Case Study of Camp Fire Employing Novel Metric for Time Series Analysis of Vegetation Recovery

Alissa Sherbatov[1], Evan Hsiang[1], Cassie Kilburn[1], Joseph Ortiz[1], and Benjamin Koppe[1]

[1]GLOBE Program

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Abstract

Abstract—Wildfires are a major global issue, costing the United States 71.1 to 347.8 billion dollars annually (Graham, 2020). Rising global temperatures have increased the frequency and intensity of wildfires (Cuevas-Gonzales, 2009). Climate change has thus created a need for new methods to examine the effects of wildfires. In this research, we evaluated how the 2018 Camp Fire environmentally impacted land cover in California, and the extent to which the area's land cover suffered from long-term damage. Our hypothesis was that the affected land was damaged significantly, but recovered partially by the end of the investigated period. In order to assess the healing of a patch of land burnt in the Camp Fire, corrected reflectance images of the patch collected from NASA Worldview were analyzed using Python to return each image's Pixel Greenness Value (PGI)–an original metric developed by our team that analyzes an image's color content to return a numerical value corresponding to vegetation health. These values were then plotted. Over the course of 26 weeks after the Camp Fire, the patch of land partially regained its PGI. Major recovery occurred between weeks 7 and 15. We concluded that the area burnt in the Camp Fire only partially recovered, as the moving average of the PGI value only reached 81% of the baseline value by the end of the investigated period. Our findings demonstrate the environmental damage that wildfires can cause and the potential of PGI as a useful metric for assessing the impact of wildfires. Future studies could compare PGI results with those of the Normalized Difference Vegetation Index (NDVI), known for its usage in such vegetation recovery analyses. The case study could also repeat the experiment with Landsat data taken from the United States Geological Survey website, to account for the lack of atmospheric correction in NASA Worldview data. Key words: extreme event, wildfire, land cover, environmental science, programming

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Alissa Sherbatov[1], Evan Hsiang[2], Cassie Kilburn[3], Joseph Ortiz[4], Benjamin Koppe[5], and Peder Nelson[6]
[1]Bergen County Academies, Hackensack, New Jersey
[2]W.B. Ray High School, Corpus Christi, Texas
[3]Heritage High School, Palm Bay, Florida
[4]Las Vegas High School, Las Vegas, Nevada
[5]Advanced Technologies Academy, Las Vegas, Nevada
[6]Oregon State University, Corvallis, Oregon

***Abstract*—Wildfires are a major global issue, costing the United States 71.1 to 347.8 billion dollars annually [1]. Rising global temperatures have increased the frequency and intensity of wildfires [2]. Climate change has thus created a need for new methods to examine the effects of wildfires. In this research, we evaluated how the 2018 Camp Fire environmentally impacted land cover in California, and the extent to which the area's land cover suffered from long-term damage. Our hypothesis was that the affected land was damaged significantly, but recovered partially by the end of the investigated period. In order to assess the healing of a patch of land burnt in the Camp Fire, corrected reflectance images of the patch collected from NASA Worldview were analyzed using Python to return each image's Pixel Greenness Value (PGI)–an original metric developed by our team that analyzes an image's color content to return a numerical value corresponding to vegetation health. These values were then plotted. Over the course of 26 weeks after the Camp Fire, the patch of land partially regained its PGI. Major recovery occurred between weeks 7 and 15. We concluded that the area burnt in the Camp Fire only partially recovered, as the moving average of the PGI value only reached 81% of the baseline value by the end of the investigated period. Our findings demonstrate the environmental damage that wildfires can cause and the potential of PGI as a useful metric for assessing the impact of wildfires. Future studies could compare PGI results with those of the Normalized Difference Vegetation Index (NDVI), known for its usage in such vegetation recovery analyses. The case study could also repeat the experiment with Landsat data taken from the United States Geological Survey website, to account for the lack of atmospheric correction in NASA Worldview data.**

I. Introduction

Wildfires have significant environmental and socioeconomic consequences. In 2020, 58,250 wildfires burned about 10.3 million acres of land [3]. Wildfires also incur great monetary costs. In 2018, California paid damages of $102.6 billion, including health costs and structural damages, and California's connection to the national economy created another $45.9 billion of indirect losses [4]. Climate change has contributed to an increase in the frequency and intensity of wildfires [5]. Higher global temperatures have partially led to longer fire seasons and faster spread of fires [6,7]. Considering the growing threat of wildfires, a new method for measuring the extent of a wildfire's impact is thus in need to ensure effective prevention and reconstruction policies.

This investigation aims to determine the extent of the damage of California's Camp Fire to burnt land, and track the recovery of the land for 6 months after the fire. Our study seeks to test the usefulness of the Pixel Greenness Index (PGI), our developed metric of the health of vegetation, in assessing land cover changes due to wildfires. Our hypothesis was that the Camp Fire will have a significant, long-term impact on the PGI of the impacted area.

II. Methods

All image data in this investigation was Moderate Resolution Imaging Spectroradiometer (MODIS) corrected reflectance data taken from NASA Worldview, an open-source database containing daily remote sensing satellite imagery of the Earth. Screen captures were taken of a patch of land in Paradise, California, where the fire left the most visible damage. Paradise has a Mediterranean climate, and, prior to the fire, was surrounded by many deciduous and evergreen trees. Data was taken so that only the burnt patch would be visible because the non-burnt sections could interfere with data analysis.

One major issue in using the NASA Worldview tool for our analysis is that the land is sometimes covered by clouds. The addition of the white color of the clouds to the pictures taken modifies the mean color of the picture, and thus creates a data inconsistency that could interfere with analysis. This issue was corrected by only taking one measurement per week. This allowed room to choose the day of the week in which the sky over the patch of land is the clearest. In total, 28 images were taken using a screen capture–1 baseline image, 1 image immediately after the fire, and 1 image for each of the following 26 weeks–and then stored locally on a device.

Our method to obtain PGI values from the images is split into two steps. The first step is to obtain the mean color of each image in BGR format. The lower the value of a color is, the less there is of that color in the image. This can be done using a Python program by using the cv2.imread and numpy.average methods. The portion of this data that corresponded to G, or green, is the PGI value.

III. Results/Discussion

After the 28 PGI values were determined from the images, they were plotted on a graph using Excel [Figure 1]. A second series was created on the same plot to display the three-day moving average (not inclusive of the baseline measurement). A trendline (calculated by Excel's trendline function) is shown on the same graph.

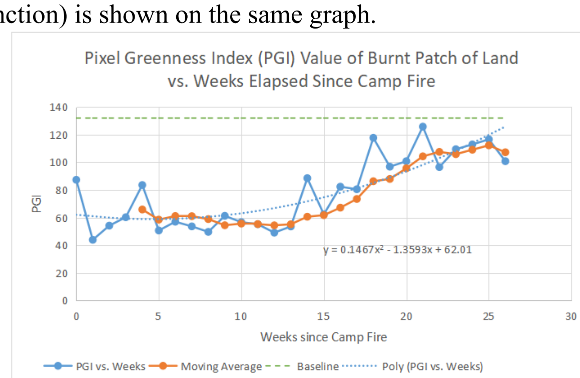

Figure 1: PGI value of burnt patch of land over the course of 26 weeks after the Camp Fire. Graph of PGI of burnt patch

of land over the 26 weeks following the Camp Fire is displayed, along with a three-week moving average, polynomial trendline and a line representing the baseline PGI.

The PGI vs weeks line shows that the PGI value at week 0 of about 87 was significantly lower than the baseline value of 132. The PGI values never return to this baseline level, with the highest subsequent PGI value of 126 and the final week's value of 101. By week 26, the moving average graph's PGI was only 81% of the baseline PGI. Thus, recovery was significant but not complete by week 26. Furthermore, the PGI value at week 0 is about 34% lower than the baseline PGI value. Therefore, the damage done by the wildfire can also be considered significant.

The PGI values generally decreased to week 12. The values then increased between week 12 and week 25. The moving average similarly shows low values until week 13, an increase from weeks 13-22, and a leveling-off from weeks 22-26. The polynomial trend line gives a clearer view of the trends. Using the first derivative of the polynomial, the PGI is approximately shown to decrease from weeks 0-7, increase from weeks 7-24, and decrease from weeks 24-26. Using the second derivative of the polynomial, the rate at which PGI changes over time decreases from weeks 0-7 and weeks 15-24, and the rate at which PGI changes over time increases from weeks 7-15 and weeks 24-26. Combining both derivative tests, the largest increase in recovery rate occurs between weeks 7 and 15.

PGI levels increased faster as more time went on, so the equation of best fit, $0.1467x^2 - 1.3593x + 62.01$, is quadratic. According to this equation, PGI levels are expected to return to their original value of 132 by week 27.

The slight decrease in PGI from weeks 0-7 may suggest that the fire's intensity or scope expands soon after its development. However, the overall increase in values shows that the patch of land recovered significantly after 26 weeks, but did not regain its baseline PGI, suggesting that full recovery may take longer.

A variety of errors may have occurred. Weekly measurements allowed for choice of images least affected by cloud cover. However, this human choice may have also introduced bias in image selection. As a result, the improvement or initial drop in PGI may have been exaggerated. Furthermore, the single baseline measurement may stray from the pre-fire PGI, thus affecting conclusions about the extent of recovery.

In addition, while corrected reflectance data was used, NASA Worldview's data is not atmospherically corrected, which could decrease the accuracy of the data. To remedy this potential source of error, we intend to conduct a future investigation repeating the case study using atmospherically corrected Landsat satellite data from the official United States Geological Survey website. This study could also compare the performance of our PGI metric with that of the Normalized Difference Vegetation Index, or NDVI, which is known for its usage in such time series analyses.

Another study analyzing MODIS satellite data with NDVI and normalized difference shortwave infrared index suggests that complete recovery could take over 13 years [2]. The same study found that evergreen forests may recover more rapidly than deciduous forests. While our study did not compare two wildfires, there were deciduous and evergreen trees in the burnt region, making an estimation of complete recovery time difficult.

Our study sought to assess the severity of the wildfire. While the time for recovery may be an indication of the burn severity, the 34% drop in PGI from the baseline measurement to the week 0 measurement demonstrated the wildfire's substantial impact on vegetation. Other methods exist for evaluating the damage done by wildfires. Each method has benefits and shortcomings. NDVI and PGI are connected to the concentration of chlorophyll. The Normalized Difference Water Index (NDWI) measures moisture and is more resistant to atmospheric effects like cloud cover. NDVI and NDWI also allow for mapping. The partial focus on greenness of vegetation in NDVI and PGI can lead to inaccurate readings of the health of non-green vegetation [8]. Nonetheless, the usage of open-access satellite data makes our findings and methods relevant to other wildfires. Our results thus give insight into the time for recovery and the impact of wildfires on vegetation.

The methods explored in this investigation can also aid researchers and legislators in developing plans for reconstruction by helping to predict the effect of wildfires or other extreme events. Such planning will only become more important as climate change increases the frequency with which wildfires occur. In addition, the results of this study could serve as evidence to push for greater limitations on carbon emissions and extensive preservation of natural land.

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