

USING THE TASSELED CAP TRANSFORMATION TO IDENTIFY CHANGE IN THE MISSOURI OZARK FORESTS

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Abstract: In this research the "wetness" component from the tasseled cap transformation was investigated as a means of determining forest biomass change from multi-temporal Landsat TM satellite scenes for the Missouri Ozark Forests. Three satellite scenes were chosen with similar anniversary dates and a two-year time-step between scenes. The tasseled cap transformation was applied to each scene and the wetness components were extracted and compiled into a single scene. A forest mask was generated based on previous land cover classifications of Missouri. The composite image was intersected with the forest mask. The resulting scene contained only those areas that were forested when the classifications were produced. Unsupervised classification was then applied to the masked scene. Each cluster was assigned to one of three change classes: forest biomass decrease, stable forest biomass, and forest biomass increase. The resultant classification was compared to a Forest Service stand management polygon shapefile of areas that had experienced one of three management class activities during the change detection time period (regeneration cuts, intermediate cuts, and salvage cuts). The classification detected over 80% of all management activities on Forest Service lands.

INTRODUCTION AND BACKGROUND

Oak decline and the red oak borer are currently affecting large portions of the Missouri Ozarks (Lawrence *et al.*, 2002). The challenge to resource managers is that once the decline is visible on the ground, the forest stand is beyond treatment and must be salvage logged. The forest change methodology investigated here is in response to United States Forest Service and Missouri Department of Conservation desires to have a technique that is capable of detecting subtle changes in forest health, so remediation measures can be applied before the stand is totally lost. Actual spatial locations of known mortality are currently unavailable, therefore by dividing U.S. Forest Service stand management data into categories based on extent and nature of activity, we will assess our ability to detect subtle management activities (intermediate cuts and salvage cuts) analogous to mortality caused by oak decline and the red oak borer.

Franklin *et al.* (2002) created an Enhanced Wetness Difference Index for the Landsat Thematic Mapper (TM) Tasseled Cap Transformation (TCT) to detect forest change. This technique looked for differences in wetness between images to depict forest change over a large area and long time span in southeastern New Brunswick, Canada. It was noted by Franklin *et al.* (2002) that the TCT is a useful tool in forest change

detection and additional forest change detection examples are needed to help understand the role that the tool can play in forest management applications.

The goal of this project was to determine the role of the TCT in detecting subtle forest change using only the wetness component. The Tasseled Cap Wetness (TCW) technique employed in this project will prove to be a useful tool for forest management by providing an easy and inexpensive technique to detect changes in forest biomass.

STUDY AREA

The study area for this project is situated within the Mark Twain National Forest (MTNF) of the Ozark Highlands region (Figure 1). The Ozark Highlands region is the rugged and hilly country of southern Missouri, northern Arkansas, northeastern Oklahoma, and a minute portion of southeastern Kansas (Larsen *et al.*, 1997). This study focused on the area within Missouri. The uplift and erosion of the last 300 million years have resulted in a topography of hills, plateaus, and deep intervening valleys, which distinctively sets this region apart from the flat plains that surround it (Unklesbay and Vineyard, 1992). The total area of the Ozark Region is estimated to be approximately 60,000 square miles, which is larger than the state of Arkansas (Browne, 1956). The unifying physiographical characteristics that define the Ozark Highlands region include greater relief and steeper slopes than surrounding areas; surface rocks that are older than those exposed outside the Ozarks; the abundance of karst features, such as springs, caves, and sinkholes; the prevalence of average to poor soils except in the stream valleys; the extensive forests of oak, hickory and pine; and the abundance of high-quality water resources, including rather swift-flowing streams and large man-made reservoirs (Rafferty, 1980).

During the late nineteenth and early twentieth centuries the Missouri Ozark Forests were heavily logged (Larsen *et al.*, 1997). A large portion of the Missouri Ozark forests, primarily the southeast Ozark Highland area, were comprised of pure shortleaf pine (*Pinus echinata* Mill) or mixed hardwood-pine stands (Smith, 1992). The logging companies moved throughout the region harvesting trees of a specified size until there were no longer trees of value remaining (Cunningham and Hauser, 1989). As the regeneration of the felled forests occurred, various factors allowed the oak species to dominate sites once populated by shortleaf pine. This is problematic because oak species are less resilient to drought and fire and much more short-lived than the pine species (Larsen *et al.*, 1997). Approximately every fourteen years the Ozarks experience oak mortality due to drought. However, since 1999, increased oak mortality has occurred due to an insect known as the red oak borer (Lawrence *et al.*, 2002). As a result significant portions of the Ozark forests are dying, decreasing the overall health and productivity of the forest (Lawrence *et al.*, 2002). The TCW technique will be used to monitor changes in the forest biomass and potentially extend the results to the detection of oak mortality, which has yet to be done.

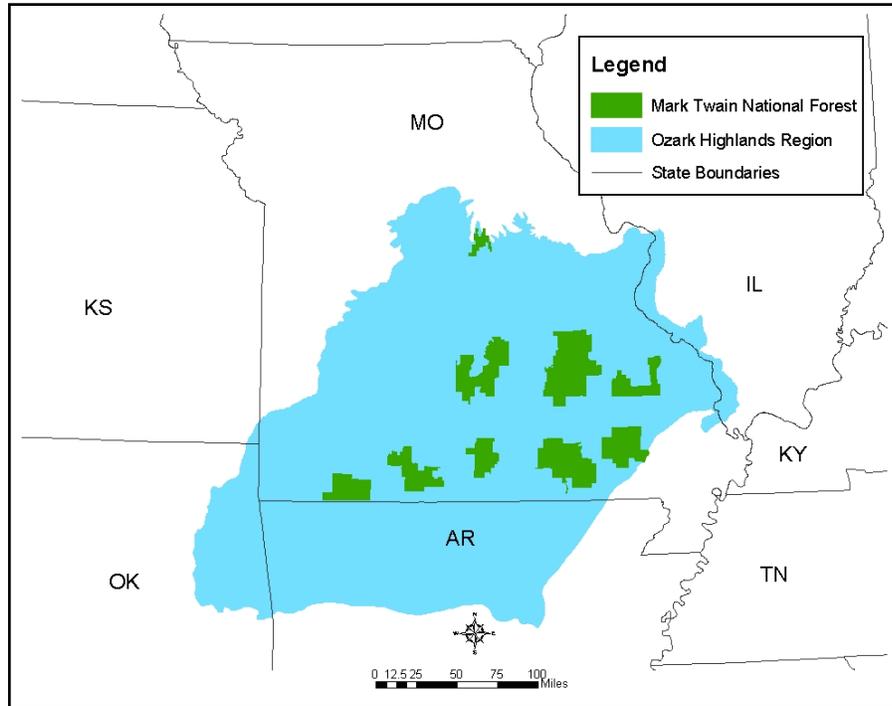


Figure 1. Study area.

METHODS

Data Acquisition

In order to cover the entire MTNF, eight Landsat TM path/rows of imagery were required. To facilitate detection of subtle changes in forest biomass a time step of 2 years between each satellite image was chosen (late August/early September of 1996, 1998, and 2000). This short time step was chosen because the view of the Missouri Ozark forests from satellite shows that disturbed vegetation often appears fully regenerated on imagery within 5 years. The late summer time period was chosen to ensure that all tree species were in full bloom just before senescence begins, which in this region occurs in early to mid October. It was not always possible to obtain imagery at a two-year interval during late summer due to the quality of available scenes. Therefore, in a few instances, the acquisition dates were in early to middle summer and/or there is a one-year to three-year interval between scenes.

Data Preprocessing

All images were geometrically registered to a 15 meter panchromatic TM reference image. Ground control points were evenly spaced throughout each scene to achieve a root mean square error of 0.5 pixels or less. A cubic convolution resampling algorithm was used to resample the images to a 30 m output image.

Tasseled Cap Transformation

Simplistically, the TCT is a guided and scaled principal components analysis, which transforms the 6 Landsat TM bands into 3 bands of known characteristics; soil brightness, vegetation greenness, and soil/vegetation wetness. The wetness component contrasts the sum of the visible and near infrared bands with the longer infrared bands to determine the amount of moisture being held by the vegetation or soil. The longer infrared bands are the most sensitive to soil and plant moisture, therefore, the contrast of visible and near infrared bands with the longer infrared bands highlights moisture levels within a scene (Crist and Cicone, 1984). Previous studies have used the TCT to detect changes in forest biomass using various combinations of the three primary components of the transformation. Cohen *et al.* (1998) contrasted the brightness and greenness values between MSS images and used brightness, greenness, and wetness values from TM images to assess forest biomass change in the Pacific Northwest from 1976-1991. Clearcut harvest activity was detected in over 90 percent of the known clearcuts. Zheng *et al.* (1997) contrasted the differences between MSS and TM TC brightness and greenness to quantify rates of change in forest cover between 1972 and 1988 in China and North Korea. Their study was based on the techniques used by Cohen *et al.* (1998) and successfully detected rates and patterns of forested landcover change to non-forest. The TCT wetness component has been used on its own to measure forest structural complexity (Hansen *et al.*, 2001). Hansen *et al.* (2001) used the TM TCT to illustrate that wetness values were highly correlated to stand age and structural complexity in mature and old growth forest stands. An enhanced wetness difference index has been used to detect changes in forest biomass (Franklin *et al.*, 2002). Franklin *et al.* (2002) was able to estimate the total area of total forest change in southeastern New Brunswick. However, there have been no published reports of using solely the TC wetness component to detect changes in forest biomass, which is the goal of this project.

Further Processing and Data Classification

The Tasseled Cap Wetness (TCW) technique was used to create a forest change dataset for the Missouri Ozarks. The TCW technique utilizes the “wetness” component from the TCT as a means of detecting change from multi-temporal satellite scenes. The use of the TCT wetness component to detect changes in forest biomass was prompted by successful applications in determining stand structure and complexity (Hansen *et al.*, 2001) and forest change detection (Franklin *et al.*, 2002). The TCT was performed on all TM images. The wetness bands from each of the three dates from each path/row were then stacked to create a single composite image containing all three wetness bands.

To reduce confusion during the classification process, a forest mask was applied to the composite wetness image for each path/row. Multiple landcover datasets (LUDA, NLCD, and GAP) were used to create the mask. The mask was a union of the forest landcover from each dataset. Any landcover type other than forest was omitted from the mask layer. This ensured that only forested areas were included in the clustering and classification processes.

An unsupervised Isodata clustering algorithm was used to divide each path/row of data into 75 clusters. The clusters were examined visually to determine the biomass change class (forest biomass decrease, stable forest biomass, or forest biomass increase) best represented by the cluster. Cohen *et al.* (1998) used visual interpretation to classify clusters into the appropriate biomass change category with accuracy greater than 90 percent. According to Sader (1995) automated image differencing techniques often overestimate the amount of forest biomass change because the method is unable to differentiate between seasonal phenology, shadows, and difference in the image color. Visual assessment of the clusters allows the user to distinguish between these differences. Forest biomass decrease was characterized by healthy vegetation in the 1996 and /or 1998 image(s) and loss of healthy vegetation in the 1998 and/or 2000 image(s). Stable forest biomass was characterized by no visual change in forest biomass between any of the imagery dates.

Forest biomass increase was characterized by visible disturbance of forest biomass in the 1996 and/or 1998 image(s) followed by vegetation regeneration in the 1998 and/or 2000 image(s). These classes are similar to those used by Sader (1995). Following the classification all scenes were mosaicked together to create a synoptic forest change layer (Figure 2).

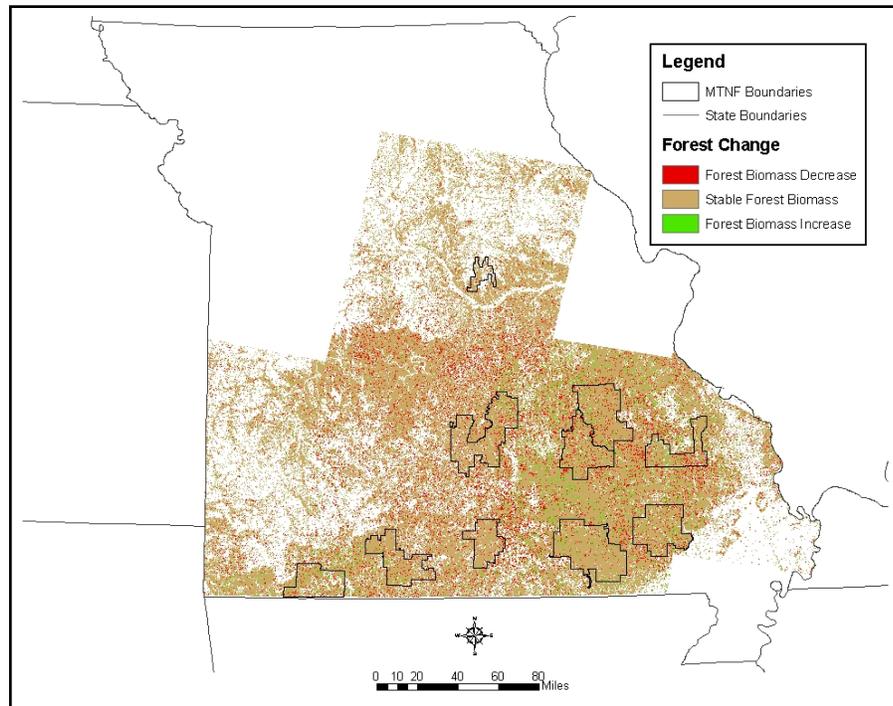


Figure 2. Mosaic of scenes.

Data Validation

The use of GIS forest stand management data allowed for validation from the results of the TCW technique. Cohen *et al.* (1998) used historical forest stand data to validate change detection results in the Pacific Northwest forests of Oregon. Stand-level forest management data for the MTNF in Southern Missouri was acquired from the U.S. Forest Service to assist in validating the results of the TCW change detection technique. The stand management data were coincident with the dates of satellite imagery used (1995-2000). To validate the change detection results, the stand management data was intersected with the forest biomass change data to determine what type of change (forest biomass decrease, stable forest biomass, or forest biomass increase) occurred within each stand. When changes in biomass were coincident with management activities occurring at the same spatial location, co-occurrence was present. There was a high level of confidence in using this technique due to the alignment of management polygon data and the forest change classification (Figure 3). The forest management activity data was divided into three categories based on the nature and extent of the activity. Agreement or co-occurrence was assessed for each category. The three categories included regeneration cuts, intermediate cuts, and salvage cuts. Regeneration cuts include clearcuts and are activities in which the greatest amount of biomass reduction occurs within large contiguous areas. Intermediate cuts can vary in size but are generally referred to as thinnings and are dispersed in a salt and pepper pattern throughout the stand. Salvage cuts are similar in size and nature to regeneration cuts, but are applied to dead or dying trees. Both intermediate and salvage

cuts, which are generally smaller scale biomass changes will be used in this study to infer how well subtle changes (due to oak mortality) can be detected.

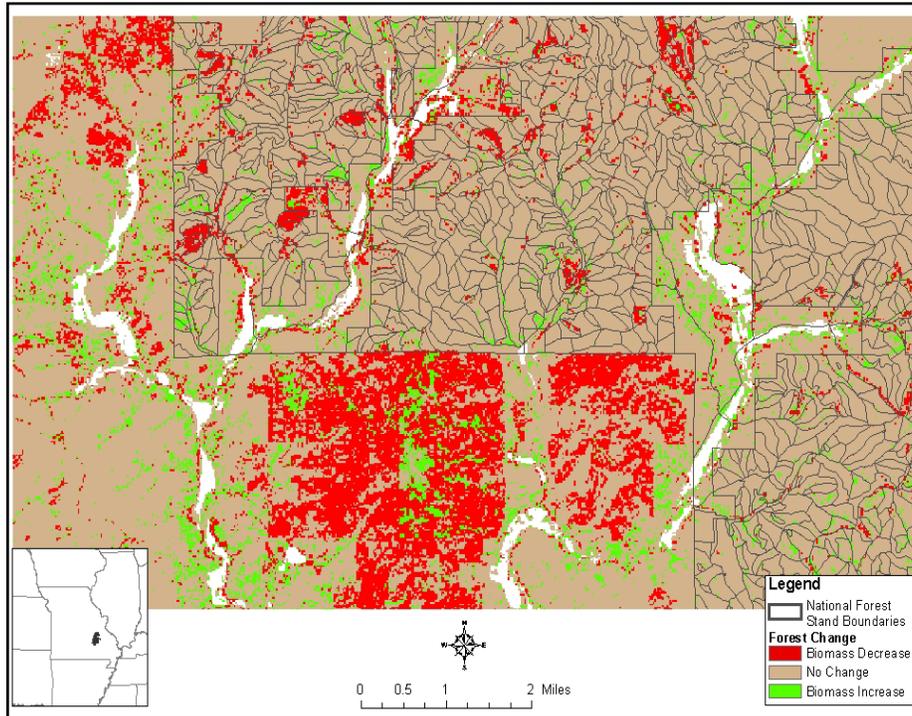


Figure 3. Stand boundaries and change detection data.

RESULTS AND DISCUSSION

Validation was performed on all forest stands within the MTNF. Figure 4 shows the level of co-occurrence for regeneration cuts between 1996 and 2000. The chart shows that in 60% of the stands in which regeneration cuts were applied, biomass decrease was detected for 1996. The lower value of co-occurrence for 1996 can be attributed to the amount of forest regeneration that occurred in those stands from 1996 to 2000. Within five years of biomass reduction, the vegetation on satellite imagery appears as if the forest had not been disturbed, even though the forest is not fully regenerated. In addition, fiscal year was used to denote activity in the stand management database, therefore some of the cuts could have been applied in fall of 1995 but the earliest images were for late summer 1996. Some level of vegetative regeneration may have occurred and was classified as forest biomass increase, instead of forest biomass decrease. In other cases, the management was prescribed in the fiscal year noted in the database but wasn't applied until the following year. There was a steady increase in the percent of co-occurrence from 1997 and 2000. By 2000, 100% of the stands in which regeneration cuts were applied showed biomass decrease. Overall, forest biomass decrease occurred in 88.2% of the stands that experienced regeneration cuts between 1996 and 2000 (Table 1).

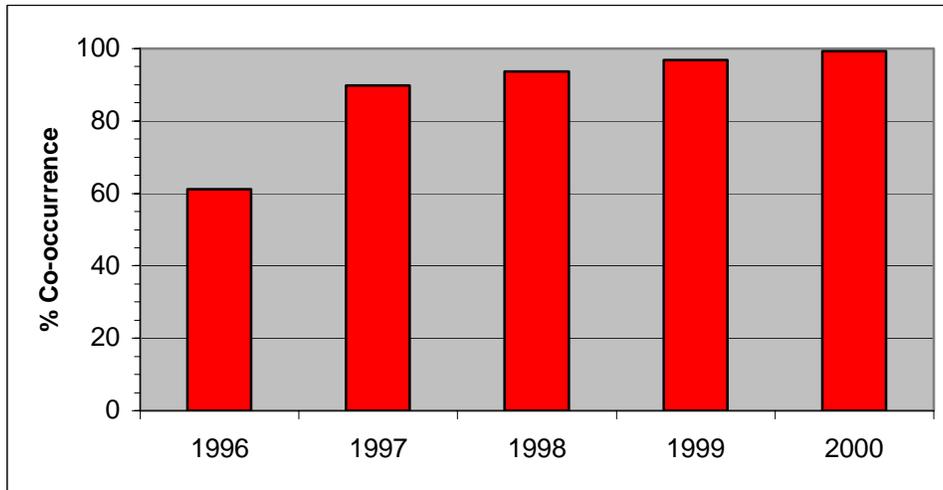


Figure 4. Percent co-occurrence for regeneration cuts.

The percent co-occurrence trend for intermediate cuts follows that for regeneration cuts (Figure 5). The 1996 levels of co-occurrence were less than the other years, which are predominantly influenced by the amount of time given for vegetation regeneration. From 1997 to 2000 approximately 80% of the intermediate cut forest stands experienced forest biomass decrease (Table 1). This is a high rate of co-occurrence given the small size and scattered nature of the intermediate cuts. These cuts were more difficult to detect with Landsat TM imagery due to the differences in spatial resolution between the regeneration cuts and the TM pixel. This technique was an appropriate technique to detect mid-scale forest biomass changes such as thinnings/intermediate cuts.

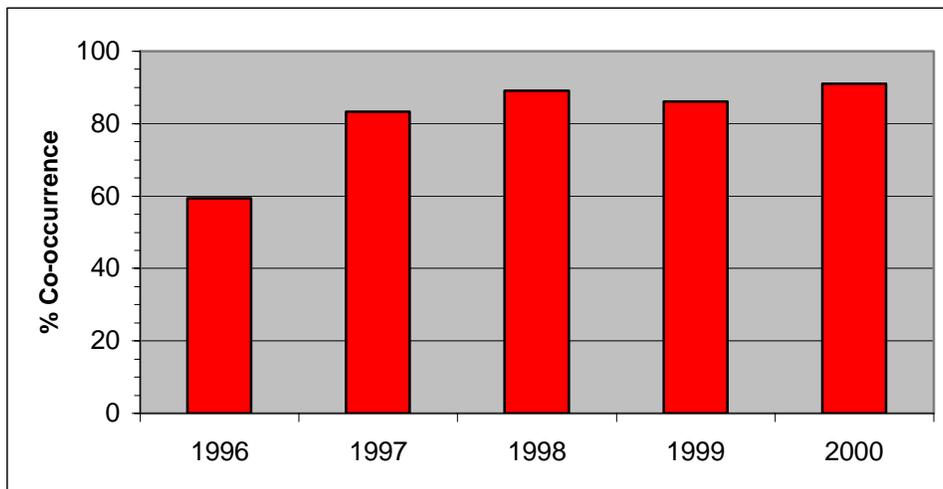


Figure 5. Percent co-occurrence for intermediate cuts.

The final category of cuts were salvage cuts, which are the smallest in extent and most difficult to detect. It was difficult to detect salvage cuts because the trees being harvested are already dead or unhealthy. Therefore, the wetness values from the foliage are low, which, upon removal, often result in relatively

minor changes in the TCW component. Nonetheless, the TCW technique was able to detect forest biomass decrease in 73.2% of the stands that experienced salvage cuts between 1996 and 2000 (Figure 6 and Table 1). The detection of often-subtle changes such as salvage cuts was the most important and encouraging result of this project. The validation results show that the TCW technique was appropriate for forest biomass change detection from large to small-scale forest disturbances, potentially including mortality due to oak decline and insect infestation.

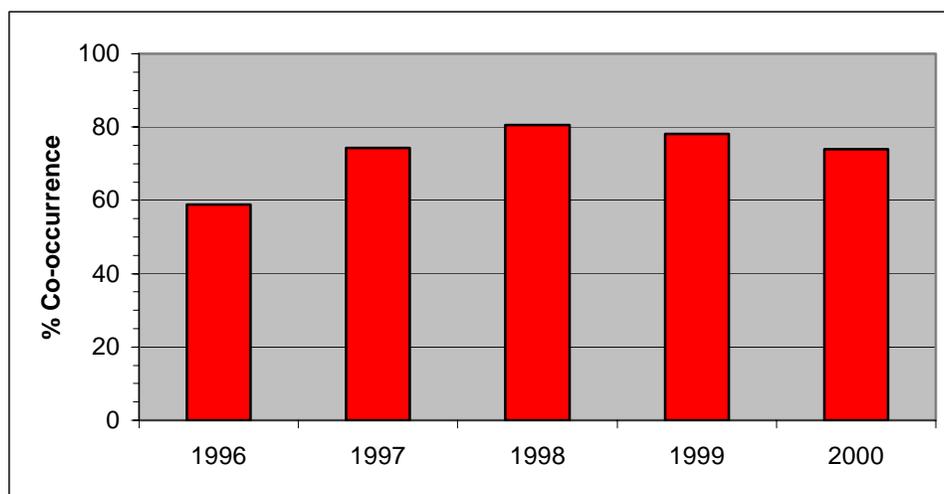


Figure 6. Percent co-occurrence of salvage cuts.

Table 1. Summary of Co-occurrence from 1996 to 2000.

	Forest Biomass Decrease
Regeneration Cuts	88.2 %
Intermediate Cuts	80.4 %
Salvage Cuts	73.2 %

Application

To demonstrate the utility of the forest change dataset created above a potential application would be to put the management activities of public forests into the context of the “forest” as a whole. Crow *et al.* (1999) noted that there is a strong interaction between ownership and ecosystem and that differential management creates very different landscape patterns. However, both public and private lands commonly exist within a single ecosystem, which points to the importance of monitoring landscape changes within lands of both ownership types.

The rates of forest change on both public and private forestlands within the state of Missouri were calculated. Public forestland included Forest Service, National Park Service, Missouri Department of Conservation, and State Park properties that were forested. Private forestlands were considered to be everything that was not public forestland. For Missouri, 87% of the forestlands are privately owned and 13% are publicly owned (Figure 7). It is important to monitor changes in forest structure for both

ownership categories because changes in one ownership class can affect the entire ecosystem (Saunders *et al.*, 1991). This is especially true in Missouri where the vast majority of the forests are privately held. The rates of forest biomass change between public and private land provides insight into the contrasting ways in which land owners manage their land. Between 1996 and 2000, 11.2% of all private forested lands experienced forest biomass decrease, whereas only 4.9% of all public lands experienced forest biomass decrease. The rate of forest biomass decrease on private land was twice that of public forestlands. What was more telling than the rates of forest biomass decrease were those of forest biomass increase. Forest biomass increase occurred on 3.8% of private land and 3.8% of public land between 1996 and 2000 (Figure 8). The rate of forest biomass increase on private land was proportionately less than on public lands. This indicates that some of the areas experiencing forest biomass decrease on private land were potentially being converted to other land uses and/or land cover types, while public lands were essentially regenerating at the same rate they are being removed.

Wolter and White (2002) investigated rates of forest change between public and private lands in northeastern Minnesota and found similar rates of reduction for a five-year period (1990-1995). Approximately 10% of private forests and 5% of public forests experienced biomass decrease. The forest change detection technique used by Wolter and White was referred to as the short-wave infrared/near infrared ratio (SWIR/NIR) and was applied to Landsat TM data. This is a common technique used extensively in the eastern United States to detect changes due to insect outbreaks and forest decline.

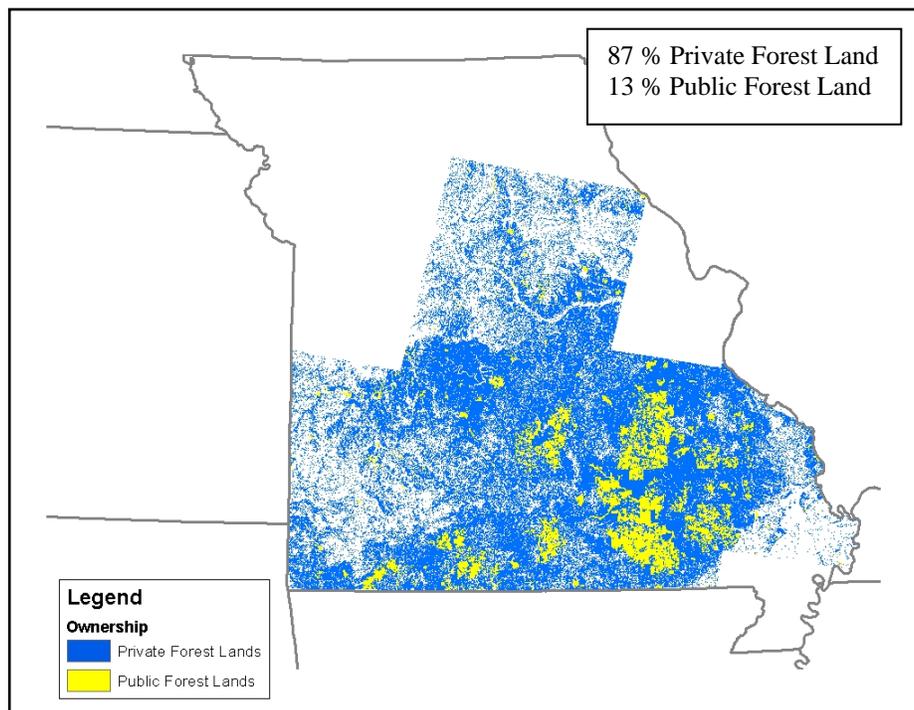


Figure 7. Public and private forested lands.

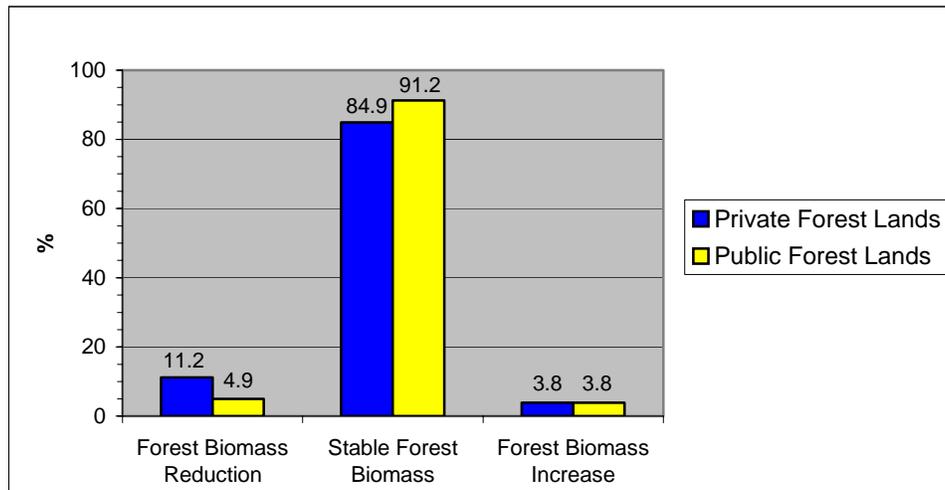


Figure 8. Private and public forest change within Missouri.

Conclusion

The TCW change detection technique sought to detect subtle changes in forest biomass using only the wetness component of the TCT. This technique allowed for successful detection of forest biomass change within the deciduous oak/hickory forests of Southern Missouri. The technique was capable of detecting forest biomass change at multiple spatial extents including relatively subtle changes occurring within salvage cuts. Detection of subtle changes to forest biomass, such as mortality due to the red oak borer or oak decline may be detectable using this technique. Spatial data of known forest mortality due to insect and disease are needed in order to quantifiably answer that question.

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