COMPARING POTENTIAL FUEL TREATMENT TRADE-OFF MODELS
Initial results

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Abstract: Understanding the trade-offs between short-term and long-term consequences of fire impacts on ecosystems is needed before a comprehensive fuels management program can be implemented nationally. We are evaluating 3 potential trade-off models at 8 locations in major U.S. fuel types. We present results of the initial testing of the 3 selected models/modelling approaches and a 4th model on the Bitterroot National Forest (BNF) in western Montana. The selected models/modelling approaches were 1) the Fire Emissions Trade-off Model (FETM), 2) sequential use of the SIMPPLLE and MAGIS models, 3) the Vegetation Dynamics Development Tool (VDDT), and 4) the LANDscape SUccession Model (LANDSUM). We simulated 3 fuel treatments over 50 years: 1) no action, 2) prescribed burning in ponderosa pine and Douglas-fir types at 2 different rates, and 3) timber harvesting that returns the stand to a reproduction stage. Simulation results for all models suggested that the acreage of Douglas-fir and ponderosa pine types would not be appreciably altered by the fuel treatments. Most models suggested the harvest treatment would reduce area burned by wildfire and smoke emissions; some models suggested the prescribed fire treatment would reduce wildfire acreage. All models suggested that the harvest treatment would reduce acreage of pole-size trees; some models suggested the fire treatment would increase acreage of . sapling-size trees.

1.   INTRODUCTION AND LITERATURE REVIEW

Silvicultural operations such as thinning and prescribed burning can modify and/or reduce fuels in many forested systems. Wildfire activity over the last decade has heightened interest in the use of these management tools to reduce the risk of large, high-intensity, stand-replacing wildland fires as well as to treat accumulated fuels in fire-prone ecosystems. Use of prescribed fire may have short-term consequences on air quality, recreational use, property and ecosystem structure and function. Mechanical removal of accumulated fuels may result in soil loss and compaction, nutrient and soil productivity loss, stream warming and sedimentation, and damage to the residual stand. Land and fuel managers must understand the trade-off between short-term and long-term consequences of fire impacts on ecosystems before an effective comprehensive fuels management program can be implemented nationally. The uncertainties associated with a fuels management program must be clearly understood and quantified. These uncertainties include undesirable ecological effects, prescribed fire escapes, decreased atmospheric visibility, degraded air quality, and inability of treatments to achieve desired effects. Lack of fuel treatment presents its own set of effects including undesirable fire behaviour, abnormal ecosystem dynamics, and periods of locally heavy smoke.

Mathematical models can be useful for quantifying the risks and trade-offs of fuel management policies and programs. Given the long time horizon associated with land management planning, models are generally the only tool available to provide managers with information on future landscapes. These models can range from simple growth and yield models to elaborate process simulation models. Regardless of type, models are only approximations of reality. Both incorrect model formulation and incorrect input data can affect the model outputs introducing elements of risk to decisions based on evaluations from these models.

Quantitative fuel treatment trade-off planning through the use of simulation models is a recent innovation compared to more strategic model use. Strategic fire planning models such as the National Fire Management Analysis System and the Wildland Fire Situation Analysis have been developed and applied since the mid-1970s. Fuels trade-off models, however, have been under development only since the late 1980s. Several models have been built upon simulators such as the Forest Vegetation Simulator (FVS) (Wykoff et al. 1982). Models such as the Fuel and Fire Effects Extension and SAFE FORESTS use information produced by FVS limiting their use to forested ecosystems.

Some ecosystem process models have been adapted to fuels trade-off-- mathematical models and carbon budget models. An example of a

mathematical model is FIRESUM (Keane et al. 1989), created from a gap-replacement model developed from JABOWA (Botkin et al. 1972). A recently developed class of models—dynamic global vegetation models—can potentially incorporate fire (Fosberg et al. 1999). MC1--a combination of the MAPSS biogeography model (Neilson 1995), the CENTURY biogeochemical model (Parton et al. 1994) and a process-based fire model, MC-FIRE (Lenihan et al. 1998) is a dynamic global vegetation model. While these models might potentially be used to evaluate fuel treatment effects on landscapes and fire in a variety of terrestrial ecosystems, they were not available at the beginning of this study.

As part of the current study (Weise et al. 2000), we are parameterizing the models at 8 locations representative of major fuel types found on lands managed by federal and state agencies. At each location, we will simulate a set of fuel treatments and compare model results with regard to wildland fire occurrence, smoke emissions and vegetation distribution. The selected models/modelling approaches were 1) the Fire Emissions Trade-off Model (FETM), 2) sequential use of the SIMPPLLE and MAGIS models, 3) the Vegetation Dynamics Development Tool (VDDT), and 4) the LANDscape SUccession Model (LANDSUM). This paper reports initial results of setting up and running the models at the 1st location. Although the 3 originally selected modelling systems overlap in functionality, design emphasis differs substantially. The SIMPPLE/MAGIS models are spatial and designed to provide decision support at the project/watershed level for treatment type and sequencing on the landscape (Jones et al. 2000). FETM (Schaaf et al. 1998) and VDDT (Arbaugh et al. 2000) are non-spatial larger-scale planning models, intended to support forest level decisions. FETM has a more detailed prescribed and wildland fire component than VDDT to emphasize the trade-off of fire management actions. VDDT is a more general model than FETM and includes a large array of other disturbance factors presently not available in FETM. We included LANDSUM, a spatially explicit, deterministic vegetation dynamics simulation model in which disturbance is treated as a stochastic process (Keane et al. 1997) since it had also been parameterised for the Bitterroot National Forest.

2.   METHODS

The Bitterroot Front area, including the western portions of the Stevensville and Darby Ranger Districts of the Bitterroot National Forest, was selected for testing since much of the necessary work required to use SIMPPLLE and MAGIS had been already completed. The test area (454, 750 acres) consisted primarily of national forest (75%) and private (24%)

land on the western side of the Bitterroot Valley in western Montana. However, based on decisions by the modelling groups, the actual acreage included in the simulated landscapes was roughly 274,000 acres for VDDT (non-forest types excluded); 417,000 for FETM; 455,000 for SIMPPLE/MAGIS; and 467,000 for LANDSUM. Most of the fires that burned in 2000 on the Bitterroot National Forest (BNF) occurred south and east of the test area where forest cover is not dissected by east-west oriented valleys. Vegetation data, topography, fire history, and vegetation successional responses to different disturbances were the basic data used to set up the models. The vegetation data were regrouped as needed by each of the models.

2.1   Fire behavior simulation

The fire history data were used to determine fire occurrence probabilities and mean fire sizes. For VDDT, the BNF fire history data were combined with other information (Merzenich et al., in press) to assign the probability of fire occurrence and the percentage of fires that occurred as stand-replacing (high intensity), mixed intensity, or low intensity wildfires. Wildfire probability was fixed and did not change as fuel treatments were applied. In FETM, the fire history data were separated into 4 fire weather classes (Deeming et al. 1977): low, medium, high, and extreme. The segregated data were fit to a Poisson distribution that was used to simulate the annual number of fires in a fire weather class. When a fire occurs, its expected size is determined as a weighted average of potential fire sizes. A potential fire size is estimated for each fuel and weather class combination. The weights are determined by the fraction of total acres in each fuel class at the beginning of each year in the simulation. The weights are assumed invariant within a year, but change between years depending on changes in vegetative composition from one year to the next (Schaaf et al. 1998).

In LANDSUM, fire spread modelling uses a three-parameter Weibull hazard function to account for accumulation of fuels in probability of ignition, a series of equations based on wind and slope to model spread, and another probability distribution function to define overall fire size. Fire size was not related to polygon size. Dry and wet years were stochastically simulated. As a result, area burned by decade can have high variability. However, differences in data formats precluded the use of the finer detail and robust science of fire spread just described. All fires were modelled at the stand level, or on a polygon-to-polygon basis.

In SIMPPLLE fire history data were used to determine wildfire probabilities on a per acre basis. These probabilities along with the probabilities for other disturbance processes were used for each plant

community in a classical Monte Carlo method to simulate the timing and location of wildfire occurrence. Logic tables based on a plant community's vegetative attributes, disturbance process and treatment history determined what type of fire event resulted. The fire process spread through adjacent plant communities based on the unique pattern of adjacent plant communities and their vegetative attributes, disturbance and treatment history.

Smoke emission production is related to fire behavior simulation and was calculated using $\mu = Awe$ where μ is the total mass for a smoke component (particulate matter, CO, CO_2, etc.) for a vegetation class, A is the total area burned in the vegetation class, w is the biomass consumed per unit area for the vegetation class, and e is the emission factor (mass of smoke component produced per unit mass of vegetation class burned). The emission factors used in this study, a combination of both active flaming and smoldering combustion phases, were derived for use with FETM and applied to VDDT and LANDSUM (Ottmar et al. 1993). SIMPPLLE/MAGIS used emission factors from Hardy et al. (2000).

2.2   Fuel treatment scenarios and model simulations

While many different fuel treatments and sequences of treatments might be potentially applied to forest types of the BNF to reduce the risk of wildfires, we chose to simulate 2 simple fuel treatments. The treatments were restricted to the ponderosa pine (*Pinus ponderosa*) and Douglas-fir/mixed conifer (*Pseudotsuga menziesii*) types and applied to the landscape over a 50 year time period. The scenarios were 1) no action, 2) prescribed fire with a mean treatment interval of 20 years for ponderosa pine (PP) and 50 years for Douglas-fir/mixed conifer (DF), and 3) shelterwood or seed tree harvest that returned the PP and DF stands to a regeneration stage over a 50-year period. For VDDT, these fuel treatments equate to annual probabilities of 5% and 2% for the fire and harvest treatments, respectively. Because SIMPPLLE and MAGIS were spatial models, they are capable of modelling numerous spatial arrangements of treatments that meet the criteria for scenarios 2 and 3. Logic was needed to choose among these in developing the scenarios for comparison. Spatial treatment schedules were developed by minimizing the risk of fire in each successive decade beginning with the 1st decade. It is unknown whether the 2 basic fuel treatment scenarios selected for these model comparisons are feasible to implement given existing societal and political constraints.

Each scenario was run multiple times for FETM (100), SIMPPLLE/MAGIS (10), and VDDT (100). A single simulation for each scenario was run with LANDSUM. Results of multiple simulation runs with

LANDSUM using the same options as Stevensville West Central scenarios (Chew et al., in press) found little stochastic variation between runs, except for the first 10-20 years. Overall average was 3-8 percent depending on the complexity of fire regimes in the simulated landscape. Mean values for vegetation type acreage, acres burned by wildfire, and tons of wildfire smoke were calculated from the multiple simulations for each scenario for FETM, SIMPPLLE/MAGIS, and VDDT. Standard errors or standard deviations were calculated to estimate the variability of the mean values. The simulation time step varied between each model so statistics were summarized on a decadal basis.

3.   RESULTS

There are a variety of outputs from the models such as acres burned by intensities of wildfire, acres of vegetation conditions, acres impacted by insect and disease processes, and fire suppression costs. Three primary outputs from each of the models are being compared—vegetation distribution, wildfire acres, and wildfire smoke emissions. The no-action scenario provided a comparison of the ability of each model to simulate current fire occurrence on the BNF. Based on the fire history data, two estimates of annual acreage burned were determined and used by different models. FETM and SIMPPLLE used an average of 6470 acres burned per year from 1986-1995 or 64,700 acres per decade derived for the entire BNF. VDDT and LANDSUM used an average of 2680 acres burned per year or 26,800 acres per decade derived from fires occurring within the study area (Table 1). Mean wildfire acreages varied little between simulation runs for the fuel treatment scenarios for FETM, VDDT, and SIMPPLLE. Standard errors ranged from 1-3% of the mean for VDDT, to 4-5% for FETM and 8-10% for SIMPPLLE. The single LANDSUM simulation for each treatment scenario produced a greater range of burned acreage by decade.

SIMPPLLE results suggested that both scenarios might reduce the number of acres burned by all types of wildfire (Table 1). FETM results suggested that the harvest treatment only might reduce wildfire acres. VDDT results did not show any reduction in total wildfire acreage over the 50 years because of the constant rate of wildfire occurrence. If we assume the 5th decade results for LANDSUM vary only 3-8%, then both treatments may also reduce total wildfire acres. When only stand replacement wildfires (SRF) were considered, SIMPPLLE showed an increase in SRF acreage for the no action scenario and little or no increase for both treatments (Table 2). VDDT predicted an increase in SRF acreage for the no action and harvest scenarios; the prescribed burn scenario showed a slight decrease in SRF.

Table 1. Simulated area burned by wildfire (*acres*) and smoke emissions (*tons*) by decade for 3 fuel treatment scenarios.

Scenario	Model	Decade				
		1	2	3	4	5
		Wildfire acres				
1. No action	FETM	66,687	67,113	65,695	63,374	64,858
	LANDSUM	20,732	27,374	27,571	13,680	9,051
	SIMPPLLE	63,563	56,837	59,510	59,032	59,521
	VDDT	24,716	24,588	23,977	23,596	23,226
2. Prescribed fire	FETM	66,963	67,270	65,222	65,442	63,745
	LANDSUM	26,783	2,318	49	1,691	20,855
	SIMPPLLE	10,494	10,478	10,990	9,385	9,673
	VDDT	25,164	25,947	26,213	26,570	26,699
3. Harvest	FETM	64,628	61,420	58,374	56,051	52,796
	LANDSUM	20,989	997	8,077	10,362	4,984
	SIMPPLLE	9,990	9,918	11,743	11,862	11,451
	VDDT	24,678	24,548	23,943	23,523	23,177
		Wildfire smoke emissions				
1. No action	FETM	11,836	11,759	11,825	11,833	11,797
	LANDSUM	5,173	6,883	6,726	3,367	2,267
	SIMPPLLE	3,221	2,649	2,724	2,044	1894
	VDDT	4,739	4,765	4,742	4,720	4,681
2. Prescribed fire	FETM	12,081	12,092	12,526	12,672	12,218
	LANDSUM	6,160	568	11	393	5,000
	SIMPPLLE	583	626	725	599	596
	VDDT	6,601	6,864	7,000	7,057	7,085
3. Harvest	FETM	10,087	9,631	9,128	8,905	8,817
	LANDSUM	5,343	237	1,909	2,495	1,115
	SIMPPLLE	421	389	360	336	390
	VDDT	4,806	4,808	4,774	4,701	4,647

Smoke emissions responded like the number of wildfire acres. The relatively lower total emissions predicted by SIMPPLLE/MAGIS are a function of either lower emissions factors used or different levels of fuel consumption. The wildfire smoke emissions produced by the harvest treatment decreased for all models except VDDT for the reason noted previously. Total smoke emissions (wildfire + prescribed fire) for the prescribed fire treatment were greater than the harvest treatment for all models and greater than the no action scenario for most models.

Even though several different species and species groups are present on the BNF, the effects of the treatments on vegetation distribution will be described only for the PP/PP-DF cover types and for the moist DF types where the fuel treatments were applied. With the exception of LANDSUM, the proportion of the landscape occupied by the PP/PP-DF and moist DF types did not change markedly over time for any of the 3 scenarios.

However, for LANDSUM, the proportion of landscape occupied by PP/PP-DF decreased and by moist DF increased over time for all 3 scenarios.

Table 2. Simulated area burned by stand-replacement (high intensity) wildfire for 3 fuel treatment scenarios.

Scenario	Model	Decade				
		1	2	3	4	5
		Wildfire acres				
1. No action	SIMPPLLE	6,677	9,966	9,508	8,886	9,342
	VDDT	12,978	13,886	14,851	15,448	16,152
2. Prescribed fire	SIMPPLLE	1,751	2,276	2,252	1,936	1,882
	VDDT	12,347	12,193	12,094	11,775	11,811
3. Harvest	SIMPPLLE	1,705	2,236	2,576	2,779	2,465
	VDDT	13,067	14,068	15,188	15,878	16,589

The simulated fuel treatments affected the distribution of vegetation types between size classes (Figure 1). Much of the study area is currently in the pole and large size classes and only a small percentage is in the sapling stage. After 50 years of simulated fuel treatments and growth, most models predicted that a large proportion of the landscape would remain in the large size class; however, the prescribed fire treatment increased the area occupied by sapling-size trees.

4.   LESSONS LEARNED

The initial testing of 4 different models that might be potentially used to determine the trade-offs of potential fuel treatments identified several potential problems involved in comparisons of this type. While all 4 modelling groups started with the same initial data and treatment scenarios, the modification of the input data and simulation of the treatment scenarios diverged somewhat from the plan. This was due in part to model architecture and modeller interpretation. Basic differences in the representation of successional vegetation pathways existed among the models as did the fire simulation algorithms. The complexity of the potential scenarios to be evaluated was limited by the capabilities of the simplest model. While we were able to compare a prescribed fire scenario with all models, we were not able to compare spatial allocation of the prescribed fire treatment on the landscape because only 2 of the 4 models were spatial and only 1 of the 4 contained the ability to allocate treatments spatially based on some criterion. Nor were we able to compare different sequences of fuel treatments. However, all decisions regarding fuel

treatment application do not have a spatial context and many of the effects of fuel treatment sequences on ecosystem processes are unknown.
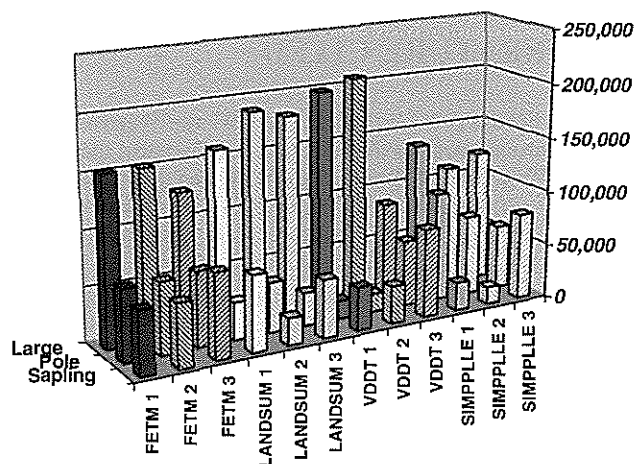

Figure 1. Size class distribution (acres) for all species after 50 years of simulation for No Action and 2 fuel treatment scenarios.

This initial testing suggests that we must coordinate more closely to insure that all models are using the same initial landscape, input data, and interpretation of input data. Explicit description of treatment scenarios will be required so that between-model comparison is possible in both a qualitative and quantitative sense. Regardless of the limitations of this 1st comparison of the FETM, SIMPPLLE/MAGIS, VDDT, and LANDSUM models, the partial agreement of these outputs after 50 years of simulated fuel treatments is promising. Further testing of the models in similar and dissimilar vegetation types will help identify model weaknesses and problems in application.

5.   ACKNOWLEDGEMENT

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