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REMOTELY DETECTING TREE DAMAGE IN YOSEMITE NATIONAL PARK

by

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THESIS APPROVAL PAGE

This is to certify that the thesis prepared by Karla King entitled Remotely Detecting Tree Damage in Yosemite National Park has been approved by the thesis committee as satisfactorily completing the thesis requirements for the degree Masters of Science in Environmental Science.

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ABSTRACT

Remotely Detecting Tree Damage in Yosemite National Park

Karla King

United States Park Service and Forest Service managers are increasingly concerned with identifying methods to quickly and efficiently monitor environmental conditions. This study investigates updating the USDA Forest Service's current method of mapping tree damage with remote sensing techniques in Yosemite National Park.

Two change detection methods using Landsat TM satellite imagery were tested and compared to the USFS manual method of annual aerial over flights. The methods tested include: 1) a cross correlation analysis incorporating a feature class from 2006 and imagery from 2011 for use in a Z-score algorithm; and 2) subtracting the greenness component of a 2011 tasseled cap transformation from the greenness component from a 2006 image. The study found the cross correlation analysis to detect damage at 79% accuracy, the image subtraction method to detect damage at 82% accuracy, and the current USFS Aerial Detection Surveys to perform at 64% accuracy.

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CHAPTER 1

Introduction

The world is experiencing exponential population growth, higher concentrations of greenhouse gases in the atmosphere, and natural resource depletion at unsustainable rates. Increasing uncertainty in the earth's environmental systems is inherent in all environmental analysis and research today. It is more important than ever to develop accurate and efficient methods to monitor fluctuations in natural resources before degradation is irreversible.

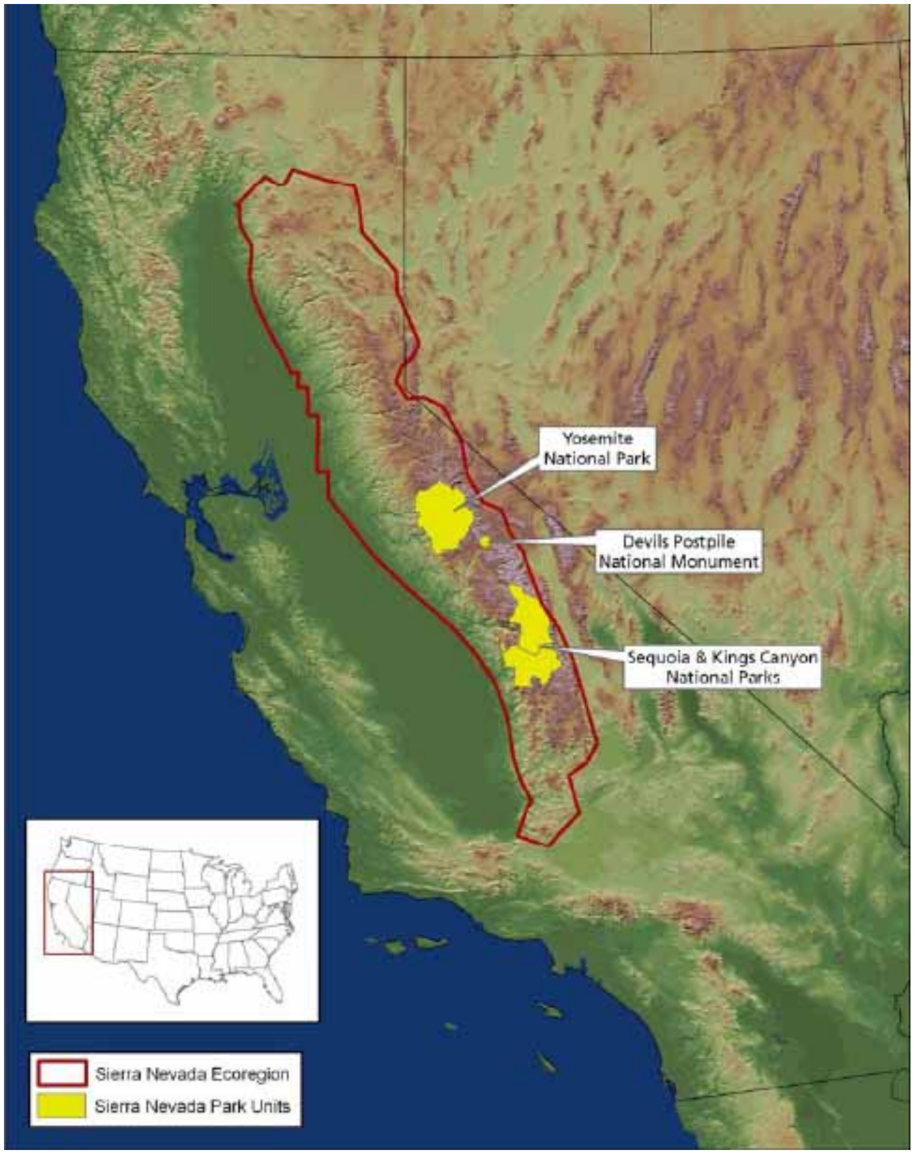
The Sierra Nevada Park Network is a group of four National Parks located in the Sierra Nevada mountain range in California (Figure 1). This park network protects some of the most pristine and monitored wilderness in the United States. The wealth of data available on the Park System's environmental conditions makes it a good indicator of how the environment is changing. The National Park Service is working to integrate data to understand the dynamic causes of change. An additional basis for this research is the theory that, if degradation is detected at the highest level of federally protected land, then it is an indicator that scientists should investigate for similar situations throughout the world.

There are a unique set of transformations occurring in the Sierra Nevada mountain range making it especially difficult and necessary to predict the pattern of tree damage. Annual mean temperature has been rising more quickly than projected as a result of regional and global climate change. Also, annual rainfall amounts have been decreasing (Davey et al., 2007). These fluctuations, coupled with the use of fire suppression, are altering the state of the public lands in the Sierra Nevada Park Network. National Park Service (NPS) scientists believe fire suppression in the Sierra Nevada Park Network (SIEN) has degraded forest health. Lack of fire has resulted in increased tree density making forest stands more susceptible to insect and pathogen outbreak (Hagle et al.,2000). NPS researchers are preparing a project investigating the spatial correlation of outbreak and fire suppression in forests. In order to begin this analysis, a database of forest damage is necessary.

The USDA Forest Service (USFS) has been mapping insect outbreaks through aerial detection surveys in their Pacific Southwest Region since 1993. Mortality and defoliation are sketch mapped by an observer identifying yellow to reddish brown trees in orthophographics captured during aerial over flights. The mapping technique being used, however, is thought to be crude and inefficient. There are multiple advantages of using remotely sensed data, such as the ease of manipulation using image processing software (Rock et al., 1986). Insect outbreaks are one of the leading causes of natural disturbance in North American forest stands today (USFS, 2002). My research will focus on a method to depict the extent and intensity of tree damage due to pests and disease using remotely sensed data.

The SIEN park network includes Devils Postpile National Monument, Sequoia and Kings Canyon National Parks, and Yosemite National Park (NPS, 2010). Research correlating fire suppression with insect and disease outbreak will require the use of a method such as the one described below to map forest damage for the entire SIEN network. Before the entire network may be mapped, however, a method must be selected to map efficiently and consistently forest damage using remote sensing technology. For this reason, this project will map forest damage in one National Park as a pilot project to test an appropriate method and determine if it can be applied to the entire SIEN network.

Figure 1. Map of the Sierra Nevada Park Monitoring Network



(Source: National Park Service, 2010)

This project will focus on Yosemite National Park, hereafter described as Yosemite. The abundance of ancillary data and national importance of Yosemite make it an exemplary place to begin the task of mapping forest damage across the Sierra Nevada Park Network. Park managers in Yosemite are also leading the larger forest pest damage and fire project making coordination with these scientists and planners key to the success of the research.

Figure 2. Map of the Study Area

(Source: Esri, 2012)

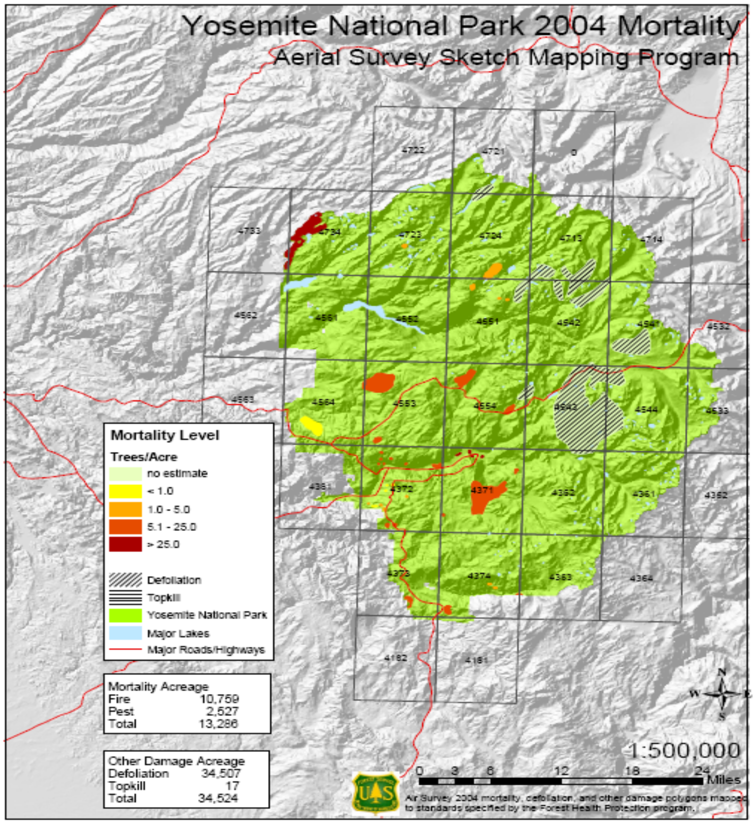
Statement of the Problem

This project will serve as an effort to map the extent of forest damage in Yosemite National Park as a basis for correlating fire suppression with destructive outbreaks. The method relies on the use of remotely sensed data and digital image processing software to execute a statistical method called cross correlation analysis to detect change in land cover where forest damage and mortality are likely to have occurred. Data include existing aerial survey maps, the 2006 National Land Cover Dataset, and Landsat Thematic Mapper (TM) imagery from 2006 and 2011. The consecutive images will be processed and compared resulting in one map displaying areas of change between the two maps. Therefore, each year's map of damage and mortality will be reliant on the previous year's classified image. Change detection will be based on forest cover classifications, or a "feature class," that must be developed accurately.

Purpose of the Study

Current mapping of tree mortality and defoliation is conducted by the United States Forest Service for the USFS Region 5; including the entire SIEN network. Figure 3 is an example of the database of maps derived from annual aerial flights to identify forest health issues. Although the USFS mapping technique has yielded useful results with some degree of consistency since 1993, it is a costly approach for mapping tree mortality and defoliation. It is possible to use satellite imagery to conduct the surveys more efficiently (B. Kuhn, personal comm.). This research assesses two remote sensing methods to replace the current manual method.

Figure 3. Yosemite National Park 2004 Mortality Map, Aerial Survey Mapping Program



(Source: U.S. Forest Service, 2004)

Figure 3 is an example of one of the mortality maps created by the US Forest Service. Aerial surveys conducted from 1993 to 2008 document a total 293,415 acres of damaged forest in Yosemite National Park alone (USFS, 2010).

A chief advantage of using remote sensing technology is the ability to monitor forest conditions in the extreme wilderness that may be otherwise difficult or impossible to constantly supervise. The ability to quickly detect symptoms of outbreaks, such as defoliation, equips park managers with the ability to frequently assess park health in-house at a low cost using aerial and satellite imagery. Once a method is developed, it can be readily used to assess if outbreaks are occurring more frequently, or if spatial patterns of defoliation are changing over time. A baseline outbreak map can be used to monitor the spread of damage and to inspect environmental conditions favorable for a pathogen to occur (Campbell, 2007). This process also has broader applications that can investigate how climate change may be regionally influencing forest conditions. Ultimately, it is the goal to use this analysis in conjunction with other data in the SIEN to establish an efficient and accurate method to promote forest health.

Hypothesis

The study is based on the working hypothesis that remote sensing interpretation provides an efficient means to map forest damage that is as accurate as manual techniques. The study includes the following statistical hypotheses:

1) The remotely sensed map displaying forest damage and the USFS aerial sketch survey map will have comparable accuracies.
2) A map created using remote sensing techniques will display forest damage in a pattern spatially and statistically similar to USFS aerial sketch survey maps.

Delimitations

This study includes the following delimitations:

- Forest cover will be assessed for two time periods resulting in one map of damage detection. The time periods to be compared are 2006 and 2010.
- The study will focus solely on Yosemite National Park and its surrounding areas.
- Only Landsat 5 Thematic Mapper imagery captured during summer months for 2006 and 2011 will be used for the project.

Definitions

For this study, the following key terms are defined:

anniversary images - anniversary images are those captured on nearly the same date of the year. The use of anniversary images reduces the effect of seasonality and annual defoliation of deciduous trees on the study.

Landsat 5 Thematic Mapper – The Landsat 5 TM satellite is operated by U.S. Geological Survey (USGS). Landsat 5 is a satellite that captures 7 spectral bands of information at a spatial resolution of approximately 30 meters. A free catalog of all images captured is available online at http://glovis.usgs.gov (USGS, 2011).

spatial resolution – the level of visible detail in an image. Fine, or high resolution, allows you to pick out small features in images (Campbell, 2002 pp. 272).

spectral resolution – the ability of a sensor within an image's associated satellite to define fine wavelength intervals (Campbell, 2002 pp. 273).

Limitations

The study has the following limitations:

- The proposed method divides each pixel into exclusive classes. In reality, there is often an issue of "mixed pixels;" or more than one type of land cover present within one pixel. This phenomenon is common in remote sensing and can result in misleading classifications (Campbell, 2002 pp. 277).

- Landsat 5 Thematic Mapper (TM) imagery has a spatial resolution of approximately 30 meters. A review of literature shows this is sufficient to complete a project of this nature. Remotely sensed data with higher spatial resolution would likely create more accurate results.

- The seasonal influence of snowfall, rise and fall of water levels and de foliation of deciduous trees has a great effect on remotely mapping land cover; especially in this project because it compares images on a pixel by pixel basis. This will be addressed as best as possible through the use of “anniversary images.”
- The accuracy of change detection is only as good as the forest cover classifications used to assess forest cover change.

CHAPTER 2

Review of Literature

Introduction

One frequently cited study conducted by Rock et al. (1986) found that, “Plant responses to stress may have spectral “signatures” that could be used to map, monitor, and measure forest damage.” This provides a basis to begin exploring techniques to identify and map these specific spectral signatures. Through reviewing relevant literature, it is clear a vast range of methods exist to conduct analysis of forest health using remote sensing imagery. General information regarding specific tree, insect, and pathogen species of interest in Yosemite is also included in this section.

Riley (1989) explored applications of remote sensing to entomology. One main application was detecting the effects of insects (most commonly plant damage). It compares the use of aerial photography and satellite mutli-spectral scanning as techniques to detect the effects of insects on the landscape. He cited the ratio vegetation index (band 4/ band 2) as a good indicator of vegetation change. It also states that reflectance of near-infrared imagery is proportional to leaf density and the reflectance of the red region is inversely proportional to chlorophyll density. This technique is a simpler predecessor to the widely used normalized difference vegetation index (NDVI). He also states that Landsat imagery is not well suited for detecting dying vegetation because the yellow to orange color characteristic of stress is added to the top of the green band and to the bottom of the red band (Riley, 1989).

Appropriate spectral indices and compositing methods to best monitor the effects of gypsy moth defoliation in the central Appalachian Mountains was investigated by de Beurs, et al. The region is primarily hardwood deciduous forest and dominated by Oak species. It concluded that imagery from the Moderate Resolution Imaging

Spectroradiometer, or MODIS, can be confidently used to monitor tree defoliation using NDVI, Normalized Difference Water Index, Enhanced Vegetation Index, and two versions of the Normalized Difference Infrared Index (NDIIb6 and NDIIb7) (de Beurs, et al., 2008).

A more recent study by Lee and Cho (2006) recognized the difficulty of mapping damaged pine trees using conventional remote sensing techniques. It suggested the use of high spatial resolution data (one meter or less) to detect this specific type of damage. While high resolution (one meter or less) data is costly to obtain, and not feasible for all research because of the limited number of spectral bands, it does yield useful information about which transformations are optimal for detection.

A study conducted in Korea analyzing tree species similar to Yosemite's used a time series of images to detect change by comparing two NDVI indexes (Lee et al., 2006). It also explored the maximum and minimum filtering that can be used to detect individual tree crowns. This is only possible using high spatial resolution data. Fraser & Latifovic (2005) found that coarse imagery can be used confidently to map wide spread conifer damage caused by pests. Coarse resolution imagery is especially effective when assessing forest patches larger than 5 to 10 square kilometers.

Ecological Based Studies

Many ecological studies have investigated different applications of multispectral analysis for estimating green leaf area index (LAI). They concluded that ecological research was one of the main applications of estimating this data through remote sensing (Curran, 1983). Bréda (2003) found that, "measures of leaf area index characterize the earth's atmosphere**,** where most of the energy fluxes exchange. It is also one of the most difficult to quantify properly, owing to large spatial and temporal variability." Bréda conducted a comparison of the direct and indirect methods of measuring total LAI. LAI is a fitting measurement for quantifying insect defoliation because it indicates simply how much leaf area exists in the tree stand of interest. Furthermore, it is a method that can be employed directly (data collection in the field) or indirectly (through remote sensing). The same study also found that indirect measurements of LAI are shown to “significantly underestimate” total leaf area. This finding provides grounds to verify the information products generated in the lab with direct measurements in the field (ground truthing).

It is common in remote sensing analysis to plot different combinations of multispectral bands to assess their ability to describe land cover phenomenon. The tasseled cap transformation provides a means to incorporate the 7 bands of Landsat data through a principal components analysis. This transformation was developed by R.J. Kauth and G.S. Thomas in 1976. The transformation yields data distributed into three distinct orthogonal axes. Each axes, or component, display a unique characteristic of the earth’s surface. Those components are: brightness, wetness and greenness. Though originally developed for crop analysis, it has become a popular method among scientists to analyze vegetation (Esri, 2012).

Fassnacht, et al. (1997) linked specific vegetation indices and bands generated by the Landsat 5 TM to LAI, finding a strong association between a Tasseled Cap component and predicting LAI. The green/ mid infrared band showed a strong correlation especially in hardwood forests. “Multiple variable models were found to offer substantial improvement over single-variable models, especially for hardwood stands,” (Fassnacht et al., 1997).

Kharuck and his colleagues conducted a study in Siberia to “detect and map” insect outbreak in the region (2003). It proved that mapping the successional patterns of forests after insect outbreak is possible. Varying stages of succession show significant difference in reflectance especially in Landsat bands 2 (0.525–0.605 μm), 4 (0.750–

0.900 μm), 5 (1.55–1.75 μm), and 6 (10.40–12.50 μm).The different land cover classes identified included clearcuts and fire scars; nonforest; sparse birch regeneration; dense young birch stands; mature birch stands; immature and premature mixed coniferous–deciduous stands; Siberian pine–spruce stands; fir–spruce stands; and fresh fire scars. There was no class called outbreak, damaged forest, or defoliation. Such a classification is a good basis to assess change in forest cover; however, it does not directly describe forest damage. Other useful information includes the finding that damage to the forests caused an increase in radiometric temperature (20.20 ± 0.04°C for damaged forests versus 19.47 ± 0.02°C for healthy forests). This study was conducted using Landsat imagery and a supervised classification approach for image processing.

Change Detection

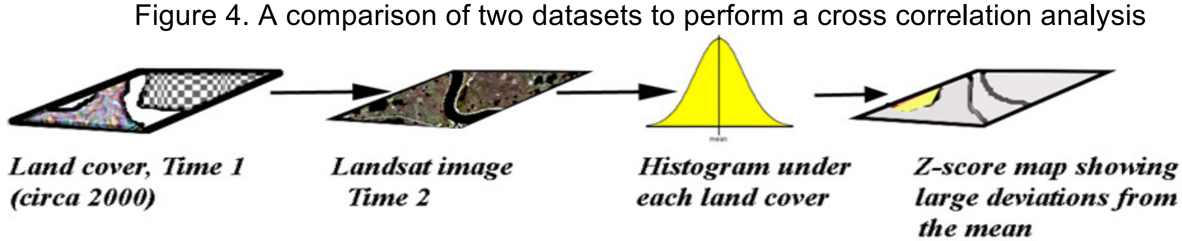
Many studies to detect insect defoliation compare two remotely sensed images in order to identify spectral variation from one year to another, (Joria and Ahearn, 1991; Muchoney & Haack, 1994; Luther et al., 1997; Chalifoux et al., 1998; Radeloff et al., 1999). Macomber and Woodcock (1994) used both change detection and ecological principles in remote sensing as a tool for mapping and monitoring conifer mortality. All of the conifer species discussed in the article are species of interest in Yosemite. The Li-Strahler canopy estimation method is employed along with other ecological modeling systems to correlate forest cover with the ability to map change between images. This article presents one method to complete my study, but is complex and a bit dated.

Kennedy et al. (2010) demonstrated the LandTrendr process in the Pacific Northwest on a series of Landsat 7 Extended Thematic Mapper (ETM) anniversary images spanning 1985 through 2007. Trajectory segmentation is used to model individual pixels' behavior over a period of time while smoothing environmental noise and detecting spikes in spectral change. Overall, LandTrendr captured small disturbance events, such as harvest and forest fire, and identified long term variances, such as regrowth and decrease in health due to insect stress. This method provides a sound means of extracting change detection information of the Landsat archive in a robust manner that minimizes environmental noise.

Cross Correlation Analysis

Cross correlation analysis is one method of change detection that relies on statistical methods to compare two images in a series. The Canada Centre for Remote Sensing recently compared three change detection techniques' ability to identify forest cover fluctuations in Landsat images from 2000. It diagrams how a cross correlation analysis involves the use of two forms of data in figure 3 below:

Figure 4. A comparison of two datasets to perform a cross correlation analysis



(Source: Canada Centre for Remote Sensing)

The first necessary piece of data is a feature class image displaying a land cover classification. The second piece of data is an image of interest to be processed. Beginning with raw imagery is problematic because The feature class creates spectral cluster statistics including mean and standard deviation of each class. The Z-statistic deviations are calculated from statistical images generated and the image of interest to be processed. Canada Centre for Remote Sensing found cross correlation to be a very effective method. However, it did conclude cross correlation had a tendency to underestimate change.

A paper by Koeln (2000) also details the methodology of cross correlation. Described as a two-step process, it explains classifying pixels to generate “expected” class spectral responses to generate Z-score values similar to the Canada Centre for Remote Sensing project. It highlighted the experimental character of the procedure. Threshold levels vary between studies and it is necessary to develop class boundaries experimentally. Koeln and his colleagues also found that minimizing class spectral variance allows one to separate real change from false change. The Earth Satellite Corporation has used cross correlation analysis to assist the Environmental Protection Agency, the Maryland Department of Natural Resources and the United States Fish and Wildlife Service in detecting land cover. It reports having 90% accuracy for four of its validated projects.

Tree Species, Hosts, Insects and Pathogens

Forest ecosystems are a complex network of relationships. Pests and disease are an integral part of maintaining a forest’s natural function. They influence nutrient cycling and induce small-scale disturbance. This disturbance often is in the form of tree mortality (Dale et al., 2001). The concept of intermediate disturbance also supports this by stating that ecological health is accompanied by disturbance that is neither too frequent or too rare (Roxburgh et al., 2004). The majority of these damage-causing species are naturally occurring parts of the ecosystem. It is hypothesized that outbreaks are not random, but rather are correlated with forests under strain exhibiting unhealthy or unnatural characteristics, such as fire suppression (Wickman, 1992). Table 1 below lists trees in the Sierra Nevada Park Network that are susceptible hosts for insects and pathogens along with its associated destructive inhabitant. The species of pathogen or insect is specialized to populate specific tree species. In most situations, the inhabitant is indigenous to the region.

Table 1. Host tree species in the Sierra Nevada

Tree Species	Destructive Inhabitant
Lodgepole pine *(Pinus contorta)*	Insect
White fir *(Abies contorta)*	Insect
Sugar pine *(Pinus lambertiana)*	Insect, Fungi
Ponderosa pine *(Pinus ponderosa)*	Insect
Jeffery pine *(Pinus jeffreyi)*	Insect
Douglas fir *(Pseudotsuga menziesii)*	Insect
Whitebark pine *(Pinus albicaulis)*	Fungi
Western white pine *(Pinus monticola)*	Fungi

(Source: USFS, 1994)

Tables 2 and 3 list the prominent beetle, fungi, and other pest species responsible for the majority of all forest disturbances occurring in the Sierra Nevada mountain range. All listed inhabitant species prey on one or more specific tree species listed in table 1. The only potentially destructive inhabitant listed below that is not native to the Sierra Nevada is White pine blister rust. In recent years, the lodgepole miner has become an overwhelming problem in the Sierra Nevada Park Network. It damaged 7 percent of Yosemite's total forested area in 2002. Table 4 lists other pests that are agents of large scale disturbance throughout the SIEN.

Table 2. Fungi Inhabiting Conifer Host Trees

Root disease (*Heterobasidion annosum*)
Root disease (*Amillaria*)
White pine blister rust (Cronartium ribicola)

(Source: USFS, 1994)

Table 3. Beetle species inhabiting host trees

Mountain pine beetle *(Dendroctonus ponderosae)*
Western pine beetle (*Dendroctonus brevicomis*)
Jeffery pine beetle *(Dendroctonus jeffreyi)*
Flatheaded fir borer *(Melanophila californica)*
Fir engravers *(Scolytus ventralis)*
Pine engravers (*Ips species)*

(Source: USFS, 1994)

Table 4. Other significant pests

Douglas-fir tussock moth *(Orgygia pseudotsugata)*
Pandora moth *(Coloradia Pandora)*
Lodgepole needle-miner *(Coleotechnites milleri)*

(Source: USFS, 1994)

CHAPTER 3

Procedures and Methodology

Introduction

Mapping tree damage via satellite derived data depends on detecting very small differences in spectral response. Traditional methods of supervised and unsupervised classifications of pixels rely on computer software to separate the pixels into a set number of classes. The spectral variety in land covers makes it especially difficult for computer software to delineate classes that appear to be damaged tree cover (King, 2010). A different route to determine areas of forest damage is to identify pixels that have changed. Change detection is an alternative method with a basis in statistics yielding a map of areas that have changed between two images. Change detection can identify small fluctuations in an image.

Subject of Study

Nestled in the Sierra Nevada Mountain range that runs through the interior of California, Yosemite National Park is one of the first National Parks to be designated as protected wilderness in the country. It is well known for its striking geomorphic features including glacial valleys, granite monoliths, waterfalls, alpine lakes and steep elevation gradients. It contains a high concentration of old growth forest tracks containing deciduous and evergreen tree species including the well-known Sequoia tree. These forests support a diverse set of flora and fauna (USFS, 2010).

Collection of Data

Change detection in remote sensing requires two images. The 2006 National Land Cover Dataset (NLCD) for Yosemite National Park serves the baseline image to detect change (time one). When using a change detection method, it is necessary to have an accurate feature class map to begin. The accuracy of this study can only be as good as the accuracy of a proper feature class map. The NLCD is a 16-class land cover classification that spans the United States with a spatial resolution of 30 meters. The classification scheme is based on an unsupervised classification of Landsat Enhanced Thematic Mapper+ data from 2006. This dataset is available digitally from the USGS. It will be clipped to the study area and serve as the basis to analyze change.

The image for time two to be processed is a Landsat scene captured in 2011 and is accessible at http://usgs.glovis.gov. The image is a summer image reflecting full foliation of deciduous forest and has below five percent cloud cover. Landsat imagery has 7 bands of spectral information and 30 by 30 meter pixel resolution. A third central piece of data is the Yosemite National Park Mortality maps created from 2006 – 2011 by the US Forest Service as part of their Aerial Sketch Survey Program. These data serve as the manual method of mapping mortality and defoliation to test the hypotheses. The Mortality Maps are available on the USFS Region 5 website. Supporting vector data used include: a park boundary vector file obtained on the USFS website, historic insect and pathogen outbreak data, and historic fire burn maps for Yosemite National Park. Google Earth also serves as a free source of high resolution imagery available for a range of consecutive years.

Data preprocessing includes converting the Landsat image (scene) downloaded from the USGS Glovis Web site from tar.gz format to .tiff files. The .tiff files are then converted to Idrisi format for analysis in Idrisi Taiga. In order to enhance the results, a circular mask low-pass filter is applied to the image to remove low frequency noise. The scene is reformatted to center on Yosemite National Park because the images cover an area much larger than that of the study area. The x, y coordinates used to reformat the image are as follows: upper left (245588, 4233445) and lower right (307056, 4145852).

The park boundary vector file is overlaid all images for context. The Yosemite National Park Mortality Maps are available in .kmz format. For comparison with the Landsat images in the remote sensing software, it is necessary to convert the data into Idrisi format in the same projection using IDRISI Taiga.

Data Analysis

A cross correlation analysis is used to statistically detect areas likely to have changed between the two images. GIS analysis is used to extract statistical attributes of the feature class image to delineate spectral clustering. The attributes are applied to images displaying statistical information for the Yosemite vegetation map. These statistical attribute maps are compared to the 2011 Landsat raster image to generate a Z-score map that displays the standard deviation between the spectral signatures for each pixel. Areas displaying change in land cover more than likely changed due to disturbance, such as insect outbreak or spread of disease, resulting in damaged canopy.

Cross correlation requires the use of two central forms of data: 1) a feature class to delineate spectral cluster statistics for time 1; and 2) a Landsat image from a later date (time 2) to compare with the feature class image. The feature class in this situation will be the 2006 NLCD map. The image to be processed will be the greenness component of the tasseled cap transformation which is generated from the 2011 Landsat image using the Idrisi remote sensing program.

Cross Correlation Analysis

The tasseled cap transformation is generated for the 2011 Landsat scene. The tasseled cap transformation generates three components through the conversion of the readings in a set of channels into composite values; or by creating weighted sums and placing them into separate channel readings. The components created describe roughly the image's greenness, brightness and wetness characteristics (Huang et al., 2010). The comparison of the 2006 statistical image and the 2011 greenness component is the final step to assess where change in the forest cover has occurred.

Image Processing: *Average* and *Population standard deviation* attributes fields are generated for the NLCD feature class map. These attribute fields are assigned to images creating the raster files *Mean* and *Standard Deviation.* The greenness component is generated from the 2011 Landsat bands. Using the image calculator function in Idrisi software, the *Mean* and *Standard Deviation* images are compared to the 2011 greenness component to create a final Z-score image. The calculation uses this equation: ABS (Greenness–Mean / Standard Deviation). The resulting image displays the amount of variation between the 2011 greenness tasseled cap component scene and the baseline vegetation feature class map. To enhance interpretation of these results, the Z-score values are divided into three categories: definite change, possible change, and no change. This research considers anything above two standard deviations away from the forest class image values as definite change. Possible change is defined by values below three and above one standard deviation away and no change are those values one or less than one standard deviation away from the forest cover image values. Areas of possible change and definite change are considered damaged. A quality control will be conducted at this stage of mapping. Polygons of damaged forest that are not due to defoliation will be removed. The resulting map will be the final product of the remotely sensed technique.

Accuracy Assessment: An accuracy assessment of the extent and intensity of forest damage is conducted using higher resolution images and field visits. The sampling method is stratified to favor results from the damaged forest area, which will be disproportionately smaller and otherwise unlikely to be randomly selected. First, in Idrisi

Taiga, a systematic random sampling method gathers 20 points randomly within the damaged forest area and 35 points are selected in a completely random manner. Twenty-five points are taken provided by the USFS historical fire dataset. The points are compiled and compared to high resolution Google Earth images to assess whether change has occurred and if the change detection analysis has correctly categorized the pixels. Ground truth data collected in the field enhances the validation of accuracy. The ground truth information and remotely detected damage polygons are compared for all points using the ERRMAT feature in Idrisi. For this research, a minimum accuracy of 75 percent will be accepted. The method of accuracy assessment described above is also be applied to the USFS Aerial Detection Survey data.

In order to answer the hypotheses with a high degree of certainty, the final products must be properly validated through the use of ground truth data collection. A review of literature also found research suggesting that cross correlation analysis has a tendency to underestimate change in land cover making this aspect of research especially important (Bréda, 2003). Fourteen sites are selected that are both of interest and feasible to sample. Areas of interest include those where damage was detected using the remote sensing method or areas where damage has been reported or can be viewed using higher resolution imagery. Areas feasible to sample include those along trails. 0.1 hectare plots are delineated at each site. Information is collected for all trees present within the plot. Data gathered includes: species, stem densities of each species, diameter at breast height for each tree above breast height, whether a tree is dead, dying or alive, presence of insects of disease on dead and dying trees, evidence of fire damage, canopy closure, and understory vegetation. Photographs of tree cover and GPS coordinates are collected. These data are compared to the change detection map as an additional, more in depth form of accuracy assessment that yields useful information for the long-term study correlating fire history and damage occurrence.

Statistical Analysis

The results of the following statistical analysis address the research hypotheses. First, the final Z-score map displaying forest damage is directly compared to the USFS Aerial Detection Survey map using a contingency table and a statistical map.

Figure 5. The direct comparison of two maps' classifications to assess similarity

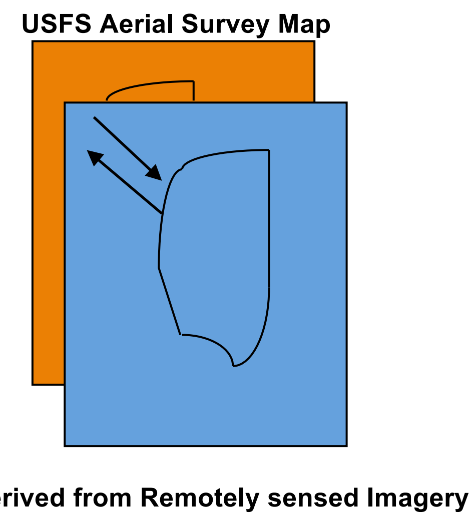
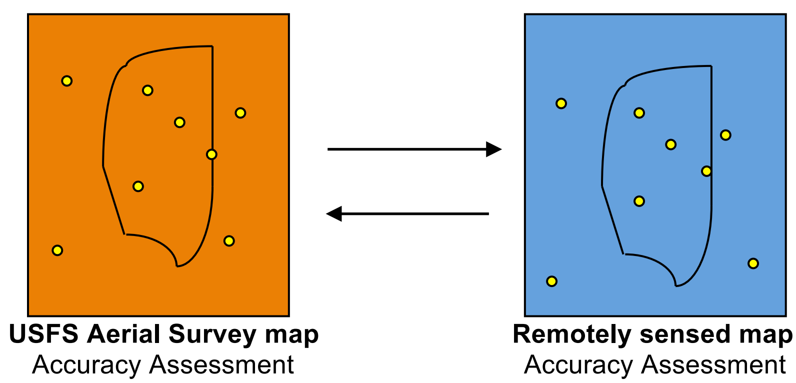


Figure 5 depicts the direct comparison of two classified maps. The CROSSTAB feature generates a contingency table comparing the frequency of classes observed in two classified maps. The classes in this project are: low, medium, and high probability of damage. The data in the contingency table yields useful statistics including the chi square and p-level. The p-level ranges from zero to one. A p-level of one indicates complete similarity. P-levels exceeding .75 indicate the maps are statistically similar. A map of the areas of disagreement between the maps is also created when running CROSSTAB. If pixels of disagreement are clustered, then the discrepancy between the two techniques is not a random phenomenon and they do not display forest damage in a spatially similar pattern. This can be analyzed using the joint-count statistic. Using statistical software and Microsoft excel, a joint-count analysis will assess the spatial clustering of disagreement between two maps. The resulting p-value and joint-count statistic address the hypothesis that a map created using remote sensing techniques will display forest damage in a pattern statistically and spatially similar to the USFS Aerial Detection Survey data.

Next, the accuracy assessments conducted for both the final Z-score map displaying forest damage and the USFS Aerial Detection Survey map are compared. The accuracy assessments use the ERRMAT feature in Idrisi by comparing randomly generated points within a classified map (predicted) with what is observed in reality (observed).

Figure 6. The comparison of two maps' accuracy assessment



Data for the actual points is found through ground-truthing techniques relying on high resolution imagery available on Google Earth and field visits to the points of interest. The ERRMAT feature produces an error matrix and the Cohen's Kappa coefficient and is run for each map using the same ground-turthed points. The Cohen's Kappa statistic is a level of agreement ranging from zero to one. In this situation, it describes the level of agreement between the observed and actual points. The observed Cohen's Kappa for each method is compared to address the hypothesis that a remotely sensed map displaying forest damage will as accurate as the USFS aerial sketch survey map.

CHAPTER 4

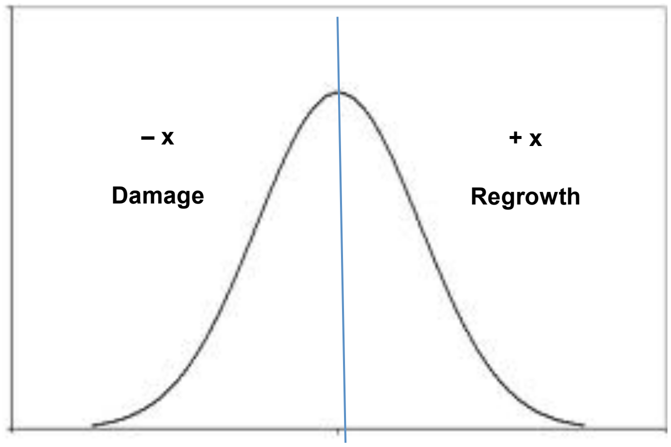
Data Analysis and Results

Introduction

This research explored methods of identifying and mapping tree damage in Yosemite National Park using remote sensing techniques. Preliminary results showed a low accuracy of the cross correlation procedure. For this reason, I reexamined the research parameters and the cross correlation method employed. In order to maintain the basic Z-score method discussed in Chapters two and three, I adjusted the threshold and distribution of data to reflect the specific and unique nature of detecting damaged forest. Thus, the parameters were modified, but the theory of cross correlation analysis was still tested.

Forested land cover types exhibit specific spectral characteristics. This research searches to detect damaged forest. This type of land cover change is strongly associated with decreases in the green component of the tasseled cap transformation. It is also helpful to note that this change is one directional, and can be found skewed to the left of the normal distribution, making a strong argument to leave values as integers rather than absolute as described in the research methods. This allows the analyst to differentiate damage from regrowth. This concept, displayed in Figure 6, gave cause to isolate the negatively skewed values as representing land cover that has been degraded within vegetation classes.

Figure 7. Standard distribution of change in forested land cover



Change in forest cover also appears to fall within a specific range of standard deviations. A discussion with the committee raised concerns that change within forest cover may occur under the 2 standard deviation threshold set based on a 95% confidence level. A review of preliminary results showed:

a) Instances of forest degradation most frequently displayed standard deviations ranging from –.05 ~ –3.0.
b) Land cover classes other than forest displayed common Z-score values exceeding –1.5 where no damage occurred.

Table 5. Research thresholds by class for cross correlation method

Land Cover	Damage Threshold
Open water	–13
Perennial water/ snow	–1.2
Urban	–2.74
Barren land	–4
Forest	–0.43
Shrub land	–6.87
Herbaceous	–1.89
Wetlands	–2.75

This discovery gave precedence to set thresholds specific to each class. Using the land cover classes depicted in the NLCD 2006 dataset, eight classes were extracted from the total Z-score image. The land cover classes and their associated thresholds are displayed in Table 5. Z-scores are standardized values, meaning they have been normalized and are no longer a measure of the greenness component used for analysis. The final map yielded values between –17 and 15. Thresholds were set manually by considering each classes' Z-score distribution. Manual selection involved sampling 15 to 30 points within each land cover type and noting the Z-score value and if damage had occurred. A census of Z-scores is the basis for the analyst to select a threshold that best indicates damage.

In addition to refining the cross correlation method, a second method of change detection was incorporated. While generating the tasseled cap transformation during the image processing phase, I noted a strong correlation between the greenness component and fire burns. Further investigation into existing literature suggests a method of tasseled cap differencing for change detection. Therefore, I thought the study would be remiss to exclude an analysis of this method. To execute a hybrid tasseled cap change analysis, the greenness component of an image is subtracted from a more recent image's greenness component. This study subtracted the greenness component of a 2011 Landsat image from the greenness component of a 2006 Landsat image. These dates were selected to reflect the time range present in the cross correlation method and the USFS Aerial Detection Survey data for ease of comparison. The resulting values in the change raster ranged from –84.46 to 86.77. Again, a threshold was set manually by sampling 50 points within the study area noting the value and if change had occurred. From this sample, a tolerance was set at –6.0, classifying values –6.00 and below as having experienced damage.

These modifications resulted in two remotely sensed damage detection maps. These maps were then compared to the USFS Aerial Detection Survey map to test the research hypotheses described in the methodology and displayed below in Figures 8 and 9.

Figure 8. The comparison of three maps' accuracy assessment based on a collection of ground truth points

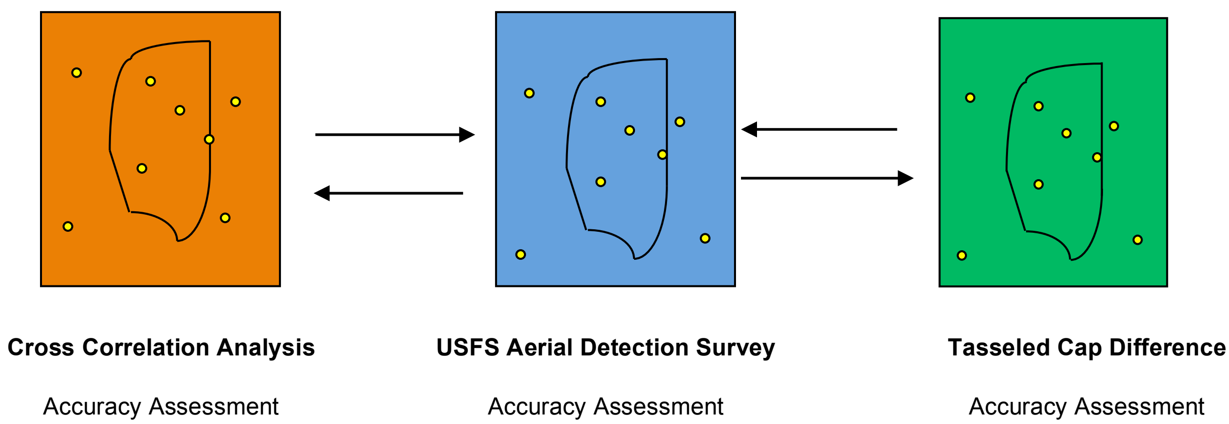
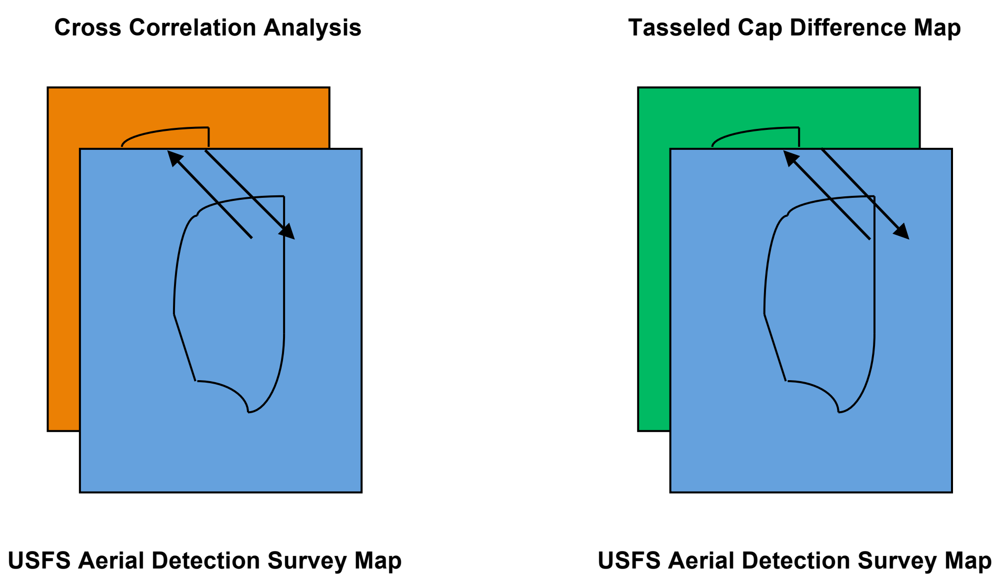


Figure 9. The direct comparison of both change detection methods with the USFS Aerial Detection method



Description of Data

Three total maps depicting forest damage in Yosemite National Park were prepared for comparison. The three maps were classified into two exclusive classes: no damage (1), and damage (2). The maps were tested for accuracy through confusion matrix analysis and tested for statistical and spatial similarity through a cross tabulation method and scalar analysis.

Confusion Matrix Analysis

A total of 90 ground truth assessment points were compiled to perform the accuracy assessment. The points included in the assessment are listed in table 6 by their source. The ground truth point dataset remained the same for all three maps, excluding the final 17 stratified points. The stratified points were randomly sampled over each maps' damage class. This technique was implemented because the nature of change maps produces an image largely comprised of negative space. Simple random point selection, therefore, tends simply to test how well a map accurately detects no change where no change is present. Stratifying the sample over the damaged class introduces more ground truth points that test how well the map detects change where change is present.

Table 6. Ground truth points by source

Source	**Point count**
Field observation	13
USFS Fire History Data	25
Random	35
Stratified (map specific)	17
Total	90

Given the two classes, four outcomes were possible for every point tested: 1) Agreement that no damage has occurred, 2) agreement that damage has occurred, 3) damage was predicted but not observed (type I error), or 4) damage was observed but not predicted (type II error). The results of the accuracy assessment are displayed in confusion matrices in Tables 7 to 9. The cross correlation and tasseled cap difference processes produced Figure 10 and 11 and the USFS Aerial Detection Survey data is displayed in Figure 12.

Figure 10. Map produced by the cross correlation procedure

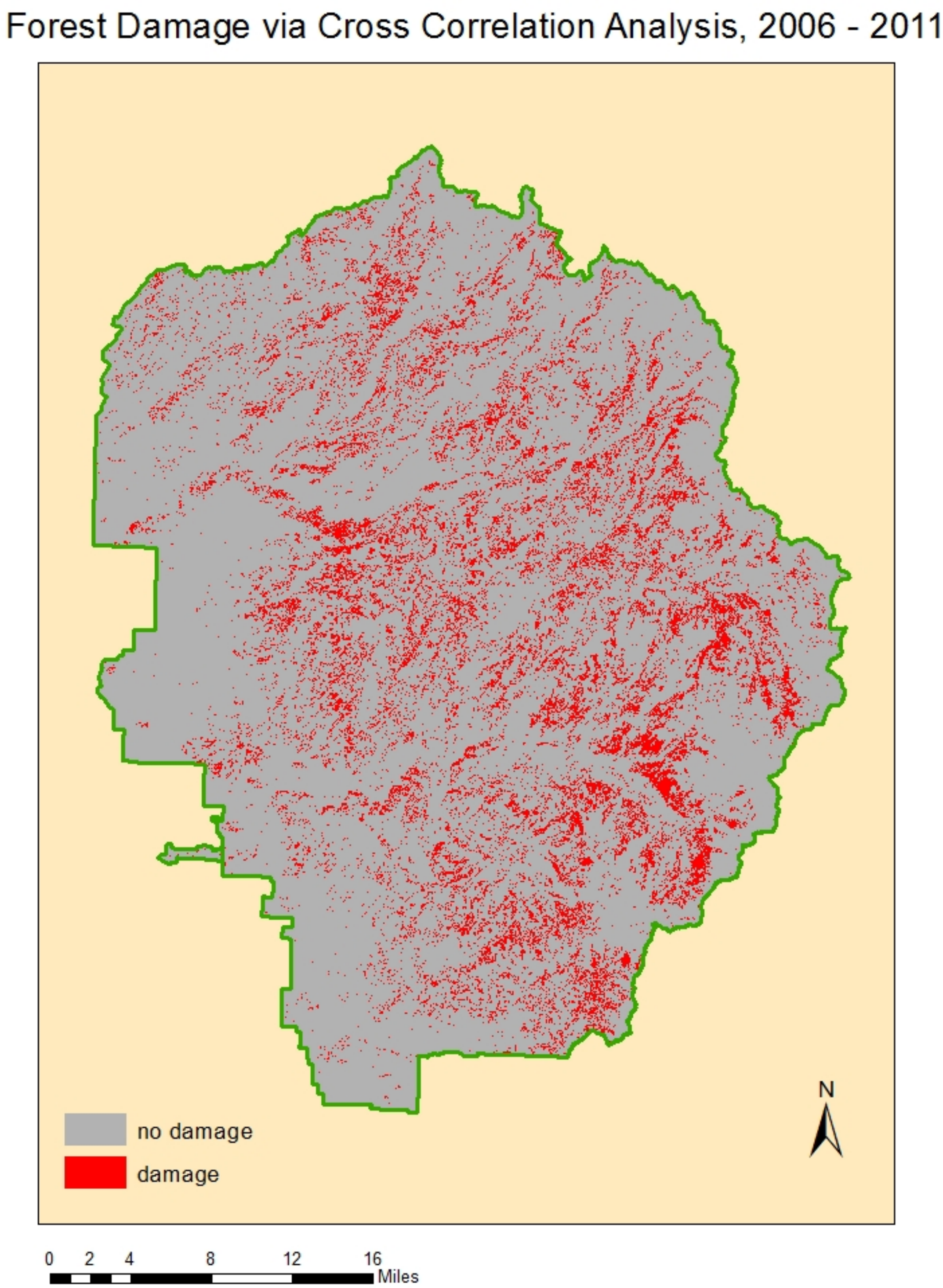


Figure 11. Product of the tasseled cap difference method

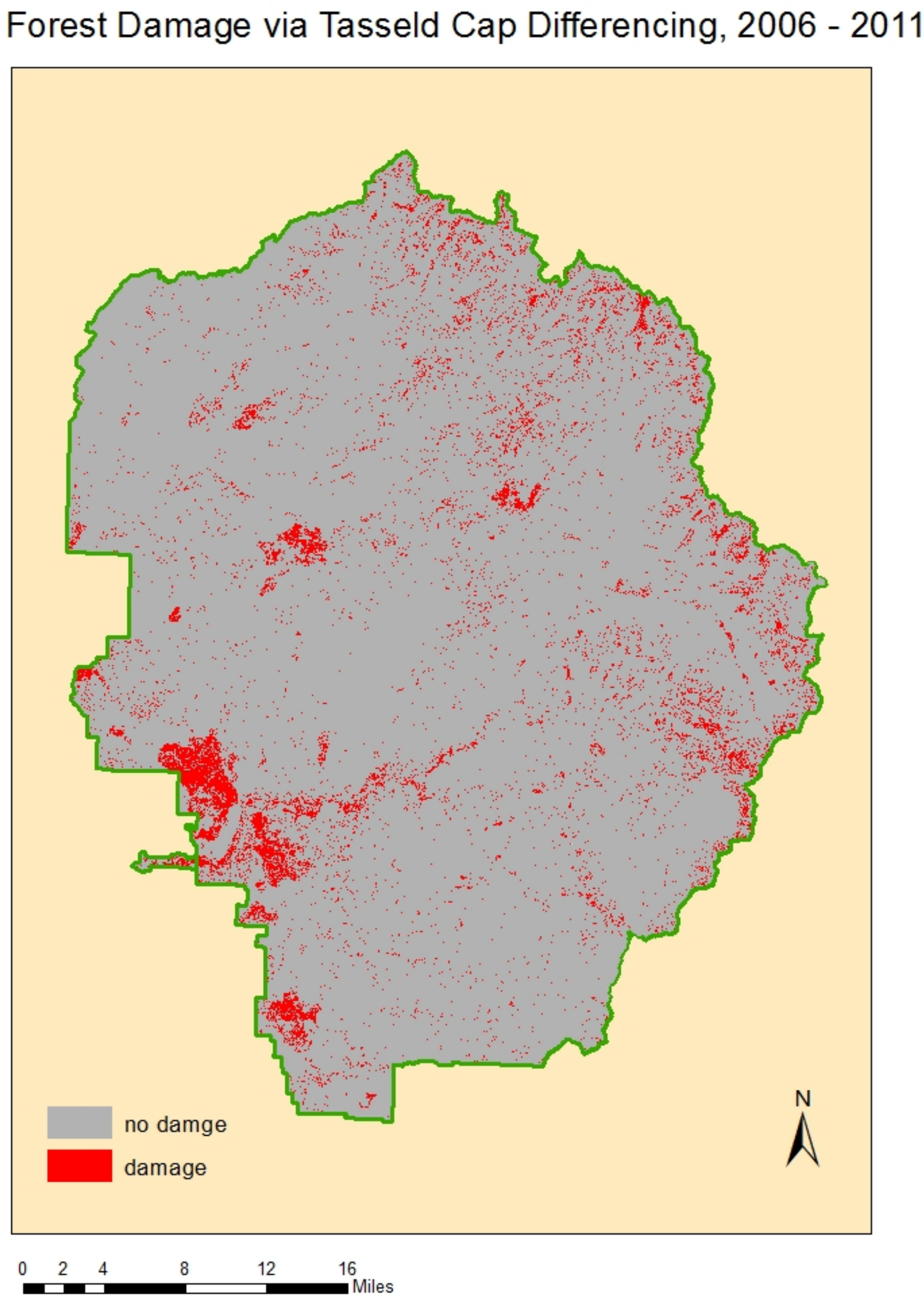


Figure 12. Compilation of the USFS Aerial Survey Detection maps from 2006 - 2011

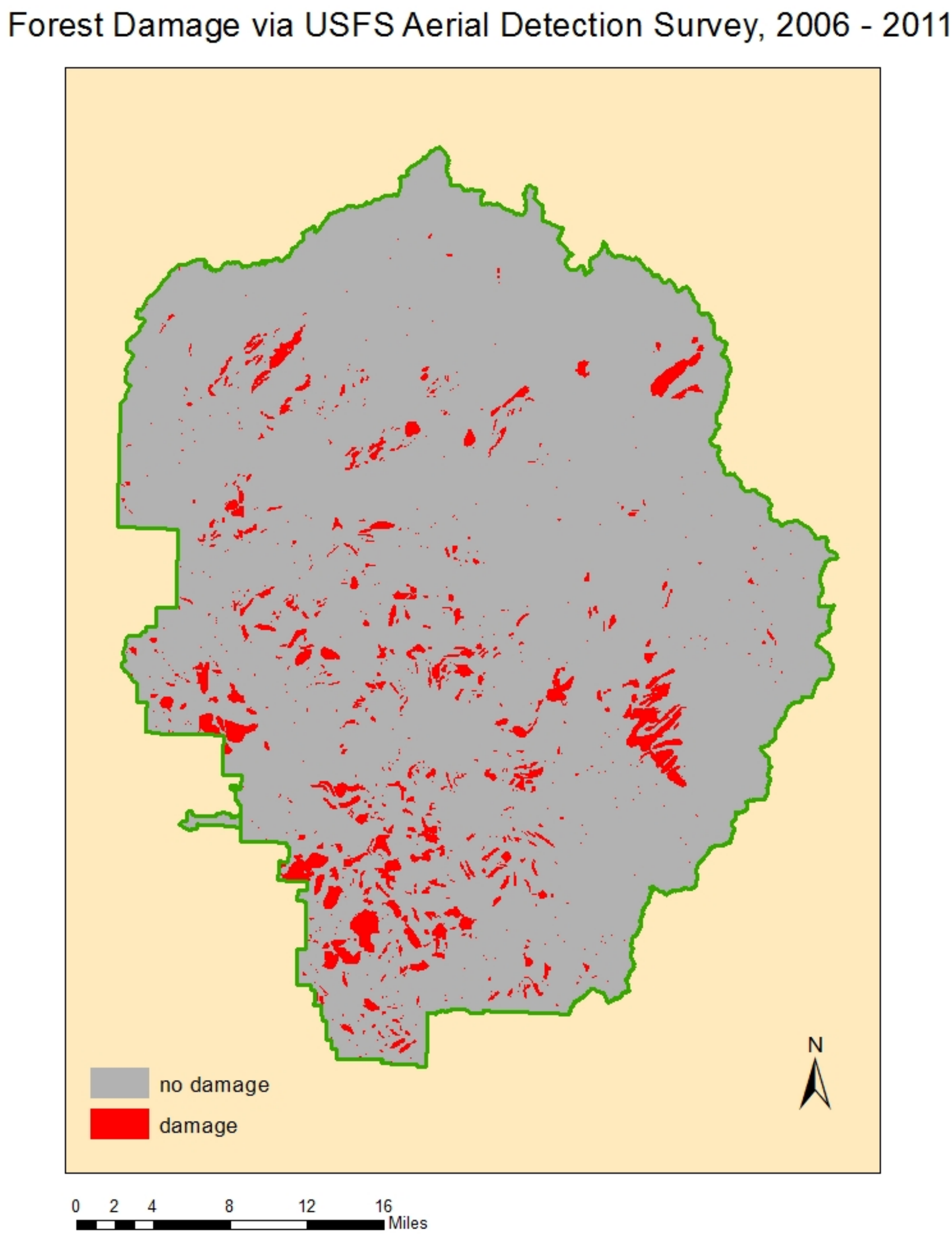


Table 7. Error matrix for cross correlation analysis

Predicted	Observed 1	2	sum
1	57	13	70
2	6	14	20
sum	63	27	90

Damage accuracy	0.519
P(a)	0.789
K	0.556

Table 8. Error matrix for tasseled cap difference

Predicted	Observed 1	2	sum
1	60	10	70
2	6	14	20
sum	66	24	90

Damage Accuracy	0.583
P(a)	0.822
K	0.649

Table 9. Error matrix for USFS Aerial Detection Survey

Predicted	Observed 1	2	sum
1	52	21	73
2	11	6	17
sum	63	27	90

Damage accuracy	0.222
P(a)	0.644
K	0.491

Maps created for this research will be accepted as sufficient with accuracies of 75% or higher. The results displayed in Tables 7 to 9 show the tasseled cap difference method had the highest accuracy with 82% agreement. The cross correlation method had an acceptable accuracy of 79%, while the USFS Aerial Detection Survey method tested at a failing accuracy of 64%. Furthermore, the analysis included a calculation of damage accuracy, dividing the number of correctly predicted cases of damage by the total number of observed damaged points. The results of the damage accuracy assessment showed the cross correlation method to detect change with 52% accuracy and the tasseled cap difference with an accuracy of 58%. The remote sensing methods failed to surpass the discipline's standard of 75% specific to damage. The USFS Aerial Detection Survey method had a low accuracy in this category of only 22%.

Cohen's Kappa coefficient (κ) is another measurement of agreement. κ considers the possibility that agreement occurred randomly, and therefore, has been cited as a more statistically robust measure than percent agreement. A common interpretation of κ by Landis and Koch denote values zero and below as demonstrating no certain agreement, 0–.20 as slight, .21–.40 as fair, .41–.60 as moderate, .61–.80 as substantial, and .81–1 as near perfect. According to Landis and Koch, the cross correlation method had a κ of .56, or moderate agreement while the tasseled cap differencing method had a κ of .65, or substantial agreement. The USFS Aerial Detection Survey method also displayed moderate agreement with the lowest κ value observed of .49.

Cross Tabulation Analysis

A cross tabulation compares the frequency of nominal data observed in two classified maps. Tables 10 and 11 below compare the frequency of classes in the USFS Aerial Detection Survey to each remotely sensed method in cross tabulation tables. The occurrence of each class is reported in meters. This analysis is concerned with assessing the statistical similarity of the remotely-sensed maps with the traditional method of aerial surveys. Cohen's Kappa coefficient (κ) proves to be a useful measurement of similarity once again because it accounts for the possibility that the statistical similarity is random rather than due to environmental phenomenon being mapped. Table 12 displays the resulting κ values based on observed values (USFS Aerial Detection Survey) and expected values (the remotely sensed methods).

Table 10. Cross tabulation comparing cross correlation method and USFS Aerial Detection Survey (km^2)

	Cross correlation analysis		
USFS	1	2	sum
1	2500.07	359.21	2859.28
2	146.60	24.55	171.12
sum	2646.68	383.74	3030.41

Table 11. Cross tabulation comparing tasseled cap difference method and USFS Aerial Detection Survey (km^2)

	Tasseled cap difference		
USFS	1	2	sum
1	2670.07	179.59	2849.66
2	156.81	14.35	171.17
sum	2826.88	193.95	3020.84

Table 12. Calculation of Cohen's Kappa coefficient: USFS Aerial Detection Survey map compared to cross correlation map and tasseled cap difference map

	Cross correlation analysis	Tasseled cap difference
P(a)	0.833	0.889
P(e)	0.007	0.886
Kappa	0.011	0.019

Table 12 represents the assessment of the remote sensing maps' ability to display a statistically similar map to the USFS Aerial Detection Survey. In order to draw conclusions from the κ values, it is necessary to recall Landis and Koch's interpretation of the statistic (0–.20 slight, .21–.40 fair, .41–.60 moderate, .61–.80 substantial, and .81–1 near perfect). The low κ values are interpreted to represent a low statistical association between the mapping methods being compared. The tasseled cap method displayed a higher κ of .19, approaching the common interpretation of “slight” similarity, which is visualized in Map 6 below.

Scalar Analysis

Finally, the research states remote sensing can produce a map spatially similar to the USFS Aerial Detection Survey Map. A scalar analysis compares two datasets by delineating the outcomes into new classes. These assessments overlay the remotely detected maps with the USFS Aerial Detection Survey Map. The map inputs contain two classes: damaged and not damaged. The scalar analysis produces a map containing four classes: agreement of static conditions, agreement of damage, USFS damage, and remotely sensed damage. Figure 13 and 14 display the results of the scalar analysis.

Figure 13. Spatial Comparison of cross correlation and USFS Aerial Detection Survey

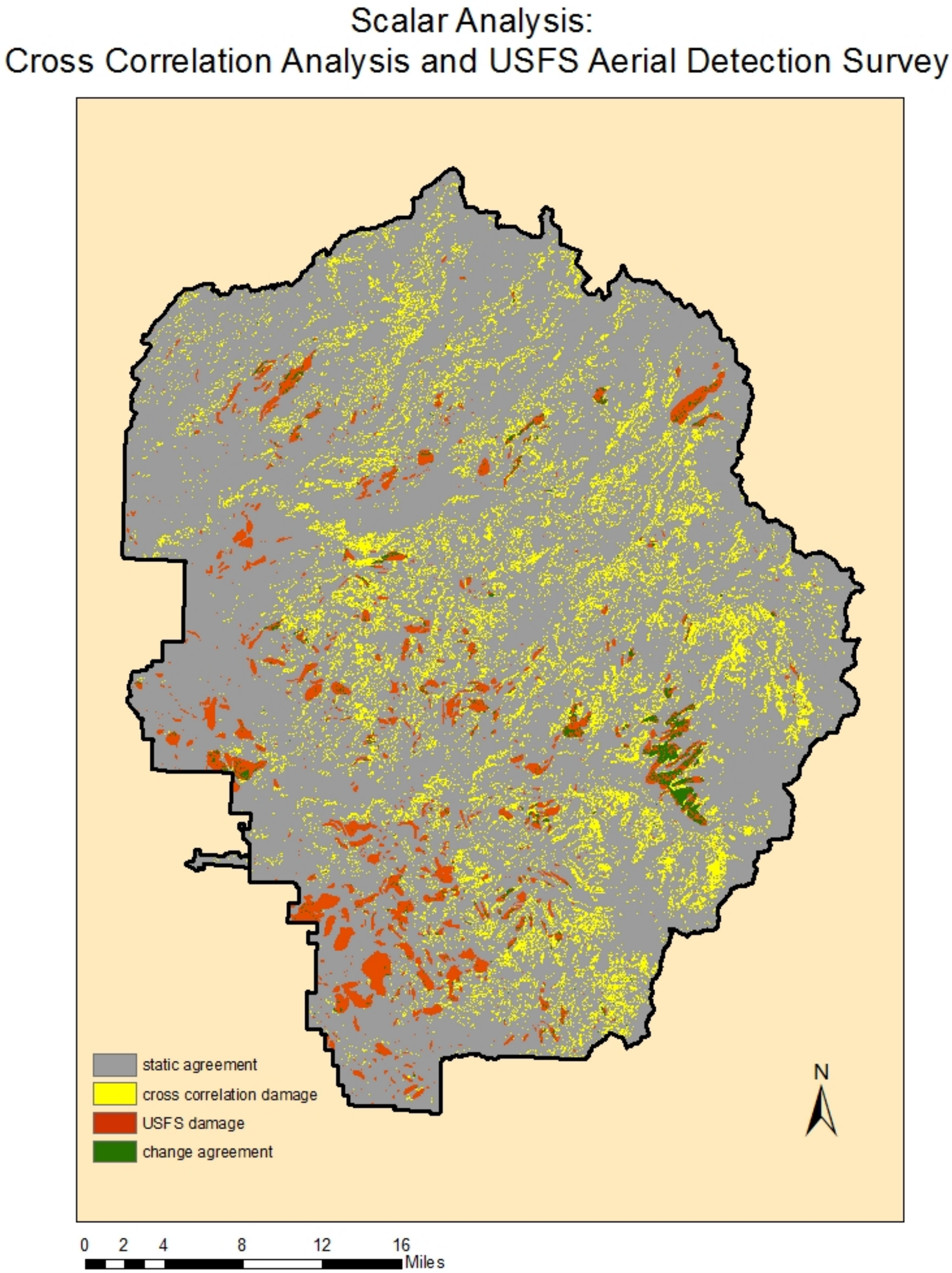
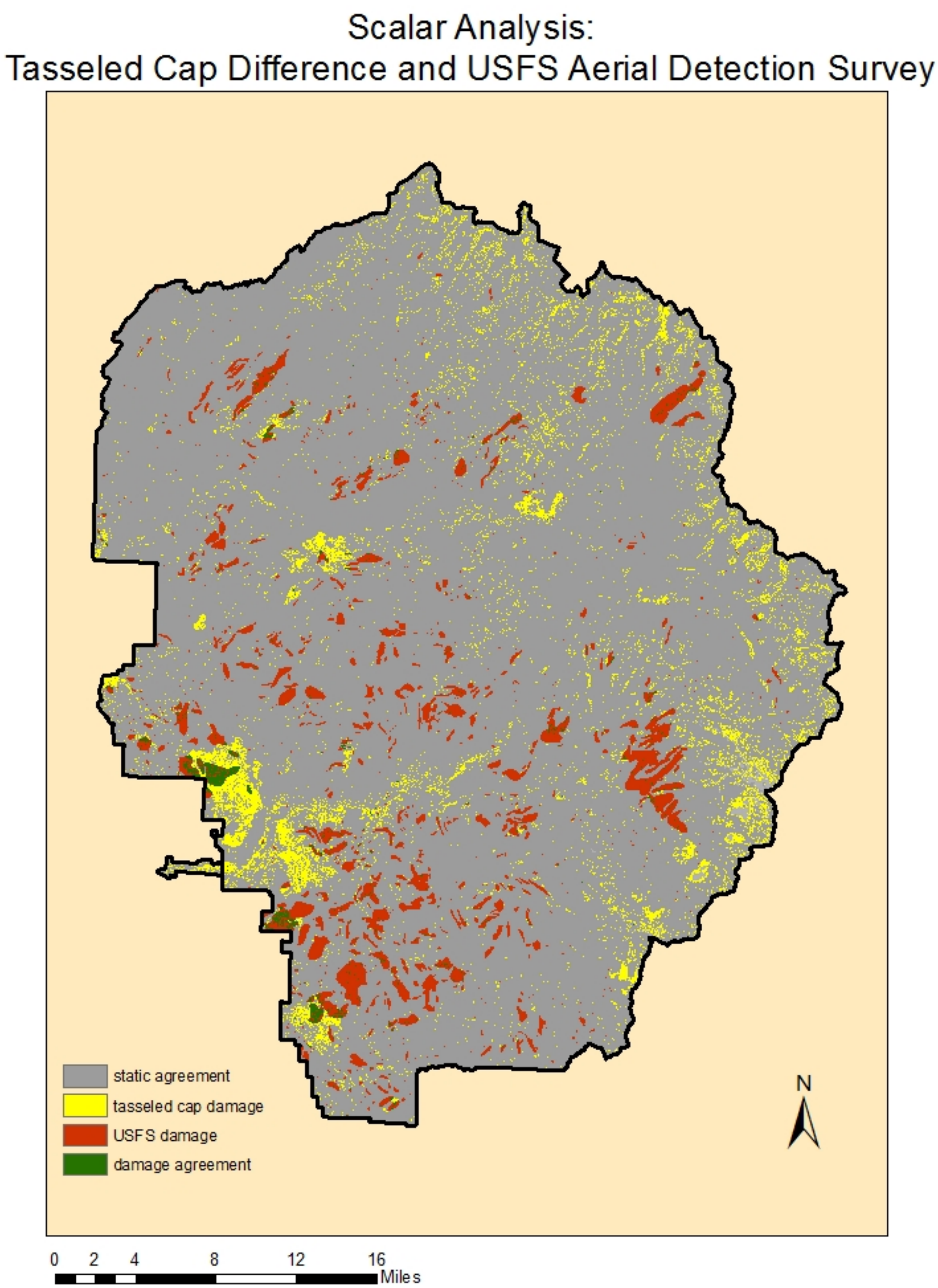


Figure 14. Spatial Comparison of tasseled cap map and USFS Aerial Detection Survey



The scalar analysis maps can be interpreted qualitatively. Figure 13 displays a region of agreement between the cross correlation method and the USFS Aerial Detection Survey method in a high elevation region located in the southeast of the Park. The map also shows a vast amount of inconsistency across the entire park. Specifically, the cross correlation method detects damage in a greater distribution throughout the higher elevations, while the USFS Aerial Detection Survey identifies damage in a more clustered pattern. In large part, the map displays very low agreement between the methods' damage class. Figure14 shows the product of overlaying the tasseled cap difference map and the USFS Aerial Survey Detection map. There are four distinct areas where both maps identify damage located primarily in the western portion of the Park. Both techniques detect damage to forest cover in a pattern more clustered than the cross correlation method. Many of the clustered areas are in disagreement in Figure 14.

Hypothesis Testing

The statistical analyses above were performed to address the working hypotheses proposed by this research. The data presented in the preceding tables is discussed as it relates to each assumption below.

1) The remotely sensed map displaying forest damage and the USFS Aerial Detection Survey maps will have comparable accuracies.

Cohen's Kappa coefficient was calculated as a measurement of agreement among observed values and predicted values. Both remotely sensed mapping methods produced κ values far exceeding that of the USFS Aerial Detection Survey's. The tasseled cap difference method had a value of .69 demonstrating substantial agreement and the cross correlation displayed moderate agreement with a value of .51. Common interpretations of κ (Landis and Koch) describe values below zero, such as the USFS Aerial Detection Survey's method, as having no agreement. Additionally, both remotely sensed maps had damage and overall accuracies significantly higher than the USFS Aerial Detection Survey map's. Given any one of these metrics, the remotely sensed methods produced not only comparable, but higher accuracies. Based on these findings, the first hypothesis can be accepted as true.

2) A map created through remote sensing techniques will display forest damage in a pattern statistically and spatially similar to USFS Aerial Detection Survey maps.

Each remotely sensed map was compared to the USFS Aerial Detection Survey map using Cohen's Kappa coefficient. The results of both tests yielded κ values below .2, allowing us to accept the null hypothesis that no statistical association exists. The cross correlation method had a κ value of .11 while the tasseled cap difference method produced a κ approaching slight similarity of .19. The scalar analysis shows the cross correlation method to display three areas of damage in common with the USFS Aerial Detection Survey while the tasseled cap method had and five. Maps 5 and 6 are qualitatively interpreted to have little to no spatial association. These metrics do not support the assumption that both remotely sensed maps display damage in a pattern statistically similar to the USFS Aerial Detection Survey maps. The second hypothesis is rejected given these results.

Discussion

The remote sensing methods had accuracies exceeding that of the manual method and displayed little to no statistical and spatial similarity to the manual method. The first research hypothesis was accepted as true. The tasseled cap difference method produced the most accurate map of forest damage (82% p(a), .649 κ) and displayed a stronger association to the USFS Aerial Detection Survey (.19 κ) than the cross correlation method (79% p(a), .556 κ, .11 κ).

The remotely sensed maps performed similarly when examining their ability to identify damage specifically. The cross correlation analysis detected damage at 52% and the tasseled cap difference method at 58%. The current manual method employed by the USFS Aerial Detection Surveys performed significantly worse in this category of special interest, identifying damage at only 22% accuracy. While the remote sensing methods exceeded the USFS Aerial Detection Survey in damage detection, no single method surpassed the research's target accuracy of 75%, which brings into question whether any of the methods tested are suitable for identifying damage in the wilderness. Qualitatively, it should be noted that the USFS Aerial Detection Survey appears to map general areas of forest degradation quite well, however, is not very precise. Accuracy assessment's conducted in the field of remote sensing favor highly precise results given the (30 meter) pixel by pixel basis for analysis. For example, a test point identified as "damaged" may appear one pixel to the right of an entire polygon denoted as change. The method calls this an error, allowing very little room for geo-registration inaccuracies.

The remote sensing techniques tested exhibited type I errors in a particular pattern that is cause for concern. Type I errors are those instances where damage is predicted but not observed. Fluctuations in seasonal and natural environmental conditions are inherent in remote sensing methods. Areas of high elevation are more likely to have these variations present due to sheer rock exposure and snow and snow melt variations from year to year. Areas of high elevation are therefore more susceptible to display change when it has not occurred. This phenomenon was evidenced in both the cross correlation analysis and tasseled cap difference techniques' final products. A large majority of type I errors were located in the mountainous regions of the Park. Normalizing for this phenomenon would further enhance the remote sensing techniques. The cross correlation analysis had an anomalous amount of damage detected in the higher elevation regions of the Park. This is particularly evident in Figure 13, displaying a great amount of damage where the USFS Aerial Detection Survey did not. The cross correlation analysis may be more sensitive to seasonal variations as discussed above. Another hypothesis holds that the cross correlation analysis method is truly capturing some small environmental change in phenology not readily detectable through other methods or viewed by the eye. This is a viable explanation because high elevation ecosystems are the first to demonstrate the impacts of climate change.

In conclusion, a remote sensing method exists that yields equally, if not more, accurate results when detecting damage to tree cover. The research, based on a method of stratified and random sampling, found the tasseled cap difference technique a superior means to produce maps of damage to forest cover in Yosemite National Park than the current manual method.

CHAPTER 5

Summary and Conclusions

Introduction

The USDA Forest Service maps forest damage throughout its Pacific Southwest Region. The Agency currently employs a method of aerial over flights to yield this valuable monitoring data. Aerial over flights are costly and inefficient, and the technique is associated with some amount of inaccuracy. This research investigated the capability of remote methods to produce damage maps relying on a free database of Landsat TM satellite imagery provided by the US Geological Survey. The study focused on Yosemite National Park, located within the USFS Pacific Southwest Region. Two remote sensing methods were tested.

The study was based on two working hypotheses to test remote sensing's ability to create a map of forest damage that is: 1) accurate; and 2) similar to the USFS Aerial Detection Survey data. While creating a map depicting damage in an accurate manner is the primary concern of this study, assessing similarity to the current method is also noteworthy due to the implication of replacing the manual method. Accuracy assessments were conducted on the remotely sensed maps and the USFS Aerial Detection Survey data using a set of ground observation points. Accuracy was determined through confusion matrix analysis and Cohen's Kappa coefficient: a robust measurement of agreement. The κ values of each method were compared to one another to address the assumption of accuracy. Similarity was tested by comparing the USFS Aerial Detection Survey data to each remotely sensed map through a cross tabulation. The cross tabulation matrix produced κ to assess the level of correlation present. A scalar analysis was produced to assess the maps spatial correlation qualitatively.

Summary of Procedures

Two methods of remote sensing were used to map forest damage in Yosemite National Park. A cross correlation analysis technique has proven useful to map small scale perturbations in wetlands, however is widely absent in the literature of remote sensing. Therefore, the method seemed suitable to test on forest cover for use in this study. After preliminary results demonstrated marginal success of the cross correlation method, a second traditional method of image subtraction was added. The cross correlation method extracted values from the green component of the tasseled cap transformation of a 2011 Landsat image to the land cover zones delineated by the 2006 National Land Cover Data set. The average and standard deviation from the 2011 image of interest were used to generate Z-scores. These Z-scores were used to represent areas likely to have changes since 2006. The image subtraction technique relied on a 2006 and 2011 Landsat image. The tasseled cap transformation was applied to both images, and the green component of each was used in the following calculation: 2011 – 2006. Each map had a unique range of values spanning negative to positive. The negative values were isolated as representing degradation and thresholds were set manually to represent areas having experienced damage. The result of this process produced two classes: damage and no damage.

The two damage maps produced by this study were tested for accuracy against a set of 90 ground observation points. The USFS Aerial Survey Detection data from 2006 – 2011 was also tested for accuracy using the same method. The ground truth points were gathered from a range of sources including: field observations, random sampling,

sampling from historical fire data, and stratified sampling of each maps' damaged class. Confusion matrices were generated based on the results of the accuracy assessment and Cohen's Kappa coefficient was calculated for each. The κ values of the three maps were then compared to assess which practice was most effective in mapping damage to forest cover that had occurred between 2006 and 2011.

The two damage maps created through remote sensing techniques were then directly compared to the USFS Aerial Detection Survey to test for statistical and spatial similarity. The frequency of classes present in the cross correlation analysis map and tasseled cap difference map was compared with the frequencies present in the USFS Aerial Detection Survey in a cross tabulation matrices. Cohen's Kappa coefficient was calculated for each situation. The resulting κ values were interpreted to assess if statistical similarity to the manual method was observed in either remotely sensed map. Each remotely sensed map was directly overlaid with the USFS Aerial Detection Survey data to inspect for spatial similarity. A scalar analysis classified the overlaid images into four categories: agreement of static conditions, agreement of damage, USFS damage, and remotely sensed damage. These images were used to qualitatively assess spatial similarity.

Summary of Findings

The study found the remote sensing techniques tested provide a sound means for mapping damage to tree cover. The tasseled cap difference and cross correlation techniques had accuracies above 75% while the USFS Aerial Survey Detection performed at a significantly lower accuracy of 64%. These results allowed us to accept the first hypothesis. The study also tested for spatial and statistical similarity to the USFS

Aerial Survey Detection data. The results showed little to no correlation with the USFS data, allowing us to reject the second hypothesis.

Conclusions

Given the limitations of the study and based upon the results of this research, remote sensing methods exist that yield equally, if not more, accurate results when detecting damage to tree cover than the current manual method of annual over flights. The tasseled cap difference method had the highest accuracy. Of the 90 ground observations, 74 points were identified correctly. It also had the highest Cohen's Kappa coefficient, demonstrating its accuracy was not likely due to random chance. The tasseled cap difference method detected damage correctly only 58% of the time. This poor performance, however, was still better than both the cross correlation analysis (52%) and USFS Aerial Detection Survey (22%) within this specific category of interest. While the tasseled cap difference method was most effective at detecting damage within Yosemite National Park, it performed only slightly better than the cross correlation analysis. The cross correlation analysis, however, displayed type I errors in a manner that is particularly concerning; giving cause to favor the tasseled cap difference method. Neither remotely sensed method produced a damage map statistically and spatially similar to the USFS Aerial Survey Detection Method.

Discussion and Implications

Park Service and Forest Service managers are increasingly concerned with identifying methods to quickly and efficiently monitor environmental conditions. Current manual processes are time consuming, giving precedence to explore remote sensing methods of change detection. This study offers a means to eliminate the cost and labor associated with the manually derived maps. While the tasseled cap difference method appears to have produced a superior method for detecting damage to forest cover accurately, it should be stated the USFS Aerial Detection Survey maps do a good job of identifying large scale area of fire burns and infestation, but are not competitive at the level of precision used in remote sensing (pixel by pixel). Therefore, further trials should be run before confidently replacing a remote method for the manual method.

The central focus of the study was to test remote sensing's ability to accurately detect change. The fact that we were able to accept the first hypothesis as true, demonstrating a low accuracy of the manual method, makes the second hypothesis of creating a map similar to the manual method less significant. Therefore, the implications of rejecting the second hypothesis are less adverse.

The tasseled cap difference technique proved to be the most effective method of damage detection in Yosemite National Park. A further argument to apply this method more widely is its minimal data requirements and relatively simple execution. The cross correlation method requires a feature class data set to exist from the first time period of interest. For this study, the 2006 National Land Cover Data set was used; however, the current manual method is produced annually, which would require analysts to produce accurate land cover maps each year. Producing accurate land cover maps is a challenging and time consuming task in its self. The cross correlation method also involves a more complicated algorithm subject to error. Since the study sought to identify a more efficient method to replace the current Aerial Detection Surveys, the tasseled cap difference method proves superior in a number of ways.

The findings of this research also have ecological implications. Some amount of disturbance due to insects and fire are natural and imperative for the function of a healthy forest. Another portion of damage results from human influence, or environmental anomalies. The distinction between the two is not easily observable. Providing a means to quickly and frequently monitor forest health allow scientists to correlate climate change data, historic fire suppression, and other trending information with damage. This capability could assist park managers in assessing whether certain instances of disturbance are natural and healthy, or man-made and harmful.

Recommendations for Further Study

A major complication facing change detection in mountainous regions via remote sensing is the variety of topography. It is recommended this factor be better accounted for in future studies. Enhanced forms of topographic correction incorporating digital elevation models may help account for this issue. The Teillet-C correction outlined by Meyer et al., (1993) uses elevation, solar elevation and azimuth, and samples from land cover to create regressions for each band, reducing the influence of topography on the overall scene. While the calculations are somewhat complicated, this type of preprocessing may reduce the number of type I errors demonstrated in this study.

Another area prime for further investigation is manipulating the accuracy assessment method. The method employed by this study assesses correctness on a pixel by pixel basis. This process favors highly precise techniques. I believe it would be helpful to consider the purpose of the product and what level of precision is required. It would be worthwhile to investigate techniques of expanding points to include a diameter of 100 meters or including the eight pixels adjacent to the ground truth observation.

APPENDICIES

Appendix A – Description of ground truth points

	LONG W	LAT N	Point ID	Location	
1	-119.55199	37.74794	Plot 1	Mirror Lake	Healthy Mixe
2	-119.38958	37.87805	Plot 2	Tuolumne Meadows	Diseased and
3	-119.48701	37.80725	Plot 3	Olmstead Point	Healthy Cano
4	-119.52145	37.81471	POI 1	Off route 120, North West of Olmstead Point	Widespread
5	-119.61020	37.5052	Plot 4	Mariposa Grove	Pine and Shu
6	-119.60431	37.50387	POI 2	Bachelor and Three Graces	Sequioa Tree
7	-119.68400	37.5763	POI 3	Mosquito Creek	Large, Matur
8	-119.60820	37.7168	Plot 5	Elephant Rock	Hardwood dc
9	-119.54563	37.80639	POI 4	Porcupine Flat	Immature Re
10	-119.22525	37.95109	Plot 6	East of Park, near Mobile Mart	Aspen Stand
11	-119.26125	37.88964	Plot 7	Dana Meadows	Lodgepole D
12	-119.75068	37.72546	POI 5	Big Oak Meadow	Regeneratior
13	-119.83806	37.76966	POI 6	Off Rockafeller Path	Dead, Burnec
14	-119.82341	37.76748	POI 7	Rockafeller Grove	Sugar Pine S

Appendix B – Photographs of ground truth points

Point 1

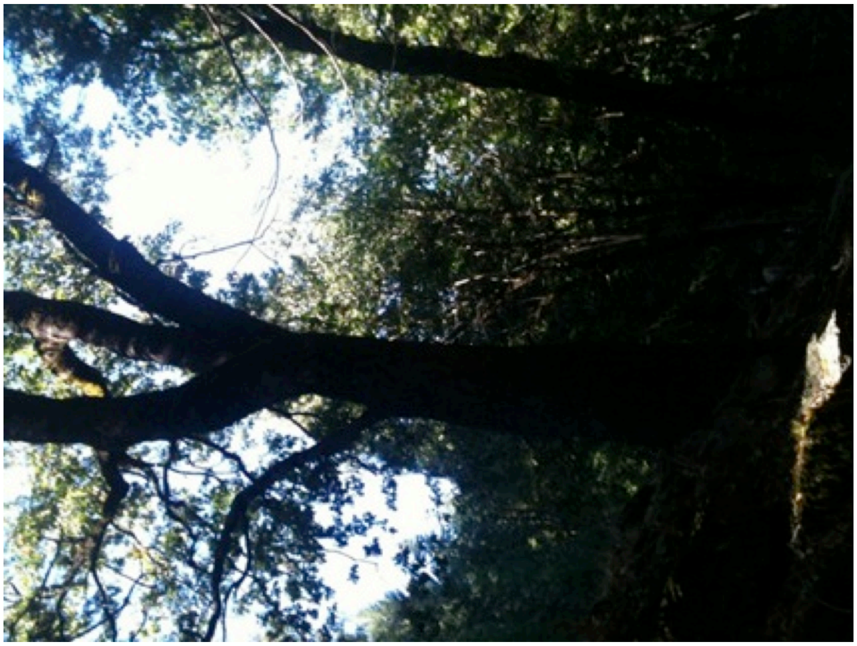
Point 2

Point 3

Point 4

Point 5

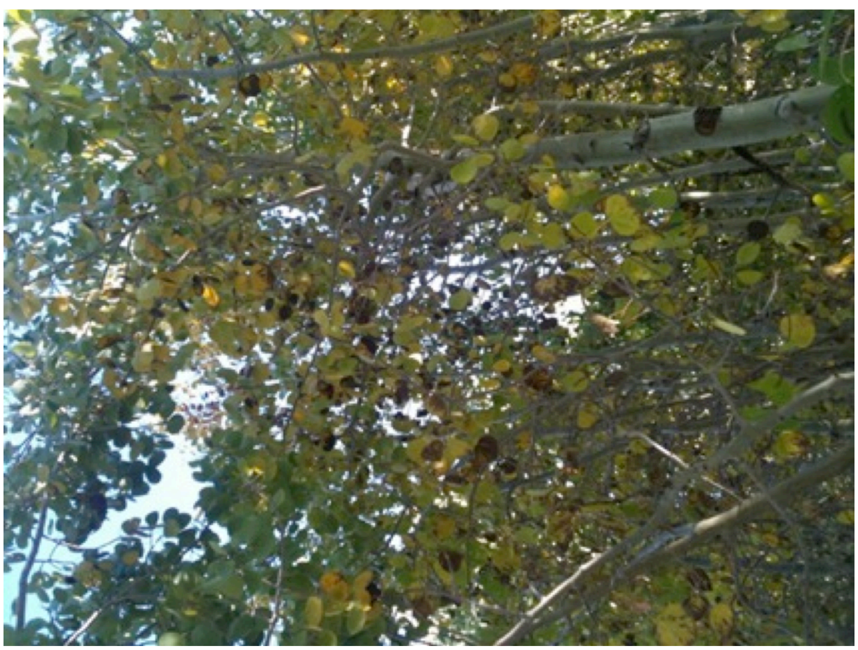
Point 6



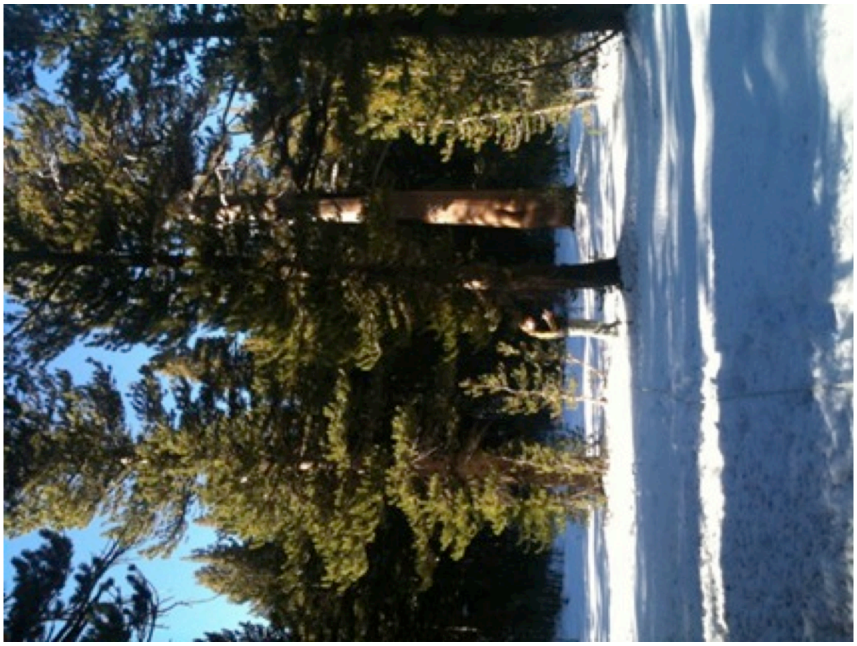
Point 7

Point 8

Point 9



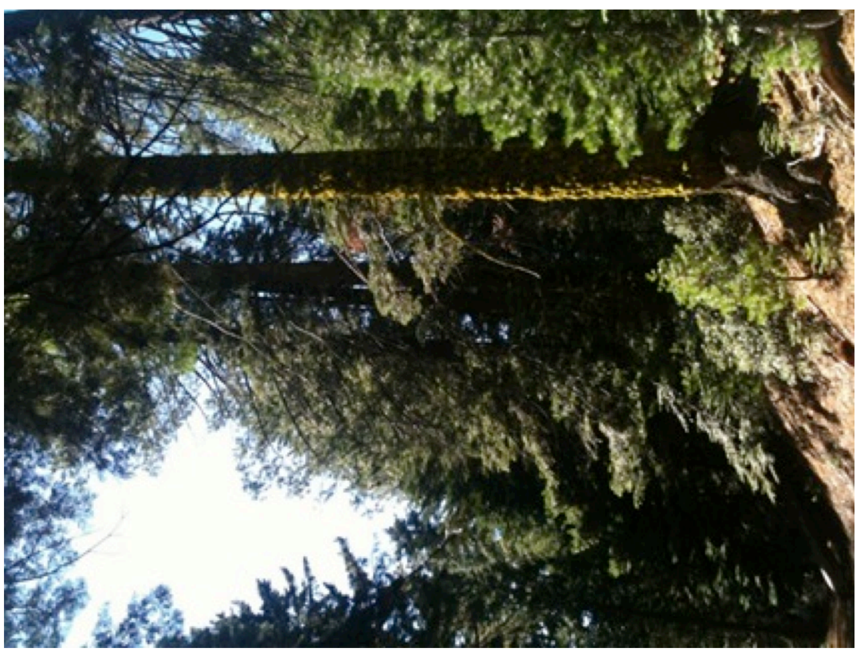
Point 10



Point 11

Point 12

Point 13



Point 14

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