Using a Terrain-based Vegetation Model to Map Carolina Northern Flying Squirrel Distribution

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Abstract: We tested an a priori plant community classification model, developed using topographic characteristics and GIS, to determine if it could be used to predict the distribution of the endangered Carolina northern flying squirrel *(Glaucomys sabrinus coloratus)* in the Balsam Mountains of western North Carolina. Nest boxes were used to sample northern flying squirrel populations in areas of predicted presence versus areas of predicted absence. There was no difference between the two site types for presence or absence of northern flying squirrels. However, significant differences were found for number of squirrels captured and nest boxes used between types. The mixed results of our analyses suggested that our definition of predicted present and predicted absent sites was flawed. Northern flying squirrels were present in spruce/northern hardwood ecotones (predicted present), however they were also present in low densities in spruce/red oak ecotones (predicted absent), though only in portions of the ecotone dominated by spruce. Landowners and managers can utilize the model to help predict whether northern flying squirrels occur, however it should not be used as the sole discriminator.

Key Words: Carolina northern flying squirrel, *Glaucomys sabrinus coloratus*, distribution, GIS

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The Carolina northern flying squirrel is a rarely encountered inhabitant of nine mountain ranges in western North Carolina, Tennessee, and southwestern Virginia (U.S. Fish and Wildlife Service 1990, Weigl et al. 1999). In North Carolina, most northern flying squirrels occupy areas of elevation >1350 m. These areas have been recently impacted by massive tree mortality due to the balsam wooly adelgid *(Adelges piceae).* As a result, the U.S. Fish and Wildlife Service listed the Carolina northern flying squirrel endangered in 1985.

Weigl et al. (1999) explored many aspects of the ecology of this subspecies and found nine populations remain extant. Despite their effort, much information remains unknown. For example, Weigl et al. (1999) estimated >33,000 ha of occupied habitat, and an additional 5,000(±) ha of potential habitat in North Carolina and Tennessee. However, their estimates did not account for inclusions of unsuitable habitat within the high elevation range of the species. Thus, the area occupied by northern flying squirrels may be only a portion of those 38,000 ha.

Based upon previous studies (Wells-Gosling and Heaney 1984, Payne et al. 1989, U.S. Fish and Wildlife Service 1990, Weigl et al. 1999), northern flying squirrels were found in boreal habitats dominated by mixed conifer and northern hardwood forest types. In the Southern Appalachians, their habitat has been characterized as a mosaic and/or ecotone of conifer and northern hardwood forests. In North Carolina, these are comprised of red spruce *(Picea rubens),* Fraser fir *(Abies fraseri),* yellow birch *(Betula alleganiensis),* American beech *(Fagus grandifolia),* maples *(Acer rubrum* and *Acer saccharum),* and hemlock *(Tsuga canadensis).* Many conditions typical of old growth forests abound in habitats known to support northern flying squirrels including large old trees, much downed woody debris, and abundant fungi and lichens (Weigl et al. 1999). Despite considerable effort to identify key habitat components such as plant species composition and structure, soil characteristics, moisture levels, elevation, and other factors, there is no single determinant of habitat suitability for this species nor an inclusive list of habitat components and structure.

Northern flying squirrels typically nest in hardwood tree hollows, or occasionally in the foliage of trees, and their nests are constructed of finely shredded yellow birch bark. In North Carolina, northern flying squirrel nests can be distinguished from nests of sympatric southern flying squirrels *(Glaucomys volans)* and red squirrels *(Tamiasciurus hudsonicus)* (Weigl et al. 1999). All three species will utilize birch bark in their nests and occasionally other materials are used; however, despite similarities, they can be distinguished by virtue of the small size and exclusivity of birch bark strips typical of northern flying squirrel nests in North Carolina (A. C. Boynton, Virginia Department of Game and Inland Fisheries, pers. commun.).

To abide by the provisions of the U.S. Endangered Species Act, all human activities within high elevation habitats that may support this species must be scrutinized to determine if negative effects are likely. Therefore, landowners first must determine if northern flying squirrels occur in a given area. The Appalachian Northern Flying Squirrel Recovery Plan (U.S. Fish and Wildlife Service 1990) identifies subjective steps that can be used to help determine the probability of northern flying squirrel occurrence. Once a determination has been made that an area includes potential habitat for the species, it must be either assumed that they occur, or sufficient trapping effort (with either live traps or nest boxes) must be undertaken. Both survey techniques require considerable time and effort.

Another reason for attempting to determine northern flying squirrel presence or absence is to assess the population dynamics within and between discrete populations. To manage this species into the future we must know what population levels are, where suitable habitat exists, and where the habitats are in relation to each other.

Odom and McNab (2000) used multivariate discriminant analysis and geographic information system (GIS) techniques to predict plant community types (Schafale and Weakley 1990) across the Balsam Mountains of western North Carolina, based upon measurement of vegetation characteristics, slope, elevation, aspect, terrain shape index (TSI; McNab 1989), and landform index (LFI; McNab 1993). Independent field validation of the model resulted in 86% correct classification of field plots (Odom and McNab 2000).

Northern flying squirrels were known to occur in the Balsam Mountains (Weigl et al. 1999, U.S. Fish and Wildlife Service 1990); however, the extent and distribution of them within the Balsam Mountains was unknown. Odom and McNab's (2000) model provided a means to quantify habitat for northern flying squirrels across that landscape without having to sample/trap the entire area. Given that the model was reasonably good at predicting plant community types, this study aimed to determine if Odom and McNab's vegetation model could also accurately predict the presence or absence of northern flying squirrels. If the model could depict areas within this mountain range that supported the squirrels and areas that did not, landowners and managers would be much better equipped to assess population and habitat changes of this endangered species through time. In addition, the vegetation modeling techniques used in the Balsams could be applied to the other northern flying squirrel populations to provide a meaningful depiction of habitat availability now and into the future across the entire geographic area occupied by this endangered squirrel.

Study Area

The Balsam Mountain range of western North Carolina traverses southern Haywood and northern Jackson and Transylvania counties. Odom and McNab (2000) modeled vegetative communities with elevations >1200 m; however, the lowest elevations used in this study were >1350 m. The highest elevations in the Balsams exceed 1900 m.

While no climate recording stations were located in the area, general conditions reflected cool temperate conditions typical of higher elevations in the Appalachians. Odom and McNab (2000) estimated precipitation to be 150–250 cm per year, including common snow and ice events during winter.

Forests dominated the landscape within the study area, although there were areas of open or field/shrub habitat. The higher peaks and ridges supported pure or scattered fir/red spruce stands. The red spruce communities predicted by the model were described as dominated by red spruce, but contained smaller proportions of yellow birch, fraser fir, mountain ash *(Sorbus americana),* and other northern hardwoods (Schafale and Weakley 1990). The other plant communities commonly encountered in the study area above 1400 m were northern red oak and northern hardwoods. Northern red oak communities were dominated by northern red oak *(Quercus rubra),* but may have contained chestnut oak *(Quercus montana),* beech, red maple, and minor amounts of other species (Schafale and Weakley 1990). Northern hardwood communities were dominated by yellow birch and beech, with significant amounts of yellow buckeye *(Aesculus flava),* red and sugar maples, and with an understory often comprised of rhododendron (*Rhododendron* spp.) and various other species (Schafale and Weakley 1990).

Methods

The result of Odom and McNab's (2000) study was a map depicting the predicted distribution of spruce, northern hardwood, and northern red oak communities across the landscape. We used their map to select flying squirrel sampling locations. Based upon published information (Payne et al. 1989, U.S. Fish and Wildlife Service 1990, Weigl et al. 1999) and expert opinion (A. C. Boynton, Virginia Department of Game and Inland Fisheries, pers. commun., N. Murdock, U.S. Fish and Wildlife Service, pers. commun.), we hypothesized that northern flying squirrels would be present in northern hardwood-spruce ecotones, and absent from the northern red oak-spruce ecotones.

The Recovery Plan for Appalachian Northern Flying Squirrels (U.S. Fish and Wildlife Service 1990) recommended that presence/absence be determined by live trapping or the use of nest boxes (checked annually for a minimum of two years). We used nest boxes due to the constraints of available time and manpower. We examined the vegetation model in IDRISI GIS (Eastman 1992) software and identified 40 areas in the proper habitats and of sufficient size to contain a transect of 15 nest boxes spaced approximately 50 m apart. Many of the sites proved to be inaccessible due to the terrain, density of vegetation, and other factors. Therefore, we chose a subset of the sites that were accessible. Random selection of sites was not feasible due to constraints on our ability to access the sites during the winter, available time to check nest boxes, and other logistic factors. Instead we chose to distribute the sites across the geographic range to account for variability between sites. Besides geographic representation, the only other factor considered in selecting sites was the vegetative community prediction of Odom and McNab. In fact, it did not matter whether the vegetation type on the ground matched their community description because we wanted to see if their community predictions would accurately define squirrel distribution. We selected 22 sites, 11 where northern flying squirrels were predicted present and 11 where they were predicted absent.

We constructed 330 nest boxes (15 cm square by 30 cm tall) of exterior grade 1.25 cm plywood with a 3.75 cm square opening on one side below the roof. The bottom of the box was a piece of 1.25 cm mesh hardware cloth. The nest box design has been in use in North Carolina for a number of years and has been effective in previous efforts to capture northern flying squirrels (Weigl et al. 1999). The boxes were affixed 240–300 cm off the ground to the trunk of a tree that was branch-less to at least 360 cm from the ground. The box rested upon two aluminum nails driven into the trunk, and 18-gauge wire was fastened around the box and tree to hold the box in place. Any tree >20 cm dbh with an open approach was suitable, and no attempt was made to standardize the direction of the box opening.

We oriented nest-box transects along or perpendicular to vegetative community boundaries in an effort to encompass the ecotones, depending upon accessibility of each site. Transects often followed old roads and trails to facilitate access. In all cases, boxes were placed 40–100 m apart along transects, depending upon obstacles and habitat features. Global Positioning System (GPS) locations were recorded for 305 box locations using Trimble Pathfinder basic plus GPS unit. The remaining 25 were located on maps by noting position and distance from the nearest differentially corrected location.

We installed nest boxes between August and November 1995. We checked each box once per winter (January to March 1996–1999), as weather and other conditions permitted, to maximize annual capture rates (P. Weigl, Wake Forest University, pers. commun.) while minimizing disturbance to squirrels during the breeding season (March–August).

We captured nesting squirrels with a cone-shaped net (0.3 cm mesh) held over the entrance hole of each box, as it was shaken, tapped, or probed through the bottom. Northern flying squirrel sex, mass, and hind foot measurements were recorded. Each individual was fitted with a numbered ear tag (National Band and Tag, #1005-size one Monel) and released back into the box or onto the tree trunk. We recorded characteristics of each nest. We considered northern flying squirrels present at each box with a typical northern flying squirrel nest, even if no individuals were captured.

We tested the hypothesis that northern flying squirrel presence/absence did not differ between northern hardwood/red spruce and northern red oak/red spruce ecotones using a 2-tailed Fisher's exact test. We used Wilcoxon ranked sums and a 2-tailed Mann-Whitney test to test the hypothesis that number of northern flying squirrels captured did not differ between ecotone types. We used the same procedure to test the hypothesis that number of nests constructed between ecotone types did not differ. All tests were conducted at $\alpha = 0.05$. Because sample sizes were small, P-values were estimated using interpolation from small sample table values of the Mann-Whitney test (Conover 1999). Statistical analysis was performed using SAS (SAS 1990).

Results

We captured 161 northern flying squirrels. One hundred and forty-three northern flying squirrels were captured at 8 of 11 predicted present sites, while only 18 were captured at 5 of 11 predicted absent sites (Table 1). One additional site where northern flying squirrels were predicted present (Wet Camp Gap) had sufficient evidence of northern flying squirrel nesting to be classified as such despite no captures (Table 2). Presence of northern flying squirrels nor presence and nests differed between northern hardwood/red spruce and northern red oak/red spruce ecotones ($P = 0.39$ and $P = 0.18$, respectively). However, more northern flying squirrels were captured at predicted present sites than at predicted absent sites ($T = 95.5$, $P = 0.04$, Table 1). The number of boxes where northern flying squirrels were captured at predicted present sites was greater than predicted absent sites ($T = 96$, $P = 0.04$). They were captured at 35 total boxes in predicted present sites (mean = 3.2 boxes/site) and at only five boxes at predicted absent sites (mean = 0.5 boxes/site). Also, the number of boxes with nests in addition to captures was greater at predicted present sites versus predicted absent sites ($T = 87.5$, $P < 0.01$). Captures and nests combined occurred at 53 boxes in predicted present sites (mean = 4.8 boxes/site) and only nine boxes in predicted absent sites (mean = 0.8 boxes/site).

We recorded 25 recaptures or suspected recaptures (squirrels with definitive

Table 1. Captures and (recaptures) of northern flying squirrels in the Balsam Mountains of North Carolina, 1996–1999.

Site name by type					
PP[a]	PA[b]	1996	1997	1998	1999
Bearpen Gap			11	(1)	9
Beartrail Ridge			5		
Buckeye Creek		3	8	11(4)	9(4)
Flat Laurel Branch		3	5	10(2)	6(2)
Graveyard Ridge			5	4(1)	1(2)
Little Sam Knob		8	8(1)	8(5)	11(1)
Possum Hollow			11	2(1)	4
Sweetwater Spring				1	
	Beech Gap				1
	Haywood Gap W.			4	
	Reinhart Gap		1(1[c])	4	5
	Reinhart Gap S.	2			
	Rich Mountain	1			

a. PP = predicted present (northern hardwood/spruce ecotone).
b. PA = predicted absent (northern red oak/spruce ecotone).
c. Recapture from Reinhart Gap S. site.

tears at the location of initial ear-tagging) (Table 1). Consistently (24/25) recaptures occurred at predicted present sites.

We recorded 36 southern flying squirrel captures during the course of the study. All southern flying squirrel captures occurred at five sites where northern flying squirrels were predicted absent. Only one site (Haywood Gap W.) yielded both northern and southern flying squirrels, with captures of northern flying squirrels occurring in box #'s 1 and 2, while captures of southern flying squirrels occurred in boxes 5, 6, 9, 12, and 13.

Discussion

By sampling for northern flying squirrels at the ecotone of northern hardwood and spruce and the northern red oak/spruce ecotone (as predicted by Odom and McNab 2000), we could not predict absolute presence or absence of northern flying squirrels. However, with regard to the northern hardwood/spruce predictions of their model, we captured northern flying squirrels at 8 out of 11 of those sites, and found nesting evidence at one additional predicted present site. Therefore the model was actually very good at predicting presence of the species. The only two predicted present sites that did not yield northern flying squirrels or their nests both appeared to provide excellent habitat for them (Devil's Courthouse and Rough Butt Bald). In fact, Weigl et al. (1999) captured four northern flying squirrels within approximately 150 m of the Devil's Courthouse site of the present study. Northern flying squirrels were captured at the Rough Butt Bald site in the summer of 1999 as well (S. Loeb, U.S. Forest Service, pers. commun.). Therefore, we know that all predicted present sites in

Table 2. Number of northern flying squirrel nests or possible nests recorded in nest boxes of the Balsam Mountains of North Carolina (not including boxes where squirrels were captured), 1996–1999.

Site name by type		
PP[a]	PA[b]	No./site
Bearpen Gap		2
Buckeye Creek		2
Flat Laurel Branch		3
Graveyard Ridge		3
Little Sam Knob		2
Possum Hollow		3
Sweetwater Spring		1
Wet Camp Gap		3
	Haywood Gap W.	2
	Reinhart Gap S.	1

a. PP=predicted present (northern hardwood/spruce ecotone).
b. PA=predicted absent (northern red oak/spruce ecotone).

this study area do support northern flying squirrels, though data from these two sites could not be used in our analysis.

The evidence suggests that Odom and McNab's (2000) model can be useful to predict where northern flying squirrels occur in the Balsam Mountains. However, our application of the model clearly had shortcomings (i.e., the inability to predict where northern flying squirrels do not occur). Because of the way we combined Odom and McNab's (2000) predicted northern red oak and spruce into predicted absent sites, we found northern flying squirrels where we did not expect them.

The fundamental problem with our approach was that we used the northern red oak/spruce ecotone as our predicted absent site type. Those sites either traversed from red oak into spruce communities (or vice versa) or followed the edges of the two. Three of the five instances where we captured northern flying squirrels or found nests in predicted absent sites (Haywood Gap West, Beech Gap, and Reinhart Gap South) were in the spruce portion of the site. The two remaining predicted absent sites where northern flying squirrels were captured had small areas of suitable habitat, perhaps not extensive enough to be predicted at the model's resolution, or they occurred in proximity to other suitable habitat. Areas predicted to be spruce communities did support northern flying squirrels, regardless of whether they were adjacent to northern hardwood or northern red oak communities.

We did find significant differences between the number of captures and the numbers of nest boxes used (including captures as well as nests) between predicted present sites and predicted absent sites. In addition, recapture data indicated that persistence of northern flying squirrels was far greater in predicted present sites than in predicted absent sites. The fact that we did not capture any southern flying squirrels in predicted present sites provides additional support for the model's ability to predict good northern flying squirrel habitat, in that there may be competitive interaction between northern and southern flying squirrels as suggested by Weigl 1978, Weigl et al. 1999). Therefore, while the model couldn't be used in the framework of our sites to predict absolute presence or absence, it did have some capability to detect differences in relative abundance, distribution, and continued habitation within the framework of our site types. These characteristics may be reflective of the differential quality of the habitats predicted by the model and could prove important when considering various management activities to benefit the species. Management could be focused upon the best habitats (as predicted by the model), and provide more return on investment than focusing on poor quality habitat.

Odom and McNab's (2000) vegetation model is not 100% accurate, and neither was our attempt to use it to predict where northern flying squirrels occurred in the Balsams. However we did show that it has some utility, which, combined with minimum amounts of other information, (i.e., relative size of a particular habitat patch, or position relative to other predicted suitable habitat), can minimize the amount of northern flying squirrel survey effort needed in the Balsam mountains to assess impacts upon this endangered species.

This vegetation modeling technique holds promise yet for delineating Carolina northern flying squirrel distribution within GRA's. Specifically, had we tested the vegetation predictions against northern flying squirrel sampling in each of the habitat types predicted by the model (i.e. red spruce, northern hardwood, and northern red oak) independently, we would likely have seen a clearer distinction between predicted present and predicted absent sites. In fact we have begun a study in the next nearest GRA (Black/Craggy Mountains) utilizing similar vegetation modeling techniques but assigning squirrel sampling locations to each of the predicted vegetation types. Preliminary results there indicate a difference between northern hardwood, spruce, and northern red oak in predicting squirrel occurrence, with the former two types supporting and the latter not supporting Carolina northern flying squirrels.

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