An Evaluation of the Economic Tradeoffs of Fuel Treatment and Fire Suppression on the Angeles National Forest Using the Fire Effects Tradeoff Model[1]

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Abstract

In this study, the Fire Effects Tradeoff Model (FETM) was used to evaluate the economic tradeoffs between fuels treatment and fire suppression on the Angeles National Forest located in southern California of the United States. FETM uses historical weather data, fire history data, current vegetation maps, prescribed-fire planning data, fuels treatment and wildfire costs and benefits, and surface and stand composition data to simulate the future annual wildland fire area burned, landscape composition, smoke emissions, and the present net value of fire suppression and fuels treatment over any time period. Five fire suppression and fuels treatment alternatives were evaluated, combining one of two fire suppression program options with five prescribed-fire intensities ranging from 0 to 52 percent of the available chaparral area per decade. Our results show that maintaining a larger suppression program with a low level of fuels treatment substantially reduces the wildfire area burned. However, the increased costs associated with this program are not met with a commensurate reduction in resource loss and suppression costs. Similarly, our results show that a smaller fire suppression program coupled with an aggressive prescribed-fire treatment option substantially reduces the wildfire area burned, but the increased costs of treatment are likewise not met with a commensurate reduction in resource loss and suppression costs. We found instead that a smaller and less costly fire suppression program, matched with a moderate intensity fuels treatment program targeting only the highest loading classes of chaparral, provides the most cost-beneficial fire protection strategy for the study area.

Introduction

In the United States today, an estimated 79 million hectares of state and federal forests and rangelands, an area twice the size of California, face high risk of large-scale wildfire and are in need of ecosystem restoration. Effective fire suppression and prevention over the past decades has resulted in the present accumulation of dense undergrowth, brush, and dead-and-down woody debris uncharacteristic of fire-adapted forest and rangeland ecosystems (GAO 1999). This unhealthy ecosystem condition, combined with recent drought conditions, disease and insect infestations,

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and invasion by exotic species, makes the forests and rangelands in many areas of the country vulnerable to costly and environmentally disruptive wildfires. A major effort is currently underway to identify and treat areas with fuels buildups posing the greatest risk of catastrophic wildland fire (USDA Forest Service 2000).

The chaparral-covered mountainous slopes of southern California are among the most hazardous and fire prone in all of the United States. Chaparral is a vegetation community composed largely of broadleaf evergreen shrubs between 1 and 4 meters tall. These communities typically occupy the steepest slopes and most skeletal soils in the mountainous areas of southern California below 2,000 meters in elevation. The leaves of the chaparral species are sclerophyllous and aromatic, and resist decay upon falling from the twigs. As the plants age, the ratio between dead wood and active stems and twigs increases dramatically, setting the stage for large-scale brush fires (Minnich 1988; Schoenherr 1992). The longer the period between fires, the greater the magnitude and intensity of the subsequent fire.

Throughout the United States, but especially in southern California, it is increasingly common to see new homes and other types of structures constructed in wildland environments (Minnich 1988). This has created an expansion of the wildland-urban interface area in which structures are located adjacent to highly flammable vegetation. Because of their location, these structures are highly vulnerable to fire should one occur in the surrounding area. In 1999, nearly 750 structures were lost in nine fires in California. One particularly devastating event was the Jones fire near Redding, California, in which 428 structures were lost in a single 10,500-hectare blaze. The tragic Oakland fire in 1988, and the wildfires of October 2003, focused national attention on the recurrent natural hazard of wildfires around California's urban areas.

Land managers and fire personnel in southern California have long sought to reduce the wildfire hazard through a combination of methods, including: education, building standards that require the use of fire-resistant materials, enhanced fire suppression capabilities, and fuels treatment programs on federal lands and in the wildland-urban interface. One lingering question for the public and land managers is the overall effectiveness of large-scale fuel reduction programs aimed principally at reducing the size and intensity of wildfires before they grow into more populated areas.

Landscape simulation modeling of disturbance processes provides an objective framework for weighing the short-term risks against the long-term benefits of fuels treatment and other restoration programs on high priority lands. In this investigation, we use the Fire Effects Tradeoff Model (FETM) to explore the economic consequences of five prescribed-fire and fire suppression program alternatives on the Angeles National Forest (ANF) in southern California. The short- and long-term consequences of these management actions are also measured in terms of the reduction in wildfire area and smoke emissions.

Methods

Study Area and Vegetation

The study area is a 234,061-hectare portion of the ANF, administered by the United States Department of Agriculture (USDA) Forest Service. The ANF is located in the San Gabriel Mountains northeast of Los Angeles, California, U.S.A, (*fig. 1*). The vegetation of the area is largely chaparral (Ottmar and others 2000), consisting of four separate species groups: northern mixed chaparral, semi-desert chaparral, chamise chaparral, and montane chaparral (*table 1*). Roughly one-half of the remaining vegetation (23 percent) is conifer woodlands (primarily *Juniperus* spp. and *Pinus* spp.), and the remainder (21 percent) is composed of hardwoods and sagebrush, or is non-vegetated.

Figure 1—Vicinity map of the Angeles National Forest in the San Gabriel Mountains of southern California, U.S.A. The study area comprises all of the Los Angeles River and San Gabriel River Ranger Districts, and that portion of the Santa Clara/Mojave Rivers Ranger District lying southeast of Highway 14. Note: 10 miles = 16 km.

Table 1—*Vegetation composition of the Angeles National Forest study area.*

Vegetation type	Area (hectares)	Percent of total area
Northern mixed chaparral	92,972	40
Semi-desert chaparral	21,741	9
Chamise chaparral	8,206	4
Montane chaparral	7,393	3
Conifer woodland	54,424	23
Hardwoods	19,958	9
Sagebrush	15,044	6
Grass	333	0.1
Non-vegetated	13,990	6
Total	234,061	100

Chaparral is highly adapted to fire disturbance. Because of its ability to stump-sprout, chaparral quickly restores its coverage of a site following fire. Many chaparral species are dependent on frequent fire for reproduction and renewal (Vankat 1979). Frequent fires have led to a mosaic of different stand ages, which vary in species composition, vegetation height, and biomass.

For purposes of this analysis, the area in each of the four main chaparral groups was sub-divided into five fuel loading classes. For northern mixed chaparral and semi-desert chaparral, the loading classes were: I—less than 2.2 metric tons hectare^{-1}, II—2.2 to 22 metric tons hectare^{-1}, III—23 to 40 metric tons hectare^{-1}, IV—41 to 54 metric tons hectare^{-1}, and V—55 to 72 metric tons hectare^{-1}. For chamise chaparral and montane chaparral, the loading classes were: I—less than 2.2 metric tons hectare^{-1}, II—2.2 to 16 metric tons hectare^{-1}, III—17 to 29 metric tons hectare^{-1}, IV—30 to 38 metric tons hectare^{-1}, and V—39 to 45 metric tons hectare^{-1}. These loading classes were used to establish priorities for prescribed-fire treatment.

Fire Frequency and Magnitude

During the 29-year period from 1970 through 1998 (USDA Forest Service 1997), a total of 4,439 fires consumed 142,379 hectares of chaparral and other vegetation within the ANF. This yields an annual average of 153 fires and 4,910 hectares (±2,450 hectares standard deviation) consumed. The median fire size was 0.04 hectares. The maximum fire size was 19,179 hectares (*fig. 2*).

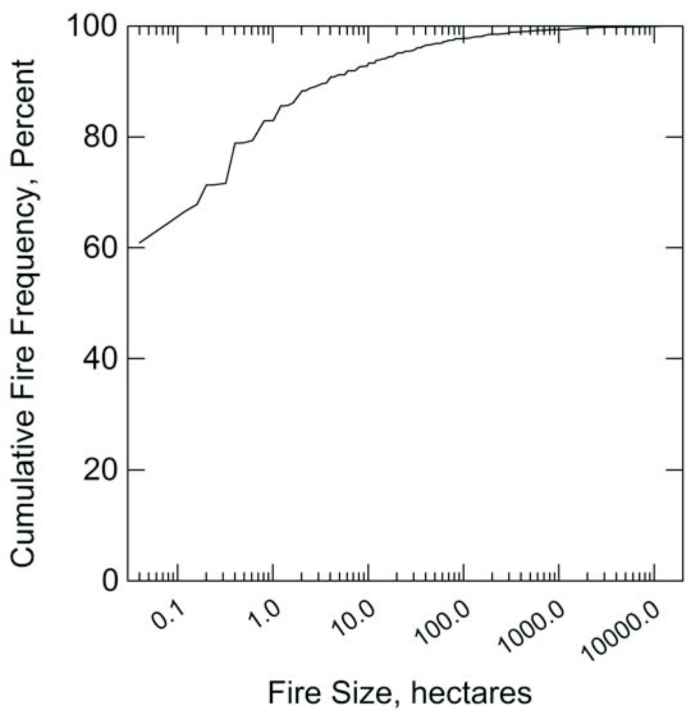

Figure 2—Cumulative fire frequency distribution for the Angeles National Forest for the period from 1970 through 1998 (USDA Forest Service 1997).

Prescribed-Fire and Fire Suppression Alternatives

Five alternatives were evaluated, each involving a different level of prescribed- fire treatment in combination with one of two fire suppression program options (*table 2*). Alternative 1 contains the larger of the two fire suppression programs (C20) coupled with the smallest prescribed-fire treatment area (zero hectares annually). Alternative 3 contains the smaller of the two suppression programs (M30) coupled with the largest prescribed-fire treatment area (12,141 hectares annually). The other three alternatives match the C20 or M30 suppression program with intermediate levels of prescribed-fire treatment.

Table 2- *Fuel treatment and suppression program alternatives for Angeles National Forest*

Alternative	Annual prescribed fire treatment area (hectares)[†]	Suppression program option (annual program cost)
1 – Larger C20 suppression program / No prescribed fire	0	C20: Current + 20 percent ($14.4 million)
2 – Larger C20 suppression program / Smallest prescribed-fire treatment area	3,035	C20: Current + 20 percent ($14.4 million)
3 – Smaller M30 suppression program / Largest prescribed-fire treatment area	12,141	M30: Most efficient level - 30 percent ($10.3 million)
4 – Smaller M30 suppression program / Intermediate prescribed-fire treatment area	6,070	M30: Most efficient level - 30 percent ($10.3 million)
5 – Smaller M30 suppression program / Variable prescribed-fire treatment area	<6,070	M30: Most efficient level - 30 percent ($10.3 million)

[†]Targets chaparral only.

The two candidate fire suppression programs (C20 and M30) were selected by ANF staff from a list of 32 available options. The two options differ in the number of hand crews, engines, and aerial firefighting resources available to respond to fires.

Chaparral was the only vegetation category targeted for prescribed-fire treatment. Each of the four chaparral groups was targeted in rough proportion to the proportion of the total chaparral area that each occupies (*table 1*). Northern mixed chaparral, with the largest initial area (92,972 hectares, or 71 percent of the total chaparral area), received the largest area of prescribed-fire treatment (8,855 hectares annually, or 73 percent of the total under Alternative 3). Montane chaparral, with the smallest initial area (7,393 hectares, or 5.7 percent of the total chaparral area), received the smallest area of prescribed-fire treatment (650 hectares annually, or 5.4 percent of the total under Alternative 3).

The fuel treatments were prioritized from the highest to the lowest fuel loading class. The highest class (V) was treated first, followed by the second highest class (IV) and so forth until the treated area equaled the planned annual area. In the case of Alternative 5, only the highest two loading classes (IV and V) were targeted for treatment in each species group. Over time, this treatment exhausted the available area in the highest chaparral loading classes, which caused the actual prescribed-fire area to drop below the 6,070-hectare planned area. Successional processes were insufficient to make up the shortfall in the area available for treatment.

Each model simulation was run for a period of 100 years and with 200 iterations for each year. The results therefore represent the "expected" outcome of fuels treatment and fire suppression at each time step.

Fire Effects Tradeoff Model

FETM[6] version 4.8.8 was used to simulate the short- and long-term effects of the five prescribed-fire treatment and fire suppression program alternatives (Schaaf and others 2004). FETM is a landscape-scale disturbance effects model designed to simulate the relative effects of alternative land management practices over long periods of time and under diverse environmental conditions, natural fire regimes, and fuel and fire management strategies. The model is based on a classical stationary Markov formulation (Feller 1968). Stationary Markov models are mathematical models that utilize matrices of empirically determined probabilities to predict vegetation class replacement, and therefore composition, over time. The transition probabilities in a stationary Markov model are analogous to the flow coefficients in a Stock and Flow simulation model (Forrester 1961). More specifically, one could interpret FETM as representing an ecosystem as a system of first-order, homogeneous, linear difference equations with constant coefficients (Luenberger 1979).

The first-order difference equation used in FETM to describe landscape change over time is:

$$\widetilde{a}_{t,p} = \mathbf{S}\left\{\left(\widetilde{a}_{t\text{-}1,p} + \sum_{r=1}^{8} \widetilde{s}_{t,p,r}\left(\mathbf{M}_r - \mathbf{I}\right)\right) + \widetilde{w}_{t,p}\right\} \tag{1}$$

where $a_{t,p}$ is an area vector (~) of fuel characteristic classes (FCC) (Sandberg and others 2001) in simulation year t for prescribed-fire treatment level p, **S** is a natural succession matrix, $s_{t,p,r}$ is a vector of area scheduled for treatment by FCC, $\mathbf{M}_r$ is an effects matrix for disturbance r (range 1 to 8), **I** is the identity matrix, and $w_{t,p}$ is a wildland fire acreage net-change vector, given by:

$$\widetilde{w}_{t,p} = \sum_{i=1}^{4} \left(\mathbf{W}_i - \mathbf{I}\right) \widetilde{F}_{t,p,i} \tag{2}$$

where $\mathbf{W}_i$ is a wildland fire effects matrix for fire weather severity class i (range 1 to 4), and $F_{t,p,i}$ is a column-vector of expected FCC area burned for year t, prescribed-fire treatment level p, and fire weather class i. FETM calculates the $F_{t,p,i}$ vector each year on the basis of the current landscape composition, number of fire starts, and predicted single-event wildfire sizes for a set of weather conditions and associated fire behaviors.

FETM is dynamic, predicting annual changes in landscape composition and effects over any time period ranging from one to 300 years. For each independent run, the starting composition in any year of simulation is linked to the previous year's results. The model is stochastic; random variables include wildfire frequencies in each of the four National Fire Danger Rating System (NFDRS; Bradshaw and others 1983) weather classes, and the potential wildfire size in the event that fuel loadings exceed the range of historical variability. FETM is a non-spatial model, capable of predicting disturbance effects within an area by vegetation class, but not capable of

[6] FETM website: www.fs.fed.us/r6/aq/fetm

predicting where those impacts will occur on the landscape or whether the impacts are contiguous or dispersed.

One feature that differentiates FETM from other landscape models is its use of fire behavior algorithms to determine the size and intensity of fire events. Rather than relying exclusively on historical fire data as the basis for determining future fire sizes and effects, FETM integrates aspects of physical fire behavior modeling into its simulations. This integration of classical fire behavior modeling into landscape simulation modeling allows FETM users to evaluate the consequences of changes in the fire environment (e.g., fuel loading, canopy structure, weather, topography) on wildfire area and other fire effects. For example, FETM can evaluate the effect of a change in surface fuel loading or stand configuration on the potential for crown fires. Integration of fire behavior modeling also offers an opportunity to quantify the level of fuel consumption and smoke emissions over time, which is an increasingly important factor in implementing management activities across the landscape.

Economic Analysis

In this investigation, the primary measure of economic efficiency is the present net value (PNV) of costs and benefits, annualized over the simulation period. More specifically, PNV is the 100-year sum of future annual fire suppression costs (FSC), annual fuel treatment costs (FTC), and monetary and non-monetary net value change (NVC) values discounted at a 4-percent real discount rate (Forest Service Handbook, FSH 1909.17). ANF staff provided the economic cost and natural resource value inputs used in this analysis.

Following the accounting procedure in the USDA Forest Service National Fire Management Assessment System (USDA Forest Service 1999), wildland fire suppression costs were calculated on the basis of two component costs: the average acre cost (AAC), and the unit mission cost (UMC). AAC is the average per-acre cost incurred during active fire suppression. UMC is the fixed cost associated with dispatching a suppression resource to a fire irrespective of whether the suppression resource engages in fire line building. The unit (that is, per hectare) costs for each vary by fire size class. Typically, the smallest fires have the highest unit FSC, and the largest fires have the lowest unit FSC.

The FTC values were computed based on user-provided per-acre fuel treatment costs, which typically vary by treatment activity and vegetative class. The ANF provided an average prescribed-fire treatment cost of $555 per hectare.

The NVC resulting from fire disturbance is the algebraic sum of the economic effects of fire on the value of natural resource outputs, both positive and negative. Here, a positive NVC represents an economic loss or cost, and a negative NVC represents an economic gain or benefit. NVC varies directly with the area burned by fire intensity level (FIL). The higher the FIL, the higher the unit NVC. The FIL is a measure of the resistance to suppression, and corresponds to different flame length ranges: FIL 1, 0- to 2-foot flame lengths; FIL 2, 2- to 4-foot flame lengths; FIL 3, 4- to 6-foot flame lengths; FIL 4, 6- to 8-foot flame lengths; FIL 5, 8- to 12-foot flame lengths; and FIL 6, 12+-foot flame lengths. Net value change is computed for both monetary resources (timber and range resources) and non-monetary resources (e.g., recreation, water storage, wildlife, and fish) on National Forest System lands only. The NVC values used in this analysis do not account for resource benefits or losses associated with fires that burn outside the ANF; that is, off-site resource impacts are not included in this assessment of economic tradeoffs. Off-site property losses are likewise not included.

Results

Fire Area and Emissions

Under Alternative 1, the mean annual wildfire area increases from ~3,900 hectares in year 1 to 4,300 hectares by year 40 (fig. 3a). Combining the larger fire suppression program with the smallest prescribed-fire treatment area, Alternative 2, results in a steady decrease in wildfire area over the first three decades to a relative stabilization after year 35 (fig. 3b). A similar pattern can be observed for the smaller fire suppression program coupled with largest prescribed-fire treatment area, Alternative 3 (fig. 3c). Under this alternative the wildfire acreage decreases rapidly over the first decade, followed by an increase in wildfire area over the next four decades and a relative stabilization by year 50. The increase in wildfire area over time is attributed to the high level of prescribed-fire treatment, which converts the predominantly chaparral vegetation to grass. Grass is slightly more flammable than chaparral (that is, produces larger fires) in the moderate fire weather class under which the majority of the fire starts occur each year.

In Alternative 4, the combination of a smaller suppression program with an intermediate level of prescribed-fire treatment (6,070 hectares per year) results in a rapid decline in wildfire area over the first two decades followed by a relative stabilization at the lowest level of any of the alternatives: 2,600 hectares per year (*fig. 3d*).

In Alternative 5, targeting only the highest two chaparral loading classes for treatment results in a rapid decline in wildfire area over the first two decades. This is followed by a small but steady increase in the annual wildfire area, from a mean of 2,600 hectares in year 20 to 2,900 hectares in year 100 (*fig. 3e*). In year 20, 4,166 hectares are treated by prescribed fire compared to 6,070 hectares in Alternative 4 (*table 3*).

In general, the greater the wildfire and prescribed fire area, the higher the $PM_{2.5}$ emissions (*table 3*). This pattern holds for all the alternatives except one, Alternative 3. In this alternative, FETM shows that the most aggressive prescribed-fire treatment rapidly converts the predominantly chaparral vegetation to grass, which has lower loading and lower consumption than chaparral, and therefore produces fewer emissions per hectare consumed.

Table 3-*FETM-predicted wildfire area, prescribed fire area, and $PM_{2.5}$ emissions in year 20.*

Alternative	Wildfire area (hectares)	Prescribed fire area (hectares)	$PM_{2.5}$ emissions (tons)
1	4,027	0	939
2	3,040	3,035	1,473
3	2,806	12,141	1,703
4	2,594	6,070	1,826
5	2,651	4,166	1,518

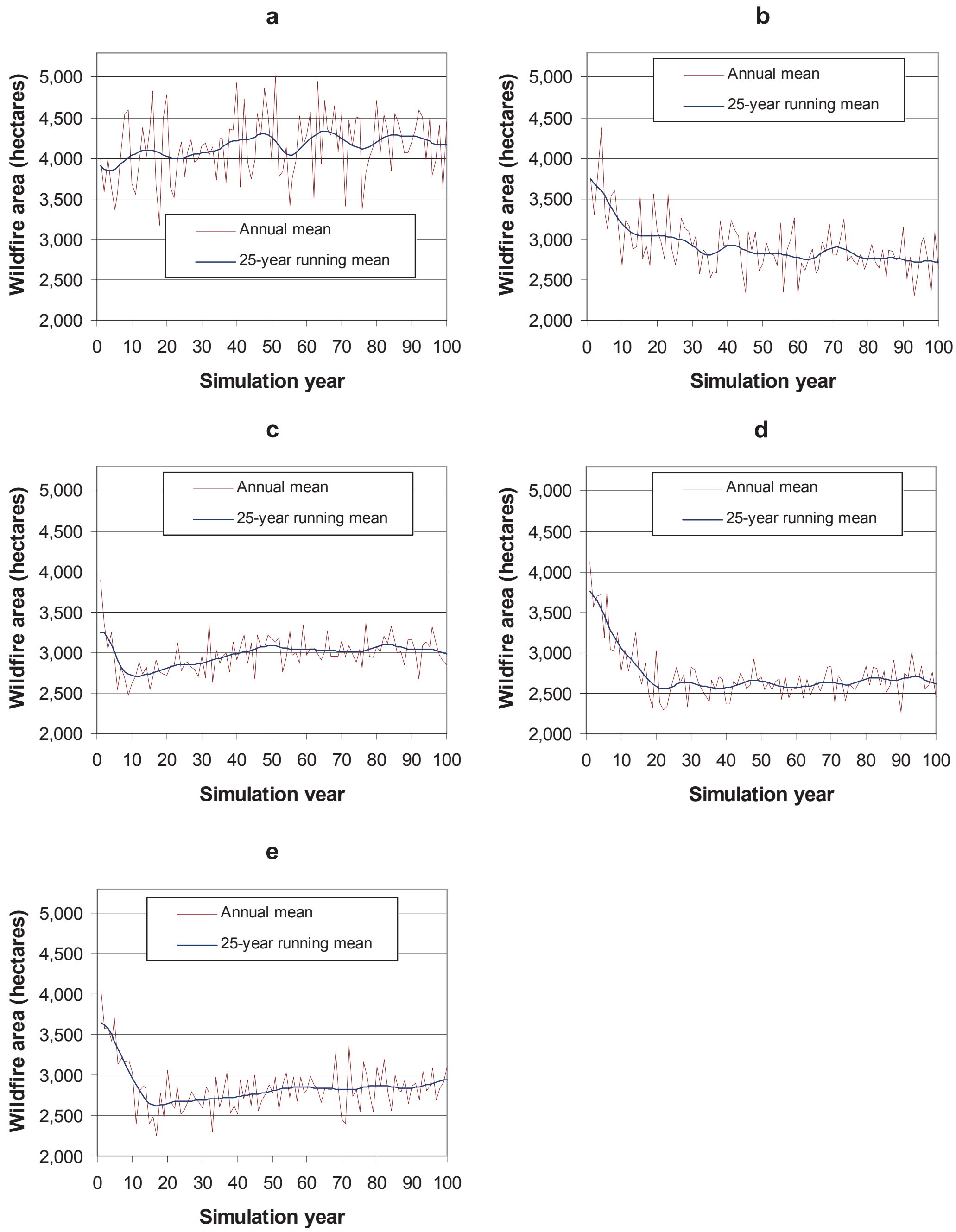

Figure 3—Time series plot of annual-average wildfire area burned for (a) Alternative 1 – Larger C20 suppression program with no prescribed fire, (b) Alternative 2 – Larger C20 suppression program with 3,035 hectares of prescribed fire annually, (c) Alternative 3 – Smaller M30 suppression program with 12,141 hectares of prescribed fire annually, (d) Alternative 4 – Smaller M30 suppression program with 6,070 hectares of prescribed fire annually, and (e) Alternative 5 – Smaller M30 suppression program with < 6,070 hectares of prescribed fire annually.

Annualized Present Net Value

The annualized PNV values for the five alternatives range from $21.3 million to $24.9 million (*table 4*). Forty to 60 percent of the annualized PNV is in program costs, depending on the alternative (*tables 2 and 4*). The C20 suppression program in Alternatives 1 and 2 has substantially higher annualized program costs than the M30 program in Alternatives 3 through 5.

Table 4-*Annualized present net value (PNV) of future costs and revenues ($1,000s of dollars).*

Alternative	Program cost	FSC	FTC	NVC wildfire	NVC prescribed fire	Total PNV
1	15,019	7,089	0	2,268	0	24,376
2	15,019	5,645	1,758	1,455	994	24,871
3	10,744	5,447	7,033	572	997	24,793
4	10,744	5,558	3,517	926	1,056	21,802
5	10,744	5,643	2,821	999	1,159	21,336

Fire suppression costs vary in direct proportion to the wildfire area consumed by fire size class. Alternative 1 contains no prescribed-fire treatment and consequently has the greatest annual wildfire area and the highest FSC. Alternative 3 has the lowest annualized FSC in spite of the fact that it has a larger annual wildfire area than Alternatives 4 and 5 because most of the wildfire area is in smaller size classes with concomitantly lower unit FSC values (*tables 3 and 4*).

Fuel treatment costs vary in direct proportion to the prescribed-fire area. Alternative 1 has no prescribed-fire area and no FTC. Alternative 3 has the largest area of prescribed-fire treatment and the highest FTC (*tables 3 and 4*).

The net value change associated with wildfire varies in direct proportion with the wildfire area. Alternative 1 has the largest wildfire area and also the highest annualized NVC for wildfire (*N.B*. Alternative 1 contains the larger suppression program but no prescribed-fire treatment). Alternative 3 has the lowest annualized NVC even though its wildfire area is larger than the area burned under either Alternatives 4 or 5. This is because most of the wildfire area in Alternative 3 is in grass vegetation, which burns at lower FIL than chaparral and with concomitantly lower unit NVC values (*tables 3 and 4*).

The net value change for prescribed fire varies in direct proportion with the prescribed-fire area. Alternative 1 has no prescribed-fire treatment program and therefore no prescribed-fire NVC. Alternatives 2 and 3 have similar prescribed-fire NVC, despite the fact that the latter has four times more prescribed-fire area than the former. The reason for this is that over time the more aggressive prescribed-fire treatment program in Alternative 3 produces a lower average FIL, as well as a lower NVC, than the less aggressive treatment program in Alternative 2. The same explanation can be applied to a comparison of Alternatives 3, 4, and 5 (*table 4*).

The total PNV of Alternatives 1 through 3 are similar and within two percent of each other (*table 4*). This is due to tradeoffs in program and fuel treatment costs. For example, in Alternative 1 the savings in fuel treatments costs are entirely offset by the higher cost of wildfire suppression (*table 4*). Similarly, Alternative 3 has substantially lower program costs than the previous two alternatives, but these savings are offset by higher fuel treatment costs. With the two larger suppression (C20) alternatives, total NVC costs are similar, but differ in their wildfire and prescribed fire contributions.

Alternative 4 has substantially lower annualized PNV than Alternative 3 due to the lower combined FTC and NVC.

Alternative 5 has a lower annualized PNV than Alternative 4 because the lower combined FTC and NVC more than offsets the higher FSC (*table 4*). Alternative 5 has the lowest annualized PNV of all the alternatives.

Conclusions

This study's examination of economic tradeoffs between fuels treatment and fire suppression on the ANF found that substantial economic benefits in reduced overall fire protection program costs and natural resource loss can be achieved with a smaller fire suppression program coupled with a moderate fuels treatment program targeting only the highest loading classes of chaparral. These results are based on the evaluation of five fire suppression and fuels treatment alternatives and combine one of two fire suppression programs (annualized program costs of $14.4 and $10.3 million, respectively) with five prescribed-fire treatment intensities, ranging from 0 to 52 percent of the available chaparral acreage per decade.

More specifically, our results show that the larger C20 suppression program coupled with a small prescribed-fire treatment program (Alternative 2) substantially reduces the wildfire area compared to the no-prescribed-fire alternative (Alternative 1). However, the increased cost associated with this fuels treatment program is not met with a commensurate reduction in natural resource loss and suppression cost. In examining the smaller M30 fire suppression program coupled with an aggressive prescribed-fire treatment program (Alternative 3), our results show a slight increase in protection benefits over Alternative 2. However, the increased cost associated with this fuel treatment program is still not met with a commensurate reduction in natural resource loss and suppression cost. We found, instead, that a smaller and less costly fire suppression program, matched with a moderate intensity fuels treatment program targeting only the highest loading classes of chaparral (Alternative 5), provides the most cost-beneficial fire protection strategy for the ANF. Based on the USDA Forest Service's historical budgeting process, which does not consider off-site resource impacts, there appears to be little or no economic advantage in adopting alternatives with the larger of the two fire suppression programs. However, recent experience in Southern California shows that off-site property losses can be overwhelming. Including the risk of off-site impacts and associated economic losses would very likely alter the conclusions of this analysis.

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