A COMPARISON OF FOREST CHANGE DETECTION METHODS AND IMPLICATIONS FOR FOREST MANAGEMENT

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by
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The undersigned, appointed by the Dean of the Graduate School,
Have examined the thesis entitled.

A COMPARISON OF FOREST CHANGE DETECTION METHODS AND IMPLICATIONS FOR FOREST MANAGEMENT

Present by Ronald D. Lea

A candidate for the degree of Master of Arts in Geography

And hereby certify that in their opinion it is worthy of acceptance.

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ABSTRACT

Currently, oak decline and the red oak borer are affecting large portions of the Missouri Ozarks. 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. Local forest resource managers are interested in a remote sensing technique that is capable of detecting subtle changes in forest health, so that remediation measures can be applied before the stand is totally lost. Therefore, the goal of this project is to determine the ability of the Tasseled Cap Transformation (TCT) to detect forest change in the Mark Twain National Forest using only the wetness component (TCW), and compare this technique to the more common Short wave-infrared/Near-infrared (SWIR/NIR) ratio technique used extensively in the eastern United States for forest change detection. This project tested the usefulness of this easy and inexpensive technique by applying it to the Missouri Ozark forest landscape in order to detect changes in forest biomass, characterize the structure of forest change patches, and assess contrasting rates of change on public and privately owned forests. This study found that the TCW detected biomass decrease as well as the SWIR/NIR ratio, forest change patch shapes worked well in identifying anthropogenic change, and that rates of biomass change were higher on private lands than public lands.

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Chapter 1

Introduction and Literature Review

Introduction

Many researchers have used remotely sensed imagery to monitor land cover changes through time (Aldrich 1975; Vogelmann and Rock 1988, 1989; Collins 1994; Green, Kempka, and Lackey 1994; Cohen et al. 1998; Lyon et al. 1998; Mas 1999; Franklin et al. 2000, 2002a, 2002b; Fuller 2001; Hansen et al. 2001; Sader 2001). The use of satellite imagery allows researchers to inventory and study the state of vegetation in a large region, while reducing the need to be in the field. The results produced by remotely sensed imagery can provide valuable information to resource managers by aiding in the management decision making process (Franklin et al. 2002a). Forest managers are frequently interested in information regarding canopy changes caused by short-term natural phenomena, including insects, flood, drought, human activities, and reforestation (Coppin and Bauer 1994).

Currently, oak decline and the red oak borer are affecting large portions of the Missouri Ozarks (Lawrence and Moser 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. Local forest resource managers are interested in a remote sensing technique that is capable of detecting subtle changes in forest health, so that remediation measures can be applied before the stand is totally lost. This project will investigate the ability of the Tasseled Cap Transformation wetness (TCW) component to detect forest change at multiple scales and compare this method against a commonly used and well researched forest vegetation ratio: the Short-wave Infrared/Near Infrared (SWIR/NIR) (Vogelmann and Rock 1988, 1989). Franklin et al. (2002b) noted that the Tasseled Cap Transformation (TCT) is a useful tool in forest change detection, and additional forest change detection examples are needed to help understand the role that the TCT can play in forest management applications. Therefore, the goals of this project are to determine the role of the TCT in detecting forest change in the Mark Twain National Forest using only the wetness component and to compare this technique to the more common SWIR/NIR ratio technique used extensively in the eastern United States for forest change detection. The end results of this project seek to provide a useful tool for forest management by providing an easy and inexpensive technique to detect changes in forest biomass, characterize the structure of forest change patches, which aid in the comparison of change detection techniques, and assess forest change throughout the ecosystem by identifying rates of change on public and privately owned forests.

Study Area

The study area for this project is situated within the Mark Twain National Forest (MTNF) of the Ozark Highlands region (Figure 1.1). 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, Metzger, and Johnson 1997). Uplift and erosion of the last 300 million years has produced 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, an abundance of karst features, such as springs, caves, and sinkholes, a prevalence of average to poor soils except in the stream valleys, extensive forests of oak, hickory and pine, and the abundance of high-quality water resources, including swift-flowing streams and large man-made reservoirs (Rafferty 1980).

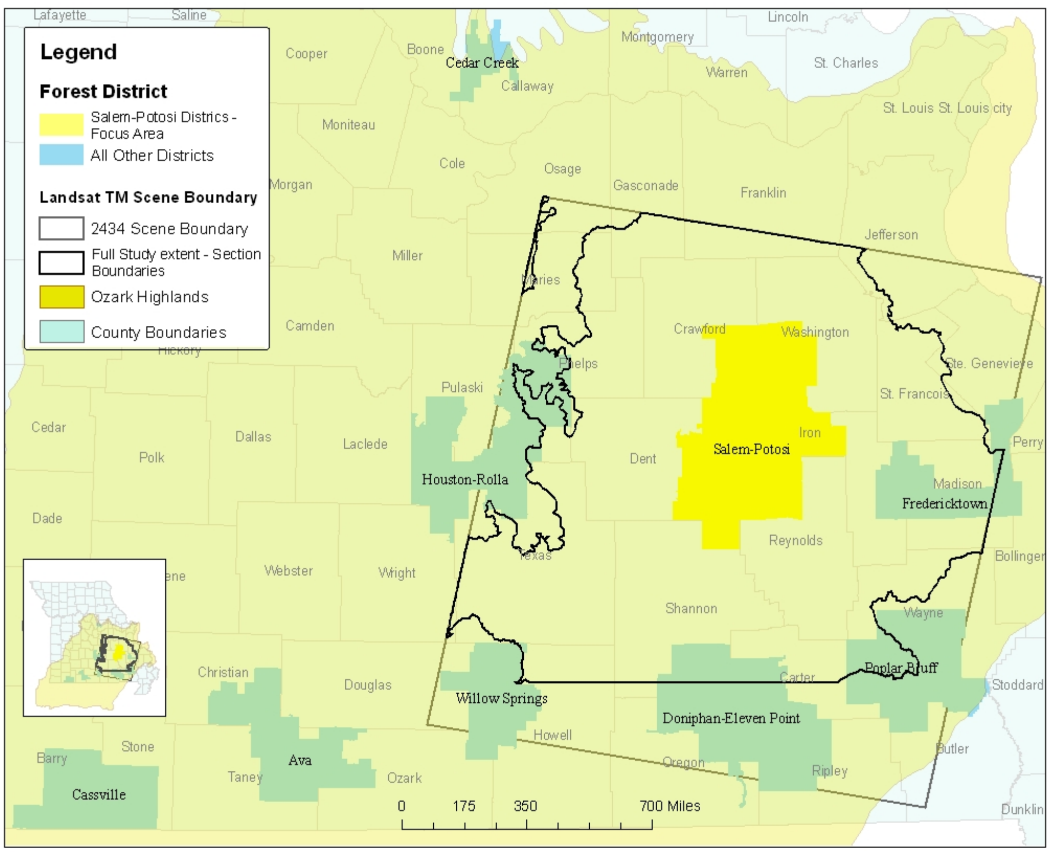


Figure 1.1. Study area (Salem-Potosi Districts) in the Eastern Missouri Ozarks and the Mark Twain National Forest Ranger Districts.

Historical Perspective

During the late nineteenth and early twentieth centuries, the Missouri Ozark Forests were heavily logged (Larsen, Metzger, and Johnson1997). A large portion of the Missouri Ozark forests, primarily the southeast Ozark Highland area, was comprised of nearly pure stands of shortleaf pine (*Pinus echinata*) or mixed hardwood-pine stands (Smith 1992). Logging companies from the east 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, factors such as fire suppression and livestock grazing 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 pines (Larsen, Metzger, and Johnson 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 and Moser 2002). As a result, significant portions of the Ozark forests are dying, decreasing the overall health and productivity of the forest (Lawrence and Moser 2002). Therefore it is important to monitor changes in the forest biomass to determine locations and severity of oak decline.

Mark Twain National Forest (MTNF)

The MTNF was established in 1939 and covers approximately 607,000 hectares of land that spans the southern half of Missouri (Figure 1.1). The total forest acreage of the MTNF represents 11% of all forested land in Missouri. The eastern upland oak hardwood and southern pine forests converge here with the drier western bluestem prairie

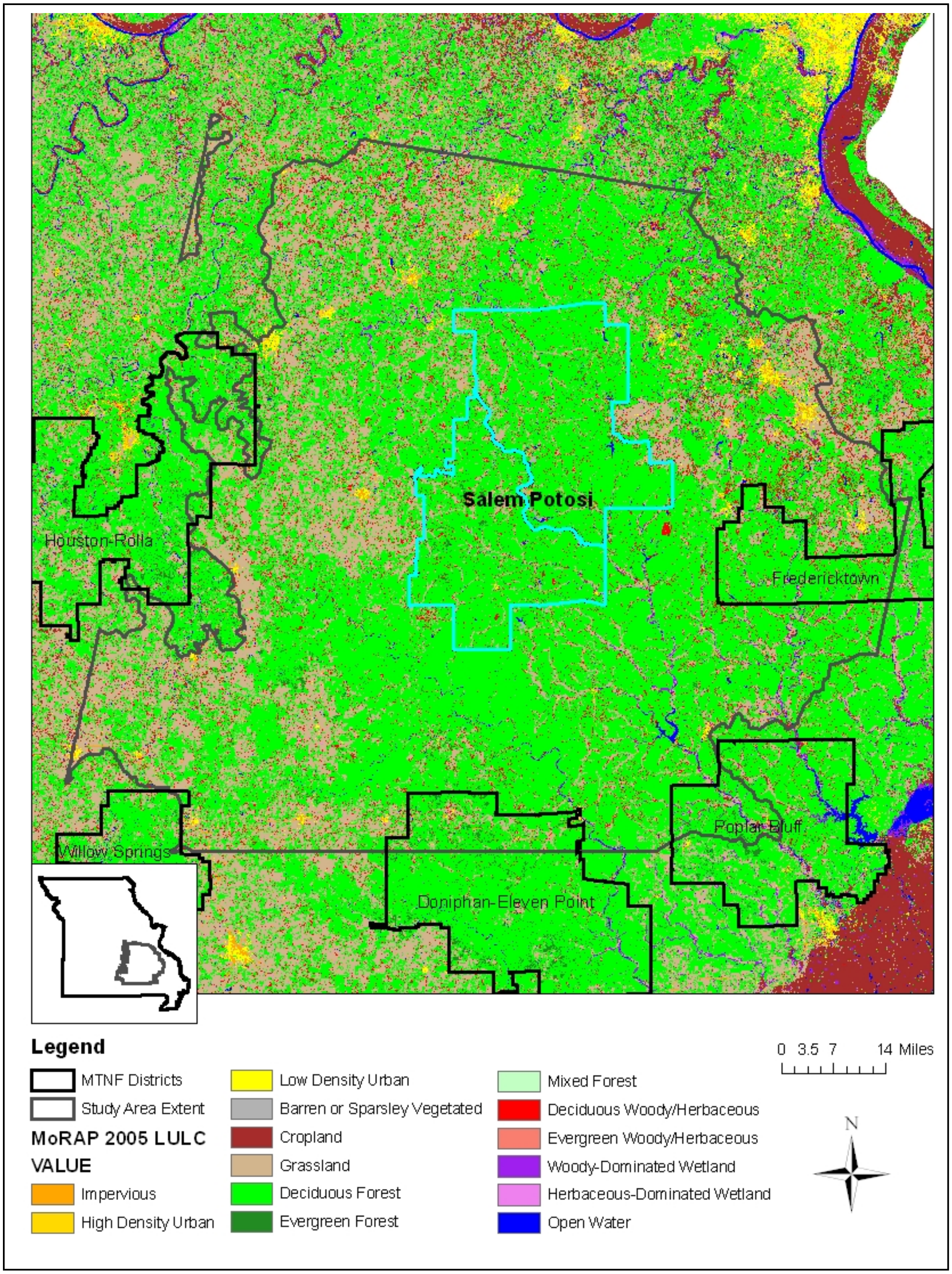


Figure 1.2. LULC for study area illustrates that it is heavily forested. The Salem/Potosi districts are almost entirely forest.

of the Great Plains, creating a distinctive array of open grassy woodlands and savannas (Figure 1.2). A trademark of the MTNF is plant and animal diversity. The diverse and ecologically complex natural communities provide a home for nearly 750 species of native vertebrate animals and over 2,000 plant species. The MTNF has land in 29 Missouri counties. There are six Ranger Districts on the forest with offices in Ava/Cassville/Willow Springs, Doniphan, Winona, Fredericktown, Houston, Van Buren, Salem, Potosi, Poplar Bluff, Houston, Rolla and Cedar Creek (Figure 1.1) (MTNF, webpage, accessed 10/07/2005).

Salem/Potosi Forest District

The focus area of analysis for this project is located in the Salem and Potosi Ranger Districts within the MTNF. Salem/Potosi Ranger Districts are found within the Missouri counties of Crawford, Dent, Iron, Reynolds, Shannon, and Washington (Figure 1.2). The total area within the Salem/Potosi Districts is approximately 78,000 hectares (USDA Forest Service 2002). The major forest type found in these districts is eastern upland oak hardwoods (USDA Forest Service 2002).

The combination of drought conditions, occurrence of scarlet and black oak (especially on dry sites like broad ridges and upper slopes) and advancing age of trees make the forest within the Salem/Potosi District especially susceptible to attack by insects and disease (Oliveria et al. 2001). Over the past twenty years, decline and mortality of scarlet and black oak have occurred in portions of the MTNF. The latter years of the 1990s and early 2000s saw below average precipitation. According to Mielke (2001), the Salem/Potosi Districts have experienced the most significant mortality and decline of black and scarlet oaks within the MTNF. More than 6,475 hectares of mortality were mapped on the Salem/Potosi Districts by aerial survey in September of 2000 (Oliveria et al. 2001). The Salem/Potosi Districts were chosen to be the study area because of the severe decline and mortality occurring within their boundaries.

Factors In Oak Decline

Oak decline is caused by numerous stressors, including particular environmental site conditions that predispose trees to decline at both long-term and short-term time frames. Over the long-term, thin soils, poor sites, poor soil drainage, advanced tree age, south facing slopes, and ridge tops all predispose oak trees to reduced productivity and even mortality. Other contributing factors to decline over the long-term include insects such as the red oak borer and chestnut borer and disease such as root rot (Moltzan 2003). More immediate, short-term factors contributing to oak decline include drought, ice storms, pollution, and defoliating insects (Moltzan 2003). Decline had been incited by severe drought each year from 1999 to 2001, which has caused repeated early spring defoliation (Oliveria et al. 2001)

In southern Missouri, the majority of affected trees are in the red oak group: mostly scarlet oak (*Quercus coccinea*)**,** black oak (*Quercus velutina*), and red oak (*Quercus rubra*; Oliveria et al. 2001). Trees commonly experiencing mortality are 70-80 years old and are located on rocky soils of ridges or west or south facing slopes. Older trees are stressed by competition for light, water, and nutrients, which causes the trees to grow slowly. Slow growth results in fewer leaves on the trees, causing the trees to be less resistant to insects, disease, and drought. Oak decline symptoms include branch dieback from tips, sparse foliage, and reduced growth (Moser and Melick 2003). A high percentage of scarlet oaks and blacks oaks are growing on lands once dominated by shortleaf pine. When the pine was harvested around the 1920s, scarlet and black oaks replaced the more resilient short leaf pine, white oaks, and post oaks, leaving the forest susceptible to drought, insect damage, disease, and other disturbances (USDA Forest Service 2002).

Aerial surveys taken in September of 2000 show at least 6,475 hectares of the Salem/Potosi Districts were severely affected by oak decline. In June of 2001, it was estimated that over 121,405 hectares of the Ozark National Forest in Arkansas had been affected. Additional field checks since 2001 have shown that at least 80,937 total hectares of the MTNF have been affected by oak decline (Oliveria et al. 2001). The MTNF, Missouri Department of Conservation, Ozark National Forest, and the Arkansas Forestry Commission have been collecting information about the forest decline in the Ozarks and are interested in monitoring the progression of decline in order to limit impacts of forest mortality (USDA Forest Service 2002). Therefore, it is important to determine an effective method to identify and monitor potential areas of decline using readily available satellite imagery, taking advantage of large area coverage, early detection, and efficient analysis provided by the imagery. By identifying areas of change resulting from forest management activity from the U.S. Forest Service stand management database, one can potentially differentiate between natural change and anthropogenic change. The differentiation could allow forest managers to identify areas of decline and prescribe remediation measures before the stand is totally lost.

Remote Sensing

Use of Remotely Sensed Data

Remote sensing (RS) has been effectively used to monitor eastern deciduous forests by many researchers (Vogelmann and Rock 1989; Muchoney and Haack 1994; Turner, Wear, and Flamm 1996; Fuller 2001). Change detection techniques that quickly and accurately delineate forest canopy alteration can provide the information necessary to make intelligent management decisions (Nelson 1983). The emerging focus on sustainable forestry and detection of insect damage has generated a need for annual or even seasonal updates to monitor changing landscapes (Franklin et al. 2000), which suggests that a simple, yet robust image processing technique is required. Multi-temporal forest change detection provides valuable information and is a critical component of the required reporting and monitoring mechanism for sustainable forest management.

The overall objective in change detection is to compare the radiance differences between the same spatial locations by controlling variance from image to image. Biomass changes in land cover result in changes in radiance due to land cover changes with respect to other potential radiance changes caused by other factors such as differences in atmospheric conditions, soil moisture, and sun angles (Price, Pyke, and Mendes 1992; Green, Kempka, and Lackey 1994; Mas 1999). Given the right RS product that has been properly processed and classified (geo-referenced, classified to land-cover, etc.), satellite imagery can itself be an important asset to the development of landscape scale planning, research, and monitoring because of its large area coverage, repeat viewing and digital nature (Griffiths and Mather 2000). Thus, remote sensing provides a source of data from which updated land cover information can be extracted efficiently and cheaply in order to monitor these land cover changes effectively (Mas 1999; Woodcock et al. 2001).

In order to monitor land cover changes and rates of change, an appropriate set of imagery must be selected to fit the needs (spatial, temporal, and spectral resolution) of the study. Many sensors, including Landsat Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper Plus (ETM+) consistently collect data for the same spatial location at regular intervals. As a result, multi-temporal change detection has become a major application of remote sensing due to the repetitive acquisition of satellite imagery at short temporal intervals over the earth's surface. TM spectral resolution was developed to make maximum use of dominant factors controlling leaf reflectance, such as leaf pigmentation, leaf and canopy structure, and moisture content (Jensen 2000, 194). In order to take advantage of regularly acquired imagery for purposes of continuous forest monitoring, spectral resolution designed for studying vegetation, and the moderate spatial resolution usable at multiple scales, TM imagery was selected for this project.

It is important to understand the fundamental biophysical properties of the features being studied when using RS data, in order to properly interpret what is occurring. For vegetation, there are three basic properties that influence the spectral quantity and quality of solar reflected radiation received by satellite sensors: abundance, composition, and condition (Rogan, Franklin, and Roberts 2002). Abundant, homogeneous, and healthy vegetation will produce a dramatically different amount of reflected radiation than a sparsely vegetated landscape in poor health. The reflectance and absorption of radiation for healthy vegetation generally appears as a high amount of absorption in the visible wavelengths, high reflectance in the near-infrared wavelengths, and high absorption in the mid or shortwave-infrared wavelengths. One reasonably consistent finding in the various mortality studies and in clear cut mapping is that visible wavelength reflectance tends to increase, near-infrared wavelength reflectance tends to decrease, and shortwave infrared wavelength reflectance tends to increase with decreasing amounts of vegetation (Franklin et al. 2000). These principals will be used to determine the cause of what is detected on the landscape and explain the differences in the results of the two forest change methods.

Forest Change and Composition Related to Ownership

Not only is the monitoring of change important, but the rates of change by owner can also provide valuable information. There have been numerous studies wherein researchers have used RS forest change detection results to determine rates of forest change on public and privately owned forest lands (Wear and Flamm 1993; Spies, Ripple, and Bradshaw 1994; Turner, Wear, and Flamm 1996; Zheng, Wallin, and Hao 1997; Crow, Host, and Mladenoff 1999; Franklin et al. 2002b; Wolter and White 2002). Crow, Host, and Mladenoff (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 forests for both ownership categories because changes in one ownership class can affect the entire ecosystem (Saunders, Hobbs, and Margules 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.

A number of studies have found conclusive evidence that rates of forest change differ based on ownership. Spies, Ripple, and Bradshaw (1994) found that annual rates of change on public lands in Oregon between 1972-1988 was 0.95% and 2.14% on privately owned forests. 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. Turner, Wear, and Flamm (1996) found that privately owned forests were more fragmented and had smaller average patch sizes than publicly owned forests. Understanding what type of change is occurring in both public and privately owned forests allows forest managers and ecologists to better understand the dynamics of the ecosystem in question (Spies, Ripple, and Bradshaw 1994).

Change Detection Techniques

Researchers involved in change detection studies using satellite imagery have conceived a large number of methodologies. Change detection procedures can be grouped under three broad headings characterized by transformation procedures and analysis techniques used to delimit areas of significant changes: image enhancement, multi-date data classification, and comparison of two independent land cover classifications (Mas 1999). Broadly, the method used for this study falls within the multi-date data classification technique. More precisely, the method used for this study is referred to as the spectral-temporal change classification (STCC) or the composite change classification technique by Muchoney and Haack (1994). STCC, or layered temporal change detection, is based on a single analysis of a merged multi-date data set using standard data transformation, pattern recognition, and classification techniques. STCC requires the pre-processed data to be merged into a single data set. The technique is based on the premise that because the data sets would otherwise be similar, changes would be significantly different statistically. This technique simplifies the steps of classification by requiring only one dataset to be classified when performing multi-temporal change detection, instead of classifying multiple datasets.

<u>Data Transformations, Ratios, and Vegetation Indices</u>

In the 1970s, remote sensing researchers gained a better understanding of how different wavelength bands provide different kinds of information and how the ratio of different bands yields information not directly obtainable (Botkin et al. 1984). Since this discovery, vegetation monitoring by remotely sensed data has been carried out using vegetation indices, band ratios, and data transformations, which are mathematical transformations designed to assess the spectral contribution of green, healthy vegetation from multi-spectral observations (Maselli 2004). Vegetation indices are defined as dimensionless, radiometric measures that function as indicators of relative abundance and activity of green vegetation, often focusing on leaf area index, chlorophyll content, and green biomass (Jensen 2000, 361). Vegetation indices are mainly derived from reflectance data of discrete red and near-infrared bands. Vegetation indices operate by contrasting intense chlorophyll pigment absorption in the red band against the high reflectance of leaf mesophyll in the near-infrared (Maselli 2004). The purpose of vegetation indices and band ratios is to maximize sensitivity to plant biophysical parameters, normalize external effects for consistent temporal comparisons (e.g., sun angle and viewing angle), normalize internal effects (e.g., canopy background, topography, and soil), and be associated with some measurable biophysical parameter (e.g., biomass; Jensen 2000, 361).

Several change detection studies have shown that interdate changes in vegetation properties are best identified when image data are enhanced using vegetation indices, band ratios, or data transformations prior to image differencing (Coppin and Bauer 1996; Mas 1999; Rogan, Franklin, and Roberts 2002). Use of vegetation indices not only strengthens the association between spectral data and the biophysical characteristics of vegetative canopies, but it also provides a mechanism for data volume reduction (Coppin and Bauer 1994). The "vegetation indices" used in this study to identify forest biomass change is the Shortwave-Infrared/Near-Infrared (SWIR/NIR) ratio also known as the Moisture Stress Index (MSI), developed by Rock et al. (1986), and the TCT developed by Crist and Cicone (1984), which is a data transformation and not a vegetation ratio. Both are frequently used in vegetation monitoring.

Tasseled Cap Transformation

The Tasseled Cap Transformation (TCT) was first introduced by Kauth and Thomas (1976) as a data transformation to be used with Landsat Multi-Spectral Scanner (MSS) data that provided valuable soil and vegetation information for agricultural assessments. The TCT was later updated by Crist and Cicone (1984) and Crist (1985) for use with Landsat TM data. 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 brightness is simply the weighted sum of all six reflective TM bands and is responsive to the physical properties that affect total reflectance (e.g., differences in particle sizes of soil). The second component, greenness, contrasts the sum of the visible bands (TM bands 1, 2, and 3) and the near-infrared band (TM band 4), while the longer infrared bands (TM bands 5 and 7) essentially cancel each other out. Greenness responds to the combination of high absorption of chlorophyll in the visible bands and high reflectance of leaf structure in the near-infrared band, which is characteristic of healthy green vegetation. The wetness component contrasts the sum of the visible and near infrared bands (TM bands 1, 2, 3, and 4) with the longer infrared bands (TM bands 5 and 7) to determine the amount of moisture being held by the vegetation or soil, thus termed wetness. 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). Plant moisture is a biophysical parameter that is directly associated with vegetation stress and biomass reduction (Jensen 2000, 367).

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 Landsat MSS images and used brightness, greenness, and wetness values from TM images to assess forest biomass change in the Pacific Northwest from 1976-1991. Clear cut harvest activity was detected in over 90 percent of the known harvested areas. Zheng, Wallin, and Hao

(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 land cover 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) determined that wetness values were highly correlated to stand age and structural complexity in mature and old growth forest stands. The wetness component is sensitive to canopy moisture and water content and wetness values rise with increasing amount of canopy (i.e., age) until maximum canopy cover is achieved. Non-forested areas have minimal moisture content, thus have the lowest wetness values (Hansen et al. 2001).

Franklin et al. (2000) compared TCT, Normalized Difference Vegetation Index (NDVI), and Principal Component Analysis (PCA) for forest change detection. They found that when detecting clear cuts and partial harvest treatments that most of the change was concentrated in the 1^{st} and 2^{nd} principal components and the wetness component of the TCT. The NDVI was confused by dense understory vegetation, which was the same conclusion that Sader (1995) came to in his study. Collins and Woodcock (1996) explained the reliability of detecting forest change in the wetness band due to changes in the mid-infrared and concluded that wetness is a reliable indicator of forest change. The use of the wetness component consistently showed that increases in mid-infrared radiance, which measures canopy turgidity, are associated with increases in mortality. They also determined that there were insignificant changes in results between data that had been atmospherically corrected and data that had not been atmospherically corrected. They concluded that measurements of interdate forest change using brightness, greenness, and wetness should be a good indicator of change.

An enhanced wetness difference index (EWDI) has been used to detect changes in forest biomass caused by clear cuts and partial harvesting (Franklin et al. 2002b). Franklin et al. (2002b) were able to accurately estimate the area of total forest change in southeastern New Brunswick. The EWDI was developed by subtracting the TM wetness value from each preceding image date and linearly enhancing them to emphasize the forest differences of interest. Thresholds were applied based on field knowledge of areas disturbed by clear cutting, partial harvesting, or silvicultural treatments. The thresholds of wetness differences were then used to develop a change map. The TM wetness indices showed distinct patterns associated with forest structure changes known to have occurred as a result of silvicultural and harvesting operations. The areas that exhibited the greatest differences in the wetness values were classified as clear cuts, and the lesser values were classified as partial harvests. It was noted by Franklin et al. (2002b) 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 research performed by Collins and Woodcock (1996), Zheng, Wallin, and Hao (1997), Cohen et al. (1998), and Franklin et al. (2000, 2002b) prompted the desire to use the wetness component alone in a slightly different manner to detect forest change ranging from clear cuts to natural changes. There have been no published reports of using solely the TCT wetness component without further manipulation to detect changes in forest biomass. The goal of this project is to assess the ability of using a multitemporal dataset of Landsat TM TCT wetness (TCW) to detect composite forest change. The premise is similar to the EWDI used by Franklin et al. (2002b); the wetness components from each year of imagery will be extracted from the TCT data and stacked into a single image. By doing so, the differences of wetness values from year-to-year will be highlighted by the composite value and areas of like change will be identified using an unclassified classification method. Since the TCW approach has never been used, it would be ideal to compare it against a common forest change detection method, such as the SWIR/NIR ratio.

The SWIR/NIR Ratio

The SWIR/NIR ratio, also referred to as the Moisture Stress Index (MSI), has been used extensively in the eastern United States to detect changes in forest cover due to insect outbreaks and forest decline (Rock et al. 1986; Vogelmann and Rock 1988 and 1989; Vogelmann 1990; Muchoney and Haack 1994; Collins and Woodcock 1996; Jensen 2000, 362; Wolter and White 2002). The SWIR/NIR ratio was first developed and utilized by Rock et al. (1986) and is based on the Landsat TM near-infrared (TM band 4) and middle-infrared (TM band 5) bands. It measures several different highly correlated and largely inseparable vegetation parameters: biomass, damage, and water content (Vogelmann and Rock, 1988). Prior to the SWIR/NIR ratio, the 7/4 band ratio was commonly used as a vegetative index to detect forest change in the form of moisture stress (Nelson, 1983). Both TM bands (5 and 7) are within the longer infrared region, which is sensitive to the turgidity of biomass. Vogelmann and Rock (1988) compared the ability of both TM 5/4 and 7/4 ratios to detect forest change. Results were similar with both, but the TM 5/4 was most closely correlated with ground data. Therefore, the 5/4 ratio was selected over the previously preferred 7/4 ratio.

The SWIR/NIR ratio is influenced by the SWIR region, where moisture content influences reflectance: **SWIR/NIR = SWIR** $\mathbf{(MidIR)_{TM5}/NIR_{TM4}}$ (Vogelmann 1990). Moisture differences in vegetation are known to alter the relative amplitude of spectral reflectance in the SWIR band (TM band 5, 1.65µm) and the mid-infrared band (TM band 7, 2.20 µm), providing an accurate indication of leaf water content. As a leaf becomes dryer, reflectance increases in these spectral regions. In contrast, reflectance in the NIR band (TM band 4, 0.83 µm) is relatively unaffected by changes in moisture content. Thus, the dryer a leaf becomes, the higher the SWIR/NIR ratio will become (Vogelmann and Rock 1988).

Vogelmann and Rock (1989) used the SWIR/NIR ratio to detect insect damage to sugar maples (*Acer saccharum)* in the northeastern United States. The results of their study indicated that the SWIR/NIR ratio may be used to assess the state of deciduous forest defoliation. In further studies, Vogelmann (1990) compared the SWIR/NIR ratio with the widely used NDVI for change detection of coniferous and deciduous forests. NDVI was one of the first vegetation indices developed and is influenced by the visible portion of the spectrum where plant pigments impact reflectance and the near-infrared portion of the spectrum (Rouse et al. 1974). Vogelmann (1990) found that the SWIR/NIR ratio detected insect-induced defoliation in coniferous forests much better than the NDVI and detected comparable amounts of change in deciduous forests. However, for deciduous forests, the SWIR/NIR ratio was only able to discriminate between severely defoliated and non-defoliated areas. Subsequently, the NDVI was found to better identify high, medium, and low damage categories than the SWIR/NIR ratio because of the use of the visible bands, which detect chlorophyll absorption (Vogelmann 1990). The results of the 1990 study suggested that both indices, SWIR/NIR and NDVI, are appropriate for global scale monitoring of vegetation, with the SWIR/NIR ratio being suitable for both deciduous and coniferous conditions and the NDVI only suitable for deciduous forests. This illustrates that the SWIR/NIR ratio is as good as the widely used NDVI for detecting forest change, and thus will be used in this study as a baseline for comparing the effectiveness of the TCW technique.

Problem Statement

Information derived from monitoring forests via satellite imagery is useful in identifying appropriate forest management strategies. Many methods have been devised to detect changes in forest biomass, with varying degrees of effectiveness. Efficient and effective methods of using RS imagery to monitor forests are needed because there continues to be a paucity of good, practical examples of satellite RS imagery used in detection of silvicultural, partial harvest, and natural forest changes (Franklin et al. 2002b) and specifically to put forest change on private land throughout the Missouri Ozarks into context of that occurring on public lands. This project will investigate the ability of the TCW component, not previously used alone, to detect forest change at multiple scales and compare this method against a commonly used and well researched forest vegetation ratio, SWIR/NIR. As a result, this project seeks to:

1. Identify a useful tool for forest management by providing an easy and inexpensive technique to detect changes in forest biomass.

2. Characterize the structure (size and shape) of forest change patches as detected by each method, in order to compare the manner in which each method detects forest biomass change.
3. Assess forest change throughout the ecosystem by identifying rates of change on public and privately owned forests, as an aide to determine overall changes throughout the forested landscape.

Chapter 2

Methods

Change detection of vegetation using satellite imagery allows resource managers to better understand the composition and health of the vegetated environment in question. The objective of this study is to compare the infrequently used wetness component of the well-known Tasseled Cap Transformation to the commonly used SWIR/NIR ratio (Landsat TM band 5 / Landsat TM band 4) to test the effectiveness of the TCT wetness component as an indicator of forest vegetation change. The assumption is that the method using the TCT wetness component will more accurately depict forest change because it focuses on all of the spectral regions generally used to detect vegetation change (red TM band 3, near-ir TM band 4, and short wave-ir TM band 5), whereas the SWIR/NIR ratio only considers two. Detected forest change will be analyzed by areas that received silvicultural activity and determine the effectiveness of each method to detect and characterize areas of known change by extent and shape, and expand this to the detection of natural changes, such as oak decline. Differences in rates of change by owner are also of interest. Based on previous studies of forest change by ownership, it is anticipated that public land will have lower annual and gross rates of change than private lands (Turner, Wear and Flamm 1996; Crow, Host, and Mladenoff 1999; Wolter and White 2002). The end result will provide information on how each method detects forest change and determine the TCT wetness components role in forest change detection and forest monitoring.

Procedural overview

Landsat TM imagery was acquired at 2 year intervals from 1996 to 2000, with similar anniversary dates. All non-forested areas were masked out resulting in only forested areas for each image, which were the target of this study. Each image was further subset by ecological subsections that intersected with the Salem/Potosi forest districts. After subsetting, the TCT and SWIR/NIR ratio were applied to each image. The wetness band was extracted from each TCT image and stacked to create one composite Tasseled Cap Wetness (TCW) image. The SWIR/NIR ratio for each image was also stacked to create a SWIR/NIR composite image. Each image was then clustered using and unsupervised isodata clustering algorithm and then manually classified (Figure 2.1).

Data Acquisition

Landsat Thematic Mapper (TM) satellite imagery data were used in this study. This imagery has seven spectral bands including three in the visible (0.45-0.69 µm, TM bands 1, 2, and 3), one near infrared (0.76-0.90 µm, TM band 4), one short wave infrared (1.55-1.75 µm, TM band 5), one thermal infrared (10.40-12.50 µm, TM band 6), and one mid-wave infrared (2.08-2.35 µm, TM band 7); a spatial resolution of 30 meters, and a temporal resolution of 16 days (Ray 1994). The images were acquired from the United States Geological Survey (USGS) National Center for Earth Resources Observation and Science (EROS) Data Center. World Reference System (WRS) path 24 row 34 imagery was used for this study with acquisition dates of 09-28-1996, 09-2-1998, and 08-30-2000.

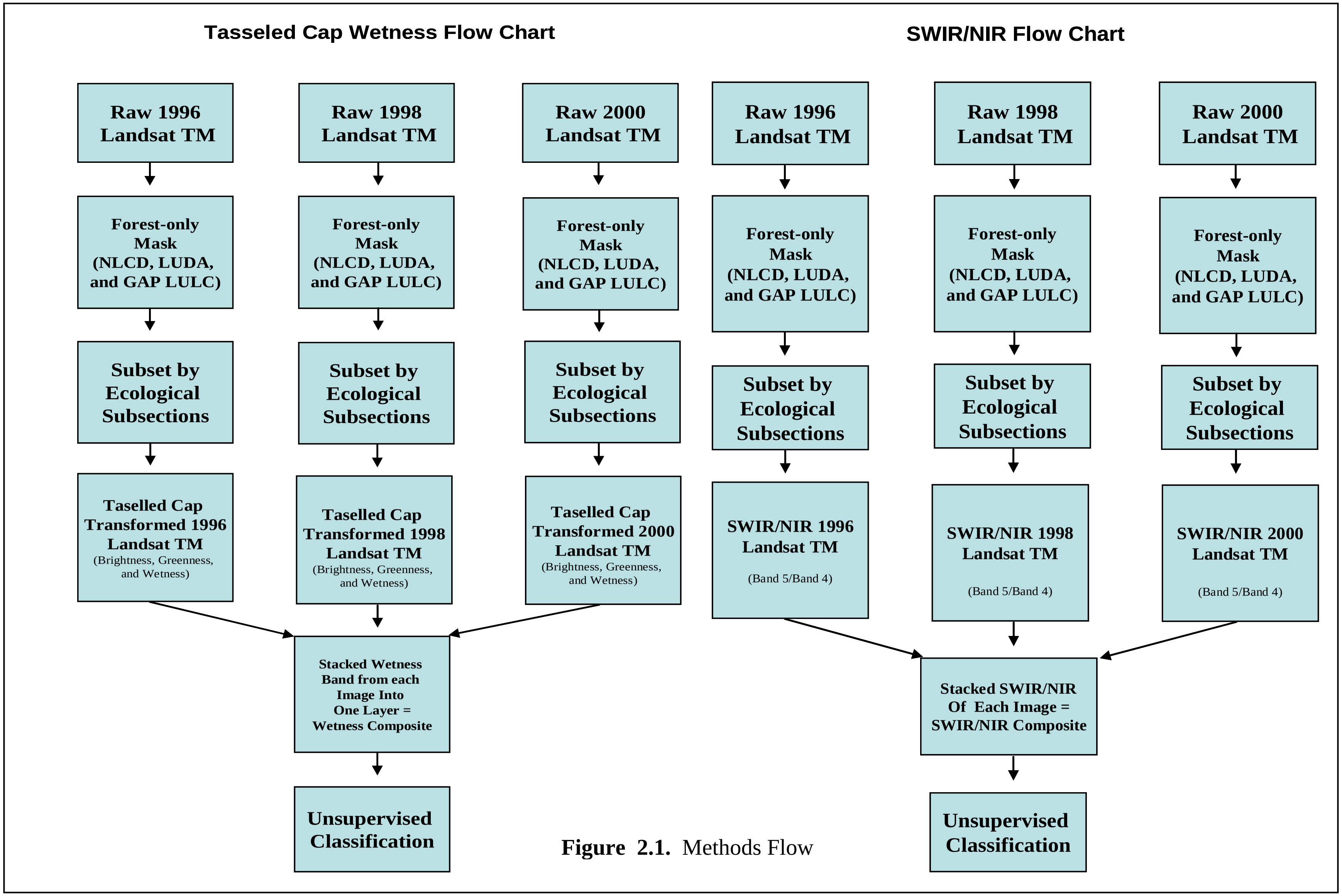


Figure 2.1. Methods Flow

Lunetta et al. (2004) indicated that a minimum of 3-4 year interval is required to monitor vegetation change events and suggested that reduction in change omission errors and detection of small, subtle changes could be achieved by decreasing temporal intervals to 1-2 years. While it is important to obtain imagery with similar anniversary dates so that phenological differences between images are not falsely interpreted as actual vegetation change (Singh 1986), it is not always possible due to the quality of available scenes (e.g., cloud cover). For this study, a time step of approximately 2 years between each satellite image was chosen (late August/early September of 1996, 1998, and 2000). This short time step was chosen primarily because the view of the Missouri Ozark forests from satellite shows that disturbed vegetation often appears fully regenerated on imagery within 5 years of disturbance (Aldrich 1975; Mike Schanta MTNF, personal conversation). The late summer time period was chosen to ensure that all tree species had a full canopy just before senescence began, which in southern Missouri generally occurs in early to mid October.

Change detection using imagery alone is not as powerful or accurate as when it is combined with ancillary GIS field data (Green, Kempka, and Lackey 1994). When the results of the image-to-image change detection are placed in the context of other spatial data layers, such as topography, property ownership, and forest stand management information, the information gains powerful data analysis capabilities. By combining the change detection information with more detailed ground and site information, one can identify various correlations and relationships between change and site conditions to better understand the phenomena in question.

The Mark Twain National Forest (MTNF) GIS Stands Inventory Database with management data from 1986 to 2003 was acquired from the MTNF staff to serve as a validation data set (Figure 2.2). The forest stands database contains multiple attributes for each stand. The information most important to this study was the year and type of silvicultural activities that have occurred within the stand. The MTNF GIS Stands Inventory Database was used along with the Missouri Public Lands GIS polygon layer and the Ozark National Scenic Riverways GIS polygon layer, which were provided by the Missouri Resource Assessment Partnership (MoRAP), to identify public and private lands within the study area. This allowed for the comparison of forest change on public versus private lands. The combination of all GIS datasets with the change detection data product enhanced the amount of information that could be deriv

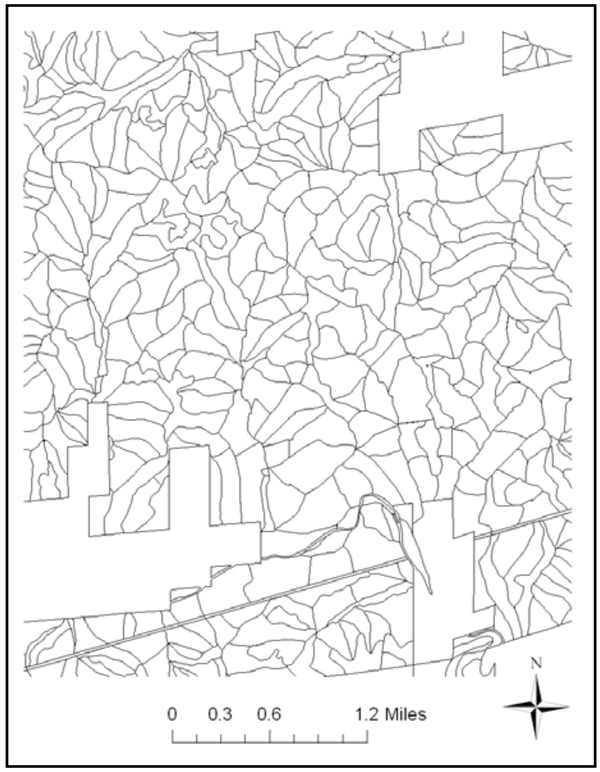


Figure 2.2. Sample of MTNF GIS Stands Inventory Database polygons.

Data Preprocessing

Rectification

Image-to-image georectification was performed on the Landsat TM images using ERDAS Imagine 8.7 remote sensing software. Georectification of satellite imagery is required so that other images and GIS data layers that encompass the same area are precisely aligned with one another in order to perform spatial analysis. Each Landsat image was geometrically registered to a 15-meter panchromatic TM reference image with a Universal Transverse Mercator (UTM) projection, zone 15, North American Datum 1983 (NAD83). All other datasets were projected to UTM, zone 15, NAD83 projection. Ground control points were evenly spaced throughout each scene to achieve a root mean square error (RMSE) of 0.5 pixel or less, which means that the registration of the image must be less than half a pixel or 15 meters from the base image. A cubic convolution resampling algorithm was used to resample the image to a 30 meter output pixel size.

Data Subsetting

Multiple land cover data sets were obtained to create a forest only mask. They included USGS Land Use Data and Analysis (LUDA) at 1:250,000 scale, 30 meter Missouri GAP, and 1:100,000 National Land Cover Data (NLCD) land use/land cover (LULC). The datasets were obtained from the Missouri Spatial Data Information Service (MSDIS) at http://msdisweb.missouri.edu/, except for the NLCD, which was provided by the MoRAP. A forest only mask was created to reduce confusion during the classification process and to include all possible forested areas. Each LULC dataset has slight differences in classification as well as different spatial scales. The mask was created by selecting the forest classes from all LULC data and performing a union. Any LULC class other than forest was omitted from the mask layer. This ensured that only forested areas, according to the various land cover datasets, would be included in the clustering and classification processes. The forest-only mask was applied to each

Landsat TM image using the mask function in ERDAS Imagine. Despite efforts to mask out all non-forest areas, inclusion of non-forest areas in the forest-only mask are probable and can be attributed to the differences in classification scheme, date of imagery used, and spatial scales of the LULC datasets.

Initially, one of the goals of the project was to distinguish between potential natural variations in forest change by analyzing change by ecological subsection. Subsequently, the forest-only masked Landsat TM images were additionally subset to the ecological subsections that intersected the Salem/Potosi ranger district, which included the Central Plateau (OZ5), Current River Hills (OZ8), Meramac River Hills (OZ9), and the St. Francois Knobs and Basins (OZ10). The final result of the subsetting phase produced three Landsat TM images (1996, 1998, and 2000) that contained only forest and were subdivided by the four ecological subsection boundaries. However, analysis by ecological subsection did not provide insightful or useful information, which is why the imagery is subset to their boundaries but there is no analysis by ecological subsection.

Application of Vegetation Indices

<u>Tasseled Cap Transformation</u>

The TCT was applied to each of the three Landsat TM images after the masking procedures. The default TCT coefficients in ERDAS Imagine were used for this study. The results of the TCT produce an Imagine image file that consists of three bands which have been attributed to soil brightness, vegetation greenness, and soil or vegetation wetness. For the purposes of this study the vegetation wetness band was extracted from each of the three TCT images and stacked into one composite TC wetness (TCW) image using the ERDAS Imagine layer stack function. The stack of the TCW values for all images was used to provide the change information over the entire temporal period from 1996 to 2000. The hypothesis was that the TCW composite would detect more change than the SWIR/NIR because it takes into account all three of the spectral regions frequently used for vegetation studies (red TM band 3, near-ir TM band 4, and mid-ir TM band 5), whereas the SWIR/NIR ratio only consider two of the three.

SWIR/NIR

The SWIR/NIR index was applied to each of the three masked TM images within a custom made ERDAS Imagine model. A model was created due to the absence of a SWIR/NIR ratio built into the Imagine software. Simply, the model calculated the SWIR/NIR ratio for each image by dividing TM band 5/TM band 4 (Vogelmann and Rock 1988) and storing the ratio values for each image in a temporary file, the temporary files were then stacked to

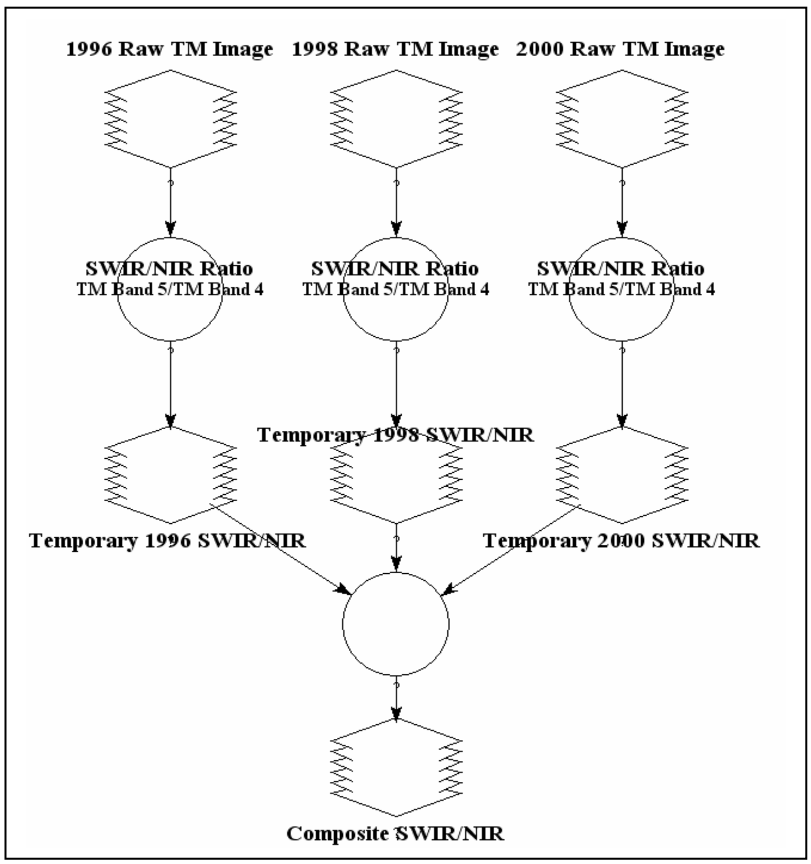


Figure 2.3. SWIR/NIR model created to convert raw Landsat TM data to SWIR/NIR ratio values.

create one composite image, just as with the TCW technique above (Figure2.3).

Unsupervised Data Classification

An unsupervised Isodata clustering algorithm was used to divide the TCW and SWIR/NIR files into spectrally similar clusters. An unsupervised classification method was used because the nature of multi-temporal change detection is often too complex for a supervised classification and requires human interpretation. Unsupervised classification employs a computer algorithm that locates concentrations of pixels with similar spectral values and generates clusters of pixels that generally belong to the same class (Schowengerdt 1997). On the other hand, a supervised classification requires spectral signatures to be generated for each class to be used in the classification. The spectral signatures are then used to train the computer program what class each pixel belongs to (Schowengerdt 1997). The classes used in this study had so much variability that a supervised classification would not provide adequate results.

In order to achieve enough separation and ensure relatively pure clusters, 75 clusters were generated for each of the two images. Each cluster was examined visually to determine the biomass change class that it best represented. 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 biomass differences. Because of this suggestion and the lack of atmospheric correction, the visual interpretation of forest change was chosen.

The act of labeling clusters consisted of comparing the state of the vegetation encompassed by each cluster on each of the three original Landsat TM images to determine what the nature of change was from 1996 to 1998 to 2000. Three forest change classes were used: forest biomass decrease, stable forest biomass, and forest biomass increase. Forest biomass decrease was characterized by healthy vegetation in the 1996 and /or 1998 image and loss of healthy vegetation in the 1998 and/or 2000 image (Figure 2.4). Stable forest biomass was characterized by no visual change in forest biomass between any of the image dates (Figure 2.5). Forest biomass increase was characterized by visible disturbance or lack of forest biomass in the 1996 and/or 1998 image followed by vegetation regeneration in the 1998 and/or 2000 image (Figure 2.6).

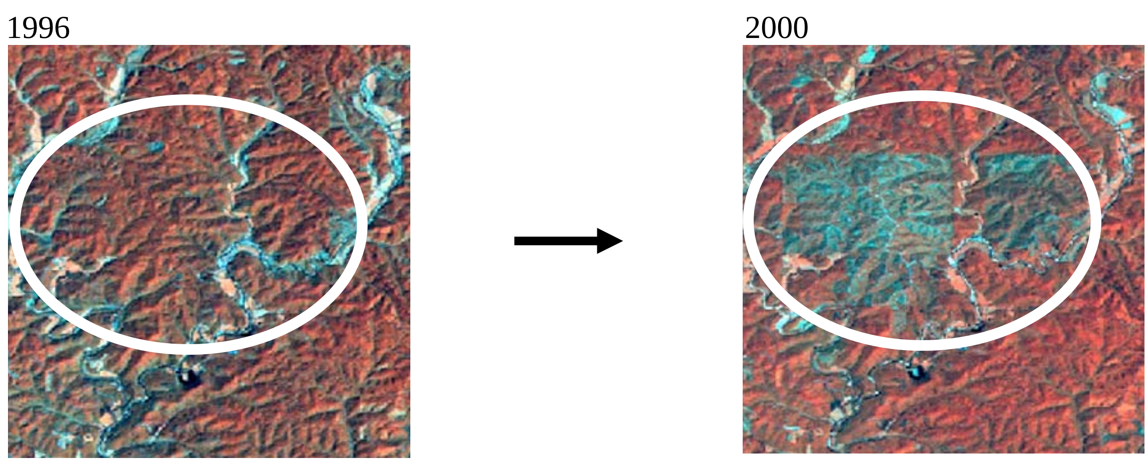


Figure 2.4. Typical example of area of biomass decrease. Note vegetated area (appears as red) in 1996 image and lack of vegetation in 2000 image (appears as cyan), which indicates biomass decrease as a result of forest harvesting.

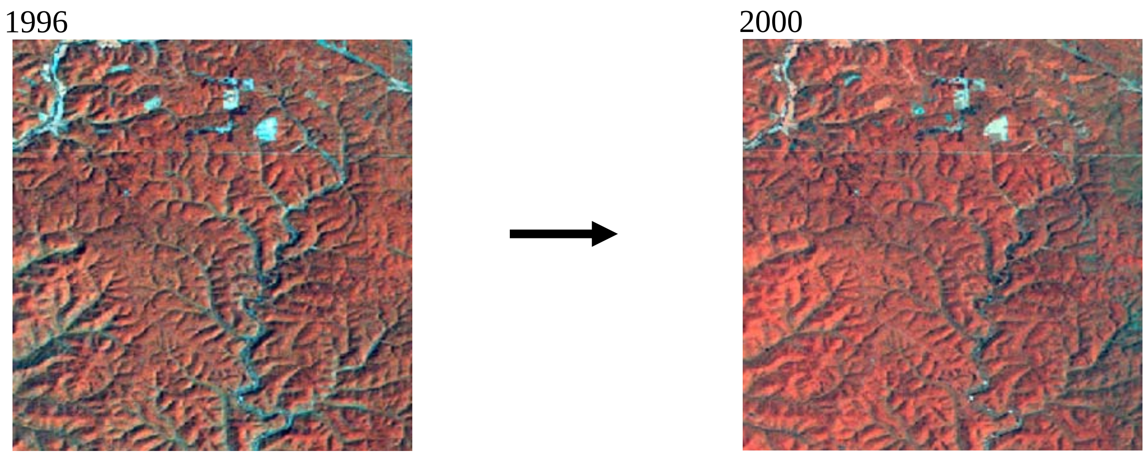


Figure 2.5. Typical example of area of stable biomass. Note vegetated area (appears as red) in 1996 image and same vegetation in 2000 image, which indicates that no changes in biomass occurred between 1996 and 2000.

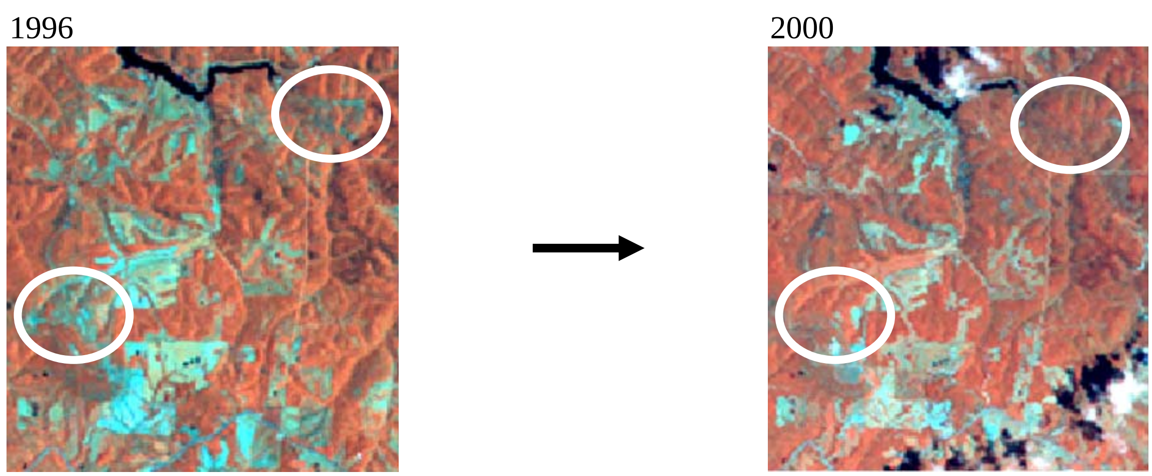


Figure 2.6. Typical example of area of biomass increase. Note unvegetated areas (appear as cyan) in 1996 image and increase in vegetation in 2000 image (appears as red), which indicates biomass increase as a result of forest regeneration.

Analysis

Public and Private Forest Delineation

Delineation of public and private forests was achieved by using a number of GIS polygon datasets related to land ownership. The datasets used consisted of the MTNF GIS Stands Inventory Database, a Missouri Public Lands GIS polygon layer, and the Ozark National Scenic Riverways GIS polygon layer. These GIS layers were used to identify public forestland, which included Forest Service, National Park Service, and Missouri Department of Conservation properties that were forested. The three GIS layers were merged in ArcGIS to create one pubic lands polygon file. The public lands polygon file was then converted to a grid with a 30 meter cell size so that it would correspond with the change information for the TM imagery, which has a 30 meter spatial resolution. It was assumed that private forestlands were everything that was not public forestland. Within the grid, the public land delineated by the GIS layer was given a public lands code and the remaining land was given a private lands code. This was performed on the TCW detected forest biomass change layer only based on its ability to detect forest change. In order to combine the ownership data with the forest change data, the TCW forest change image was converted to a grid with 30 meter cells. The ownership grid layer and the forest change layer were added together to create a forest change by land ownership grid.

Percent Change in Stands by Activity and Year

The Forest Service GIS stand polygons were subset by silvicultural activity type and year of activity to represent different extents and nature of change at these extents. Each activity type (clear cuts, intermediate cuts, and salvage cuts) was divided into separate GIS layers by year of activity between 1996 and 2000, which corresponds with the image dates. A layer of Forest Service stands that received no management during the same time frame was also created. The resulting GIS layers were overlayed onto the change detection grids produced by the TCW and SWIR/NIR techniques. The tabulate areas function in ArcView was used to calculate the percentage of each change class for all stands within a given activity (including no-management stands) and year for each technique. The results indicate the percent of area within each management activity that experienced change or no change. This helps to summarize the characterization of change depicted by each method by year and silvicultural activity type in the form of proportion of the area of the stand that was altered. The results also help to verify the different extents of each silvicultural activity.

Landscape Metrics

Landscape metrics are measures frequently used to study the ecological state of a landscape. They can be used to determine the interaction between landscape patterns and ecological processes, and can be used to study both natural and anthropogenic change (Jensen 2000, 367). The use of a standardized patch shape is one of a number of metrics that can be used to identify patterns within a landscape. Patch shapes indicate the extent of human influence on a landscape's structure and can be used as indicators of natural and anthropogenic stressors. Humans create simple landscape patterns, whereas nature creates complex patterns (Jensen 2000, 367; Wolter and White 2002). Therefore, the Normalized Landscape Shape Index (NLSI) was used to determine the patch shape for each silivicultural activity and the type of change that occurred within that activity (i.e., biomass reduction, stable biomass, and biomass increase).

Biomass reduction patches in stands that received management should have simple shapes due to the relatively uniform shape indicative of forest harvests. Conversely, the areas of biomass increase, or regeneration, should have relatively more complex landscapes due to the lack of uniformity of natural vegetation regeneration. Biomass decrease and increase patches occurring in stands that did not receive management should be relatively more complex, because they are assumed to have been caused by natural phenomena (e.g., drought, insects, windthrow, etc.). The NLSI was used to help reinforce the detection of anthropogenic and natural changes in the landscape.

Normalized Landscape Shape Index

The NLSI provides a simple measure of class homogeneity or heterogeneity. When the patch type is relatively rare or relatively dominant, the range between the minimum and maximum total edge is relatively small, whereas when the patch type is intermediate in abundance the range is quite large. NLSI essentially measures the degree of aggregation given this variable range. The actual equation measures the total length of edge for a given class minus the minimum possible length of total edge if the class were maximally aggregated divided by the maximum possible length of total edge minus the minimum possible length of total edge to give a value between 0 and 1. A value of 0 indicates that a class is maximally aggregated and has a perfectly square shape and becomes increasingly disaggregated until a value of 1 is reached and is considered maximally disaggregated. (McGarigal et al. 2002). Generally, areas of anthropogenic disturbance should have simpler shapes than areas of natural disturbance. The NLSI gives a good indication of general class shape to identify the spatial nature of how each method detects change and potential change agents (man or nature).

Co-Occurrence

The percent of co-occurrence provides a rough idea of accuracy of each change detection method. The MTNF forest stand database indicates what year and type of management activity that a stand received, but not where within the stand the treatment was applied. Therefore, co-occurrence is used in place of a traditional error matrix because the ground data does not allow point-to-point comparison. Co-occurrence is characterized by the presence of biomass reduction pixels in stands that received forest management cuts.

To calculate the percent of co-occurrence, the GIS layers created to generate the aforementioned percent change information where used along with the TCW and SWIR/NIR forest change products. Zonal statistics by change method (SWIR/NIR and TCW) for each GIS layer were generated. If the biomass reduction value was present within a stand, then co-occurrence of forest management activity and detected forest change exists. This method of accuracy assessment lends itself to mostly errors of commission. A single misclassified or spurious pixel could indicate co-occurrence, when in fact the actual silivicultural activity was not detected. This would primarily be an issue with salvage cuts because of their small size, whereas intermediate and clear cuts generally comprise a large proportion of each stand.

Chapter 3

Results

The results exhibit similarities and differences between TCW and the SWIR/NIR ratio (Figures 3.1, 3.2, and 3.3). Both methods compare similarly with regards to aerial extents of biomass reduction, patch shape complexity, and levels of accuracy, while the main differences reside in the detection of biomass increase and accuracy of salvage cut detection. However, both methods are capable of accurately detecting broad and medium scale changes in forest biomass. Each method detects the percent of biomass reduction area expected for each management activity's spatial extent. Both methods also show that biomass reduction in managed stands has the simplest patch shapes, with biomass increase having more complex shapes. The most complex shapes are found with forest change occurring in forest stands that did not receive management from 1996 to 2000, portraying the detection of natural change within forests.

The differences found between the two methods are important in determining the appropriate applications of each. TCW consistently detected a higher volume of biomass increase than the SWIR/NIR ratio. TCW also had a higher level of accuracy when detecting stands of salvage cuts. These differences depict TCW as being better-suited for the detection of subtle changes to forest biomass and the SWIR/NIR ratio best for the detection of gross canopy changes.

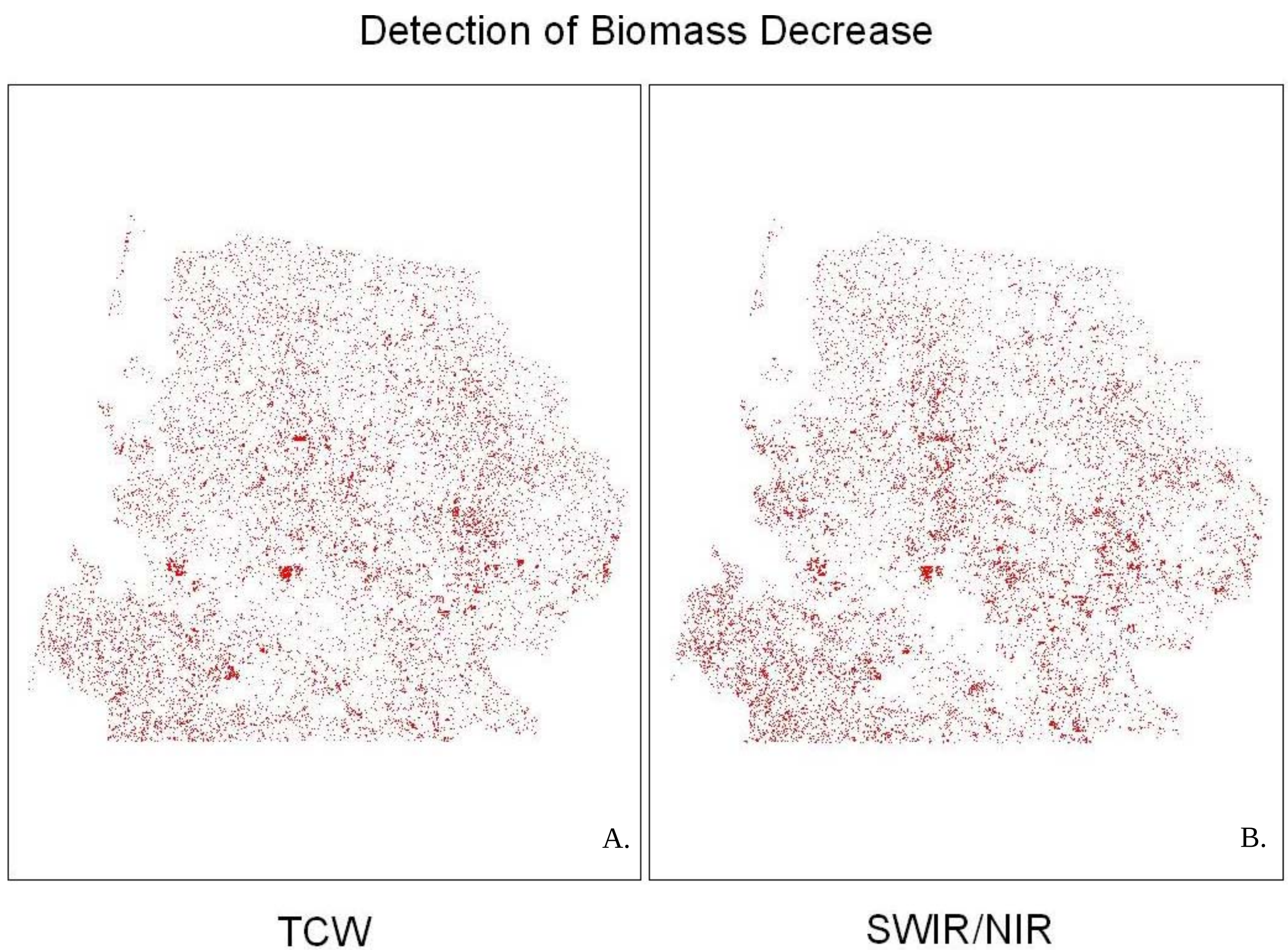


Figure 3.1. A) TCW detection of forest biomass decrease over entire study area. B) SWIR/NIR ratio detection of forest biomass decrease over entire study area.

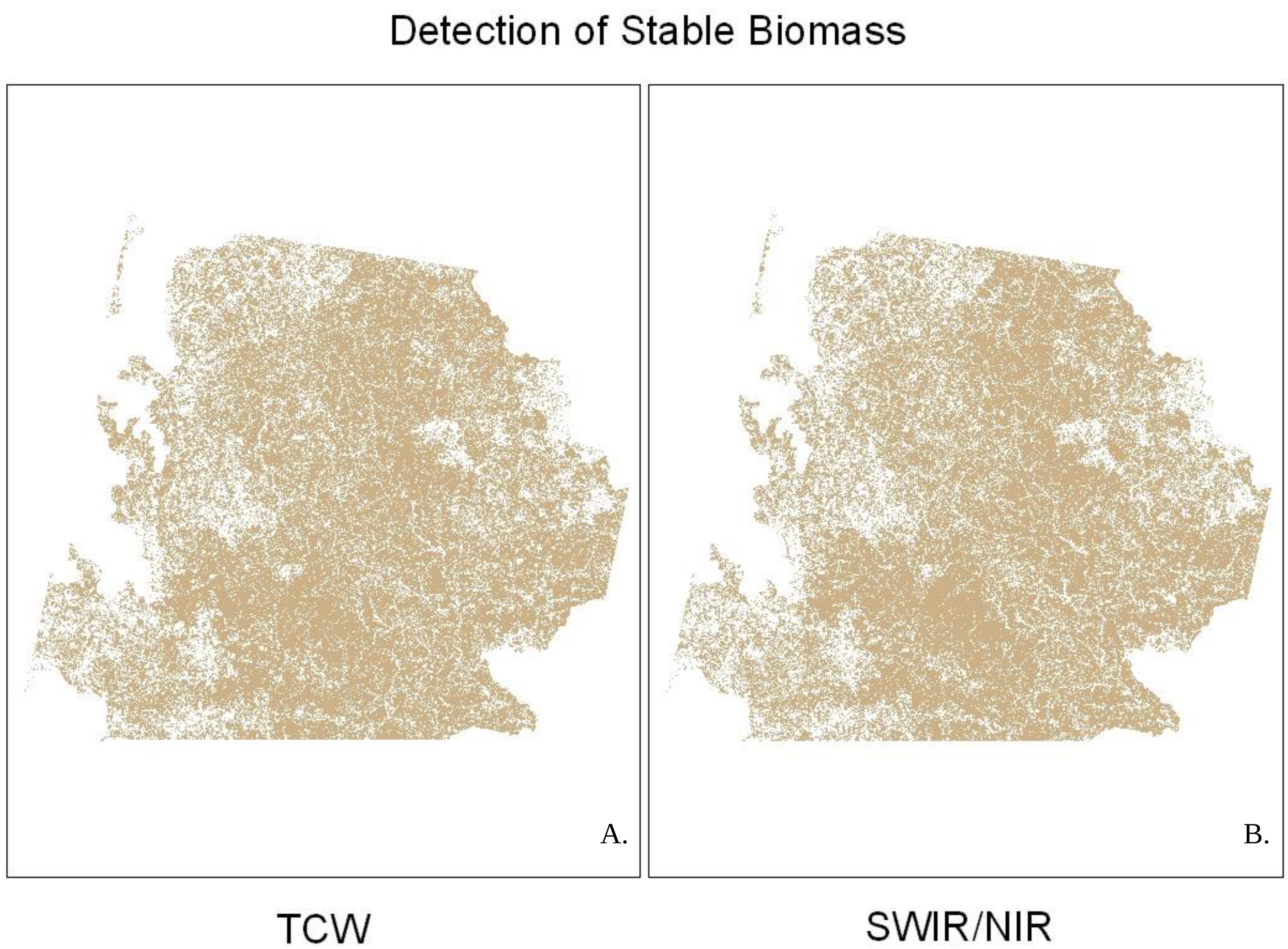


Figure 3.2. A) TCW detection of stable forest biomass over entire study area. B) SWIR/NIR ratio detection of stable forest biomass over entire study area.

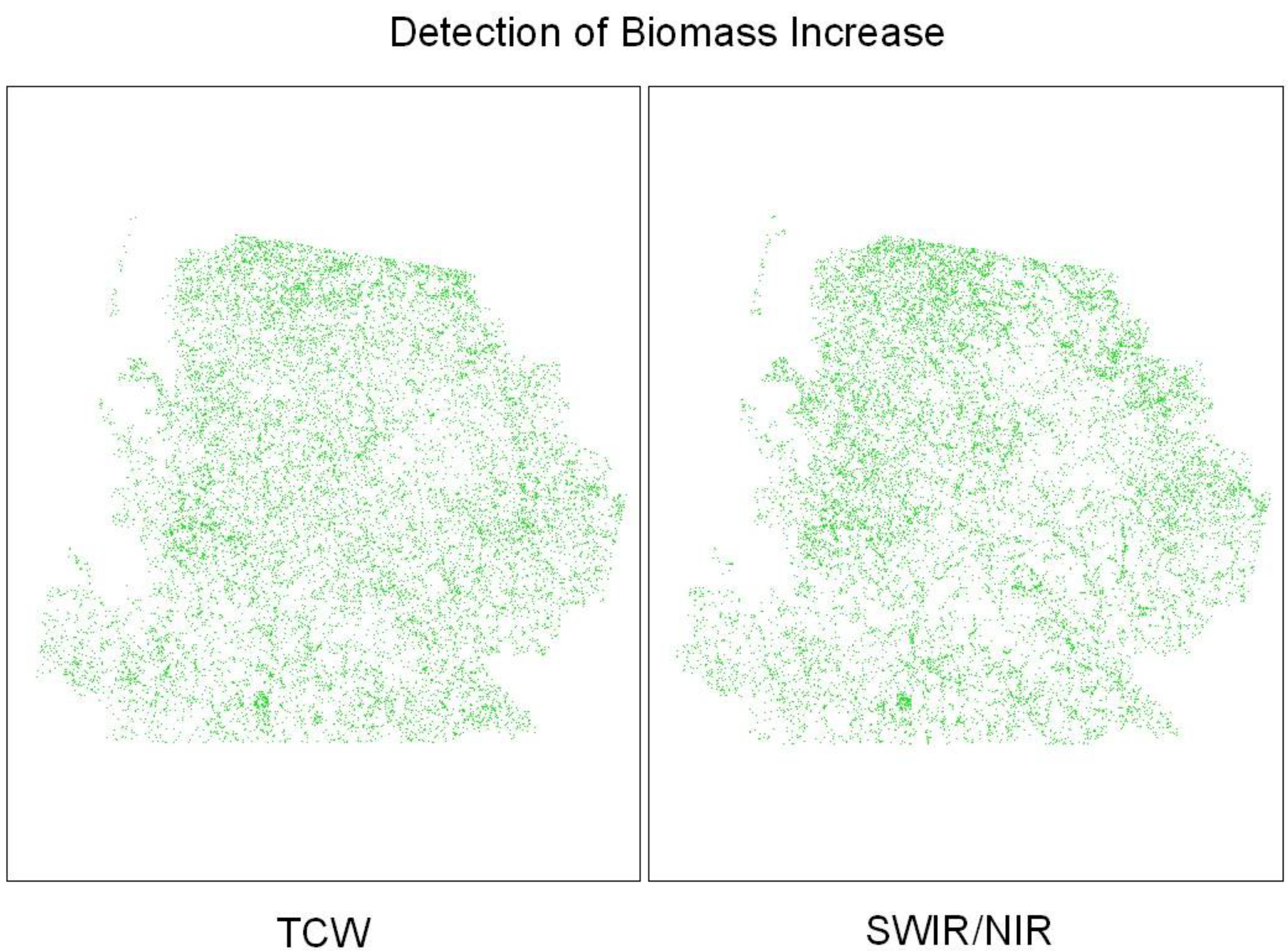


Figure 3.3. A) TCW detection of stable forest biomass over entire study area. B) SWIR/NIR ratio detection of stable forest biomass over entire study area.

Percent Change By Activity and Change Detection Method

Percent change verifies that each method (TCW and SWIR/NIR ratio) is detecting the various extents of change by each management type, including stands with no management. It identifies the proportional area of change by each management activity and change detection method relative to total area of stands that received management activity in the Salem/Potosi Ranger Districts from 1996 to 2000. The total area of the stands receiving a given activity type for a given year is divided by the area within a given change class, which produces the percent area of change activity by management activity. For example, the total area of biomass decrease within 1996 clear cut stands is divided by the total area of all stands that received clear cuts in 1996 to produce the percent area of biomass decrease for 1996 clear cut stands. Clear cuts would be expected to have a greater percentage of change, as these cuts are larger in extent, followed in descending order by intermediate cuts, salvage cuts, and stands with no management activity. This measure gives an indication to the general extent of each activity type by stand.

For all activity types, a relatively higher percentage of biomass increase would be expected in the cuts applied in 1996 and 1997 when considering change annually, because there has been a significant amount of time between the cut and the most recent imagery (2000) for regeneration to occur. As the application of the activities gets closer to the most current image date of 2000, an increase in the percentage of biomass reduction would be expected, as there has been less time for regeneration to occur. For clear cuts, a greater percentage of change, either biomass reduction or regeneration, is expected because this activity covers the greatest extent, often, but not always, the size of an entire stand. The percentage of change in stands with intermediate cuts is expected to be less than that of clear cuts because the general size of an intermediate cut is smaller, and percent change in salvage cut stands is expected to be less than intermediate cuts, because the activities are the smallest in extent. Stands with no management activity should have the least percentage of change because theoretically, no change should be occurring in these stands; therefore any change is a result of natural change, error, or activity prior to 1996.

In general, when considering change by activity over the entire time frame, biomass increase should have its highest value for activity applied in 1996. For applications applied in 1996 the most common change class is biomass increase because the vegetation has been disturbed prior to image acquisition and thus regenerates until 2000, unless the cut is applied after the image acquisition date, which would then be classified as biomass decrease. A higher percentage of biomass reduction than biomass increase is expected for activities that were applied from 1998 to 2000 because the initial change from vegetation in an earlier image to no or very little vegetation in a later image is what defines biomass decrease. The classification scheme was devised as such because the primary goal was identify a simple method to detect initial changes in forest biomass from 1996 to 2000.

<u>% Change Clear Cuts</u>

The results show a similar trend between each RS method in the percent area of change detected for clear cuts; however, there are differences as well. Stands that were clear cut in 1996 show a forest biomass increase in 28.63% of the area, stable forest biomass in 59.95%, and forest biomass decrease in 11.42% of the area using TCW (Figure 3.4A). The SWIR/NIR ratio had a larger percent of biomass increase at 33.65%, a similar stable biomass at 60.02%, and a lesser biomass decrease at 6.33% (Figure 3.4A). Stands that were clear cut in 1996 exhibit the highest proportion of biomass increase and the lowest proportion of biomass decrease despite the method used. The majority of the 1996 stands were cut prior to image acquisition, therefore the only potential change classes would be biomass increase in the case of vegetation regeneration, or stable biomass in the case of no regeneration. The amount of time

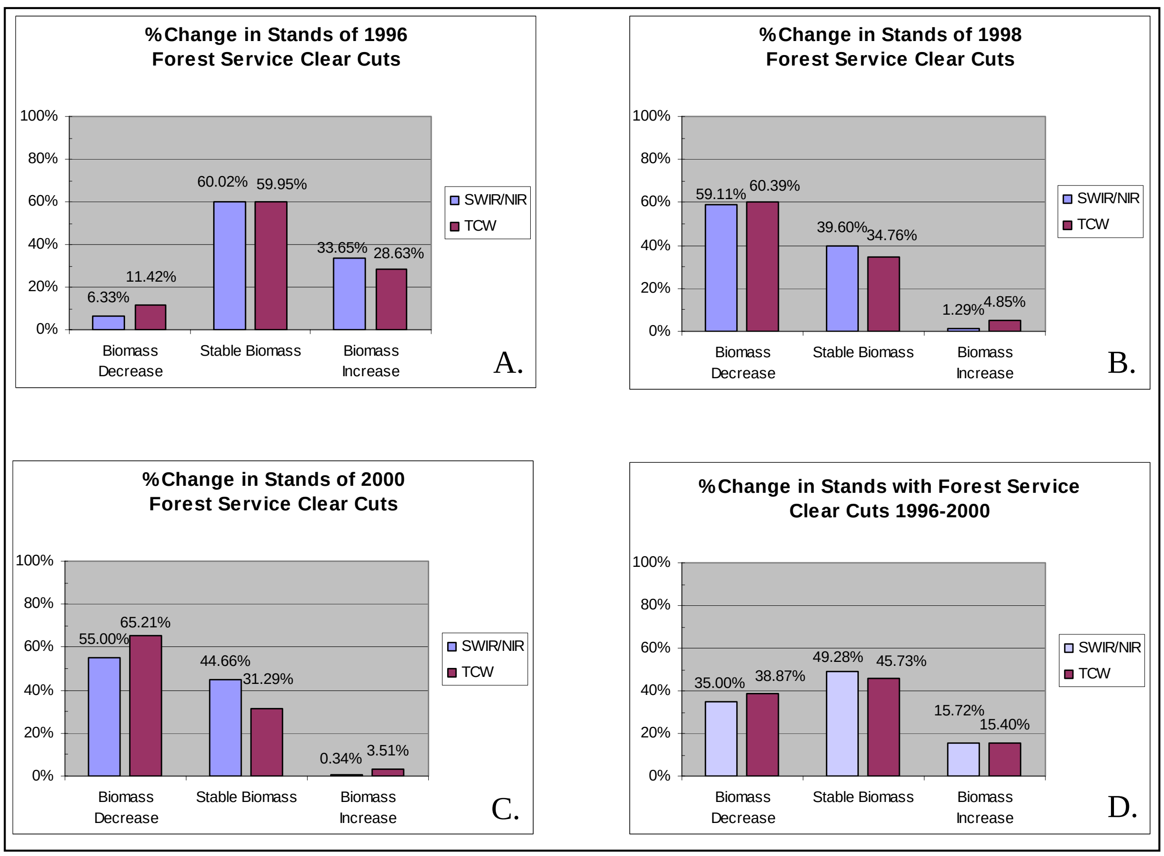


Figure 3.4. Percent forest biomass change in stands receiving clear cuts by change method. A) Percent forest biomass change by method for stands clear cut in 1996. B) Percent forest biomass change by method for stands clear cut in 1998. C) Percent forest biomass change in stands clear cut in 2000 by change method. D) Cumulative percent biomass change in all clear cut stands from 1996 to 2000 by change method.

between the first image of data (1996) and the last (2000) is enough for significant regeneration to occur.

As expected, biomass decrease for 1996 was generally low, and biomass increase had a relatively high value for both change methods used. However, TCW detected about twice as much biomass decrease for 1996. This could potentially be attributed to the principle that TCW is more sensitive to understory vegetation, which is almost completely removed during clear cuts. Whereas, the SWIR/NIR ratio is only capable of detecting the most dramatic vegetation changes and does not detect understory changes well.

Percent changes in 1998 clear cut stands using the TCW show that biomass decrease was detected in 60.39% of the stand area and biomass increase was detected in only 4.85% of the stand area (Figure 3.4B). The SWIR/NIR ratio percent changes in stands clear cut in 1998 exhibit the same general trend as the TCW, with 59.11% biomass decrease and 1.29% as biomass increase (Figure 3.4B). Both methods detected even more change in 2000 clear cut stands. TCW detected biomass decrease in 65.21% of the stand area and biomass increase in only 3.51% of the stand area (Figure 3.4C). The SWIR/NIR ratio indicated that 55% of the stand area experienced biomass decrease with only 0.34% experiencing biomass increase for the 2000 clear cut stands (Figure 3.4C). The high percentage of biomass reduction pixels in the 1998 and 2000 stands, despite the method used, is a result of them being in the middle of the time frame, leaving little time for regeneration to occur.

Expectations suggest that the percent biomass decrease pixels in stands that were clear cut in 2000 would be even higher, but some stands may not have been cut until after the acquisition date of the 2000 image. This would result in a detection of stable biomass in these stands. Over the entire time frame (1996 to 2000), TCW detected biomass decrease in 38.87% of the area and biomass increase in 15.4% of the area (Figure 3.4D). For the same time period, the SWIR/NIR ratio detected biomass decrease in 35% of the area and biomass increase in 15.72% of the area (Figure 3.4D). The parallel trends in the percent of biomass change by both methods indicate that they are each detecting virtually the same changes for clear cuts.

<u>% Change Intermediate Cuts</u>

The same general trend for clear cuts should also be expected for intermediate cuts; a higher percentage of biomass increase than biomass decrease in 1996 and a greater percentage of biomass decrease in 1998 and 2000. However, the percentage of change overall should be lower than clear cuts, because the extent of the cut is smaller. Overall, there was significantly less change detected for intermediate cuts than clear cuts, which indicates that there is a clearly observed difference in the percentage of stand area altered by these activity types.

The general trend for biomass decrease is the same for each method, but the biomass increase trends for each method are exactly opposite of one another. Stands that received intermediate cuts in 1996 show that TCW detected biomass decrease in 7.61% of the stand area and biomass increase in 5.59% of the area, with 86.81% of the area remaining stable (Figure 3.5A). The SWIR/NIR ratio detected a similar trend with 11.75% of the area as biomass decrease and biomass increase in 2.85% of area (Figure 3.5A). The biomass increase and decrease values are low because of the small size of

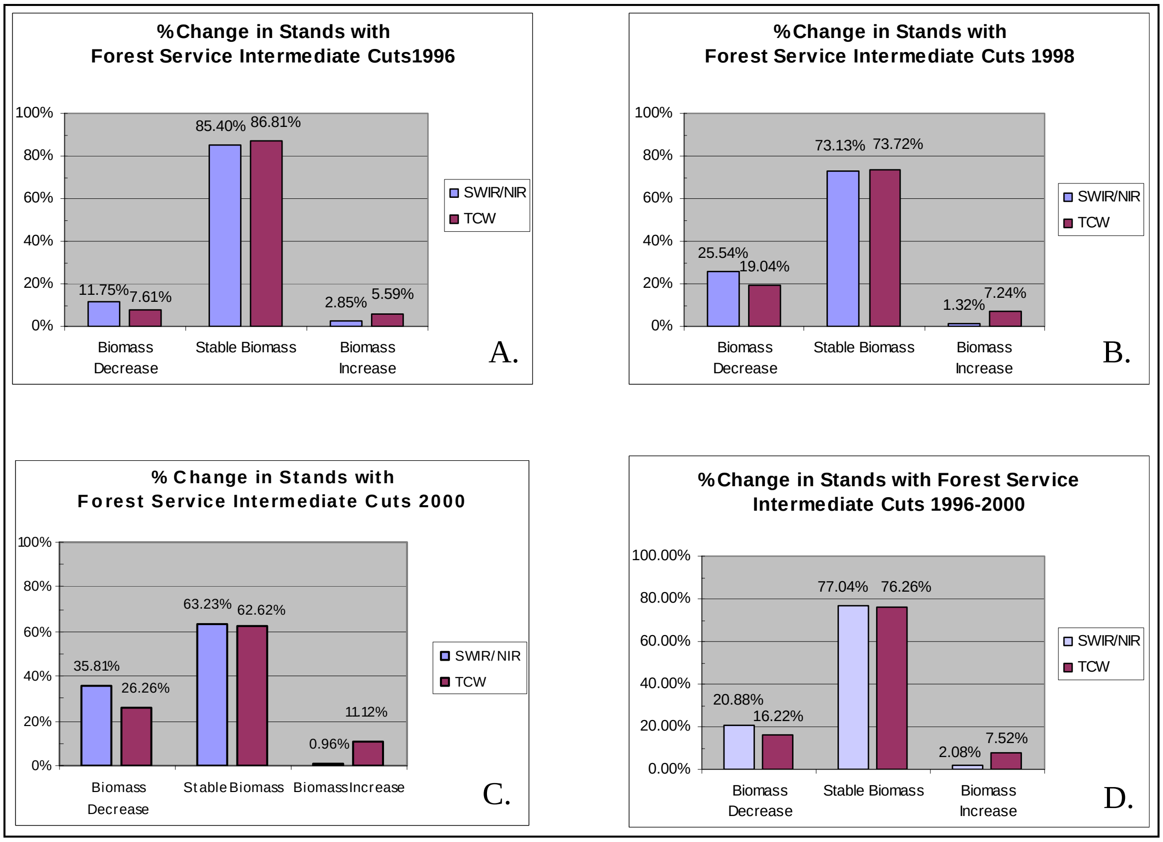


Figure 3.5. Percent forest biomass change in stands receiving intermediate cuts by change method. A) Percent forest biomass change by method for stands intermediate cut in 1996. B) Percent forest biomass change by method for stands intermediate cut in 1998. C) Percent forest biomass change in stands intermediate cut in 2000 by change method. D) Cumulative percent biomass change in all intermediate cut stands from 1996 to 2000 by change method.

intermediate cuts, which makes some more difficult to detect. The amount of biomass decrease would be expected to be less than that of the biomass increase based on the aforementioned principal regarding the passage of time since the harvesting activity; however the results show the opposite. One potential explanation is that many of the cuts were made after the acquisition date of the 1996 image and appear as biomass decrease between 1996 and 1998.

TCW detected 19.04% of the area of intermediate cuts applied to stands in 1998 as biomass decrease and 7.24% as biomass increase (Figure 3.5B). The SWIR/NIR ratio shows that 25.54% of the area experienced biomass decrease and only 1.32% experienced biomass increase (Figure 3.5B). Intermediate cut stands in 2000 show even more area classified as biomass decrease with 26.26% and a biomass increase of 11.12% using TCW (Figure 3.5C). The SWIR/NIR ratio also showed an increase in the area that was classified as biomass decrease with 35.81% and a decrease in the area of biomass increase at 0.96% for intermediate cuts applied in 2000 (Figure 3.5C). TCW shows the overall change within stands that received intermediate cuts from 1996 to 2000 as biomass decrease in 16.22% of the total stand area and biomass increase in 7.52% of the area (Figure 3.5D). For the same time period, the SWIR/NIR ratio detected a slightly higher percentage of biomass decrease at 20.88% of the area and less biomass increase at 2.08% of the area (Figure 3.5D).

The gradual increase in the amount of biomass decrease detected is related to the application of the cut in relation to the final image date. The closer to 2000 the cuts were applied, the better the chance is that they will be detected. Both methods show ideal trends for biomass decrease. They also showed less percent area of change than clear cuts. More biomass decrease is detected by the SWIR/NIR ratio likely because of its inability to recognize remaining understory vegetation, thus only detecting major canopy changes. The TCW is likely able to detect the same canopy change, but also recognizes that there is vegetation in the understory resulting in a lower percentage of biomass change detected. The SWIR/NIR ratio shows the most logical trend for biomass increase values, with the area of biomass increase declining as the cuts get closer to the 2000 imagery date. The TCW shows the opposite trend, with biomass increase values actually rising as the cuts get closer to the imagery date. It is not clear why this difference in biomass increase trends exists.

% Change Salvage Cuts

The percentage of overall change for salvage cuts is expected to be less than clear cuts and intermediate cuts, because salvage cuts are the smallest in spatial extent. Many times, salvage cuts are performed in the understory and may not be visible from the view of a satellite. The overall percentage of biomass reduction detected was indeed less than both the intermediate and clear cut areas. The amount of biomass increase detected is less than that of clear cuts, but comparable to that of intermediate cuts.

Both methods show similar results for biomass decrease in salvage cut stands, but again show diverging values for biomass increase. Stands that were salvage cut in 1996 show biomass increase in 8.34% of the total area and biomass decrease in 5.47% of the area with TCW (Figure 3.6A). The SWIR/NIR ratio had 7.22% of the area as biomass increase and 6.32% of the area as biomass decrease for 1996 intermediate cuts (Figure 3.6A). As with clear cuts, more area is classed as biomass increase than decrease due to the timing factor. TCW biomass decrease in 1998 salvage cut stands increases to 22.11% with biomass increase dropping to 5.73% (Figure 3.6B). The same is true for the SWIR/NIR ratio with an increase to 21.61% biomass decrease and only 1.21% of biomass increase (Figure 3.6B). Less area of biomass increase is detected when using the SWIR/NIR ratio, which is likely related to its inability to detect subtle changes in biomass.

TCW used for stands that received salvage cuts in 2000 shows an unexpectedly high percentage of area experiencing biomass decrease at 50.49% and higher percentage of biomass increase at 12.51% (Figure 3.6C). The SWIR/NIR ratio also has an unexpectedly high percentage of biomass decrease in 2000 with 56.7% but, again, much lower biomass increase than TCW at 2.80% (Figure 3.6C). The high percentage of biomass decrease in 2000 is mostly attributed to the small sample size with very few stands receiving abnormally large salvage cuts. The overall percent change values provide a more accurate indication as to the proportion of salvage cut stands that experienced biomass change. From 1996 to 2000, TCW found biomass decrease in 13.08% of the area and biomass increase in 8.09% of the area (Figure 3.6D). The overall percentage for the SWIR/NIR ratio biomass decrease is 14.07% and 5.46% for biomass increase (Figure 3.6D). These overall values indicate that both methods are detecting the amount of biomass removed by salvage cuts that would be expected in relation to clear cuts and intermediate cuts.

The difference in the detection of forest biomass decrease between the two methods is minimal; however, the difference in the amount of biomass increase detected is relatively significant. Again, the gradual increase in area of biomass decrease as the cuts are closer to the 2000 imagery is what would be expected and illustrates that each method is detecting the salvage cuts. The trend for biomass increase for salvage cut stands is similar to that of the intermediate cut stands.

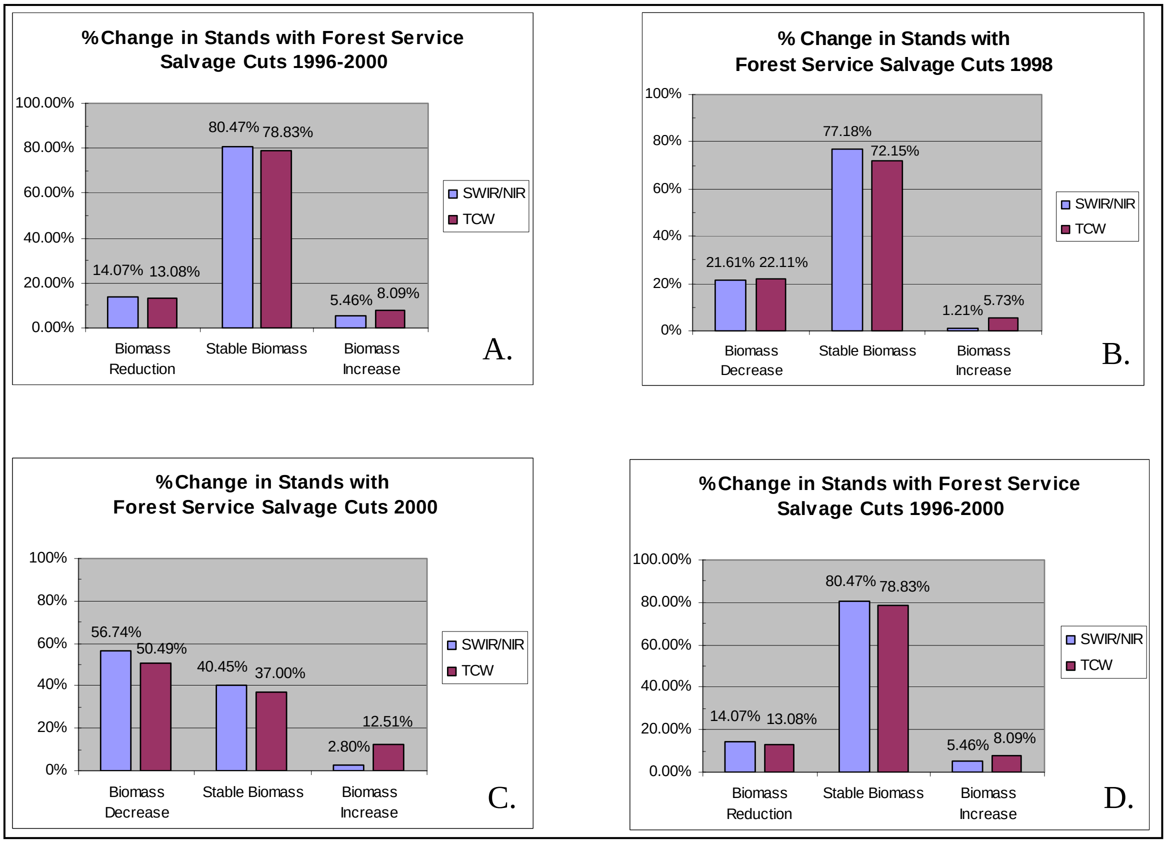


Figure 3.6. Percent forest biomass change in stands receiving salvage cuts by change method. A) Shows percent forest biomass change by method for stands receiving salvage cuts in 1996. B) Percent forest biomass change by method for stands receiving salvage cuts in 1998. C) Percent forest biomass change in stands receiving salvage cuts in 2000 by change method. D) Cumulative percent biomass change in all salvage cut stands from 1996 to 2000 by change method.

<u>% Change In Stands Not Receiving Management Activity</u>

All Salem/Potosi stands that did not receive Forest Service management cuts from 1996 to 2000 were used to calculate these values. Stands that received no management should exhibit the lowest levels of change, if any. It is assumed that any biomass reduction that occurred in these stands is caused by natural disturbances or is from activity prior to 1996. Any biomass increase is attributed to regeneration in areas that received some type of forest service activity immediately prior to the acquisition of the earliest imagery date used or is regeneration from a natural disturbance. The "no management results" could be used to identify potential sites that have experienced decline due to natural causes (e.g.,, drought, insect infestation, windthrow, etc.).

During the entire time period from 1996 to 2000, TCW indicated biomass decrease in 4.86% of the area that had no Forest Service activity and biomass increase in 6.39% of the area (Figure 3.7). The SWIR/NIR ratio showed biomass decrease in 5.92% of the area from 1996 to 2000, and biomass increase in 3.53% of the area (Figure 3.7). The fact that change was detected indicates that natural change occurred in these stands. From these results, it appears as though the SWIR/NIR ratio is detecting the same instances of biomass decrease but much less of the biomass increase. The greater percentage of area experiencing biomass increase detected by TCW could be attributed to its ability to detect more subtle regeneration as mentioned in the previous sections.

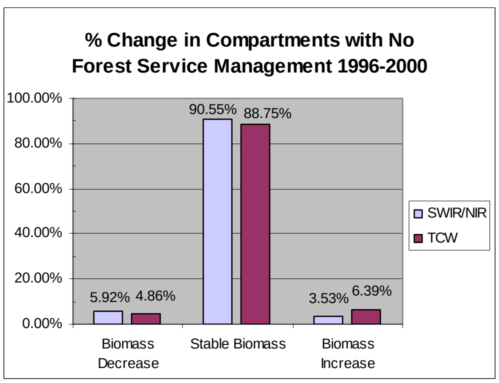


Figure 3.7. Percent forest biomass change in stands receiving no management cuts.

Co-Occurrence

The GIS forest stand database provides valuable information regarding when stands were treated and what type of treatment were applied, however it does not indicate exactly where within the stand the treatment was applied. As a result, a traditional point-to-point error assessment was not used to define accuracy, instead co-occurrence was used. Co-occurrence is a rough estimate of the accuracy of each method to detect biomass reduction within stands that received silvicultural treatments between 1996 and

2000. It is simply the percentage of stands that received some type of management treatment with subsequent biomass decrease detected in those stands. If biomass reduction occurred within a stand that received management then that was deemed a co-occurrence. The higher the percentage of co-occurrence, the greater the accuracy is assumed to be. Values for each management type are expected to be slightly different due to the scale of change and image resolution. One would expect clear cuts to have the greatest percentage of co-occurrence, because the activity is broader in extent and easier to detect. Intermediate cuts should have similar or lower percentages of co-occurrence, because they are still relatively broad in extent but vary in size and are more difficult to detect than clear cuts. Salvage cuts are expected to have the lowest percentage of co-occurrence, because these are the smallest activities based on aereal extent, and some may not be detectable due to small size or application of cuts that occur in the understory.

<u>% Co-occurrence</u>

Despite the management activity, TCW has a slightly greater percentage of co-occurrence than the SWIR/NIR ratio. The percent co-occurrence of biomass decrease values in Forest Service stands that received clear cuts from 1996 to 2000 is 73.98% for the SWIR/NIR ratio method and 76.87% for TCW (Figure 3.8), which roughly indicates that TCW is slightly more accurate at detecting clear cuts than the

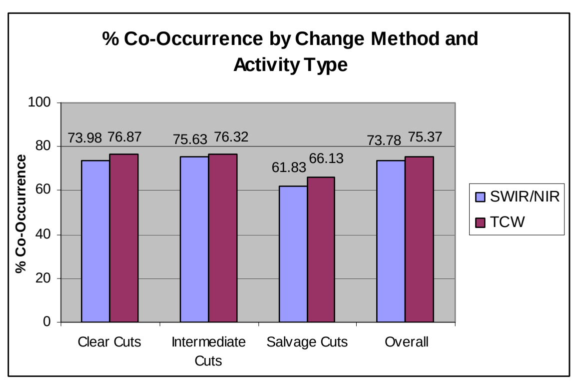


Figure 3.8. Percent co-occurrence of biomass change by management activity and change method.

SWIR/NIR ratio. Each method does an even more comparable job detecting intermediate cuts. The TCW detected a co-occurrence of biomass decrease at 76.32% for intermediate cut stands from 1996 to 2000 (Figure 3.8). The SWIR/NIR ratio had roughly the same level of co-occurrence at 75.63%. The similar levels of co-occurrence between each method indicate that they both do an adequate job of detecting biomass decrease resulting from intermediate cuts. The greatest difference in co-occurrence values are found in the detection of salvage cuts. The TCW detected a co-occurrence of biomass reduction at 66.13% for salvage cut stands from 1996 to 2000. The SWIR/NIR ratio has a much

Table 3.1. Co-occurrence values for 1996-2000 for all management types and both RS methods. Note slightly greater ability of TCW to detect biomass decrease in stands that received Forest Service silvicultural treatments.

Activity	TCW # of stands with co-occurrence	SWIR/NIR # of stands with co-occurrence	Total # of stands receiving silvicultural treatments
Clear Cuts	319	307	415
Intermediate Cuts	883	875	1157
Salvage Cuts	123	115	186
Overall	1325	1297	1758

lower level of co-occurrence compared to TCW at 61.83%. Overall co-occurrence combined all management activities to determine co-occurrence from all stands receiving management from 1996 to 2000. The TCW had overall co-occurrence in 75.37% of the stands, whereas the SWIR/NIR ratio had overall co-occurrence in 73.78% of the stands.

Normalized Landscape Shape Index – Clear Cuts

The NLSI values for both methods show that, overall, biomass decrease within the stands that received clear cuts are relatively homogeneous in shape, stable biomass values are relatively complex, and biomass increase values are the most complex. In the biomass decrease class, the TCW has a slightly less complex shape than the SWIR/NIR ratio with a value of 0.288 compared to 0.321 (Figure 3.9). The stable biomass class shows no difference between the two methods. TCW has a value of 0.442, and the SWIR/NIR ratio has a value of 0.441. The greatest discrepancy between the two methods is found in the biomass increase class. TCW has a much more complex shape in biomass increase with a value of 0.567 compared to the SWIR/NIR ratio, which has a value of 0.439.

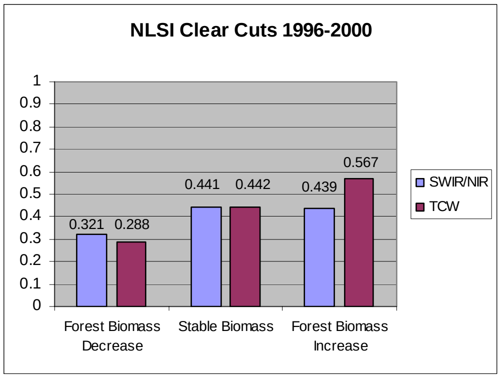


Figure 3.9. Normalized Landscape Shape Index for Intermediate Cut stands from 1996 to 2000.

The comparable NLSI value for biomass decrease shows that both methods are detecting the man-made harvested patches. The stable biomass is relatively complex compared to other management activities, because there was much more disturbance in clear cuts stands than the other stands. This left smaller areas of stable biomass with more complex edges. Biomass increase shapes are dramatically different due to significantly more small complex patches of biomass increase detected by the TCW.

Normalized Landscape Shape Index – Intermediate Cuts

The NLSI for biomass reduction in the detection of intermediate cuts with the SWIR/NIR ratio has less complex shapes than the TCW method with values of 0.389 and 0.461 respectively (Figure 3.10). There is relatively no difference in the shape of areas of stable biomass with a SWIR/NIR value of 0.214 and a TCW value of 0.225. NLSI values for biomass increase indicates highly complex shapes with values of 0.723 for the SWIR/NIR ratio and 0.762 for TCW.

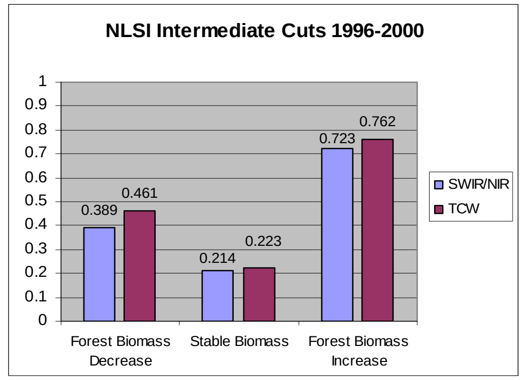


Figure 3.10. Normalized Landscape Shape Index for Intermediate Cut stands from 1996 to 2000.

NLSI shows that, overall, intermediate cuts that were detected have a more complex shape than clear cuts, which is what would be expected due to the more heterogeneous nature of thinnings. Thinnings, which comprise a large proportion of intermediate cuts, are often applied throughout a stand in a non-uniform manner. Also, intermediate cuts are not as large as clear cuts and may not be as homogeneously detected by the imagery at the resolution used. Biomass decrease of intermediate cuts shows a more complex shape than clear cuts and a similar shape complexity to salvage cuts, despite the method being used. Biomass increase values indicate significantly more complex shapes for intermediate cut stands than clear cuts stands, which is a function of the smaller, more complex nature of intermediate cuts compared to clear cuts.

The SWIR/NIR ratio detected a greater percentage of biomass reduction and shows that patches are less complex in shape than the TCW patches. This can be attributed to the TCW's ability to still detect the understory vegetation that remains after an intermediate cut, resulting in more complexly shaped patches. TCW has a more complex biomass increase shape than the SWIR/NIR ratio because TCW is likely able to detect more subtle biomass regeneration, which emerges in a more heterogeneous manner. NLSI values show that intermediate cuts are being detected in the shape and general size that is expected.

Normalized Landscape Shape Index – Salvage Cuts

Both methods show the same trend of NLSI values for salvage cuts. NLSI values for biomass reduction of salvage cut activities using the SWIR/NIR ratio method is 0.399 and 0.439 for the TCW method (Figure 3.11). The shape of stable biomass between each method is relatively similar, with a NLSI value of 0.215 for SWIR/NIR ratio and value of 0.220 for TCW. The forest biomass increase values are also similar with a NLSI measure of 0.614 for SWIR/NIR and 0.682 for TCW.

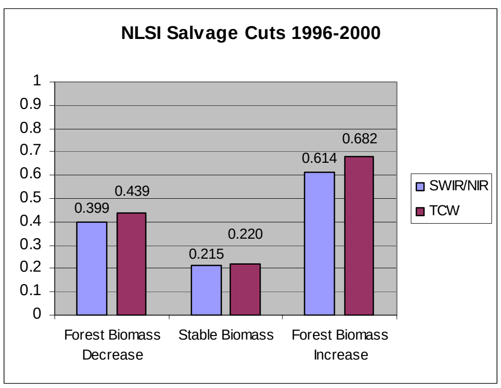


Figure 3.11. Normalized Landscape Shape Index for Salvage Cut stands from 1996 to 2000.

The NLSI indicates that forest biomass reduction is occurring in a more uniform manner than biomass increase within salvage cut stands. This indicates that the salvage cuts are being detected, because they should be more uniform and less complex in shape than biomass increase. Biomass increase is complex, because areas that were cut do not grow back evenly. Salvage cut biomass reduction shape is similar to that of intermediate cuts. This is acceptable and explainable, because both types of cuts do not occur in a large uniform manner as clear cuts; therefore, they should have a relatively more complex shape than clear cuts. However, ideally, salvage cuts would have a more complex shape than intermediate cuts due to their smaller size and “salt-and-pepper” nature. The unexpected difference between salvage cuts and intermediate cuts occurs in the biomass increase class, where intermediate cuts have a much more complex shape relative to salvage cuts. One would expect the values to be more similar, as with the biomass decrease values, or for the salvage cuts to have a slightly more complex biomass increase shape due to the scattered nature and smaller size of the cuts. At least two factors may likely explain this difference: the small sample size of salvage cuts compared to intermediate cuts and the difficulty detecting biomass increase in salvage cut stands. Because salvage cuts are often undetectable due to application in the understory, only the largest most uniform of the salvage activities are detected, which produces the relatively simple patch shapes.

The fundamental difference of the detection ability between each method influences shape complexity of detected biomass change classes. The SWIR/NIR ratio detected a slightly greater percentage of biomass reduction than TCW but resulted in a more homogeneous patch. TCW detected more heterogeneous biomass increase patches, likely because of its sensitivity to subtle vegetation changes, which occur in a non-uniform manner. The SWIR/NIR ratio only detects the most dramatic changes and is therefore more homogeneous than the TCW detection of biomass increases.

Normalized Landscape Shape Index – Stands Not Receiving Management Activity

Overall, the same trend is present as previously seen, but TCW identifies more complex patch shapes. The SWIR/NIR ratio shows slightly more homogeneous biomass reduction patches at 0.508 than TCW at.618 (Figure 3.12). As with the stands that received intermediate and salvage management activity, the stable biomass for stands with no management activities has a simple shape and is quite similar between change methods. The SWIR/NIR ratio has a value of 0.071 and TCW has a value of 0.077**.** Biomass increase shows that SWIR/NIR (0.579) has slightly more homogeneous patch shapes than TCW (0.638). TCW consistently had more complex patch shapes, which means that it is either accurately detecting subtle changes or has many misclassified spurious pixels.

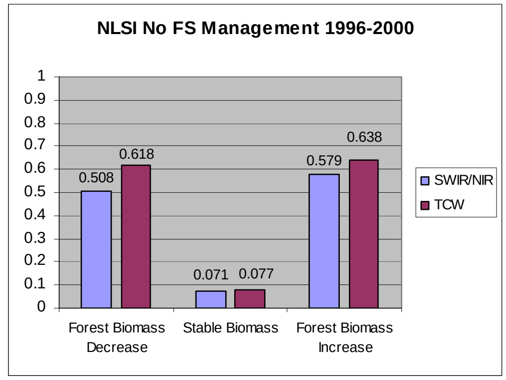


Figure 3.12. Normalized Landscape Shape Index for stands with no management from 1996 to 2000.

Patch shape for biomass reduction is far more heterogeneous and complex for areas with no management than areas with management. This is a positive sign that natural changes with rough and complex shapes are potentially being detected. Biomass increase patches show the most similarity in NLSI value with salvage cuts, which is again promising in that natural changes in biomass due to drought or insects would be most similar in size and shape to salvage activity. It also shows that biomass reduction patches are equally heterogeneous as biomass increase patches, which is a departure from the stands that received silvicultural activities where biomass reduction patches were far more homogeneous than biomass increase patches.

Rates of Change on Public and Privately Owned Land

Cumulative

Cumulative change illustrates change over the entire forested landscape within the study area. Public lands, which include Forest Service, Missouri Department of Conservation, and Ozark National Scenic Riverways lands, comprise 22.54% of the study area, whereas privately held land accounts for 77.46% of the study area (Figure 3.13). The TCW technique detected different rates of forest biomass change by land ownership.

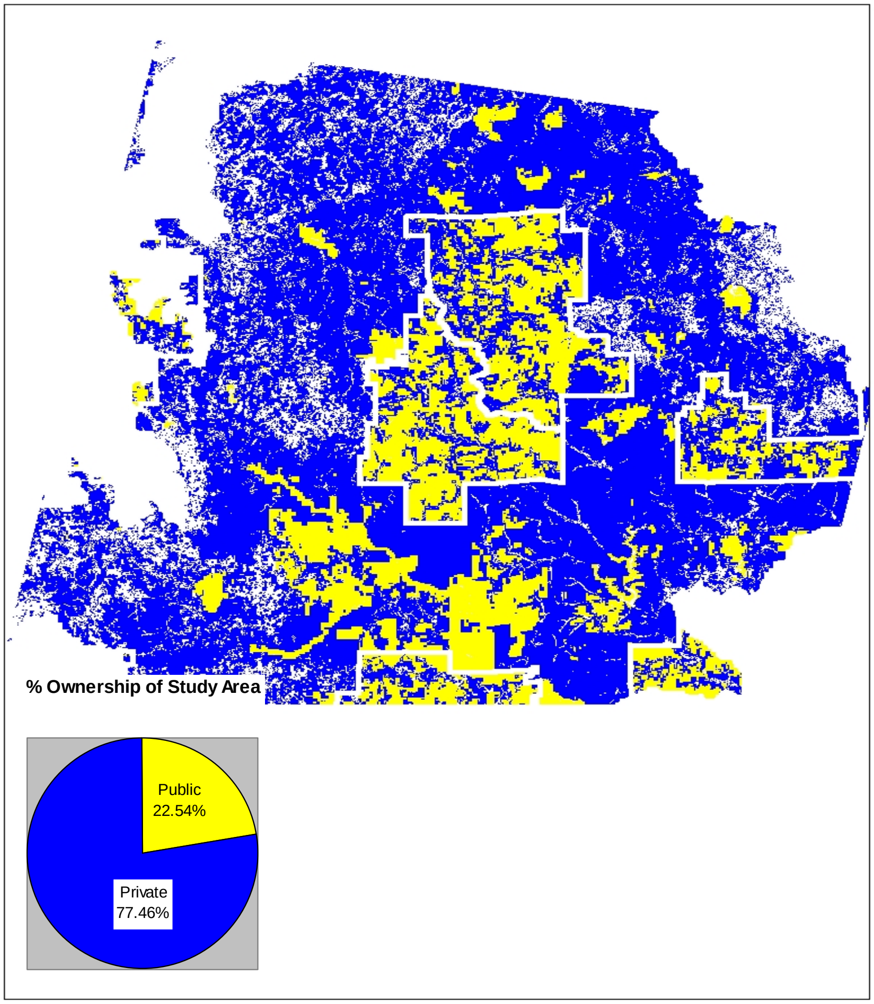


Figure 3.13. Percent Land Ownership in the study area.

Biomass reduction occurred on 10% of the forested area, with 8.64% occurring in privately owned forests and 1.36% occurring on publicly owned forests (Figure 3.14). Biomass increase occurred on approximately 11% (9.41% on public lands and 1.62% on private lands) of the forested area.

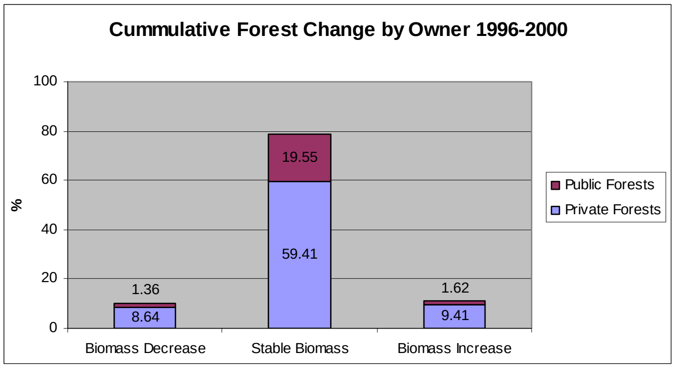
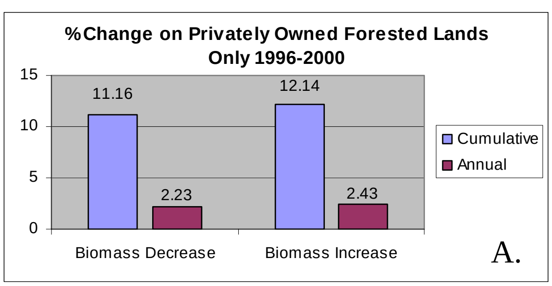


Figure 3.14. Cumulative forest change within study area separated by owner.

Relative Forest Change by Owner

In contrast to cumulative change, rates of change on only private and only public forest lands were calculated to determine relative differences in rates of change within public and private forests. Within private forests, 11.16% (2.23% annually) experienced biomass reduction, while 12.14% (2.43% annually) experienced biomass increase (Figure 3.15A). Within all public forest lands, 6.05% (1.21% annually) experienced biomass decrease and 7.19% (1.44% annually) experienced biomass increase (Figure 3.15B).



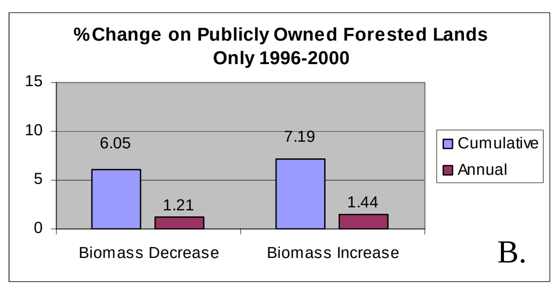


Figure 3.15. A) Cumulative and annual change on only privately owned lands. B) Cumulative and annual change on only publicly owned lands.

Other studies (Spies, Ripple, and Bradshaw, 1994; Zheng, Wallin, and Hao 1997;Wolter and White 2002) have also found rates of harvesting higher on private forests than public due to the lack of land management restrictions (Figure 3.17). However, despite that fact, the privately owned lands had almost twice as much biomass change. Because private lands also had twice the decrease of public lands, both had relatively even rates of biomass change (i.e., same biomass decrease and increase values), which is surprising.

Table 3.2. Biomass change by owner and management status.

		Biomass Decrease (ha)	Stable Biomass (ha)	Biomass Increase (ha)
Public - Forest Service Lands				
	Clear Cut Stands	622	732	246
	Intermediate Cut Stands	919	4321	426
	Salvage Cut Stands	131	786	81
	Stands Not Receiving Treatment	6,877	125,463	9,034
	Total Forest Service Lands	8,548	131,302	9,787
Other Public		9,216	139,010	12,960
	Total All Public	17,764	270,312	22,747
Private		148,184	1,018,787	161,316
	Total	165,949	1,289,099	184,062

<u>Change on Public Lands</u>

Public lands are managed by the Forest Service, National Park Service, and the Missouri Department of Conservation. According to the Forest Service management plan, the Forest Service harvests approximately 1% of its forests on an annual basis (USDA Forest Service 2002). To determine differences in rates of change by different managers of public lands, the Forest Service lands were separated from the public lands resulting in Forest Service lands and other public lands. The overall rates of change on only Forest Service lands were 6.29% biomass reduction (1.26% annually) and 6.59% biomass increase (1.32% annually; Figure 3.16A). Other public lands experienced biomass reduction in 5.72% (1.14% annually) of the area and biomass increase in 8.04%

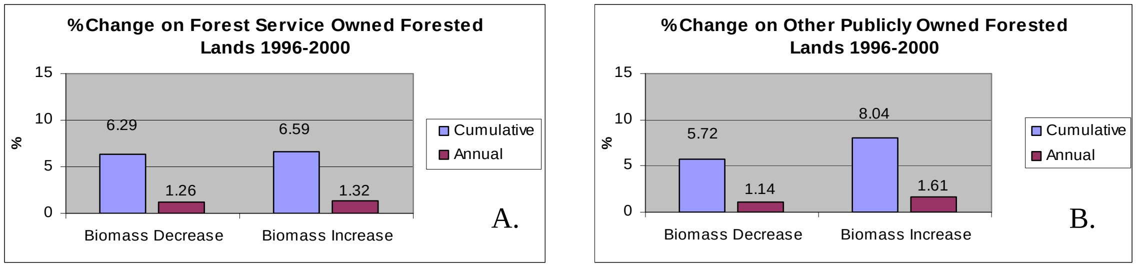


Figure 3.16. A) Comparison of overall forest change on Forest Service public lands. B) Comparison of annual forest change on Other public lands.

(1.61% annually) of the area (Figure 3.16B). Rates of biomass decrease should be lower on other public lands, because much of this area is not actively harvested.

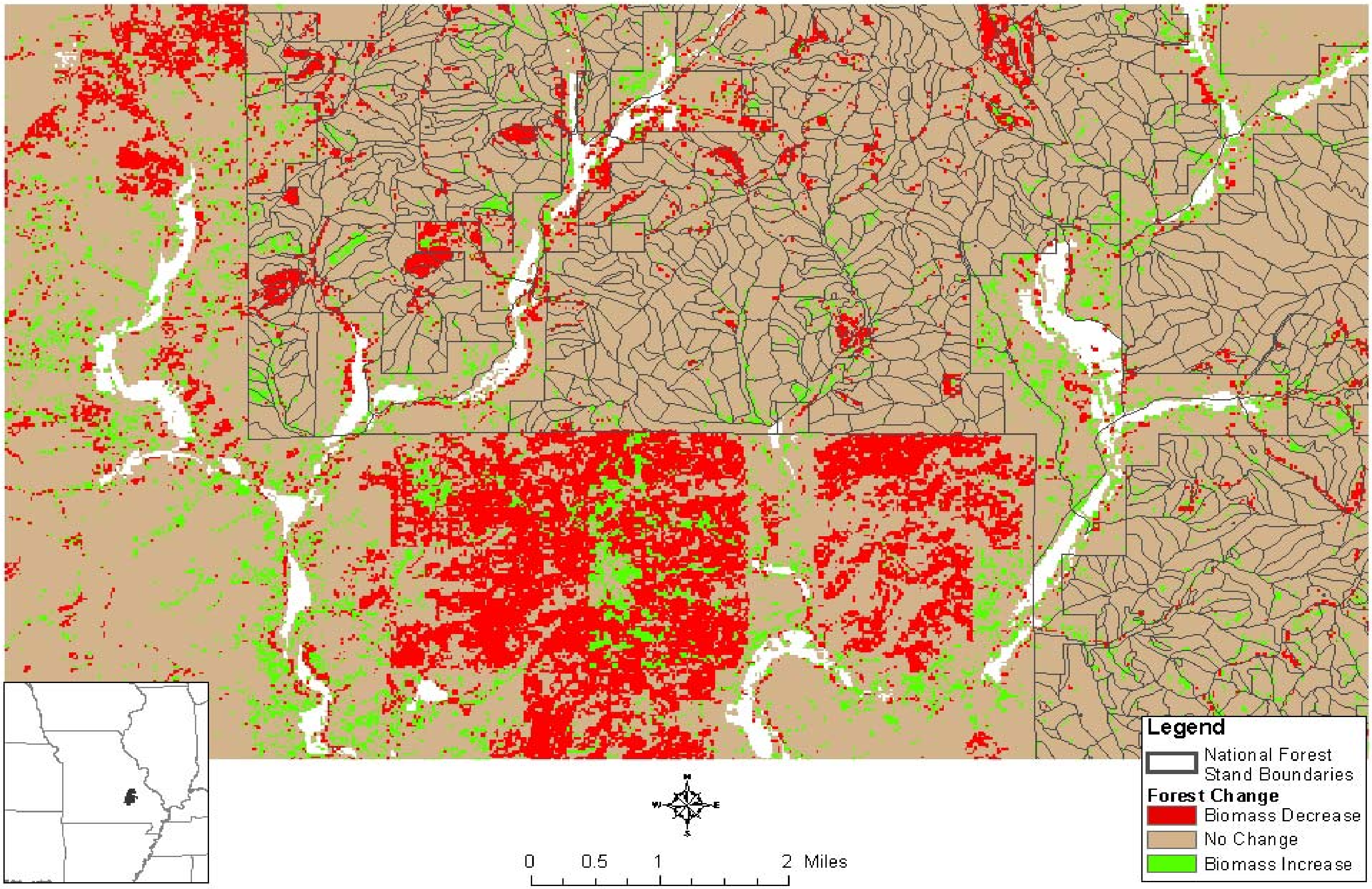


Figure 3.17. Sample of forest change on public land in relation to private land. Note large areas of forest biomass decrease on private land directly adjacent to public Forest Service land boundaries.

Chapter 4

Discussion

The TCW appears to detect forest biomass decrease as well as the SWIR/NIR ratio, but did a better job of mapping forest biomass increase. Rates of co-occurrence indicate that the TCW is slightly more accurate at detecting biomass decrease due to forest harvesting activity, especially at the smallest extent of salvage cuts. Because TCW detected salvage cuts better than the SWIR/NIR ratio, it may also detect natural changes better as well due to their similarly small extents. However, co-occurrence is a rough estimate and the methods have very similar values. Patch shapes and the percent area of change indicate that both methods do a good job of detecting all types of forest management activity. Rates of forest change by owner indicate that there is much more change occurring on private lands than public lands, but surprisingly biomass decrease roughly equals biomass increase for both owners.

TCW vs. SWIR/NIR ratio

The TCW and SWIR/NIR ratio both detected the expected extent and NLSI patch shape of biomass decrease in all management activities well, including stands that did not receive forest management treatments (Figures 4.1 and 4.2). The largest amount of biomass decrease area was found in clear cuts followed by intermediate cuts, salvage cuts, and stands that did not receive management. The primary difference between the two methods is in the detection of biomass increase, which is detected at a relatively much higher rate by TCW (Figure 4.3). This can be explained by at least two different factors; 1) the TCW is capable of detecting biomass increase slightly better due to the influence of the visible portion of the spectrum, 2) an effect of the phenological state of vegetation due to differences in imagery anniversary dates (this could produce false positives of biomass increase). Because more biomass increase is detected by the TCW, it could be asserted that it is better able to discriminate between subtle changes in vegetation biomass. However, the order of imagery starts from latest in the season (9-28-96) in 1996 and gradually becomes earlier in the season in 1998 (9-2-98) and 2000 (8-30-00), which could produce many false positives, mainly in the biomass increase class (Table 4.1). This is especially noticeable in the stream valleys, where some vegetation tends to die off earlier in the season than the main forested areas (Figure 4.3). Nonetheless, the TCW is more sensitive to subtle changes as a result of actual vegetation loss or seasonal defoliation because the SWIR/NIR ratio did not detect as much biomass decrease, false positives or not.

Table 4.1. Effects of image anniversary dates and resulting phenological differences of vegetation on the classification of false positives of biomass increase.

Image Date	**State of vegetation and effects on classification**
9-28-96	Vegetation is beginning to lose leaves for the season in some places, beginning with less leaf area, especially in stream valleys.
9-2-98	Vegetation is earlier is season than 1996 image and has more leaf biomass, producing a false positive in biomass increase.
8-30-00	Earlier in season than previous two images, may cause further false positives in biomass increase class.

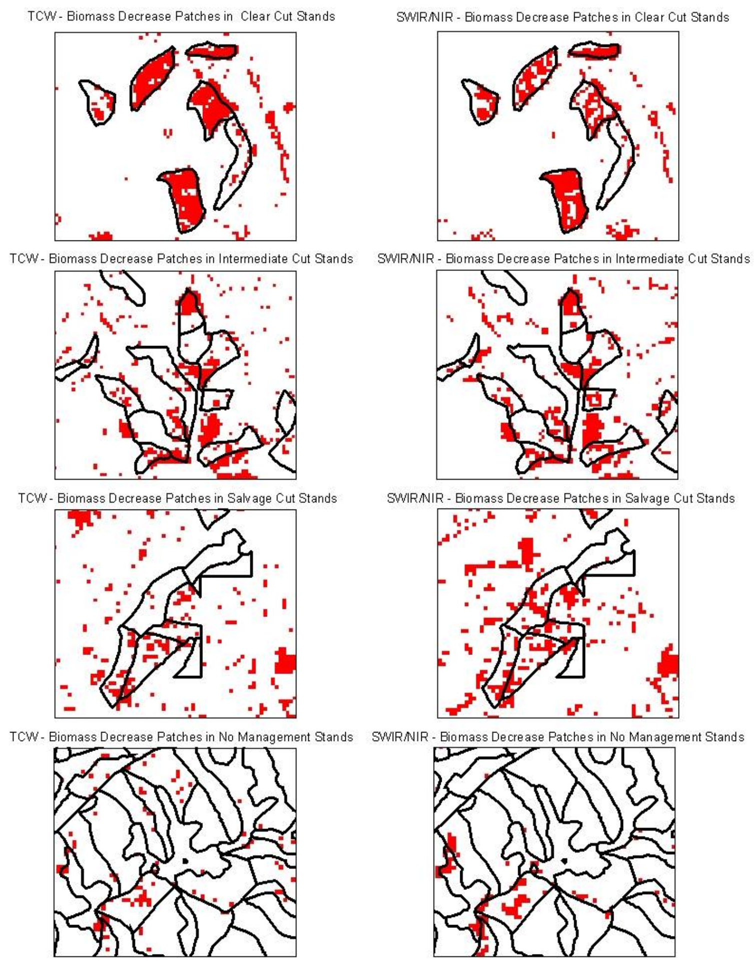


Figure 4.1. Example USDA FS stand management units that illustrate the ability of each method to detect biomass decrease for different management types. Note that TCW detects more homogeneous clear cut patches, but the other management types are generally more homogeneous for the SWIR/NIR ratio. Also note the different extents of each activity types with clear cuts being largest down to stands that did not receive management.

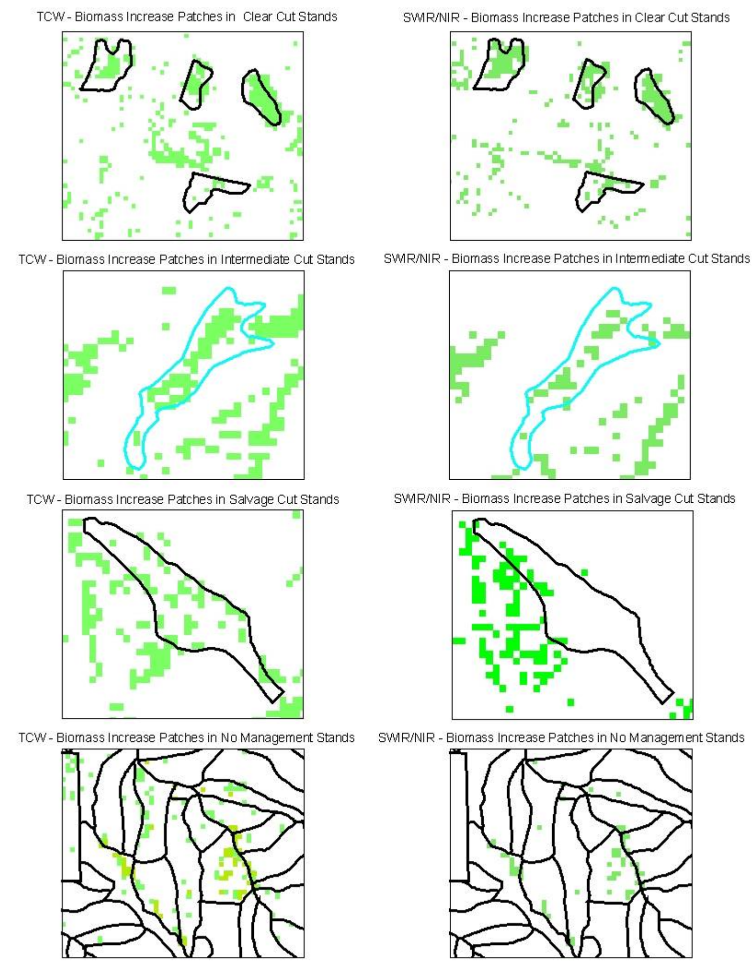


Figure 4.2. Example of USDA FS stand management units that illustrate the ability of each method to detect biomass increase for different management types. Note that TCW generally detects more biomass increase in all management types except for clear cuts.

Even though the TCW was more accurate in the detection of intermediate and salvage cuts, TCW consistently detected more biomass increase and less biomass decrease than the SWIR/NIR ratio (Figures 4.1 and 4.2). The differences in detection of different types of change for each method can be attributed to the fact that the TCW is more sensitive to chlorophyll absorption than the SWIR/NIR ratio. Intermediate and salvage cuts are not applied in the same manner as clear cuts. They are applied at a smaller extent and not all of the vegetation is removed. Since the SWIR/NIR ratio is only capable of detecting gross biomass change, the removal of the canopy is detected by the SWIR/NIR ratio and it does not detect the remaining understory vegetation. The TCW detects the same removal of vegetation, but also detects the vegetation remaining and therefore does not detect as much total biomass reduction as the SWIR/NIR ratio. Because the TCW is sensitive to understory vegetation and the SWIR/NIR ratio is not, a higher percentage of biomass increase is detected by TCW. The SWIR/NIR ratio only detects the most dramatic regeneration, but the TCW is able to detect the more subtle regeneration as well as the obvious regeneration.

The lowest percentages of biomass decrease and increase were found in areas where the most subtle changes in vegetation were expected to occur, stands having no management activities applied to them. No management stands should exhibit the lowest percent area of change because theoretically, little change should occur in these stands and the change that is detected is assumed to be natural change or the result of harvesting prior to 1996. The low percent areas of change indicate that each method is detecting minor changes to the forest biomass and has the ability to subtle changes to forest vegetation. The NLSI results for biomass decrease and biomass increase values within

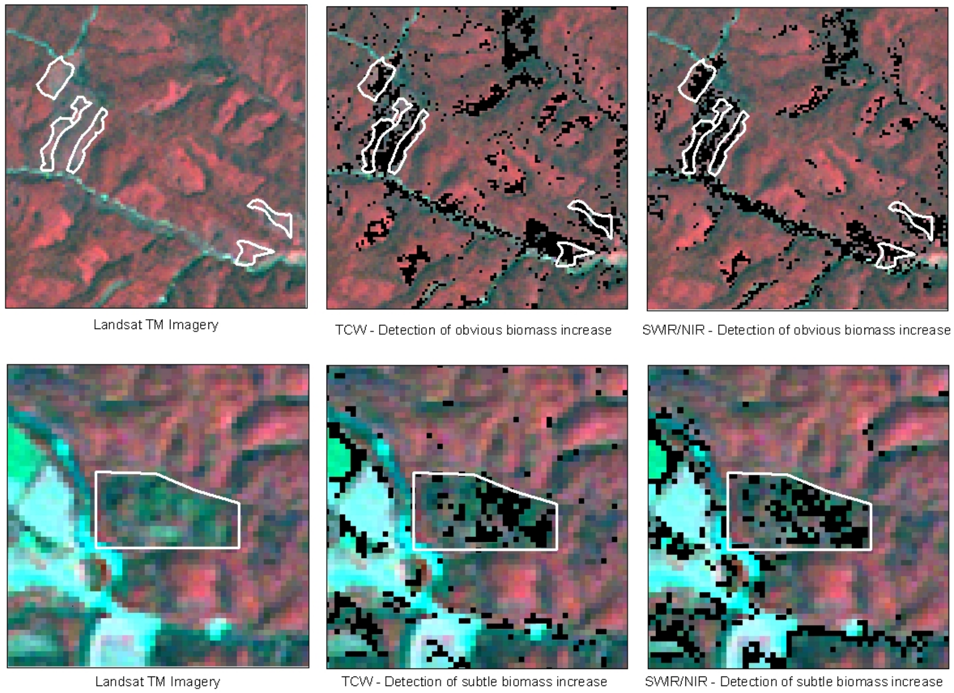


Figure 4.3. Top images illustrates the comparable ability of each method to detect obvious forest biomass increase and effects of false positives in stream valleys. Note TCW's more homogeneous patches. Bottom illustrates comparable ability to detect subtle biomass increase.

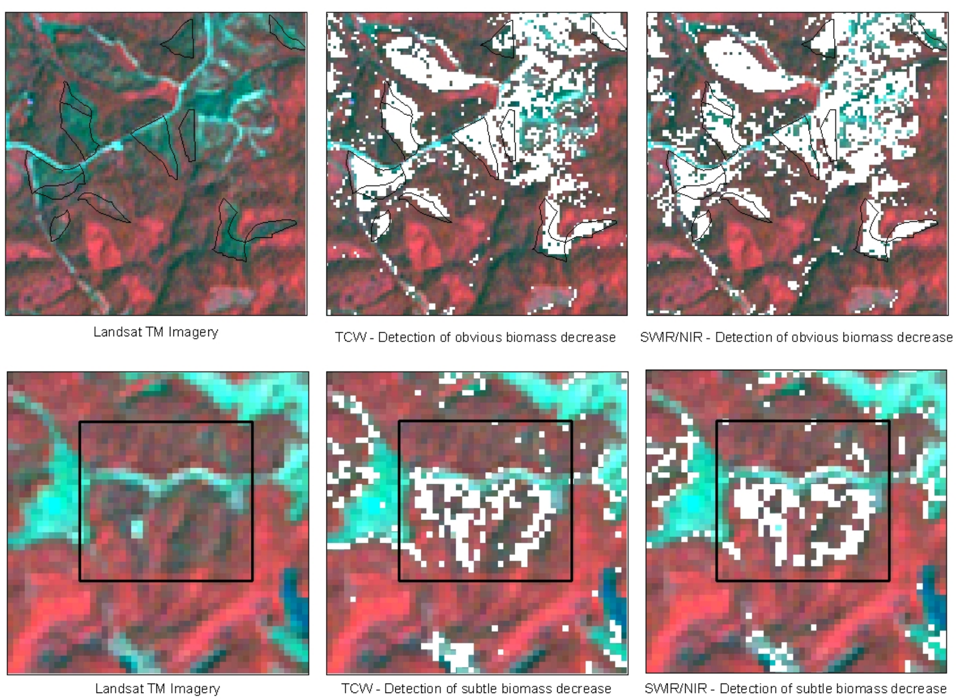


Figure 4.4. Top images illustrate the similar ability of each method to detect obvious biomass decrease, but TCW detects it in a slightly more homogeneous manner. Bottom row illustrates the comparable ability of each method to detect relatively subtle biomass changes.

forest stands that received no forest management indicate that subtle changes indicative of natural disturbances are being detected. Jensen (2000, 367) noted that differentiating between anthropogenic and natural disturbances is relatively simple when considering patch shape. Change patches as a result of anthropogenic change are much simpler than patches resulting from natural disturbances. Stands receiving no management activities had the most complex shapes for biomass decrease and increase and the simplest shape for stable biomass, which is indicative of natural disturbances, especially when compared to patch shapes of stands that did receive management activities. In general, the NLSI results further validate that both methods adequately detect forest biomass decrease due to forest management activity and that the TCW detects biomass increase in a more scattered heterogeneous manner (Figures 4.1 and 4.2). TCW consistently had more complex patch shapes, which means that it is either accurately detecting subtle changes or has more misclassified spurious pixels than the SWIR/NIR ratio. Despite these results, the co-occurrence results indicate that the TCW detected salvage cuts, which were used to further test the ability of each method to detect natural changes, much more accurately than the SWIR/NIR ratio

In a previous study it was determined that the SWIR/NIR ratio was only able to discriminate between severely defoliated and non-defoliated areas for deciduous forests (Vogelmann, 1990). Therefore the spectral changes in the SWIR/NIR ratio are primarily influenced by dramatic differences between presence of vegetation and vegetation loss. This accounts for the comparable detection of percent area of biomass decrease in clear cuts and intermediate cuts between methods. However, it does not account for the comparable amount of area of biomass decrease for salvage cuts between each method, but is explained by the greater co-occurrence values of TCW for detecting salvage cuts. By just considering the percent area and NLSI results one would conclude that each method does a relatively accurate job of detecting clear cuts and partial harvests. However, the co-occurrence values used as a rough estimate of accuracy assessment paints a slightly different picture.

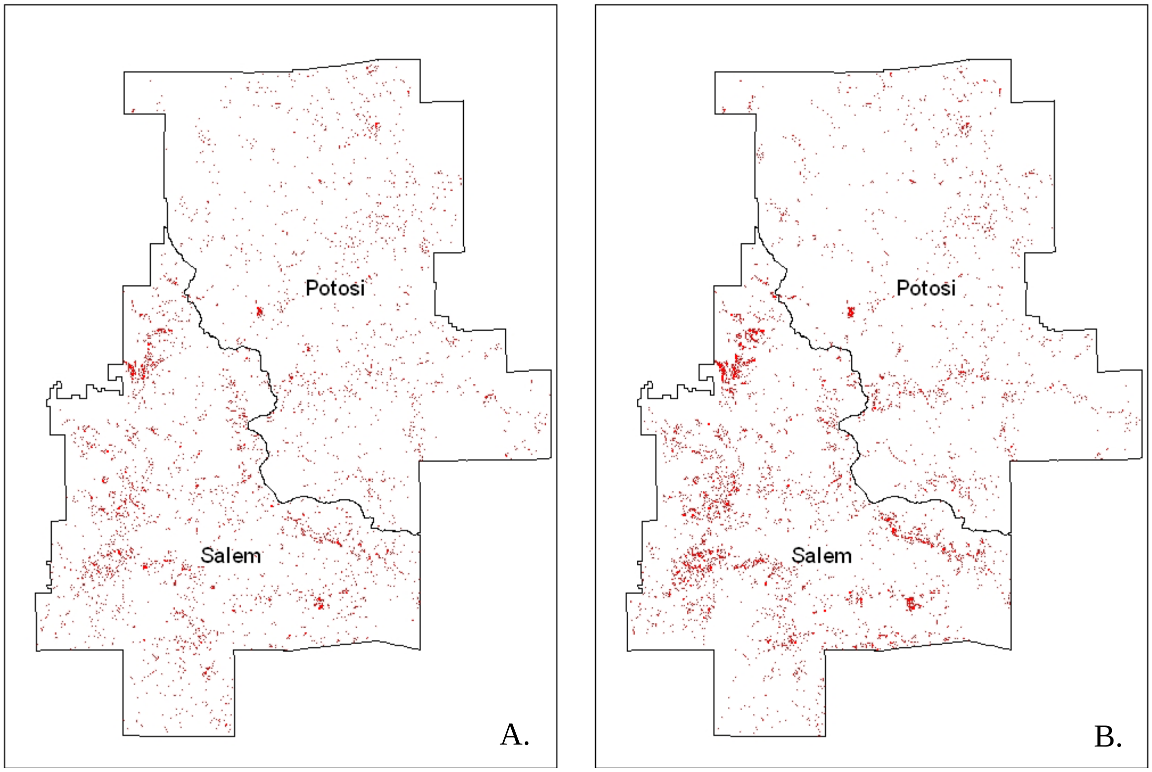
The TCW and SWIR/NIR ratio similarly detected all clear cut and intermediate management activities, based on the expected spatial extent of each activity. However, this does not give a full indication to the accuracy of each method in detecting biomass change. The co-occurrence values for clear cuts and intermediate cuts are marginally different for each method, which further validates the ability of both methods to accurately detect biomass changes at broad and medium extents. The greatest difference in co-occurrence is found for salvage cuts, which indicates that the TCW is relatively much more accurate at detecting fine-scale salvage cuts than the SWIR/NIR ratio. However, the percent area results indicate that both methods did a comparable job of detecting the general extent of salvage cuts. TCW may be more accurate at detecting salvage cuts, but with the uncertainty of the co-occurrence measure it could also be the result of errors of commission. Further studies would be required to fully validate the accuracy of each method. Nonetheless, these results indicate that overall, there is little difference in the detection of forest change over multiple extents between each method. However, the TCW is just as good at detecting broad and medium scale changes as the SWIR/NIR ratio, and definitively better at detecting fine scale changes.

It has been concluded that both of the methods are quite comparable and are useful. However, there are slight differences in the ability of each method to detect biomass changes and each has applications that they are best suited for. If the goal of a forest change study is to detect obvious broad scale biomass decreases, then either method would suffice and produce virtually the same results. On the other hand, if one is interested in detecting biomass changes with a wide range in severity and extent, including biomass regeneration, the TCW will produce better results.

Oak Decline

The results have indicated that TCW is more accurate at detecting salvage cuts, which served as a surrogate for natural change. This leads to the assumption that the detection of natural changes is possible. The detection of subtle changes was further illustrated by the detection of biomass decrease occurring in forest stands that did not activities. Biomass decrease in stands that did not receive management stands was characterized by small, complex patches. This is another indication that these changes are natural, opposed to anthropogenic. Changes caused by harvesting generally exhibit a much simpler shape.

Biomass decrease in stands that did not receive management treatments throughout the Salem/Potosi districts generally appear to be evenly diffused throughout the landscape (Figure 4.5). However, biomass decrease in the southern portion of the study area is slightly denser and gradually becoming less dense to the north. There are significant clusters of biomass decrease in southeastern and eastern portions of the Salem/Potosi districts. Because these clusters are relatively large and homogeneous in shape, yet occur within stands that did not receive management, they could be caused by management activity that was applied prior to 1996.



TCW Biomass Decrease in Stands Not Receiving Management

SWIR/NIR Ratio Biomass Decrease in Stands Not Receiving Management

Figure 4.5. A) Depiction of biomass decrease as detected by TCW in areas of stands that did not receive management activity. B) Depiction of biomass decrease as detected by SWIR/NIR ratio in stands that did not receive management activity. The general patter is identical, with the SWIR/NIR ratio detecting biomass decrease in a more clustered pattern, whereas TCW detected biomass decrease in a more diffuse pattern and is perhaps more sensitive to subtle changes, which cause a diffuse pattern. The detection of biomass decrease in no change stands is assumed to be natural change, perhaps oak decline. Notice a higher density of biomass decrease in the south and the pattern becomes less dense to the north.

have any change occurring within them, just as this study has. They could then visit the identified stands to further investigate the causes of change and determine what actions should be taken, if any.

Rates of Change on Public and Privately Owned Land

Rates of change by owner were only calculated for the TCW change technique, as it has been proven that the method detects forest change at multiple scales as good, if not better, than the well studied SWIR/NIR ratio. Rates of change by owner for the TCW change detection product indicate that more biomass decrease is occurring on private lands than public lands, which is in line with the findings of many other studies (Wear and Flamm 1993; Spies, Ripple, and Bradshaw 1994; Turner, Wear, and Flamm 1996; Zheng, Wallin, and Hao 1997; Crow, Host, and Mladenoff 1999; Franklin et al. 2002b; and Wolter and White 2002). Rates of biomass change, both decrease and increase, on private lands was twice that of change on public lands. Clear cuts on private lands also appear to be dramatically larger in scale than those on public lands. Public forests show similar rates of biomass increase and decrease indicating sustainable management

Forest managers are interested in monitoring forests adjacent to forests under their jurisdiction to understand what is occurring in the big picture. Frequently, forest managers do not know the types of changes that are occurring in adjacent lands of differing ownership. The public forests are managed following sustainable forestry practices, which provide important habitat for many species of flora and fauna. A dramatic change in the forest loss in private lands adjacent to public lands has implications such as the migration of wildlife due to habitat loss and increased erosion impacting streams. To effectively mange the forests of the Missouri Ozarks it is important to understand the context in which forest change is occurring throughout the forest. By detecting forest biomass change on lands of all owners over a broad study area, forest managers can better manage their forests based on how adjacent land owners are managing their lands.

Forest harvesting surveys are distributed to private land owners on an annual basis in order to determine the amount of harvesting they is being performed. Unfortunately, very few land owners actually fill out the survey, therefore forest managers are generally unaware what is occurring on private lands. Through the results provided by this study, land managers can see the big picture and manage their lands accordingly. For example, dramatic clear cuts were applied to private forests directly adjacent to the Salem/Potosi boundary that forest managers were unaware of (Figure 4.6) (Mike Schanta, MTNF, personal conversation). This knowledge helped to make informed management decisions in the MTNF Draft Environmental Impact Statement (USDA Forest Service 2005b).

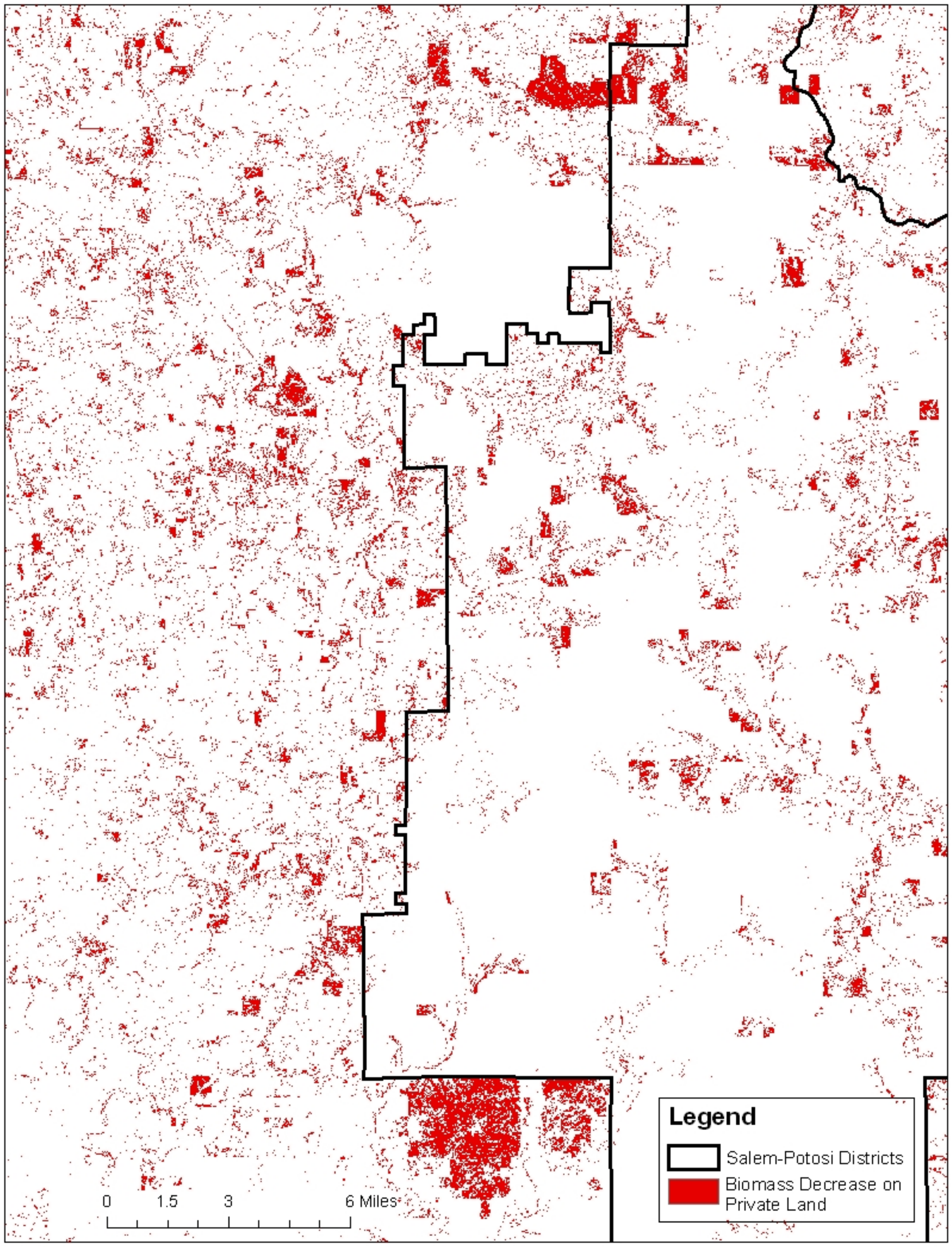


Figure 4.6. Red patches indicate biomass decrease on private land, including inholdings ,and black polygons indicate public Forest Service land. Note significant areas of biomass decrease of private forests adjacent to and among in-holdings of public forests

Chapter 5

Conclusions

With the increased spread of oak decline and mortality occurring in the Missouri Ozark forests it is important to identify a simple and inexpensive technique that will detect subtle changes in forest biomass over a large spatial extent. Such a tool would allow forest mangers to monitor forest health as well as management practices on all lands in a comprehensive manner. The use of satellite imagery allows researchers to inventory and study the state of vegetation in a large region, while reducing the need to be in the field. The results produced by remotely sensed imagery can provide valuable information to resource managers by aiding in their decision making processes (Franklin et al. 2002a).

This project investigated the ability of the wetness component of the Tasseled Cap Transformation (TCW) to detect forest change at multiple scales and compared this method against a commonly used and well researched forest vegetation ratio: the Short-wave Infrared/Near Infrared (SWIR/NIR) (Vogelmann and Rock 1988, 1989). Franklin et al. (2002b) note that the Tasseled Cap Transformation (TCT) is a useful tool in forest change detection, and additional forest change detection examples are needed to help understand the role that the TCT can play in forest management applications. This project tested the usefulness of this technique by applying it to the Missouri Ozark forest landscape in order to detect changes in forest biomass, characterize the structure of forest change patches in order to compare the manner in which each method detects biomass change, and assess contrasting rates of change on public and privately owned forests. A further application of the technique will help identify areas within this region where oak decline is occurring.

This study found that TCW was as capable of detecting human induced forest biomass decrease as well as the SWIR/NIR ratio and, was perhaps better at detecting biomass regeneration. TCW detected significantly more biomass increase than SWIR/NIR, due to its inclusion of the visible portion of spectrum. This leads this researcher to believe that the TCW is better suited to detect forest regeneration. The detection of multiple scales of forest harvesting activity within MTNF forest stands indicated that the TCW was indeed detecting these changes based on size of activities detected and shape of change patches. Patches of biomass decrease as a result of harvesting activities were simple in shape, indicating the detection of forest harvests. TCW was relatively much more accurate in the detection of small salvage cuts, which infers that it is also able to natural changes. By assessing biomass change in forest stands that did not receive forest management it was determined that TCW is able to detect subtle changes akin to natural changes. Most of the biomass changes in the no management stands were further deemed to be natural change based on the low percent of area of biomass decrease and the complex shape of the biomass decrease values, which indicate change due to natural causes (i.e.,, windthrow, drought, disease, and insect infestation). However, without ground data of known spatial locations of natural change (i.e., oak decline) it is not possible to assert the ability of the TCW to detect oak decline.

After validating the ability of the TCW to detect forest change in a comparable manner as the SWIR/NIR ratio, rates of change on public and private lands, as detected by TCW, were assessed. Rates of biomass decrease on private lands were almost double of those on public lands. However, for both ownership types, biomass increase was relatively equal to biomass decrease, indicating that changes in land use were not occurring in the study area between 1996 and 2000. By assessing rates of forest change by owner, forest managers are able to understand the change within their forests in context to what is occurring in the forest as a whole and mange their lands accordingly.

Caveats

Not all change detected is actually change due to natural or anthropogenic causes. Significant amounts of change was found in stream valleys, which is actually a result of differences in the phenological state of the vegetation due to the slight differences in anniversary date and amount of rainfall from year-to-year. This affects when senescence occurs. In addition, the LULC datasets used to generate the forest mask occasionally included areas that were forests at the time of the creation of the LULC datasets and have been subsequently converted into pastures or cropland prior to the acquisition dates of the imagery used for this study. These locations were included in the classification and depending on the anniversary date of the imagery and state of vegetation, change may have been detected that is not representative of forest change.

Future Directions

Future directions of this project could include more field data and statistical analysis to more definitively verify the results of the study. Ground data indicating the spatial location of known oak decline locations would allow for a definitive assertion that the TCW is or is not able to detect subtle changes as a result of oak decline. Better ground data that could more explicitly identify where forest harvesting occurred would allow for a more traditional accuracy assessment. The GIS forest stand database used in this study only provided the year, type of management activity, and the stand that activity was applied to, but not exactly where within the stand the harvesting occurred. Further statistical analysis could be used to help explain why the TCW detected less biomass decrease and more biomass increase than the SWIR/NIR ratio. The reasons for the differences in each method found in the Chapter 3 and Chapter 4 are derived from verbal explanations of each method and preliminary findings by Franklin et al. (2001, 298) and Vogelmann and Rock (1989). Using spectral statistics and more precise ground-truth data one could provide a more definitive explanation of the strengths and weaknesses of each method.

If the TCW proved to be capable of detecting oak decline upon further validation measures briefly described above, application of the results of this study to isolate potential areas of natural forest biomass change for field-checking could easily be implemented. By creating thresholds based on patch shape complexity, patch size, and stand management status, queries could be run on the data to identify biomass decrease likely caused by natural changes. Field-checking would then be required to determine what the agent of change for each location was. This could be a valuable time and money saving tool in the detection and monitoring forest health.

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