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Fuel characterization in the southern Appalachian Mountains: an application of landscape ecosystem classification

Aaron D. Stottlemyer[A,F], *Victor B. Shelburne*[B], *Thomas A. Waldrop*[C], *Sandra Rideout-Hanzak*[D] and *William C. Bridges*[E]

[A]Wildlife Technology, Penn State University, DuBois, PA 15801, USA.
[B]Department of Forestry and Natural Resources, Clemson University, Clemson, SC 29631, USA.
[C]USDA Forest Service, Southern Research Station, Clemson, SC 29631, USA.
[D]Department of Range, Wildlife and Fisheries Management, Texas Tech University, Lubbock, TX 79409, USA.
[E]Department of Applied Economics and Statistics, Clemson University, Clemson, SC 29631, USA.
[F]Corresponding author. Email: ads175@psu.edu

Abstract. Prescribed fire has been widely used in the south-eastern United States to meet forest management objectives, but has only recently been reintroduced to the southern Appalachian Mountains. Fuel information is not available to forest managers in this region and direct measurement is often impractical owing to steep, remote topography. The objective of the present study was to determine whether landscape ecosystem classification (LEC) site units support different types and amounts of fuel in the Chauga Ridges, a subregion of the Blue Ridge Mountain Province. Ecosystem classification identifies vegetation assemblages that are the expressive result of soils, physiography and vegetation, and recur predictably on the landscape. Four fuel complexes were identified using LEC units and field measurements of fuel characteristics. Fuel bed depth, duff (Oe + Oa) thickness, 1000-h fuel loading, and *Rhododendron maximum*, *R. minus*, and *Vaccinium* spp. ground cover were discriminating fuel characteristics of xeric, intermediate, submesic, and mesic site units. Discriminant function analysis provided an overall 64% cross-validation success rate using 138 undisturbed, randomly located plots. This method of characterizing fuel complexes may also be possible in other forested ecosystems where LECs or other ecological vegetation classifications have been developed.

Additional keywords: Chauga Ridges, discriminant analysis, ecological units, ericaceous fuels, fuel loading, physiography, wildland fire.

Introduction

The southern Appalachian Mountains (USA) have long been appreciated for supporting a diversity of plants and plant communities. A highly dissected topography accommodates species of varied climatic adaptations (Whittaker 1956), although land use history and ecologically significant events including the virtual elimination of American chestnut (*Castanea dentata* (Marsh.) Borkh.) (Stephenson 1986) and fire exclusion likely reduced diversity and perpetuated current species assemblages in this region. However, the historic role of fire in shaping plant community composition and structure in the southern Appalachians is recognized and appreciated (Delcourt and Delcourt 1997).

Prescribed fire has been widely used in the south-eastern United States for many management objectives but was not reintroduced to the southern Appalachian Mountains until the 1980s (Phillips and Abercrombie 1987). Fuel is the accumulation of live and dead vegetative material and combines with weather and topography to comprise the fire environment (Pyne *et al.* 1996). Estimates of fuel load are needed as input to mathematical models (e.g. Rothermel 1972; Scott and Burgan 2005) that predict fire behavior in computer-based fire management applications (Pyne *et al.* 1996). However, fuel models for south-eastern fuel types are outdated and assume homogeneous fuel loading across the landscape (Andrews 1986). Moreover, values for live and larger-diameter fuels are not included in recent fuel models (Scott and Burgan 2005) and the remoteness and extreme topography of many Appalachian forests render direct measurement of fuel loading costly and labor-intensive.

Environmental factors including aspect (Mattson *et al.* 1987), slope gradient (Harmon *et al.* 1986; Agee and Huff 1987), and slope position (Rubino and McCarthy 2003) have been found to influence fuel distribution and accumulation. However, there have been few attempts to characterize the cumulative influence of these and other physiographic variables on fuels in the southern Appalachian Mountains. Waldrop *et al.* (2007) recently found few fuel differences among five topographic positions

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that represented an assumed productivity gradient in the southern Appalachians. The topographic positions were defined by aspect and slope position (Waldrop *et al*. 2007). However, in some areas, productivity has been found to be more highly influenced by protection from adjacent topography, slope steepness, and topographic shape (Hutto *et al*. 1999; Carter *et al*. 2000; Abella *et al*. 2003).

Ecological land classification attempts to summarize the productivity potential of landscapes as a function of physiography. Ecological units exhibit differences in forest productivity (Barnes *et al*. 1998), which greatly influences the rate of accumulation of woody debris (Harmon *et al*. 1986). Decomposition of woody debris is also impacted by differences in microclimate associated with ecological units (Mattson *et al*. 1987; Muller and Liu 1991) and species (Harmon *et al*. 1986).

Prescribed fire operations in this region frequently target ericaceous species (Elliott *et al*. 1999; Waldrop and Brose 1999) as these species reduce diversity in ecosystems and impede tree regeneration (Elliott and Hewitt 1997; Brose and Waldrop 2006). Further, ericaceous shrubs contribute to higher fuel loads and occupy different ecological site units. Therefore, it seems reasonable that fuel loads would vary with ecological classes.

Landscape ecosystem classification (LEC) integrates soil and landform variables and vegetation data into a multi-factor, ecological land classification (Barnes *et al*. 1998). Four distinct ecological site units were found in an LEC of the Chauga Ridges, a subregion of the Blue Ridge Mountain Province (Hutto *et al*. 1999). In their study, xeric sites were steep, upper-slope areas of high exposure to radiant energy and prevailing wind and restricted forest floor decomposition. Intermediate sites were mid-slope areas generally having northerly or easterly aspects or mid-lower slope areas with southerly aspects and were transitional in exposure between xeric and submesic sites. Submesic sites were protected, low-slope areas where concave microsite conditions influenced moisture accumulation. Mesic sites were cool, moist areas of highly protected and steep cove slopes where forest floor decomposition was rapid.

Stottlemyer *et al*. (2006) found that the four ecological units in the Chauga Ridges were characterized by *Rhododendron maximum* L. biomass, *R. minus* Michx. ground cover, *Vaccinium* L. spp. ground cover, duff depth, and 1000-h fuel loading. However, in this preliminary study, approximately half of the sampled land area exhibited evidence of episodic disturbance (e.g. fire scarring, dead vegetation, exposed duff and mineral soil, felled trees or large quantities of coarse woody debris) (Stottlemyer *et al*. 2006), which the authors suggested may have had undue influence on the ability to characterize fuel load.

Addressing disturbance-related fuel variability may reveal additional relationships between the environmental gradient and fuel loading. Moreover, fire and other disturbances have been excluded from many areas in the southern Appalachians where fire is being reintroduced. Therefore, a model based on fuel loading in undisturbed study plots may be valuable to regional managers.

We hypothesized that there are multiple fuel complexes present in the southern Appalachian Mountains, which are influenced by an environmental gradient defined by LEC. Therefore, the objective of the present study was to determine whether LEC site units support distinctive fuel complexes.

Methods

Study area

The study was conducted on the southern portion of the Andrew Pickens Ranger District, Sumter National Forest, Oconee County, South Carolina, USA. The Andrew Pickens Ranger District is located in western Oconee County and encompasses ~32 000 ha of the Sumter National Forest. The study area is bounded to the north by the higher elevations and steeper, broken topography of the Blue Ridge Mountain Region and to the south and east by the Piedmont Province. The Chattooga River flows south and forms the region's western boundary. The area is known as the Chauga Ridges region and is named after the Chauga River, which bisects and drains the majority of the area. The climate of the study area is transitional from the warmer Piedmont region to the south and cooler Blue Ridges to the north. Mean January low temperature is approximately −1.6°C. Mean July high temperature is ~29.4°C. Precipitation is distributed evenly throughout the year and totals 174 cm on average annually in nearby Long Creek, South Carolina.

Short, steep slopes trend south-west to north-east with the Brevard Fault Zone, a narrow band of low-grade metamorphic rock. Climate, soils, and topography of the Chauga River watershed are influenced by this zone (Tobe *et al*. 1992). Elevations in the study area range from 305 to 579 m. Soils are well drained to excessively drained on narrow ridges and steep slopes and well drained on broad ridges and gentle side-slopes. The most common soils of the uplands are fine-loamy oxic mesic Typic Hapludults.

Plot location followed the stratification of a 25.90 km^2 research unit into five strata based on relative slope position and aspect. The stratification was based on the generalization that available moisture increases from upper slopes to lower slopes and from south-westerly aspects to north-easterly aspects (Hutto *et al*. 1999). The five strata were: north-east-trending lower slopes, south-west-trending lower slopes, north-east-trending middle slopes, south-west-trending middle slopes, and upper slopes and ridges. A Geographic Information System generated 55 random coordinates within each of the five strata and functioned as waypoints for navigation to the plots using Global Positioning Systems.

Field procedure

Seven environmental variables were measured from plot center including: landform index (LI) (McNab 1993), terrain shape index (TSI) (McNab 1989), distance to the nearest point of terrain reversal in the aspect direction or 'distance-to-bottom' (Hutto *et al*. 1999), slope gradient, transformed aspect (Beers *et al*. 1966), elevation, and duff thickness. Large LI values for a plot indicated greater protection from radiant energy and prevailing wind by surrounding topography. Large positive TSI values indicated that the landform geometry at the plot was concave. Large negative TSI values indicated convex landform geometry at the plot.

The field model developed by Hutto *et al*. (1999) was used to determine the ecological site unit membership of each plot. The physical environments of plots belonging to different ecological units were different with respect to the vector of variables as determined by this model (Table 1). Additionally, each plot

Table 1. Ranges and means (in parentheses) of the environmental variables used to classify plots by landscape ecosystem classification (LEC) site unit according to the field model developed by Hutto *et al*. (1999) for the Chauga Ridges region in South Carolina, USA

Transformed aspect was not involved in the classification, but is presented for the reader's information. Means within a row followed by the same superscript letter within the parentheses are not significantly different at the 0.05 level

Environmental variable	LEC site unit			
	Xeric ($n = 68$)	Intermediate ($n = 168$)	Submesic ($n = 15$)	Mesic ($n = 24$)
Duff (Oe + Oa) thickness (cm)	0.64–9.53 (3.07^{a})	0.28–4.52 (2.26^{b})	0.71–4.88 (2.57^{ab})	0.36–4.93 (2.21^{b})
Distance-to-bottom (m)[A]	5–67 (58^{a})	0–61 (26^{b})	0–30 (11^{c})	1–61 (19^{b})
Transformed aspect (degrees)[B]	0–2.0 (0.9^{a})	0–2.0 (0.8^{a})	0–2.0 (1.2^{a})	0–2.0 (1.2^{a})
Landform Index (%)[C]	1.0–29.9 (14.0^{d})	3.6–37.5 (20.2^{c})	30.3–38.4 (33.5^{b})	31.0–54.0 (37.5^{a})
Terrain Shape Index (%)[D]	−16.9–44.9 (0.4^{b})	−20.6–26.9 (0.7^{b})	1.5–30.9 (8.9^{a})	−2.1–37.8 (9.8^{a})
Slope gradient (%)	1.0–75.5 (28.0^{b})	5.0–74.5 (34.6^{b})	9.5–49.0 (30.3^{b})	50.0–96.0 (62.2^{a})

[A]Hutto *et al*. 1999.
[B]Beers *et al*. 1966.
[C]McNab 1993.
[D]McNab 1989.

was categorized as either disturbed or undisturbed based on comparisons of visual evidence (fire scarring, dead vegetation, exposed duff and mineral soil, felled trees or large quantities of coarse woody debris) and a detailed stand history provided by Andrew Pickens Ranger District personnel. Stand history was used to confirm physical boundaries and temporal patterns of prescribed burning activity. Areas where disturbance was not observed or documented in stand histories were apparently free from major anthropogenic disturbance for at least 30 years and possibly 100 years or more.

Brown's (1974) planar intersect method was used to tally dead and down woody material at each plot. Each plot consisted of three 15.24-m sampling transects, which were established using measuring tapes. The inner transect was extended from a plot center marker in a random direction. Two transects were placed at +22° and −23° from the inner transect to form a 45° angle by the two outer transects.

Dead and down woody particles 0.00–0.64 cm, 0.64–2.54 cm, 2.54–7.62 cm, and 7.62+ cm in diameter that intersected the sampling plane were tallied as 1-, 10-, 100-, and 1000-h time-lag size classes. Each 1000-h log was tallied by sound or rotten condition, diameter, and whether the log was hardwood or pine. Fuel quantities for each size class were converted to dry tons per acre using Brown's (1974) equations. Alternate values for specific gravities of fuels specific to the south-eastern United States given by Anderson (1978) were substituted into Brown's (1974) equations. Fuel-bed and litter (Oi) depth and duff (Oe + Oa) thickness were measured at three equally spaced points along each transect. Fuel bed depth was measured from the surface of mineral soil to the highest dead and downed woody fuel particle that intersected the transect (Brown 1974).

Measuring tapes were extended 6.71 m perpendicular to both ends of the middle fuel transect to form a 15.24 × 6.71 m (0.01 ha) sample plot. Crown dimensions were measured for all *Kalmia latifolia* L., *Rhododendron maximum* L., and *R. minus* Michx. shrubs rooted within the 0.01-ha plot. Total percentage cover estimates were made for *Vaccinium* spp. (*V. arboreum* Marsh., *V. stamineum* L., *V. vacillans* Torrey, *V. atrococcum* (Gray) Porter) rooted inside the 0.01-ha plot.

Statistical procedure

Differences in fuel complexes among ecological units were characterized using a combination of stepwise discriminant analysis followed by multivariate analysis of variance (MANOVA). Stepwise discriminant analysis was used to select a parsimonious vector of variables that maximize the separation of groups. Data were standardized before discriminant analysis because different fuel variables had different scales and variances. The standardization procedure resulted in discriminant analysis based on correlation matrices instead of covariance matrices.

The results of the discriminant analysis were evaluated with two approaches. First, cross-validation was used. A reclassification matrix was used to determine the number of plots that were reclassified into the correct ecological unit grouping. The percentage of plots classified correctly was used to evaluate the ability of the variables selected by the discriminant analysis to separate the ecological unit grouping, and thereby elicit distinctive fuel complexes.

Second, MANOVA was used to determine if the vectors of selected variables from the discriminant analysis were significantly different among the ecological units. Differences in vectors of selected variables between specific pairs of ecological unit vectors were evaluated with Hotelling's T^2 statistic.

Correlation analysis was used to determine whether certain fuel variables were significantly related to other measured fuel variables. All calculations were performed using PROC GLM, PROC STEPDISC, PROC MANOVA, and PROC CORR of the *Statistical Analysis System* (SAS Institute, Cary, NC).

Results

Analytical results

Evidence of disturbance was observed at 137 of the 275 study plots and resulted from prescribed fire, forest harvesting, insect-related tree mortality, or wind-throw. However, fire was the most commonly encountered disturbance type (data not shown). Disturbed plots were withheld from the discriminant analysis to produce a model that represents the relationship between the physical environment and fuel loading in the Chauga Ridges.

Table 2. Ranges and means (in parentheses) of different fuel variables by landscape ecosystem classification (LEC) site unit in the Chauga Ridges region in South Carolina, USA

Means within a row followed by the same superscript letter within the parentheses are not significantly different at the 0.05 level

Fuel variable	LEC site unit			
	Xeric ($n = 68$)	Intermediate ($n = 168$)	Submesic ($n = 15$)	Mesic ($n = 24$)
1-h loading (Mg ha^{-1})	0.07–1.19 (0.54^{a})	0.09–1.59 (0.52^{a})	0.07–1.16 (0.56^{a})	0.16–1.61 (0.65^{a})
10-h loading (Mg ha^{-1})	0.25–8.60 (2.71^{a})	0.27–8.87 (2.33^{a})	0.20–6.07 (2.20^{a})	0.22–6.29 (2.64^{a})
100-h loading (Mg ha^{-1})	0–39.31 (10.57^{a})	0–35.44 (8.60^{a})	0–26.52 (8.02^{a})	0–29.93 (8.42^{a})
1000-h loading (Mg ha^{-1})	0–202.20 (24.77^{c})	0–192.39 (28.78^{bc})	0–195.64 (52.57^{ab})	0–361.78 (65.43^{a})
Litter depth (cm)	0–8.18 (4.06^{a})	0–7.42 (3.99^{a})	2.34–7.77 (4.37^{a})	2.90–6.35 (4.78^{a})
Duff (Oe + Oa) thickness (cm)	0.64–9.53 (3.07^{a})	0.28–4.52 (2.26^{b})	0.71–4.88 (2.57^{ab})	0.36–4.93 (2.21^{b})
Fuel bed depth (cm)	2.54–27.66 (8.26^{a})	1.07–66.32 (7.32^{a})	2.54–18.62 (7.90^{a})	1.42–30.20 (9.98^{a})
Kalmia latifolia ground cover (%)	0–100 (16^{a})	0–100 (11^{a})	0–91 (22^{a})	0–100 (16^{a})
Rhododendron minus ground cover (%)	0–100 (4^{a})	0–66 (2^{a})	0–18 (1^{a})	0–100 (9^{a})
R. maximum ground cover (%)	0–44 (1^{c})	0–100 (1^{c})	0–100 (12^{b})	0–100 (37^{a})
Vaccinium spp. ground cover (%)	0–95 (11^{a})	0–75 (4^{b})	0–1 (<1^{b})	0–0 (0^{b})

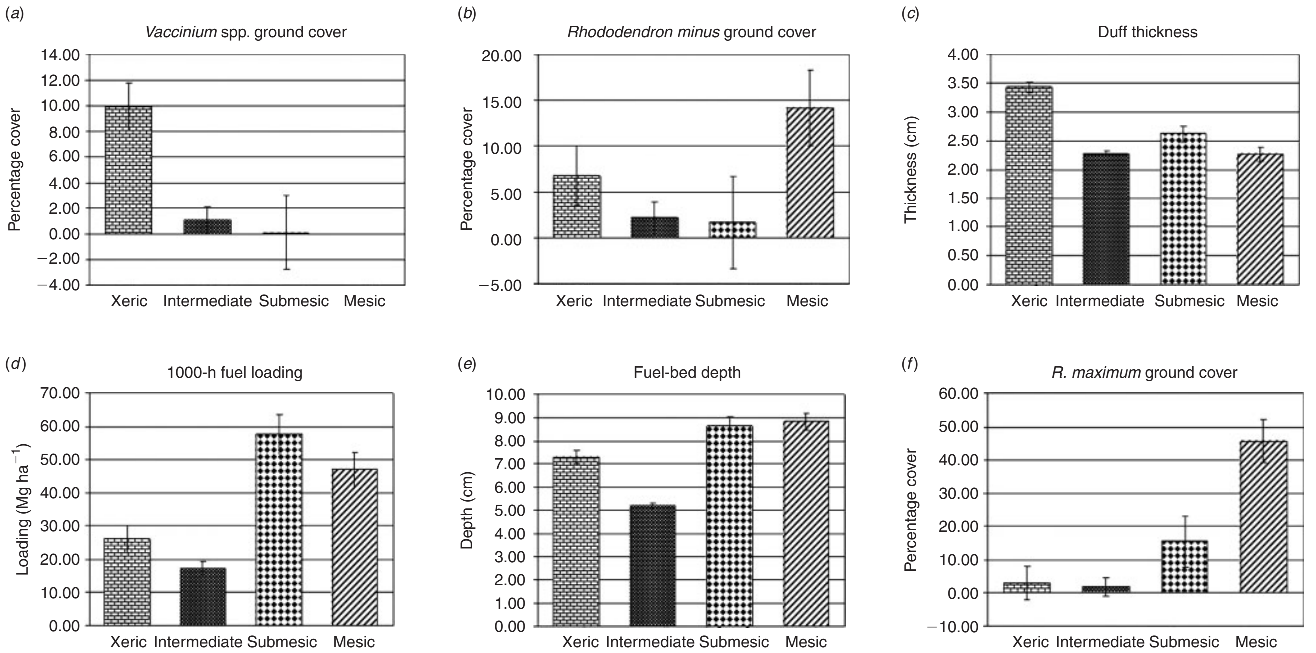

Fig. 1. Six fuel variables (*a–f*) characterize differences in fuel complexes among ecological site units in the Chauga Ridges region in South Carolina, USA. Vertical bars represent standard error of the mean.

However, results are presented for the 11 fuel variables to give a sense of the uncertainty in fuel loading associated with each LEC site unit in areas containing undisturbed and disturbed forest land (Table 2).

The fuel variables 1-, 10-, and 100-h fuel loading, litter depth, and *Kalmia latifolia* ground cover did not differ substantially among ecological units and were not selected to the parsimonious vector of fuel variables in the stepwise discriminant analysis. The fuel variables fuel bed depth, duff thickness, *Rhododendron minus*, *R. maximum*, and *Vaccinium* spp. ground cover, and 1000-h fuel loading were selected in the discriminant analysis (Fig. 1*a–f*) with disturbed plots withheld. We suspected that lower 1000-h fuel loading in intermediate site units may have been responsible for lower fuel bed depths. Correlation analysis, however, indicated that fuel bed depth was not related to 1000-h fuel loading ($r = 0.145$).

The discriminant analysis yielded a 64% correct reclassification. However, 86 of the 138 plots were in intermediate site units and 80% of intermediate plots were classified correctly. MANOVA corroborated these findings as all paired comparisons of the vectors of fuel variables selected in discriminant analysis were significantly different among ecological units based on Hotelling's T^2.

Testing revealed that the assumption of equal correlation matrices in the discriminant analysis was violated. However, the reclassification was not improved when the K-nearest neighbor non-parametric method was used, which suggested that the violation of the equal correlation matrices assumption was not of a magnitude to influence the results of the discriminant analysis.

The fuel complexes of ecological units might be expected to exhibit different burning characteristics as a result of varying levels of down woody and live ericaceous fuels. Inherent differences in the physiography (Hutto *et al*. 1999) and associated microclimates of ecological units may accentuate differences in fire behavior and effects. A brief description of the physiography and fuels follows for each site type.

Summaries of the fuel complexes of LEC site units

Xeric sites

Xeric sites are more exposed to solar radiation and prevailing winds than other site types. *Vaccinium* spp. cover was highest on xeric ridge tops (Fig. 1*a*). Oak and pine species dominate xeric sites and contribute foliage to the fuel complex that may be more flammable (Stottlemyer *et al*., in press) and slowly mineralized compared with that of non-oak tree species (Abrams 2005). Xeric sites can also exhibit extreme slopes that may contain dense thickets of *Rhododendron minus* (Fig. 1*b*). In our study area, xeric sites generally have a substantial duff layer (Fig. 1*c*) and are further characterized by lower 1000-h fuel loading (Fig. 1*d*), fuel bed depth (Fig. 1*e*), and *R. maximum* cover (Fig. 1*f*) than submesic and mesic sites.

Intermediate sites

Intermediate sites are less exposed than xeric sites but more so than submesic and mesic sites. *Vaccinium* spp. may occur on intermediate sites, but will not reach densities as high as those found on xeric sites (Fig. 1*a*). Oak and pine species dominate the overstorey. Therefore, litter fuel composition is similar to that of xeric sites. Intermediate sites are less suitable to *Rhododendron minus* than the other site types (Fig. 1*b*) and rarely contain high densities of *R. maximum* (Fig. 1*f*). On steep slopes, larger fuel material may be lost from intermediate and xeric sites by gravity. Lower 1000-h fuel loading and fuel bed depth also differentiate intermediate sites from submesic and mesic sites (Fig. 1*d*). The highest percentage of land area (62% of plots sampled) in the Chauga Ridges was classified intermediate.

Submesic sites

Submesic sites are more exposed than mesic sites but less than intermediate sites. *Vaccinium* spp. are not major fuel components in submesic sites (Fig. 1*a*) and *Rhododendron minus* will not typically reach high densities (Fig. 1*b*). Submesic sites are not as suitable as mesic sites to *R. maximum* thickets (Fig. 1*f*). These sites are potentially more productive and contain large, mature trees that contribute coarse woody debris through natural pruning of branches. Moreover, trees may be more susceptible to uprooting on submesic sites owing to shallow root systems. Slope gradient of submesic sites is less than that of mesic sites (Hutto *et al*. 1999) and may accumulate coarse material lost from higher slope positions. Therefore, submesic sites will generally contain higher 1000-h fuel loading than the other site types (Fig. 1*d*). Thin duff (Fig. 1*c*) and greater fuel bed depth (Fig. 1*e*) also differentiate submesic sites from intermediate and xeric sites.

Mesic sites

Mesic sites are highly protected from solar radiation and prevailing winds by adjacent topography. Tree species such as eastern hemlock (*Tsuga canadensis* (L.) Carr.), yellow-poplar (*Liriodendron tulipifera* (L.)), and green and white ash (*Fraxinus pennsylvanica* (L.) and *F. americana* (Marsh.), respectively) are common overstorey dominates that contribute foliage to the fuel complex that may be less flammable (Stottlemyer *et al*., in press) than that of xeric and intermediate sites. Slopes of mesic sites will always be steep as the mesic classification depends, in part, on a slope gradient of 50% or more (Hutto *et al*. 1999). Tree productivity and debris input in mesic sites are probably similar to those of submesic sites. Steep slopes of mesic sites may lose some larger debris to redistribution. However, these sites at the lowest slope positions may accumulate large debris from higher slope positions. Mesic sites can support dense *Rhododendron maximum* thickets (Fig. 1*f*) but *Vaccinium* spp. are uncommon (Fig. 1*a*).

Discussion

In an earlier study, Stottlemyer *et al*. (2006) suggested that fuel variability related to forest disturbance may have a masking effect on the actual relationship between the physical environment and fuel loading. In our study, removing disturbance-related fuel variation resulted in a 12% improvement in the cross-validation of the discriminant model compared with the results of Stottlemyer *et al*. (2006). In addition, removing disturbed plots resulted in the selection of an additional fuel parameter (fuel bed depth) in discriminant analysis. Furthermore, fire and other disturbances have been excluded from many areas in the southern Appalachians for many years where fire is being reintroduced (Elliott *et al*. 1999; Vandermast and Van Lear 2002). Therefore, a model that reflects fuel loading in undisturbed forests may be of greater value to managers in the region.

Mesic and submesic sites had greater 1000-h fuel loading than intermediate and xeric plots. These results are similar to those of Rubino and McCarthy (2003) and Spies *et al*. (1988) at lower slope positions and in moist sites in the north-eastern and Pacific north-western United States respectively. Downed woody fuels in smaller size classes were not significantly different among LEC site units in the Chauga Ridges (current study) or across topographic positions in other areas of the southern Appalachians (Waldrop *et al*. 2007).

Mean duff thickness of xeric plots was greater than that of other site units. Mean duff thickness of submesic and mesic plots was greater than that found by Hutto *et al*. (1999) in the same region. We attributed this to greater ericaceous species composition in submesic and mesic plots in the present study than those of Hutto *et al*. (1999). In their study, areas with a mid-storey canopy were avoided because the authors sought areas having late successional characteristics and periods of *Kalmia latifolia* and *Rhododendron maximum* recruitment have been found to coincide with disturbance (Monk *et al*. 1985) or the cessation of factors such as cattle grazing and fire (McGee and Smith 1967) in the southern Appalachian Mountains. Thick duff layers have been found in other areas of the southern Appalachians that have a significant ericaceous shrub component (Abella *et al*. 2003).

Kalmia latifolia cover was not different among ecological units. Other researchers have found greater densities of *K. latifolia* on dry, exposed slopes and ridges (Monk *et al*. 1985; Abella *et al*. 2003). However, our results indicate that in forests of the Chauga Ridges, the species exhibits ubiquitous growth, covering 20% of land area, on average. *K. latifolia* is probably less abundant at higher elevations in the southern Appalachians (Waldrop *et al*. 2007). *Rhododendron maximum* was most abundant in mesic plots with a mean cover of 46%. *R. minus* is probably a relatively minor component of fuel complexes in higher elevations of the southern Appalachians (Whittaker 1956).

Rhododendron maximum cover in mesic sites was greater than that of the other site types. These results suggest that only mesic sites of the Chauga Ridges are suitable for *R. maximum* to grow to thicket-like densities and are consistent with those reported by Monk *et al*. (1985), Baker and Van Lear (1998), and Vandermast and Van Lear (2002). Monk *et al*. (1985) found that collectively, *Kalmia latifolia* and *R. maximum* may constitute up to 9% of the total standing biomass and as much as 32% of the total leaf biomass in forests of the Coweeta Basin, Nantahala National Forest in North Carolina.

Vaccinium spp. cover was greatest in xeric sites and was almost absent in submesic and mesic sites. These results are similar to those reported by Hutto *et al*. (1999), Carter *et al*. (2000), and Abella *et al*. (2003) in comparable ecological units in neighboring areas of the southern Appalachian Mountains. Hutto *et al*. (1999) reported that *V. vacillans* often comprised 70–80% of the ground cover in xeric sites in the same area as the present study. It is probable that the magnitudes of our results are lower because we estimated the shade cast on the plot by the plants and much of the field work was performed before full leaf-out or after leaf fall.

In another study, few significant differences in fuel load were found along an ecological gradient in different areas of the southern Appalachians. Waldrop *et al*. (2007) concluded that disturbance history and type were more useful than topographic position in predicting fuel load. However, it is important to note that the productivity gradient used by Waldrop *et al*. (2007) was based on aspect and slope position. Plots in the Chauga Ridges were grouped according to the LEC developed by Hutto *et al*. (1999), which employs a different set of environmental variables. Therefore, the use of different methods to delineate ecological units may explain the differences between the results of the two studies.

Conclusions

Fuel loading information is lacking for the southern Appalachian Mountains. Fuel models and other resources traditionally used by fire managers are over-generalized or applicable to some southeastern fuel types but not others. We proposed that distinctive fuel complexes exist and correspond with LEC site units in the Chauga Ridges region. Stepwise discriminant analysis provided a parsimonious list of fuel variables that characterize distinct fuel complexes of LEC site units. The fuel complexes of xeric, intermediate, submesic, and mesic site units were defined by fuel bed depth, 1000-h fuel loading, duff thickness, and *R. minus*, *R. maximum*, and *Vaccinium* spp. ground cover. Differences in physiography and microclimate may accentuate differences in fire behavior among LEC site units in the Chauga Ridges.

Intermediate sites represented 86 of the 138 undisturbed plots in our study area. Furthermore, 80% of intermediate plots were classified correctly in cross-validation. These results indicated the success of the discriminant analysis in selecting variables that differentiated the fuel complex of this widespread ecological site type from the others.

Fire and other disturbances have been excluded from many areas in the southern Appalachians for many years where fire is being reintroduced and classification of fuels was based on undisturbed study plots. Therefore, ecological units will be most useful in relatively undisturbed areas where the reintroduction of prescribed fire is proposed and initial fuel loading information is needed.

Using disturbance type as the response variable in the same way ecological units were used in the present study may be more effective for predicting fuel loading in actively managed areas (Brudnak *et al*. 2006; Waldrop *et al*. 2007). Fire managers may use these fuel complexes in combination with physiographic and other variables to better predict fire behavior in the southern Appalachians. The characterization of fuel complexes may also be possible in other forested ecosystems where LECs or other ecological classifications have been developed.

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