

# **The Future of Wildfire Risk in the Santa Monica Mountains**

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# **The Future of Wildfire Risk in the Santa Monica Mountains**

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Subject: Geographic Information System, Climate Change, Social Science

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## **Abstract and Keywords**

Wildfire is increasing dramatically in the state of California, and this is simply due to the increase of climate change. By looking at future climate projections in the Santa Monica Mountains and working with the RCDSMM, this research aims to look at conservative, non-conservative, and moderate estimates, and how exactly these future projections of temperature and precipitation changes intersect with the human and natural elements in the urban landscape. This research will also be taking into account the IPCC projections for global warming, and will assess how the risk of wildfires in the Santa Monica Mountains transition based on climate change and secondary effects. Looking at data and various climate models, it will determine the possible future climate projections for the Santa Monica Mountain area, using different weight overlays to see the potential and relative wildfire risk. The key outcomes for the project aim to provide insight into climatological, environmental, and anthropogenic factors in climate change, consolidate relevant scientific literature regarding climate change in the SMM, and consult on the future priorities of the RCDSMM and potential areas of research.

Keywords: Geographic Information System, Intergovernmental Panel on Climate Change, Weighted Overlay, Wildfire

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## **1. Introduction**

This project is a collaborative effort between University of Southern California Geodesign students and the Resource Conservation District of the Santa Monica Mountains (RCDSMM), specifically their Executive Officer and Architect, Clark Stevens. Stevens and the RCDSMM are asking the students to research the specific ways in which climate change will impact wildfire risk and behavior in the Santa Monica Mountains, so that they can better achieve their mission of promoting land stewardship and resources conservation.

Project team members will utilize the UN Intergovernmental Panel on Climate Change (IPCC) 2050 global climate projections, as well as data on the existing land conditions of the Santa Monica Mountains. Findings will be organized in an interactive ArcGIS dashboard and presented to Stevens upon completion. This proposal defines the project research question and approach, cites relevant literature, and outlines the team's management plan.

## 1.1. Research Question

Considering the IPCC 2050 projections for global warming, how will the risk of wildfires in the Santa Monica Mountains transition based on climate change and secondary effects?

Looking at conservative, non-conservative, and moderate estimates, how will future projections of precipitation and temperature changes intersect with the human and natural elements in the urban landscape?

## 1.2. Study Area

The client of the Resource Conservation District of the Santa Monica Mountains (RCDSMM), an organization that promotes land stewardship and conservation across the Santa Monica Mountains in Southern California. The Santa Monica Mountains span multiple counties, over 153,000 acres, and multiple land use types including watersheds, parkland, open space, and urban living areas. The RCDSMM works closely with other environmental and conservation federal and state agencies, community members, and other stakeholders in its implementation of their many services, projects, and educational programs. For this project, the RCDSMM is interested in how different future climate scenarios will affect wildfire behavior in the Santa Monica Mountains of California. This literature review is in preparation for project deliverables that will help guide the RCDSMM's ecological planning and habitat restoration efforts.



**Figure 1:** The district map of the Resource Conservation District of Santa Monica Mountains ([rcdsmm.org](http://rcdsmm.org)).

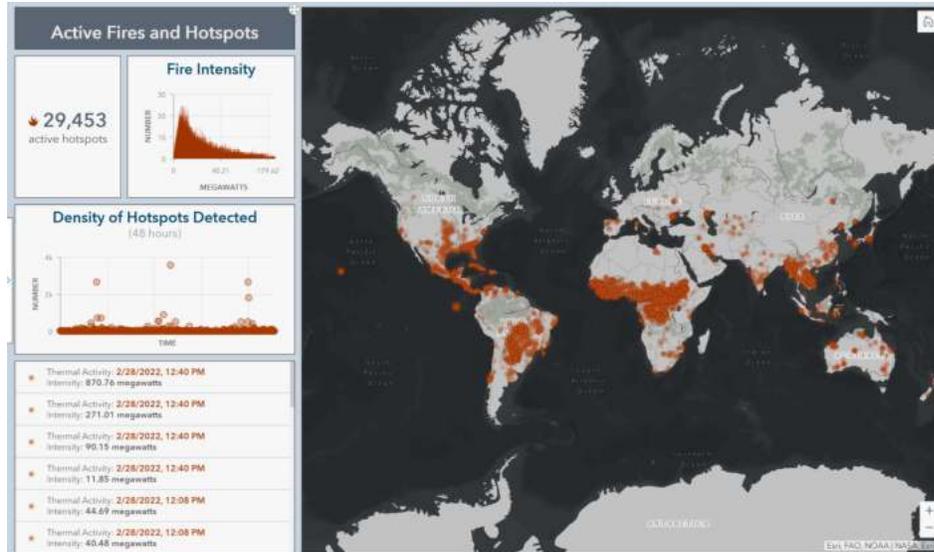
### 1.3. Project Approach

The project approach is to understand the ways in which climate change will affect wildfire behavior and requirements for fire management in the Santa Monica Mountains region. In order to understand this phenomena this project will use the IPCC 2050 climate change projections to present the fire risks due to climate change in these mountains. One goal of the project is to create various scenarios that mimic the conservative, no-change and best case scenarios of climate change in the Santa Monica Mountains. Lastly, this project will create an assessment of the annual rate of temperature change compared to the second degree effects such as human impact and regional ignition patterns.

To visualize the project findings, the ArcGIS Dashboard will contain maps and models of these outcomes. This project will reference other ArcGIS Dashboards to gain inspiration for formatting and representing the effects of climate change on the Santa Monica Mountains.

The ArcGIS Dashboard creates a basemap that overlays vital information on top. For example, the ArcGIS Dashboard titled as *Active Fires and Hotspots Dashboard*, presents thermal activity provided from the MODIS sensor and is a part of NASA's Earth Observing System Data and Information System (EOSDIS). EOSDIS combines remote sensing and GIS technology to form its MODIS global hotspots/ fire locations. This dashboard presents fire statistics such as the Fire Radiative Power intensity attribute and this is a measure of the fire's total energy output in megawatts. This dashboard also included a fire static of the density of the fire hot spots within the last 48 hours.

This project will utilize similar attributes and features from the *Active Fires and Hotspots Dashboard* to explain how climate change affects wildfire in the Santa Monica Mountains. The project's ArcGIS Dashboard will visualize the data of the fire intensity and the data of the density of hotspots in the Santa Monica Mountains. Other elements of the dashboard will feature maps of the four IPCC models which are of the low, moderate, high and very high fire hazard zones. Another section of the dashboard will be the visualization of the historical data of fire zones in the Santa Monica Mountains. Finally, the project's dashboard will include data layers on important environmental features such as sea level rise, the effects on the regional vegetation and the changes in precipitation.



**Figure 2:** Active Fires and Hotspots Dashboard ([ArcGIS](#))

## 1.4. Deliverables

The project is broken down into two main deliverables. Deliverable one is an interactive ArcGIS Dashboard which shows four scenario maps. Deliverable two is a comprehensive report reflecting on the possible scenarios in Santa Monica.

### 1.4.1. Deliverable One

The ArcGIS dashboard conveys information with an interactive map that uses location based analysis. These dashboards aid in making decisions and show trends, tailor to the audience and present real time information/ data. We are able to add charts, figures, links, and multiple maps which would be fully integrated with ArcGIS and data from ArcGIS Online. There is also control over sharing settings of being private or public.

The design idea is centered around simulating, assessing, visualizing, and linking. Simulate conservative, no-change and best case scenarios of climate change in the Santa Monica Mountains. Assess climatological, environmental, and anthropogenic factors. Visualize fire intensity, historical patterns and risk in particular hotspots within the Santa Monica Mountains. Link to other resources to help understand the data and issue of wildfire.

### **1.4.2. Deliverable Two**

Deliverable two's purpose is to help interpret weighted overlays on the ArcGIS dashboard; provide insight into climatological, environmental, and anthropogenic factors in climate change; consolidate relevant scientific literature regarding climate change in the SMM; and to consult on the future priorities of the RCDSMM and potential areas of research.

## **2. Background**

Wildfires, and the management strategies required of them, have always been a part of California's populated history. These strategies date back to Indigenous populations in pre-colonization California, whose oral histories of wildfire knowledge and management have endured colonization but not without subjugation by present-day state and federal wildfire policies (Eriksen, & Hankins, 2014). The natural occurrence of wildfires in California's chaparral, oak woodland, and shrubland biomes are perpetually expected, but have intensified in frequency and severity as global climate change exacerbates. According to the California Department of Forestry and Fire Protection (Cal Fire), eight of the state's ten largest fires on record – and twelve of the top twenty – have happened within the past five years. The new reality of wildfires in California created by climate change warrants a thorough (re)evaluation of California's approach to wildfire suppression, management and resilience.

This effort towards wildfire resilience is complicated, however, by the complex nature of wildfire prediction and occurrence. Wildfire risk assessment, management strategies, and economic impacts are highly variable across factors such as vegetation cover, urban context, topography, and microclimates. Methodologies such as geospatial technologies, information sciences, and Carl Steinitz's Geodesign Framework are important tools that can be implemented in the construction of solutions to these innately complex environmental problems.

Wildfire behavior is strongly influenced by temperature, soil moisture, and vegetation, which all will be affected as climate change creates warmer and drier conditions (Center for Climate and Energy Solutions). Historically, most wildfires in Southern California occur in autumn due to the season's Santa Ana winds, residual high temperatures from summer, dried out vegetation, and low soil moisture (Yue, Mickley, and Logan). California's low levels of precipitation also correlate to the state's high fire risk, and this will continue to be true even as climate change influences precipitation patterns.

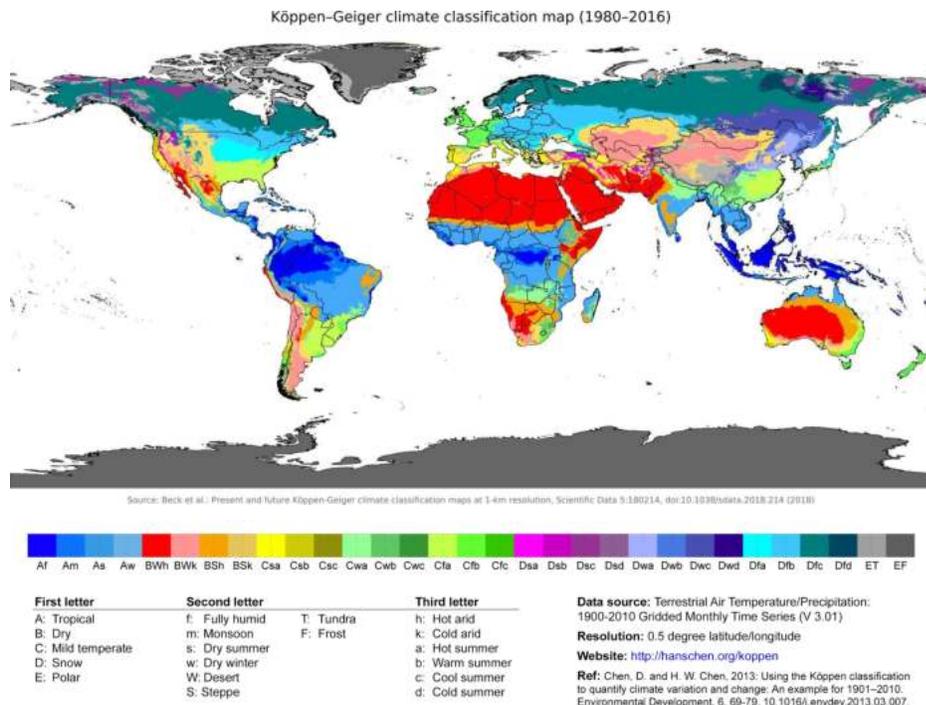
California had more wildfires in 2021 than any other state, with a total of 2,040,600; 9,260 acres were burned, and 2.2 million properties were at risk (Insurance Information Institute). The adaptability of wildfire and its ability to spread quickly makes it a significant threat for the state

and for the Santa Monica Mountains, and this threat will only intensify with the progression of climate change.

## 2.1. Intergovernmental Panel on Climate Change (IPCC) and Köppen Climate Classification

In helping to predict future climate scenarios for the Santa Monica Mountains, we will be using information from the Intergovernmental Panel on Climate Change (IPCC). The IPCC is a United Nations organization that assesses climate-related scientific research for potential climate implications and risks, and provides international political entities with regular updates about those risks. Their reports contain information on short- and long-term climate change projections and associated vulnerabilities. For Southern California in particular, their reports have focused on extreme weather events, temperature change, and drought conditions. The IPCC will be a valuable resource for this project moving forward.

Another valuable tool we will be using is the Köppen Climate Classification, which is a National Geographic system that categorizes areas of the world into one of five main climate zones: tropical, dry, warm/mild, continental, and polar. It is primarily based on temperature and precipitation, which are significant determining factors of vegetation growth and type.



**Figure 3:** Köppen climate classification world map from 1980 to 2016 (National Geographic Society) and classification code (Hans Chen)

Southern California is classified as a dry, Mediterranean climate – Zone B. More specifically, Los Angeles is Zone BSk, meaning it has a dry and cold arid climate with steppe landscape. Other regions of the world in Zone BSk include Northern Portugal, Northwest Spain (A Coruña), and Cape Town. For the purposes of our project, we can look into the wildfire management strategies in these other regions with climate conditions similar to the Santa Monica Mountains. Potential case studies include Portugal’s Portimao City fire of 2018, Spain’s Andalucía fire of 2021, and Cape Town’s Table Mountain fire of 2021.

In terms of fire management, the Portuguese National Fire Control Agency (AGIF) works to educate the public on how their use of fireworks and bonfires could potentially cause a wildfire. They also restructured the country’s fire organization, created a protection action list for residences, and imposed polycentric system of governance which gave authority and resources to solve fire problems locally. Spain’s wildfire management strategies, according to the journal article “Towards a Comprehensive Wildfire Management Strategy for Mediterranean Areas: Framework Development and Implementation in Catalonia, Spain,” include fuels treatments in forestlands to create a fire-resilient landscape with burning, land use, and fuel-breaks, as well as promoting fire-adapted communities. Cape Town has undertaken similar strategies, such as implementing controlled burns and periodically re-assessing maintenance procedures. They have also developed inter-agency programs to manage wildfires, and are focused on maintaining accurate fire history records to track changes over time (South African National Parks).

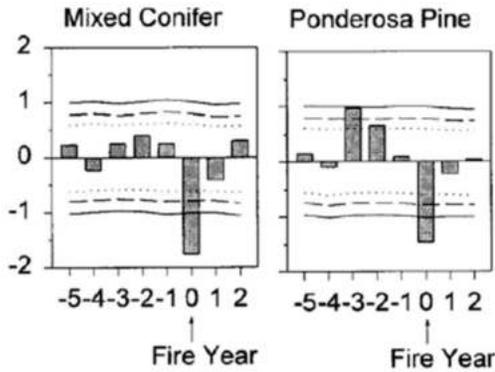
Additional research concerning the impact of climate change on wildfire management involves the use of Geographic Information Systems (GIS), which has already been used to examine wildfire lifecycles, develop strategies, and create response programs (ESRI). The real-time visualization capabilities of GIS enable agencies’ emergency response efforts through seamless data-sharing, communication, coordination, and management strategies (ESRI). It can be used throughout the duration of a wildfire’s lifecycle, allowing for easier fire management and communication with the public.

## **2.2. Temperature and Precipitation in Relation to Wildfire Behavior**

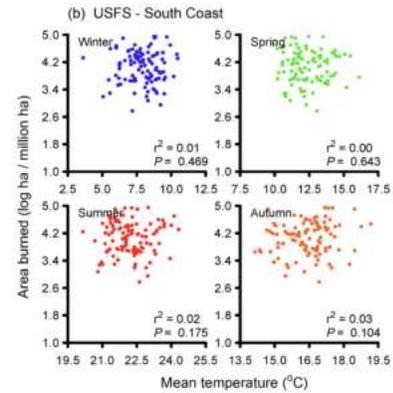
As current literature goes about the relationship between “wildfire regimes,” as they’re called, and climate fluctuations, a lot is inconclusive. Differences in vegetation, spatial and temporal scales, anthropogenic influences, and other confounding variables make this relationship hard to pin down.

Jon Keeley and Alexandra Syphard take a broad approach to this complex relationship in “Climate Change and Future Fire Regimes: Examples from California,” with a particular focus on precipitation and temperature changes. They note initially that warm, dry weather before fire season causes decreased moisture of fire fuels, whereas wetter years

prior to the season cause a greater volume of fuels, both eventually leading to more intense and widespread fires. Fuel moisture and volume each have different relationships to fire season depending on the type of vegetation involved, as seen in Figure 4.



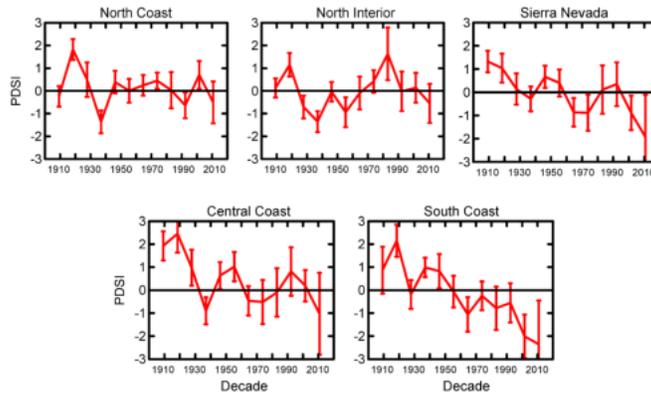
**Figure 4:** Y-Axis is Palmer Drought Severity Index (measure of how wet [positive] / dry [negative] a year is). Preceding wet years lead to a very dry fire year.



**Figure 5:** In Southern California, mean temperature and area burned do not seem to be related.

These weather patterns of wet/dry years are also all related to patterns of El Nino/Southern Oscillation, so understanding these processes will be crucial in addition to understanding drought year patterns as well as temperature change. Keeley and Syphard express that global temperature change due to climate change is generally accepted to be an increase anywhere between 3 to 6 degrees Celsius in the next century, but annual area burned is not correlated with the measure of annual temperature increases. This reinforces that it will be much more important to understand how seasonal climate is changing, as well as the influence on anthropogenic factors, such as ignition patterns, that are largely unaccounted for in studies and modeling. In Figure 5, we see that in studying the South Coast Region, (which includes the Santa Monica Mountains) there is no statistically significant correlation between temperature and fire area burned.

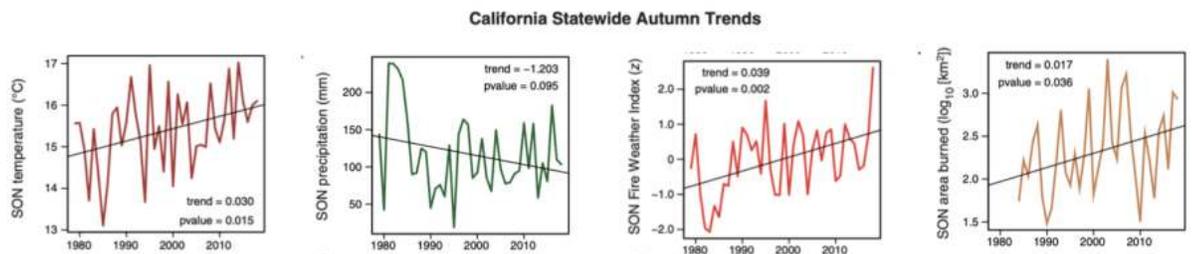
Keeley and Syphard also investigated drought and precipitation patterns and their relationship between climate change and wildfire regimes. Drought's relationship with climate change is difficult to pin down, as some of the world's most intense droughts occurred before anthropogenic impacts on climate, and scientists project anywhere between a 5% increase or decrease in precipitation in California by the year 2060. Figure 6 communicates that, according to the PDSI reading of droughts, the South Coast region (Southern California) has certainly become drier in the past couple of decades.



**Figure 6:** The severity of drought in the South Coast Region (which includes Santa Monica Mountains) has increased in the past few decades, coinciding with more severe wildfires.

However, even if climate change causes precipitation to increase, increased temperatures will still lead to higher water stress and have effects on evapotranspiration. These climate impacts on vegetation profiles and human behavior may be more important to study in relation to fire than their direct impact.

In their paper “Climate Change is Increasing the Likelihood of Extreme Autumn Wildfire Conditions Across California,” Michael Goss and his colleagues examined the connection between weather and extreme autumn wildfires in California. Wildfire season in California is known to be affected by atmospheric temperature, snowpack, and precipitation. Climate change will contribute to aridification across the state, leading to warmer springs and summers, less precipitation, and earlier snowpack melting—all of which increase the risk of large wildfire events in the future (Goss et al., 2020).



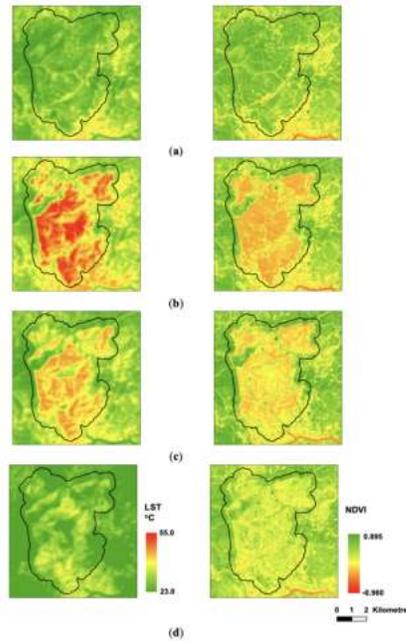
**Figure 7:** Observed state-wide trends in autumn climate and area burned over California in September through November (SON).

Such changes have already been observed. Goss (2020) found a statistically significant trend toward autumn weather that is increasingly conducive to wildfire risk in California, including temperatures increasing by 0.3°C per decade and precipitation decreasing by 12.03mm per decade, between 1979 and 2018. Figure 7 shows these historical meteorological trends, as well as increasing Fire Weather Index and total area burned

during fire season. Climate change is going to worsen these trends and extreme fire weather conditions will become much more frequent throughout the state, even if the Paris Climate Agreement is strongly adhered to (Goss et al. 2020).

One final article explored was Lidia Vlassova’s investigation of wildfires via remote sensing in “Analysis of the Relationship between Land Surface Temperature and Wildfire Severity in a Series of Landsat Images.” Although the study area takes place in a different Mediterranean climate zone (Spain), the methodologies of investigating Landsat data to see the impact of wildfire on land surface temperatures could be supplemental to investigating the fire-drought-climate change feedback loop introduced in the Littell article. As Landsat data is available through Esri’s Living Atlas, a similar study of recent Santa Monica Mountains fires could reveal how wildfire is affecting climate in the area, and what areas are most crucial to preventing severe and dangerous fires in the future. Figure 6 shows visualizations of LST (Land Surface Temperature) and NDVI (Normalized Difference Vegetation Index [Plant health]) before the fire and in three summers after the fire.

**Figure 4.** Spatial distribution of LST (left panel) and NDVI (right panel) before the fire event and in the three post-fire summer seasons. (a) 13 July 2009 (pre-fire); (b) 29 July 2009; (c) 16 July 2010; (d) 4 August 2011.



**Figure 8:** The effect of a wildfire significantly changes the patterns of plant health and land surface temperature, even almost two years after the fire itself.

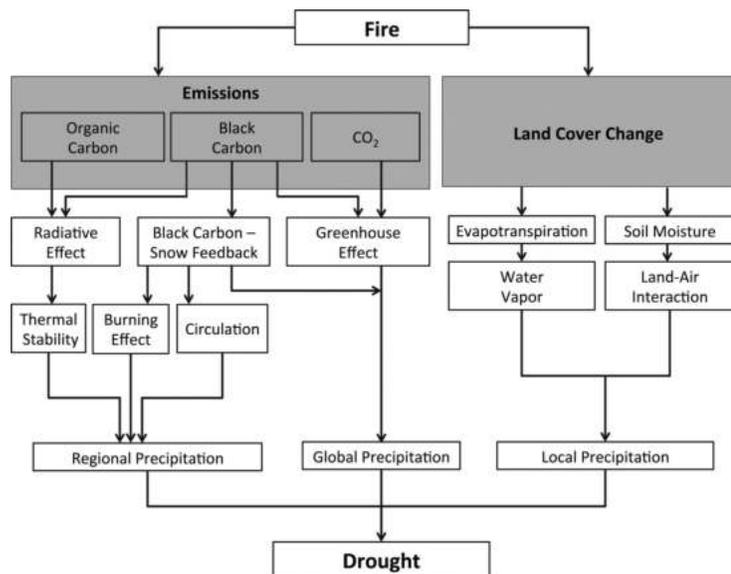
### 2.3. Evapotranspiration and Drought in Relation to Wildfire Behavior

Jeremy S. Littell’s paper, “A review of the relationships between drought and forest fire in the United States,” focuses more on drought specifically, and highlights what indices and data points can be used to investigate precipitation’s relation to changing fire

behavior in different regions of the United States. One interesting effect of extreme drought is that it can nullify other factors that normally protect from intense or widespread wildfire activity, such as moisture on northern faces of mountains. Drought also is directly related to fuel availability (as Keeley agrees), and ignition patterns. Increased evapotranspiration will make drought more common in the summer season, leading to more wildfire activity, and the resulting change in vegetation profile will lead to understory fires being more prevalent and intense.

Various indicators of drought that Littell explores in relation to wildfire are the following: PDSI, SPI, ERC, KBDI, FFWI, and evapotranspiration. Palmer Drought Severity Index, which Keeley and Syphard also explore, is moderately associated with fire occurrence in the Western United States, especially PDSI from the October before fire season. Standardized Precipitation Index (SPI) is also a significant factor for predicting fire occurrence. A 2013 study by Riley et al. reveals that 3-month SPI can account for 70% of the variation in area burned and 83% of the variation of number of large fire occurrences in the Western US. Energy Release Component (ERC) is an index that measures fuel moisture and availability. In Northern California, it correlates with area burned.

The Keech-Byram Drought Index (KBDI) is another drought indicator which correlates positively with fire hazard across most of the United States. Fosberg Fire Weather Index (FFWI) can significantly explain fire occurrences in the Western US. Evapotranspiration, as also emphasized by Keeley and Syphard, has the highest correlation with forested area burned in Southern California. Studying how these factors relate to climate change will be important for gauging how fire intensity, hazard, burn area, and ignition factors will change in the Santa Monica Mountains region. Littell also diagrams the feedback loops of fire occurrence and drought due to the effects of smoke and landscape change, illustrated in Figure 9.



**Figure 9:** Wildfire and drought form a feedback loop, where each can increase the intensity and occurrence of the other

John T. Abatzoglou and Crystal A. Kolden published their study, entitled “Relationships between climate and macroscale area burned in the western United States,” in 2013, visualizing the specific correlations between months in fire season, climatological factors, and increased burn areas. This article provides lots of information for the southern half of California, showing much more intense correlation between these factors (temperature, precipitation, evapotranspiration, etc.) in forested areas. This study reinforces the importance of evapotranspiration, and shows that Southern California is not as directly affected by climate change factors, leading one to believe that the more overarching effects of climate change on fire behavior are more valuable to study. It would be valuable to replicate this study, with the much more homogenous and small study scale of the Santa Monica Mountains. Figure 10 shows that there is a significant increase in ERC (fuel availability and burnability) in the Southern California / Santa Monica Mountain area.

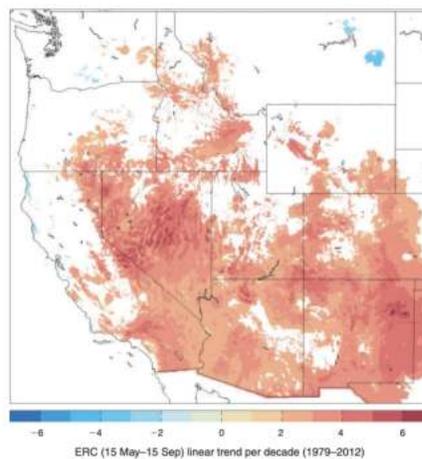


Fig. A3. Map of western United States demonstrating linear least-squares trends of Energy Release Component (fuel model G) averaged over 15 May–15 Sep (1979–2012) expressed in change per decade. Data not exhibiting statistically significant trends at the  $P < 0.05$  are omitted.

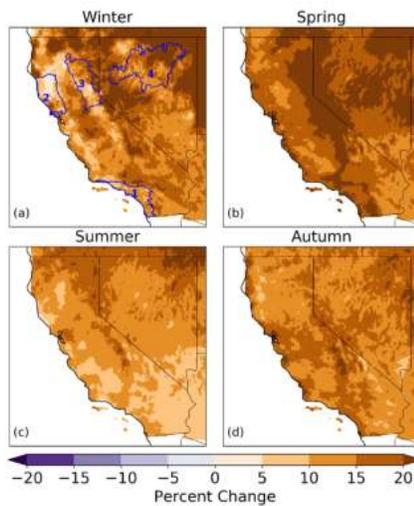
**Figure 10.** Like most of the Western U.S., the Santa Monica Mountains has significantly increased in ERC, which represents availability and moisture of fuels, from 1979 to 2012.

In another paper, “Projected Changes in Reference Evapotranspiration in California and Nevada: Implications for Drought and Wildland Fire Danger,” Daniel J. McEvoy and his team explored the connection between evapotranspiration and wildfires in California. They noted that evaporative demand ( $E_0$ ) is strongly correlated with drought and wildfire risk in the western part of the US.  $E_0$  is affected by temperatures, wind speed, humidity, and shortwave radiation, and has been increasing due to climate change (McEvoy et al., 2020). Other studies have found that, historically, the days with extreme Evaporative Demand Index (EDDI) values were also the days that major wildfires in California began,

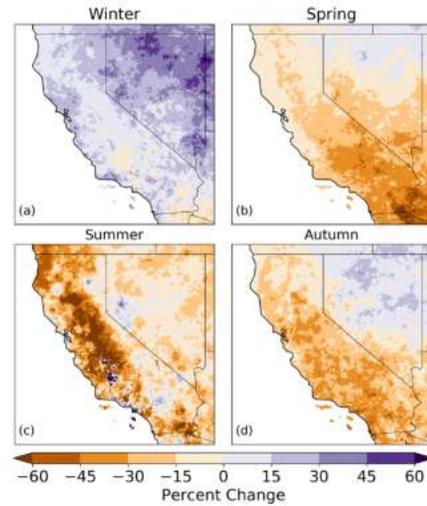
indicating a strong positive correlation between the two. This can be largely attributed to multi-year droughts and lack of fuel moisture (McEvoy et al., 2020).

The team began their own study by calculating the EDDI at two-week timescales, using factors such as rapid onset drought, meteorological events like wind, and persistent weather patterns like pressure—all of which impact fuel moisture and flammability (McEvoy et al., 2020). They also looked at multiyear droughts using the Standardized Precipitation Index (SPI) and the Standardized Precipitation and Evapotranspiration Index (SPEI). The SPI only considers precipitation, whereas SPEI is the difference between precipitation and evapotranspiration.

Their findings predict consistent increases in evapotranspiration across the state by the end of the century, and less consistent changes in precipitation which will vary spatially and seasonally (McEvoy et al., 2020). Figures 11a and 11b illustrate these variations in evaporative demand and precipitation, respectively. Autumn is fire season, so autumn weather is key to fire risk. By the end of the century, California is predicted to have 15% greater evaporative demand and 9% less precipitation, relative to the historical baseline (McEvoy et al., 2020).



**Figure 11a:** Seasonal percent change in evaporative demand for the late century period (2070-2099) relative to the base period (1950-2019). Blue boundaries in (a) show Predictive Service Areas used in the study.



**Figure 11b:** Seasonal percent change in precipitation for the late century period (2070-2099) relative to the base period (1950-2019).

McEvoy (2020) also predicted that the number of days with EDDI values in the 95th percentile (EDDI95) will increase 6-10 times in summer and 4-6 times in autumn, and the number of autumn days with 95th percentile Fire Weather Index (FWI) values will

double. The EDDI95 represents a more long-term sustained fire potential, and the FWI represents more short-term weather events.

McEvoy (2020) and his colleagues also found an increased frequency in extreme multiyear droughts lasting 36 months or longer by the end of the century. Multiyear droughts can increase fire danger by decreasing fuel moisture and increasing flammability. Multiyear droughts in combination with extreme EDDI days and low autumn precipitation only worsens wildfire risk.

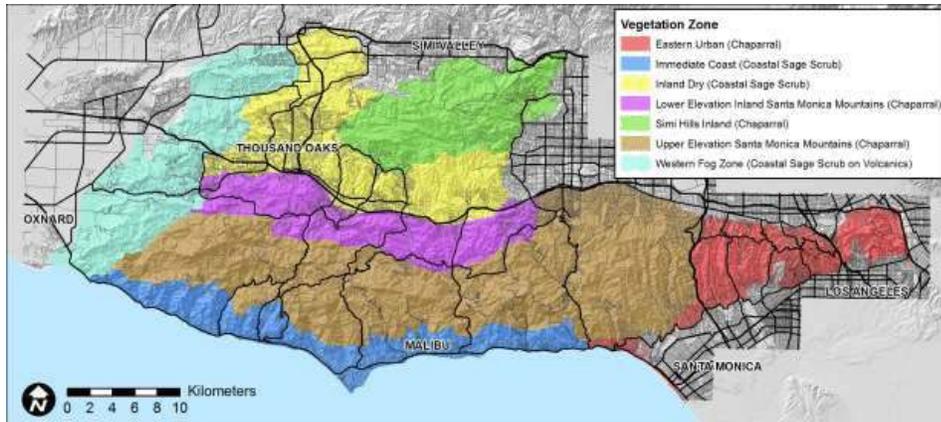
#### **2.4. Fire Ecology and Vegetation of the Santa Monica Mountains**

Among the vegetation in Southern California, Coastal California shrubland is the most prevalent among the Santa Monica mountains, and these shrubs have adapted to be resilient to wildfires, and have characteristics that allow them to recover very quickly. Even though the shrubland is acclimated to the wildfires, it is not necessarily part of a fire dependent ecosystem, and while a few species do rely on fire to reproduce, most of the common variations of chaparral are not fire dependent and actually grows during the time where there is not a fire. These vegetation communities, of which there are 12, are determined by the following factors: elevation, soil, aspect, presence of water, proximity to the ocean, and the presence or frequency of fire. Even though most of the vegetation will recover normally postfire, there are still concerns surrounding the relationship the ecosystem has with these wildfires, like short fire return intervals, high fire frequency and climate change/drought.

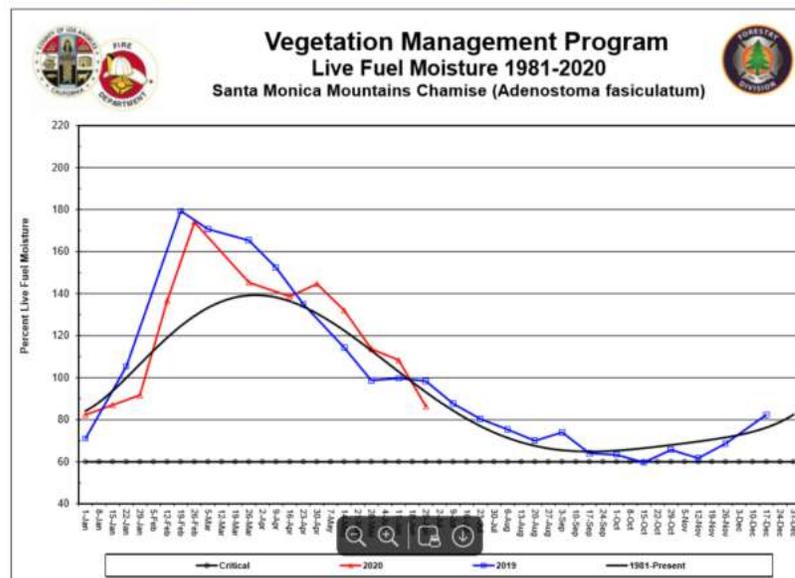
With the high fire frequency, there is cumulative mortality in all vegetation groups except the most vigorous resprouters, such as laurel sumac, that reduces shrub populations and the amount of shrub cover. Repeated fire disturbance favors the establishment of rapidly reproducing non-native annual grasses that have a higher ignition probability and produce cooler fires. With the establishment of grasses and forbs, which are flowering herbaceous plants, in place of shrubs can lead to a positive feedback loop called the *grass-fire cycle*.

The process of change from a native shrubland to a non-native dominated grassland is called *type conversion*. Type conversion leads not only to the loss of dominant shrubs, but also to the loss of the native annuals that contribute to rich postfire species diversity in the Santa Monica Mountains. Plant mortality also happens when drought occurs, fires typically follow, which puts the vegetation at risk for drought-induced mortality. In Figure 12, you can see the temperature rising and the drought increasing which live fuel moisture levels will be critical at earlier parts of the year and for a longer period of time which will possibly extend the length of the fire season as a whole. According to Joey Algiers, an ecologist who serves the Santa Monica Mountains National Park, “these plants are adapted to a fire regime, but we’re experiencing way too much of it, there are predictions that we’ll experience more conditions like these, which means we would

continue to see these really large fires (NPC). Algiers said that the increasing frequency of fire causes a feedback loop in which burn-scarred landscapes are more susceptible to invasive plants, which puts the native vegetation population at risk. Since so many of the non-native species are highly flammable, they in turn ignite more often, which can further exacerbate the severity of a fire. In some places, over the coming decades, Algiers expects to see whole areas morph from one ecosystem to another, like from shrublands to grasslands, in what’s called “type conversion.”



**Figure 12:** Areas of different types of vegetation are clearly delineated, showing the location of where these plants are in the Santa Monica Mountain area and insinuating the slow change of a changing landscape and ecosystem in which Algiers described would happen over time.



**Figure 13:** Live fuel moisture readings for the Santa Monica mountains and the LFM peaks in the spring months and is at the lowest point in the fall which coincides with Santa Ana winds.

## **2.5. Linkages Between Infrastructure, Land Use, Wildfire, and Climate Change of the Santa Monica Mountains**

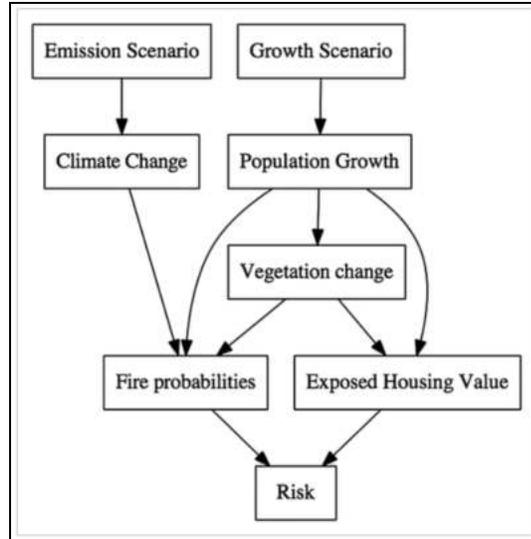
The connection between California wildfires and the built environment is vital to understand because how we use the land will affect how wildfires will function. The design of both the infrastructure of a house and the land use such as the distribution of the population in the area should consider fire resistant techniques and planning. As climate change continues to increase the likelihood of wildfires in California, it is important to realize how much influence design decisions have on wildfire growth.

According to the RCDSMM website there have been projects designed in order to discover fire resilient ways to educate California homeowners on how to protect their property. The Harper Group displayed a 120 square foot, 12 foot tall interpretive structure to present fire safe materials and techniques (rcdsmm.org). This project also focused on treating the areas around the home as well. The next step was to show four various types of garden styles that maintain ecosystem values (rcdsmm.org).

The text by David Carle, “Introduction to Fire in California,” explains how building materials for homes are classified into classes based on the material’s resiliency to fire. Class A includes materials such as clay and concrete tiles or metal roofing with asphalt composition shingles and these are considered the best materials for fire protection. Class B materials are wood materials treated with fire resistant coating. The best fire resistant home utilized a metal roof, enclosed eaves, fire resistant walls and decks on the ground (Carle 239-240). These design decisions that can be made onto the home create a fire resilient environment.

The article titled, “Scenarios for future wildfire risk in California: links between changing demography, land use, climate, and wildfire,” ties together the relationship between land use, wildfire and climate change. This relationship was shown through the use of representing different types of growth/ sprawl scenarios with many climate conditions for the study of the Bay Area and the Sierra foothills. It was concluded that the residential areas with the most risk to wildfire had high-growth scenarios alongside the most extreme climates projected (Bryant, B. P., Westerling, A. L.). The focal point here is that current land use decisions impact future residential wildfire risks.

This article asserts that there is an interlinking relationship between fire risks and climate, vegetation, and the distribution of people also changes as time continues (Bryant, B. P., Westerling, A. L.). Figure 14 displays the interlinked relationship between climate change and growth scenarios that both affect the fire probabilities and risks in the future.



**Figure 14:** Conceptual model of how climate change and growth affect long-term fire risk.

The article mentions that the phenomenon of increased development in an area decreases the amount of vegetation available for fuel for wildfires (Bryant, B. P., Westerling, A. L.). However, the increase in population in an area may lead to the increase of human-caused ignitions of wildfires.

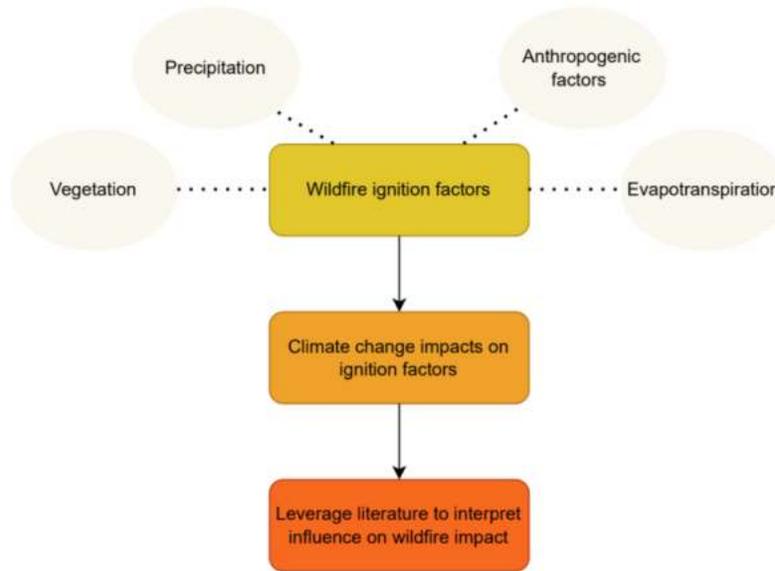
The effects of wildfires on Southern California will be indubitably influenced by the rapid exacerbation of global climate change. However, the ways in which climate change will impact wildfire frequency, severity, and damage are still being researched with vague and sometimes uncertain predictions. Factors that together can *cause* wildfire conditions— precipitation, soil moisture, drought, and temperature— are themselves ambiguous as to how they will be impacted by climate change, making future wildfire scenarios and predictions all the more difficult.

However, it is reasonable to state that wildfires will become a more significant natural occurrence due to climate change, as each climate change scenario, whether it displays extreme drought or floods or various iterations of temperature change, the natural equilibrium of wildfires is certain to be disturbed.

### 3. *Data and Methods*

When considering the impact climate change will have on wildfire presence in Southern California, it is important to acknowledge the large degree of unpredictability that comes with modeling future climate change patterns at large. The only prediction scientists can say for certain about future climate models is that the global average temperature will get warmer, but the subsequent impacts of global warming are hard to predict.

This study was approached with aims to model the impact climate change can have on an array of wildfire ignition factors against IPCC precipitation and temperature models across low, moderate, high, and very high scenarios of RCP projections. Thereafter, secondary effects on wildfire risk can be interpreted from these four climate change scenario models using previous scientific literature.

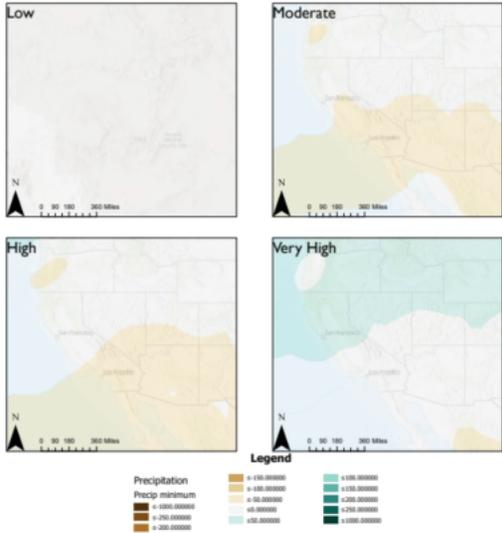


**Figure 15:** Diagram of the conceptual approach to predicting wildfire risk through wildfire ignition models.

<b>Data</b>	<b>Source</b>	<b>Description</b>
Climate Models: 2040 - 2059 Low, Moderate, High, Very High - Precipitation <b>Map 1</b>	Esri_observa tions (ArcGIS Online Living Atlas)	Layers generated from the IPCC’s 2014 Climate Report depicting best case (RCP 2.6) through worst case (RCP 8.5) projections of future greenhouse gas emissions between 2040 and 20589. These layers show the change in precipitation expected.
Climate Models: 2040 - 2059 Low, Moderate, High, Very High - Temperature <b>Map 2</b>	Esri_observa tions (ArcGIS Online Living Atlas)	Layers generated from the IPCC’s 2014 Climate Report depicting best case (RCP 2.6) through worst case (8.5) projections of future greenhouse gas emissions between 2040 and 20589. These layers show the change in temperature expected.
LA County Fire Hazard Severity Zones (SRA)	LA County GeoHub	Designating different levels of fire hazard in State Responsibility Areas (SRAs)

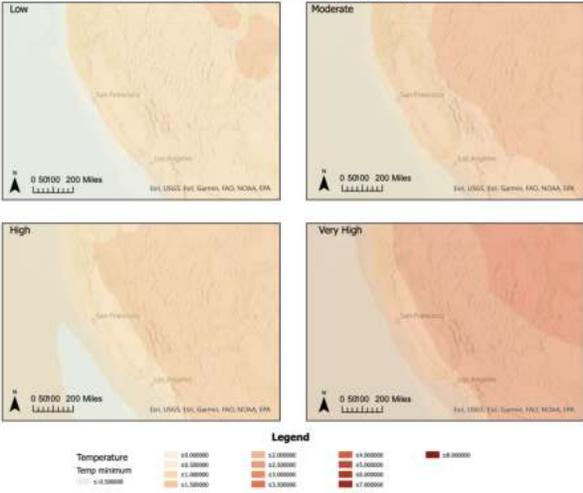
Data	Source	Description
<b>Map 3</b>		
Actual Evapotranspiration <b>Map 4</b>	Esri Living Atlas	This raster layer shows evapotranspiration at a decent spatial scale. This, paired with the potential evapotranspiration layer, could be valuable for gauging differences in fire risk due to climate change
RCDSMM Fire Frequency Map <b>Map 5</b>	Rchstudios (user on ArcGIS Online)	Fire Frequency and Mean Fire Return Interval (FRI) for fires from 1925 - 2018.
Land Cover- 2018 vs. 2050 <b>Map 6</b>	Esri Environment	Shows changing land cover projections between 2018 and 2050- showing increasing urbanization

Climate Models 2040-2059 (Precipitation)



Map 1

Climate Models 2040 - 2059 (Temperature)



Map 2



The scientific replication constraint reflects the interconnectedness of climate change impacts and the constant release of new scientific literature. This indicates there is no straightforward process for modeling climate change. The solution to address the constraint is to target specific wildfire ignition sources and interpret impacts with an extensive literature review.

The temporal scale constraint refers to the time spread of the data collected from and projected. With climate change, there are historical data, climate data, and future models.

While these constraints of data sources are impactful on the project, recognizing them and thinking about how to minimize the effect thus enables the study to be accomplished by minimizing the possible flaws in possible outcomes and accuracy.

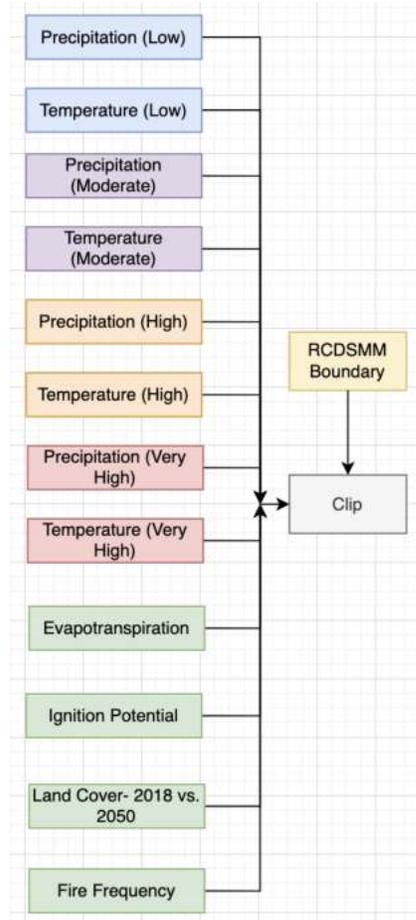
### **3.2. The Workflow Method**

Workflow for creating maps for the dashboard is modeled in Figure 16. After the input datasets are successfully clipped to the Santa Monica Mountains Study Area shapefile boundary, four layers will have to be generated for display on the final dashboard product. To do this, a weighted overlay method will be utilized. The weighted overlay geoprocessing tool requires inputs to be all raster datasets, and will also require reclassifications as the inputs are not all units that can be directly compared. The reclassification involves assigning a 1 to 10 value for how input factors relate to fire risk, with 1 being the least amount of fire risk, and 10 being the highest amount. Each input data layer will then be assigned a certain weight for how valuable it would be to determining fire risk. The factors are as follows: projected precipitation, projected temperature, (both for low, moderate, high, and very high scenarios) evapotranspiration, historic fire frequency, land cover, and ignition potential.



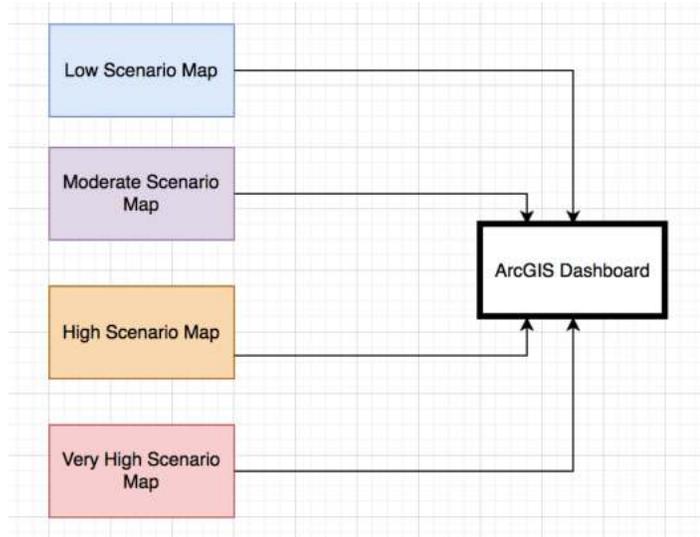
**Figure 16:** The Weighted Overlay Process

These four generated layers will show common fire risk areas, but will show the variability of the IPCC climate projections as to what regions will be possible future areas of concern.



**Figure 17:** Clipping Datasets to RDCSMM Boundaries.

Figure 17 displays an important step in the data trimming process of clipping every dataset to the RDCSMM boundaries so that data management is simpler and more efficient.



**Figure 18:** The integration of analyses maps into a shareable ArcGIS platform.

Our last deliverable is to summarize and communicate the analyses and research conducted into an ArcGIS dashboard, publically accessible.

### 3.3. Reclassification for Overlay

When approaching the weighted overlay, reclassification of data occurred to enable proper comparison between the six different data layers used. In ArcGIS, reclassification tools reclassify values based on determined criteria. Reclassification is to translate different rasters scales into a comparable and analyzable common measurement scale.

In the weighted overlay used in the study, reclassification was done on a 1 to 10 scale, with 10 being the highest risk and 1 being the lowest risk. Using the literature review, we determined the reclassification values for each layer. Note that for the precipitation and temperature four scenarios, we assigned increasing values in accordance with the low, moderate, high, and very high maps being 4, 6, 8, and 10. The layers Land Cover 2018 vs. 2050, Actual Evapotranspiration, RCDSMM Fire Frequency, and Wildfire Ignition Potential, Santa Monica Mountains Region, CA were reclassified for a new “fire risk” metric. The Land Cover dataset involved the highest risk assigned to urbanized areas, with lower risk to the unurbanized zones. For Evapotranspiration, Fire Frequency, and Ignition Potential, Jenk’s Breaks were used to split up the relevant wildfire data metric (mm/year, amount of fires, and risk level, respectively) into 10 groups, and a new 1 through 10 classification was generated.

### 3.4. Weights Used in Overlay

Although assigning weights to fire risk, especially in climate change scenarios, is a subjective task, relevant literature was consulted to justify each selection. In the case of the two dynamic variables for the IPCC projections, temperature and precipitation, Keeley and Syphard's text was crucial to understanding the relation to Southern California wildfire behavior. Figure 19 displays the weights that were chosen for the final weighted overlay generation.

In the instance of temperature, a weight of 7% was assigned as it is found that mean temperature changes are not strongly correlated with wildfire activity in the region (Keeley and Syphard). However, temperature increase surely does have relations to other crucial factors, such as dryness of fuel, weather patterns such as El Nino, and other ignition factors. In the case of precipitation, Keeley and Syphard similarly point out the effects of precipitation on wildfire is hard to pin down, but emphasize that it is crucial, especially due to second order effects. Both increases and decreases in precipitation have been known to increase wildfire behavior, therefore it was given a weight of 14%.

Another important subject that was explored during the literature review was the characteristics of the Wildland Urban Interface (WUI) and how that would impact wildfire risk, ignition factors, and burning patterns, especially as the profile of the Santa Monica Mountains changes. This brings in the Land Cover change dataset, which was given a weight of 14%. The Land Cover change dataset simply highlights new areas of urbanization within the Santa Monica Mountains region, which allows insight into how not only climate will be changing into 2050, but anthropogenic ignition factors. As locations of humans and infrastructure doubly serves as an increase of risk in the form of ignition danger and threat to safety, this was given a relatively significant weight. Ideas about defensible space and how human structures interface with the natural environment are prominent in discussion of fire risk. The American Planning Association outlined their guide on the importance of the relationship between wildfire mitigation and the WUI, and this was used as both the basis for the weighting of 14% (Schwab and Meck).

Vegetation and evapotranspiration factors are crucial to how wildfires burn in the Southern California Region. Evapotranspiration is a significant variable, as noted by many of the referenced sources, as it accounts not just for vegetation types but how dry/wet they can be expected to be. Keeley and Syphard noted that evapotranspiration is the single factor most correlated with wildfire behavior in Southern California, earning it a weight of 18%.

The final two factors explore previous fire and ignition behavior. The fire frequency layer analyzes historical fire occurrences in the Santa Monica mountains, and shows their historical boundaries. Higher frequencies are classified as higher risk areas. This was given a weight of 15%, as it incorporates wildfire history of the area, but is not a dead ringer for

where the next fire could be. Finally, there is the Ignition potential layer that was created by the Conservation Biology Institute. This layer takes into account a lot of factors unaccounted for by our model, such as Santa Ana winds, topography, and most importantly, anthropogenic ignition factors such as roads, electric infrastructure, etc.. This model has a thorough consideration of many factors important not only to ignition, but to risk and safety in relation to fires, and it was assigned a weight of 27%.

Raster Layer	% Weight
Temperature (Low, Mod, High, Very High)	7
Precipitation (Low, Mod, High, Very High)	14
Land Cover	14
Fire Frequency	15
Evapotranspiration	23
Ignition Potential	27

**Figure 19:** The raster weighted overlay table.

#### 4. *Results*

The result from the weighted overlay is the ArcGIS dashboard:

“The Future of Wildfire Risk in the Santa Monica Mountains,” available at [www.arcgis.com/apps/dashboards/0cca1279541f4800a3911de4326b7ed7](http://www.arcgis.com/apps/dashboards/0cca1279541f4800a3911de4326b7ed7).

The dashboard, also pictured below as Figure 20, displays four different weighted overlay maps in accordance with the four IPCC climate scenario predictions. These weighted overlay maps were built using the data sources: Climate Models: 2040 - 2059 Low, Moderate, High, Very High’s Precipitation and Temperature, Land Cover 2018 vs. 2050, Actual Evapotranspiration, RCDSMM Fire Frequency Map, and Wildfire Ignition Potential, Santa Monica Mountains Region, CA. Furthermore, in addition to the weighted overlay maps on the dashboard there are also pie charts of wildfire risk level distribution.

Note that the input precipitation and temperature datasets will be different for each scenario, but weights will remain constant amongst each scenario map for all data layers.

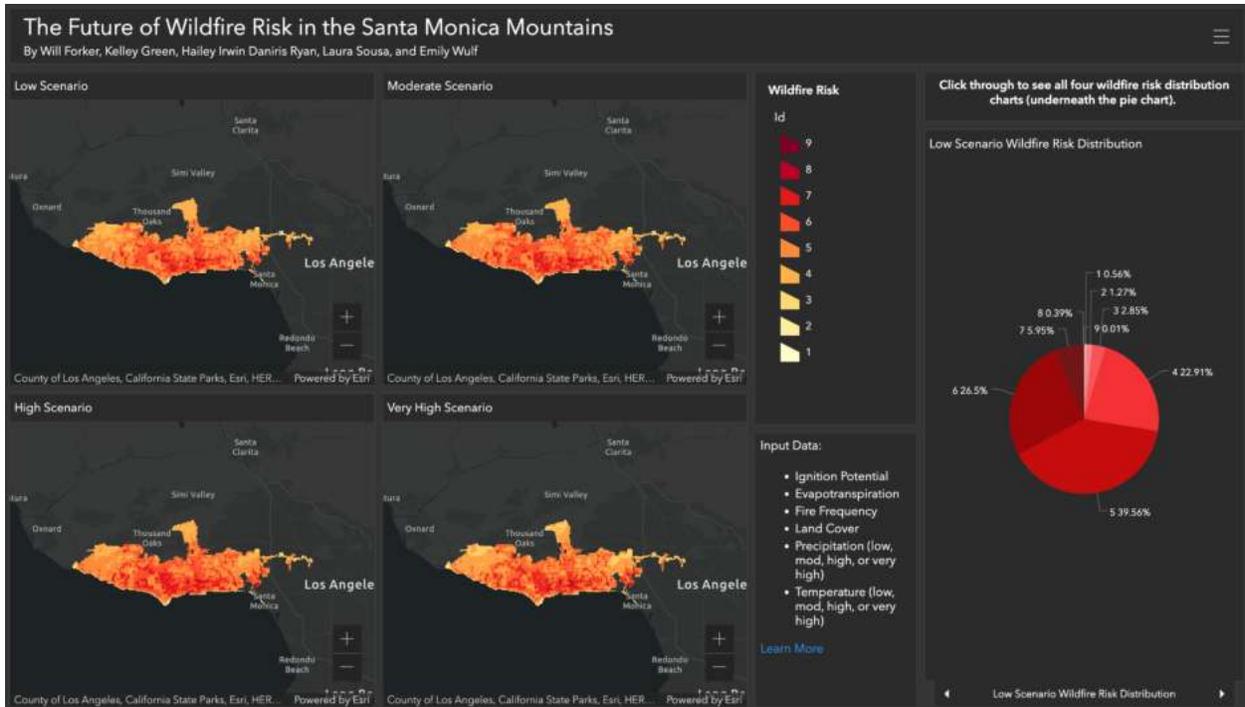


Figure 20: The interactive dashboard project.

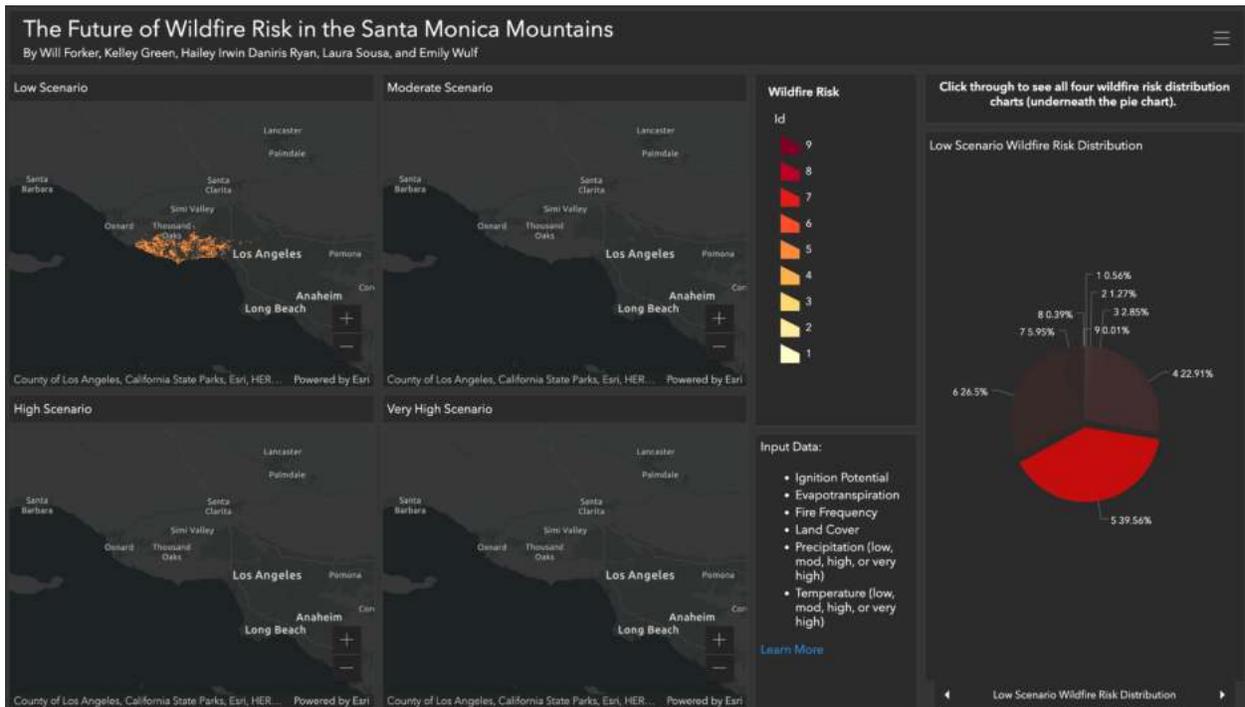
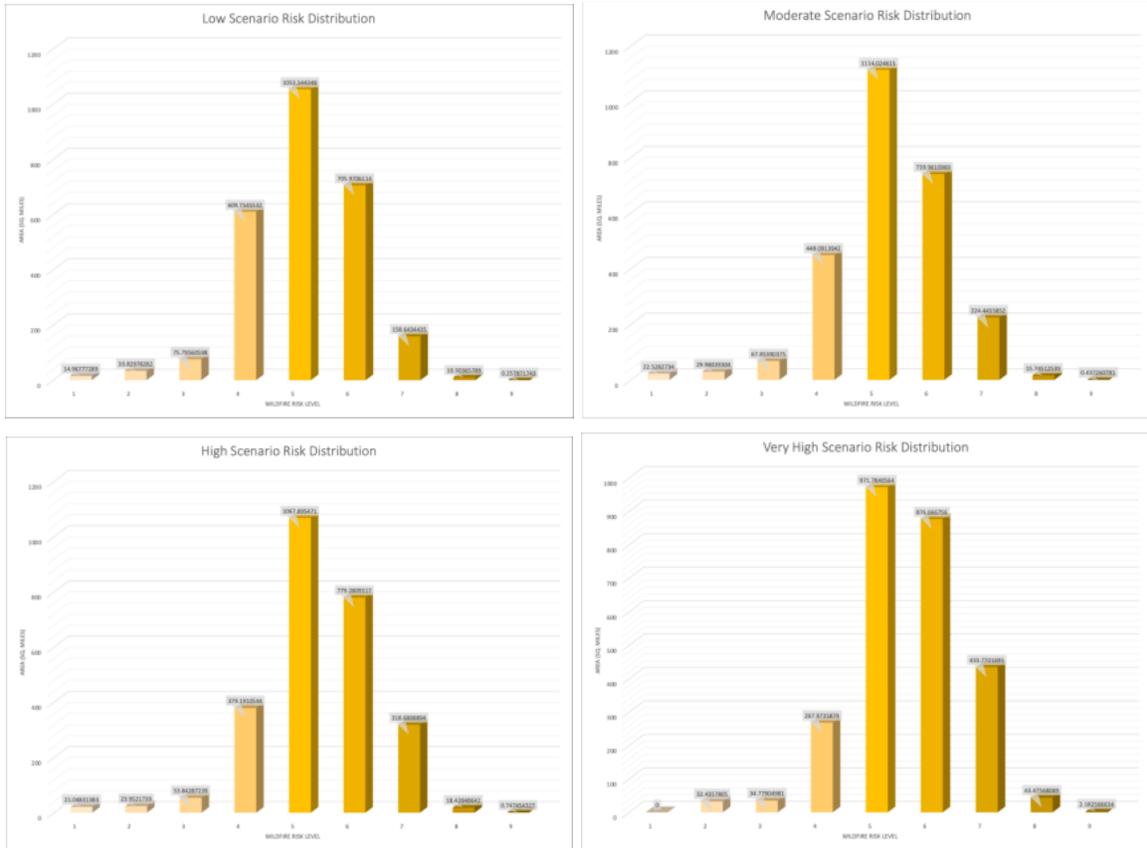


Figure 21: The enhancement of the graphs in displaying map products.

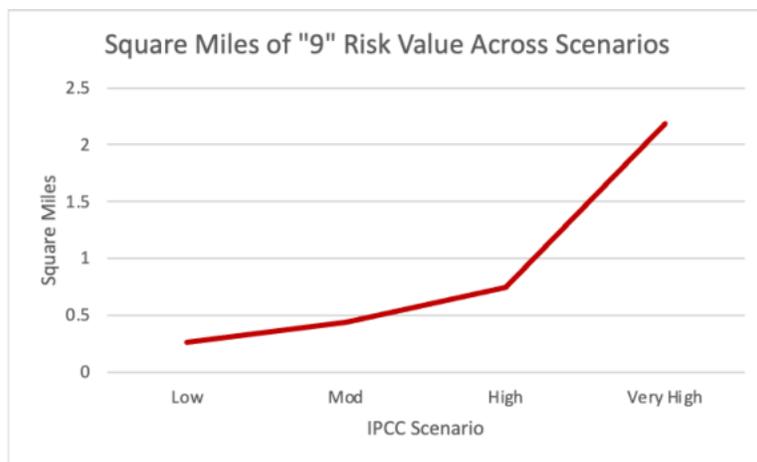
#### 4.1. Distribution of Fire Risk Severity

Across all four scenarios, the greatest amount of land within the study area is categorized as a level 5 fire risk, averaging about 1,051 square miles in total. But as we progress from

the low to very high scenario, the proportion of land with a greater fire risk increases. The total amount of level 6 and 7 land increases from approximately 865 to 1311 square miles. This is a 51.6% increase of high fire risk land, which shows how severely climate change might impact wildfire risk.



**Figure 22:** Four charts that display risk distribution for the four scenario models across the nine wildfire risk levels, in square miles.



**Figure 23:** This figure shows that the highest “9-level” risk level is increasing at nearly an exponential rate.

## 5. *Discussion*

The four maps in the dashboard show that the spatial distribution of wildfire risk remains relatively consistent amongst the four climate scenarios. The central area of the Santa Monica Mountains, around the northern part of Malibu, has a very high risk in all scenarios. The area just a few miles west has a high risk as well, with patches of very high risk. The east and west portions of the Santa Monica Mountains have a relatively lower risk than other parts of the study area.

The dashboard is intended to be used only by the RCDSMM to promote wildfire resiliency in the Santa Monica Mountains. It can be used to pinpoint the specific areas that are most likely to be at risk of wildfire in the near future, which will help concentrate RCDSMM efforts in the most needed areas. This will make RCDSMM’s wildfire resilience efforts more effective and efficient. It also helps visualize how the spatial distribution and intensity of wildfire risk will change depending on the severity of climate change. The low emissions climate scenario is no longer considered likely, and the very high scenario is increasingly being considered as a probable reality. It may be useful in the future to duplicate this study with updated climate models that most accurately reflect the expected future climate scenarios.

An additional step that could be taken to progress the current version of The Future of Wildfire Risk in the Santa Monica Mountains ArcGIS Dashboard is to supply supplementary information with the use of tabs to various websites and links to sources of data layers. These resources can aid in increasing the user’s understanding of the topic of wildfires in the Santa Monica Mountains. Potential tabs could include fire intensity information of hotspot areas and historical maps that visualize historic patterns within this region.

Areas for future research should include the future projections for evapotranspiration, the change in the vegetation profile and the fuel build up of the Santa Monica Mountains. Gathering these types of data and creating visualizations of these points of interests will establish a fuller scope for the research and form an accurate scenario of the future of wildfire risk in these mountainous areas.

## **5.1. Recommendations**

### **5.1.1. Improvements to the Study**

This study was limited in terms of data type and availability. It could be improved by incorporating more fire-risk data into the weighted overlay, such as wind speeds and patterns. Wind plays a crucial role in fire behavior, as strong winds can exacerbate a fire's spread. Wind patterns will change because of climate change's impacts on weather, and based on what is known about climate change in general, it is reasonable to assume that winds will become stronger and more frequent. Incorporating historic and/or projected wind patterns into the study will create a much more comprehensive fire risk analysis.

Furthermore, the study could be improved by using IPCC projection data at a larger spatial scale (i.e. more fine-grained). The global data that was used in this study, although accurate, is not very precise and does not provide a highly detailed look into projected temperature and evapotranspiration anomalies. Using larger scale data could improve the precision of the map results, which would provide the RCDSMM with highly accurate and precise fire-risk models. The study could also be duplicated in the future with updated IPCC models, including the soon to be released 2021 models.

### **5.1.2. Future Areas of Research**

As mentioned earlier in this report the future projections for evapotranspiration, the change in the vegetation profile and the fuel build up can aid in understanding the ongoing wildfire risk in the Santa Monica Mountains. From Jeremy S. In Littell's text, it was gathered that evapotranspiration helped to play an important role in the land cover change and it can influence the wildfire and drought feedback loop. The future projections of the change in the vegetation profile is vital to expose wildfire risks as the Santa Monica Mountains continue to change its landscape. This report highlighted that there was a positive feedback loop called the grass-fire cycle between vegetation such as grasses and forbs and the wildfire ignitions. Including the change in vegetation profile is necessary because vegetation impacts live fuel moisture readings for the area. Another factor to consider is the future fuel build up projections for the Santa Monica Mountains. The fuel build up can include all types of vegetation and unnatural fuel buildups that support the occurrence of a wildfire.

## **6. Conclusion**

This study investigates future wildfire risk in the Santa Monica Mountains as related to global climate change. As the impacts of global climate change are already felt by Southern California, it is integral that impending climate change risk be explored to inform and prepare wildfire management approaches in the near future. The four standard RCP models created by the IPCC in 2014 were used as the backbone of weighted overlays that displayed wildfire risk across low,

moderate, high, and very high greenhouse gas emission scenarios projected between 2040 to 2059. Overall, all four scenarios revealed substantial areas of high wildfire risk, inculcating the widespread scientific consensus that wildfire management should anticipate– and not only seek to prevent– heightened risk brought about by climate change. The below sections outline overall risk distribution along with specific areas of extreme risk.

### 6.1. Areas of Extreme Risk

Pepperdine University: Only one region has a level 9 risk level in the lowest scenario. It is a small piece of agricultural land in close proximity to the Pepperdine campus. This risk is most likely due to steep topography, human proximity, and a large amount of dry fuels. This stands to be amplified by the effects of climate change, creating hotter, drier weather patterns in the area. This area would be an extra concern due to its proximity to a populated college campus as well as multiple neighborhoods. This could possibly be mitigated by a partnership with the local community, or Pepperdine itself, to organize regular clearing of possible fire fuels as well as adaptation of a defensible space zone.



Figure 24: Images of Pepperdine University from the ArcGIS Dashboard..

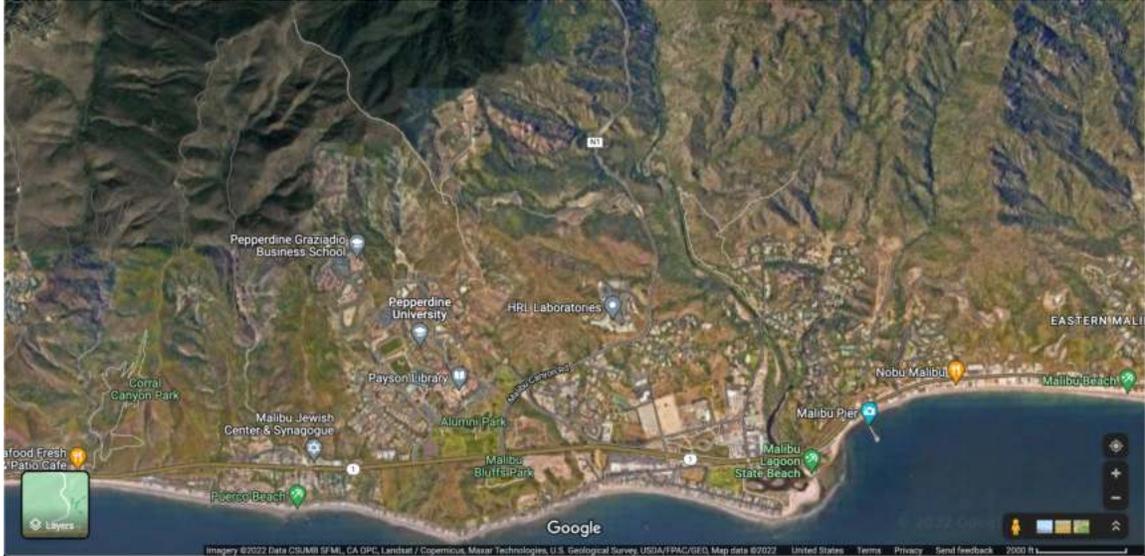
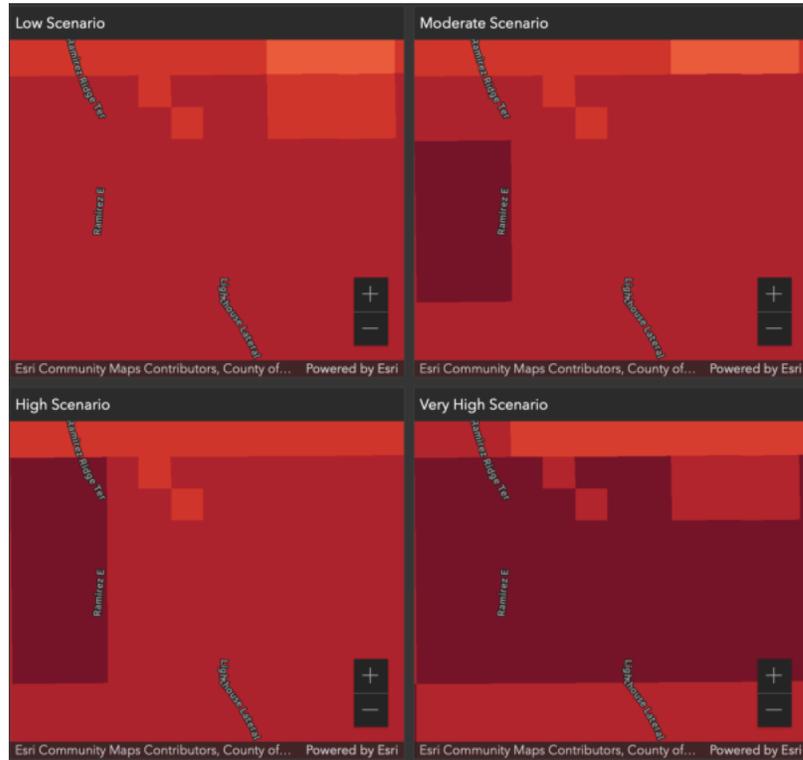
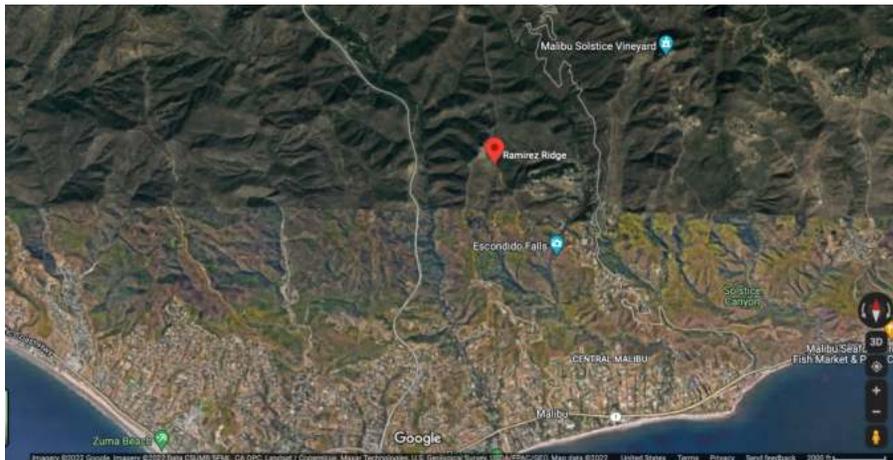


Figure 25: Images of Pepperdine University from satellite imagery.

Ramirez Ridge Terrace: This area has a very high wildfire risk in all four scenarios. It is a canyon with deep ridges and dry fuels. Although there is limited human presence in the area, there are power lines for the handful of residences.



**Figure 26:** ArcGIS Dashboard image of ramirez ridge terrace.



**Figure 27:** Satellite imagery of ramirez ridge terrace.

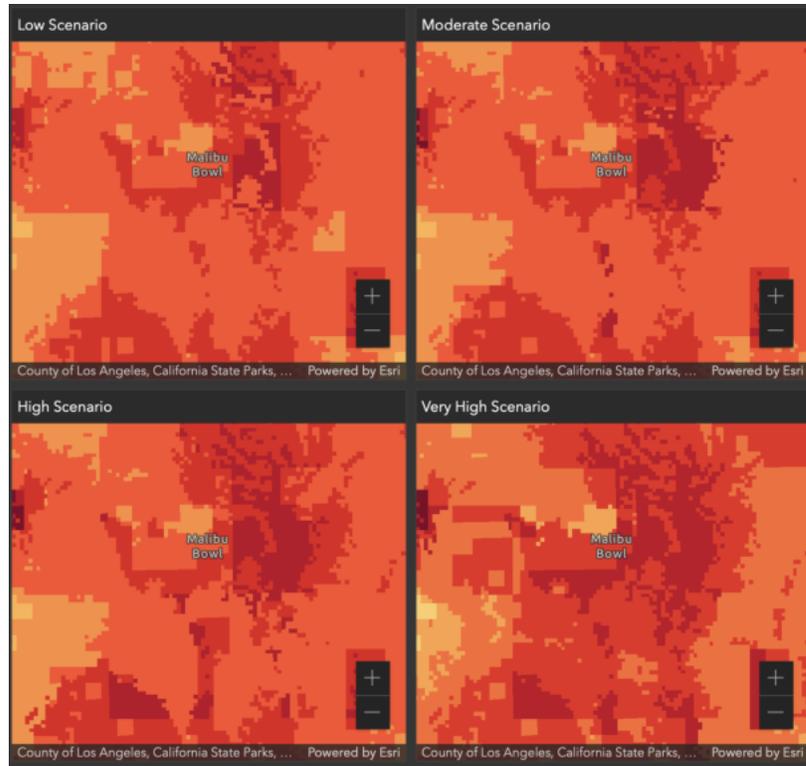


**Figure 28:** Satellite imagery of ramirez ridge terrace.



**Figure 29:** Images of the Ramirez Ridge Terrace from the ArcGIS Dashboard and satellite imagery.

Malibu Bowl: This area also has very high wildfire risk in all four climate scenarios. It is a small residential neighborhood near schools and shopping centers, so a fire's risk to human life is notable. The area has steep topography, dry fuels, high tree canopies near homes, and houses at all elevations.



**Figure 30:** ArcGIS Dashboard image of Malibu bowl.

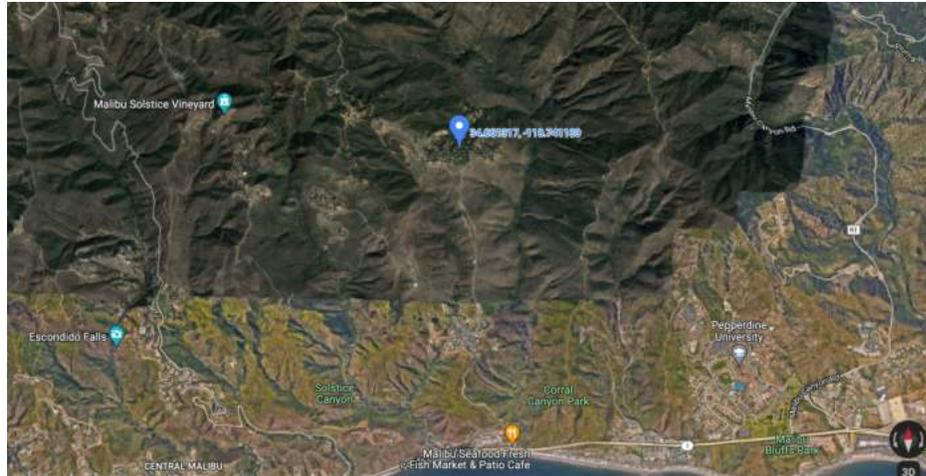


Figure 31: Images of Malibu Bowl from the ArcGIS Dashboard and satellite imagery.

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