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HOME RANGE AND HABITAT CHARACTERISTICS OF THE ENDANGERED  
CAROLINA NORTHERN FLYING SQUIRREL (*Glaucomys sabrinus coloratus*) IN  
THE UNICOI MOUNTAINS OF NORTH CAROLINA

A Thesis

by

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Submitted to the Graduate School

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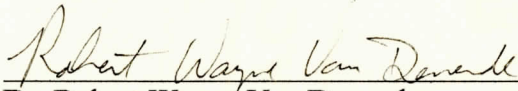
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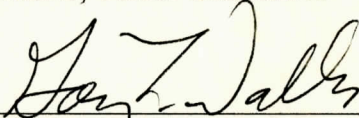
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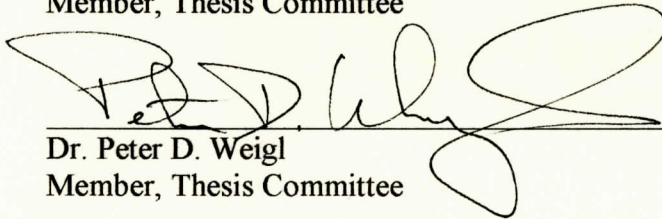
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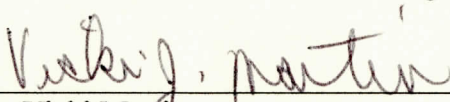
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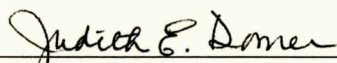
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## ABSTRACT

### HOME RANGE AND HABITAT CHARACTERISTICS OF THE ENDANGERED CAROLINA NORTHERN FLYING SQUIRREL (*Glaucomys sabrinus coloratus*) IN THE UNICOI MOUNTAINS OF NORTH CAROLINA. (August 2003)

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In 1989 and 1990, small populations of the endangered Carolina northern flying squirrel (*Glaucomys sabrinus coloratus*) were discovered in the Haw Knob area of the Unicoi Mountains of southwestern Graham County, North Carolina along the corridor of the newly built Cherohala Skyway. These populations are of particular conservation interest, as they inhabit atypical habitat consisting of northern hardwoods in pure stands or in mixed association with eastern hemlock (*Tsuga canadensis*). Moreover, opportunity to obtain critical ecological information for this endangered species is offered. Flying squirrels from these populations were studied from September 1994 – March 1996 using trapping and radiotelemetry. Twenty-five northern flying squirrels were captured at five sites along an 18.1 km section of the Skyway. Ten squirrels were radiocollared and monitored from 12 January 1995 to 23 February 1996. Overall and seasonal home ranges were estimated for seven flying squirrels from three different sites: two were radio-tracked in winter only, four in winter and summer, and one in spring. Overall home

ranges averaged 13.9 ha, winter home ranges averaged 12.5 ha, and summer home ranges averaged 8.3 ha. The seasonal home ranges did not differ significantly and there was no major seasonal adjustment to home ranges. Overall and seasonal home range estimates from this study did not differ from similar estimates for typical habitat at Roan Mountain NC-TN. Lack of seasonal differences in home range size and adjustment indicates flying squirrels did not respond to changes in resource availability, environment, or energetic needs. The lack of differences in home range sizes between this study and Roan Mountain suggests that resource availability is similar between the different locations.

For the four flying squirrels tracked in both summer and winter, habitat was sampled in randomly assigned plots within high-use and low-use areas of their home ranges. Habitat was also sampled in unoccupied habitat nearby. Twenty significant differences were found for 16 of 19 habitat variables tested across areas of use (high-use/low-use), seasons, sites, and sexes. Of the 20 differences, 17 were between seasons and sites and the remainder were between areas of use. One habitat difference was found between occupied and unoccupied areas. These results suggest the habitat features I examined were not the salient features required by northern flying squirrels in the Unicoi Mountains. General characteristics of the habitat demonstrate that conifers are not a necessary component of suitable habitat. In addition, high-elevation north facing slopes, cool moist conditions, prevalence of snags, scattered old-growth trees, and abundant coarse woody debris found in the Unicoi Mountains are shared with more typical sites throughout the central and southern Appalachians. Moreover, old-growth trees, prevalence of snags, abundant coarse woody debris, and high moisture are characteristics of old-growth forests shared with northern flying squirrel habitat in other parts.

## ACKNOWLEDGEMENTS

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I would like to graciously thank Dr. Peter Weigl for his guidance, sharing his flying squirrel expertise, his moral and professional support, friendship, and willingness to sit on my Thesis Committee as an adjunct member. I also would like to thank my field assistant David C. Battle for his assistance and willingness to become “nocturnal” while working odd hours away from his family. Additional field assistance from Steven Henderson, Tim Milling and Chris McGrath is greatly appreciated. A gracious thank you goes to my advisor and Committee Chair, Dr. Matthew Rowe, who shared his scientific expertise with me and provided guidance and moral support over the “many years” of my thesis preparation. I also would like to thank Drs. Wayne Van Devender and Gary Walker for their assistance as committee members and for their helpful instruction during the preparation of this thesis. Lastly, I would like to sincerely thank all of my family and friends for their support and encouragement over the last seven years; without them I wouldn’t have made it this far.

## DEDICATION

I dedicate this thesis to my family, especially my parents Charles and Faith who lovingly and willingly supported my passion to be a scientist and naturalist. I will always be grateful to them!

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## INTRODUCTION

### *Background*

The northern flying squirrel (*Glaucomys sabrinus*) is a small, strictly nocturnal mammal capable of gliding as a form of locomotion. The distribution of the northern flying squirrel generally mirrors that of the boreal spruce (*Picea* spp.), fir (*Abies* spp.), and northern hardwood forests across northern North America (Jackson 1961, Weigl 1968, Hall 1981, Linzey 1984, Wells-Gosling and Heaney 1984). Their primary range (main range) extends from the northern United States to northern Canada and stretches from eastern Canada to interior Alaska (Fig. 1). In the western U.S. the range of the northern flying squirrel continues southward through the Pacific Northwest and high elevations of the Sierra Nevada and Rocky Mountains, while in the eastern U.S. the range becomes disjunct and narrowly restricted to high elevations of the central and southern Appalachians.

There is ample evidence to suggest that the geographic distribution of the northern flying squirrel was molded by post-glacial changes in climate and habitat. The Holocene epoch (period from last glacial maximum to present) is generally considered a period of radical environmental change (Davis 1981). At the beginning of the Holocene, 18,000 years ago, boreal forests grew over much of the southern and south central United States (Davis 1981, Delcourt and Delcourt 1981, Delcourt and Delcourt 1984, White et al. 1993). Fossil remains extracted from caves and erosion deposits in the



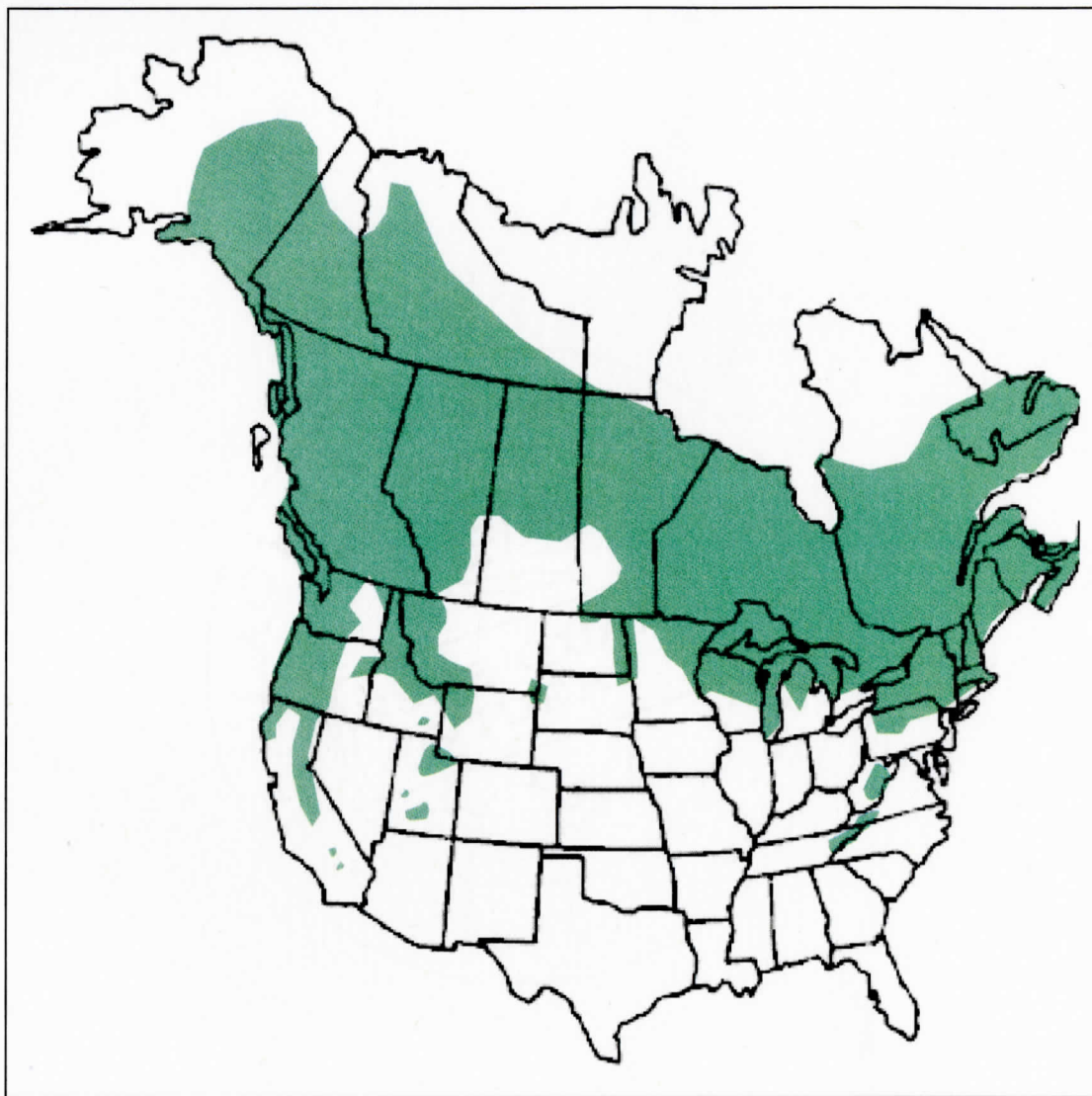


Fig. 1. Distribution of the northern flying squirrel, *Glaucomys sabrinus*, in North America. Map source: University of Calgary, Canada. Distribution adapted from Wells-Gosling and Heaney (1984)

eastern U.S. demonstrate that a variety of vertebrate species, including the northern flying squirrel, flourished in these extensive boreal forests. As the climate moderated, however, boreal forests migrated northward as did many of the vertebrate species. In addition, many species became extinct in the southeast (e.g., wolverine, *Gulo gulo*) as their populations moved northward with the boreal forests and as the same habitat became rare and isolated in the south (Brooks 1971, Kurtén and Anderson 1980). However, other, and usually smaller, species were able to utilize the small, remnant areas of the boreal forests left behind in the high elevations of the central and southern Appalachians. Northern flying squirrels moved both altitudinally and latitudinally with the boreal forest into the unique distribution we see today. This distributional pattern is shared by a number of other mammals, including the northern water shrew (*Sorex palustris punctulatus*), rock vole (*Microtus chrotorrhinus carolinensis*), least weasel (*Mustela nivalis allegheniensis*), smoky shrew (*Sorex fumeus*), long-tailed shrew (*Sorex dispar*), and star-nosed mole (*Condylura cristata*) (Brooks 1971, Guilday 1971, Handley 1971, Handley 1991).

Two recognized subspecies (Hall 1981) of northern flying squirrel occur in limited and discontinuous distributions in the central and southern Appalachian regions (Lee et al. 1982, Wells-Gosling and Heaney 1984, Linzey, 1984; United States Fish and Wildlife Service (USFWS) 1990, Weigl et al. 1999). The West Virginia northern flying squirrel (*G. s. fuscus*) occupies the moderate elevations of the Allegheny Plateau in the central Appalachians of central West Virginia and western Virginia. The Carolina northern flying squirrel (*G. s. coloratus*) occupies the high elevations of the southern Appalachians of southwestern Virginia, western North Carolina and eastern Tennessee

(Fig. 2). Within their respective distributions, *G. s. coloratus* and *G. s. fuscus* occur in small, discontinuous and isolated populations, which are tied closely to the remaining patches boreal forest habitat. Consequently, both subspecies are perceived as rare and vulnerable to natural and human-induced impacts including: habitat destruction and alteration; acid precipitation and other pollutants; global warming; and insect pests such as the balsam wooly adelgid (*Adelges piceae*) (USFWS 1990, Weigl et al. 1999). The vulnerability of both Appalachian subspecies and their habitat, compounded by the limited ecological knowledge of the species in general are reasons leading to their addition to the Endangered Species List in 1985 (USFWS 1990). Fewer than 30 specimens from only eight localities are known from prior to 1985 throughout the central and southern Appalachian regions (USFWS 1990). In addition, very little was known about either subspecies at the time of their listing outside the work of a few investigators (Weigl 1968, Weigl and Osgood 1974, Weigl 1978) and somewhat more information was available for the species in the Pacific Northwest and boreal regions of North America (Dice 1921, Dice 1938, Jackson 1961, Mowrey and Zasada, 1984, Wells-Gosling and Heaney 1984). A formal recovery plan for both Appalachian subspecies of northern flying squirrel includes a four-part strategy outlining steps for recovery and delisting: 1) determining actual distribution of the Appalachian northern flying squirrels in the central and southern Appalachians; 2) protecting areas known to support the species; 3) making a rigorous effort to obtain ecological information for both subspecies, particularly their habitat requirements, diet, and competition with the southern flying squirrel (*G. volans*); and 4) measuring/evaluating the response of



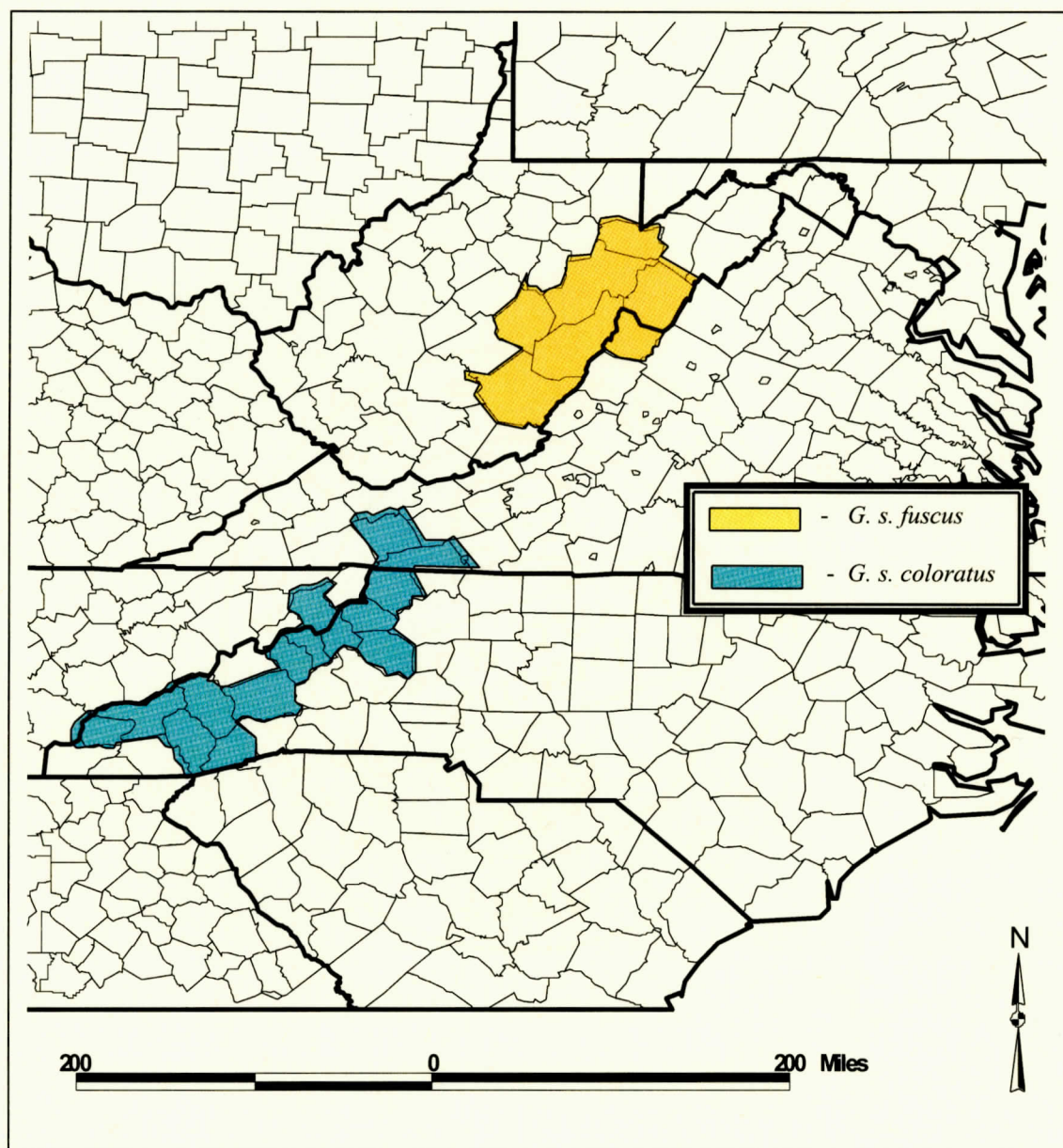


Fig. 2. Distribution of the Appalachian northern flying squirrels, *G. s. fuscus* and *G. s. coloratus*, in the central and southern Appalachians, respectively. Shaded areas are counties in which Appalachian northern flying squirrels are known to occur. Map generated using ArcView<sup>®</sup> (ESRI, Redlands, California, USA).

northern flying squirrels to various habitat modification/management actions (USFWS 1990).

### ***Habitat associations***

The northern flying squirrel inhabits a wide range of habitats throughout its range and is considered to be somewhat of a habitat generalist (Doyle 1990, Rosenberg and Anthony 1992). For example, some of the habitats northern flying squirrels utilize include: white spruce (*Picea glauca*) and paper birch (*Betula papyrifera*) forests in Alaska (Dice 1921); mixed white spruce (*Picea engelmannii* × *glauca*), subalpine fir (*Abies lasiocarpa*), lodgepole pine (*Pinus contorta*) and trembling aspen (*Populus tremuloides*) in old- and second-growth forests in British Columbia (Cotton and Parker 2000a, 2000b); and Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), fir (*Abies* spp.), and western red cedar (*Thuja plicata*) forests in the Pacific Northwest (Rosenberg 1990, Doyle 1990, Rosenberg and Anthony 1992, Witt 1992, Carey 1995, Waters and Zabel 1995, Carey et al. 1999). Around the Great Lakes, northern flying squirrels inhabit mesic forests dominated by mature coniferous and deciduous trees in mixed association (Jackson 1961). In Pennsylvania the species occupies mature northern hardwood forests mixed with eastern hemlock (*Tsuga canadensis*) (Weigl and Osgood 1974, Woleslagle 1994). Other known habitats include white cedar (*Thuja occidentalis*) swamps, jack pine (*Pinus banksiana*) forests, and pure northern hardwood forests (Wells-Gosling and Heaney 1984, Weigl et al. 2002).

To date, most research on the habitat requirements of northern flying squirrels is focused on the Pacific Northwest because northern flying squirrels are one of the primary prey items of the threatened northern spotted owl (*Strix occidentalis*)



(Rosenberg et al. 1994). In this region northern flying squirrels prefer coniferous forests, especially old growth forests dominated by old growth Douglas-fir and western hemlock; but, some squirrels also utilize second-growth forests and in managed forests (Rosenberg 1990, Rosenberg and Anthony 1992, Witt 1992, Carey 1995, Waters and Zabel 1995, Carey et al. 1999, Waters et al. 2000). In the Pacific Northwest several habitat characteristics associated with old-growth forests are consistently associated with abundance and activity (based on capture frequencies) of northern flying squirrels regardless of forest age. These characteristics include: large older trees and large snags in the overstory; a well-developed understory consisting of high shrub/sapling density and a prevalence of ericaceous shrub species (e.g., *Rhododendron macrophyllum* and *Vaccinium* spp.); abundant decomposing logs and stumps (coarse woody debris); a rich fern layer on the forest floor; and high levels of moisture (Rosenberg 1990, Rosenberg and Anthony 1992, Carey 1995, Waters and Zabel 1995, Carey et al. 1999).

Three correlates of old-growth forests and northern flying squirrel abundance — large trees (both live and dead), ericaceous shrub species, and coarse woody debris — are also correlated with abundance and diversity of epigeous (above ground) and hypogeous (below ground; often referred to as truffles) ectomycorrhizal fungi, which make up a significant portion of the northern flying squirrel diet (Trappe and Maser 1977, Maser et al. 1985, Maser et al. 1986, Luoma 1991, Witt 1992, Carey 1995, North et al. 1997, Zabel and Waters 1997, Carey et al. 1999, Currah et al. 2000). In western Oregon northern flying squirrels throughout the year consume both epigeous and hypogeous fungi, but summer diets are nearly 100% hypogeous fungi and lichens (Maser et al. 1985).

### *Appalachian northern flying squirrel ecology*

Despite the federally endangered status of the two Appalachian subspecies of the northern flying squirrel, our knowledge of their ecology is limited compared with flying squirrel studies from the Pacific Northwest. Most current information stems from only nine studies since the subspecies were added to the Endangered Species List. The studies are: an analysis of the habitat characteristics associated with both subspecies (Payne et al. 1989); a study of the habitat characteristics, home range size and activity patterns of *G. s. fuscus* (Urban 1988); a broad ecological study focused on distribution, population status, habitat characteristics, diet, home range size, and movements and activity patterns of *G. s. coloratus* (Weigl et al. 1999); an assessment of the impact of a roadway on the ecology of several small populations of *G. s. coloratus* (Weigl et al. 2002); three papers on the development and testing of computer models using a Geographical Information System (GIS) (Odom 1995, McCombs 1997, McGrath 1999); a dietary analysis of *G. s. fuscus* (Mitchell 2001); and an examination of truffles in *G. s. coloratus* habitat by Loeb et al. (2000).

High-elevation, mesic, north-facing forests dominated by a mixture of red spruce (*Picea rubens*), Fraser fir (*Abies fraseri*), and northern hardwoods characterize the typical habitat of Appalachian northern flying squirrels (Payne et al. 1989, Weigl et al. 1999). This habitat is found primarily in the ecotone formed at the junction of pure spruce and spruce -fir with pure hardwood forest types. Outside the Great Smoky Mountains National Park (GSMNP), the largest remaining expanse of Appalachian spruce-fir forest and the only virgin old growth Appalachian spruce-fir forest (Pyle 1984, Rheinhardt 1984), the ecotonal forest habitat is associated with small islands of

disturbed, second growth boreal forests. Typical habitat follows a distinct gradient of increasing elevation with decreasing latitude (White 1984, Payne et al. 1989, USFWS 1990). For example, northern flying squirrels are commonly found at elevations less than 800 m in northern Appalachian regions such as New England, New York and Pennsylvania; whereas they are typically found at elevations ranging from 1000-1350m in the central Appalachian region (USFWS 1990). In the southern Appalachians *G. s. coloratus* are generally found above 1540 m (although a few have been captured at lower elevations) (USFWS 1990, Weigl et al. 1999). In addition, size of habitat patches (islands) becomes smaller and the patches are increasingly fragmented and more isolated as one goes from north to south. The range of *G. s. fuscus* habitat is generally larger and more continuous than that of *G. s. coloratus* in the southern Appalachians (USFWS 1990, Weigl et al. 1999).

Some differences exist in the dominant tree species that characterize the typical habitat in each Appalachian region. In the central Appalachians the dominant coniferous species in *G. s. fuscus* habitat is red spruce, but spruce and Fraser fir co-dominate the coniferous component in *G. s. coloratus* habitat in the southern Appalachians (Payne et al. 1989, USFWS 1990, Weigl et al. 1999). Northern hardwoods found in typical central Appalachian habitat are predominantly yellow birch (*Betula lutea*) with various combinations of sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), black cherry (*Prunus serotina*), and northern red oak (*Quercus rubra*) sometimes mixed in (Urban 1988, Payne et al. 1989). Red spruce, yellow birch and red maple are the top three species of occurrence in ten different *G. s. fuscus* capture sites in the central Appalachians (Payne et al. 1989). Northern hardwoods associated with typical *G. s.*



*coloratus* habitat are richer in beech. Red spruce, beech, yellow birch, and Fraser fir have top importance ranking at 34 different capture sites in western North Carolina (Weigl et al. 1999). Additional overstory characteristics of habitats for both subspecies include a prevalence of snags and older trees. Payne et al. (1989) found snags in every plot they sampled from 10 central Appalachian and 3 southern Appalachian study sites. Similarly, Weigl et al. (1999) found snags were prevalent among 34 different southern Appalachian study sites, and noted that old growth trees, though not abundant, were almost always present.

The shrub/sapling and vegetative ground cover layers of typical Appalachian northern flying squirrel habitats vary in species composition and density and are not good indicators of suitable habitat or predictors of flying squirrel presence (Urban 1988, Payne et al. 1989, Weigl et al. 1999). However, fern abundance is positively correlated with high-use areas of home ranges for *G. s. fuscus* (Urban 1988). Across southern Appalachian study sites the shrub/sapling and vegetative ground cover layers varies in density and species composition (Weigl et al. 1999). In addition, large amounts of coarse woody debris are present.

Although there is much to be learned about the habitat requirements of the Appalachian northern flying squirrels, there also is a need to determine the extent of potential northern flying squirrel habitat throughout the central and southern Appalachians. Identifying and delineating the extent of potential habitat is critical for recovery efforts for both subspecies. *Glaucomys sabrinus coloratus* are known from nine locations in the southern Appalachians, while *G. s. fuscus* are known from six locations in the central Appalachians. However, suitable habitat seems to cover a larger

area of the central and southern Appalachians. There may be a large area of suitable habitat that is not yet identified or surveyed, which may harbor populations of flying squirrels (USFWS 1990, Weigl et al. 1999).

One step outlined in the recovery plan for identifying suitable habitat includes development of general indices based on vegetative and physical features of known flying squirrel habitats to identify other areas of suitable habitat. Classifying vegetation and landscapes using a Geographical Information System (GIS) makes it possible to develop models that can quickly identify areas of potential Appalachian northern flying squirrel habitat, and to predict the presence or absence of the species (Odom 1995, McCombs 1997). A field test of one of these GIS models (Odom 1995) is currently underway. McGrath (1999) suggests considerable refinement of the model will be needed to confidently delineate and predict potential habitat and additional flying squirrel populations.

An important aspect of the ecology of any animal is the way it occupies space in the environment. One measure of this characteristic, the home range of the animal, is roughly the way it occupies space in its environment over time (White and Garrott, 1990). Inherent in home range studies is the recognition that the size and placement of an animal's home range is a function of the abundance and availability of resources (Fridell and Litvaitis 1991, Phillips et al. 1998). Determining home range sizes for northern flying squirrels may provide additional insight into resources that limit this species. For example, in the Pacific Northwest home ranges of northern flying squirrels were studied to determine if home range sizes are influenced by the same characteristics



between old-growth and second-growth stands that might ultimately explain habitat selection patterns for spotted owls (*Strix occidentalis*) (Martin and Anthony 1999).

Despite the extensive research on northern flying squirrels in the Pacific Northwest, home range ecology is limited and comes from two studies. Witt (1992) reports an average home range area in western Oregon of 3.9 ha ( $\pm 0.2$  ha) using the inclusive boundary strip method and 3.7 ha ( $\pm 0.5$  ha) using the minimum convex polygon (MCP) method (Jennrich and Turner 1969). Northern flying squirrel home ranges in central Oregon average 4.9 ha ( $\pm 0.6$  ha) using the adaptive kernel method (Martin and Anthony 1999).

Other studies of northern flying squirrel home ranges come from British Columbia, New Brunswick, and the central and southern Appalachians. In British Columbia Cotton and Parker (2000a) report an average core nest area is 2.7 ha ( $\pm 0.6$  ha) using the MCP method, with males having larger ( $3.7 \pm 0.9$  ha) ranges than females ( $1.4 \pm 0.4$  ha). In addition, two studies cited by Cotton and Parker (2000a) cited two other studies that used the MCP method to estimate northern flying squirrel home ranges: 10.3 ha for all sexes in British Columbia (Mahon and Steventon (in litt.)) and 12.5 ha for males and 2.8 ha for females in New Brunswick (Gerrow 1996). In the two studies of Appalachian northern flying squirrels, home range sizes are 5.2 ha ( $\pm 1.1$  ha) for *G. s. fuscus* (Urban 1988) and 8.9 ha ( $\pm 2.2$  ha) for *G. s. coloratus* (Weigl et al. 1999). Larger home ranges are probably associated with poorer quality habitat. As suggested by Weigl et al. (1999) who found largest home ranges were for males in winter.

### *Northern flying squirrels in the Unicoi Mountains*

In 1989 a population of *G. s. coloratus* was discovered in the Haw Knob area of the Unicoi Mountains of southwestern North Carolina in a mixed northern hardwood-hemlock cove forest along the corridor of a newly built scenic road, the Cherohala Skyway (Weigl et al. 1999). The Cherohala Skyway connects the town of Tellico Plains, TN and Robbinsville, NC by traversing a rugged and scenic segment of the Unicoi Mountains. North Carolina Wildlife Resources Commission (NCWRC) researchers initially captured three animals during a survey of the habitat along the Skyway in 1989. This habitat, although atypical, was considered potential northern flying squirrel habitat based on elevation ( $>1402$  m), aspect (northerly) and because a few northern flying squirrels had been captured in similar habitat elsewhere in the central and southern Appalachians. The capture of one *G. s. coloratus* in 1988 close to Haw Knob (Whigg Meadow) by Dr. Michael Kennedy of Memphis State University begins our knowledge of this species in the Unicoi Mountains (P. Weigl personal communication). Subsequent trapping surveys revealed several more *G. s. coloratus* from two other areas in close proximity to the Skyway: one area adjacent to the Skyway near Big Junction and the other area away from the Skyway near Huckleberry Knob (Fig. 3). Pure northern hardwood forests devoid of any coniferous tree species characterize the habitat at the two additional sites.

Thus, the cluster of small populations of *G. s. coloratus* in the Unicoi Mountains is important for several reasons: First, the Unicoi Mountain populations are the southernmost known populations in the eastern U.S.; second, the habitat associated with these populations is unique and has not yet been studied to any extent; third, an

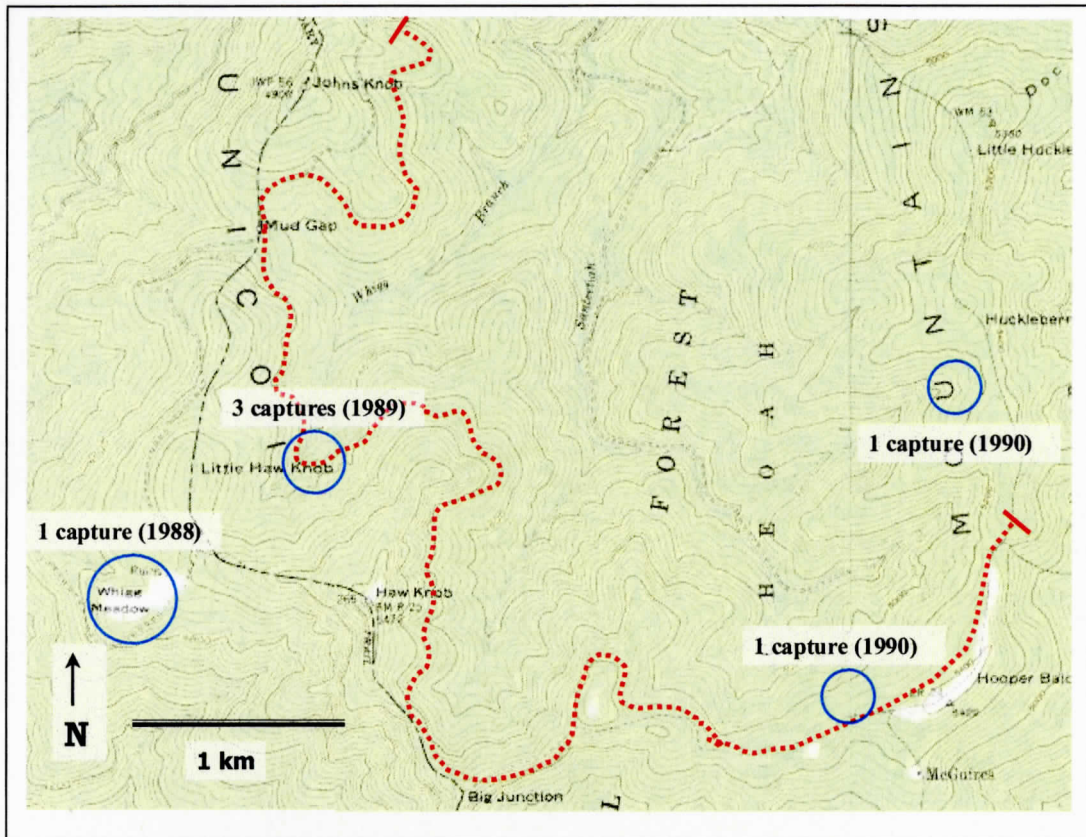


Fig. 3. Locations of *G. s. coloratus* captures along the Cherokee Skyway prior to the present study. The 1988 specimen was captured by Dr. Michael Kennedy from Memphis State University; the three 1989 specimens were captured during the initial survey by NCWRC and WFU researchers; and the two 1990 specimens were captured by students from WFU (P. Weigl pers. comm.). (map source: Maptech, Inc., Amesbury, Massachusetts, USA)



opportunity exists to study the impacts of road building on flying squirrel populations (i.e., fragmentation); and last, additional ecological information such as home range size, movement, activity, population size, reproduction, denning characteristics, etc. can be gathered from these populations.

The presence of *G. s. coloratus* populations in the Unicoi Mountains demonstrates that northern hardwood and hardwood-hemlock habitat is suitable for the species to survive and suggests the Appalachian northern flying squirrels are more plastic in their habitat requirements than once thought. Several additional records exist of Appalachian northern flying squirrel captures in similar habitat types, which provides additional evidence to suggest hardwood and hardwood-hemlock habitat is suitable for the species. Two northern flying squirrels were captured in a riparian northern hardwood-hemlock-rhododendron site in Montgomery County, Virginia by Dr. Jack Cranford of Virginia Polytechnic Institute and State University and an old record of one *G. s. coloratus* capture at Blanket Mountain in the GSMNP in a hardwood-hemlock cove forest demonstrate that northern flying squirrels do use these habitats on occasion (USFWS 1990, Weigl et al. 1999). The extent of this usage remains problematic.

In 1994 a two-year field study was initiated to determine the potential impacts of the Cherohala Skyway to the cluster of northern flying squirrel populations found along a segment of the Skyway's length in NC. The four primary objectives of this study were to determine: 1) the status and distribution populations along the Haw Knob-Wright's Creek section of the Cherohala Skyway; 2) the potential and existing impact of the roadway on northern flying squirrel movements and ecology; 3) any special ecological characteristics of these southernmost populations associated with atypical habitat; and

4) possible conservation and management strategies which might mitigate the effects of the Skyway (aspects of particular concern were the fragmentation of populations and habitats resulting from this road and future roads in critical habitat).

### ***Study objectives***

Because there is a critical need for additional ecological information relevant to the recovery of *G. s. coloratus*, I chose objective 3 of the initial study as the focus of my thesis. The research presented herein was designed to examine in detail a habitat type not typically associated with Appalachian northern flying squirrels and not studied to any degree. Also, given that the habitat in the Unicoi Mountains is atypical, an attempt was made to identify any feature(s) that might help explain the presence of *G. s. coloratus* in the Unicoi Mountains. Moreover, an opportunity was presented to estimate the home range sizes of *G. s. coloratus* in atypical habitat for comparisons with home ranges in typical habitat. Therefore, the objectives I chose for this study were: 1) to estimate the seasonal (summer and winter) home range size for northern flying squirrels in the atypical habitat of the Unicoi Mountains, and to compare my estimates to those reported by Weigl et al. (1999) for Roan Mountain NC-TN; 2) to describe in detail the characteristics associated with the Unicoi Mountain habitat; 3) compare the habitat characteristics between high-use and low-use areas within home ranges; and 4) to compare the habitat in occupied sites and unoccupied sites.

## STUDY AREA

### *Physiographic Characteristics*

The study area was located in the Unicoi Mountains of southwestern Graham County, North Carolina. It encompassed an 18.1 km section of the 66 km long Cherohala Skyway and adjacent forest bounded by John's Knob to the west and Hooper Bald to the east (Fig. 4). Throughout the study area the Skyway was positioned on the north slopes of the mountains and ridge-tops running along hillsides and passing through steep drainages. The Skyway had a gentle slope over most of its length with the highest portion located within the study area peaking at 1615 m just east of Big Junction (Fig. 4).

High, forested ridges and peaks with moderate to steep side slopes and deep, narrow valleys characterized the topography of the study area. Elevation of the Cherohala Skyway ranged from 1305 m to 1615 m. Aspect of the side slopes and coves of the entire study area ranged from westerly to southeasterly, and slope ranged from gentle to steep. Cool, moist, low-light conditions were characteristic of the northwest to northeast facing slopes and coves, which occurred throughout much of the study area. Cold, swift-flowing streams were common in the deep valleys, and in some locations networks of small, intermittent, finger-like drainages commonly occurred on headwater slopes, as did many springs and seeps.

Northern hardwoods dominated the forest throughout the study area with the exception of a few coves containing eastern hemlock. Even in these coves, hemlock was typically



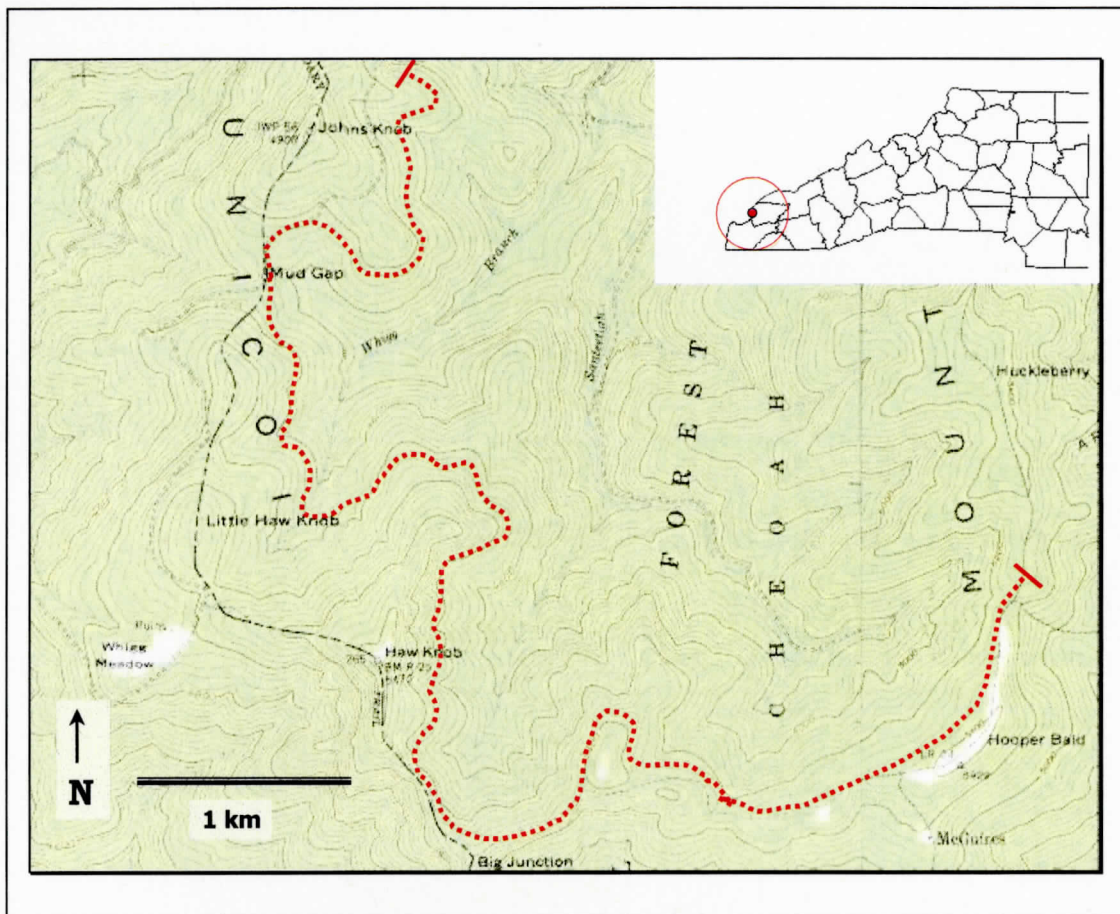


Fig. 4. The 18.1 km section of the Cherohala Skyway chosen as the study area starting from John's Knob to the northwest extending southeastward to Hooper Bald. The study area was located in southwestern Graham County, North Carolina. (map source: Maptech, Inc., Amesbury, Massachusetts, USA).

mixed with hardwoods and was not widely distributed. Hemlock did, however, increase in abundance in other coves and stream systems outside the study area at lower elevations. No other coniferous species (i.e., spruce-fir) was found within the study area. In fact, the nearest spruce-fir forest is located 45 km away in the Great Smoky Mountains National Park.

American beech, yellow birch, and sugar maple characterized the northern hardwood forests. Other less abundant hardwood species included yellow buckeye (*Aesculus flava*), Carolina silverbell (*Halesia carolina*), black cherry (*Prunus serotina*), fire cherry (*Prunus pensylvanicum*), red maple (*Acer rubrum*), serviceberry (*Amelanchier arborea*), cucumber magnolia (*Magnolia acuminata*), and earleaf magnolia (*Magnolia fraseri*). Northern red oaks were observed on some slopes and ridge-tops but were infrequent and were found as high as 1615 m on some south-facing slopes near the Skyway, particularly in the Hooper Bald area. A few red oaks were found in the upper Whigg Branch drainage. Black cherry was found in the study area but was infrequent. Residual large, older trees (old growth relicts) that punctuated the forest overstory were widely dispersed throughout most of the study area. These relicts were likely trees unfit for harvest during logging operations that occurred in the 1950's and were left uncut.

The shrub and ground cover layers consisted of a wide array of woody and herbaceous plant species of varying density. The shrub layer contained saplings of the overstory species but also included, but was not limited to, shrub species such as hobblebush (*Viburnum alnifolium*), thornless blackberry (*Rubus canadensis*), mountain maple (*Acer spicatum*), *Vaccinium* spp., great rhododendron (*Rhododendron maximum*), striped maple (*Acer pensylvanicum*), witch hazel (*Hamamelis virginiana*), and largeleaf

holly (*Ilex montana*). A great diversity of herbaceous plants (i.e., forbs), mosses, and ferns (*Dryopteris* spp.), shining clubmoss (*Huperzia lucidulum*), and Christmas fern (*Polystichum acrostichoides*) dominated the ground cover during summer months, whereas fall and winter ground cover was predominantly mosses, woody seedlings, Christmas fern, wood ferns, and shining clubmoss.

Other habitat characteristics varied in occurrence and abundance throughout the study area. For example, soil depth appeared variable throughout the study area and the forest floor was very rocky in places with occasional large boulders. Dead and down wood (course woody debris) was common throughout much of the forest. Large windrows of rotting wood and debris, a result of clearing the right-of-way, occurred along the Cherohala Skyway at the forest edges.



## METHODS

### *Capture and telemetry*

Eight trap sites were chosen along the Cherohala Skyway (Fig. 5) based on certain physiographic and vegetative characteristics similar to those associated with northern flying squirrel populations in other regions of the southern Appalachians. Specifically, sites at or above 1372 m (4500 feet) in elevation on northwesterly to northeasterly facing slopes and coves were targeted based on what has been reported from other studies (Payne et al. 1989, Weigl et al. 1999). Aspect ranged from northwest to east. Forests within this range of elevation and aspect are persistently moist and cool. Other characteristics such as the presence of streams and seeps, as well as the presence of relict trees, abundant snags and the prevalence of coarse woody debris, needed to be present. Trap sites situated on both sides of the Cherohala Skyway were considered wherever possible.

Modified Tomahawk #201 live traps (Tomahawk Live Trap Company, Tomahawk, Wisconsin, 54487) were nailed 1.5 m high to the boles of selected trees (usually the largest trees in the area) with the openings of the traps flush with the trunk. Natural materials (i.e., bark, branches, moss, etc.) were placed on the top of each trap for camouflage and to provide captured animals protection from the elements. Small shelters constructed from half-gallon paper milk and juice cartons were stuffed with polyfil or cotton batting and placed inside each trap to give captured animals additional protection

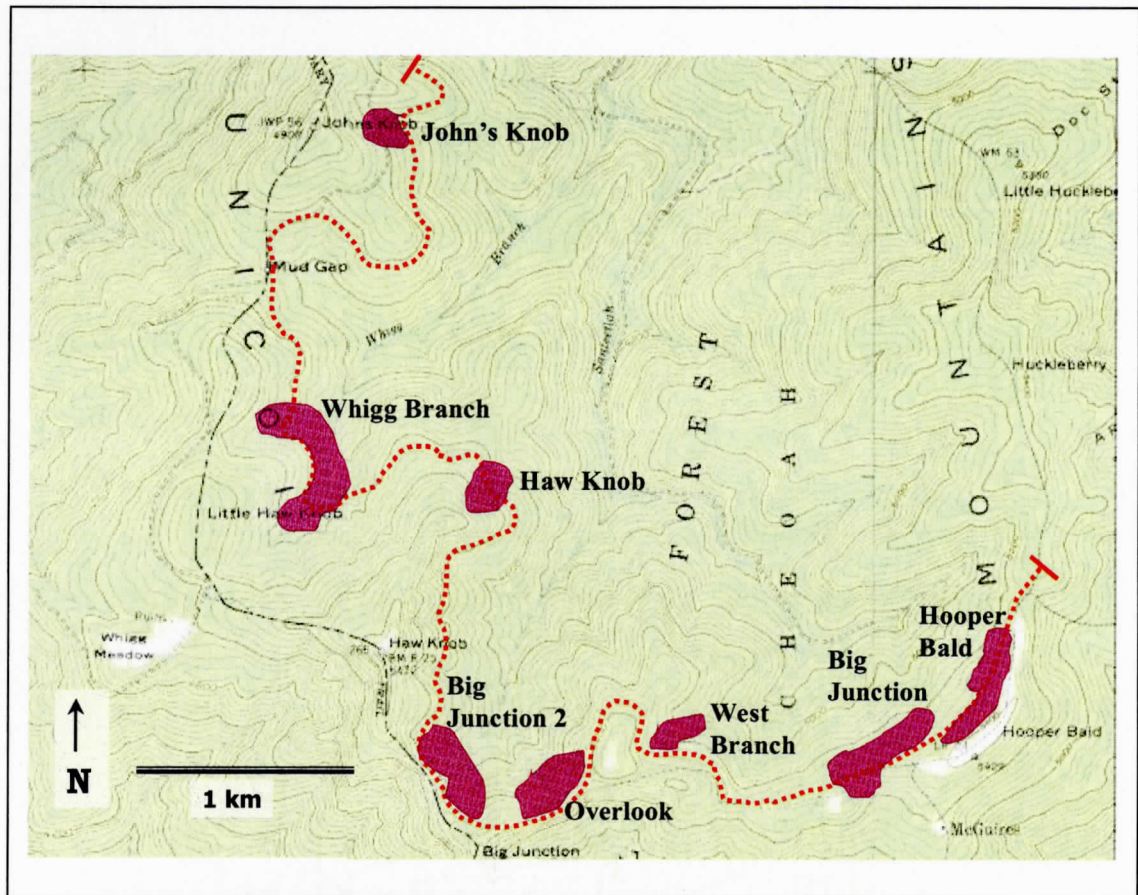


Fig. 5. The eight trap sites established along the Cherohala Skyway represented by the shaded polygons. The shaded area delimits the approximate extent of the area trapped. (map source: Maptech, Inc., Amesbury, Massachusetts, USA).

from harsh weather. Each trap was set and baited with a mixture of peanut butter, oatmeal, bacon grease and a slice of apple. Traps were checked and closed in the mornings then reset in the evenings. Trapping was carried out from 26 September 1994 through 26 January 1996.

Twenty-nine nest boxes were established to facilitate northern flying squirrel captures. The nest boxes were constructed of half-inch plywood and fastened to selected trees at a height of about 4 m using fencing wire. Twenty-four nest boxes were placed in trapping sites and the remaining five were placed in an additional site that contained



potential habitat. The boxes were checked only once during the study, in late spring 1995 (31 March - 5 April).

I recorded the sex, weight, ear length, hind foot length, tail length, total length, and reproductive condition for each captured flying squirrel. Approximate age was estimated from weight and pelage coloration. Blood and fecal samples (when available) were collected for allozyme and parasite analyses, respectively. All captured flying squirrels were ear-tagged, and each individual >100 grams in weight was affixed with a 3.5 -6 g AVM model SM1 transmitter using a collar-style attachment (Weigl et al. 1999). All animals were released at their original capture site immediately after handling.

Each radiocollared flying squirrel was monitored once or twice a week during nightly activity periods, and diurnal den sites were located one to three times per week for each squirrel via radiotelemetry. Radiotelemetry data were collected for each radiocollared flying squirrel while the transmitter remained functional (i.e., transmitter life). The radiotelemetry equipment used in the study included two receivers — one AVM (model LA12-DS) receiver and one Telonics (model TR2) portable receiver — and two AVM collapsible 3-element hand-held Yagi antennas.

Telemetry locations and activity were recorded for only one individual per nightly monitoring session. Telemetry locations were estimated via triangulation using two observers positioned at known locations on or near the Cherohala Skyway. To triangulate, each observer simultaneously determined the direction of the strongest (peak) radio signal and recorded the azimuth ( $0^{\circ}$  -  $359^{\circ}$ ) of the peak signal with a Suunto™ compass. Telemetry readings were recorded every 15 minutes throughout the duration of squirrel activity.



Radiotelemetry was conducted from 12 January 1995 to 23 February 1996 at four sites: Whigg Branch, Overlook, Big Junction, and Hooper Bald (Fig. 5). Of the four sites, Big Junction and Whigg Branch were chosen for the home range and habitat analyses, as they were the most productive trapping sites. Flying squirrel activity was monitored during one or more of three nightly monitoring sessions: evening sessions took place from sunset up to midnight; morning sessions took place between midnight and sunrise; and all-night sessions encompassed the entire night between sunset and sunrise. In addition to taking telemetry locations, I recorded the general weather conditions (i.e., temperature, moon phase, time of sunset/sunrise, and any other pertinent information) during each monitoring session.

The accuracy of the radiotelemetry system was tested by placing two beacon transmitters (White and Garrott 1990) in each of two different sites containing radiocollared flying squirrels. I chose sites with radiocollared squirrels specifically for the purpose of duplicating field conditions. Once the beacon transmitters were deployed, one other observer and myself recorded beacon azimuths from each of the observer positions (receiving stations) established along the Cherohala Skyway that we had used to triangulate on the radiocollared squirrel using that site. The differences between the true (actual) azimuths and the beacon (estimated) azimuths — measure of error — were then calculated for each receiving station. The error measurements were averaged across all the receiving stations to formulate the mean error (a measure of bias) and an associated standard deviation (a measure of precision) for each beacon (White and Garrott 1990).

### *Home Ranges*

Radiotelemetry locations were used to estimate the sizes and placement of home ranges for each radio-tracked flying squirrel. I used the minimum convex polygon (MCP) (Jennrich and Turner, 1969) method, using the computer software TELEM88 (Coleman and Jones 1988), to generate home range estimates for summer and winter seasons and an overall home range that included all telemetry locations. The harmonic mean (Dixon and Chapman 1980) method of home range estimation was used to determine areas of high and low concentrations of telemetry points, which reflected squirrel activity. I chose a 35% isopleth (35% of the most concentrated telemetry points) to represent the high-use area within each home range, and a 95% isopleth (boundary encompassing 95% of the telemetry points, including the most widely scattered locations) to represent low-use areas. The results of the harmonic mean analysis, including both isopleths, were displayed as an overlay on a digital map of a given squirrel's MCP home range. A random numbers table was then used to select the locations of the vegetation plot centers (using Universal Transverse Mercator (UTM) coordinates) established within the high-use and low-use areas of that squirrel's home range. The UTM coordinates for each plot's center were transferred to a 1": 400' orthophoto map, which was then used to locate the actual plot centers in the field.

Because the home range analysis was designed to examine whether or not home range sizes differed between summer and winter seasons, two time periods designated as summer and winter were developed that were close to, but did not necessarily fall within, the calendar designations of summer and winter. Each defined season was based primarily on changes in climate and vegetative conditions of the area such that summer

included the period of June – September, where temperatures were well above freezing and woody and herbaceous plants were growing and were fully vegetated. Conversely, winter included radiotelemetry data collected during the months of mid-October – mid-April, when the temperatures were commonly near and below freezing and the vegetation was dormant.

Thus, for seasonal home range estimates, only the radiotelemetry data collected within the designated summer and winter periods were included in the analyses. On the other hand, all the radiotelemetry points, regardless of season, were included in estimates of overall home ranges.

### ***Habitat Analysis***

Habitat was sampled within 10 m radius (314 m<sup>2</sup>) plots were placed within each flying squirrel's MCP home range. A total of six plots were placed within each flying squirrel MCP home range by systematically placing three randomly assigned plots within high-use areas and three within low-use areas. In addition, randomly assigned plots were placed in areas trapped that did not produce flying squirrel captures, which were considered sites not occupied by northern flying squirrels.

I used a series of nested quadrats to sample the habitat variables within each plot. Overstory variables were sampled within the entire 10 m radius plot. Nested in the center of the 10 m plot was one 5 m radius (79 m<sup>2</sup>) circular quadrat in which the shrub/sapling layer was sampled and four 1-m<sup>2</sup> quadrats placed in each cardinal direction at 5 m from plot center to sample ground cover variables and canopy closure. Figure 6 illustrates the nested quadrat configuration.



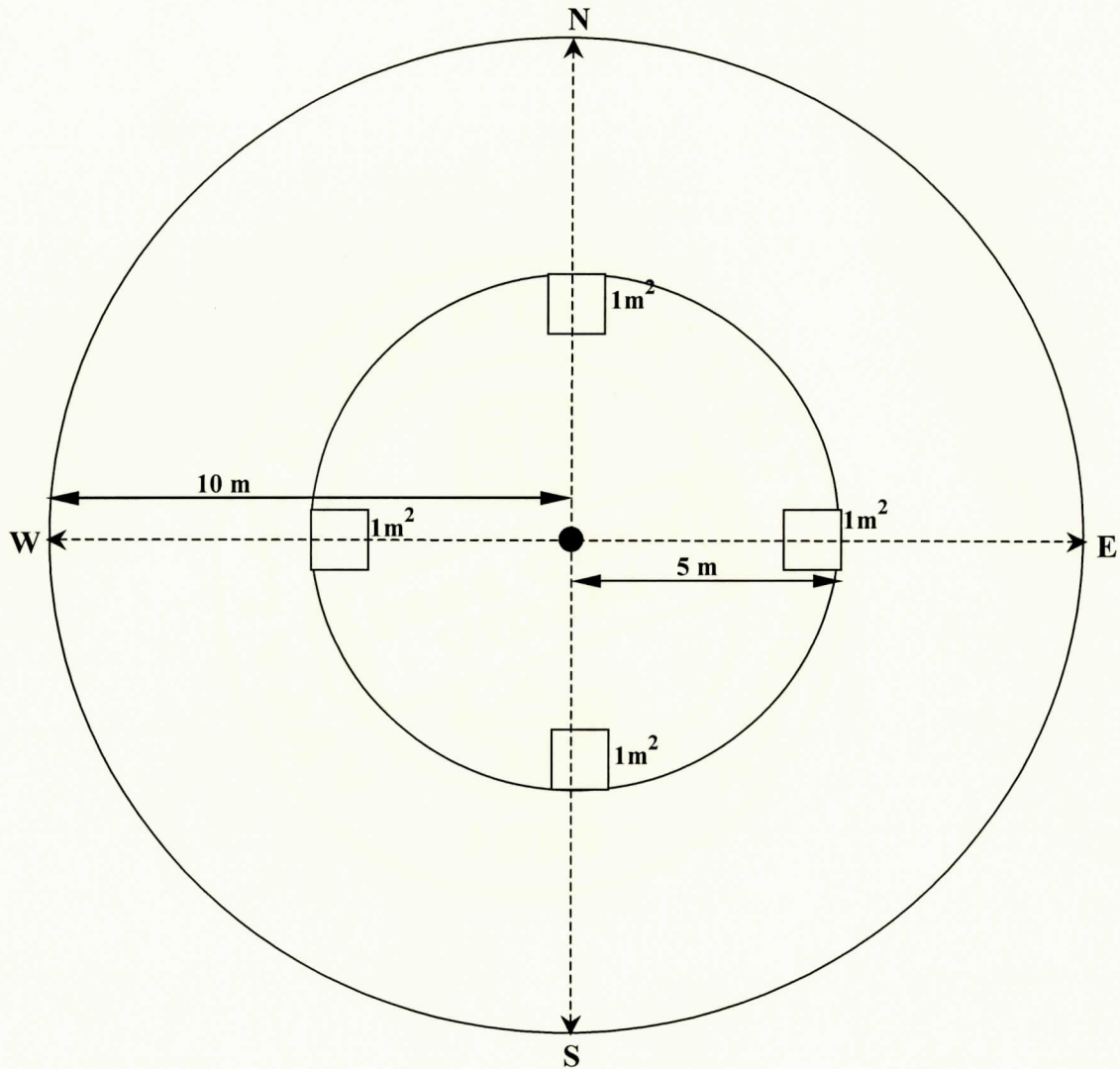


Fig. 6. Diagram of the nested plot configuration used to sample the habitat characteristics.

At each plot site, I recorded slope, aspect, and presence/absence of open water (flowing streams, springs and spring seeps). Various measurements were taken in the stratified plots to examine the overstory, shrub, and ground cover layers of the habitat (Table 1). Within the entire 10 m plot the diameter at breast height (dbh) of each overstory tree and snag ( $>4$  cm dbh) was measured and placed in one of five diameter classes: 4 cm – 10 cm,  $>10$  cm – 20 cm,  $>20$  cm – 30 cm,  $>30$  cm – 40 cm, and  $>40$  cm. Snags were assigned to one of 9 decomposition classes, where class 1 represented an intact dead tree (least decomposed) and class 9 represented the most decomposed snag (see Thomas et al. 1979). Also within the entire 10 m plot all logs  $\geq 10$  cm in diameter were tallied; their length and width were measured to calculate an area ( $\text{m}^2$ ) of coverage (an average of the diameters measured at both ends was used as the width); and each log was assigned to one of five different decomposition classes, where class 1 was a newly fallen tree and class 5 was a log in the most advanced stage of decomposition (see Maser et al. 1979). The total number of shrubs and saplings (woody stems  $<4$  cm dbh at heights between 1 - 3 m) were counted within the 5 m quadrat.

A vegetation profile board was used to estimate the horizontal density, or obscurity (opaqueness), of the shrub/sapling layer (adapted from Nudds 1977). The board was 3 m in height and approximately 30 cm wide and marked in alternating colors of black and white at half-meter intervals. The board was placed at plot center and “read” from a distance of 15 m in each cardinal direction. Reading the board entailed estimating the portion of each half-meter interval of the board covered by vegetation. These measurements were then averaged to obtain the obscurity for the plot.

Table 1. List of all habitat variables measured within each habitat plot and how each variable was measured and treated for analyses.

Variable	How measured	Location sampled	Final measure
Aspect (0 - 360°)	Compass	Plot center	Single direction
Slope (%)	Clinometer	Plot center	Single percentage
Open water	Presence/absence	Entire plot	
Canopy Closure (%)	Spherical densiometer (Lemmon 1956)	Each 1 m <sup>2</sup> <sup>a</sup>	Average
Overstory Trees (≥4 cm dbh and >3 m in height)	Measured and assigned to appropriate dbh class: (1) 4 - 10 cm; (2) 10 ≤ 20 cm; (3) 20 ≤ 30 cm; (4) 30 ≤ 40 cm; (5) >40 cm	Entire plot	Total number
Height of canopy (feet)	Clinometer	Entire plot <sup>b</sup>	Average height
Snags (≥4 cm dbh)	Measured and assigned to appropriate dbh class and assigned to 1 of 9 decomposition classes (see Maser et al., 1979).	Entire plot	Total number
Course woody debris (>10 cm diam.)	Length and width measured and assigned to 1 of 5 decomposition classes (see Thomas et al., 1979).	Entire plot	Total area
Shrubs/saplings (<4cm dbh and ≤3 m in height) number	All stems tallied.	5 m radius	Total number
Obscurity (%)	Percentage of each ½ meter increment covered with vegetation (see Nudds, 1977).	Plot center <sup>c</sup>	Average
Ground Cover (%): Leaf litter Fine woody debris Soil Water Exposed rock Seedling/sapling Forbs Ferns Moss Shining clubmoss Sedges Lichens Fungi	Percentage of quadrat covered; each variable measured separately.	Each 1 m <sup>2</sup>	Average

<sup>a</sup> Measurement taken at each 1 m<sup>2</sup> quadrat.

<sup>b</sup> Three trees representative of the overstory (co-dominant position) were measured.

<sup>c</sup> Measurement taken in each cardinal direction 15 m from board (placed at plot center).



In each of the four 1-m<sup>2</sup> quadrats ground cover features (variables) were measured by estimating the portion (percentage) of the quadrat covered by that feature and then averaged across the four 1-m<sup>2</sup> quadrats. Also, overstory canopy closure was estimated at each 1-m<sup>2</sup> quadrat using a spherical densiometer (Lemmon 1956) and then averaged across the four plots.

### *Statistics*

#### Home ranges

For the home range analyses I used an unpaired *t*-test (Zar 1996) to examine differences in the average size of summer vs. winter home ranges for northern flying squirrels. Additionally, I used an unpaired *t*-test to determine whether the home range sizes of *G. s. coloratus* in this study were significantly different than the home range sizes of *G. s. coloratus* reported by Weigl et al. (1999) from Roan Mountain, NC-TN.

#### Habitat analyses

To examine the habitat at various levels within flying squirrel home ranges as well as examine the habitat between occupied and unoccupied locations I used analysis of variance (ANOVA) (SAS Institute, Inc, Cary, North Carolina). For the analyses of habitat within home ranges, I wanted to determine if there were, for each habitat variable, differences between: 1) high-use and low-use areas (areas of use) within home ranges; 2) summer and winter (seasons) home ranges; 3) male and female home ranges; and 4) Big Junction and Whigg Branch (site) home ranges. To test for differences in the habitat associated with each of these four treatments, I ran multiple single-factor (one-way) ANOVA tests, one for each habitat variable-treatment combination. This, however, required that for each ANOVA, the habitat data associated with the treatment being

examined were pooled across the remaining treatments. For example, to test for differences in a particular habitat variable between areas of use (high-use vs. low-use) the data collected in all high-use areas, regardless of site, sex, or season, was combined or pooled.

To examine the habitat associated with occupied locations (i.e., home ranges) and unoccupied locations, I again used a single-factor ANOVA design. The habitat data for the occupied sites were pooled across areas of use, sites, and sexes, but for the winter season only. The reason for this is that I sampled the plots in unoccupied sites during the winter season only.

The statistical analyses for home ranges were calculated by hand and the statistical analyses for the habitat variables were performed using a PC version of SAS (SAS Institute, Inc., Cary, NC). The level of statistical significance for all tests was  $P < 0.05$ .

## RESULTS

### *Trapping*

Trapping was almost continuous during the trapping period from 26 September 1994 - 26 January 1996. Trapping resulted in 58 captures of 25 individual *G. sabrinus* from five of the eight sites, with no escapes and four mortalities (Table 2). In addition, trapping resulted in 15 captures of 12 individual *G. volans* from two of eight sites, with one escape and no mortalities. A total of 2,054 trapnights yielded a trapping efficiency of 55.2 trapnights per squirrel regardless of species. Split out by species, *G. sabrinus* had a trapping efficiency of 35.4 trapnights per squirrel, while the trapping efficiency for *G. volans* was 136.9 trapnights per squirrel.

The Big Junction Trap Site was clearly the most productive for northern flying squirrels, resulting in 12 individuals captured 29 times representing 48% of individual captures and 56% of the total captures (Table 2). The Whigg Branch Trap Site was the second most productive capture site yielding nine individual northern flying squirrels captured 25 times representing 36% of all individual captures and 37% of total captures. The Hooper Bald Trap Site yielded only two northern flying squirrels, one male and one female, in 20 nights of trapping (176 trapnights) representing 8% of all individual captures and 5% of total captures. The Overlook Trap Site was trapped for seven nights (49 trapnights) and yielded one male northern flying squirrel, which represented 4% of all individual captures and 2% of total captures. The West Branch Trap Site also yielded one



Table 2. Summary of trapnights and captures of northern and southern flying squirrels for 8 sites trapped in the Unicoi Mountains along the Cherohala Skyway, NC throughout the entire study from September 1994 through March 1996.

Trap site	Days trapped	Trap-nights	<i>Glaucomys sabrinus</i>			<i>Glaucomys volans</i>		
			Total individuals	Total captures	Trapnights/capture	Total individuals	Total captures	Trapnights/capture
Whigg Branch	68	1,001	9	24	41.7	8	12	83.4
Big Junction	47	524	12	29	18.1	0	0	0.0
Hooper Bald	20	176	2	3	58.7	0	0	0.0
Haw Knob	16	237	0	0	0.0	0	0	0.0
Overlook	7	49	1	1	49.0	0	0	0.0
West Branch	5	35	1	1	35.0	0	0	0.0
John's Knob	5	20	0	0	0.0	4	5	4.0
Big Junction 2	2	12	0	0	0.0	0	0	0.0
Overall <sup>a</sup>	170	2,054	25	58	35.4	12	15	136.9

<sup>a</sup> These Fig's are for all trap sites combined.

male northern flying squirrel, which was captured on the fifth night of trapping (35 trapnights).

The Whigg Branch site produced the most southern flying squirrel captures, resulting in eight individuals captured 10 times, representing 32% of all individual flying squirrels and 67% of total southern flying squirrel captures. The remaining four southern flying squirrels were captured at the John's Knob Trap Site in five nights of trapping (Table 2), representing 11% of all individual captures and 33% of total southern flying squirrel captures.

Other mammal species commonly captured included red squirrels (*Tamiasciurus hudsonicus*), deer mice (*Peromyscus maniculatus*), and red-backed voles (*Clethrionomys gapperi*). One gray squirrel (*Sciurus carolinensis*) was captured at the Big Junction site on the southern side of the Cherohala Skyway, and one spotted skunk (*Spilogale putorius*) was captured several times at the Big Junction site on the northern side of the skyway. Numerous chipmunks (*Tamias striatus*) were observed in all the trap sites but none were captured. Weigl et al. (1999) noted that red squirrels were more abundant in their more productive northern flying squirrel capture sites. I observed a similar pattern in this study.

### ***Radiotelemetry***

Mean error calculated for the Big Junction site was 6.8 degrees ( $\pm 5.8$  SD). Two standard deviations from the true azimuth (11.6 degrees) — the outer limits of a 95% confidence polygon (White and Garrott, 1990) — would cover a total of 23.2 degrees. Similarly, a mean error of 6.9 degrees ( $\pm 5.2$  SD) was calculated for the Whigg Branch site, and two SD's would cover a total of 20.8 degrees.

Table 3. Summary of all northern flying squirrels radio-tracked from 12 January 1995 - 23 February 1996 in the Unicoi Mountains along the Cherohala Skyway, NC. Winter was designated as the period mid-October – mid-April and summer was designated as the period June – September.

Sq. #	Sex	Site	Date first tracked	Date last tracked	No. nights monitored		Telemetry locations
					Winter	Summer	
#3	M	Big Junction	12 Jan 1995	19 Apr 1995	17	—	65
#12	F	Big Junction	21 Feb 1995	17 Sept 1995	10	17	198
#16	M	Big Junction	21 Feb 1995	10 Apr 1995	9	—	66
#27	F	Big Junction	2 Aug 1995	9 Aug 1995	—	3	0 <sup>a</sup>
#28	M	Big Junction	29 Aug 1995	4 Jan 1996	19	7	187
#5	F	Whigg Branch	23 Jan 1995	18 Sept 1995	19	17	208
#23	F	Whigg Branch	—	—	—	—	0 <sup>b</sup>
#25	M	Whigg Branch	30 Jul 1995	23 Feb 1996	19	10	191
#19	M	Hooper Bald	21 Apr 1995	22 May 1995	4	—	41
#32	M	Overlook	—	—	—	—	0 <sup>c</sup>
Total					97	54	956

<sup>a</sup> Locations for this squirrel were questionable because its home range was in a rugged area away from the skyway. In addition, total numbers of points were too small for a reliable home range estimate.

<sup>b</sup> Flying squirrel was tracked briefly in the spring, but no nightly activity data was obtained prior to premature radio failure.

<sup>c</sup> Only diurnal den site locations obtained. No nightly activity observed for this flying squirrel although attempts were made to monitor this squirrel.

### Home Range Estimation

Ten adult northern flying squirrels were radiocollared and monitored over the entire period of 12 January 1995 - 23 February 1996; seven of which were included in the home range analysis. Four northern flying squirrels (#5, #12, #25, #28) had radiotelemetry locations that fell within both defined summer and winter seasons, two (#3 and #16) had radiotelemetry locations that fell within the winter only, and one (#19) had no radiotelemetry locations that fell within either defined summer or winter season (Table 3). Thus, six flying squirrels were used for winter home range estimates, four were used for summer home range estimates, and seven were used for calculating overall home range size.



Of the three flying squirrels that were not included in the home range analyses, two (#23 and #32) did not provide any nightly locations, and all the locations for the third (#27) were excluded from the analyses because erroneous signal direction (i.e., signal “bounce”) was suspected for the few telemetry locations that were recorded.

The overall home range estimates (i.e., based on all telemetry locations regardless of seasonal demarcation) for the seven radio-tracked flying squirrels ranged from 3.7 ha to 27.7 ha (Table 4) with an average of 13.9 ha ( $\pm 3.7$  SE). The home range estimates for the six flying squirrels radio-tracked in winter ranged from 1.5 ha to 27.7 and averaged 12.5 ha ( $\pm 3.3$  SE), while the home range estimates for the four flying squirrels tracked in summer ranged from 2.9 ha to 14.8 ha and averaged 8.3 ha ( $\pm 2.3$  SE) (Table 4). Although the average winter home range sizes for the six winter flying squirrels appears larger than the summer average for the four summer flying squirrels, they were not significantly different ( $t = 0.7$ ,  $df = 9$ ,  $P = 0.51$ ).

The average overall home range appeared greater for males (17.5 ha) than for females (4.9 ha). In fact, the largest home ranges were 27.7 ha and 24.0 ha for males #3 and #16 tracked in winter, respectively. Weigl et al. (1999) found that winter males had the largest home ranges in their study at Roan Mountain NC-TN. Unfortunately, my sample size of only two females prevented any statistical testing for differences between male and female home range sizes in this study.

Table 4. Home range estimates using the minimum convex polygon (MCP) method for seven adult northern flying squirrels radio-tracked from three sites along the Cherohala Skyway in the Unicoi Mountains, NC. Winter was designated as the period mid-October – mid-April and summer was designated as the period June – September.

Sq. #	Sex	Site	Winter	Summer	Overall
#3	Male	Big Junction	27.7	—	27.7
#12	Female	Big Junction	1.5	4.6	5.0
#16	Male	Big Junction	24.0	—	24.0
#28	Male	Big Junction	7.2	14.8	18.9
#5	Female	Whigg Branch	3.6	2.9	4.7
#25	Male	Whigg Branch	10.7	11.0	13.0
#19	Male	Hooper Bald	—	—	3.7
Mean±SE			12.5±3.3	8.3±2.3	13.9±3.7

To determine whether the sample sizes of telemetry locations were adequate for home range estimates the cumulative nightly area used by each flying squirrel, for each defined summer and winter season (#19 was included although he was tracked outside the summer and winter periods), were plotted against the number of nights radio-tracking occurred (Fig's 6a and 6b). Bekoff and Mech (1984), cited by Swihart and Slade (1985) concluded that approximately 100 – 200 telemetry locations were necessary to reliably estimate home range area. Other studies have reported reliable home range estimates occur when area-observation curves (cumulative home range area plotted against observations) become asymptotic; that is, a leveling off of the area-observation curve (indicated by  $\leq 10\%$  increase in home range size over three or more successive observation periods) occurs (Phillips et al., 1998; Reynolds and Laundre', 1990). Shown by the graph in Fig's 7a and 7b, the cumulative area was asymptotic for #3 winter home

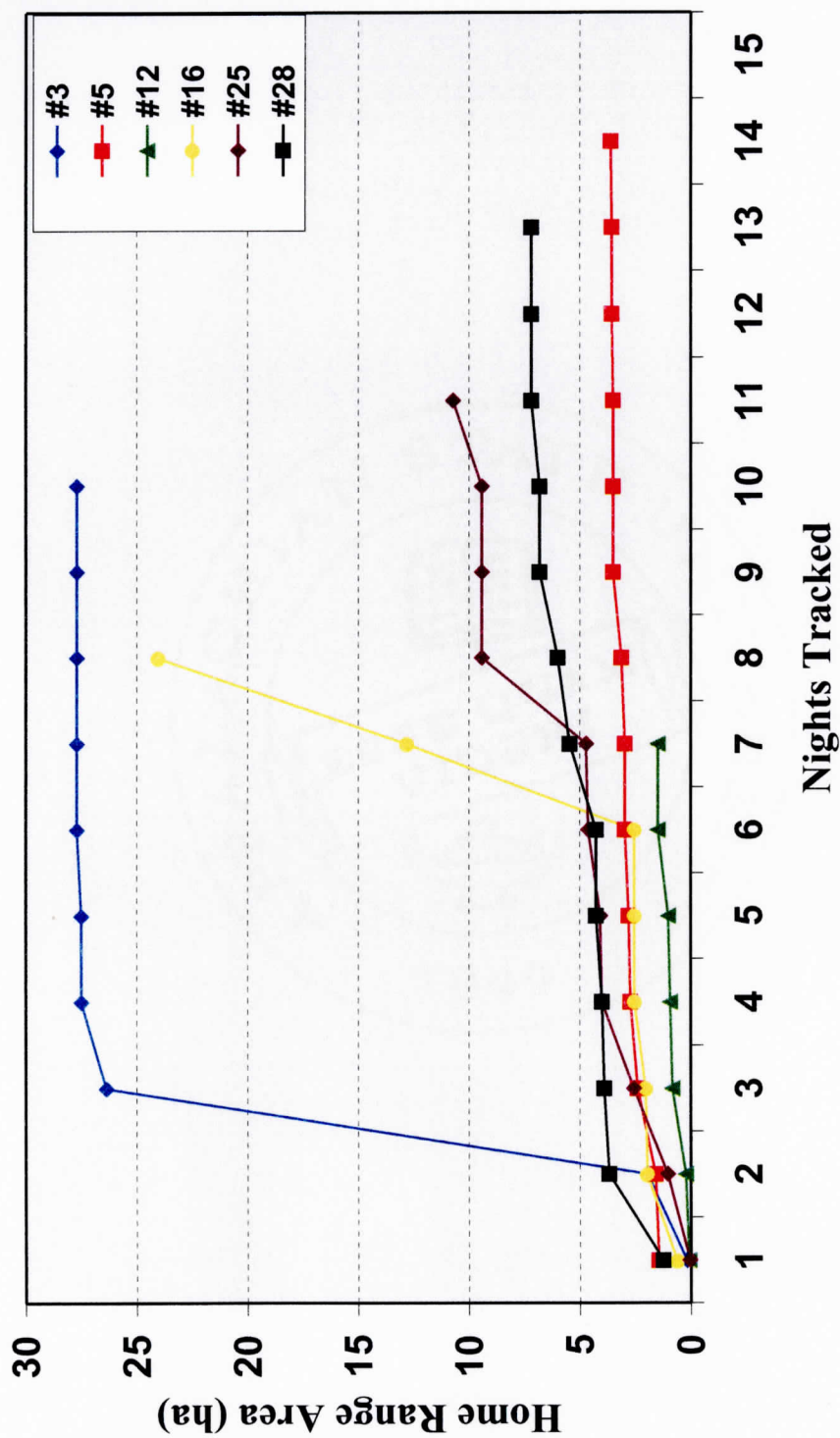


Fig. 7a. Cumulative area curves for the winter home ranges (ha) for six northern flying squirrels as a function of nights radio-tracked. Home range areas were determined using the minimum convex polygon (100%) method. The winter season defined for this study represents the period of November – mid-April.



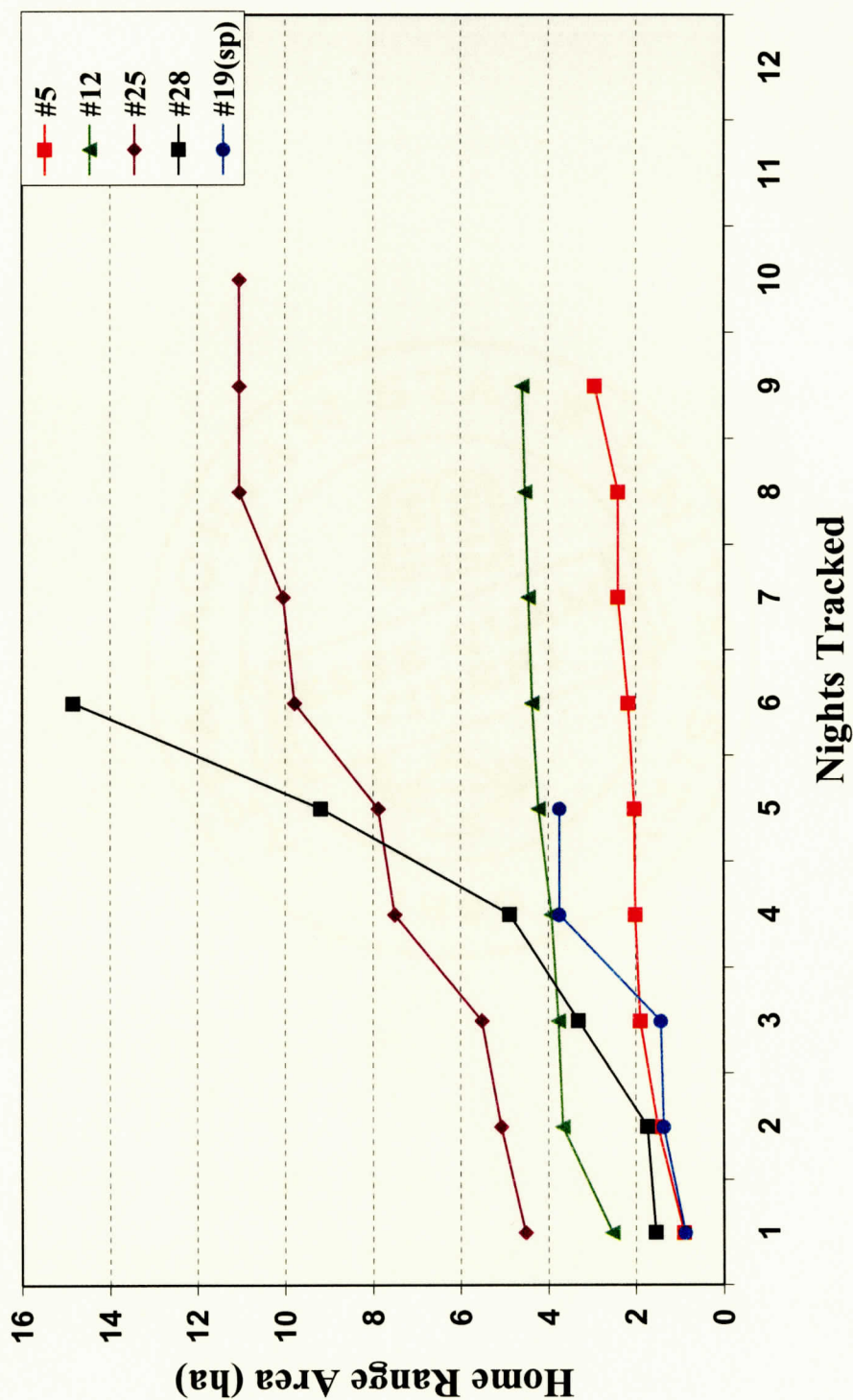


Fig. 7b. Cumulative area curves for the summer home ranges (ha) for four northern flying squirrels and one spring home range as a function of nights radio-tracked. Home range areas were determined using the minimum convex polygon (100%) method. The summer season defined for this study represented the period of June – mid-September. Radio-tracking #19 occurred after the winter and prior to the summer seasons and was given a spring (sp) designation.

range (winter), #5 (winter), #12 (summer), #25 (winter), #25 (summer), and #28 (winter) after six, nine, four, eight, six, and nine nights, respectively. Conversely, the cumulative area was not asymptotic for #16 (winter) and #28 (summer) after eight and six nights, respectively. The cumulative area for #12 (winter) and #19 appeared asymptotic, but each had only two consecutive nights where the cumulative area increased  $\leq 10\%$  after six and four nights, respectively. Similarly, the cumulative area for #5 (summer) appears to level off after seven nights, but increased just above 10% each night.

For the four flying squirrels that I had radio-tracked during both summer and winter no dramatic shifts or movement of their home ranges between seasons was observed (Fig's 8a – 8d). However, the home range sizes for flying squirrels #12, #25, and #28 decreased in size from summer to winter, while the home range size for flying squirrel #5 increased slightly from summer to winter (Table 4), but these differences could not be tested statistically. I did compare the seasonal home range sizes for these four flying squirrels and found the average winter home range size of 5.8 ha ( $\pm 2.0$  SE) was smaller but not significantly different from the average summer home range size of 8.3 ha ( $\pm 2.3$  SE) ( $t = 0.3$ ,  $df = 8$ ,  $P = 0.26$ ).

I compared the home range estimates from this study (atypical habitat) to home range estimates in typical habitat at Roan Mountain NC-TN reported by Weigl et al. (1999). They estimated the home range sizes of 10 adult northern flying squirrels, five were tracked during the winter and five tracked during the summer (Table 5). Weigl et al. found a mean overall (across both seasons) home range size for the 10 flying squirrels to be 8.9 ha ( $\pm 2.2$  SE), which was smaller than the mean overall home range size of 13.9 ha

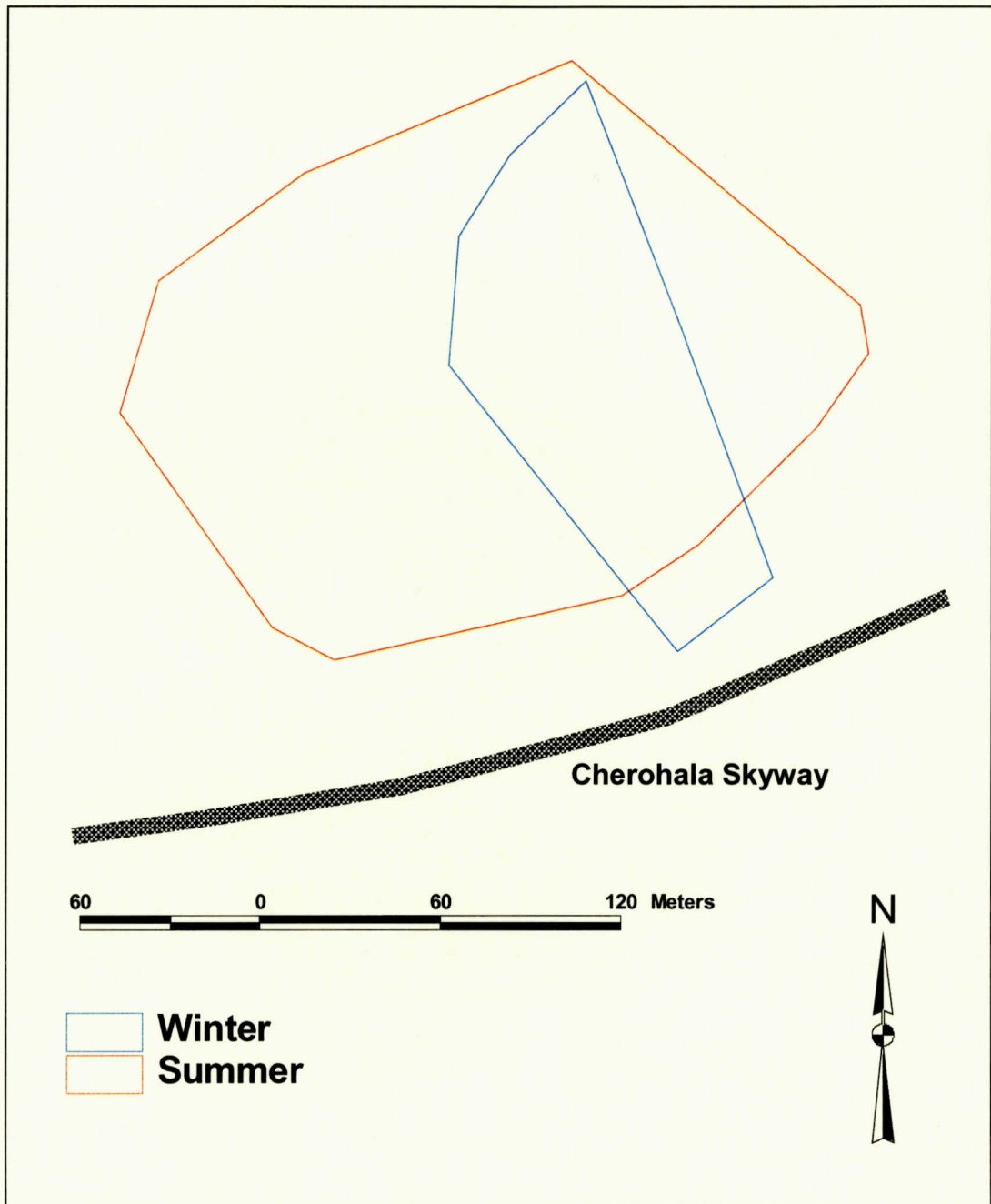


Fig. 8a. Winter and summer home ranges (minimum convex polygon (100%)) for flying squirrel #12 radio-tracked in the Big Junction site along the Cherohala Skyway in the Unicoi Mountains, NC.



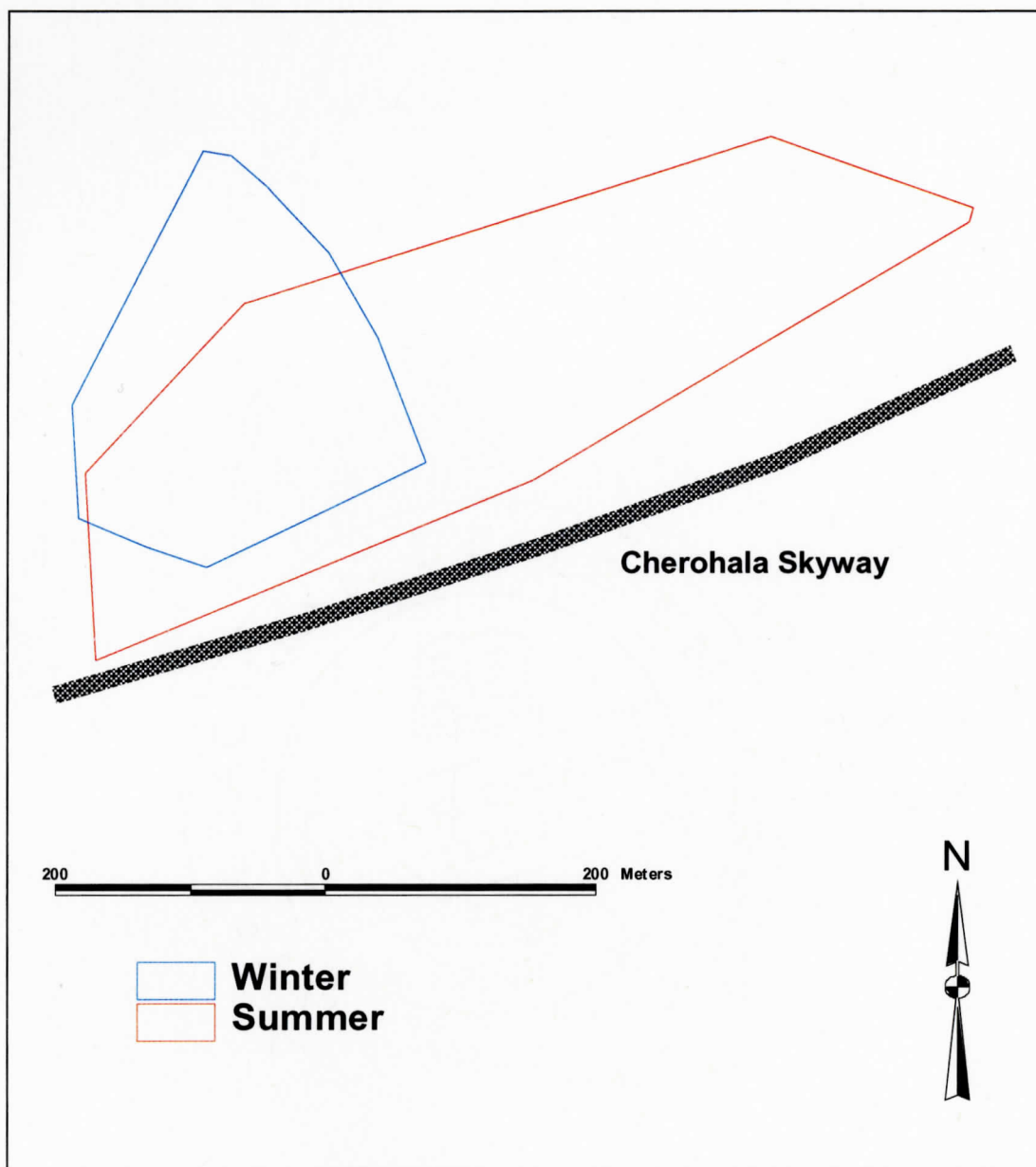


Fig. 8b. Winter and summer home ranges (minimum convex polygon (100%)) for flying squirrel #28 radio-tracked in the Big Junction site along the Cherohala Skyway in the Unicoi Mountains, NC.

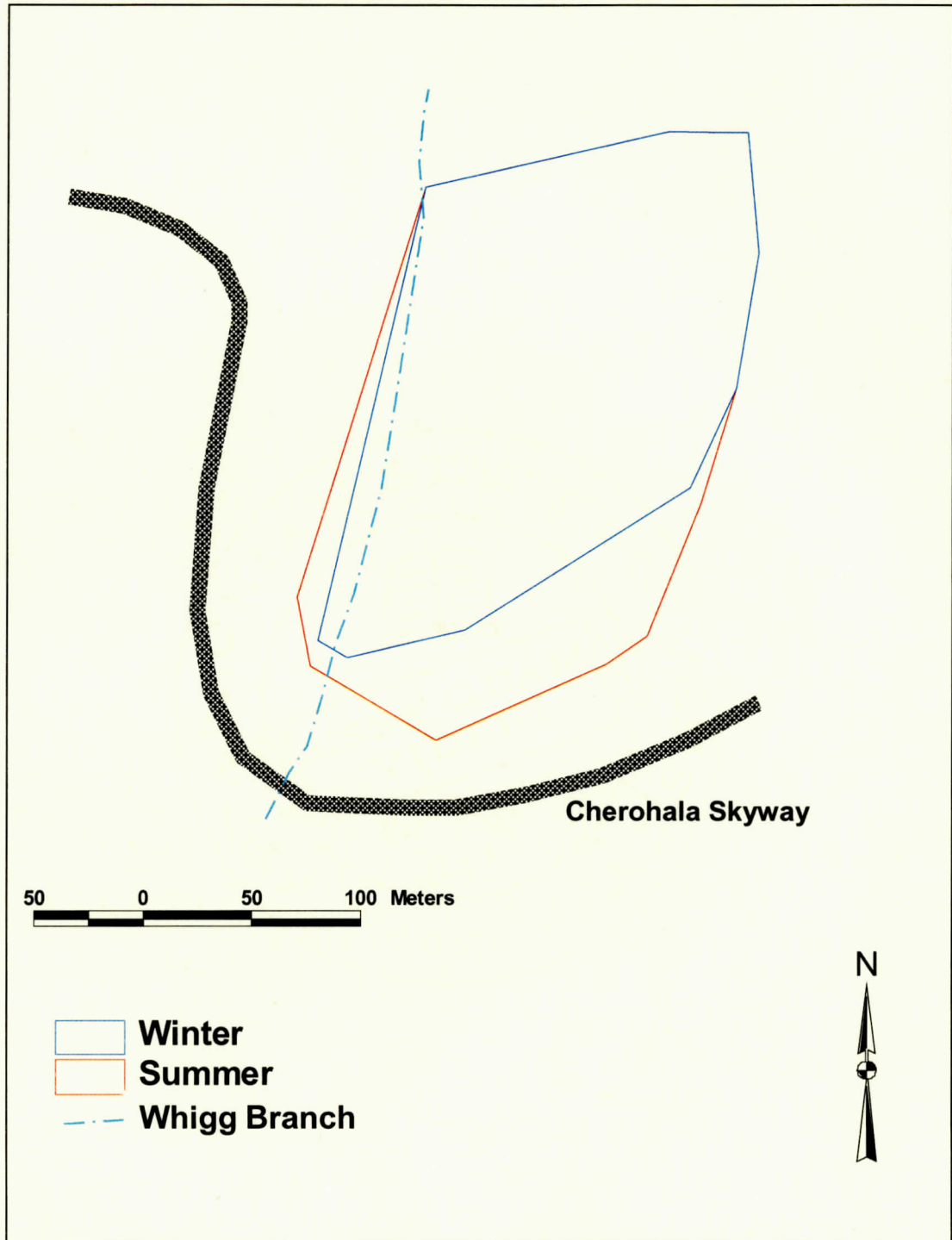


Fig. 8c. Winter and summer home ranges (minimum convex polygon (100%)) for flying squirrel #5 radio-tracked in the Whigg Branch site along the Cherohala Skyway in the Unicoi Mountains, NC.

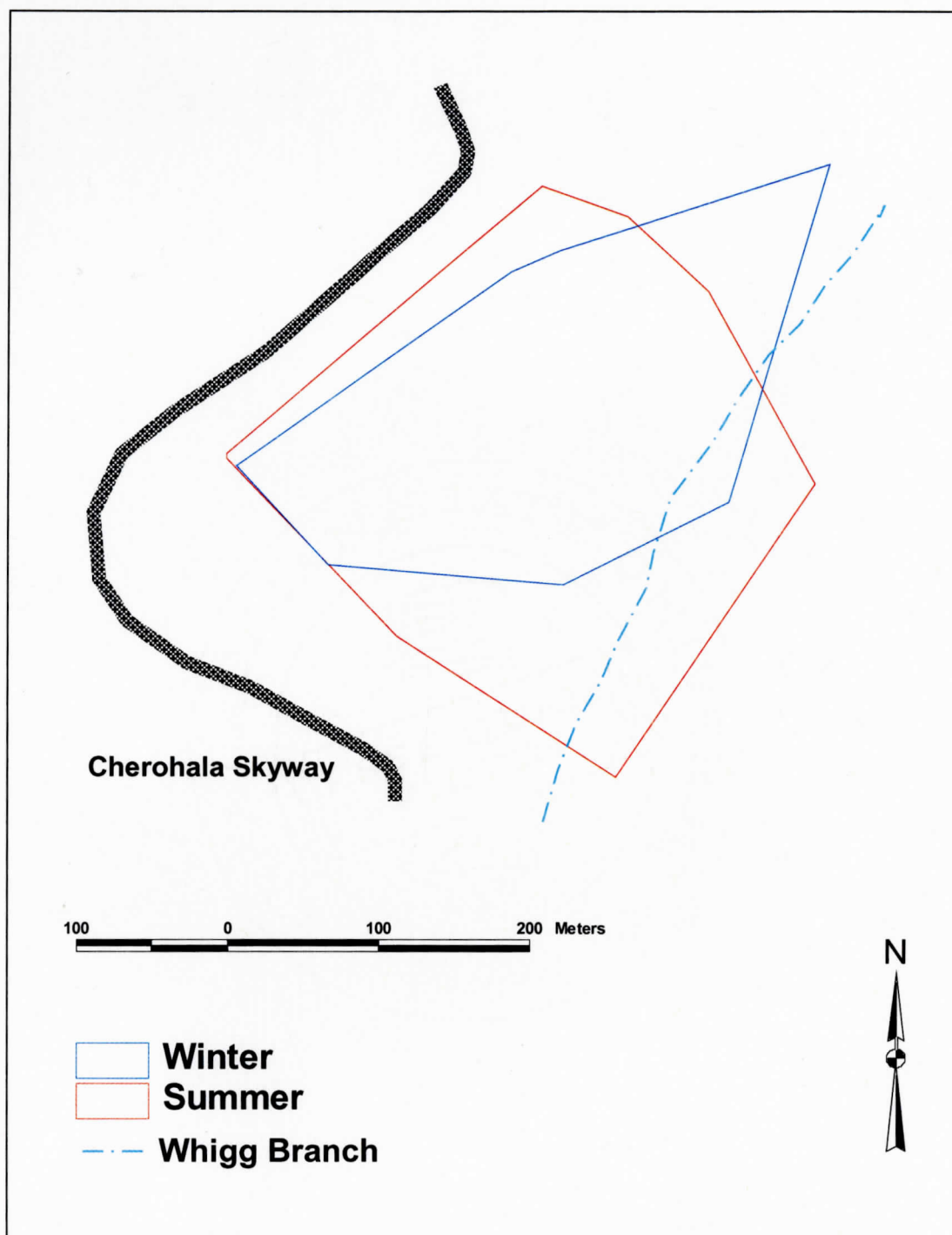


Fig. 8d. Winter and summer home ranges (minimum convex polygon (100%)) for flying squirrel #25 radio-tracked in the Whigg Branch site along the Cherohala Skyway in the Unicoi Mountains, NC.



Table 5. Home range estimates derived using the minimum convex polygon (MCP) method for 10 adult *G. s. coloratus* from Roan Mountain, NC-TN. Table adapted from Weigl et al. (1999).

Sq. #	Sex	Season tracked	Home range (ha)
NC 231	M	Winter 1990	22.6
TN 227	M	Winter 1990	16.3
TN (018)	M	Winter 1990	11.7
NC 240	F	Winter 1990	5.6
NC (007)	F	Winter 1990	1.2
Mean $\pm$ SE			11.5 $\pm$ 3.8
TN 291	M	Summer 1990	2.8
NC 287	M	Summer 1990	2.9
NC 242	M	Summer 1990	4.5
TN 297	F	Summer 1990	12.4
NC (007)	F	Summer 1990	8.5
Mean $\pm$ SE			6.2 $\pm$ 1.9

( $\pm 3.7$  SE,  $n = 7$ ) found in this study. This difference, however, was not significantly different ( $t = 1.25$ ,  $df = 15$ ,  $P = 0.24$ ). The average winter home range size of 12.5 ha ( $\pm 3.3$  SE,  $n = 6$ ) found in this study was not significantly different than the average winter home range size of 11.5 ha ( $\pm 3.8$  SE,  $n = 5$ ) found at Roan Mountain ( $t = 0.17$ ,  $df = 10$ ,  $P = 0.88$ ). Similarly, the average summer home range size of 8.3 ( $\pm 2.3$ ,  $n = 4$ ) was not significantly different from the average summer home range size of 6.2 ( $\pm 1.9$ ,  $n = 5$ ) found at Roan Mountain ( $t = 0.48$ ,  $df = 8$ ,  $P = 0.53$ ).

### ***Habitat characteristics***

I had both winter and summer home range data for four flying squirrels (#5, #12, #25, #28) representing two different sites (Big Junction and Whigg Branch); given that six vegetation plots were located within each of the squirrel's summer and winter home

ranges (3 in high-use areas and 3 in low-use areas), the total number of plots sampled was 48. In addition, a total of six plots were sampled in areas unoccupied by northern flying squirrels.

#### Big Junction and Whigg Branch site characteristics

The Whigg Branch and Big Junction sites differed physiographically in a number of ways. The sites were separated a linear distance of approximately 2.5 km (4.7 km via the Cherohala Skyway). The Whigg Branch site was situated at approximately 1427 m, an elevation lower than the elevation for other *G. s. coloratus* sites that typically fall at or above 1540 m. The Big Junction site was higher, falling within the typical elevational range, situated at approximately 1615 m. The Big Junction site was positioned at the top of a slope near the crest of a saddle and ridge-top (Fig. 4). The aspect of this site averaged 339° (range = 310° - 360°) and the slope averaged 18.4% (range = 12% - 24%). By contrast, the Whigg Branch site was a north-facing cove situated below higher ridge-tops. Although the Whigg Branch site was northerly in aspect (mean = 11°) there was a wide range of aspects (328° - 90°) due to the east-facing and west-facing side slopes. An average slope of 12.7% (range = 3% - 24%) was more moderate than the Big Junction site.

The floral characteristics of the overstory at Big Junction and Whigg Branch sites were both similar and different (descriptively) in a number of ways. Beech, yellow birch, and mountain maple (*Acer spicatum*), ranked in order of importance, were the predominant overstory tree species at the Big Junction site, whereas, yellow birch, American beech, eastern hemlock (*Tsuga canadensis*), and red maple (*Acer rubrum*) were the predominant overstory tree species at Whigg Branch (Tables 6 and 7). Some of

the trees within the overstory strata at both sites were old-growth relicts (>40cm dbh), but were widely scattered throughout both sites. At Big Junction, 1.1% of the overstory trees were old-growth relicts, whereas 4.1% of the overstory trees at the Whigg Branch site were old-growth relicts. Snags were prevalent in the overstory at both sites. At the Big Junction site 10.3% of the overstory was composed of snags, with beech and mountain maple being the predominant snag species (Table 8), whereas at the Whigg Branch site 19.2% of the overstory was composed of snags, with yellow birch and beech being the predominant species (Table 9).

Similarly, the floral characteristics of the shrub/sapling layer of the understory at Big Junction and Whigg Branch sites were both similar and different in a number of ways. The shrub/sapling layer at the Big Junction site ranged in density from 0.3 stems/m<sup>2</sup> to 1.4 stems/m<sup>2</sup> and was dominated by hobblebush, beech saplings, and thornless blackberry, ranked in order of importance (Table 10), whereas the shrub layer at the Whigg Branch site ranged from 0.05 stems/m<sup>2</sup> to 3.3 stems/m<sup>2</sup> with rhododendron, thornless blackberry and beech saplings being the predominant species (Table 11).

The herbaceous ground layer varied somewhat in coverage and composition between the Big Junction and Whigg Branch sites. The herbaceous ground cover layer at both sites was comprised of a wide variety of forbs, sedges, mosses, ferns, and lichens. Both sites had moss, lichens, ferns (*Dryopteris* spp.), and shining clubmoss dominate the herbaceous ground cover layer, with moss ranking among the top three ground cover



Table 6. Vegetation characteristics for the overstory trees (does not include snags) at the Big Junction site in the Unicoi Mountains along the Cherohala Skyway, NC.

Species	Density (no./ha)	Relative density	Dominance (m <sup>2</sup> /ha)	Relative dominance	Frequency	Relative frequency	Importance value
<i>Fagus grandifolia</i>	1120.0	65.00	13.100	55.24	1.00	20.0	140.2
<i>Betula alleghaniensis</i>	225.6	13.10	4.800	20.24	1.00	20.0	53.3
<i>Acer spicatum</i>	204.4	11.90	1.500	6.25	1.00	20.0	38.2
<i>Acer saccharum</i>	46.4	2.70	0.500	2.11	0.46	9.0	13.8
<i>Aesculus octandra</i>	19.9	1.20	0.700	2.95	0.38	8.0	12.2
<i>Ilex montana</i>	43.9	2.60	0.200	0.84	0.42	8.0	11.4
<i>Amelanchier arborea</i>	30.5	1.80	1.600	6.75	0.05	1.0	9.6
<i>Prunus serotina</i>	10.6	0.60	0.400	1.69	0.33	7.0	9.3
<i>Acer rubrum</i>	8.0	0.50	0.400	1.70	0.21	4.0	6.2
<i>Magnolia acuminata</i>	10.6	0.60	0.400	1.69	0.08	2.0	4.3
<i>Vaccinium</i> spp.	1.3	0.08	0.010	0.04	0.08	2.0	2.1
<i>Prunus pensylvanicum</i>	1.3	0.08	0.100	0.42	0.04	0.8	1.3
<i>Cornus alternifolia</i>	1.3	0.08	0.005	0.02	0.04	0.8	0.9
Total	1723.8		23.715		5.09		

Table 7. Vegetation characteristics for the overstory trees (does not include snags) at the Whigg Branch site in the Unicoi Mountains along the Cherohala Skyway, NC.

Species	Density (no./ha)	Relative density	Dominance (m <sup>2</sup> /ha)	Relative dominance	Frequency	Relative frequency	Importance value
<i>Betula alleghaniensis</i>	452.5	29.9	6.40	26.1	0.96	14.80	70.8
<i>Fagus grandifolia</i>	192.4	13.5	4.44	18.1	0.83	12.80	44.4
<i>Tsuga canadensis</i>	100.9	7.1	3.73	15.2	0.79	12.20	34.5
<i>Acer rubrum</i>	69.0	4.9	2.13	8.7	0.46	7.10	20.7
<i>Prunus pensylvanicum</i>	25.2	1.8	1.55	6.3	0.29	4.50	12.6
<i>Acer spicatum</i>	35.8	2.5	0.24	1.0	0.54	8.30	11.8
<i>Acer saccharum</i>	39.8	2.8	0.78	3.2	0.29	4.50	10.5
<i>Amelanchier arborea</i>	22.6	1.6	0.55	2.2	0.29	4.50	8.3
<i>Halesia carolina</i>	31.9	2.2	0.40	1.6	0.29	4.50	8.3
<i>Prunus serotina</i>	13.3	0.9	0.92	3.7	0.21	3.20	7.8
<i>Aesculus flava</i>	18.5	1.3	0.26	1.2	0.25	3.90	6.4
<i>Ilex montana</i>	4.5	0.3	0.08	0.3	0.29	4.50	5.1
<i>Magnolia fraseri</i>	13.3	0.9	0.71	2.9	0.13	0.02	3.8
<i>Tilia americana</i>	6.6	0.5	0.32	1.3	0.08	1.20	3.0
<i>Acer pensylvanicum</i>	8.0	0.6	0.07	0.3	0.13	0.02	0.9
<i>Hamamelis virginiana</i>	9.2	0.7	0.04	0.2	0.13	0.02	0.9
Total	745.8		24.55		6.50		

Table 8. Snag characteristics for the Big Junction site in the Unicoi Mountains along the Cherohala Skyway, NC.

Species	Density (no./ha)	Relative density	Dominance (m <sup>2</sup> /ha)	Relative dominance	Frequency	Relative frequency	Importance value
Unknown	55.7	28.8	384.7	59.2	0.83	31.2	119.2
<i>Fagus grandifolia</i>	73.0	37.8	214.7	33.0	0.79	29.7	100.5
<i>Acer spicatum</i>	42.5	22.0	18.0	2.8	0.63	23.7	48.5
<i>Betula allagheniensis</i>	9.3	4.8	23.4	3.6	0.21	7.9	16.3
<i>Acer saccharum</i>	5.3	2.7	3.6	0.6	0.08	3.0	6.3
<i>Magnolia acuminata</i>	2.7	1.4	1.0	0.2	0.08	3.0	5.9
<i>Amelanchier arborea</i>	2.7	1.4	4.6	0.7	0.04	1.5	3.6
Total	19.8		650.0		2.66		

Table 9. Snag characteristics for the Whigg Branch site in the Unicoi Mountains along the Cherohala Skyway, NC.

Species	Density (no./ha)	Relative density	Dominance (m <sup>2</sup> /ha)	Relative dominance	Frequency	Relative frequency	Importance value
Unknown	98.2	41.3	6.62	80.6	0.88	30.1	152.0
<i>Betula alleghaniensis</i>	61.0	25.7	0.32	3.9	0.38	13.0	42.6
<i>Fagus grandifolia</i>	22.6	9.5	0.33	4.0	0.46	15.8	29.3
<i>Tsuga canadensis</i>	8.0	3.4	0.27	3.3	0.13	4.3	11.0
<i>Acer rubrum</i>	6.6	2.8	0.06	0.7	0.17	5.8	9.3
<i>Ilex montana</i>	8.0	3.4	0.03	0.4	0.13	4.3	8.1
<i>Tilia americana</i>	5.3	2.2	0.20	2.4	0.08	2.7	7.3
<i>Halesia carolina</i>	5.3	2.2	0.04	0.5	0.13	4.5	7.2
<i>Hamamelis virginiana</i>	8.0	3.4	0.03	0.4	0.08	2.7	6.5
<i>Magnolia fraseri</i>	1.3	0.6	0.20	2.4	0.08	2.7	5.7
<i>Prunus pensylvanicum</i>	2.7	1.1	0.07	0.9	0.08	2.7	4.7
<i>Acer saccharum</i>	5.3	2.2	0.02	0.2	0.04	1.4	3.3
Total	237.6		8.19		2.64		



Table 10. Vegetation characteristics for the shrub layer at the Big Junction site in the Unicoi Mountains along the Cherohala Skyway, NC.

Species	Density (no./ha)	Relative density	Dominance (m <sup>2</sup> /ha)	Relative dominance	Frequency	Relative frequency	Importance value
<i>Viburnum alnifolium</i>	3052.0	37.2	0.2300	36.1	1.00	21.6	94.90
<i>Fagus grandifolia</i>	2340.8	28.5	0.1800	28.2	1.00	21.6	78.30
<i>Rubus canadensis</i>	1682.6	20.5	0.1300	20.4	0.50	10.8	51.70
<i>Acer spicatum</i>	392.8	4.8	0.0300	4.7	0.71	15.3	24.80
<i>Betula alleghaniensis</i>	212.4	2.6	0.0200	3.1	0.46	9.9	15.60
<i>Ilex montana</i>	122.0	1.5	0.0100	1.6	0.38	8.2	11.30
<i>Hydrangea</i> sp.	207.0	2.5	0.0200	3.1	0.04	0.9	6.50
<i>Acer saccharum</i>	58.4	0.7	0.0040	0.6	0.21	4.5	5.80
<i>Ribes</i> spp.	53.0	0.7	0.0060	0.9	0.13	2.8	4.40
<i>Vaccinium</i> spp.	74.4	0.9	0.0060	0.9	0.08	1.7	3.50
<i>Amelanchier arborea</i>	5.4	0.1	0.0004	0.1	0.04	0.9	1.06
<i>Magnolia accuminata</i>	5.4	0.1	0.0004	0.1	0.04	0.9	1.06
<i>Cornus alternifolia</i>	5.4	0.1	0.0004	0.1	0.04	0.9	1.06
Total	8211.6		0.6372		4.63		

Table 11. Vegetation characteristics for the shrub layer at the Whigg Branch site in the Unicoi Mountains along the Cherochala Skyway, NC.

Species	Density (no./ha)	Relative density	Dominance (m <sup>2</sup> /ha)	Relative dominance	Frequency	Relative frequency	Importance value
<i>Rhododendron maximum</i>	4187.90	44.43	0.2400	44.004	0.54	17.71	106.14
<i>Rubus canadensis</i>	3742.40	39.67	0.1800	33.003	0.33	10.82	83.49
<i>Fagus grandifolia</i>	488.32	5.18	0.0400	7.334	0.33	10.82	23.33
<i>Betula alleghaniensis</i>	329.08	3.49	0.0300	5.501	0.17	5.57	14.56
<i>Viburnum alnifolium</i>	207.00	2.20	0.0160	2.934	0.25	8.20	13.33
<i>Tsuga canadensis</i>	79.62	0.85	0.0060	1.100	0.25	8.20	10.15
<i>Halesia carolina</i>	90.10	0.96	0.0060	1.100	0.21	6.89	8.95
<i>Ilex montana</i>	95.54	1.01	0.0100	1.834	0.17	5.57	8.42
<i>Aesculus flava</i>	53.08	0.56	0.0040	0.733	0.17	5.57	6.87
<i>Acer pensylvanicum</i>	26.54	0.28	0.0020	0.367	0.17	5.57	6.22
<i>Acer spicatum</i>	21.22	0.23	0.0020	0.367	0.17	5.57	6.16
<i>Hamamelis virginiana</i>	42.66	0.45	0.0030	0.550	0.13	4.26	5.26
<i>Magnolia fraseri</i>	37.16	0.39	0.0030	0.550	0.04	1.31	2.25
<i>Acer saccharum</i>	5.30	0.06	0.0020	0.367	0.04	1.31	1.73
<i>Ribes</i> spp.	15.92	0.17	0.0010	0.183	0.04	1.31	1.66
<i>Sambucus pubens</i>	5.30	0.06	0.0004	0.001	0.04	1.31	1.37
Total	9427.14		0.5454		3.05		

variables at both sites (Tables 12 and 13). Moss was ubiquitous in among the plots sampled. Shining clubmoss was present in 36 of 48 (75%) of the home range plots. In the Big Junction site sedges were nearly ubiquitous (present in 23 out of 24 plots), sometimes found in dense carpets. By contrast, sedge abundance in the Whigg Branch site was less, as only 4 of 24 plots contained this feature.

Both Big Junction and Whigg Branch sites were mesic in quality, as both sites had numerous springs, seeps and a series of intermittent drainages. The Whigg Branch site, however, contained the headwaters of a permanent free-flowing stream and several large seeps were present. By contrast, the seeps at the Big Junction site were much smaller. Of the plots sampled at the Whigg Branch site 66.7% contained water, while 62.5% of the plots sampled at the Big Junction site contained water.

Dead and rotting logs (i.e., coarse woody debris) were prevalent in both sites, but varied in area ( $\text{m}^2$ ) of covering the forest floor. Coarse woody debris at the Big Junction site covered an average of  $6.2 \text{ m}^2$  (range =  $0.06 \text{ m}^2$  -  $11.7 \text{ m}^2$ ), while at the Whigg Branch site it averaged  $8.5 \text{ m}^2$  (range = 0 -  $17.0 \text{ m}^2$ ).

### *Statistical habitat analyses*

The single-factor ANOVAs revealed 20 significant differences associated with 16 of the 19 habitat variables tested across the four treatments: areas of use; seasons; sexes and sites (Table 14). The habitat differed mostly between the seasons and between the sites, where eight of the 19 habitat variables differed between summer and winter, while nine differed between the Big Junction and Whigg Branch sites. The habitat in high-use and low-use areas differed for only 3 of the 19 variables, while no difference in the habitat between male and female home ranges was observed. The two-way



Table 12. Characteristics for ground cover vegetation at the Big Junction in the Unicoi Mountains site along the Cherokee Skyway, NC.

Species	Dominance	Relative dominance	Frequency	Relative frequency	Importance value
Moss	8.29	23.93	0.78	21.61	45.54
Sedges ( <i>Carex</i> spp.)	10.01	28.86	0.54	14.99	43.85
<i>Dryopteris</i> spp. (wood ferns)	6.30	18.17	0.51	14.12	32.29
<i>Viburnum alnifolium</i>	3.87	11.16	0.40	10.95	22.11
<i>Huperzia lucidulum</i> (shining clubmoss)	1.70	4.90	0.42	11.53	16.43
Lichens	1.20	3.46	0.41	11.24	14.70
<i>Fagus grandifolia</i>	0.96	2.77	0.17	4.61	7.38
<i>Rubus canadensis</i> (thornless blackberry)	0.69	2.00	0.13	3.46	5.46
<i>Acer spicatum</i>	0.72	2.08	0.07	2.02	4.10
<i>Vaccinium</i> spp.	0.33	0.95	0.05	1.44	2.39
<i>Acer pensylvanicum</i>	0.26	0.75	0.04	1.15	1.90
<i>Euonymus obovatus</i> (strawberry-bush)	0.13	0.37	0.04	1.15	1.52
<i>Acer saccharum</i>	0.15	0.43	0.03	0.86	1.29
<i>Ribes</i> spp.	0.04	0.12	0.01	0.29	0.41
<i>Ilex montana</i>	0.03	0.09	0.01	0.29	0.38
<i>Prunus serotina</i>	0.01	0.03	0.01	0.29	0.32
Total	34.68		3.61		

Table 13. Characteristics for ground cover vegetation at the Whigg Branch site in the Unicoi Mountains along the Cherohala Skyway, NC.

Species	Dominance	Relative dominance	Frequency	Relative frequency	Importance value
Moss	11.656	46.966	0.81	33.09	80.06
<i>Dryopteris</i> spp. (wood ferns)	4.271	17.209	0.43	17.38	34.59
<i>Huperzia lucidulum</i> (shining clubmoss)	3.854	15.529	0.30	12.29	27.82
Lichens	0.599	2.414	0.29	11.88	14.29
<i>Rhododendron maximum</i>	1.081	4.356	0.14	5.50	9.86
<i>Viburnum alnifolium</i>	0.914	3.683	0.09	3.83	7.51
<i>Rubus canadensis</i> (thornless blackberry)	0.510	2.054	0.09	3.83	5.88
<i>Fagus grandifolia</i>	0.734	2.958	0.06	2.56	5.52
<i>Acer saccharum</i>	0.120	0.483	0.06	2.56	3.04
<i>Euonymus obovatus</i> (strawberry-bush)	0.322	1.297	0.04	1.71	3.01
<i>Prunus pensylvanica</i>	0.063	0.254	0.03	1.26	1.51
<i>Halesia carolina</i>	0.149	0.600	0.02	0.86	1.46
<i>Ilex montana</i>	0.260	1.048	0.01	0.41	1.46
Sedges ( <i>Carex</i> spp.)	0.104	0.419	0.01	0.41	0.83
<i>Tsuga canadensis</i>	0.074	0.298	0.01	0.41	0.71
<i>Sambucus pubens</i>	0.052	0.210	0.01	0.41	0.62
<i>Acer pensylvanicum</i>	0.035	0.141	0.01	0.41	0.55
<i>Acer rubrum</i>	0.015	0.060	0.01	0.41	0.47
<i>Prunus serotina</i>	0.004	0.016	0.01	0.41	0.42
<i>Ribes</i> spp.	0.001	0.004	0.01	0.41	0.41
Total	24.818		2.46		

ANOVAs, which examined the six possible combinations of treatments, tested two at a time, revealed 13 significant interactions for 12 of the 19 habitat variables. Three of the 19 habitat variables (number of shrubs/saplings, coarse woody debris (CWD) category D4, and total coarse woody debris; Table 14) exhibited no significant differences in any of the single-factor or two-way ANOVAs.

#### High-use vs. low-use areas

The three habitat variables that differed significantly between high-use and low-use areas within home ranges, determined by the single-factor ANOVAs, were obscurity of the shrub/sapling layer, area ( $\text{m}^2$ ) covered by class 3 CWD, and forb coverage (%) (Table 14). The shrub/sapling layer in low-use areas was significantly more obscured (mean =  $69\% \pm 25$ ) than in the high-use areas (mean =  $59\% \pm 23$ ) ( $F_{1,47} = 4.7$ ,  $P = 0.04$ ). Though these results indicate flying squirrels are found less often in areas with a more obscured shrub/sapling layer; the results likely reflect a difference associated with the two sites rather than a pattern associated with differences between high- and low-use areas. The average obscurity found in the Whigg Branch site ( $75\% \pm 20$ ) was significantly greater than that for the Big Junction site ( $53\% \pm 23$ ) ( $F_{1,47} = 26.9$ ,  $P < 0.0001$ ). Areas of low-use within home ranges had more area covered with decay class 3 CWD (mean =  $2.1 \text{ m}^2 \pm 1.6$ ) than did the high-use areas (mean =  $1.1 \text{ m}^2 \pm 1.3$ ) ( $F_{1,47} = 5.3$ ,  $P = 0.03$ ). In addition, the high-use areas of flying squirrel home ranges contained significantly higher forb coverage (mean =  $9.9\% \pm 17$ ) than in the low-use



Table 14. Results from the single-factor and two-way ANOVA designs for the 19 habitat variables tested across the four treatment levels of areas of use (high-use, low-use), seasons (summer, winter), sexes, and sites (Big Junction, Whigg Branch). Results from the single-factor ANOVA for the occupied vs. unoccupied areas is also depicted. Significant differences of  $P < 0.05$  (\*),  $P < 0.01$  (\*\*), and  $P < 0.005$  (\*\*\*) are denoted.

Variable	Single-factor ANOVAs					Two-way ANOVAs				
	Areas of use	Seasons	Sites	Sexes	Occupied vs unoccupied areas	Areas by seasons	Areas by sexes	Seasons by sexes	Seasons by sites	Sexes by sites
Canopy closure		***	*						*	
Snag density		***							**	
Obscurity	*	*	***		*				***	
Shrub/sapling density										
CWD area (D2)			*							
CWD area (D3)	*								*	
CWD area (D4)										
CWD area (D5)			***							*
CWD area (4/5)			*							
CWD area (total)										
Open water			*							
Exposed rock		*					**			
Woody seedlings		***	**						*	
Forbs	*	***					*			*
Ferns		***								
Sedges		*	***					*		
Shining clubmoss										
Moss						*				
Lichens			*			**			*	

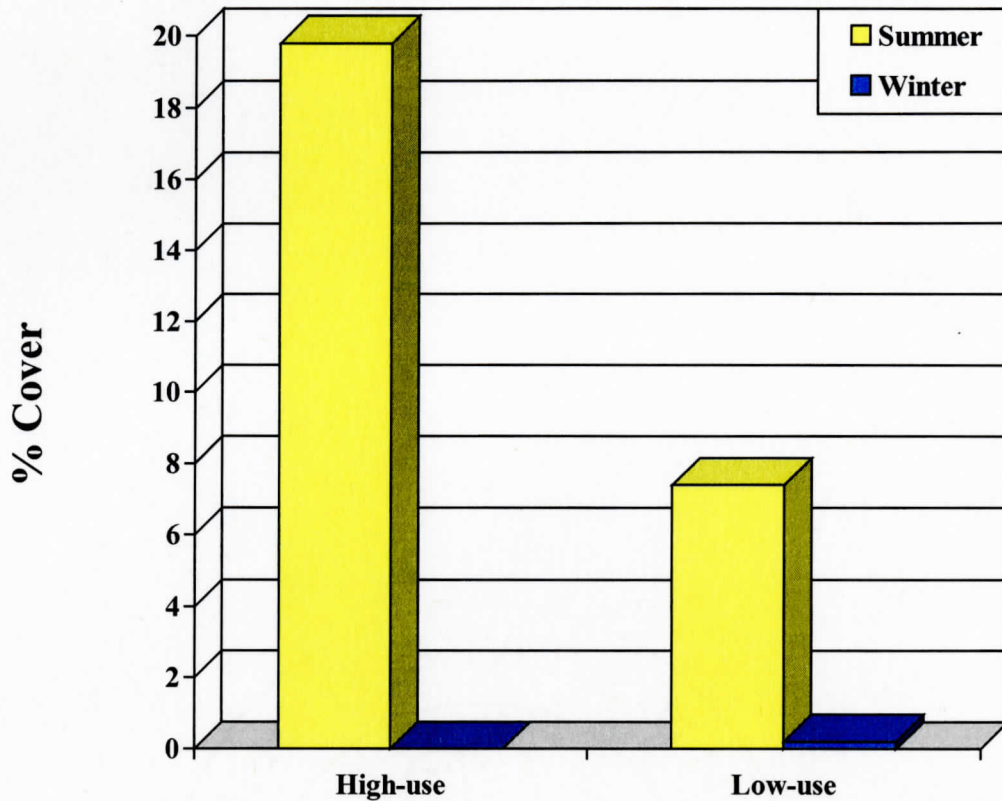


Fig. 9. Average coverage (%) of forbs in high-use and low-use areas during summer and winter seasons. Results are from a two-way ANOVA that examined area of use (high-use vs. low-use) and seasons (summer vs. winter).

areas (mean =  $3.8\% \pm 7.3$ ), but only slightly ( $F_{1,47} = 4.57$ ,  $P = 0.04$ ). The two-way ANOVA results that tested the effects of area of use and season for forb coverage revealed the degree to which high-use and low-use areas differed in forb coverage depended on the season (Fig. 9).

#### Summer vs. winter

The single-factor ANOVAs that examined all the habitat variables by season revealed eight significant summer vs. winter comparisons (Table 14): overstory canopy closure; density of snags; obscurity of shrubs/saplings; coverage (%) of rock; coverage (%) of seedlings; coverage (%) of forbs; coverage (%) of ferns; and coverage (%) of

sedges. Of these, canopy closure, obscurity of the shrub/sapling layer, and coverage of seedlings, forbs, ferns, and sedges were expected to differ between the seasons.

For snag density, the single-factor ANOVA showed the mean density of snags per hectare found in the summer home ranges ( $284.9/\text{ha} \pm 205$ ) was significantly greater than the mean density found in the winter home ranges ( $114.5/\text{ha} \pm 82.7$ ) ( $F_{1,47} = 9.5$ ,  $P = 0.004$ ). A significant interaction was revealed by the season-by-site two-way ANOVA test for snag density (Table 14). This result indicated snag density, though different between seasons, was dependant on the site. Indeed, the Whigg Branch summer home ranges contained significantly more snags than the winter home ranges (Fig. 10), which likely drove the large seasonal difference depicted by the single-factor ANOVA.

#### Big Junction vs. Whigg Branch

Among the four treatments tested via the single-factor ANOVAs, the habitat variables differed more often between the sites than between the sexes, across the seasons, or in high- vs. low-use areas; indeed, the Big Junction and Whigg Branch sites differed significantly in 9 of the 19 vegetation measures (Table 14). The Whigg Branch site had significantly greater canopy closure ( $F = 4.4$ ,  $\text{df} = 47$ ,  $P = 0.04$ ), obscurity of the shrub/sapling layer ( $F_{1,47} = 26.9$ ,  $P < 0.0001$ ), coverage of class 5 CWD ( $F_{1,47} = 12.8$ ,  $P = 0.001$ ), coverage of class 4/5 (classes combined) CWD ( $F_{1,47} = 4.8$ ,  $P = 0.04$ ) and coverage of open water ( $F_{1,47} = 5.92$ ,  $P = 0.02$ ). Conversely, the Big Junction site had greater coverage of class 2 CWD ( $F = 5.95$ ,  $\text{df} = 47$ ,  $P = 0.02$ ), woody seedlings ( $F = 4.9$ ,  $\text{df} = 47$ ,  $P = 0.03$ ), sedges ( $F = 19.3$ ,  $\text{df} = 47$ ,  $P = 0.0001$ ), and lichens ( $F = 4.4$ ,  $\text{df} = 47$ ,  $P = 0.04$ ) (Fig's 11 and 12).



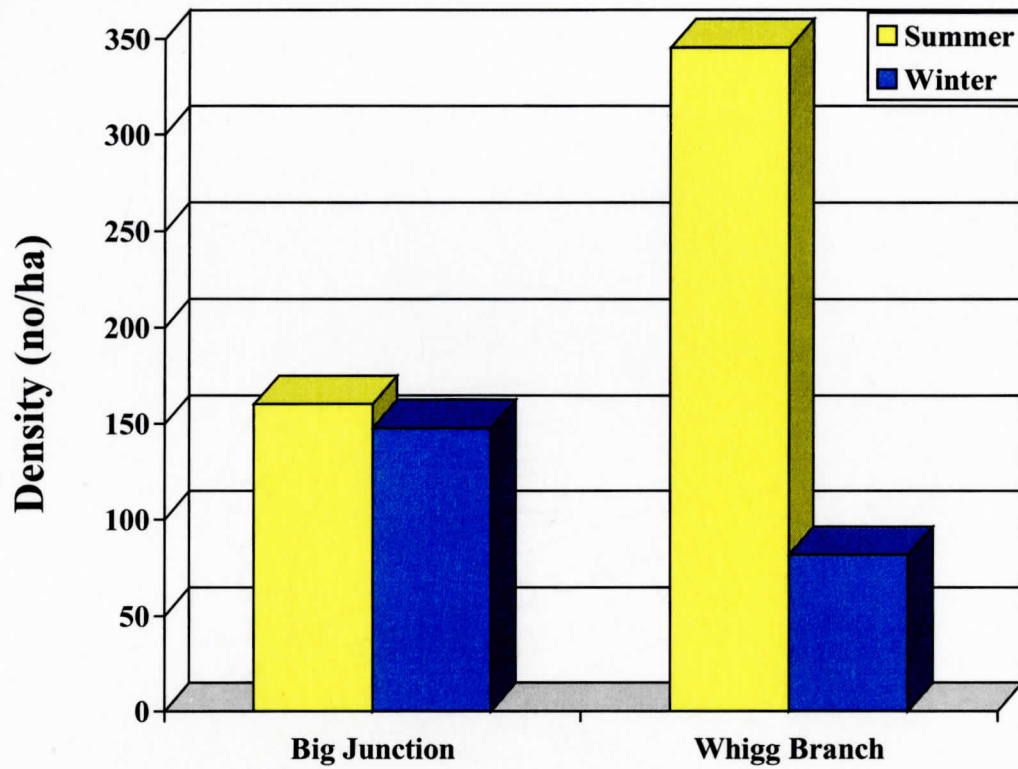


Fig. 10. Average density (no./ha) of snags in the Big Junction and Whigg Branch sites during summer and winter seasons. Results are from a two-way ANOVA that examined the sites (Big Junction vs. Whigg Branch) and seasons (summer vs. winter).

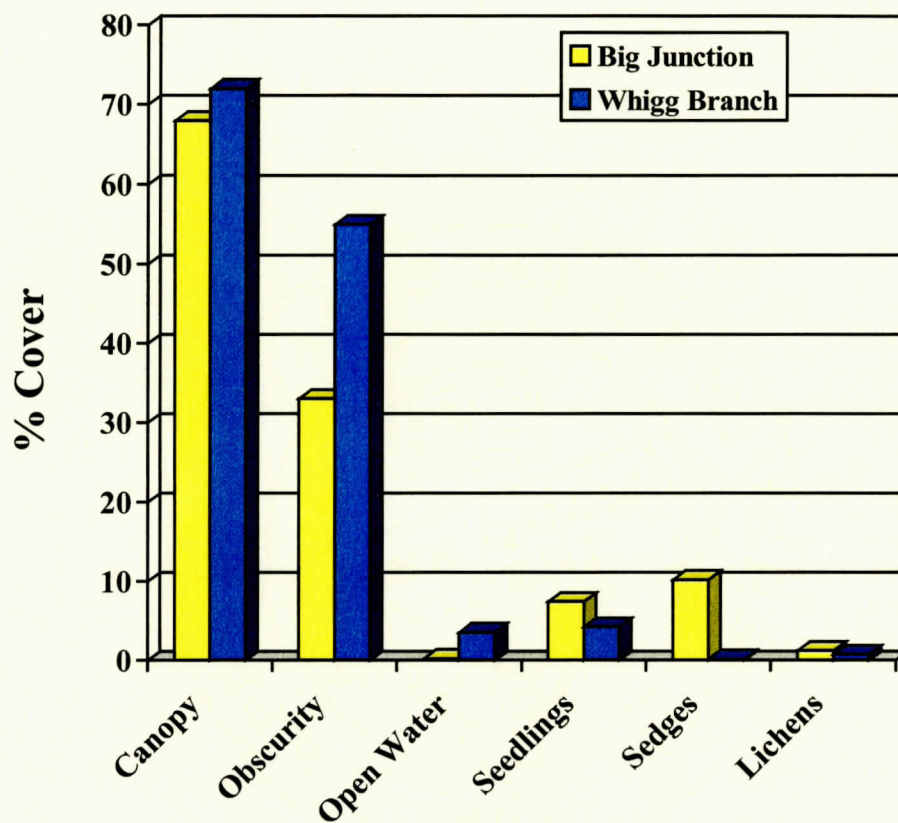


Fig. 11. Differences in mean percent coverage of six ground cover habitat variables between the Big Junction and Whigg Branch sites in the Unicoi Mountains, along the Cherohala Skyway, NC.

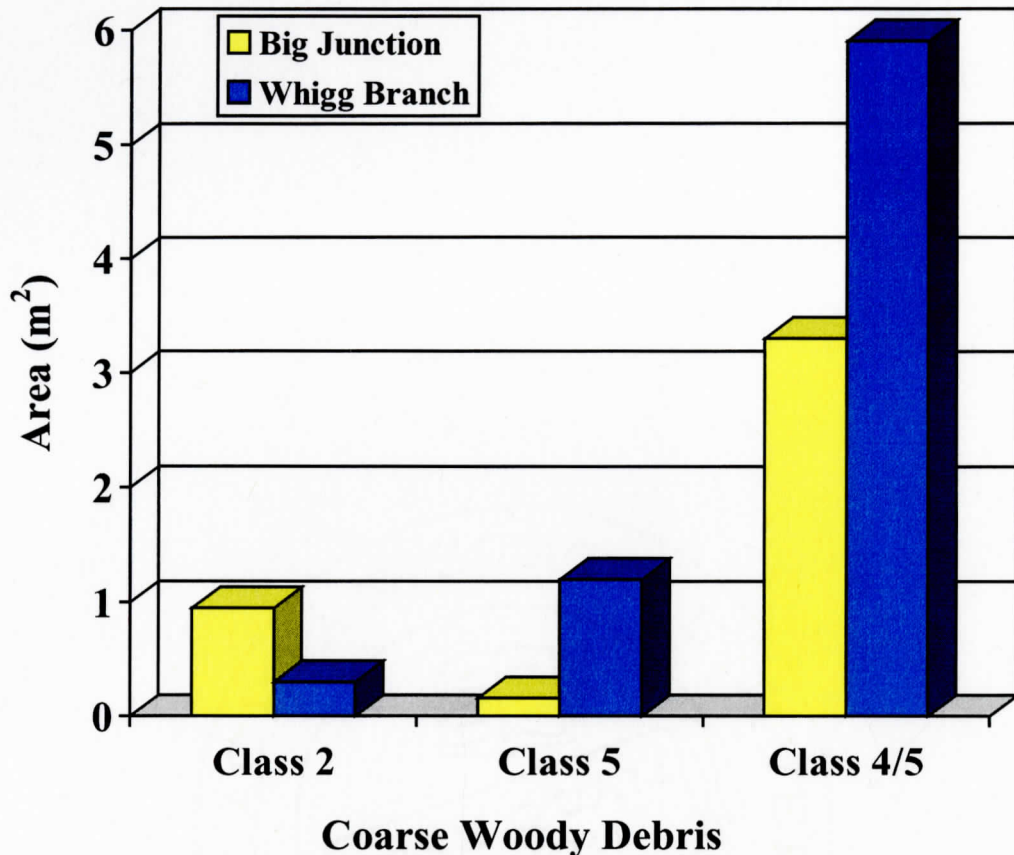


Fig. 12. Differences in mean area of coverage for coarse woody debris of decay classes 2, 5, and 4/5 (classes 4 and 5 combined) between the Big Junction and Whigg Branch sites in the Unicoi Mountains, along the Cherohala Skyway, NC.

#### Occupied vs. unoccupied sites

The habitat in occupied (winter home ranges) and unoccupied (trap sites with no captures) sites differed only in regard to obscurity of the shrub/sapling layer (Table 14). No differences were detected for any of the other habitat variables examined. The shrub/sapling layer was more obscured in the occupied areas (mean =  $58\% \pm 30$ ) than the unoccupied areas (mean =  $40\% \pm 10$ ) ( $F_{1,47} = 7.1$ ,  $P = 0.01$ ), as rhododendron was present in the Whigg Branch site.



## DISCUSSION

### *Radiotelemetry*

The use of radiotelemetry to study northern flying squirrel home ranges, habitat use, and den-sites has been employed in a number of studies throughout North America and provides the only means to examine home ranges of the species. For example, in northwestern North America studies incorporating radiotelemetry were conducted in interior Alaska (Mowrey and Zasada 1984), northwest British Columbia (Cotton and Parker 2000a, 2000b), central Oregon (Martin and Anthony 1999) and western Oregon (Witt 1992). Until now radiotelemetry studies in the eastern U.S. have been limited to summer work in West Virginia (Urban 1988) and in Pennsylvania and western North Carolina (Weigl and Osgood 1974). Weigl et al. (1999) and this study represent the only two studies to include both winter and summer telemetry data on eastern populations of northern flying squirrels.

Despite the common use of radiotelemetry in wildlife field studies, the accuracy of the telemetry systems when used for plotting locational data gathered via triangulation is usually not ascertained. Ultimately, the objectives of a study will determine how much telemetry error is acceptable (White and Garrott 1990). For example, in habitat use studies accurate and precise telemetry locations are very important because the investigators need to determine which specific habitat patch the study animals are using. If animals are located in habitat "A" when actually they were in habitat "B" misleading

conclusions will result (Samuel and Kenow 1992). Therefore, accurate and precise telemetry locations are desired in habitat use studies. Habitat use was not a focus of this study; therefore, accurate and precise locations of flying squirrels within the habitats were not essential. Instead, I used the telemetry locations to identify concentrations of telemetry locations for estimating high-use areas within home ranges; thus, the error associated with each telemetry location is more acceptable. Only two of the northern flying squirrel studies that utilized radiotelemetry for home ranges considered the precision and accuracy of the telemetry locations. Martin and Anthony (1999), working in the Cascade Mountains of Oregon, reported an average bearing error (difference between estimated vs. true bearings) of  $14^{\circ}$  (range = 0 - 45.5) in old-growth stands and  $12^{\circ}$  (range = 0 - 29) in second-growth stands that resulted in a mean error of location (distance the estimated location was from the actual location of transmitter) of 23.8 m in old-growth stands and 24.6 m in second-growth stands. Milling (2000) in a study of northern saw-whet owl home ranges in the southern Appalachians found an average error angle (i.e., average bearing error) of  $9^{\circ}$ . The mean errors (i.e., average bearing error) in this study were  $6.8^{\circ}$  ( $\pm 5.8$  SD, range = 0 - 27) and  $6.9^{\circ}$  ( $\pm 5.2$  SD, range = 0 - 24) for the Big Junction and Whigg Branch sites, respectively. It is apparent that radiotelemetry systems used for triangulation in mountainous and rugged terrain can have relatively large errors associated with the telemetry locations. Unfortunately, little can be done to correct this error, especially when working in rugged and remote terrain, outside of redesigning study objectives.

### *Home ranges*

The MCP method employed in this study essentially uses the outermost telemetry points as the outside boundary of the home range. The major disadvantage of this method is that as the number of telemetry locations increases so does the home range size (Jennrich and Turner 1969) because this method estimates total area utilized not the area used during normal movements (White and Garrott 1990). Thus, as more telemetry locations are added the greater the chances non-normal movements will be included. To reduce this problem, and increase the likelihood of capturing normal movements, outlier locations associated with non-normal movements must be eliminated (White and Garrott 1990). I eliminated a number of outlier locations for flying squirrels #3 and #28. For flying squirrels #3 and #28 several long distance forays outside their respective home ranges were considered non-normal movements as they occurred infrequently (only twice for male #3 and once for male #28); therefore, I eliminated the telemetry locations associated with them. The cumulative area curves plotted for all radio-tracked flying squirrels (Fig. 6) indicated four to nine nights of monitoring provided reliable home range estimates for most of the flying squirrels.

### Unicoi Mountains

Home ranges in the Unicoi Mountains did not differ between summer and winter for the four radiocollared flying squirrels in this study, a result that was largely unexpected. I expected summer home ranges to be larger than winter home ranges because I observed greater nightly activity in summer (mean = 4.4+ hrs of squirrel activity/telemetry night) than in winter (mean = 2.0+ hrs of squirrel activity/telemetry night) (Weigl et al. 2002), but this was not the case. In fact, the opposite would have



resulted had the outlier telemetry locations for males #3 and #28 not been excluded from the analyses. The similarity in the seasonal home range sizes, and provided I did not observe any major adjustments in home-range placement (high degree of fidelity), suggests the flying squirrels in this study did not respond seasonally to changing resource availability, environmental changes, or energetic needs (Fridell and Litvaitis 1991; Phillips et al. 1998). Northern flying squirrels are capable of switching their diet during different times of the year (Maser et al. 1985, Weigl et al. 1999), which might suggest their home ranges would not need to change much from season to season. Maser et al. (1985) found that northern flying squirrels in the Pacific Northwest feed chiefly on truffles during the summer months then switch to lichens in winter months when truffles are less abundant (North et al. 1997).

Although the differences between male and female home ranges for this study could not be analyzed statistically, a pattern of larger home range sizes for males is suggested by the home range estimates (Table 5). Though these observations are speculative, other northern flying squirrel studies show a similar pattern between male and female home ranges (Urban 1988, Witt 1992, Gerrow 1996, Martin and Anthony 1999, Weigl et al. 1999, Cotton and Parker 2000a). It has been suggested that male northern flying squirrels are more mobile than females, which explains the larger home ranges for males (Weigl et al. 1999). Although it is unclear why this is so, Weigl et al. (1999) speculated this pattern might be a reflection of social interactions or resource utilization. They observed that long distance movements of males at Roan Mountain coincided with a period of late winter breeding, which suggests these movements are related to finding mates and would explain in part why home ranges of males were larger

than females. Although in my study the breeding condition of males #3 and #28 was not known at the time their long distance forays were made, their movements were clearly atypical. These forays were extensive (#28 traveled a linear distance of over 1 km) and were obviously deliberate, as these squirrels covered these distances within relatively short time periods. My trapping records show other male flying squirrels were in breeding condition (distended testes) close to the times these males exhibited this behavior. Thus, my observations provide evidence to suggest social interactions influence the home ranges of male northern flying squirrels.

Alternatively, larger home range size for male northern flying squirrels might be explained by differences in resource utilization between the sexes. At Roan Mountain, Weigl et al. (1999) observed numerous small pits on the forest floor in areas male northern flying squirrels traveled to during long distance forays and suggested these animals moved great distances to utilize truffles. Fridell and Litvaitis (1991) observed significant differences in male and female home range sizes for southern flying squirrels and found male home ranges contained significantly more mast trees and female home ranges had significantly more snags. Their findings strongly suggested male and female southern flying squirrels utilize habitat differently based on resource utilization that was reflected in larger home range sizes for males.

#### Unicoi Mountain vs. Roan Mountain

It has been suggested that the northern hardwood and northern hardwood-hemlock habitats found to support northern flying squirrels in the southern Appalachians might be marginal (Weigl et al. 1999). Thus, one might expect, based on the differences in appearance of the Unicoi Mountain and Roan Mountain habitats, that resource abundance

and availability are different between them. If true, one would expect the home range sizes to be different between the marginal habitat in the Unicois and the more suitable habitat of Roan Mountain. The fact the average home range size for my study (mean =  $13.9 \pm 3.7$  ha) is not significantly different than the average home range size found at Roan Mountain (mean =  $8.9 \pm 2.2$  ha) ( $t = 1.25$ ,  $df = 15$ ,  $P = 0.24$ ) suggests resource abundance and availability is similar between the two areas despite the differences in the appearance of the habitat between the two areas.

I found the average northern flying squirrel home range size in the Unicoi Mountains appears larger than the average home range sizes reported in other areas (Table 15 provides a summary of the average home range sizes reported for northern flying squirrels), though Mowrey and Zasada (1984) reported one estimated home range (in Alaska) to be 31 ha. The reasons for these differences are largely unknown; however I speculate this pattern largely reflects differences in habitat quality between the southern Appalachians and other locations. Thus, larger home range sizes in the southern Appalachians might indicate food resources are either less abundant or widely spaced in a patchy distribution. In support, Weigl et al. (1999) suspected that truffles might be patchily distributed across the landscape at Roan Mountain indicated by the long distance movements of male flying squirrels. However, if this were true home ranges for females would be larger and they too might demonstrate the capacity to move great distances in search of resources.



Table 15. Summary of home range sizes for northern flying squirrels reported in North America. Table adapted from Cotton and Parker (2000a).

Location	Home Range (ha) <sup>a</sup>	Range (ha)	<i>n</i>	Sex	Source
SW North Carolina	13.9 ± 3.7	3.7-27.7	7	Sexes Combined	Current study
Western North Carolina	8.9 ± 2.2	1.2-22.6	10	Sexes Combined	Weigl et al. (1999)
West Virginia	5.2 ± 1.1	3.1-6.8	3	Males	Urban (1988)
NW British Columbia	3.7 ± 0.9 <sup>b</sup>	0.9-8.6	9	Males	Cotton and Parker (2000a)
	1.4 ± 0.4	0.03-2.2	6	Females	
NW British Columbia	10.3 <sup>c</sup>	2.1-14.5	5	Sexes combined	Mahon and Steventon (in litt.) <sup>d</sup>
Central Oregon	5.9 ± 0.8	2.6-17.0	20	Males	Martin and Anthony (1999)
	3.9 ± 0.4	1.9-8.0	19	Females	
New Brunswick	12.5 <sup>e</sup>		7	Males	Gerrow (1996) <sup>d</sup>
	2.8 <sup>e</sup>		8	Females	
Western Oregon	4.2 ± 0.3		4	Sexes combined	Witt (1992)

<sup>a</sup> Mean ± SE.

<sup>b</sup> Calculated from den-site locations not activity.

<sup>c</sup> Mean only.

<sup>d</sup> Cited by Cotton and Parker.

<sup>e</sup> Median only.

### *Habitat*

#### Statistical considerations

When studying a rare species that occurs in remote and rugged terrain and is not easily captured, it is often difficult to obtain large sample sizes of animals (Weigl et al. 1999). For example, over the course of two years (1989 - 1991) Weigl et al. (1999) radiocollared a total of 19 adult *G. sabrinus*, 10 of which provided enough data to estimate home ranges. Urban (1988) captured 23 individual *G. s. fuscus* in 4820 trapnights and was able to radio-track only three individuals for home range and activity analyses. My study was no exception, as a total of 25 individual northern flying squirrels

were captured in 2042 trapnights (Table 2), 10 of which were radiocollared. Because I was interested in seasonal home ranges and habitat characteristics, I was limited to a small sample size of four flying squirrels for which both summer and winter home range data were collected, and for which to sample the habitat. Because the four flying squirrels were split evenly between the two sites and split between sexes, I had to take into consideration the differences between the two sites and possible differences in habitat utilization between sexes (as demonstrated by *G. volans*, Fridell and Litvaitis 1991). Therefore, I could not use the flying squirrels ( $n = 4$ ) as a sample of independent replicates for the habitat analysis. Instead, I used the habitat plots ( $n = 48$ ) as my sample of replicates led to testing for treatment effects using non-independent replicates, which led to pseudoreplication (Hurlbert 1984, Zar 1996). However, given that obtaining a large sample size of flying squirrels was impossible, and that any information regarding the habitat requirements of this endangered subspecies might be critical, I felt that statistical analyses were appropriate in spite of pseudoreplication. Still, interpretations drawn from these analyses should be considered preliminary pending confirmation from future studies.

#### Physiographic features

Although the vegetational composition of the northern flying squirrel habitat in the Unicoi Mountains is considered atypical, the physiographic character and many of the non-vegetative characteristics are similar to other, more typical sites in the southern Appalachians. For example, the elevations of the five capture sites averaged 1567 m and ranged from 1427 m at the Whigg Branch site to 1615 m at the Hooper Bald site. Incidentally, the Whigg Branch site is one of two sites in the southern Appalachians

where *G. s. coloratus* has been recorded below 1540 m; the other site is Blanket Mountain in the Great Smoky Mountains National Park where one animal was captured at 1230 m (USFWS 1990, Weigl et al. 1999).

The sites known to harbor northern flying squirrels in the Unicoi Mountains generally lie on north-facing mountainsides, top slopes, and coves (aspect ranged from northeasterly to northwesterly), characteristic of other sites in the southern Appalachians. Both Payne et al. (1989) and Weigl et al. (1999) recognized the importance of high elevation north-facing sites to both subspecies; however, Payne et al. (1989) found that in the northern portion of the distribution of *G. s. fuscus* aspect is more variable. Additionally, Weigl et al. (1999) pointed out that north-facing coves and high-elevation valleys (e.g., Long Hope Valley, Watauga County, North Carolina) can support both boreal habitat and northern flying squirrels at lower elevations than the surrounding mountaintops. The Whigg Branch site in this study is a good example of a sheltered cove site situated at an elevation lower than the typical elevation of flying squirrel habitat. Generally, north-facing slopes and coves receive much less direct sunlight, generating cool, moist conditions favorable to northern flying squirrels (Weigl et al. 1999). The mesic quality of northern flying squirrel habitat throughout the species range is well documented (Dice 1938, Jackson 1961, Wells-Gosling and Heaney 1984, Carey 1995, Waters and Zabel 1995, Carey et al. 1999, Weigl et al. 1999). According to Carey (1995) and Carey et al. (1999) high moisture levels are characteristic of old-growth forests, which support larger populations of northern flying squirrels than younger and managed forests. Moreover, high moisture levels favor the growth of epigeous and hypogeous fungi (Trappe and Maser 1977, North et al. 1997, Carey et al. 1999).



### High-use vs. low-use areas

The high-use and low-use areas within northern flying squirrel home ranges differed only in obscurity, area of class 3 coarse woody debris, and in forb coverage (Table 14). The biological importance of these differences, however, is unclear. The obscurity of the shrub/sapling layer was greater in low-use areas than in high-use areas, which suggests the northern flying squirrels in this study avoided areas with a more obscured shrub/sapling layer. However, I feel this pattern reflected greater obscurity associated with the presence of rhododendron in the understory in the Whigg Branch site (i.e., site differences). Indeed, the average obscurity found in the Whigg Branch site ( $75\% \pm 20$ ) was significantly greater than that for the Big Junction site ( $53\% \pm 23$ ) ( $F_{1,47} = 26.9, P < 0.0001$ ).

The habitat analysis revealed greater forb coverage associated with high-use areas than low-use areas, particularly in the summer. The results from the two-way ANOVA show a significant interaction between areas of use and seasons (Fig. 9). These results produced a mean of  $19.8\% (\pm 19.7\%)$  for forb coverage in summer high-use areas, which is significantly greater than the mean of  $7.4\% (\pm 9.1\%)$  for summer low-use areas ( $F_{1,47} = 4.89, P = 0.03$ ). These results suggest that in the summer northern flying squirrels concentrated their activity in areas where forbs were more abundant. Assuming foraging is the primary activity that occurs during nightly activity periods, a greater forb coverage might aid northern flying squirrels in avoiding predators, as has been suggested in other studies. For example, Urban (1988) found that fern abundance (fern coverage) was correlated with core activity areas in *G. s. fuscus* home ranges and speculated that dense ground cover offered northern flying squirrels protection from predators. Similarly,

Bendel and Gates (1987) found a greater density of shrubs in core-areas within the home ranges of *G. volans* and inferred the dense understory offered the flying squirrels protection from their enemies. If northern flying squirrels in this study were avoiding more open areas, I would have expected high-use areas in winter to contain greater cover, i.e., greater shrub density, but this was not observed. Alternatively, and more plausible, a denser forb layer associated with high-use areas perhaps signifies microenvironmental and soil conditions (e.g., deep, organic soils, soil pH, moisture, etc.) are favorable for the development of some truffle species. North et al. (1997) reported that large clusters of the truffle *Elaphomyces granulatus* are often associated with thick organic soils comprised of a dense mat of roots. In the central and southern Appalachians truffles of the genus *Elaphomyces* ranks high in the diet of both *G. s. coloratus* and *G. s. fuscus* (Weigl et al. 1999, Mitchell 2001).

#### Occupied vs. unoccupied areas

I assumed because the unoccupied areas were “non-capture” trap-sites — therefore, devoid of flying squirrels — I would have observed differences in the habitat, but I did not, the results of which were largely unexpected. The only difference determined by the analyses occurred with regard to the obscurity of the shrub/sapling layer. I feel this difference, however, was largely driven by the presence of rhododendron associated with the occupied areas (specifically the Whigg Branch site), a species that was not found in the unoccupied areas. Nonetheless, the data suggest occupied and unoccupied areas were not very different in terms of the habitat I sampled. Indeed, I found more habitat differences between the Big Junction and the Whigg Branch sites, which were both occupied sites than between occupied and unoccupied areas. These

results indicate the habitat features most important to the flying squirrels are not the features I measured, at least at the level I examined.

### Seasons and sites

The results of my analyses showed that habitat differed mostly between the seasons and between the sites. Eight of the 19 variables differed between the seasons, while 9 of them differed between the sites (Table 14). The significant differences detected by the single-factor ANOVAs for seasons were expected for six of the eight variables because of the deciduous nature of the study site; e.g. canopy closure and forb coverage. The seasonal differences observed for snag density, however, was unexpected. Snag density was greater in summer home ranges (mean density =  $284.9/\text{ha} \pm 205$ ) than winter home ranges (mean density =  $114.5/\text{ha} \pm 87.2$ ), which might indicate that during summer flying squirrels utilized areas with a greater density of snags. However, results from the two-way ANOVA show a significant interaction between sites and seasons, where the density of snags in the Big Junction site was fairly consistent across the seasons, but the density of snags in the Whigg Branch site was much greater in the summer (Fig. 10). This pattern suggests either the Whigg Branch flying squirrels shifted their home ranges seasonally, or the summer habitat plots fell within areas that contained more snags. Figures 8c and 8d illustrate very little change in the location of the home ranges for each flying squirrel occurred between seasons; therefore, home range adjustment is not a plausible explanation. Perhaps these results were simply an artifact of sampling, where a few summer plots were placed in areas that contained more snags. The results of the analyses of the two sites showed nearly half of the habitat features I measured differed between them (Table 14). Considering these differences occurred



between the two sites that produced the most captures indicates that I did not measure the features most important to the flying squirrels. Furthermore, these findings demonstrate *G. s. coloratus* is more general in its habitat requirements as has been suggested by others (Doyle 1990, USFWS 1990, Weigl et al. 1999).

### ***General habitat characteristics***

Though the statistical habitat analyses did not reveal any key habitat features among those I measured, comparable to other Appalachian northern flying squirrel studies (Urban 1988, Payne et al. 1989, Weigl et al. 1999), the descriptive characteristics of the Unicoi Mountains are important to discuss. My study is the first to describe in detail the characteristics associated with habitat considered atypical for *G. s. coloratus* outside the typical spruce-fir/hardwood ecotonal forests. Moreover, like some of the physiographic characteristics, there are a number of vegetational characteristics that are found in more typical habitats in the central and southern Appalachians.

### **Overstory characteristics**

As previously discussed, northern flying squirrels occupy a wide range of habitat types throughout their primary range; yet, all these habitat types typically contain a coniferous element. (Dice 1921, Dice 1938, Jackson 1961, Weigl and Osgood 1974, Wells-Gosling and Heaney 1984, Payne et al. 1989, USFWS 1990, Doyle 1990, Wolesslagle 1994, Weigl et al. 1999). Results of earlier research on Appalachian northern flying squirrels have demonstrated the presence of red spruce and/or Fraser fir as an integral component of suitable northern flying squirrel habitat (Payne et al. 1989, USFWS 1990, Weigl et al. 1999). For example, both Payne et al. (1989) and Weigl et al. (1999) found red spruce ubiquitous throughout their study sites associated with known *G.*

*s. fuscus* and *G. s. coloratus* populations. Likewise, Urban (1988) studied *G. s. fuscus* in mature red spruce forest mixed with northern hardwoods. Furthermore, the fact that much of the Unicoi Mountain habitat is pure northern hardwood forest that lacks a coniferous component altogether indicates conifers are not essential in suitable *G. s. coloratus* habitat. Prior records of Appalachian northern flying squirrels being captured in northern hardwood-hemlock habitat away from spruce-fir (i.e., Blanket Mountain, North Carolina and Montgomery County, Virginia (USFWS 1990, Weigl et al. 1999) provide additional support. Though coniferous trees are known to be the host of a variety of hypogeous fungi consumed by northern flying squirrels (Trappe and Maser 1977, Maser et al. 1986, North et al. 1997, Carey et al. 1999, Waters et al. 2000), northern hardwood species such as beech and birch are also host to a variety of truffles (Trappe and Maser 1977).

Although the overstory species composition of the habitat in the Unicoi Mountains is considered atypical, the presence of snags and older trees in the Unicoi Mountain habitat is characteristic of typical flying squirrel habitat (Payne et al. 1989, USFWS 1990, Weigl et al. 1999). I found snags made up a significant proportion of the overstory (19.2% at the Whigg Branch site and 10.3% at the Big Junction site), which is higher than reported for typical sites. For example, Weigl et al. (1999) found snags averaged 10% of the overstory in their study, while Payne et al. (1989) found snags averaged of 8% of the overstory among 13 study sites sampled in both central and southern Appalachian sites. Furthermore, Payne et al. (1989) observed snags, although variable in numbers, were one of a few habitat features that occurred in every study site. Similarly, I found snags were ubiquitous, but varied in density, among the flying squirrel

home ranges at my study sites in the Unicoi Mountains. These findings strongly suggest snags are an important feature in flying squirrel habitat in the southeastern U.S. and are comparable to the findings of other studies in other geographical regions. For example, several studies in the Pacific Northwest recognized snags as an essential feature of old-growth forests and linked this feature, in part, to the abundance of northern flying squirrels (Rosenberg and Anthony 1992, Carey et al. 1999). It has been suggested that old-growth forests provide an abundance of available nesting sites that favor a greater abundance of flying squirrels (Witt 1992). However, snags, although utilized for denning, are not limiting as northern flying squirrels utilize a wide variety of structures as den sites (Wells-Gosling and Heaney 1984, Clark 1995, Carey et al. 1999, Weigl et al. 1999, Cotton and Parker 2000a). Weigl et al. (2002) observed that 29% of the den sites they located ( $n = 45$ ) were snags. Clark (1995) and Cotton and Parker (2000a) observed a greater use of live trees with structural deformities than snags for cavity den sites. Alternatively, Carey et al. (1999) found that decadence (i.e., overall decomposition within the forest that includes snags, stumps, coarse woody debris, leaf litter and other decomposing matter) was the habitat variable that best predicted flying squirrel activity areas and flying squirrel carrying capacity in Pacific Northwest forests. Further, a number of truffle species, several which are consumed by northern flying squirrels, are associated with coarse woody debris (Trappe and Maser 1977, Carey et al. 1999). Perhaps snags, being an important part of the decadence of the forest, comprise a standing source of decomposing wood that in later stages of decay will fall to the forest floor as coarse woody debris, ultimately providing substrate for some truffle species.



Large trees were not included in the statistical analyses because they did not make up a significant proportion of the forest, yet they occurred in both Big Junction and Whigg Branch sites. These large, older trees are in essence relict old-growth trees left over from past logging events; hence their gnarled appearance and widely scattered distribution. Given these trees are consistently found in sites occupied by northern flying squirrels throughout their range, regardless of species composition and stand age (old-growth vs. second-growth), testifies to their importance (Rosenberg 1990, Rosenberg and Anthony 1992, Woleslagle 1994, Clark 1995, Carey 1995, Carey et al. 1999, Weigl et al. 1999). The function the large trees serve to northern flying squirrels is not fully understood, yet some investigators speculated they serve as launch sites and pathways, thereby facilitating locomotion and offer a source of den sites. For instance, Clark (1995) found that large living trees (old-growth relicts) with structural deformities (i.e., ice and wind damage) were used for denning by northern flying squirrels more frequently than expected. By contrast Carey et al. (1997) found northern flying squirrels in the Oregon Coast Range denned in residual live trees less than expected; however, when available, residual live trees with decay were typically used. Similarly, Cotton and Parker (2000a) found larger, older trees did not occur frequently in their British Columbia study area but were preferred for denning when available. Thus, it appears that relict old trees may benefit northern flying squirrels as sources of den sites. In the southern Appalachians hard winters result in periods of significant icing and snowfall, therefore large trees with structural damage are common. In the Unicoi Mountains the result of severe icing was evident in the crowns of most trees. Further, other studies have suggested northern flying squirrel diet is related to the presence of old-growth trees. Rosenberg (1990) and

Rosenberg and Anthony (1992) found northern flying squirrel abundance was correlated to old-growth features that included old-growth trees. These old-growth features are also correlated with greater ectomycorrhizal fungi abundance (Carey 1995, Waters and Zabel 1995, Carey et al. 1999). Old-growth trees may therefore provide a suite of important resources to northern flying squirrels, from supplying an abundance of ectomycorrhizal hypogeous fungi, to serving as launch sites, to offering cavities for shelter and for food caching (although it still is unknown whether northern flying squirrels cache food).

#### Shrub/sapling characteristics

The shrub/sapling layer of the Big Junction and Whigg Branch sites was a mosaic of woody species varying in density and makeup. Each site differed in species composition, from a hobblebush dominated shrub/sapling layer, typical of the Big Junction site, to a rhododendron dominated shrub/sapling layer at the Whigg Branch site (Tables 10 and 11). Although the analysis determined there was not a significant difference in average shrub/sapling density between the two sites ( $0.83/\text{m}^2$  – Big Junction vs.  $0.80/\text{m}^2$  – Whigg Branch), this layer was actually a mosaic of shrubs and saplings varying in density throughout each site. For example, shrub/sapling density ranged from  $0.3 \text{ stems}/\text{m}^2$  to  $1.4 \text{ stems}/\text{m}^2$  in the Big Junction site and  $0.05 \text{ stems}/\text{m}^2$  to  $3.3 \text{ stems}/\text{m}^2$  in the Whigg Branch site widely throughout each site. Comparable patterns exist in other areas of the southern Appalachians. For example, Weigl et al. (1999) found that understory species composition and density varied a great deal across their study sites. Similarly, Payne et al. (1989) found a highly variable understory, in both species composition and density, among their study sites. They concluded the understory characteristics of northern flying squirrel habitat in the central and southern Appalachians

are of little importance to both subspecies and are not good indicators of suitable northern flying squirrel habitat. Thus, no obvious relationship exists between northern flying squirrels and the shrub/sapling layer in the Unicoi Mountains, or elsewhere in the central and southern Appalachians.

However, several Pacific Northwest studies found a relationship between northern flying squirrel abundance and understory characteristics. Rosenberg (1990), Rosenberg and Anthony (1992), Carey (1995), and Carey et al. (1999) found that although understory density is highly variable in northern flying squirrel habitat, the prevalence of ericaceous shrubs (e.g., *Rhododendron macrophyllum* and *Vaccinium* spp.) within the understory was positively correlated with flying squirrel abundance. Indeed, Carey (1995) suggests that ericaceous shrubs are important to northern flying squirrels and can be considered a predictor of flying squirrel abundance. Though I found ericaceous shrubs in the Big Junction and Whigg Branch sites (e.g., great rhododendron and *Vaccinium* spp.), they were not prevalent in shrub/sapling layer, a pattern that differs from the Pacific Northwest studies. *Rhododendron* was found only in the Whigg Branch site in close proximity to the stream and its associated flood plain, but was not found far from this zone. *Vaccinium* spp. were found occasionally in the understory, but were widely scattered and occurred primarily in the Big Junction site. The differences in understory characteristics of the Unicoi Mountain habitat, and those reported by Weigl et al. (1999) and Payne et al. (1989), to those found in the Pacific Northwest could be due to factors such as climatic differences (boreal climate of the central and southern Appalachian highlands vs. hot dry summers and cool, moist winters of the Pacific Northwest), soil quality, and forest history (disturbed and impacted forests of the



Appalachians vs. the old- and second-growth forest of the Pacific Northwest). It is also possible the importance of the ericaceous shrub component identified in the Pacific Northwest studies is spurious.

#### Ground cover characteristics

The ground cover layer consisted of different vegetative and non-vegetative features. A number of these features were sampled within the plots and represented a majority of the 19 habitat variables measured. Of the 19 variables, 15 were associated with the forest floor (Table 1) and were chosen because of their potential importance to flying squirrels. I found the presence of coarse woody debris was nearly ubiquitous among the plots sampled (e.g., 47 out of 48 plots). Although the analysis revealed significant differences in area for some of the different decay classes, the area covered by coarse woody debris regardless of decay class was not different across the four treatments (Table 6). Though the Big Junction and Whigg Branch sites did not differ in the average coverage of coarse woody debris (all decay classes combined) the abundance of this feature was variable within each site. For instance, in the Big Junction site area of coarse woody debris ranged from 0.06 m<sup>2</sup> to 11.7 m<sup>2</sup> and in the Whigg Branch it ranged from none to 17 m<sup>2</sup>. Payne et al. (1989) and Weigl et al. (1999) observed prevalent, but variable, amounts of coarse woody debris among their respective study sites; a pattern similar to what I found. Therefore, the prevalence of coarse woody debris in Appalachian northern flying squirrel habitat provides evidence to suggest this habitat feature is a fundamental component of suitable habitat in the Appalachians. This association is logical considering decomposing logs are considered important for the development of

some truffle species utilized by northern flying squirrels as food (Trappe and Maser 1977, Maser et al. 1985, Maser et al. 1986).

The most common vegetative ground cover features were those typical of cool, moist environments that included mosses, sedges, ferns and shining clubmoss, with mosses and sedges being ubiquitous. Both moss and ferns were among the highest in importance in both sites throughout the year, but in summer a variety of forbs dominated the ground cover layer. In the Big Junction site sedges were abundant and dominated the ground cover in most plots (Tables 12 and 13). Despite the differences in forest composition between the Unicoi Mountain habitat and typical habitat, the presence and abundance of moss, ferns, and sedges found in this study are similar to typical sites. For example, Weigl et al. (1999) found moss and sedges ranked second and third in importance among their study sites. Urban (1988) found fern abundance greater in core areas of *G. s. fuscus* home ranges. Payne et al. (1989) found that moss and ferns were ubiquitous but highly variable in abundance. Clubmoss was also present in most of the sites examined by Weigl et al. and Payne et al. Once again a shared pattern indicates the importance of a rich floral component of suitable habitat.

### ***Summary and conclusions***

#### **Home ranges**

The results of the home range analysis — which determined average home range size was not different between seasons in the Unicoi Mountains and not different between atypical and typical habitat — suggest that the quality of the habitat is similar between the Unicoi Mountains and Roan Mountain (typical sites). Further, the fact that average home range sizes in this study are among the largest home ranges reported in the

literature (Wells-Gosling and Heaney 1984, Urban 1988, Witt 1992, Martin and Anthony 1999, Cotton and Parker 2000a) might suggest that northern flying squirrel habitat quality in the central and southern Appalachians is marginal compared to the habitat associated with the main range populations. There is much more to be learned about resource selection, movement patterns, and habitat utilization of Appalachian northern flying squirrels through home range study. An evaluation of home range size in the spring and fall seasons could reveal changes in movement patterns or resource selection during the transition from summer to winter and winter to summer, or how home range sizes are adjusted in response to reproductive activity. Additionally, it would be important to know how flying squirrels partition their home ranges across the landscape and how this relates to population densities. For example, we do not know how much overlap occurs among Appalachian northern flying squirrel home ranges, though some overlap does occur (Urban 1988, Weigl et al. 1999). Knowing the arrangement of home ranges can be important when assessing the status of populations relative to the size of the habitat area. Further, additional research focusing on home range dynamics relative to road construction or additional roadways already in place (i.e., Blue Ridge Parkway) is very important to consider for the conservation of the species and its habitat (USFWS 1990). For example, the results from the initial Unicoi Mountain study investigating the potential impacts of the Cherohala Skyway on the populations of northern flying squirrels revealed the Skyway was a barrier to northern flying squirrel movements (Weigl et al. 2002).



## Habitat

The results of the habitat analysis were a bit surprising, as I had hoped by comparing the habitat characteristics between high- and low-use areas as well as occupied and unoccupied areas I could have identified a key habitat feature that might rigorously explain the presence of northern flying squirrels in the Unicoi Mountains. However, I found few differences in the habitat between high- and low-use areas and between occupied and unoccupied sites. Moreover, I found most of the differences in the habitat were seasonal differences and differences between the Big Junction and Whigg Branch sites. Thus, based on the habitat analyses, I can conclude that the habitat features I examined were not the salient features required by *G. sabrinus* in the southern Appalachians. The general habitat characteristics of the Big Junction and Whigg Branch indicate that the two sites are similar in many ways to each other and to more typical sites throughout the species' range. The descriptive analysis of the habitat testifies to the importance of the physiographic characteristics and old-growth character of suitable habitat, which includes: high elevation ( $\geq 1402$  m) north-facing slopes; cool, moist (mesic) conditions; prevalence of snags; scattered old-growth trees; and prevalence of coarse woody debris.

Indeed, a different and more refined approach is needed to examine Appalachian northern flying squirrel habitat. Perhaps a fine scale approach (i.e., fourth-order level, Johnson, 1980) such as examining feeding sites might be the appropriate avenue in determining what are the salient features required by Appalachian northern flying squirrels. This research could focus on microclimate, soils, and habitat/fungal associations. To date only one study examined truffles and their relationship with typical

northern flying squirrel habitats in the southern Appalachians (Loeb et al. 2001) but their inferences were limited due to a small sample size of truffles. Additional research should focus on truffle/habitat associations to follow up on Loeb et al.'s work, especially considering *G. s. coloratus* diet in pure northern hardwood and northern hardwood-hemlock habitat has not been examined. The northern flying squirrel is considered a mycophagist in the forests of the Pacific Northwest and plays a key role in dispersing spores of symbiotic fungi (i.e., truffles) (Trappe and Maser 1977, Maser et al. 1985, Maser et al. 1986, Waters and Zabel 1995, Waters et al. 2000). However, we know little about the role Appalachian northern flying squirrels play in terms of mycophagy in the fragile and declining high-elevation ecosystems. One can assume that because we know *G. s. coloratus* and *G. s. fuscus* eat hypogeous ectomycorrhizal fungi to a large extent they are important to the forest. It appears that fungi make up the majority of the diet of Appalachian northern flying squirrels, but other foods (i.e., staminate conifer cones and beech nuts) are eaten in quantity when they are available (Weigl et al. 1999, Mitchell 2001).

Additionally, the fact that pure northern hardwood and northern hardwood-hemlock forests located far away from spruce-fir, and at lower elevations (e.g., north-facing coves such as the Whigg Branch site) can support *G. s. coloratus* populations is valuable information. This is not to say, however, that spruce-fir is not important to the ecology of *G. s. coloratus*, but merely points out the fact that conifers are not an essential component of suitable habitat. This suggests that *G. s. coloratus* is more of a habitat generalist than once thought and is capable of utilizing different habitat types in the southern Appalachians. However, the consistent presence of old-growth features in

northern flying squirrel habitat throughout its range, despite variation in forest composition and age, terrain, altitude, and latitude, does suggest the northern flying squirrel might actually be a habitat specialist and reaffirms the importance of old-growth characteristics in the habitat.

### ***Conservation and management recommendations***

The conservation and management of the Appalachian northern flying squirrel presents a challenge to say the least. Though we still do not have a real clear understanding of what it is that allow Appalachian northern flying squirrels to persist in the habitat they do, old growth characteristics of the habitat undoubtedly play a part. The recovery of the Appalachian northern flying squirrels rests largely on the management and protection of the habitat. The Recovery Plan outlines a number of steps that is mostly geared toward identifying, delineating, protecting and studying suitable and potential suitable habitat (USFWS 1990). Determining the extent of potential suitable habitat is critical to the recovery of the two subspecies as the status and distribution of the populations and habitat of the two subspecies can be more accurately assessed. The steps outlined in the Recovery Plan for identifying suitable habitat include using indices based on vegetative and physical features such as high elevation north-facing slopes, cool moist conditions, abundance of coarse woody debris, and presence/availability of lichens and fungi to determine areas of potential suitable habitat and delineate its distribution (USFWS 1990). Although past records demonstrate Appalachian northern flying squirrels can occupy atypical habitats, and the recovery plan suggests surveying atypical habitat, rigorous surveys of atypical habitats have not taken place.



Based on the research I presented in this thesis I recommend the following:

- 1) Survey mature northern hardwood forest and northern hardwood-hemlock cove forests that occur above 1080 m on north-facing aspects.
- 2) Consider northern hardwood and northern hardwood-hemlock as suitable habitat (i.e., forest type) when developing new or refining existing GIS-based habitat models (e.g., GIS model developed by Odom, 1995).
- 3) Managing habitat for old-growth characteristics, such that if forests are harvested large trees, snags, and abundant downed woody material are retained. Clear-cut harvesting should be avoided.
- 4) Consider protection of mature and/or old growth north-facing, high-elevation northern hardwood or northern hardwood-hemlock forests.
- 5) Dietary research in conjunction with additional habitat research should be carried out in the Unicoi Mountains.

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## AUTHOR RESUME

Ronald S. Hughes was born in Johnson City, New York, on April 9, 1966. Shortly thereafter he moved to Maine, N.Y. where he attended school; graduating in 1984 from Maine-Endwell Senior High. Subsequently, he attended and graduated with an A.A.S. degree from S.U.N.Y. Ag. & Tech. College (Morrisville, N.Y.) in 1986. Ron then attended The Pennsylvania State University and graduated in 1988 with a B.S. degree in Wildlife Science.

During some of his college years and after graduating, Ron had assisted as a volunteer and worked in both temporary and permanent job assignments in the wildlife biology discipline for a wide array of agencies. His work experience was diverse and includes: field assistance with great-horned owl, woodcock, and ruffed grouse research at Penn State; field assistance on a Rocky Mountain bighorn sheep study in Utah with the U.S. Forest Service/Brigham Young University; research assistance in two Biological Technician positions first with Shenandoah National Park, VA studying habitat, brook trout, and black bears and secondly, with the U.S. Fish and Wildlife Service studying woodcock, waterfowl, and big game (moose and deer); research assistance in woodcock and bobwhite quail research in Louisiana for the Louisiana State University; research assistance in woodcock, snowshoe hare, wild turkey, river otter studies with the Virginia Department of Game and Inland Fisheries (VDGIF); professional work as a Wildlife Biologist Assistant and Forest Stewardship Biologist, and currently as a District Wildlife Biologist with VDGIF managing habitat and wildlife populations on VDGIF lands, providing technical assistance to private landowners, hunt clubs, sportsmen groups, and various natural resource agencies as well as carry out a variety of educational, policy and administrative activities associated with VDGIF.

Ron left VDGIF in 1994 to provide research assistance on the study of the impacts of the Cherohala Skyway on northern flying squirrels in the Unicoi Mountains, which consequently lead him to pursue a Master's of Science degree at Appalachian State University. Over the course of 7+ years Ron has diligently worked on his Master's degree program that was completed in August 2003.