



S e s s i o n

VI

**Fuel Treatment, Prescribed Fire, and Fire Restoration:
Are the Benefits Worth It?**

Chairs: Susan Husari and Melanie Miller

Applying Simulation and Optimization to Plan Fuel Treatments at Landscape Scales¹

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Abstract

Fuel treatment activities are analyzed at the landscape scale by using both simulation and optimization. Simulating vegetative patterns and processes at landscape scales (SIMPPLLE), a stochastic simulation modeling system, is initially applied to assess wildfire risks on the current landscape without management treatments but with fire suppression. These simulation results are input into a multi-resource analysis and geographic information system (MAGIS), an optimization modeling system, for scheduling activities that reduce these risks and address other management objectives. The derived treatment schedules are used in additional SIMPPLLE simulations to examine the change in wildfire risk and other natural processes. Fuel treatment effects are quantified as changes in the predicted extent and intensity of future wildfires and the resulting economic benefits.

Past management practices have excluded fire from what are now known as fire-dependent plant communities. Over time this has resulted in the unnatural build-up of fuels, increasing the probability of catastrophic wildfire (Arno 1996b, USDA Forest Service 1996a). Historically, some of these fire-dependent communities were modified by frequent, low-intensity ground fires; stand-replacing crown fires occurred rarely if at all (Arno 1996a, Williams 1995).

Fuel treatment activities are being applied to address this problem of fuel build-up. But it is not known what strategies are most effective for answering the questions of when, where and how to treat these fuels. Is it more effective to target the acres where the problem is most severe, but where the per-acre treatment costs are very high? Or is it better to target acres that are not now critical, but will become so in the future if not treated? Because the per-acre treatment costs for these areas are less, more acres can be treated with the same budget. How can managers identify the fuel conditions that are most effective to treat without addressing the spatial pattern of fuels and how treatments will be applied over time? Fuel treatments, however, are but one of many issues of concern to land managers. Ultimately management activities must be planned and implemented in view of a variety of objectives and constraints that arise from the Forest Plan and scoping done by forest resource specialists and the public. Managers must be able to develop and evaluate alternatives that address the objectives and constraints that sometimes conflict. This assessment of alternatives and the implementation of the selected alternatives are carried out in a spatial context at the landscape level.

Quantitative techniques are needed by which the spatial arrangement and timing of fuel treatment options can be analyzed in the ecosystem landscape assessment and planning process. These techniques need to address the likely changes in the extent and intensity of wildfire that result from fuel treatments, the economic payoffs in terms of reduced fire suppression costs and net value loss, and finally, impacts on other resources.

The Bitterroot Ecosystem Management/Research Project (BEMRP) is a cooperative project involving the USDA Forest Service's Rocky Mountain Research Station, Bitterroot National Forest, and Northern Region, and The

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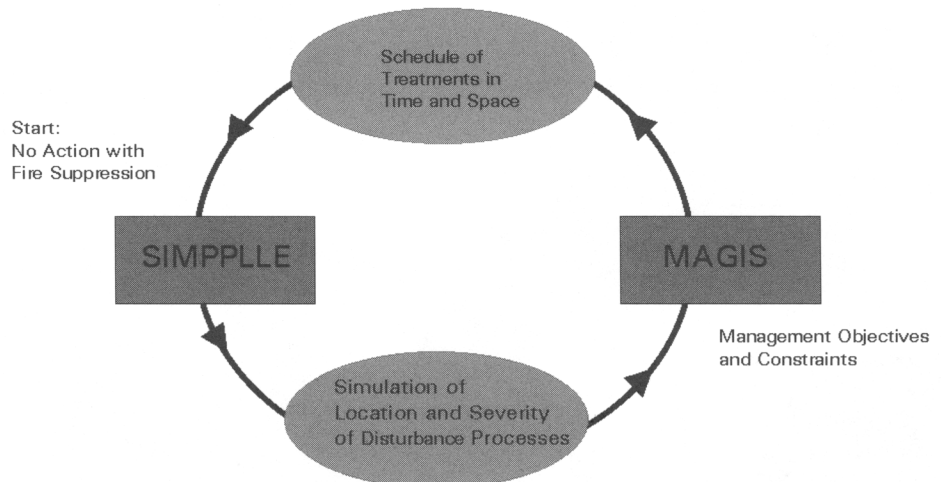
University of Montana. Scientists and land managers in the Landscape Analysis Group of BEMRP have developed and implemented a modeling framework that uses two modeling systems: simulating vegetative patterns and processes at landscape scales (SIMPPLLE) and the multi-resource analysis and geographic information system (MAGIS), that interact with data in a spatial and temporal context. SIMPPLLE is a model that projects changes in vegetation over time and space by using a state/pathway approach (Chew 1995). A vegetative state is defined by dominant tree species, size class, and density as well as association with a habitat type group (Pfister and others 1977). MAGIS is a microcomputer-based spatial decision support system (SDSS) for planning land management and transportation-related activities on a geographic and temporal basis in the presence of multiple and sometimes conflicting objectives (Zuuring and others 1995). These models permit land managers to predict vegetation change over landscapes, change in the probability of disturbance processes relative to vegetation change, and future effects on resource values.

The Approach

Although some analysts using a single modeling system approach have addressed these problems, we have chosen to use two landscape modeling systems that are integrated for project planning purposes. A simulator and an optimizer are used and executed as separate entities that share information between them. In this way the analyst uses the strengths of both modeling systems (*fig. 1*).

The process begins by using SIMPPLLE to project the frequency and location of natural disturbances for the "no action" management alternative with fire suppression. These results are then used to compute a risk index for each stand on the basis of the most likely type of disturbance and the probability of its occurrence. This index is incorporated into a management relation, built in MAGIS, to evaluate fuel treatments and their economic payoffs. Additional management relations that together comprise a planning scenario handle other issues. Examples of such relations are acres in various stand size classes, equivalent clear cut acres by watershed, sediment production by watershed, big game hiding cover by third order drainage, pine marten habitat index by third order drainage, and net revenues from several accounting stances. Amounts are calculated for these management relations when MAGIS is run in either simulation mode (managers choose the location and timing of activities) or optimization mode (the solution process chooses the timing and location of activities on the basis of the stated objectives). In a fuel treatment situation the analyst is usually interested in minimizing a risk index subject to a set of constraining management relations while attaining a reasonable net revenue

Figure 1
Analysis approach that uses the strengths of both modeling systems: simulating vegetative patterns and processes at landscape scales (SIMPPLLE) and multi-resource analysis and geographic information system (MAGIS).



(not maximized but costs are at least covered by revenues). The solution yields outputs in the form of stand acres that are multiplied by their corresponding risk index and summed over all stands. In this manner a number of alternative planning scenarios, each consisting of a series of treatments applied over time and space, can be compared (on the basis of certain criteria) to identify those alternatives that reduce or eliminate the risk. The schedule of activities proposed by MAGIS is imported into SIMPPLLE where additional simulations are run to evaluate the changes in location and extent of disturbances associated with these activities.

Methods

The sequential approach of applying SIMPPLLE and MAGIS was applied on the 58,084-acre Stevensville West Central area of the Bitterroot National Forest in Montana. SIMPPLLE and MAGIS applications were initially developed in cooperation with Forest staff and applied in an integrated resource analysis of that area (USDA Forest Service 1996b). The area modeled includes 25,284 acres in the Selway-Bitterroot Wilderness, 14,155 acres of National Forest outside Wilderness, and 18,645 acres in private ownerships. No treatments were proposed for the private land. It was instead included to capture interactions in functions and processes with adjacent National Forest lands.

The first step was to run stochastic simulations of SIMPPLLE over 5 decades for the "no action" management alternative with fire suppression. The number of acres impacted by four specific natural processes and their associated frequencies of occurrence in stands located across the landscape were computed. These four processes were stand-replacement fire, mixed-severity fire, light-severity fire, and western spruce budworm.

A risk index was developed to capture the relative importance of various natural processes and their frequency. This index can be thought of as a measure of undesirability of these processes, or alternatively, a prioritization for the application of fuel treatments. The weights assigned to this risk index are:

Weight value	Risk source	Frequency of source
0	Stand not listed	
2	Light spruce budworm	≥ 50 pct
2	Mountain pine beetle	≥ 50 pct
4	Low probability of stand replacing fire	1 - 10 pct
6	Severe spruce budworm	≥ 50 pct
8	Moderate probability of stand replacing fire	11 - 20 pct
10	High probability of stand replacing fire	≥ 20 pct

The distribution of these index weights was determined on the basis of the frequency of these processes on the landscape (*fig. 2*). For each stand, risk index weights were entered into MAGIS, and a risk index management relation was constructed. This risk index management relation multiplies the risk index assigned to the stand by the stand acres and sums this product across the stands as follows:

$$\text{Risk index management relation} = \sum_a \sum_s \sum_p r_{asp} * X_{asp}$$

in which:

- X_{asp} = Treatment option a applied to stand s in decade p ,
- r_{asp} = Risk index value in decade p as a result of applying treatment option a to stand s . For "no action," r_{asp} equals the index assigned by SIMPPLLE. If a treatment is undertaken that addresses the risk, r_{asp} after treatment is reduced accordingly.

Table 1-Specifications for four fuel treatment scenarios for the Stevensville West Central area on the Bitterroot National Forest, Montana.

Issue	Scenario			
	1	2	3	4
Prescribed fire permitted in Wilderness	X	X		
Minimum risk index in decade 1	X		X	
Minimum risk index in decade 3		X		X
Water yield limits			X	X
Sediment yield limits			X	X
Harvest volume per decade < 10,000 CCF	X	X	X	X

The next step was to run MAGIS in simulation mode to compute the risk index management relation value for the "no action" alternative. MAGIS was then used to develop four fuel treatment scenarios for the landscape (table 1). Scenarios 1 and 2 both permit prescribed burning in the Wilderness area. They differ in that Scenario 1 requires the risk index to be minimized in decade 1, while the timing is relaxed in Scenario 2 to minimize risk by decade 3. Fuel treatments for Scenarios 3 and 4 are limited to the 14,155 acres of National Forest outside the Wilderness, and water and sediment yields were limited to Forest Plan direction in six individual watersheds. Like the first two scenarios, Scenarios 3 and 4 differ by the decade for minimizing risk index: decade 1 for Scenario 3 and decade 3 for Scenario 4. All four scenarios limited the volume of timber harvest per decade to 10,000 CCF or less, assuming that larger harvests would be politically unacceptable.

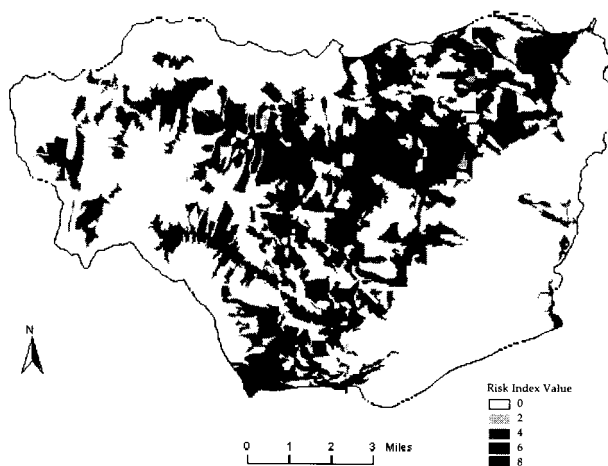
Each scenario was solved by first minimizing the risk index management relation for the specified decade, then achieving a second solution in which present net value was maximized while holding that risk index management relation to an amount slightly above the previously attained minimum value. The other conditions for the scenarios (table 1) were in effect in these solutions. This sequence develops an economically efficient scenario for minimizing risk while meeting the other scenario conditions. These solutions schedule treatments both spatially and temporally (fig. 3).

Results

The results pertaining to the four scenarios and the "no action" alternative were determined (table 2). The risk index associated with the "no action" alternative was 93,196. Scenario 1 reduced the risk index to 26,000 in decade 1, but with a net cost of \$2,518,000. This scenario contained 14,856 acres of broadcast burning in decade 1, as well as fuel treatments involving 306 partial cut and 298 regeneration cut acres that resulted in commercial timber harvests. Postponing the minimization of the risk index until decade 3 (Scenario 2) resulted in a positive

Figure 2

The spatial distribution of risk index based on natural processes occurring over 5 decades.



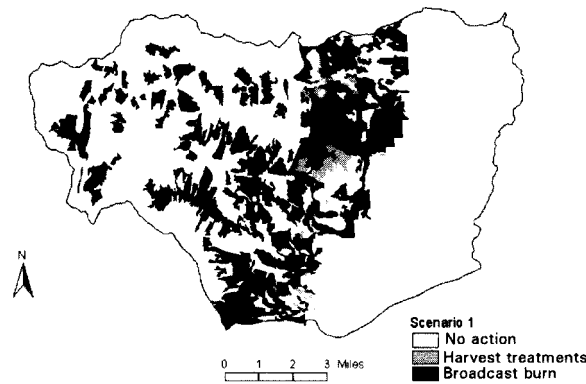


Figure 3
The spatial distribution of decade 1 burning and harvesting fuel treatments for Scenario 1.

present net value of \$148,000 associated with the treatments. When the broadcast burning was postponed until decade 3, the treated area was reduced by 1,145 acres as compared to Scenario 1.

For Scenarios 3 and 4 where fuel treatments are limited to only the public non-Wilderness area, the risk index was reduced to 52,000. Broadcast burning reduced to 8,525 in decade 1 for Scenario 3 and to 7,556 acres in decade 3 for Scenario 4. Acres of fuel treatments involving timber harvests for Scenarios 3 and 4 approximated those for Scenarios 1 and 2. The fewer prescribed burning acres resulted in an improved financial situation with present net values, \$-608,000 for Scenario 3 and \$979,000 for Scenario 4.

Next, the four management scenarios were entered into SIMPLLE to model the effect of these treatment schedules on acres of stand-replacing fire (SRF), mixed-severity fire (MSF), light-severity fire (LSF), and western spruce budworm (WSBW), as well as the net effect on smoke production, and fire suppression costs. Twenty simulations were run for 5 decades for each scenario. For SRF, the pattern over the 5 decades for Scenarios 1 and 3 is similar to "no action," but with about 200 fewer acres burned on the average (*fig. 4*). For Scenarios 2 and 4, SRF acres are initially higher than "no action," decrease substantially for decades 2-4,

Table 2-Summary of solution amounts for selected management relations "no action" and Scenarios 1 - 4.

Management relation	Units	No Action	Scenario			
			1	2	3	4
Present net value ¹	\$1000	0	-2,518	148	-608	979
Risk index for decade 1	Index	93,196	26,000	90,637	52,000	91,042
Risk index for decade 3	Index	93,196	25,918	26,000	52,000	52,000
Harvest volume-decade 1	CCF	0	7,872	10,000	10,000	10,000
Harvest volume-decade 2	CCF	0	0	6,746	489	8,463
Harvest volume-decade 3	CCF	0	4,659	3,301	7,269	3,562
Under-burning-decade 1	Acres	0	0	0	24	15
Under-burning-decade 2	Acres	0	0	0	0	0
Under-burning-decade 3	Acres	0	0	0	0	0
Broadcast burning-decade 1	Acres	0	14,856	0	8,526	0
Broadcast burning-decade 2	Acres	0	0	0	0	0
Broadcast burning-decade 3	Acres	0	0	13,711	0	7,556
Pre-commercial thin-decade 1	Acres	0	34	34	34	34
Pre-commercial thin-decade 2	Acres	0	0	0	0	0
Pre-commercial thin-decade 3	Acres	0	0	0	0	0
Partial cuts-decade 1	Acres	0	306	1,240	306	1,068
Partial cuts-decade 2	Acres	0	0	105	0	105
Partial cuts-decade 3	Acres	0	0	0	0	0
Regeneration cuts-decade 1	Acres	0	298	27	401	83
Regeneration cuts-decade 2	Acres	0	0	374	32	510
Regeneration cuts-decade 3	Acres	0	213	27	324	27

¹Discounted at 4 percent.

and then level off. Scenarios 1 and 2, which treat Wilderness acres, result in fewer acres of SRF from decades 3-5.

For MSF, all the fuel treatment scenarios showed about the same number of acres in decade 1 as "no action" (*fig. 5*). After decade 1, Scenario 1 showed the most reduction in acres burned relative to "no action" and remained among the lowest over the 5 decades. Scenarios 3 and 4 also showed fewer acres burned, with acres burned over the 5 decades varying between "no action" and Scenario 1. Interestingly, Scenario 2, which rose above "no action" in burned acres in decade 2, eventually had the fewest MSF acres by decade 5. For LSF, the pattern of fire associated with fuel treatment scenarios was dependent on whether risk was minimized in decade 1 or 3 (*fig. 6*). For Scenarios 1 and 3 (minimize risk in decade 1) the burned acres were very low, but increased to the "no action" acres by decades 2 and 3. For Scenarios 2 and 4 (minimize risk in decade 3), the initial LSF acres exceeded "no action," dropped to almost zero by decade 3, then increased to approximate "no action" by period 4.

With regard to severe WSBW, Scenarios 1 and 3 (minimize risk in decade 1) showed a sharp decrease in the mean number of acres infested in decades 1 to 3 relative to "no action" (*fig. 7*). Scenarios 2 and 4 (minimize risk in decade 3) began with the number of infested acres only slightly less than "no action," but decreased to approximate the low level of severe WSBW of the other scenarios by decade 3. Severe WSBW remained low for all scenarios after decade 3.

Figure 4

Estimated mean number of acres affected by stand-replacement fire over 5 decades

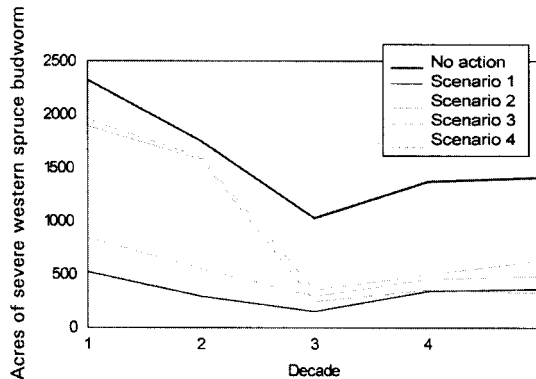


Figure 5

Estimated mean number of acres affected by mixed-severity fire over 5 decades.

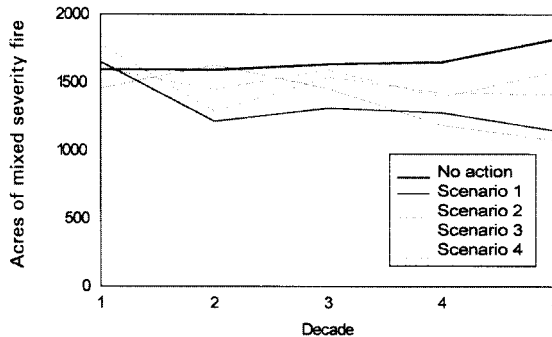
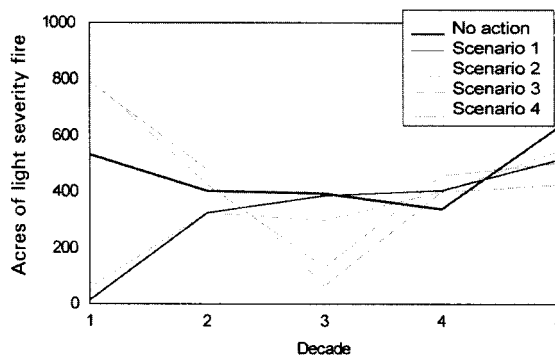


Figure 6

Estimated mean number of acres affected by light-severity fire over 5 decades



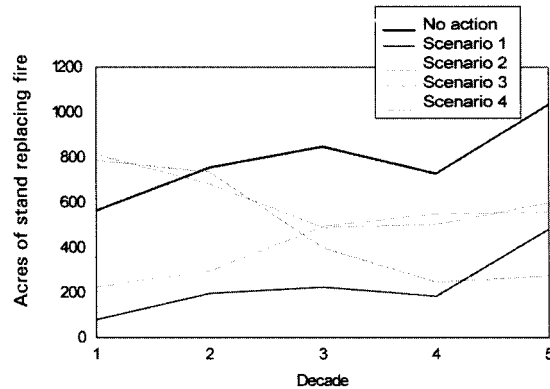


Figure 7

Estimated mean number of acres affected by severe western spruce budworm over 5 decades.

Discussion

Several trends were observed from the four treatment scenarios. As might be expected, substantially fewer acres of the modeled natural processes were occurring in the initial decade for the scenarios where risk was minimized in decade 1 (Scenarios 1 and 3). The scenarios with risk minimized for decade 3 (Scenario 2 and 4), however, were approaching Scenarios 1 and 3 by decade 3 for most processes.

The scenarios having fuel treatments applied in Wilderness (Scenarios 1 and 2) did result in fewer total acres of undesirable natural processes over the 5 decades. The differences were most distinct for stand-replacing fire and mixed-severity fire, and minor for light-severity fire and severe western spruce budworm. It is interesting to note that by decade 5, Scenario 2 had the fewest acres for each of the four modeled natural processes.

The difference in net fuel treatment cost was substantial between the scenarios minimizing risk in decade 1 versus decade 3. The difference was that minimizing risk in the later decade provided the opportunity to implement more fuel treatments in the form of commercial timber harvests. This provided revenue that offset costs to result in positive net revenues for fuel treatments in Scenarios 2 and 4.

More fuel treatment scenarios could be developed for the Stevensville West Central area and the trade-offs could be measured in terms of costs and reductions in acres affected by various processes. The real value of this and other modeling approaches is to identify and measure trade-offs so that more informed decisions are possible. The integration of simulation and optimization models such as SIMPPLLE and MAGIS have great potential for developing spatially-specific fuel treatment scenarios for landscapes and effectively quantifying the trade-offs associated with those scenarios. This provides the opportunity to better understand, manage, and monitor forested landscapes.

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