MAPPING FOREST HURRICANE DAMAGE USING AUTOMATED FEATURE EXTRACTION

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ABSTRACT

In September of 2003 Hurricane Isabel, a category 2 storm, hit Petersburg National Battlefield (PNB). With wind gusts of 90 mph and soaking rains, the remnants of this storm leveled stands of hardwood and coniferous trees in PNB and the surrounding areas. In order to reduce wildfire threats and to focus the timber removal efforts, a map of the downed woody debris was required. This map and subsequent removal plan was especially necessary at PNB because the park is located in a heavily populated wildland urban interface and is visited by thousands of visitors each year. Using digital aerial photography flown in March of 2004, affected forest stands were mapped with VLS's Feature Analyst, an object oriented classifier. This study demonstrates that object-oriented classification procedures that can be used to produce timely and accurate maps of downed trees and related damage to assist with wildfire planning and management.

KEYWORDS. Automated feature extraction**,** object-oriented classification, landscape altering events, fire fuel mapping, wildland urban interface.

INTRODUCTION

In the past one hundred years, over 120 hurricanes have struck the US between Texas and Virginia (Wade et al., 1993). Numerous studies have focused on the vegetation effects of large scale wind events such as hurricanes (Brokaw and Walker, 1991; Foster and Boose, 1992; Merrens and Peart, 1992). Furthermore, studies examining relationships between landscape position and wind damage (Boutet and Weishampel, 2003; Foster and Boose, 1992; Kulakowski and Veblen, 2002) have also occurred. In addition to immediate forest damage, wind events can also lead to dramatic longer term effects such as changes in susceptibility to insect and disease infestations (Greenberg and McNab, 1997). Coarse woody debris (woody debris greater than 3 inches) is a vital natural part of the ecosystem; however a dramatic increase resulting from a hurricane can alter the existing

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vegetation, introduce invasive species, and set the stage for a wildfire (Brown et al., 2003).

Petersburg National Battlefield (PNB) is located in the Wildland Urban Interface (WUI) and as a result the large hurricane related increases in downed woody debris raise the potential for catastrophic wildfire in PNB. When wildfires do occur in the WUI, they can have costly and deadly consequences. While most reported wildfires occurring in the WUI happen in the western United States; the eastern United States is susceptible to them especially in the early spring and late fall. The vast majority (98% in 2005, National Interagency Fire Center, 2006) of wildfires in the eastern United States are caused by humans either by accident, e.g. escaped debris burning or on purpose, e.g. arson. In 2001, over 178,000 acres burned across Kentucky, most of those fires were started by humans (Kentucky Division of Forestry, 2006) in areas classified as the WUI (University of Wisconsin, 2006). In Tennessee in 2004, 76 structures were destroyed by wildfire (Tennessee Department of Agriculture, 2006). From 1995 to 2005, on average, there were 3,881 fire starts in Florida, burning 185,000 acres yearly (Florida Department of Agriculture and Consumer Services, 2006). In 1947 "the year Maine burned," statewide, more than 200,000 acres burned and over 1,000 structures were destroyed (National Park Service, 2006).

Disturbances like hurricanes and ice storms damage or destroy billions of dollars worth of timber (Jacobs, 2000; Bragg et al., 2003). After an event immediate attention is required to identify damaged areas and then reducing wildfire risks (Saveland and Wade, 1991). Next, developing a best management practice for salvage operation and dealing with various legal issues is required; all the while the reduction of annual harvestable timber and its economic ramifications has to be addressed (Holmes, 1991).

Numerous remote sensing techniques have been utilized in the management of forests ranging from large area stand characteristic mapping (Sanborn, 2004) and small area tree species identification (Hajek, 2005). These techniques have been used to assist with damage classifications from storm events similar to the hurricane situation at PNB. Following Hurricane Hugo, an aerial survey guided the salvage operations and wildfire mitigation plans on the Francis Marion National Forest in South Carolina (Sheffield and Thompson, 1992). However no automated remote sensing techniques were used to identify or quantify areas of downed timber in this effort. On the Francis Marion, millions of dollars and thousands of man hours were devoted to the removal of woody debris and the creation of fire breaks, but all aerial interpretations were done manually (Saveland and Wade, 1991). Following a Mississippi ice storm, damaged forest areas were surveyed with an aerial video camera. Still images from this video were geo-referenced using available GIS data to determine the extent and severity of damage (Jacobs, 1994). This data was used by land managers to develop suppression and pre-suppression plans in the event of a wildfire and develop a plan for salvaging timber.

After a devastating storm in 1999 several European studies used various remote sensing techniques to map areas of forest damage. Dwyer et al. (2000) published a classification of windthrown forests in France using pre and post event images from the European

Remote Sensing Satellite. The image pairs were effective in differentiating between damaged and undamaged forest. Fransson et al., (2002) effectively utilized CARABAS-II VHF SAR to record backscatter from the radar to map areas of downed trees and estimate the volume of damaged timber in Sweden. Jackson et al. (2000) utilized an Aerial Thematic Mapper to record windthrown canopy gaps of the Cwm Berwyn Forest in central Wales, with a resulting accuracy of 93.8 percent. Schwarz et al. (2003) compared available remote sensing imagery and analysis methods to determine which combination of data image platform source (Spot-4 or Ikonos) and analysis method (per-pixel or object-oriented) was better suited to indicate forest windthrown areas across large areas of Switzerland. The object-oriented classification resulted in a slightly higher accuracy than the per-pixel methods in both image types.

The objective of our study was to map the areas of downed woody debris at PNB, facilitating the creation of updated vegetation and fire fuel load datasets. No studies were found that focused on updating techniques for these geospatial datasets after a landscape altering event had occurred. In addition no literature was found that reports on the use of an automated feature extraction technique to map areas of forest damage.

METHODS

Petersburg National Battlefield is located in and around Petersburg, VA which is 25 miles south of Richmond, VA (Figure 1). PNB is not a contiguous park, but consists of four areas: Five Forks, City Point, Eastern Front and the Western Front. Current vegetation in PNB consists of managed grasslands, deciduous forests, coniferous forests, mixed hardwood/pine forests, and abandoned pine plantations. PNB's forest makeup consists of various hardwood species, such as American beech (*Fagus grandifolia*), northern red oak, (*Quercus rubra*), yellow poplar (*Liriodendron tulipifera*), red maple (*Acer rubrum*), and yellow birch (*Betula alleghaniensis*) and pine species including loblolly (*Pinus taeda*) and Virginia pine (*Pinus virginiana*).

Hurricane Isabel passed over PNB during the early morning hours of September 19, 2003. The Eastern Front section of PNB suffered major damage, as did several Western Front sections, but the Five Forks and City Point regions of PNB suffered only minimal damage and therefore were not included in this study.

True color (TC) and color infrared (CIR) digital aerial photography were captured on March 13, 2004, mosaiced and orthorectified by SkyComp Inc. of Columbia, MD. These files were delivered to North Carolina State University's Center for Earth Observation in the summer of 2004. Upon initial visual inspection of the aerial photography, areas of downed woody debris were easily identified. The ground resolution of the digital aerial photomosaics was one-half meter per pixel making individual trees discernable (Figure 2). Manual delineation of the forest damage areas presented a lengthy and costly alternative. Thus, an automated approach to classifying the areas of downed woody debris was desired. Initial attempts utilizing traditional per-pixel spectral analyses using both supervised and unsupervised classifications with Leica's ERDAS Imagine 8.7 resulted in many obviously apparent miss-classifications. Visual inspection of the

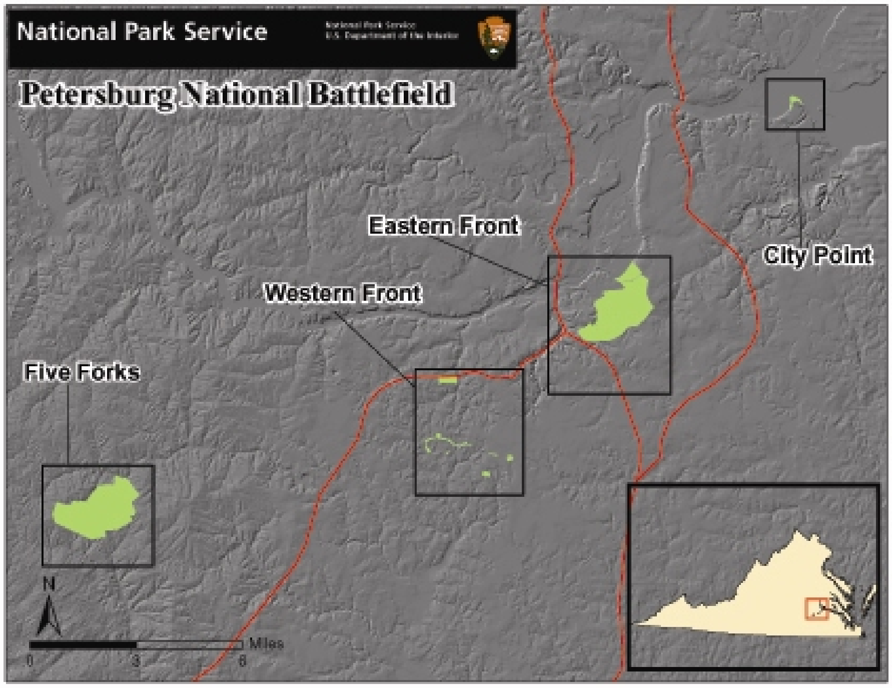

Figure 1. Location of Petersburg National Battlefield.

resulting classifications showed consistent spectral confusion between areas of dead herbaceous matter (grassfield) and areas of downed woody debris. A Normalized Difference Vegetation Index classification of the image was also performed, but the results were poor as there was little green vegetation upon which the index could take place. It was apparent that per-pixel spectral analyses could not be used to identify areas of downed woody debris.

While the capability, availability and resolution of remotely sensed data has increased over the decades, classification procedures still rely heavily on 1970's per-pixel methods (Blaschke and Strobl, 2001). Many issues related to the delineation of features and positional accuracies have been solved, but some issues remain, such as the occurrence of a mixed pixel or "mixel." A mixel refers to a pixel which contains multiple classification classes (road, grass, and forest). Merely increasing the spatial resolution of an image does not solve this problem; it just creates new mixed pixels (Blaschke et al., 2000).

With downed trees easily discernable on the aerial photography, a classification technique that capitalized on the visibility of those objects was desired. Two software programs were identified while looking for such a system, Definiens Imaging's eCognition (Definiens, 2004) and Visual Learning System's (VLS) Feature Analyst (Visual Learning Systems, 2006). eCognition approaches automated feature extraction using image segmentation, where an image is broken or segmented into units of similar spectral and spatial patterns. This process is repeated at several scales beginning with a single pixel. Groups of homogeneous pixels are then merged together to form a series of segmented areas across an entire image. In contrast, Feature Analyst uses a hierarchical approach to automated feature extraction. This technique uses manual interventions which build hierarchical rules for object recognition on iterative automated interpretations of several training sites within the image. Feature Analyst was considerably cheaper to purchase than eCognition and appeared to be capable of producing acceptable results and was therefore chosen for this study. Feature Analyst 3.5 was used as an extension to ESRI's ArcGIS ArcMap 9.0, where downed individual trees and areas were the target delineations.

Figure 2. Downed woody debris found at Petersburg National Battlefield.

At the outset, polygon training sites containing visible downed trees were digitized. The training sites included several examples of the different types of downed woody debris found at PNB, from single tree boles and associated root-balls to the bole and crown of a downed tree. Each polygon digitized consisted of at least 20 pixels. Next, Feature Analyst was instructed how to look for downed trees, by setting up a number of user-defined parameters (see Shedd, 2006, for a detailed list of the user defined parameters). The Foveal pattern recognizer, (filter controlling how Feature Analyst analyzes an image) was found by experimentation to provide better classification results for the initial identification. The Foveal classifier analyzes an image by regions, with the center of the search window very detailed with feature similarity restriction decreasing as distance from the center increases.

In subsequent iterations, when a more precise classification was desired, the Bull's Eye pattern recognizer, specifically Bull's Eye 1 and Bull's Eye 4, provided more accurate classifications (Figure 3). These filters were designed to indicate linear features such as roads and rivers. After each iteration, a few areas of the "best" classification were manually identified through visual inspection (i.e. areas that best captured the distribution of damaged and undamaged areas) and the process repeated until a satisfactory training site classification was accomplished. This hierarchical procedure allowed Feature Analyst to adjust and learn what spatial and spectral patterns to look for in subsequent iterations. For all sections of PNB exhibiting downed woody debris, this trial and error iterative process, validated by visual interpretation, was repeated until an acceptable classification was reached.

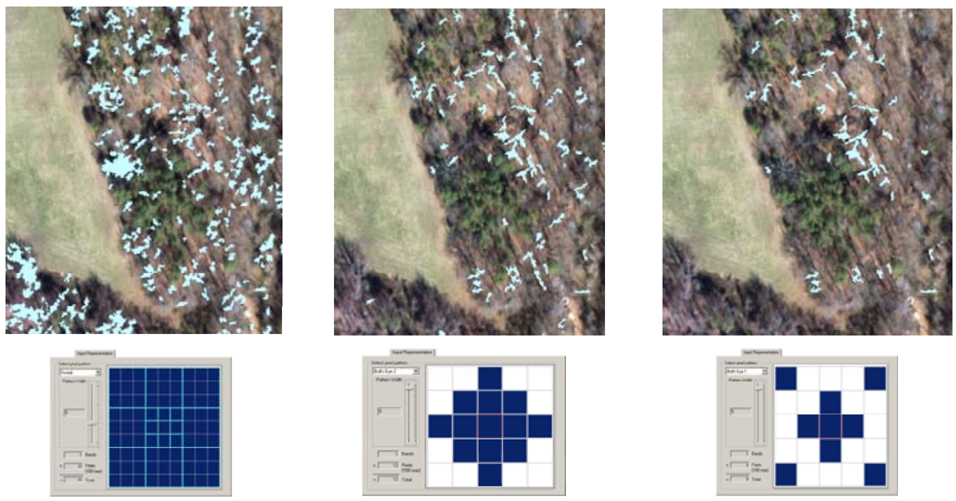

Figure 3. Foveal, Bulls Eye 2 and 4 Pattern Recognizers used with resulting classification.

For this study, TC was selected for use as investigations of downed trees of the Fort Gregg area (portion of Western Front) of PNB indicated that TC imagery consistently provided more accurate results through all iterations when compared to the mapping results based on the CIR imagery. This conclusion was verified through visual inspection of the images and associated mapped areas.

For the Eastern Front section of PNB, two sets of training sites were created, one for deciduous trees and another for coniferous trees. (Coniferous trees are smaller in size and typically black in color while deciduous trees are larger and either white or brown in color). The separate training site shapefiles representing the different species of the downed woody debris sharpened the Feature Analyst classification and thus reduced the number of iterations needed to achieve an acceptable classification. An accurate classification of coniferous downed woody debris was reached in four iterations, and only three iterations were needed for deciduous downed woody debris. These classifications were then merged together, using the “combine features” tool, forming the final classification of downed woody debris for the Eastern Front of PNB.

Once accurate automated classifications for all affected areas of PNB were reached, the results were merged into one data layer. Confusion still existed in areas where shadows of tree branches or the tree branches themselves overlaid homogeneous areas (fields), creating a spatial pattern similar to downed woody debris. A manual edit of areas not containing downed woody debris reduced the number of polygons from 14,256 to 7,726.

RESULTS

Feature Analyst excelled in its ability to identify areas of downed woody debris (Figure 4). Forty accuracy assessment ground truth points (20 damaged and 20 non-damaged points) were used to validate the mapping results. All of the points labeled damaged had coarse downed woody debris within three meters of the predetermined point. Of the points labeled non-damaged, 16 of the 20 points did not have any downed woody debris within three meters, resulting an overall accuracy of 90% (Table 1).

Figure 4. Example of downed woody debris identified by Feature Analyst.

To aid in the creation of fire-related GIS data layers, fuel load measurements were collected following Brown's Transects and Burgan-Rothermel Ocular Estimations (Brown, 1974; Burgan and Rothermel, 1984) in areas identified by Feature Analyst as having downed woody debris. At these plots, 1-, 10-, 100-, and 1,000-hour downed woody debris were measured and visual estimations of the vegetation characteristics (grass, shrub and tree) were made. The hour classification represents the time required for a fuel's moisture content to reach equilibrium (with current atmospheric conditions) and is determined by the fuel's diameter. One-Hour fuels measure less than 0.25 inches in diameter, 10-Hour Fuels are 0.25 to 1 inch in diameter, 100-Hour fuels are 1 to 3 inches in diameter and 1000-Hour fuels account for any downed woody debris over 3 inches in diameter (Burgan and Rothermel, 1984; Brown, 1974; Anderson, 1982).

Table 1. Error matrix of Feature Analyst mapped areas.

		Reference				
Classification		Damage	No Damage	Total	Commission Error	User's Accuracy
	Damage	20	0	20	0	100
	No Damage	4	16	20	4	80
	Total	24	16	**40**		
	Omission Error	4	0			
	Producer's Accuracy	83	100			***Overall 90***

Twenty four plot measurements were taken throughout PNB. The average tons per acre for the hour fuels were as follows; 1-Hour fuels equaling 0.135, 10-Hour fuels equaling 3.115, 100-Hour fuels equaling 3.03, and the average total tons per acre calculated was 47.83. These numbers represent a dramatic increase in the amount of downed woody debris, both in the fine and coarse woody debris classes recorded before the hurricane (Smith, 2003). In Smith's study the following measurements were recorded, the average 1-Hour fuel load equaling 0.084, the average 10-Hour fuel load equaling 0.23, the average 100-Hour fuel load equaling 0.61, and the average total tons per acre equaling 3.34.

DISCUSSION

While the initial objective of this study was to update the fire fuel model maps for PNB, the resource management division of PNB uses the Feature Analyst mapping classification daily, in their efforts to remove timber and to conduct archaeological digs in areas where the uprooted rootball of a tree has displaced large amounts of soil. In this study, the downed woody debris of PNB could not be classified based on per-pixel spectral values alone. Only by classifying the spatial patterns of downed woody debris were downed trees mapped. Using Feature Analyst to accurately classify an image based on spatial relationships was time consuming, primarily depending on the size of the image. However, the ease with which Feature Analyst operated, negated the need for the significant technical expertise required for traditional automated classification techniques, reducing the overall time and cost of the project. However Feature Analyst and other hierarchical object identification procedures are not without drawbacks. Desired classifications are often reached only after extensive trial and error, which can be time consuming. Furthermore, object-oriented classification may require the interpreter to be familiar with the geographic area or object of interest prior to completing a classification. Acquiring leaf-off photography was crucial for this study; as identifying downed woody debris occurring in deciduous forests was successful, whereas Feature Analyst was not as successful in coniferous forests. This was partially attributed to Feature Analyst's inability to see beneath the forest canopy cover.

CONCLUSIONS

Despite the misclassification of conifer dominated areas, the use of Feature Analyst led to a time-efficient and accurate classification of downed woody debris. The Feature Analyst mapping results allowed land managers to allocate their limited funds to damaged areas that posed the most risk to the surrounding communities, reducing the time and cost of field operations. If multi-temporal imagery is available, a surrogate to mapping downed woody debris might be mapping canopy gaps. A change analysis could indicate gaps created as a result of downed trees, and inferences could be made about the number of downed trees, from the size of the canopy gap. LIDAR data could be used to create a surface map of the tree canopy, with holes in the canopy indicating canopy gaps. Furthermore, future studies using object-oriented classification to estimate the volume of timber by mapping individual tree crowns and estimating the volume of merchantable timber lost due to a natural disaster could be explored.

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