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Spatiotemporal variability time-series analysis of North American wildfire intensity on vegetation recovery using NDVI, EVI, and GPP

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ABSTRACT

Wildfires are major disturbances that can leave lasting impacts on the ecosystem, biodiversity, and our society. Just this past year, over 4 million acres of land were burned across California, making the 2020 fire season the largest ever recorded in the state. Using three indices derived from satellite data, NDVI, EVI, and GPP, the post-fire recovery values in the indices were analyzed, and use results were used to determine whether vegetation type could affect the recovery. Three fires from the 2004 fire season in Alaska were selected to mimic the forest ecosystems in California without direct disturbances from human activities. MODIS-derived images were extracted from the Earth Explorer database every year from 2000-2018 and individually processed in QGIS to calculate NDVI, EVI, and GPP. The data of pre-fire areas from 2000-2003 was averaged and used as a control and reference area. NDVI and EVI values in post-fire recovery were extremely similar in areas with dense conifer populations and took an average 8 years to recover, while GPP values show quicker recovery at only 3 years. Results also demonstrate that an area with a balance of 46\% shrubs and 40\% conifers recovered much faster, at around 3 years for all indices, in comparison to areas with 76\% dense conifer populations. Using only one index is not enough for the most accurate results and it is critical to implement a variety of remote-sensing techniques in forest planning and recovery.

Keywords: *Satellite Imagery, NDVI, EVI, GPP, Wildfire*

I. INTRODUCTION

The North American Boreal Forest, which spans from Alaska to Newfoundland, covers 1.5 billion acres and is a crucial carbon sink. However, wildfires, which are major disturbances to boreal forests, are becoming more prevalent and intense with each coming year, particularly in the North American Boreal Forest. These fires drastically change the productivity, ecological diversity, and vegetation in the boreal forests.

Observing the burn site after a wildfire is vital for ensuring the sustainability of the region and selecting appropriate post-fire treatments. Through the data gathered, growth rate and recovery are analyzed to detect patterns and responses. In many cases, this is a tedious process because these sites need to be continuously monitored for plant growth and damage to the soil. Due to the increase in frequency, intensity, and area of these fires, it is much harder to monitor post-fire recovery accurately (Ryu, 2018).

Other methods of monitoring wildfire intensity and recovery have also been used, such as several varieties of simulation techniques, as well as spectral indices. Spectral indices are particularly useful and have been widely used for remotely tracking vegetation

(Forkel, 2013). These indices are able to compare multiple bands in the electromagnetic spectrum such as the visible, near-infrared (NIR), and mid-infrared sections (MIR), which is helpful for observing vegetation and therefore recovery during forest fires.
One such index is the Normalized Difference Vegetation Index (NDVI) It utilizes both the red and NIR bands and has been used extensively to identify vegetation health and density. It is one of the most commonly used vegetation indices, with readily available data from NASA's satellite sensors. In this case, it will be able to show burned areas as well as actively map the recovery rate of the region.

Similarly, an index that can also be used is the Enhanced Vegetation Index (EVI). Similar to NDVI, it also can be used to monitor vegetation growth. However, EVI is more sensitive to areas with denser vegetation and also reduces the influence of the atmosphere on vegetation values. It is also effective to correct canopy background noise (Matsushita, 2007).

An index that does not occur in many research papers regarding wildfire severity and recovery is the Gross Primary Production (GPP). Unlike NDVI and EVI, GPP is not a spectral index, as it focuses more on the amount of carbon produced during photosynthesis than spectral reflectance bands on the electromagnetic spectrum. GPP can be used to make connections between carbon dynamics and photosynthesis, which can then be used to draw the physiological state of a forest (Zhou 2017).

In many previous studies, NDVI and the Normalized Burn Ratio (NBR) have been used to monitor recovery and vegetation growth. In his 2019 study, Bright mainly used the NBR to examine post-fire recovery in three different North American forest types (Bright, 2019). In 2005, Epting, et.al, combined NBR and Composite Burn Index (CBI) in order to analyze fire intensity (Epting, 2005). A further study in 2020 conducted by Lacouture, et.al, used NDVI as their primary source for detecting vegetation recovery in a fire-frequented habitat (Lacouture, 2020). However, these studies focus typically on only one or two vegetation indices, which, because of the differences in band-type for these indices, may not provide the full results on vegetation coverage.

II. METHODS

The Study Area

The 2004 fire year was chosen as a study year for monitoring the fire trends, when Alaska experienced a record amount of large wildfires. Within the 2004 fire year, several burn sites were chosen based on different ecoregions and the variety of wildlife in the area (Oyler, 2009). The fires chosen are the Billy Creek Fire, the Camp Creek Fire, and the Evansville Fire, which burned 460539, 173441, and 138193 acres respectively. The data (Fig. 1) for burn severity, area, and location were extracted from the United States Geological Survey (USGS) Monitoring Trends in Burn Severity (MTBS) product database which was chosen because of its accuracy in the mapping of the extent and severity of wildfires (Langford, 2018).

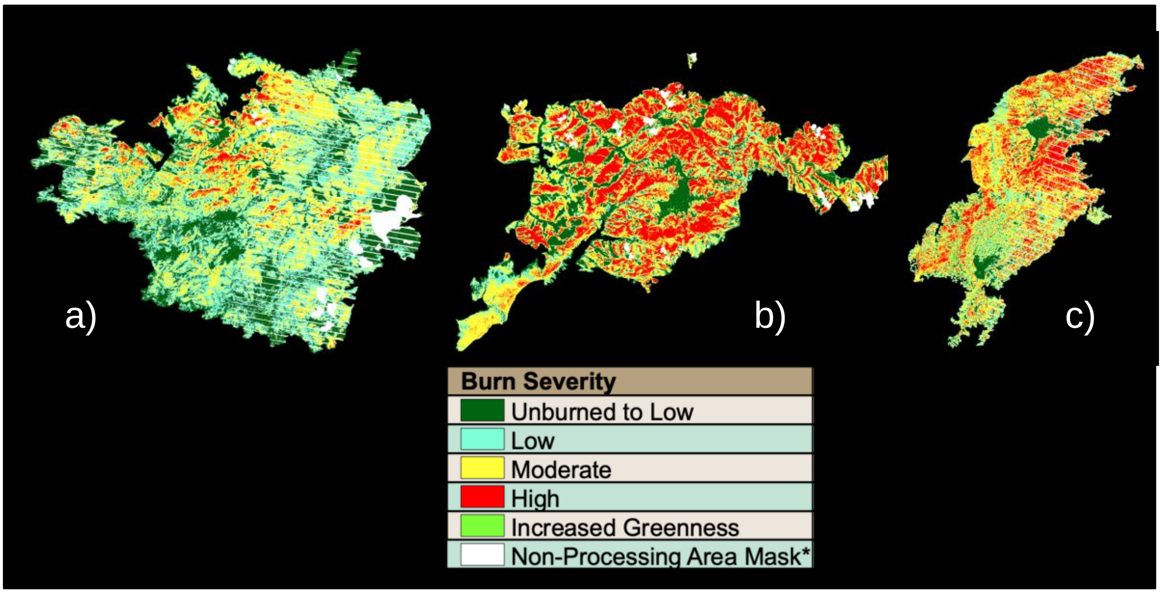

Fig. 1. MTBS data burn area with severity. Data shows a) Billy Creek Fire, b) Camp Creek Fire, and c) Evansville Fire respectively.

The Billy Creek Fire and the Camp Creek Fire were selected because of the similarities in the vegetation, displaying many of the same types of vegetation (Fig. 2). In contrast, the Evansville Fire was selected because of the differences in vegetation in order to test whether different indices show different results for varying vegetation types. Although the vegetation showed significant contrasts, all areas showed a significant decrease in the mean NDVI value after the fires occurred (Fig. 4).

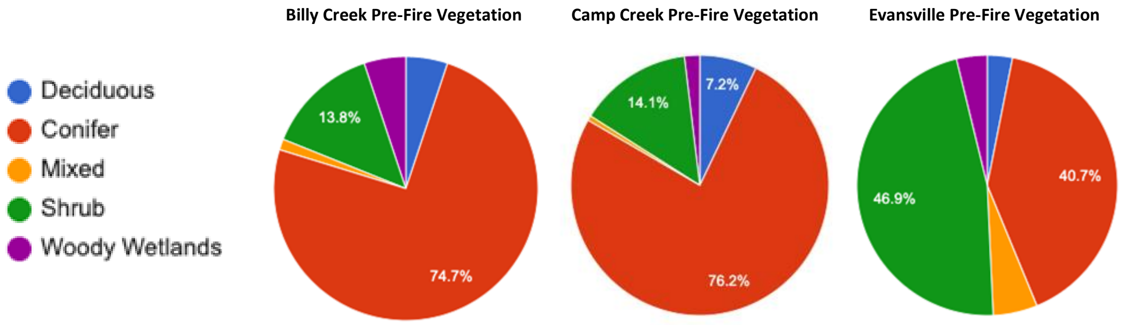

Fig. 2. Pre-fire vegetation types and values summarized within the burn area (Oyler, 2009)

The Billy Creek Fire and the Camp Creek Fire are both located in the Yukon Tanana Uplands ecoregion of Alaska, while the Evansville Fire is located in the Kobuk Ridges and Valleys ecoregion of Alaska (Fig. 3). In order to keep the variation in vegetation relatively constant, two controls were selected from the unburned areas in the Yukon Tanana Uplands ecoregion as well as one in the Kobuk Ridges and Valleys ecoregion of Alaska.

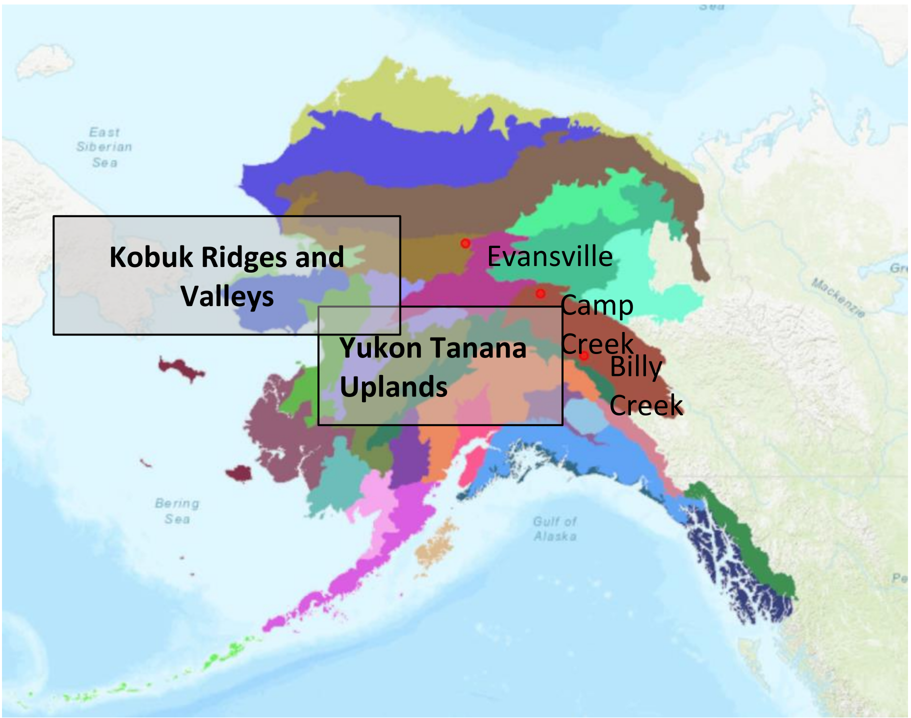

Fig. 3. Location of three burn sites including the respective ecoregions.

The Satellite Data

Satellite data from the MOD13 dataset collected by the Terra/Moderate Resolution Imaging Spectroradiometer (MODIS) was extracted from the USGS Earth Explorer (EE) database and used to calculate NDVI, EVI, and GPP.

NDVI is calculated by subtracting the red band from the NIR band and then dividing that value by the sum of the red band and NIR band ((NIR - red)/(NIR + red)). Because chlorophyll absorbs visible light, the reflectance of red wavelengths is less. The cell structure reflects infrared light, so the denser the vegetation, the more NIR is reflected (Matsushita, 2007). The data from the MODIS dataset was extracted based on the yearly phenological cycle growing season, from April to October. Only data that contained less than twenty percent of cloud coverage were included in the final values. The images were then processed with the QGIS software in order to obtain the NDVI values every year over a span of 15 years, from 2004-2018.

EVI monitors vegetation health mainly in areas of denser vegetation and is computed as follows: 2.5 * (NIR - red)/(NIR + 6.0 * red - 7.5 * blue + 1.0). In order to find the EVI values, the data from the MODIS dataset that had less than twenty percent of cloud coverage was extracted from April to October every year from 2004-2018. They were once again computed individually using the QGIS software.

For GPP values, data from the Terra/MODIS GPP database was used. The data were cross-verified by using the Land Process Distributed Active Archive Center (LPDAAC) dataset.

Because increasing inter-annual variability and noisy signals in NDVI time series often decreases the ability to detect trends and accurately analyze the time series, the Savitzky-Golay smoothing algorithm was applied to each dataset (Forkel, 2013). The Savitzky-Golay filter was selected because it has been shown to perform relatively well when it was applied in similar MODIS datasets (Langford, 2018). Figure 4 is a sample of the Billy Creek fire site in 2004, from the start to the end of the growing season. The red line represents the Savitzky-Golay smoothing of the data.

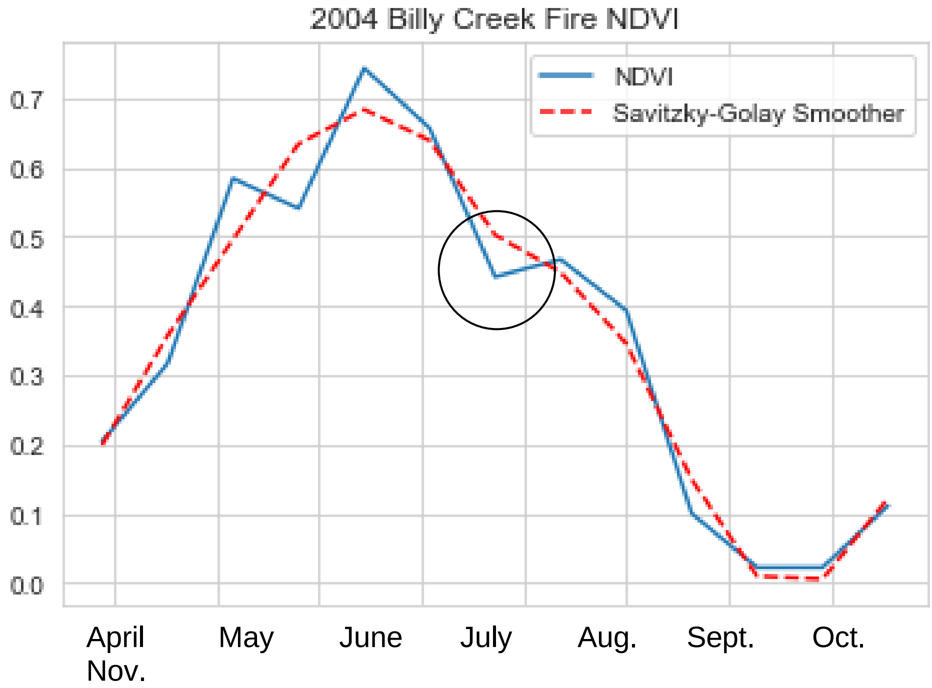

Fig. 4. Sample of the Billy Creek Fire NDVI values in 2004. Following a fire in July, NDVI values dropped significantly. Raw NDVI data is shown with the blue line and the trend after applying the Savitzky-Golay smoother is shown with a red dashed line.

For each fire and for each of the indices, the averages were taken from June and July to use in the analysis graphs because most of the vegetation growth reaches a peak during those times. Because pre-fire values are nearly constant for all vegetation indices, the averages of the values from 2000-2003 were taken as a constant.

III. RESULTS

The NDVI, EVI, and GPP values all dropped significantly after the fire started. However, different indices demonstrated different rates of recovery and varying post-fire trends. Table 1 shows the year of recovery for the individual fires based on the three indices.

	NDVI (Year of Recovery)	EVI (Year of Recovery)	GPP (Year of Recovery)
Billy Creek	2012	2011	2009
Camp Creek	2012	2010	2007
Evansville	2006	2008	2007

Table 1. The year of recovery as shown by three indices in three different fires.

In all the pre-fire values for all vegetation indices, the values were nearly constant each year. As a result, averages were taken and used as a reference to compare recovery values as shown in Fig. 5. The values of the NDVI and EVI indices in the fires reach recovery levels if they have less than a 0.05 amount of deviation from the reference area. The values of the GPP index in the fires reach recovery levels if there is less than a 0.001 deviation from the reference area.

The NDVI pre-fire reference value for the Billy Creek Fire is around 0.74, and the recovery levels in that area came close to meeting pre-fire values in 2012, with an NDVI value of 0.73. After meeting the recovery levels in 2012, the NDVI started to decrease again but increased after 2014 allowing the area to just barely meet the recovery level (Fig. 5a). Similarly, in the Camp Creek Fire, with a pre-fire reference value of 0.71, recovery levels were met in 2012 and the reference values were surpassed after 2016 (Fig. 5d). EVI results were extremely similar to the NDVI and showed many of the same patterns in terms of recovery and post-fire trends. The Billy Creek Fire had an EVI reference value of 0.33 and surpassed it in 2011. The Camp Creek Fire had an EVI reference of 0.32 and reference values were surpassed in 2010 (Fig. 5b, e, respectively).

However, the GPP values in both fires showed very different patterns from NDVI and EVI values. The GPP recovery levels were met in the Billy Creek Fire and Camp Creek Fire in 2009 and 2007 respectively. While NDVI and EVI levels mostly remained under the reference values even after reaching recovery levels, GPP values grew quickly and eventually largely exceeded the reference values (Fig 5c, f, respectively).

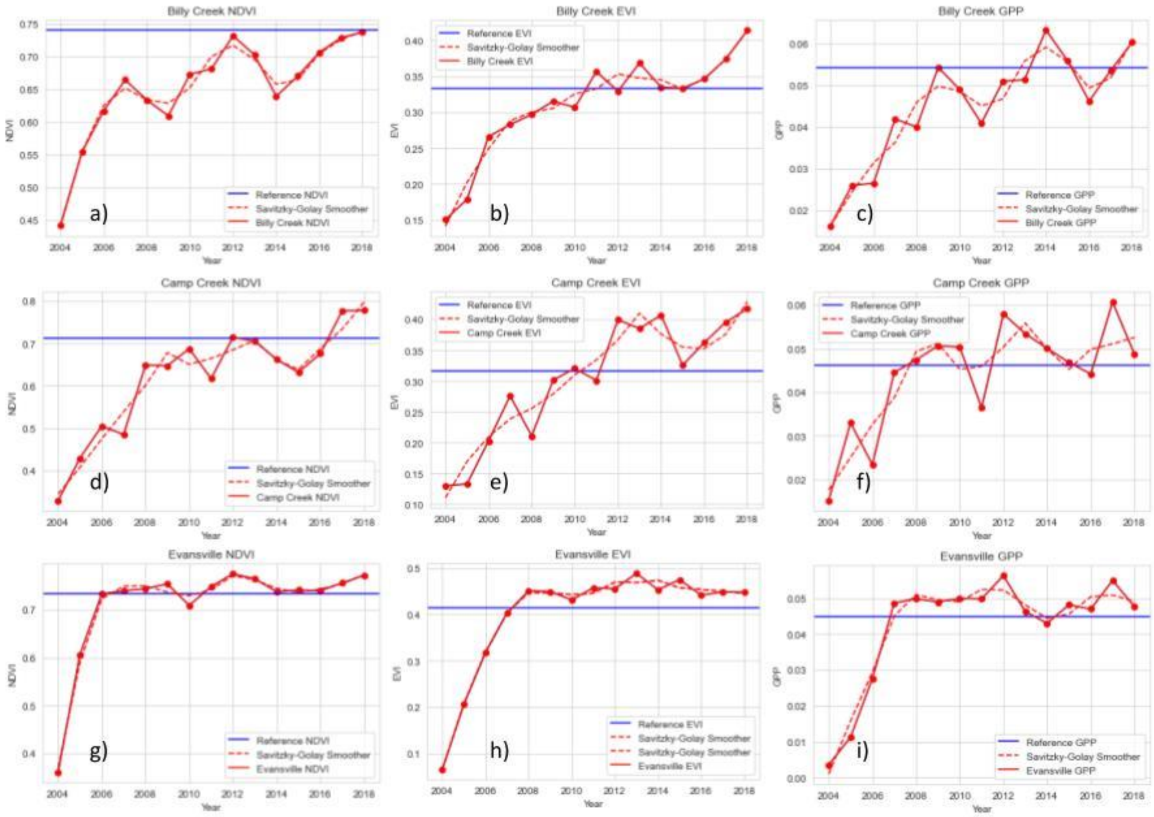

Fig. 5. NDVI, EVI, and GPP values shown in all three fire areas. Graphs a, b, and c are from the Billy Creek Fire. Graphs d, e, and f are from the Camp Creek Fire. Graphs g, h, and i are from the Evansville Fire.

The divergent behaviors between the post-fire trajectories of the Billy Creek, Camp Creek, and Evansville fires are also prominent. While the Billy Creek and Camp Creek fires both took a relatively longer time to recover in both NDVI and EVI values, the recovery in the Evansville fires was immediate in all indices as shown in Fig. 5g, 5h, and 5i. NDVI, EVI, and GPP values greatly surpassed reference values in 2006, 2008, and 2007 respectively.

IV. DISCUSSION

Though the EVI results are extremely similar to NDVI results given the data that was collected, there are still many differences between the two indices which could contribute to significant differences in future studies. One of the main differences would be the environment and the amount of noise signals and atmospheric interferences there would be in the data. The data collected indicates that the analysis of post-fire recovery is not limited to only one vegetation index, but rather, a variety of different indices should be taken into consideration in order to yield the most accurate results. There are different variables that should be used to classify whether an area has fully recovered, including both vegetation health and density as well as photosynthetic activity.

GPP recovery was noticeably the fastest out of all the indices to recover and even surpass the recovery levels. This could be due to technical errors, but the trends of the GPP on all three different fires have persisted. There could also be a variety of ecological and biophysical effects that have impacts on GPP. A 2020 paper by Ritter, et.al., suggests that precipitation and higher rainfall variability on both intra-annual and interannual timescales could lead to increased productivity in boreal forests (Ritter, 2020). Another plausible reason could be due to climate change, as stated by Zhou (Zhou, 2017), in which the warming climate could contribute to the increase of the annual mean GPP in higher latitudes.

Results from data indicate that the type of vegetation, or the different ecoregions in Alaska, greatly affect the recovery rate and trends in different vegetation indices. The heterogeneity of the Evansville Fire area could be an indicator of why it was able to recover at such high rates. Around 46% of the Evansville pre-fire vegetation consists of shrubs and 40% of the area consists of conifers, compared to the 75% and 76% of conifers in the pre-fire vegetation of the Billy Creek and Camp Creek Fires respectively. The rapid regrowth of shrubs and possibly other types of vegetation could contribute to the Evansville Fire area becoming populated and more dense in vegetation at such rates. In a 1985 study by Armesto and Pickett, they find that when large disturbances, like forest fires, occur, certain types of plants become more abundant in the recovery period because of the low amounts of competition (Armesto & Pickett, 1985). Likewise, the Evansville Fire could experience an extreme regrowth in the amount of shrubs or other types of diversity, and the post-fire vegetation could possibly be altered.

V. CONCLUSION

Through the data collected from this experiment, it can be concluded that different vegetation indices show recovery of vegetation after a disturbance at varying rates. The NDVI and EVI indices are used mainly for monitoring vegetation density and health and yield similar results in this experiment, taking on average 8 years to reach recovery levels in areas with dense levels of conifer. Whereas, GPP, a monitoring system for the physiological conditions of plants, shows a much faster recovery, at 3 years, after the initial fire. The initial hypothesis was not accurate; it can be shown that different indices should be taken into consideration when evaluating wildfire damage and recovery, and multiple remote-sensing techniques should be implemented in forest planning.

Additionally, the data from this experiment also concludes that there is not one designated vegetation index to be used on certain types of vegetation. Even though similar vegetation with similar characteristics can yield like results, a variety of vegetation indices with different functions should be used for higher accuracy.

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