APPLYING SIMULATION AND OPTIMIZATION TO ADDRESS FOREST HEALTH ISSUES AT LANDSCAPE SCALES

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ABSTRACT.—SIMPPLLE (**SIM**ulating Vegetative **P**atterns and **P**rocesses at **L**andscape Sca**LE**s) is a stochastic simulation model for projecting vegetative change over time in the presence of natural processes, either with or without management treatments. The interaction of various natural processes on a landscape are modeled, making it a powerful tool for assessing forest health in time and space. MAGIS (**M**ulti-resource **A**nalysis and **G**eographic **I**nformation **S**ystem) is an optimization modeling system for integrating ecological and social information and scheduling management practices spatially and temporally for a landscape. A wide variety of land management practices can be accommodated and a transportation component is available for trails and roads. Various management relationships can be developed for issues applied to an entire planning area, or geographic subcomponents. We present an approach for addressing forest health in a landscape planning context which takes advantage of the strengths of both modeling approaches. SIMPPLLE is used to assess health risks on the current landscape due to the interaction of various natural processes. MAGIS is then employed to schedule management activities which reduce these risks, as well as address other management objectives present for the area.

KEYWORDS: Simulation, Optimization, Vegetation projection, Forest health, Geographic information systems.

INTRODUCTION

The modeling framework presented in this paper is one product of a collaboration between scientists and land managers working on the Landscape Analysis Group of the Bitterroot Ecosystem Management/ Research Project (BEMRP), a project which was initiated in October 1994 (Carlson et al 1996). The goals of BEMRP were to predict landscape level influences of vegetation management on multiple resource outputs and values in an altered Rocky Mountain ecosystem, and to demonstrate to the public the feasibility of landscape-level rehabilitation management. The specific objective was to address the effects of landscape-level vegetation management: 1) on wildfire hazard at the wildland/urban interface, 2) on a major esthetic resource, 3) on quantity and quality of timber resources, 4) on wildlife, including elk, deer, small mammals, and birds, 5) on economics and social implications of ecosystem management, and 6) on restoring health in low and high elevation forests.

Through close cooperation and collaboration with the Bitterroot National Forest, the University of Montana, and the Rocky Mountain Research Station considerable progress has been made towards achieving the above objectives. Specifically, a GIS database has been completed for the 58,083-acre Stevensville West Central (SWC) Integrated Resource Analysis unit. Two modeling systems, SIMPPLLE and MAGIS have been developed to interact with the GIS database. SIMPPLLE (**SIM**ulating Vegetative **P**atterns and **P**rocesses at **L**andscape Sca**LE**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 an association with a habitat type group (Pfister et al 1977). MAGIS (**M**ulti-Resource **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

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on a geographic and temporal basis in the presence of multiple and sometimes conflicting objectives (Zuuring et al 1995). These models permit land managers: (1) to predict vegetation change over landscapes, (2) to predict change in the probability of disturbance processes relative to vegetation change, and (3) to predict future effects on resource values.

THE PROBLEM

Land managers are interested in projecting vegetation into the future while accounting for the presence of various natural processes such as fire, mountain pine beetle, spruce budworm, and root rot at landscape scales for project planning purposes. Specifically they want to estimate and compare the effects of various management alternatives against the ‘no action’ alternative. Forest health, however, is 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 sometimes conflicting objectives and constraints. This assessment of alternatives and the implementation of the selected alternative is carried out in a spatial context at the landscape level. Models like SIMPPLLE and MAGIS serve as useful tools for addressing forest health problems but great care must be taken to properly formulate the planning problem.

With regard to forest health, a workable definition and an objective means of quantifying it are needed. The term “forest health” suffers from a plurality of definitions thus making it a fuzzy phrase. Our definition of forest health deals with a situation in which natural processes and ecosystem functions are allowed to operate at a landscape level. A proxy for forest health is a risk rating which is associated with pathological and entomological agents operating at the stand level. The question is how can such a rating be computed and what sort of modeling system is needed to determine a schedule of management activities applied over time and space that minimizes such risks at landscape scales.

THE SOLUTION

Although the above problem has been addressed by some analysts using a single modeling system approach, 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, allowing the analyst to utilize the strengths of both modeling systems (Fig. 1).

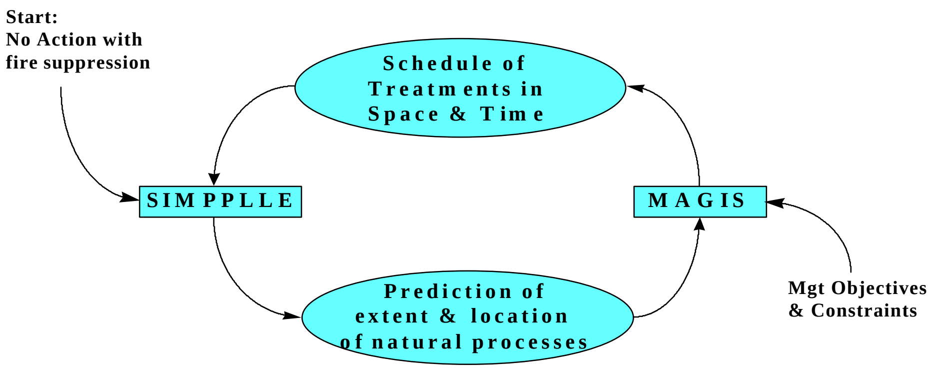

Figure 1.—Analysis approach flowchart.

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 address forest health issues. Other issues are handled by additional management relations that together comprise a planning scenario. Examples of such relations are: 1) acres in various stand size classes, 2) equivalent clear cut acres by watershed, 3) sediment production by watershed, 4) big game hiding cover by third order drainage, 5) pine marten 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 a forest health 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 (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.

AN APPLICATION

A landscape planning process has been undertaken on the Stevensville West Central area of the Bitterroot National Forest that addresses ten issues:

1. Pine Marten habitat index by third-order drainage
2. Pileated Woodpecker index by third-order drainage
3. Old growth (acres) by third order drainage
4. Big game habitat characterized by hiding and thermal cover (acres) by third order drainage

5. Watershed impacts characterized by sediment, water yield, and equivalent cut acres
6. Visual quality
7. Unroaded acres
8. Economic viability (feasibility)
9. Size class distribution
10. Ecosystem restoration characterized by improved forest health and wildlife habitats

The first step was to run stochastic simulations of SIMPPLLE over five decades for the “no action” management alternative with fire suppression. This permitted land managers to evaluate the current situation because there were concerns about the potential spatial distribution and size of areas disturbed by natural processes, especially fire. The number of acres impacted by three specific natural processes and their associated frequencies of occurrence in stands located across the landscape were computed. These three processes were: a) stand replacement fire, b) western spruce budworm, and c) mountain pine beetle in ponderosa pine. From these results, a risk index was constructed based on the conditions listed in Table 1. This risk index is a relative quantity based on an analyst’s notion of the desired future condition (DFC) of a landscape and the undesirable effect that these processes have on achieving those desired conditions. For each stand risk, index values were entered into MAGIS, and a risk index management relation was constructed. The next step was to calculate the risk index for the “no action” alternative, and to calculate the effects on the issues incorporated in Alternative 1 developed by Forest managers. MAGIS was run in simulation mode to calculate those effects. Alternative 1 would implement various harvest treatments on 4,821 acres with a total harvest volume of 3.6 MMBF, pre-commercial thinning on 1,159 acres and under- burning on 5,206 acres. These treatments were applied on 14,155 acres of non-wilderness USDA Forest Service lands. No treatments were prescribed in the planning process for the 25,283 acres in Wilderness and 18,645 acres in private ownership within the SWC unit.

Table 1.—Risk index values by source and frequency cutoff

Value	Risk Source	Freq. Cutoff
		percent
0	stand not listed	
2	low prob. stand replacing fire	$\geq$ 20 and < 50
4	high prob. stand replacing fire	$\geq$ 50
6	light spruce budworm	$\geq$ 50
8	mountain pine beetle	$\geq$ 50
10	severe spruce budworm	$\geq$ 50

MAGIS was then run in optimization mode to formulate additional management alternatives which quantified one or more of the ten issues. These alternatives varied in the manner by which specific issues were addressed. Table 2 presents the specifications for three of the more interesting alternatives developed through MAGIS. Like Alternative 1, treatments were prescribed only for non-wilderness Forest Service lands. Each of the three alternatives restrict harvest volume in each decade to the harvest volume of Alternative 1 in decade 1. Alternatives 3 and 6 were developed by first minimizing the risk index from SIMPPLLE, then achieving a second solution in which PNV was maximized while holding the risk index to the previously attained minimum value.

Table 2.—Objectives and constraints addressed by three alternative planning scenarios

Issue	Alt 3	Alt 6	Alt 7
Harvest Vol ≤ Alt 1	X	X	X
Alt 1 Burn & PCT[a]		X	X
Water Disturbance Limits	X		X
Wildlife ≥ Alt 1	X		X
Seed tree & Clearcut = 0	X		X
Risk Index ≤ Alt 1			X
Min Risk/Max PNV[b]	X	X	
Maximize PNV			X

[a] pre-commercial thin
[b] present net value

Table 3 summarizes the results pertaining to the three alternatives mentioned above as well as the “no action” alternative and Alternative 1. Alternative 7 is most like Alternative 1 since it yields the same or improved values for all the quantified issues, with an increase of over $500,000 in overall present net value and $400,000 in decade 1 alone. Alternative 6 shows that additional reductions in the Risk Index are possible, with further improved present net values, but only after relaxing the watershed disturbance limits and wildlife objectives achieved in Alternative 1. Alternative 3 does not include the pre-commercial thinning and under-burning treatments of Alternative 1, but does achieve the lowest risk index of the listed alternatives with the highest present net values.

Table 3.—Summary of solution amounts for selected management relations from four alternatives and the “no action” alternative

Management relation	Units	NoAct	Alt1	Alt3	Alt6	Alt7
PNV-overall	Thous $	0	-779	867	664	-233
PNV-Decade 1	Thous $	0	-544	531	-27	-142
Risk Index	Index	23,956	20,215	14,900	15,427	20,189
Harvest Vol-Decade 1	MBF	0	3,631	3,600	3,600	3,600
Harvest Vol-Decade 2	MBF	0	0	3,600	3,600	2,220
Harvest Vol-Decade 3	MBF	0	0	3,600	3,600	1,307
Under-burning	Acres	0	5,206	1,011	6,068	6,206
Pre-commercial Thin	Acres	0	1,159	0	1,159	1,159
Sanitation/salvage Cuts	Acres	0	1,288	31	0	130
Commercial Thin	Acres	0	491	386	429	395
Selection Cuts	Acres	0	2,963	844	4	1,134
Regeneration Cuts	Acres	0	79	16	61	80

The “no action” alternative shows a risk index value of 23,956 and zeros for all other decision variables. Alternative 1 which is the one developed by the ID team, indicates a negative PNV of $779,000, a risk index of 20,215 and the largest amount of acres in selection cuts. The most attractive solution appears to be Alternative 3 because present net value (PNV) is positive ($867,000) and the Risk Index is the lowest (14,900). Both Alternative 6 and 7 indicate the highest number of acres receiving under-burning and it appears that the increased harvesting in periods 2 and 3 occurring with Alternative 6 over that of Alternative 7 yields a positive PNV of $664,000 and the second lowest Risk Index of 15,247.

Finally the above four management alternatives were entered into SIMPPLLE and five simulations were conducted over five decades for each of three natural processes: a) stand replacing fire, b) western spruce budworm (WSBW), and c) mountain pine beetle (MPB) in ponderosa pine. The mean sizes of areas (in acres) estimated to be affected by each of the above three natural processes for each of five decades were computed and plotted for the four alternatives and the "no action" alternative in Figure 2a-c. The number of acres burned by stand replacement fires over all five decades was similar for all five management alternatives with the exception of alternative 7 which exhibited a decrease in decade 3. All alternatives showed a sharp increase in burned acres by decade 5. With regard to severe WSBW, all alternatives exhibited a sharp decrease in the mean number of acres infected from decade 1 to decade 2, which continued modestly until decade 3, and then slowly increased up to decade 5. The "no action" alternative generally displayed the highest acres infested over all five decades. The mean number of acres infected with MPB in ponderosa pine was highly variable for all alternatives over all five decades with the "no action" alternative exhibiting the highest acreage at decades 2, 3, and 4. Alternative 6 showed a sharp increase in the mean number of acres infected by MPB by decade 5. The number of acres disturbed by both severe WSBW and MPB in ponderosa pine were reduced over time by all four alternatives compared to the "no action" alternative. Further improvements on the 58,000-acre area were hampered by the fact that treatments are possible only on the 14,155 acres of non-wilderness Forest Service lands.

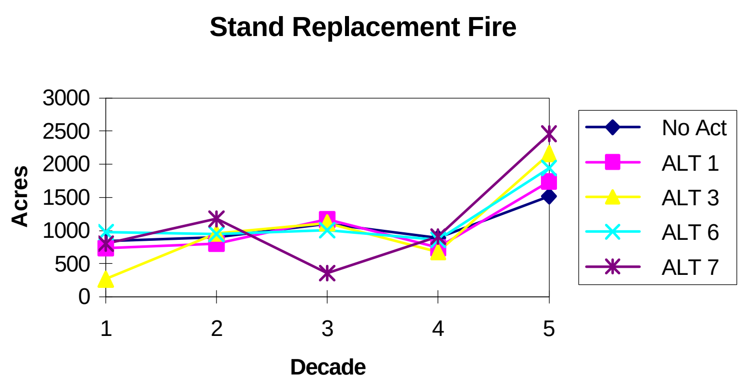

Figure 2a.—Estimated mean number of acres affected by stand replacement fire over five decades.

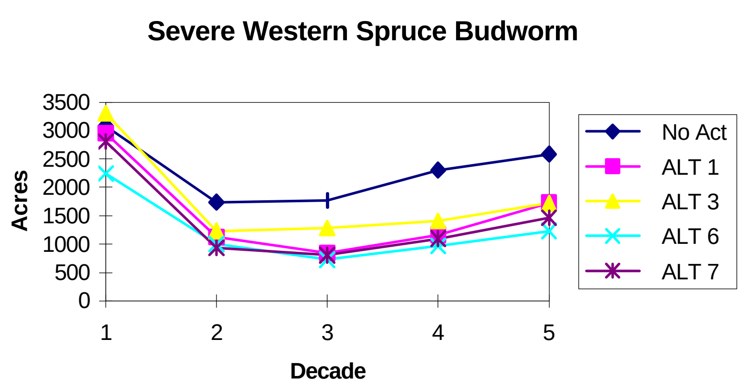

Figure 2b.—Estimated mean number of acres affected by severe western spruce budworm over five decades.

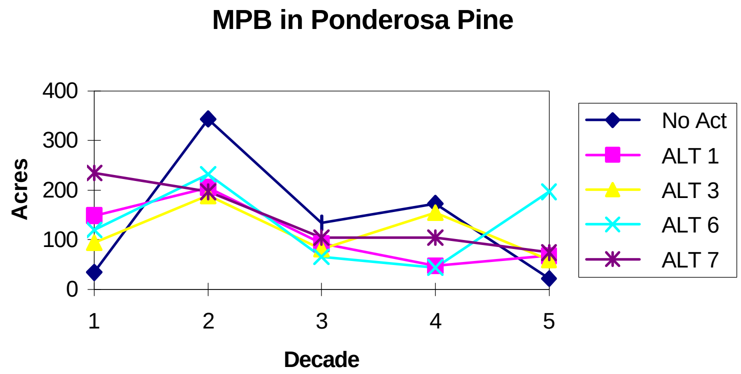

Figure 2c.—Estimated mean number of acres affected by mountain pine beetle in ponderosa pine over five decades.

DISCUSSION

This research indicates a potentially big payoff by integrating simulation and optimization models such as SIMPPLLE and MAGIS. First, a simulation model like SIMPPLLE is valuable for predicting vegetative changes under no management and the likely extent and location of various natural processes. The stands at risk can be prioritized and entered into MAGIS, which then chooses the timing and location of activities based on this priority as well as the other objectives associated with issues and concerns. This schedule of activities addresses the health issues to the extent possible while meeting the other environmental and social objectives. The resulting schedule of activities can then be entered into SIMPPLLE and the future can again be simulated in terms of vegetative change and extent of natural processes. This provides a good measure of the effectiveness of the activities in addressing forest health issues and in creating the desired future stands. Through the utilization of new tools such as GIS, SIMPPLLE, and MAGIS that support ecosystem management and landscape analyses the ability to better understand, manage, and monitor Bitterroot and Northern Rocky Mountain ecosystems is becoming a reality.

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