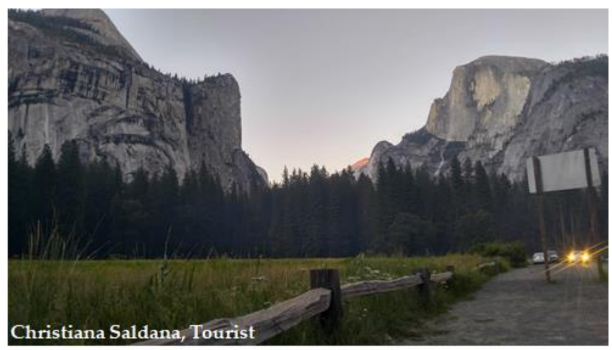
Tourism is on Fire:
Yosemite's Ferguson Fire



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Introduction and Context

Recent California wildfires have significantly affected local ecosystems and communities. Yosemite National Park has experienced severe stress, both ecological and economic. This stress comes as the result of drought, invasion of bark beetle and wildfires such as the 2018 Ferguson Fire. This fire's proximity and direct effects on Yosemite National Park, arguably one of California's most sought after destinations, raises many questions about the effects of wildfire on tourism. Tourism sectors that depend on the economic driver that is our National Park system have always dealt with the ebb and flow of natural disaster. However, increasing occurrence of intense wildfire and other climate change related phenomena have brought about a higher frequency of economic insecurity. Through highlighting the spatial implications of where fire damage occurred, we intend to highlight how changes in the picturesque nature of the park and predictability of park closures contribute to both short-term and long-term degradation of local tourism.

The Ferguson Fire ignited on July 13th, 2018 and was not 100% contained until September 19th 2018. Located in the Sierra National Forest and Stanislaus National Forest of Central California, the fire burned a total of 94,263 acres. At its peak ~3,000 people from many countries were assigned to fight the fire. There were a total of 2 fatalities and 19 injuries, with 10 structures destroyed (U.S. National Forest Service 2018). Yosemite Valley, the main camping, accommodation and recreation area for tourists was under evacuation from July 21st to around August 7th. Unpredictable road closures made visiting the park difficult even after portions of the park began to re-open . Major entrances such as Arch Rock, Big Oak Flat, Hetch Hetchy and South entrance were affected by these closures leading to sharp declines in visitor traffic. The main fuel types involved in the fire included chaparral, short grass and timber.

The majority of Yosemite National Park is in Mariposa County, CA with small portions of the park and most local residents in Madera County, CA. The nearest major city is Fresno, CA in neighboring Fresno County, CA. Madera County has a total population of ~157,672 that is primarily White and Hispanic. The median household income ~$48,210 (U.S. Census Bureau 2019b). Mariposa County has a total population of ~17,471, is primarily White with a median household income of ~$51,385 (U.S. Census Bureau 2019a). Mariposa County and the smaller communities within it are slightly wealthier than those within Madera County. While both counties are gateway communities to Yosemite consisting of many State and tourism related jobs, other notable job sectors include agriculture.

In the following sections, the details of data, methods and results will be elaborated with the goal of drawing conclusions about the effect the Ferguson Fire had on tourism in Yosemite. With the 1st (Rim Fire 2013) and 2nd (Ferguson Fire 2018) largest fires in the Yosemite's history occurring in under a decade, broad conclusions will also be drawn about the potential effects of wildfire in the area should trends continue.

Data and Methods

Data

The data used in this project was acquired from California Department of Forestry and Fire Protection (CalFire), California Department of Transportation (Caltrans), Environmental Systems Research Institute (Esri) and United States Census Bureau (U.S. Census).

Source of Imagery

Satellite images were obtained from the United States Geological Survey's Earth Explorer online platform provided by the Earth Resources Observation and Science (EROS) Center. A search criterion was established for California (Table 1). The date range selected for this project includes a pre-fire satellite image one year before on 07/16/2017 and a post-fire satellite image of 09/24/2018. Data sets were obtained from the Sentinel-2 satellite, a product generated by the European Space Agency (ESA) and distributed by the USGS.

Latitude	Longitude
38° 42' 02''	119° 10' 30''
38° 41' 55''	120° 12' 38''
36° 59' 46''	119° 53' 01''
37° 01' 05''	118° 56' 20''

Table 1: Location criteria for the study area satellite images

Sensor

Images where obtained from the Sentinel-2 satellite, a wide swath, multispectral, high resolution instrument with 13 spectral bands. Sentinel-2 is a mission of twin satellites as part of the European Commission's Copernicus program that were launched by the European Space Agency (ESA) on June 23, 2015 for Sentinel-2A and March 7, 2017 for Sentinel-2B. It provides services such as land monitoring of artificial surfaces, forest, agriculture, wetlands and small water bodies. This satellite supports emergency management covering and monitoring risks from natural hazards, relief efforts and humanitarian crises. Furthermore, the mission contributes to security concerns and monitors climate change. Sentinel-2 has a spatial resolution divided into four bands at 10 m, six bands at 20 m and three bands at 60 m with an orbital swath width of 290 km and a radiometric resolution of 12-bit. This satellite provides multispectral images every 10 days with a revisit time of 5 days at the equator. Sentinel-2 revisits and covers places such as all continental land surfaces between latitudes 56° south and 83° north, all coastal waters up to 20 km from the shore, all EU islands, the Mediterranean Sea and all closed seas.

Analysis Approach

Image Pre- Processing

The images obtained from the United States Geological Service Earth Explorer (USGS 2019) were processed using the ESRI ArcMap software. Images downloaded were a group of single band images that needed to be converted into one image that contained all the spectral bands needed for the assessment. First, imagery was converted from JPEG format to IMG files in the ArcMap software. For this process the Composite Bands tool was used because this tool allows for combining groups of single band images into a multispectral image. The composed image resulted in a multispectral image of 13 bands with a cell size of 60x60 and a pixel depth of 16 bit. The images used in this analysis were projected to California Teale Albers with North American Datum 1983.

Normalized Burn Ratio (NBR)

Images of the study area were analyzed using the spectral index Normalized Burn Ratio (NBR). NBR is used to remotely detect change over time, locate burned locations and vegetation growth after a fire. This type of analysis allows to compare pre-fire and post-fire multispectral satellite images to monitor the wildfire's burn scar and calculate changes in vegetation and burn severity. This technique is used to detect, identify and map earth surfaces to observe change in processes (Esri 2019). In forestry the technique is used in fire monitoring to identify delineation, severity, detection, regeneration after wildfires (Esri 2019). This NBR index uses an algorithm that requires a Shortwave Infrared (SWIR) band and a Near-Infrared (NIR) band using a formula. The results of the NBR will have values ranging from -1 to 1, where positives indicate vegetated areas and negatives indicate bare soil or burned areas. When NBR values decline, fire severity increases (Esri 2019). For the purpose of this analysis the technique was applied using the NBR tool in ArcGIS Pro. The tool is in the Imagery tab, Tools group, Indices tools. In the selection the Landscape group will have the NBR tool option. That option must be clicked with the multispectral image selected and it is important to indicate which is the Shortwave Infrared (SWIR) band and Near-Infrared (NIR) band numbers depend on the sensor. The NBR tool will generate an image with the NRB values classification.

Differenced Normalized Burn Ratio (dNBR)

To detect change over time, the Differenced Normalized Burn Ratio (dNBR) was used. This index allows to monitor absolute changes in NBR images before and immediately after the fire. The algorithm uses a formula that subtracts the pre-fire image from the post-fire image. This index will result in values where negative numbers indicate where vegetation in regenerating or was not burned. Positive numbers indicate burned areas or locations where vegetation has not begun to regenerate (Esri 2019). If the dNBR image is classified a Burned Area Reflectance Classification (BARC), a map can be generated that indicate categories of burn severity based on pixel values (Esri 2019). The USGS (2019) has provided an index for the BARC (see table 2). To calculate the dNBR in ArcGIS Pro the NBR for pre-fire and post-fire most be calculated first and use the Difference tool. The pre-fire NBR must be selected, then holding Shift, the post-fire NBR must be selected in that order. While the images are selected, navigate to the Imagery tab. In the Tools group, click process and select Difference. The resulting image will have the values for the dNBR classification.

dNBR range	Burn severity level
< -0.25	High post-fire regrowth
-0.25 to -0.1	Low post-fire regrowth
-0.1 to 0.1	Unburned
0.1 to 0.27	Low-severity burn
0.27 to 0.44	Moderate- to low-severity burn
0.44 to 0.66	Moderate- to high-severity burn
> 0.66	High-severity burn

Table 2: Burned Area Reflectance Classification Index (USGS 2019)

GIS Analysis

Data used in this project was analyzed in ArcGIS Pro using diverse methods. Most calculations where done in the attribute table for each data. Tools that were used include Intercept, Union, Select by Location and Symmetrical Difference. This method allowed for identification of Yosemite National Park as well as the Ferguson Burn Scar area. This detects how much area of the park was burned by the studied fire, as well as other fires in the Yosemite's history. The polygons from the Union and Intersect where used to calculate the Coefficient of Areal Correlation (CAC) or the percent of area that is in common or that overlap between the park and the fire. To measure the error of omission the Symmetrical Difference tool was used. This technique is used to represent the area that is not in common or overlap by the area of the park and the area of the fire. The Select by Location allows to detect spatial relationship between features. This technique was used to detect roads, trails, highways, entrances and fire stations that were affected by the Ferguson Fire. This method also allows to identify the historic fires that occurred in the same area of the Ferguson Fire.

Results

The effects of wildfire on tourism appear to fall within 1 of 2 categories, short-term or long-term. Resulting data from analysis in the form of maps and charts aid in visualization of disturbance to the park and related tourism sectors. First and important to contextualize these results, is fire history within the park and burn severity. Fire frequency has increased in Yosemite National Park as seen in Figure 4. A total of 22 fires affected the park in 2013 including the Rim fire that burned a total of 256,176 acres, about 34% of the total area of the park. The Ferguson fire became the second largest fire in Park's history, burning 94,263 acres or 13% of the total area of the park (Figure 5). The Ferguson fire caused 54% of moderate severity burn directly to the park and only 7% of the area received high severity burn (Figure 6). Other fires have burned the same area of the park before the Ferguson Fire (Figure 2) affecting burn severity. Burn severity values increases if the area has not been burned in a long time (Figure 7). A summation of information generated about the fire can be seen in Table 3.

Analysis	Result
Area Burned by Ferguson Fire (ac)	94,263.37
Yosemite National Park Area (ac)	748,770.50
Percent of Area Burned in the Park	13%
Intercept Park & Fire Bun Scar (ac)	9,111.86
Union Park & Fire Burn Scar (ac)	833,921.97
Coefficient of Areal Correlation (CAC) or Area in Common	1%
Symmetrical Difference or Area not in Common (Error of Omission) in Park (ac)	739,658.60
Symmetrical Difference or Area not in Common (Error of Omission) in Burn Scar (ac)	85,151.51
Affected Fire Stations	1
Historic Fires Overlap with Ferguson Burn Scar 1908 -2017	29

Table 3: Results from the GIS analysis

Short-Term

Tourists mean economic security for surrounding gateway communities. In 2017, Yosemite had 4,336,889 visitors who contributed ~$451,782.00 and ~6,666 jobs to the local economy (National Park Service 2018). In particular, Oakhurst, CA, Bass Lake, CA and Coarsegold, CA were impacted both by proximity to the fire and unpredictability of tourism conditions. This included the expected drop in visitors due to closures, but also included the sudden influx of destination-less tourists who were evacuated from Yosemite Valley. Oakhurst, Bass Lake and Coarsegold were directly impacted in all sectors seen in Figure 8. Data in Figure 8 is derived from 2017, as 2018 data has not yet been published. However, from this we can draw inferences about the economic impact park closures would have on the largest revenue generating sectors. Visitor spending occurs most for hotels at $5.5 billion and restaurants at $3.7 billion, both of which were the main focus of media attention regarding human impacts of the fire (Fresno Bee 2018).

These values are heavily dependent upon peak season, June-September, which was directly impacted. The percent of total traffic that passes through the specified entrances in Figure 9 accounts for a large percentage of annual visitor traffic overall. Calculation of percent of total these peak months account for out of total visitor traffic was determined by summing the annual totals and dividing that total by the total visitors from only the months of June- September. For the South entrance alone, the percent of visitors during peak months in 2017 accounted for 47% of visitors. By 2018, those months only accounted for 39% of the annual total. The Hetch Hetchy entrance percent of total during peak months dropped from 74% in 2017 to 47% in 2018. The Big Oak entrance went from 63% in 2017 to 51% in 2018. To visualize the drop in monthly traffic counts collected annually, Figure 9 was created showing data from 2012 to 2018. This date range highlights the drop in tourists, immediate and subsequent, after the Rim and Ferguson Fires. Also interesting, is that traffic count appears to recover quickly. This is a positive finding and consistent for each entrance (National Park Service 2018a).

Yosemite is #2 in terms of recreation fees collected, only surpassed by Grand Canyon National Park. The most recent data available is from 2014, during which Yosemite collected $18,790 (U.S. Government Accountability Office 2015). Any park closure significantly impacts the National Park Service's ability to operate the park and address Yosemite's $582,670,827 maintenance backlog (Siler 2018). If we took the percent of total calculated from the traffic count data, which would be appropriate as entrance fees are collected per vehicle, the projected loss in recreation fees is staggering.

Long Term

Historic Fires

Using data from the California Department of Forestry and Fire Protection (CalFire), the GIS analysis identified that a total of 29 fires that have burned the same area as the Ferguson fire from 1908 to 2017 (see Table 3). Fires throughout Yosemite's history typically occur on the western portion because of the lower elevation and "light flashy fuels" (U.S. Forest Service 2018). However, the historic data includes burn scars of older fires that have no information or name to ensure the occurrence of such fires (CalFire 2019). To obtain a more accurate result, this study obtained data of the three largest known fires, from which it has been suggested that the Ferguson fire is the second largest fire that has affected the park in history as previously noted (Figure 2). It can also be observed in Figure 5, that these fires have only burned a small portion of the total area of the park. Observing Figure 2, it can be reasoned that these large burn scars covered areas inside and outside the park's boundary. While most of the fires have directly impacted the tree of the four park's entrances, the South entrance has remained untouched by past and recent fires (Figure 2). Only one fire station was directly impacted by the fire. Several more were within a 20-mile radius and could have responded; however, the western side of Yosemite also contains large swaths of inaccessible terrain complicating the ability to respond for all fires in this area.

Burn Scar

The NBR analysis from the pre-fire image and the post-fire image allowed to identify when the Ferguson fire burn scar became visible. However, this type of analysis does not give values about the area that was burned as it can be seen in Figure 3. For this purpose, an in-depth analysis was made using the dNBR algorithm to identify the burn severity. The USGS (2019) issued a BARC index to classify values for burn severity (see Table 2). Since it has been noted that large fires only affect a small area of the park directly (see Figure 2), specific values were used to obtain accuracy. In Figure 6, the burn severity values of the entire burn scar were compared to the burn severity values of the part of the burn scar that directly affected the park. A small portion of the Ferguson fire directly affected the park, however, this portion received 54% of moderate severity burn, 32% of low severity burn and 7% of high severity burn (see Figure 6). This analysis also detected low values that are classified by the BARC index as post-fire regrowth, however, the difference between both analyzed images is only of 1 year. Additionally, burn severity values for each of the largest fires were compared in this analysis (see Figure 7). It must be noted that values differ by the burn scar size of each of the fires. In comparison to the Ferguson fire, burn severity values for the Rim and Ackerson burn scars identified areas with post-fire regrowth that are clarified by the fact that few years have passed after these two large fires allowing vegetation to regenerate (see Figure 7). The analysis also demonstrated that all the large fires burn scars presented values for low, moderate and high severity burn, indicating that the Ferguson fire burned areas that had been affected by these past fires. It is after all the natural fire regime for the Yosemite National Park's ecosystem (Yosemite Mariposa County Tourism Bureau 2019). Which means wildfire has been and will remain an issue requiring constant attention from Park officials.

The picturesque nature of the park is experienced by car, but primarily through trails. Yosemite has 20 miles of paved walking and bicycle paths, as well as 800 miles of hiking trails (National Park Service 2018b). No major trails were directly impacted, as a majority the most popular trails (Half Dome, Clouds Rest, Mist Trail, Nevada Falls trails) are in the eastern portion of the park in higher elevation near stunning granite formations. The fire did cut access to other trailheads, while air quality hindered hiking for the duration of the fire (Wawona Meadow, Chilnualna Falls, Biledo Meadow, Wawona Swinging Bridge trails). The scenery of the smaller Alder Creek trail and Bishop Creek trail were burned, impacting the entire south fork of the Merced River (Figure 1). Trails along the south fork of the Merced River and other small tributaries are prone to fire due to the "light flashy fuels" mentioned previously (U.S. Forest Service 2018).

While the cause of the fire was noted as "unknown" by official sources (U.S. Forest Service 2018), Wikipedia lists the cause as sparks from a catalytic converter. We include this simply for context purposes, as the narrative behind the cause of a fire is important to how it is perceived by the community and was important to how fire was discussed in class. Whether fires were of natural or human causes will be important to uncover moving forward in a time of increasing visitor traffic to Yosemite. Also, important to note is the U.S. Forest Service's acknowledgment of the "abundance of dead material within the live crown of the brush component surrounding the fire area" and the "significant amount of bug kill timber" referring to tree die-off caused by bark beetle. Long-term mitigation will need to include a continuance and perhaps increase of public engagement and strategic park management.

Conclusion

The closure of Yosemite National Park's Valley floor from July 21st to August 7th was the main factor in what was a slew of impacts that come with intense wildfire in popular tourist areas. The impacts, short and long-term, had local and global effects because of Yosemite is a highly regarded travel destination at home and abroad. Thousands of tourists along with local business owners and residents found themselves in an unpredictable situation for months after the fire began. In the future, businesses in the gateway communities who typically sustain themselves throughout the year with revenue generated during peak season may find themselves in a continuous state of economic recovery (U.S. Forest Service 2018). Should fires of this magnitude continue as suggested in Figure 4, the compounding effects of scarred vegetation, declining fee collection and visitor spending will impact Yosemite's ability to accommodate the National Park Service's mission, as well as the local tourism economies. On a positive note, visitors appear eager to continue traveling to Yosemite regardless of fire. What remains to be seen is if and when there is a breaking point, at which time increased tourism and increased fire will prove too much for the park. Burn scars in the Yosemite Valley and the surrounding open forest are a visual reminder of a tourism industry that is both literally and figuratively, on fire.

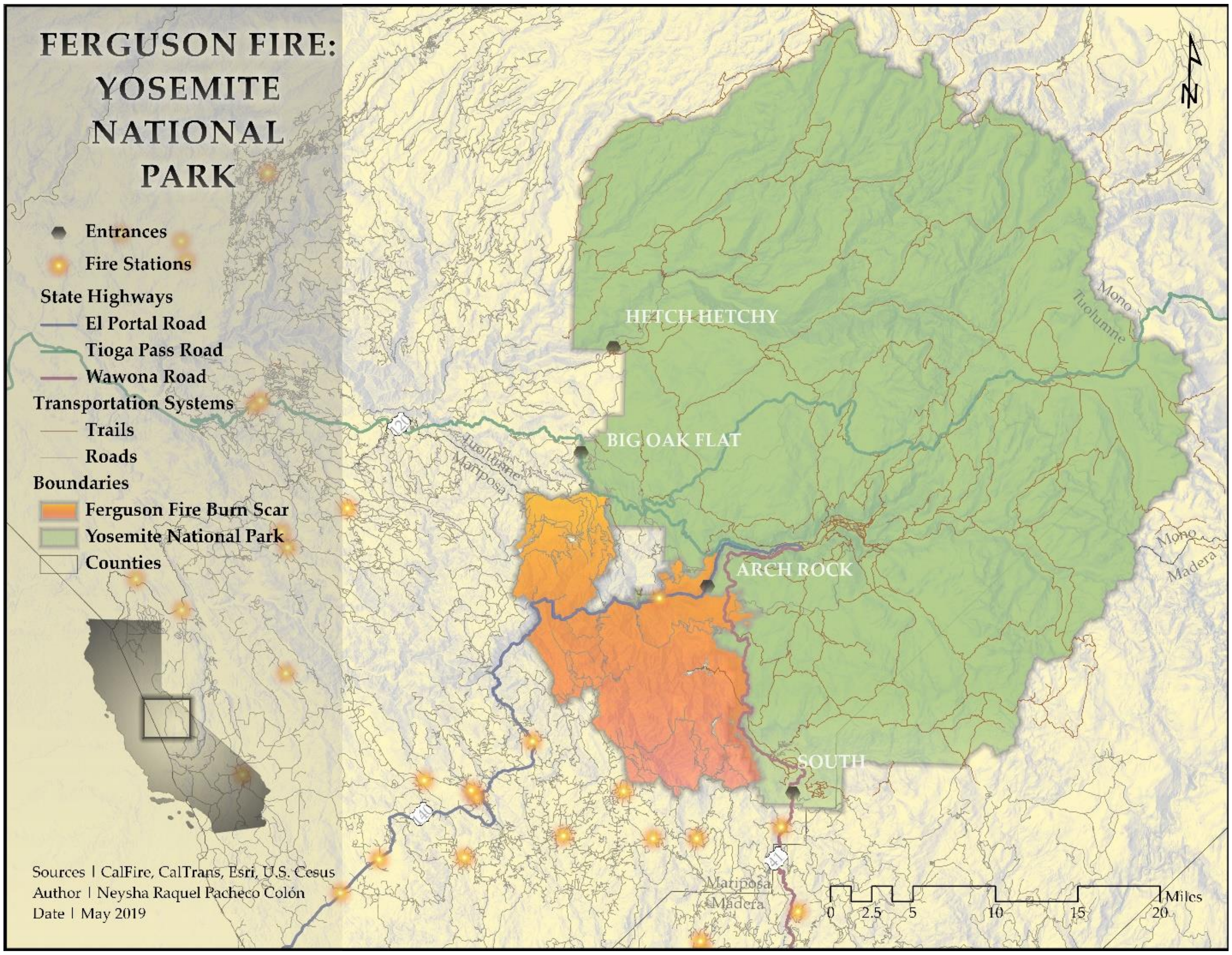

Figure 1: Ferguson Fire effects of Yosemite National Park.

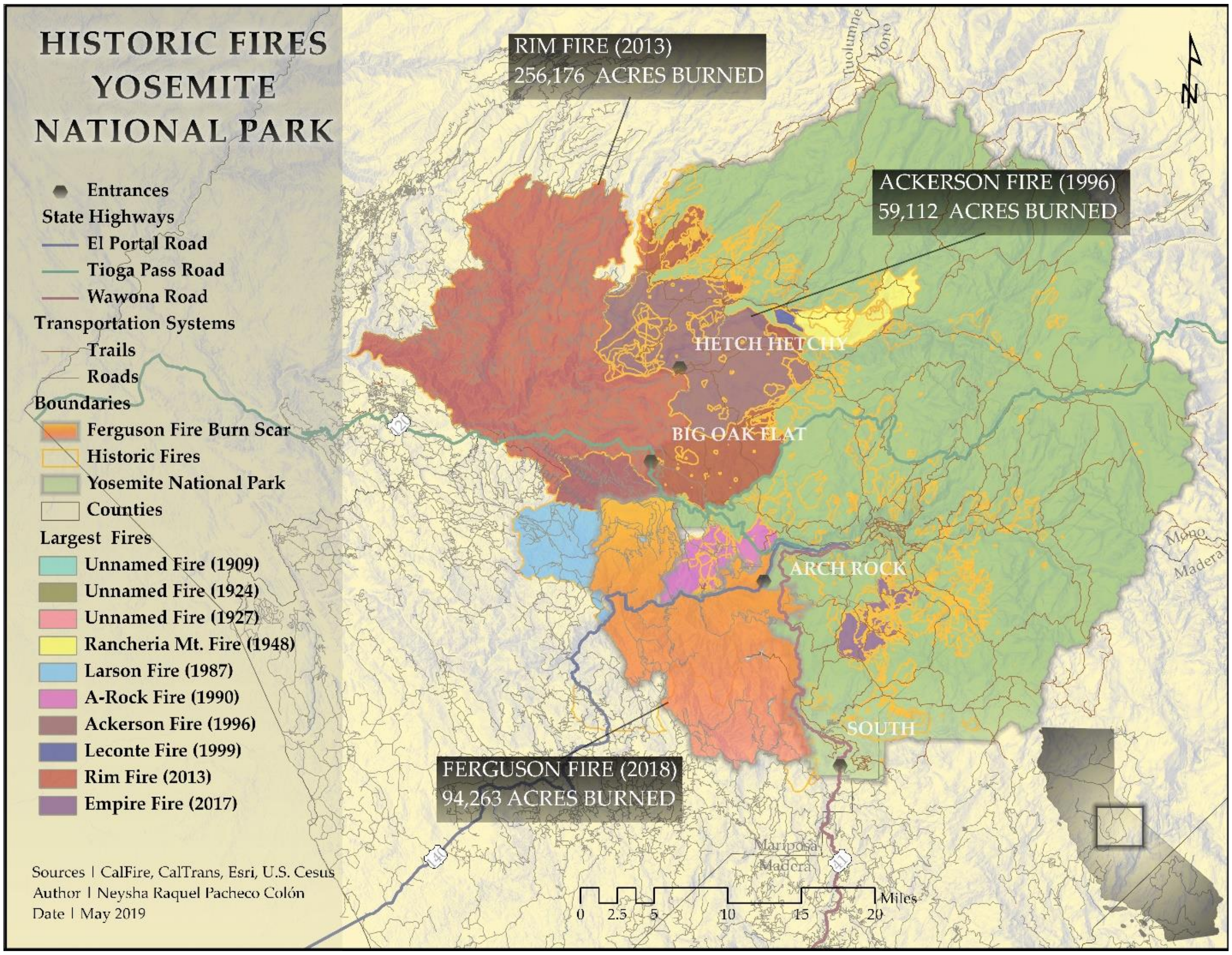

Figure 2: Largest historic fires that have affected Yosemite National Park.

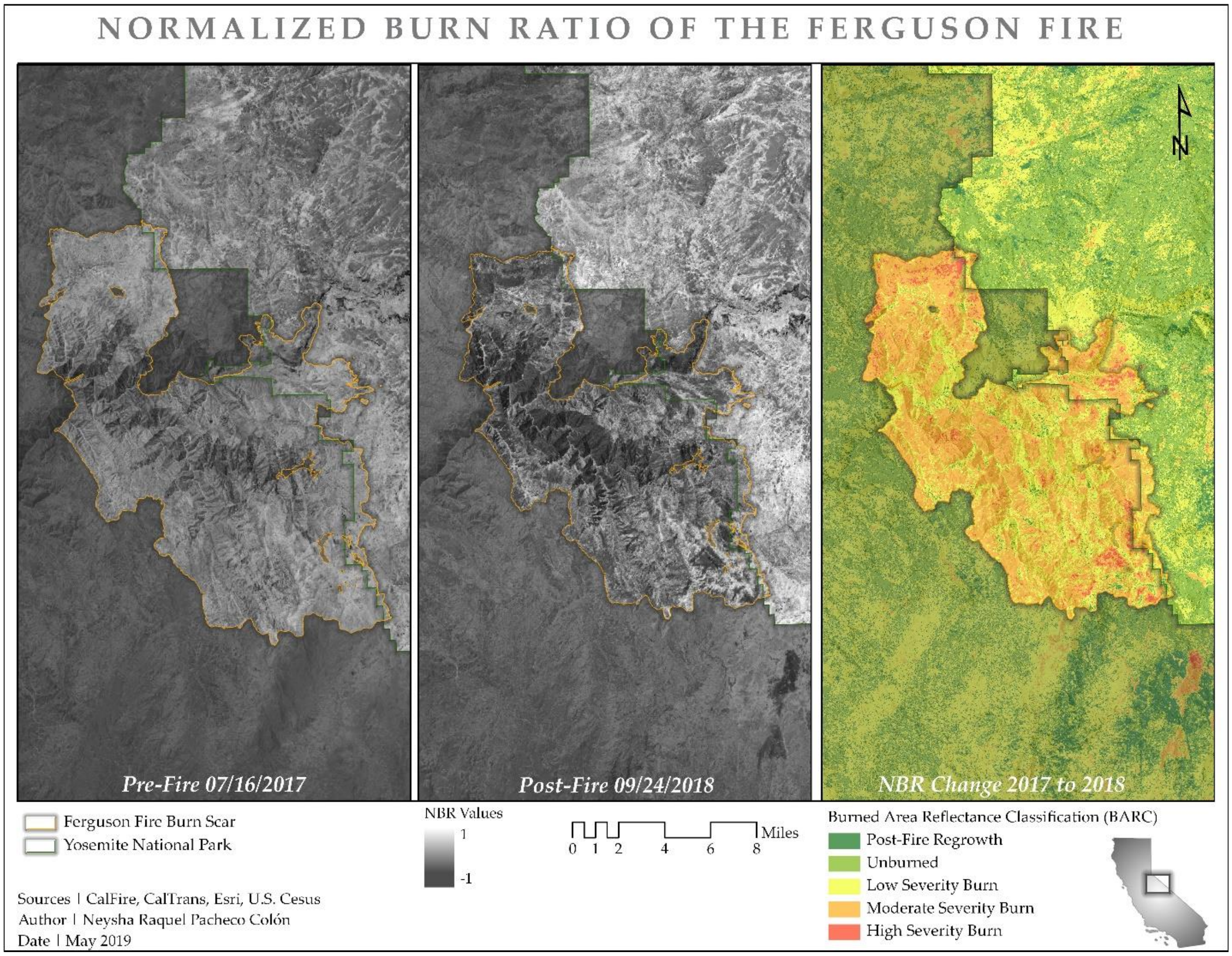

Figure 3: NBR values of pre and post-fire illustrate where the fire scar is located. The dNBR values are classified using the Burned Area Reflectance Classification (BARC) by the USGS (2019).

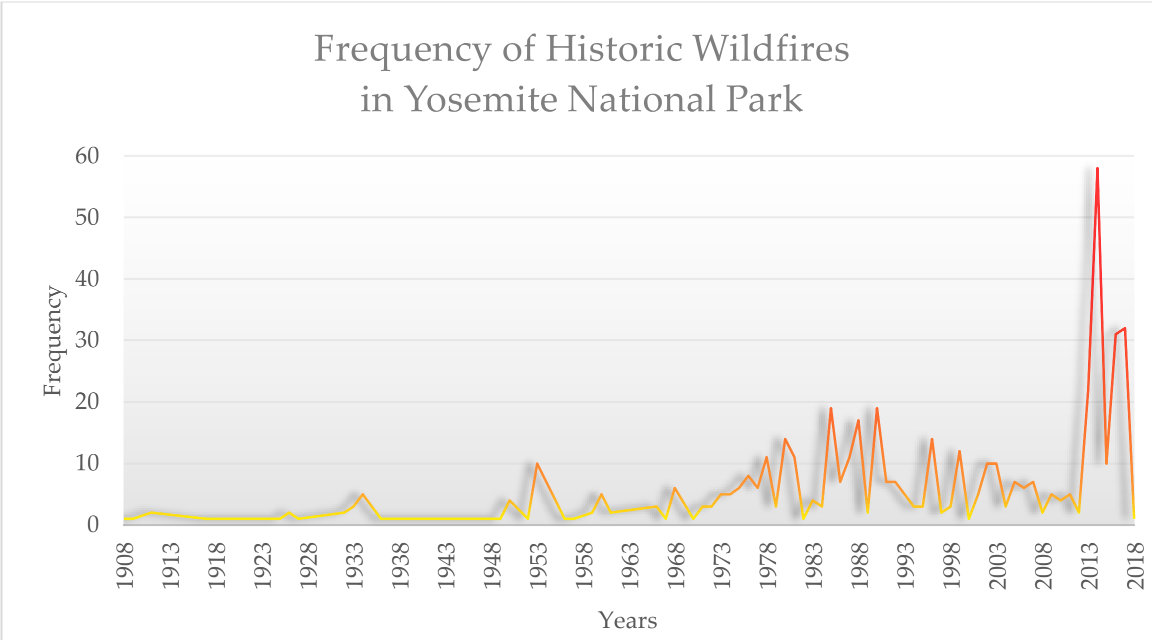

Figure 4: Frequency of wildfires that have affected Yosemite National Park since 1908 (CalFire 2019). The graph shows increase of wildfires frequency in the last decade.

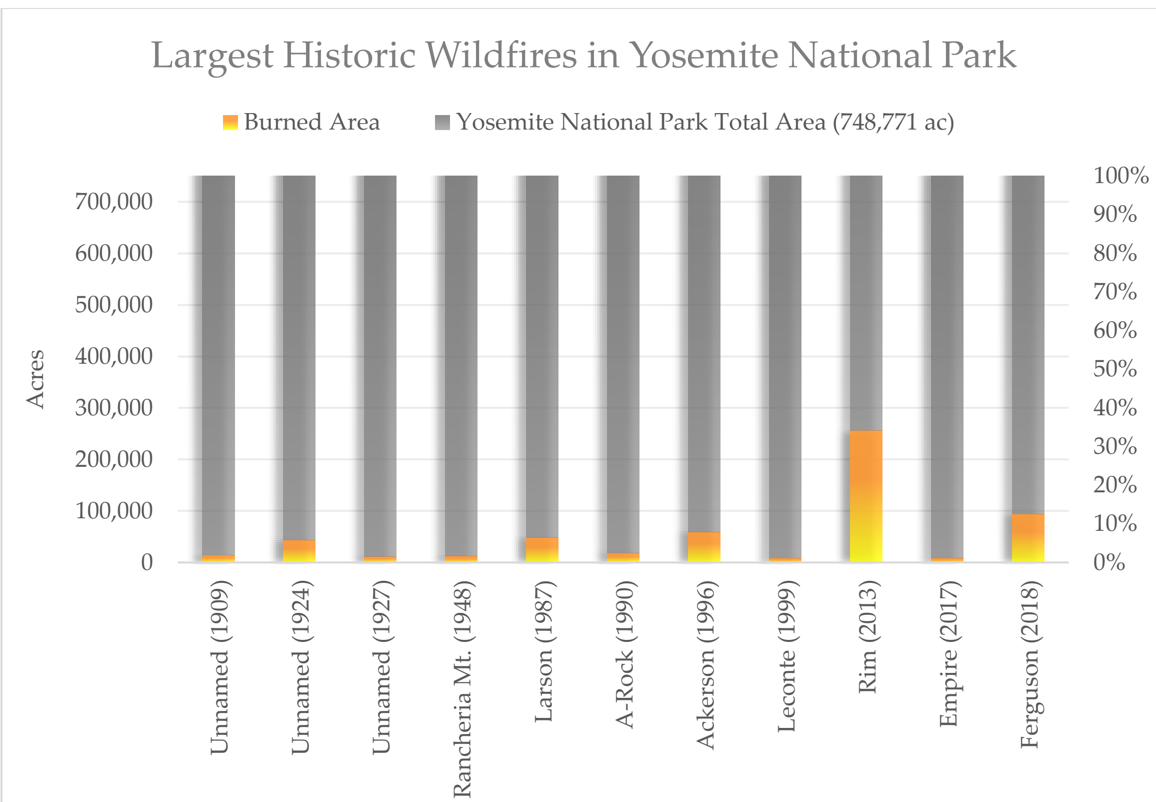

Figure 5: Area that was burned by the largest fires in the park's history (CalFire 2019).

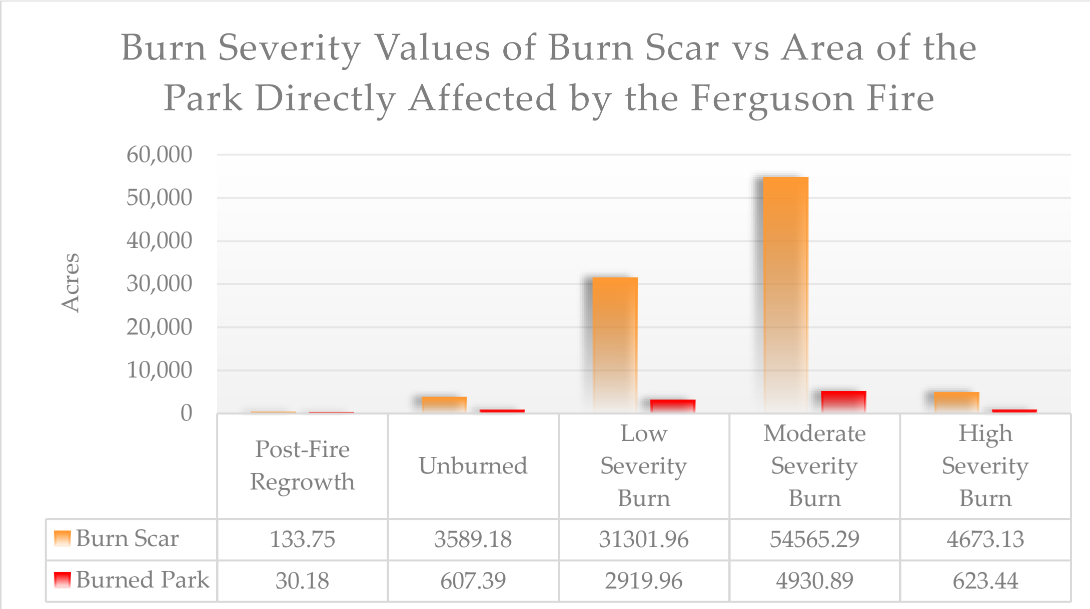

Figure 6: Comparison between the burn severity values of the Ferguson fire burn scar and the area of the park that was directly affected by this fire. This graph shows how much area received each severity value of the dNBR classification.

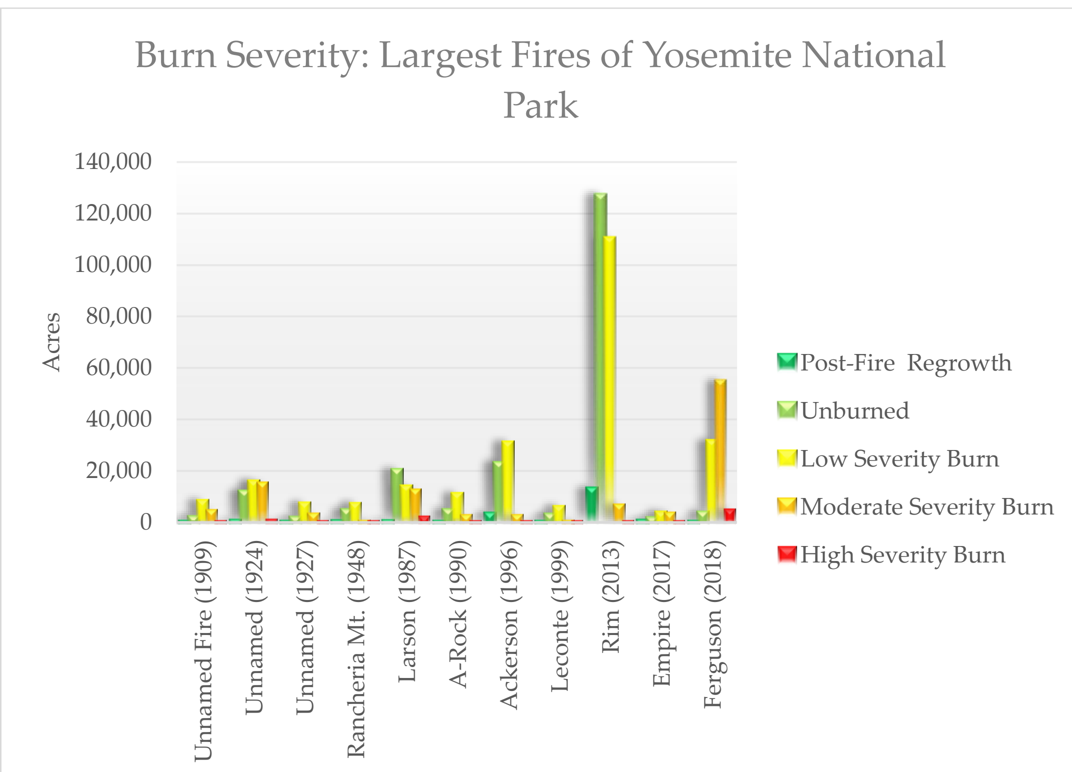

Figure 7: This graph shows dNBR burn severity values for each of the largest fires that have affected the park (CalFire 2019).

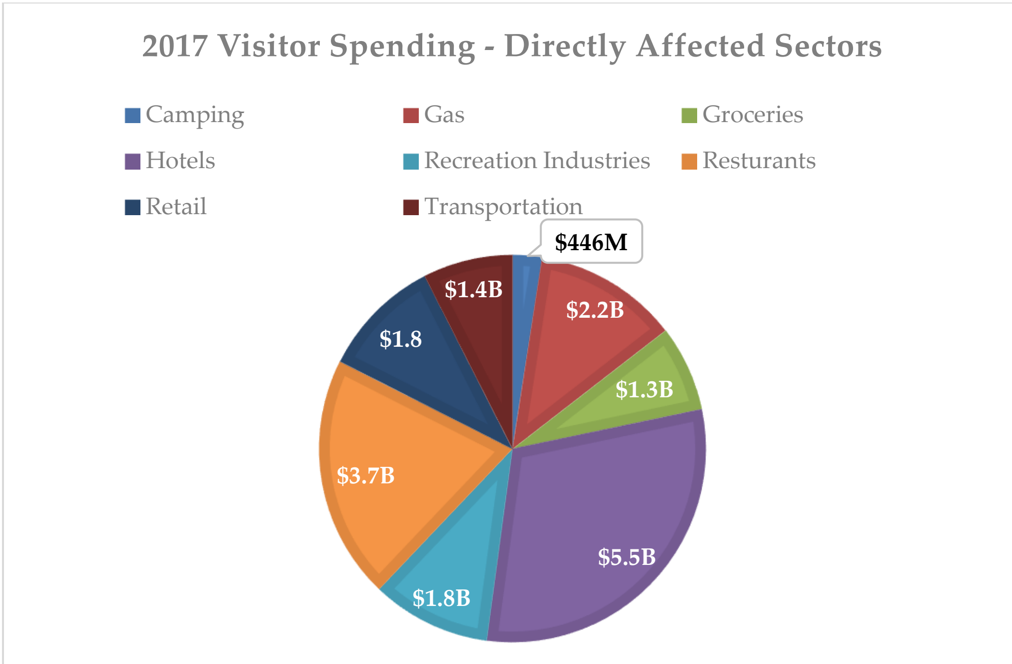

Figure 8: Directly Affected Sensors (National Park Services 2018a)

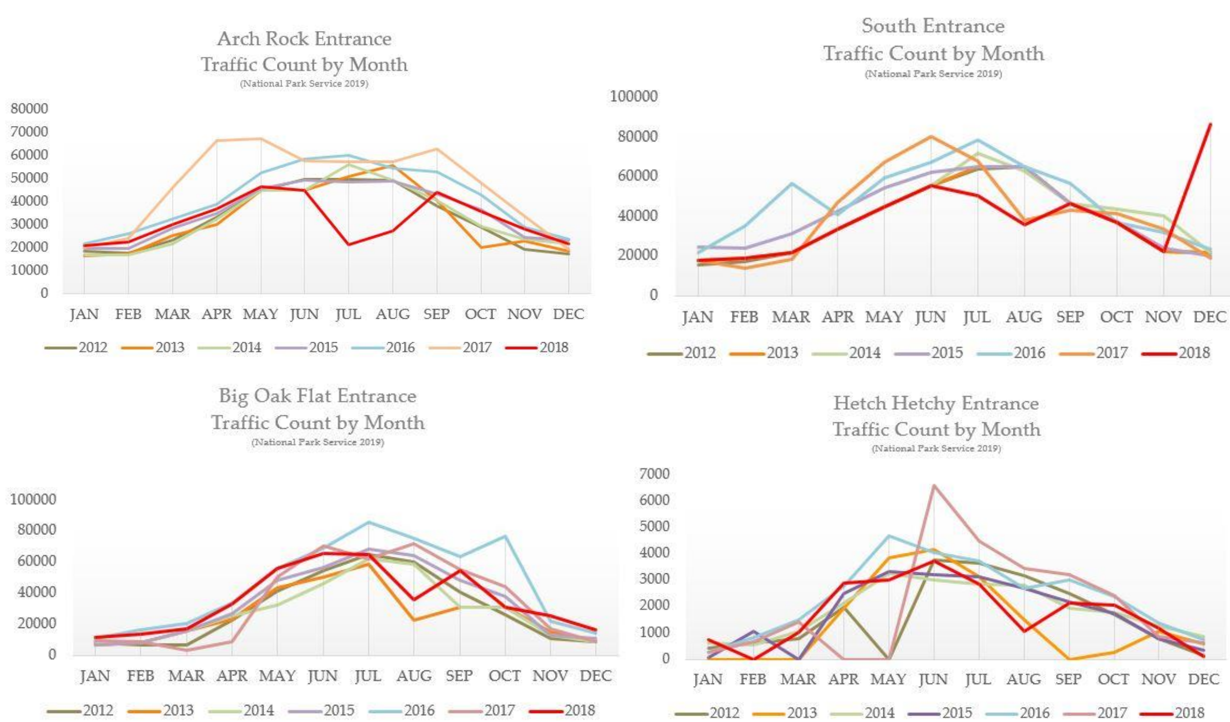

Figure 9: Traffic Count by Month

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