USDA

United States Department of Agriculture

Forest Service

Northeastern Research Station

Research Paper NE-729

A Habitat Model for the Virginia Northern Flying Squirrel (*Glaucomys sabrinus fuscus*) in the Central Appalachian Mountains

Jennifer M. Menzel
W. Mark Ford
John W. Edwards
Leah J. Ceperley

Abstract

The Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*) is an endangered sciurid that occurs in the Allegheny Mountains of Virginia and West Virginia. Despite its status, few of its ecological requirements have been synthesized for landscape-level predictive distributions to facilitate habitat delineation efforts. Using logistic regression, we developed a GIS-based habitat model for the Virginia northern flying squirrel using micro- and macrohabitat relationship data in West Virginia. Important habitat characteristics obtained from radio-collared squirrels included: (1) elevation over 1036 m; (2) northerly aspects; and (3) red spruce (*Picea rubens*) and mixed northern hardwood-red spruce cover types. A final model retaining elevation and forest cover type showed reasonably high predictive power across a large portion of the Allegheny Mountains in West Virginia.

Authors

JENNIFER M. MENZEL is a research wildlife biologist, formerly with the USDA Forest Service, Northeastern Research Station, Parsons, WV 26287.

W. MARK FORD is a research wildlife biologist, USDA Forest Service, Northeastern Research Station, Parsons, WV 26287.

JOHN W. EDWARDS is an associate professor, Division of Forestry, West Virginia University, Morgantown, WV 26506.

LEAH J. CEPERLEY is an ecologist, USDI Fish and Wildlife Service, Canaan Valley National Wildlife Refuge, Davis, WV 26260.

Cover Photos

Left, view of North Fork Mountain looking east from Spruce Knob, Pendleton County, West Virginia; right, Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*) courtesy of Craig Stihler, West Virginia Division of Natural Resources.

Manuscript received for publication 16 September 2005

Published by:
USDA FOREST SERVICE
11 CAMPUS BLVD SUITE 200
NEWTOWN SQUARE PA 19073-3294

March 2006

For additional copies:
USDA Forest Service
Publications Distribution
359 Main Road
Delaware, OH 43015-8640
Fax: (740)368-0152

Visit our homepage at: **http://www.fs.fed.us/ne**

Introduction

Managing endangered species is often a daunting task for natural resource professionals, as typically there is a paucity of species-specific conservation guidelines. For common wildlife species, data are gathered through both detailed macro- and microhabitat research on habitat use, home ranges, food habits, etc. (Shriner et al. 2002) that enables natural resource professionals to develop scientifically based management strategies (Vanderpoorten et al. 2005). However, for many endangered species, the consequence of uncertainty is that management plans frequently are not developed. Geographic information systems (GIS) can be used to construct spatially explicit habitat models for both common and rare wildlife species (McCombs 1997, Gibson et al. 2004, Posillico et al. 2004). With adequate data collection, such models often can analytically identify specific habitat characteristics across wider landscapes with high predictive power and therefore provide considerable utility. Accordingly, habitat models are especially useful for rare, threatened, or endangered species, such as the Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*) that inhabit forested landscapes, yet are difficult to physically survey because of their low population density, patchy distribution, and cryptic nature. By identifying occupied or potentially occupied areas for the Virginia northern flying squirrel, recovery efforts through forest-habitat conservation and active restoration can focus on specific habitats delineated by the habitat model (Schuler et al. 2002).

The Virginia northern flying squirrel is one of two federally endangered subspecies of the northern flying squirrel restricted to relict, montane boreal and northern hardwood forests in the central and southern Appalachians. The Virginia subspecies occurs or could possibly occur in nine counties located in the high elevations of the Allegheny Mountains in eastern West Virginia and extreme northwestern Virginia (Well-Gosling and Heaney 1984, U.S. Fish and Wildlife Service 1985, Odom et al. 2001). Live trapping and nest box surveys over the past two decades have shown that the Virginia northern flying squirrel is mostly associated with forest stands dominated by red spruce (*Picea rubens*) (Urban 1988, Stihler et al. 1995, Ford et al. 2004). This forest type was estimated to exceed 200,000 ha in this region prior to the exploitative logging and widespread wildfires in the early 20th century (Korstian 1937). At present, however, less than 15 percent of the original area remains dominated by red spruce with the remainder having been replaced by northern hardwood forests with a much reduced conifer component (Adams and Stephenson 1989, Schuler et al. 2002). Under the aegis of the United States Endangered Species Act of 1973, the presence of Virginia northern flying squirrels severely restricts active management for most purposes of remaining montane boreal stands in the Allegheny Mountains. Trepidation to undertake management activities, such as red spruce restoration that could benefit the Virginia northern flying squirrel, is due in part to the poorly defined distribution of the species in the region. Nonetheless, the restricted distribution of this subspecies makes it an excellent candidate for a habitat model because the range is large enough to encompass a landscape-level analysis, but small enough to be geographically definable and logistically manageable.

Preliminary predictive habitat models were developed for a restricted portion of the Virginia northern flying squirrel's distribution in Virginia and West Virginia using an "exclusionary approach" generated from capture data from trapping and nest box monitoring (McCombs 1997, Odom et al. 2001). This method provided a useful quantitative "first step" for modeling endangered species distributions where specific habitat requirements are difficult to obtain. It is important to note, however, a generally untested assumption of the exclusionary modeling approach is that capture locations are indicative of quality habitat. If individuals are artificially attracted to an area, or if presence is enhanced via baiting, or if a capture method such as nest boxes provides artificial den sites, the results of the habitat model could be misleading.

Although robust for predicting nonoccurrence, the attempt by Odom et al. (2001) to model Virginia northern flying squirrel habitat was inconclusive in its ability to accurately predict presence in habitats not surveyed directly by nest boxes or trapping. Odom et al. (2001) suggested that more detailed microhabitat data would be required to develop more accurate habitat models. Therefore, our primary objective was to use spring and summer nest-tree and habitat-use data from a concurrent radiotelemetry study of Virginia northern flying squirrels (Menzel 2003) to quantify a descriptive habitat model that would prioritize areas for conservation and management of the subspecies. Following Ford et al. (2004) as well as other anecdotal evidence and expert opinion, we hypothesized that increasing elevation and forest stand dominance of red spruce and other high-elevation montane conifers, such as the widely planted exotic Norway spruce (*Picea abies*) and the native eastern hemlock (*Tsuga canadensis*), would result in progressively increasing probability of occurrence of Virginia northern flying squirrels.

Materials and Methods

Study Area

To obtain habitat-use data to incorporate into our habitat modeling, we radio-tracked Virginia northern flying squirrels in the Allegheny Mountains from May to September 2000 and from May to August 2001 on the MeadWestvaco Ecosystem Research Forest (MWERF) near Adolph, WV (38.74ºN, 80.05ºW; Randolph County) and on the Monongahela National Forest (MNF) near Parsons, WV (38.55º N, 79.83º W; Randolph and Tucker counties). Specific sites on the MNF included Stuart Knob, Canaan Heights, and McGowan Mountain areas.

The MWERF is 3,360 ha intensively managed industrial forest (Ford and Rodrigue 2001); whereas the MNF is a 367,455 ha national forest that contains a variety of forest conditions and stand ages from seminatural unmanaged mature second-growth to large plantations of Norway spruce. Our habitat model study site was centered on the proclamation boundary of the MNF and the MWERF; however, we included several other areas of state, federal and privately owned land within and adjacent to the MNF and the MWERF, such as Canaan Valley National Wildlife Refuge, Kumbrabow State Forest, and Snowshoe Mountain Resort.

Regionally, topography consisted of northeast- to southwest-oriented steep ridges divided by narrow valleys. Elevation ranged from 700 to 1450 m. The climate is generally cool and moist with annual precipitation ranging from 120 to 150 cm, much of which occurs as snow during the winter months (Stephenson 1993). The forest community at the higher elevations (>1000 m) was comprised of red spruce, eastern hemlock, sugar maple (*Acer saccharum*), red maple (*A. rubrum*), yellow birch (*Betula alleghaniensis*), American beech (*Fagus grandifolia*) and black cherry (*Prunus serotina*).

Scattered throughout the higher elevations were planted stands of Norway spruce. The forest community at the lower elevations (<1000 m) was a mixed mesophytic type composed of yellow-poplar (*Liriodendron tulipifera*), basswood (*Tilia americana*), northern red oak (*Quercus rubra*), black birch (*B. lenta*), red maple, sugar maple, American beech, hickory (*Carya* spp.), chestnut oak (*Q. montana*), and white oak (*Q. alba*) in varying amounts, depending on aspect and site quality.

For the habitat model, we used all or portions of 44 U.S. Geological Survey (USGS) 7.5-minute topographic quadrangle maps from eastern West Virginia: Adolph, Bergoo, Beverly East, Blackbird Knob, Bowden, Cass, Circleville, Davis, Droop Mountain, Durbin, Edray, Elkins, Fork Mountain, Glady, Greenbank, Greenland Gap, Harman, Hightown, Hillsboro, Hopeville, Laneville, Lead Mine, Lobelia, Marlinton, Mingo, Mill Creek, Mount Storm Lake, Mozark Mountain, Onego, Parsons, Pickens, Samp, Sharp Knob, Sinks of Gandy, Snowy Mountain, Spruce Knob, Synder Knob, Thornwood, Valley Head, Webster Springs SE, Webster Springs SW, Whitmer, Widell and Woodrow. These areas are known to encompass the known distribution of the Virginia northern flying squirrel and/or high elevation montane habitats in West Virginia.

Habitat Model Construction

Data from Menzel (2003), Menzel et al. (2004), and Menzel et al. (in press) were used to build a predictive model of occupancy. These data showed that forest types dominated by either red or Norway spruce and northern hardwoods with a considerable spruce component (≥ 50 percent) were selected preferentially over pure northern hardwood or mixed mesophytic forest types. Additionally, north-facing slopes and elevations greater than 1036 m were used more than would be expected based on landscape availability. Therefore, we incorporated these parameters into the construction of our habitat model.

Because previous attempts to model Virginia northern flying squirrel habitat using the exclusionary approach had been equivocal (McCombs 1997, Odom 2001), we included quantitative microhabitat data into a model to more accurately reflect habitat quality. We constructed our habitat model using the variables of nest tree (elevation) and vegetative community (montane conifer) characteristics (Menzel 2003, Ford et al. 2004). Significant variables in the habitat analysis included land cover types and topographic surface characteristics obtained from spatial information generated from monitoring radio-collared Virginia northern flying squirrels. A more detailed explanation of the variables in the nest tree and habitat use portion is provided by Menzel (2003) and Menzel et al. (2004, In Press).

We determined land-cover types from a variety of sources, including stand data (Combined Data System, CDS) from the MNF, West Virginia Gap Analysis (GAP) data from IKONOS satellite imagery (Space Imaging , Thornton, CO), and MeadWestvaco's Forest Resource Inventory System (FRIS) data for the MWERF. We used images from IKONOS and GAP data for areas of private ownership inside the MNF proclamation boundary and outside the boundary, respectively, where forest stand data largely was absent. The IKONOS imagery was obtained in October 2001 with leaf-off conditions and <20 percent cloud cover. Leaf-off imagery was necessary to identify areas of spruce and spruce-northern hardwood areas. Imagery was 1-m resolution in true color with a Universal Transverse Mercator (UTM) projection using the World Geodetic System 1984 (WGS84) datum. We classified the IKONOS imagery into land-cover types using both unsupervised and supervised classification in ERDAS IMAGINE® (ERDAS 1997). We used the ISODATA method for land cover classification in the unsupervised classification.

To determine cover types for areas not included in the CDS or FRIS data, we used classifications from the GAP data (Glenn and Ripple 2004). With these three sources to determine land cover, we were able to create a complete data set of land cover for the entire study area, albeit one with variable resolution and classification accuracy. Only forested land cover types were used in the analysis and were given binary values for analysis (i.e., oak = 0, spruce = 1). We created topographic surfaces, such as elevation and aspect, for the GIS using ArcView Spatial Analyst® from a digital elevation model (DEM) for each 7.5-minute topographic quadrangle obtained from the USGS. Aspect in degrees was transformed to the format of the habitat model using the formula [1-cosine (aspect)] + [1-sine (aspect)] to linearize the data so that xeric, southern aspects ranged from 135-225° and mesic northern aspect ranged from 315-45° (McCombs 1997).

The variables used in the Virginia northern flying squirrel habitat model were determined using stepwise logistic regression (Hosmer and Lemeshow 2000). Habitat characteristics at 884 (87 occupied and 797 vacant) nest box sites were entered into a logistic regression model to determine characteristics indicative of flying squirrel habitat. Because previous studies in the area found nest trees not a limiting factor for flying squirrels, it is possible that the use of nest boxes do provide some insight into preferred habitat, though an untested assumption (Menzel et al. 2004). To assess fit and relative strength of the selected model, we used the Hosmer and Lemeshow goodness-of-fit test and Nagelkerke's rescaled R^2, respectively (SAS Institute 1995). We used the probabilities from the logistic regression to derive a predictive habitat map from the significant habitat characteristics across the landscape at threshold values of <50, 50-75, and >75 percent predictive probabilities of occurrence to show possible distribution of Virginia northern flying squirrels. For model validation, we used a jackknife procedure to compute a percentage correct classification for correctly assigned presence (sensitivity) and absence (specificity) for the model (SAS Institute 1995).

Table 1.—Logistic regression model of habitat variables surrounding occupied Virginia northern flying squirrel nest boxes (n = 87) and randomly located vacant boxes (n=797) in the Monongahela National Forest, West Virginia.

Variable	Parameter estimate	SE	Wald's Chi-square	*P*	Odds ratio
Land cover	2.3424	0.3945	35.255	0.0001	10.407
Elevation (m)	0.0027	0.0010	7.689	0.0056	1.003

Table 2.—Occurrence of Virginia northern flying squirrel occupied and vacant nest box locations by probability class for areas across the Monongahela National Forest, West Virginia.

Probability class	Interval	Present	Absent	Total
1	0-49 %	5	84	89
2	50-75 %	24	3	27
3	>75-100 %	58	0	58
Total		87	87	

Results

Our stepwise logistic regression identified two significant variables, elevation and forest cover type, that contributed to the most parsimonious model identifying Virginia northern flying squirrel habitat based on habitat variables at nest box locations (Table 1). The best approximating model equation was as follows:

Virginia northern flying squirrel occupancy = $(1/1+\exp^{(-4.4279 - (2.3424 * \text{Forest Type}) - (0.0027 * \text{Elevation (m)}))})$.

This model had a reasonably high predictive capability (Nagelkerke's adjusted $R^2 = 0.4967$) in identifying Virginia northern flying squirrel habitat with good overall model fit (Hosmer-Lemeshow $\chi^2 = 13.79$; $P = 0.087$). Overall correct classification was 81 percent with a model sensitivity of 79.3 percent and a model specificity of 82.8 percent. Predicted occurrence by probability class analysis indicated that we could successfully predict the spatial extent of high probability of occupancy (> 75 percent), potentially occupied (50-75 percent) and low probabilities (< 50 percent) of occupancy (Table 2). The inclusion of aspect in a three-variable model did not improve model performance. Spatially, our model identified 19,162 ha of area with >75 percent predicted probability of occurrence and 224,285 ha of 50-75 percent predicted probability of across eight counties in eastern West Virginia (Fig. 1). Approximately 63.2 percent of area designated 50 percent or greater of probability occurred on public land such as MNF, Canaan Valley National Wildlife Refuge or state parks or forests. The model is available at http://www.fs.fed.us/ne/parsons/webdata/data/gis/.

Discussion

Our Virginia northern flying squirrel habitat model is not a definitive attempt to predict presence or absence, but rather an attempt to identify areas where conservation and/or forest-habitat enhancement could be prioritized. Our deductive modeling approach allows the use of statistically significant quantitative data to build a habitat model that describes areas similar to those used by radio-collared animals (DeMers 2000). By identifying congruencies in habitat features across the Allegheny Mountains that are considered potentially occupied by Virginia northern flying squirrels, restoration efforts could be directed to increase suitable habitat patch size and connect neighboring patches (Rosenblatt et al. 1999, Miller and Cale 2000). Outside of the MNF and MWERF areas, detailed forest habitat information is less resolute; however, our model's utility in predicting marginal probability of occurrence also is useful for understanding the potential extent of the subspecies'

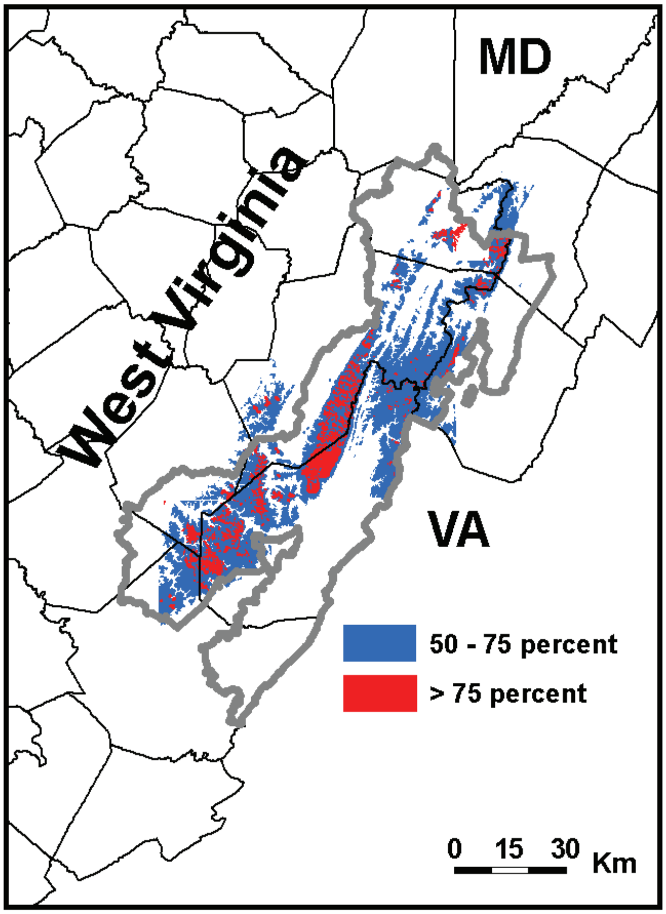


Figure 1.—Location of predicted Virginia northern flying squirrel habitat in 8 counties of eastern West Virginia. The dark gray outline denotes the proclamation boundary of the Monongahela National Forest. See text for details.

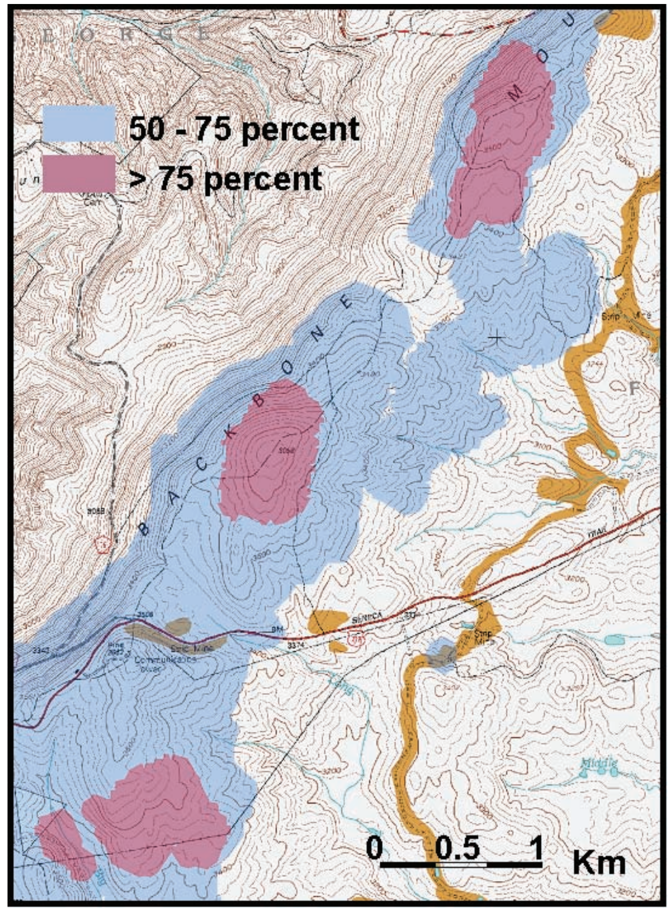


Figure 2.—Predicted Virginia northern flying squirrel habitat on a section of the Leadmine 7.5-minute topographic quadrangle map in Tucker County, West Virginia.

former and future distribution in this high-elevation landscape (Fig. 2). From a regulatory management standpoint, this model could contribute to protection and mitigation efforts on private lands in the region where mining, recreational development, and wind-energy development currently are under way (Schuler et al. 2002, Arnett et al. 2005).

Virginia northern flying squirrels essentially are restricted to high elevation forest "islands" surrounded by a matrix of less- or unsuitable forest habitats (Lomolino and Davis 1997, Weigl et al. 1999). Both endangered subspecies of northern flying squirrel in the Appalachians already have begun to show indications of restricted gene flow and loss of genetic variability (Brown 1984, Brown et al. 1999, Steele and Powell 1999). Genetic isolation combined with unsuitable habitat greatly increases the chances of localized extirpation or complete extinction of these subspecies. Also, there are many other natural and modified landscape features that could function as physical barriers to movement by flying squirrels. Our predictive maps could be used as a first step to identify marginal habitat in or near optimal patches where active forest management or restoration activities could improve vegetative or structural conditions in the future (Schuler et al. 2002). Such efforts could improve the Virginia northern flying squirrel's potential for long-term viability and/or for eventual subspecies recovery and de-listing by increasing genetic diversity and decreasing competitive pressures by increasing available habitat (Browne et al. 1999). With increasing habitat patch size in an island biogeography theory approach (MacArthur and Wilson 1967) or a meta-population context (Castleberry et al. 2002), resources should become more abundant making competition less severe. With decreasing distance between patches, Virginia northern flying squirrel populations should become more panmictic and genetic diversity conserved or enhanced (Brown et al. 1999).

Optimal areas of potential occupancy that are both surrounded by marginal habitat and are in close proximity to other optimal habitat patches could have the highest success rate for restoration. Additionally, optimal patches that are surrounded by poor habitat and are isolated from other patches likely would be more difficult to connect to other optimal habitats. These patches may represent areas where Virginia northern flying squirrels were extirpated and were unable to recolonize because of the unsuitable surrounding habitat. Many of these isolated patches are areas that in most need of management. Nonetheless, it is important to note that our habitat model possibly failed to identify all existing patches of potentially occupiable habitat, especially the smaller suitable forest patches. Due to resolution problems, this is a common error that occurs in habitat modeling that must be recognized. However, the scale of this project and the simplicity of the habitat model may significantly reduce this error (Moilanen 2002).

Wildlife habitat modeling is replete with assumptions. For example, we assumed that the vegetative communities and habitat characteristics used by the radio-collared flying squirrels reported in Menzel (2003) and Menzel et al. (2004) represented typical selection by the targeted species (Millspaugh and Marzluff 2001). Because of the difficulty in measuring factors, such as competition and the effects of human activity (Posillico et al. 2004), our model assumes that the collared Virginia northern flying squirrels were selecting habitats that were most desirable and not selecting habitats that were in suboptimal areas (Cody 1981, Ozesmi and Mitsch 1997, Rosenblatt et al. 1999, Miller and Cale 2000). There has been a dramatic alteration in the extent and quality (i.e., stand structure and composition) of high elevation red spruce forests of West Virginia over the past century (Clarkson 1968, Mielke et al. 1986). Accordingly, it may be possible that the areas occupied by Virginia northern flying squirrels today represent the best of what is currently available even though it may not be "optimal" from the subspecies' perspective. Quite likely, the best forest habitats represented by overmature or old-growth montane-boreal communities have characteristics that can only develop over time. For the purpose our study, we were constrained to describe the vegetational communities and habitat characteristics used by the radio-collared flying squirrels as potentially occupied habitat in the present landscape. Although we cannot say with certainty what characteristics constitute highly optimal habitat, we believe our designations were justified due to the evidence of successful breeding and natal production observed in the study areas (Menzel 2003, Menzel et al. in press).

Despite our relatively high percentage of correct classification, we do urge caution in overly extending the results of our modeling based on the quality and quantity of data used. There was a small sample size of nest boxes that were occupied - only 87 (10 percent) of the total 884 boxes, most of which were not placed across the landscape at random but in forested areas that were similar to areas where Virginia northern flying squirrels have been previously captured (e.g., red spruce stands or other high elevation forests with significant conifer cover). This bias undoubtedly made it more difficult to distinguish differences between occupied and vacant sites. Additionally, the presence of natural cavities in forest stands with nest-boxes also could influence nest-box use, as stands with high cavity abundance might have a lower rate of nest box use whereas the opposite might be true in stands with low cavity availability.

Although the earlier habitat model produced by Odom et al. (2001) produced equivocal results, it demonstrated the importance of montane conifer cover in explaining Virginia northern flying squirrel presence and absence on the landscape. Certainly our model, combined with the stand-level work provided by Ford et al. (2004), provides a more compelling link between the subspecies and montane confier habitats. Odom et al. (2001) used an inductive approach to habitat modeling, whereas we used a deductive approach based on previously gathered quantitative data. Additionally, our habitat model adds a more detailed forest composition component to the habitat model of Odom et al. (2001).

In summary, our habitat model should be useful to land managers as it shows where the critical or highly optimal habitats from an occupancy perspective exist in the Allegheny Mountains. Secondly, based on the proposition that Virginia northern flying squirrels should be dependent on the areas outlined by the model, this model spatially shows where the highest concentrations of Virginia northern flying squirrel habitat (and therefore presumably squirrels themselves) is probable. Because this species is secretive and difficult to capture, our model should help reduce the time and efforts for future Virginia northern flying squirrel surveys and/or research activities. Thirdly, this model provides a baseline for future management prior to any active habitat management for the northern flying squirrel (Schuler et al. 2002, Carey 2003a). Finally, our model provides a spatial map that shows how all of the optimal habitat patches are spatially related to each other. This could be useful in conservation planning and/or long-term habitat restoration efforts such as the release of understory spruce or the connecting of optimal patches with habitat corridors that would allow inter-patch movement. Single-species focal management efforts usually fail over the long term, therefore ecosystem-based approaches with spatial elements that introduce forest structure heterogeneity and increase biocomplexity typically benefit a greater number of species, including the targeted single species (Carey 2001, Nordlind and Ostund 2003, Carey 2003b). For example, of other wildlife in the region that are associated with the montane boreal forest type, greater than 80 percent of both the known endangered Cheat Mountain salamander (*Plethodon nettingi*) collection sites and the USDA Forest Service Region 9 sensitive-listed northern goshawk (*Accipiter gentilis*) nesting sites that occur within the MNF proclamation boundary have been located where the predicted probability of Virginia northern flying is 50 percent squirrels or greater (T. Evans, USDA Forest Service, pers. comm.). Accordingly, we believe our habitat model for the Virginia northern flying squirrel can help facilitate multi-species ecosystem-based management efforts within high elevation forests in the Allegheny Mountains.

Acknowledgments

Funding for this study was provided by the West Virginia University Division of Forestry and the USDA Forest Service's Scientist Recruitment Initiative program. We thank E. Rowan, K. Nightingale, K. Leonard, and J. Rodrigue for study assistance.

Literature Cited

Adams, H.S.; Stephenson, S.L. 1989. **Old-growth red spruce communities in the mid-Appalachians.** Vegetation. 85: 45-46.

Arnett, E.B.; Erickson, W.P.; Kerns, J.; Horn, J. 2005. **Background and study area location.** In: Arnett, E.B., ed. Relationship between bats and wind turbines in Pennsylvania and West Virginia: an assessment of fatality search protocols, patterns of fatality, and behavioral interactions with wind turbines. Austin, TX: Bat Conservation International: 12-23.

Brown, J.H. 1984. **On the relationship between abundance and distribution of species.** American Midland Naturalist. 124: 255-279.

Browne, R.; Weigl, P.; Eagleson, E.; Kelly, J.; Steele M. 1999. **Mountaintops as islands: genetic variation among southern Appalachian populations of the endangered northern flying squirrel, *Glaucomys sabrinus* (Mammalia: Sciuridae).** In: Eckerlin, R.P., ed. Proceedings of the Appalachian biogeography symposium. Spec. Publ. No. 7. Martinsville, VA: Virginia Museum of Nat. History: 205-214.

Carey, A.B. 2001. **Experimental manipulation of spatial heterogeneity in Douglas-fir forests: effects on squirrels.** Forest Ecology and Management. 152:13-30.

Carey, A.B. 2003a. **Restoration of landscape function: reserves or active management.** Forestry. 76: 221-230.

Carey, A.B. 2003b. **Biocomplexity and restoration of biodiversity in temperate coniferous forests:**

inducing spatial heterogeneity with variable-density thinning. Forestry. 76: 128-136.

Castleberry, S.B.; King, T.L.; Wood, P.B.; Ford, W.M. 2002. **Microsatellite DNA analysis of population structure in Allegheny woodrats (*Neotoma magister*).** Journal of Mammalogy. 83: 1058-1070.

Clarkson, R.B. 1964. **Tumult on the mountain: Lumbering in West Virginia 1770-1920.** Parsons, WV: McClain Printing Co. 436 p.

Cody, M.L. 1981. **Habitat selection in birds: the roles of vegetation structure, competitors, and productivity.** BioScience. 31: 107-113.

DeMers, M.N. 2000. **Fundamentals of geographic information systems.** New York: John Wiley & Sons. 498 p.

ERDAS. 1997. **ERDAS field guide, 4th ed.** Atlanta, GA: ERDAS, Inc. Leica Geosystems Geospatial Imaging. 357 p.

Ford, W. M.; Stephenson, S.L.; Menzel, J.M.; Black, D.R.; Edwards, J.W. 2004. **Habitat characteristics of the endangered Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*) in the Central Appalachians.** American Midland Naturalist. 152: 430-438.

Ford, W.M.; Rodrigue, J.L. 2001. **Soricid abundance in partial overstory removal harvests and riparian areas in an industrial forest landscape of the central Appalachians.** Forest Ecology and Management. 152: 159-168.

Gibson, L.A.; Wilson, B.A.; Aberton, J.G. 2004. **Landscape characteristics associated with species richness and occurrence of small native mammals inhabiting a coastal heathland: a spatial modeling approach.** Biological Conservation. 120: 75-89.

Glenn, E.M.; Ripple, W.J. 2004. **On using digital maps to assess wildlife habitat.** Wildlife Society Bulletin. 32: 852-860.

Hosmer, D.W.; Lemeshow, S. 2000. **Applied logistic regression.** New York: Wiley-Interscience. 373 p.

Korstian, C.F. 1937. **Perpetuation of spruce on cut-over and burned lands in the higher southern Appalachians.** Ecological Monographs. 7: 125-167.

Lomolino, M.V.; Davis, R. 1997. **Biogeographic scale and biodiversity of mountain forest mammals of western North America.** Global Ecology and Biogeography Letters. 6: 57-76.

MacArthur, R.H.; Wilson, E.O. 1967. **The theory of island biogeography.** Princeton, NJ: Princeton University Press. 224 p.

McCombs, J.W. 1997. **Geographic information system topographic factor maps for wildlife management.** Blacksburg, VA: Virginia Polytechnic Institute and State University. 141 p. M.S. thesis.

Menzel, J.M. 2003. **An examination of the habitat requirements of the endangered Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*) by assessing nesting sites, habitat use and the development of a habitat model.** Morgantown, WV: West Virginia University. 122 p. Ph.D. dissertation.

Menzel, J.M.; Ford, W.M.; Edwards, J.W.; Menzel, M.A. 2004. **Nest tree use by the endangered Virginia northern flying squirrel with recommendations for habitat restoration.** American Midland Naturalist. 151: 355-368.

Menzel, J.M.; Ford, W.M.; Edwards, J.W.; Terry, T.M. In Press. **Homerange and habitat use of the endangered Virginia northern flying squirrel *Glaucomys sabrinus fuscus* in the Central Appalachian Mountains.** Oryx.

Mielke, M.E.; Soctomah, D.G.; Marsden, M.A.; Ciesla, W.M. 1986. **Decline and mortality of red spruce in West Virginia.** Report No. 86-4. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Pest Management Methods Application Group. 26 p.

Miller, J.R.; Cale, P. 2000. **Behavioral mechanisms and habitat use by birds in a fragmented agricultural landscape.** Ecological Applications. 10: 1732-1748.

Millspaugh, J.; Marzluff, J.M. 2001. **Radio tracking and animal populations.** New York: Academic Press. 474 p.

Moilanen, A. 2002. **Implications of empirical data quality to metapopulation model parameter estimation and application.** Oikos. 96: 516-530.

Nordlind, E.; Ostlund, L. 2003. **Retrospective comparative analysis as a tool for ecological restoration: a case study in a Swedish boreal forest.** Forestry. 76: 243-251.

Odom, R.H.; Ford, W.M.; Edwards, J.W.; Stihler, C.W.; Menzel, J.M. 2001. **Developing a habitat model for the endangered Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*) in the Allegheny Mountains of West Virginia.** Biological Conservation. 99: 245-252.

Ozesmi, U.; Mitsch, W.J. 1997. **A spatial habitat model for the marsh-breeding red-winged blackbird (*Agelaius phoemiceus*) in coastal Lake Erie wetlands.** Ecological Modeling. 101: 139-152.

Posillico, M.; Meriggi, A.; Pagnin, E.; Lovari, S.; Russo, L. 2004. **A habitat model for brown bear conservation and land use planning in the central Apennines.** Biological Conservation. 118: 141-150.

Rosenblatt, D.L.; Heske, E.J.; Nelson, S.L.; Barber, D.M.; Miller, M.A.; MacAllister, B. 1999. **Forest fragments in east-central Illinois: islands or habitat patches for mammals? American Midland Naturalist.** 141: 115-123.

SAS Institute, Inc. 1995. **Logistic regression examples using the SAS System. Version 6, First ed.** Cary, NC: Statistical Analysis and Software Institute, Inc. 1028 p.

Schuler, T.M.; Ford, W.M.; Collins, R.J. 2002. **Successional dynamics and restoration implications of a montane coniferous forest in the central Appalachians.** Natural Areas Journal. 22: 88-98.

Shriner, S.A.; Simons, T.R.; Farnsworth, G.L. 2002. **A GIS-based habitat model for wood thrush, *Hylocichla mustelina*, in Great Smoky Mountains National Park.** Chapter 47. In: Scott, J.M.; Heglung, P.J.; Morrison, M.L., et al., eds. Predicting species occurrences: issues of accuracy and scale. Washington, DC: Island Press: 529-535.

Sokal, R.R.; Rohlf, F.J. 1987. **An introduction to biostatistics.** 2nd edition, New York: W. H. Freeman and Co. 363 p.

Steele, M.A.; Powell, R. A. 1999. **Biogeography of small mammals in the southern Appalachian: patterns of local and regional abundance and distribution.** In: Eckerlin, R.P., ed. Proceedings of the Appalachian biogeography symposium Spec. Publ. No. 7. Martinsville, VA: Virginia Museum of Natural History: 155-165.

Stephenson, S.L. 1993. **Upland Forests of West Virginia.** Parsons, WV: McClain Printing Co. 295 p.

Stihler, C.W.; Wallace, J.L.; Michael, E.D.; Pawelczyk, H. 1995. **Range of (*Glaucomys sabrinus fuscus*), a federally endangered subspecies of the northern flying squirrel in West Virginia.** Proceedings of the West Virginia Academy of Science. 67: 13-20.

Urban, V. 1988. **Home range, habitat utilization and activity of the endangered northern flying squirrel.** Morgantown, WV: West Virginia University. 54 p. M.S. thesis.

U.S. Department of Interior, Fish and Wildlife Service. 1985. **Final rule for listing Carolina northern flying squirrel and Virginia northern flying squirrel as endangered.** Federal Register 50 FR 27002, July 1, 1985.

Weigl, P.; Knowles, T.W.; Boynton, A.C. 1999. T**he distribution and ecology of the northern flying squirrel, *Glaucomys sabrinus coloratus*, in the southern Appalachians.** Raleigh, NC: North Carolina Wildlife Resources Commission. 93 p.

Wells-Gosling, N.; Heaney, L.R. 1984. ***Glaucomys sabrinus.*** Mammalian Species. 229: 1-8.

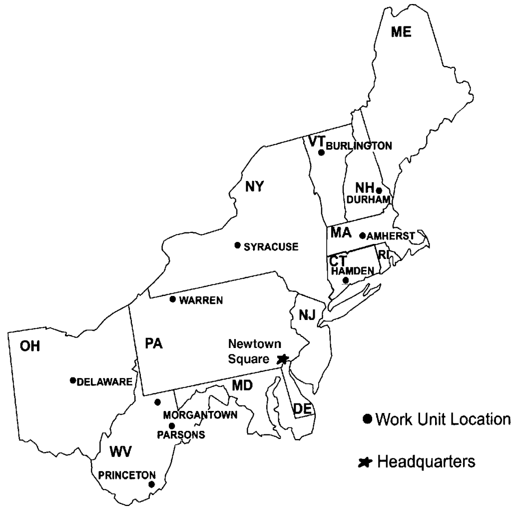
Vanderpoorten, A.; Sotiaux, A.; Engels, P. 2005. **A GIS-based survey for the conservation of bryophytes at the landscape scale.** Biological Conservation. 121: 189-194.

Menzel, J.M.; Ford, W.M.; Edwards, J.W.; Ceperley, L.J. 2006. **A habitat model for the Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*) in the central Appalachian Mountains.** Res. Pap. NE-729. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 10 p.

The Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*) is an endangered sciurid that occurs in the Allegheny Mountains of Virginia and West Virginia. Despite its status, few of its ecological requirements have been synthesized for landscape-level predictive distributions to facilitate habitat delineation efforts. Using logistic regression, we developed a GIS-based habitat model for the Virginia northern flying squirrel using micro- and macrohabitat relationship data in West Virginia. Important habitat characteristics obtained from radio-collared squirrels included: (1) elevation over 1036 m; (2) northerly aspects; and (3) red spruce (*Picea rubens*) and mixed northern hardwood-red spruce cover types. A final model retaining elevation and forest cover type showed reasonably high predictive power across a large portion of the Allegheny Mountains in West Virginia.

Key Words: Allegheny Mountains, *Glaucomys sabrinus fuscus*, GIS, habitat model, Virginia northern flying squirrel

Printed on Recycled Paper



Headquarters of the Northeastern Research Station is in Newtown Square, Pennsylvania. Field laboratories are maintained at:

Amherst, Massachusetts, in cooperation with the University of Massachusetts

Burlington, Vermont, in cooperation with the University of Vermont

Delaware, Ohio

Durham, New Hampshire, in cooperation with the University of New Hampshire

Hamden, Connecticut, in cooperation with Yale University

Morgantown, West Virginia, in cooperation with West Virginia University

Parsons, West Virginia

Princeton, West Virginia

Syracuse, New York, in cooperation with the State University of New York, College of Environmental Sciences and Forestry at Syracuse University

Warren, Pennsylvania

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternate means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination, write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, S.W., Washington, DC 20250-9410, or call (800)795-3272 (voice) or (202)720-6382 (TDD). USDA is an equal opportunity provider and employer.

"Caring for the Land and Serving People Through Research"