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# Using Digital Terrain Modeling to Predict Ecological Types in the Balsam Mountains of Western North Carolina

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**Abstract**

Relationships between overstory composition and topographic conditions were studied in high-elevation (>1300 meters) forests in the Balsam Mountains of western North Carolina to determine whether models could be developed to predict the occurrence of vegetative communities in relation to topographic factors. Size and number of woody species and topographic variables (elevation, landscape position, surface geometry, slope gradient, aspect) were measured on 0.10-hectare plots located across a range of mountainous landforms. Analysis of species density and dominance using multivariate classification and ordination techniques identified five ecological types. Multivariate discriminant analysis indicated that elevation and landscape position were the most important environmental variables associated with presence of ecological types. Landscapes in the study area >1300 meters were classified into predicted ecological types by applying discriminant functions to digital terrain models, using a desktop computer-based Geographic Information System. Accuracy of the classification, evaluated with an independent data set, indicated 86 percent agreement with model predictions. This approach may offer a relatively quick method for analyzing and predicting with limited data the distribution of important ecological conditions over large areas. To explore potential applications of this approach, results were applied in the Balsam Mountains and nearby Nantahala Mountains to predict occurrence of potential habitat for the endangered Carolina northern flying squirrel (*Glaucomys sabrinus coloratus*) and to aid in making decisions about recovery efforts and field surveys for the species.

**Keywords**: Carolina northern flying squirrel, discriminant analysis, *Glaucomys sabrinus coloratus*, northern hardwoods, potential habitat, spruce-fir.

## Introduction

Forest ecosystems in the Southern Appalachian Mountains of Eastern North America have long been recognized as some of the most diverse on the continent (Braun 1950). The variable geologic parent materials, complex topography, high rainfall, and diverse biotic communities of this bioregion create an array of ecological conditions that have posed substantial challenges for resource managers since the days of Schenck and Pinchot. Over the last 50 years, a number of studies have documented both local- (Day and Monk 1974, McLeod 1988, Mowbray and Oosting 1968) and landscape-level (Braun 1950, Davis 1930, Whittaker 1956) relationships between plant communities and various environmental gradients that are primarily controlled by topography. In addition to influencing environmental gradients, such as soil moisture and atmospheric temperature regimes, topography has also played a major role in determining the extent and severity of disturbances, such as drought (Hursh and Haasis 1931) and lightning-caused forest fires (Barden and Woods 1976), in these landscapes. These studies have provided a basis for understanding the ecological relationships among vegetation, landform, and soils in the Southern Appalachians. Using this knowledge, land managers can apply forest management activities in appropriate ecological contexts (Barnes and others 1982).

Ecological land classification provides a framework through which ecological knowledge, such as plant-site relationships, can be applied at various scales to support land use planning and forest resource management (Barnes and others 1982, Driscoll and others 1984, McNab 1996). However, information needed on soils and vegetation communities to adequately define and map ecological units at appropriate scales (e.g., ≥1:50,000) is not available for many areas in the Southern Appalachians, especially ecosystems at high elevations. It is at these scales that most forest management activities occur and where patterns of biodiversity are often most apparent, e.g., the contrast between riparian, cove hardwood, and upland communities along a landform gradient from stream to ridge top.

This paper describes preliminary results of a study that predicted ecological types (a predictable forest community with a typical species composition inhabiting sites with a

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common set of environmental conditions) from topographic attributes derived from digital terrain data. Large-scale digital terrain data are available for most areas of the United States and can be used to analyze terrain conditions and topographically delineate similar landscape units in mountainous terrain (Blaszczynski 1997, McNab 1991, Odom 1998). Because many environmental gradients and disturbance patterns in mountainous areas are often correlated with topography, analysis of digital terrain data in a Geographic Information System (GIS) may provide an efficient means of predicting the spatial distribution of ecological types and other important ecological attributes (Ford and others 2000; Iverson and others 1997; McNab 1996; Wilds 1997). In this paper we (1) describe the principal ecological types of high-elevation [> 1 300 meters (m)] ecosystems in the Balsam Mountains, (2) develop and test predictive models for the ecological types, and (3) demonstrate application of the ecological types to predict potential habitat for the Carolina northern flying squirrel (*Glaucomys sabrinus coloratus*), a federally listed endangered species.

## Methods and Analysis

### Study Area

The study was conducted in the Balsam Mountains of western North Carolina approximately 50 kilometers (km) southwest of Asheville, NC (fig. 1). This mountain range is one of the larger massifs in western North Carolina with approximately 28 000 hectares (ha) above 1 300-m elevation. The Balsams contain large areas of the Pisgah and Nantahala National Forests, two designated wilderness areas, over 75 km of the Blue Ridge Parkway (Parkway), municipal watersheds for several communities, and both industrial and nonindustrial private forests. Portions of the Balsams were heavily logged in the early 1900's and some areas, such as the Shining Rock-Graveyard Fields area, were severely disturbed by logging-related fires and subsequent soil erosion. As in other areas of the Appalachians, the introduction and spread of chestnut blight [*Endothia (Cryphonectria) parasitica*] essentially removed the American chestnut [*Castanea dentata* (Marsh.) Borkh.] as a dominant overstory species in mid- to low-elevation forests

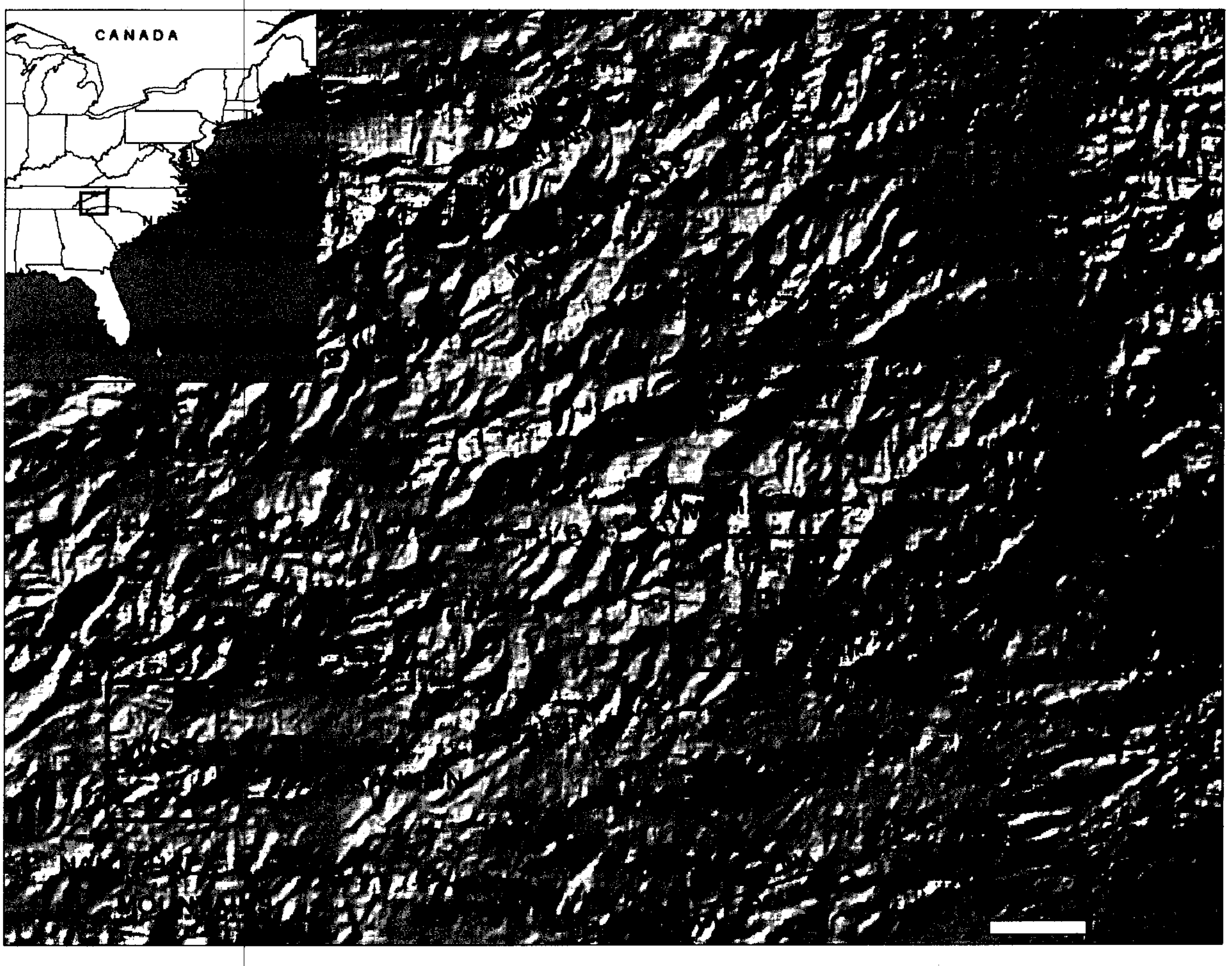


Figure 1—Location of Balsam Mountains (BM) and Wine Spring Creek (WSC) study areas (outlined in black) in the Southern Appalachian Mountains of western North Carolina.

by the 1930's. Over the last 30 years, the balsam wooly adelgid (*Adelges piceae*) has severely impacted all Fraser fir [*Abies fraseri* (Pursh) Poir.] stands in the Balsam Mountains (Dull and others 1988). With the exception of the Shining Rock area, specific ecological impacts of early logging, settlement, and other disturbances are mostly undocumented in the Balsams. Most of the area is currently covered in closed forests from 50 to over 130 years of age.

Fraser fir forests once occupied the highest elevations in the Balsams, generally above 1 800 m. Many of these stands are now composed primarily of standing dead trees and snags as the result of balsam wooly adelgid infestations. Dense thickets of blackberry (*Rubus allegheniensis* Porter) or rhododendron (*Rhododendron catawbiense* Michx.) often dominate the understory in heavily impacted stands; fir regeneration and a variety of shrub species are common where stands are more intact. Exposed knobs and ridges between 1 600 and 1 800 m are occupied by mixed red spruce (*Picea rubens* Sarg.)-Fraser fir forests, often interspersed with hardwood species on slightly lower or more sheltered landforms. Older spruce stands on relatively exposed sites have a very open understory with little vertical structure, while those on more mesic sites contain dense spruce and fir regeneration as well as a higher diversity of shrub and herbaceous species. High-elevation northern red oak (*Quercus rubra* L.) forests dominate exposed landforms and south-facing slopes between 1 200 and 1 600 m, with American beech (*Fagus grandifolia* Ehrh.) as a common associate. Individual trees are often open and poorly formed in comparison to northern red oak on cove sites at lower elevations. Understories are generally open with relatively low species diversity. The sedge *Carex pensylvanica* Lam. is a common ground cover. Northern hardwood forests dominated by yellow birch (*Betula alleghaniensis* Britt.), American beech, sugar maple (*Acer saccharum* Marsh.), and yellow buckeye (*Aesculus octandra* Marsh.) occur on concave landforms and on north-facing slopes between 1 300 and 1 600 m. Serviceberry (*Amelanchier laevis* Wieg.) is very common in the midstory. Shrub and small tree diversity on mesic sites under spruce-fir and northern hardwood overstories is often high and characterized by a number of ericaceous shrubs, mountain ash (*Sorbus americana* Marsh.), mountain maple (*Acer spicatum* Lam.), fire cherry (*Prunus pensylvanica* L.f.), serviceberry, yellow birch, and American beech. Mosses and ferns are the predominant ground covers, with herbaceous species becoming more common on concave sites. Cove hardwood communities occur on lower slope positions and concave landforms below 1 400 m in the Balsam Mountains. Overstories may contain many of the species listed except Fraser fir and usually include additional species such as Eastern hemlock [*Tsuga canadensis* (L.) Carr.], Carolina silverbell (*Halesia carolina* L.), black cherry (*P. serotina* Ehrh.), cucumber tree (*Magnolia acuminata* L.), and basswood (*Tilia heterophylla* Vent.). Dense thickets of rosebay rhododendron (*R. maximum* L.) are common in some cove forests, and herbaceous communities dominate the ground flora (Schafale and Weakley 1990, White and others 1993).

Annual precipitation at Haywood Gap, within the study area at an elevation of about 1 650 m, averages about 215 centimeters (cm) and is equally distributed throughout the year. Specific temperature data are not available for the Balsam Mountains but may be inferred from long-term average temperatures recorded at Waynesville, NC, which is situated 10 to 15 km north of the study site at an elevation of 790 m. Annual temperature averages 12.2 °C, ranging from an average monthly minimum of 1.8 °C in January to an average monthly maximum of 21.1 °C in July. Orographic effects associated with the higher elevation study site would probably result in a similar temperature regime with lower average values.

Elevations in the study area range from 1 200 to more than 1 900 m, and the topography is rugged and steep. Geologic formations are composed primarily of pre-Cambrian acid silicate rocks such as quartzite, biotite gneiss, and mica schist. Major soil groups include deep (> 100 cm), mesic Umbric Dystrochrepts in coves to very shallow (< 50 cm) frigid Lithic Dystrochrepts on higher ridges and peaks. Typic Dystrochrepts predominate on side slopes. Soils are moderately to strongly acidic (pH 5.5 to 6.0) depending on parent material (U.S. Department of Agriculture, Natural Resources Conservation Service 1997).

**Data Collection**

Forty .10-ha circular plots were located throughout the study area over the range of landforms above 1 300 m. Plots were located subjectively, but without conscious bias, to sample the major landform types (e.g., ridges and coves), slope positions (e.g., upper, middle, and lower slopes), and aspects. Areas that appeared to be highly or recently disturbed were not sampled. The following information was recorded for each plot:

- species and diameter at breast height (d.b.h.) of all stems > 10 cm d.b.h.,
- basal area ($m^2$ per ha),
- visual ecological type,
- evidence of past disturbance, e.g., old road beds,
- elevation (estimated from 1:24,000 topographic map),
- aspect (degrees azimuth),
- average maximum slope gradient (percent),
- terrain shape index (TSI), and
- landform index (LFI).

The latter two parameters have been used extensively by the authors to characterize meso- and micro-scale landforms in the Southern and Central Appalachians (Ford and others 2000; McNab 1989, 1993; Odom 1996, 1998). Terrain shape index quantifies plot surface shape as a continuous variable and generally ranges from <-0.05 (convex) to >0.05 (concave). Landform index characterizes the plot location as being part of a ridge (LFI < 0.15), slope (LFI 0.15 to 0.25) or cove (LFI > 0.25) landform and can be viewed as an indicator of exposure to solar radiation, wind, and other biological and meteorological factors. Terrain shape index and LFI are determined by algebraically averaging slope readings taken from the center of a plot to the edge of the plot and to the horizon, respectively.

**Data Analysis**

Vegetation and topographic data were analyzed using a series of multivariate techniques. An average importance value (AIV) of each species was calculated for each plot:

AIV = (relative density + relative dominance) / 2,

where

relative density = (number of individuals of species / total number of individuals) x 100 and
relative dominance = (dominance of a species / dominance of all species) x 100,

where

dominance = mean basal area per tree x the number of trees of the species or all species.

Individual plots were classified into groups of similar vegetation using Two-Way Indicator Species Analysis (TWINSPAN), a widely used computer program that objectively forms clusters of plots based on similar species composition and abundance (Hill 1979a). Detrended Correspondence Analysis (DECORANA) (Hill 1979b) was used for indirect gradient analysis of species and plots to gain insight into their relationship with major environmental gradients and for objective grouping into ecological types. Ecological types, defined as recurring groups of species and their physical environment, were identified based on the classification and ordination analysis, and named based on descriptions of vegetative communities (Schafale and Weakley 1990). Multivariate discriminant analysis was then used to develop a prediction model for each ecological type based on the topographic variables measured at each plot (McNab 1991).

A GIS (IDRISI™, Eastman 1992) was used to apply topographic-vegetation relationships to produce a map of predicted ecological types. Digital elevation models (DEM's), corresponding to the Sam Knob and Shining Rock, NC 7.5' U.S. Geological Survey topographic quadrangles, were used to create digital maps of elevation, landform index, terrain shape index, slope gradient, and aspect. These maps had a resolution (pixel size) of 30 by 30 m or 0.09 ha. Using algorithms in IDRISI™, the predictive relationship derived from the discriminant analysis for each ecological type was applied to each pixel on the two DEM's. Pixels were classified and assigned color values based on the highest probability of dominance by one of the predicted ecological types.

**Classification Validation**

Accuracy of the classification was evaluated by the junior author, who was not involved in field plot location or collection of the analysis data used for model development. A validation data set was obtained from the Parkway, which provided a 23-km linear transect through the study area. Designated overlook parking areas along the Parkway were considered as randomly situated sample points. A sample site beyond the disturbed road right-of-way along the Parkway was randomly located from each sample point. Based on experience of the observer, the predominant vegetation observed at each sample site was visually classified into one of the ecological types identified from the analysis data. Geographical coordinates of the validation sample sites were determined with a global position system receiver capable of 2- to 5-m accuracy. Coordinates of the validation sites were entered in the GIS to determine (1) the point (pixel) in the digital version of the classified landscape at which the field validation site was situated, and (2) its predicted ecological type. The G statistic was calculated for the log-likelihood ratio goodness of fit (Zar 1996) to test the null hypothesis of no significant differences among ratios of observed and predicted ecological types at the $p = 0.05$ level of probability.

## Results and Discussion

**Ecological Types**

Five ecological types were identified for the Balsam Mountains study area: Fraser fir forest, red spruce-Fraser fir forest, northern hardwood forest, high-elevation red oak forest, and rich cove forest. A few species were common, although not equal in importance, to all five ecological types. Those species occurring on more than 45 percent of the plots within a type were considered ubiquitous and included red spruce, yellow birch, serviceberry, and American beech (table 1). Species occurring on less than 45 percent of the plots within a type were classified as restricted and were important in separating one type from another. Species such as Fraser fir, fire cherry, mountain ash, and mountain maple are well-known associates of high-elevation forests in the Southern Appalachians but were not found on sites dominated by northern red oak or in cove forests. Northern red oak was clearly the indicator species for drier portions of the study area; these sites were the only ones where this species dominated the overstory. Typical cove species, such as eastern hemlock, sugar maple, cucumber tree, and silverbell, defined the rich cove type, although red spruce and yellow birch were also very common. Most rich cove plots were located at the heads of coves or in gaps at relatively high elevations (mean elevation 1 301 m) and lacked species such as yellow poplar (*Liriodendron*

**Table 1—Constancy of ubiquitous and restricted woody species on forty .10-ha plots located in the Balsam Mountains of western North Carolina**

| Principal species | Rich cove (4)[a] | Northern hardwood (11) | High-elevation red oak (10) | Red spruce-Fraser fir (12) | Fraser fir (3) |
|---|---|---|---|---|---|
| | Ecological type | | | | |
| | *Percent* | | | | |
| Ubiquitous | | | | | |
| Red spruce | 80 | 90 | 80 | 100 | 100 |
| Yellow birch | 100 | 100 | 30 | 91 | 100 |
| Serviceberry | 60 | 80 | 80 | 100 | 33 |
| Beech | 60 | 80 | 40 | 64 | 0 |
| Restricted | | | | | |
| Northern red oak | 20 | 10 | 100 | 36 | 0 |
| Fire cherry | 25 | 50 | 0 | 36 | 100 |
| Yellow birch snag | 40 | 50 | 10 | 55 | 33 |
| Fraser fir | 0 | 30 | 0 | 55 | 100 |
| Mountain ash | 0 | 10 | 0 | 27 | 100 |
| Hemlock | 80 | 10 | 40 | 0 | 0 |
| Silverbell | 80 | 0 | 50 | 0 | 0 |
| Sugar maple | 60 | 50 | 10 | 9 | 0 |
| Black cherry | 20 | 30 | 20 | 18 | 0 |
| Mountain maple | 0 | 30 | 0 | 9 | 33 |
| Yellow buckeye | 0 | 50 | 0 | 18 | 0 |

[a] Numbers in parentheses are the number of plots for each ecological type.

*tulipifera* L.) and basswood. This type probably represents a transitional community between true cove forests at lower elevations and montane boreal forests on the higher slopes (Schafale and Weakley 1990).

Many species occurred throughout the study area but varied in their importance among ecological types. Red spruce AIV declined from 37.7 in the spruce-fir type to 3.2 in rich cove forests, but maintained its presence in both the overstory and understory at lower elevations. Yellow birch had AIV of approximately 13 across spruce-fir, northern hardwood, and rich cove types but was almost entirely absent (AIV 1.8) from most plots dominated by northern red oak. In contrast, northern red oak was present in 4 of the 5 ecological types but importance ranged from an AIV of 19.8 in the red oak type to 8.9, 4.3, and 1.5 in spruce-fir, northern hardwood, and rich cove types, respectively. American beech was important in both northern red oak (AIV 19.5) and northern hardwood (AIV 16.3) types.

Table 2 shows the mean topographic conditions for the five ecological types. Elevation was the most important discriminating variable among ecological types. Fraser fir forests were correlated with high elevation (> 1 800 m), exposed landscapes which are very restricted in the Balsam Mountains. Slopes were generally moderate and sites tended to be somewhat convex. Red spruce-Fraser fir forests were associated with slightly lower landscapes between 1 650 and 1 800 m but still on relatively exposed ridges and upper slopes. Landscape position, aspect, and slope steepness were highly variable within this type and at least two subtypes appeared to occur. In general, yellow birch, Fraser fir, and serviceberry were more important components of red spruce-Fraser fir forests on more sheltered or north-facing slopes, while northern red oak and beech were more important on exposed convex ridges and south-facing slopes. Many of the dome-shaped knobs that dot the crest of the Balsam Mountain range are covered by well-developed, mature stands of red spruce with many large-diameter (60 to 75 cm d.b.h.) stems. The age of several trees in these stands was more than 120 years (determined by increment core analysis), and understories were generally open with little ground cover.

Xeric landscape positions, such as steep, south-facing slopes and ridges below 1 650 m with no higher landforms nearby, were correlated with the high-elevation red oak type. Seventy percent of plots dominated by northern red oak occurred on sites with S-SW-W aspects. At approximately 1 650 m, northern red oak communities blended with beech and red spruce to form mixed stands. On sites that appeared to be more disturbed, American beech was codominant with

**Table 2—Mean terrain attributes associated with ecological types in the Balsam Mountains of western North Carolina**

| Ecological type | Terrain attribute | | | | |
|---|---|---|---|---|---|
| | Elevation | Aspect | Gradient | LFI | TSI |
| | *Meters* | *Degrees* | *Percent* | | |
| Rich cove | 1301 | 64 | 32 | 0.25 | 0.08 |
| Northern hardwood | 1644 | 137 | 43 | .24 | .05 |
| High-elevation red oak | 1500 | 161 | 28 | .12 | .01 |
| Red spruce-Fraser fir | 1706 | 190 | 36 | .14 | -.01 |
| Fraser fir | 1858 | 262 | 18 | .09 | -.03 |

LFI = landform index, TSI = terrain shape index.

red oak in the overstory and often formed pure beech thickets in the understory. Some of these sites occurred on relatively flat knobs or ridge tops close to the Parkway and may have received concentrated use during construction of the roadway. The sedge *C. pensylvanica* was the predominant ground cover in these areas.

Both northern hardwood and rich cove types occupied relatively sheltered landscape positions or were associated with northerly aspects or concave microsites when they occurred on more upper slope positions of ridges. Plots classified as rich cove ecological type occurred at lower elevations and on more moderate slopes than those classified as northern hardwood. As noted by Schafale and Weakley (1990, pp. 28–29), these two communities are difficult to separate at moderately high elevations where cove landforms are not pronounced and true cove species are not abundant.

Elevation and LFI were the most important discriminating factors in the classification of study plots (fig. 2), although all terrain variables seemed to play a role in defining land types associated with the five ecological types. Approximately 85 percent of the 40 analysis plots were correctly classified by the discriminant functions (table 3). No pattern of errors was evident among the six misclassified plots, although most occurred in the northern red oak ecological type. The discriminant functions predicted nearly

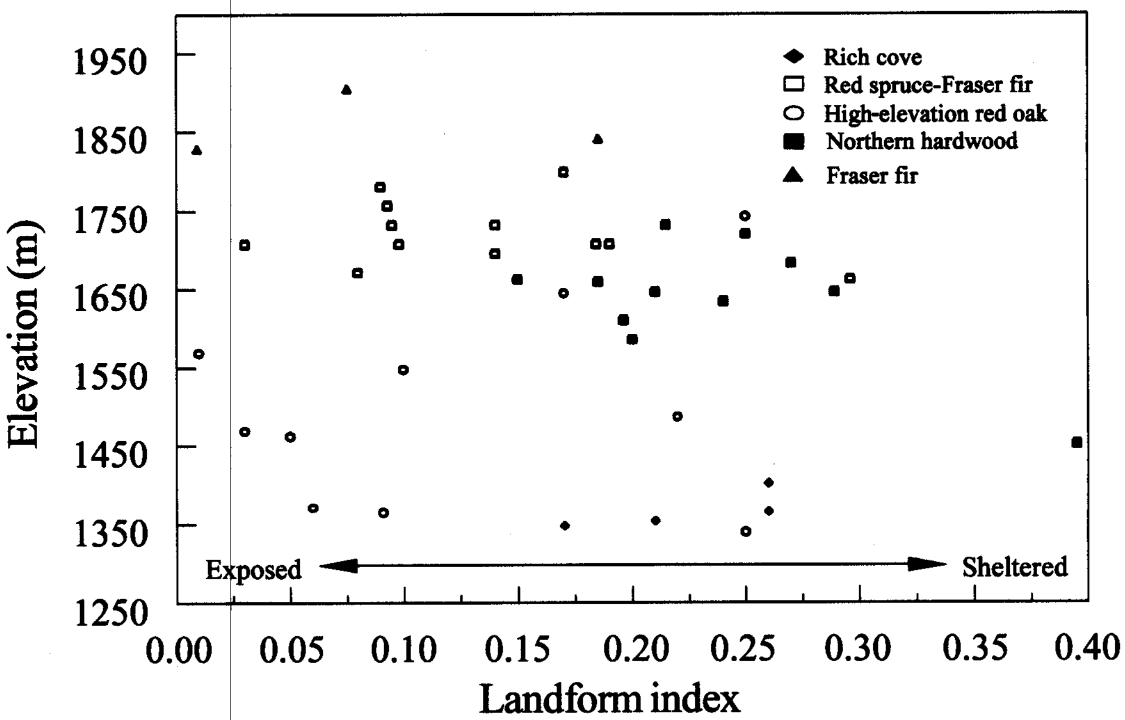


Figure 2—Distribution of study plots coded by ecological type along elevation and landform index gradients in the Balsam Mountains of western North Carolina.

**Table 3—Classification summary of observed and predicted ecological types for the analysis and validation data sets, Balsam Mountains of western North Carolina**

| Observed ecological type | Predicted ecological type: Fraser fir | Red spruce-Fraser fir | Northern hardwood | Northern red oak | Rich cove | Total |
|---|---|---|---|---|---|---|
| Analysis data | | | | | | |
| Fraser fir | 3 | — | — | — | — | 3 |
| Red spruce-Fraser fir | — | 11 | 1 | — | — | 12 |
| Northern hardwood | — | 1 | 9 | 1 | — | 11 |
| Northern red oak | — | 1 | 1 | 7 | 1 | 10 |
| Rich cove | — | — | — | — | 4 | 4 |
| Total | 3 | 13 | 11 | 8 | 5 | 40 |
| Validation data | | | | | | |
| Fraser fir | 1 | — | — | — | — | 1 |
| Red spruce-Fraser fir | — | 14 | — | — | — | 14 |
| Northern hardwood | — | 4 | 1 | — | — | 5 |
| Northern red oak | — | — | — | 7 | — | 7 |
| Rich cove | — | — | — | — | 2 | 2 |
| Total | 1 | 18 | 1 | 7 | 2 | 29 |

— = no plots classified as a combination of predicted and observed ecological types.

equal probabilities of occurrence for two or more of the five possible ecological types on half of the misclassified plots.

In general, the association of ecological types with topographic conditions in this study area compare favorably with those identified by Whittaker (1956) and others for the Southern Appalachian Mountains. Plot elevation and protection relationships displayed in figure 2 were compared with Whittaker's mosaic charts for several species common to both areas. The distributions with regard to elevation and landform were strikingly similar. Whittaker did not identify northern hardwood as a type, but seems to have included stands dominated by mixtures of beech, yellow birch, buckeye, or sugar maple as part of the spruce-fir, beech gap, or cove hardwood types. Separating northern hardwoods as a type was difficult in this study; this type may occur in the Balsam Mountains landscape only as a narrow transitional element between more clearly identifiable forest associations.

## Validation of Ecological Types

Almost half of the observed validation plots were situated in the red spruce-Fraser fir ecological type (table 3) because the Parkway follows the main crest of the Pisgah Ridge through the Balsam Mountains, with elevations ranging from 1 600 to 1 700 m. An average 86 percent of the validation plots were classified correctly (table 3), which is consistent with classification results achieved using the analysis plots. The log-likelihood test indicated no significant difference ($p = 0.05$) between the observed and predicted ratios of ecological types. All of the misclassifications occurred in the northern hardwoods type, which occurred in the validation area as a complex mosaic of small patches interspersed with red spruce. Apparently, lack of sensitivity of the discriminant function for northern hardwoods combined with inaccuracies of the DEM resulted in inability to accurately model the mosaic of these two species. Results were best (100 percent correct) for the northern red oak type, where the canopy was usually dominated by this single species. Although results were good for the Fraser fir and rich cove types, these types were insufficiently represented in the validation area and did not provide a statistically valid test.

The final map depicting the predicted distributions of the five ecological types in the Balsam Mountains (fig. 3) was subjectively evaluated by the authors and by biologists from the North Carolina Wildlife Resources Commission who are familiar with the Balsam Mountains landscape. The consensus was that the map portrayed the distribution of ecological types in a manner consistent with our sense of where these communities should occur on the landscape.[2] In addition, given the preliminary nature of this study and the very limited field data collected, achieving an 86 percent correct classification rate for validation plots leads us to believe that this approach deserves more attention and a more rigorous evaluation.

[2] Personal communication. 1998. Chris McGrath, Wildlife Biologist, North Carolina Wildlife Resources Commission, 315 Morgan Branch Road, Leicester, NC 28748.

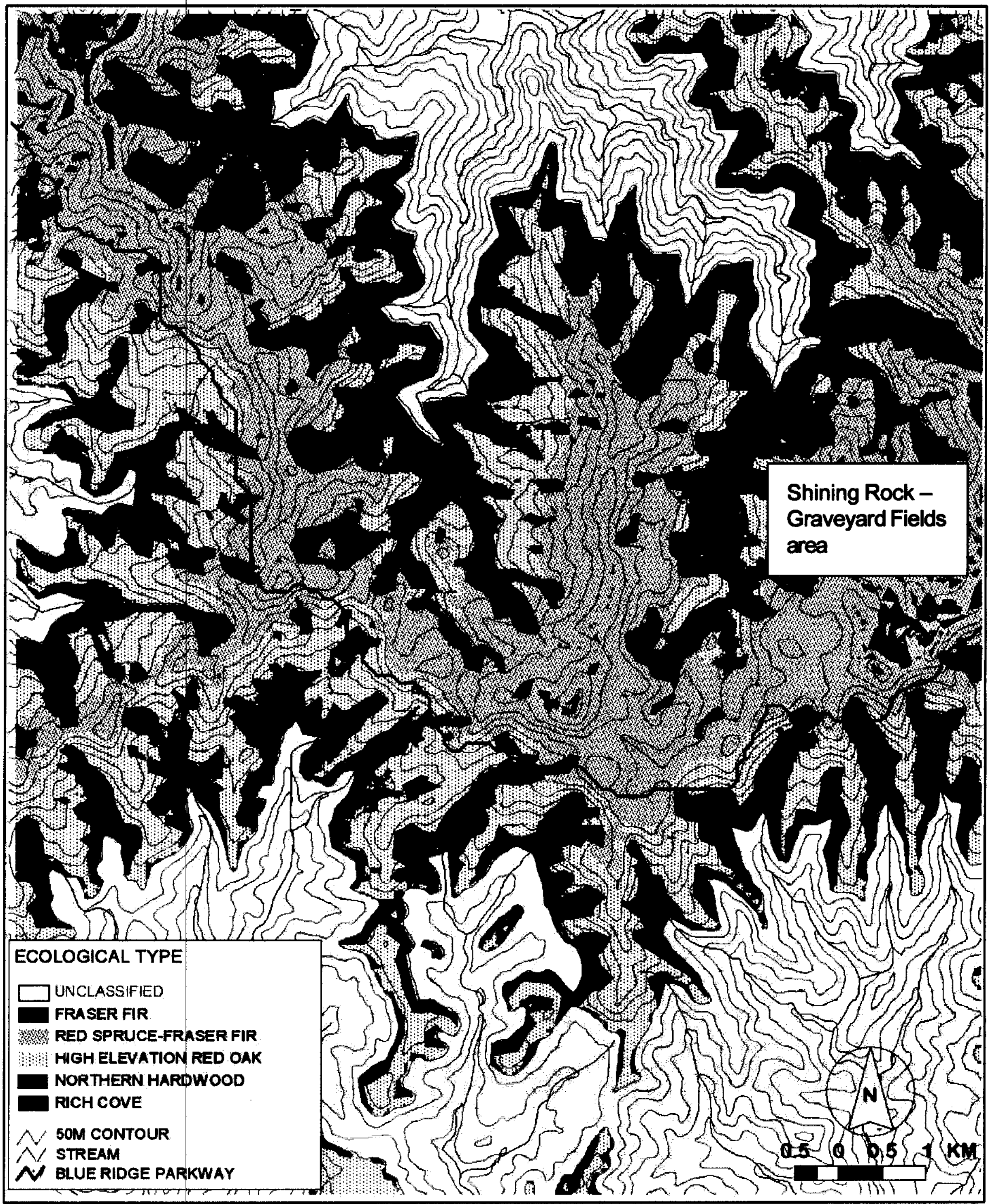


Figure 3—Map of predicted ecological types resulting from implementation of multivariate discriminant models in a geographic information system for the Sam Knob, NC 7.5' topographic quadrangle.

Potential users of these models in geographic areas other than the Balsam Mountains should conduct on-site analyses of relationships between vegetation and topography before relying on our model predictions for management decisions. For example, similar vegetative communities of the Balsam Mountains occur also in the Black Mountains, about 80 km northeast of our study area (Braun 1950, Davis 1930, Dull and others1988, McLeod, 1988). However, similar climatic, geologic, and edaphic conditions with different disturbance regimes in the Black Mountains could combine to produce significantly different environmental relationships for some ecological types, especially red spruce (Sullivan and others 1980). Additional study would determine the area over which our discriminant functions are applicable.

## Potential Applications

### Predicting Potential Habitat for the Carolina Northern Flying Squirrel

A current study of Carolina northern flying squirrel (CNFS) populations in the Southern Appalachians offers an opportunity to test the utility of our approach in predicting the extent of potential habitat for this species. The CNFS, a federally listed endangered species, occupies high-elevation northern hardwood and mixed conifer-hardwood forests in the Southern Appalachian Mountains (Weigl 1990, Weigl and others 1999) and is known to occur at several sites in the study area (see footnote 2) and region (Cantrell 1997). The CNFS appears to be restricted to relict islands of high-elevation forest that were more widely distributed during the Pleistocene. The Recovery Plan for the CNFS outlines a number of research questions and management issues regarding conservation of the species that need to be addressed (U.S. Department of the Interior, Fish and Wildlife Service 1990). These questions and issues include the lack of good information about the spatial distribution of potential habitat.

Squirrels have been found most often in forests above 1 500 m with an overstory of northern hardwoods, red spruce, and Fraser fir. However, they have also been captured in mixed hardwood-hemlock forests on northerly aspects or in coves. This species does not commonly occur in forests dominated by mast-bearing species, such as northern red oak, or in pure stands of spruce-fir. Weigl and others (1999, pp. 52–53) point out that while the composition and structure of the vegetation among CNFS sites can be variable, these sites are usually characterized by cool, moist conditions and high soil organic matter. Can these conditions be defined by topographic variables and delineated using terrain-based modeling?

Results from the Balsam Mountains ecological classification study were used to assess potential CNFS habitat in the Balsam Mountain study area and at a site in the Nantahala Mountains where similar classification work has been done (McNab and Browning 1993). In the Balsams, the map of predicted ecological types was used to select 22 locations for placement of 330 CNFS nest boxes in 1995. Half of the sites were in areas predicted to be suitable (i.e., northern hardwood-spruce ecotone). The boxes were monitored for squirrel activity for 4 years. Complete results have not been published, but preliminary indications are that CNFS were found more often in areas predicted as northern hardwoods by the Balsam Mountain model (see footnote 2).

The Wine Spring Creek (WSC) watershed is located approximately 70 km west of the Balsam Mountains study site (fig. 1), and although elevations are somewhat lower, topographic conditions and ecological types in the WSC area were found to be similar to those in the Balsam Mountains.[3] Fraser fir and red spruce-Fraser fir ecological types do not occur in the WSC area; however, northern hardwood-hemlock, high-elevation red oak, and cove types do occur in areas with topographic conditions similar to those in the Balsam Mountains (table 4). Northern hardwood forests occurred on steep, somewhat concave, and north-facing slopes in both areas; and the presence of hemlock was confirmed in the WSC drainage by examination of color-infrared aerial photos and field observations. Although CNFS have not been found in the WSC watershed (extensive surveys have not been done), the distribution of ecological types in the WSC area appears to represent a disjunct continuum of those in the Balsam Mountains and may represent potential habitat for CNFS. The Unicoi Mountains, 40 km west of WSC, are a similar area of disjunct habitat (without the red spruce-Fraser fir type) where the CNFS has been found recently (Cantrell 1997).

Predicting the distribution of ecological types known to support CNFS populations may or may not provide important insights into what habitat components are critical to their survival. For example, a large part of the diet of CNFS includes lichens and sporocarps of mycorrhizal fungi (Weigl and others 1999), which may be associated with the spruce-fir ecological type (Maser and others 1978). However, if the species composition and topographic setting of forest communities that support squirrel populations do reflect other important habitat conditions such as food abundance, then an ecological type classification based on easily derived topographic data may be a good starting point for delineating potential habitat for this and other endangered species.

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[3] Odom, R.H. 1996. Application of an ecological landscape classification model for the identification of Carolina northern flying squirrel (*Glaucomys sabrinus coloratus*) habitat in the Wine Spring Creek watershed, Nantahala National Forest, North Carolina, U.S.A. 6 p. Unpublished final report on file with: Southern Research Station, Bent Creek Experimental Forest, 1577 Brevard Road, Asheville, NC 28806.

Table 4—Comparison of mean terrain attributes associated with ecological types in the Balsam Mountains and Wine Spring Creek study areas, western North Carolina

| Ecological type | Terrain attribute | | | | |
|---|---|---|---|---|---|
| | Elevation | Aspect | Gradient | LFI | TSI |
| | *Meters* | *Degrees* | *Percent* | | |
| Balsam Mountains | | | | | |
| Rich cove | 1301 | 64 | 32 | 0.25 | 0.08 |
| Northern hardwood | 1644 | 137 | 43 | .24 | .05 |
| High-elevation red oak | 1500 | 161 | 28 | .12 | -.01 |
| Wine Spring Creek | | | | | |
| Rich cove | 1051 | 216 | 35 | .34 | .07 |
| Northern hardwood | 1415 | 157 | 33 | .22 | .05 |
| High-elevation red oak | 1472 | 188 | 24 | .09 | -.04 |

LFI = landform index, TSI = terrain shape index.

### Ecological Restoration

In addition to predicting potential wildlife habitat based on current vegetation-site relationships, our approach to landscape modeling may be useful in targeting areas for ecological or habitat restoration projects. As mentioned, the Balsam Mountains study area included the Shining Rock-Graveyard Fields area, which was severely impacted by logging, fire, and erosion in the early part of the 20th century. This area was predicted by the Balsam Mountain classification model to be covered primarily by Fraser fir, red spruce-Fraser fir, and northern hardwood types (fig. 3) and represents approximately 30 percent of the landscape in the study area above 1500-m elevation.

While recolonization rates by tree species have not been documented, much of the area remains in open grass-forb-shrub communities or forested stands that do not appear to contain the species diversity and structure of surrounding, less disturbed forests. Nevertheless, CNFS have been caught in nest boxes in wooded habitats along the margins of open areas and in riparian zones (see footnote 2). Areas in this landscape that may be more conducive to reestablishment of northern hardwood-red spruce communities due to soil depth, soil moisture, or organic matter build-up, e.g., concave or north-facing sites, could be targeted for habitat restoration work. Selection of the most favorable parts of the Shining Rock-Graveyard Fields area for restoration of northern hardwood-red spruce communities would appear to be a cost-effective way of focusing limited resources for habitat restoration in areas where the likelihood of success is greater.

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