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Abstract

The purpose of the study was to assess a method of remote sensing of wildland fire burn severity and burned area for application in southeastern U.S. vegetation types. This method uses Landsat satellite imagery to calculate the Normalized Burn Ratio (NBR) of reflectance bands sensitive to vegetation and exposed soil cover, and the change in NBR from pre- to post-fire (dNBR), to estimate burn severity. To determine ranges of dNBR that correspond to levels of burn severity, we measured burn severity on the ground using the Composite Burn Index (CBI) at 731 locations within the Apalachicola and Osceola National Forests in Florida and the Okefenokee National Wildlife Refuge in Georgia, USA. CBI plots were stratified among plant community types, season of assessment, and time since fire (initial versus extended assessment) to determine reflectance value breakpoints that delimit levels of burn severity. Estimates of levels of burn severity within three months of the burn on average exhibited 79 % percent agreement between dNBR and CBI. We also traced the perimeters of selected burned versus unburned areas on the ground using global positioning system (GPS). Corresponding burned areas were estimated remotely using the newly determined dNBR breakpoints for comparison with surface-measured areas. The average percent bias in estimating burned area was -1 % (± 7 % SE) and was not significant based on T-tests. However, the percent error of commission and error of omission ranged from 0-38 % (average 14 %). Finally, a series of Landsat images were used to determine how long after fire burned areas can be remotely detected. Results showed that the detectable area decreases rapidly and linearly after one month following fire. Our findings suggest that dNBR imagery may provide an unbiased method for inexpensively monitoring burn severity and burned areas under most conditions in common southeastern U.S. habitats if the provided guidelines are followed.

Background and Purpose

Increasing concerns about the effects of unnaturally large and severe wildland fires on ecosystem sustainability and pollution emissions has increased the need for development of remote sensing methods to measure fire effects. In response to this need, satellites have been increasingly used to effectively estimate burn severity (changes in vegetation and soil due to fire) (Bobbe et al. 2003). The benefits of remote sensing of burn severity include measurement of large burned areas, relatively low expense compared to on-the-ground monitoring, and availability of frequently updated data.

Although much work has been done in the western U.S. to calibrate and determine the accuracy of methods of remote sensing burn severity (see Cocke et al. 2005; Epting et al. 2005; Key and Benson 2006; Kasischke et al. 2008 for examples), there has been limited work done within the plant communities of the southeastern U.S. (see Pennington 2006; Wimberly and Reilly 2006 for exceptions). Use of remote sensing may face challenges particular to this region, including rapid regrowth of vegetation following fire, low fire severity in frequently burned areas, fluctuating hydrology in pyrogenic wetlands, and frequent cloudiness. However, validated remote sensing methods would be widely useful given that over 1.6 million hectares of prescribed burning occurs annually within 13 southeastern states combined (Peterson and Ward 1993; Haines et al. 2001) and routine burn monitoring occurs only in select examples of publicly owned land.

The Landsat Thematic Mapper (TM) is one of the most commonly used satellites for remote sensing of burn severity because of its moderate resolution (30 m) and frequent image capture of 18 days (Chuvieco and Martin 1994). Algorithms have been developed to reclassify Landsat TM reflectance values to indicate levels of burn severity.

One of the most widely used image reclassification techniques is the Normalized Burn Ratio (NBR). NBR is the ratio between Landsat TM bands 4 and 7, which are sensitive to vegetation and exposed soil cover (Key and Benson 2006).

To identify changes in vegetation and soil exposure resulting from fire, a prefire NBR (unburned) image can be combined with a postfire NBR image to yield a differenced Normalized Burn Ratio (dNBR) image (Key and Benson 2006). Higher (positive) dNBR values correspond to reduction in vegetation and increased soil exposure interpreted as burn severity, and lower (negative) dNBR values correspond to regrowth of vegetation (Key and Benson 2006). Given that dNBR is sensitive to other sources of land cover change, including tree harvesting or changes in hydrology, some prior knowledge of the location and size of burns and occurrence of other land changes in the area is generally needed for confident interpretation of burn severity.

Remote sensing of burn severity depends on calibration of reflectance images using on-the-ground measurements of burn severity. A commonly used metric for this purpose is the Composite Burn Index (CBI) developed by Key and Benson (1999). CBI rates changes in soil substrates and vegetation attributable to fire within a few weeks of the remote image capture to calculate an overall categorical level of burn severity. Once CBI has been measured on the ground, ranges of dNBR corresponding to those levels can be determined and thus used to calibrate the remote sensing method. These ranges may differ among vegetation types, season, and time elapsed between the fire and burn severity measurement (Key 2005; Hammill and Bradstock 2006). Thus, it is important to determine the most appropriate dNBR breakpoints delineating levels of burn severity among different conditions within the region in which the method is applied.

The overall goal of this study was to determine the applicability of the dNBR method for measuring burn severity in southeastern U.S. plant community types and provide guidelines for its most effective use. Specific objectives were to 1) determine levels of dNBR that most accurately represent levels of burn severity in three natural vegetation community types (pine sandhills, pine flatwoods, depression swamps), three seasons of assessment (dormant, early growing, late growing), and time since burn (initial assessment 0-3 months following burn versus extended assessment 3-12 months following burn), 2) report the accuracy of burn severity estimates for the fires studied, 3) quantify the accuracy of dNBR for estimating burned area using ground-measured perimeters, 4) determine the effect of time since fire on accuracy of estimates of burned area, and 5) calculate the probability of obtaining at least one interpretable Landsat image per each month of the year. The approach included calculating values of dNBR from satellite imagery, using the ground-based measurements to calibrate and test the accuracy of dNBR estimates of burn severity and area, and analyzing a series of satellite images to determine how detection of burned area changes over time.

Study Description and Location

Study Area

The study was conducted within the southeastern U.S. Coastal Plain on the Apalachicola National Forest (ANF) in North Central Florida (ca. 30º20'N -84°21W), Osceola National Forest (ONF) in Northeast Florida (ca. 30º18'N -82°26'W), and the Okefenokee National Wildlife Refuge (ONWR) in Southeast Georgia (ca. 30º44'N -82°7'W; Fig. 1). The work was originally proposed to occur only on the ANF, but we took the opportunity to partner with U.S. Fish and Wildlife Service (USFWS), which provided support for two field assistants to collect additional ground-based data on the ONWR in the wake of the Big Turnaround/Bugaboo Wildfire complex in spring 2007. Work was also expanded to the ONF to take advantage of the 2007 fires, as high severity burns and burns in depression swamps were limited on the ANF. Each of these properties is dominated in various proportions by the three plant community types studied: pine sandhills, wet pine flatwoods, and depression swamps. These community types historically covered most of the eastern portion of the southeastern U.S. Coastal Plain from the Mississippi River to North Carolina and currently cover most public lands in the region (Stout and Marion 1993; Fig. 1).

Upland pine sandhills are dominated by droughty, nutrient poor, sandy mineral soils (Myers 1990). Longleaf pine (*Pinus palustris*) and wiregrass (*Aristida stricta*) are characteristic in areas without a history of intensive agriculture and where prescribed fire is applied frequently (1-4 year fire interval). Turkey oak (*Quercus laevis*), bluejack oak (*Quercus incana*), laurel oak (*Quercus laurifolia*), and other hardwood species dominate in areas with longer fire-free intervals. Relatively low rates of plant productivity and dominance of fine fuels result in relatively low severity surface (Myers 1990). All of the sandhills studied were on the ANF, where fires were prescribed burns applied at 2-3 year intervals at various times throughout the year.

Wet pine flatwoods typically exhibit flat topography and may undergo hydrologic fluctuations, including flooding of the organic or sandy soils (Abrahamson and Hartnett 1990). The historic fire return interval is 1-3 years (Glitzenstein et al. 2003). The pine canopy is dominated by longleaf pine or slash pine (*Pinus elliottii*). The understory consists of a mixture of grasses, forbs, and flammable evergreen shrubs, including saw palmetto (*Serenoa repens*), gallberry (*Ilex glabra*), fetterbush (*Lyonia lucida*), and sweet gallberry (*Ilex coriacea*) (Stout and Marion 1993). High productivity of flammable woody vegetation and buildup of litter may result in moderate to high severity surface or shrub crown fires (flame lengths up to 10 m) in areas that have been fire-excluded for more than 10 years (Sackett 1975). Wet flatwoods were studied on the ANF, ONF, and

ONWR. Most of the fires on the ANF were prescribed fires applied at 2-3 year fire-free intervals, whereas those on the ONF and ONWR were associated with the Big Turnaround/Bugaboo Wildfire complex of May-June 2007 in areas with widely variable times since last fire.

Depression swamps (also called basin swamps, gum swamps, bayheads, cypress domes, and other names; FNAI 1990) are non-riparian wetlands with lower surface elevation than the surrounding pine forest. Soils are typically flooded for most of the year (FNAI 1990), although depression swamps in this study were dry for most of the study period because of drought. High plant productivity and frequently flooded soils lead to a build up of subsurface organic materials (peat) (Cypert 1961). Titi (*Cyrilla racemiflora*), black gum (*N. sylvatica*), pond cypress (*Taxodium ascendens*), slash pine (*Pinus elliottii*), and red maple (*Acer rubrum*) are characteristic of depression swamps (Ewel 1990; FNAI 1990) and were the most common species in the areas studied. Fire intervals can vary from 1-100+ years depending on the amount of soil moisture and hydrologic cycles (Loftin 1998). Fire behavior and effects vary widely and include low severity surface fires, severe ground fires where organic soil is sufficiently dry, and crown fires where fire has been excluded for one or more decades (Ewel 1990; Loftin 1998). Two depression swamp fires were studied on the ANF and the rest were studied on the ONF and ONWR in the wake of wildfires in 2007.

Surface Estimates of Burn Severity using the Composite Burn Index

In order to calibrate dNBR, we measured burn severity on the ground for wildfires and prescribed burns on the ANF, ONF, and ONWR using the Composite Burn Index (CBI) developed by Key and Benson (Key and Benson 2006). The CBI method assesses the vegetation and soil changes resulting from fire within a 30 m diameter circular ground plot by calculating an overall continuous severity index ranging from 0-3, with 0 indicating unburned to 3 indicating maximum fire severity (Fig. 2). Individual CBI values are calculated for each of the five fuel strata: substrate (litter, duff, soil), vegetation <1 m high (herbs, low shrubs, trees), vegetation 1-5 m high (tall shrubs and trees), subcanopy trees, and upper canopy trees. Each of these strata have 4-5 rating factors that are assigned a value ranging from 0-3 following specific criteria, as listed on the CBI data collection form (Appendix I: Key and Benson 2006). Our specific interpretations of the CBI criteria as applied to the studied community types are provided in Appendix II. These rating-factors scores are averaged to determine the CBI score for each stratum. The overall CBI score is then calculated as the average of CBI among strata. For purposes of this study, the overall CBI scores were classified into the following levels of burn severity: unburned (0-0.75), low severity (0.75-1.25), low-moderate severity (1.25-1.75), moderate-high severity (1.75-2.25), and high severity (2.25-3.00). Each CBI plot was georeferenced using a Trimble GPS receiver (Trimble, Sunnyvale CA).

To account for the effect of time between burn date and burn severity measurement, CBI measurements are usually categorized as either Initial Assessment (IA; 1-3 months post-burn) or Extended Assessment (EA; 3-12 months post-burn), which capture immediate and longer-term effects of fire, respectively (Key and Benson 1999). It is ideal to have an image capture within a few weeks of either IA or EA CBI measurements, so that images can be correctly interpreted when taken at varying times following the burn (Key 2005; Zhu et al. 2006). However, because of rapid regrowth of surface vegetation in the studied vegetation types, we found that images corresponding to the timing of EA usually failed to display interpretable levels of burn severity, even though there was still evidence of burn severity on the ground (e.g., trees killed by fire, soil consumption). Therefore, our approach was to use image captures taken within 3 months following the burn to predict both initial and extended fire effects. That is, IA and EA measurements of CBI were independently compared to satellite reflectance images taken with 3 months following the burn to calibrate dNBR separately for each assessment period. Thus, subsequent references to EA refer to the timing of measurement of CBI plots, but not the timing of the screen capture. Although the proposal stated that each of the CBI plots was to be measured for IA and again for EA, we sampled a separate set of plots for IA and EA, mostly to avoid leaving marked plots on public land. Although some burns that occurred during the dormant season were given EAs, no EAs were conducted during the dormant season, because it was too difficult to distinguish between dead and live deciduous woody plants.

Some additional modifications to the proposal were made with regard to distribution of CBI plots. Instead of sampling only the dormant season (Dec-Jan) and early growing seasons (May-Jun), we divided the year into three segments, which were dormant season (Nov-Feb), early growing season (Mar-Jun), and late growing season (Jul-Oct), and made CBI plot measurements throughout the year (Table 1). Although an attempt was made to evenly distribute CBI plots among levels of burn severity, the prevalence of low severity fires characteristic of the studied herb and shrub-dominated community types sometimes resulted in disproportional representation of low severity plots.

We measured a total of 731 CBI plots for fires that occurred on the ANF, ONF, and ONWR during 2006-2008 (Table 1). Plots were distributed among 15 combinations of community type, assessment season, and assessment type, with an average of 48 plots per combination (Table 1).

Remote Sensing of Burn Severity

We obtained Landsat TM 4-5 30 m resolution imagery from the U.S. Geological Survey for each clear day available to incorporate pre- and post-fire images for fires that occurred from December 2006 to July 2008. Generally, one Landsat scene was needed to cover burns in the ANF and another to cover burns in the ONF and ONWR. All Landsat raw images were radiometrically corrected and reprojected using Erdas Imagine (Leica 2008). NBR values for each pixel were calculated using the equation NBR = [R4-R7]/[R4+R7], where R4 is the value of Landsat TM band 4 which is sensitive to changes in vegetation and R7 is Landsat TM band 7 which responds to soil reflectance (Key and Benson 2006). NBR values ranged from approximately 1000 (regrowth) to -1000 (high fire severity). Values of dNBR were calculated with Erdas Imagine Modeler (Leica 2008) using the formula dNBR = (pre-fire NBR – post-fire NBR)*1000, such that dNBR values ranged from approximately -2000 (regrowth) to 2000 (high fire severity). Each pre-fire NBR image was taken approximately one year prior to the post-fire NBR image to minimize error due to between-image seasonal differences in vegetation (Key and Benson 2006).

In order to determine the dNBR burn severity value for each CBI plot, the image and CBI data were imported into ArcGIS 9.3 (ESRI 2008). Given that the 30 m diameter CBI plots generally overlapped with 2-4 dNBR pixels, we sampled dNBR values from five points systematically located within each CBI plot (Fig. 2) to capture potential variation in reflectance among pixels. These values were then averaged to determine the dNBR value for each plot. In order to calculate the breakpoint between unburned and low severity values of dNBR, we selected 133 points in areas known to be unburned near to previously measured CBI plots and gave them a CBI value of 0 (unburned). These points were used in subsequent analyses as if they were CBI plots, in addition to the 731 plots referenced above.

To determine if community type, season, and assessment period significantly influenced reflectance value breakpoints delimiting levels of burn severity, we first calculated best-fit general linear models describing the relationship between CBI and dNBR for each of 15 combinations of conditions (Table 1). CBI was considered the response variable and dNBR the independent variable. Each combination was represented by 13-96 plots (mean = 57). CBI and dNBR values were natural log transformed in order to meet assumptions of homogeneity of variance (Sokal and Rohlf 1997) using Levene's test (SPSS 2006). Best-fit linear models were determined using Sigmaplot 11.0 (Sigmaplot 2009).

A 3-coefficient sigmoidal curve provided the best fit model for each combination of assessment conditions. To determine whether linear models were significantly different from one another under the different combinations of conditions, we used an ANCOVA with CBI as the continuous independent variable, dNBR as the continuous response variable, and community type, burn season, assessment period, and interaction terms as independent factors (SPSS 2006). The intention was to lump data for which the tested factors were not significantly different. However, all factors turned out to be significant as a main effect or interaction, as described below. Thus, the linear models estimated for each combination of conditions were used to calculate the dNBR breakpoints for the burn severity categories based on the CBI breakpoint values.

Once the breakpoints for each burn severity class were determined, dNBR images were reclassified to assign each pixel a specific burn severity class. To calculate the percentage of correctly classified plot locations (to be referred to as percent agreement), the burn severity class of each CBI plot was compared to that estimated by the dNBR images and error matrices were calculated for each of the 15 combinations of conditions (Table 1). In addition to percent agreement, we calculated the index of accuracy called K_{hat}, which takes sample size into account (Congalton et al. 1983). K_{hat} was calculated as:

$$K_{hat} = \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{ir} * x_{ic}) / (N^2 - \sum_{i=1}^{r} (x_{ir} * x_{ic}))$$

where r is the number of rows, x_{ii} is total of the correct cells, x_{ir} is the row total, x_{ic} is the column total, and N is the total number of cells in the error matrix (Congalton et al. 1983).

Remote Estimation of Burned Area

To test the ability to remotely sense burned area and perimeter, we used Global Positioning System (GPS; Trimble Geoexplorer XT) to trace boundaries between burned and unburned areas on the ground within 7 prescribed burn units of the ANF in 2007 and 2008 (Table 2). The burns were classified as having occurred in either sandhills or flatwoods community types, although narrow or isolated depressions swamps were embedded in the flatwoods. Burned areas were traced on foot within three months of the burn with the guideline of staying within 2 m of the burned/unburned boundary. All burned or unburned patches larger than approximately 15 m diameter were traced. GPS data were exported to polyline shapefiles (ESRI 2008) using GPS Pathfinder Office (Trimble 2006) and used to hand-digitize polygons representing the burned areas. Area was then calculated for each digitized burned polygon for comparison to remote estimates of burned area.

To create dNBR burned area coverages for the fires of interest, one pre-fire and one post-fire radiometrically corrected Landsat TM 4-5 image was provided by the

United States Geological Survey (USGS) for each of the three study seasons including dormant (November-February), early growing (March-June), and late growing season (July-October) in 2007 and 2008 for a total of 12 images (Table 2). After dNBR was calculated and each image imported into ArcGIS v9.3 (ESRI 2008), the ArcGIS Spatial Analyst Extension was used to reclassify the image into levels of burn severity using the IA breakpoints for each season and community type as determined above. A majority filter was applied to the two-class image to decrease the commission error by eliminating small, isolated pixels interpreted as burned but were likely unburned. This "cleaned" raster image was converted to a polygon shapefile. The area of each burned polygon was then calculated and summed for the burn unit.

To assess the spatial accuracy of estimates of burned area, remote sensing errors of commission (unburned areas interpreted as burned) and omission (burned areas interpreted as unburned) were calculated for each burn. Polygons representing areas of commission and omission were generated in ArcGIS v9.3 (ESRI 2008) using the X-Tools Pro Erase Features extension (Data East 2008) by overlaying surface measured polygons and remotely sensed polygons. Errors of commission, omission, and area bias (commission - omission) were reported as a percent error relative to the ground-based measurement of burned area.

In order to determine whether consistent biases existed in estimates of burned acreage among burns (without regard to precise spatial accuracy), a paired T-test (SPSS 2006) was used to compare dNBR remote estimates of burned areas with those measured on the ground using the 7 burn units as replicates. Homogeneity of variance was confirmed using Levene’s test (SPSS 2006). The mean, standard deviation, and standard error of the bias among the 7 burns were also reported.

To test the presumption that imagery may become less reliable at mapping burned areas as vegetation has time to recover (Key 2005), separate Pearson correlation tests were performed to determine the affect of post-fire time until image capture on dNBR percent errors of omission, commission, and bias in burned area estimates using the 7 burns as replicates (SPSS 2006). Differences between community types (flatwoods and sandhills) were also considered but not statistically tested because of the small sample sizes (3 and 4 burn units, respectively).

Effect of Time Since Burn on Estimates of Burned Area

We further assessed the effect of time since burn on the accuracy of dNBR estimates of burned area over time for 42 prescribed burns on the ANF in 2006. Specifically, we compared postfire dNBR images taken within 30 days of fire (initial image) with subsequent dNBR images taken in 30 day increments to 480 days postfire. The dNBR images were converted to 2-class burned/unburned images by using the burned/unburned breakpoints calculated as part of this study. Burn units analyzed were categorized by season (dormant versus growing) and dominant community type (flatwood or depression swamp). Early and late growing season burned areas were combined into one growing season category because there were only two units burned during the 2006 late growing season. Sandhills were not considered because no prescribed fires occurred within sandhills on the ANF during 2006. The percent agreement between burned pixels in the initial image and those in images within each of the subsequent 30 day periods was determined using the Spatial Analyst Raster Calculator Tool in ArcMap (ESRI 2008), with the assumption that the initial estimate most closely represented the actual burned area. Data was viewed both by season of burn with community types pooled and by community type for dormant season burns, since flatwoods were underrepresented in the growing season (N = 3).

Ability to Obtain Usable Remote Sensing Images

To determine the probability of obtaining at least one 95% cloud free Landsat TM 4-5 image per month for locations on the ANF, we evaluated the number of available images for the two scenes covering the area (path 18 row 39 and path 18 row 40) over a ten year period (1999-2008) using the GLOVIS image viewer (USGS 2009). Because the two scenes have an approximately 67 % overlap, we also calculated the probability of obtaining a monthly Landsat image using both images for the total area covered.

Key Findings

Remote Sensing of Burn Severity

The relationship between dNBR and CBI were significantly affected by season of burn, assessment period, and most interaction effects, as determined by the ANCOVA (Table 3; Fig. 3). Goodness-of-fit between dNBR and CBI data and breakpoints corresponding to levels of burn severity are provided for each of the 15 combinations of period of burn, assessment period, and community type (Table 4).

Using the sigmoidal linear model to relate CBI to dNBR, it appeared that CBI was usually limited to a certain level of burn severity under a given set of conditions, despite representation of NBR or dNBR levels that typically would represent much higher burn severity (Fig. 3). The result was that the number of levels of burn severity for which dNBR could calibrated varied among combinations of community type, assessment season, and assessment type (Table 5, Fig. 3), depending on the range of burn severity measured in CBI plots. Several groups were limited in range to the low-severity burn severity class, particularly in the sandhills (Table 5; Fig. 3). Although representation of burn severity was limited in this study, such relatively low burn severity levels are typical of these vegetation community types within this region, attributable to sandy soils that are minimally affected by fire, the dominance of herbaceous vegetation in the understory, pine needles and hardwood litter fuels, fire resistant pines in the canopy, and a general lack of crown fires (Myers 1990). Limitations on level of CBI despite representation of high levels of dNBR may be because satellites are detecting variations in soil exposure, moisture, or vegetation cover that are not easily perceived during CBI plot observations or do not weigh heavily in the calculation of CBI. However, assuming CBI captures the ecological variables of greatest interest, these models likely capture real limits to burn severity in the studied community types. Other studies of burn severity have similarly found that CBI levels plateau with increasing values of dNBR (higher burn severity) (van Wagtendonk et al. 2004; Wimberly and Reilly 2006).

The goodness-of-fit, percent agreement, and K_{hat} between remotely estimated and surface measured levels of burn severity varied significantly among combinations of fire conditions. These three metrics, which generally mirrored each other, were overall higher for sandhills relative to flatwoods and depression swamps (Table 4). They were also generally highest for the late growing season burns, followed by dormant season burns and then early growing season burns (Table 4). IA had higher goodness-of-fit, percent agreement, and K_{hat} than EA overall (Table 4). The reported levels of goodness-of-fit and K_{hat} are comparable to those found in studies in the western United States that are currently used for routine burn severity monitoring (Cocke et al. 2005; Epting et al. 2005)

Remote Sensing of Burned Area

Differences between the average remotely sensed estimates of burned area and surface measurements were not significant (t = -0.427, df = 6, P = 0.685). The area of burn severity was slightly underestimated with habitat types combined (-0.6 % for dNBR). Comparisons of remote estimates of burned area with ground measurements revealed errors of commission ranging from 3-44 % (average 16 %) and errors of omission ranging from 2-43 % (average 17 %) for the 7 burns examined (Table 6; Fig 3). Commission errors were generally higher in flatwoods than in sandhills, and conversely omission errors were lower in flatwoods than in sandhills (Table 6). Changes in area of standing water within flatwoods and depression swamps may have contributed to errors of commission, given that rains occurred between the burn and burn assessment for at least one of the burn units. Conversely, higher errors of omission in the sandhills were likely due to visible patches of open sand characteristic of the habitat (Myers 1990) which might reduce the differential reflectance between pre-burn and post-burned pixels required to classify areas as burned (White et al. 1996).

Using the 7 burn units as replicates, image capture time since fire had a significant positive effect on error of omission for dNBR (R^2 = 0.614, P = 0.037, df = 7), but not on error of commission or bias. This trend in error of omission is attributable to vegetation having sufficient time to regrow and thus obscure the division between burned and unburned areas (Hammill and Bradstock 2006).

Effect of Time Since Burn on Estimates of Burned Area

Interpretation of the satellite image series in 2006 showed that the percent agreement between the initial and subsequent estimates of burned area decreased linearly with time since burn (Figs. 6, 7). The average percent agreement decreased fastest for dormant season burns (Slope = -0.22) when compared to growing season burns (Slope = -0.16), and the slope was slightly more negative for flatwoods (Slope = -0.24) compared to depression swamps (Slope = -0.21) burned during the dormant season. Overall, the results describe an approximately 7 % loss in average percent agreement for every 30 days between fire date and image capture date.

Ability to Obtain Usable Images

The probability of obtaining at least one Landsat image per month was variable, ranging from 20 %-100 % (Mean = 57 %) among months for the two scenes separately and combined (Figs. 8-10). However, there were similar trends in the distribution of percent probability of image acquisition between the two scenes. February was the best month for image acquisition with the probability of obtaining an image being ≥80 %. June was the worst month for image acquisition with the probability of obtaining an image ≤20 %. The probability of image acquisition was ≥50 % for March, April, September, October, November, and December. Overall, there were 2-9 viable images per year (Mean = 6) that generally fall within the months of February-April and November-December.

Management Implications

The dNBR method of remote sensing of burn severity appears to be applicable in southeastern U.S. community types studied, given levels of accuracy that are comparable to studies in the western U.S. where the methodology was developed (Cocke et al. 2005; Epting et al. 2005). However, our results suggest that some special considerations are needed to minimize limitations to the method that are particular to these and similar community types.

The results suggest that there is no single set of reflectance breakpoints that is appropriate for all community types, seasons of assessment, or time between burn and assessment. Although measuring CBI plots to calibrate particular fires in specific vegetation types is always ideal, we suggest using the specific sets of breakpoints presented in this study for their corresponding community types and seasons of the year where applicable. These might also be applied to community types expected to have similar fuel structure and fire behavior as those studied.

Perhaps the most obvious limitation to the method is the short period following fire that burned area and burned severity are accurately perceptible using remote sensing because of rapid regrowth of top-killed vegetation. For most applications, we suggest that post-burn images be acquired within two months of the burn, and acquisition within one month is preferable. Given rapid rates of vegetation regrowth, having pre-fire and post-fire images captured during the same time in the season is important to avoid seasonal changes in vegetation being misinterpreted as burn severity (Key 2005). This consideration is especially important if the images are captured during transition periods between the dormant and growing seasons when changes in vegetation are particularly rapid. Where images can not be obtained within this time frame, estimates of burned area might be approximated using the linear trends in loss of perceptibility presented in this study.

Another limitation to use of the method in flatwoods and depression swamps, and presumably most other southeastern U.S. wetlands, is the potential effect of periodic variations in soil moisture and hydrology on interpretation of burn severity using dNBR imagery (Key and Benson 2006). Obtaining an image capture as soon after the fire as possible is important for minimizing the likelihood of post-burn hydrological fluctuations. Where such fluctuations have occurred between pre- and post-burn image captures, but not between the burn and image capture, use of NBR alone may be advantageous, although calibration of NBR to CBI is outside the scope of this study.

Use of the dNBR method of remote sensing can also be limiting in the region because of frequent cloud cover. The goal of acquiring imagery within two months of the burn may be difficult to obtain during the mid-winter and late summer months. However, seasonal changes in vegetation are also less rapid during these periods, presumably providing more flexibility in the required time between the burn and image capture. Conversely, availability of imagery is relatively high during the spring and summer months when changes in vegetation are rapid.

The use of dNBR for estimating burned area and burn perimeter showed considerable error on a per burn basis, such that its use for mapping burn perimeters with a high degree of accuracy may be problematic in the studied community types. However, the relatively small average bias among burns suggests that the method might be used for monitoring where estimating total burned acreage for multiple fires is the primary goal. However, further validation of remote sensing of burned area is warranted to reinforce the observed lack of bias or establish average bias for particular community types.

Our results suggest that the dNBR methods may be used to estimate smaller burned areas than typically targeted to date. The burns measured in this study ranged from 26-343 hectares with a level of accuracy that was comparable to previous studies that focused on areas ranging from 18,000 to 28,000 hectares (e.g., Holden et al. 2005). The ability to reliably measure burn severity and burned acreage on smaller fires is especially important in the southeastern U.S. where burns are typically much smaller than in the west because of patterns of land ownership.

In summary, the dNBR method should provide a low-cost and accurate way of monitoring burn severity and burned area in the southeastern U.S. within the limitations discussed. Given that all imagery taken within the past 30-years is currently available free of charge via USGS GLOVIS (USGS 2009), the method should be particularly valuable for determining historic fire regimes in process of developing fire atlases for properties or areas of interest. Application of the method to providing reliable estimates of burned area at the state and regional levels would significantly improve assessments of wildfire effects, wildlife habitat quality, wildfire risk, and air pollution emissions from fire.

Relationship to Other Findings and Ongoing Work on This Topic

Much interest has been generated recently within the southeastern U.S. for remotely monitoring burned areas using satellite imagery. The U.S. Forest Service (USFS), National Park Service (NPS), U.S. Fish and Wildlife Service (USFWS), Archbold Biological Station, Disney Wildlife Preserve, and Eglin Air Force Base are all currently working on monitoring fires with CBI plots to calibrate dNBR imagery for use in monitoring burn severity on their properties. All data gathered in this project will be transferred to the ANF, ONF, and ONWR to assist with their fire effects monitoring. The Georgia and Florida state forestry and wildlife agencies have also shown interest in using the dNBR method for monitoring prescribed fire and wildlife habitat. All of this interest in remote sensing applications to monitor burn severity underscores the importance of continuing related work within the Southeast.

NPS has begun to monitor the burn severity of fires within the Everglades, Big Cypress, Shenandoah, and Mammoth Caves National Parks, all within the southeastern U.S. Although CBI data has been collected, it has not been used to threshold dNBR imagery to determine appropriate burn severity breakpoints. We have begun to compile these data into a database that will be continuously updated to determine appropriate dNBR burn severity breakpoints specific to each vegetation community type.

Pending further support, we are planning to assist the Nature Conservancy Disney Wildlife Preserve (DWP) in Kissimmee, FL with image processing so that they may begin monitoring their prescribed burns using dNBR calibrated with CBI plots. These calibrations will provide a test of generality of our dNBR burn severity breakpoints in similar habitats (flatwoods, depression swamps) elsewhere. DWP has also collected over 20 years of prescribed burn boundary data that occurs within preserve, which they can use to ground-truth estimates of burned areas. Currently, Monitoring Trends in Burn Severity (MTBS) is monitoring all fires within the southeastern U.S. that are larger than 200 hectares. We have submitted burn severity breakpoints used in this project to improve MTBS' ability map burn severity within the southeastern U.S., in particular for fires that are less than 200 hectares on public lands.

We are also providing estimates of burned area to those administrating the Bluesky system (Larkin et al. 2009) to assist in validation of $PM_{2.5}$ emission estimates which are based on coarse scale (1 km) resolution satellite imagery.

Future Work Needed

Although the flatwood, sandhill, and depression swamp community types are widely representative of natural areas within the southeastern U.S. Coastal Plain, they may or may not accurately represent other community types in region in their reflectance characteristics. Continued calibration of remote burn severity estimates using CBI to update the burn severity breakpoints in additional community types over a wide range of climatic and fuel loading conditions will progressively refine the results presented here for application under specific sets of conditions.

Determining the minimum size of burned areas that can be accurately monitored using remote sensing would be a valuable focus of future research, particularly in the southeastern states where many wildfires and prescribed burns are of small acreage. Current monitoring in the region provided by Monitoring Trends in Burn Severity (MTBS) and NOAA Hazard Mapping Systems (HMS) focus on fires that are less than 200 hectares, and the latter uses coarse-scale (1 km^2) to estimate particulate emissions. This spatial scale presumably misses most fires in the southeastern U.S. Further validation of dNBR methods for small burned areas (10 or more hectares) would lend support to a statewide system of burn monitoring utilizing remote sensing techniques in combination with other fire occurrence data (i.e. burn permits and wildfire records) to greatly increase the accuracy in estimates of burned area for monitoring wildfire risk, wildlife habitat, and particulate emissions.

The use of the dNBR method within the limitations described in this study might provide validation and calibration of other sources of burn severity and area information. For example, it could be used to calibrate burned area data from state agency prescribed fire authorizations and incident reports, which might be biased for various reasons. Such validation and calibration might greatly increase the utility of such comprehensive sources of fire information.

Deliverables (see also uploads to JFSP website: http://www.firescience.gov).

Deliverables Crosswalk

Proposed	**Delivered**	**Status**
Project Website	http://www.talltimbers.org/burnseverity/ANF.html	Updated
Annual Reports	(1) 2007-see JFSP website (2) 2008-see JFSP website	(1-2) Completed
Final Report	Final Report	Completed 2009
Workshops	1) Burn Severity Workshop-Tall Timbers Research Station (2) Burn Severity Workshop-Okefenokee National Wildlife Refuge (3) Burn Severity Workshop-TNC Disney Wildlife Preserve	(1-3) Completed 2009
Training Sessions	(1) CBI Protocol Demonstration-Apalachicola National Forest (2) CBI Protocol Demonstration-Osceola National Forest (3) CBI Protocol Demonstration-Okefenokee National Wildlife Refuge	(1) Completed 2007 (2) Completed 2007 (3) Completed 2008
Presentations	(1) Invited Presentation-Validation of National Burn Severity Mapping Project techniques within the Apalachicola National Forest. Tall Timbers Research Station, Tallahassee, FL. (2)Invited Presentation-Modeling fire behavior and assessing post fire burn severity for the 2007 Big Turnaround Fire Complex. Seven Hills Regional User Group for GIS (SHRUG) Conference, Tallahassee, FL. (3)Invited Presentation-Monitoring burn severity within North Florida Sandhills. North Florida Sandhills Working Group, Tallahassee, FL. (4)Poster Presentation-Burn monitoring using satellite imagery in the Apalachicola National Forest. Southeastern Regional USDA Forest Service Conference, Little Rock, AK. (5)Invited Presentation-Remote Sensing of burn perimeters using Landsat TM imagery within the southeastern United States. Tall Timbers Fire Ecology Conference, Tallahassee, FL.	(1) Completed 2007 (2) Completed 2007 (3) Completed 2008 (4) Completed 2008 (5) Completed 2009
Brochure	Satellite mapping of fire perimeters and severity within the Apalachicola National Forest: Methods and applications brochure.	(1) Completed 2008
Peer-reviewed Papers	See citation database (currently includes 2 in preparation for peer-reviewed publications)	Completed 2009
Databases	CBI, NBR, and dNBR database	Completed 2009-database posted on website
Burn Severity Breakpoints	2007-2008 Burn severity breakpoints	Completed 2009-data posted on website
Burn Severity Maps	2000-2009 Burn severity downloadable images	Completed 2009-data posted on website

Workshops

During the spring and summer of 2009, we hosted workshops at Tall Timbers Research Station, Okefenokee National Wildlife Refuge, and The Nature Conservancy Disney Wilderness Preserve. At each of these workshops there were 20-42 participants representing federal, state, and private entities including Alachua County, Apalachicola National Forest, Archbold Biological Station, Avon Park Air Force Range, Big Cypress National Park, Disney Wilderness Preserve, Eglin Air Force Base, Lower Suwannee National Wildlife Refuge, MTBS, Ocala National Forest, Ocmulgee Ranger District, Okefenokee National Wildlife Refuge, Osceola National Forest, Project Orion, and the State of Florida Department of Forestry. Each workshop provided information about monitoring burn severity and burned areas using NBR and dNBR remote sensing techniques and the on-the-ground CBI estimation of burn severity.

Final Report

Picotte, J.J. and K.M. Robertson. 2009. Validation of National Burn Severity Mapping Project techniques in selected southeastern U.S. ecosystems. Final Report (JFSP Project Number: 06-2-1-31). September 01, 2009. Tallahassee, FL.

Publications

Picotte, J.J. and K.M. Robertson. 2009. Remote sensing of wildland fire burned area in southeastern U.S. coastal plain habitats. Pages 000-000 in K.M. Robertson, R.E. Masters and K.E.M Gallery (Eds.). Proceedings of the 24th Tall Timbers Fire Ecology Conference: The Future of Fire: Public Awareness, Health, and Safety. Tall Timbers Research Station, Tallahassee, FL, USA (submitted).

Picotte, J.J. and K.M. Robertson. 2009. Validation of burn severity within southeastern U.S. ecosystems. International Journal of Wildland Fire. (in preparation).

Websites

Validating Burn Severity of Southeast Ecosystems Website. http://www.talltimbers.org/burnseverity/ANF.html

ArcServer Apalachicola National Forest Burn Severity Interactive Web Application. http://nbci.ttrs.org/BurnMap_ANF/default.aspx

ArcServer Okefenokee National Wildlife Refuge Interactive Web Application. http://nbci.ttrs.org/BurnMap_ONWR/default.aspx

Workshops

Picotte, J.J. and K.M. Robertson. 2009. Validating burn severity within southeastern U.S. ecosystems workshop. Tall Timbers Research Station. April 07, 2009. Tallahassee, FL.

Picotte, J.J. and K.M. Robertson. 2009. Validating burn severity within southeastern U.S. ecosystems workshop. Okefenokee National Wildlife Refuge. April 21, 2009. Folkston, GA.

Picotte, J.J. and K.M. Robertson. 2009. Validating burn severity within southeastern U.S. ecosystems workshop. The Nature Conservancy Disney Wilderness Preserve. June 29, 2009. Kissimmee, FL.

Professional Presentations and Invited Talks

Picotte, J.J. and K.M. Robertson. 2007. Validation of National Burn Severity Mapping techniques within the Apalachicola National Forest. Tall Timbers Research Station, April 04, 2007. Tallahassee, FL.

Picotte, J.J. and J. Noble. 2007. Modeling fire behavior and assessing post fire burn severity for the 2007 Big Turnaround Fire Complex. Seven Hills Regional User Group (SHRUG), November 13, 2007. Tallahassee, FL.

Picotte, J.J. and K.M. Robertson. 2008. Monitoring prescribed fire using remote sensing methods. Sandhill Working Group Workshop, September 09, 2008. Tallahassee, FL.

Picotte, J.J. and K.M. Robertson. 2009. Remote sensing of burn perimeters using Landsat TM imagery within the southeastern United States. Tall Timbers Fire Ecology Conference, January 12, 2009. Tallahassee, FL.

Posters

Picotte, J.J. and K. Gordon. 2008. Satellite mapping of fire perimeters within the Apalachicola National Forest: methods and applications. Tall Timbers Research Station, Tallahassee, FL.

Picotte, J.J. and K. Gordon. 2008. Burn monitoring using satellite imagery in the Apalachicola National Forest brochure. Tall Timbers Research Station, Tallahassee, FL.

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Tables

Table 1. Composite Burn Index plots proposed for sampling and actually sampled on the Apalachicola and Osceola National Forests and Okefenokee National Wildlife Refuge 2006-2008.

Assessment	Season	Community	Proposed	Completed
Initial	Dormant	Sandhill	60	40
Initial	Dormant	Flatwoods	60	43
Initial	Dormant	Depression Swamp	60	40
Initial	Early Growing	Sandhill	60	40
Initial	Early Growing	Flatwoods	60	40
Initial	Early Growing	Depression Swamp	60	42
Initial	Late Growing	Sandhill	0	40
Initial	Late Growing	Flatwoods	0	40
Initial	Late Growing	Depression Swamp	0	38
Extended	Dormant	Sandhill	60	0
Extended	Dormant	Flatwoods	60	0
Extended	Dormant	Depression Swamp	60	0
Extended	Early Growing	Sandhill	60	60
Extended	Early Growing	Flatwoods	60	85
Extended	Early Growing	Depression Swamp	60	41
Extended	Late Growing	Sandhill	0	60
Extended	Late Growing	Flatwoods	0	74
Extended	Late Growing	Depression Swamp	0	48
Total			720	731

Table 2. Pre-fire image, burn, and post-fire image dates for examined flatwoods and sandhill burn units for which burn perimeters were traced on the ground using GPS.

Burn Unit	Vegetation Type	Pre-fire Image Date	Burn Date	Post-fire Image Date	Post-fire Image Time Since Fire (days)
231	Flatwood	12/19/2006	1/8/2008	2/24/2008	45
304	Flatwood	3/25/2007	4/17/2008	5/14/2008	27
302	Flatwood	8/16/2007	7/12/2008	7/17/2008	5
248	Sandhill	3/25/2007	3/12/2008	3/27/2008	15
248b	Sandhill	2/24/2008	1/10/2009	2/10/2009	31
249	Sandhill	3/25/2007	3/17/2008	3/27/2008	10
254	Sandhill	8/16/2007	6/25/2008	9/19/2008	86

Table 3. ANCOVA results testing effects of CBI (continuous variable), community, season, assessment (categorical variables), and their interaction terms on dNBR. The overall model was significant (F = 34.762, P < 0.000, 15/716 df).

Source	df	Type III SS	Mean Square	F-value	Pr>F
CBI	1	6.873	6.873	35.453	<0.0001
Community	2	4.148	2.074	10.699	<0.0001
Season	2	0.696	0.348	1.796	0.169
Assessment	1	3.236	3.236	16.693	<0.0001
Community*Season	4	2.405	0.601	3.101	0.015
Community*Assessment	2	3.640	1.820	9.389	<0.0001
Season*Assessment	1	0.005	0.005	0.025	0.875
Community*Season*Assessment	2	5.250	13.541	13.541	<0.0001

Table 4. Goodness-of-fit (R^2), percent agreement (% Agr.), and K_{hat} between CBI and dNBR variables for each combination of community type, assessment season, and assessment period, as well as averages for each combination.

Community	**Season**	**dNBR R^2**	**dNBR % Agr.**	**dNBR K_{hat}**
		Initial Assessment		
Sandhill	Dormant	0.88	100%	100%
Sandhill	E. Growing	0.70	75%	73%
Sandhill	L. Growing	0.92	100%	100%
Sandhill	*Averaged*	0.83	92%	91%
Flatwood	Dormant	0.64	65%	62%
Flatwood	E. Growing	0.47	46%	38%
Flatwood	L. Growing	0.76	98%	93%
Flatwood	*Averaged*	0.62	70%	64%
D. Swamp	Dormant	0.81	71%	59%
D. Swamp	E. Growing	0.61	63%	44%
D. Swamp	L. Growing	0.78	93%	80%
D. Swamp	*Averaged*	0.74	76%	61%
Averaged	Dormant	0.78	79%	74%
Averaged	E. Growing	0.59	61%	52%
Averaged	L. Growing	0.82	97%	91%
Averaged	*Averaged*	0.73	79%	72%
		Extended Assessment		
Sandhill	E. Growing	0.58	93%	78%
Sandhill	L. Growing	0.73	85%	58%
Sandhill	*Averaged*	0.65	89%	68%
Flatwood	E. Growing	0.62	60%	52%
Flatwood	L. Growing	0.55	52%	47%
Flatwood	*Averaged*	0.59	56%	50%
Flatwood	E. Growing	0.65	51%	39%
Flatwood	L. Growing	0.73	73%	60%
D. Swamp	*Averaged*	0.69	62%	50%
Averaged	E. Growing	0.62	68%	56%
Averaged	L. Growing	0.67	70%	55%
Averaged	*Averaged*	0.64	69%	56%
Overall Average		0.70	75%	66%

Table 5. dNBR breakpoints representing levels of burn severity for each of the 15 combinations of fire conditions studied. Negative numbers are in parentheses.

Community	Season	Unburned	Low	Low-Mod	Mod-High	High
			Initial Assessment			
Sandhill	Dormant	(2000) - (5)	(4) - 2000	X	X	X
Sandhill	E. Growing	(2000) - 118	119 - 173	174 - 2000	X	X
Sandhill	L. Growing	(2000) - 7	8 - 2000	X	X	X
Flatwood	Dormant	(2000) - 105	106 - 229	230 - 2000	X	X
Flatwood	E. Growing	(2000) - 26	27 - 256	257 - 483	484 - 823	824 - 2000
Flatwood	L. Growing	(2000) - 20	21 - 2000	X	X	X
D. Swamp	Dormant	(2000) - 16	17 - 183	184 - 298	299 - 2000	X
D. Swamp	E. Growing	(2000) - 26	27 - 80	81 - 145	146 - 2000	X
D. Swamp	L. Growing	(2000) - 60	61 - 2000	X	X	X
			Extended Assessment			
Sandhill	E. Growing	(2000) - 11	12 - 2000	X	X	X
Sandhill	L. Growing	(2000) - 74	75 - 2000	X	X	X
Flatwood	E. Growing	(2000) - 77	78 - 228	229 - 398	399 - 2000	X
Flatwood	L. Growing	(2000) - 171	172 - 261	262 - 2000	X	X
D. Swamp	E. Growing	(2000) - 112	113 - 201	202 - 295	296 - 497	498 - 2000
D. Swamp	L. Growing	(2000) - 82	83 - 164	165 - 289	290 - 2000	X
Overall Mean		(2000) - 60	61 - 197	198 - 318	319 - 660	661 - 2000

Table 6. Commission error (CE), omission error (OE), and bias between actual burned area (surface measured) and dNBR estimated burned areas. Burned areas have been subdivided into their respective community types by season of burn. Mean values, SD, and SE were calculated for both community types and all data.

Burn Unit	Vegetation	Season	dNBR		
			CE	OE	Bias
231	Flatwood	Dormant	9%	24%	-15%
304	Flatwood	Early Growing	6%	13%	-7%
302	Flatwood	Late Growing	44%	6%	+38%
Mean	Flatwood	Combined	19%	14%	+5%
SD	Flatwood	Combined	21%	9%	29%
SE	Flatwood	Combined	5%	3%	5%
248b	Sandhill	Dormant	13%	2%	+11%
248	Sandhill	Early Growing	8%	8%	0%
249	Sandhill	Early Growing	5%	22%	-17%
254	Sandhill	Late Growing	30%	43%	-13%
Mean	Sandhill	Combined	14%	19%	-5%
SD	Sandhill	Combined	11%	18%	13%
SE	Sandhill	Combined	3%	4%	4%
Mean	**Combined**	**Combined**	**16%**	**17%**	**-1%**
SD	**Combined**	**Combined**	**14%**	**14%**	**20%**
SE	**Combine**	**Combined**	**6%**	**6%**	**7%**

Figures

Figure 1. Location of study sites within Georgia (A) and Florida (B), USA. Study sites were located in the Apalachicola National Forest (C), Okefenokee National Wildlife Refuge (D), and Osceola National Forest (E).

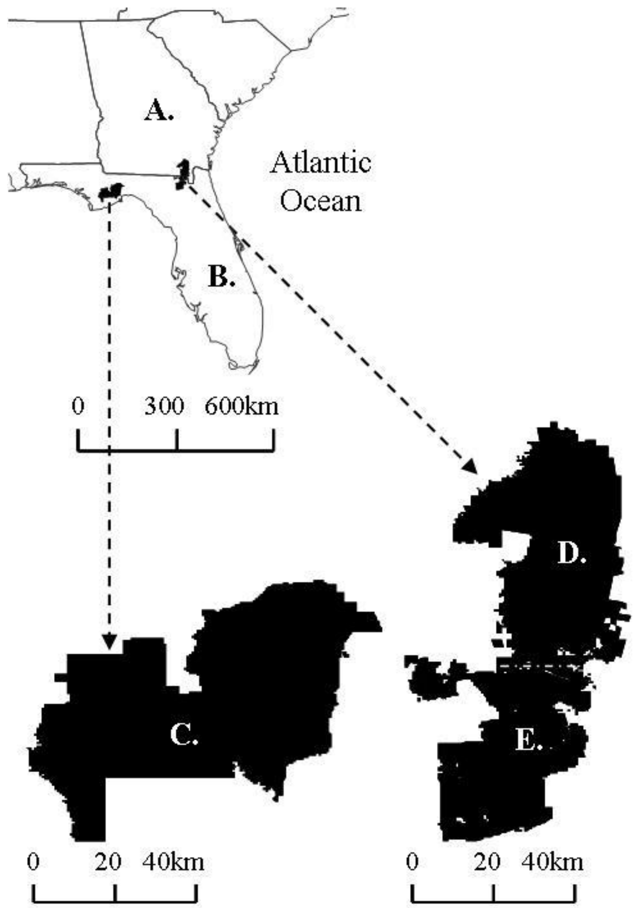


Figure 2. Composite Burn Index (CBI) ground plots (A) were overlain on dNBR reflectance raster pixels (B) in GIS. Five dNBR burn severity values were digitally sampled within the CBI plot (C) and averaged to compare with the CBI estimated throughout the plot.

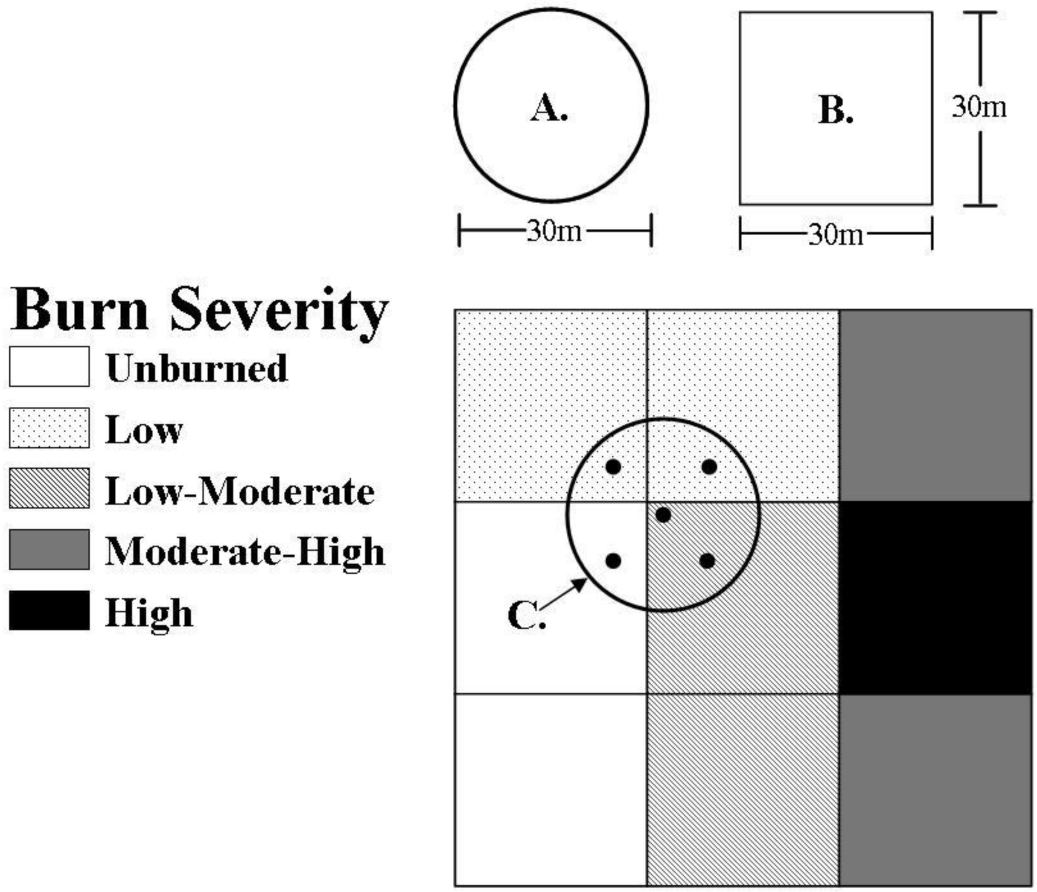


Figure 3. Curves relating dNBR to CBI for each of the 15 combinations of assessment type, community type, and season. CBI burn severity categories are labeled as follows: H = high severity, M-H = moderate-high severity, L-M = low-moderate severity, L = low severity, U = unburned.

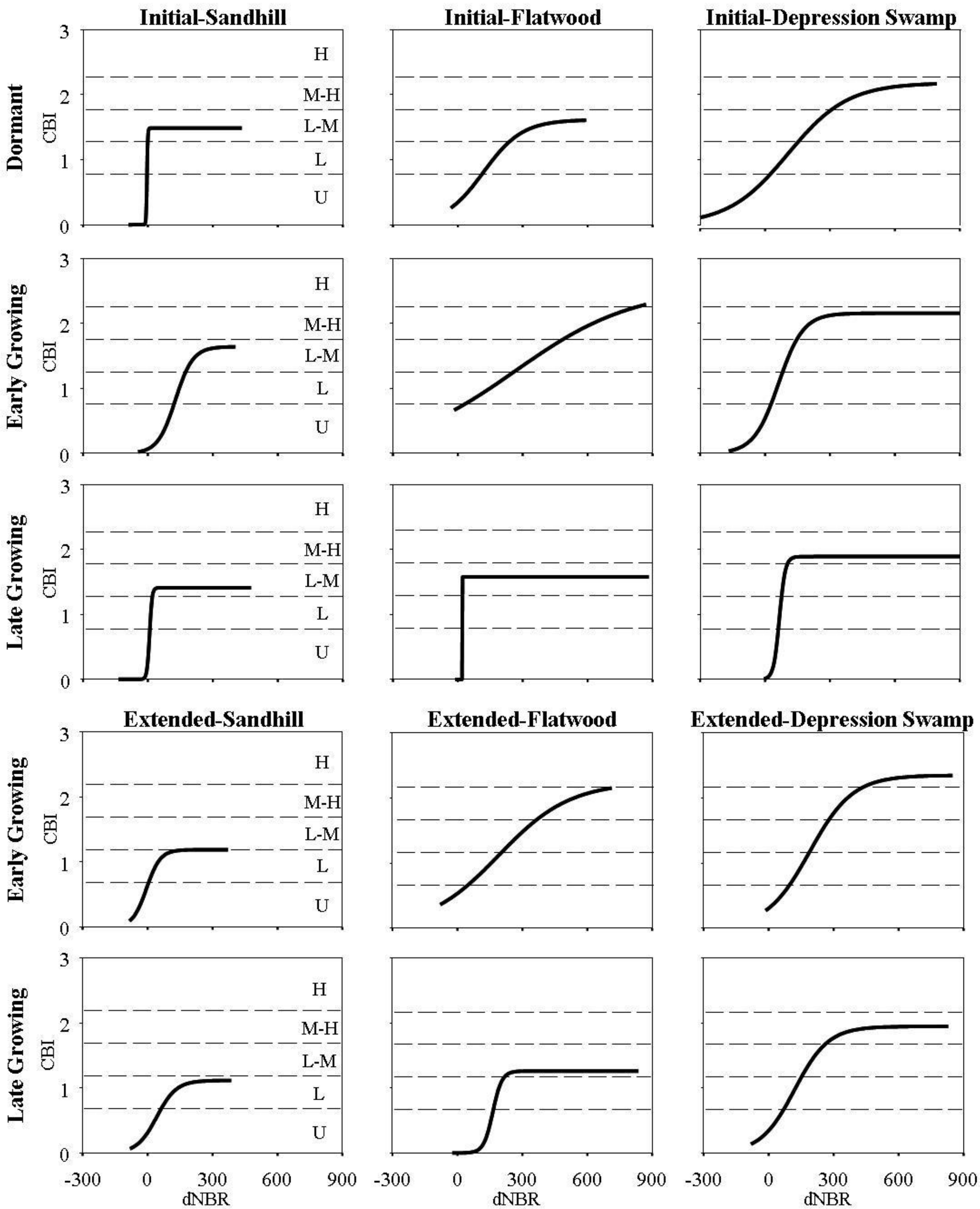


Figure 4. GPS and dNBR burn mapping methods to trace the extent of all 7 traced areas. Unburned areas lacking color within burned areas are indicated by white.

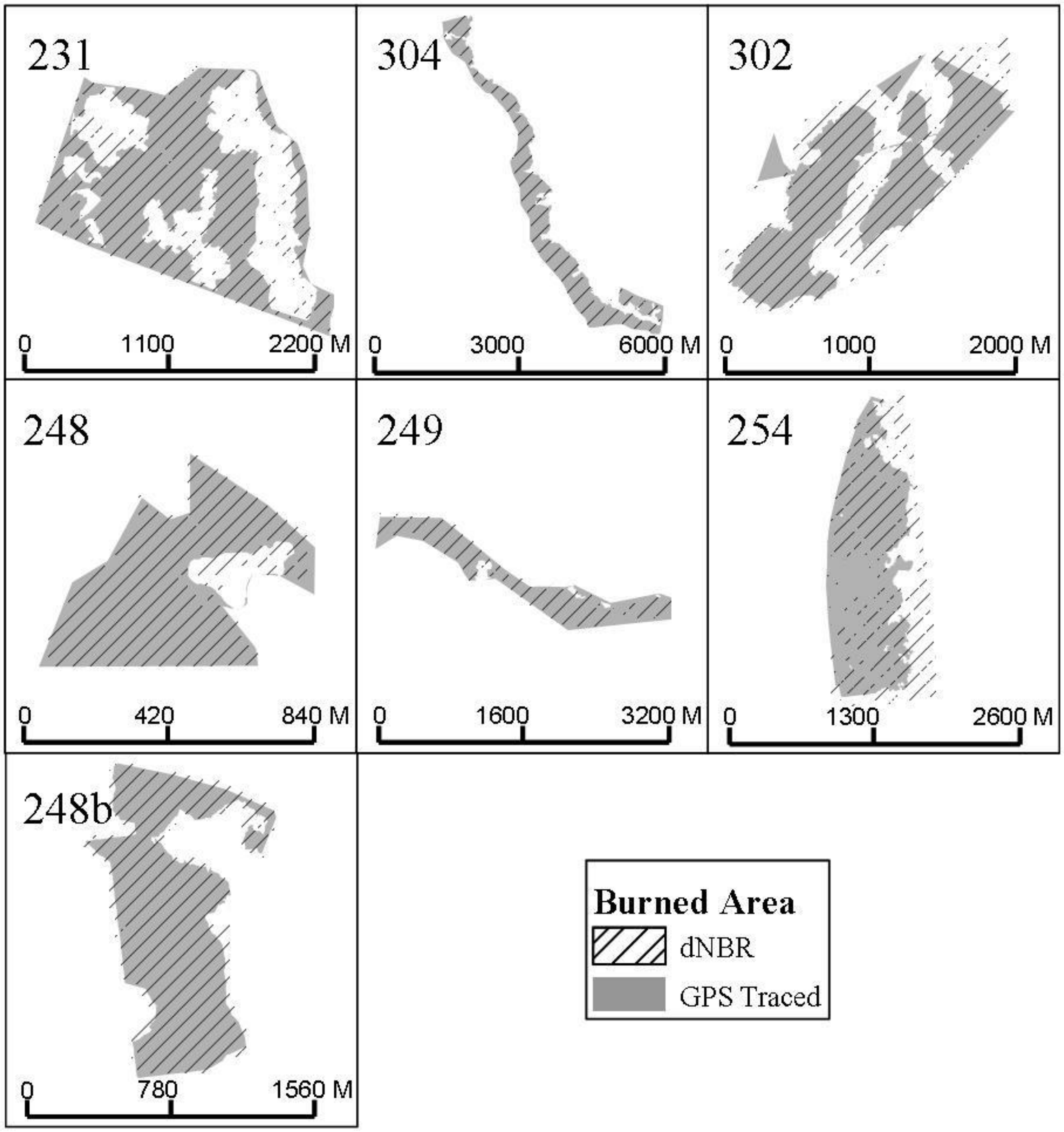


Figure 5. GPS traced and dNBR area estimates, measured in hectares, are indicated within this histogram for each of the 7 prescribed burns (burn unit numbers) monitored within this study.

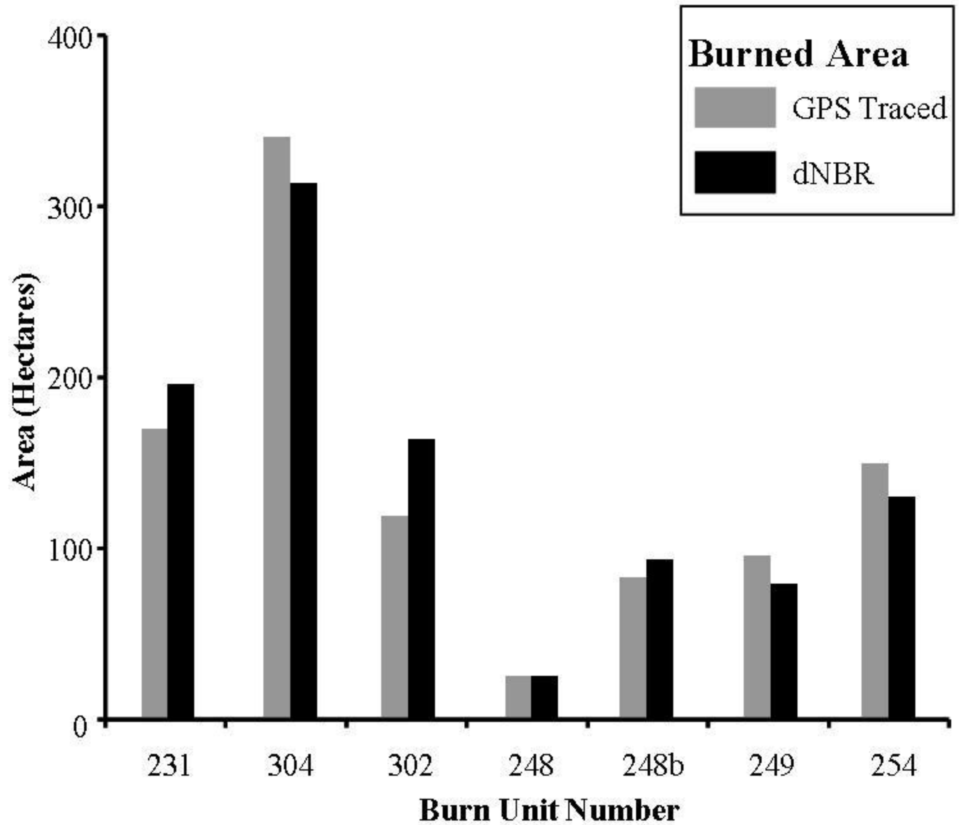


Figure 6. The average percent agreement (y-axis) between initial and subsequent dNBR estimated burned areas were plotted by categorized days since fire (x-axis) over the entire 480 day period from December 2005-March 2007 for 42 burns occurring either during the dormant versus growing seasons, community types combined. Error bars reflect the standard deviation of all percent agreement values averaged per categorized days since fire.

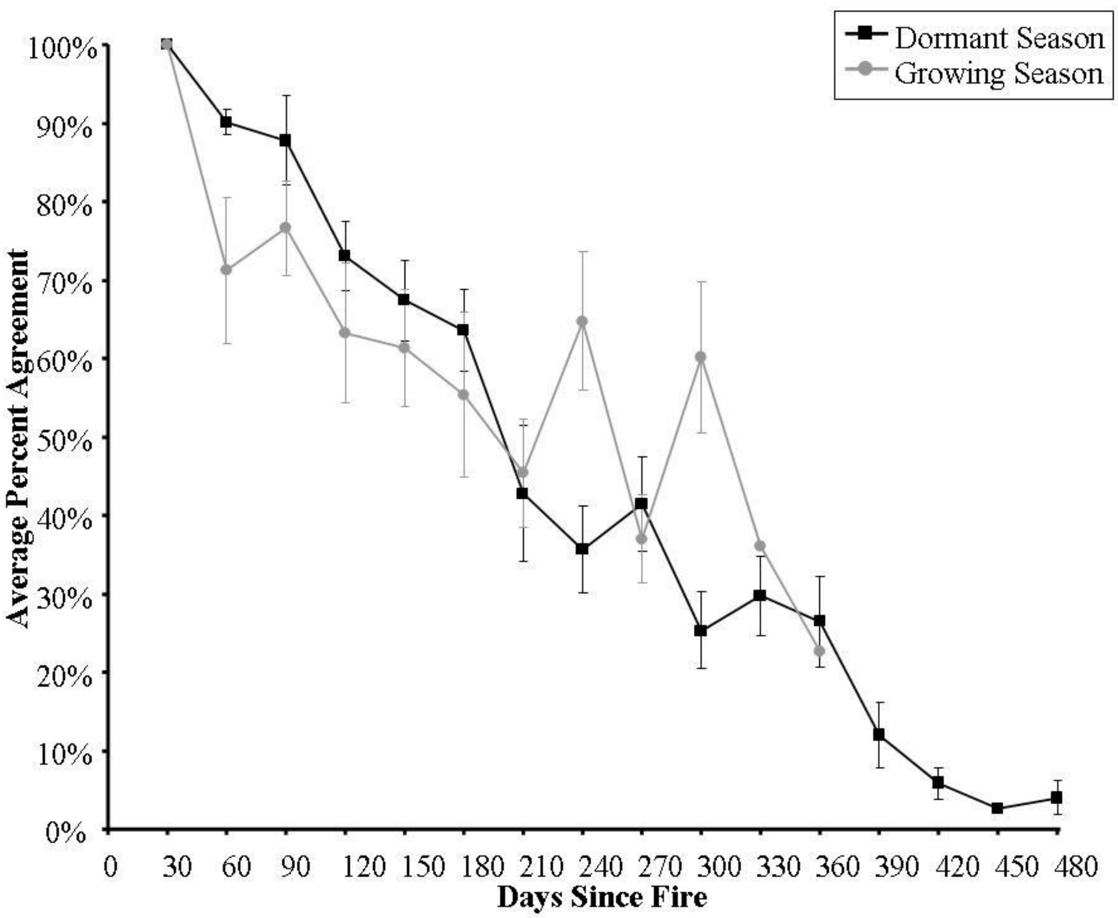


Figure 7. The average percent agreement (y-axis) between initial and subsequent dNBR estimated burned areas were plotted by categorized days since fire (x-axis) over the entire 480 day period from December 2005-March 2007 for 42 burns occurring during the dormant season within flatwoods and depression swamp community types. Error bars reflect the standard deviation of all percent agreement values averaged per categorized days since fire.

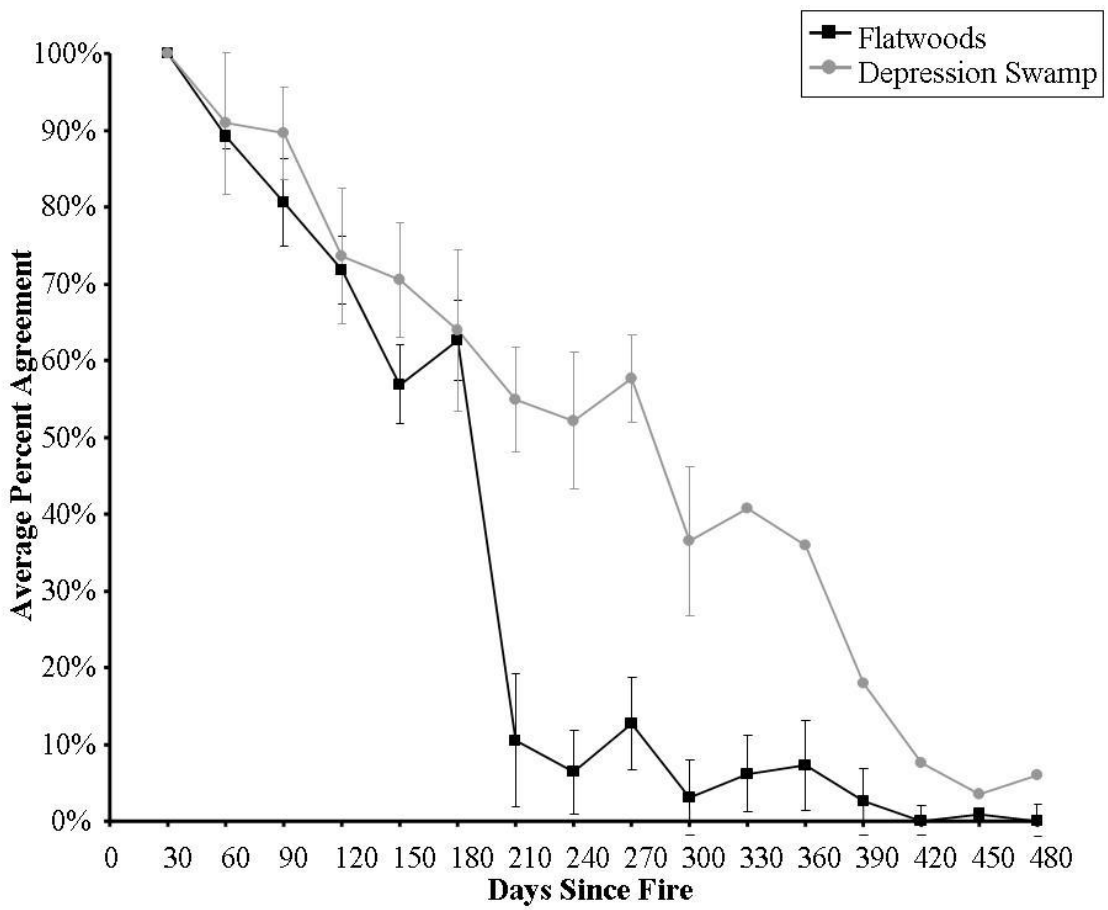


Figure 8. The monthly (1-12) probability of obtaining at least one Landsat TM image for 18/39 (path/row) are indicated within this histogram.

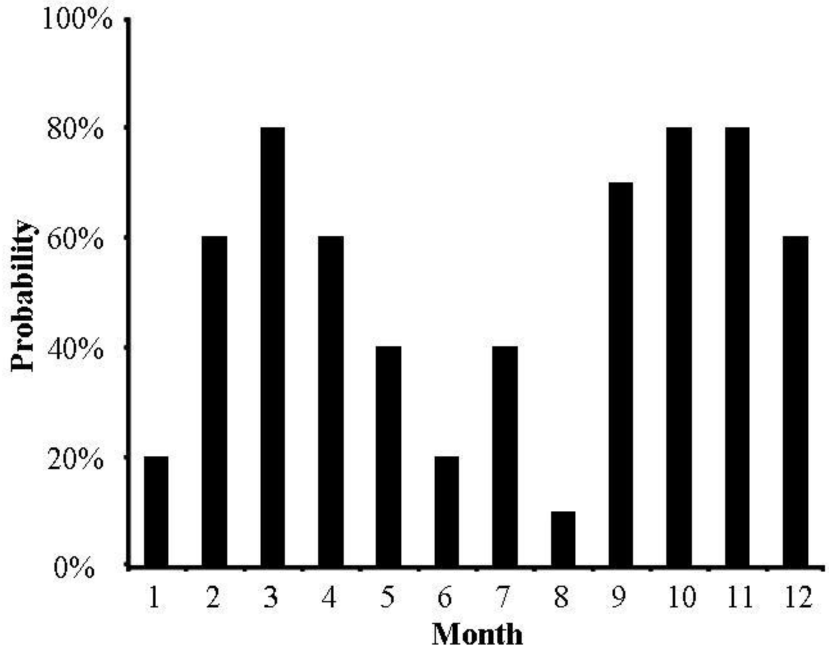


Figure 9. The monthly (1-12) probability of obtaining at least one Landsat TM image for 18/40 (path/row) are indicated within this histogram.

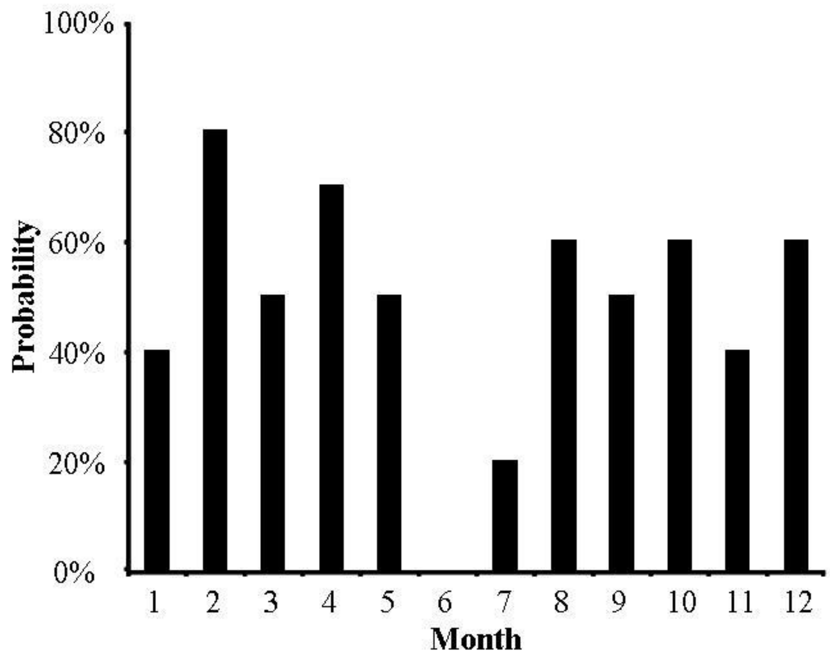
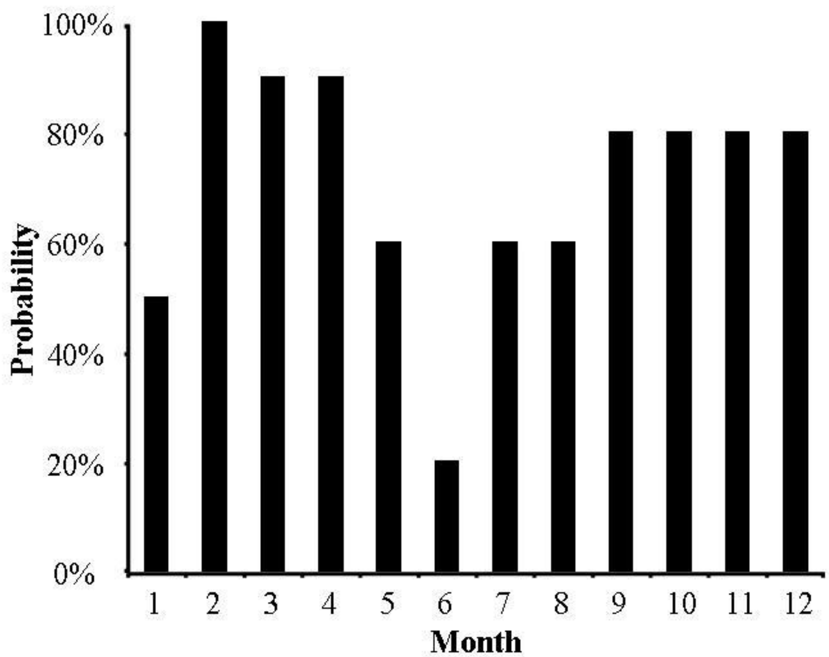


Figure 10. The combined monthly (1-12) probability for paths 18/39 and 18/40 (path/row) of obtaining at least one Landsat TM image are indicated within this histogram.



Appendix I: CBI Data Sheet

FIREMON LA Form

BURN SEVERITY -- COMPOSITE BURN INDEX (BI)

PD - Abridged	Examiners:			Fire Name:	
Registration Code		Project Code		Plot Number	
Field Date mmddyyyy	/ /	Fire Date mmyyyy	/		
Plot Aspect		Plot % Slope		UTM Zone	
Plot Diameter Overstory		UTM E plot center		GPS Datum	
Plot Diameter Understory		UTM N plot center		GPS Error (m)	
Number of Plot Photos		Plot Photo IDs			

BI – Long Form	% Burned 100 feet (30 m) diameter from center of plot =						Fuel Photo Series =		
STRATA RATING FACTORS	**BURN SEVERITY SCALE**							**FACTOR SCORES**	
	No Effect	**Low**		**Moderate**		**High**			
	0.0	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**		
A. SUBSTRATES									
% Pre-Fire Cover: Litter = Duff = Soil/Rock = Pre-Fire Depth (inches): Litter = Duff = Fuel Bed =									Σ =
Litter/Light Fuel Consumed	Unchanged	--	50% litter	--	100% litter	>80% light fuel	98% Light Fuel		
Duff	Unchanged	--	Light char	--	50% loss deep char	--	Consumed		N =
Medium Fuel, 3-8 in.	Unchanged	--	20% consumed	--	40% consumed	--	>60% loss, deep ch		
Heavy Fuel, > 8 in.	Unchanged	--	10% loss	--	25% loss, deep char	--	>40% loss, deep ch		$\bar{X}$ =
Soil & Rock Cover/Color	Unchanged	--	10% change	--	40% change	--	>80% change		
B. HERBS, LOW SHRUBS AND TREES LESS THAN 3 FEET (1 METER):									
Pre-Fire Cover = % Enhanced Growth =									Σ =
% Foliage Altered (blk-brn)	Unchanged	--	30%	--	80%	95%	100% + branch loss		
Frequency % Living	100%	--	90%	--	50%	< 20%	None		N =
Colonizers	Unchanged	--	Low	--	Moderate	High-Low	Low to None		
Spp. Comp. - Rel. Abund.	Unchanged	--	Little change	--	Moderate change	--	High change		$\bar{X}$ =
C. TALL SHRUBS AND TREES 3 to 16 FEET (1 TO 5 METERS):									
Pre-Fire Cover = % Enhanced Growth =									Σ =
% Foliage Altered (blk-brn)	0%	--	20%	--	60-90%	> 95%	Signifcnt branch loss		
Frequency % Living	100%	--	90%	--	30%	< 15%	< 1%		N =
% Change in Cover	Unchanged	--	15%	--	70%	90%	100%		
Spp. Comp. - Rel. Abund.	Unchanged	--	Little change	--	Moderate change	--	High Change		$\bar{X}$ =
D. INTERMEDIATE TREES (SUBCANOPY, POLE-SIZED TREES)									
Pre-Fire % Cover = Pre-Fire Number Living = Pre-Fire Number Dead =									Σ =
% Green (Unaltered)	100%	--	80%	--	40%	< 10%	None		
% Black (Torch)	None	--	5-20%	--	60%	> 85%	100% + branch loss		N =
% Brown (Scorch/Girdle)	None	--	5-20%	--	40-80%	< 40 or > 80%	None due to torch		
% Canopy Mortality	None	--	15%	--	60%	80%	%100		$\bar{X}$ =
Char Height	None	--	1.5 m	--	2.8 m	--	> 5 m		
Post Fire: %Girdled = %Felled = %Tree Mortality =									
E. BIG TREES (UPPER CANOPY, DOMINANT, CODOMNANT TREES)									
Pre-Fire % Cover = Pre-Fire Number Living = Pre-Fire Number Dead =									Σ =
% Green (Unaltered)	100%	--	95%	--	50%	< 10%	None		
% Black (Torch)	None	--	5-10%	--	50%	> 80%	100% + branch loss		N =
% Brown (Scorch/Girdle)	None	--	5-10%	--	30-70%	< 30 or > 70%	None due to torch		
% Canopy Mortality	None	--	10%	--	50%	70%	%100		$\bar{X}$ =
Char Height	None	--	1.8 m	--	4 m	--	> 7 m		
Post Fire: %Girdled = %Felled = %Tree Mortality =									

Community Notes/Comments:	**CBI = Sum of Scores / N Rated:**	**Sum of Scores**	**N Rated**	**CBI**
	Understory (A+B+C)			
	Overstory (D+E)			
	Total Plot (A+B+C+D+E)			

% Estimators: **20 m Plot:** 314 m^2 1% – 1x3 m 5% – 3x5 m 10% – 5x6 m
30 m Plot: 707 m^2 1% – 1x7 m (<2x4 m) 5% – 5x7 m 10% – 7x10 m

After, Key and Benson 1999, USGS NRMSC, Glacier Field Station.
Version 4.0 8 27, 2004

Strata and Factors are defined in FIREMON Landscape Assessment, Chapter2, and on accompanying BI "cheatsheet." www.fire.org/firemon/lc.htm

Appendix II: Interpretations of CBI Data Sheet Used in this Study.

Initial Assessment CBI

Strata:	**Comments:**
A. Substrates	
Litter/Light Fuel Consumed	Interpret what the effects of the burn immediately after fire to determine immediate fire effects.
Duff	
Medium Fuel, 3-8 in.	
Heavy Fuel, >8 in.	
Soil & Rock Cover/Color	
B. Herbs Low Shrubs and Trees < 1 m	
% Foliage Altered (blk-brn)	Only consider stems present during the fire, ignoring suckers or resprouts. Top-killed stems are considered dead.
Frequency % Living	
Colonizers	
Spp. Comp. - Rel. Abund.	
C. Tall Shrubs and Trees 1-5 m	Pallmettos are often in the tall shrub category.
% Foliage Altered (blk-brn)	Only consider stems present during the fire, ignoring suckers or resprouts. Top-killed stems are considered dead, including palmetto.
Frequency % Living	
% Change in Cover	
Spp. Comp. - Rel. Abund.	
D. Intermediate Trees (Canopy, Pole-Sized Trees)	
% Green (Unaltered)	New needle growth from meristems should not be included in % Green. New growth is informative as to whether needles were merely scorched or if meristems were killed for determination of % Canopy Mortality.
% Black (Torch)	
% Brown (Scorch/Girdle)	
% Canopy Mortality	Only consider plants present during the fire and with green leaves or needles.
Char Height	Distinguish fresh char from past charring.
E. Big Trees (Upper Canopy, Dominant, Codominant Trees)	
% Green (Unaltered)	Refer to Strata D explanations.
% Black (Torch)	
% Brown (Scorch/Girdle)	
% Canopy Mortality	
Char Height	

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Extended Assessment CBI

Strata:	**Comments:**
A. Substrates	
Litter/Light Fuel Consumed	Interpret differences between pre-fire and current state attributable to the fire.
Duff	
Medium Fuel, 3-8 in.	
Heavy Fuel, >8 in.	
Soil & Rock Cover/Color	
B. Herbs Low Shrubs and Trees < 1 m	
% Foliage Altered (blk-brn)	Interpret difference between pre-fire and current state attributable to the fire.
Frequency % Living	Consider genetic individuals to be alive if resprouts occur within 0.5 m of the base of the dead stems.
Colonizers	Suckers are defined as new stems that are > 0.5 m from the dead stems. If suckers are present, then consider as colonizers.
Spp. Comp. - Rel. Abund.	Consider genetic individuals rather than abundance of foliage.
C. Tall Shrubs and Trees 1-5 m	Pallmettos are often in the tall shrub category.
% Foliage Altered (blk-brn)	Interpret difference between pre-fire and current state attributable to the fire.
Frequency % Living	Count top-killed tall shrubs as dead unless the respouting shrubs are projected to have approximately the same height and stem diameter within two years.
% Change in Cover	Consider Foliage, not % Living
Spp. Comp. - Rel. Abund.	Consider genetic individuals rather than abundance of foliage.
D. Intermediate Trees (Canopy, Pole-Sized Trees)	
% Green (Unaltered)	Interpret changes from pre-fire to current state attributable to the fire.
% Black (Torch)	
% Brown (Scorch/Girdle)	
% Canopy Mortality	
Char Height	
E. Big Trees (Upper Canopy, Dominant, Codominant Trees)	
% Green (Unaltered)	Refer to Strata D explanations.
% Black (Torch)	
% Brown (Scorch/Girdle)	
% Canopy Mortality	
Char Height	