or declining populations in my area. The next largest home ranges for southern flying squirrel reported in the literature was done on a managed timber woodlot in Arkansas (Taulman and Smith 2003). The southern flying squirrel habitat in their study was fragmented greatly by areas that were clear cut for logging. This supports the idea that fragmentation does played a large role in determining home range and habitat selection for southern flying squirrel in my study. Possibly, fragmentation is driving home range size in Arkansas and in northeastern Iowa.

Small population size also could be a result of fragmentation in northeastern Iowa. Although southern flying squirrel was highly vagile, it likely was restricted in its movement in areas with some tree cover in my study. This could be driving population dynamics and gene flow in the northeastern Iowa.

An understanding of the space-use and microhabitat requirements for rare species, specifically peripheral populations, is critical for long-term conservation of the species (Sonenshine 1981; Lavers et al. 2006). This is especially true for species within fragmented habitats such as southern flying squirrel in northeastern Iowa. Dispersal is necessary for metapopulation survival in fragmented landscapes in which remnant areas might no longer be able to sustain wildlife populations (Noss 1983). The MoSRA is connected to other forest patches, specifically in the southwestern portion of the park. However, the mosaic of forests in northeastern Iowa is interspersed with cropland and it is likely that the populations of southern flying squirrel that were left in the area operate as metapopulations regionally.

The results of my study suggested that southern flying squirrel were not reliant on any specific forest type. Maybe, a heterogeneous mix of tree species is needed to sustain populations throughout the year. Some squirrels undergo rapid home range shifts throughout the year in order to use all available resources within their habitat (Fridell and

Litvaitis 1991). This could be why some males had extremely large home ranges in my study area. My results suggested that the southern flying squirrel responded to habitat structure, such as understory cover (forb and litter depth), distance-to-nearest-tree, and tree height. In my study southern flying squirrel was more likely to be found in areas with less forb cover, higher litter depth, higher tree density (trees closer together), and shorter tree height. It is unlikely that forb and litter depth were directly involved in habitat selection by southern flying squirrel. Rather, it probably was associated with a more open understory, which allowed successful glides. These variables also could change throughout the year, thus southern flying squirrel could respond accordingly. Both northern flying squirrel and red squirrel (*Tamiasciurus hudsonicus*) populations might be limited by food availability in old growth and second growth forests of British Colombia (Ransome and Sullivan 1997). This was similar to the vegetation structures I saw in northeastern Iowa.

If management decisions do have to be made regarding this species within northeastern Iowa my findings should be taken into account. Management plans at the MoSRA are likely already conducive to sustaining southern flying squirrel populations (Legg 1981). Successional mast producing trees likely were needed throughout the year in order to maintain southern flying squirrel populations. Probably, larger stands of old-growth and secondary growth forests were needed for maintaining populations in northeastern Iowa. Therefore, oak-hickory associations should be maintained within the park.

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TABLES

**Table 1.** -- Home range size of the southern flying squirrel (*Glaucomys volans*) in my study in northeastern Iowa as compared to literature values. Taulman and Smith (2003) represent the home range sizes for males and females in a fragmented habitat. These data come from a forest in Arkansas that is actively logged for timber. Values from Holloway and Malcolm (2007) represent more average home range sizes found in large tracts of undisturbed forest. This study did not show a significantly different between home range sizes of males and females. My data shows large home ranges and variability for both males and females when compared with literature values.

| **Average Home Range Size (Ha)** | **Male (Mean ± S.E)** | **Female (Mean ± S.E)** |
|---|---|---|
| Current Data | 45.87 ± 25.83 | 16.60 ± 9.55 |
| Arkansas with timber harvest (Taulman and Smith 2003) | 16.03 ± 4.36 | 5.9 ± 0.74 |
| Undisturbed habitat (Holloway and Malcolm 2007) | 5.25 ± 2.14 | 5.02 ± 0.87 |

**Table 2.** – Results of percentage coverage data calculated from Daubenmire frames in relation to quarters of the plot area for habitat of southern flying squirrel (*Glaucomys volans*) in northeastern Iowa. These data were averaged over all habitats measured (Used and Available). Percent coverage was calculated in relation to quarters of the plot area i. e., whether the coverage is between 0-5, 5-25, 25-50, 50-75, or 75-95, or 95-100 percent (Daubenmire 1959). These data were averaged over all habitats measured (Used and Available). Results from each class were averaged across the entire study to give the below values. Those data marked with * were those measured most commonly between both habitats.

| **Cover Class** | **Percent Value** (Mean ± S.D) |
|---|---|
| ***Forb** | **30.84 ± 58.46** |
| ***Leaf** | **28.24 ± 29.29** |
| Grass | 2.42 ± 10.82 |
| ***Soil** | **14.67 ± 21.84** |
| Rock | 1.35 ± 8.79 |
| Fungus | 0.08 ± 0.44 |
| Nuts | 0.48 ± 1.39 |
| Wood | 4.60 ± 8.66 |

**Table 3.** -- Results of Mann-Whitney U tests for tree size variables (Mean ± SE) in Used and Available habitat for southern flying (*Glaucomys volans*) in northeastern Iowa. Three categories were selected to determine if age and maturity of trees influenced the habitat selection of southern flying squirrel. Variables were Mast trees (trees that produce nuts) <25cm DBH (Mast), Mast trees >25cm DBH (Mast >25), all other hardwood trees <25cm DBH (Hardwood), hardwood trees > 25cm DBH (Hardwood >25cm DBH), Maple trees <25cm DBH (Maple), Maple trees >25cm DBH (Maple >25), Deadstands <25cm DBH (Deadstand), and Deadstands >25cm DBH. All tests were non-significant (NS) Between Used and Available locations.

| Habitat Variables | Used (n = 43) | Available (n = 53) | P-value |
|---|---|---|---|
| Mast | 11.31 ± 5.4 | 43.78 ± 19.38 | NS |
| Mast > 25 | 44.26 ± 5.8 | 14.69 ± 5.59 | NS |
| Hardwood | 11.92 ± 5.82 | 12.17 ± 5.25 | NS |
| Hardwood > 25 | 41.18 ± 12.45 | 47.37 ± 28.53 | NS |
| Maple | 14.12 ± 7.3 | 11.52 ± 5.16 | NS |
| Maple > 25 | 32.15 ± 8.01 | 60.09 ± 41.39 | NS |
| Deadstand | 11.18 ± 5.36 | 11.19 ± 5.66 | NS |
| Deadstand > 25 | 38.72 ± 9.04 | 44.08 ± 16.17 | NS |

**Table 4.** -- Average percent home range overlap between genders and minimum convex polygon home range determinations as well as Analysis of Variance (ANOVA) results for southern flying squirrel (*Glaucomys volans*) in northeastern Iowa. The one way ANOVA was non-significant for differences on central tendencies ($\alpha = 0.05$). This suggests that males and females do not choose to overlap more or less with different genders. However, This could be due to sample size bias as there are not as many male home ranges which overlap with other individuals and thus, where not included in the analysis. Anecdotally, it appears that males overlap less (44%) with other males that do females with the same gender (62%).

| | Average % Overlap (ha) | n | df | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Male-Male | 44 | 6 | | | | |
| Female-Male | 53 | 16 | | | | |
| Female-Female | 62 | 7 | | | | |
| ANOVA Results | | | 2 | 0.32 | 0.73 | 3.69 |

**Table 5.** -- Mann-Whitney U tests for central tendency differences between Used and Available sites for southern flying squirrel (*Glaucomys volans*) in northeastern Iowa. For structural habitat characteristics that were not normally distributed I applied Mann-Whitney U tests individually to test for central tendency differences between Used and Available sites. Results were all non-significant between habitats.

| Habitat Variables | Used (n = 43) | Available (n = 53) | *P*-value |
|---|---|---|---|
| Density (trees/Ha) | 247.18 ± 203.2 | 336.76 ± 340.79 | NS |
| DBH | 19.51 ± 7.7 | 22.24 ± 11.78 | NS |
| BA($m^2$) | 0.035 ± 0.03 | 0.05 ± 0.06 | NS |

**Table 6.** -- Discriminate Function Analysis (DFA) for Used and Available locations for southern flying squirrel (*Glaucomys volans*). The DFA showed a distinct separation between Used and Available locations that was statistically significant. Subsequent t-test results for individual parameters for the variables included in the DFA are shown here ($\alpha = 0.05$). All variables were included in the analysis. It appears that distant-to-nearest-tree, tree height, forb cover, and litter depth were more significant in explaining the presence of southern flying squirrel (* denotes significant P-values).

| Variable Set | Used | Available | P-value |
|---|---|---|---|
| Distance to nearest tree | 3.74 ± 1.58 | 4.57 ± 2.11 | 0.013* |
| Tree Height | 12.70 ± 3.35 | 14.09 ± 4.14 | 0.047* |
| DBH | 19.49 ± 7.82 | 23.18 ± 12.02 | 0.08 |
| Forb Cover | 2.38 ± 0.87 | 2.69 ± 0.79 | 0.04* |
| Litter Depth (cm) | 2.7 ± 1.61 | 1.91 ± 1.62 | 0.02* |
| Soil Cover | 1.65 ± 0.99 | 1.52 ± 0.91 | 0.16 |
| Leaf Cover | 2.45 ± 1.27 | 2.11 ± 1.2 | 0.12 |

**Fig 1.** Map of both historical and recent land cover of Iowa. Historical and recent land cover of Iowa. The state was once dominantly tallgrass prairie and lowland forests. The forests were found most commonly in riparian areas in the eastern portion of the state. These are likely where populations of southern flying squirrels were able to subsist. Modern land forms of Iowa shows the state largely has been converted to crops and grazing land. Forests have been isolated mainly to riparian areas. Northeastern Iowa still has some sufficiently sized forests to support southern flying squirrel populations (after Little and Harr 2005).

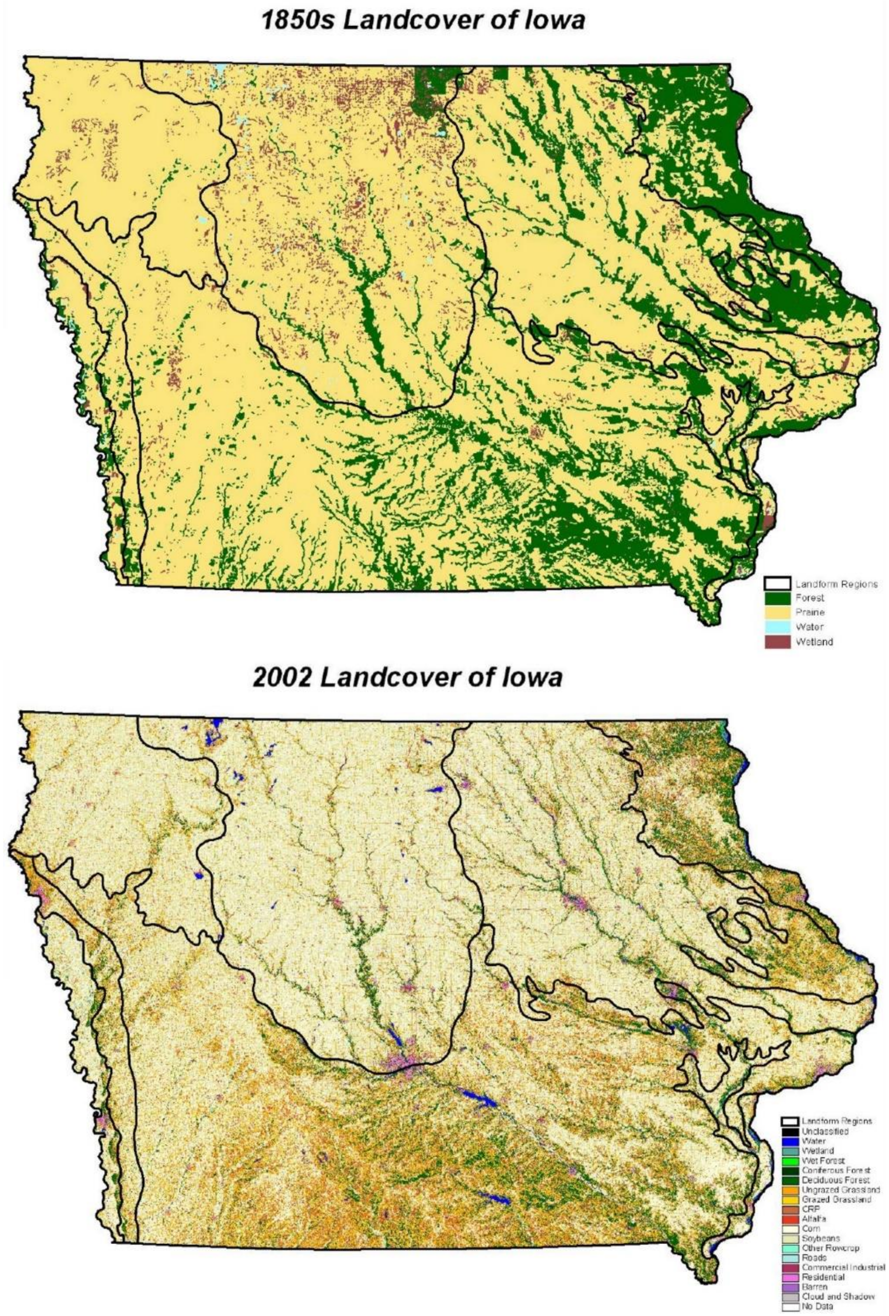


**Fig 2.** Species distribution of the southern flying squirrel (*Glaucomys volans*) (after Dolan and Carter 1977). Southern flying squirrel are closely associated with Eastern deciduous forests in the United States, Southern Canada, as well as parts of Mexico and Central America (Dolan and Carter 1977).

**Fig 3**. My study sites in northeastern Iowa; Clayton and Dubuque counties.

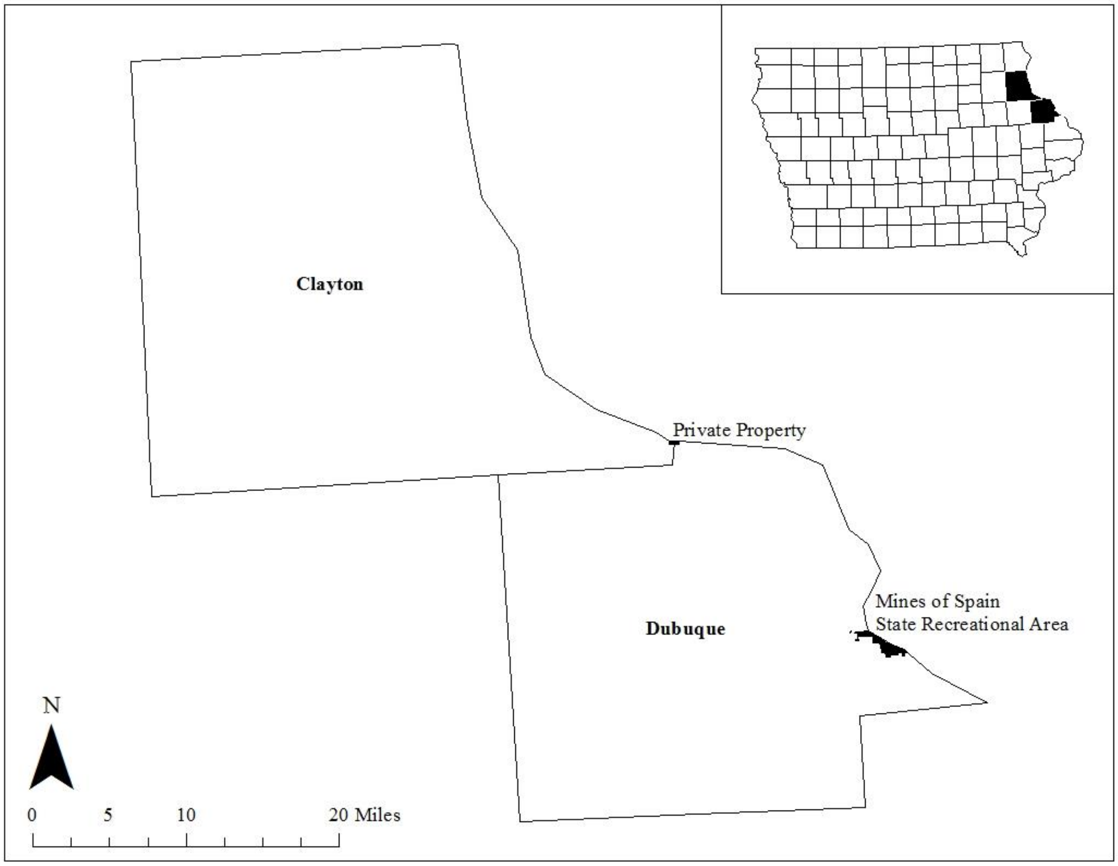


**Fig 4**. Land cover map of Mines of Spain State Recreational Area (A) and the Wolter property (B) in northeastern Iowa. These areas are both a mosaic of primary and secondary old growth hardwood forests, as well as tallgrass upland prairies. There is a high abundaces of oaks (*Quercus spp*) and hickories (*Carya spp*) thought to support southern flying squirrel populations. Other habitat includes maple-basswood, aspen-birch forests, and junipers (*Juniperus spp*.). The area of the MoSRA is approximately 527ha in area, while the Wolter property is approximately 80ha.

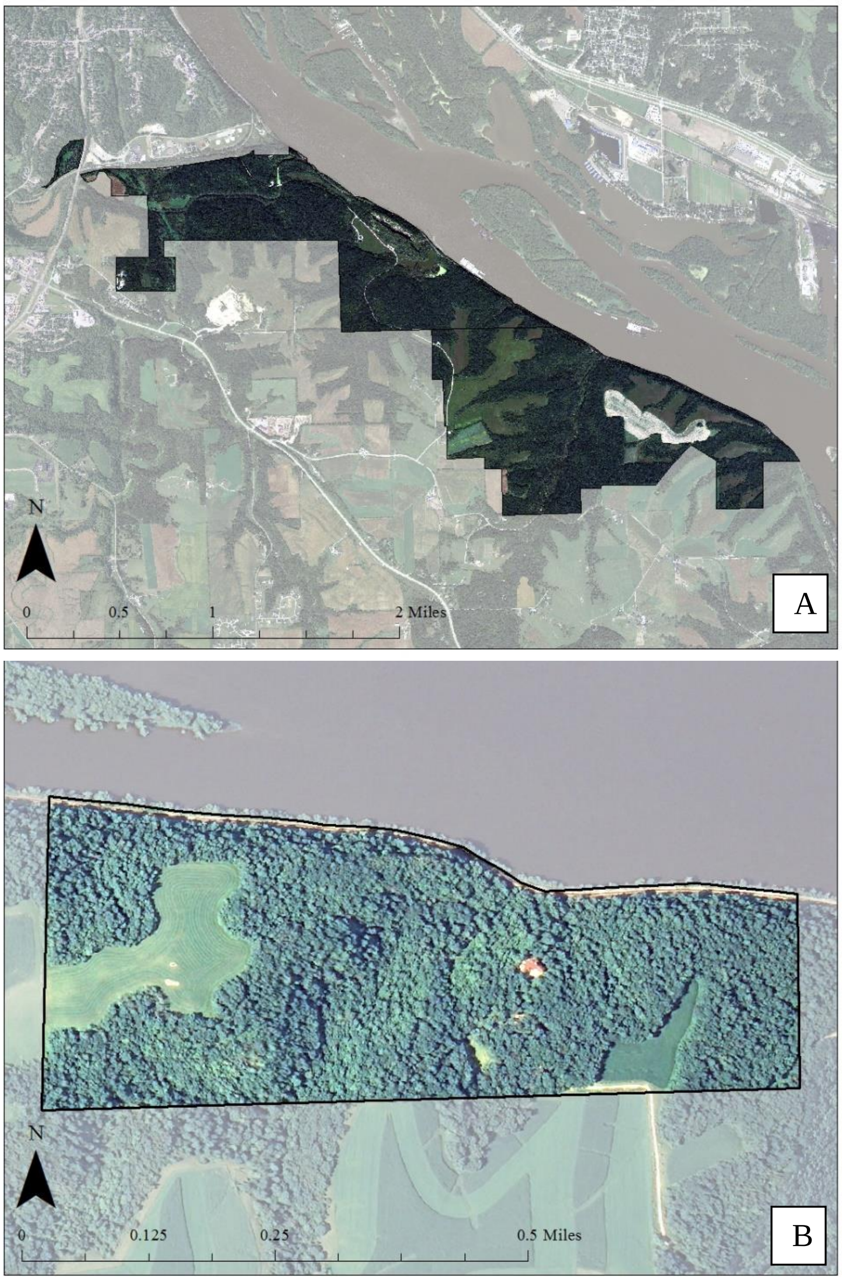


**Fig 5.** An example of quadrate design for vegetation sampling. The center tree was determined randomly using preset coordinates generated in ArcGIS or walking a random distance from another site. Quadrats (Q1-Q4) were placed by determining North with a compas and labeling clockwise.

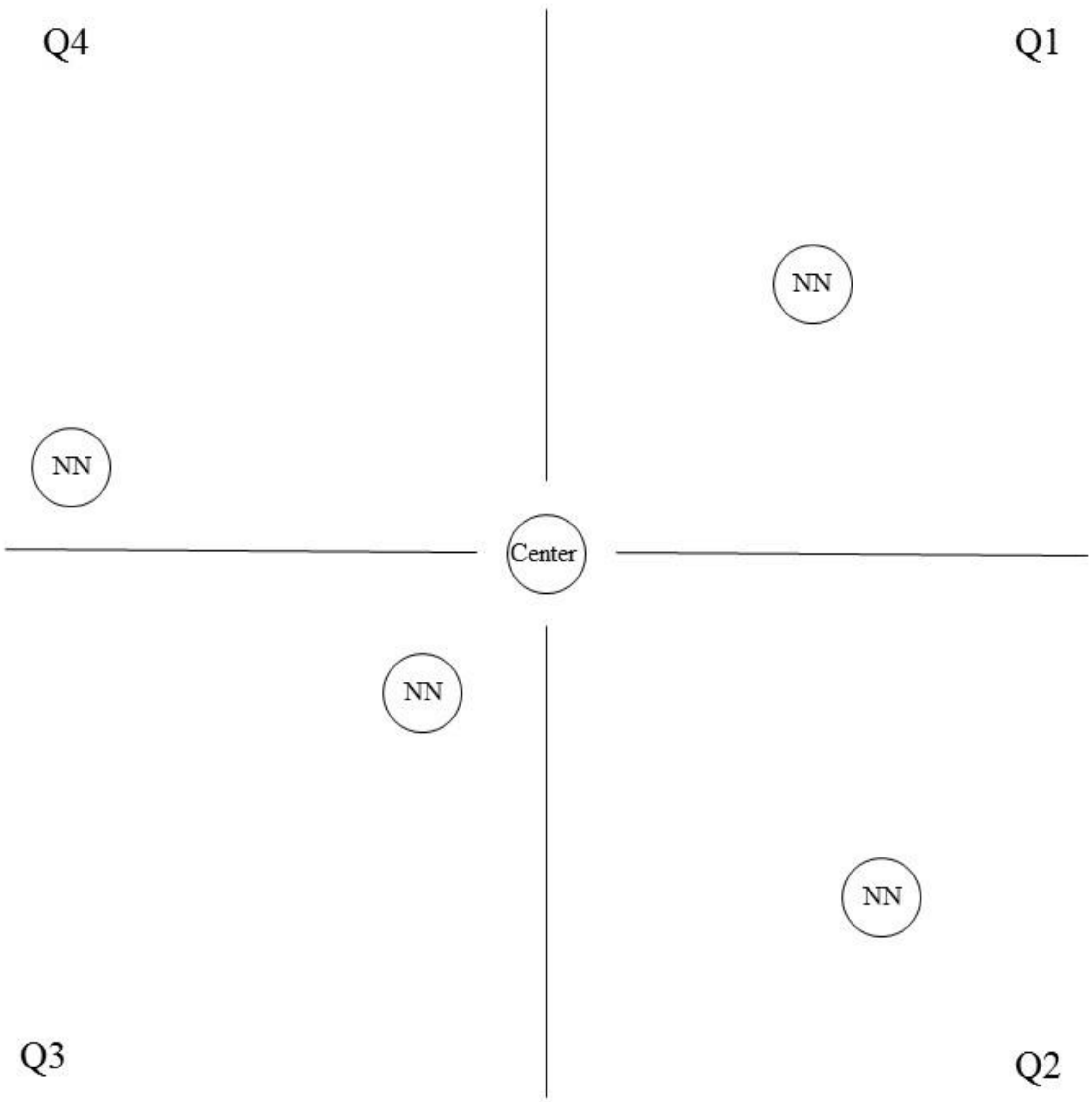


**Fig 6.** Kernel density estimation (KDE) built using the isopelth functions in Geospatial Modelling to calculate home ranges (95% fixed kernel estimates) and core areas (50% fixed kernel estimates) by use of the least squares cross validation (LSCV) technique. Outliers were removed prior to calculation. 95% kernels give an estimation of overall space use within the habitat. Core areas are where the individual was located most of the time during my data collection. It is likely that core areas are where the animal spends a majority of its time**.**

**Fig 7.** Example of a minimum convex polygon (MCP) determination. This home range determination was used to compare with literature values. This area is approximately 71 ha in size; one of the largest recorded in my study. The fragmented nature of this system; there is a high abundance of prairie upland within the range. This suggests that males must travel farther to find said resource needs.

**Fig 8.** Capture abundance of all small mammals across all study seasons in my study. Non-target species included the white-footed mouse (*Peromyscus leucopus*), eastern chipmunk (*Tamias striatus*), eastern grey squirrel (*Sciurus carolinensis*), and eastern fox squirrel (*Sciurus niger*). The white-footed mouse

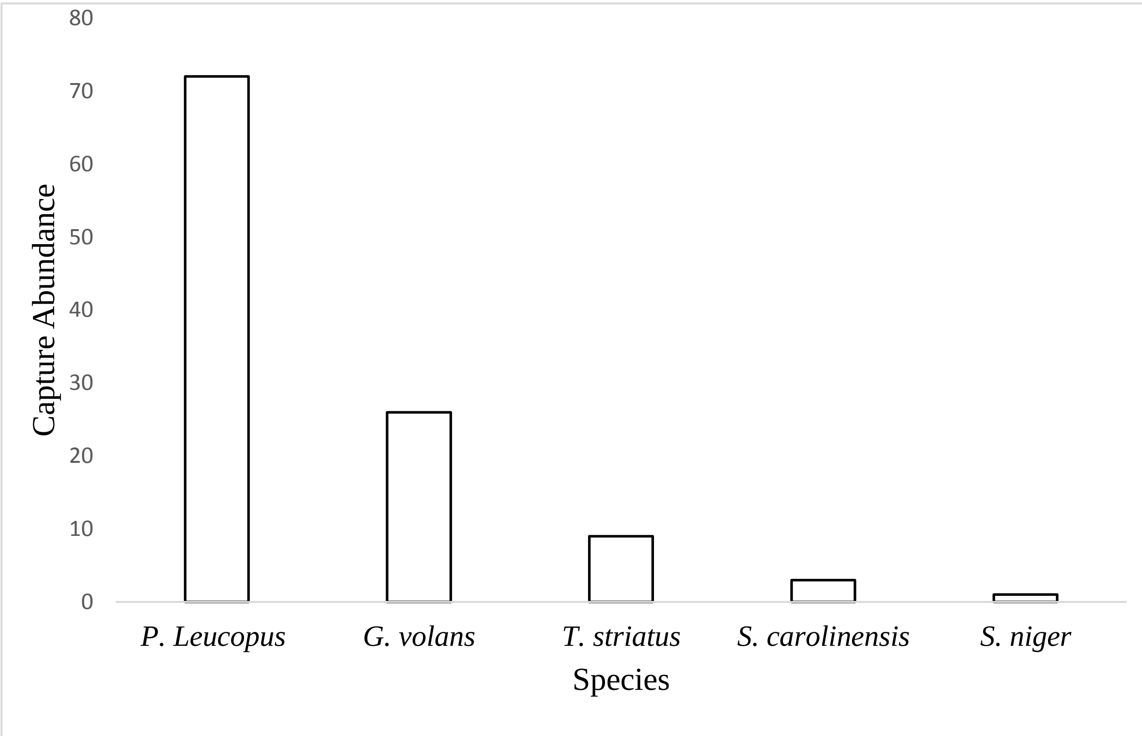


**Fig 9.** A box and whisker plot showing the variation between male (1) and female (2) home range size and (fixed kernel density esitmate 95%). Males are larger and show much more variation than females.

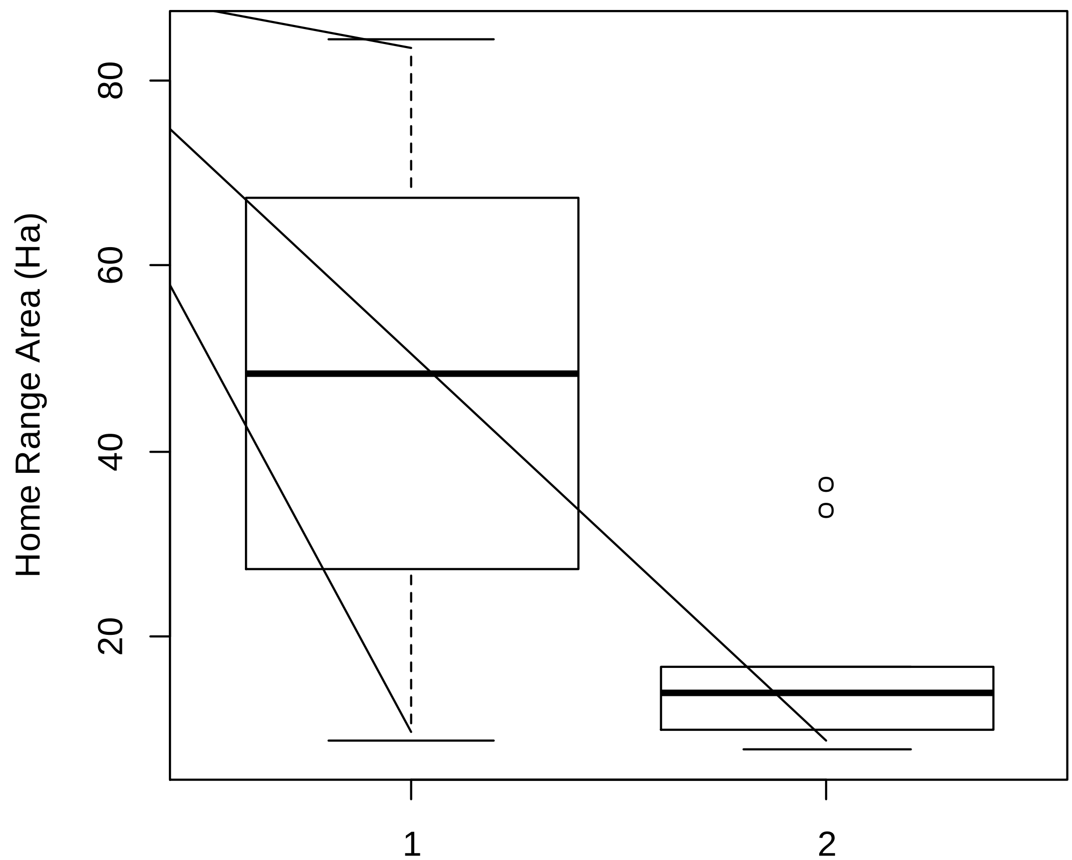


**Fig 10.** A box and whisker plot showing the variation between male (1) and female (2) core area size and distribution (kernel density estimate 50%). Home range size in males was larger on average and also show much more variation than females.

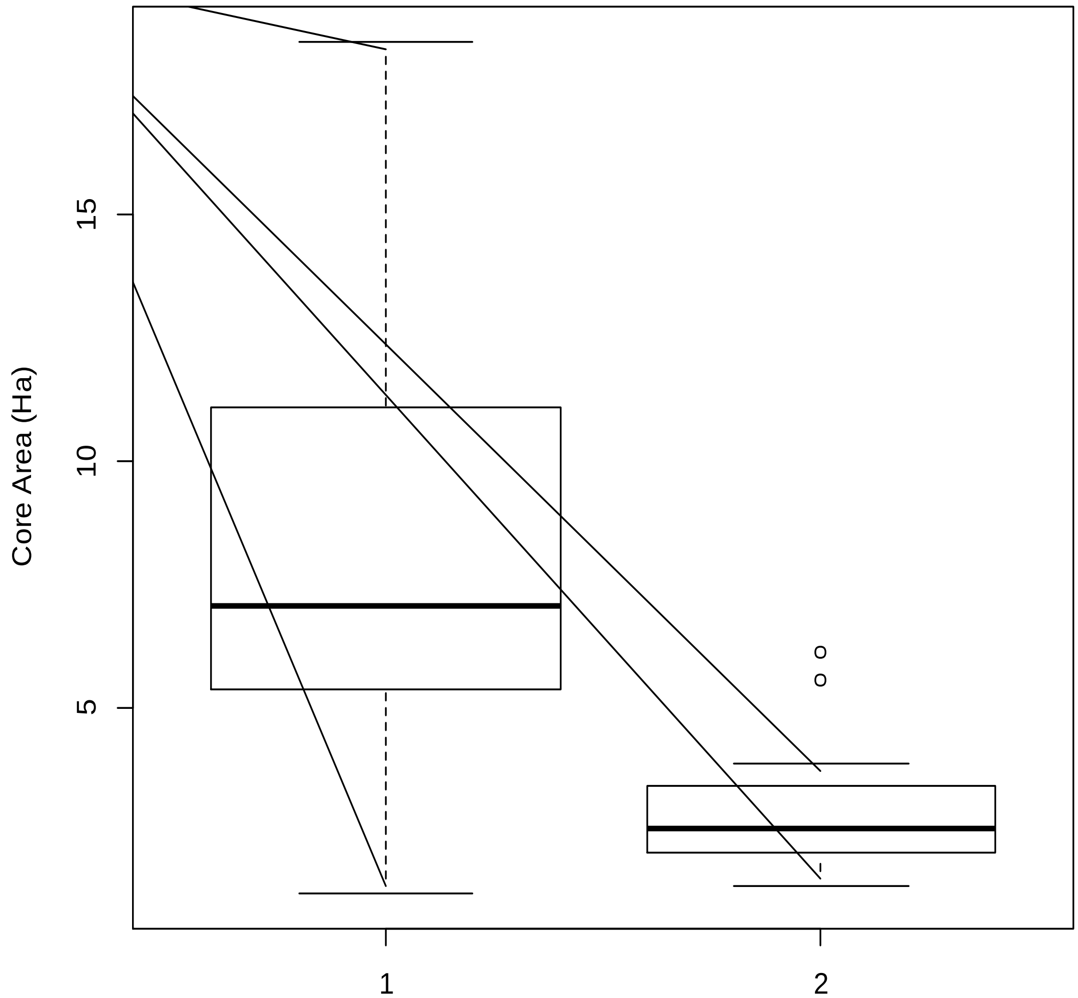


**Fig 11.** Discriminant function analysis results for habitat variables in Used (1) and Available (2) locations. The grouping in multivariate space suggests that southern flying squirrel do respond strongly to variables sampling. The axes represent linnear discriminant functions which measure the differences between groups measured based on imput values.

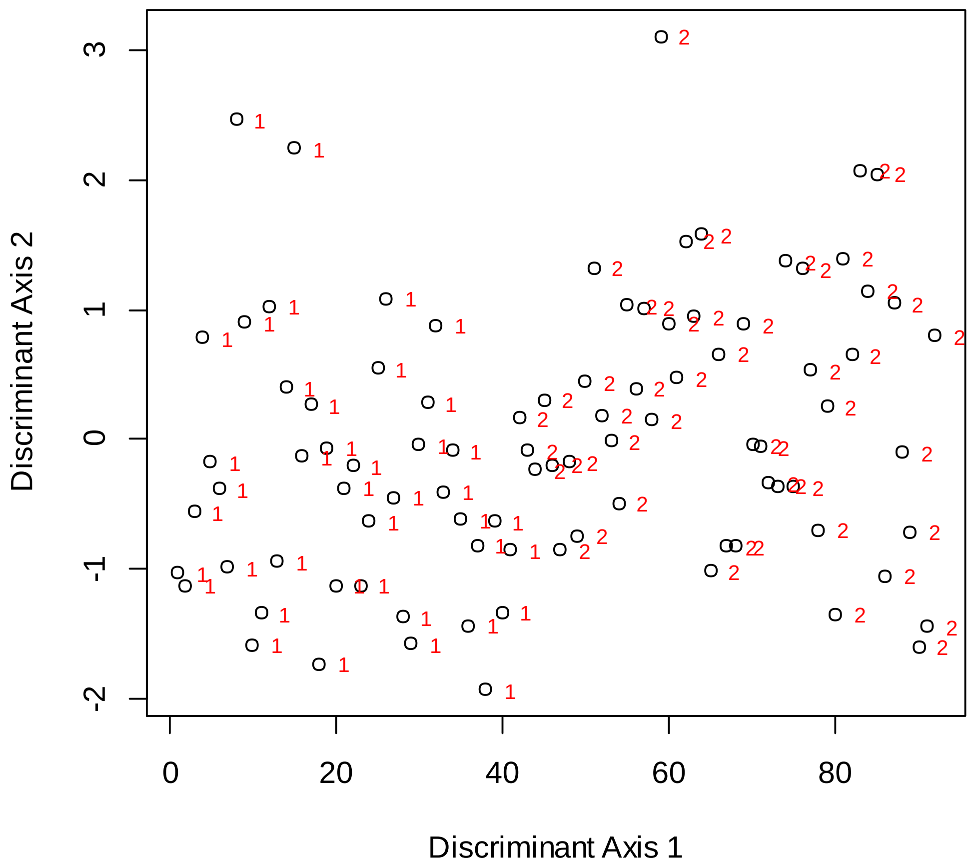
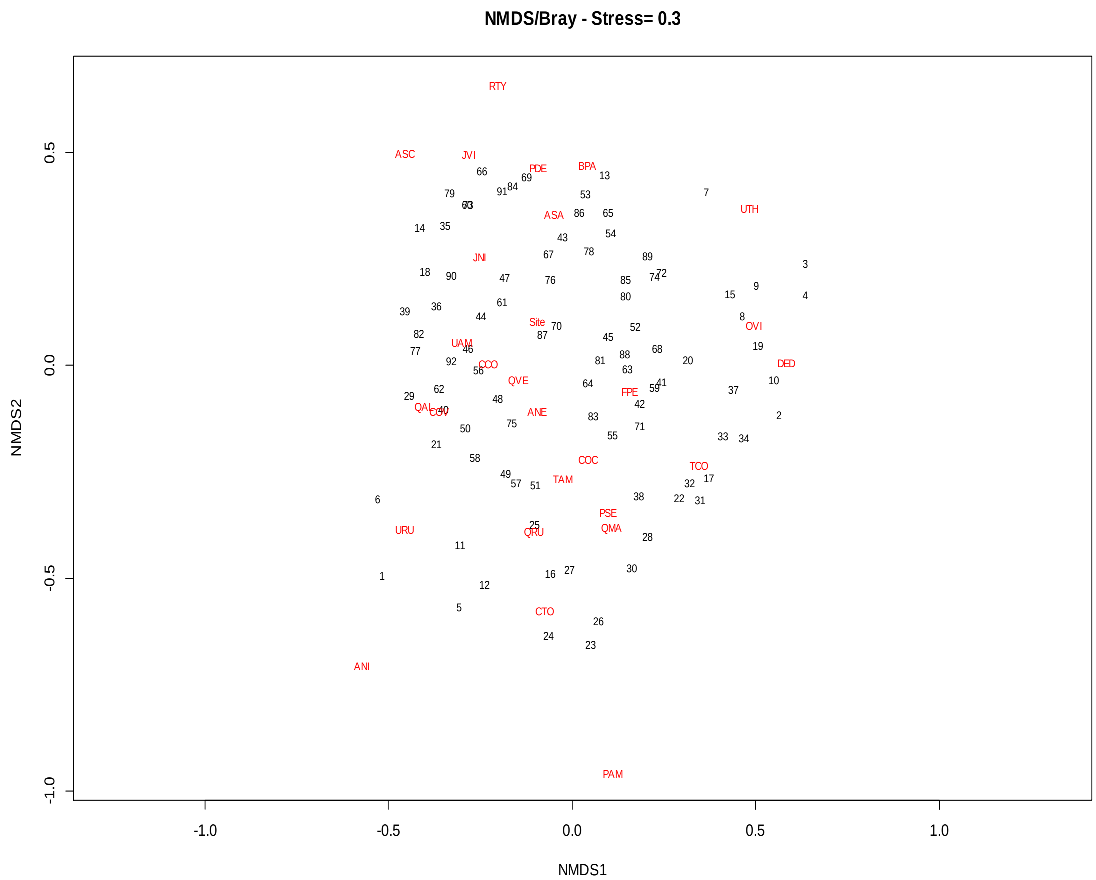


**Fig 12.** A Bray-Curtis plot from a Non-metric Multidimensional Scaling test for southern flying squirrel (*Glaucomys volans*) location and presence of tree species. Tree species are represented by three letter abbreviations. Numbers correspond to combined Used and Available locations. This test had relatively low stress, suggesting that data is displayed well in multidimensional space. However, there is no specific trend or distinct clusters. This suggests that southern flying squirrel do not respond to specific tree species as is often suggested in the literature.



APPENDICIES

**Appendix 1.** – Project approval by the Fort Hays State University Institutional Animal Care and Use Committee protocol number 14-0003.

FORT HAYS STATE UNIVERSITY
*Forward thinking. World ready.*

Institutional Animal Care and Use Committee

To: Dr. Elmer J. Finck

From: Dr. Y. Kobayashi, Institutional Animal Use and Care Committee YK

Re: Revised IACUC protocols # 14-0002 (Status of Franklin's ground squirrel in Kansas), 14-0003 (Space-use patterns of southern flying squirrel in northeastern Iowa) and 14-0006 (Survey of fringe mammals in western North Dakota)

Dr. Finck

I have completed reviewing the IACUC protocols (14-0002, 14-0003, and 14-0006). The protocol was accepted by the FHSU IACUC with decision of "modification required". Upon reviewing of the re-submitted protocol, I am satisfied with correction and modifications you have made on the protocol to sufficiently address questions and concerns raised by the committee. Therefore, I approve the study proposed in this protocol. Your protocols can be terminated prior to expiration date, upon your request, if studies are completed. Please refer to the IACUC protocol numbers assigned (14-0002, 14-0003, or 14-0006) when requested. The record of this decision also will be kept in the file and you will not receive any further notice regarding the decision on this protocol. Please feel free to contact me if you have any questions or concerns regarding the decision on your protocol.

Please note that the IACUC is required to review and approve, prior to initiation, proposed modifications to an approved protocol.

All approved research protocols must be updated annually, and must be reviewed by the IACUC every three years. All teaching activities using vertebrate animals are reviewed annually.

IACUC approved activities may be subject to further review and approval by university officials; however, those officials may not approve an activity involving the care and use of animals if it has not been approved by the IACUC.

The Principal Investigator is responsible for following federal guidelines and university policies and procedures regarding the care and use of animals.

cc: Leslie Paige (OSSP)

approved 2/7/2014 YK

**Appendix 2.** -- Tree species richness is 25 across all locations and habitat types. Comparison of relative importance of value (% of total forest composition) of dominant tree species of the forest canopy at the two different site treatments (Used and Available habitat locations) is shown below.

| Species | Common Name | Used | Available |
|---|---|---|---|
| *Acer negundo* | Boxelder | 3.75 | 4.45 |
| *Acer nigrum* | Black Maple | 0.00 | 0.34 |
| *Acer saccharum* | Sugar Maple | 7.92 | 10.27 |
| *Acer saccharinum* | Silver Maple | 1.67 | 2.74 |
| *Betula papyrifera* | Paper Birch | 0.42 | 0.34 |
| *Carya cordiformis* | Bitternut Hickory | 6.25 | 0.34 |
| *Carya tomentosa* | Mockernut Hickory | 9.58 | 2.74 |
| *Carya ovata* | Shagbark Hickory | 6.67 | 0.68 |
| *Celtis occidentalis* | Common Hackberry | 1.67 | 10.62 |
| Deadstand | | 7.08 | 9.59 |
| *Fraxinus pennsylvanica* | Green Ash | 1.25 | 0.00 |
| *Juglans nigra* | Black Walnut | 2.92 | 8.22 |
| *Juniperus virginiana* | Eastern Red cedar | 2.50 | 2.74 |
| *Ostrya virginiana* | American Hornbeam | 2.08 | 4.45 |
| *Populus deltoides* | Eastern Cottonwood | 0.83 | 1.71 |
| *Prunus americana* | American Plum | 0.00 | 0.34 |
| *Prunus serotina* | Black cherry | 5.83 | 1.37 |
| *Rhus typhina* | Sumac | 2.50 | 2.40 |

| | | | |
|---|---|---|---|
| *Tilia americana* | Basswood | 4.58 | 4.79 |
| *Tilia cordata* | Little Leaf Linden | 0.42 | 0.00 |
| *Ulmus Americana* | American Elm | 0.83 | 2.40 |
| *Ulmus rubra* | Slippery Elm | 8.33 | 5.82 |
| *Ulmus thomasii* | Rock Elm | 8.75 | 10.62 |
| *Quercus alba* | White Oak | 3.75 | 3.08 |
| *Quercus macrocarpa* | Burr Oak | 3.75 | 1.37 |
| *Quercus rubra* | Red Oak | 3.75 | 5.48 |
| *Quercus velutina* | Black Oak | 0.42 | 3.08 |