*California Prescribed Burn Spatial Analysis*

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Threat level

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Publicly owned land

Cities

\*Threat level estimates shown are not limited to publicly owned land

1. **Introduction**
   1. Background

In 2020, wildfires in California burned over 4,200,000 acres and caused roughly $9 billion in property damage (California Department of Forestry and Fire Protection, Bellisario et al. 2021). The past four years have produced the eight largest wildfires in California history, which not only destroyed thousands of structures but also caused hundreds of millions of dollars in medical costs and contributed to climate change by emitting 112 metric tons of carbon (Dooley 2021). While wildfires are a staple to many California ecosystems, the rate at which they burn, spread, and destroy structures have placed California in a crisis.

Fire experts are turning to prescribed burning to curb the amount of property damaged and number of acres burned by wildfires (CAL FIRE). Prescribed burning is intentionally igniting an area on fire to reduce fuel for future fires and to rejuvenate growth within that area. It is a practice that was originally developed by Native Californians who labeled the practice “cultural burning.” They used prescribed burns for spiritual practices as well as to “shape the landscape and attract game” (Sommer). However, in the 1900s, the California government implemented a policy that banned cultural/prescribed burns and the effects of this policy are evident in the record-breaking wildfires that have swept across the state in recent years. Partially due to the ban on cultural burns as well as California’s negligence to let nature’s cycle take its course, decades of fuel has built up on California’s landscape. The longer an area goes without fire, the more explosive and out-of-control the next fire will be (Sommer). Realizing that prescribed burns are an important tool for mitigating the risk of out-of-control wildfires that can potentially destroy properties, California has returned to using the Native practice.

In this report, I explore the best areas to have prescribed burns with the goal of minimizing property damage from future wildfires.

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*Figure 1: Continuous wildfire threat levels in California*

1. **Methods**
   1. Data

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| --- | --- | --- |
| **Dataset Name** | **Description** | **Source** |
| California Boundaries | Boundary shapefile for the state of California. | <https://data.ca.gov/dataset/ca-geographic-boundaries> |
| Continuous Fire Threat Level | A raster layer containing the fire threat level for the whole United States. | <https://www.fs.usda.gov/rds/archive/catalog/RDS-2016-0034-2> |
| Landcover type | A raster layer of all landcover types for the whole United States. | <https://www.usgs.gov/centers/eros/science/national-land-cover-database?qt-science_center_objects=0#qt-science_center_objects> |
| Building footprints | A shapefile containing every building in California. | <https://github.com/microsoft/USBuildingFootprints> |
| Zillow price estimates | A csv with the median price for every zip code in California. | Provided by Professor Nolte |
| Zip code boundaries | A shapefile with all California zip code boundaries. | <https://data2.nhgis.org/downloads> |
| California landownership | Public landownership for California. | [https://gis.data.ca.gov/datasets/f73858 e200634ca888b19ca8c78e3aed/explore](https://gis.data.ca.gov/datasets/f73858%20e200634ca888b19ca8c78e3aed/explore) |
| Travel Time Proxy | A raster layer for travel times for the whole world. | Provided by Professor Nolte (Lab 2) |

* 1. Creating the Dataset

The datasets listed above were all used to help create the final dataset that is used for the spatial analysis. These are the steps taken to reach the final dataset:

1. Create price estimates for each building.

* Merge Zillow zip code median house prices with zip code boundaries shapefile.
* Assign each building to a zip code using the zip code boundaries (spatial join).
* Determine the estimated price for each building based on the assumed linear relationship between building area and the median price for zip code.

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*Figure 2: Visualization of Zillow Median Price Estimates*

1. Create selection units.

* Determine the size of selection units (~89 acres which is halfway between the median and average controlled burn sizes in California).
* Create a grid of selection unit sizes.
* Keep only selection units that are within the publicly owned land area (spatial join).
* Remove all selection units that overlap a structure.
* Remove all selection units with no threat (threat level = 0).
* Remove irrelevant selection units based on landcover (i.e. water, developed land)

Chart

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*Figure 3: Visualization of publicly owned land in California used to create selection units.*

1. Determine the cost of having prescribed burn on each selection unit.

* Use landcover type as main indicator of selection unit price (Fight & Barbour 2004).
* Use travel time and assume a linear relationship between the difference in mean travel time and the travel time to the selection unit to approximate cost.
* Use threat level and assume a linear relationship between the difference in mean threat level to approximate cost (higher threat implies more fuel for wildfires).

|  |  |
| --- | --- |
| *Shrub* | *$45/acre* |
| *Grassland* | *$45/acre* |
| *Pasture* | *$45/acre* |
| *Mixed Forest* | *$254/acre* |
| *Deciduous Forest* | *$75/acre* |
| *Evergreen Forest* | *$125/acre* |
| *\*Selection units with landcover that does not contain natural wildfire fuel were excluded* |  |

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*Figure 4: Visualization of landcover types used to determine the cost of selection units.*

1. Find buildings that are within a radius of selection units (1- and 2-mile radii).

* Find the centroid of each selection unit.
* Create buffer radius from the centroid (selection units are square but used circular boundaries).
* Use spatial join to find all buildings within a radius of the selection unit (no buildings overlapping a selection unit—don’t want to do burn on land with a building on it).
* Remove buildings that were duplicated (don’t want to count the avoided cost of a building more than once).
* Complete these steps for 1-mile and 2-mile radii (from edge of selection unit).
  + Buildings within a 1-mile radius have 100% property damage avoided, whereas buildings within a 2-mile radius have property damage avoided as a function of their distance outside of the initial mile.

1. Aggregate building statistics and perform inner merge with selection units.

* Group by selection unit ID to compute aggregate statistics about the cost, area, and the number of buildings avoided by selecting that unit.

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*Figure 5: All possible selection units for 1-mile radius. Selection units are ~89 acres.*

* 1. Assumptions

Due to time constraints and my limited knowledge of property valuation and fire risk management, I made the following simplifying assumptions regarding my explorations:

* + 1. There is a linear relationship between the area of the structure and the property value.
    2. Selection units can only be on publicly owned land.
    3. All selection units are the same size.
    4. All selection units are square.
    5. All selection units are accessible.
    6. There is a linear relationship between the selection unit area and the cost of selection (based on multiple predictors).
    7. A property can only belong to one selection unit (i.e. if a structure falls within the boundaries of multiple selection units, it can only belong to one so we do not calculate its avoided cost multiple times).
    8. There are no other prescribed fire risks to be accounted for other than no structures on selection units.
    9. California can have prescribed burns on Federal land, but California has to pay for it.
  1. Budget

This year governor Gavin Newsom proposed a $323 million budget in his “Wildfire Resilience Package,” and has increased it to $677 million for 2022. Within the Wildfire Resilience Package, Newsom allocated $235 million for forest management strategies which are labeled as “Wildfire Fuel Breaks.” Among the different strategies, $35 million is reserved for prescribed burns for 2022 (CA LEGISLATIVE ANALYST’S OFFICE). I will use $**35 million as the budget** for selecting units for prescribed burns.

* 1. Processes for selection

The following scenarios show how different policy design choices affect the outcome of selection units. Each scenario has a specific way for choosing prescribed burn locations.

Scenario 1—Best cost-benefit ratio:

* Calculate the cost-benefit ratio of each selection unit by dividing the value of selection unit by the estimated avoided property damage value. Then sort the selection units in ascending order (lowest is the best cost-benefit ratio) and select each unit until there is no more budget left.

Scenario 2—Best cost-benefit ratio with adjusted threat levels:

* Use the same cost-benefit ratio from Scenario 1 but filter out units that have a threat level lower than the median threat level. Then sort the selection units by ascending order of cost-benefit ratio and choose each unit until there is no more budget left.

Scenario 3—Worst threat levels:

* Sort selection units by maximum threat level, choose units until there is no more budget left.

Scenario 4—Highest average avoided cost with adjusted threat levels:

* Filter out units that have a threat level less than the median threat level. Then, sort by highest average avoided cost and choose units until there is no more budget left.

Scenario 5—Largest area with adjusted threat levels:

* Same threat level adjustment as before, then sort by largest area avoided and select units until there is no more budget left.

Scenario 6—Most avoided buildings with adjusted threat levels:

* Same threat level adjustment as before, then sort by most avoided buildings for each unit and select the units until there is no more budget left.

Repeat Scenarios 1-6 for the dataset that encapsulates avoided cost estimates within a 2-mile radius of the selection unit.

*\*Scenarios 7, 8 are only applied to the dataset with 1-mile radius avoided cost estimates.*

Scenario 7—Giving stipend to communities near prescribed burn\*:

* Give each household within a prescribed burn boundary a $100 stipend as an incentive to allow the prescribed burn near their property. Add the cost of the stipend program to the cost of selection unit and recalculate the cost-benefit ratio. Proceed with the same process as Scenario 2.

Scenario 8—Randomness to selection unit costs:

* Add randomness to the cost for each selection unit. Each location likely has different requirements, and this randomness encapsulates the many different costs that have not been factored in yet. Recalculate cost-benefit ratio and select as in Scenario 2.

*\*One of the challenges that policymakers face when determining where to have prescribed burns is smoke and air quality management. Many communities don’t want prescribed burns near their properties because it significantly affects the air quality during and after the prescribed burns (Schultz et al. 2018).*

1. **Results**
   1. The Numbers

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When only sorted by cost-benefit ratio, it appears that the most property damage is avoided by a very wide margin. However, this selection has some caveats which will be discussed in the next section. Scenarios 2, 4-6, 8 for both 1- and 2-mile radii produced very similar results. Scenario 7 (1-mile radius) significantly reduced the cost and area avoided while driving up the cost per selection unit.

* 1. Policy Visualizations

Chart, bar chart

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*Figure 6 (Top): Bar plot showing the results from scenarios 1-8 for a 1-mile radius.*

*Figure 7 (Bottom): Bar plot showing the results from scenarios 1-6 for a 2-mile radius.*

* 1. Map of selection units

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*Figure 8: Map of selection units for 1-mile (left) and 2-mile radius (right) when sorted by cost-benefit ratio and adjusted threat level (Scenario 2). Each dot is a location to have a prescribed burn.*

*Diagram

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*Figure 9: All scenarios (for 1-mile radius) selection units maps. High-res download* [*here.*](https://drive.google.com/file/d/1bObN7vTpHCVCWTcy4b8oKTbALU2Y3Q38/view?usp=sharing)

**An interactive map of selected units for Scenario 2 can be found** [**here**](https://drive.google.com/file/d/1hdb2jZAz7dP7KcEMSHZFFeqaNRErK4zO/view?usp=sharing) **(download and open file).**

1. **Discussion**

A scenario in which selection units are sorted by their cost-benefit ratio and then chosen until the budget runs out clearly avoids the most property damage, buildings, and structural area burned. It is also the most cost-efficient solution. However, this scenario comes with many caveats: most significantly, it does not consider the threat level of a surrounding area. Without observing the estimated threat level, this scenario opens the possibility for millions of dollars to be spent protecting areas that are relatively low risk and would not have been damaged by major wildfires—which would mean that the numbers for this situation are significantly less than projected while the budget stays the same.

To account for wildfire threat level, scenario two filters out all selection units that are below the median threat level. From this sub-selection, the selection units are sorted by cost-benefit ratio and then chosen as the first scenario. While this reduces the projected impact by nearly $5 billion from the first scenario, the areas chosen for prescribed burns are likely more effective in protecting properties that would actually be at risk of being damaged by wildfires. Because of this, the first scenario is unrealistic and would not be considered in policy implementation.

Scenario three represents a policy that prioritizes the threat level of certain areas and selects locations for prescribed burns based on the most urgent areas to protect. After observing the numbers and bar charts, it is apparent that while we are protecting more critically threatened areas, we are not maximizing the budget in terms of property damage, area, and the number of buildings avoided. This interpretation too, has a caveat: the threat level of a given area can be viewed as a probability of a wildfire starting in that area. Therefore, scenario three possibly gives a better estimate of how much property damage will be avoided given the fact that the chance of wildfire in those areas is high. Similarly, this implies that scenario two contains some selected areas that are not likely to be damaged by wildfires.

Scenarios four through six present very similar numbers to scenario two. However, the maps of selection unit distributions (figure 9) show that each policy scenario affects the placement of selection units. These scenarios represent different policy decisions that would have to be made, especially because they all produce relatively similar quantitative outcomes.

Finally, scenarios seven and eight introduce some realism into the modeling. Scenario seven offers households surrounding a controlled burn a $100 stipend for allowing the prescribed burn to take place. In an analysis of prescribed burn policy barriers, smoke and air quality control is one of the largest difficulties policymakers face when choosing areas to have a prescribed burn (Schultz et al. 2018). There is often not a large perceivable incentive for people to allow prescribed burns, so having a stipend gives a small incentive for prescribed burns while selecting the areas with the newly adjusted best cost-benefit ratio. Adding this cost into the scenario drastically reduces the number of units able to be selected and therefore reduces the effectiveness of the program.

Because selection unit costs are rough estimates, scenario eight introduces randomness into the cost given some areas will have higher costs (for labor, fire control, accidents, and unforeseen extraneous factors). This randomness does not affect the policy effectiveness when compared to Scenario 2.

1. **Conclusion**

In 2020-2021, California outspent its emergency wildfire funding by about $900 million for a total of about $1.3 billion (Brown 2020). Prescribed burns not only reduce fuel for wildfires and significantly reduce the probability of out-of-control fires, but they are also—not surprisingly—significantly cheaper than fighting a wildfire. In 2020, wildfires cost an estimated $9 billion in damage, and referring to the prescribed burn policy scenarios above, a little less than $2 billion in future potential property damage can be avoided by implementing prescribed burns in the areas dictated by the model. In other words, by spending only a fraction of a cost (3.5%) of the emergency wildfire budget from 2020-2021, California can preemptively avoid nearly $2 billion of structural damage. Furthermore, the budget used in modeling prescribed burn placements has been approved by the California government and is specifically allocated for prescribed burning (though this would also require approval from the federal government for burns on federal land).

Prescribed burns are placed in areas that will help avoid the most property damage by significantly reducing the probability of a wildfire in that surrounding area. Because the policy scenarios have shown the promise of avoiding billions of dollars in property damage while staying under California’s allocated budget, implementing prescribed burns in areas such as the ones selected is highly recommended. To adjust for selection unit cost randomness as well as eliminate bias towards certain areas that are very wealthy or have much larger buildings, Scenario 8 likely depicts the most realistic approach to finding the best places to have prescribed burns. It is unrealistic for California to consider having 4591 individual controlled burns in one year, especially because weather often plays a significant role in the viability of a prescribed burn. But prescribed burns significantly reduce the threat of wildfire for many subsequent years, and the locations selected by the model hold significance in avoiding the most property damage per unit cost. Therefore, a deeper analysis into a sub-selection of these 4591 units would likely result in a much more realistic target for a single calendar year, and in the following years the selection unit locations can be reevaluated.

While the policy scenarios created represent real placements that would significantly reduce property damage from wildfires, the selection units do not come without caveats. The first is that prescribed burns significantly reduce the probability of property damage from wildfires, but they do not fully eliminate the threat. The models created assume that for at least the structures within a one-mile radius of a prescribed burn the threat of wildfire will be completely eliminated. Second, locations for prescribed burns do not have any structures on them, however, there is no limit as to how close to communities or structures that the burns can be. In addition, no fire modeling has been done to add more precise fire threat predictions to structures. Finally, the policy scenarios do not account for population density, or any other demographic factors. To create a cost-effective and equitable plan for prescribed burning, it would be important to consider some of these factors so that property damage prevention is not severely biased— specifically with regards to wealth and race. To further the accuracy and viability of this policy model, these caveats would need to be addressed.

**All code used for this spatial policy analysis can be found** [**here**](https://github.com/dskahill/prescribed-burn-analysis-ca/tree/main)**.**

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