Cost-Effective Fire Management for Southern California's Chaparral Wilderness: An Analytical Procedure[1]

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Abstract: Fire management has always meant fire suppression to the managers of the chaparral covered southern California National Forests. Today, Forest Service fire management programs must be cost effective, while wilderness fire management objectives are aimed at recreating natural fire regimes. A cost-effectiveness analysis has been developed to compare fire management options for meeting these objectives in California's chaparral wilderness. This paper describes the analytical procedure using examples from a study currently being conducted for the Los Padres National Forest, and discusses some preliminary results.

The southern California National Forests (Los Padres, Angeles, San Bernardino, and Cleveland) were originally established to protect the area's chaparral watersheds from fire, but now bear many additional demands and values. For example, over 35 percent of the Los Padres National Forest is designated or proposed wilderness. The goal of fire management in Forest Service wilderness is the restoration and continuance of natural fire regimes (USDA Forest Service 1986). Fire is a natural component of chaparral ecosystems. But, restoring fire's natural role will be difficult and expensive given past fire suppression policies and present urban-wildland interface conditions. Forest managers are now charged with restoring this natural fire regime in a cost-effective manner.

Prescribed lightning fire management, prescribed burning, and the use of "appropriate suppression responses" are legal wilderness fire management options (USDA Forest Service 1984). Prescribed lightning fire management is the use of highly detailed prescriptions to monitor and manage lightning fires. The prescriptions include environmental conditions, air quality constraints, fire and weather histories, limitations on size and intensity, probability that the fire will remain within acceptable size limits, safety of firefighters and the public, and availability of suppression forces if the fire leaves prescription and must be suppressed. Prescribed burning is similar to prescribed lightning fire management except that Forest Service land managers ignite the fires on their own time schedule when burning conditions are optimal (which often means out of the natural fire season).

Any fire not classified as a prescribed fire is a wildfire and must receive an appropriate suppression response. But, Forest Service policy no longer requires this response to be intensive suppression efforts aimed at keeping the fire as small as possible (a control response), as a wildfire can now be contained or confined. Containment is to surround a fire with minimal control lines and utilize natural barriers to stop its spread. Confinement is to limit a fire's spread to a predetermined area principally by the use of natural barriers, preconstructed barriers, and environmental conditions (USDA Forest Service 1984).

Southern California Forest managers are planning to continue intensive suppression efforts on wildfires and to maintain chaparral wilderness fire regimes through prescribed burns (USDA Forest Service 1988). However, appropriate suppression responses or lightning fire management might be more cost-effective approaches (that is, might reduce the costs and impacts of fire suppression and allow more acres to burn under natural conditions). This paper has three main objectives:

1. To describe a cost-effectiveness analysis (CFA) to compare fire management options for California's chaparral wilderness.
2. To illustrate its use through examples from a study being undertaken for the San Rafael and Dick Smith Wilderness Areas on the Los Padres National Forest.
3. To discuss some of the preliminary findings of the Los Padres Analysis.[3]

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[3]The Los Padres CEA is currently being conducted through a McIntire Stennis grant from the Natural Resources Management Department at Cal Poly, San Luis Obispo, and in cooperation with the Los Padres National Forest. The final results of this CEA will be available by April, 1989 from the authors.

BACKGROUND

Several economic models have been developed to evaluate fire management programs (Saveland 1986; Mills and Bratten 1982; USDA Forest Service 1987). Most of these models are intended for large-scale fire management planning and cannot evaluate the effects of anything less than intensive suppression responses. Furthermore, many are based on the "cost plus net value change" (C + NVC) economic efficiency criterion.

For example, the National Fire Management Analysis System (NFMAS--USDA Forest Service 1987) is used for fire management planning by all National Forests. NFMAS develops fire occurrence probabilities from forestwide fire occurrence histories, then uses computer models of fire behavior and suppression efforts to determine average annual suppression costs and burned areas for different fire management budget levels and management emphases (for example, allocating more dollars for fuels management than for suppression forces or prevention programs). From burned area estimates, net resource value changes caused by fire (NVCs) are calculated based on acreage burned by intensity level. The budget level and management emphasis which minimizes the sum of fire management costs and NVCs is considered the most efficient.

This type of analysis is inappropriate for wilderness fire management planning for several reasons. First, basing fire occurrence rates on large area fire histories misrepresents the fire regime of small, remote wilderness areas. The greatest cause of fire on the Los Padres is arson, while almost 80 percent of the fires in the Dick Smith and San Rafael Wilderness Areas during the past 25 years were remote lightning-caused fires, often occurring under less than extreme fire weather conditions (Los Padres fire reports from 1963-87).

Second, expected cost and burned area values are derived from fire containment computer programs. Two different programs are available, but neither is capable of evaluating the effects of any suppression response other than control.

Third, current limitations of Cost + Net Value Change (C + NVC) evaluations make it inadequate for wilderness fire management planning. C + NVC is a cost-benefit economic efficiency analysis. Cost-benefit analysis is a comparison of the costs of meeting an objective against the returns or benefits. In theory, economic efficiency is achieved when the costs equal the benefits, or by the minimization of the sum of the costs and benifits (as in C + NVC). To be complete, a cost-benefit analysis must include a measure of all of the costs and all of the benefits (Williams 1973). To define the change in a resource's value caused by fire, the value of the resource itself must be defined. Currently, C + NVC evaluations include values for most primary forest resources such as timber, minerals, and forage. Net Value Changes (NVCs) have also been placed on many wilderness outputs such as water, fish and wildlife habitat, and recreational use. But, these resources are only secondary outputs, or by-products of wilderness (Saveland 1986). Without a measure of the primary value of the resource--wilderness itself in this case--a cost-benefit analysis will be incomplete, and very likely misleading (that is, the effects of fire on these by-products is not the same as its effects on a wilderness ecosystem).

Despite these problems, most of the work that has been done on the economics of wilderness fire is based on C + NVC (Condon 1985, Mills 1985). One exception is an economic evaluation of fire management options for a portion of the Frank Church--River of No Return Wilderness Area (Saveland 1986). This analysis is a cost-effectiveness comparison of four different fire management programs. The costs of each alternative are the expected annual suppression costs. And, "effectiveness" is the approximation of the average "natural" annual burned area based on what fire history studies reveal:

> Plant communities require a certain amount of fire, just as they require a certain amount of precipitation .... Altering the average annual burned area would be like altering the average annual rainfall (Saveland 1986).

Though Saveland's analysis was for a different fire regime, his definitions and much of his methodology are appropriate for California's chaparral.

COST-EFFECTIVENESS ANALYSIS

A cost-effectiveness analysis (CEA), in its truest form, is a comparison of the costs of different alternatives, where each alternative will meet the desired objectives, or have the same effects. There are five key elements of a CEA: the objectives; the alternatives; the costs; the model; and a criterion for ranking the alternatives (Quade 1967).

The Objective

The main objective of wilderness fire management is to allow lightning fire to play, as nearly as possible, its natural ecological role in restoring the natural fire regime. Research suggests that the natural fire return interval for chaparral is about 30 years (Minnich 1983, Byrne 1979). The fire records of the Los Padres (1911-1987) suggest that the chaparral burns every 45 years (USDA Forest Service 1988). The 45-year rotation was chosen for this study. Using the 45-year return interval, an average of over 5,000 acres (2024 ha) of the 231,500 acre (93,687 ha) study area would have to burn annually.

The Alternatives

Four alternatives were chosen for the Los Padres CEA. Alternative 1 is the Forest Service's past policy: Control all wildfires regardless of cause, and attempt to meet annual burned area objectives through prescribed burning. Alternative 2 is the fire management strategy proposed in the Los Padres' Land Management Plan: Contain all fires which occur under low intensity and control all moderate to high intensity fires, while pursuing an active prescribed burning program (USDA Forest Service 1988). Alternative 3: confine all low intensity starts, contain moderate to high intensity starts, and control only the starts which occur under extreme fire weather conditions. Alternative 4: the same as 3 with the addition of an approved plan for prescribed lightning fire management. Alternatives 3 and 4 would be augmented by a smaller prescribed burning program to meet average annual burned area objectives, since more acres will have been burned by wildfires and lightning caused prescribed fires.

The Costs

All measurable variable costs must be included in a CEA. Fixed costs, such as those for staffing lookouts or firefighting units, do not have to be included in the analysis as long as they remain the same for each alternative. For example, the appropriate suppression force staffing levels for the Los Padres were determined through NFMAS and by budget constraints. These levels are based on an average of over 100 fires per year, while less than 2 fires a year occur in the case study area. Therefore, wilderness fire suppression strategies will not affect forestwide personnel requirements. The variable costs that must be considered are annual suppression costs, NVCs, and costs of any prescribed burns.

The Model

The model is a simplified representation of the real world which includes all of the relevant features. The role of the model is to predict the costs of each alternative and the extent to which each would meet management objectives (Quade 1967). Decision trees can be used to evaluate alternative fire management programs in the face of uncertainties about future fire occurrences, weather, behavior, and sizes (Hirsch et al. 1981). Decision trees develop expected values, which are probability weighted averages of all possible outcomes. Probabilities are derived from fire history records for fire management planning. Cost and burned area figures can be drawn from historic fire management records, records of adjacent or comparable fire management programs, or some form of fire gaming if no historic or comparable records are available. Every wildfire is a unique event and past fire occurrences cannot be considered predictors of future fires. Thus, "expected values" are not predictions (actual future values may or may not be similar), but they do provide relative values for comparison. Therefore, decision trees make an appropriate model for our CEA.

A Criterion

The criterion for ranking alternatives is dependent upon the agency's goals and objectives. In wilderness fire management planning, many different rankings are possible. Prescribed lightning fire management might be justified even if it was more costly than intensive suppression. For example, the National Park Service considers acres burned under natural conditions more important than the cost of a fire management program (Agee 1985). Both cost and burned area are important considerations for Forest Service wilderness fire management programs, so both values must be developed.

THE LOS PADRES EXAMPLE

The decision tree for Alternative 1 of the Los Padres study (table 1) illustrates the values and probabilities which must be developed for a wilderness fire management CEA. A decision tree must be completed for each alternative, using the same probabilities, but with different suppression responses, and thus different cost and burned area values. The probabilities for each branch of the trees were calculated from the last 25 year fire history of the San Rafael and Dick Smith Wilderness Areas (including the proposed 16,500 acre--6,680 ha--addition to the San Rafael Wilderness Area).

For the first branch of the trees, all 44 fires (34 lightning- and 10 person-caused fires) were mapped by point of origin. Representative fire locations (R.L.s) were chosen to represent each historic fire (fig. 1). The probability of a fire occurring at each R.L. was based on the number of fires represented by that R.L. For example, 13 fires are represented by R.L. 1, thus 13/44, or 0.296 is the probability of a fire occurring under conditions represented by R.L. 1. The second branch was the probability of occurrence by cause. These probabilities were dependent upon the fires represented by that R.L. For example, 5 lightning- and 8 person-caused fires were represented by location 1, thus the probability of an R.L. 1 fire being caused by lightning is 5/13, or .385.

For the third branch, the 1400-hr weather observations from nearby weather stations were retrieved for the day of ignition of each historic fire and the following 30 days to develop month-long weather patterns. Weather patterns were divided into groups, based on the Santa Barbara Ranger District's prescribed burn weather parameters:

	Low	Optimum	High
Fuel stick			
1 hour	8	6	5
10 hour	14	9	7
100 hour	18	13	9
Live fuel moisture	110	70	60
Relative humidity (pct)	50	30	25
Wind speed (mi/hr)	0	5	13
Temperature (degrees F)	60	75	85

These parameters represent a window of environmental conditions which would allow for safe management of a prescribed fire, but still meet burned area objectives. Environmental conditions must remain within these parameters throughout the life of a fire for it to still be "in prescription." Prescriptions must be modified for site specific conditions and burn objectives, but these general parameters were used to distinguish fires burning under "good" conditions (low to moderate fire intensity level) and fires burning under "bad" conditions (high to extreme intensity). Four weather patterns were distinguished: (A) weather that started within prescription parameters and continued within these parameters for at least two weeks (a good-good pattern); (B) weather that started within prescription, but soon moved out of prescription (a good-bad pattern); (C) weather that started out of prescription, but soon cooled to within prescribed conditions (a bad-good pattern); and (D) weather that started out of prescription and stayed out (a bad-bad pattern). These patterns were then used to calculate the probability of lightning- and person-caused fires occurring under each pattern (table 1). For example, 15 of the 34 lightning fires occurred under "good-good" weather patterns so the probability is 0.441.

Once probabilities have been calculated, cost and burned area values must be developed for probability weighting. These values should represent the range of potential fire costs and sizes. Saveland (1986) used average costs and sizes drawn from similar fire management programs on adjacent wilderness lands. To date, no contain or confine suppression responses, lightning fire management, or prescribed burns have been

Table 1--The decision tree for Alternative 1 of the Los Padres CEA, representing the control of all fires.

	REPRESENTATIVE LOCATION	CAUSE	WEATHER PATTERN[1]	SUPPRESSION RESPONSE[2]	GAMED SIZE (acres)	EXPECTED ANNUAL BURNED AREA (acres)	GAMED COST (dollars)	EXPECTED ANNUAL COST (dollars)
ALTERNATIVE 1 (1.76 fires)	R.L. 1 (.296)	Lightning (.385)	A(.441)	CR	0.5	0.0	6,351	562
			B(.118)	CR	10.0	0.2	7,230	171
			C(.147)	CR	118.0	3.5	74,942	2,210
			D(.294)	CR	40.0	2.4	32,238	1,901
		Person (.625)	A(.100)	CR	0.5	0.0	6,351	207
			B(.200)	CR	10.0	0.7	7,230	471
			C(.200)	CR	118.0	7.7	74,942	4,880
			D(.500)	CR	40.0	6.5	32,238	5,348
	R.L. 2 (.341)	Lightning (.933)	A(.441)					
			B(.118)					
			C(.147)					
			D(.294)					
		Person (.067)	A(.100)					
			B(.200)					
			C(.200)					
			D(.500)					
	R.L. 3 (.364)	Lightning (.938)	A(.441)					
			B(.118)					
			C(.147)					
			D(.294)					
		Person (.062)	A(.100)					
			B(.200)					
			C(.200)					
			D(.500)					
			(preliminary) TOTALS:			(21ac/yr)		($15,650/yr)

[1]Weather patterns are divided into four groups based on prescribed burn parameters: A = good-good weather pattern; B = good-bad weather pattern; C = bad-good weather pattern; D = bad-bad weather pattern.

[2]Suppression response options include: control (CR); contain (CA); confine (CF); or prescribed lightning fire management (Px).

attempted in southern California wilderness. Thus, a fire gaming approach was taken.

Fire gaming is the prediction of representative fire sizes by fire management professionals. Predictions are based on the interactions of estimated fire behavior conditions and given suppression force responses (Harrod and Smith 1983). It is an acceptable technique to predict final fire sizes and costs, and has been used for Forest Service fire management planning in the past (Joseph and Gardner 1981). Gaming accuracy is dependent upon the abilities and knowledge of the fire garners (Harrod and Smith 1983). The Los Padres fire management personnel participated in fire games for the 1980 National Forest budgeting process. A 1982 fire started near a gamed location and under similar weather conditions. The resulting 825-acre (335-ha) fire was very similar in both costs and size to the gamed fire. The same gaming team (as many of the members as possible) was reassembled to game representative fires for our study.

Fire gamers include the Forest's Fire Management Officer (F.M.O.), the Assistant F.M.O., the Fuels Management Officer, the recently retired Fire Prevention Officer ("Budget 80" games leader), and two District F.M.O.s (one recently retired). All but the Forest F.M.O. were involved in the 1980 games so little training was necessary.

Gaming materials include 15-minute topographic maps and aerial photographs of the R.L.s and adjacent areas, Mylar (clear plastic) overlays, representative weather patterns (one pattern from each of the four categories was chosen for each R.L.), a list of the resources that would be dispatched initially to each R.L. (based on the Forest's current dispatch plan), a fire history map which includes all fires 300 acres (121 ha) or greater that occurred in the study area since records were started, and assorted tabulation sheets to record resources used, hours, miles of travel, and other suppression costs that would be encountered during the life of each "gamed fire" (Harrod and Smith 1983).

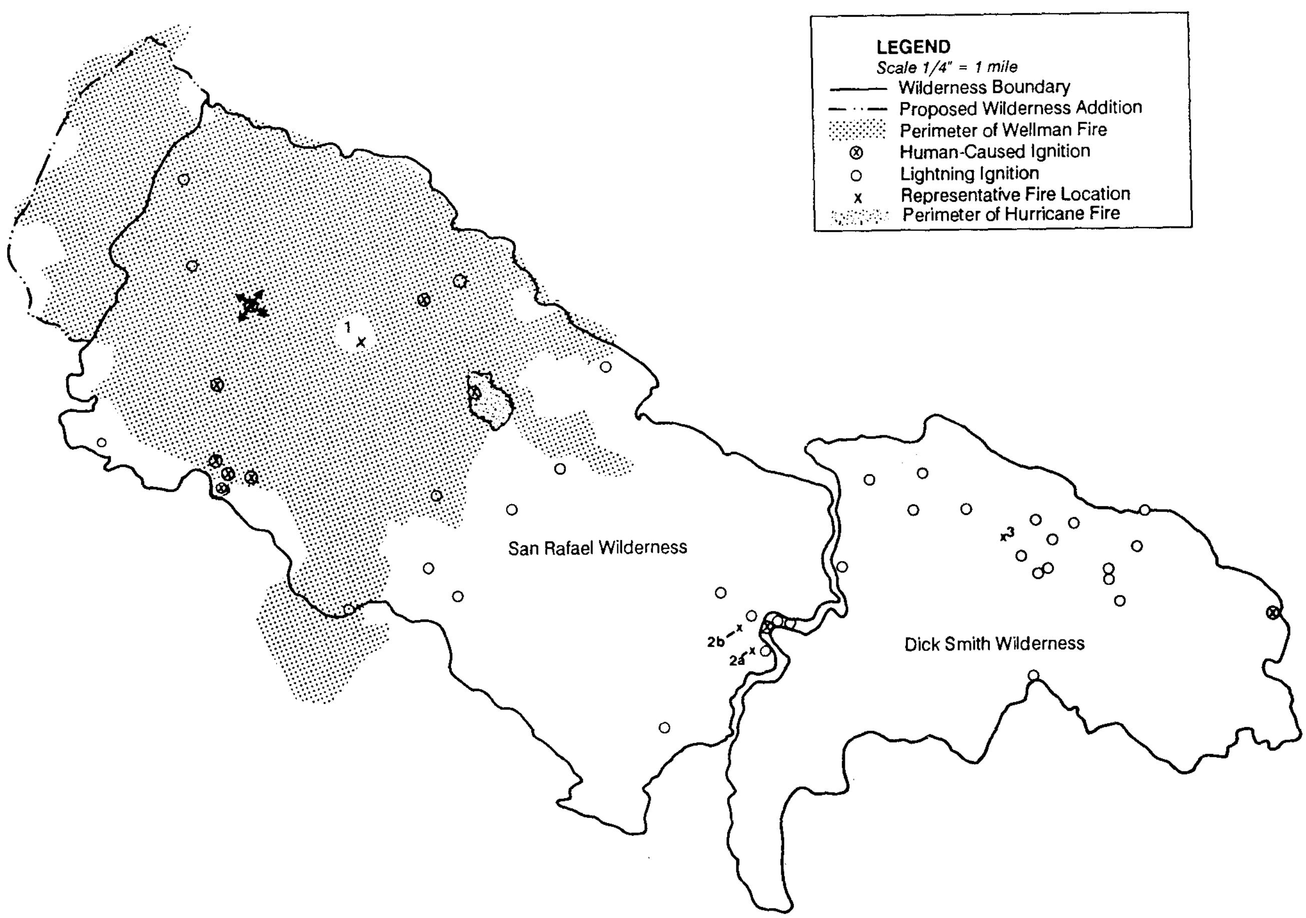

Figure 1--The last 25 year fire history of the Dick Smith and San Rafael Wilderness Areas and the corresponding representative fire locations.

Actual games consisted of first mapping an overlay of the free-burning fire spread (without any suppression efforts) from time of ignition to report and then for a series of time periods thereafter. Fire spread rates were determined from the computer program "Firecast" (Cohen 1983) based on slope and fuel conditions at the R. L., and the given weather pattern. Spread rates were subjectively modified by garners to account for changes in fuel conditions, local weather patterns, diurnal weather changes, and changes in topography as fires spread. Four weather patterns were gamed at each location. Fires started under "good" weather conditions were then gamed four times: controlled, contained, confined, and managed as a prescribed fire. Fires starting under "bad" conditions were only controlled and contained since these fires would be out of prescription, and good weather would be necessary to confine fires in these unbroken fuelbeds.

PRELIMINARY RESULTS

The results of the fire gaming for R.L. 1 and some preliminary gaming results for R.L. 2 are presented in table 2. The R.L. 1 values were then run through the appropriate decision tree for their use and preliminary expected values for average annual cost and burned area were calculated (table 3). For example, all fires were controlled in Alternative 1, thus the control gaming results were used throughout this tree (table 1). Alternative 2 results represent the containment of both fires which started under good weather conditions and the control of the two which started under bad conditions. Alternative 3 results represent the confinement of the first two fires and the containment of the latter two. Alternative 4 results were calculated similar to the third, except that 25 percent of the low intensity lightning caused fires (both good conditions) were considered prescribed fires.

Table 3 also compares each alternative's cost per area managed and average annual cost per burned area for fires represented by R.L. 1. The figures for cost per area managed are based on 68,500 acres (27,722 ha), or 29.6 percent of total wilderness.

NVCs are determined by the size and intensity level of each gamed fire. The Los Padres currently calculates these values for all 300+ acre (121 ha) fires. Only three gamed fires burned more than 300 acres at R.L. 1 and these were in a "low valued" watershed. Thus, the NVC's for R.L. 1 do not have much effect on our preliminary expected annual costs. NVCs will be

Table 3--Average annual cost, cost per area managed, average annual burned area, and average annual cost per area burned for four alternative fire management programs for Representative Fire Location 1 of the Dick Smith and San Rafael Wilderness Areas[1]

	Average annual cost	Cost per acre (ha) managed	Average annual burned acre (ha)	Average annual cost per burned acre (ha)
Historical (before suppression)			1500+ (607+)	
Alternative 1	$15,650	$0.23 ($0.57)	21.0 (8.5)	$745 ($1841)
Alternative 2	$15,096	$0.22 ($0.55)	21.0 (8.5)	$719 ($1776)
Alternative 3	$13,898	$0.20 ($0.50)	153.1 (62.0)	$91 ($224)
Alternative 4	$13,908	$0.20 ($0.50)	153.1 (62.0)	$91 ($224)

[1]Representative Fire Location 1 represents 29.6 percent of the case study fires, thus figures are calculated from 29.6 percent of the 231,500 acre (93,687 ha) site, or 68,500 acres (27,722 ha).

Table 2--Final size and cost figures for gamed fires.

	CONTROL		CONTAIN		CONFINE		Px Lightning Fire	
	Size (acres)	Cost ($)	Size (acres)	Cost ($)	Size (acres)	Cost ($)	Size (acres)	Cost ($)
Representative fire location 1								
Good-good weather pattern	0.5	6,351	0.5	3,883	4.0	2,919	4.0	3,207
Good-bad weather pattern	10.0	7,230	10.0	4,365	457.0	6,135	457.0	6,622
Bad-good weather pattern	118.0	74,942	270.0	45,791	N/G		N/G	
Bad-bad weather pattern	40.0	32,238	390.0	39,086	N/G		N/G	
Representative fire location 2[1]								
Good-good weather pattern	0.5	2,903	0.5	2,548	99.0	3,038	738.0	28,697
Good-bad weather pattern	66.7	36,759	780.0	41,367	[2]2300+	100,000+		

[1]Cost figures for representative fire location 2 have not been formally reviewed by the fire garners, thus they are subject to minor changes. However, the relationships between responses will probably not change.

[2]The confine fire game for good-bad weather at R.L. 2 has not yet been completed, but the fire will be over 2,300 acres and will probably cost over $100,000. The prescribed fire game has not been started.

important cost considerations when more valuable watersheds become involved.

DISCUSSION

The values presented in table 3 are only preliminary results as they represent only one R.L. And, R.L. 2 results cannot be run through the decision trees until all of the games for that R.L. have been completed. The values in table 3 are provided to illustrate calculation techniques and some of the results that can be developed through this type of CEA. Expected annual suppression costs and burned areas will be much higher when the decision trees are completed, and the relationships between the alternatives will probably change. Therefore, comparisons of these preliminary values are difficult to justify since they are based on such a small database (one series of games).

Despite this small database, some patterns have become evident. Many fire management personnel consider the use of confinement or prescribed lightning fire management impossible in decadent chaparral fuelbeds (for example, two fire garners before our games began). Both responses were successful at R.L. 1 (the least expensive response under good-good weather and only slightly more expensive than containment under good-bad). This R.L. is covered by fairly young (22-year-old) mixed chaparral. The relatively light fuels and extraordinarily high humidities in both good weather patterns helped confine the fires. This pattern is not being repeated at R.L. 2, where confinement and prescribed lightning fires are becoming the most expensive responses. These results suggest that confinement or prescribed lightning fire management will not be cost effective, at least until much more of these decadent fuelbeds are broken up by younger fuel mosaics and our ability to reliably forecast weather conditions increases.

Containment was feasible under moderate conditions at R.L. 1 (little more than half of the cost of control under good-good weather, and the least expensive response under good-bad), and this pattern is continuing at R.L. 2 (though it was slightly more expensive than control under the moderate intensity, good-bad fire at R.L. 2). Containment was also the least expensive response under the highest intensity fire gamed thus far (bad-good weather at R.L.1), which suggests that containment could provide some substantial fire suppression savings on fires in these wildernesses. This pattern will be closely monitored in future games, as more data will be necessary for validation of this finding.

Expected annual burned areas illustrated the anticipated pattern of more area burned under the less intensive suppression responses. The annual expected burned area for alternatives 3 and 4 is somewhat low. But, this can be attributed to the young fuels and high humidities which led to moderate burning conditions. Gamed fire sizes for confinement and prescribed lightning fires are becoming much higher at R.L. 2, and the higher pattern is probably more representative of these wildernesses.

Some unanticipated, but valuable observations of these early fire games are not directly related to our CEA. The garners--all "old-school" firefighters--originally raised questions about the feasibility of containing or confining chaparral fires. Our games compelled these fire managers to consider what they would do when required to use these responses in the field, either through policy or when suppression forces are not available.

Another important finding of our preliminary games is the value of the Forest's pre-attack manuals. During the 1960's and early 1970's, the Los Padres was divided into "pre-attack blocks". Each block was mapped, marked, and signs were posted designating potential dozer lines, hand lines, helispots, water sources, fire camp locations, and other valuable fire suppression information. These plans have recently been discarded by many fire management staffs, but have proved invaluable to the garners for the confinement and containment responses. This suggests that if appropriate suppression responses are ever to be utilized on the Los Padres, these manuals should be updated and made more readily available to fire management personnel. Even if control remained the most appropriate suppression response for the Forest, up-dated pre-attack manuals would be valuable tools for prescribed burn managers.

SUMMARY

In summary, cost-effectiveness analysis is appropriate for wilderness fire management planning. Decision trees help us predict future fire occurrence potentials, and intensive gaming efforts can help us predict fire sizes and costs associated with the implementation of appropriate suppression responses and prescribed lightning fire management. These values are important to land managers who are now faced with the cost-effective management of natural fire regimes in chaparral wilderness. This type of analysis is especially valuable for southern California land managers who have little field experience with any fire management program other than intensive suppression efforts and off-season prescribed burning, especially given the risks associated with fire in volatile chaparral ecosystems. Fire games are not only providing a valuable evaluation of appropriate suppression responses and prescribed lightning fire management, but are also proving educational to "old school" fire management personnel and illustrating some potentially cost effective alternatives to intensive suppression efforts.

ACKNOWLEDGMENTS

We thank the following persons, all with the Forest Service, U.S. Department of Agriculture: Santa Lucia and Santa Barbara Ranger District Fire Management Officers Chet Cash, and Tom Goldenbee (recently retired), Los Padres National Forest Fire Prevention Officer Dennis Ensign (recently retired), Forest Fuels Management Officer Harold Cahill, and Forest Assistant Fire Management Officer Lonnie Briggs for their extensive time commitments to fire gaming; Economist Eric Smith of the Regional Office, San Francisco, CA. for technical counsel; Economist Armando Gonzalez-Caban of the Forest Fire Laboratory, Riverside, CA. for technical counsel and review; Santa Barbara Ranger District Fuels Management Officer Jim Shackelford for technical review; and Jane Cochrane of the Los Padres' Business Management Staff for extensive editorial review. This project was funded by a McIntire Stennis grant from the Natural Resources Management Department, California Polytechnic State University, San Luis Obispo.

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