Mapping Fire Induced Vegetation Changes in Kings Canyon National Park

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ABSTRACT

Wildfire suppression in Western United States forests began suppressing wildfires in the late 1800s leading to dry, dense, and homogenous forests. Overtime, the accumulation of surface level fuels has resulted in severe and catastrophic wildfires seen today across different forest ecosystems. In order to reintroduce fires that will help shape and maintain fire-adapted forests, it is crucial to understand the behaviors and effects of managed wildfires through research and adaptive management. In 1973, Kings Canyon National Park initiated a policy allowing fires to burn naturally in the Sugarloaf Basin. I hypothesize that this action has increased landscape heterogeneity, decreased mixed conifer density, and increased relative patch sizes of shrubs, sparse meadows, and dense meadows. The goal of this project is to better understand the effects of fire by using geospatial imagery and informational systems to quantify fire induced vegetation changes which will aid in altering current forest management schemes to focus on reducing forest fire hazards and increasing forest safety. The Sugarloaf Basin in Kings Canyon National Park has experienced 40 years of managed wildfires, in which there was some change in forest cover and other major vegetation cover types. Managed wildfires appeared to have increased the vegetation abundance and has likely shifted the dominant vegetation types in Sugarloaf Basin. My findings demonstrate that fire, of all forms, is the likely cause of vegetation changes and redistribution in the Sugarloaf Basin.

KEYWORDS

Landscape fire, eCognition, ERDAS Imagine, heterogeneity, plant diversity, vegetation cover types, forest density, GIS, spatial distribution, area

INTRODUCTION

Many forested landscapes in the United States have evolved alongside wildfires and depend on fire's natural process to recycle nutrients, start plant succession processes, and contribute to overall watershed health (Dombeck et al. 2004). Although wildfires have played large roles in natural processes, the preconceived notions by American organizations and citizens have inflated the destructive nature of forest fires and completely altered the acceptance of historical fire management in America (Cox 1983). The stigma surrounding wildfires heightened in the late 1880s leading the federal government to amend forest policies by suppressing natural ignitions and in 1944, Smokey Bear became the mascot for educating the public about the destructive nature of forest fires. Smokey Bear illustrates the pervasive and widespread ideology that wildfires do more harm than good, and has persisted as America's icon for the fight against fire for 70 years (www.smokeybear.com).

The forest policy amendments created agencies and substantial infrastructure dedicated to suppressing high frequency and low severity wildfires, consequently leading to extremely dry forests with high levels of surface fuels (Stephens 2005; Agee 1974). Paradoxically, the cumulative effects of these trends have dramatically increased, rather than decreased forest fire hazards (Kilgore 1973). From 1940 to 2000, southwestern United States forests experienced approximately 109 severe wildfires for every 400,000 hectares labeling the region with the highest relative total number of fires (Stephens 2005). An increase in the severity and frequency of wildfires in southwest forest regions initiated the conversation of altering fire suppression policies to reduce fuel hazards and increase forest safety in all forests throughout the United States (Stephens 2005). Cumulative awareness of increasing forest fire hazards guided federal agencies to begin developing fire policies tailored to the unique characteristics of forests throughout the United States (Stephens 2005; North 2015).

Reintroducing wildfire plays a large role in shaping and maintaining forests (Kilgore 1973; Collins 2007). Wildfires eradicate smaller, more vulnerable trees and burn excess vegetation on the forest floor releasing surrounding fire- tolerant species from competition by redistributing resources to surviving plants. The cumulative effects of frequent and low severity wildfires inevitably alter dense forests into mosaic terrains, which promote forest health by redistributing the plant communities at a landscape scale (Collins 2007; Forrestel 2011).

Wildfires can also maintain healthy forests by increasing forest heterogeneity, reducing stand density, and increasing the distribution of resources (White 2008). Controlled natural ignitions can be an effective form of management for dense forests if employed properly (Collins 2007). However, each forest ecosystem requires a fire regime tailored to its specific needs, and approaches can vary from a reduction in surface level fuel loads to a reduction in shade tolerant species, and several alternatives in between. This approach to managing forests is also known as adaptive management; a method in which forest researchers collect data and design experiments to test management outcomes. Science and management are then integrated to achieve the micro-ecosystem's goals for increasing forest health and safety. Adaptive management and continued research are essential in changing the negative preconceived notions of wildfires to allow fire-hazard-reduction projects to move forward (North 2015).

Understanding the behaviors and effects of wildfires through research and adaptive management is crucial for raising public awareness about the benefits of fire regimes (North 2015). The National Park Service revised its fire policy in 1968, which led to Yosemite and Sequoia- Kings Canyon National Park incorporating prescribed fires and wildfires as part of their management operations (Stephens 2005). The National Park Service's decision to reinstate wildland- fire- use paved a way for other forest agencies to follow suit and commence their own research in fire philosophy (Stephens 2005). Despite various studies that prove wildfires to be a beneficial and effective form of forest management, controlled burns and other fire regimens are still widely unaccepted as a form of management throughout the western United States (North 2015). Ongoing wildfire research will provide additional data to enhance the global knowledge of fire philosophy and aid land managers in implementing proper and sustainable management regimens in between natural ignitions (Larson and Churchill 2012; Stephens 2005).

In this project, I utilize remote sensing technologies to analyze how reintroducing wildfires have shifted the vegetation types in Sugarloaf Basin, Kings Canyon National Park, where fires have burned since 1973. This study specifically aims to determine whether Sugarloaf Basin's vegetation cover types have spatially redistributed themselves since allowing wildfires back into the park's management system in the early 1970s. Specifically, I ask what are the changes that have occurred related to vegetation cover types in the Sugarloaf Basin since the sanctioning of naturally ignited fires? I expect to see an increase in landscape heterogeneity, decrease in mixed conifer density, and an increase in the total area of shrubs, sparse meadows, and dense meadows after reinstating natural wildfires into the densely forested Sugarloaf Basin. The goal of this project is to utilize geospatial imagery to create historic vegetation maps enabling the quantification of fire induced vegetation changes and to analyze the changes in vegetation abundance and quantify the shifts in vegetation types in the Sugarloaf Basin. If I find support for my hypothesis, then it may be important to revise and further promote forest fire policies in the Sequoia- Kings Canyon. The research done for Sequoia- Kings Canyon National Park will be used as supportive data to raise awareness about impacts of wildfire and ultimately shift the public's negative notions on wildland- fire- use.

METHODS

Study site

The Sugarloaf Basin in Kings Canyon National park is a 15000 ha basin in the southern region of the Sierra Nevada mountains (36.5316 N, 118.3318 W) and ranges in elevation from 1400m to 3000m (Figure 1). The basin has a Mediterranean climate consisting of cool, moist winters and warm, dry summers. The forest within the region is characterized as mixed conifer with dominant vegetation including: Jeffrey Pine (*Pinus Jeffreyi)*, lodgepole pine (*Pinus contorta*), white fir (*Abies concolor*), and red fir (*Abies magnifica*) and interspersed with shrubs and meadows (Collins et al. 2007). The region's two major influences, climate and vegetation, interact to promote a diverse range of habitats. In an effort to increase the efficiency of forest management and forest productivity, wildland fire use programs were introduced in the early 1970s after fire policies were amended for national parks. Sugarloaf Basin was chosen as a model system due to its progressive fire management history, which allows for the analysis of vegetation changes induced by fire over the last four decades (Collins et al. 2007).

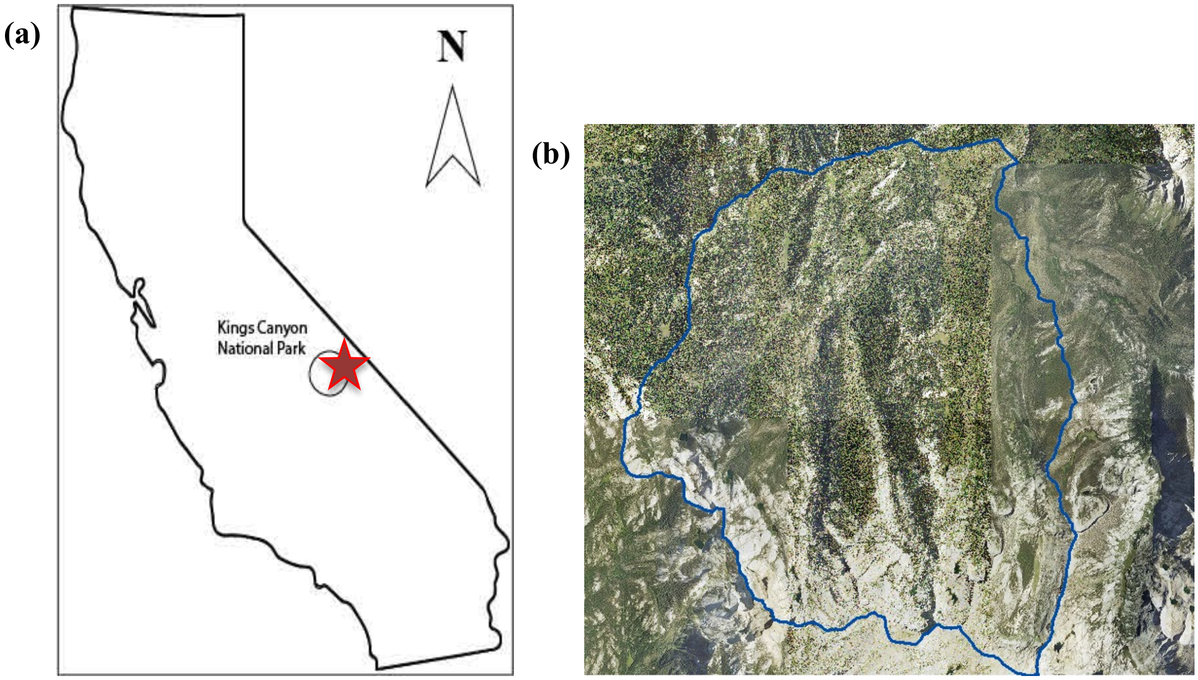

Figure 1. Kings Canyon National Park. (a) An outline of California displaying the location of Kings Canyon National Park and the red star signifying the Sugarloaf Basin watershed. **(b**) The boundaries of the Sugarloaf Basin.

Data collection methods

To determine the historical vegetation distribution, I used a set of thirteen National Agriculture Imagery Program (NAIP) images with 1-m resolution, 38 black and white 1973 high- resolution scanned aerial images with 600dpi (dots per inch), and 2016 ground truth data. The NAIP images' data source were pre-defined as the 1984 Pseudo Mercator World Geodetic System for its projection, the 1980 Geodetic Reference System for its spheroid, and the 1983 North American Datum for its datum. The 1984 Pseudo Mercator WGS projection was used for this project because it covers the globe in one coordinate system, with the center of the Earth as the origin. The GRS 1980 spheroid was used because this model consists of a global reference ellipsoid and a gravity field model that best fits the earth's imperfect, gravitational surface and the NAD 1983 was used because it is the United State's official datum replacing the NAD 1927, and older, less accurate datum. Researcher Gabrielle Boisrame collected the ground truth data using a Garmin GPS device in the summer of 2016.

I processed the collection of 1973 high- resolution scanned aerial images to remove geometric errors within the images by applying a Digital Elevation Model and block triangulation to create an orthorectified image. In order to execute the orthorectification process, I gathered the necessary NAIP and scanned aerial images of Sugarloaf from 2014 and 1973, respectively. I pre-processed the NAIP and aerial images using ArcMap 10.4.1 and Adobe Photoshop to change the format of the NAIP files to IMG and crop the edges of the aerial images. The processed files were then imported into ERDAS Imagine Leica Photogrammetry Suite (http://www.hexagongeospatial.com/products/producer- suite/erdas-imagine), a remote sensing application with the ability to edit raster graphics. Raster graphics are used in geospatial information science typically representing graphics composed of grids of pixels, such as the aerial images. I used ERDAS Imagine to enhance the digital images by assigning geospatial map coordinates using the NAIP imagery for reference, and resampling pixels of the image to conform to the projected map grid. The properties of the resulting orthorectified images have latitude, longitude and height values assigned to individual pixels.

I imported the orthorectified 1973 aerial images and NAIP images into ArcMap to be overlaid and stitched to compose a vegetation map that represented historical fire suppressed conditions. Eight vegetation maps were generated to reduce the file size of each map, which speeds up the object-based segmentation and analysis performed later. A map of recorded fire perimeters in Kings Canyon since 1973 were overlaid on the vegetation map and digitized to create a polygon layer which were used later to identify and assess changes induced by fire. Brandon Collins, a member of Scott Stephens Lab and a staff for the Center for Fire Research and Outreach, provided the map of fire perimeters.

Data analysis methods

I began my data analysis by importing the NAIP images and 1973 orthorectified historical aerial photos into eCognition (produced by Trimble, www.ecognition.com), an object-based analysis software used to assess the NAIP imagery and aerial photos' properties derived from bands of color and texture. Traditional remote sensing techniques were impractical to implement for this project because the historical black and white aerial images does not contain multiple bands. Therefore, eCognition was an appropriate method to use because it assessed property values of objects by automating forestland classification and conducting vegetation identification using two successive steps: image segmentation and image object classification using the nearest neighbor approach (Mathieu et al. 2007). The images were segmented into meaningful objects classified as granite, mixed conifer forest, sparse meadow, dense meadow, and shrubland. Meadows are defined as areas dominated by grasslands and forbs; dense meadows encompassed wetlands and have little to no bare ground while sparse meadows have larger areas of visible bare ground and may appear brown. Granite was identified using the 2014 NAIP images first because it is more easily distinguishable from any vegetation compared to the black and white aerial images. Visual verification of randomly selected points and 2016 ground truth data were used to compare predicted classes and assess the accuracy of data, which will aid in detecting and analyzing the vegetation changes (Congalton 1991). The forest classifications and image properties were used to analyze the changes in Sugarloaf Basin from the fire-suppressed conditions to the present managed wildfire conditions.

After classifying the image- objects in eCognition, I assessed the vegetation changes between the NAIP images and vegetation maps. This assessment determined whether natural ignitions have contributed to reducing the density of mixed conifer forests and increasing relative patch sizes of shrubs, dense meadows, and sparse meadows. Several methods were used to detect and analyze the changes between the black and white vegetation maps and 2014 NAIP images to identify whether the change could be due to fire or chance and time. The 2014 NAIP and black and white classifications were validated using ground truth points and the process of randomly selecting point locations and comparing a visual classification of the points to the automated classification. Changes in landscape composition between the fire- suppressed conditions and the contemporary conditions were assed in terms of a shift in landscape composition and change in total area of each vegetation cover. Total land cover was calculated for granite and each vegetation type in both years and classification accuracy was propagated into the change estimates. After performing these analyses, I compared the areas of detectable changes by using the fire perimeter data to assess whether changes were significantly induced by fire or time.

RESULTS

Changes in vegetation cover types following the introduction of wildfire

I found that each vegetation type varied in trends and changes. In year 1973 and 2014, the mixed conifer class was consistently the dominant cover type occupying 76% of the area and slightly inclining to 80% in 2014 (Figure 2). Overall, spatial distribution of the mixed conifer class was relatively stable, and 68% of this class area was derived from already existing mixed conifer regions (Table 1). The most distinct shift in vegetation land cover was from shrubs to mixed conifer accounting for 6.25% of the total area, with minor losses to sparse meadow (Table 1).

My results revealed the area of sparse meadow, the second largest class, slightly increasing from 9.2% to 9.8% (Figure 2). Although the largest proportion of area loss in sparse meadows were to mixed conifers, most of the area loss in mixed conifer was to sparse meadow, therefore evening out the change in area in the sparse meadow vegetation class (Table 1).

The area of shrubs, the third largest class, slightly decreased from 10.35% to 7% (Figure 2). Spatial distribution of this class seems to be less scattered and most of the area loss in shrubs were to mixed conifers (Table 1).

Figure 2 shoes granite to be a relatively static class from 1973 to 2014, occupying approximately 3% of the study area. My results show that about 2.4% of the granite area remained granite from 1973 to 2014 and .5% was misclassified as sparse meadow (Table 1).

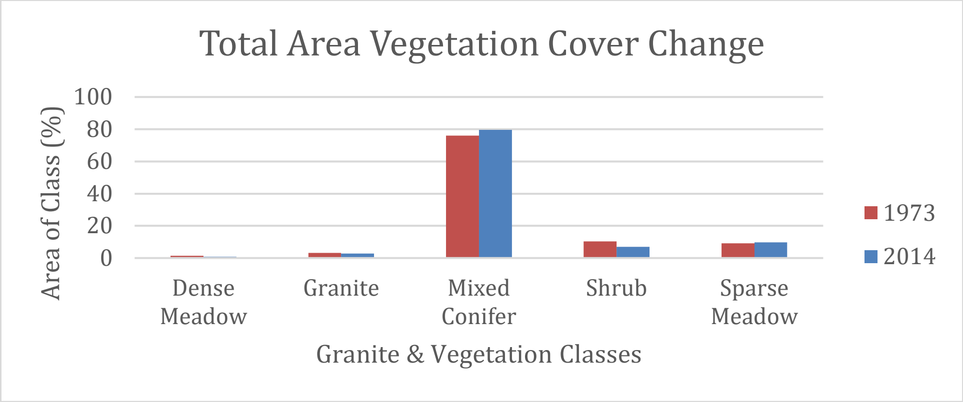

Figure 2. Total Area Vegetation Cover Change. The total change in area of vegetation cover types was calculated using the sum of the vegetation area divide by the total study region. The largest shift in vegetation classes is the increase in total area of mixed conifer forests.

Table 1. Vegetation Shift and Percent Change in Area. The values in under code range from 1 through 5 and signify vegetation such as mixed conifer (MC), shrubs (S), granite (G), sparse meadows (SM), and dense meadows

(DM), respectively. The code values were calculated using the Raster Calculator tool in ArcMap 10.4.1 to express a shift in vegetation over the years. The codes 11, 22, 33, 44, and 55 signify no change in mixed conifer, shrubs, granite, sparse meadows, and dense meadows, respectively. (Example: The second row indicates a value of 21 signifying 4,004 objects classified as shrub shifted to mixed conifer from 1973 to 2014 with a total percent change of 6.19%).

Code	Change	Count	Area (m^2)	Percent Change
11	MC	44,038.00	39,634,200.00	68.04
21	S - MC	4,004.00	3,603,600.00	6.19
41	SM - MC	3,525.00	3,172,500.00	5.45
14	MC- SM	2,646.00	2,381,400.00	4.09
12	MC- S	2,377.00	2,139,300.00	3.67
44	SM	2,164.00	1,947,600.00	3.34
33	G	1,555.00	1,399,500.00	2.40
22	S	1,522.00	1,369,800.00	2.35
24	S - SM	1,196.00	1,076,400.00	1.85
55	DM	475.00	427,500.00	0.73
51	DM - MC	221.00	198,900.00	0.34
42	SM - S	206.00	185,400.00	0.32
54	DM - SM	92.00	82,800.00	0.14
52	DM - S	66.00	59,400.00	0.10
15	MC- DM	60.00	54,000.00	0.09

Burned regions

From 1973 to 2014, I found regions that burned in the Sugarloaf Basin watershed indicating an increase in total area of mixed conifers by 2% (Figure 3). Figure 3 expresses that the mixed conifer class is the dominant vegetation cover type in the burned areas with sparse meadows leading as the second largest class. Figure 3 also conveys that sparse meadows have increased in area by 1.2% and regions that have been burned show a loss in shrub area with a loss of 3.2%. In Figure 4, the region in focus has frequently burned from 1973 and 2014 and displays a shift from mixed conifer to sparse meadow.

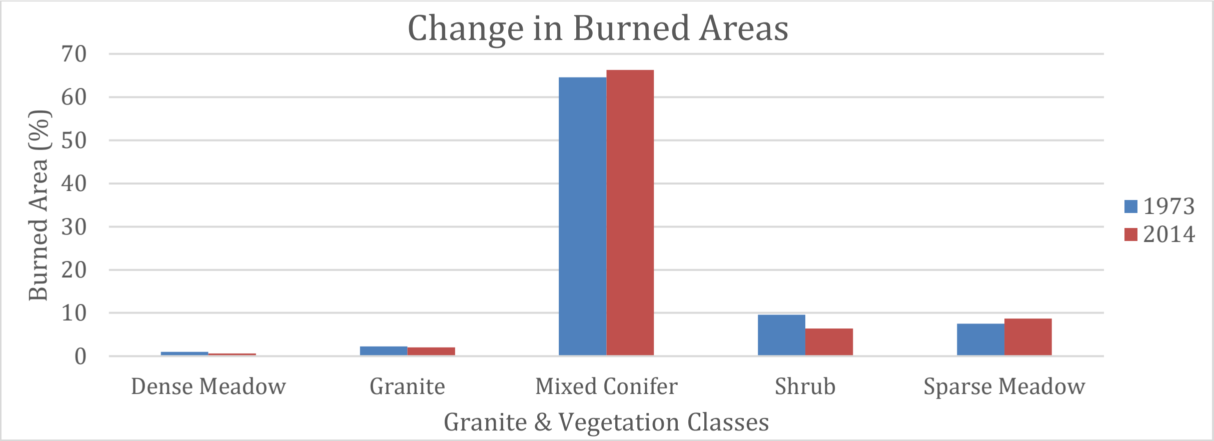

Figure 3. Change in Burned Areas. The change was calculated using the sum of the burned area divide the sum of the total area of the region. This calculation was used to standardize the area for the purpose of later comparison.

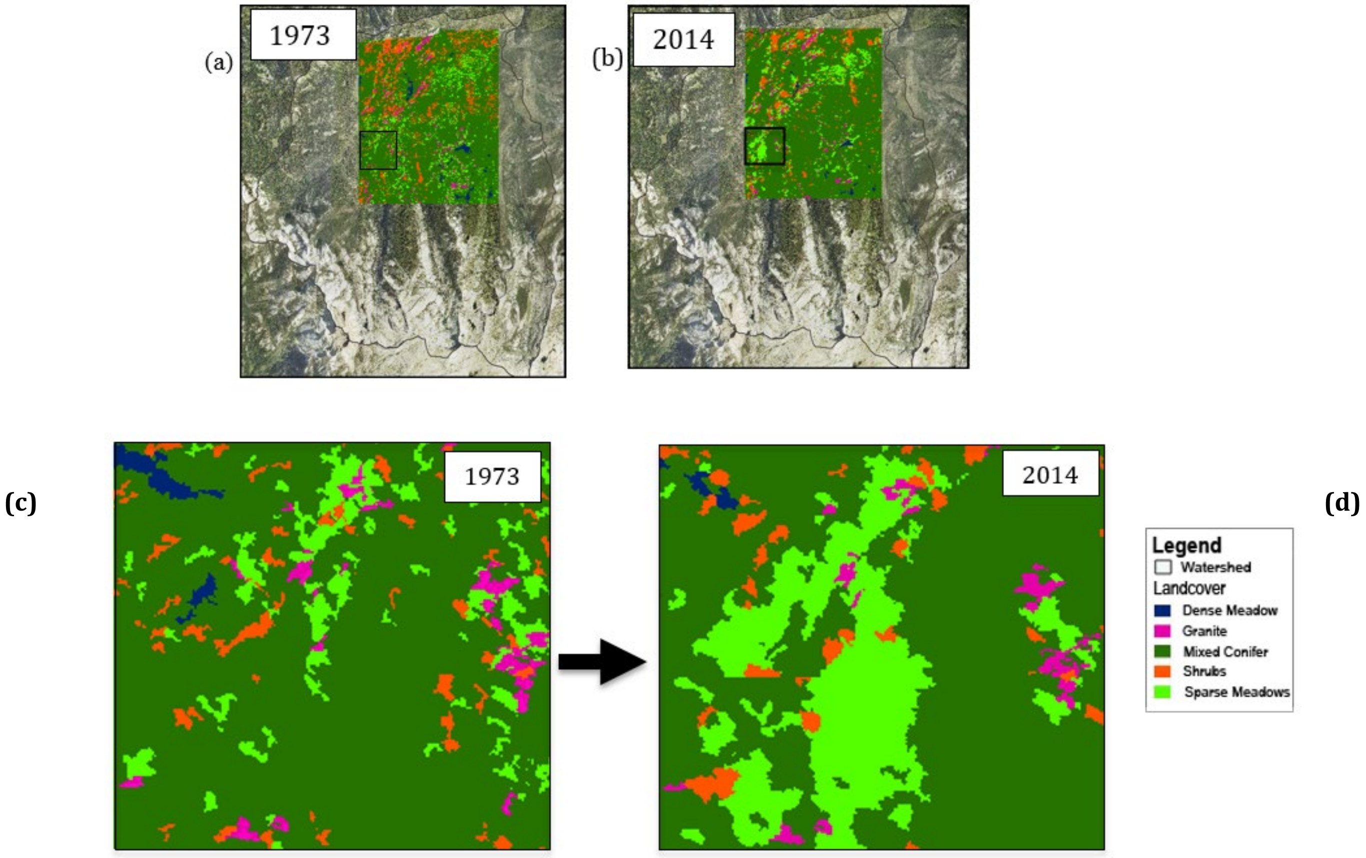

Figure 4. A shift from Mixed Conifer to Sparse Meadows. In 1973, the dominant land cover was mixed conifer forests. Over the years, this region experience frequent fires and has since shifted to sparse meadow as the dominant land cover. Figure **(a)** shows the classification for 1973 and figure **(b)** shows the classification for 2014. From 1973 to 2014, Figure **(d)** displays there was an increase in sparse meadow due to a reduction in a region dominated by mixed conifer in Figure **(c)**.

Unburned regions

The unburned regions in the Sugarloaf Basin watershed increased in total area of mixed conifers by 2% (Figure 5). The mixed conifer class is the dominant vegetation cover type in the unburned regions with sparse meadows leading as the second largest class (Figure 5). Regions that have not been burned from 1973 to 2014 display a small loss in shrub and sparse meadow areas with both classes losing approximately .5% and there was not a significant change in the area of dense meadows (Figure 5).

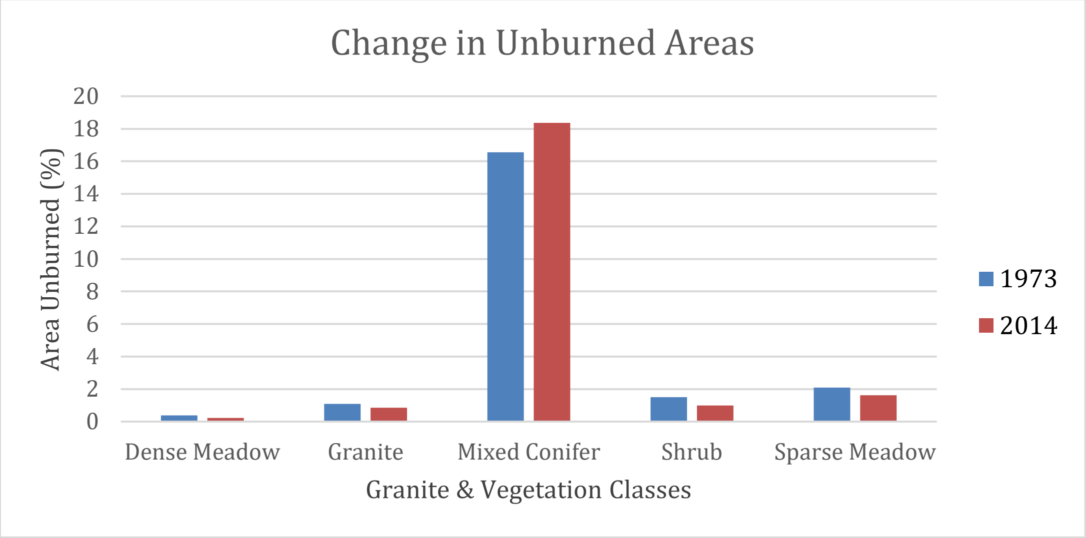

Figure 5. Change in Unburned Areas. Change in total unburned areas of major cover types shown as percent. Change was calculated using the sum of the unburned regions divide the sum of the total area of the region. This method was used to standardize the unburned area for the purpose of later comparison.

Classification uncertainty

As expected, the proportion of each class area occupied by uncertain objects was sensitive to shadows and imagery resolution. Other contributing factors that have likely increased the number of uncertain objects include the process of orthorectification and image segmentation. The method of resampling pixels to project onto a pre-existing map grid may stretch and alter the image in a way that may distort the image segmentation process. The highest overall proportions of uncertain objects were found in the shrub class. I saw that the mixed conifer class consistently had the lowest proportion of uncertain objects than other classes. Prevalence of the shrub class had a slightly higher proportion of uncertain objects with an average value of uncertainty of .23 (Table 2). Granite had generally lower proportions of uncertain areas compared to other classes, because the area of granite relatively remained the same over the years.

Classification Accuracy

I measured the accuracy of change in vegetation cover types using verified random point selection and 2016 ground truth data to generate a confusion matrix for both the black and white 1973 high- resolution aerial images and the NAIP images. The overall accuracy for the black and white 1973 image classification is 67%, which was calculated by dividing total number of correct classifications by total number of verified classifications. Table 2 states the highest accuracy for the black and white 1973 aerial images is the mixed conifer class with an 86% accuracy value and the lowest accuracy to be the shrub class with a 20% accuracy value.

Table 2. A Confusion Matrix for the black and white 1973 high- resolution aerial image classification. Change in major cover types shown by class count of objects in the black and white image's classification. (Example: The first row indicates that of the 59 objects that were classified as mixed conifer in the verified random point selection, 51 of those objects were classified as mixed conifer, 4 as sparse meadow, 0 as dense meadow, and 4 as shrub).

From Class	**To Class**				**Total Count**	**Producer's Accuracy**
	Conifer	**Sparse Meadow**	**Dense Meadow**	**Shrub**		
Conifer	51	4	0	4	59	0.86
Sparse Meadow	10	6	0	0	16	0.37
Dense Meadow	0	0	1	0	1	1
Shrub	9	3	0	3	15	0.2
Total Count	70	13	1	7		
User's Accuracy	0.73	0.46	1	0.43		

The overall classification accuracy for the NAIP imagery is 79%. Table 3 conveys that the mixed conifer class has the highest accuracy of classifications with a 90% accuracy value and the shrub class has the lowest accuracy with a 25% accuracy value. The possible reason for lower accuracy for shrubs is due to the automatic classifications of the objects because shrub regions often times had similar color band values and texture to dense meadows and small areas of regenerating mixed conifer patches.

Table 3. A Confusion Matrix for the 2014 NAIP imagery classification. Change in major cover types shown by class count of objects in the 2014 NAIP image's classification. (Example: The first row indicates that of the 21 objects that were classified as mixed conifer in the 2016 ground truth data, 19 of those objects were classified as mixed conifer, 2 as sparse meadow, 0 as dense meadow, and 0 as shrub).

From Class	**To Class**				**Total Count**	**Producer's Accuracy**
	Conifer	**Sparse Meadow**	**Dense Meadow**	**Shrub**		
Conifer	19	2	0	0	21	0.90
Sparse Meadow	0	4	0	0	4	1
Dense Meadow	3	0	1	0	4	0.25
Shrub	2	0	0	2	4	0.50
Total Count	24	6	1	2		
User's Accuracy	0.79	0.67	1	1		

DISCUSSION

Reintroducing fire into mixed conifer forests in the Sierra Nevadas appears to have created a vegetation disturbance that has impacted the landscape of the Sugarloaf Basin by altering the dense, homogenous structure of the forest and the land around it. The burned areas in the study region exhibited moderate to high changes in vegetation cover type in areas burned by fire, which is a contrast to the non-burned areas. The non-burned areas exhibited some change but it is likely to have been driven by natural processes over time. This research demonstrates that fire disturbance may benefit in area by reducing mixed conifer forest stand sizes, increasing plant diversity, and increasing the relative patch sizes of dense meadows, sparse meadows, and shrubs. These findings are supported by studies that have found fire to be one of the main processes driving heterogeneity, which is highly correlated to forest health and biodiversity (Moritz and Stephens 2008; Collins et al. 2011).

Stand density

Natural fires effectively reduce the density of mixed conifer stands by killing saplings, small trees, and diminishing the forest floor fuel loads and fire hazards (Huisinga et al. 2005). Wildfires have the ability to effectively maintain a sparse understory and without the presence of fire, mixed conifer stands tend to be dense and shaded by thick understory and tree canopy (Collins et al. 2011). White fir trees (*Abies concolor*) largely contribute to the forest's understory density and fuel hazards because they do not naturally shed their lower branches (Habeck and Mutch 1973). Shade tolerant species like white firs thrive in dense understories because they have the ability to persist with little to no sunlight making them an encroaching on other vegetation's resources (Habeck and Mutch 1973). Low hanging white fir branches also create ladder fuels potentially leading to crown fires which are detrimental to forest health and structure (Stephens and Maghaddas 2005). Although the presence of high frequency and low severity fires effectively eliminate saplings and lower branches of white fir trees and dead, woody debris amid the forest floor, my results showed that between the two periods of 1973 and 2014, there was an increase in mixed conifer stands sizes after reintroducing fire. Despite the increase in total area of mixed conifer in both burned and unburned regions (Figure 2), the burned regions displayed an increase in sparse meadows (Figure 3). The vegetation shift from mixed conifer to sparse meadow is the fourth likeliest process to occur in the Sugarloaf Basin, which is likely due to mixed conifer stands being unable to regenerate after fires have frequented the area (Table 1). My results supports the concept of fire maintaining a sparse understory by illustrating that burned areas in forest regions have seemingly become more sparse and patchy. Reducing dense forest patches by means of fire opens up the availability of natural resources and growing space for other vegetation types, which will increase the plant diversity in the area (Heinselman 1981). Although the unburned areas of the Sugarloaf Basin exhibited an increase in total mixed conifer area, it was less than that of the burned regions, and the unburned regions showed signs of a decrease in sparse meadows (Figure 5). It is important to pay attention to the reduction in sparse meadows because there is a high probability of mixed conifers encroaching into sparse meadows areas in the absence of high frequency and low severity fires (Figure 4).

Plant Diversity & Heterogeneity

Reintroducing fire has the likelihood of increasing plant diversity in the Sugarloaf Basin by allowing different flora and fauna to flourish in the open spaces. Amidst the rich soil buried under layers of litter and duff lie dormant seeds of various species unable to germinate or reach sunlight (Kercher and Axelrod 1984). Fire consumes the accumulation of down, woody debris, litter, and duff, which allows both fire tolerant seeds to reach rich mineral soil and for sunlight to reach dormant seeds (Turner et al. 1997). Low intensity fires usually leave fire sensitive species undamaged while burning in patches, which provide the necessary heat and processes for the seeds of fire tolerant species to germinate, release, and disperse (Turner et al. 1997). The major change seen in the Sugarloaf Basin from 1973 to 2014 is the heterogeneous spatial distribution of the new cohort such as shrubs and meadows brought about by the regeneration of the germinated and dispersed seeds (Figure 4). The processes of fire allows germination for vegetation regeneration increasing the plant diversity in Sugarloaf Basin and establishing a mosaic like structure, which dramatically changes the landscape's features.

Relative Patch Area

The Sugarloaf Basin management service has allowed low severity and high frequency fires to burn throughout the region for 40 years, which seems to be correlated to an increase in total vegetation cover of meadows and shrubs. Before the introduction of wildfire and fire treatments to the area, studies show that large patches of mixed conifer forests often dominated the region and the landscape's structure was construed as homogenous (Collins and Stephens 2007). The homogenous landscape underwent a major change when low severity fires began spreading throughout shrubs in Sierra Nevada forests due to high seed dispersal and quick germination in open sites leading to post-fire succession in the surrounding areas (Huisinga et al. 2005). In my study, the change from mixed conifer forests to shrubs is the fifth most likely process to occur in areas of high frequency fires (Table 1). Areas of shrubs, herbs, and forbs that survived intense fires resort to local seed dispersal to establish their seedlings in nearby mixed conifer patches that have also been burned (Turner et al. 1997). Burning mixed conifer stands releases growing space and nutrients after high frequency fires because of the decrease in large forested patches. My results indicate an increase in shrubs and meadow in certain regions that have frequently been affected by fire (Figure of areas of change in forest to shrub/ meadow). The release then allows for an expansion of dense meadows, sparse meadows, and shrubs within and around the burned areas in the Sugarloaf Basin increasing landscape heterogeneity.

Limitations and future directions

My research's study area is restricted to a relatively small region of the Sierra Nevada forests, which inevitably leads to a localized difference in landscape vegetation and other biotic factors due to the inherently large variation of the Sierra Nevada Mountain's microclimatic and vegetation characteristics. Due to the limited number of classifications in the study area and the entire Sierra Nevadas, it would cause major scientific bias to generalize my results for the regions as whole. Although the experimental design of my research project covered all classifications of vegetation cover and used standard accuracy tests, I would like to further reduce bias and increase the accuracy of my hypothesis by means of other statistical tests such as ANOVA or binomial regression in my future research. The limitations of my study suggests that possible future research projects should incorporate larger regions and use other statistical methods to further explore the beneficial vegetation changes induced by fire throughout the Sierra Nevada forests.

My findings suggest that future research should focus on the different types of fire management and how they could be applied and monitored to further measure the changes in a landscape over a given period of time. A theoretical project would be to determine the effects of fuel treatments and applied fire regimens on potential fire behavior and how this affects Sugarloaf Basin's composition and structure. It can be assumed that the landscape would continue to change toward a more fire- adapted landscape with richer soil composition and healthier vegetation. The future of fire research is advantageous in altering current policies that suppress fires to decrease forest hazards and increase ongoing interactive fire management. Raising awareness is an important first step in diminishing the stigma around wildfires and incorporating the application of fire regimens.

Broader implications

The lack of wildfires, fuel reduction treatments, and fire regimens have dramatically affected the structure of not only the Sierra Nevada but also the Western United States' forests causing them to be dense, dry and difficult to manage due to the lack of viable management options for large forest regions (Collins et al. 2011). It is crucial to recognize the impacts of a century of fire exclusion such as an increase in forest density and heavy, dry fuel loads on the forest floor. Recognizing these impacts allow for accurate assessment of present forest conditions, species dominance, and the impacts of fuel loads to fully understand how the landscape's health and structure is affected by these factors. Embracing fires into forests will radically change forest structure for the better by redistributing plants and enhancing landscape diversity across the region (Schmidt et al. 2008). Lessening the stigma that all fires are bad requires the cooperation of the federal government and forest management agencies, which is a difficult task to fulfill given the opposing interests of each agency.

A century of adamant fire exclusion policies have altered the direction of forest management funds. Instead of funding research and development on forest fire management, state and federal funds were invested toward putting out all fires both big and small. Due to the uncontrollable risk factors of wildfires, stomping out fires required manpower and money, which became an economically inefficient method to spend state and federal subsidies for the use of managing forests (Stephens and Ruth 2005). Studying the effects of fire induced vegetation changes is a major key to gaining a new understanding of which regimen combination will be most effective in reviving the Sierra Nevada forest structure and composition. Reducing the need to suppress fires will inevitably increase the economic value of forests and reroute funds to more appropriate uses like research and development on viable management options.

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REFERENCES

Agee, J.K. 1974. Fire Management in the National Parks. Western Wildlands 1:27-33.

Collins, B. M., R. G. Everett, and S. L. Stephens. 2011. Impacts of fire exclusion and recent managed fire on forest structure in old growth Sierra Nevada mixed-conifer forests. Ecosphere 2:1–14.

Collins, B., and S. Stephens. 2007. Managing Natural Wildfires in Sierra Nevada Wilderness Areas. Frontiers in the Ecology and the Environment 5:523-527.

Congalton, R.G., 1991. A review of assessing the accuracy of classifications of remotely- sensed data. Remote Sens. Environ. 37, 35–46.

Cox, T. R. 1983. Review of Fire in America: A Cultural History of Wildland and Rural Fire. Environmental Review: ER 7:297–299.

Dombeck, M. P., J. E. Williams, and C. A. Wood. 2004. Wildfire Policy and Public Lands: Integrating Scientific Understanding with Social Concerns across Landscapes. Conservation Biology 18:883–889.

Forrestel, A. B., M. A. Moritz, and S. L. Stephens. 2011. Landscape-Scale Vegetation Change following Fire in Point Reyes, California, USA. Fire ecology.

Habeck, J. R., and R. W. Mutch. 1973. Fire-dependent forests in the Northern Rocky Mountains. Quaternary Research 3:408–424.

Heinselman, M. L. 1981. Fire and Succession in the Conifer Forests of Northern North America. Pages 374–405 *in* D. C. West, H. H. Shugart, and D. B. Botkin, editors. Forest Succession. Springer New York.

Huisinga, K. D., D. C. Laughlin, P. Z. Fulé, J. D. Springer, and C. M. McGlone. 2005. Effects of an Intense Prescribed Fire on Understory Vegetation in a Mixed Conifer Forest. The Journal of the Torrey Botanical Society 132:590–601.

Kercher, J. R., and M. C. Axelrod. 1984. A Process Model of Fire Ecology and Succession in a Mixed-Conifer Forest. Ecology 65:1725–1742.

Kilgore, B. M. 1973. The ecological role of fire in Sierran conifer forests: Its application to National Park management. Quaternary Research 3:496-513.

Larson, A. J., and D. Churchill. 2012. Tree spatial patterns in fire-frequent forests of western North America, including mechanisms of pattern formation and implications for designing fuel reduction and restoration treatments. Forest Ecology and Management 267:74–92.

Mathieu, R., Freeman, C., and A. Jagannath. 2007. Mapping private gardens in urban areas using object-oriented techniques and very high-resolution satellite imagery. Landscape and Urban Planning 81: 179-192.

Miller, J., H. Safford, M. Crimmins, and A. Thode. 2009. Quantitative Evidence for Increasing Forest Fire Severity in the Sierra Nevada and Southern Cascade Mountains, California and Nevada, USA. Ecosystems 12:16-32.

Moritz, M. A., and S. L. Stephens. 2008. Fire and sustainability: considerations for California's altered future climate. Climatic Change 87:265–271.

North, M.P., S.L. Stephens, B.M. Collins , J.K. Agee, G. Aplet, J.F. Franklin, and P.Z. Fulé. 2015. Reform forest fire management: Agency incentives undermine policy effectiveness. Science 18: 1280-1281.

Schmidt, D. A., A. H. Taylor, and C. N. Skinner. 2008. The influence of fuels treatment and landscape arrangement on simulated fire behavior, Southern Cascade range, California. Forest Ecology and Management 255:3170–3184.

Stephens, S. L., and J. J. Moghaddas. 2005. Experimental fuel treatment impacts on forest structure, potential fire behavior, and predicted tree mortality in a California mixed conifer forest. Forest Ecology and Management 215:21–36.

Stephens, S.L. 2005. Forest fire causes and extent on United States Forest Service lands. International Journal of Wildland Fire 14:213-222.

Stephens, S. L., and L. W. Ruth. 2005. Federal forest-fire policy in the United States. Ecological Applications 15:532-542.

Turner, M. G., W. H. Romme, R. H. Gardner, and W. W. Hargrove. 1997. Effect of Fire Size and Pattern on Early Succession in Yellowstone National Park. Ecological Monographs 67:411–433.

van Wagtendonk, J. W., K. A. van Wagtendonk, and A. E. Thode. 2012. Factors Associated with the Severity of Intersecting Fires in Yosemite National Park, CA, USA. Fire Ecology 8:11-31.

White, J. D., K. J. Gutzwiller, W. C. Barrow, L. J. Randall, and P. Swint. 2008. Modeling Mechanisms of Vegetation Change Due to Fire in a Semi- Ari Ecosystem. Ecological Modeling 214:181-200.