A RISK-BASED COMPARISON OF POTENTIAL FUEL TREATMENT TRADE-OFF MODELS

David R. Weise, Richard Kimberlin, Michael Arbaugh, USDA Forest Service
Forest Fire Laboratory, 4955 Canyon Crest Dr., Riverside, CA, 92507
Phone: (909) 680-1500
E-mail: dweise/psw_rfl@fs.fed.us

Jim Chew, Greg Jones, USDA Forest Service
Forestry Sciences Laboratory, 800 E. Beckwith, Missoula, MT, 59807

Jim Merzenich, USDA Forest Service
P.O. Box 3623, Portland, OR, 97208

Jan W. Van Wagtendonk, USGS Western Ecological Research Center
Yosemite Field Station, El Portal, CA, 95318

Marc Wiitala, USDA Forest Service
Forestry Sciences Laboratory, 1221 SW Yamhill, Suite 200, Portland, OR 97205

ABSTRACT

Understanding the trade-off 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 comparing three vegetation models that may be used to predict the effects of various fuel management treatments at seven locations in major U. S. fuel types. The models being implemented and evaluated are the **F**ire **E**ffects **T**rade-off **M**odel (FETM), the **SIM**ulating vegetative **P**atterns and **P**rocesses at landscape sca**LE**s/**M**ulti-resource **A**nalysis and **G**eographic **I**nformation **S**ystem (SIMPPLLE/MAGIS), the **V**egetation **D**isturbance **D**ynamics **T**ool/**T**ools for **E**xploratory **L**andscape **S**cenario **A**nalyses (VDDT/TELSA), and SAFE Forests. We will evaluate the implementation of each model and estimate the uncertainty associated with predictions from the four models using simulation. This uncertainty is a component of the risk associated with a fuel management program. The model comparison will identify model components that are needed for a national strategic fire planning model.

INTRODUCTION

Increasing the frequency and size of prescribed fires is potentially an important tool for reducing the risk of large stand-replacing wildland fires. Increased use of prescribed fire may also have short-term consequences on air quality, recreational use, property and ecosystem structure and function. Land and fuel managers must understand the trade-off between short-term and long-term consequences of fire impacts on ecosystems before a comprehensive fuels management program can be implemented at the national level. The uncertainties associated with a fuels management program must be clearly understood and quantified. These uncertainties include undesirable ecological effects, prescribed fire escapes, decreased visibility and air quality. Lack of fuel treatment presents its own set of uncertainties, including large stand-replacing fires, abnormal ecosystem dynamics, and periods of locally heavy smoke emissions.

Mathematical models can be useful for quantifying the risks and trade-offs of fuels management policies and programs.. Given the long time horizon (50 years) associated with land management planning, models are indispensable for providing 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. As a result, their outputs are subject to differing degrees of uncertainty and error. This introduces an element of risk to decisions based on evaluations from these models.

A number of models are presently in various stages of development and application for use in understanding and predicting the effect of fuels management strategies on forest health, smoke emissions, and commercial harvest. Most models have been applied to few locations, so it is not clear if each model can be applied nationally. Documentation and evaluation of models have been sporadic, due largely to development needs being driven by regional and sub-regional needs, rather than national. An assessment of the number and scope of the various models available indicate that presently no model contains all of the desired abilities needed for a nationally applied model system. Several models might potentially develop into a nationally applied trade-off model, but it is not clear from literature reviews how the models actually perform in field applications. Our project seeks to address some of these questions surrounding fuel treatment models and their use.

PROJECT OBJECTIVES

1. Perform a comprehensive sensitivity analysis of SIMPPLLE/MAGIS, VDDT/TELSA, FETM, and SAFE Forests to determine the reliability of each model, and document the justification of the approach used in the internal algorithms.

2. Parameterize FETM, SIMPLLE/MAGIS, VDDT/TELSA, and SAFE Forests at 7 locations representative of major fuel types found on lands managed by USDA, USDI, DOD, and state agencies. This will include two sites where the models will be implemented with historical information to conduct model validation.

3. Simulate a set of fuel treatments for each model and compare/contrast model results with regard to wildland fire occurrence, smoke emissions and vegetation distribution.

4. Develop methods to use the models to estimate the uncertainty (risk) associated with vegetation changes resulting from fuel treatments in each of the fuel types studied.

BACKGROUND AND LITERATURE REVIEW

The terms “risk” and “hazard” are often used interchangably. However, in decision-theory, risk is defined as a function describing the expected loss associated with a particular decision rule. Hazard can be defined as a potentially dangerous condition. Feary and Neuenschwander (1998) defined hazard as “a threat to humans and their welfare” and risk as “the probability of hazard occurrence.” With the advent of remote-sensing imagery and geographic information systems, numerous authors have developed methodology to describe both fire hazard (potentially dangerous situations) and fire risk (probability of those situations occurring) (e.g.. Chuvieco and Congalton 1989, Vidal et al. 1994).

Risk assessment in wildland fire has historically focussed on determining the risk of fire occurrence. Regional fire danger rating systems evolved into the National Fire Danger Rating System (NFDRS) which essentially is designed to quantify the probability of a fire occurring within a particular management area (Deeming et al. 1977, Bradshaw et al. 1983). Remote-sensing and geographic information system technology have been utilized to estimate fire risk by using satellite imagery of vegetation (e.g. Gonzalez-Alonso et al. 1998, Chuvieco and Congalton 1989). Components of the NFDRS are being coupled with satellite imagery to estimate fire potential (Burgan et al. 1998). The focus of this type of modeling is on fire occurrence modeling. With the increased availability of this technology to land managers, wildland fire risk assessment is now beginning to estimate the risk posed to various resources by a wildland fire (e.g.. Burton et al. 1998).

Quantitative fuels trade-off planning using simulation models is a recent innovation. Fuels trade-off models have been under development only since the late 1980’s. These models are a subset of the many vegetation disturbance models that have developed recently (Schmoldt et al. 1999). During the 1990’s several separate modeling developments were initiated, or adapted to examine aspects of the general question of trade-off between fuels treatments and the effect of these treatments on wildland fire hazard.

Several models have been built upon mensurational simulators such as the Forest Vegetation Simulator (FVS) (Wykoff et al. 1982). The FVS forecasts forest development at the stand level. It has a decade time step, and is usually applied to 100-300 year time periods. Originally developed in the Rocky Mountains it has subsequently been applied to 17 forest regions of the U.S. (Teck et al 1996). The model is designed to simulate management actions, such as harvest, thinning, and planting on long-term forest structure.

At least two trade-off models have been designed to use information from FVS to predict the consequences of fuel management treatments on long-term forest structure and wildland fire hazard. The Fuels and Fire Extension (FFE) (Reinhardt and Hardy, unpublished) simulates long-term fuel accumulation and decomposition. Presently it has been applied to the Inland Empire (Idaho Panhandle, western Montana) variant of FVS. In FFE surface fuels are calculated from litter fall, activity fuels and tree mortality. Fuels are reduced by decomposition, combustion and management treatments. The model predicts surface fire behavior using BEHAVE (Andrews 1986), and transitional and crown fire behavior. Fire effects, including fuel consumption, tree mortality and smoke production are simulated using FOFEM (Reinhardt et al. 1997).

Another recent trade-off model that uses FVS information is SAFE Forests (Sessions et al. 1997). This model was developed as part of the Sierra Nevada Ecosystem Project (1996). The emphasis of this model was to examine trade-offs between forest management approaches that would increase the general extent and complexity of late-succession forests in the Sierra Nevada. The model includes many types of fuels treatments, such as harvest, thinning and prescribed fire. It also simulates wildland fires and their impact on stand structure. The effects of management on wildland fire hazard was determined by selection of an optimal management scenario for each area without the influence of wildland fire. Wildland fire was then stochastically simulated and the results were examined. Additional modifications have been made to SAFE Forests such as development of an interface with the FARSITE fire spread simulator (Finney, personal communication, Finney 1998).

Other model approaches include ecosystem process models that were developed to examine interactions of ecosystem process and function. Two general approaches 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). FIRESUM was created by modifying SILVA (Kercher and Axelrod 1981), which is a gap-replacement model developed from JABOWA (Botkin et al. 1972). It was designed to simulate the effect of different fire regimes on tree composition, stand structure, and fuel loading in the inland north-western US. It simulated individual tree growth and death in 400 m areas. Tree growth is calculated using theoretical and empirical relationships of height and diameter modified by several site factors, including light availability, water stress and temperature. Tree establishment and mortality are simulated using Monte Carlo techniques. Fire can be user defined (for prescribed fire) or stochastic (wildland fire).

More recent modeling efforts in the ecosystem community have focused on developing quantitative models for simulating carbon flow through ecosystems. One adaptation of this approach for trade-off analysis is FIRE-BGC (Keane et al 1996). This model is a mechanistic biogeochemical succession model used to investigate the role of fire on long-term landscape scale forest dynamics in the Rocky Mountains. Stand-level processes are simulated daily and accumulated annually using a biogeochemistry approach. Stand-level processes, including tree establishment, growth and mortality, fire and seed dispersal are simulated annually from stand information. It is spatially explicit, thus the effects of topography on various processes are included in the model. Wildland fire is simulated using FIRESTART (a fire occurrence simulator) and FARSITE (Finney 1995, 1998). Fire occurrence is stochastic and fire spread is determined by topography, vegetation, weather and fuels.

An alternative approach to modeling vegetative dynamics is the use of transition functions and pathways to track changes in vegetative conditions through time. In this approach models may use transition functions, flow rates and pathways to simulate movement of acres between vegetative classes through time. Presently there are at least three models developed using this general approach: The Programmatic Fire Effects Trade-off Model (FETM), Vegetation Disturbance Dynamics Tool (VDDT/TELSA), and Simulating vegetative Patterns and Processes at Landscape Scales/ Multi-resource Analysis and Geographic Information System (SIMPPLLE/MAGIS).

JUSTIFICATION FOR SELECTED MODELS

Several characteristics are needed for a model to be useful for national application including: the ability to be applied across a variety of ecosystems, including forest, shrub and grass; the ability to be applied across ecosystems with varied or mixed ownership; and ease of use by users with a broad spectrum of abilities and viewpoints. Complex models, especially those using spatially referenced data, will never be simple enough for non-experts to develop and parameterize without help, but once parameterized non-experts should be able to run alternative scenario simulations.

Using these criteria, 4 models were chosen for this study, SIMPPLLE/MAGIS, FETM, VDDT/TELSA, and SAFE Forests. These models all use transition probabilities to move acres between vegetation or fuel characteristic classes. Other model approaches, such as FVS variants, lack the ability to be applied to all forest, savanna, brush and grassland ecosystems that are currently managed by various federal and state agencies. Applicatoin of SAFE Forests to nonforested ecosystems may be difficult. Process models can be applied across many ecosystems, and several models have been applied globally to all terrestrial ecosystems. These models, however, often require data not commonly gathered on forests/districts, and parameterization, application and interpretation would require expert input. For instance, FIRE-BGC would require estimates of leaf area, tree respiration rates and tree nitrogen status for each species in the simulation area. In addition, process model application to new ecosystems is expensive and time-consuming. FIRESUM does not have this problem because it uses mathematical-empirical relationships; however, model application to non-tree ecosystems would require the development of new mathematical relationships within the model. It is also not clear how mixed brush and tree ecosystems would be handled within the model.

RESEARCH METHODS

Site Selection and Location

Sites have been located in both the western and eastern U. S. in both forest and shrub ecosystems that are managed by several federal agencies (see Table 1). Current vegetation and topographic information stored in a GIS system and a comprehensive fire history database containing fire occurrence by final size and vegetation class are necessary data for all models. One other location will be selected for the historical retrospective.

The models are intended for application at diverse geographical scales ranging from < 10,000 ha to > 500,000 ha. We will simulate fuel treatments on landscapes of 100,000 – 200,000 ha which is a common size where all models should perform.

Model Evaluation

We will address the following questions as part of the model evaluation:

1. What ability do individual trade-off models have to simulate fuel management treatments across diverse terrestrial ecosystems managed by federal and state agencies?

2. What is the uncertainty (risk) associated with the various model projections of future vegetation distribution?

3. What future model development needs to occur before one or more models is ready for implementation nationally by diverse state and federal land management agencies?

Model evaluation will begin with a comprehensive sensitivity analysis of each model to determine the present limitations of each model for national application, and any areas where internal algorithms break-down. Given the complexity of these models, analytical methods of partial derivatives are impractical. Instead sensitivity analysis will be performed using simulation techniques. Key portions of the models will be examined in detail, but not all parts of the model. The objective of the sensitivity analyses is to determine which of the input variables or processes have a strong influence on model predictions. As an example, the influence of the probabilities in the vegetation transition matrices in FETM/TOM and VDDT/TELSA on final vegetation distribution can be determined.

Location	Fuel Types	Year
California	various Sierra Nevada	1999
California	chaparral	1999
Montana	various northern Rockies	1999
New Mexico	various southern Rockies	2000
Alabama / Florida	longleaf pin	2000
Michigan	jack pine	2001
Utah	sagebrush, pinyon-juniper	2001

Table 1. Data collection and model parameterization schedule for major U. S. fuel types.

Following the sensitivity analyses, two types of model evaluation will be conducted, a retrospective model application and an application to test sites. We are conducting retrospective studies at 2 sites: Yosemite National Park and a 2^nd^ site to be chosen. Historical vegetation distribution for Yosemite National Park is based on the Vegetation Type Maps (VTM) and plots that were surveyed by the National park Service in conjunction with the California Forest and Range Experiment Station in the 1930s. The purpose of the retrospective analysis is to determine whether models, given known historical vegetation (Fig. 1), management and wildland fire information (Fig. 2), can reproduce current ecosystem structure. Since not all of the models are spatial, only total area in each vegetation class will be compared for all models. Spatial analysis will be used for those models with spatial output. One potential measurement of agreement between observed and predicted vegetation distribution is the K (Kappa) statistic which is used in the analysis of error matrices in remote sensing and classification

Figure 1. Vegetation distribution for Yosemite National Park as determined by the Wieslander survey of 1937. Each polygon represents a unique vegetation classification.

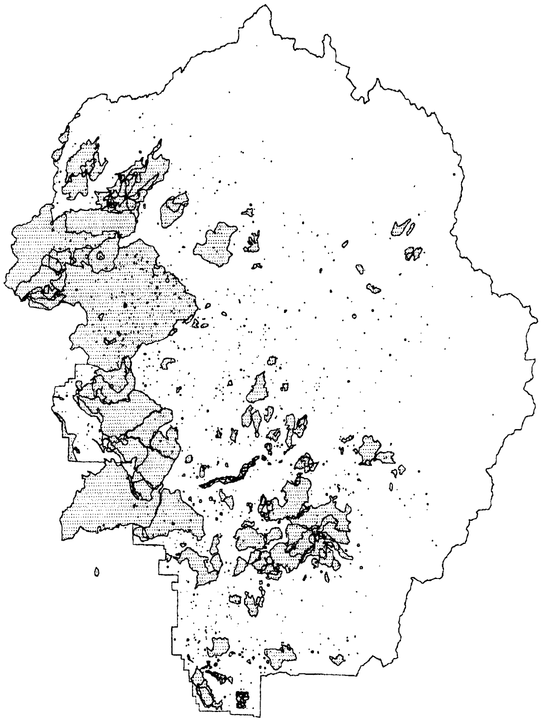

Figure 2. Fire occurrence in Yosemite National Park from 1930 to 1998. Wildland fire types included are lightning and human-ignited prescribed fires.

(Congalton and Green 1999). Components of the models (such as the mechanism to simulate fire occurrence and size) will also be compared with observed data.

Although the 4 modeling systems overlap in functionality, design emphasis differs substantially among the three. SIMPLE/MAGIS is designed to provide decision support at the project/watershed level for treatment type and sequencing on the landscape. FETM, VDDT/TELSA, and SAFE Forests are 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. The emphasis of the model comparison analysis will be 1) to test if general vegetation predictions are comparable between models, and 2) to identify future model development changes for each model that will ensure comparability of basic vegetative and management affects between models, rather than to identify a 'best' model.

In addition to the retrospective analysis, the models are being applied to several sites nationally to determine adequacy for present day planning and trade-off needs. Both the technical aspects needed for trade-off evaluation and the user-friendliness (ease of use) of the models will be evaluated. A principal trade-off evaluated will be smoke emissions. The estimation of total mass of a smoke component (such as CO or particulate matter) produced in a given time step for a vegetation class is $\mu_{iv} = \rho_v A_v w_v \epsilon$ where μ_{iv} is the total mass for smoke component *i* for vegetation class *v*, ρ_v is the proportion of vegetation class *v* that is burned, A_v is the total area of vegetation class *v*, w_v is the biomass consumed per unit area for vegetation class *v*, and e_i is the emission factor for smoke component *i* (mass of smoke component *i* produced per unit mass of vegetation class *v* burned). Summation of μ_{iv} across all vegetation classes equals total mass of smoke component *i* produced. e_i and w_v will be kept constant for each model so differences in total emissions for each model will be a function of the predicted area for each vegetation class and the proportion of the vegetation class burned. In addition to total emissions, the predicted proportion of total area occupied by each vegetation class will be compared between the individual models.

Model assumptions and formulations will be examined to determine differences in model outputs for each location. Once each model is parameterized for a location, estimating the uncertainty associated with model projections is a relatively simple effort. We will estimate confidence intervals for total emission estimates as well as area occupied by each vegetation class. The process is similar to sensitivity analysis. Values of the input variables will be altered according to published values and expert knowledge, then the models will be run. Model outputs will be summarized to produce empirical probability distributions for vegetation distribution and total emissions. Since predicted vegetation will be one of several possible types, the empirical distribution function will most likely be the multinomial distribution. The empirical frequency distributions describe the uncertainty of the model outputs and the risk associated with model errors.

The combination of testing, application, and uncertainty analysis should identify changes in the model components and user interface needed to make individual models more effective and comparable tools for land planning and fuels treatment planning, both for land managers and for affected publics and other agencies. We expect that the advantages of each system will become apparent as the models are applied. Thus this study will result in feedback to the separate model development efforts for future versions that incorporate the strong points of each modeling strategy. One possible outcome of this study is that none of the current models are satisfactory for use nationally as a strategic fire planning model. However, each of the current models might have component parts that should be included in a national model if such a model is deemed necessary.

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