

Integrating Landsat-Derived Disturbance Maps with FIA Inventory Data: Applications for State-Level Forest Resource Assessments

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Abstract: *Landsat images have been widely used for assessing forest characteristics and dynamics. Recently, significant progress has been made towards indepth exploration of the rich Landsat archive kept by the U.S. Geological Survey to improve our understanding of forest disturbance and recovery processes. In this study, we used Landsat images to map forest disturbances at biennial intervals from 1984 to 2007 for the State of Mississippi. Forest Inventory and Analysis plot data were used to characterize and validate the mapped disturbances. These products were used to produce multi-county forest assessments, which were compared with those derived from inventory data. We conducted our study, in part, to support a larger conterminous U.S.-level LANDFIRE effort.*

Keywords: Disturbance, FIA, LANDFIRE, Landsat, Mississippi.

Introduction

Foresters have long combined remotely sensed data, such as aerial photography, with field-collected data to aid in estimating population means and totals, develop regression equations, and study forest characteristics over varying spatial scales. Remotely sensed data provide a low-cost means for evaluating large areas when compared with increasing costs of plot-based surveys. This is particularly true now that the U.S. Geological Survey has begun providing free user access to historical Landsat data via the Internet.

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The Landsat program has been in operation since 1972, and imagery from the program has been used for multiple purposes in the fields of forestry, geology, agriculture, and even sociology, among others. The number of scientific articles referencing the Landsat program and its data exceeds 3,200, according to NASA (NASA <http://landsat.gsfc.nasa.gov/about/appl.html>). This unique time-series imagery, coupled with increasingly sophisticated imagery analysis software, provides scientists with a wide array of information related to vegetation change over time, which previously was possible only through the collection of field data (Cohen and Goward 2004).

The USDA Forest Service, Forest Inventory and Analysis (FIA) program has been collecting data in the field since the mid-1930s. Data collected by FIA includes plot and tree characteristics that may be used to evaluate changes in vegetation characteristics, including data specifically related to plot-level and tree-level disturbances. Field crews attempt to revisit the same plots through time so that trend analysis is possible. While some changes to the FIA plot design have occurred, and some changes in plot locations have been unavoidable, the FIA program still provides one of the best records of field-collected forest inventory data, worldwide.

In this study, we used Landsat images to map forest disturbances at biennial intervals from 1984 to 2007 in the State of Mississippi. FIA plot data were used to characterize and validate the mapped disturbances in a five-county area for disturbance year 2006. These products were used to produce multi-county forest assessments, which were compared with those derived from inventory data. We conducted our study in part to support a larger, conterminous U.S.-level LANDFIRE effort.

Methods

Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) images constituting a nominal temporal interval of 2 years per acquisition were used to map forest disturbances using the vegetation change tracker (VCT) method (Huang and others in press). The VCT process creates two attributes per detected disturbance: disturbance year and disturbance magnitude. For our study's purposes, we focused solely on disturbance year. Disturbance year was defined by the acquisition year of the earliest available Landsat image acquired after the disturbance. For each acquisition year, the VCT algorithm creates a map consisting of 7 categories: 0 = background (nonsampled); 1 = persisting nonforest (nonforest); 2 = persisting forest (forest); 4 = persisting water; 5 = previously disturbed (forest); 6 = current disturbed (nonforest); 7 = prior disturbance (nonforest). In this study, the map acquisition year assessed was 2006.

Five counties were selected for analysis based on the availability of 2006 Landsat thematic imagery for counties in southern Mississippi and those analyses

were based on a prior knowledge of disturbances that occurred in 2005 as a result of Hurricane Katrina. The five counties considered were Hancock, Pearl River, Lamar, Marion, and Forrest Counties along the Mississippi River (figure 1).

Output from the VCT from 2006 was converted from ENVI format to ESRI GRID format then tiled using tools in ArcMap™ Version 9.2. The raster mosaic was then clipped by the five-county polygon layer using Hawth's Tools. We imported Forest Service FIA plots into ArcMap™ and projected them to match the raster mosaic. Forest Inventory plots were located using actual (not fuzzed and swapped) latitudes and longitudes. Hawth's Analysis Tools 3.2 was used to assign a raster category to each forest inventory plot. We then exported FIA plot data and the corresponding disturbance category into comma-delimited files and imported them into SAS® (version 8) for summarization with additional FIA characteristics (e.g. condition and tree records on each plot).

We examined the agreement between FIA field-based classification and the Landsat-based classification using a standard confusion matrix (a tabulation of agreement and disagreement). For this assessment, four categories were considered: forest (VCT categories 2 and 5), nonforest (VCT categories 1, 6, and 7), water (VCT category 4), and nonsampled. In addition to examining agreement,

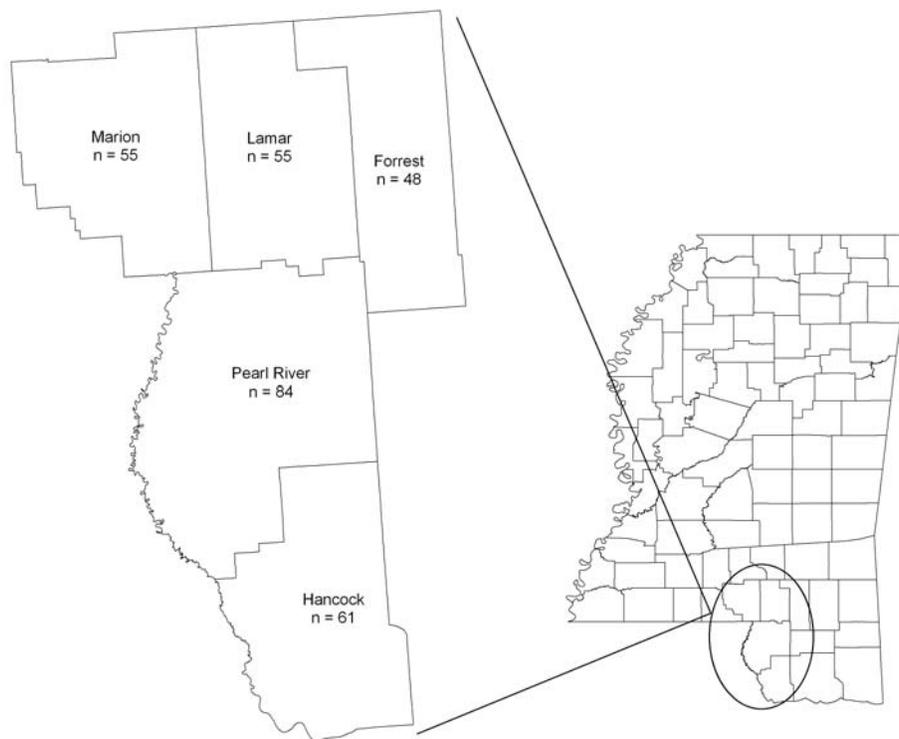


Figure 1: Five-county study area in Mississippi with number of sample plots and county name.

commission errors, and omission errors, we also performed a Kappa analysis. Kappa analysis is a multivariate technique that takes into account both diagonal and off-diagonal elements of the confusion matrix and provides an index of the agreement improvement between the classified image and reference data over that obtained by chance (Congalton and Mead 1983).

We also examined forested plots within each disturbance category for differences in forest structure. The disturbance categories used were persisting forest, post disturbance, and current year (2006) disturbance (categories 2, 5, and 6). Generally, we would expect tree density to be higher in post-disturbance forest and lowest in current year. We used mixed models analysis of variance and least square means to test the null hypothesis of no difference in the average number of trees per acre among VCT disturbance categories, controlling for diameter class, and to test the null hypothesis of no differences in average trees per acre by hardwood and softwood among disturbance categories.

Traditional FIA protocols for recording condition-level disturbances specify minimum impacted areas of at least 1 acre, and mortality and/or damage to at least 25 percent of all trees in a stand or 50 percent of an individual species' count (U.S. Department of Agriculture 2005). The Southern Research Station FIA program added regional protocols for collecting wind-related damage on plots in Mississippi following Hurricane Katrina in 2005 (U.S. Department of Agriculture 2005). The wind damage protocols do specify a minimum area of impact or minimum number of trees. Therefore, if any tree in any condition has been damaged, that condition receives a designation of damaged. Additional variables allow cruisers to indicate the degree of damage that occurred to each tree. We also compared plot level disturbance rates with the VCT-derived disturbance categories.

Results and Discussion

Forest-Nonforest Classification Agreement

We evaluated the agreement of 300 FIA plots in five counties with VCT classification in four categories: forest, nonforest, water, and nonsampled. The overall agreement across categories was 62.7 percent (table 1). With respect to the forest category, 91.9 percent of the pixels classified as forest by VCT also were identified as forest based on the FIA plots. However, the VCT classification had an omission error of 43.7 percent for the forest category. Based on the confusion matrix, 97 plots identified as forest by FIA were classified as nonforest based on the VCT classification. This led to a relatively high commission error rate for the nonforest category (63.3 percent). Disagreements between forest and nonforest classification led to a moderately low Kappa (Khat) value of 31.5. However, about 80 percent of the commission errors likely are due to differences in the definition of forest between FIA and the VCT algorithm (table 1).

Table 1: Forest Inventory and Analysis versus vegetation change tracker forest/nonforest confusion matrix with Khat value

Field-based classification	Vegetation change tracker classification					Agreement	Commission error
	Forest	Nonforest	Water	Non-sampled	Total		
Forest	125	97			222	56.3	43.7
Nonforest	10	58			68	85.3	14.7
Water		2	5	1	8	62.5	37.5
Nonsampled	1	1			2	0.0	100.0
Total	136	158	5	1	300		
Agreement	91.9%	36.7%	1	0	Overall agreement	62.7	
Omission error	8.1%	63.3%	0	1	Khat	31.5	

The national FIA program defines forest land as “land at least 10 percent stocked with forest trees of any size, or formerly having had such tree cover, and not currently developed for nonforest use,” (Bechtold and Patterson 2005). Although the area studied is not a naturally sparse forest ecosystem, regenerating forests typically have sparse canopy cover during the first years following disturbance. VCT does not use a specific definition of forest, but it likely maps young, regenerating forest land as post-disturbance nonforest (class 7), even though it meets the FIA definition of forest land and is classified as forest in the FIA database. Remaining commission errors may be attributable to the effects of forest edges on the VCT sample. Because VCT uses tens of images to produce disturbance maps, forest edges are more likely to be classified as nonforest due to residual registration errors in the satellite images.

Characteristics of Landsat Categories based on FIA Plot Data

The average density of trees (trees per acre) was similar among all VCT categories when diameter class was controlled ($p = 0.27$), and there were no notable interactions between diameter and VCT category ($p = 0.37$). Hardwood trees had the highest density among all classifications in the five-county area studied ($p = 0.0083$). When species group was controlled, trees per acre did not differ among VCT category ($p = 0.9$).

Average per-acre basal area was similar between persisting forest and post-disturbance forest classifications ($p = 0.99$). Average per-acre basal area was also similar between the persisting nonforest and nonforest disturbed in the year of measurement ($p = 0.99$). Persisting forest basal area (mean = 90.4) was higher than post-disturbance nonforest ($p = 0.006$; mean = 61.9). Post-disturbance forest basal area (mean = 87.0) was also higher than post-disturbance nonforest ($p = 0.03$). Category 7 post-disturbance nonforest was least like any of the groups, with the lowest average per-acre basal area. Category 6 post-disturbance

nonforest, though not significantly different from the other categories, had the next lowest average per-acre basal area.

Recorded Hurricane Katrina Disturbances

Ninety percent of FIA plots classified as persisting forest had experienced wind damage from Hurricane Katrina in 2005. Ninety-one percent of FIA plots classified as post-disturbance forest had experienced damage from Hurricane Katrina.

Although most plots showed some degree of damage, the proportion of trees on FIA plots that received damage was low, as shown in previous studies (Oswalt and Oswalt 2008). The proportion of trees damaged on plots was similar across all Landsat classifications. Sixteen percent of trees on plots classified as persisting forest had recorded damage, and 22 percent of trees on plots classified as post-disturbance forest were recorded as having had damage, while 20 percent of trees on plots classified as either post-disturbance nonforest or persisting nonforest were recorded as damaged.

Traditional FIA Disturbance Variables

Major disturbances were recorded on 125 of 222 forested FIA plots in the five-county area we studied. VCT detected about 58 percent of the disturbances noted by FIA cruisers (table 2). Weather-related events accounted for 36 percent of the disturbances noted. The majority (89 percent) of those weather events were wind-related, presumably a result of Hurricane Katrina. Sixty percent of FIA plots classified by VCT as persisting forest experienced major disturbances (primarily weather-related, but some fire and disease damage was recorded, as well). Forty-seven percent of plots classified as post-disturbance forest experienced major disturbance, while 49 percent of plots classified as post-disturbance nonforest and 12 percent of plots classified as persisting nonforest experienced major disturbances.

Table 2: Forest Inventory and Analysis versus vegetation change tracker disturbance confusion matrix with Khat value

Field-based classification	Vegetation change tracker classification			Agreement	Commission error
	No disturbance	Disturbance	Total		
Disturbance	52	73	125	58.4	41.6
No disturbance	38	59	97	39.2	60.8
Total	90	132	222		
Agreement	42.2%	55.3%	Overall agreement	50.0	
Omission error	57.8%	44.7%	Khat	-2.4	

Conclusions

Landsat TM images analyzed using VCT algorithms require further study before they will be useful to the FIA program in a production mode. Several things preclude the ability to incorporate the VCT data into typical FIA outlets at this time. First, the file storage space and processor memory required to join and analyze FIA data in the spatial context of the imagery is larger than many laptops or standard personal computer towers may be able to handle without overloading systems and causing delays, particularly if users attempt to study State-level or larger areas. For example, analyses repeatedly caused system errors while conducting this study using a USDA Forest Service Lenovo model T7400 laptop equipped with an Intel®Core™2 processor, 100GB hard drive, and 2GB of random access memory running on Windows XP Service Pack 2. Landsat VCT images were stored remotely on an external 250GB hard drive. To avoid system errors, we chose to subset the State-level datasets to a more manageable five-county area.

A second potential challenge to using the VCT product in FIA production reports is the learning curve necessary to understand the imagery, merge the imagery with FIA data, and analyze the two datasets simultaneously. Many of the computer programs used to analyze remotely sensed data (e.g. ERDAS, ENVI, ARCGIS) require advanced knowledge of the software that extend beyond the expertise of scientists who do not work with geospatial data on a daily basis. As a result, the process of learning the programs while concurrently learning the product capabilities takes a long time, something that is not suitable for reports that require a quick turnaround.

More work will also be necessary to study the agreement rates between FIA field data and the VCT algorithms. In our study, images analyzed using VCT algorithms detected a little over one-half of the disturbances recorded by cruisers on FIA plots. Some of the disagreement between the image detection and the FIA field call probably can be explained by further examination of change magnitude maps in the context of FIA definitions of disturbance. For example, the VCT algorithm does a better job of detecting stand-clearing disturbances than relatively minor disturbances. Therefore, some disturbances that result in minor defoliation or crown dieback on a large enough scale to meet the FIA definition of disturbance may not cause enough of a change in spectral signature for algorithm detection. Thus, the VCT algorithm may be more useful for detecting harvests, land-use change (reversions and diversions), or massive natural disasters than for detecting other disturbance components.

In addition to disagreement between field-recorded disturbance and VCT-detected disturbance, there was disagreement in terms of field classifications of forest versus nonforest and VCT algorithm forest versus nonforest. Some of the disagreement can be explained by a known weakness in the imagery analysis,

whereby forest edge is assigned to the nonforest category. For example, the fact that basal area values are significantly lower for post-disturbance nonforest VCT categories suggests that either forest definitions differ (e.g. VCT is missing regeneration plots—a known phenomenon) or many of the plots were forest edge and were therefore classified by VCT as nonforest. Therefore, either the FIA data or the VCT algorithm could be further analyzed to try and isolate cases where forest and nonforest conditions exist on FIA plots; and/or pixels obviously are on a forest edge; to evaluate how much forest edge contributed to the agreement issue.

Additionally, forest/nonforest values were extracted from VCT imagery at FIA plot center, while FIA plots actually cover a 3 by 3 pixel square. In the future, it may be best to work with an average of the 3 by 3 area because of pixel-level spatial variation. Another potential explanation for disagreements is simply whether or not forest, as defined by FIA, is equivalent to forest as defined by the VCT algorithm. Finally, Global Positioning System receivers are prone to some error, particularly under a closed canopy. Therefore, FIA plot locations are generally, but not always, within 15m of a plot, introducing another, unavoidable, source of error.

The FIA program strives to quantify both the current status and the change in forest conditions in the United States. Estimators used by FIA require the stratification of forest inventory plots into approximately 4-6 strata. The purpose of stratification is to group like plots together, in order to reduce the variance of estimates. Currently, stratification schemes vary among FIA regions. However, they are all based on geospatial data at any single time. For example, the Southern FIA unit uses the National Land Cover Database to group inventory plots into the following stratum: forest, forest edge, nonforest, and nonforest edge. This stratification scheme does reduce the variance of current estimates of, for example, forest area but it likely does not decrease the variance of change estimates. The VCT data provides an excellent opportunity to stratify field inventory plots for estimating the components of change. We recommend that the VCT data be examined for its use in stratified estimation.

The change detection imagery produced using the VCT algorithm has the potential to be a tremendously useful product when coupled with FIA data, particularly for long-term land-use change analysis, in depth looks at harvest levels, and ecosystem-level analyses. The imagery has the potential to be particularly useful in cases where FIA data may not be sufficient (e.g. fine scales) or where data collection is particularly difficult (e.g. in Alaska). VCT products need to be improved and better characterized before they can be used as production-level products. More studies comparing and contrasting FIA field data with the VCT algorithm results are necessary, as well, to refine the VCT product and to understand how the two relate.

References

- Bechtold, W.A.; Patterson, P.L., Editors. 2005. The enhanced forest inventory and analysis program—national sampling design and estimation procedures. Gen. Tech. Rep. SRS–80. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 85 p.
- Cohen, W.B.; Goward, S.N. 2004. Landsat's role in ecological applications of remote sensing. *Bioscience*. 54(6): 535–545.
- Congalton, R.G.; Mead, R.A. 1983. A quantitative method to test for consistency and correctness in photointerpretation. *Photogrammetric Engineering and Remote Sensing*. 49(1): 69–74.
- Huang, C.G.; Schleeweis, S.N.; Thomas, K. [and others]. [In press]. Dynamics of national forests assessed using the Landsat record: case studies in Eastern U.S. remote sensing of environment. *Remote Sensing of Environment*.
- Oswalt, S.N.; Oswalt, C.M. 2008. Relationships between common forest metrics and realized impacts of Hurricane Katrina on forest resources in Mississippi. *Forest Ecology and Management*. 255: 1692–1700.
- U.S. Department of Agriculture Forest Service. 2005. Forest inventory and analysis national core field guide. Volume 1: Field data collection for phase 2 plots, version 3.0. [Online]. Arlington, VA: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program. http://fia.fs.fed.us/library/field-guides-methods-proc/docs/2006/core_ver_3-0_10_2005.pdf [July 7, 2008].