

# ADDING VALUE TO THE FIA INVENTORY: COMBINING FIA DATA AND SATELLITE OBSERVATIONS TO ESTIMATE FOREST DISTURBANCE

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**Abstract.**—In addition to being one of the primary drivers of the net terrestrial carbon budget, forest disturbance also plays a critical role in regulating the surface energy balance, promoting biodiversity, and creating wildlife habitat. With climate change and an ever growing human population poised to alter the frequency and severity of disturbance regimes across the globe, improved monitoring of forest disturbance, especially at the landscape scale has taken on renewed importance. Because forest disturbance manifests at a variety of spatial and temporal scales and has varying impacts which affect the canopy, understory, and forest floor, effective monitoring will likely require a composite approach where localized field data collected by the Forest Inventory and Analysis (FIA) Program are combined with repeat observations from remote sensing satellites such as Landsat. As Landsat offers nearly 40 years of well calibrated and systematically collected imagery at no cost, it is now economically feasible to monitor year to year trends in forest disturbance over large areas. In addition to its use in mapping forest change, Landsat data can also serve as a valuable backdrop for collecting detailed human interpretations of disturbance. When collected over a design-based sample such as FIA plots, these manually derived interpretations offer a wealth of potential uses ranging from map validation to estimation of new disturbance-related attributes. Here satellite observations and FIA data are used to estimate the area impacted by several types of forest disturbance occurring in the Uinta Mountains of northern Utah. This study aims to evaluate two types of satellite observations in the context of FIA's estimation procedure, including the use of human interpretations as an augmented response variable and the use of disturbance maps for stratified variance reduction.

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## INTRODUCTION

The U.S. Forest Service Forest Inventory and Analysis (FIA) Program is required to produce timely and accurate estimates of a wide range of forest attributes. These attributes, which often include forest area and volume, are used to provide information on the current status and health of forests over varying geographical extents. Typically, areal estimates derived from inventory plots are used to quantify

how much forest there is while maps derived from remote sensing imagery are used to delineate forest location and extent. Reporting population estimates which describe a forests current condition has long been a primary function of FIA. With climate change and population growth poised to alter the rate and severity with which forests are disturbed, a renewed emphasis has been placed on determining how much forest is changing, where it's changing, and what's changing it. Monitoring the status and trends of forest disturbance can be challenging for inventory programs as they typically have long temporal gaps between plot remeasurements (e.g., FIA remeasures plots every 5 years in the east and every 10 years in the west) likely resulting in missed disturbance events. But because small amounts of disturbance occur each

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year it is also important that measurements be made frequently and over large areas. Thus there is potential for national forest inventories to improve their change-monitoring capabilities by incorporating more frequent measurements of disturbance from remote sensing satellites such as Landsat.

## **MONITORING FOREST DISTURBANCE WITH LANDSAT IMAGERY**

With a 40+ year historical archive and a 16-day repeat cycle, Landsat imagery offers an excellent platform for monitoring forest disturbance over large areas. The 30 m spatial grain and 7 spectral bands are capable of capturing many types of forest disturbance, especially those that impact the upper canopy. With the entire Landsat archive now freely available, it is now economically feasible to monitor disturbance through time using dense stacks of images. The free availability of images has also resulted in the development of several new algorithms which are capable of producing maps of disturbance in an automated manner. Two of these algorithms, the Vegetation Change Tracker or VCT (Huang et al. 2010) and the Landsat-based detections of trends in disturbance and recovery, or LandTrendr (Kennedy et al. 2010), are being tested and applied over large regions. For example, the North American Forest Dynamics (NAFD) project is currently using VCT to produce a wall-to-wall, seamless forest disturbance map for the conterminous United States. Given the increased availability and seamless coverage of these maps, it is important to determine if these national products can help FIA improve the timeliness and accuracy with which they monitor and estimate forest disturbance. Early attempts at using disturbance maps to stratify FIA variables have been met with mixed results, although it is possible this has more to do with variable definition and lack of remeasured data than poor map quality. Thus, a more comprehensively-defined disturbance response variable (e.g., one that is measured annually and includes all disturbance types) which is more in tune with the satellite perspective might yield improved stratification results.

One new strategy for collecting measurements of disturbance comes through the use of a human interpreter to analyze yearly time series of Landsat images (Cohen et al. 2010). When analyzed with periodic, high resolution imagery from Google Earth, these human interpretations yield highly accurate records of timing and cause of most natural and anthropogenic disturbance events. If these human-interpreted measurements of disturbance are made over a statistically based set of sample locations, such as FIA plots, they can be used for estimation purposes just like any other FIA variable. The objective of this study is to explore the utility of augmenting FIA plots with these human-interpreted measurements for the purpose of estimating the area impacted by several different types of disturbance. In testing potential improvements to the disturbance response variable, we will also test whether maps from VCT and LandTrendr can be used to improve the precision of the derived disturbance estimates.

## **STUDY AREA**

The study area consists of the non-overlapping portion (or Thiessen scene area, TSA) of Landsat scene path 37 row 32, which covers the Uinta Mountains of northern Utah (Fig. 1). Approximately 56 percent of the study area is forested and includes broad expanses of conifer, mixed deciduous and pure aspen stands at high elevations, and sparse pinyon-juniper woodlands on drier, lower elevation slopes. According to the U.S. Forest Service forest type map (Ruefenacht et al. 2008) the majority of forest within the study area falls in five major group types. These include pinyon-juniper (18 percent), aspen/birch (12 percent), fir/spruce/hemlock (12 percent), lodgepole pine (10 percent) and Douglas-fir (3 percent). The diversity of forest types and land management objectives in this region have led to a number of known disturbance events including harvests, fires, insects, and mechanical treatments such as chaining. The broad array of disturbances, along with the presence of both dense and sparse forest types, makes this area an excellent location for evaluating FIA's potential use of satellite observations of disturbance.

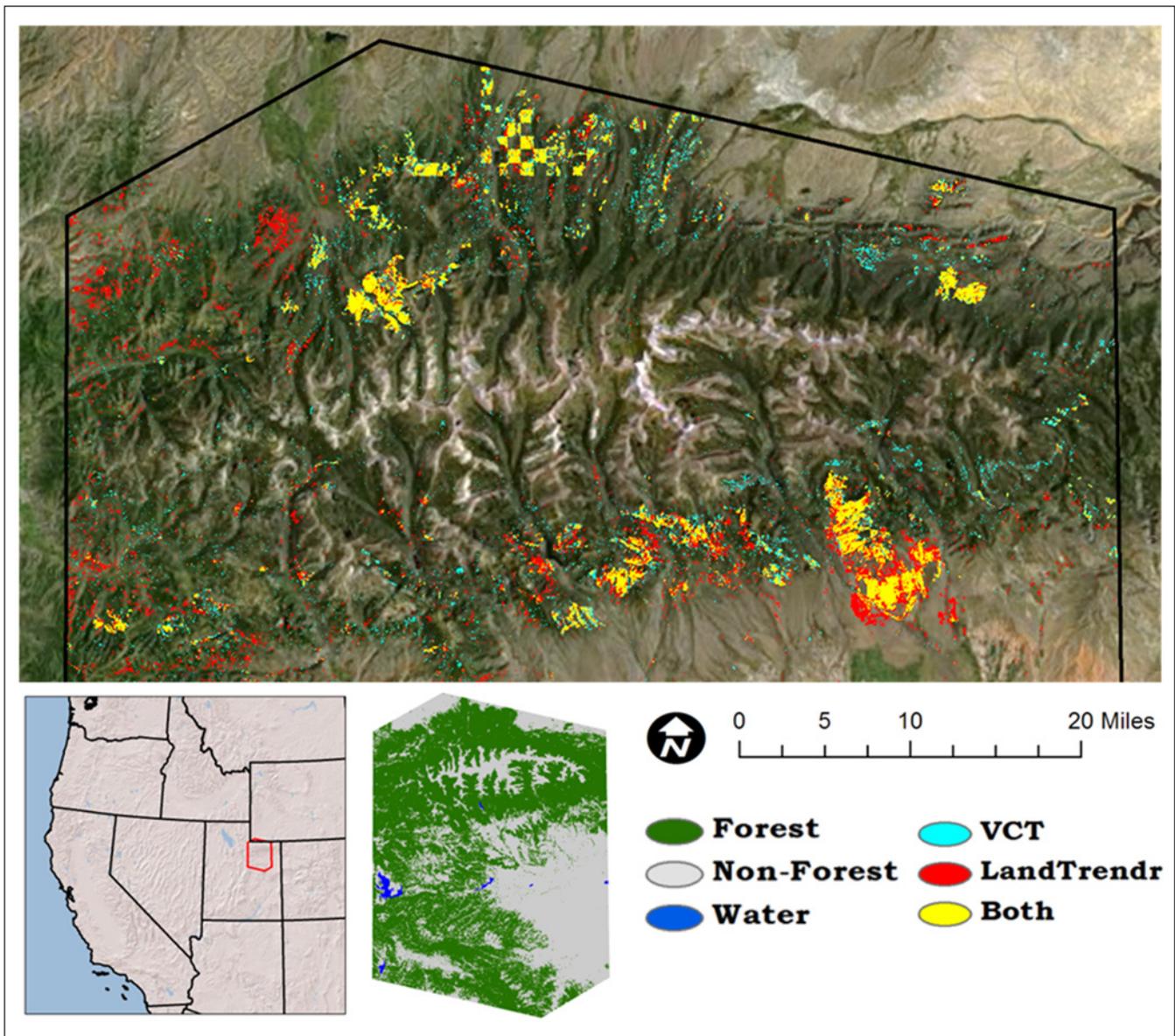


Figure 1.—Uinta Mountains study area with Vegetation Change Tracker (VCT) and LandTrendr forest disturbance.

## METHODS

### Satellite Disturbance Observations

The annual FIA plots ( $n=802$ ) falling within the boundary of the study area were queried and loaded into a GIS for analysis. The plots containing at least one forest condition class ( $n=478$ ) were identified so that a human interpreter could analyze and record the disturbance history of each plot. The interpretation process, similar to the one outlined in Cohen et al. (2010), entailed simultaneously viewing the full time series of Landsat images (acquired annually between

1987 and 2010) so that both the immediate plot area and its surrounding neighborhood could be easily surveyed for changes and supporting context. In a separate window, spectral trajectories for the plot were displayed using a number of different bands and indices. To aid the interpretation of the Landsat data, the interpreter used the high resolution, multi-date images found in Google Earth. These high resolution images covered several dates and were instrumental in detecting the first signs of stress-related crown mortality, such as from disease, insects, and drought.

Taken together, the multi-scale information from Landsat and Google Earth allowed the interpreter to accurately record the year and type of disturbances found on the FIA plots.

## Satellite Disturbance Maps

Both VCT and LandTrendr have been successfully used to map disturbances across a broad range of forested ecosystems. Although the goal of both algorithms is to infer change on the ground from changes in the spectral signal captured by multiple Landsat images, both do so in different ways. For example, VCT is designed to locate abrupt forest disturbances such as fire and harvesting, whereas LandTrendr is designed to detect both abrupt events as well as slower, longer-term changes across all lands. Here we used each algorithm to generate maps of disturbance for the study area using Landsat images acquired annually between 1987 and 2009. Because LandTrendr maps disturbance across all lands, a forest cover map (Ruefenacht et al. 2008; see inset map Fig. 1) was used to remove disturbance from nonforested areas. For consistency, the VCT map was also merged with this forest cover map. Additionally, the time period of mapped disturbance was restricted to 1995-2009 to better coincide with the measurement window of the annual FIA plots.

## RESULTS

### Satellite and FIA Disturbance Observations

The image interpretation process identified a total of 129 disturbance events between 1995 and 2009. These 129 satellite disturbances were grouped into 10 categories as shown by the blue bars in Figure 2. The most prevalent disturbance types were insect and insect/disease which together accounted for more than 75 percent of the total observations. From the satellite perspective, these two classes represent distinct patterns of crown mortality which were distinguishable in the air photos. The insect label indicates the visible presence of red attack damage likely caused

by mountain pine beetle, whereas the insect/disease label reflects conditions where dead gray crowns were observed, but the exact cause of death could not be inferred. The importance of the high resolution air photos was apparent, as more than half of these chronic stress related disturbances were only detectable in Google Earth. Fires were the next most abundant (11 percent) disturbance type, followed by harvesting (7 percent) and mechanical treatments such as chaining and brush saw (2 percent). Not surprisingly, the types and frequency of disturbances detected by FIA were similar to those observed by satellite interpretation (see red bars in Fig. 2). In total, FIA detected 86 disturbance events, of which the majority (72 percent) belonged to the insect and disease categories. Since FIA plots are field measured, we expect their insect and disease classes to be more accurate than those derived by satellite interpretation. Additionally, FIA was also able to detect smaller-scale impacts such as from animal grazing and weather, which could not be picked up from the satellite perspective. Over the 14-year period of observation (1995-2009), both the satellite and FIA measurements showed a noticeable trend of increasing disturbance with time as seen in Figure 3a and 3b (note different y axes). Despite the temporal similarities, it is important to note that in most cases FIA and the satellite captured different disturbance events. This results in considerably more disturbance when the data sets are combined than was found only by FIA (Fig. 3c).

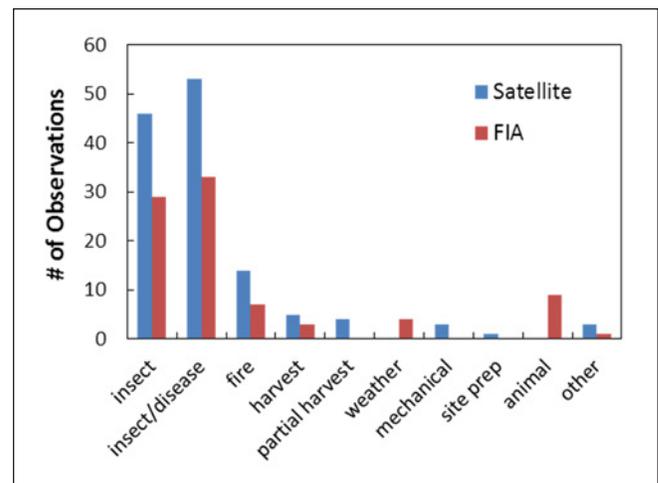


Figure 2.—Frequency of disturbance types observed by FIA and satellite interpretation.

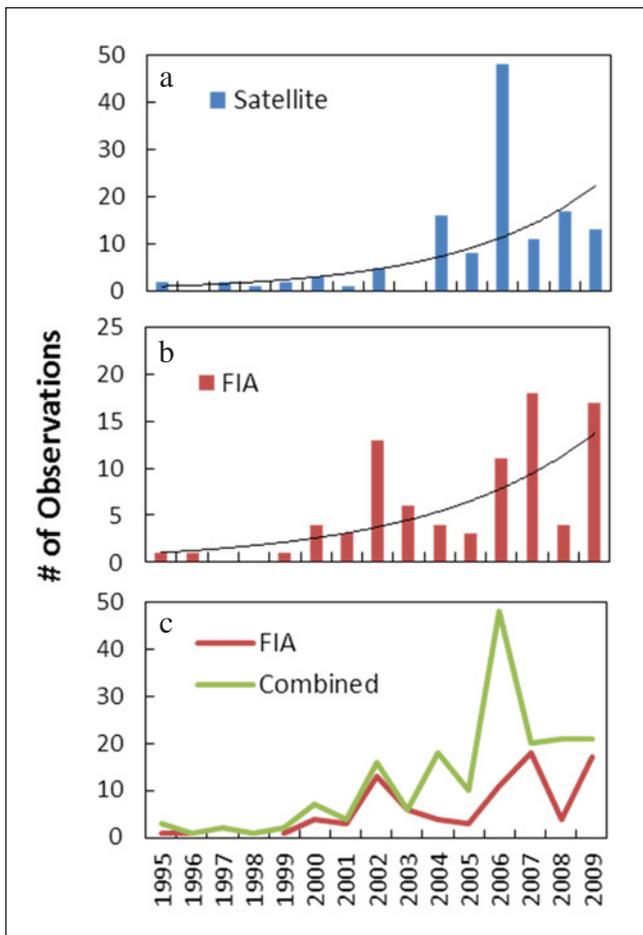


Figure 3.—Frequency of disturbance observed by (a) FIA interpretation, (b) satellite interpretation, and (c) FIA and satellite combined.

## Satellite Disturbance Maps

Both the VCT and LandTrendr algorithms were used to derive forest disturbance maps for the study area. The algorithms produced noticeably different spatial (Fig. 1) and temporal (Fig. 4) patterns, with LandTrendr finding nearly twice as much disturbance as VCT. Despite these differences, both maps resulted in similar accuracy metrics when compared with the satellite interpretations of disturbance (VCT overall accuracy 87 percent, kappa = 0.42; LandTrendr overall accuracy 86 percent, kappa = 0.38). Unfortunately, combining the two disturbance maps did little to improve accuracy (combined overall accuracy 86 percent, kappa = 0.43).

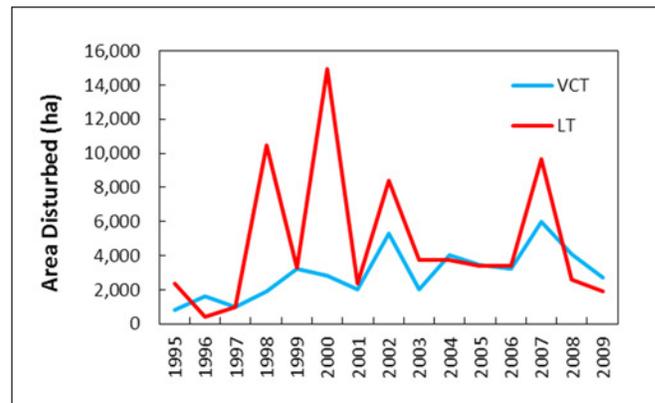


Figure 4.—Area of disturbance (in hectares) mapped by Vegetation Change Tracker (VCT) and LandTrendr.

## CONCLUSION

The estimation and stratification results are currently being finalized and will be presented at the FIA Science Symposium in December 2012. Nonetheless, we believe the data gathered so far highlights the potential importance of augmenting FIA measurements with satellite observations of disturbance.

Undoubtedly, the combination of these data sets will lead to larger estimates of disturbance than would otherwise be obtained from FIA data alone. In addition to improving estimates of disturbance, we also believe better disturbance histories will help enhance the overall analysis capability of the FIA plot data.

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