

Sequential Use of Simulation and Optimization in Analysis and Planning

Hans R. Zuuring
Jimmie D. Chew
J. Greg Jones

Abstract—Management activities are analyzed at landscape scales employing both simulation and optimization. SIMPPLLE, a stochastic simulation modeling system, is initially applied to assess the risks associated with a specific natural process occurring on the current landscape without management treatments, but with fire suppression. These simulation results are input into MAGIS, an optimization modeling system, for scheduling activities that reduce these risks and address other management objectives. The derived treatment schedules are utilized in additional SIMPPLLE simulations to examine the changes in risks and other natural processes. Treatment effects are quantified as changes in the predicted extent and frequency of occurrence of a specific natural process and the resulting economic benefits. An application involving the analysis of fuel treatments applied over time and space to reduce wildfire risks is presented to illustrate this modeling framework that utilizes the strengths of both simulation and optimization.

Management activities are being applied to address a host of resource problems. Frequently planners do not know what strategies are the most effective for answering the questions of HOW, WHEN, and WHERE to apply these treatments. 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? Since the per acre treatment costs for these areas are less, more acres can be treated with the same budget. How can managers identify the conditions that are most effective to treat without addressing the spatial pattern of vegetation and how treatments will be applied over time? Ultimately, management activities must be planned and implemented in light of a variety of objectives and constraints that arise from the Forest Plan and are identified by Forest resource specialists and the public. Managers must be able to develop and evaluate alternatives that address the sometimes-conflicting objectives and constraints. This assessment of alternatives and the implementation of the selected alternative are carried out in a spatial context at the landscape level.

In: Smith, Helen Y., ed. 2000. The Bitterroot Ecosystem Management Research Project: What we have learned—symposium proceedings; 1999 May 18-20; Missoula, MT. Proceedings RMRS-P-17. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Hans R. Zuuring, corresponding author, is a Professor, School of Forestry, University of Montana, Missoula, MT 59812, e-mail: hrz@forestry.umt.edu, telephone: (406) 243-6456. Jimmie D. Chew is a Forester, and J. Greg Jones is a Research Forester, USDA Forest Service, Rocky Mountain Research Station, P.O. Box 8089, Missoula, MT 59807, e-mail: jchew@fs.fed.us AND gjones@fs.fed.us, telephone: (406) 542-4171 and 4167, respectively.

Quantitative techniques are needed by which the spatial arrangement and timing of vegetation 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 frequency of occurrence of a specific natural process that result from management activities, the economic payoffs, and finally impacts on other resources.

Scientists and land managers in the Landscape Analysis Group of the Bitterroot Ecosystem Management Research Project (BEMRP) have developed and implemented a modeling framework that utilizes two modeling systems, SIMPPLLE and MAGIS, that interact with data in a spatial and temporal context. SIMPPLLE (**S**IMulating **V**egetative **P**atterns and **P**rocesses at **L**andscape **S**cale**S**) is a model that projects changes in vegetation over time and space 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 (**M**ulti-**R**esource **A**nalysis and **G**eographic **I**nformation **S**ystem) 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 (1) vegetation change over landscapes, (2) change in the probability of disturbance processes relative to vegetation change, and (3) future effects on resource values.

The Approach

Although some analysts using a single modeling system approach have addressed the above problem, we have chosen to utilize two landscape-modeling systems that are integrated for project planning purposes. A simulator and an optimizer are employed and executed as separate entities that share information between them. In this way the resource analyst utilizes 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 utilized to compute a risk index for each stand, based on 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 resource treatments and their economic payoffs. Additional management relations that together comprise a planning scenario handle other issues. Examples of such relations are:

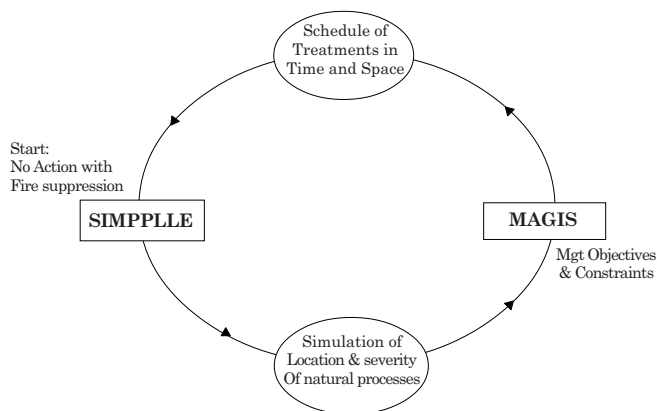


Figure 1—Analysis approach flowchart.

1. Acres in various stand size classes.
2. Equivalent clearcut acres by watershed.
3. Sediment production by watershed.
4. Big game hiding cover by third order drainage.
5. Pine marten (*Martes americana*) habitat index by third order drainage, and
6. 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 based on the stated objectives). In most planning situations the analyst is usually interested in *minimizing* some risk index that has an adverse effect on resources subject to a set of constraining management relations while attaining a reasonable net revenue (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 (based on 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

For years fire has been excluded from fire-dependent plant communities, which has resulted in excessive fuel buildups. Such unnatural accumulations of fuels present a hazard and increase the risk of catastrophic wildfire and their subsequent effects on other resources (Arno 1996b; USDA Forest Service 1996a). Historically, frequent, low-intensity ground fires modified some of these fire-dependent communities; stand-replacing crown fires occurred rarely if at all (Arno 1996a; Williams 1995).

The sequential approach of applying SIMPPLLE and MAGIS was used to analyze the effect of fuel treatments on the risk of wildfire and the economic consequences of such

activities on the 58,084-acre Stevensville West Central area of the Bitterroot National Forest. 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 includes 25,284 acres in the Selway-Bitterroot Wilderness, 14,155 acres of National Forest outside Wilderness, and 18,645 acres in private ownership. No treatments were proposed for the private land. It was included to capture interactions in functions and processes with adjacent National Forest lands.

The first step was to run stochastic simulations of SIMPPLLE over five 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. The four processes were (1) stand-replacement fire, (2) mixed-severity fire, (3) light-severity fire, and (4) western spruce budworm (*Choristoneura occidentalis*).

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 as follows:

Weight value	Risk source	Frequency of source
0	Stand not listed	
2	Light spruce budworm	≥ 50 pct
2	Mountain pine beetle (<i>Dendroctonus ponderosae</i>)	≥ 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

Figure 2 shows the distribution of these index weights based on the frequency of these processes on the landscape. 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:

$$\text{Risk index management relation} = \sum_a \sum_b \sum_c r_{asp} * X_{asp}$$

where:

X_{asp} = Acres of stand s receiving treatment option a 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} following treatment is reduced accordingly.

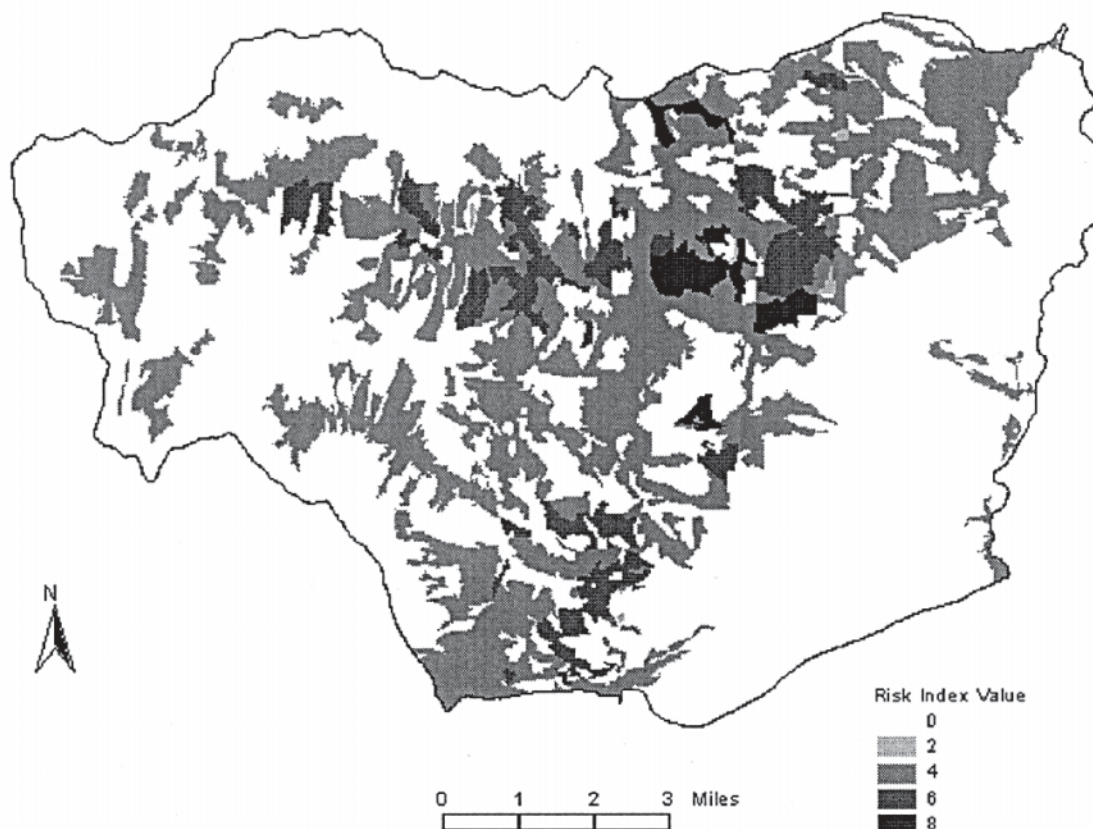


Figure 2—Map showing the spatial distribution of risk index based on natural processes occurring over 5 decades.

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 permitted prescribed burning in the Wilderness area. They differed in that Scenario 1 required the risk index to be minimized in decade 1 while the timing was relaxed in Scenario 2 to minimize risk by decade 3. Fuel treatments for Scenarios 3 and 4 were 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, they differed by the decade for minimizing risk index; minimize

risk in 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 (hundred cubic feet) 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 listed for the scenarios in 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, as shown in figure 3.

Table 1—Specifications for four fuel treatment scenarios for the Stevensville West Central area.

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

Results

Table 2 summarizes the results pertaining to the four scenarios mentioned above as well as the “no action” alternative. 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

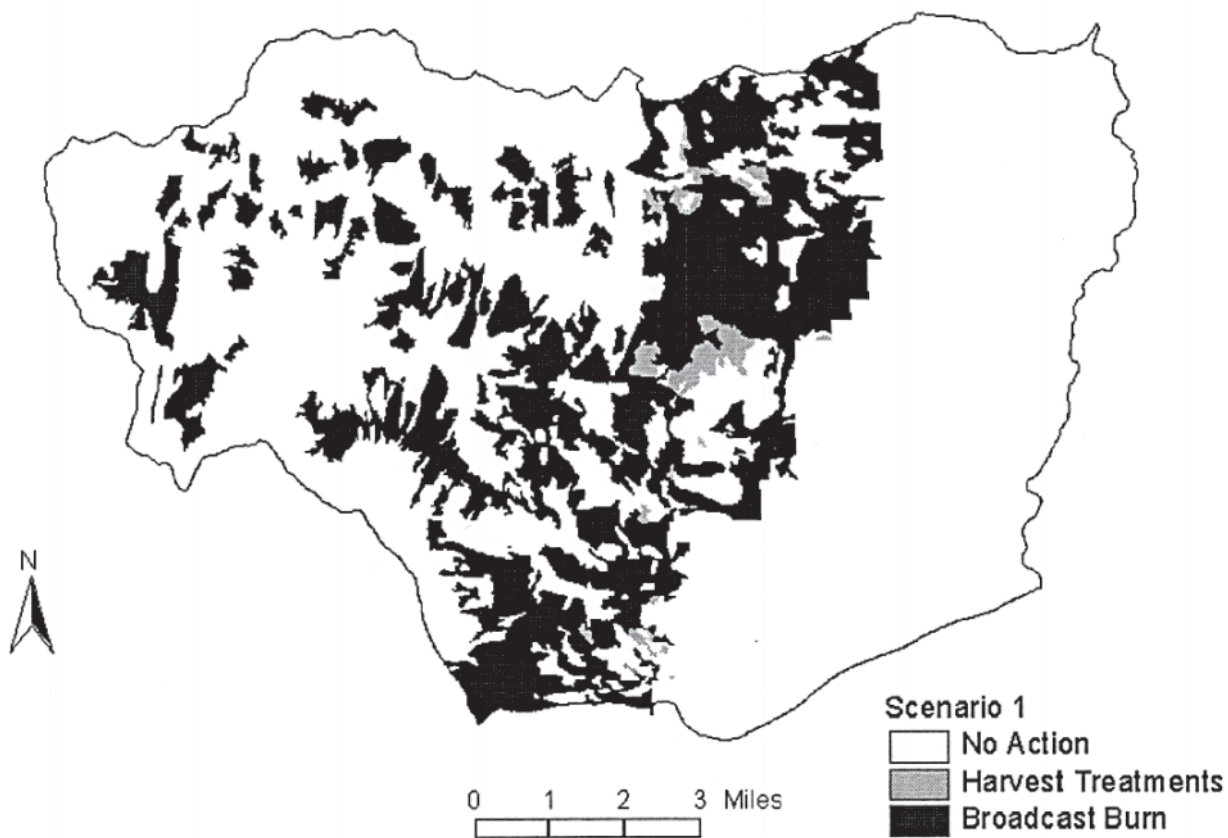


Figure 3—Map showing the spatial distribution of decade 1 burning and harvesting fuel treatments for Scenario 1.

Table 2—Summary of solution amounts for selected management relations “no action” and Scenarios 1 to 4.

Management relation	Units	Scenario				
		No Action	1	2	3	4
Present net value ^a	Thous \$	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 vol-decade 1	CCF	0	7,872	10,000	10,000	10,000
Harvest vol-decade 2	CCF	0	0	6,746	489	8,463
Harvest vol-decade 3	CCF	0	4,659	3,301	7,269	3,562
Underburning-decade 1	Acres	0	0	0	24	15
Underburning-decade 2	Acres	0	0	0	0	0
Underburning-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

^aDiscounted at 4 percent.

of the risk index until decade 3 (Scenario 2) resulted in a positive 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 **8,526** 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 five decades for each scenario. With regard to SRF, the pattern over the 5 decades for Scenarios 1 and 3 is similar to “no action,” but with approximately **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 to 4, and then level off. Scenarios 1 and 2, which treat Wilderness acres, result in fewer acres of SRF from decades 3 to 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

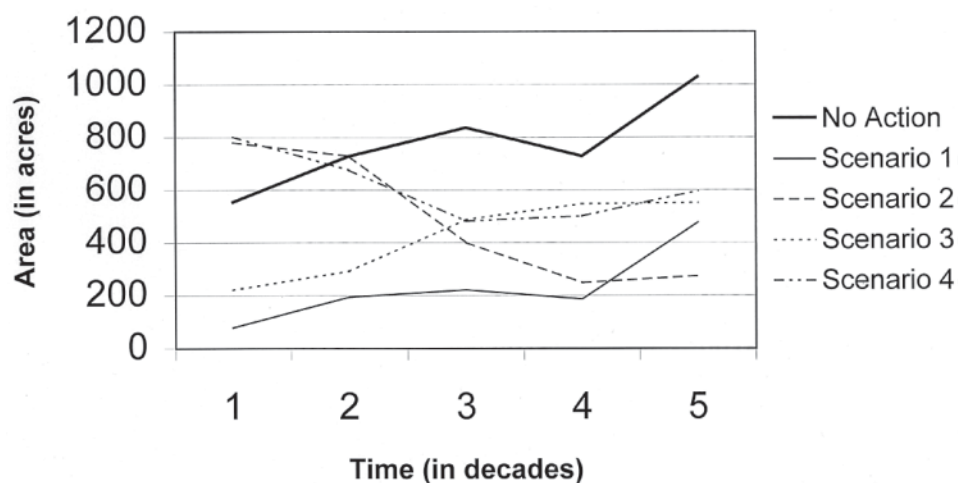


Figure 4—Estimated mean number of acres affected by stand-replacement fire over five decades.

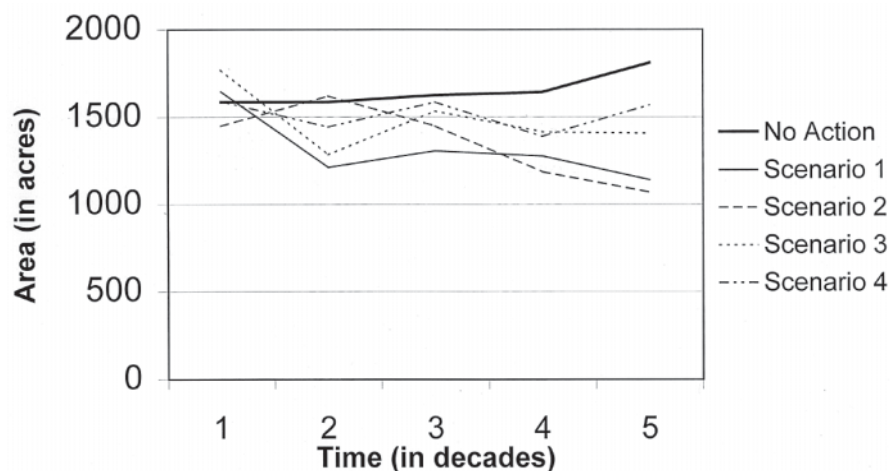


Figure 5—Estimated mean number of acres affected by mixed-severity fire over five decades.

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 rose to approximate 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,” then 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) exhibited 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.

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

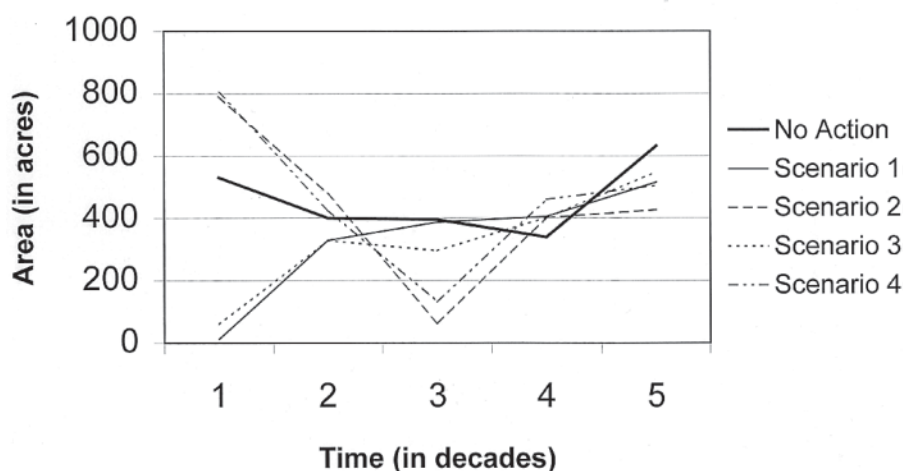


Figure 6—Estimated mean number of acres affected by light-severity fire over five decades.

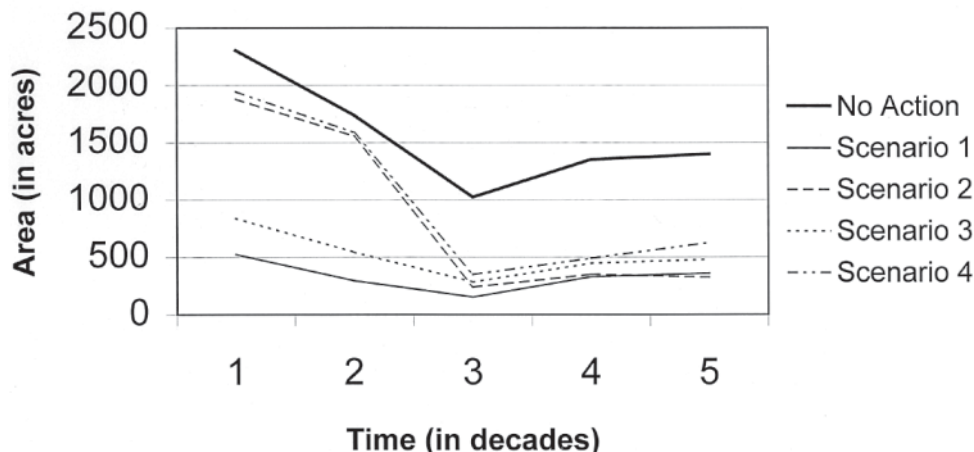


Figure 7—Estimated mean number of acres affected by severe western spruce budworm over five decades.

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.

Many more fuel treatment scenarios could be developed for the Stevensville West Central area and the tradeoffs 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: Hardy, C.C.; Arno, S.F., eds. *The Use of Fire in Forest Restoration*. Gen. Tech. Rep. INT-GTR-341. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 37-38.
- Arno, S.F. 1996b. The Seminal Importance of Fire in Ecosystem Management—Impetus for This Publication. In: Hardy, C.C.; Arno, S.F., eds. *The Use of Fire in Forest Restoration*. Gen. Tech. Rep. INT-GTR-341. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 3-5.
- Chew, J.D. 1995. Development of a System for Simulating Vegetative Patterns and Processes at Landscape Scales. Missoula, MT: University of Montana. 182 p. Dissertation.
- Pfister, R.D.; Kovalchik, B.L.; Arno, S.F.; Presby, R.C. 1977. Forest Habitat Types of Montana. Gen. Tech. Rep. INT-GTR-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.
- U.S. Department of Agriculture, Forest Service. 1996a. Land Management Consideration in Fire-Adapted Ecosystems: Conceptual Guidelines. FS-590. Washington, DC: U.S. Department of Agriculture, Forest Service, Fire and Aviation Management. 23 p.
- U.S. Department of Agriculture, Forest Service. 1996b. Stevensville West Central Environmental Assessment. Stevensville, MT: U.S. Department of Agriculture, Bitterroot National Forest, Stevensville Ranger District.
- Williams, J. 1995. Aligning Land Management Objectives with Ecological Processes in Fire-Dependent Forests. In: Covington, W.W.; Wagner, P.K., tech. coords. *Conference on adaptive ecosystem restoration and management: restoration of Cordilleran conifer landscapes of North America*. Conference Proceedings. 1996 June 6-8; Flagstaff, AZ. Gen. Tech. Rep. RM-GTR-278. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 32-34.
- 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: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 6 p.