Effects of the 2018 Woolsey Fire

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Problem Statement

Our goal in this project is to analyze the effects of the Woolsey fire on the surrounding Malibu area. We will be doing this through three different lenses: terrain and sloped hillsides, change in vegetation, and effects on residents.

Background Information

The Woolsey fire occurred in Malibu in 2018. It destroyed over 1,600 structures and burned 96,949 acres north of Malibu, California. The fire was sparked on the Santa Susana Field Laboratory property. The fire began on November 8, 2018 and was fully contained on November 21, 2018. Unfortunately, three lives were lost due to the fire and three firefighters were injured during the event.

View from Pacific Coast Highway during the fire

Terrain

One way of analyzing effects of wildfire is by analyzing debris flow. Debris flow includes many types of movement of matter on hillsides, including mudflows, mudslides, and landslides. Debris flow can be very dangerous and destructive, and it is one of the most hazardous results of rainfall on burned terrain. Some of the material that might be found in debris flow is soil, rocks, water, vegetation, boulders, and trees. Generally, the steeper a slope is the more susceptible it is to debris flow. After wildfires, hillsides are often at risk of debris flow due to lack of vegetation and inability of the soil to retain water.

Just a few weeks following the Woolsey fire, the Malibu area saw an intense storm. The heavy rains caused numerous landslide events, particularly affecting canyon areas in the Santa Monica Mountains and in several locations close to Highway 1 and Highway 101. Oftentimes, debris flow can result in infrastructure damage, such as damage to public roads, bridges, drains, flood control facilities, and water supply and sewer facilities, which local governments are required to manage. In one case, a hiking trail in the Zuma Canyon was hit by the Woolsey fire and then suffered from major debris flow, causing 5 separate landslides. Several regions of this trail, the Backbone Trail, had to be rebuilt with bridges. This project was completed in 2022. Landslides can also occur in urban areas, which can cause major damage to residential homes.

Populations

The areas that were evacuated during the Woolsey fire were Bell Canyon, Point Mugu Naval Air Station, Camarillo Springs, Vallecito Trailer Park, California State University Channel Islands, Dos Vientos, Oak Park, Wood Ranch & Long Canyon, Gated Oaks, Monte Nido, Hidden Hills, Malibu, Malibu Canyon, Topanga Canyon, West Hills, Calabasas, Westlake Village, and Agoura.

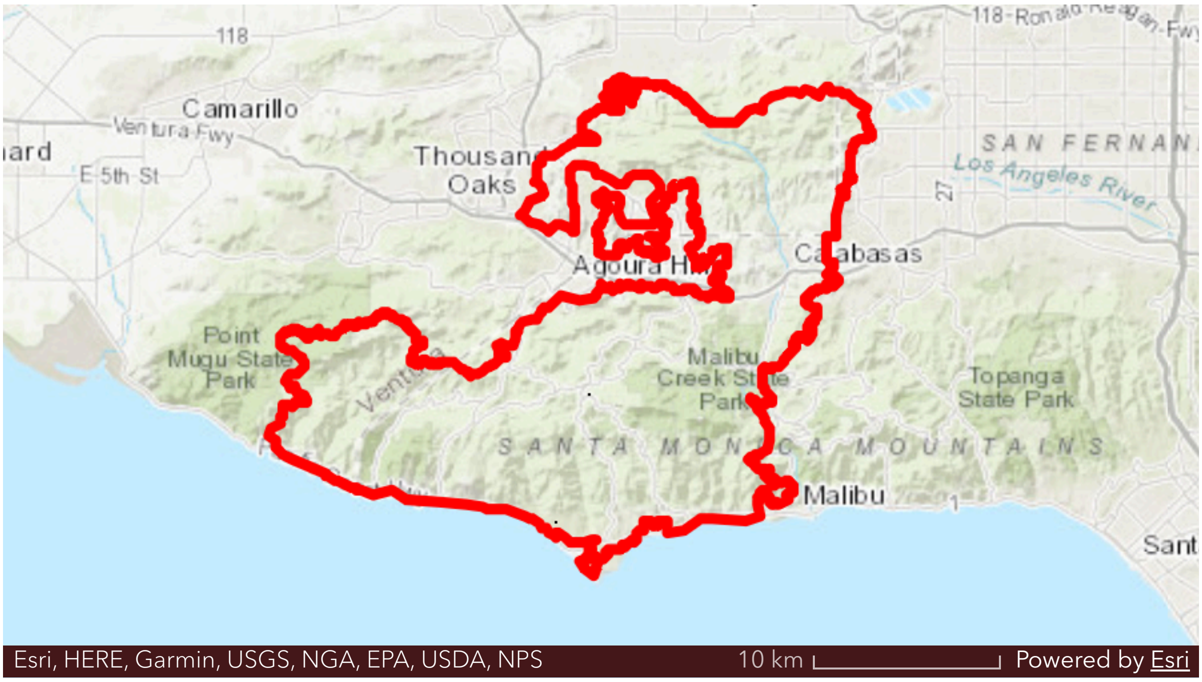
Characteristics of a good evacuation site involves being easily accessible, safe from potential hazards (such as flood zones, fault lines, etc.), designed to handle large amounts of people, and must have resources nearby. Most importantly, evacuation sites must have multiple routes to reach it and be regularly inspected in case of emergencies.

During the fire, there were multiple roadways that were closed, including Pacific Coast Highway, Potrero Road, Highway 1010, Bell Canyon Road & Valley Circle Boulevard, and more. For example, Pacific Coast Highway (PCH) was closed due to impacts from the fire. Work was done to repair the road, including clearing of drainage lines, removal of burned debris, restoration of damaged signs, and placing netting across impacted slopes.

Vegetation

Within the Woolsey fire extent, mainly three forms of vegetation are prevalent: mixed northern chaparral, coastal sage scrub, and riparian. Chaparral contains plants like laurel sumac, chamise, and oaks. Among coastal sage scrub, one can find buckwheats and sages, while in riparian areas trees such as willow and sycamore grow. Chaparral predominates and has the potential to burn easily because of the density and oily species of the plants.

In general, riparian vegetation grows fast and occurs close to water bodies. In contrast, chaparral and coastal sage scrub seem to need several years to regenerate fully. Chaparral, due to its density, is the slowest grower. Coastal sage scrub falls in between.



Map of the Woolsey Fire Perimeters (From: Woolsey_VisitMap)

Data Sets

Open Topography Elevation data

This dataset is titled "Post-fire Debris Flows in Santa Monica Mountains, CA 2019" from open topography. This is raster data that comes in the form of .vrt files. This data was collected in 2019 after the Woolsey fire using lidar data collected by the National Center for Airborne Laser Mapping. The data only covers a portion of where the Woolsey fire burned, only about 60 km^2 near Zuma Creek. The projected coordinate system is WGS 1984 UTM Zone 11N and the geographic coordinate system is WGS 1984. This elevation data will be used to make a slope map using just the terrain and not the vegetation data.

Santa Monica Mountains Local Coastal Program

This data set, titled "Hazards" includes landslide area and liquefaction zones from Santa Monica Mountains Local Coastal Program of LA County in 2014. These datasets are shapefile feature classes in order to display the areas of interest. The projected coordinate systems are NAD 1983 StatePlane California V FIPS 0405 (US Feet) and the geographic coordinate systems are NAD 1984. While we ultimately did not use this data in the spatial analysis, it was helpful to see where potentially hazardous landslide and liquefaction areas would be in the specific area of interest for this project.

Backbone Trail Bridge in Zuma Canyon Closure

While not a dataset, this image was used in order to georeference a landslide event onto the map. This map came from the National Parks Service detailing where the trail closure was in order to build bridges in landslide areas that were damaged after the fire. This image was published April 1, 2022, and the downloaded file format was a ,jpeg.

Cal Fire Historical Fire Perimeters

The data we used from this website is found in the “Wildfire: Fuel, Hazard, and Risk” section. Specifically, we used the dataset “Historical Fire Perimeters.” This data from 2023 provided outlines of fires in California, including the Woolsey fire as shapefiles. The data comes in the form of a geodatabase. This data uses the NAD 1983 California (Teale) Albers (Meters) projected coordinate system and the NAD 1983.

Hill and Woolsey Fires

This data is not actually put into ArcGIS, but rather used as a reference to look specifically at the road closures to trace, along with the location of evacuation sites. It is simply a user-made Google MyMaps published on November 12, 2018.

Census Data

This is 2020 Census data for California from the U.S. Census Bureau. This data did not work properly, so other data was utilized (see below).

NHGIS Data

This data is from 2024 in the form of a Geodatabase. The data is from the website IPUMS NHGIS. This census data did actually work, and it is what we used to add up the population sizes in Malibu (and its surrounding areas). This data uses the NAD 1983 projection.

Landsat 8 data

As a basis for the NDVI analysis (vegetation health), we retrieved Landsat 8 Collection 1 data from the USGS database. We accessed the data on December 5, 2024 AND filtered for relevant acquisition dates pre-fire, post-fire as well as several years before and after the fire. Data from before the fire was necessary to try and set a benchmark of the pre-fire vegetation density may fluctuate from year to year depending on weather conditions.

Landsat Spectral Bands

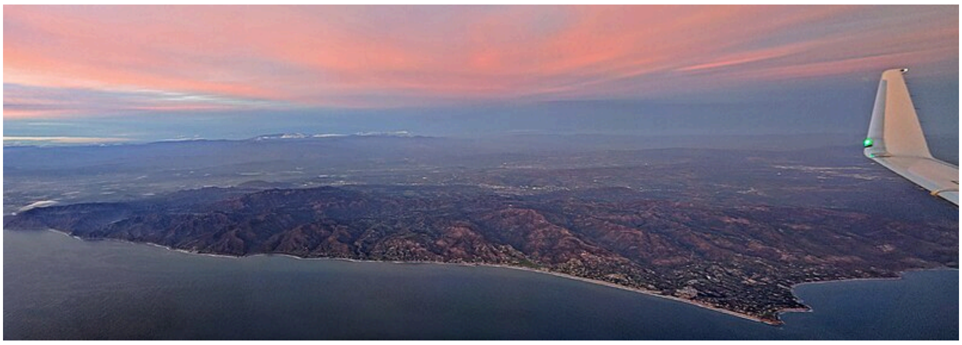
We retrieved data from November 3rd, 2018, 5 days before the fire and for subsequent years data from late November until mid January depending on cloud cover. It was crucial to select data from the same time of the year to make the vegetation status comparable. Also, selecting Landsat data from the same path and row was crucial since the map extent had to be the same. For each acquisition date, we downloaded specific bands of the satellite data. Bands 4 and 5 were used to calculate NDVI, since band 4 reflects from chlorophyll during photosynthesis and is hence crucial for determining vegetation health or density. Band 5 is near infrared and reflected by inner leaf structures of plants.

Normalized Burn Ratio

We also downloaded band 7, which corresponds to the shortwave infrared 2 spectrum. It is used to detect the moisture content in vegetation and soil. We used it to calculate the normalized burn severity (NBR) within the fire extent. Ultimately, however, we focused our analysis on vegetation recovery and did not include burn severity in the results.

Creating a Hillshade

Furthermore, we downloaded a 90m digital elevation model of California in order to create a hill-shade useful for highlighting vegetation (non-) recovery relative to slope. Also, a hill-shade made it easier in general to see relevant pixels in our case. We retrieved it from databsasin.org. It is based on SRTM data sets resulting from a collaborative effort by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency.



Burn Scar from Woolsey Fire

Methodology

Landslide Map

Our first step in analyzing the terrain was researching debris flow following the Woolsey fire. After researching and collecting datasets, we uploaded many into ArcGIS. Unfortunately, most of them were unusable. Some of the data we attempted to use included post-fire satellite data from Maxar, hazard zones from Cal Fire, hazard zones from Santa Monica Mountains Local Coastal Program, and moisture index data from Sentinel-2 L1C from the Copernicus. One data set that was particularly useful was elevation data from Open Topography. After importing this layer, we used the “Slope” tool in order to create a layer that displays the slope of the hillside for any given area within the region. We used the stretch effect in the symbology panel in order to create the given effect. We also applied the stretch effect to the elevation layer, made it transparent and gave it a color gradient in order to layer on top of the slope map. However, there were so many elements that we ultimately didn’t use it on this map in order for a clear final result. We attempted to find interesting data to use with the slope layer, such as soil data for a soil analysis, however there wasn’t any available for the area of interest on this map. So, we ended up researching individual landslide events to mark on the map.

One landslide event was on Backbone Trail in the Santa Monica Mountains National Recreation Area. To find the exact location, a .jpeg from the National Park Service was imported and then georeferenced to the base map projections. About 20 reference points were made and it used a 3 dimensional analysis. After this, a new line feature class was made in the geodatabase to trace where the landslide occurred. Two other landslide events were found via researching news articles that took place just following the fire during a storm. These landslides took place in more residential areas, and line feature classes were created in order to represent those on their exact streets. After creating these feature classes, we conducted an analysis using the “Buffer” tool in order to find the area within 100 meters of each landslide event. After creating this area for all three of the debris flow events, we used the “Extract by Mask” tool to clip the slope map with the found buffer area for each landslide. This clipping was then used to calculate the zonal statistics in the buffer area using the “Zonal Statistics as Table” tool. Particularly, we were interested in the mean slope to see how the average slopes of the buffer areas differed between landslide events. Once finding this, we added the mean slope to the attribute table of the buffer layer. To complete the map, the landslide events were color coded and a legend detailed in order to explain the phenomena. Other map necessities were also added, such as a title, scale bar, and north arrow

Evacuation Map

First, we gathered and downloaded data, selecting the Woolsey fire extent and major roads in LA using the "Select by Attributes" tool. We identified key points outside the Woolsey Fire area, such as 1163 Sparrow Dr., NAS Point Mugu, CA 93041, and other listed addresses. Using the "Locate" tool, we added pins to the map at these locations. To narrow down population areas, we used the "Select" tool, preferably the lasso, to delete census data around these points. Next, we created a new feature class in the geodatabase named "RoadClosures" under "Catalog." Using the "Edit" tool, we traced roads individually, referencing the map and the "Locate" tool for starting and ending points. We customized road line thickness and color in the RoadClosures layer settings. For the population data, we opened the attribute table for the US_tract_2020_ExportFeatures and used the lasso tool to select areas for evacuation. We added a numeric field named "Evac" to assign evacuation numbers (1, 2, 3, and 4) to selected areas, using our best judgment. Using "Calculate Fields," we ensured the evacuation numbers aligned with their respective sites. We changed the symbology to display unique values, selecting Evac instead of GISJOIN. We summarized the population data (column U7H001) by setting the statistic type to "Sum" and renamed the values 1-4 to represent the population totals for each evacuation area. Finally, we added evacuation sites as a new point feature class to distinguish them from polygons and display them in the legend. These evacuation sites represented the furthest areas outside the Woolsey Fire zone.

Vegetation Map

After gathering the Landsat 8 data, we imported the relevant bands into ArcGis pro. For calculating the normalized difference vegetation index (NDVI), we added bands 5 and 4 of the electromagnetic spectrum. Using the raster calculator tool, we applied the following formula to create the first NDVI layer (pre-fire):

NDVI= (Band5 - Band4)(Band5 + Band4)

We then proceeded to adjust the symbology so that the color grading shows red as negative 1 value and green as positive one. We also adjusted the labeling, imported the Woolsey fire burn extent as an outline and used the extract by mask tool to only apply the data to the fire burn extent. We repeated this step for 2 years before the fire and 4 years after the fire. Due to very dry weather in the 2 years before the fire, the data was not suitable for creating a relevant benchmark since it would have falsified the results. We decided to rely on the data from November 3rd, 2018 as pre-fire status.

Importing the California 90m DEM allowed us to create a hillshade with the respective tool in ArcGis pro. We set the hillshade to partly transparent and added it as an overlay.

We also calculated the normalized burn severity (NBR) according to the following formula after importing band 7:

NBR=(Band5 - Band7)(Band5 + Band7)

Next, we added the NBR layer and changed the symbology to different shades of red. However, for the remaining analysis, we relied on NDVI and changes in NDVI to assess vegetation recovery over time.

In order to classify recovered and non recovered vegetation zones, we first subtracted the respective NDVI layers of later years from the

previous ones to yield the change in vegetation health. Next, we reclassified and thus simplified vegetation health changes into three values.
-1: vegetation health loss

0: no change

1: vegetation health gain

After creating a layer showing vegetation health loss from pre to post fire, we continued only with values 0 and 1 to examine vegetation recovery for the subsequent years.

In order to give 0 and 1 a spatial reference, we applied the following conditional formula to the raster calculator to assign the two values to differences in NDVI:

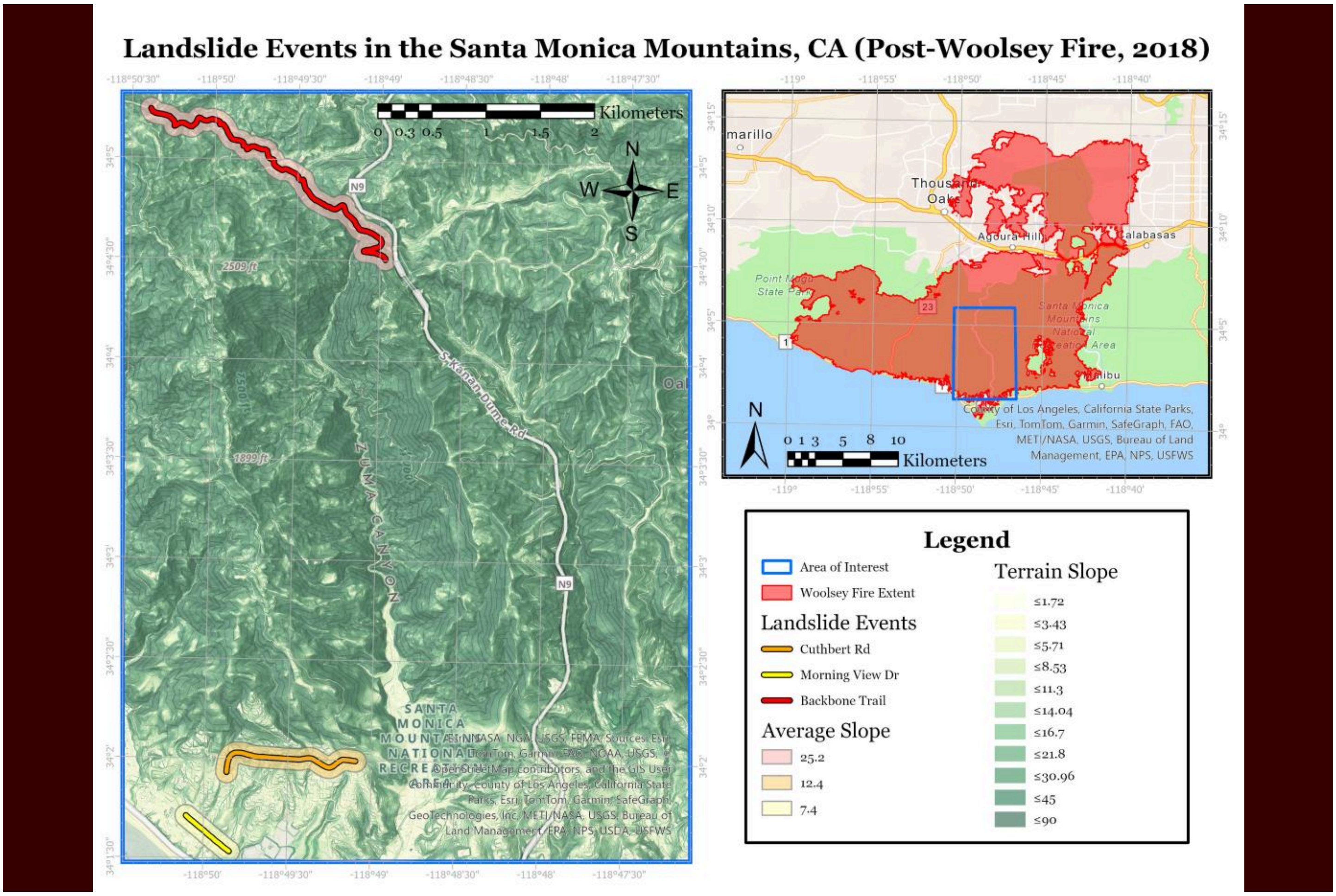
Con((“year_change”>0.9,1,0))

As a result, each pixel showing an improvement in vegetation health compared to the previous year was assigned the value 1, and else a 0 if no change. We changed the symbology to show pixels assigned 0 and 1 in different colors, respectively, to map vegetation recovery in specific areas and to show where vegetation has not recovered.

We subtracted the 2019 vegetation recovery layer from the 2020 recovery layer to show only the additional recovery that had occurred by 2020, since by 2019 already approximately 94% had recovered. In order to quantify the recovery rate within the Woolsey burn extent, we applied the “zonal statistics as table” tool in ArcGis pro. Previously, we had resampled the different data layers so they have an equal pixel size of 30m. We then used the tool to count the total number of pixels within the burn area. We also counted the number of recovered (value 1) pixels within the area and divided the two values to receive the ratio or percentage of vegetation recovery within the burn extent.

Results and Discussion

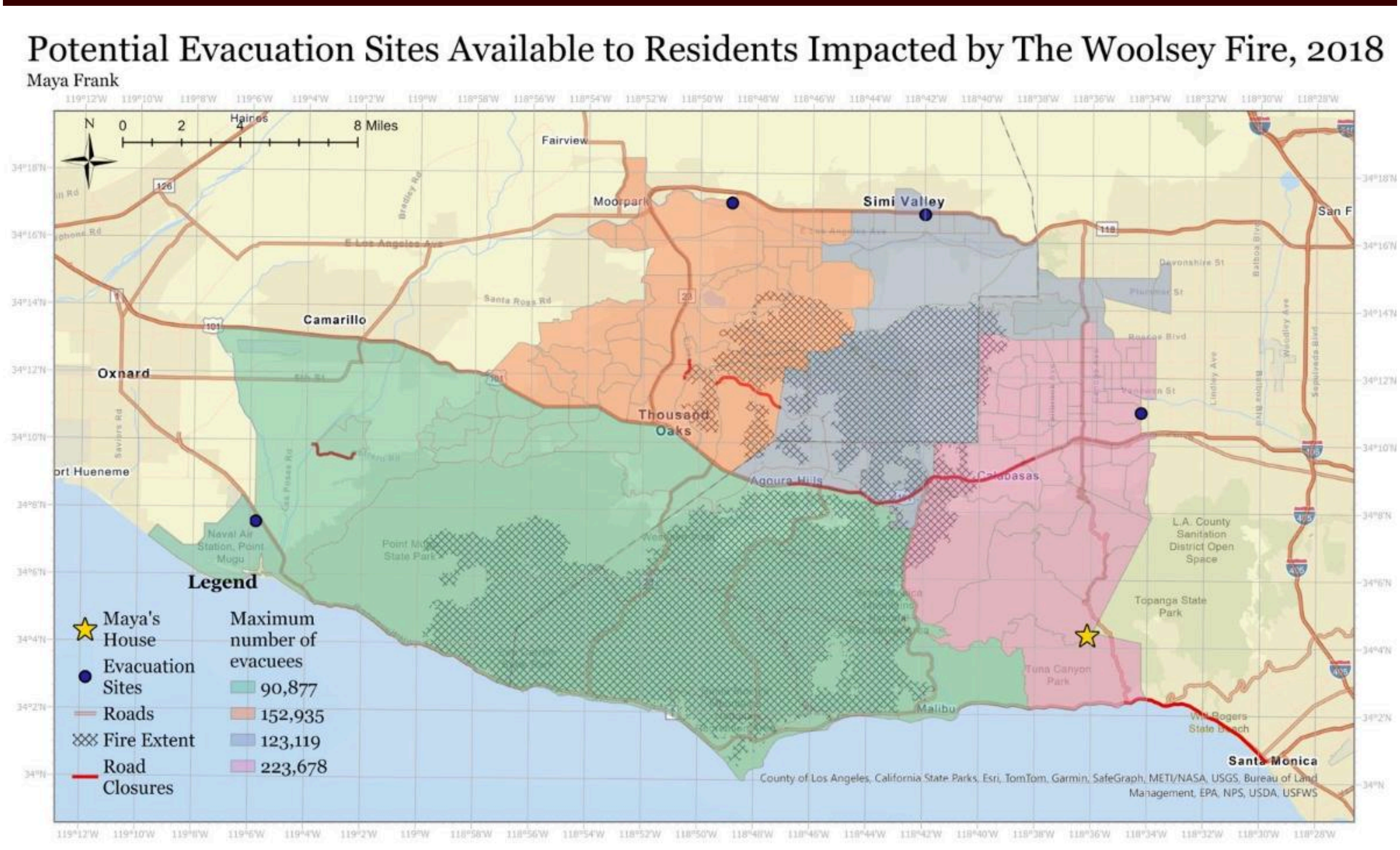
Map 1 - Jazlyn Piera



Based on our analysis, we found that the biggest landslide events are the ones with steeper average slopes. The Backbone Trail debris flow, which suffered from 5 different landslide events, had an average slope value 25.2. This is because the trail is located in the mountain, which was earlier shown to be at a higher risk debris flow. The landslide events with smaller average slopes within the buffer area were smaller in scale, and also in residential vicinities. It is hard to say what kind of damage each landslide event did without actually getting to see them, so they are tough to compare in that sense.

Additionally, an issue we found with this analysis is that most of the reported landslides in local news were surrounding roads or walkways. This is most likely because they are highly used and socially valuable, so they made the news. This method was not successful in finding landslides in rural areas, so the full scale of debris flow within the area of interest is still unknown. However, based on these results, it is safe to suggest that communities and governments continue hazard assessment and mitigation on areas with higher average slopes. This way, if there is surrounding infrastructure, it can be protected. Should this analysis be conducted again, we think more research and data could be gathered to find all landslide events to get a better understanding.

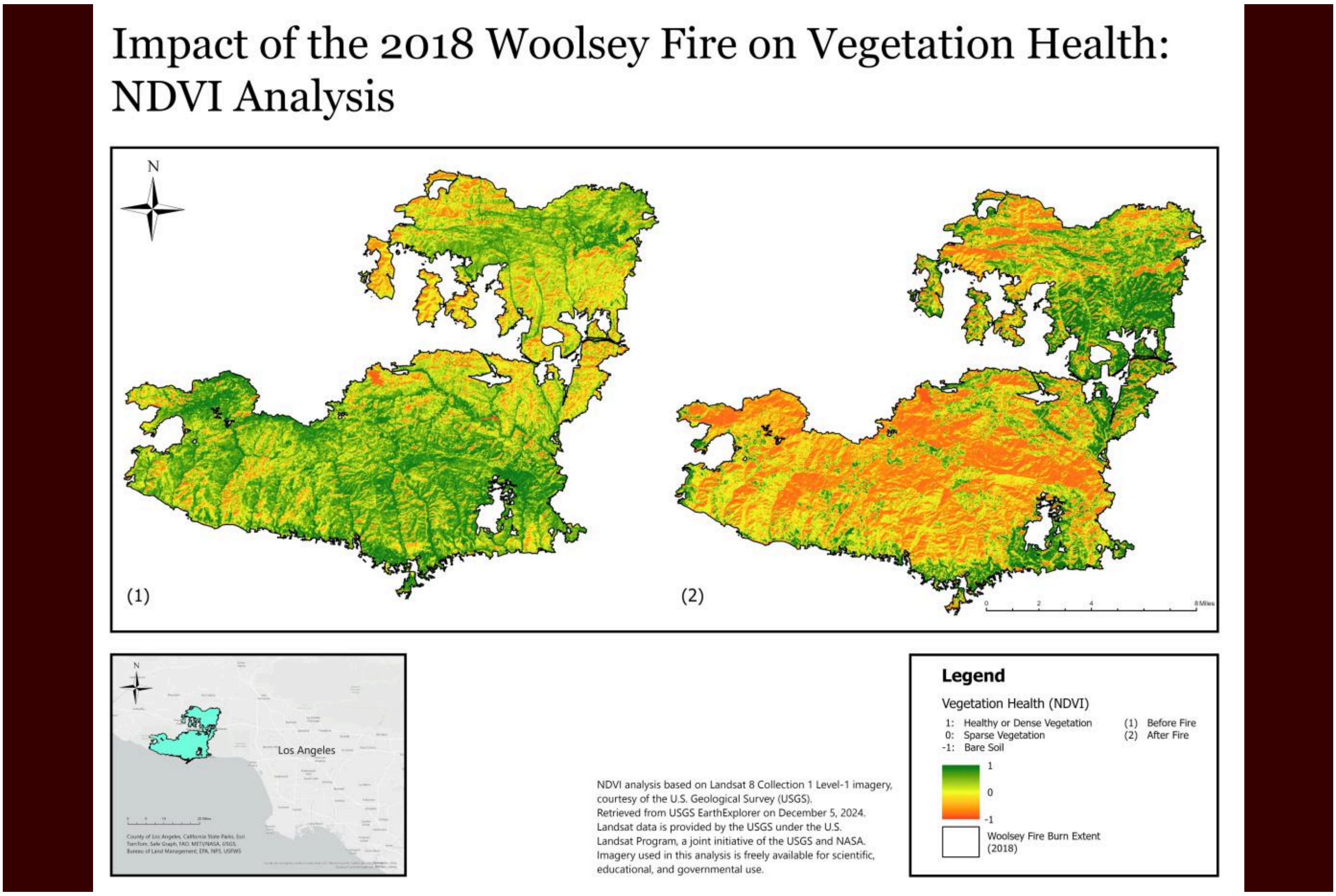
Map 2 - Maya Frank



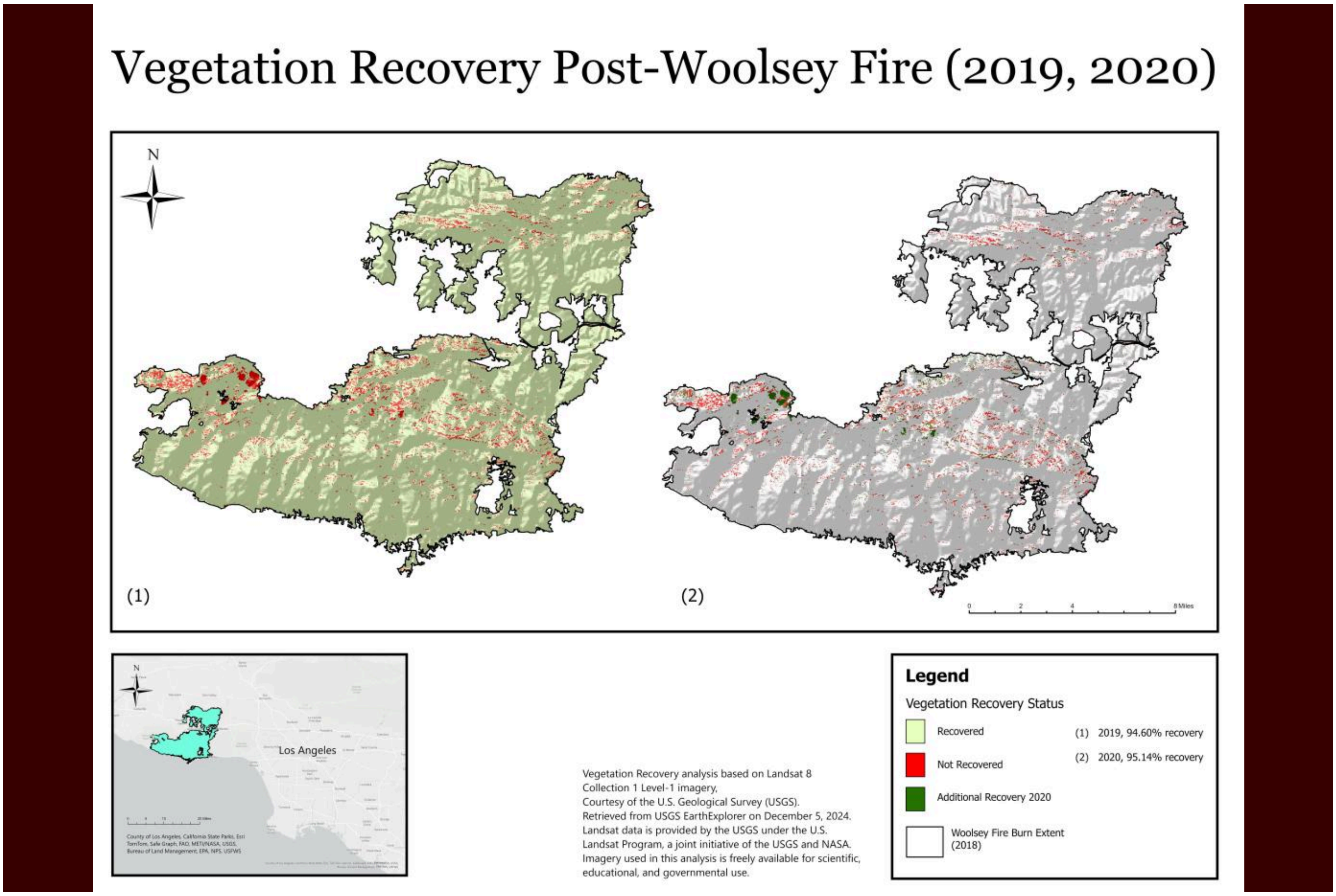
With the information from the map that we currently have, it can be assumed that the areas with the highest populations (Topanga and Calabasas with 223,000 residents) may need better evacuation roads to rely on since there are two largely used main roads that were closed. The lowest population density happened to be near state parks, and there were no significantly impactful road closures. The main point of concern is the fact that the most densely populated areas were impacted by the largest road closures.

Something we would do differently if we were to repeat this project is potentially measure the distances from each area (or at least bigger, key areas) to make a more accurate assumption of which evacuation site is closer to the home of the evacuees, rather than guessing. We could also do more research on the road closures to see how much of an actual impact it would have on residents needing to evacuate. In Maya's experience, although her main road was closed, she still had ways to evacuate down the mountain, but we would like to know if that was specific to her and there were potentially people who couldn't evacuate in that area.

Map 3 - Micha Goll



The analyses of pre and post fire difference in vegetation health (NDVI) as well as vegetation recovery rate from 2018-2020 revealed that roughly seventy percent of the vegetation within the area of the Woolsey fire changed to sparse vegetation or almost bare soil. Also, the results give the stark impression that vegetation suffered more on hillslopes as can be seen thanks to the hill-shade layer. Fire spreads faster uphill since heat rises. For every 10 degree slope increase, the fire spread approximately doubles. Also, on hills, flames are closer to the ground, transferring greater heat to vegetation and the ground. After the fire, slopes are subject to greater erosion, delaying vegetation recovery.



It was impressive to see how 94.60% of the vegetation could be classified as more or less recovered after only one year. In 2020, after 2 years, the recovery rate had risen to 95.14%.

Looking at the spatial data, the unrecovered areas after 2 years mainly remain on slopes and higher elevation, and very rarely in valleys. This can be explained with the previously mentioned dynamics as well as with generally greater water flow, water accumulation and humidity in valley-like areas .

A significant limitation needs to be mentioned since only one pre- fire status was assessed as benchmark due to the very dry years before 2018. We did not include any further years after 2020, since vegetation health declined after 2019, so we may describe the 2020 status as fully or nearly fully recovered. 95% of the vegetation health recovered within 2 years after the fire, and we have to account for error due to the limited prefire benchmark and slight weather differences when comparing the acquisition month of November for each year.

We conclude the vegetation health difference and recovery study with some key takeaways and practical implications. First, the recovery speed was impressive despite the sheer extent of vegetation loss after the fire. Secondly, sloped areas seem to struggle with vegetation recovery.

One should monitor specific plants predominately found on slopes and fauna partly or fully dependent on them, especially after a recent wildfire. Further research is needed on which vegetation type is most affected in the study area and on how to help sloped areas recover in terms of vegetation health.

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