A COMPARISON OF THREE METHODS FOR CLASSIFYING FUEL LOADS IN THE SOUTHERN APPALACHIAN MOUNTAINS

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Abstract—As the wildland-urban interface in the Southern Appalachian Mountains has grown and become more complex, land managers, property owners, and ecologists have found it increasingly necessary to understand factors that drive fuel loading. Few predictive fuel loading models have been created for this important region. Three approaches to estimating fuel loads are compared here. Community type, landscape position, and disturbance may all affect fuel loading, but no prior studies have compared them as predictors of fuel loading. The Landscape Ecosystem Classification system uses information about landform, vegetation, and soils to identify distinct forest community types. Slope position and aspect also contribute to the effects of topography on forest community types. Finally, disturbance type is discussed in the context of its contribution to fuel accumulation. Using discriminant analysis, we found significant differences in resubstitution success rates among the methods. However, the vectors of discriminating fuel variables for these methods are similar, indicating the importance of ericaceous fuels in the Southern Appalachian Mountains.

INTRODUCTION

Following 50 years of fire exclusion on public lands, we are rediscovering the importance of natural fire regimes in forests of the Southern Appalachian Mountains. However, a much greater use of fire may be necessary to reduce hazardous fuels and to restore fire-dependent communities such as Table Mountain pine (*Pinus pungens* Lamb.) and pitch pine (*P. rigida* Mill.) (Vose 2000, Waldrop and others 2000). To some extent, the limited use of this management tool has resulted from too little knowledge of the nature and character of fuel loads over the highly variable topography of the Southern Appalachian Mountains (Vose 2000). Changes in forest structure that have resulted from the succession of fire-dependent pine-hardwood communities to hardwood-dominated stands, as well as an abundant ingrowth of flammable understory species such as mountain laurel (*Kalmia latifolia* L.), have made it necessary to update fuel load estimates for the region (Harrod and others 2000, Vose and others 1999).

To establish a baseline characterization and quantification of fuel complexes in the region, in April 2003, we began a study of fuel loads on three sites. We used three methods for classifying fuel loading to help determine which was most useful and accurate. The information we gathered will help fire managers create more effective fire plans.

STUDY SITES

We took measurements within one 10-square-mile study area at each of 3 sites in the Southern Appalachian Mountains: the Chattahoochee National Forest in northeastern Georgia, the Nantahala National Forest in western North Carolina, and the Great Smoky Mountains National Park in southeastern Tennessee. The Chattahoochee National Forest study area is characterized by short, steep slopes, with elevations ranging from 800 to 2,000 feet. The Nantahala National Forest lies in an area described as the high rainfall belt of the Southern Appalachians, receiving an average of about 80 inches of rainfall annually (Carter and others 2000). Slopes in this study area are steep, and elevations range from 2,000 to 4,500 feet. The Great Smoky Mountains National Park also lies in the high rainfall belt of the Southern Appalachians; elevations here range from 1,100 to 3,000 feet, with topography characterized by long ridges, steep slopes, and deep ravines.

METHODS

Field Measurements

Plot locations were generated randomly within each 10-square-mile study area using ArcView® geographic information system (GIS) software and were stratified by slope position and aspect. Fifty plots each were located on middle and lower slopes, northeast and southwest aspects, as well as on ridgetops, for a total of 250 plots per study area. We used a global positioning system receiver to locate the plots in the field. Data collection for this study is ongoing; this analysis presents data from only 647 plots.

Fuels were measured in a 50- by 44-foot area using Brown's (1974) planar intersect method. Orientation of each plot was determined randomly by looking at the sweep hand of a wristwatch and multiplying those seconds by six; the resultant number was the azimuth assigned to the center fuels transect. Adding 23 to the center transect azimuth established the right transect, and subtracting 22 from the center transect azimuth established the left transect.

Along the first 6 feet of each transect, we counted the numbers of 1- and 10-hour fuels (0- to 0.25-inch diameter and 0.25- to 1-inch diameter, respectively); along the first 12 feet of each transect, we counted the number of 100-hour fuels (1- to 3-inch diameter). All fuels > 3 inches in diameter were classified as 1,000-hour fuels and were counted along the entire length of each transect. We grouped the 1,000-hour fuels by diameter, species (hardwood or softwood), and decay class (solid or rotten). At the 12-, 25-, and 40-foot marks along each of the 3 transects, we measured litter depth, duff depth, and down and dead woody fuel height.

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All trees taller than 4.5 feet were measured within the entire plot area. Trees were identified by species, assigned to a 2-inch diameter class, and given a crown class of 1 (dominant or codominant; receiving sunlight), 2 (midstory; crown mingling with the dominants), or 3 (understory; crown completely below midstory). We also noted a tree's status as live or dead.

On one half of each plot, we estimated the percent coverages of ericaceous shrubs (primarily *Rhododendron maximum* L. and *K. latifolia* L.). Also on one half of each plot, we recorded the coverage of lowbush blueberry (*Vaccinium pallidum* Ait.) and highbush blueberry (*V. constablaei* Gray, *V. corymbosum* L., *V. fuscatum* Ait., and *V. stamineum* L.).

We visually estimated evidence of disturbance and assigned one of five disturbance categories to each plot: none, fire, logging, beetle kill, or windthrow. To corroborate field observations, we obtained disturbance records for each site from offices of the appropriate jurisdiction, e.g., National Park Headquarters.

Landscape Ecosystem Classification (LEC) systems are area-specific models that use vegetation, soils, and topographic variables to apportion the landscape into distinct site units. Areas having the same site unit classification will have similar community assemblages (Jones 1991). We used an LEC model developed for the Chauga Ridges region of South Carolina by Hutto and others (1999) to test whether areas within the same LEC site unit also had similar fuel loading characteristics. Because Hutto's model requires data for specific environmental variables, we also collected landform index (LFI), terrain shape index (TSI), elevation, and root-mat data at each plot. We calculated LFI as the mean of 8 slope measurements—taken in 45° increments—to the horizon (McNab 1993). Similarly, we calculated TSI as the mean of 8 slope measurements to a point 60 feet away at eye-level (McNab 1989). We recorded elevation and estimated distance from plot center to the bottom of the slope. Finally, we measured root-mat thickness (the distance from the top of the mineral soil to the bottom of the litter layer). We used these variables to assign each study plot one of four LEC site unit classifications: xeric, intermediate, submesic, or mesic.

We distinguished 5 strata for the 250 plots at each study area based on a combination of slope position and aspect. In the field, we visually estimated slope position and categorized it as either an upper or lower slope. If the landscape appeared to decrease in elevation on at least two sides, we categorized a plot location as ridgetop. Aspects were considered northeast-facing if they fell within the range of azimuths from 325° to 125° and southwest-facing if within 145° and 305°.

Statistical Analyses

We used a multivariate analysis of variance to test for an effect of LEC class, slope/aspect position, and disturbance type on fuel loads. In order to determine which fuel variables best predict LEC class, slope/aspect position, and disturbance type for each plot, we applied stepwise discriminant function analysis. This analysis provides maximum differentiation among groups within these three fuel loading classification methods. Resubstitution success rates in discriminant function analysis are derived from a comparison of plot classifications using all fuel variables, as well as plot classifications using only the discriminating fuel variables. To test for significant differences in resubstitution success rates among the three methods, we performed pairwise binomial proportion comparisons. Differences were considered to be significant at $\alpha = 0.05$.

RESULTS

Multivariate analysis of variance tested for the effects of LEC class, slope/aspect position, and disturbance type based on all fuel variables. Our results showed that different LEC classes, slope/aspect positions, and disturbance types were affected by different vectors of fuel variables. Stepwise discriminant function analysis revealed the important fuel variables that make up those vectors (table 1). Fuel types considered important in the stepwise discriminant function analysis were similar among the three methods. Nearly all ericaceous fuel variables measured were deemed discriminating under each of the three methods, as were litter and duff depths. The smaller 1- and 10-hour time-lag fuels were discriminating under the LEC method, whereas the larger 100- and 1,000-hour time-lag fuels were singled out under the slope/aspect position method. Rhododendron was characteristic of lower northeast-facing slopes in the stepwise discriminant function analysis. Down and dead woody fuel height as well as all time-lag (except 1,000-hour) fuels were discriminating under the disturbance type method. The 1-hour time-lag fuels were characteristic of logging disturbance, while lowbush blueberry, 1-, 10-, and 100-hour time-lag fuels were strong discriminators of beetle-kill disturbance.

Table 1—Important discriminating fuel variables for Landscape Ecosystem Classification class, slope/aspect position, and disturbance type

LEC class	Slope/aspect position	Disturbance type
Duff depth	Duff depth	Duff depth
Litter depth	Litter depth	Litter depth
Kalmia latifolia coverage	*Kalmia latifolia* coverage	*Kalmia latifolia* coverage
Rhododendron maximum coverage	*Rhododendron maximum* coverage	*Rhododendron maximum* coverage
Vaccinium pallidum coverage	*Vaccinium pallidum* coverage	*Vaccinium pallidum* coverage
1-hour fuels	*Vaccinium* spp. coverage	Fuel height
10-hour fuels	100-hour fuels	1-hour fuels
	1,000-hour fuels	10-hour fuels
		1,000-hour fuels

LEC = Landscape Ecosystem Classification.

Resubstitution matrices for LEC class (table 2), slope/aspect position (table 3), and disturbance type (table 4) demonstrate the success with which each discriminant function equation allowed reclassification of each plot into a given category. We determined "success" by considering the efficacy of a discriminant function equation in reclassifying a plot into its initial LEC class, slope/aspect position, or disturbance category (table 1). This is a measure of how well the discriminant function equation's classification of plots—based on a subset of discriminating fuel variables—matches our *a priori* classification which is based on the entire vector of fuel variables. The resubstitution success rates for the LEC class method, slope/aspect position method, and disturbance type method were 43 percent, 38 percent, and 44 percent, respectively.

Table 2—Percent resubstitution success for the Landscape Ecosystem Classification class method

LEC class	Intermediate[a]	Submesic	Mesic	Xeric	n
	- - - - - - *percent*	- - - - - -			
Intermediate[b]	28.68	16.28	31.78	23.26	129
Submesic	15.67	30.60	26.12	27.61	134
Mesic	13.10	16.67	44.05	26.19	84
Xeric	12.33	9.33	23.67	54.67	300

LEC = Landscape Ecosystem Classification.
[a] The LEC classes in the first row represent the way the plots were classified by the discriminant function equation, based only on that subset of fuel variables deemed to be discriminating of LEC class by the discriminant function analysis.
[b] The LEC classes in the first column represent the way the plots were classified prior to discriminant function analysis, based on the entire vector of fuel variables.

Table 3—Percent resubstitution success for the slope/aspect position method

Position	NE upper[a]	NE lower	Ridgetop	SW upper	SW lower	n
	- - - - - - - - - -	- - - *percent*	- - -	- - - - - - - - - -		
NE upper[b]	37.61	17.09	12.82	12.82	19.66	117
NE lower	16.52	41.74	4.35	6.96	30.43	115
Ridgetop	20.34	2.82	32.20	11.30	33.33	177
SW upper	17.74	5.65	15.32	30.65	30.65	124
SW lower	15.79	10.53	5.26	16.67	51.75	114

NE = northeast; SW = southwest.
[a] The slope/aspect positions in the first row represent the way the plots were classified by the discriminant function equation, based only on that subset of fuel variables deemed to be discriminating of Landscape Ecosystem Classification class by the discriminant function analysis.
[b] The slope/aspect positions in the first column represent the way the plots were classified prior to discriminant function analysis, based on the entire vector of fuel variables.

Table 4—Percent resubstitution success for the disturbance type method

Disturbance	None[a]	Fire	Logging	Beetle kill	Windthrow	n
	- - - - - - - -	- - - -	- - *percent*	- - - -	- - - - - - - -	
None[b]	45.44	14.48	17.86	5.75	16.47	504
Fire	27.27	30.30	18.18	15.15	9.09	33
Logging	17.65	20.59	50.00	5.88	5.88	34
Beetle kill	11.11	11.11	16.67	61.11	0.00	18
Windthrow	27.59	15.52	13.79	12.07	31.03	58

[a] The disturbance types in the first row represent the way the plots were classified by the discriminant function equation, based only on that subset of fuel variables deemed to be discriminating of Landscape Ecosystem Classification class by the discriminant function analysis.
[b] The disturbance types in the first column represent the way the plots were classified prior to discriminant function analysis, based on the entire vector of fuel variables.

Binomial tests for significant differences in resubstitution success rates of the three methods showed mixed results. LEC class resubstitution (43 percent success) and disturbance type resubstitution (44 percent success) were not significantly different ($p = 0.36$). However, slope/aspect position resubstitution (38 percent success) was significantly different from both LEC class resubstitution ($p = 0.03$) and disturbance type resubstitution ($p = 0.01$).

DISCUSSION

The role of ericaceous shrubs as live fuel has received little attention in previous studies. However, such fuels, along with litter depth and duff depth, recur as discriminating variables in each of the methods we considered. This seems to indicate a congruence among fuel loading classification methods, despite the significant differences in resubstitution success rates. Because similar patterns seem to emerge no matter which method is used, the decision to use or not to use a particular method can be made on the merits of time and resources. Use of the LEC model method is area specific; therefore one must be sure to use an LEC model developed for the area of interest. Because the LEC model used in this study was developed for the Chauga Ridges region of South Carolina, it may not be suitable for broad application across the entire Southern Appalachian region. Perhaps a fusion of this LEC model with the high rainfall belt LEC model developed by Carter and others (2000) or the development of a unique LEC model for the entire Southern Appalachians will prove necessary. However, because implementation of LEC is not widespread, many locations may not have had models developed yet. Such logistical considerations, and not necessarily differences inherent in the three methods we examined, probably will be the key to choosing one method of fuel load classification over another. Both the slope/aspect position and disturbance type methods are easy to use, and neither requires specialized equipment or expertise. However, arriving at a given slope/aspect position or disturbance type classification is subjective and may generate error. In addition, forest disturbance types are often not discrete. For example, a beetle-kill disturbance may result in forest conditions so compromised that subsequent windthrow events occur more readily. Further method development to deal with such disturbance complexes should improve the disturbance type classification problem.

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