Spatial Allocation of Market and Nonmarket Values in Wildland Fire Management: A Case Study[1]

John W. Benoit, Armando González-Cabán, Francis M. Fujioka, Shyh-Chin Chen, José J. Sanchez[2]

Abstract

We developed a methodology to evaluate the efficacy of fuel treatments by estimating their costs and potential costs/losses with and without treatments in the San Jacinto Ranger District of the San Bernardino National Forest, California. This district is a typical southern California forest complex containing a large amount of high-valued real estate. We chose four sites to represent different land use types – real estate, mixture of real estate and wilderness, recreation use and non-use. Within each site, we iteratively ran the FARSITE fire simulation model using different random starting locations and weather scenarios. Weather data for the simulations was extracted from both a remote automatic weather station data stream and a high-resolution weather model.

These simulations were repeated to incorporate simulated fire suppression and fuel treatments. We define heuristics for simulating suppression tactics based on actual fire line production rates. Fire suppression resources were simulated and incorporated into the fire spread simulations. We simulated fuel treatments by applying collected treatment data over the landscape and adjusting fuel models using ArcFuels, a GIS-based fuel management and risk assessment tool.

The economic value of each land-use type in the San Jacinto wilderness was estimated spatially using tax assessment data, recreation values, and water resource values. Costs of suppression and treatments were estimated from actual data.

Key Words: Decision-making, FARSITE, fire spread simulation, fuel treatments, GIS, Monte Carlo simulation, San Jacinto Wilderness.

---

[1] An abbreviated version of this paper was presented at the Fourth International Symposium on fire Economics, Planning, and Policy: Climate Change and Wildfires, 5-11 Nov 2012, Mexico city, Mexico

[2]Computer Specialist, Research Economist, Emeritus Research Meteorologist, Meteorologist, Mathematical Statistician, respectively; USDA Forest Service, Pacific Southwest Research Station, 4955 Canyon Crest Drive, Riverside, CA 92507, USA; jbenoit@fs.fed.us, agonzalezcaban@fs.fed.us, fmfujioka@fs.fed.us, schen@fs.fed.us, jsanchez@fs.fed.us.

Introduction

Commonly asked questions in the fire community have to do with the risk, cost, and effectiveness of fuel treatments and fire suppression. However, quantifying such values is often difficult if not impossible. Many costly fire planning decisions are therefore based on 'gut' feelings. It would help planners to have better estimates of the costs and benefits of different strategies. In this study, we developed a methodology to provide such costs and benefits estimates.

The San Jacinto Ranger District (SJRD) in the San Bernardino National Forest lies amidst a well-populated region of southern California. It contains a mixture of wilderness and high-priced homes, and is a favorite spot for recreational activities. The threat of wildfires in this district is a serious concern, as there is great potential for destruction monetarily, environmentally, and in terms of life. For our study, we gathered several data layers for San Jacinto, including geographic, climatological, and economic data.

Economic data layer development

We estimated economic values spatially by examining three sources: real estate, recreational use, and water replacement cost. Real estate values were obtained by tax assessment data inflated to 2005 values. The majority of high-priced housing was in Idyllwild. Much of the surrounding area had little or no housing (Figure 1). Recreational attractions included 128 km of hiking trails and an aerial tramway from the Palm Springs area that attracts 350,000 visitors annually. Two ranger stations and a state park office issue usage permits to visitors, which allows the annual visitation to be tracked and regulated. Recreational usage value was obtained from these permits. Finally, the value of water resources was estimated by considering the cost to replace water supplies that would be contaminated due to post-fire erosion. The three sources of economic value were then aggregated into a spatial data layer. The data layer estimated total economic values of every 30-meter square pixel in the SJRD

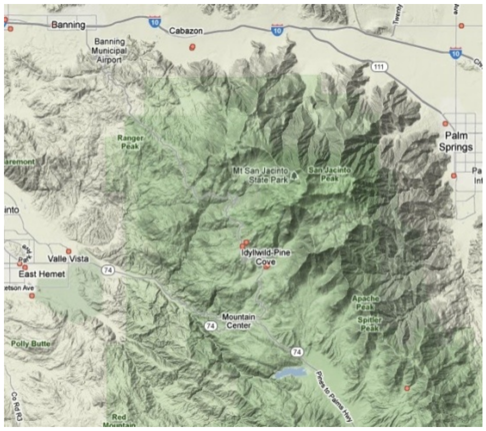

Figure 1—The San Jacinto Ranger District. The Idyllwild-Pine Cove community near the district's center accounts for most of its developed area. Source: Google Maps.

Batch fire simulations

We collected several geographic data layers for the district, such as a map of elevation values. A fuel model map was obtained from the California Department of Forestry and Fire Protection's FRAP website (FRAP 2007). This map identified the observed arrangement of fuel models in the SJRD in 2004. Fuel models are used in modeling fire behavior.

We chose four sites within the district to represent different land uses: Real Estate, Real Estate Edge, Recreation Only, and Non-Use. The Real Estate site represented high-valued properties and was centered on the town of Idyllwild. The Real Estate Edge site was located in an area consisting of approximately half real estate (Idyllwild) and half undeveloped wilderness. Two areas along the main highway through the San Jacinto district were selected to represent Recreation Only use. Finally, a generally inaccessible, non-utilized area was chosen that represented the Non-Use site. All sites have the same area of approximately 12.6 square kilometers (Figure 2).

Within each of the four sites, 100 *x*-*y* coordinate pairs were randomly and uniformly selected. These locations served as the simulated ignition points of fires for the fire model used. Additionally, 100 starting times were randomly selected without replacement for each site from June 1, 2005 to July 10, 2006, a period for which we had modeled 1km spacing, hourly gridded wind and weather data for the San Jacinto area using Meso-scale Spectral Model (MSM, Juang 2000). The simulation was done by forcing MSM with roughly 60km spacing operational analysis from National Centers for Environmental Prediction.

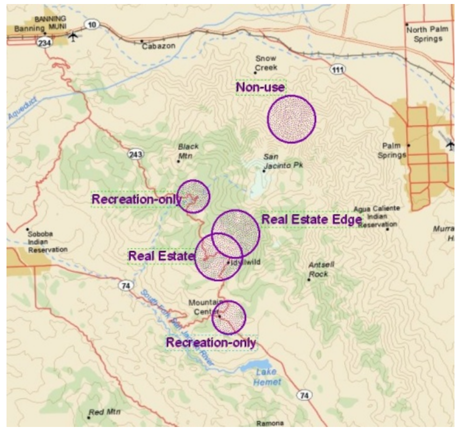

Figure 2—Locations of selected study sites in the San Jacinto Ranger District.

In addition, temperature, relative humidity and precipitation were used in the fire model as a single stream of hourly values representing the entire modeling domain. Data for these variables came from the Keenwild weather station located near Idyllwild, and was collected for the same period as that covered by the gridded RSM wind data.

Each unique combination of the randomly selected locations and starting times at each site defined the scenario for a single fire growth simulation. We used FARSITE version 4.1.0 fire area simulator to perform the simulation runs for these scenarios. FARSITE is a popular tool among fire managers in the United States for predicting both prescribed fire and wildfire behavior. It is typically run as a Microsoft Windows application, allowing the user to visualize predicted fire behavior given terrain, fuels, and weather as input parameters. Output can also include raster grid files of the arrival times, fire line intensities, flame lengths, and spread rates, as well as vector files of simulated fire perimeters (Finney 1998).

We created a command line version of the program that could be iteratively driven by a Perl script. The script used different input parameters for each run based on the random locations and starting times. Terrain and fuel conditions at and around each location, along with weather conditions, would determine the modeled fire behavior. We set a maximum of six hours simulation time on each run. Realistically there are fires that burn much longer than this time limit; however, the intent was to model *free-burning* fires without significant suppression activity taken.

A total of 40,000 attempted *free-burning* fire simulations were made (100 locations x 100 starting times x 4 sites). Each run produced an output grid of arrival time values over the same 30-meter cells that the input landscape data layers were divided into. The arrival time of each cell is the amount of time (in hours) that the fire took from the ignition pointto each cell. All arrival time grids from each site's completed simulation runs were compiled into a summary grid, where cell values represented the total number of times they had positive arrival time values during the runs. This summary grid could be interpreted as a two-dimensional histogram, indicating how often each cell was 'burnt' during the simulated fires. Estimated probabilities of burning were obtained by dividing the cell values by the number of successful runs. Multiplying this grid of probability values by the economic data layer produced a map of expected loss due to wildfire.

Fire suppression modeling

After the initial set of free-burning simulations, asecond set wasperformedusing the same random locations and times butincluding simulated fire suppression. We developed a system for suppression actions by predefiningtactics as a set of rules to use in FARSITE. FARSITE allowed obstructions to fire growth to be specified, given point-to-point paths and rates or coverage lengths. We defined a set of firefighting resources for suppression actions, which emulated actual resources that could be available to a forest district (Table 1); and included production rates and costs. Resource attributes were taken from estimates given in resource allocation studies (Donovan and Rideout 2003, Wiitala 1999) and adjusted by the U.S. Consumer Price Index.

These fire simulations were allowed to run unrestricted for the first hour to model the time between which the fire ignites and fire suppression begins. After the initial hour, these simulations ran for only five hours in simulation time, and thus were *six*-hour simulations like the free-burning ones. As in the unsuppressed case, a total of 40,000 simulations were run. The modified driving script decided suppression tactics given the first hour perimeter (unsuppressed) of each fire. Costs of resources used during each simulation were included with the arrival time grid output. Another expected loss map was then produced using the same method as with the unsuppressed simulations.

Table 1—*Suppression resources modeled in fire simulations.*

Resource	Quantity	Cost
Type II Hand crew	2	Flat fee: $1260.69 Per hour: $ 160.96
Type I Hand crew - "Hotshots"	1	Flat fee: $1600.01 Per hour: $ 225.35
Engine - 600 gallon capacity	1	Flat fee: $ 435.35 Per hour: $ 76.56
Engine - 1000 gallon capacity	1	Flat fee: $ 317.62 Per hour: $ 76.56
Air tanker - 1200 gallon capacity	1	Per drop: $9271.71
Air tanker - 200 gall	1	Per drop: $5150.95

on capacity		
Helicopter - 375 gallon capacity	1	Per drop: $1064.65
Helicopter - 1000 gallon capacity	1	Per drop: $2839.06

Fuel treatment modeling

The costs and effectiveness of fuel treatments in the SJRD was of interest. We incorporated fuel treatment effects into our simulations by obtaining actual treatment information for SJRD for 2004 to 2010 (Region 5 – Geospatial Data 2012). These records included descriptions of treatment activities and costs. Most of the treatments occurred around Idyllwild or along the main highways through the forested region. A new fuel models map was built using ArcFuels that presented the effects of fuel treatments on the area (Vaillant and others 2012). We reran the unsuppressed fire simulations (40,000) using the modified fuels map and all original information. As before, we created an expected loss map based on these runs. To compute costs for the four study areas (Figure 3), it was necessary to assign the treatments to only one area each. This allowed treatment costs to be summed and used to represent total preventative costs for each study area.

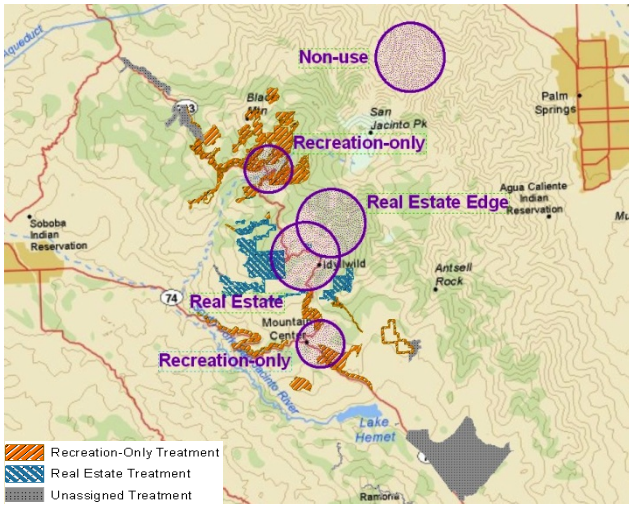

Figure 3—Fuel treatments applied to the San Jacinto Ranger District from 2004-2010. The Recreation Only and Real Estate study areas were assigned costs of nearby treatments. Costs for treatments far from the study sites were disregarded. The Real Estate Edge and Non-Use sites had no treatment costs since there were none in their proximity.

Combined modeling

Finally, we performed a set of suppressed fire simulation runs on the treated landscape. These runs were similar to the previous runs in all other aspects besides the use of treated fuels and suppression resources and rules. Output was again saved and processed to produce an expected loss map.

Results

We attempted a total of 160,000 simulation runs, but some problematic situations occurred[1]. All FARSITE simulations were run deterministically – effects such as random spotting were disabled. Not having any random components in the fire model meant that perimeter differences could then be attributed solely to particular ignition points, weather scenarios, and to using or not using suppression or fuel treatments.

Figure 4 shows charts of the total simulated costs spent for protection, total burned area of successful runs, and losses due to damage. The Cost charts represent money spent on suppression resources, fuel treatments, or both. The Real Estate Edge and Non-Use sites had no treatment costs because none were applied in these areas. Also, the proximity of treatments applied to the Real Estate site resulted in differences in the Real Estate Edge treated versus untreated cases.

We computed loss from the developed economic data layer discussed earlier.

[1]Because of space limitations these are not presented here, and are not considered in the results.

Loss was accumulated from the economic values of 'burned' pixels for all simulation runs for each of the four sites. Overall total loss values tended to be exceedingly large partly because of high-priced real estate (mainly in the Idyllwild area) loss included values.

Total area burned is the sum of the final (6-hour) perimeter sizes of the fire simulations for each case. As we expected, in most cases, area burned was reduced when simulated suppression efforts were applied. In suppressed cases for the Real Estate and Real Estate Edge sites, adding treatments appeared to actually *increase* loss and area burned (Table 3). This may indicate that fuel parameters are misspecified or that fuel maps used in the fire model are inaccurate. This phenomenon may also be due to the change of fuel types 'slowing down' the line production rate from simulated fire crews and thus allowing more escaped fires. More analysis will be needed to reveal cause of the increased burned area in the treated and suppressed cases. Additionally, for the unsuppressed cases of Real Estate and Real Estate Edge sites, areas burned decreased when treatments were applied, but losses *increased*. This may happen if a fuel type was changed to one that allowed fires to burn fewer but higher-valued pixels than before treatments – an undesirable effect.

Finally, there were two situations where adding suppression to fires on treated landscapes appeared to slightly increase loss (Recreation Only site) or area burned (Real Estate site). This likely occurred because simulated fire line is included in computed fire size for each run. If suppression efforts did not greatly alter the final perimeter size of a fire, it would appear that the fire was smaller without suppression intervention. This situation seemed to occur mainly with fires that remained relatively small at the end of the simulated six-hour time period.

Figure 4—Charts of total protection cost, area burned, and loss for each of the four sites for the four cases. Note that the columns in the Suppressed, Treated case for Cost are simply the sums of the Suppressed, Untreated and Suppressed, Treated columns.

Of the four sites, Real Estate exhibited the lowest area burned values but highest loss in each of the four cases. The small fire sizes at this site may be the result of earlier fuel management practices for which the effects are reflected in the 'untreated' landscape used for the fire simulations. Potential damage by such fires would be great, as they would be occurring within the largest inhabited area within the district.

Table 3—*Total sums of costs for protection, area burned, and losses for the four sites.*

Site	Protection Cost	Area Burned (Ha)	Loss
Recreation Only			
Unsuppressed, Untreated	$0	7,701,358	$73,950,098,015
Suppressed, Untreated	$80,346,991	6,399,367	$73,690,421,333
Unsuppressed, Treated	$11,646,751	6,646,165	$68,161,910,849
Suppressed, Treated	$89,278,608	5,598,839	$68,281,014,079
Real Estate			
Unsuppressed, Untreated	$0	823,324	$304,332,752,013
Suppressed, Untreated	$62,899,279	471,933	$111,446,356,075
Unsuppressed, Treated	$8,197,408	664,961	$309,458,665,154
Suppressed, Treated	$67,544,194	672,204	$305,190,933,121
Real Estate Edge			
Unsuppressed, Untreated	$0	1,026,896	$195,790,547,680
Suppressed, Untreated	$106,832,043	599,295	$75,269,486,390
Unsuppressed, Treated	$0	1,022,757	$198,186,376,318
Suppressed, Treated	$102,309,409	919,693	$177,385,793,990
Non-Use			
Unsuppressed, Untreated	$0	3,747,335	$593,915
Suppressed, Untreated	$58,755,176	3,317,480	$528,227
Unsuppressed, Treated	$0	3,747,335	$593,915
Suppressed, Treated	$58,755,176	3,317,480	$528,227

Discussion

Results of running these nearly 160,000 fire simulations surprisingly showed minimum loss to occur when suppression was applied to a landscape that did not undergo treatment. This does not necessarily mean actual treatments did not have any beneficial effect. It is possible that the resulting treated fuels were misspecified, or that other factors were not taken into consideration. Suppression and treatments had less of an effect on area burned than we expected. The random placement and times of simulated fires may have produced unrealistic scenarios that were not accounted for when treatments were placed. Suppression heuristics could have been insufficient to completely stop the simulated fires. Run output will have to be more closely analyzed to find the source of the unexpected results.

The methodology we used is a framework to estimate cost, area burned, and damage due to fire under different protection scenarios. Adding a suppression heuristics component allowed us to include simulated firefighting effects. We were able to model the effects of fuel treatments on fire as well.

From the results presented here it is clear the potential for improvements in the methodology. The random ignition locations and starting times could have been selected using a more realistic distribution based on local fire history, thus reducing potential overrepresentation of simulated ignitions in p[articular seasons.

We implemented a version of FARSITE that employed an older set of fuel models used in the U.S. Forest Service. The system we used to determine fuel distribution after treatment required the use of a newer set of fuel models, which posed difficulty when trying to incorporate the treated fuels landscape in FARSITE. This created uncertainty and possible incorrect matches between the two sets. This version of FARSITE also only allowed for single streams of temperature, relative humidity, and precipitation values to represent weather in a large region, whereas we had modeled gridded weather data available to us. Only gridded wind values were allowed in our version. It would be advantageous to have the capability of using the other gridded weather fields rather than the single streams when modeling fires.

Improving the accuracy of the data layers we used would help produce more realistic fire simulations, suppression and treatment costs, and economic loss estimates. Work is currently underway to gather more accurate economic values for the district. This work involves surveying wilderness users to estimate nonmarket values of the region.

Fire suppression decisions could have been simulated in a number of ways, but the simplest was to define a set of heuristic rules on how resources should be deployed based on existing conditions matching real world tactics in deploying resources. Some improvement may be gained by correcting or redefining these rules, or by allowing suppression actions to be altered during the course of each fire simulation run. Such changes would likely make the simulated fire suppression decision-making component more realistic.

Results from this methodology must be interpreted carefully. The modeled behavior seen when adding or removing suppression and/or fuel treatments has not been empirically tested. Also, the spatial economic data layer we developed incorporated the nonmarket values of wilderness, water replacement costs, and real estate values. Putting too much emphasis on protecting mainly the highest value areas may lead to leaving a majority of less valued areas at a lower protection level. Since cost amounts of resources and treatments were rough estimates, the final computed monetary values may be not be as accurate as would be desired. We intend to improve the accuracy of these input values in future studies.

References

Anderson, H. E. 1982. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT- 122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

Broyles, George. 2011. Fireline production rates. 1151 1805P. San Dimas, CA: U.S. Department of Agriculture, Forest Service, San Dimas Technology and Development Center. 23 p.

Donovan, Geoffrey; Rideout, Douglas B. 2003.An integer programming model to optimize resource allocation for wildfire containment.Forest Science. 49 (2) 331-335.

Finney, Mark A. 1998. *FARSITE:* Fire Area Simulator—model development and evaluation. Res. Pap. RMRS-RP-4, Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 47 p.

FRAP – Fire and Resource Assessment Program. 2007. California Department of Forestry and Fire Protection.Web. 22 April 2012 <http://frap.fire.ca.gov/>.

Juang, H.-M. H. 2000. The NCEP Mesoscale spectral model: A revised version of the nonhydrostatic regional spectral model. Mon. Wea. Rev. 128: 2329-2362.

NWCG – National Wildfire Coordinating Group.2004a. Fireline Handbook.PMS 410-1, NFES 0065.Web. 24 April 2012. <http://www.nwcg.gov/pms/pubs/410-1/410-1.pdf>.

NWCG – National Wildfire Coordinating Group.2004b. Interagency Air Tactical Group Supervisor's Guide.NFES 1393.Web. 26 April 2012. <http://gacc.nifc.gov/eacc/library/Dispatch/aviation/ATGSguide.pdf>.

NWCG – National Wildfire Coordinating Group.2006. Incident Response Pocket Guide. PMS 461, NFES 1077.

Region 5 – Geospatial Data.2005. USDA Forest Service. 31 August 2012. <http://www.fs.usda.gov/detail/r5/landmanagement/gis?cid=STELPRDB5327833>

Scott, Joe H.; Burgan, Robert E. 2005. Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. Gen. Tech. Rep. RMRS-GTR-153. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 72 p.

Trethewey, Diane. 2007. Development of an index for quick comparison of helicopter costs and benefits. International Journal of Wildland Fire 16(4): 444-449.

USDA Forest Service. 2009. Aviation Operations and Safety Plan. Pacific Southwest Region.<http://www.fs.fed.us/r5/fire/aviation/pdf/09_av_ops_safety_plan.pdf>.

Vaillant, Nicole M.; Ager, Alan A.; Anderson, John; Miller, Lauren. 2012. ArcFuels User Guide: for use with ArcGIS 9.X. Internal Report. Prineville, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Western Wildland Environmental Threat Assessment Center. 247 p.

Wiitala, Marc. 1999. A dynamic programming approach to determining optimal forest wildfire initial attack responses. Symposium on Fire Economics, Planning, and Policy: Bottom Lines, April 5-9, 1999, San Diego, CA. Gen. Tech. Rep. PSW-GTR-173. Berkeley, CA: USDA Forest Service, Pacific Southwest Research Station; 115-123.