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Comparative Analysis of Post Fire Vegetation Change Across Three California Wildfire Sites Using NAIP Derived NDVI (2016-2022)

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AUTHOR BIO

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ABSTRACT

In California, wildfires have grown significantly more severe and frequent in recent years, with the 2020 fire season alone burning over 4 million acres across the state (2020 Fire Season | Welcome to CAL FIRE, 2020). This study explores the post-fire vegetation change in three of the major California wildfires from 2020: the August Complex, the Creek Fire, and the SQF Complex. Normalized Difference Vegetation Index (NDVI) data gathered from 2016 and 2022 National Agriculture Imagery Program (NAIP) aerial imagery was used to measure the vegetation health and density both before and after the fire. The change in NDVI was then calculated at each site to find the magnitude of vegetation loss and recovery. Pearson's correlation revealed significant negative relationships between the pre-fire NDVI and NDVI change in all three of the sites. Welch's T-tests confirmed that statistically significant differences in mean NDVI change between all three sites exist, establishing a ranking of August Complex being most severe, followed by the Creek Fire, and lastly the SQF Complex. The SQF Complex ended up with a slightly positive mean change in NDVI despite the damage to its giant sequoia population. This suggests that some ecosystems, like the giant sequoia forests, have a higher potential to recover fast due to their fire-resistant properties. This indicates that fire impact on vegetation is shaped by certain ecological factors beyond just the vegetation density. This also implies the advantages of more site-specific fire management that is modified to fit unique ecosystems and their needs.

Keywords: Wildfire recovery, Normalized Difference Vegetation Index, California wildfires, Wildfire vegetation loss, August Complex, Creek Fire, SQF Complex, Fire risk assessment, Ecosystem resilience

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INTRODUCTION

In California, wildfires are a rising threat to both residents and the environment. In the past decade, the state has experienced some of the largest and most destructive fires in its recorded history. One particularly prominent year for wildfires in California was in 2020. This study examines three major wildfires that occurred during the 2020 California fire season.

The 2020 August Complex fire originated as the result of 38 distinct fires caused by lightning strikes along the Coast Range of California. By September 9, less than a month after the fire's inception, it surpassed the record for the largest wildfire to ever exist within the state (2020 Fire Season | Welcome to CAL FIRE, 2020). In addition to harming California residents, the fire damaged roughly 98% of the Mendocino National Forest, a critical wildlife conservation area. It covered large areas of fire-prone chaparral, oak woodlands, and serotinous conifers (Esri, 2023).

In Central California's Sierra National Forest, the Creek Fire ignited on September 4, 2020, in Fresno and Madera Counties. The Creek Fire ultimately burned around 379,000 acres, destroyed 856 structures, and caused over $500 million in damage, ranking among the largest single (non-complex) wildfires in California's recorded history (Miller, 2021).

In Sequoia National Forest, the SQF Complex burned across the Giant Sequoia National Monument and Sequoia National Park. It proved especially devastating to the region's giant sequoias trees. A subsequent report by the National Park Service and U.S. Geological Survey estimated that the fire killed between 7,500 and 10,600 large giant sequoias, representing 10 to 14 percent of all such trees remaining on Earth (NPS, 2023). Sequoia trees are known for their fire-resistant characteristics, like their thick and spongy bark to protect them from wildfire heat, and their high-growing branches that can avoid the flames altogether (Wildfires Kill Unprecedented Numbers of Large Sequoia Trees, n.d.).

We hypothesize that areas with higher pre-fire NDVI will show significantly greater post-fire vegetation decline, and the magnitude of vegetation change will differ significantly between the three fire sites due to differences in ecosystem composition and fire severity. We are aiming to discover how vegetation health changed following three major California wildfires (SQF Complex, August Complex, and Creek Fire), and whether pre-fire vegetation density predicted the magnitude of that change.

METHODS

Study Sites

Table 1
Coordinates and Locations of Each Study Site.

Name	SQF Complex Fire	August Complex Fire	Creek Fire
Central Coordinates	36.255°N, 118.497°W	39.765°N, 122.673°W	37.191°N, 119.261°W
Location	Sequoia National Forest	Mendocino National Forest	Sierra National Forest

Three wildfire sites from the 2020 California fire season were selected: The August Complex, Creek Fire, and SQF Complex. These sites were chosen to represent both geographically and ecologically separate types of forests within the Sierra Nevada and Coast Range while all occurring within the same fire season, giving a controlled comparison of the post fire vegetation response across a two year interval of recovery. A 9 km by 9 km bounding box centered on each fire's approximate central coordinates was used to define the study area at each site.

Imagery Source

Four band (Red, Green, Blue, Near Infrared) aerial imagery was gathered from the National Agriculture Imagery Program (NAIP) through California Department of Fish and Wildlife's public ArcGIS Image Server. Imagery from 2016 was used as a baseline before the fires, and imagery from 2022 was used to assess post fire vegetation, providing roughly a 2-year post fire recovery window consistent across all three sites. Both years were confirmed to be a 0.6-meter spatial resolution. All of the imagery was processed in the EPSG:3857 coordinate reference system (CRS), which was the NAIP default.

NDVI Calculation

The Normalized Difference Vegetation Index (NDVI) was calculated for each aligned raster using the formula:

$$NDVI = (NIR - Red) / (NIR + Red)$$

Where NIR and Red correspond to the near infrared and red bands of the NAIP imagery (USGS, 2024). NDVI was calculated separately for each site's 2016 and 2022 imagery using the GDAL (Geospatial Data Abstraction Library) command gdal_calc.py. A pixel NDVI difference layer (2022 NDVI - 2016 NDVI) was then calculated for each site to represent the magnitude and direction of vegetation change over the study period. The NDVI difference was mapped for each site.

Sampling and Normalization

To make raster processing manageable on a laptop, each site's rasters (originally 15,000 × 15,000 pixels) were downsized to 300 × 300 pixels (90,000 sample points) prior to statistical analysis. For each sampled pixel, 2016 NDVI and NDVI change values were taken and paired for each coordinate.

Two normalization methods were used for the NDVI change values at each site: The first was Z score normalization, calculated as (value − site mean) / site standard deviation. The other method was Min/max normalization, calculated with (value − site minimum) / (site maximum − site minimum) and then scaled to a 0–100% range (Codecademy, 2026).

Statistical Analysis

Pearson's correlation coefficient was calculated between each site's 2016 NDVI values and each one's NDVI change value to assess whether the pre fire vegetation density could predict the magnitude of following changes. The change in NDVI was compared between sites using a Welch's T-test (which does not assume equal variance between groups). The T-test was conducted on a random sample of 200 points per site rather than the full 90,000 point dataset. All this statistical analysis was enacted in Python. Additionally, a significance threshold of $p < 0.05$ was used throughout.

Disclosure

Claude was used to assist with the creation of computer scripts used for the data processing pipeline. All outputs were reviewed and validated by the author.

RESULTS

Table 2
Mean NDVI Change, Standard Deviation, and Minimum and Maximum Change.

Site	Mean NDVI change	Standard Deviation	Min change	Max change
August Complex	-0.333	0.185	-0.895	0.535
Creek Fire	-0.135	0.198	-1.563	1.142
SQF Complex	0.0253	0.234	-1.388	1.318

The August Complex showcases the lowest mean at -0.33, against the less negative means from the Creek Fire and SQF Complex Fire. This means the August Complex experienced the most net vegetation loss by 2022, two years after all three fires started.

SQF Complex shows a slightly positive mean NDVI change. This could be due to the fact that my 9km x 9km bounding box only represents around 10% of the burned area, meaning the most extreme changes could have potentially been left out. Another justification is the fact that two years have passed since the fire, so enough time has passed for regrowth to occur. In this case, the SQF Complex could have the fastest rate of regrowth, considering the NDVI became more positive.

Table 3
Pearson's Correlation and T-test Results

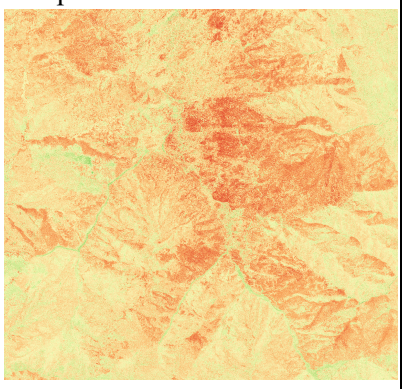
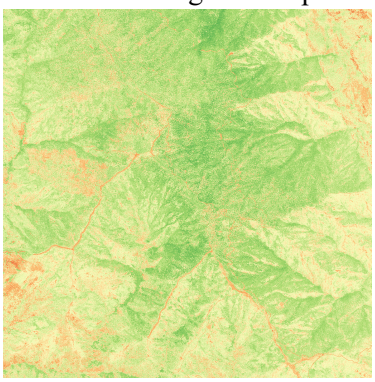
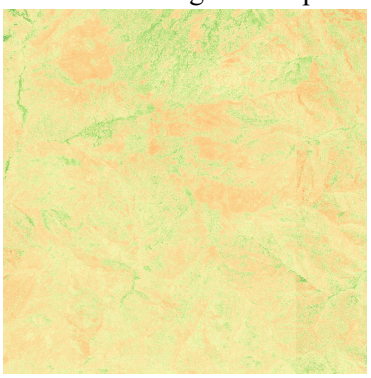
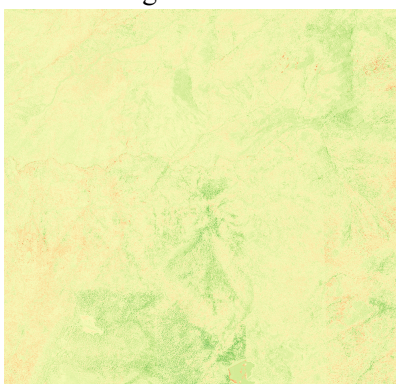
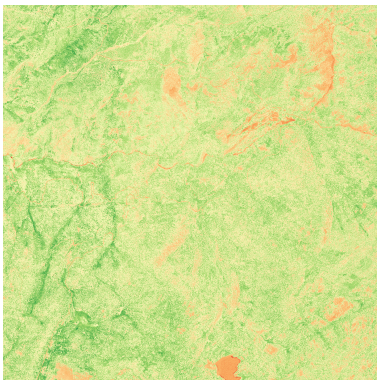
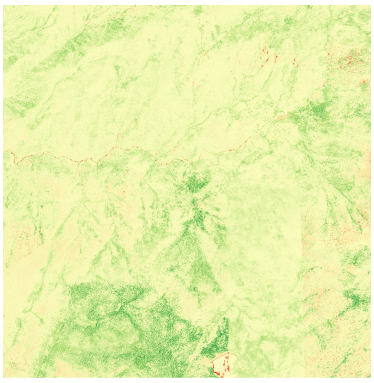
Comparison	**Test**	**Statistic (r)**	**Result**
SQF: 2016 NDVI vs change	Pearson's Correlation	-0.217	Significant
August: 2016 NDVI vs change	Pearson's Correlation	-0.801	Significant
Creek Fire: 2016 NDVI vs change	Pearson's Correlation	-0.349	Significant
Comparison	**Test**	**T-value**	
SQF vs August Complex	T-test	29.986	
SQF vs Creek Fire	T-test	17.524	
August vs Creek Fire	T-test	-15.316	

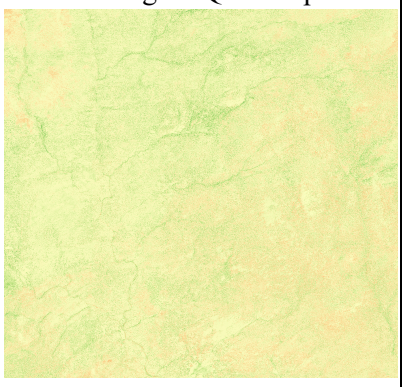
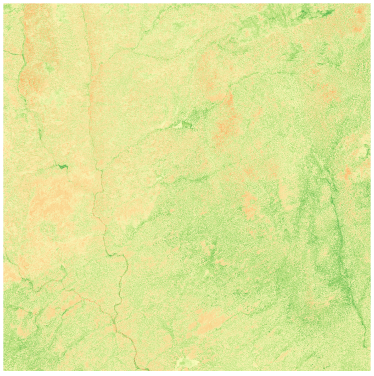
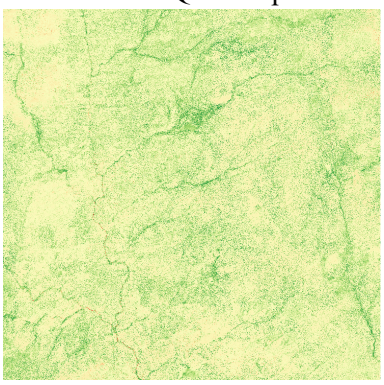
Pearson's Correlation compares the relationship between starting NDVI and NDVI change. All results are negative, which indicates that as the 2016 NDVI increased, the change in NDVI would go down, or become more negative. This makes sense in context because areas with more initial vegetation will experience greater loss. The greater magnitude of r means a greater correlation between the two variables. The August Complex had the greatest correlation with a r value of -0.801.

The T-test determines whether the difference in means of each fire's NDVI change is due to chance. The large magnitudes of T-values that I got indicate a significant difference between sites. Welch's T-tests comparing mean NDVI change between each pair of sites revealed statistically significant differences for all three comparisons. The effect sizes were large across all comparisons, indicating that these differences reflect the meaningful differences in vegetation response. The SQF Complex showed a significantly higher mean NDVI change than both August Complex and Creek Fire, and August Complex showed significantly lower mean NDVI change than Creek Fire. Together, these results establish a

consistent ranking of vegetation impact across the three sites: August Complex > Creek Fire > SQF Complex, in order of decreasing severity of net vegetation decline.

Figure 1
Maps of NDVI Change, initial, and final NDVI.

NDVI Change: August Complex 	2016 NDVI: August Complex 	2022 NDVI: August Complex 
NDVI Change: Creek Fire 	2016 NDVI: Creek Fire 	2022 NDVI: Creek Fire 

NDVI Change: SQF Complex	2016 NDVI: SQF Complex	2022 NDVI: SQF Complex
		

Note. Warmer colors represent more negative NDVI values (less vegetation/vegetation loss), while green represents more positive NDVI values (more vegetation/vegetation growth). Maps were created by the author in QGIS. Imagery source: National Agriculture Imagery Program, 2016 and 2022, accessed via California Department of Fish and Wildlife.

DISCUSSION

The results of this study support the hypothesis that pre-fire vegetation density predicts the severity of post-fire vegetation decline, and that the magnitude of vegetation change differs significantly across fire sites. All three fires showed significant negative correlations between the 2016 NDVI and the NDVI change (Pearson's Correlation). Additionally, comparisons between the three sites confirmed a severity ranking from greatest to least of August Complex > Creek Fire > SQF Complex. The large effect sizes from the T-test show that these results are statistically significant. While vegetation density alone does not fully determine fire impact, it is demonstrated to be a considerable factor.

Each of the three fires burned through a completely different forest ecosystem. The differences in each ecosystem help to justify the different patterns observed. The August Complex burned mostly through Mendocino National Forest's mixed timber, chaparral, and tall grassland, damaging over one million acres (August Complex Fire, n.d.). Because of the fire prone nature of this biome, it produced a uniform severe damage pattern. Creek Fire, by contrast, burned through the Sierra National Forest's mixed conifer terrain, which is a region that had already experienced significant bark beetle declines due to drought in the years prior. This left a large number of standing dead trees amongst the fewer living ones. This created a pre-fire condition of live and dead vegetation mixed rather than a single fuel type, contributing to a lower initial NDVI in 2016, and therefore a lower change. The SQF Complex fire turned out to be the most distinct case ecologically, burning through the Sequoia National Forest's giant sequoia groves. Sequoia trees are known to be adapted to low and moderate intensities of fires. Not only that, but they can even benefit from some effects of the fire, like bare ground to support new growth, and opened

cones to release and scatter seeds. This understanding explains the slight positive outcome after the two-year recovery period, because the forest was able to make up for what was lost by fueling new growth.

CONCLUSION

This study found that vegetation health declined following all three wildfires, with the magnitude of that decline varying significantly by site and consistently ranking the August Complex as most severely affected, followed by the Creek Fire, then lastly the SQF Complex. Pre fire vegetation density was shown to predict the severity of this decline at every site, confirming the study's hypothesis, though the strength of that relationship differed considerably, indicating that NDVI alone is an incomplete predictor, and that ecological conditions at each site also significantly shape fire impact. Taken together, these findings indicate that wildfire's impact on vegetation is not uniform, nor fully explained by pre fire density alone, highlighting the need for more ecosystem specific approaches to fire risk assessment and recovery planning across California's vastly different types of forest landscapes.

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