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Habitat Characteristics of the Endangered Virginia Northern Flying Squirrel (Glaucomys sabrinus fuscus) in the Central Appalachian Mountains

ABSTRACT.—We compared 11 ecological variables thought to be important for assessing the habitat of the endangered Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*) at 11 occupied and 9 unoccupied sites within northern hardwood-montane conifer forests in the central Appalachians of West Virginia. Forest stands at sites occupied by *G. s. fuscus* had significantly higher relative importance values of montane conifers such as red spruce (*Picea rubens*) and little or no presence of northern red oak (*Quercus rubra*) than did sites that were believed unoccupied. Probabilities derived from logistic regression analyses indicated that sites were considered occupied when relative importance values of montane conifers in forest stands exceeded approximately 35%. Conversely, we detected no differences in elevation, absolute forest basal area, overstory tree species richness, total shrub density, percent coarse woody debris cover, percent herbaceous cover, percent emergent rock cover and percent soil organic matter (humus) between occupied and unoccupied sites. We observed low levels hypogeal fungi across all sites and fungi presence did not differ between occupied and unoccupied sites. Patchily distributed fungi combined with the much reduced and altered forest habitat in the region provide additional insights into the rarity of *G. s. fuscus* in the central Appalachians.

INTRODUCTION

The Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*) is restricted to high elevation (typically >900 m) northern hardwood-montane conifer forests in the Allegheny Mountains of the central Appalachians across eastern West Virginia and western Virginia (Pagels *et al.*, 1990; Stihler *et al.*, 1995; Reynolds *et al.*, 1999). Most of these relict montane forest communities were severely degraded in composition and structure during exploitative railroad logging and widespread burning from 1880 to 1930. In West Virginia, red spruce (*Picea rubens*)-dominated forests were reduced from approximately 200,000 ha at the beginning of that period to 20,000 ha today (Korstian, 1937; Schuler *et al.*, 2002) and very little old-growth of this type remains (Adams and Stephenson, 1989). Consequently, the naturally disjunct populations of *G. s. fuscus* in the region probably were further isolated by these anthropogenic disturbances and reductions in suitable habitat (Odom *et al.*, 2001). Along with the Carolina subspecies (*G. s. coloratus*) in the southern Appalachians, *G. s. fuscus* is listed as endangered by the U.S. Fish and Wildlife Service (USFWS, 1985).

Despite its endangered status for nearly two decades, aspects of *Glaucomys sabrinus fuscus*' natural history and habitat requirements necessary for subspecies recovery are not well understood beyond fairly broad parameters (Odom *et al.*, 2001). In both the central and southern Appalachians, *G. s. fuscus* and *G. s. coloratus* have shown considerable plasticity in habitat use of high elevation forests (Stihler *et al.*, 1995; Weigl *et al.*, 2002; Menzel, 2003). Optimal conditions in both the central and southern Appalachians and elsewhere are believed to be mature to old-growth stands with open understories, scattered large conifers, deciduous trees, snags and coarse woody debris, as well as abundant lichen and hypogeal fungi availability (Wells-Gosling and Heaney, 1984; Maser *et al.*, 1986; Carey *et al.*, 1999; Weigl *et al.*, 1999; Carey, 2000; Cote and Ferron, 2001; Smith and Nichols, 2003). Menzel (2003) found that radio-collared *G. s. fuscus* in West Virginia always used forests with a conifer component, primarily red spruce. Their use of that forest type was more than would be expected based on availability across the landscape, stand and home range scales. Similarly, using low resolution satellite imagery, Odom *et al.* (2001) observed that occupied *G. s. fuscus* nest-box sites were more likely to be closer to montane conifer cover than nest-box sites where squirrels were absent. Lichens and hypogeal fungi comprise a large proportion of *G. s. fuscus* diets in the central Appalachians, so their availability also may be important determinants in northern flying squirrel presence and habitat use (Mitchell, 2001). Hypogeal fungi presence in the southern Appalachians where northern flying squirrels occur was linked to the presence of red spruce (Loeb *et al.*, 2000).

Although most known *Glaucomys sabrinus fuscus* locations are restricted to the Monongahela National Forest in West Virginia and an adjacent small portion of the George Washington National Forest in Virginia, recent surveys have revealed a larger distribution regionally than previously thought (U.S. Fish and Wildlife Service, unpubl. data; West Virginia Division of Natural Resources, unpubl. data; Stihler *et al.*, 1995). Many of these new observations occur where its presence conflicts with ongoing land-clearing activities associated with forest management, recreational/second-home development and wind-farm construction on private lands. Because *G. s. fuscus* occur at low densities and are exceedingly difficult to captue (Menzel, 2003), there is a critical need to be able to probabilistically relate simple forest habitat characteristics to its presence or absence. Based on previous records, we hypothesized that the presence of *G. s. fuscus* would be positively related to elevation, stand basal area, montane conifer cover, hypogeal fungi presence and humus depth (as a growth medium for fungi and an indirect indicator of fire periodicity) and negatively related to overall tree species richness, amount of northern red oak and total shrub density. Therefore, our objective was to comparatively examine forest habitat variables at nest-box and live-trapping survey sites where *G. s. fuscus* had been captured with sites where surveys had not, documented squirrels (Stihler *et al.*, 1995; West Virginia Division of Natural Resources, unpubl. data) and then to construct a presence/absence habitat model suitable for forest stands in the central Appalachians.

STUDY AREA AND METHODS

We examined forest habitat variables from mid-June to early August of 2001 at 11 nest-box or live-trapping survey sites where *Glaucomys sabrinus fuscus* had been documented (occupied) and 9 sites where nest-box or live-trapping surveys had failed to document their presence (unoccupied) after 3 consecutive years of effort (Stihler *et al.*, 1995; Odom *et al.*, 2001; Menzel, 2003). Eighteen sites (10 occupied and 8 unoccupied) were located on the Monongahela National Forest in Pocahontas, Randolph and Tucker counties, West Virginia and two sites (one occupied and one unoccupied) were located on the MeadWestvaco Ecosystem Research Forest, also in Randolph County (Appendix 1). Site selection was not random. We were logistically constrained to sample sites within the northern half of the distribution of *G. s. fuscus* and in areas where either nest boxes remained or geo-referenced data on where live-trapping transects occurred since the mid-1980's (Stihler *et al.*, 1995). All study sites were located within the unglaciated Allegheny Mountain and Plateau Physiographic Province, a region that is characterized by steep side slopes, narrow valleys and broad plateau-like ridgetops (Fenneman, 1938). Elevations range from 892 to 1262 m. The climate is cool and moist with a growing season of approximately 140 d and annual precipitation that often exceeds 150 cm, much of which occurs as snow during the winter months (Strausbaugh and Core, 1978). Vegetation at the 20 sites consisted of mature second-growth forests containing northern hardwood-montane conifer species such as American beech (*Fagus grandifolia*), yellow birch (*Betula alleghaniensis*), sugar maple (*Acer saccharum*), red maple (*A. rubra*), black cherry (*Prunus serotina*) in the deciduous component and eastern hemlock (*Tsuga canadensis*) and red spruce in the conifer component (Mitchell, 2001; Menzel, 2003; Owen *et al.*, 2003). In addition to eastern hemlock and red spruce, two sites contained large amounts of Norway spruce (*Picea abies*) planted by the Civilian Conservation Corp, one site contained balsam fir (*Abies balsamea*) associated with a wetland complex and one site, Gaudineer Scenic Area, contained patches of unharvested old-growth red spruce and northern hardwoods (Adams and Stephenson, 1989).

At each of the 20 survey sites, we established five 50-m parallel transects approximately 10 m apart centered on or near localities where nest boxes occurred or where live-trapping had taken place by various state, federal and university personnel since the mid-1980s. Following methods described by Adams and Stephenson (1983), we measured trees >10 cm dbh to calculate overstory basal area, overstory tree richness and relative importance values for montane conifers (eastern hemlock, red spruce, Norway spruce and balsam fir) and northern red oak using the point-center quarter method (Cottam and Curtis, 1956) at midpoint of the first, third and fifth segments of each transect and then pooled these across transects for each survey site. Overstory importance for montane conifers and northern red oak were expressed as percent values and represented the sum of relative density in stem numbers and relative basal area divided by 2 (Curtis and McIntosh, 1951). We tallied the number of

TABLE 1.—Comparison of habitat variables between survey sites where Virginia northern flying squirrels (*Glaucomys sabrinus fuscus*) were present ($n = 11$) and absent ($n = 9$) in the central Appalachian Mountains of West Virginia, June–August 2001

Habitat variables	Present		Absent		
	$\bar{x}$	SE	$\bar{x}$	SE	P[a]
Elevation (m)	1123.1	21.6	1087.2	32.9	0.19
Overstory basal area (m^2/ha)	31.3	4.3	30.7	3.3	0.79
Overstory species richness	6.2	0.6	6.8	0.6	0.43
Montane conifer RI[b]	56.5	21.7	21.1	12.2	0.003
Northern red oak RI[b]	0.0	0.0	6.5	4.3	0.05
Shrub density (100 m^2)	2986.4	1013.0	1111.11	454.7	0.15
Coarse woody debris % cover	14.3	1.7	17.4	1.7	0.21
Herbaceous % cover	19.5	5.7	29.2	7.0	0.28
Emergent rock % cover	4.4	1.7	6.8	2.0	0.31
Soil organic matter (%)	34.7	5.8	33.5	6.0	0.82

[a] Wilcoxon test

[b] Relative percent importance value (*see* text)

woody shrubs (>0.5 m height) in one 2 × 10 m plot randomly located along each transect and then pooled these data across all transects for each survey site. We estimated percent cover of coarse woody debris, herbaceous plants and emergent rock, and we surveyed for the presence of the sporocarps of hypogeal fungi by establishing 1 m^2 subplots in each of the 10 m segments in each transect for a total of 25 subplots across each survey site. At each subplot we removed the entire litter layer and the first few cm of mineral soil and sifted the entire organic and soil layers by hand (Loeb *et al.*, 2000). We counted and retained any fungi found for later identification following the key established by Castellano *et al.* (1989). To determine percent soil organic matter, we collected separate humus and soil samples at each transect and then pooled these across transects for each of the 20 survey sites for calculation of percent soil organic matter using the weight loss on ignition method (Cox, 1985). We determined elevation for each survey site within a GIS coverage previously established for each of the nest-box and live-trapping sites (Odom *et al.*, 2001).

To assess forest habitat differences between occupied and unoccupied *Glaucomys sabrinus fuscus* survey sites, we compared overstory basal area, overstory richness, relative importance values for montane conifers, relative importance values for northern red oak, total shrub counts and percent soil organic matter using non-parametric Wilcoxon tests (Steel and Torrie, 1980). Because we observed few hypogeal fungi, sites were scored simply as fungi observed or not observed and we then tested for independence between fungi and *G. s. fuscus* presence or absence using a Fisher's Exact test (Stokes *et al.*, 1995). When Wilcoxon tests or the Fisher's Exact test indicated significance ($P < 0.10$) between forest habitat variables at sites occupied or unoccupied by *G. s. fuscus*, we used stepwise logistic regression to examine the strength of that relationship with a variable entry criterion of $P < 0.25$ (SAS Institute, 1995) and to construct predictive habitat models (Odom *et al.*, 2001; Teixeira *et al.*, 2001; Ford *et al.*, 2004). We assessed the percent correct classification of observations within logistic regression models using an approximated jackknife procedure (SAS, 1995).

RESULTS

Elevation, absolute overstory basal area, overstory tree richness, shrub counts, percent coarse woody debris cover, percent herbaceous cover, percent emergent rock cover and percent organic matter in soils did not differ ($P > 0.10$; Table 1) where *Glaucomys sabrinus fuscus* had been documented with where it had not been observed. We recorded hypogeal fungi at 7 of 11 sites where northern flying squirrels were present and 5 of 9 where they were absent. Fungal genera/species detected included: *Elaphomyces granulatus* (7 sites), *Elaphomyces variegates* (3 sites), *Elaphomyces muricatus* (2 sites), *Gautieria*, *Glomus*

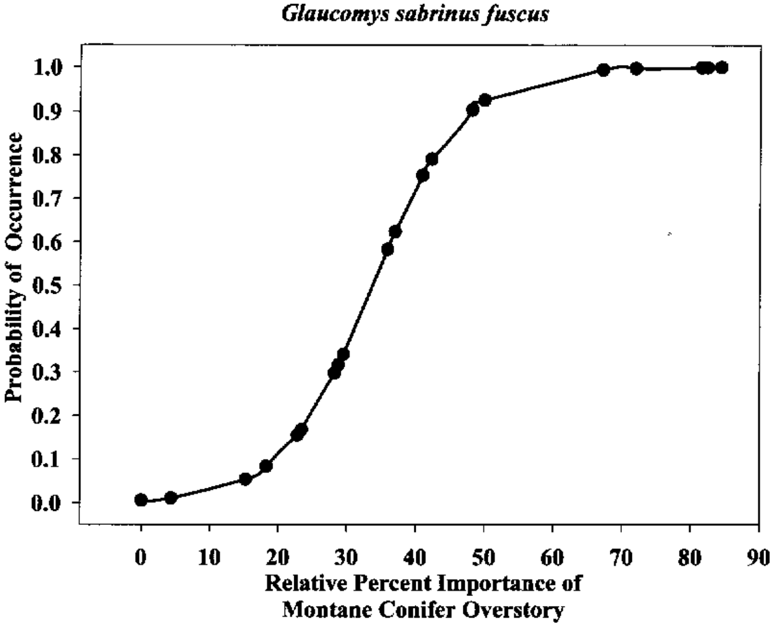

FIG. 1.—Predicted probability of occurrence of the endangered Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*) as a function of increasing importance of montane conifer tree species in the overstory in high-elevation central Appalachian forests of West Virginia. Montane conifers include: eastern hemlock (*Tsuga canadensis*), red spruce (*Picea rubens*), Norway spruce (*P. abies*) and balsam fir (*Abies balsamea*)

caledonium, *Glomus.*, *Hydnotrya cubispora* and *Tuber.* At 9 of 12 sites where hypogeal fungi occurred in sample plots, we observed fewer than 30 sporocarps. We failed to observe any relationship between presence of *G. s. fuscus* or absence and hypogeal fungi (Fisher's Exact test, P = 0.53). The importance value of northern red oak was less at survey sites where northern flying squirrels were present than where they had not been documented (P = 0.05), whereas the importance values of montane conifers were greater where northern flying squirrels had been observed (P = 0.003). Higher montane conifer importance values were related to a higher probability for northern flying squirrel presence (Fig. 1) with a good logistic regression model fit (rescaled $R^2 = 0.70$; intercept estimate = –5.27, $\chi^2 = 4.01$, P = 0.05; relative importance of montane conifer estimate = 0.16, $\chi^2 = 4.12$, P = 0.04; Homer and Lemeshow goodness-of-fit, $\chi^2 = 5.64$, P = 0.58). The relative importance of northern red oak failed to enter our model because northern red oak only occurred at 3 survey sites, all where *G. s. fuscus* was absent. Based on the relative importance of montane conifers, 10 of 11 sites were correctly predicted as having northern flying squirrels present and 8 of 9 sites were correctly predicted as not having *G. s. fuscus* for an overall correct classification rate of 90%.

DISCUSSION

The link between montane conifer forests and northern flying squirrel presence has been well-noted in the central and southern Appalachians by a number of authors (Payne *et al.*, 1989; Stihler *et al.*, 1995; Reynolds *et al.*, 1999; Wiegl *et al.*, 1999; Odom *et al.*, 2001), and our study further supports this association. Albeit weakly, our study is the first to demonstrate this relationship in a comparative and quantitative manner. Previous research relied solely on general habitat descriptions where *Glaucomys sabrinus fuscus* had been documented, but did not include unoccupied but otherwise suitable habitat.

Consequently, our study provides further insight to what constitutes potential or suitable northern flying squirrel habitat in the central Appalachians. The logistic regression model we provide could be a simple ecological tool to assess habitat and/or to predict a probability of occurrence at the patch or stand scale. Along with the coarse-grained landscape habitat models generated by Odom *et al.* (2001) and Menzel (2003), our observations enhance the ability to identify other environmental factors that might influence *G. s. fuscus* presence such as northern hardwood-montane conifer patch size, patch configuration or distance among occupied patches. Accordingly, the need for expensive and logistically difficult trapping to ascertain northern flying squirrel status might be reduced at predetermined probabilities such as >75% where presence could be assumed with a high degree of confidence.

Without a further field validation of our montane conifer/*Glaucomys sabrinus fuscus* relationship model, we would urge caution in relying solely on predictive habitat models in lieu of efforts to document *G. s. fuscus* in the central Appalachians by nest-box surveys or trapping based on 2 caveats. First, it is possible that some sites we considered unoccupied by *G. s. fuscus* (based on 3 y without a capture) were in fact occupied. Although the likelihood of this is unknown, we are only aware of a few locations where *G. s. fuscus* have been documented following a 3-y survey effort in the Allegheny Mountains (Menzel, 2003). Secondly, Weigl *et al.* (1999) believed that optimal *G. s. coloratus* habitat in the southern Appalachians was the ecotone between northern hardwoods and pure conifer stands dominated by red spruce and Fraser fir (*Abies fraseri*) rather than pure conifer stands. Whereas there is a far larger land area of high-elevation northern hardwood-montane conifer forests in the central Appalachians than in the southern Appalachians, elevations in the central Appalachians generally are insufficient for pure montane conifer stands to occur in large contiguous patches (Stephenson and Clovis, 1983; Cogbill and White, 1991). Supporting our data linking montane conifer cover to *G. s. fuscus* presence, Menzel (2003) found that radio-collared individuals in a variety of high elevation central Appalachian landscapes and vegetation combinations preferentially used habitats with large components of either red spruce or Norway spruce at the landscape, stand and local levels.

Other than the differences seen in the relative importance of northern red oak, our failure to find differences in the remaining habitat variables is not surprising. The various subspecies of *Glaucomys sabrinus* occur in a variety of forest stand conditions throughout their geographic range, from massive and structurally complex conifer forests in the Pacific Northwest to small stature boreal forests in Canada (Wells-Gosling and Heaney, 1984; Rosenberg and Anthony, 1992: Carey *et al.*, 1999; Cote and Ferron, 2000). Whereas elevation is an important general factor in delineating the habitat of *G. s. fuscus* in the central Appalachians (Odom *et al.*, 2001; Menzel, 2003), within our study the elevation range was only 369 m between highest and lowest survey sites, and our lowest sites were still approximately 150 m higher than the lowest known northern flying squirrel observation in West Virginia (Stihler *et al.*, 1995). Perhaps there are upper and lower thresholds for habitat variables such as absolute basal area or shrub density for *G. s. fuscus*, but our survey did not encompass that full range in habitat variation to detect differences. Although Weigl *et al.* (1999) state that open understories with abundant herbaceous cover probably are the optimal microhabitat conditions, Payne *et al.* (1989) found *G. s. coloratus* in the southern Appalachians across a range of sites with both low and high (>40%) shrub cover of rosebay rhododendron (*Rhododendron maximum*) that was more similar to our observations. None of our forest sites had been recently disturbed by forestry activities. All sites had moderate to well-developed overstories and understory herbaceous cover, coarse woody debris cover and emergent rock cover were highly variable.

The loss of much of the original extent of high-elevation forests from logging in the late 19^{th} and early 20^{th} Centuries followed by widespread fire was compounded by altered tree species composition and structure in the regenerated stands (Korstian, 1937; Schuler *et al.*, 2002). Many of the fires destroyed much of the humus layer (Clarkson, 1983) and undoubtedly much of the large coarse woody debris associated with the original old-growth forest leaving a depauperate forest floor condition in second-growth forests. Based on research conducted in the central Appalachians and other regions, these events reduced the growth medium suitability for hypogeal fungi or substantially changed the fungal species composition locally (Waters *et al.*, 1994; North and Greenberg, 1998; Ferris *et al.*, 2000; Orrock and Pagels, 2002). Loeb *et al.* (2000) noted that hypogeal fungi are patchily distributed and vary greatly in their abundance in northern hardwood-red spruce forests in the southern Appalachians. They also observed an associative link of truffles with red spruce rather than with hardwood tree species. Although our temporally limited survey may have failed to document actual hypogeal fungi abundances, the irregular fungal distribution combined with an association to red spruce, coarse woody debris and deep humus-layers that were altered or reduced may help explain the rarity of *Glaucomys sabrinus fuscus* within regional high-elevation forests when compared to northern flying squirrel populations and habitat relationships for regions such as the Pacific Northwest (Carey, 1995; Carey *et al.*, 1999; Lehmkuhl *et al.*, 2003). Also, these same historic disturbances that diminished the area and quality of the high-elevation habitats increased the amount of hard-mast tree species such as northern red oak. Increased oak mast would benefit the southern flying squirrel (*Glaucomys volans*) by providing a cachable, high-energy food in a zone that is otherwise too energetically demanding throughout much of the dormant season. Expanded zones of sympatry could negatively impact northern flying squirrels as the southern flying squirrel is thought to be a superior den-site competitor and is a parasite-mediated competitor as a *Strongyloides* host (Wiegl *et al.*, 1999; but *see* Pagels *et al.*, 1990).

The mycophagic food habits of *Glaucomys sabrinus fuscus* (Mitchell, 2001), the relatonship between red spruce and hypogeal fungi (Loeb *et al.*, 2000) and our observation of increased *G. s. fuscus* presence with increased montane conifer along with the expected decrease regionally in eastern hemlock from hemlock adelgid (*Adelges tsugae*) infestation (Jenkins *et al.*, 1999) would suggest the prudence of expanding red spruce forests and accelerating the time to achieve old-growth structure (Schuler *et al.*, 2002). Nonetheless, the status of the *G. s. fuscus* and its associated high-elevation forest in the central Appalachians will continue to be plagued by uncertainty unless efforts continue to more clearly define its macro- and micro-habitat associations. Efforts to clarify those relations, as well as to identify other potential limiting factors such as den site availability (Carey, 1983; Hackett and Pagels, 2003) or habitat configuration and forest condition (Menzel, 2003) need to be continued.

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W. MARK FORD, Northeastern Research Station, Parsons, West Virginia 26287; STEVEN L. STEPHENSON, Department of Biological Sciences, University of Arkansas, Fayetteville, 72701; JENNIFER M. MENZEL, Northeastern Research Station, Parsons, West Virginia 26287; DAWN R. BLACK, Department of Environmental and Plant Biology, Ohio University, Athens, 45701; AND JOHN W. EDWARDS, Division of Forestry, West Virginia University, Morgantown, 26506. *Submitted 1 December 2003; accepted 31 March 2004.*

APPENDIX 1.—Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*) habitat variable survey sites in the central Appalachian Mountains of West Virginia, June–August 2001. Forest types are as follows: BF = balsam fir (*Abies balsamea*), EH = eastern hemlock (*Tsuga candensis*) NH = northern hardwood, NS = Norway spruce (*Picea abies*) and RS = red spruce (*Picea rubens*)

Site	County	Latitude-longitude	Forest type	Squirrel presence
Big Run	Tucker	39°06′18.7″N, 79°33′48.7″W	RS-NH	YES
Blister Run	Randolph	38°36′24.2″N, 79°51′41.5″W	RS-BF-NH	YES
Canaan Heights	Tucker	39°05′57.4″N, 79°26′18.7″W	NS	YES
Canaan Pipeline	Tucker	39°04′52.5″N, 79°27′36.1″W	RS	YES
Cheat Bridge	Randolph	38°37′08.4″N, 79°51′57.8″W	RS-NH	NO
Cromer Run #1	Randolph	38°38′27.6″N, 79°55′16.9″W	RS-NH	NO
Cromer Run #2	Randolph	38°39′51.0″N, 79°54′29.8″W	RS-NH	NO
Cromer Run #3	Randolph	38°38′35.5″N, 79°53′47.8″W	EH-NH	YES
Cromer Top	Randolph	38°38′00.4″N, 79°55′20.0″W	NH	YES
Durbin	Pocahontas	38°32′30.8″N, 79°49′12.2″W	EH-NH	NO
Gaudineer Scenic Area	Randolph	38°38′06.4″N, 79°50′18.6″W	RS-NH	YES
Iron Bridge	Pocahontas	38°38′22.6″N, 79°48′16.8″W	EH-NH	NO
Middle Mountain #1	Pocahontas	38°44′27.1″N, 79°42′30.6″W	NH	NO
Middle Mountain #2	Pocahontas	38°42′44.9″N, 79°44′07.7″W	NH	NO
Middle Mountain #3	Pocahontas	38°40′03.0″N, 79°43′29.6″W	NS	YES
Moore Run	Tucker	38°59′57.6″N, 79°41′16.7″W	EH-NH	YES
Olson Tower	Tucker	39°06′28.9″N, 79°36′04.9″W	EH-NH	YES
Rocky Run East	Randolph	38°40′57.0″N, 80°06′59.1″W	EH-NH	YES
Rocky Run West	Randolph	38°40′09.7″N, 80°05′41.3″W	EH-NH	NO
Smoke Camp Knob	Pocahontas	38°33′11.3″N, 79°42′16.0″W	NH	NO