POST-FIRE REGENERATION ASSESSMENT IN YOSEMITE NATIONAL PARK

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ABSTRACT

Assessing ecological change is increasingly important to Yosemite National Park managers. The park experienced some of its largest fires in recent history that significantly changed its ecosystems and landscapes. Change detection techniques were utilized in assessing post-fire regeneration in Yosemite for fires that occurred in 1988, 1990, and 1996. Change patterns were detected with a time-series of Normalized Difference Vegetation Index (NDVI) and Normalized Difference Moisture Index (NDMI) images derived from Landsat TM and ETM+ imagery. The commonly known change detection method of image differencing was applied to the transformed images to create two-year interval change maps categorized by classes of increasing and decreasing standard deviations to distinguish significant changes. In addition, a less commonly known change method, the RGB-NDVI and RGB-NDMI unsupervised classification was implemented to create composite change maps from seven image dates. Fieldwork was conducted at the three study areas to document present forest stand characteristics. Remote sensing techniques in conjunction with fieldwork identified distinct patterns of regeneration in the post-fire areas. Some of the most distinctive patterns are primarily linked with *Ceanothus* sp., an early successional shrub species. This study will provide natural resource managers at Yosemite with data to aid in long-term fire management plans.

INTRODUCTION

Wildland fires rapidly change the landscape and are ecologically important. Fire is an ecological disturbance causing severe damage to vegetation cover and altering soil characteristics, but fire-adapted systems benefit from the drastic changes. Government agencies at all levels are interested in monitoring and assessing these changes for policy decisions. In particular, changes in National Parks are important for policy decisions in which these changes influence wildlife habitat, fire conditions, aesthetics and other resource values (Yosemite National Park). This project addresses post-fire landcover changes across Yosemite using satellite imagery.

Satellite images provide a wealth of information and can contribute as a cost-effective means to achieve forest management goals. Remotely sensed data utilized for projects addressing landcover changes traditionally concentrate on detecting deforestation; however, studies have also successfully detected forest regeneration and succession with remotely sensed data (Foody et al., 1996; and Fiorella and Ripple, 1993). Remote sensing technologies extend knowledge about ecological changes such as regeneration. Short-term catastrophic impacts resulting from fires, such as burn severity, are studied extensively in the park (van Wagtendonk et al., 2004). A thorough fire management plan includes long-term considerations such as assessing forest regeneration, which creates important but not always obvious forest changes.

During the summer of 2005, our team participated in the NASA human capital development intern program called DEVELOP and studied post-fire regeneration as a subtle long-term change to aid Yosemite natural resource managers in long-term fire management decisions. The DEVELOP program is a NASA Science Mission Directorate Applied Sciences Program that extends research to local, county, state, federal, and tribal governments. Students demonstrate prototype applications of NASA science measurements and predictions addressing local policy issues to community leaders. The activity is student led, with advisors from NASA and other partner organizations. Our partner organization for this project was the National Park Service at Yosemite and our objective was to implement remote sensing techniques for assessing post-fire regeneration with Landsat imagery. The methods utilized multiple remote sensing techniques and were supported by fieldwork.

STUDY AREA

Yosemite National Park is a reserve in the Sierra Nevada of California covering about 300,000 hectares and elevations ranging from 600 to 4000m (van Wagtendonk et al., 2004). Uplifted granitic rocks and deeply eroded valleys greatly contribute to Yosemite's world famous majestic views. These striking formations also create many complex and diverse ecosystems, which respond to a range of climates created by the steep elevation gradient.

A total of four fire sites were assessed for this project: A-Rock, which burned in 1990; Steamboat, 1990; Walker, 1988; and Ackerson, 1996 (Figure 1). The sites were selected based on the criterion of resource management interest, accessibility and availability of cloud free imagery. The Steamboat and A-Rock fires burned separately but simultaneously, and are considered as one study area for this project. The A-Rock and Steamboat fires and the Ackerson fire were large catastrophic fires that likely burned unnaturally high fuel loads due to fire suppression (van Wagtendonk et al., 2002). The Ackerson fire burned 47,000 acres and for this reason, this study focused on only a section of the fire defined by obvious physical features such as Hetch Hetchy reservoir. All four fires were naturally started by lightening and burned various vegetation zones.

The A-Rock and Ackerson sites, consisting of elevations ranging from 500-1600 m and 500-2200 m respectively, include areas that are within the foothill chaparral woodland vegetation zone. This ecosystem is dominated by Whiteleaf manzanita (*Arctostaphylos viscida*) and ceanothus (*Ceanothus cuneatus*), and is intermixed with interior live oak (*Quercus wislizenii*) and canyon live oak (*Quercus chrysolepsis*). The A-Rock and Ackerson sites also have elevations in the lower montane forest, and the Steamboat (1400-1700 m) site is entirely in this vegetation zone. The lower montane forest is characterized as a mixed coniferous forest that has a mostly open canopy. Dominant tree species are Ponederosa pine (*Pinus ponderosa*), white fir (*Abies concolor*), incense-cedar (*Calocedrus decurrens*), and California black oak (*Quercus kelloggi*). Whiteleaf manzanita *(Arctostphylos viscida)* and deerbrush *(Ceanothus intergerimus)* also have a strong presence in this forest type. The Walker site is in the upper montane forest with an elevation range of 1900-2200 m; the Ackerson site also has elevations in this vegetation zone. The upper montane forest consists of coniferous forests that are dominated by stands of red fir (*Abies magnifica*) mixed with western white pine *(Pinus monticola*), Jeffrey pine *(Pinus jeffreyi*), western juniper *(Juniperus occidentalis)* and quaking aspen *(Populus tremuloides*). Some dominant shrub species include greenleaf manzanita *(Arctostphylos patula)* and mountain whitethorn *(Ceanothus cordulatus).* The Walker site also has meadows consisting of herbs, grasses and sedges (Van Wagtendonk et al. 2002).

METHODS

Data

USDA Forest Service supplied the DEVELOP team with Landsat imagery for the time period of 1973 to 2004 from the MSS, TM and ETM+ sensors. Imagery from the TM and ETM+ sensors were selected from 1988 to 2004, which includes the time of the oldest fire to the most recent image available. Imagery was acquired for a July anniversary window to minimize reflection caused by seasonal vegetation fluxes and sun angle differences. July is the peak of the summer season in Yosemite and an optimal time to acquire imagery, but a few images used were acquired as early as June and as late as August. The Forest Service collected the imagery from various sources and topographically corrected and geometrically registered the imagery to less than one pixel in the UTM NAD 27 zone 10 projection. In addition to imagery, the DEVELOP team obtained GIS ancillary data layers from the Yosemite GIS team, ranging from base data such as roads and rivers to a detailed vegetation layer based on 1997 aerial photography and topographic information.

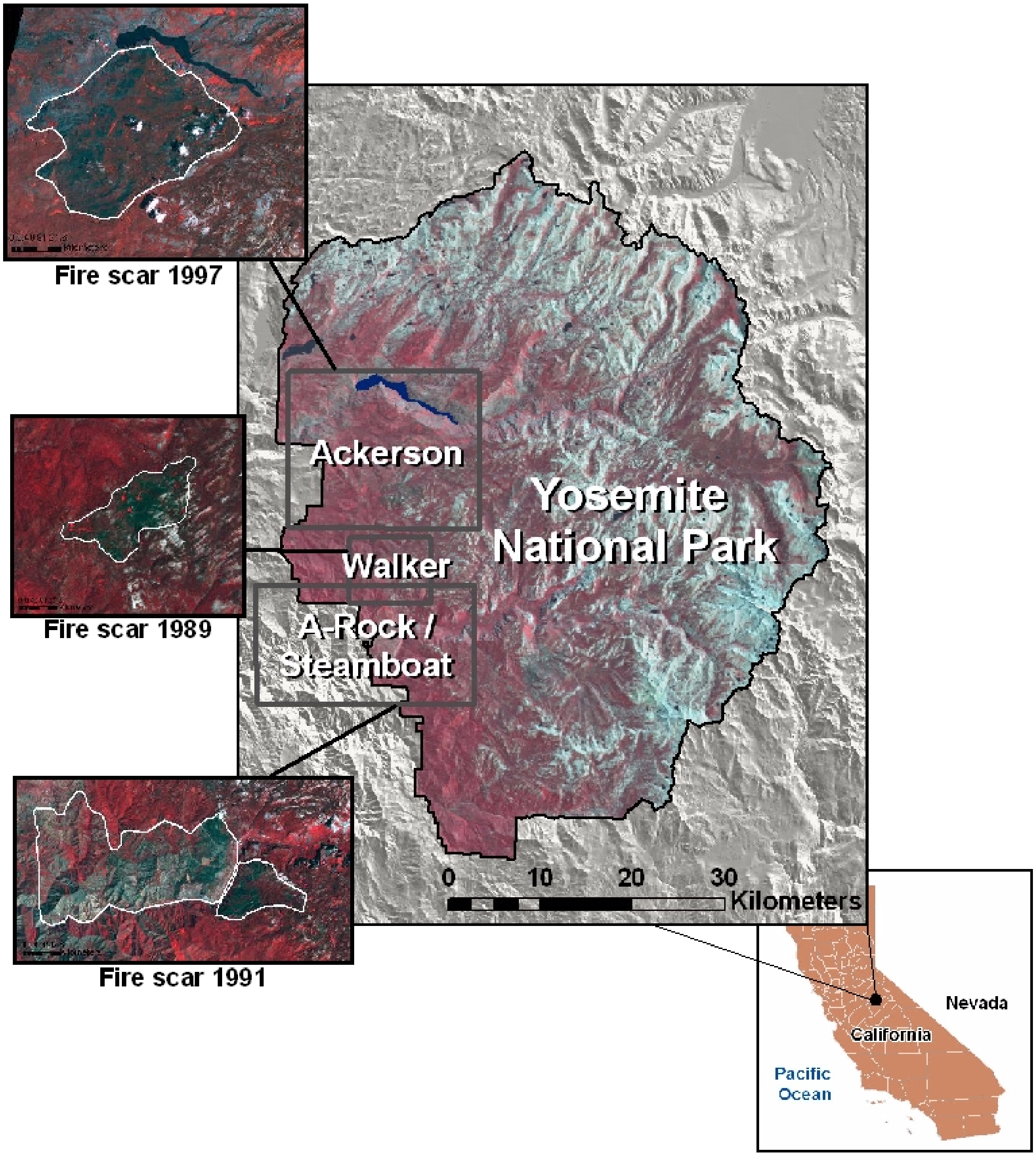

Figure 1. Landsat TM false color composites of study sites displaying outlines of fires scars from imagery the year after the fire and the location of the sites within Yosemite.
(In the A-Rock/Steamboat inset, the A-Rock site is on the left and Steamboat site is on the right)

Vegetation indices were selected to enhance interpretability of change patterns. Specifically, the normalized differenced vegetation index (NDVI) and normalized difference moisture index (NDMI) were computed for each Landsat image from 1989 to 2004. NDVI is used extensively to monitor vegetation (Jenson, 1996), but NDMI has been proven useful for detecting forest changes (Jin and Sader, 2005; and Wilson and Sader, 2002). Previous studies applied the "wetness" component of the tasseled cap transformation to distinguish forest type or forest changes (see Jin and Sader (2005) for a review). However, Wilson and Sader (2002) established NDMI to be similar to the wetness component and found NDMI to be superior to NDVI in detecting forest change. The NDMI utilizes the mid-infrared band, which has a strong correlation with regeneration and we selected this index for its ease to calculate and interpret. The NDMI calculation is similar to NDVI but the mid-infrared band is used in place of the red band. The equation for Landsat imagery is:

$$\mathrm{NDMI} = \frac{(\text{Band } 4) - (\text{Band } 5)}{(\text{Band } 4) + (\text{Band } 5)} \tag{1}$$

This research took into account the relationship between reflectance properties of the red, NIR, and MIR bands to distinguish regeneration patterns. A fire exposes bare soil, which has a higher reflectance than a forest. As a forest regenerates, the reflectance decreases in the visible bands (due to increasing vegetation and absorption of chlorophyll) and initially increases near-infrared reflectance (due to increased scattering). Near-infrared reflectance then declines during advanced stages of regeneration due to shadowing from canopy structural development. The mid-infrared reflectance decreases from water absorption and shadowing. (Foody et al., 1996; Jenson, 1996; and of Lillesand and Keifer, 2000). Thus, these reflectance properties were ideal for detecting regeneration patterns.

Traditionally, change detection employing multidate images require radiometric registration to ensure an accurate change assessment (Coppin and Bauer, 1996; Lu et al. 2004). Radiometric correction allows for change to not be influenced from atmospheric effects when image differencing. Vegetation indices slightly reduce atmospheric effects (Desbois et al. 1997; Sader and Winne, 1992), and are related to changes in an image, such as forest vs. non-forest, more so than single bands (Coppin and Bauer, 1996). A formal radiometric correction was not performed, but radiometric correction often accounts for less significant changes. This project distinguished more significant changes as being above noise by using a variety of images to define general patterns of change.

Fieldwork

Fieldwork was conducted at the end of June and in mid-July during the summer of 2005. Present forest stand characteristics (Figure 2) were documented through plot transects and collection of GPS data. Circular plots, with a 30 m diameter, were setup to document dominate species, present condition (i.e. trees surviving the fire) and estimates of species percent cover. In addition, tree diameter at breast height (DBH) and tree height were documented. A total of 65 plots were surveyed across the study sites. In addition, distinct areas of early successional homogeneous vegetation (i.e. *Ceanothus* sp.) were documented and a GPS location was recorded for comparison of major change in the field to change detection maps.

Vegetation Indices Differencing

Landscape changes were initially detected by applying image differencing, a widely applied change detection algorithm (Eastman, 2003). It involves subtracting the older date image from a newer date image, which is done on a pixel-by-pixel basis. This results in a new dataset with positive and negative values representing change and zero representing no change. Image differencing was performed in this study using NDVI and NDMI images from the first year of fire scar to 2004 in two year intervals to display a time-series of change patterns. Each differenced image was reclassified into six categories using a statistically-based simple thresholding to define the changes (Eastman, 2003). These categories broadly categorize the changes with pixel values 1 standard deviation (SD) below or above the mean representing no change areas, pixel values between 1 SD and 2 SD representing considerable change, and pixel values 3 SD and above representing significant change. To summarize the overall changes at each study area, figure 3 displays the vegetation indices change detection maps from the year with the fire scar to 2004. Essentially, this classification scheme is a means to broadly quantify the amount of change.

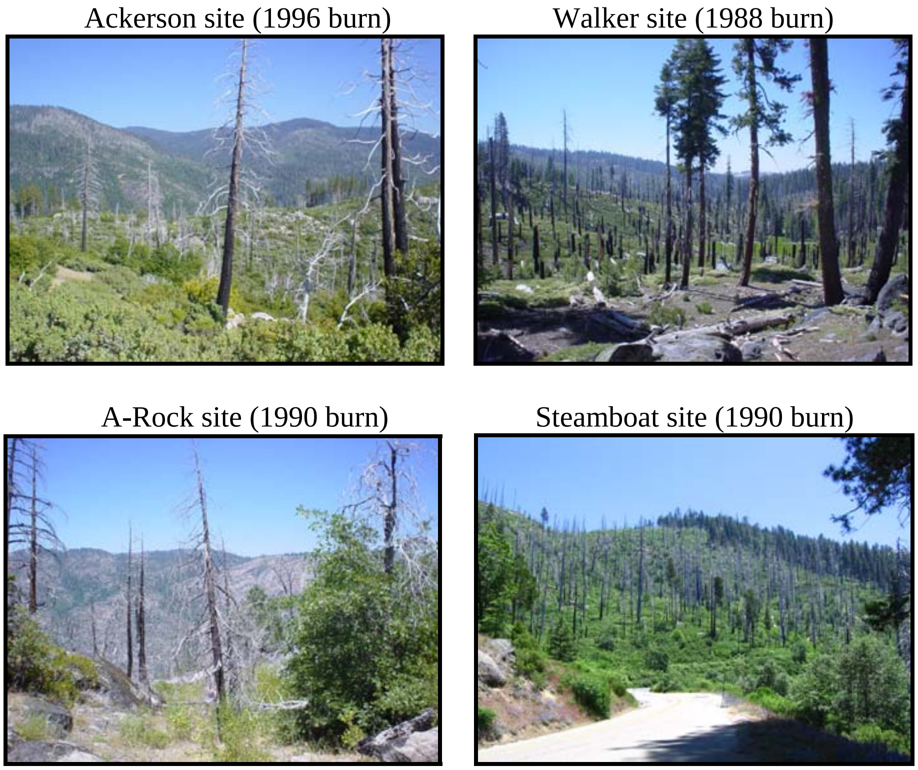

Figure 2. Pictures displaying present condition of burn sites as of July 2005.

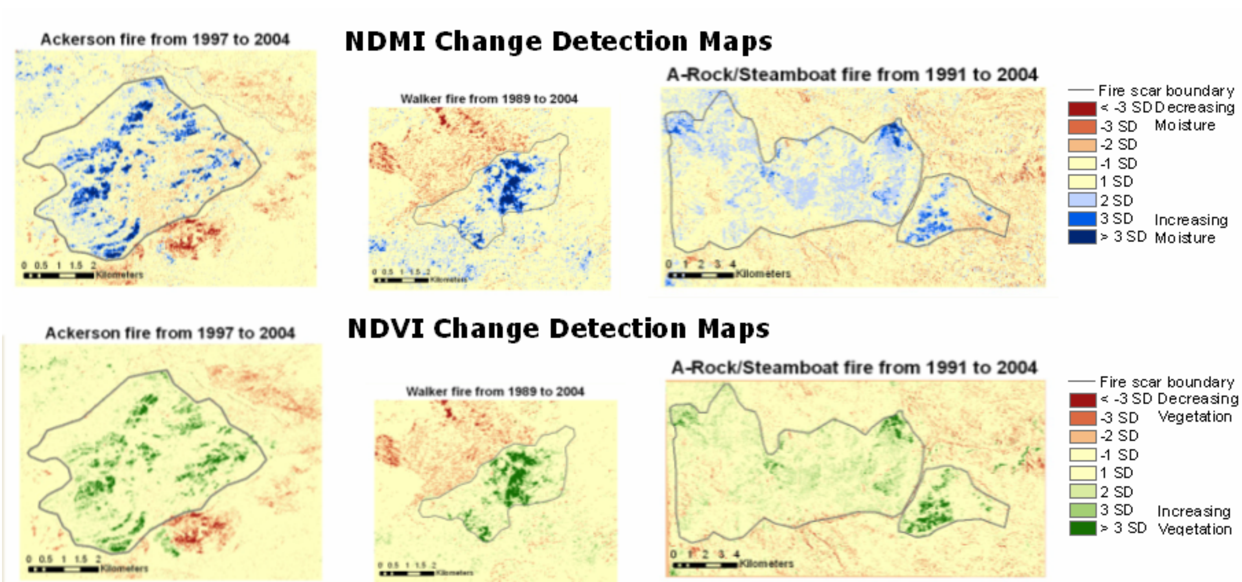

Figure 3. Change detection maps. 1 SD from the mean indicates a no change area, 2 SD from the mean indicates considerable change and 3 SD or greater indicates significant changes.

RGB-NDVI Change Method

The visual RGB-NDVI (or RGB-NDMI) method is a simple technique of creating color composites and utilizing additive color theory (Sader and Winne, 1992). These change detection maps were created to evaluate the influence of changes through time. A total of seven dates of NDVI and NDMI images were selected to create 3 composites for each study area. Each composite consisted of images sequentially stacked with dates of imagery being 2 to 3 years apart and years overlapping from one composite to another (Wilson and Sader, 2002). For instance, the first composite consists of images from 1992, 1994, and 1997 (early years), the second composite consists of images from 1997, 1998, 2000 (middle years), and the third composite consists of images from 2000, 2002, 2004 (recent years). An unsupervised classification of 5 classes was performed to each of the three composites in ERDAS Imagine using the ISODATA clustering algorithm (Wilson and Sader, 2002). This process allows for a preliminary change map to reflect vegetation (or moisture) increase, decrease, and no change. The three classified composites were stacked to create a final thematic time-series composite that was facilitated by additive color theory (Figure 4). The early years were represented with the red color write function of the computer monitor, the middle years were represented with green and the most recent years were represented with blue for each composite. Image appearance, vegetation and topographic GIS data, and fieldwork assisted in identifying change dynamics.

RESULTS AND DISCUSSION

Field results of dominant species percent cover are shown in Table 1. Three *Ceanothus* sp. were identified at most plots surveyed in the four sites. Manzanita (*Arctostaphylos* sp.) also had a strong presence at each site and was dominant at the A-Rock site. The Ackerson and A-Rock sites have more than one vegetation zone, but Table 1 characterizes these sites only in the lower montane zone. This information is based on field plots, which were restricted to ease of access to the sites and limited field time. Nonetheless, Table 1 shows that regeneration of shrub species and tree saplings is robust. The Steamboat site is particularly interesting with *Pinus* sp. being the dominant vegetation cover, possibly due to a large percentage of trees that survived the fire.

Table 1. Percent cover of dominant species derived from field plots for each study site.

Species	***Ackerson***	***A-Rock***	***Steamboat***	***Walker***
Ceanothus sp.	35%	15%	25%	40%
Manzanita (*Arctostaphylos* sp.)	8%	50%	3%	10%
Black Oak	7%	5%	-	-
Canyon Live Oak	-	8%	-	-
Ponderosa Pine	-	5%	44%	4%
Pine *(Pinus* sp.)	3%	-	-	5%
Red Fir	-	-	-	15%
White Fir	-	-	4%	-
Incense Cedar	7%	-	12%	-
Grass/Forbs	10%	-	-	5%
Other	5%	-	5%	5%
Barren Ground	25%	17%	7%	16%
Total	100%	100%	100%	100%

The NDVI and NDMI two-year interval change detection maps created by image differencing yielded similar patterns (Figure 3). All four sites had the greatest change within the first six years after the fire, and change maps for each site indicated a drought around 2001 since minimal change is shown in the maps for this period. The RGB-NDVI (or RGB-NDMI) change method corroborates change patterns seen in the NDVI and NDMI image difference change maps. However, the RGB change maps (Figure 4) capture forest change dynamics with ease of visual interpretation. For instance, the Walker change map displays an area adjacent to the study site with decreased vegetation (seen in yellow) which is in fact a fire that occurred in 2001. Although the image difference change detection maps and RGB change maps are very similar, the RGB change method summarized the temporal variation throughout the years since the fire occurred in a single thematic map. Each site displays cyan color in the RGB change method and appears to be similarly the area with significant change (3 SD from the mean) in the image difference maps. These areas of change have been identified a predominately *Ceanothus* sp. at the Walker and Ackerson sites, manzanita (*Arctostaphylos* sp.) in A-Rock, and Pinus sp. in Steamboat, and are supported by fieldwork.

This study does not attempt to calculate the rate of change, but validates the regeneration process in three different ecosystems. It is evident that these areas are in the shrub-seedling-sapling stage, the second defined stage of successional recovery (Allen 2003). However, each fire was unique in which burn severity, local topography and elevation of each fire possibly affected regeneration change patterns. For example, the Walker site consisted of tall shrubs (2 m or more) that took over the site, leaving a longer time period needed for tree saplings to dominate. The Steamboat site had many more tree saplings (as tall as 4 m) intermixed with the shrub species, which indicates that the trees will dominate sooner. Our analysis shows that all the sites consistently had the greatest change occur within the first six years of recovery and has stayed steady throughout the second stage of succession. The Ackerson site was the most recent fire (1996) evaluated in this study, indicating regeneration at this site was transitional with large areas of grasses and forbs still present and shrub species often reaching a height of only 1 m.

Future research will focus on detailed and rigorously quantified changes and implementing higher resolution imagery such as ASTER. In addition, visual inspection of NDMI and NDVI change maps indicates that NDMI is possibly more sensitive to distinguishing change patterns than NDVI, which suggests further investigation of comparing these indices for change detection.

Acknowledgements

The authors would like to thank Yosemite National Park for resources to aid us in fieldwork, and Joe Meyer of Yosemite for insightful discussion for study area selection. The authors also thank Kent van Wagtendonk and Bill Kuhn of Yosemite for supplying us with GIS data, and Brent Johnson of USGS in Yosemite sharing his wealth of knowledge about Yosemite vegetation communities and resources for field data collection. We also thank Cyrus Hiatt of NASA DEVELOP Ames for support in article production and Karin Tuxen of UC Berkeley for article review and suggestions.

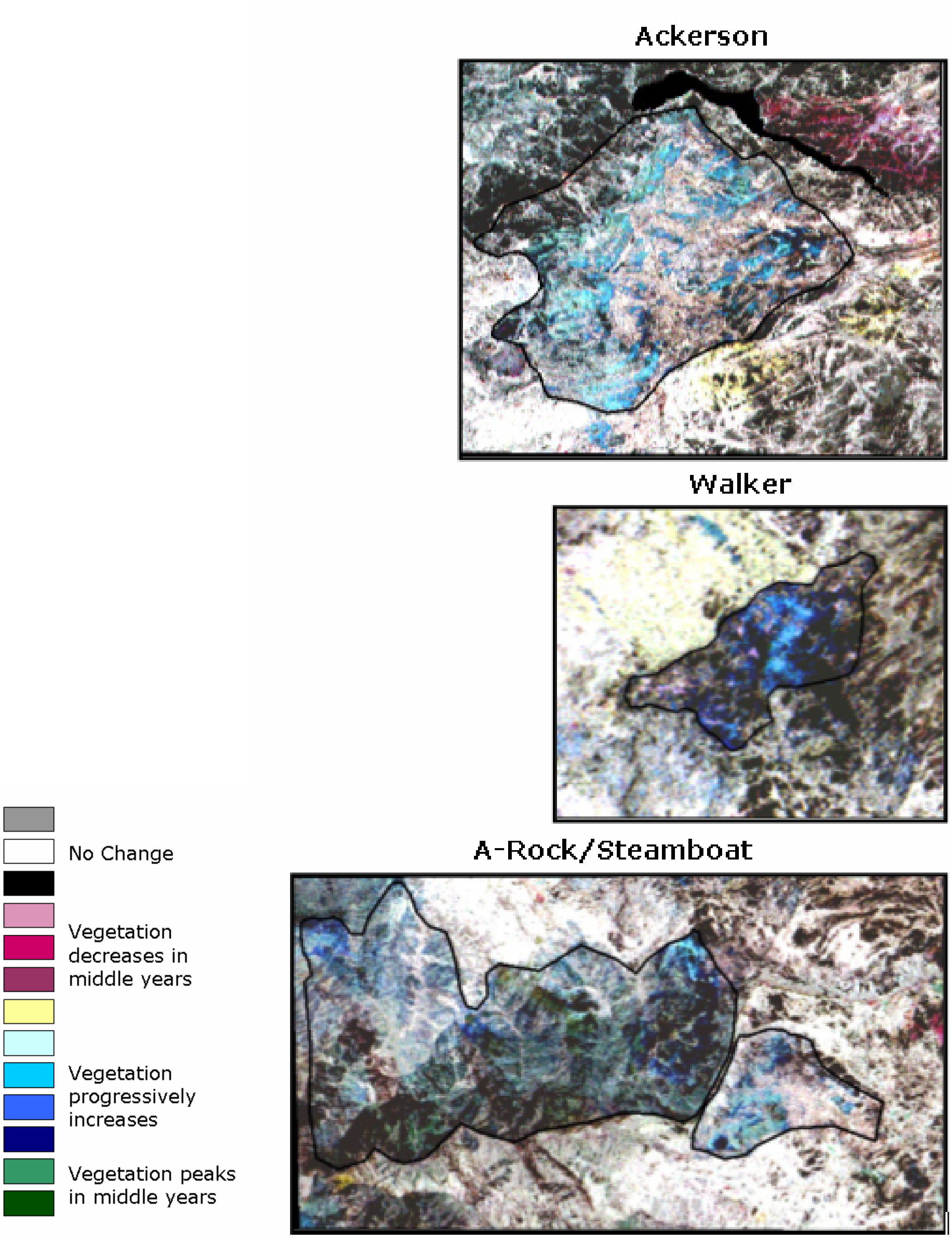

Figure 4. RGB-NDVI change maps. Red + Green = Yellow; Red + Blue = Magenta; Blue + Green = Cyan; Red + Green + Blue = White; No color = Black.

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