USING SATELLITE IMAGERY TO MAP FIRE SEVERITY AND FOREST COMMUNITY CHANGE IN THE SOUTHERN APPALACHIANS

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INTRODUCTION

Fire was historically a major influence on landscape and species diversity in the forests of the southern Appalachian (Delcourt and Delcourt 1997). It is generally thought that frequent fires set by Native Americans promoted regeneration of vellow pine and oak species on dry upper slopes and ridges, but rarely spread into moist sheltered coves and valleys. Fire remained an important part of the disturbance regime after European settlement, with forests in some parts of the region burning approximately every thirteen years (Harmon 1982). The advent of fire suppression in the 1930's has reduced the frequency and sizes of fires (Barden and Woods 1973), causing declines in yellow pine and oak dominance (Williams and Johnson 1992, Harrod et al. 1998). This low frequency of wildfires has limited our ability to study the ecological role of large, infrequent disturbances in the southern Appalachians. The recent occurrence of a 4000-ha wildfire in the in western North Carolina provides a unique opportunity for research into the effects of large-scale disturbances in these systems.

Large fires are difficult to study because of the massive amounts of data needed to characterize the spatial pattern of fire effects and ecological responses. However, satellite imagery has proved to be an extremely powerful tool for efficiently mapping and analyzing the patterns of large wildfires. Recently, a set of standardized methods have been developed for using satellite imagery to create fire severity maps. Landsat imagery is used to compute a radiometric index called the Normalized Burn Ratio (NBR), which is related to field-based measurements of field severity (Key and Benson 2002). To date these methods have primarily been applied to study fires in coniferous forests of the western United States. However, they may also prove useful for mapping fire severity in mixed conifer/hardwood landscapes of the southern Appalachians.

The objectives of this research were to 1) Use multi-temporal satellite imagery to develop a severity map for the 2000 Linville Gorge fire; 2) Assess the influences of topography and pre-fire forest community type on the spatial pattern of fire severity; and 3) Assess the relationship between predicted fire severity and post-fire changes in local species richness.

METHODS

Linville Gorge is a federally designated wilderness area located in the Blue Ridge Escarpment near Boone, NC. Topography is extremely rugged; both sides of the gorge contain prominent cliff-like bluffs that divide upper and lower slopes. The majority of Linville Gorge is unlogged and it is one of the largest remaining tracts of old-growth forest in the region. Catastrophic fires occurred in 1860 and 1915, and the last widespread surface fires occurred in the 1950's. In November 2000 a wildfire from an unattended campfire burned approximately 4000 ha in and around the wilderness area.

The presence of strong environmental gradients is reflected in a diverse assemblage of forest community types within the gorge (Newell and Peet 1998). Upper slopes are dominated by pine and oak forests which are composed of several species of yellow pine (Pinus virginiana, Pinus rigida, and Pinus pungens) and oak (Querucs coccinea, Quercus prinus, Quercus alba) in the overstory with a thick layer of ericaeous shrubs (Kalmia latifolia, Vaccinium spp.) in the understory. Rocky outcrops found within the bluffs are dominated by ericaeous shrubs such as piedmont rhododendron (Rhododendron minus). Slopes below the bluffs are dominated by chestnut oak (O. prinus) and are classified as acidic slopes and montane oak forests. Acidic slopes are distinguished by abundant rhododendron (Rhododendron maximum) in the undertsory and white pine (Pinus strobus) and red maple (Acer rubrum) present in varying amounts. Montane oak forests include tulip poplar (Liriodendron tulipifera) and dogwood (Cornus florida). Moister areas including sheltered ravines descending from upper slopes and the bottom of the gorge along the Linville River are classified as acidic coves and are dominated by eastern hemlock (Tsuga canadensis) in the canopy and thick *R. maximum* in the understory.

Field data from a total of 57 plots was obtained from three sources. The first data set consisted of 18 remeasurement plots. These were permanent vegetation plots that were initially established in 1992 (Newell and Peet 1998), and were relocated and resurveyed in 2003 to examine plant community dynamics after the fire (Reilly 1995). The locations of these plots were measured using a handheld GPS. The second data set included 14 additional unburned plots from the original 1992 survey. The locations of these plots were measured from plot locations marked on 1:12,000 aerial photographs. The third data set consisted of 25 plots that were surveyed using the FIREMON landscape assessment methodology (Key and Benson 2002) in the fall of 2004. The locations of these plots were measured using a handheld GPS.

A Composite Burn Index (*CBI*) was computed for each of these field plots (Key and Benson 2002). Estimates were based on measurements of the tall shrub/small tree, intermediate tree, and large tree strata, with weights of 1, 2, and 3 assigned to these strata to give larger trees more influence on the final index. Final indices were rescaled to range from zero to one. Unburned plots were assigned a CBI value of zero.

Two satellite images were obtained to represent pre- and post-burn landscape conditions: a Landsat 5 image from June of 2000, and a Landsat 7 image from June of 2001. Digital numbers for each image were radiometrically corrected and converted to reflectance values using the COST method of Chavez (1996). The Normalized Burn Ratio (*NBR*) was then computed for each image as

$$NBR = \frac{\left(R_4 - R_7\right)}{\left(R_4 + R_7\right)}$$

where the R_4 and R_7 values are reflectance for bands 4 and 7. Change in *NBR* following the fire was computed as

$$dNBR = NBR_{pre} - NBR_{post}$$

where NBR_{pre} is from the 2000 pre-fire image and NBR_{post} is from the 2001 post-fire image.

Non-linear regression was used to fit an equation predicting the observed *CBI* indices from the field plots as a function of *dNBR*. This equation was then used to map *CBI* for all unsampled pixels falling inside the fire perimeter. The fire perimeter was manually digitized using a 15-m false-color infrared ASTER image. GIS layers of roads and trails were also used to identify the locations of known firebreaks.

Slope and aspect values were computed from a 10m digital elevation and overlaid with the predicted *CBI* map to assess the relationship between burn severity and topography. A map of pre-fire forest communities (Newell and Peet 1998) was obtained from the USFS and overlaid with the predicted *CBI* map to assess the relationship between vegetation and fire severity. Because the forest community map only encompassed the Linville Gorge Wilderness, burned areas outside the wilderness were excluded from the vegetation analysis. Community types were reclassified into rocky outcrops, pine forests, oak forests, or hemlock forests. These represent the major cover types and fuel complexes present in the gorge.

The pre-fire and post-fire numbers of vascular plant species per 100 m^2 were available for the 18 remeasurement plots and were used to calculate the change in species richness after the fire. The relationship between *dNBR* and change in species richness was examined to assess the potential for using burn severity maps to predict biodiversity responses to fire.

RESULTS

Several candidate equation forms were examined to find one that maximized the fit of the observed data, met critical statistical assumptions, and produced predictions bounded within the possible range of *CBI* (0-1.0). Based on these criteria, the following nonlinear equation was chosen to predict *CBI* as a function of dNBR

 $CBI = 1 - \exp(-3.9733 \times dNBR)$

This equation had an R^2 of 0.71, and was used to generate a map of predicted *CBI* (Figure 1). Overlays of predicted *CBI* with topography and pre-fire vegetation indicated that fire severity was highest on steep slopes (Figure 2) and in forest communities with a large yellow pine component (Figure 3). In contrast, there was a much weaker relationship between predicted *CBI* and aspect, with a slight tendency for higher fire severity and south and west aspects (Figure 4).

Predicted *CBI* had a statistically significant logarithmic relationship (p<0.001, $R^2=0.52$) with the change in species richness (Figure 5). The largest changes in species richness were found in areas of higher burn severity. Increases in species richness were mostly due to the immigration of light seeded, wind dispersed herbaceous species.



Figure 1: Predicted CBI for the Linville Gorge Fire



Figure 2. Distribution of fire severity across different slope classes.



Figure 3. Distrubution of fire severity across different community types.



Figure 4. Distribution of fire severity across different aspects.



Figure 5. Predicted changes mean species richness per 100 m^2 as a function of dNBR.

DISCUSSION

Multi-temporal analysis of fire severity using dNBR appears to be a valid approach for mapping the severity of large wildfires in the southern Appalachians. Although the R^2 for our regression of *CBI* versus *dNBR* was reasonably high (0.71), it was considerably lower than the R² of 0.89 reported for mapping of burn severity in Yosemite National Park (van Wagtendonk et al. 2004). Several factors probably limited our ability to predict fire severity in Linville Gorge. First, our field assessment was carried out several years after the fire, whereas our post-fire satellite image was obtained in the first growing season after the fire. In addition, many portions of the Linville Gorge fire exhibited local heterogeneity in burn severity, making it difficult to locate large patches with homogeneous dNBR values. This was particularly true for the intermediate levels of fire severity, which often occurred as narrow transition zones between areas of minimal fire effects and complete overstory mortality.

Both topography and forest community type were found to constrain fire severity. These findings contrast with those from many forest ecosystems in the western United States and Canada, in which local effects of terrain and fuels are hypothesized to be minimal for the largest fires burning under the most extreme climate conditions (Turner et al. 1994, Bessie and Johnson 1995). The interspersion of pine- and oak-dominated forest communities in Linville Gorge likely had a greater influence on fire behavior than landscape patterns in western landscapes where conifer forests are the dominant community type. The occurrence of a southern pine beetle outbreak for several years prior to the fire also contributed to higher fuel loads in the pinedominated communities. Topography has a strong influence on forest community composition in Linville Gorge, suggesting that its influences on fire severity occur both through direct effects on fire behavior, and through indirect effects on forest composition and fuels.

Spatial heterogeneity in fire severity translates into variable community responses in Linville Gorge. High severity fires that kill more dominant vegetation release resources and provide opportunities colonization by new species. Although spatially variable, the change in species richness exhibits a positive linear relationship with predicted CBI, indicating that maps of fire severity can be translated into predictions of specific rates of ecological change. Our field observations suggest that there is also a strong relationship fire severity patterns and the species composition of post-fire tree seedling recruitment. Regeneration of pines such P. rigida and P. pugens are highest in pine communities experiencing complete canopy mortality, whereas oak and other hardwood sprouts are the predominant regeneration in areas of low to moderate burn severity.

CONCLUSION

Landscape-level patterns of fire severity in the southern Appalachians can be mapped based on changes in *dNBR* derived from multitemporal satellite imagery. Even through the Linville Gorge fire is considered to be an exceptionally large and severe fire for these eastern forests, there are still strong influences of topography and pre-fire vegetation on pattern of fire severity. Fire severity in turn influences the spatial distribution of plant species colonization and forest community change. Thus, large fires in the southern Appalachians may serve to reinforce, rather than reduce landscape scale patterns of landscape heterogeneity and community diversity.

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