Forest Decline Model Development With Landsat TM, SPOT, and DEM DATA

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ABSTRACT

The relationships between percent defoliation and digital near infrared reflectance data detected by the Landsat Thematic Mapper and SPOT sensors were investigated. These data were both found to be negatively correlated with defoliation data collected within the boreal montane spruce-fir ecosystem of the Black Mountains, North Carolina. Correlation coefficients were significant at the 0.05 level. Linear regression analysis demonstrated that neither source of satellite based remotely sensed data to be accurate predictors of defoliation. The addition of digital elevation data, however, as an independent variable to the regression equations significantly improved the predictive reliability of the models.

1. INTRODUCTION

Forest decline syndrome is generally defined as a chronic demise in the overall health of a forest ecosystem and has been observed in the temperate forests of North America and Europe (Schutt and Cowling, 1985; Bruck, 1984; Johnson, 1983). Visual signs of forest decline include crown defoliation, foliar discoloration, significant reductions in radial increment, and rapid mortality (Bruck and Robarge, 1988; McLaughlin, 1985; Johnson and Siccama, 1983). Biotic and abiotic factors have been identified as stress agents involved in the development of this phenomena (Bruck, 1988; Schutt and Cowling, 1985).

A significant amount of research has been conducted to assess the dynamic cause and effect relationships at work between both biotic and abiotic agents and vegetative stress (McLaughlin, 1985). Efforts have also been concentrated in quantifying and mapping the spatial extent of the syndrome (Electric Power Research Institute, 1988). Given the broad geographic distribution of the forest decline syndrome the use of remotely sensed data has become a vital component in regional long term monitoring efforts.

Forest decline conditions within the spruce-fir ecosystem of the southern Appalachian Mountains of the United States have been mapped using color-infrared (CIR) aerial photography. Maps depicting classes of forest damage, based on the number of standing dead stems, were produced from 1984 CIR photography. A repeat interpretation is currently underway using 1988 CIR photography (Dull et al., 1988).

In addition to the use of aerial photography, Landsat TM digital data have been used to delineate the spatial distribution of discrete levels of forest damage within the spruce-fir ecosystem of the southern Appalachians. Investigators found field estimates of defoliation to be significanntly correlated with the NIR waveband (Band 4) of the TM. A model quantifying this relationship was developed which predicted the level of defoliation (%) based upon the TM band 4 digital number and topographic position (Brockhaus et al., 1989). This model was then applied to digital TM and digital elevation model (DEM) data to produce a spatial data set describing the distribution of defoliation conditions throughout the ecosystem.

The spectral resolution of the TM NIR waveband (Band 4) is very similar to that of the SPOT multispectral NIR band 3, 0.76-0.90 um and 0.79-0.89 um respectively . Thus it is likely that the SPOT band 3 data could be utilized to model and map the distribution of defoliation within the spruce-fir ecosystem with the added benefit of improved spatial resolution over the Landsat TM. The objectives of the research presented in this paper were to: 1) develop a defoliation model from SPOT NIR digital data and DEM data, and 2) to compare the performance of this model to that of a Landsat TM based model.

2. STUDY SITE DESCRIPTION

The Black Mountain Range within the southern Appalachians is located in western North Carolina (NC) approximately 45 kilometers (km) north of Asheville, NC (Figure 1). This mountain range is a ridge crest consisting of a series of high

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peaks exceeding 1900 meters (m) in elevation, cut by steep gorges and saddles. Mt. Mitchell, the highest point east of the Front Range of the Rocky Mountains, is situated in the southern half of the range and with an elevation of 2037 m.

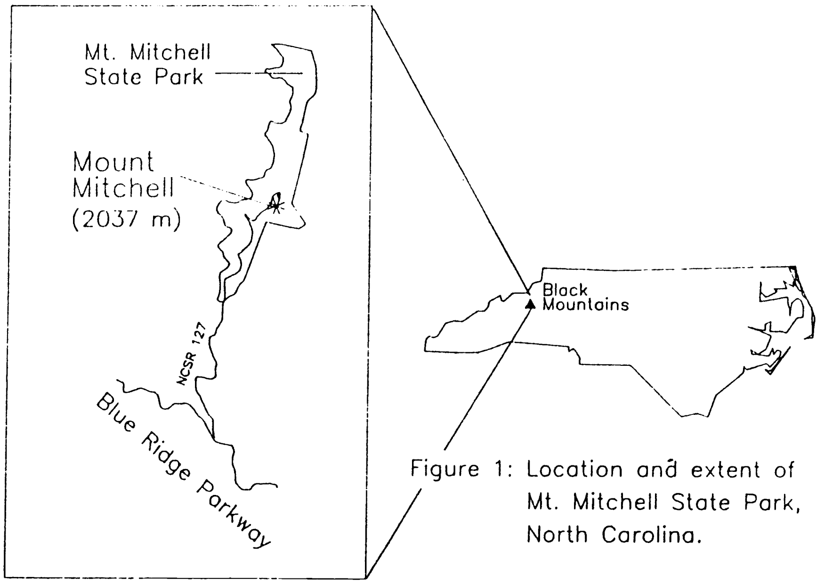
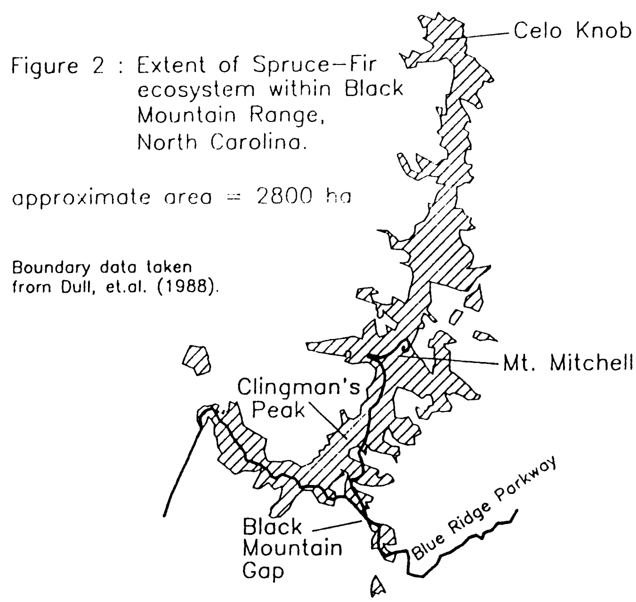


Figure 1: Location and extent of Mt. Mitchell State Park, North Carolina.

The existing boreal montane forests are distributed over approximately 2800 hectares (ha) (Figure 2). These forests are characterized by the presence of a disjunct, remnant community of red spruce (Picea rubens, Sarg.) and Fraser fir (Abies fraseri, Parsh). Distribution of these species is primarily controlled by elevation. Above 1800 m the forest is dominated by fir, with spruce generally comprising less than 25% of the overstory canopy. Pure even aged spruce stands dominate the canopy from approximately 1370 m to 1800 m.

Figure 2 : Extent of Spruce–Fir ecosystem within Black Mountain Range, North Carolina.



The climate in the Black Mountains is atypical of its southern latitude. Severe changes in elevation from surrounding terrain provides for extreme weather conditions. Annual rainfall can exceed 250 cm. Inputs from cloud interception represent a significant source of moisture for the ecosytem. Violent weather extremes such as severe winter storms with snow, rime ice, high winds, and thick ice accumulations are not uncommon at these elevations. Equally volatile summer storms bring damaging winds, torrential rains and severe lightning.

Atmospheric monitoring at the site has recorded the deposition of a variety of anthropogenic air pollutants. While rain samples have not been found to be especially acidic, cloud moisture samples have recorded values below pH 3.0. Episodic ozone concentrations near 120 ppb have been recorded, with daily mean concentrations frequently exceeding 60 ppb (Bruck et al., 1987).

Field surveys characterizing the forest condition from 1983 through 1987 (Bruck et al., 1989; Bruck and Robarge, 1988) have reported the following conclusions: 1) the balsam wooly adelgid is a major factor in the rapid decline and mortality of Fraser fir; 2) significant red spruce defoliation has occurred in the Black Mountains between 1984 and 1987; 3) levels of defoliation are positively correlated with elevation; 4) data suggest that west aspect slopes suffer greater damage than east aspect stands; 5) significant reductions in radial increment began around 1960 and continue through the present; and 6) elevated levels of anthropogenic air pollutant deposition may have a role in the observed decline phenomenon.

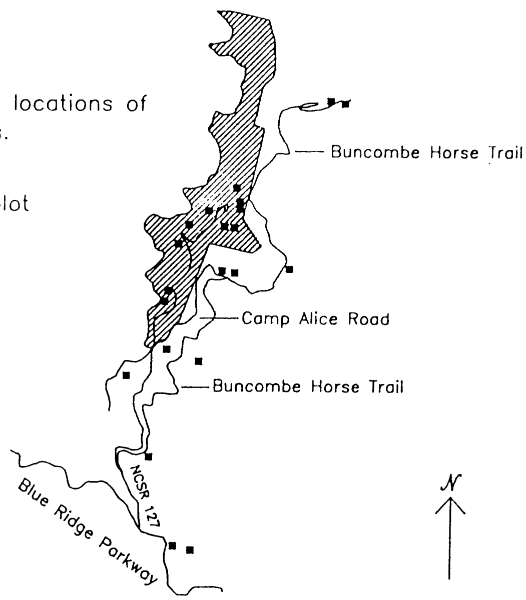
3. METHODS

3.1 Acquisition of decline characterization data

Field data characterizing the forest decline conditions within the spruce-fir ecosystem of the Black Mountains were collected between the months of May and August 1988. A total of 21 field plots were sampled (Figure 3). Sites were stratified by high (> 1830 m) versus low elevations (< 1830 m), east versus west exposures, and high versus low damage levels. Selected sample sites were required to support a spruce-fir dominated overstory canopy exhibiting homogenous defoliation levels within a minimum stand size of one hectare. Two of the 21 field plots were improperly established and were discarded from subsequent analysis leaving a sample size of 19.

Figure 3: Approximate locations of 21 field plots.

(See Appendix A for plot UTM coordinates.)



Selected plots were permanently established as a one hectare (100 m x 100 m) square, divided into 9 equal subplots (Figure 4). Occular estimates of defoliation were collected within a 9 m x 33.3 m transect bisecting each of the nine subplots. Only overstory conifer stems having a diameter-at-breastheight (DBH) > 10 cm were visually rated for percent defoliation. Information recorded on all trees, both conifer and deciduous, included species, DBH (in 10 cm classes), and crown class (dominant, codominant, intermediate, or suppressed). Several measures of forest decline were derived from these data describing average damage conditions on a plot basis including percent standing dead stems, dieback, and percent defoliation. Field plot locations were also carefully recorded on 1:12000 color aerial photographs.

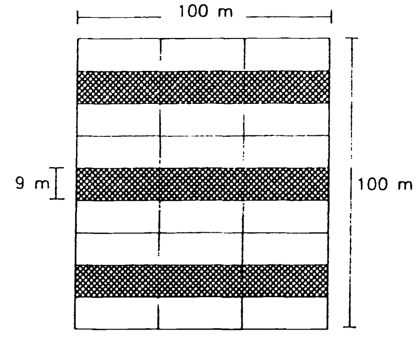


Figure 4a: Design of field plot and inventory transects. (9m x 33.3m)

Decline levels estimated from visually rating the crown defoliation on all overstory stems within inventory transects.

3.2 Acquisition of digital TM and SPOT data

Imagery (TM and SPOT) with acquisition dates as close to one another as possible were needed so that differences in sun angles and vegetative growth conditions would not complicate the comparison between the two data sets. Previous forest decline modeling efforts within the Black Mountains had utilized a Landsat TM scene acquired on September 28, 1988. A search of available SPOT imagery acquired near this date indicated that cloud coverage precluded their use in this research.

Near simultaneous cloud free TM and SPOT data over the study site were not available during the spring or summer of 1988. Winter TM and SPOT imagery, however, were identified which met the temporal and cloud coverage constraints required for the completion of this work. The TM scene selected was acquired on January 18, 1989 while the SPOT data was collected on February 12, 1989. A window of data defining the study site within the TM and SPOT data was extracted and registered to a Universal Transverse Mercator projection system. DEM data was also acquired, registered, and resampled to correspond to each of the two satellite data sets.

3.3 Forest defoliation model development

Previous research had shown that defoliation levels were highly correlated with elevation and the NIR waveband (Band 4) of the Landsat TM (Khorram, 1990). Thus, investigation of the 1989 winter imagery focused on the analysis of the NIR wavebands of the TM and SPOT sensors. Digital elevation data were also included in the analysis due to the a priori knowledge regarding the relationship between defoliation and elevation.

Aerial photography and the UTM coordinates defining the center of each of the field plots were used to locate these sites within the digital TM and SPOT data. A 3 x 3 kernal of pixels surrounding the center of each plot was extracted from the TM band 4 data. Digital numbers for these nine pixels were used to derive an average value for each plot. A similar approach was taken with the SPOT band 3 data. However, a 5 x 5 kernal of pixels was used to characterize each plot as opposed to the 3 x 3 kernal utilized with the TM data. The difference in kernal sizes is directly related to the spatial resolution of the two sensors and the number of pixels required to encompass a one ha sized field plot.

Analysis of the plot data showed that the TM and SPOT NIR data were both negatively correlated with defoliation indicating that as defoliation increases NIR reflectance decreases (Figures 5a and 5b). The basic pattern observed between the two sets of satellite data and defoliation are very similar. Defoliation was shown to have a higher degree of correlation with TM band 4 than with SPOT band 3, -0.87 and -0.74 respectively. Additionally, the two wavebands were found to be highly correlated with one another (r = 0.92). All correlation coefficients were significant at the 0.05 level.

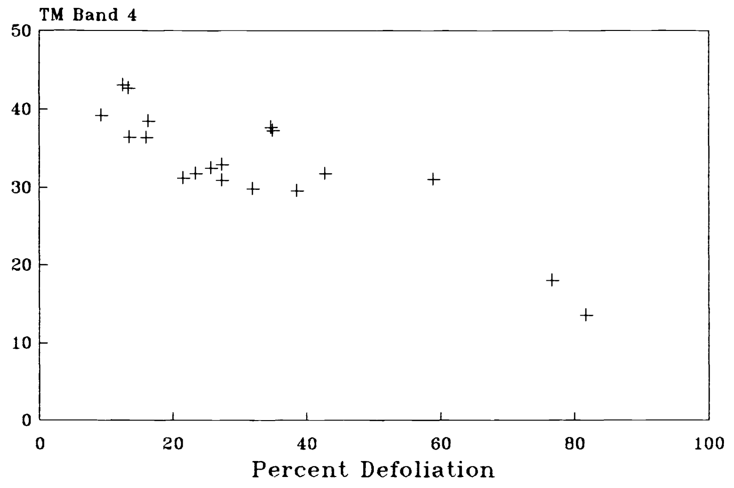


Figure 5a. Defoliation (%) vs. TM B4.

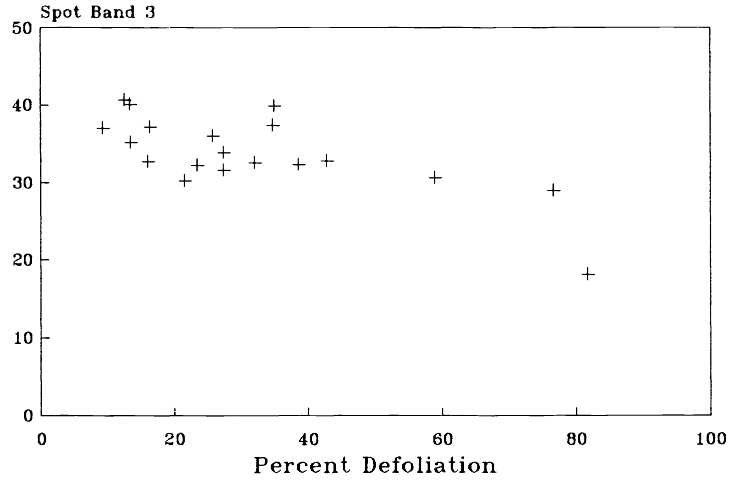


Figure 5b. Defoliation (%) vs. SPOT B3.

Preliminary regression analysis began with the evaluation of the use of TM band 4 or SPOT band 3 as single independent variables within a model predicting percent defoliation. Both the intercept and slope parameter coefficients were significant to the models at the 0.05 level. Model R^2 for the TM band 4 regression equation was 0.75 and 0.55 for the SPOT band 3 equation. The form of the models were as follows:

$$\text{Defoliation} = 112.75 - 2.46 * (\text{TM band } 4) \qquad (1)$$

$$\text{Defoliation} = 132.64 - 2.99 * (\text{SPOT band } 3) \qquad (2)$$

Root mean square error (RMSE) for the TM defoliation model was 10.46 and 14.29 for the SPOT regression equation.

Earlier research had demonstrated the importance of topographic position as an independent variable in modeling defoliation within this ecosystem. Model R^2 increased from 0.75 to 0.87 when elevation was added as an independent variable to the model along with TM band 4, while RMSE decreased to 7.77 from 10.46. A larger increase in R was observed in the SPOT defoliation regression equation when elevation was added to the model than was seen in the TM analysis, 0.55 to 0.80. RMSE was reduced from 14.29 to 9.90. Both slope parameter coefficients (TM or SPOT waveband and elevation) as well as the intercepts were significant to the models at the 0.05 level. The form of the models were as follows:

$$\text{Defoliation} = 39.42 - 2.09 * (\text{TM band 4}) + 0.28 * (\text{elev.}) \quad (3)$$

$$\text{Defoliation} = 34.51 - 2.60 * (\text{SPOT band 3}) + 0.39 * (\text{elev.}) \quad (4)$$

4. Summary

SPOT NIR digital data have been shown to be significantly correlated with percent defoliation in the spruce-fir ecosystem of the Black Mountain Range of the southern Appalachians. The relationship between these variables, as defoliation increases NIR reflectance decreases, is very similar to that observed between TM NIR data and defoliation for the same time of year. However, neither SPOT or TM NIR wâveband data were found to reliable indicators of defoliation by themselves. The addition of a topographic position variable, in this case elevation, in such a model significantly improved the predictive reliability of the model.

Linear regression parameter coefficients were found to be very similar between the TM and SPOT based models. This indicates that the two models are behaving in a similar manner. Model R^2's were higher for the TM based regression equations than for the SPOT equations, 0.87 and 0.75 respectively. The small sample size (19) of this study did not, however, allow the investigators to conclude that TM data are significantly better for assessing defoliation conditions within this ecosystem than SPOT data.

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