

APPLYING SIMULATION AND OPTIMIZATION TO EVALUATE THE EFFECTIVENESS OF FUEL TREATMENTS FOR DIFFERENT FUEL CONDITIONS AT LANDSCAPE SCALES

J. G. Jones, Research Forester
Rocky Mountain Research Station, USDA Forest Service
P. O. Box 8089 Missoula, MT 59807
Phone: (406) 542-4167
E-mail: gjones/rmrs_missoula@fs.fed.us

J. D. Chew, Research Forester
Rocky Mountain Research Station, USDA Forest Service
P. O. Box 8089 Missoula, MT 59807
Phone: (406) 542-4171
E-mail: jchew/rmrs_missoula@fs.fed.us

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 the 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.

Keywords: Landscape modeling, fuel treatments, simulation, optimization

INTRODUCTION

Fire exclusion and other management treatments have resulted in the unnatural build up of fuels on many acres in the Intermountain West. These fuel concentrations increase the probability of catastrophic wildfire, particularly in the lower elevation, fire-dependent plant communities (Arno 1996b, USDA Forest Service 1996a). Historically, 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).

Activities, such as prescribed burning, precommercial thinning, and commercial timber harvest, are being applied to address this problem of fuel build-up. But what fuel treatment strategies are most effective? Is it more cost-efficient 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 is less, more acres can be treated with the same budget. Also, given the number of acres involved and limited budgets, it is clear that treatments cannot be accomplished in all areas needing treatment. This raises questions regarding what treatment patterns are most effective in various situations.

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 objectives and constraints that sometimes conflict. This requires an understanding of the trade-offs involved. What, for example, are the likely changes in the extent and intensity of wildfire resulting from fuel treatments? What are the economic payoffs in terms of reduced fire suppression costs? What are the impacts on other resource values?

Models and decision support systems can provide information and analyses to aid managers in addressing these questions (Mowrer 1997). This paper presents a framework for analyzing fuel treatments that uses two types of landscape models, simulation and optimiza-

tion. A stochastic simulation model is used to predict the location and probability of insect, disease, and fire processes on the landscape in the absence of management treatments. This information is transferred to a spatially-specific optimization model, which schedules various types of fuel treatments in view of the location and probability of natural processes, as well as other specified biological and social objectives. The resulting treatment schedule is then transferred to the simulation model to analyze the effects of those treatments on the extent and location of the natural processes. This process develops fuel treatment scenarios that are both spatially and temporally specific, and provides costs and resource effects for evaluating those scenarios.

THE MODELING APPROACH

The simulation model used is Simulating Vegetative Patterns and Processes at Landscape Scales (SIMPPLLE) (Chew 1995). SIMPPLLE is a stochastic simulation model that predicts changes in vegetation over time and space by using a vegetative state/pathway approach. A vegetative state is defined by dominant tree species, size class/structure, and density. These states are grouped by an ecological stratification of habitat type groups (Pfister and others 1977). The change between vegetative states is a function of natural disturbance processes, including insects, disease, and fire, and management treatments. The probability of a natural process occurring in a given plant community is determined both by attributes of the state it is in and the vegetative pattern as identified by its neighboring communities in a unique landscape. The probabilities determined for each plant community in a landscape are used in a classical monte carlo method to simulate the location and timing of process occurrence. Once a process occurs for a plant community, logic is used to model its spread to neighboring plant communities. Management treatments also change vegetative state, but treatment selection is exogenous to the model. The version of SIMPPLLE used in this study defines a plant community as a stand, and uses 10-year time steps.

The optimization model is the Multi-resource Analysis and Geographic Information System (MAGIS). MAGIS is a microcomputer-based spatial decision support system 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). Managers specify an objective to maximize or minimize and other objectives as constraints that must be achieved; and the solver selects the location and tim-

ing of activities that best meets these specifications and calculates the effects. The objective and constraints are selected from the Management Relationships within MAGIS, which tabulate output quantities, acres with specified characteristics, miles with specified characteristics, costs, and net revenues. Management Relationships can be calculated for an entire planning area or specific portions such as individual watersheds. For consistency with SIMPPLLE ten-year time periods were used in this study.

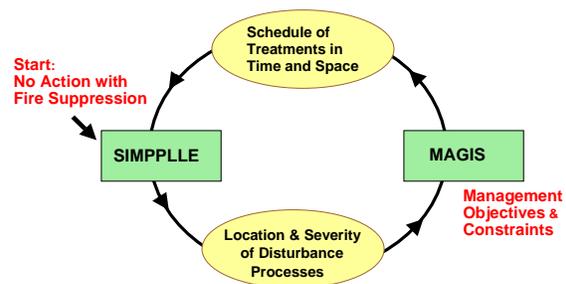


Figure 1. The modeling approach.

The modeling approach we present involves the sequential use of these two landscape models (fig. 1).

In Step 1, SIMPPLLE is used to project the frequency and location of natural disturbances for a “no action” management alternative that includes fire suppression as the only management activity. A number of stochastic simulations (approximately 20) are run, and the frequency of each natural process occurring in decades 1-5 is recorded for each stand. This frequency represents an estimate of the risk of these natural processes occurring on an individual stand over that period of time. We use these frequencies to develop a “risk index” for each stand, the values of which vary by the natural processes predicted for that stand and their frequency of occurrence. The values are chosen to represent a prioritization for fuel treatment activities.

In Step 2, MAGIS is used to develop a schedule of fuel treatment activities for the landscape including prescribed burning, precommercial thinning, and commercial timber harvest. The risk index developed from the simulation results is incorporated into a MAGIS Management Relationship that computes a composite landscape risk index. Additional Management Relationships handle other issues, such as 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 account-

ing stances. MAGIS is then used to schedule fuel treatments in time and space that best meet the objectives specified for a landscape management scenario.

In Step 3, the schedule of stand treatments proposed by MAGIS is incorporated into SIMPPLLE. Stochastic simulations are again run to predict the frequency of the natural processes occurring on the landscape, given this proposed schedule of fuel treatments. The results of these simulations are then compared with the results of the “no action” simulations to measure the effectiveness of the fuel treatment scenario. The comparison includes the predicted total acres of occurrence for each natural process and fire suppression costs computed from the predicted fire processes.

In Step 4, the results from simulations from both Steps 1 and 3 are specified in MAGIS runs to compute values for the Management Relationships including treatment costs and revenues and various resource impacts. These computations include the effects of the natural processes as well as the management treatments, and provide estimates of the resource impacts associated with “no action” as well as with the treatment scenario. In addition, the MAGIS treatment costs and revenues are combined with the fire suppression costs from Step 3 to calculate an overall economic measure of the effectiveness of fuel treatments.

APPLICATION

Test Area

This sequential approach of applying SIMPPLLE and MAGIS was applied on the 58,038-acre Stevensville West Central area of the Bitterroot National Forest in Western 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 25,283 acres in the Selway-Bitterroot Wilderness, 14,155 acres of National Forest outside Wilderness, and 18,600 acres in private ownerships. No treatments were proposed for the private land. It was only included to capture interactions in natural processes with adjacent National Forest lands.

Step 1: Simulate Processes for “No Action”

SIMPPLLE was used to run 20 stochastic simulations over five decades for the “no action” management alternative with fire suppression. The natural processes modeled were light and severe western spruce bud-

worm, mountain pine beetle in both lodgepole pine and ponderosa pine, root disease, and three intensities of wildfire: light-severity fire, mixed-severity fire, and stand-replacing fire. The frequency of occurrence over five decades for each process was recorded by stand.

Based on the researcher’s best judgement, the following index was developed to serve as a prioritization for applying fuel treatments:

Index	Natural Process	Frequency
0	Stand not listed	
2	Light spruce budworm	> 50 %
2	Mountain pine beetle	> 50 %
4	Stand replacing fire	1 - 10 %
6	Severe spruce budworm	> 50 %
8	Stand replacing fire	11 - 20 %
10	Stand replacing fire	> 21 %

The appropriate index value was assigned to each stand, based on the frequency of processes present in the 20 simulations. If more than one process was recorded for a stand, the process associated with the highest index value was assigned. Figure 2 shows the distribution of the index values assigned to the stands.

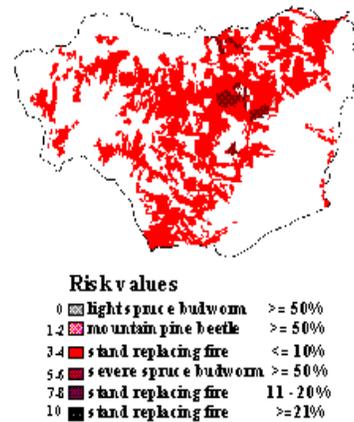


Figure 2. Spatial distribution of risk index based on natural processes occurring over 5 decades.

Step 2: Develop Fuel Treatment Scenarios

The index value for each stand was entered into MAGIS and used to develop a risk index Management Relation for computing a composite index for the landscape. This composite index multiplies the risk index assigned to a stand by the stand acres, and sums this product across the stands as follows:

$$\text{Composite Index} = \sum_a \sum_s \sum_p r_{asp} * X_{asp}$$

where:

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 any action, r_{asp} equals the index assigned by SIMPLLE. If a treatment is undertaken that addresses the risk, r_{asp} after treatment is reduced accordingly.

MAGIS was used to develop four fuel treatment scenarios for the landscape (table 1). Candidate treatments for National Forest stands outside the designated Wilderness included broadcast burning, mechanical thinning followed by broadcast burning, precommercial thinning, and several types of commercial timber harvest. Inside the Wilderness area, the candidate treatments were limited to prescribed burning without mechanical thinning. The prescribed burning options in the Wilderness area were permitted in both Scenarios 1 and 2, but were excluded in Scenarios 3 and 4. Scenarios 1 and 2 differ in that Scenario 1 requires the composite index to be minimized in decade 1, while the timing is relaxed in Scenario 2 to minimize the composite index by decade 3. Fuel treatments for Scenarios 3 and 4 are limited to the 14,155 acres of National Forest outside the Wilderness. Like the first two scenarios, Scenarios 3 and 4 differ by the decade for minimizing the risk index: decade 1 for Scenario 3 and decade 3 for Scenario 4. All four scenarios restrict new road construction and limit the volume of timber harvest per decade to 10,000 ccf (hundred cubic feet) or less, assuming that larger harvests would be politically unacceptable.

Issue	Scn 1	Scn 2	Scn 3	Scn 4
Prescribed fire in Wilderness	X	X		
Minimum risk, decade 1	X		X	
Minimum risk, decade 3		X		X
No new road construction	X	X	X	X
Decade harvest \leq 10,000 ccf	X	X	X	X

Table 1. Specifications for four fuel treatment.

Each scenario was solved by first minimizing the composite index for the specified decade, then achieving a second solution in which present net value was maximized while holding the composite index to an amount slightly above the previously attained minimum value. The road construction and harvest volume restrictions for the scenarios were in effect for both solutions. This sequence develops an economically efficient scenario for minimizing the risk index while meeting the other scenario conditions. These solutions schedule treatments both spatially and temporally.

All four scenarios apply prescribed burning on a large number of acres (fig. 3). Scenario 1 applies prescribed burning on nearly 15,000 acres, more than 37 percent of the National Forest acres in the planning area. Scenario 2 applies burning treatments to slightly fewer acres, but postpones treatments to the third decade. The same treatment patterns exist for Scenarios 3 and 4, but fewer acres are treated, because burning treatments were not permitted in Wilderness.

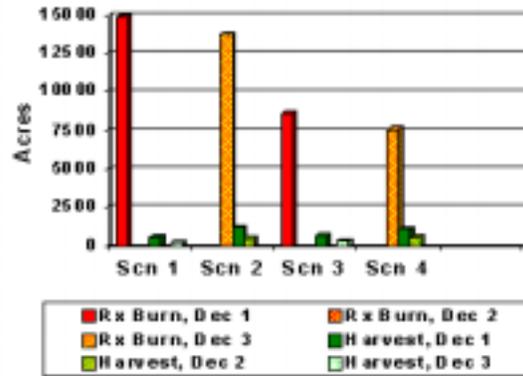


Figure 3. Acres of prescribed burning and harvesting by decade.

Commercial timber harvest outside the designated Wilderness, although applied on fewer acres, plays a significant role in these scenarios. Scenarios 2 and 4, which minimize risk in decade 3, apply harvest on the most acres, 1,270 and 1,150 respectively (fig. 3). These harvests provide sufficient revenue to offset treatment cost, resulting in a positive present net value for these scenarios, \$150 thousand and \$980 thousand, respectively (fig. 4). The large negative present net value for Scenario 1, -\$2,500 thousand, reflects all the prescribed burning included in that scenario.

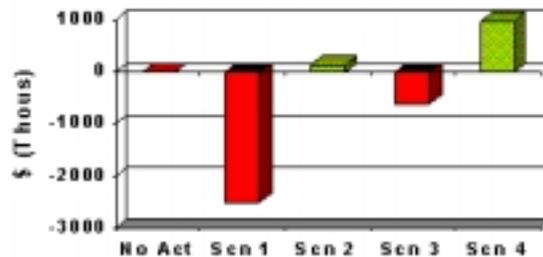


Figure 4. Present net value including the treatment costs and revenues.

The composite index value for “no action” was over 90,000 (fig. 5). The treatments scheduled for Scenario 1 brought this composite index down to approximately 26,000. Scenario 2 has only minimal reductions in the composite index relative to “no action” in decade 1, but achieves the 26,000 value in decade 3. Excluding prescribed burning in the Wilderness results in the minimum value for the composite index of approximately 52,000 in Scenarios 3 and 4.

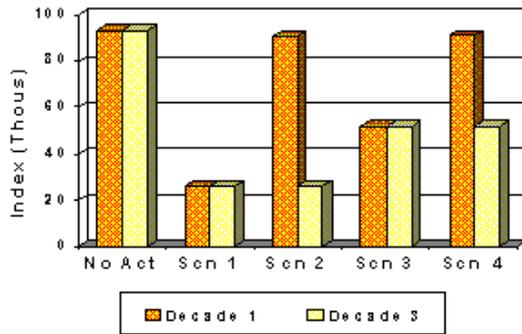


Figure 5. Composite index for decades 1 and 3.

Step 3: Simulate Processes for the Management Scenarios

The four management scenarios developed by MAGIS were imported into SIMPLLE to model the effect of these treatment schedules on the extent and frequency of natural processes and on fire suppression costs. Twenty simulations were run for five decades for each scenario.

Figure 6 presents the total number of acres disturbed over the five decades for the three fire processes modeled. A reduction in acres of stand-replacing fire occurred for each of the fuel treatment scenarios. The most reduction occurred for Scenario 3 where stand-replacing fire was about 60 percent of the amount predicted for “no action.” Acres of light-severity fire also decreased relative to “no action” for each of the fuel treatment scenarios, although the reductions were modest. Acres of mixed-severity fire increased relative to “no action” for some scenarios, most notably Scenario 4. Scenario 3 showed the least amount of acres disturbed for each of the three fire types.

Step 4: Compute Overall Effects and Costs

The natural processes and management treatments present in representative simulations from each of the four scenarios and “no action” were entered in MAGIS

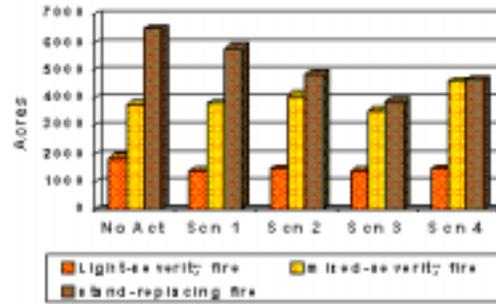


Figure 6. Total acres disturbed over five decades for the three fire severities.

and run to compute values for the Management Relationships, including treatment costs and revenues, and various resource impacts. In this application, all decisions are fixed into the model, and MAGIS is simply used to compute the results. Entering and running each of the 20 simulations for each scenario and “no action” would provide a better basis for estimating these costs and impacts, but was infeasible in this study because of the time required to do this for 100 solutions (100 = 20 x 5). An automated procedure would make this approach feasible in the future.

Figure 7 presents the discounted fire suppression costs (from Step 3) and the treatment costs and revenues from this step. Each of the fuel treatment scenarios reduced fire suppression costs compared to “no action.” The amount of reduction, which was relatively constant across the scenarios, averaged about \$860 thousand — a decrease of about 25 percent. More variation in treatment costs and revenues was predicted for the scenarios, with treatment cost for Scenario 1 by far exceeding the other scenarios. Scenarios 2 and 4, which minimized risk in decade 3, had the largest revenues.

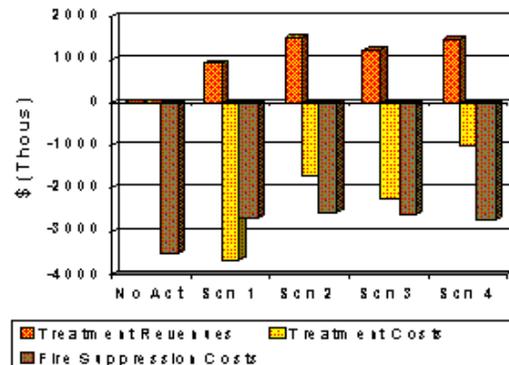


Figure 7. Discounted treatment revenues, treatment costs, and fire suppression costs.

Combining the treatment costs, fire suppression costs, and treatment revenues produces the discounted net costs in Figure 8. Each scenario results in a net cost, that is, the fire suppression costs and treatment costs exceed the treatment revenues. The fuel treatments in Scenarios 2 and 4, however, do payoff in a net cost savings relative to “no action.” That is, treatment costs in these scenarios are more than offset by the combined savings in fire suppression costs and the treatment revenues. The net cost for Scenario 3 exceeds “no action” by a small amount, while the net cost for Scenario 4 far exceeds the cost associated with “no action.” The latter reflects the costs of applying prescribed burning on nearly 15,000 acres in the first decade with relatively few acres of revenue-generating activities.

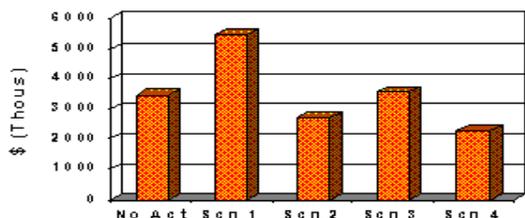


Figure 8. Discounted net cost including the treatment revenues, treatment costs, and fire suppression costs.

Resource effects were computed for “no action” and each of the treatment scenarios that include both the natural processes and treatments. One example is sediment yield (fig 9). Scenarios 3 and 4 have a slightly lower percentage increase in sediment yield over the five decades than “no action,” while the increases pre-

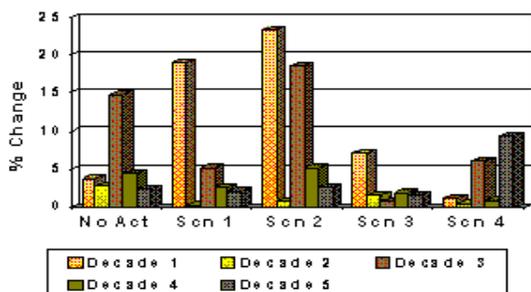


Figure 9. Percentage change in sediment from current condition, including both treatments and natural processes.

dicted for Scenarios 1 and 2 exceed “no action.” Another example was big game hiding cover. The “no action” alternative clearly provides the most big game hiding cover over the five decades (fig. 10). Scenarios 3 and 4, which treat only acres outside the designated Wilderness, provide the most hiding cover of the four treatment scenarios.

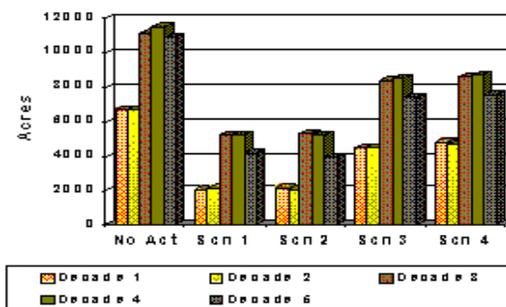


Figure 10. Acres of hiding cover by decade from treatments and natural processes.

DISCUSSION

All scenarios reduced the acres of stand-replacing fire and low-intensity fire, and accordingly reduced the fire suppression costs over the five decades modeled. However, when the treatment costs and revenues are included, a net savings in cost relative to “no action” is predicted for only Scenarios 2 and 4.

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.

The discounted net cost is negative for each scenario, reflecting the prescribed burning costs present in each to reduce the composite index to the lowest value possible. Given the treatment options modeled, net cost can be decreased only by increasing the risk index achieved. Analysis of the location of fire starts showed that a number of fires in the simulations started on private land and spread onto the National Forest. Fuel treatments on these private lands would be expected to result in further reductions in the fire suppression costs.

Often in analysis, resource effects are based only on the proposed treatments, and the effects of natural processes on resource and social values are ignored, both

for “no action” and treatment scenarios. One of the strengths of the analytical approach we present is the ability to compute tradeoffs among the treatment scenarios and “no action” that include both the effects of treatments and natural processes. Consider for example, the sediment yields computed in this study. Sediment was higher for “no action” than two of the fuel treatment scenarios. A quite different picture emerges when only the sediment production from management activities is included.

It should be noted that the index used to prioritize treatments was simply based on the researcher’s best judgement. Many other rules for assigning treatment priorities are possible. Further testing is needed to determine what logic is most effective in assigning treatments.

More fuel treatment scenarios could be developed for the Stevensville West Central area and the tradeoffs 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 tradeoffs so that more informed decisions are possible. The integration of simulation and optimization models such as SIMPPLLE and MAGIS has great potential for developing spatially-specific fuel treatment scenarios for landscapes and effectively quantifying the tradeoffs associated with those scenarios. This provides the opportunity to better understand, manage, and monitor forested landscapes.

REFERENCES

- Arno, S. F. 1996a. The concept: restoring ecological structure and process in ponderosa pine forests. In: *Proceedings of the use of fire in forest restoration*, a general session at the annual meeting of the Society of Ecological Restoration. Gen. Tech. Rep. INT-GTR-341. Ogden, UT: Intermountain Research Station, Forest Service, U. S. Department of Agriculture; 37-38.
- Arno, S. F. 1996b. The seminal importance of fire in ecosystem management - - impetus for this publication. In: *Proceedings of the use of fire in forest restoration*, a general session at the annual meeting of the Society of Ecological Restoration. Gen. Tech. Rep. INT-GTR-341. Ogden, UT: Intermountain Research Station, Forest Service, U. S. Department of Agriculture; pp 3-5.
- Chew, J. D. 1995. Development of a system for simulating vegetative patterns and processes at landscape scales. Missoula: University of Montana; 182 p. Ph.D. dissertation.
- Mowrer, H. Todd, technical compiler. 1997. *Decision support systems for ecosystem management: An evaluation of existing systems*. General Technical Report RM-GTR-296. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 154 p.
- Pfister, R. D.; Kovalchik, B. L.; Arno, S. F.; Presby, R. C. 1977. *Forest habitat types of Montana*. Gen. Tech. Rep. INT-34. Ogden, UT: Intermountain Forest and Range Expt. Stn., Forest Service, U. S. Department of Agriculture; 174 p.
- U. S. Department of Agriculture, Forest Service. 1996a. Land management consideration in fire-adapted ecosystems: conceptual guidelines. FS-590. Washington, DC: Fire and Aviation Management, Forest Service, U. S. Department of Agriculture; 23 p.
- U. S. Department of Agriculture, Forest Service. 1996b. Stevensville West Central environmental assessment. Stevensville, MT: Bitterroot National Forest, Stevensville Ranger District.
- Williams, J. 1995. Aligning land management objectives with ecological processes in fire-dependent forests. In: *Conference on adaptive ecosystem restoration and management: restoration of Cordilleran conifer landscapes of North America*. 1995 June 6-8; Flagstaff, AZ; 4 p.
- Zuuring, H. R.; Wood, W. L.; Jones, J. G. 1995. *Overview of MAGIS: a multi-resource analysis and geographic information system*. Res. Note INT-RN-427. Ogden, UT: Intermountain Research Station, Forest Service, U. S. Department of Agriculture; 6 p.