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Sensitivity analysis of the SIMPPLLE model on Lubrecht Experimental Forest, western Montana

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A Sensitivity Analysis of the SIMPPLLE Model on Lubrecht Experimental Forest, Western Montana

by

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B.A., University of Montana, 1995

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A sensitivity analysis of the SIMPPLLE model on Lubrecht Experimental Forest, western Montana.

Advisor: Robert D. Pfister RDP

A knowledge-based computer modeling system has been developed as a tool for resource managers working at the landscape level and following the concepts of ecosystem management. The model SIMPPLLE is the acronym for SIMulating Patterns and Processes at Landscape scaLEs. It is a spatially explicit computer simulation model which uses inventories describing current vegetation conditions to simulate vegetation changes in composition, cover type, and structure across the landscape at varying scales. The inventory was taken from Lubrecht Experimental Forest and the adjoining Elk Creek Drainage in western Montana. Change is simulated as a function of multiple disturbance factors including fire and insect processes, condition of neighboring polygons, and prescribed treatments. The SIMPPLLE model is at the sensitivity stage to surmise any deficiencies within the system requiring further enhancement or that may refute the output values.

A selective sensitivity analysis was chosen to ascertain deficiencies within the modeling system and to attempt to refute output values from model simulations. Sensitivity to regional abstractions built into the model and model sensitivity to selected process probabilities were analyzed. The Kolmogorov-Smirnov nonparametric test of distributions was used to analyze simulation output for differences between regional abstractions and to analyze the influence of manipulated process probabilities for mixed severity fire and severe mountain pine beetle.

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INTRODUCTION

Natural resource managers today are faced with implementing emerging principles of ecosystem management. These principles are based on the concept that ecosystems are continually changing in structure, function, complexity, and interactions among components (Kimmins 1996). In order to manage for desired conditions in diverse and changing ecosystems, resource managers must evaluate numerous environmental factors at scales ranging from the tree to the stand to the landscape to the regional level. Choosing the factors to consider when making ecosystem management decisions lies within the discretion of the resource managers and specialists, but there is no agreement among the specialists on what factors must be considered when seeking to attain desired future conditions. Yet managers must decide on the kind of treatments to apply today in order to reach sustainable ecosystems in the future.

This task of managing for ecosystems becomes more difficult with the many conflicting issues, ranging from timber harvest to aesthetic values, that must be accommodated while remaining within the constraints of a limited budget (Fox et.al. 1988). The degree of complexity associated with ecosystem management necessitates the use of spatially explicit landscape models with the ability to capture available knowledge of the processes of vegetative change that drive change without the high costs often associated with current models. Kimmins (1996) postulated that the complexity of ecosystems can best be addressed by incorporating system knowledge into a comprehensive model and then making predictions about that system and its response to disturbance. The array of modeling approaches employed by natural resource managers and researchers is an indication of the many ways natural systems can be viewed.

Development of models of vegetation change over time essentially began with Clements (1916, 1936). His premise was that of a progression of species groups occurring over time, where the presence of an early species will modify a site, thereby producing conditions less suitable for its own existence and more suitable for its successor. Eventually this progression ends with a final, climax community that is at equilibrium with its environment. More recently, the vital attributes model for succession developed by Noble and Slatyer (1977, 1980) addresses the multiple pathways that can occur as a function of the type and extent of disturbance that shapes the environment. Their successional schemes are useful for describing and predicting vegetation replacement patterns following disturbance such as fire, as well as the influence of fire exclusion (Cattelino et. al. 1979). Given disturbance intensity, type, and frequency coupled with the high diversity of species adaptations, we know that succession can and will follow a variety of pathways regardless of the starting point (Kimmins 1996).

Trying to understand the complex mechanisms by which forest ecosystems change has challenged natural resource managers and researchers for many years. By using a computer's capacity to analyze large quantities of data, computer models that depict ecosystem change can make the complexity more understandable and perhaps provide some management prognosis.

Computer Models

Computer models depicting forest growth and development can generally be grouped into three categories; historical bioassay or empirical, process simulation, and hybrid models (Kimmins 1996). An example of a historical bioassay model is the Prognosis stand growth and yield model which combines silvicultural knowledge and empirical data to estimate the expected growth of forest trees into the future. Empirical growth and yield models are limited by their massive data requirements obtained from intensive specific forest inventories. Empirical models are known for becoming unreliable for conditions not represented in the original inventory (Stage 1977).

Empirical models primarily focus on predicting outcomes and are considered the foundation for practical applications (Korzukhin et.al. 1996) but they cannot account for alternative, disturbance-induced influences on ecosystems because the approach only considers growth over time. Process, or mechanistic, models address ecosystem change from the perspective that an understanding of the key processes that determine a system's internal structure, rules, and behavior will provide the basis for predicting ecosystem change (Korzukhin et.al. 1996). Mechanistic models are limited by the processes chosen by the modeler as the key factors that describe and drive ecosystem change. Although a multiplicity of processes and factors are known to drive and influence ecological change, incorporating all of this information into a single model is impractical at this time due to the large computer capacity required to accommodate such complexity. As Kimmins (1996) postulated, models that attempt to incorporate too many processes become complex, often difficult to understand, and running such models reduces computer speed substantially; input data structure requirements are expected to increase in proportion with increased complexity.

The Forest-BGC model is one example of a stand level process model which simulates the seasonal fluxes of carbon, water, and mineral cycles, from the mechanisms of photosynthesis, transpiration, and nutrient cycling as the key processes of change (Running and Gower 1991; Running and Coughlan 1988). A second type of process model is the canopy gap model which emphasizes the disturbance, recruitment, and mortality processes that affect individual trees as agents of change (Waring and Running 1998). Other research efforts have shown that succession modeling is critical for evaluating future ecosystem and landscape trends (Keane et. al. 1996). Hybrid models are, as the name implies, driven by a combination of biogeochemistry and gap succession models according to Waring and Running (1998) or a combination of historical bioassay and process models according to Kimmins (1996). Models such as Prognosis, Forest-BGC, or any of the many algorithmic modeling approaches are very useful for modeling a portion of an ecosystem, but none are able to fully capture the complexity inherent in the structure and function in a landscape, nor are they fully adaptable to other contexts (Sweet et. al. 1997a).

Forman (1995), defines a landscape as “a mosaic where a cluster of local ecosystems is repeated in similar form over a kilometers-wide area.” Any reference to landscape or landscape scales refers to Forman’s definition of landscape in this study. Modeling at the landscape scale, a coarser level of analysis beyond the more traditional stand level, requires some method of connecting the influence of patterns and processes found at the stand level, and expanding to larger scales using spatially explicit simulation modeling.

This broader scale of ecosystem analysis can be addressed through any of several more recently developed methods of analysis including geographic information systems (GIS), database management, climatological extrapolation, and remote sensing (Waring and Running 1998). The linkage of GIS to landscape models provides the benefits of a database management system, geographic analysis, and visualization of the spatial component of the data (Polzer et. al. 1991). Development of models using climatological extrapolation and remote sensing is progressing but applying the information provided by these modeling efforts to management planning needs is difficult. The data requirements for many models require data collection procedures and data requirements that differ from protocols followed by natural resource managers. Thus, available data and reasonable data collection methods are often nonexistent at the management level. The most complete information available to managers is that provided by stand level inventories and interpretations that are in use on the forests. The question is, can resource specialists use the information available from stand level data collection and extrapolate this stand level knowledge to the broader, landscape scales?

A knowledge-based, spatially explicit computer modeling system for portraying and displaying vegetative change at landscape levels has been developed to address the problems associated with moving from fine to coarse scales of analysis (Chew 1995a, 1995b, 1995c). This model, SIMPPLLE, an acronym derived from SIMulating Patterns and Processes at Landscape scaLEs, is designed to incorporate current knowledge of vegetation dynamics into a computer simulation model for displaying changes that occur at landscape levels. Knowledge-based, or object-oriented, programming (Budd 1991) is the basis behind a new modeling paradigm that diverges from the currently accepted ecological modeling approaches. Simply stated, this approach incorporates the most current knowledge about ecosystems and landscape change, often provided by finer scale models, with the capability to add updated information whenever it becomes available. The model design builds on the information and knowledge gained from other models of stand and ecosystem components representing varying scales in order to simulate landscape-scale vegetation change.

SIMPPLLE, in its current state of development, simulates changes in vegetation composition, cover type, and structure across the landscape at varying spatial and temporal scales. Landscape change is induced by selected disturbance processes or succession, at the community level. Completion of this modeling system will also incorporate aquatic and landform components of the landscape. The SIMPPLLE modeling system was designed as a management tool for displaying vegetation change across landscapes as a function of multiple processes and their interactions with vegetative patterns; its purpose is to provide managers and resource specialists with a method of considering how existing vegetation conditions may influence future conditions and processes at landscape levels (Chew 1995a, 1995b).

SIMPPLLE Development

Development of the SIMPPLLE model began with the efforts of the USDA Forest Service, Region One "Sustaining Ecological Systems" program and has developed along with the current national policy of "Ecosystem Management." The development of SIMPPLLE from its initiation has been more of a technology transfer effort (addressing the needs of Region One and other interested forests) rather than a classical research modeling effort (Chew 1996a, 1996b).

Validation of SIMPPLLE has included comparison of projected vegetation changes with actual changes on a landscape in Coram Experimental Forest in northwestern Montana using timber types delineated from early 1930s aerial photographs. Comparisons of vegetation changes across landscapes through time is difficult due to contrasting differences in the various vegetation descriptions over time. Results from the Coram simulations were difficult to interpret because of basic differences in how vegetative communities were described in the 1930's compared to the current description (Chew 1995c).

Development of computer simulation models generally occurs sequentially as follows: 1) establishment and development of the form and scope of the model, i.e., the variables required to run the system of interest; development of the linkages between the variables such as cause/effect mechanisms within the system, 2) representation of the manner in which the mechanisms will execute, such as the use of mathematical equations and, 3) the time dynamics or simulation length required for the variables to complete cycles such as growing seasons (Running 1997; Kimmins 1996; Zuuring 1992). Once a model is running on the computer, further development includes model calibration, verification that the system is running as intended, validation or confirmation of prediction accuracy by using a data set other than that used to calibrate the model, and testing the model's predictive sensitivity of input data and perturbations to model predictions, and "gaming" with the model in an attempt to invalidate the model (Kimmins 1996; Zuuring 1992). The SIMPPLLE model is at the sensitivity stage to surmise any deficiencies within the system requiring further enhancement or that may refute the output values.

Along with the Coram validation procedure, reviews of the system's performance by United States Department of Agriculture Forest Service (USDAFS) managers at the District level throughout Region One and specialists from the USFS Regional Office in Missoula have been completed. Landscape simulations using SIMPPLLE were executed for managers on the Bitterroot National Forest as part of the Bitterroot Ecosystem Management/Research Project (BEMRP), a continuing research project begun in 1993, to examine how 1) expert opinion ties to modeling landscape dynamics, 2) risks and opportunities can be identified in designing alternatives, and 3) to evaluate land use planning alternatives. Simulations using SIMPPLLE have also been used with computer optimization modeling systems such as MAGIS (Multi-resource Analysis and Geographic Information System), a scheduling and optimization software system (Zuuring et. al. 1995). The "optimal" solution from MAGIS, a schedule of treatments, can be used in SIMPPLLE to see if the desired effect is produced by management actions and to what degree the treatments are feasible according to ecosystem changes that would occur as a result (Chew 1996a).

Sweet et al. (1997b), tested the model's sensitivity to using alternative vegetation classifications. This study hypothesized no difference in SIMPPLLE output when

Timber Stand Management Record System (TSMRS) and Satellite Image Land-cover (SILC) classifications were used to initialize the model. They also found the model seemed to behave in an ecologically correct manner to changes in input. Sweet and others (1997a) also conducted preliminary work on the development of a prototype for the aquatic component of SIMPPLLE which provides the ground work for further augmentation in the future.

The initial version of SIMPPLLE (version 1.1) became available for use within the USFS Region One in the fall of 1994. The most extensive use has been on the Bitterroot Forest through BEMRP and less extensively on the Lolo, Helena, Idaho Panhandle, and Flathead National Forests. As of October 1996, SIMPPLLE computer software is accessible through the Regional Offices' IBM, and at the Rocky Mountain Research Station (RMRS). SIMPPLLE is a work in progress and, as such, model development is on-going. For the purpose of this study, SIMPPLLE version 2.0a was used in order to maintain a standard model environment, although different versions are in various stages of completion. The basic concepts of this modeling effort have not changed since their inception. Any geographical user interface or model output problems were reported to Kirk Moeller, the RMRS computer programming specialist now in charge of SIMPPLLE development, as the simulations progressed during this study in order to refine the model with the intent of making it more user-friendly.

PROBLEM STATEMENT

It is uncertain how SIMPPLLE will behave when alternative regional abstractions are used for simulating change on a single landscape, specifically, Lubrecht Experimental Forest/Elk Creek drainage (LEF/EC) in Western Montana. The influence of initial process probabilities on simulation output is also unknown. The Northern Region, which covers western Montana and extends into Idaho, has been divided into six assessment zones that are represented by different pathways and processes within the SIMPPLLE model (Chew 1996a, 1996b). Pathways represent sequences of change in specific plant communities. The assessment zones display unique pathways, processes, and treatments that are consistent within each zone but vary among zones. The zones are derived from the national hierarchical framework of ecological units at the section scale (ECOMAP 1993). Sections are described as broad areas of similar geomorphic processes, stratigraphy, geologic origin, drainage networks, topography, and regional climate. The two assessment zones used in this study display differences that are attributable to geographical location. The differences are expected to be reflected in the output representing simulated changes across the landscape as a function of each location.

The heterogeneity of a region implies that there will be differences between sections (Forman and Godron 1986). Assessment zones represent the sections into which the northern region has been apportioned. The assessment zones yield "regional variants" of SIMPPLLE. It is uncertain whether the pathways and processes within the regional variants can transfer from one zone to another, or how sensitive the projected outcomes on the simulated landscape are to regional variability. Therefore, two regional variants, the Upper Clark Fork (UCF) and the Headwaters of the Missouri (HWM), will be used to compare simulation output based on a single data set extracted from a reconnaissance inventory of LEF/EC (Mogilefsky and Wood 1995).

Use of the Lubrecht/Elk Creek Walkthrough data set provided an opportunity to use data from an inventory source other than the Forest Service's TSMRS inventory method. The SIMPPLLE modeling system is intended to be adaptable for use with any data that broadly describes current vegetative conditions. When translating the LEF/EC data to the format requirements for SIMPPLLE, it was necessary to choose the database fields which best described the necessary vegetation attributes of size class, species, crown cover, and habitat type group necessary for simulating change in the model.

OBJECTIVES

The intent of this study is to explore the SIMPPLLE model's 1) behavior when a new type of data set is used, 2) the model's sensitivity to regional differences built into the model pathways, and 3) the model's sensitivity to selected process probabilities. The objectives of this study are: 1) to test the predictive sensitivity of SIMPPLLE to the unique pathways of two regional variants, and 2) to test the sensitivity of SIMPPLLE output to the probabilities of selected processes within one set of pathways and states.

The null hypothesis in objective 1 was that model output of total acreage distributions by size classes, compiled from the HWM and UCF regional variants following 50, 5-decade simulations, are the same. The null hypothesis in objective 2 was that the total acreage distributions by selected disturbance process of control output is identical to the total acreage distribution output from simulations executed using increased process probabilities.

METHODS

Objective 1 will be accomplished using two different pathway formulations (the Upper Clark Fork and the Headwaters of the Missouri regional variants) on a single landscape using one data set collected from LEF/EC. A selective sensitivity analysis will be performed by simulating vegetation changes using the Lubrecht walkthrough data applied to SIMPPLLE formulations for the two regional variants. Tree size-class distributions resulting from multiple simulations of the UCF and HWM variants will be compared. The second test of sensitivity for objective 2 will be accomplished by altering selected disturbance probabilities within the Upper Clark Fork formulation and analyzing how changes to process probabilities may influence SIMPPLLE acreage predictions as influenced by the processes under analysis.

The SIMPPLLE model was used to predict vegetation changes on the LEF/EC landscape complex as a consequence of the influence of different regional constraints and the influence of altered process probabilities. Analyses of model behavior were accomplished by first contrasting simulation output resulting from a single data set run through two different sets of abstractions, described earlier as the UCF and HWM regional variants. The second analyses of the model were conducted by altering selected process probabilities and using the output attained from the simulations to compare to output attained from simulations run using the default set of probabilities. Two different processes that could be expected to occur on the LEF/EC complex were chosen for analysis namely, mixed severity fire and severe mountain pine beetle.

Results are organized such that analyses of the regional variants by size class are presented first, followed by analyses of regional variants by processes, reflecting the emphases of objective 1. Influences of altered process probabilities for the UCF variant are then analyzed, reflecting the emphasis of objective 2, with mixed severity fire process presented first followed by severe mountain pine beetle.

Sensitivity Analysis

The ambiguity associated with testing and validating stochastic models is a common difficulty among researchers (Korol 1993). It has been suggested that an objective approach to testing ecological models would be to base the evaluation on model performance, with soundness and usefulness the criteria for evaluation (Korol et al. 1996). Evaluation of the SIMPPLLE model performance was achieved through a sensitivity analysis of the regional variants (specific pathways developed for the HWM and UCF variants). A second analysis of model sensitivity was conducted by evaluating the importance of selected process probabilities within the model by analyzing the effects of changed probabilities on simulation results. In this study, the SIMPPLLE model was evaluated using a goodness-of-fit approach to compare model output for size class distribution and levels of processes over repeated, simulated time steps. Simulated changes in size class output, in acres, served as quantifiable events that were measured and compared.

The SIMPPLLE Program Structure

The structure of SIMPPLLE is that of a knowledge-based computer simulation modeling system for characterizing knowledge of vegetative change at landscape scales.

Change is represented using abstractions of vegetative states which are projected via pathways and through which vegetation dynamics across landscape scales can be simulated. The model is designed to capture the knowledge often generated from fine-scale models which is extrapolated to larger scales using SIMPPLLE.

The approach followed in knowledge-based programming is to represent the system of interest using a set of classes arranged into a hierarchy. A process of classification allows for the decomposition of complex landscapes into a collection of objects and operations (Sweet et.al. 1997a). In SIMPPLLE, the classes are abstractions, or objects, which are the fundamental building blocks of the system; they are entities combining the properties of objects and operations and the manner in which they interact (Chew 1995a). Classes form a hierarchy united through inheritance relationships. A subclass will inherit attributes from a superclass higher up in the hierarchy, such as, humans, dogs, and cats are all subclasses of the abstract superclass of mammal (Budd 1991). For example, in SIMPPLLE the landscape is the abstract superclass and vegetation, aquatics, and landforms are the subclasses (Appendix A).

Application of a knowledge-based design in modeling landscape change requires identification of a set of abstractions that will best describe and capture the behavior of processes at a range of landscape scales and provide for interaction between the classes (Chew 1995a). Following this method of programming, the classes are defined such that the knowledge, often captured from other more fine-scale models, works as a single component but linked externally to other classes of knowledge. This modeling approach is not limited by the constraints of a single model when representing the multiple scales and unlimited functions and processes occurring on the landscape. Thus, the SIMPPLLE model might be better described as a modeling system.

Abstractions, represented by pathways, describe a sequence of vegetative states with stand, or plant community, development (secondary succession) processes generally being the highest probability agent of change from one state to another. Pathways are stratified by habitat type groups that are aggregations of habitat types (Pfister et. al. 1977) and are grouped according to documentation from Fischer and Clayton (1983), Fischer and Bradley (1987), and Green et.al. (1992). Habitat type groups provide a climatological, soil condition, and topographical basis to the pathway delineation (Appendix B). Potential vegetation type is recognized as an important component in site evaluation and classification in which key species may indicate specific site conditions (Daubenmire 1976).

Natural disturbances such as insect, disease, and fire processes as well as human disturbances such as, silvicultural treatments or prescribed fire, are viewed as separate processes from plant community development. Processes are driven by plant interactions based on life history characteristics, dispersal interactions, and resource availability (Chew 1995a). Geographic information systems (GIS) provide the spatial distribution of neighboring vegetative communities (polygons) so their relationships with each other (the vegetative pattern) and other landscape attributes can be implemented in modeling the processes of change by providing an element of spread. SIMPPLLE software was developed using the LISP-based (LISt Processing) commercial product GOLDWORKS from Gold Hill, Inc. LISP is a programming language designed for the manipulation of symbols as well as numbers (Chew 1995a, 1995c).

Dr. Jimmie Chew of the Rocky Mountain Research Station initiated and continues development of the SIMPPLLE model which is executable on a UNIX operating system. Dr. Chew describes SIMPPLLE as a modeling system that integrates existing knowledge of vegetative dynamics (stand development/succession) over time. It captures our knowledge of disturbance processes, the probability of their occurrence and spread, and the influence processes have on each other and the pattern of plant communities (natural disturbance ecology).

Disturbance processes are the agents of change within the modeling environment. This approach follows the multiple successional pathway concepts set forth by Noble and Slatyer (1977) and Cattelino et al. (1979). SIMPPLLE also captures knowledge of treatments, the changes they produce in community species composition and structure, and the influence they have on process probabilities (Chew 1996b). Thus, vegetational change can be expected to occur in several ways: 1) through plant community development, or secondary succession, whereby plant communities will eventually come to a relatively stable state, or a "a late-successional state" in the absence of disturbance, 2) through natural disturbances, following a multiple pathway approach in which plant community development is influenced by natural disturbance (processes) such as insect, disease, and fires, or 3) through human disturbance ecology such as silvicultural treatments and prescribed fire.

Model Input, Initiation, and Behavior

The key vegetation components, or variables, that users must provide to initialize and drive SIMPPLLE simulations can be accessed through database records containing data from any available forest inventories collected at various scales and levels of resolution such as in the TSMRS used by the U.S. Forest Service. A source of data must be provided to describe current vegetation and initialize the model. The description can be obtained from any available inventory with sufficient data to determine the current conditions of vegetation types at a level compatible with a knowledge-base related to those types. Useable inventory sources can include stand examination data, walk-through inventories, aerial photo interpretation, and/or classification of satellite imagery. The key spatial component, a list of all polygons or communities and their proximity to each other, can be obtained from most GIS software packages.

The plant community inventory must describe the physical environments that constitute the landscape being analyzed and provide enough detail so that translation to SIMPPLLE data structure requirements is possible. Site and regional classification, such as habitat type groups and sub-regional variants for different climatic regions, are techniques used to provide an ecological stratification of physical environments across a region. Aggregating site information into a higher level of organization provides a method of classifying successional change according to the influences of predominant processes, climate, existing vegetation, and geologic conditions. Methods of aggregating communities by habitat types and other predominant factors influencing stand development have been well documented in Fischer and Clayton (1983), Fisher and

Bradley (1987), and Green et.al. (1992). Vegetation classification is used to define states, or instances within the vegetative pathways, based on vegetation composition and structure. Components of the vegetation classification required to initialize the model include composition (dominant cover types), structure (physiognomy: size class and canopy cover/density), and layering (vertical structure or spatial arrangement).

Pathways are the successional process of vegetative states and the different disturbance processes are the agents for change from one state to another; pathways are the connections between states, or instances. Within the model, the amount of time spent in a vegetation class is dependent on the community type and the probability of disturbance processes that influence a vegetation community. Transitions and time-spans within vegetation pathway states were derived from regional inventory data sets and growth projections provided by the Prognosis model (Stage 1977). Successional pathways are conceptually comparable to the successional representation found in the Vegetation Dynamics Development Tool (VDDT) developed in 1995 (Beukema and Kurtz). Processes include natural succession, or stand development, which is the basic driving process as well as any number of disturbances deemed influential in the assessment zone of interest as qualified by disturbance literature and expert opinion documentation. Disturbance processes include fire, insects, diseases, windfall, or any other disturbance considered to be an influence on the landscape (or on individual stands). Processes are invoked on the basis of probabilities designated by expert analysis or through formal hazard rating systems if they are available, or a combination of these approaches.

The method of eliciting processes during a simulation can be accomplished using one of three selection criteria: 1) stand development without major disturbance events, 2) the process with the highest probability of occurrence, or 3) stochastically selecting a disturbance process based on its probability. Initial probabilities are obtained through historical information, using hazard rating systems such as mountain pine beetle risk by Amman et al. (1977) or the spruce budworm hazard rating system by Carlson and Wulf (1989), or using information developed through the interdisciplinary process. Process probabilities are then adjusted within the system to account for adjacent community conditions and processes in order to produce the spatial influence of spread. When a process occurs, it may change a vegetative state to another, or keep the state the same but change the probability of other processes occurring (Chew 1995b).

The element of stochasticity can be added following the Monte Carlo method for modeling and simulating stochastic processes (McMillan and Gonzalez 1965). In the Monte Carlo method, the elements of a random variable, its probability distribution function, and a sequence of random numbers are used to provide the stochastic element (McMillan and Gonzalez 1965). The set of random numbers assigned to the probability that a process will occur is related to the initial process probabilities by the lower limit of each set of random numbers. For example, if the occurrence of a mixed-severity fire event had an initial probability of 10%, or .10, relative to any other processes, 10 random numbers out of 100 would represent the outcome of mixed-severity fire. Therefore, in 100 simulations, the mixed-severity fire event would be expected to occur 10 times. This stochastic element is used to better emulate the randomness of processes or events occurring across landscapes because, although certain probabilities are specified, in reality a process still may or may not occur. For example, a dense stand with high fuel loading can exist for many years without a fire, but specialists know that this stand could burn at any time although the exact time is uncertain. Using this stochastic approach applied to multiple simulations results in a range of possible outcomes; therefore, no SIMPPLLE output comes out exactly the same. This provides managers with a tool to consider the full scope of potential outcomes that can be expected on a landscape.

SIMPPLLE was designed with the intent that it should be useful to resource managers. Therefore, one of its strengths lies in the fact that it can be executed on data obtained from available inventories, its output reliability is dependent on the reliability of the inventory data. Inventories containing the key components of size class, dominant species, crown cover, and habitat type group provide descriptions of the current state of forest landscapes. Given a description of the current state, the model predicts the changes a vegetative community will undergo by succession alone, or by stochastic disturbance processes invoked by the probability function. The process attributes can be displayed through SIMPPLLE's user interface in any combination.

The SIMPPLLE model provides a tool to integrate our current knowledge of vegetative change within an area using descriptions of stand inventories, site classification, and vegetation classification. The system's requirements for input must be consistent with the inventories that are used by land managers. To maintain maximum input/output flexibility, the system is not linked to any specific inventory system, a specific classification system, or a specific geographic information system. It is designed to accept spatial attributes for vegetative communities from any GIS or database management system. The display of projection results and further spatial analyses are performed by returning the resultant output to a GIS software package (Chew 1995a, 1995b, 1995c).

Although the current application of the model uses a fairly standard vegetation and site classification system, the model has a generic structure that lends itself to broader applications. The initial condition of the landscape as described by the stand inventory, translation of inventory to vegetation types, and site types provide a point of initialization for landscape changes over time. Although vegetation development is a process of continuously changing species patterns and community characteristics, it is convenient to view any plant community through a series of transitions from one state, or vegetation type, to another with the understanding that multiple pathways can be followed (Chew 1995a).

The classification and description of vegetation is tailored to fit the issues being addressed, the availability of information to predict process probabilities, and the ability of resource inventories to describe and identify the types. Stand development changes, disturbance processes, treatments, and the logic for what they do and how they interact can be "tailored" for any specific area. Initial process probabilities are derived through expert judgement, available hazard rating systems and historical information. Process probabilities are modified by existing plant community conditions coupled with an existing community's past processes, adjacent community conditions, and adjacent communities' past and current processes (Chew 1996b).

Processes vary across a landscape and can spread from one plant community to another. Therefore, the model includes an "adjacency" component to modify the disturbance probability for an object based on probability or "risk" of immediate neighboring stands. Therefore, a polygon that is initially at very low risk of mixed severity fire, for example, will be at greater risk if a neighboring polygon is at high risk of mixed severity fire. The SIMPPLLE model design is sensitive to the vegetative pattern and its impact on processes and conversely, the impact of processes on vegetation patterns. The interaction between vegetation patterns and processes provide the basis for changes occurring across the landscape.

Treatments specified by the user can change a community's vegetative state, the probability of processes, or both the state and probabilities. Processes can be set for specific communities or treatments can be scheduled at desired time-steps. Therefore, different management alternatives can be simulated by the model to produce a "what-if" scenario. For example, one can simulate the effects of thinning with an underburn, thinning with no underburn, and selective harvest activities would have on the landscape to provide a useful decision support tool for managers.

SIMPPLLE users can choose which processes to incorporate or omit in a simulation. For example, the system can execute with or without fire suppression, with stand development alone, with the highest probability processes, or with the probabilities defined "stochastically" resulting in a different output for each simulation which is interpreted as the range of natural variation that can be expected on the landscape.

Model Output and Analysis

The stochasticity built into the model provides outcome ranges over decade-long time steps when simulating potential landscape changes. The user chooses the number of decades to simulate as well as the number of simulations. Numerous stochastic simulations provide the basis for a quantitative display of variability and any trends resulting from processes as well as the trend in type and extent of disturbance across the landscape. Selected portions of an output file can be passed to other graphics packages for creation of charts and reports. The variability, expressed as both the vegetative condition and the occurrence of processes over repeated simulations, can be statistically summarized for a given landscape to test, as an example, for statistical differences in levels of process activity. This variability is consistent with a landscape that is constantly changing along with the multiple factors potentially influencing an ecosystem and the seemingly random nature of disturbances. The range of variability is related to the specific pattern of vegetation and process-types that influence the landscape. Long term simulations can be used to examine the relationship between processes and individual process simulations can be mapped. (Chew 1996b).

SIMPPLLE provides a means of considering vegetation changes at landscape scales that are driven by processes with process probabilities that reflect the most up-to-date knowledge. Stochastic simulations using SIMPPLLE represent the simulated natural variability in vegetation, and the set of disturbances that can be expected in the future for a given landscape. This variability is bounded by the occurrence of low probability, catastrophic scale events. The probabilities are set according to available hazard rating systems and expert knowledge and are the default probabilities within the model. Within one cycle (decade-long time step), the sequence of modeling is as follows: 1) any planned treatments are applied at the beginning of the step and the resultant change to vegetative state is made, 2) process probabilities are determined for each existing vegetative unit according to hazard rating or expert logic, 3) if a treatment affects the probabilities of processes in the treated or surrounding units, these adjustments are made at this time, 4) a process is selected for each vegetative unit, regardless of whether the unit had a treatment, according to the user's choice of stand development alone, highest probability, or stochastic process, 5) fire suppression logic is applied (unless no suppression was the user's choice) and if a fire process is suppressed, the process is changed to stand development for the time step, 6) another adjustment to process probabilities is made to all vegetative units based on the vegetative units that are immediate neighbors, and 7) the final set of processes for each vegetative unit provides the logic for the next vegetative state in the pathway. If the next vegetative state is nonforest, a combination of the seed source in adjacent units and the possibility of on-site seed source determines what species is regenerated unless there is a lack of conifer seed source, in which case the unit may remain nonforest for a number of time steps.

SIMPPLLE can process "historic" or reference data collected from chosen landscapes to provide a basis for comparing the levels of process occurrence and the amount and pattern of vegetative communities with current or future conditions. Using

SIMPPLLE, managers and specialists can plan for desired future conditions knowing the range of processes that can be expected on a landscape to aid in achieving goals of ecosystem management.

The Study Area

The Lubrecht Experimental Forest/Elk Creek (LEF/EC) complex lies about 35 miles northeast of Missoula, Montana on the Lolo National Forest and occupies approximately 44,000 acres with the Blackfoot River drainage running along the northern boundary (Figure 1). The area within the vicinity of the Sapphire and Garnet Mountains is a patchwork of ownerships including private, state, and federal lands. The LEF/EC complex is cooperatively managed by the University of Montana/Lubrecht Experimental Forest, Bureau of Land Management (BLM), and Montana Department of Natural Resources Conservation (DNRC). The LEF/EC landscape has not been previously simulated on the SIMPPLLE model and provides a relatively small landscape with GIS coverages already built for the area.

The Elk Creek drainage encompasses approximately 33,000 acres and is a major component of LEF. The majority of the drainage is actively managed by the BLM while about one third of the lower end of the drainage is managed by the University of Montana as part of Lubrecht Experimental Forest. The DNRC manages several sections distributed throughout the drainage. The Elk Creek drainage was inventoried using the same methods as developed for Lubrecht Experimental Forest in 1995 and data is included for the entire complex within the publicly available database.

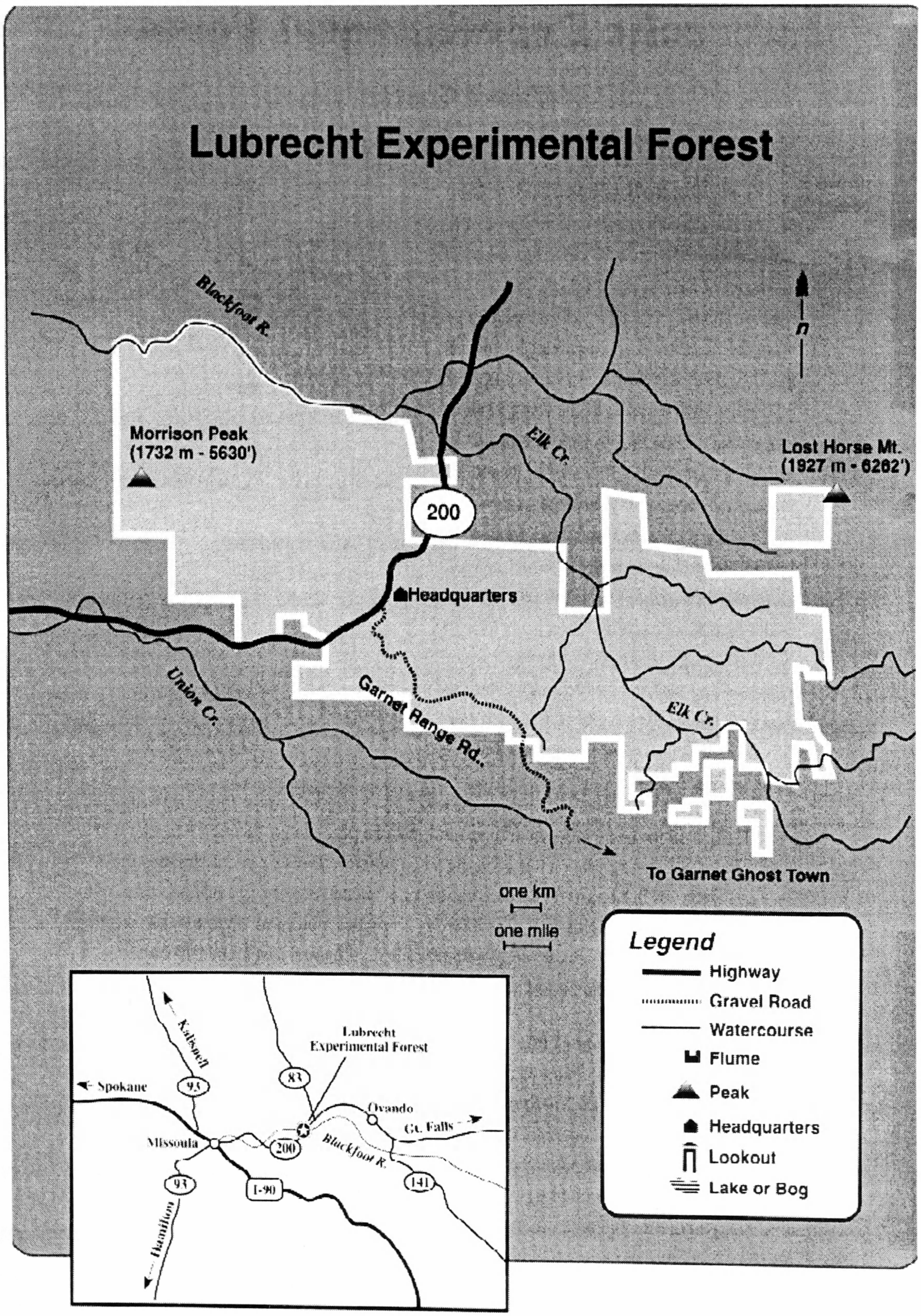


Figure 1. Location of Lubrecht Experimental Forest in western Montana (Schmidt and Friede 1996).

LEF/EC Walkthrough Database

The Lubrecht Experimental Forest and associated Elk Creek drainage were inventoried in 1995 for the purpose of providing very general forest stand information to aid planning for future projects and activities. A walkthrough forest inventory approach was used which incorporated a GIS linked database to simplify and organize record storage and retrieval in a map-based scenario (Mogilefsky and Wood 1995). The inventory is not intended to replace statistically-based sampling, nor is it a comprehensive biological-, amenity-, or commodity-based inventory system. Data collection for the Walkthrough was based on an intensive reconnaissance supplemented by point sampling and extensive photo interpretation, as well as expert biotic knowledge and forest inventory experience (Mogilefsky and Wood 1995). Managers of LEF were responsible for information from the University of Montana lands (including DNRC sections) while the BLM provided inventory information for their Elk Creek lands. Cooperation among these ownerships provided shared information and expertise for the entire LEF/EC landscape complex. This inventory provided general vegetation information following a method of data collection for both stand (polygon) and point samples. Data describing vegetation attributes as well as many other stand and point sample attributes were collected during the 1995 Lubrecht Walkthrough. The data is available to the public and located in the University of Montana School of Forestry's data repository.

The Walkthrough database structure is composed of 96 fields covering a gamut of plot- to polygon-level sample data. The mixture of point sample data and polygon-level data made interpretation of this inventory difficult and translation of the information into SIMPPLLE requirements was more of a challenge than anticipated. Some of the difficulty was attributable to the dichotomy of classification levels, plot and polygon, from which the data was collected in the Walkthrough database. The largest problem was that the majority of stands were recorded as "multiple size", thus requiring use of plot data to estimate a more specific size class for the stand. Two attempts at translation were necessary before a working copy of SIMPPLLE input was produced. Translation of the walkthrough data to the size class, density, cover type, and habitat type groups using available fields provided by the Walkthrough required some interpretation, as is the case when preparing data for most models. Following submission of test simulation output to Tom Daer, BLM silviculturist, and his associates working on the Lubrecht area, a second translation was considered necessary and will be described later.

The Regional Variants & Expert Analysis

Initially, six different regional variants of SIMPPLLE were developed to represent aggregations of pattern and process that would fully display the heterogeneity of the northern region. Those variants incorporated into SIMPPLLE version 2.0a are the Headwaters of the Missouri, the Upper Clark Fork, the Lower Clark Fork, the Clearwater Salmon, the Greater Yellowstone, and the Island zones. Although not all of these model variants were operable when this study began, the Upper Clark Fork (UCF) and

Headwaters of the Missouri (HWM) zones were ready and represented neighboring areas which the Lubrecht/Elk Creek landscape encompassed.

The pathways, or abstractions, representative of the UCF regional variant were formulated by forest experts/managers on the Bitterroot National Forest while abstractions more appropriate for the HWM zone were formulated by experts/managers from the Helena and Lewis & Clark National Forests. Using an interdisciplinary approach in a series of workshops, experts/managers addressed the extent and types of changes expected on the community types and processes that generate and influence change within the constraints of the regional variants. Information provided by the experts/managers was then used to build algorithms representing change to be incorporated into the modeling system. Vegetation community change, displayed by the pathways, is stratified by habitat type group and species mix within each geographic zone (Appendix B).

Abstractions representing change within the UCF and the HWM regional variants were formulated according to the predominant processes and community types characteristic of these geographically distinct areas. Because of the differences between the two variants, experts from the Bitterroot National Forest found that some methods of classification were more appropriate for the Upper Clark Fork area while experts from the Helena and the Lewis and Clark National Forests adopted other means of describing vegetation communities and their pathways of change in the Headwaters of the Missouri area (Appendix B). For example, stratification of the regional variants by habitat type group was developed using the old growth method of habitat type aggregation (Green et.al. 1992) on the UCF variant because expert analysts contended that the old growth method provided a better description of how change occurs on the Upper Clark Fork zone. This contrasted with the fire groups (Fischer and Clayton 1983) used on the HWM variant which expert analysts felt provided a method more in keeping with the influence of processes on the Headwaters of Missouri zone. Some size-class names differed between the variants, such that the HWM variant was comprised of a multi-story component only in the old forest size class, but the range of sizes comprising each class were the same which allowed a comparison of the two populations.

Inventory Translation

Translating existing data into SIMPPLLE data structure requirements is probably the most difficult task when running the model. Methods of data collection that are available to resource managers are many and varied, due to different management needs, most often at the stand level. Most of the input data have been taken from TSMRS inventories since this modeling effort was initiated to meet the needs of USFS managers. Translation of data collected for reasons other than the purpose at hand can be a difficult process especially when a modeling effort involves multiple-scale analysis. Translating data into a compatible SIMPPLLE format often results in a decision-making process where the translator must decide how to best fit size class, density, species composition, and habitat type group into an instance that is recognized by the model.

Just as an expert system approach was used to build the pathways and processes for the model, expert judgement was also used to analyze SIMPPLLE output to ascertain whether model behavior was displaying changes that could be expected given a certain landscape and the associated current state of knowledge of vegetative change. Tom Daer provided expert knowledge as a silviculturist working on the LEF/EC complex over the past 20 years to analyze the initial SIMPPLLE output. A preliminary 100-year simulation was executed on the model, after an initial data translation was completed, using the UCF variant. The output was presented to Daer and his associates along with the initial translation documentation. The logic for the density, species composition, and habitat type group conversions was considered sound, but the size class conversion logic required alterations.

Given Daer's broad knowledge of the LEF/EC complex and the Walkthrough database as well as his expertise as silviculturist for the BLM, his suggestions were invaluable and helped to change the translation criteria to better describe the existing vegetative state of the landscape. The translation incorporated information from fields in the Walkthrough database to provide a more accurate depiction of the landscape than was provided in the first translation (Appendix C). Daer suggested altering the initial translation to better describe existing structural conditions because certain size classes were under-represented while others were over-represented. Specifically, the large size class was under-represented whereas the pole and medium single- and multi-story size classes were over-represented.

Size Class. A comparison of the Walkthrough size class ranges (Table 1) to SIMPPLLE size class ranges (Table 2) shows that a direct translation from the Walkthrough size class field to SIMPPLLE structural requirements was not possible due to the mismatch in size class. Translation to the HWM variant required some changes to the logic used for the UCF variant process. Table 2 displays the SIMPPLLE size class naming convention in which a multistory class was only present in the Old Forest component for the HWM variant. The classes that translated to the Pole multi story (PMU), medium multi story (MMU), large multi story (LMU), and very large multi story (MU) classes for the UCF variant became Pole, Early Mature, and Late Mature size classes in the HWM variant. Aside from naming conventions, the size class translation was the same for both variants.

Table 1. Coding and size class naming conventions for DBH ranges from the Walkthrough database.

Code	**DBH Range (inches)**	**Size Class**
1	0-2	Seedling
2	2.1-5	Sapling
3	5.1-9	Small
4	9.1-15	Medium
5	>15	Large
6	–	Multi-size

Table 2. SIMPPLLE size class definitions, by regional variant naming convention and DBH ranges.

HWM	UCF	Diameter Range (inches)
NF	NF	0
SS	SS	$0 < D \leq 4.9$
Pole	Pole	$5.0 \leq D \leq 6.9$
	PMU	$5.0 \leq D \leq 6.9$, Multistory
Early Mature	Medium	$7.0 \leq D \leq 8.9$
	MMU	$7.0 \leq D \leq 8.9$, Multistory
Late Mature	Large	$9.0 \leq D \leq 13.9$
	LMU	$9.0 \leq D \leq 13.9$, Multistory
Old Forest	Very-large	$D \geq 14.0$
OFMU	MU	$D \geq 14.0$, Multistory

The stand size class field was based on the average diameter of trees found in the middle and upper canopy layers of each stand. A layer is a strata or story of trees comprising approximately 15% of the stand canopy cover (Mogilefsky and Wood 1995). Three layer or multi-story stands were coded 6 and codes 1-5 were assigned according to DBH ranges as shown in Table 1. The size class definitions for both variants of SIMPPLLE are described in Table 2. These definitions are based on guidelines associated with the Forest Service's TSMRS and follow the traditional measure of size classes based on ranges of diameter. A multistory component is also based on TSMRS's criteria for the strata element.

The fields used in the translation included SSC, STRUC, CFBA, BFBA, CFDBH, BFDBH, LSC1, LPC1, PCC, BH, LSC2, LPC2, and BA15. This second translation followed a 2-step process, first to the single story component using the SSC fields coded

1-5 and then to the multistory component using the SSC fields coded 6. The stand size class (SSC) and stand structure (STRUC) fields were used together to break up the inventory into the single story and multi story components. The SSC fields coded 1-5 designated the single story components while fields coded 6 designated the multi story components (Tables 3a and 3b). The STRUC field is coded 1-4 to provide information on stand layers. A layer is defined in the Walkthrough database description as a stratum of trees, within the same height group, containing at least 15% of the stand canopy cover where 1 indicates a single layer (upper stratum), 2 indicates two layers (middle stratum), and 3 indicates three layers (bottom stratum, closest to the forest floor). A code of 4 indicates a multistory stand with more than one distinct size class (diameter), yet less than 15 feet difference in layer heights. The logic for evaluating stand structure is to first evaluate the range and abundance of tree heights which characterize the stand canopy; second, to categorize height groups into an appropriate layer (1, 2, 3 or 4 when categories 1-3 are not applicable); and third, to evaluate the point sample tally to determine the distribution of size classes characteristic of the stand (Tables 3a and 3b).

Table 3a. Single story translation from Walkthrough database fields to SIMPPLLE single story size/structure classes for the UCF and HWM variants.

*SSC		*STRUC		*CFBA-BFBA		*CFDBH	*BFDBH	*LSC1-LPC1-PCC		SIMPPLLE
1	and	1, 2		—		—	—	—	⟶	SS
2	and	1, 2		—		—	—	—	⟶	SS
3	and	1, 2	and	CFBA >= 2 CFBA > BFBA	and	5-6"	—	—	⟶	Pole
3	and	1, 2	and	CFBA >= 2 CFBA > BFBA	and	7-8"	—	—	⟶	Medium Early Mature
4	and	1, 2	and	BFBA >= 2	and	—	< 15	—	⟶	Large Late Mature
5	and	1, 2	and	—		—	—	LSC1 = 5 LPC1 > 2 PCC > 2	⟶	Very Large Old Forest

*Conversion to SIMPPLLE single story size classes required the Walkthrough fields stand size class (SSC) numeric codes less than 6, stand structure (STRUC) numeric codes less than 3, basal area in the 5-8.9" class (CFBA) and 9" and greater class (BFBA), DBH in the 5-8.9" class (CFDBH), DBH in the 9" and greater class (BFDBH), size class for layer 1 (LSC1), percent canopy cover for layer 1 (LPC1), and percent total canopy cover (PCC).

Table 3b. Multi story translation from Walkthrough database fields to SIMPPLLE size/structure classes for UCF and HWM variants.

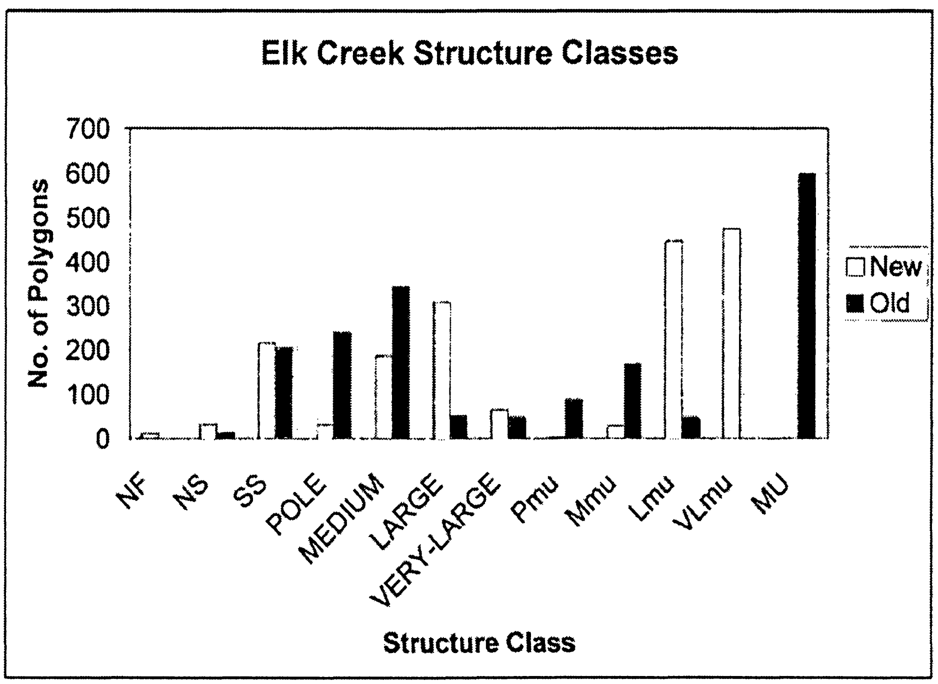
*SSC		*STRUC		*CFBA-BFBA		*CFDBH	*LSC1-LPC1-PCC		*LSC2-LPC2	*BA15		SIMPPLLE
6	and	3, 4	and	CFBA >= 02	and	5-6"	—		—	—	→	PMU
6	and	3, 4	and	CFBA >= 02	and	7-8"	—		—	—	→	MMU
6	and	3	and	—		—	LSC1 = 4 LPC1 > 2 PCC > 2		—	—	→	LMU
6	and	3	and	—		—	LPC1 <= 2 PCC > 2	and	LSC2 = 4 LPC2 > 2	—	→	LMU
6	and	4	and	BFBA >= 02	and	—	—		—	< 02	→	LMU
6	and	3		—		—	LSC1 = 5 LPC1 > 2 PCC > 2		—	—	→	MU
6	and	4	and	—		—	—		—	>= 02	→	MU OFMU

*Conversion to SIMPPLLE multi story size classes required the Walkthrough fields stand size class (SSC) numeric codes equal to 6, stand structure (STRUC) numeric codes greater than or equal to 3, basal area in the 5-8.9" class (CFBA) and 9" and greater class (BFBA), DBH in the 5-8.9" class (CFDBH), size class for layer 1 (LSC1), percent canopy cover for layer 1 (LPC1), percent total canopy cover (PCC), size class for layer 2 (LSC2), percent canopy cover for layer 2 (LPC2), and basal area per acre greater than 15" DBH where structure is coded 4 (BA15).

The CFBA field provides a measure of the average basal area to the nearest ten feet for all live trees between 5-8.9" DBH on selected variable radius plots. Similarly, the BFBA field provides a measure of the average basal area per acre to the nearest ten feet for live trees 9" DBH and greater from selected variable radius plots. Data from the two fields was used together provide an alternative method of defining the pole, medium, and large size classes based on basal area.

The CFDBH field provides average diameter of live trees 5 - 9" DBH and the BFDBH field which provides the average size tree in the 9" and greater stand component as determined from selected variable radius plots, together provide a breaking point for the pole, medium, and large size classes. Both fields list DBH to the nearest inch of the observed average size tree in the 5-8.9" stand component and the 9" and larger class of trees, respectively. The LSC1 (size class for layer 1 using the SCC codes), LPC1 (percent canopy cover for layer 1), and PCC (percent canopy cover) fields are used together to designate the very large size class in SIMPPLLE. Table 3a displays the single story translation. Translation to the SIMPPLLE multi story component followed the same method as that for the single story conversion but with the addition of the fields LSC2 (size class for layer 2 using the SSC code), LPC2 (percent canopy cover for layer 2), and BA15 (average basal area per acre greater than 15" DBH where STRUC is coded 4). Table 3b displays the logic for this translation.

The change in translation logic, as recommended by Daer acting as expert analyst, and the resultant rule set shifted size classes so as to provide greater credibility in simulation output from SIMPPLLE. The contribution of ground-level understanding of the vegetation existing on the landscape as well as the overriding processes influencing vegetation change allowed this study to proceed with greater confidence in the accuracy of model input. The shift in the number of polygons represented by the structure classes is displayed in Figure 2, where the size class distribution resulting from the initial translation (old) is compared to the distribution resulting from the final translation (new).



(Sweet 1997)

Figure 2. Bar chart comparison of structure classes following the initial translation (Old) and final translation (New) for the LEF/EC landscape prior to execution of SIMPPLLE simulations.

The most important influence of the altered translation logic can be seen in the reduction of pole, medium, pole-multi story, and medium-multi story components by several hundred polygons following the final translation. The number of polygons with large and large multi story components, previously under-represented in the initial translation, showed an increase by several hundred polygons following the final translation. Over- and under-representation of size classes in the initial translation created very questionable simulation output when analyzed by experts. There was little change in the seedling-sapling, nonstocked, nonforest, very large, and very large multi story components (VLmu and MU are equivalent). The redistribution of structural components following the final translation provided a more accurate portrayal of the LEF/EC landscape according to expert analysis by Tom Daer and his associates (Daer 1997b).

Density. Translation from the Walkthrough percent canopy cover (PCC) field was a direct conversion into the new SIMPPLLE database field labeled Density. The PCC field in the Walkthrough database contains codes 01 - 06 based on the percent of ground area covered by tree canopy for trees larger than seedling/saplings. Seedling/saplings (< 5" DBH) were coded according to trees per acre and classes were coded 07 - 10 (Table 4). The SIMPPLLE density field is also a coded system with classes split into 5 single-digit categories 0 - 4 (Table 5). Translation of the Walkthrough PCC field to the SIMPPLLE UCF density field is shown in Table 6.

Table 4. Density coding conventions based on percent canopy cover of dominant trees and trees per acre from the Walkthrough database.

Code	Percent Canopy Cover	Code	Trees per Acre
01	0-9	07	0-100
02	10-25	08	100-500
03	25-40	09	500-1000
04	40-55	10	>1000
05	55-70		
06	>70		

Table 5. SIMPPLLE density coding conventions based on canopy cover ranges of dominant trees for the UCF and HWM variants.

Code	Percent Canopy Cover (CC)
0	$CC < 10$
1	$11 \leq CC \leq 30$
2	$31 \leq CC \leq 49$
3	$50 \leq CC \leq 69$
4	$70 \leq CC \leq 100$

Table 6. Translation from Walkthrough database canopy codes to SIMPPLLE density codes for UCF and HWM variants.

Lubrecht Canopy Code		SIMPPLLE Density Code
01, 07-10	→	0
02	→	1
03	→	2
04-05	→	3
06	→	4

Habitat type groups. Habitat types were recorded in the Walkthrough data set under the field name HAB_TYP. Habitat types were coded according to Pfister's Forest Habitat Types of Montana (Pfister et al. 1977) and Hansen's riparian types (Hansen 1995) using the Automatic Data Processing (ADP) codes for National Forest Systems use. Habitat types must be aggregated into habitat type groups to meet SIMPPLLE data structure requirement requirements. The logic for aggregation on which the UCF abstractions were built was based on the premises of the old-growth forest types of the northern region described by Greene et al. (1992). Habitat type aggregation for the HWM abstractions was based on the logic presented in Fischer and Clayton's Fire Ecology of Montana Forest Habitat Types East of the Continental Divide (1983). Translation of the Walkthrough database habitat types into the UCF old-growth groups is presented in Table 7.

The habitat type groups for the HWM variant were based on the logic outlined for fire groups in which the response of tree species to fire and the roles these tree species play during successional stages provide the foundation for habitat type aggregation (Fischer and Clayton 1983). Logic for a direct translation from the old growth groups to the fire groups was derived from documentation provided by Pfister (1997), expert analysis by Tom Daer, silviculturist for the BLM, and the criteria provided by Fischer and Clayton (1983). The conversion from UCF old growth groups to the HWM fire groups are also included in Table 7.

Table 7. Conversion of Walkthrough database standard numeric ADP codes from the habitat type field (HAB_TYP) to Western Montana old-growth habitat type group with site descriptions (Greene et al. 1992) and to fire habitat type groups (Fischer and Clayton 1983).

ADP Code	UCF H.T. Groups	HWM H.T. Groups
210, 220, 230, 311, 321	WMT-A/Warm and Very Dry	FG-4/Warm, Dry (Douglas-fir Type)
250, 260, 261, 262, 282, 310, 313, 312, 320, 324, 350	WMT-B/Warm and Dry	FG-4/Warm, Dry (Douglas-fir Type)
280, 281, 283, 292, 323, 330, 370, 750	WMT-C/Warm and Moist	FG-5/Cool, Dry (Douglas-fir Type)
420, 421, 422, 470, 620, 660, 661, 662, 670	WMT-E/Cool and Wet	FG-9/Moist, Lower Subalpine
410, 440, 480, 630, 650, 961, 963, 966, 967, 968, 970, 975, 976, 977	WMT-F/Cool and Dry to Moist	FG-8/Dry, Lower Subalpine
290, 291, 590	WMT-G/Cool and Moist to Wet	FG-6W/Moist
293*, 663, 690, 720, 731, 920, 930, 940	WMT-H/Warm to Cool and Dry	FG-7/Cool, Lodgepole Pine Dominated
692, 740	WMT-I/Cold and Dry to Wet	FG-7/Cool, Lodgepole Pine Dominated

*Note: The ADP codes 273 and 295 were recorded in the Walkthrough database but were found to be misprints. Consultation with Don Wood, LEF manager and primary data collector for the Lubrecht portion of the Walkthrough database, verified the codes as erroneous and provided 293 as the correct code.

Logic for the UCF conversion was outlined during a workshop for soil scientists and silviculturists from Northern Idaho and the Flathead regions. The final objectives for habitat type grouping were to arrange habitat types and phases into the smallest number of groups that will provide logical and meaningful information and to develop rationale for cases in which habitat types or phases fall into different groups by Forest Regions. Habitat types and phases were grouped to broadly reflect differences in vegetative response to disturbance (treatments), differences in potential productivity (timber, forage, browse, etc.), potential to provide hiding and thermal cover, potential fuel loading, fire frequencies, stockability limitations, potential problems with establishing tree regeneration, and potential tree species.

The scale at which the model is intended to simulate landscape change over time and space precludes concise aggregation of the habitat types. In order to simplify the translation between the UCF and HWM variants, the conversion displayed in Table 7 is considered to be congruous but not necessarily parallel. Some exceptions, such as the habitat types coded 292, 323, and 961, for example, were placed in the respective HWM fire groups for the sake of simplifying the translation, although it may be argued that this was not an exact fit.

Species. Cover type translation from the Walkthrough database F_TYPE field into the new SIMPPLLE Species field required changing codes to species name abbreviations. Cover types were coded 1 - 9, with up to 4 species combinations listed in decreasing order of abundance within the stand. A stand described by a mixed species code must have at least 10% canopy cover of a given species. For example, a stand with Douglas-fir predominating and also containing ponderosa pine and lodgepole pine, each with greater than 10% composition would be coded 124. Translation from the Walkthrough species codes to the abbreviated species names required as input into the SIMPPLLE model for the UCF and HWM variants is displayed in Table 8.

Table 8. Translation from Lubrecht species codes to SIMPPLLE species codes for the UCF and HWM regional variants.

Lubrecht Code	Species Name	SIMPPLLE Code
1	Douglas-fir	DF
2	Ponderosa Pine	PP
3	Western Larch	L
4	Lodgepole Pine	LP
5	Engelmann Spruce	ES
6	Subalpine Fir	AF
7	Cottonwood	CW
8	Quaking Aspen	QA
9	Nonforest	NF

Since the model does not accept all species combinations it was necessary to change the order of many species groups as they were provided by the Walkthrough database. The Walkthrough inventory contained 30 species combinations which were reduced to 13 species combinations following the translation. Generally, nonexistent species combinations were the greatest source of error in the initial database, although other errors were produced by incorrect species, size class, density, or habitat type group combinations. A utility in the SIMPPLLE user-interface was executed after the translated data was loaded into the model and approximately 90% of the data was found to be in error and changes were required before simulations could be made.

The rules for changing pathway states were loosely based on first dropping the last species listed, since a majority of SIMPPLLE species groups are composed of 3 species or less. The second step was to rearrange the order of the species, such as in the case of larch combinations where larch always occurs first in the list if any larch are present in SIMPPLLE, while LEF species are listed in order of abundance. The third step was to drop the third species from the LEF list if it did not occur in any SIMPPLLE species combinations. The fourth step was to change the density because this value often was nonexistent in the species, size class, density combinations forming pathway states. Finally, when it was impossible to fit certain individual cases into a SIMPPLLE state, it was assumed that the habitat type group did not match with the species combination; since habitat types are more likely to be in error than species, the habitat type group was changed.

Data Analysis

Initial conditions for the UCF and HWM variants were first analyzed graphically and then statistically using the Kolmogorov-Smirnov goodness-of-fit test to be certain that input data translations did not result in corrupted data sets that could not be compared. The data was then loaded into the model and 50, 5-decade simulations were executed for the HWM (simulation run 1, Table 9) and then the UCF (simulation run 2, Table 9) variants on a Forest Service networked UNIX workstation for the purpose of meeting the goals of objective I. Stochastic process probabilities were set at default levels with no fire suppression. Simulation output was saved to a spreadsheet format and later loaded into the statistical package SPSS for Windows. Simulation output from the UCF variant was used as the control data set for the following analyses which focused on objective II.

To meet the goals of objective II, the UCF process probabilities were increased and model simulations were executed, similar to simulations for objective I, using the LEF/EC landscape as input with stochastic processes and no fire suppression. Output from these simulations was then compared to UCF output from simulations run with default process probabilities (control) (simulation run 2, Table 9). For treatment one, (Trt1, simulation run 3a, Table 9), a set of 50, 5-decade simulations was executed on the UCF variant with the default probabilities for severe mountain pine beetle (MPB) increased by 25% and a minimum probability of 1 percent. All other process probabilities were held constant at the default level; if the default MPB probability was set to 0 then it was increased to 1 percent. Default probabilities and model logic for MPB are shown in Appendix D1. Output from another set of 50, 5-decade simulations executed on the UCF with the default probabilities for mixed severity fire (MSF) doubled and all other default probabilities held constant formulated treatment 2 (Trt2, simulation run 4, Table 9). Default probabilities and model logic for MSF are shown in Appendix D2.

Table 9. Summary of the simulations executed on the SIMPPLLE model by variant,

treatment, and comparison made using output to meet the goals of objectives I and II.

Obj.	Simulation Run	Variant	Process	Simulation Type	Comparison
I	1	HWM	default	50, 5 decade	HWM vs. UCF
	2	UCF	default	50, 5 decade	
II	2	UCF (Control)	default	50, 5 decade	Control vs. Trt1-Trt4
	3a	UCF	MPB X 2 (Trt1)	50, 5 decade	Trt1 vs. Control
	4	UCF	MSF + 25% (Trt2)	50 runs 5 decades	Trt2 vs. Control
	5a	UCF	MPB X 4 (Trt3)	50 runs 5 decades	Trt3 vs. Control
	6	UCF	MSF + 50% (Trt4)	50 runs 5 decades	Trt4 vs. Control
	7	UCF	MPB + 100% (Trt5)	10 runs 5 decades	Trt5 vs. Control
	3b	UCF	MPB + 25% (Trt1)	10 runs (final) 5 decades	Trt1 vs. Control
	5b	UCF	MPB + 50% (Trt3)	10 runs (final) 5 decades	Trt3 vs. Control

For treatment 3, a set of 50, 5-decade simulations was executed on the UCF variant and the previously altered MPB probabilities were increased an additional 25%, relative to the change made for Trt1, and all other default probabilities were held constant (Trt3, simulation run 5a, Table 9). Treatment 4 was composed of a set of 50, 5-decade simulations executed with the MSF probabilities doubled again, relative to C2, and all other default probabilities held constant (Trt4, simulation run 6, Table 9).

Finally, for treatment 5, a smaller set of 10, 5-decade simulations was executed with process probabilities for MPB increased to 100 percent for all severe mountain pine beetle process probabilities with all other default probabilities held constant (Trt5, simulation run 7, Table 9). This set of simulations was compared to the final, 10, 5-decade simulations that were extracted from the control (Table 9). The final 10, 5-decade simulations were extracted from Trt1 and Trt3 to produce reduced data sets (simulation run 3b and 5b, Table 9) that were compared to a reduced control set.

Differences in the method of increasing process probabilities was a source of variation in the analysis. Probabilities differed by process type (MPB vs. MSF) because the process logic differed within the algorithms for insects and fire (Appendices D1-D2). Since the method of insect infestation and spread differs from the method of fire ignition and spread within SIMPPLLE, the logic for timing and influence of process probabilities also differed. The severe MPB default probabilities ranged from 5 - 80% depending on past processes, plant community hazard rating, and adjacent community influences. MSF process probabilities generally ranged from 0 - 6%, based on a different spread logic; spread is not limited by the same plant community composition or hazard rating constraints as the MPB process. In order to gain any change in process output for MSF, probabilities for processes had to be large enough to influence fire processes, but not so large that the probabilities resulted in the entire landscape succumbing to fire. Alternatively, changes to MPB were limited by the a specificity to vegetation type within the process logic and default process levels were higher than MSF process probabilities (Appendices D1-D2) . Doubling the fire probabilities while increasing insect processes by 25% was deemed a good compromise for this study. Output from these simulations was saved to a spreadsheet format, as well, and analyzed in the SPSS statistical package for Windows.

Two minor problems, and sources of variation, encountered in the data output were addressed before analyses could proceed. First, decade 1 was not tested because the version of the model used in this study displayed only initial data input for decade 1, representing the point of initialization for SIMPPLLE simulations. Changes have been made to the newer version of SIMPPLLE so that decade 1 is a simulated decade-long outcome, following the logic used for decades 2-5, rather than functioning as a point of initialization for changes in the later decades. In other words, the analysis really covered 40 years of output rather than fifty. Secondly, because of differences in stand types between the variants (Tables 2, 3a, and 3b), some regrouping of size classes in the output was necessary. The HWM variant is represented by only one multi story size class (OFMU) while the UCF variant is represented by a multi story class in all but the seedling-sapling class. The protocol for grouping output was to add the multi story size classes of pole, medium and large to the single story size classes in the UCF variant in order to compare the size class distribution to HWM.

The nonparametric method of statistical analysis chosen for this study was the Kolmogorov-Smirnov (K-S) goodness-of-fit test. Other tests, such as the median test, the Mann-Whitney test, and the parametric *t* test may also be appropriate since they are sensitive to differences between the means or medians. However, they may not detect other differences such as in variances (Conover 1973) and they measure point estimates rather than distributions. Because the K-S test is sensitive to location, dispersion, skewness, and so forth, it provides a robust method of examining whether two or more samples are governed by the same unknown distribution (Sokal and Rohlf 1987). The method that the K-S test follows for testing distributional differences is based on the unsigned differences between the relative cumulative frequency distribution of the two samples. Observed values are compared to critical values, which can be found in tables in nonparametric statistic books or evaluated approximately, to ascertain statistical significance in the differences (Sokal and Rolf 1987). Observed values greater than the critical values cause the null hypothesis, that the cumulative distributions are the same, to be rejected.

The K-S goodness-of-fit test was used to evaluate model predictive sensitivity by comparing output from the HWM and UCF variants. The K-S test compared the simulated acreage distributions of size classes for each regional variant, by decade. For example, decades 2-5 in the seedling-sapling size class output from each regional variant were compared with each decade representing a sample from the population of all possible outcomes from the model. The K-S goodness-of-fit test was also used to evaluate model sensitivity to selected process probabilities by comparing acres influenced by severe MPB and MSF processes output from the control and the increased probability simulations. Smaller sample sets were used in later treatments because of time and space constraints, and in order to discern if any difference in analysis would be detected by a reduction in sample size.

RESULTS

Model Input

Comparison of the initial conditions of the UCF and HWM variants. A graphical display of the distribution of size class acreage entered into the HWM and UCF variants following translation and prior to initializing the model simulations, provided visual indicated that the two data sets were taken from the same population (Figure 3). Slight variations in some size classes, specifically the very large (old forest), large (late mature), and nonstocked size classes for the UCF and HWM variants indicated that the translation was not a clean "cross-walk" resulting in a slight mismatch between the classes. Due to this mismatch, the two data sets were analyzed for statistical differences.

The results of the K-S test, comparing the measured cumulative size class distribution of the HWM regional variant to the UCF variant following data translation from the Walkthrough database, gave no evidence that the null hypothesis was false. Comparison of the observed maximum difference between the two cumulative frequency distributions (D_m) to the critical value (D') displayed that the observed value was small relative to the critical value indicating that the null hypothesis could not be rejected ($p = 0.05$, Table 10). The statistical analysis (Table 10) and bar graph comparison of size classes (Figure 3), further supported the premise that the LEF/EC data used to initialize SIMPPLLE simulations of the HWM and UCF regional variants provided the same input information.

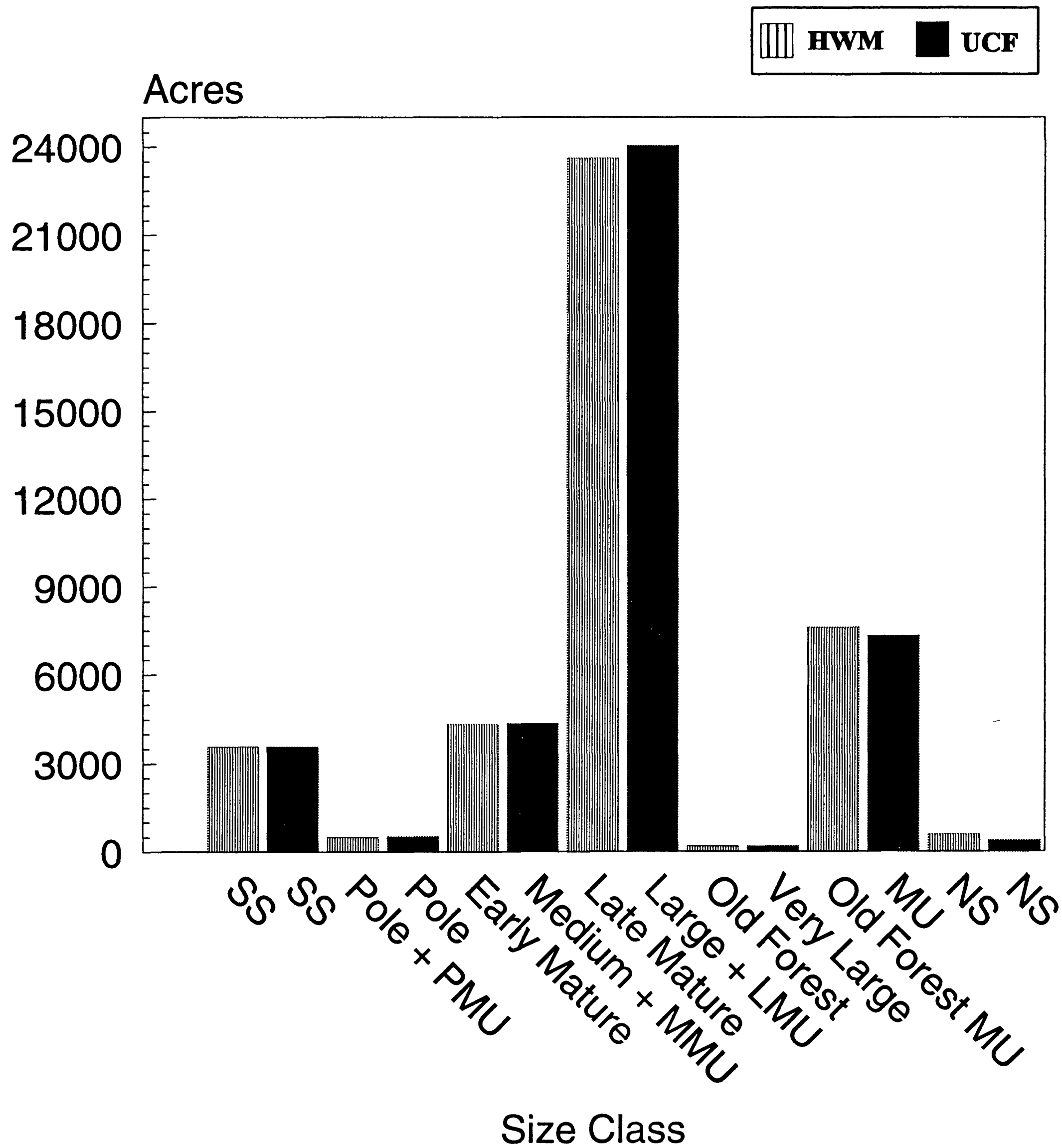


Figure 3. Distribution of initial size classes populating the HWM and UCF regional variants by acre prior to SIMPPLLE simulations.

Table10. The calculated D (D_m) compared to the critical D statistic (D' = 0.714) for cumulative frequency distributions of size class by acre on the HWM and UCF regional variants following data translation (n = 7).

Comparison	**D_m**
HWM vs UCF for size class	$0.143^{N.S.}$

N.S. No Significant Difference

Comparison of Regional Variant Projections.

A comparison of the mean acres of each size class (Table 11; Appendix E1), including the seedling-sapling, pole, medium, large, very large, multi story, and nonstocked size classes, revealed differences in mean size class for all cases. Decade 1 illustrates the initial size class composition of the landscape for all size classes while decades 2-4 represent average acres output from the 50 simulations executed on the SIMPPLLE model, by size class, for the HWM and UCF regional variants. Graphical comparisons of the average size class output from the 50 model simulations, by decade, support the premise that all size classes begin from the same, initial size class and diverge from that point. In general, seedling saplings rose rapidly then leveled off for both variants; the pole class remained level or rose slightly until decade 4 then rose substantially in decade 5; the medium class generally decreased then leveled off for the UCF with a continued decline for the HWM; the large class showed a general decrease over time; in the very large class, HWM showed a substantial increase in decade 2 then a slight decline while the UCF remained essentially constant; the multi story class declined then increased; the nonstocked class showed a general increase.

Although there were some similarities in most trends, there was a distinct gap in acreage levels between the two variants.

The smallest difference was in the medium size class, which displayed a constant decrease in the mean acreage for the HWM and UCF with distributions overlapping by the final decade. The nonstocked size class also displayed relatively smaller differences and a constant increase in mean acres over 5 decades with the distributions appearing to converge over time. The greatest difference in mean acreage was in the very large size class. Statistical analyses further corroborated that significant differences exist between output from the HWM and UCF variants in all predictions of acreage composed of each size class for all decades. Results of the K-S tests comparing the 7 size classes, by decade, support rejection of the null hypothesis of no difference between the cumulative distributions of the HWM and UCF regional variants ($p = 0.001$) in all cases (Table 11).

Table 11. Initial (Decade 1) and mean size class output from 50, 5-decade SIMPPLLE simulations of the HWM and UCF variants, by decade, including ratios of HWM to UCF. The calculated D (D_m) and critical D statistic (D' = 0.390) were compared in the K-S test for cumulative distributions of size class, by decade, on the HWM and UCF output (n = 100).

Size class	Decade	HWM Acres (mean)	UCF Acres (mean)	HWM/UCF	D_m
SS	1	3570	3578	-	-
	2	15390	13305	1.15	0.440*
	3	17353	14830	1.17	0.720*
	4	18165	15166	1.20	0.800*
	5	17293	13053	1.32	0.980*
Pole	1	507	509	-	-
	2	462	879	0.526	1.000*
	3	435	1554	0.280	1.000*
	4	413	1978	0.209	1.000*
	5	1415	4663	0.303	1.000*
Medium	1	4327	4346	-	-
	2	2479	1923	1.290	0.500*
	3	1913	852	2.245	0.940*
	4	1531	780	1.963	0.840*
	5	306	481	0.636	0.760*
Large	1	23599	24047	-	-
	2	9870	17129	1.378	0.940*
	3	6154	13412	0.459	1.000*
	4	4303	11570	0.372	1.000*
	5	1695	10499	0.161	1.000*
Very Large	1	190	190		-
	2	6795	25	272	1.000*
	3	6796	314	21.6	1.000*
	4	6554	467	14.0	1.000*
	5	6178	412	15.0	1.000*
Multi Story	1	7591	7305	-	-
	2	3511	2648	1.33	0.580*
	3	4862	3082	1.58	0.920*
	4	5781	3810	1.52	0.960*
	5	9203	5294	1.74	0.980*
Nonstocked	1	579	388	-	-
	2	2729	1744	1.56	0.800*
	3	3540	2683	1.32	0.640*
	4	4122	3464	1.19	0.440*
	5	4668	4146	1.13	0.420*

* Significant difference

A comparison of landscape processes, by acres, was then conducted, to display the influence of fire and insects on successional change. Fire and insect processes were chosen for comparison because they were the only process functions present in both variants of SIMPPLLE, so that comparisons were possible. Given the extreme differences displayed in the structural output from the model, the assumption was that the biogeographical factors, represented by processes and specific to each variant, were influencing the divergent outcomes. Generally, processes display the influence of these factors most strongly and are expected to be somewhat unique by regional variant.

A comparison of the mean acres of processes by regional variant and across five decades displayed generally greater levels of fire and MPB in the HWM while western spruce budworm (WSBW) occurred at higher levels in the UCF (Table 12). Graphical comparisons (Appendix E2) showed that the general trends in process acres were analogous in shape but differed in levels for the two variants, similar to the trends seen in the size class analyses. The greatest disparity was seen in the mixed severity fire process while light and severe mountain pine beetle displayed diverging and converging behavior. Fire processes and, to a certain extent, mountain pine beetle, reached higher average acreage levels for the HWM variant.

Notably, the acreage level of mixed severity and stand replacing fire were exceptionally high in the first decade for both variants. Conversely, western spruce budworm reached higher levels for the UCF variant compared to HWM. Statistical analyses, using the K-S test, further supported rejection of the null hypothesis indicating a significant difference between cumulative distributions of all processes for the HWM and UCF variants (Table 13).

Table 12. Comparison of mean process output for the UCF and HWM regional variants from 50, 5-decade model simulations, by decade, including ratios of HWM to UCF.

Process	Dec.	HWM Acres (mean)	UCF Acres (mean)	HWM/UCF
Light Severity Fire	1	599	397	1.51
	2	417	369	1.13
	3	410	375	1.09
	4	347	352	0.99
	5	420	354	1.19
Mixed Severity Fire	1	7976	7096	1.12
	2	6561	3514	1.87
	3	6072	2630	2.31
	4	5492	2380	2.31
	5	4966	2370	2.10
Stand Replacing Fire	1	13265	12172	1.09
	2	6671	2486	2.68
	3	5693	1817	3.13
	4	5040	1726	2.92
	5	4546	1737	2.62
Light Mountain Pine Beetle	1	436	499	0.87
	2	382	285	1.34
	3	134	138	0.97
	4	68	66	1.03
	5	75	29	2.59
Severe Mountain Pine Beetle	1	451	391	1.15
	2	582	367	1.59
	3	231	109	2.12
	4	86	65	1.32
	5	73	19	3.84
Light Western Spruce Budworm	1	4696	4586	1.02
	2	4226	5596	0.76
	3	3609	4334	0.83
	4	3015	4076	0.74
	5	2372	4268	0.56
Severe Western Spruce Budworm	1	4746	6032	0.78
	2	3164	3597	0.88
	3	2704	3424	0.79
	4	2451	3471	0.71
	5	2827	4689	0.60

Table 13. The calculated D (D_m) statistics were compared to the critical D statistic (D' = 0.122) in the K-S test for cumulative distributions of the processes for 50, 5-decade simulations from the HWM and UCF output (n = 250).

Process	D_m
Light Severity Fire	0.920*
Mixed Severity Fire	0.696*
Stand Replacing Fire	0.716*
Light Mountain Pine Beetle	0.140*
Severe Mountain Pine Beetle	0.216*
Light Western Spruce Budworm	0.340*
Severe Western Spruce Budworm	0.332*

*Significant Difference

Processes for the UCF Variant

Mixed severity fire process. Process output from the 50, 5-decade simulations with MSF default process probabilities doubled (Trt2) was compared to MSF control output from the 50, 5-decade simulations from the UCF variant run with default probabilities. First, the acres influenced by mixed severity fire were averaged for all 50 simulations by decade, and the distributions were then graphed (Figure 4). The mean distribution of MSF over 5 decades were approximately the same. Next, the acres of mixed severity fire were averaged by simulation and the trend was, again, very similar (Figure 5).

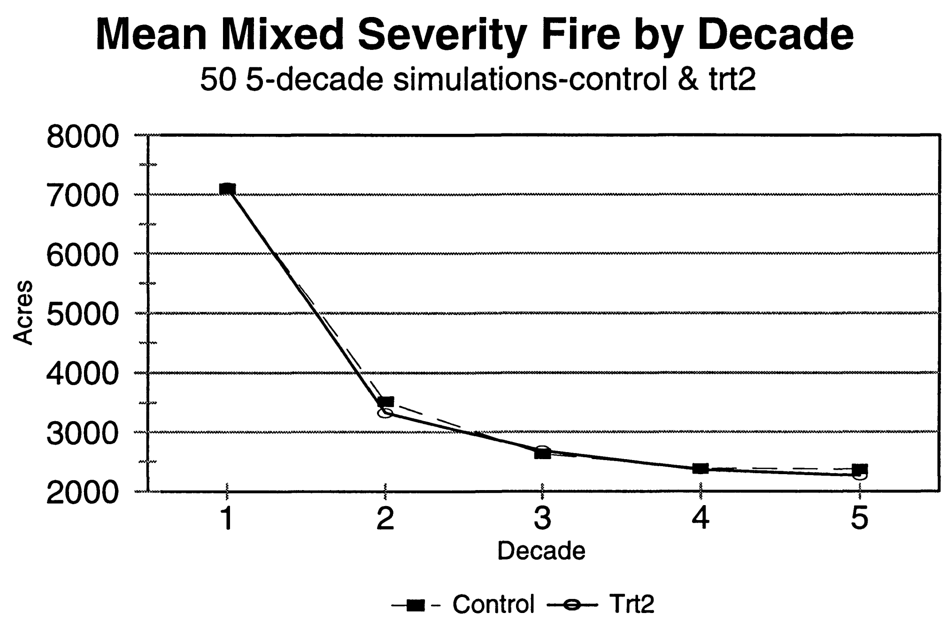


Figure 4. Comparison of acreage distribution of MSF output over 5 decades for treatment 2 versus control.

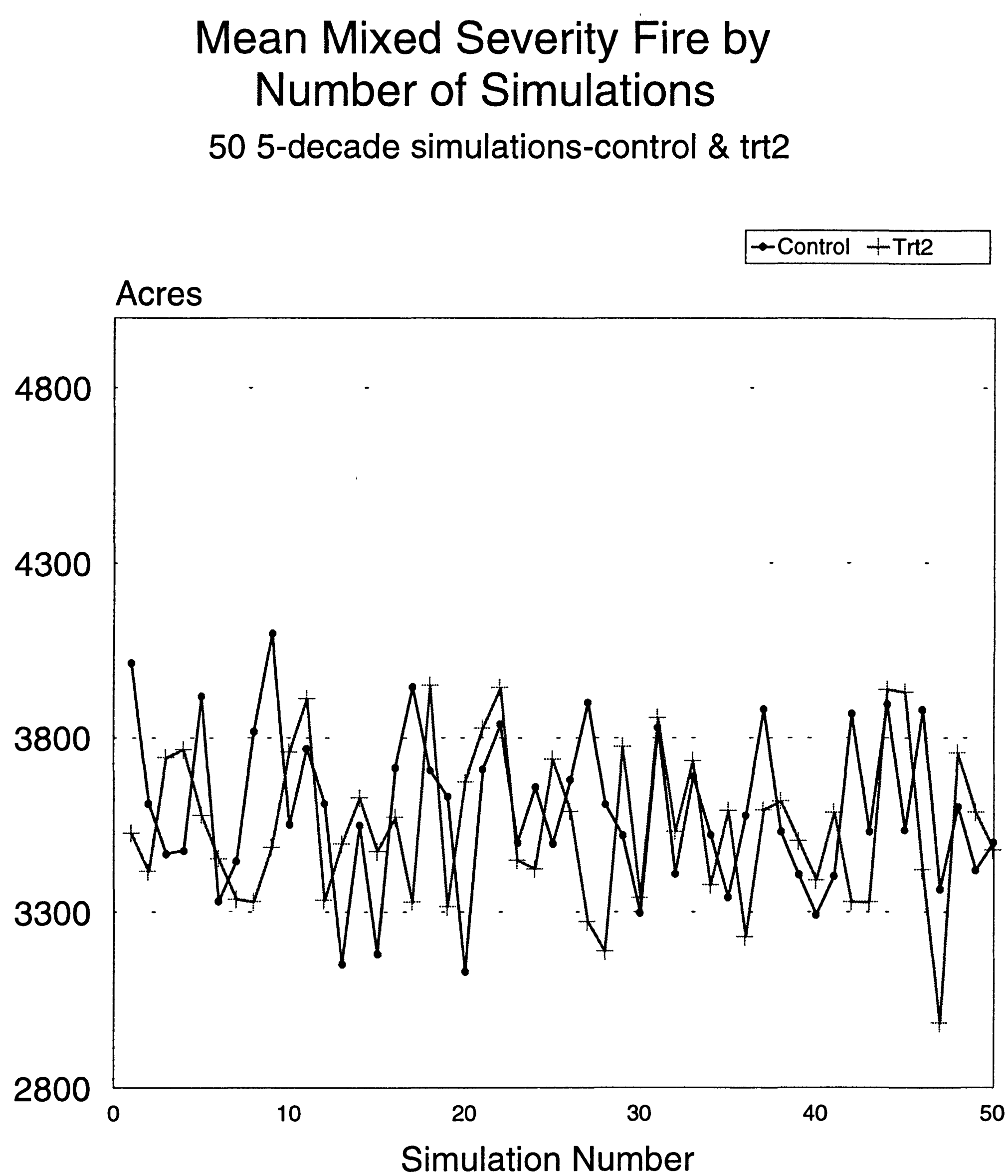


Figure 5. Comparison of acreage distribution of MSF output over 50 simulations for treatment 2 versus control.

Process output from simulations in which MSF probabilities were doubled again for Trt4 was then compared to control output. Analysis of mean acres influenced by MSF, by decade, indicated that the increased probabilities had increased the level of acres of mixed severity fire but followed similar trends (Figure 6). This result was supported by a second graphical display of mean acres of mixed severity fire over the 50 simulations, where a large difference in acreage was discernible (Figure 7).

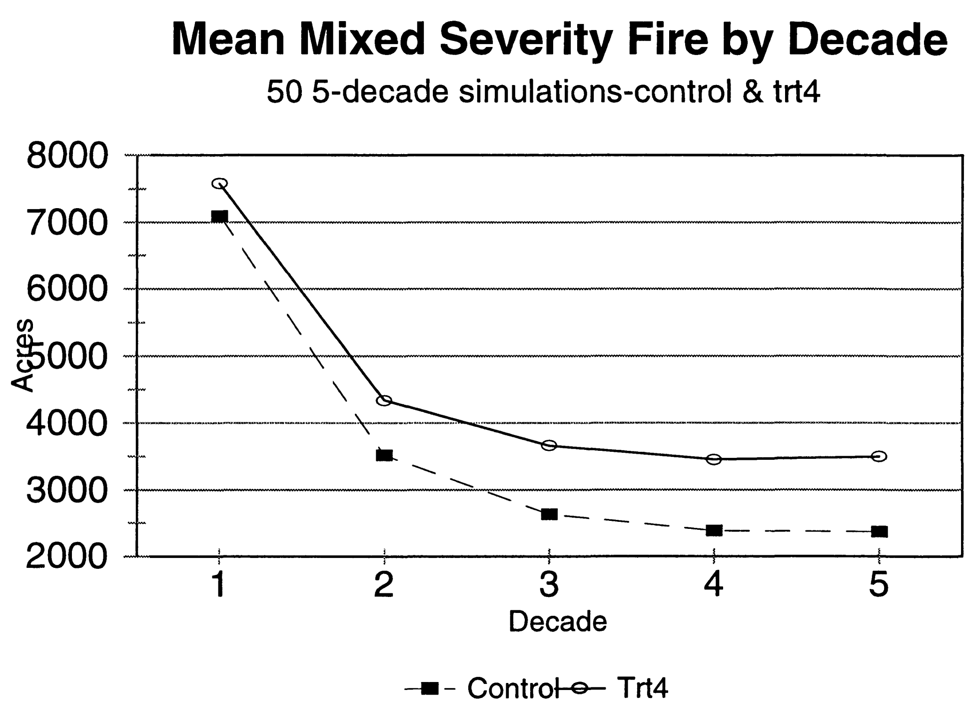


Figure 6. Comparison of acreage distribution of MSF output over 5 decades for treatment 4 versus control.

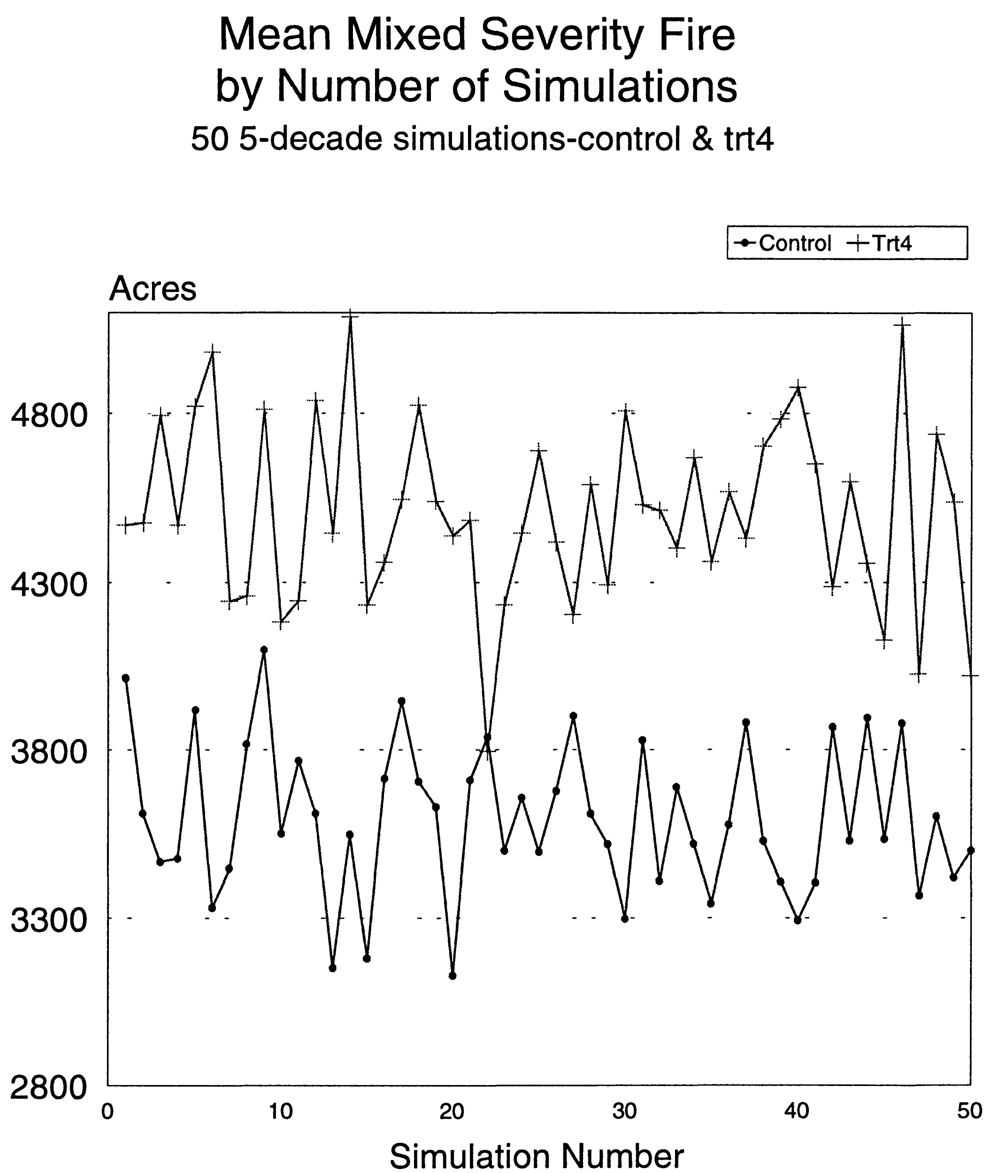


Figure 7. Comparison of acreage distribution of MPB output by number of simulations for treatment 4 versus control.

Results from the K-S tests comparing the mixed severity fire process output from the UCF control and treatment simulations indicated that the null hypothesis, no difference between cumulative distributions (p = 0.685) of the mixed severity fire process in the control and Trt2, could not be rejected. Conversely, the second comparison of the control and Trt4 indicated, with a p-value of 0.001, that the null hypothesis of no difference between cumulative distributions for the mixed severity fire process must be rejected. The distributions were significantly different. For display purposes, the critical D (D') was determined based on p-values of 0.05 in Table 14.

Table 14. The calculated D (D_m) compared to the critical D statistic (D' = 0.122) for the K-S test of cumulative frequency distributions for MSF processes, by treatment and compared to the control, using 50, 5 decade model simulations (n = 250).

Comparison	D_m
Control vs. Trt2	$0.064^{N.S.}$
Control vs. Trt4	0.428*

*Significant Difference N.S. No Significant Difference

Severe mountain pine beetle process. Process output from the 50, 5-decade simulations with the MPB default process probabilities increased 25% comprising Trt1 was compared to the control MPB output from the 50, 5-decade simulations from the UCF variant run with default probabilities. Distributions of mean acres of the severe mountain pine beetle were analyzed similarly to methods followed for mixed severity fire. First, the acres that were influenced by severe mountain pine beetle, from Trt1 and the control, were averaged for all 50 simulations, by decade, and the distributions were then compared graphically (Figure 8). The mean distribution of MPB over 5 decades were approximately the same. Next, the acres of severe mountain pine beetle were averaged by simulation and the trend was, again, very similar (Figure 9).

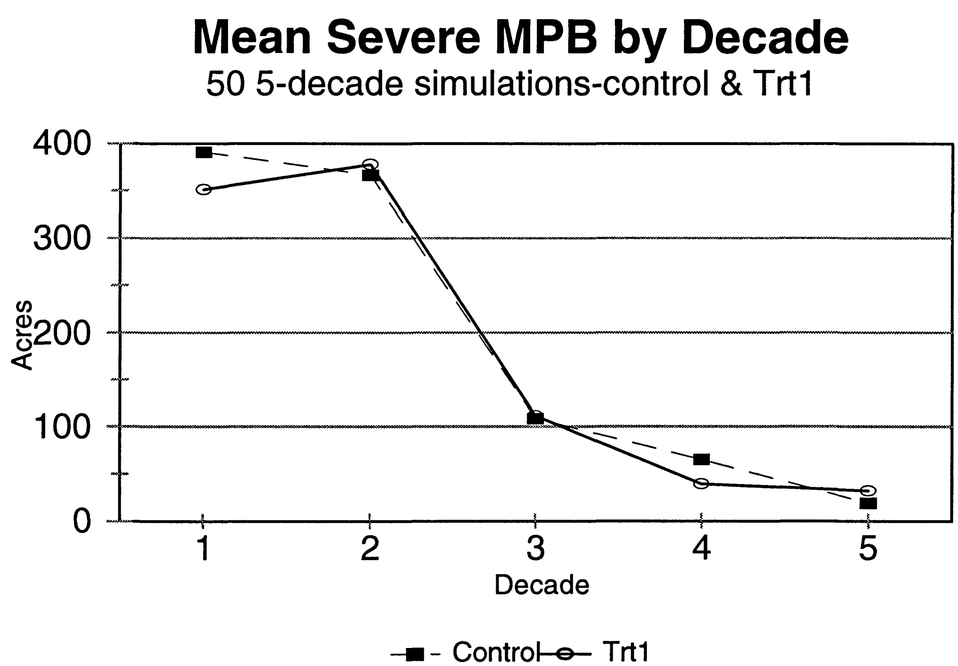


Figure 8. Comparison of acreage distribution of severe MPB output over 5 decades for treatment 1 versus control.

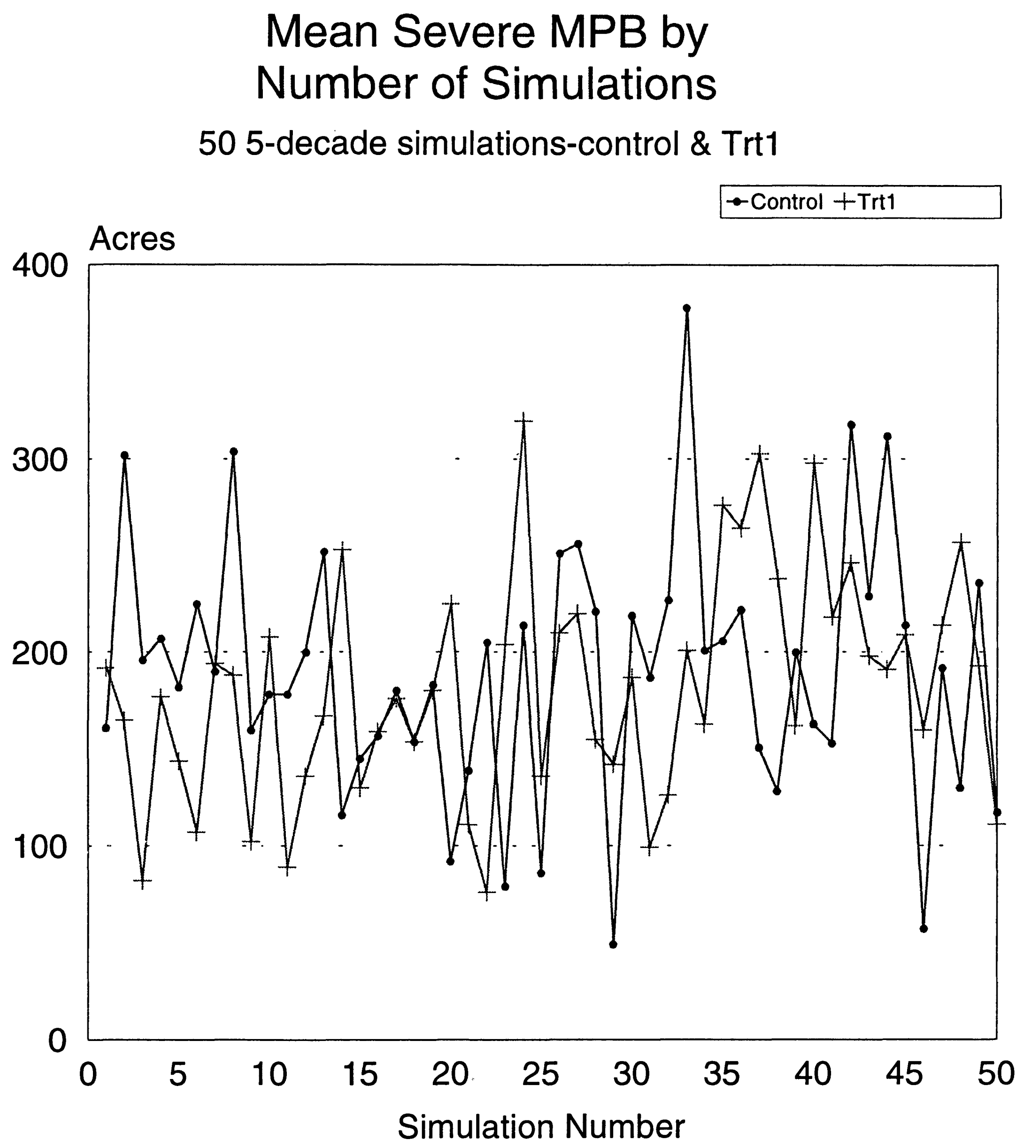


Figure 9. Comparison of acreage distribution of severe MPB output by number of simulations for treatment 1 versus control.

Process output from simulations in which MPB probabilities were increased for Trt3 was then compared to the control MPB process output. Analysis of mean acres influenced by MPB, by decade, indicated that the increased probabilities had little influence on the level of acres of mixed severity fire and the process distributions remained similar (Figure 10). This result was reflected in an analysis of mean acres of severe mountain pine beetle, by simulations, where distributions again displayed conspicuous overlap (Figure 11).

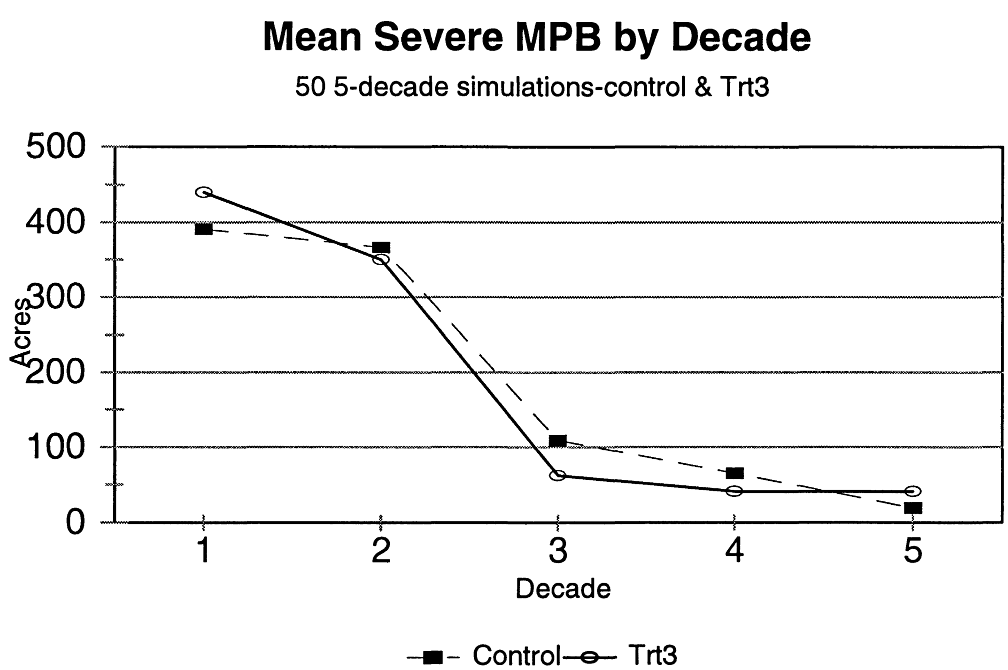


Figure 10. Comparison of acreage distribution of severe MPB output over 5 decades for treatment 3 versus control.

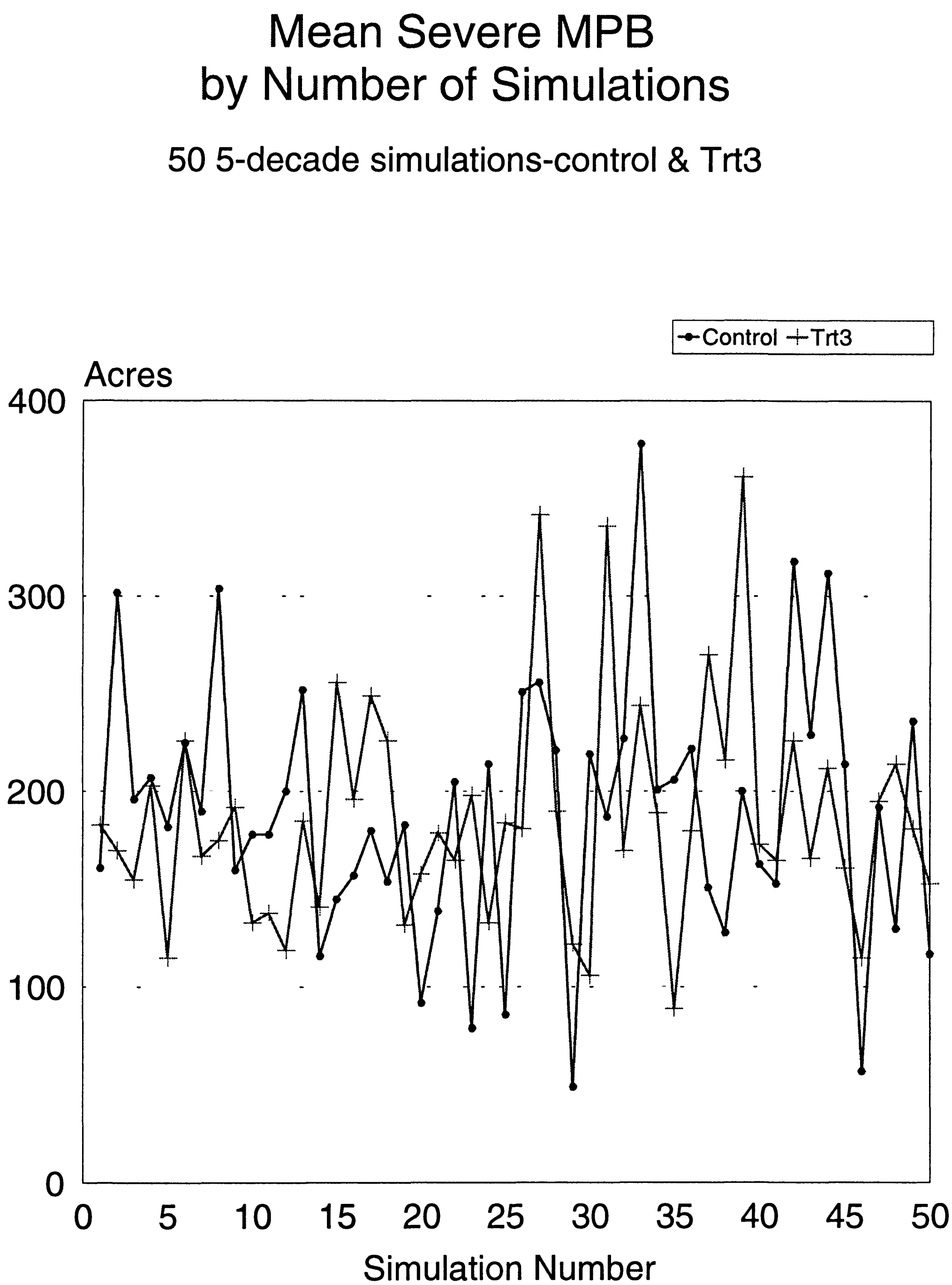


Figure 11. Comparison of acreage distribution of severe MPB output by number of simulations for treatment 4 versus control.

The sample output from Trt5, along with the reduced sample output from Trt1 and Trt3, compared to the control (final 10, 5-decade simulations) echoed similar results as those displayed in the larger samples. The MPB process levels for Trt5 did appear to affect more acres in decade 1, but dropped down to the control level by decade 2 (Figure 12). Comparison of mean acreage levels of MPB by simulation number from the control, Trt1, Trt3, and Trt5 again showed little difference between them. This was a reflection of the results obtained from the earlier analyses of with the larger sample sizes. Distribution of process output from treatment 5 did show a trend that looked somewhat different from the control (Figure 13). This perceived difference, however, did not translate into a significant difference statistically (Table 15).

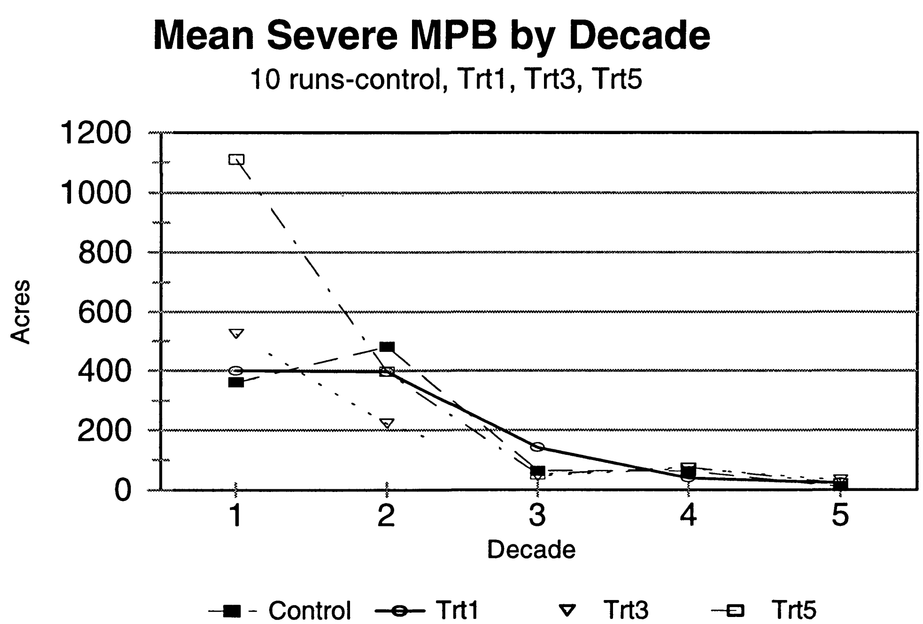


Figure 12. Comparison of acreage distribution of severe MPB output over 5 decades for treatments 1, 3, and 5 versus control.

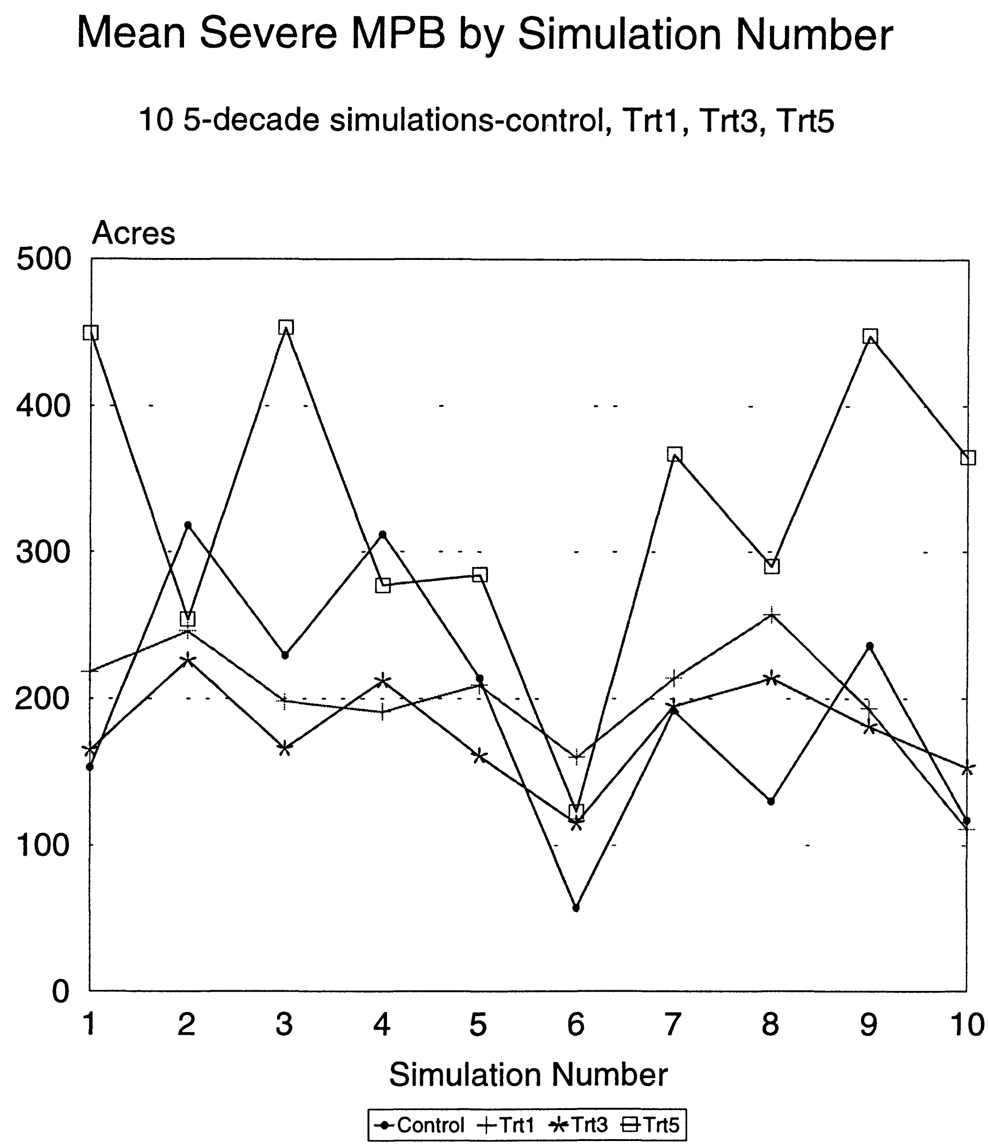


Figure 13. Comparison of acreage distribution of severe MPB output by number of simulations for treatments 1, 3, and 5 versus control.

Results of the K-S tests, comparing treatment simulation output of severe mountain pine beetle processes to the control output, indicated that the null hypothesis of no difference between cumulative frequency distributions could not be rejected for treatment 1 ($p = 0.536$) or treatment 2 ($p = 0.888$). With failure to reject the null hypothesis in the comparison of treatments 1 and 2, treatment 3 was compared to the final 10, 5 decade simulations in the control set using the K-S test. This analysis, with probabilities set to the maximum possible level of 100%, indicated that the null hypothesis of no difference between cumulative distributions could not be rejected ($p = 0.393$). Finally, the K-S test for the reduced sample sets in treatments 4 and 5, compared to the control, failed to reject the null hypothesis of no difference between distributions for both comparisons ($p = 0.997$). Table 15 summarizes the K-S test results for all cases with the p-value set at 0.05 for determination of critical D (D') values.

Table 15. K-S test associated with the calculated D (D_m) and critical D (D') K-S statistic for the cumulative frequency distributions of severe mountain pine beetle, by treatment compared to the control, using 50, 5 decade, and 10, 5 decade simulations.

Comparison	**D_m**
Control vs. Trt1	$0.052^{N.S.}$
Control vs. Trt3	$0.072^{N.S.}$
Controls vs. Trt5	$0.180^{N.S.}$
Control vs. Trt1	$0.080^{N.S.}$
Control vs. Trt3	$0.080^{N.S.}$

$^{N.S.}$ No Significant Difference

DISCUSSION

Testing and validating computer simulation models that use current knowledge to extrapolate the influences of landscape patterns and processes into the future introduces rather complex problems to computer modeling. First of all, high quality input data is an essential component of the simulation process and can provide the means to successful simulations if the data is used to its full potential (Keane et al. 1996). Model input of existing information, a key aspect of SIMPPLLE, implies that database attributes will be translatable regardless of the source. But, depending on the manner in which data is collected and organized, translation of the data into SIMPPLLE input formats and classes (without losing the original information in the translation) can be difficult. Expert knowledge is an important tool to use as confirmation of parameter validity in many modeling endeavors (Keane et al. 1996) and was indispensable in this study.

Additionally, the use of successional pathways and disturbance parameters which have undergone technical review by ecological experts and are therefore based on proven concepts, is another useful validation tool (Keane et al. 1996). The use of expert ecological knowledge, such as the expertise provided during preliminary workshops toward development of the SIMPPLLE model, is considered as another credible tool for model validation.

Finally, a knowledge-based system, such as SIMPPLLE, is composed of the knowledge gained from other tested and validated models operating at smaller scales. The assumption is that the proven logic adopted from a smaller scale model or hazard rating system, such as the lodgepole mountain pine beetle hazard rating system used for

SIMPPLLE (Amman et. al. 1977), will prove meaningful at the multiple scales at which the SIMPPLLE model runs. Or, without published and/or tested logic, generally accepted knowledge of processes must be used instead, such as that found in SIMPPLLE's fire component which was compiled using expert opinion from managers of the Forest Service, Region One. Again, expert knowledge as well as publications and vegetation databases provide the needed tools for confirmation of model parameter validity and output validity. Output from the SIMPPLLE model, then, is as valid as the knowledge on which it has been based as long as it is considered at the scales for which it was intended.

Model input

The initial and final translations demonstrated problems that can arise regardless of the database source and organization. Although problems were remedied during this study, translation will always be a difficult step, given the variety of inventory systems and methods used by resource managers and researchers. The best test of how well the data was translated was gained from the expert analysis provided by Tom Daer and his associates (Daer 1997, 1997b). Running test simulations to be analyzed by experts provided the means to develop realistic translation schemes using expert knowledge that could not have been gained any other way. However, the versatility of a landscape level simulation model is enhanced by its ability to represent vegetation change at the general level so that it is useful in a diversity of ecosystems. Therefore, moderating this strong emphasis on expert opinion, especially concerning input data, would increase the applicability and ease of model use on any landscape with available vegetation data.

The use of vegetation data is an important tool to resource conservation specialists. With the continued and growing use of models in natural resource fields, especially with the increasing scales of analysis to the landscape level and beyond, reliance on useful and available, quality data will only continue to escalate. Given the increasing scales of analysis, the widespread changes in land use, and larger data requirements, there is a demand for more information about existing natural environments. Further, the burden of data collection will increasingly fall to resource specialists and agencies other than the primary investigator or modeler or manager. This intensifies the need for a unified, peer-reviewed vegetation classification that may be applied nationwide. Problems encountered during this translation process provide a strong argument for standardizing methods of vegetation classification (FGDC 1997; Grossman et al. 1998).

Regional variants

Despite the slightly different size class designations found in the HWM and UCF regional variants, regrouping the size classes prior to simulations resulted in no distinguishable differences in input data; there was no significant difference in their distributions. Therefore, comparison of simulated acreage by size classes and decade was a reasonable method of testing model sensitivity built into the biogeographical representations. The premise was that, by initializing the model with a single data set executed on the two different variants, any differences in the output would be attributable to those unique pathways, or abstractions, that define the HWM and UCF variants. Analyses of acreage distributions provided strong indication that the HWM variant did elicit very different simulated structural changes compared to the UCF variant.

If the model logic is functioning so that the processes which are believed to predominate and influence a region result in output which displays those influences, then the model is exhibiting the desired behavior for which it was built. The HWM and UCF variants are influenced by very different fire regimes as well as other processes such as windthrow, frost damage, levels and types of insect and disease, and so on. When output results indicate that the size class distributions are not from the same population, it is reasonable to assume that the model is exhibiting the behavior that was intended.

Abstractions for the HWM and UCF regional variants are based primarily on types of disturbances, or processes, that influence and create the visible differences, or patterns, among the regional zones. For example, successional and disturbance-related changes on the HWM variant represent the broad, biogeoclimatic influences expected on the eastern side of the Continental Divide with its drier, continental climate highly influenced by mixed- and high-intensity fire regimes. Alternatively, the UCF variant is representative of a more moist, maritime climate and influenced by more low- to mixed-severity fires (Nesser et al. 1997). These biogeoclimatic differences are expressed in the model by such means as the time vegetation remains in a specific state and the influence of processes on vegetation.

Model logic associated with the time vegetation remains in a state differs between the two variants. For example, in the UCF variant the ponderosa pine-Douglas-fir species combination in the habitat type group WMT-A remains in the seedling-sapling size class for 4 decades, the pole class for 2 decades, medium class for 1 decade, large for 3 decades then skips ahead to the multi story class where it remains for at least 120 years through succession alone (Appendix B). On the other hand, the successional pathway for the same species group in Fire Group 4 on the HWM is maintained in the seedling-sapling, pole, medium, and large classes for 4 decades each, then moves to very large for 1 decade and finally remains in the multi story state until some disturbance pushes it to another structural or species state (Appendix B). The differences in successional rates were incorporated into the model abstractions as a result of expert opinion specific to changes expected within the regional variants.

The influence of processes on habitat type group-species group combinations and their associated successional changes is variable and depends on the level of process spread and intensity. Process spread and intensity is an abstraction of the specific hazard rating system or expert knowledge used in the model to provide the logic for process occurrences. The logic is the same regardless of regional variant however, variability exists according to the habitat type group, species group, size class, and density combinations.

For example, the lodgepole pine/Douglas-fir species group can be designated with a low, moderate, or high mountain pine beetle hazard rating in either the HWM or UCF variants. However, stipulation of a low, moderate or high rating is dependent on habitat type group, size class, and density. Thus, the lodgepole/Douglas-fir species group that occur in fire groups 2, 3, 4, or 5, in all size classes except pole or seedling sapling, and in density classes greater than 2, are at high risk with the HWM variant. The same species group under the UCF variant in habitat type group A or B, in all size classes except pole, pole multi story, or seedling sapling, and in density classes greater than 2, are at high risk (Appendix D1). The logic differs according to habitat type group as well as for the structural class, recalling that the HWM variant has only one multistory class to provide different simulation output. Model representation of succession and process-related change specific to vegetation structure and habitat type groups within each regional variant appear to influence simulation output.

Comparison of the mean size classes in acres, by decade and simulation number, displayed a considerable difference between the variants. However changes over time generally followed similar trends in most cases, only differing in the levels of change. The only exception was in the very large size class in which the HWM variant showed a sharp increase and remained in the range of about 6200-6800 acres while the UCF variant dropped down to 25 acres and only increased to 467 acres in the fourth decade. This is partially attributable to the differences in levels of fire process probabilities in the two variants.

In most decades, acres influenced by light severity, mixed severity, and stand replacing fire on the HWM variant were more than double the level simulated for the UCF variant. The decreasing curves displayed in the mean medium and large size class graphs represent the logic that light- and mixed severity fire will push some size classes forward more quickly and maintain the very large size class longer than succession alone. Mixed severity fire also functions to push the multi story size class back to the very large class which explains, in part, the decline in the multi story class and the sharp rise in the very large size class for the HWM variant in the first decade. The lower levels of fire within the UCF variant, differing reactions to fire built into this variant's pathway abstractions, and short time-length (one decade) of the very large size class for succession alone were all instrumental factors for the changes observed in the size class acreage after 5 decades of simulated change.

The high levels of stand replacing fire in decade 1 for both variants, 13,265 acres in the HWM and 12,172 acres in the UCF, provide evidence of the effect of initial vegetative conditions on landscape-level processes. The initial structural condition of the LEF/EC landscape is largely composed of the late mature (large and large multi story) size class which covers approximately 24,000 acres compared to the distributions of all other size classes which ranged from 200 to 7,400 acres (Figure 3).

This phenomenon follows current trends documented in present-day landscapes in which cutting practices early in this century as well as the influence of fire suppression and lack of thinning activities have resulted in a rather different vegetation composition than would have been seen historically. The general composition of many landscapes today are generally characterized as more dense, late successional systems which are highly susceptible to high intensity fires. However, these areas were historically influenced by more low intensity fires with the accompanying size classes more evenly distributed in a mosaic of successional stages which are more resistant to high intensity fires (Arno 1996). Documentation of historical management practices on Lubrecht supports this generally understood concept (Pfister and Alaback 1997).

Initial conditions of the LEF/EC landscape, characterized by very high levels of the large size class, defines a landscape with great susceptibility to fire, specifically high intensity fires, in the first simulated decade. High levels of fire is probably the primary contributor to the large increases in seedling saplings and nonstocked conditions which occurred in decade 2. This is substantiated by an appreciable reduction in the large size class in decade 2, especially in the HWM variant. The level of seedling saplings was maintained through decade 4 with only a slight drop in decade five. Pathway logic for both variants maintains most seedling sapling states for 4 decades, through succession alone, but can potentially be pushed back to nonstocked with any fire occurrence. Therefore, the distributions showing maintenance of the seedling sapling class with only a slight decline at the fifth decade, along with the nonstocked state displaying a slow increase over time, appeared to follow a logical pattern in which a great proportion of the large size class burned in the first decade to produce larger acres of the seedling sapling and nonstocked size classes.

The pole size class is structurally at a lower hazard rating sensitivity to fire and is likely to be maintained in the pole state or pushed back to the seedling sapling size class when light- or mixed severity fire occurs. The level of poles in the HWM variant was comparatively lower than in the UCF variant. This is attributable to the higher levels of light- and mixed severity fire in the HWM variant which was probably the primary reason for the reduced acres of poles in the HWM variant. The pole class is also not at high risk to MPB or WSBW, thus the general successional trend of maintenance along with a rise at the fifth decade appeared to follow a logical path since many seedling saplings would be approaching the final fourth decade in that state and making a transition to the pole class. The increase in the pole size class for both variants correlates with the decrease in acres of seedling saplings, which decreased by more than 1,000 in the HWM variant and more than 2,000 in the UCF variant in the fifth decade.

Other methods of testing model sensitivity were considered prior to this study. Differences, according to regional influences, could also have been measured using the species or density output from SIMPPLLE. In previous exercises and workshops for the USDA, Forest Service, Region 1 regional office and other land management agencies, there was consensus that the levels of change in species composition exhibited by the SIMPPLLE model provided acceptable representation of the landscape. Size class provided a more manageable number of variables for analysis than the many species groups, thereby introducing less noise in subsequent analyses. Furthermore, for the time-span (50 years) and scale of analysis (comparison of regional variants) used in this study, comparison of changes in size class would be expected to provide more information than species, which would require longer simulations to produce any measurable change. Since the same database information was provided for initialization, visible differences would not appear, presumably, until a much longer time-span than 50 years had elapsed.

Alternatively, the distribution of density classes alone did not provide enough information about forest structure to support a comparison of the regional variants. Size class provided more information about successional stages within the variants and the changes that occurred as a function of succession and disturbance. For example, the HWM variant should be more influenced by higher intensity fire activity than the UCF variant. However, both variants are influenced by fire. Decreasing and increasing density levels across the landscape would not provide much information regarding the structural changes occurring within the variants. Conversely, size class changes such as a a large shift from the medium size class to the seedling sapling class might indicate a high level of stand replacing fire influencing the landscape. The distribution of size class across an area provides information that is indicative of the type of disturbance activities, or processes, that predominate over a landscape.

The emphasis in this portion of the study was to analyze output from model simulations in order to evaluate the sensitivity of model variants within SIMPPLLE for their representation of regional biogeographical influences on individual landscapes. The mean simulated acreage changes over five decades exhibited reasonable behavior given the existing vegetation on LEF/EC. The large gaps in the mean acres of size classes, over time, for the regional variants indicated a remarkable difference between the logic within the HWM and UCF variants. The influence of biogeographical factors on the landscape are reflected in the levels of simulated processes and the accompanying structural changes displayed in the output. The mean differences indicate that the regional variants produce very divergent output from the same input. Statistical analyses comparing the cumulative distributions of size classes resulting from SIMPPLLE simulations of the HWM and UCF regional variants indicated that the null hypothesis of no difference between the distributions was not supported; output was indicative of very different population distributions. The biogeographical abstractions do exhibit influences that produce unique outputs from these representations of the Headwaters of the Missouri and Upper Clark Fork zones.

When SIMPPLLE was developed, natural resource specialists aiding in model development felt that the abstractions making up the (7) variants would provide anyone, with the data available to describe forested landscapes within Region 1, the ability to run valid landscape simulations. The newest version of SIMPPLLE is being refined to a greater level of generalization so that only two specific sets of abstractions, for the east and west sides of the Continental Divide, will have pathways yielding valid simulations across Region 1. Again, expert knowledge is being provided by specialists from Region 1 during this development phase. Results from this study provide an indication that some caution should be exercised against over-generalization for broad regions.

Processes

Prior to executing the process sensitivity analysis for this study, the intent was to compare the influence of selected process probabilities on simulated output of forest types, or changes to species groups. However, the more direct approach, using acres of landscape influenced by processes, seemed more appropriate and was chosen as an alternative method for measuring model sensitivity to selected process probabilities. The processes chosen to test model sensitivity were, first of all, selected because they have the potential of occurring on LEF/EC, given the community types and structural conditions on the study landscape. Furthermore, the particular processes used for this portion of the study were chosen because they represent two extremes along a gradient of potential process influences on the landscape.

Insect processes represent a lower level, more confined, influence on vegetation communities across the landscape compared to fire processes, which are generally a higher level, more extensive influence. Specifically, the severe mountain pine beetle process does not display the same impact or produce as great a level of structural change as the process of mixed severity fire. The factors contributing to insect initiation and contagion are more limited by forest community type and structural stage than factors influencing fire ignition and spread. Model logic was written for these specific processes with the intent of emulating the very different contributing factors of overall landscape composition and including the influence of neighboring polygon conditions, so that differences in output were expected.

Mixed severity fire. Comparison of mean acres of mixed severity fire displayed very clear confirmation that the initial increase in probabilities did not bring about any increase to the level of mixed severity fire during the simulation. However, the second increase produced a very clear separation between the treatment simulation and the control simulation.

The distributions of the 50, 5-decade simulated mean acres of MSF, by decade, all showed similar trends: high levels of mixed severity fire in decade 1, a fairly sharp drop to decade 2 and then an essentially constant level for decades 3-5. The final simulation, or treatment 4, displayed this distribution as well except with an elevated level of acres affected by MSF. This indicates that the fire process follows a similar trend for each decade reflecting the limitations on fire that are built into the logic for spread, conditions of neighboring polygons, and vegetation density across the landscape. Generally, the high levels of fire in the first decade reflect the initial conditions of the LEF/EC landscape. A large number of acres composed of the large (early mature) size class created a high fire hazard over a large proportion of the landscape so that high levels of fire occurred in the first decade. Fire levels then decreased from decade one, and leveled to a near constant, reflecting the reduction in fire-susceptible acres over time. The model logic for the fire process is to adjust the fire hazard rating to account for components that are changed during simulations. For example, the hazard is reduced for any components that are changed from the large to seedling sapling size class during the course of a simulation to better reflect actual landscape changes.

The comparison of treatment 2 and the control showed apparent similarity in the distributions of mean acres by simulation and displayed the range of average simulation output for mixed severity fire. The area affected by mixed severity fire over 50, 5-decade simulations ranged from approximately 3,100 to 4,100 acres in the control and from approximately 3,000 to 4,000 in treatment 2. The acres of MSF for treatment 3 ranged from 3800 to 5100. These ranges reflect the stochasticity of the model where the probability of events is countered by a certain level of randomness endemic to natural processes and the output produces a range of acres with the potential to be influenced by mixed severity of fire within a 5 decade time period.

Results of the K-S test comparing cumulative process distributions from the MSF control and treatment 1 simulations indicated that the null hypothesis of no significant difference between the distributions could not be rejected. Doubling the default probability for MSF did not increase the level of MSF to a great enough extent for the detection of any change in the population of the fire process distribution. However, comparison of the cumulative distribution of treatment 2 to the control did not support the null hypothesis, indicating that doubling the MSF probabilities did produce a sufficient increase in mixed severity fire.

The sensitivity of SIMPPLLE predictions to changes in MSF probabilities was quite low given that doubling the default probability did not elicit any change in outcome. Doubling the probabilities a second time, for treatment 2, did evoke a change to the MSF process. The process of mixed severity fire does not appear to be overtly sensitive to manipulation of the probabilities, however increases greater than 25% can elicit changes in simulation output.

The logic for fire processes, in the version of SIMPPLLE used for this study, was based entirely on the expert knowledge of resource professionals. Expert guidance was the method used to ascertain whether the simulated fire behavior based on the default probabilities was plausible and deemed acceptable by Daer and other LEF/EC experts (Daer 1997). Qualification of some range of probability necessary for changing output will provide users with a greater capability to set alternative scenarios with some level of understanding of the extent of fire processes that can be expected. This will reduce the number of simulations necessary, and the amount of time required, to analyze different landscapes.

Severe mountain pine beetle. Analyses of mean acres of simulated MPB in the 50, 5-decade simulations, by decade, did not display any differences between the control and treatment 1 and very little apparent differences between the control and treatment 3. Similar to the previous analysis of MSF, comparison of the mean acres of MPB, by simulation, displayed the stochastic nature of the model with mean acres ranging from 49 to 378 in the control, 89 to 361 in treatment 1, and 76 to 320 in treatment 3. There were individual simulations in which the control displayed greater acreage influenced by MPB than in the treatments, which was attributable to the stochastic influence in which a high percentage of polygons at risk for severe MPB were effected in that simulation.

The follow-up analyses with the reduced sets of simulations displayed what appeared to be a possible increased level of MPB output from treatment 5 and the control (along with the first 2 treatments) although, statistical analysis resulted in no significant difference. However, analysis of the mean MPB acres, by decade, indicated that decade 1 from simulations of treatment 5 were very high, but decreased to the same levels as the control and treatments 1 and 3 by the second decade. The high level in decade 1 was probably pulling the simulation levels up which may or may not be a function of the increased probabilities.

Results of the K-S test comparing cumulative process distributions from the MPB control and treatment 1 simulations indicated that the null hypothesis of no significant difference between the distributions could not be rejected. Similarly, this result was repeated in treatments 3 and 5 of the MPB process probabilities. There was no significant difference between the cumulative distributions of the treatments and the control.

Following model logic, any community type with a moderate to high hazard rating is designated a 5% or greater probability for severe mountain pine beetle. Analysis of the initial data set for the UCF variant revealed that the community types with the potential for severe mountain pine beetle comprised 387 of the possible 1,968 polygons, or 20% of the polygons, on the LEF/EC landscape are composed of the community types that are at risk for severe mountain pine beetle. Comparison of the simulation means indicated that the distributions of mean MPB were similar in pattern although, there is indication that the level may increase with treatment 5 which would not necessarily be detected using most statistical tests. Considering the conditional specificity written into the logic for the MPB process and given the rather limited area in which MPB could occur, an increased level of mountain pine beetle in decade 1 with decreasing levels in later decades, when the polygons at risk are exhausted, would be expected. Since only specific community types meet the conditions for initiation or spread of MPB, there is a lower ceiling to the extent of MPB that can occur. In other words, if there is a high probability for MPB but there are very few acres that are structurally at risk, very few acres will be influenced by the MPB process.

Alternative explanations for the behavior elicited by altering the probabilities of MPB may first of all, indicate that model logic using the hazard rating system that was established for the stand scale (Amman 1977) may not transfer to the landscape scale as simulated using the SIMPPLLE model. However, during earlier model development, expert analyses of model output supported SIMPPLLE output for the MPB process indicating that the logic did transfer. Another explanation for the observed model behavior may be that the logic is too specific, or limiting, to plant communities. Perhaps the only method with which a change in processes can be expected would be through changing the logic itself. However, the stochasticity built into the model is intended to simulate a range of potential outcomes that can be expected for specific processes. Given the lower potential range of the severe mountain pine beetle process, compared to the mixed severity fire process, the distribution would remain the same regardless of changes to the probabilities. The MPB process is expected to occur at much smaller scales relative to the MSF process.

Model behavior, as displayed by simulation output, appears to provide a range of acres that are influenced by the MPB process. The MPB process appears to be fairly insensitive to changes in the process probabilities. This is probably attributable to the internal limitations provided by the logic where MPB processes are specific to community type, neighboring community types, and the hazard system which defines the process. Additionally, the Monte Carlo method provides the stochastic element which limits the ranges of MPB influencing the landscape by individual simulation and decade.

Conclusions

The geographic variation built into the HWM and UCF regional variants provides large enough differences in repeated simulation output to support continued development and maintenance of the unique pathways which represent ecological regions. The interactions of initial conditions and natural processes produced by the SIMPPLLE model display the connection between vegetation patterns and processes, a foundation to the concept of landscape ecology.

Simulated output from the model displays how vegetation change occurs as a function of multiple factors ranging from simple succession to large scale disturbance events. Those factors are the key elements influencing landscape change and vary according to the biogeographical influences across Region 1. The method of incorporating this rather broad influence into the SIMPPLLE model was achieved by building the model logic based on the interactions of vegetation pattern and process as it varies according to biogeography. The logic that vegetative interactions will vary across the region is reflected in simulation output. The display of differences among landscapes within a region increases the ability of natural resource specialist to communicate with both the public and other resource specialists.

Model sensitivity to selected process probabilities is variable, depending on the process under consideration. There were enough differences to suggest that research to strengthen the reliability of probability estimates would provide greater confidence to users. Since model logic is based on the most current knowledge available, documentation of the differences and, if possible, level of error within the various models from which knowledge was adapted would provide increased confidence in SIMPPLLE. This study provides a method for quantifying the level of processes necessary for evoking change within specific model components.

The level of difficulty introduced when using the Walkthrough vegetation reconnaissance as the basis for translating inventory to "types" for model inputs was a strong indication that there is wide variation in how natural resource managers gather vegetation information. The importance of initial conditions is directly related to the types of change that can be expected from the simulated model output and accurate portrayal of the landscape is crucial to gaining some understand of landscape level change. Given the increasing importance of models to natural resource research and management, some standard for methods of vegetation inventory would greatly help resource modeling efforts.

This study explores the potential of a model for displaying the influence of regional differences on vegetation change at the landscape scale. The model uses knowledge that is available to resource managers as well as expertise provided by resource specialists to gain understanding of how to best attain desired future conditions. The SIMPPLLE modeling system is a useful tool for predicting and analyzing ranges of vegetation change temporally and spatially at the landscape scale.

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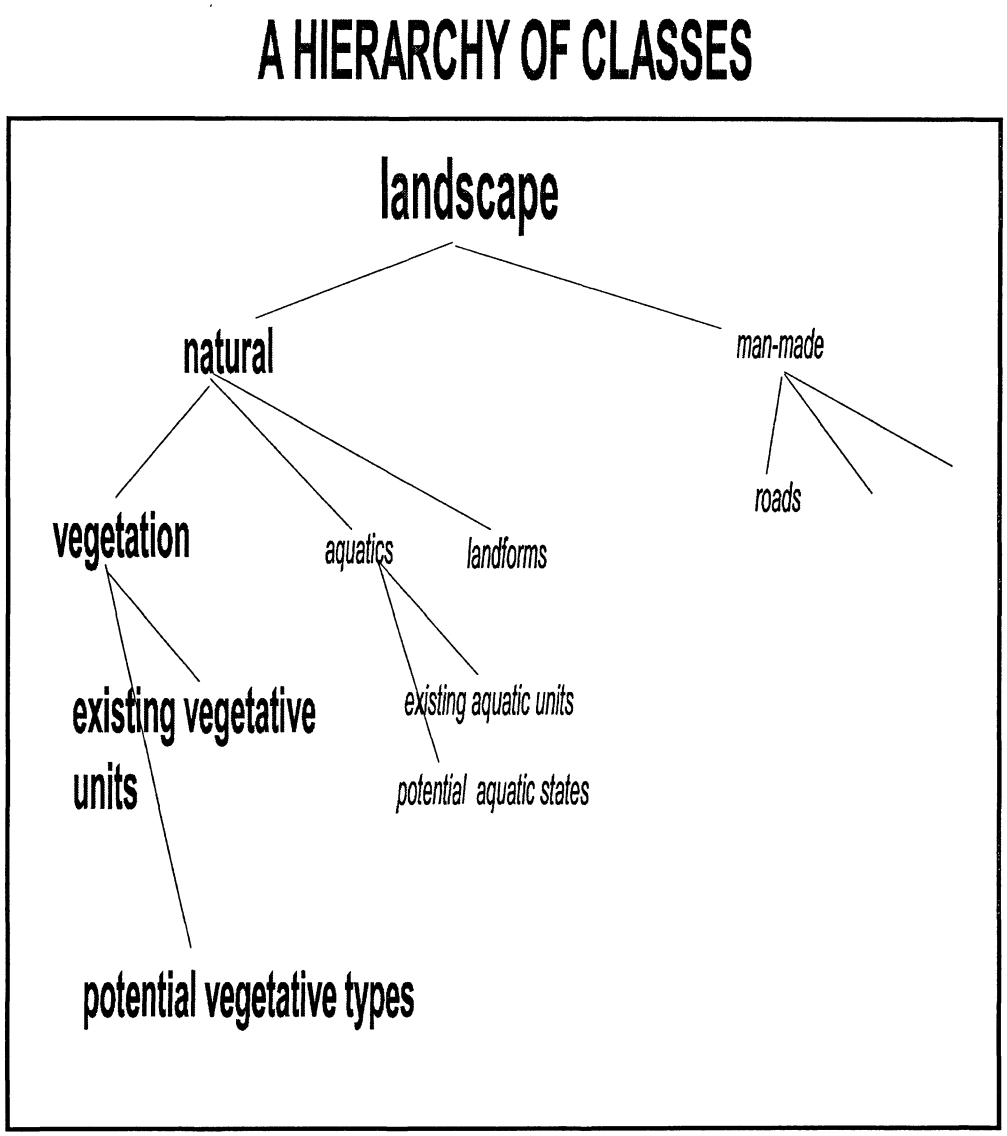
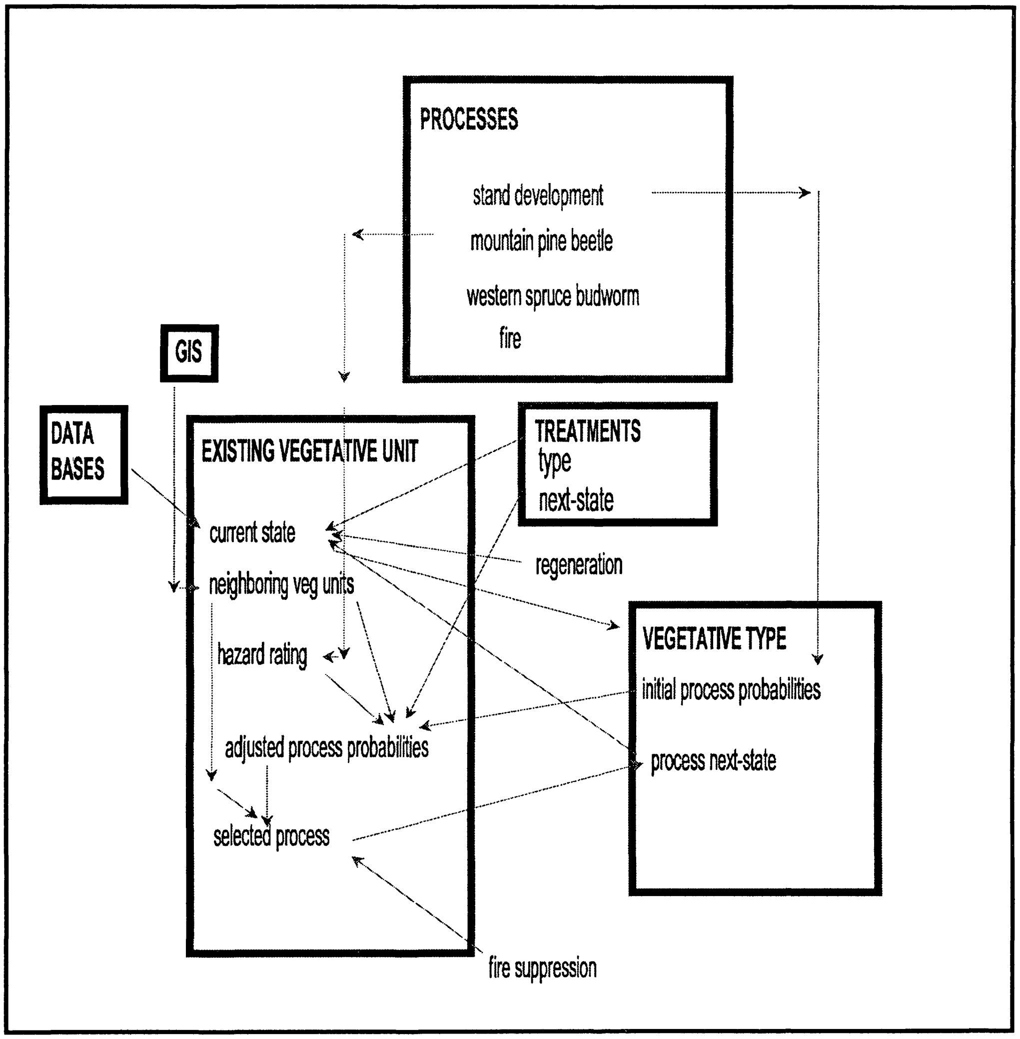
Appendix A. Structural hierarchy and component interactions of the SIMPPLLE model.



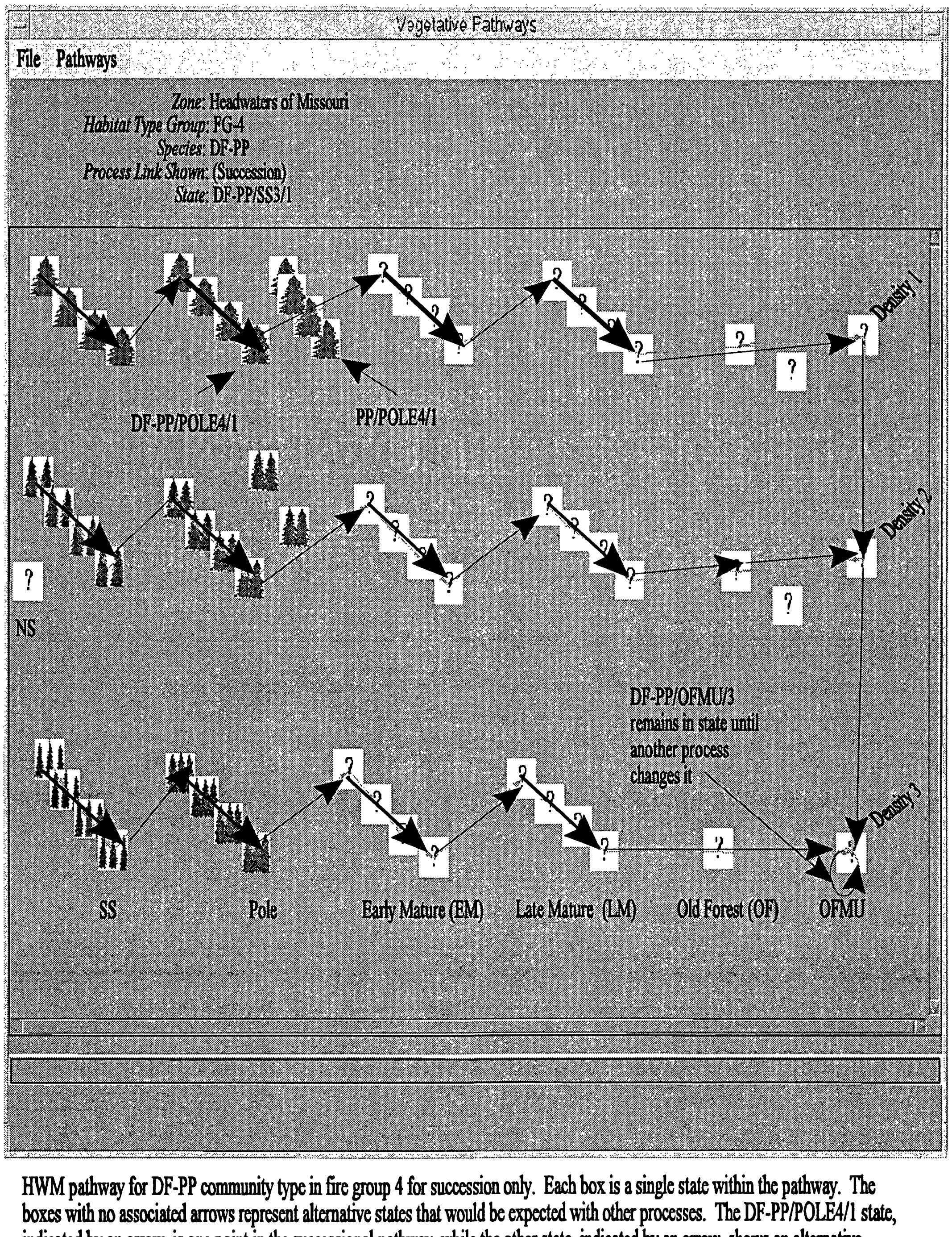
SIMPPLLE structural hierarchy displaying model structure for the vegetati component of SIMPPLLE and the aquatic and landform components that be incorporated into later versions of the model.

SIMPPLLE COMPONENT INTERACTIONS

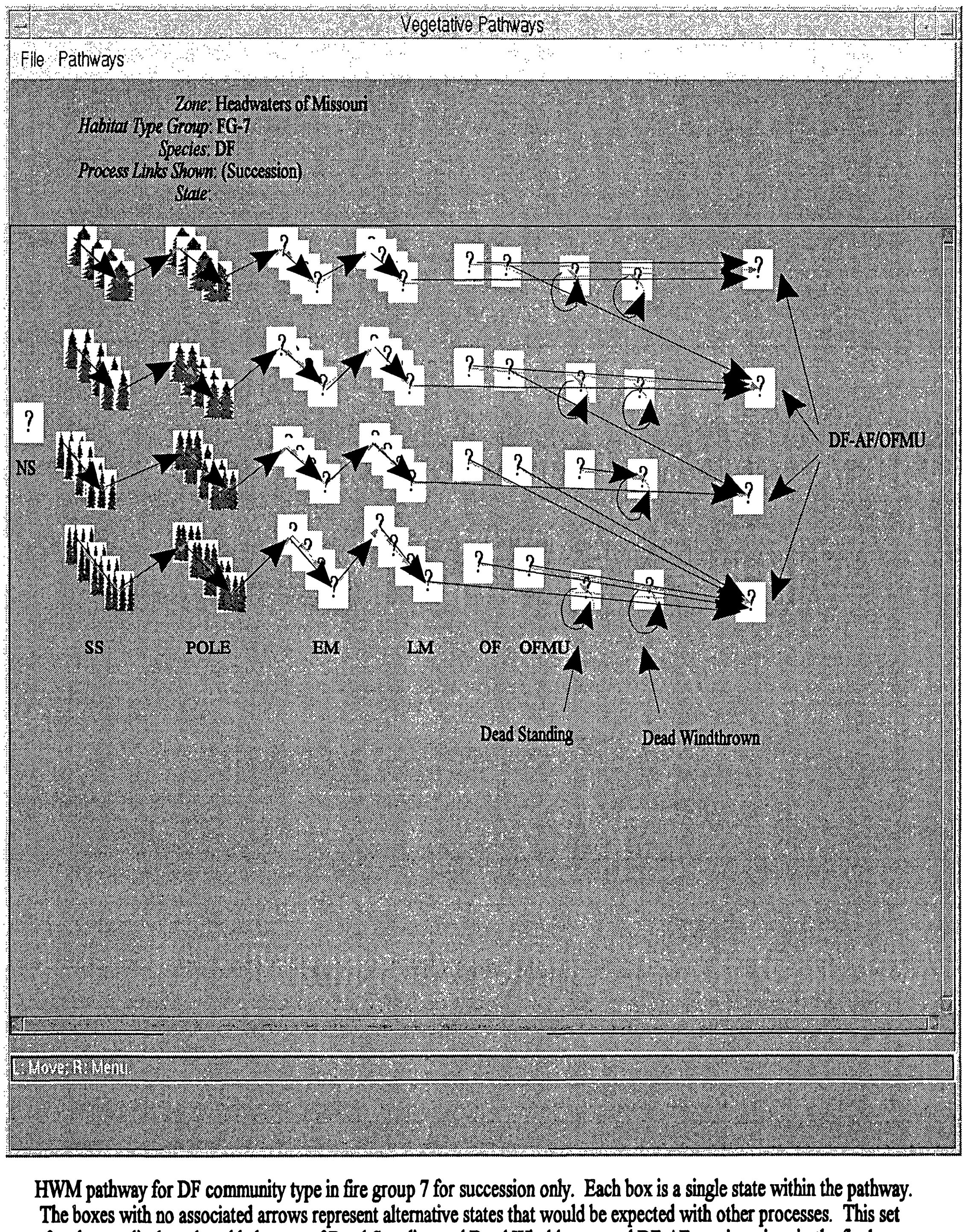


Flow diagram for the interaction between major vegetative components in the SIMPPLLE model.

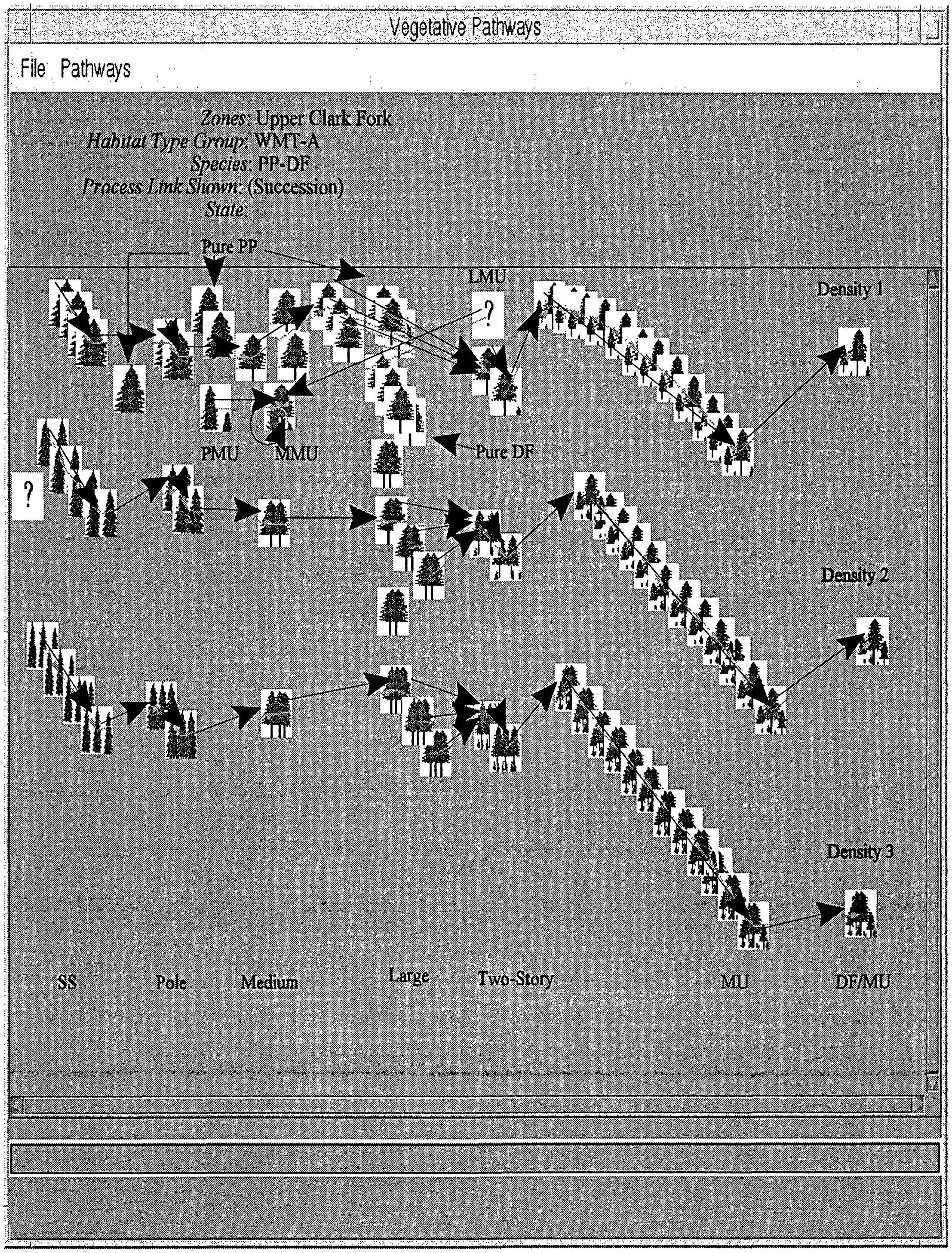
Appendix B. Vegetative community successional pathways in the SIMPPLLE model displaying HWM fire groups 4 and 7, and UCF old growth groups A and E, for Douglas-fir and Douglas-fir/ponderosa pine community types.



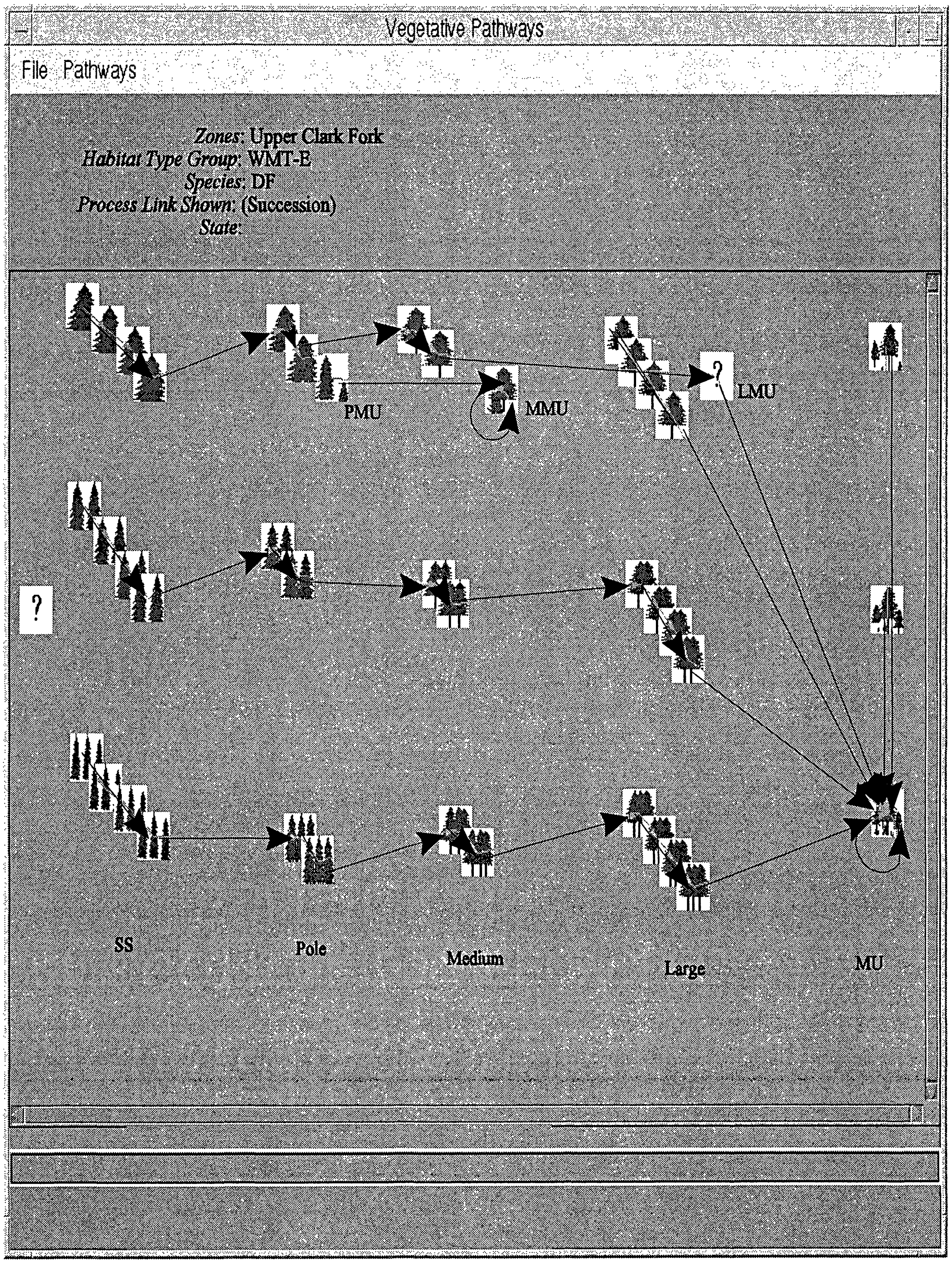
HWM pathway for DF-PP community type in fire group 4 for succession only. Each box is a single state within the pathway. The boxes with no associated arrows represent alternative states that would be expected with other processes. The DF-PP/POLE4/1 state, indicated by an arrow, is one point in the successional pathway, while the other state, indicated by an arrow, shows an alternative pathway state that is expected in the mixed severity fire process. Size classes are labeled by column, density is labeled by row.



HWM pathway for DF community type in fire group 7 for succession only. Each box is a single state within the pathway. The boxes with no associated arrows represent alternative states that would be expected with other processes. This set of pathways displays the added states of Dead Standing and Dead Windthrown and DF-AF species mixes in the final state.



UCF pathway for DF-PP comuunity type in old growth group A for succession only. With certain processes the expected transition is to pure ponderosa pine (fire process) and without fire the expected transition is to Douglas-fir at variable growth stages. The end, (climax) state is that of Douglas-fir, multi story after many decades within the PP-DF/MU state.



UCF pathway for DF comuunity type in old growth group E for succession only. A simple pathway in which all pathways end in the DF multi story state at a density level of 3. A separate set of states occurs in the first density level, where a multistory component is expected.

Appendix C. Initial translation of size class from selected Walkthrough fields to SIMPPLLE structural requirements.

In the first translation, database fields from the Walkthrough describing stand cover type (F_TYPE), stand size class (SSC), percent canopy cover (PCC), average diameter of live trees in the 5-8.9" DBH class (CFDBH), habitat type (HAB_TYP), average diameter of live trees in the 9-15" DBH class (DBH9_15), average diameter of live trees in the >15" DBH class (DBH_15), ArcInfo polygon reference number (XREF), stand number (ST_NUM), and stand acres (AC) were converted into meaningful, nonspatial SIMPPLLE vegetation attributes. This initial data conversion was performed for the UCF variant of SIMPPLLE only.

SIMPPLLE size classes were constructed from SSC, CFDBH, DBH9_15, and DBH_15 in the Walkthrough data set. The stand size class field was based on the average diameter of trees found in the middle and upper canopy layers of each stand. A layer is a strata or story of trees comprising approximately 15% of the stand canopy cover (Mogilefsky and Wood 1995). Three layer or multi-story stands were coded 6 and codes 1-5 were assigned according to DBH ranges. DBH in the 5-8.9" class was determined by calculating the average size of trees in the 5-8.9" stand component using selected point sampling. The DBH fields in the 9-15" and >15" multi story classes were populated with average DBH measures in the 9-15" class and the >15" class, respectively.

Depending on how the SSC field was coded, the next step was to consider the CFDBH field, primarily to identify the pole, medium, and large size classes. Finally, the DBH9_15 and DBH_15 fields were used along with the CFDBH field to divide the multistory component into size classes. Generally, the largest DBH recorded among the different DBH fields provided the default multistory size class call for SIMPPLLE. Table C1 displays the conditional statements to derive SIMPPLLE size classes.

Table C1. Translation from Walkthrough database fields describing stand size class (SSC) numeric coding system, DBH in the 5-8.9" class (CFDBH), DBH in the 9-15" class (DBH9_15), and DBH in the 15" and greater class (DBH_15) to SIMPPLLE size classes (UCF variant only).

SSC		CFDBH		DBH9_15		DBH_15		SIMPPLLE Size Class
If 0	And	0	And	0	And	0	→	NF
If 1 or 2	And	0	And	0	And	0	→	SS
If 3	And	0	And	0	And	0	→	Pole
If 3	And	5 or 6	And	0	And	0	→	Pole
If 3	And	7 or 8	And	0	And	0	→	Medium
If 4	And	0	And	0	And	0	→	Large
If 4	And	5 or 6	And	0	And	0	→	Pole
If 4	And	7 or 8	And	0	And	0	→	Medium
If 4	And	9	And	0	And	0	→	Large
If 5	And	0	And	0	And	0	→	Very Large
If 5	And	5 or 6	And	0	And	0	→	Pole
If 5	And	7 or 8	And	0	And	0	→	Medium
If 5	And	9	And	0	And	0	→	Large
If 6	And	0	And	0	And	0	→	SS
If 6	And	5 or 6	And	0	And	0	→	PMU
If 6	And	7 or 8	And	0	And	0	→	MMU
If 6	And	5-9	And/Or	10-14	And	0	→	LMU
If 6	And	5-9	And/Or	10-14	And/Or	>14	→	MU

Appendix D1. Lisp code for the handlers assigned to the instances of lodgepole mountain pine beetle of the process class for the purpose of displaying model logic and process probabilities.

HANDLERS FOR MPB

```
;;; -*- Mode:Lisp; Package:GW; Base:10; -*-
(in-package 'gw)

(PROCLAIM '(OPTIMIZE (SPEED 3) (SAFETY 0) (SPACE 2)))

;; VERSION 1.1

;;  created on 2-18-97
;;  all functions associated with processes are initiated as handlers
;;  attached to that process

;;  handlers are of two kinds: initial probabilities and any adjustments, and spread
;;  all probabilities start out as zero in all
;;  instances.

;; a function to just return nil as light-mpb is included in the list
;; of all processes 6-6-94  but the one function for severe really does
;; the probs for both

(define-handler
 (light-mpb :probability) (unit)
  t)

 (define-handler
  (severe-mpb :probability) (unit)
   (lp-mpb-hazard unit)
   (adjust-lp-mpb unit)
   )

 (defun lp-mpb-hazard (unit)
   (let ((unit-species (slot-value unit 'species))
         (unit-size-class (slot-value unit 'size-class))
         (unit-canopy-coverage (slot-value unit 'canopy-coverage))
         (unit-ht-grp (slot-value unit 'ht-grp)))
     (cond  ((and (member unit-species '(lp l-lp df-lp))
                (eql (member unit-size-class '(dead pole pmu ss)) nil))
```

```
 (cond ((or (eql unit-ht-grp 'wmt-j)
           (eql unit-ht-grp 'wmt-i))
        (setf (slot-value unit 'lp-mpb-hazard)
          (append (list 'lp-mpb-low) (slot-value unit 'lp-mpb-hazard))))

        ((and (or (eql unit-ht-grp 'wmt-a)
                  (eql unit-ht-grp 'wmt-b))
              (or (eql unit-canopy-coverage 3)
                  (eql unit-canopy-coverage 4)))
         (setf (slot-value unit 'lp-mpb-hazard)
           (append (list 'lp-mpb-high) (slot-value unit 'lp-mpb-hazard))))

        ((and (or (eql unit-ht-grp 'wmt-a)
                  (eql unit-ht-grp 'wmt-b))
              (or (eql unit-canopy-coverage 1)
                  (eql unit-canopy-coverage 2)))
         (setf (slot-value unit 'lp-mpb-hazard)
           (append (list 'lp-mpb-mod) (slot-value unit 'lp-mpb-hazard))))

        ((and (member unit-ht-grp '(wmt-c wmt-d wmt-e wmt-f wmt-g wmt-h))
              (or (eql unit-canopy-coverage 3)
                  (eql unit-canopy-coverage 4)))
          (setf (slot-value unit 'lp-mpb-hazard)
            (append (list 'lp-mpb-high) (slot-value unit 'lp-mpb-hazard))))

        ((and (member unit-ht-grp '(wmt-c wmt-d wmt-e wmt-f wmt-g wmt-h))
              (or (eql unit-canopy-coverage 1)
                  (eql unit-canopy-coverage 2)))
         (setf (slot-value unit 'lp-mpb-hazard)
          (append (list 'lp-mpb-mod) (slot-value unit 'lp-mpb-hazard))))
    )) ;closes cond and very first "and" combination

((and (member unit-species '(df-lp-af l-pp-lp l-lp-df))
     (eql (member unit-size-class '(dead pole pmu ss)) nil))

 (cond ((or (eql unit-ht-grp 'wmt-j)
           (eql unit-ht-grp 'wmt-i))
        (setf (slot-value unit 'lp-mpb-hazard)
          (append (list 'lp-mpb-low) (slot-value unit 'lp-mpb-hazard))))

        ((and (or (eql unit-ht-grp 'wmt-a)
                  (eql unit-ht-grp 'wmt-b))
              (or (eql unit-canopy-coverage 3)
```

```
          (eql unit-canopy-coverage 4)))
     (setf (slot-value unit 'lp-mpb-hazard)
       (append (list 'lp-mpb-mod) (slot-value unit 'lp-mpb-hazard))))

    ((and (or (eql unit-ht-grp 'wmt-a)
              (eql unit-ht-grp 'wmt-b))
          (or (eql unit-canopy-coverage 1)
              (eql unit-canopy-coverage 2)))
     (setf (slot-value unit 'lp-mpb-hazard)
       (append (list 'lp-mpb-low) (slot-value unit 'lp-mpb-hazard))))

    ((and (member unit-ht-grp '(wmt-c wmt-d wmt-e wmt-f wmt-g wmt-h))
          (or (eql unit-canopy-coverage 3)
              (eql unit-canopy-coverage 4)))
      (setf (slot-value unit 'lp-mpb-hazard)
          (append (list 'lp-mpb-mod) (slot-value unit 'lp-mpb-hazard))))

    ((and (member unit-ht-grp '(wmt-c wmt-d wmt-e wmt-f wmt-g wmt-h))
          (or (eql unit-canopy-coverage 1)
              (eql unit-canopy-coverage 2)))
     (setf (slot-value unit 'lp-mpb-hazard)
      (append (list 'lp-mpb-low) (slot-value unit 'lp-mpb-hazard))))
   )) ;closes cond and second "and" combination

  ((and (or (eql unit-species 'l-lp-df-af)
            (eql unit-species 'l-df-pp-lp))
        (eql (member unit-size-class '(dead pole pmu ss)) nil))
   (setf (slot-value unit 'lp-mpb-hazard)
        (append (list 'lp-mpb-low) (slot-value unit 'lp-mpb-hazard))))

;; for all remaining conditions -

  (t (setf (slot-value unit 'lp-mpb-hazard)
     (append (list nil) (slot-value unit 'lp-mpb-hazard))))
   )))

 ;;; function for adjusting, or setting probabilities

(defun adjust-lp-mpb (unit)
   (cond ((not (eql (car (slot-value unit 'lp-mpb-hazard)) nil))
       (let ((adj-haz-low 0)
             (adj-haz-mod 0)
             (adj-haz-high 0)
```

```
        (adj-unit-past-process 'none)
        (unit-past-process (car (slot-value unit 'process-list)))
        (unit-hazard (car (slot-value unit 'lp-mpb-hazard))))
      (dolist (adj-unit (slot-value unit 'adjacent-units))
       (cond ((eql (car (slot-value (intern (format nil
                   "EVU--S" adj-unit)) 'lp-mpb-hazard)) 'lp-mpb-low)
          (setf adj-haz-low (+ adj-haz-low 1)))
         ((eql (car (slot-value (intern (format nil
                   "EVU--S" adj-unit)) 'lp-mpb-hazard)) 'lp-mpb-mod)
          (setf adj-haz-mod (+ adj-haz-mod 1)))
         ((eql (car (slot-value (intern (format nil
                   "EVU--S" adj-unit)) 'lp-mpb-hazard)) 'lp-mpb-high)
          (setf adj-haz-high (+ adj-haz-high 1))))

       (cond ((eql (car (slot-value (intern (format nil
                        "EVU--S" adj-unit)) 'process-list))
                          'light-mpb)
          (setf adj-unit-past-process 'light-mpb)))) ;; closes to dolist

;;; above closes the dolist on the adj-units and we have values for all
;;; the variables to use below

;;;   combinations for low existing hazard

      (cond ((and (not (eql unit-past-process 'light-mpb))
              (or (> adj-haz-mod 0)
                 (> adj-haz-high 0))
              (eql unit-hazard 'lp-mpb-low))
           (setf (getf (slot-value unit 'process-probability) 'light-mpb) 5))

          ((and (eql unit-past-process 'light-mpb)
               (eql unit-hazard 'lp-mpb-low)
               (eql adj-haz-mod 0)
               (eql adj-haz-high 0)
               (eql unit-hazard 'lp-mpb-low))
           (setf (getf (slot-value unit 'process-probability) 'light-mpb) 10))

          ((and (eql unit-past-process 'light-mpb)
              (eql adj-unit-past-process 'light-mpb)
              (< adj-haz-high 2)
              (eql unit-hazard 'lp-mpb-low))
           (setf (getf (slot-value unit 'process-probability) 'light-mpb) 15))
```

```
((and (eql unit-past-process 'light-mpb)
      (eql adj-unit-past-process 'light-mpb)
      (> adj-haz-high 2)
      (eql unit-hazard 'lp-mpb-low))
  (setf (getf (slot-value unit 'process-probability) 'light-mpb) 20))

;;;   combinations for mod existing hazard

((and (not (eql unit-past-process 'light-mpb))
      (not (eql adj-unit-past-process 'light-mpb))
      (> adj-haz-high 0)
      (equal unit-hazard 'lp-mpb-mod))
  (setf (getf (slot-value unit 'process-probability) 'light-mpb) 5)
  (setf (getf (slot-value unit 'process-probability) 'severe-mpb) 5))

((and (eql unit-past-process 'light-mpb)
      (not (eql adj-unit-past-process 'light-mpb))
      (> adj-haz-high 0)
      (eql unit-hazard 'lp-mpb-mod))
  (setf (getf (slot-value unit 'process-probability) 'light-mpb) 15)
  (setf (getf (slot-value unit 'process-probability) 'severe-mpb) 10))

((and (eql unit-past-process 'light-mpb)
      (eql adj-unit-past-process 'light-mpb)
      (eql adj-haz-high 0)
      (eql unit-hazard 'lp-mpb-mod))
  (setf (getf (slot-value unit 'process-probability) 'light-mpb) 60)
  (setf (getf (slot-value unit 'process-probability) 'severe-mpb) 45))

((and (eql unit-past-process 'light-mpb)
      (eql adj-unit-past-process 'light-mpb)
      (> adj-haz-high 0)
      (eql unit-hazard 'lp-mpb-mod))
  (setf (getf (slot-value unit 'process-probability) 'light-mpb) 80)
  (setf (getf (slot-value unit 'process-probability) 'severe-mpb) 65))

;;; combinations for existing hazard of high

((and (not (eql unit-past-process 'light-mpb))
      (not (eql adj-unit-past-process 'light-mpb))
      (eql adj-haz-mod 0)
      (eql adj-haz-high 0)
      (eql unit-hazard 'lp-mpb-high))
```

```
 (setf (getf (slot-value unit 'process-probability) 'light-mpb) 5))

((and (not (eql unit-past-process 'light-mpb))
      (not (eql adj-unit-past-process 'light-mpb))
      (> adj-haz-mod 0)
      (eql adj-haz-high 0)
      (eql unit-hazard 'lp-mpb-high))
  (setf (getf (slot-value unit 'process-probability) 'light-mpb) 10)
  (setf (getf (slot-value unit 'process-probability) 'severe-mpb) 5))


((and (not (eql unit-past-process 'light-mpb))
      (not (eql adj-unit-past-process 'light-mpb))
      (> adj-haz-high 0)
      (equal unit-hazard 'lp-mpb-high))
  (setf (getf (slot-value unit 'process-probability) 'light-mpb) 10)
  (setf (getf (slot-value unit 'process-probability) 'severe-mpb) 10))

((and (not (eql unit-past-process 'light-mpb))
      (eql adj-unit-past-process 'light-mpb)
      (eql adj-haz-mod 0)
      (eql adj-haz-high 0)
      (eql unit-hazard 'lp-mpb-high))
  (setf (getf (slot-value unit 'process-probability) 'light-mpb) 50)
  (setf (getf (slot-value unit 'process-probability) 'severe-mpb) 40))

((and (eql unit-past-process 'light-mpb)
      (eql adj-unit-past-process 'light-mpb)
      (eql adj-haz-mod 0)
      (eql adj-haz-high 0)
      (eql unit-hazard 'lp-mpb-high))
  (setf (getf (slot-value unit 'process-probability) 'light-mpb) 75)
  (setf (getf (slot-value unit 'process-probability) 'severe-mpb) 60))


((and (not (eql unit-past-process 'light-mpb))
      (eql adj-unit-past-process 'light-mpb)
      (> adj-haz-mod 0)
      (eql adj-haz-high 0)
      (eql unit-hazard 'lp-mpb-high))
  (setf (getf (slot-value unit 'process-probability) 'light-mpb) 60)
  (setf (getf (slot-value unit 'process-probability) 'severe-mpb) 45))
```

```
                ((and (eql unit-past-process 'light-mpb)
                      (eql adj-unit-past-process 'light-mpb)
                      (> adj-haz-mod 0)
                      (eql adj-haz-high 0)
                      (eql unit-hazard 'lp-mpb-high))
                  (setf (getf (slot-value unit 'process-probability) 'light-mpb) 80)
                  (setf (getf (slot-value unit 'process-probability) 'severe-mpb) 65))

                ((and (not (eql unit-past-process 'light-mpb))
                      (eql adj-unit-past-process 'light-mpb)
                      (> adj-haz-high 0)
                      (eql unit-hazard 'lp-mpb-high))
                 (setf (getf (slot-value unit 'process-probability) 'light-mpb) 85)
                 (setf (getf (slot-value unit 'process-probability) 'severe-mpb) 70))


               ((and (eql unit-past-process 'light-mpb)
                     (eql adj-unit-past-process 'light-mpb)
                     (> adj-haz-high 0)
                     (eql unit-hazard 'lp-mpb-high))
                 (setf (getf (slot-value unit 'process-probability) 'light-mpb) 95)
                 (setf (getf (slot-value unit 'process-probability) 'severe-mpb) 80))

;;;               (t (format t "couldn't find any matches"))

    )
      ))))

(define-handler
  (light-mpb :spread) (unit counter)
  (cond ((and (not (eql (car (slot-value unit 'prob-list)) 'L))
              (eql (car (slot-value unit 'process-list)) 'succession))
        (let ((severe-mpb-prob (getf (slot-value unit 'process-probability) 'severe-mpb))
              (light-mpb-prob (getf (slot-value unit 'process-probability) 'light-mpb)))
          (cond ((or (>= severe-mpb-prob 10)   ;;;; CHANGE
                     (>= light-mpb-prob 10))   ;;;;; CHANGE
                 (setf (car (slot-value unit 'process-list)) 'light-mpb)
                 (setf (car (slot-value unit 'prob-list)) 'S)
;; add to landscape slot
                 (setf (slot-value (intern (format nil "~S"
                       (slot-value 'change-manager 'specified-process))) 'light-mpb-spread-to)
                       (acons counter (slot-value unit 'id)
                       (slot-value (intern (format nil "~S"
```

```
                    (slot-value 'change-manager 'specified-process))) 'light-mpb-spread-
to)))
                )) ;; close to first cond
        )))) ;closes out to handler define


;;;; note that the below uses unit number instead of polygon id,
;;;  changed as of 11-4-94

;;;  added in the spread from pp-mpb, but only to light-mpb 1-19-95
;; a dolist  for evus is called outside, then another dolist thru
;; the adjacent units -- using the process from the adj unit, the
;; handler is called -- in this case the process for the adj-unit
;; was severe-mpb

(define-handler
  (severe-mpb :spread) (unit counter)
  (cond ((and (not (eql (car (slot-value unit 'prob-list)) 'L))
            (eql (car (slot-value unit 'process-list)) 'succession))
        (let ((severe-mpb-prob (getf (slot-value unit 'process-probability) 'severe-mpb))
             (light-mpb-prob (getf (slot-value unit 'process-probability) 'light-mpb))
             (pp-mpb-prob (getf (slot-value unit 'process-probability) 'pp-mpb)))
              (cond ((or (>= severe-mpb-prob 10)     ;;;; CHANGE
                      (>= light-mpb-prob 10)     ;;;;; CHANGE
                   ) ;closes or
                   (setf (car (slot-value unit 'process-list)) 'severe-mpb)
                   (setf (car (slot-value unit 'prob-list)) 'S)
;; add to landscape slot
                   (setf (slot-value (intern (format nil "~S"
                    (slot-value 'change-manager 'specified-process))) 'severe-mpb-spread-to)
                     (acons counter (slot-value unit 'id)
                      (slot-value (intern (format nil "~S"
                       (slot-value 'change-manager 'specified-process))) 'severe-mpb-spread-
to)))
                ) ;; close to outside of first or
                  ((>= pp-mpb-prob 10)     ;;;;;CHANGE
                   (setf (car (slot-value unit 'process-list)) 'pp-mpb)
                   (setf (car (slot-value unit 'prob-list)) 'S)
;; add to landscape slot
                   (setf (slot-value (intern (format nil "~S"
                     (slot-value 'change-manager 'specified-process))) 'severe-mpb-spread-to)
                      (acons counter (slot-value unit 'id)
                       (slot-value (intern (format nil "~S"
```

```
                    (slot-value 'change-manager 'specified-process))) 'severe-mpb-spread-
to)))
     ;          (format t "changed process due to adjacent pp-mpb~%")
                ) ;; close the cond with pp-mpb
             ) ;; close the cond
           )))) ;; closes  define

;;;;   END of FILE
```

Appendix D2. Lisp code for a portion of the pathways for western Montana habitat type group A for the Douglas-fir species including all size classes and density classes, for the purpose of displaying the logic and probabilities for fire processes. Process probabilities are indicated by final number in list starting with process type.

LOGIC FOR FIRE PROCESS

```
;;
;; SIMPPLLE Pathway Habitat Type Group File
;; File: /.../cell1.msla-labs.int.fs.fed.us/fs/fsfiles/unit/fem/femproj1/simpplle-
dev/knwledge/zones/uppercf/pathways/upcfa.shg
;; Written At: 9/10/97 10:11
;; Zone: Upper Clark Fork

(SIMPPLLE-DATA)

(HABITAT-TYPE-GROUP WMT-A
 (HABITAT-TYPES 130 140 141)
 (CLIMAX-SPECIES DF PP)
 (SERAL-SPECIES PP LP L DF))


(VEGETATIVE-TYPE DF/LARGE/1
 (SPECIES DF)
 (SIZE-CLASS LARGE)
 (CANOPY-COVERAGE 1)
 (NEXT-STATE
  (SUCCESSION DF/LARGE2/1 96)
  (LIGHT-SEVERITY-FIRE DF/LARGE2/1 2)
  (MIXED-SEVERITY-FIRE DF/LARGE/1 2)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/LMU/1 0)
  (LIGHT-WSBW DF/LARGE2/1 0)
  (SEVERE-WSBW DF/LARGE/1 0))
 (POSITIONS
  (DF 417 11)
  (PP-DF 359 58)))

(VEGETATIVE-TYPE DF/LARGE/2
 (SPECIES DF)
 (SIZE-CLASS LARGE)
 (CANOPY-COVERAGE 2)
 (NEXT-STATE
  (SUCCESSION DF/LARGE2/2 96)
```

```
 (LIGHT-SEVERITY-FIRE DF/LARGE2/1 2)
 (MIXED-SEVERITY-FIRE DF/LARGE/1 2)
 (STAND-REPLACING-FIRE NS/NS/0 0)
 (ROOT-DISEASE DF/LMU/1 0)
 (LIGHT-WSBW DF/LARGE2/2 0)
 (SEVERE-WSBW DF/LARGE/1 0))
(POSITIONS
 (DF 417 105)
 (PP-DF 371 214)))

(VEGETATIVE-TYPE DF/LARGE/3
(SPECIES DF)
(SIZE-CLASS LARGE)
(CANOPY-COVERAGE 3)
(NEXT-STATE
 (SUCCESSION DF/LARGE2/3 97)
 (LIGHT-SEVERITY-FIRE DF/LARGE2/1 1)
 (MIXED-SEVERITY-FIRE DF/LARGE/1 1)
 (STAND-REPLACING-FIRE NS/NS/0 1)
 (ROOT-DISEASE DF/LMU/1 0)
 (LIGHT-WSBW DF/LARGE2/3 0)
 (SEVERE-WSBW DF/LARGE/1 0))
(POSITIONS
 (DF 415 218)))

(VEGETATIVE-TYPE DF/LARGE2/1
(SPECIES DF)
(SIZE-CLASS LARGE)
(CANOPY-COVERAGE 1)
(NEXT-STATE
 (SUCCESSION DF/LARGE3/1 96)
 (LIGHT-SEVERITY-FIRE DF/LARGE3/1 2)
 (MIXED-SEVERITY-FIRE DF/LARGE2/1 2)
 (STAND-REPLACING-FIRE NS/NS/0 0)
 (ROOT-DISEASE DF/LMU/1 0)
 (LIGHT-WSBW DF/LARGE3/1 0)
 (SEVERE-WSBW DF/LARGE2/1 0))
(POSITIONS
 (DF 427 18)
 (PP-DF 369 67)))

(VEGETATIVE-TYPE DF/LARGE2/2
(SPECIES DF)
```

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 (SIZE-CLASS LARGE)
 (CANOPY-COVERAGE 2)
 (NEXT-STATE
  (SUCCESSION DF/LARGE3/2 96)
  (LIGHT-SEVERITY-FIRE DF/LARGE3/1 2)
  (MIXED-SEVERITY-FIRE DF/LARGE2/1 2)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/LMU/1 0)
  (LIGHT-WSBW DF/LARGE3/2 0)
  (SEVERE-WSBW DF/LARGE2/1 0))
 (POSITIONS
  (DF 429 114)))

(VEGETATIVE-TYPE DF/LARGE2/3
 (SPECIES DF)
 (SIZE-CLASS LARGE)
 (CANOPY-COVERAGE 3)
 (NEXT-STATE
  (SUCCESSION DF/LARGE3/3 97)
  (LIGHT-SEVERITY-FIRE DF/LARGE3/1 1)
  (MIXED-SEVERITY-FIRE DF/LARGE2/1 1)
  (STAND-REPLACING-FIRE NS/NS/0 1)
  (ROOT-DISEASE DF/LMU/1 0)
  (LIGHT-WSBW DF/LARGE3/3 0)
  (SEVERE-WSBW DF/LARGE2/1 0))
 (POSITIONS
  (DF 425 226)))

(VEGETATIVE-TYPE DF/LARGE3/1
 (SPECIES DF)
 (SIZE-CLASS LARGE)
 (CANOPY-COVERAGE 1)
 (NEXT-STATE
  (SUCCESSION DF/LARGE4/1 96)
  (LIGHT-SEVERITY-FIRE DF/LARGE4/1 2)
  (MIXED-SEVERITY-FIRE DF/LARGE3/1 2)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/LMU/1 0)
  (LIGHT-WSBW DF/LARGE4/1 0)
  (SEVERE-WSBW DF/LARGE3/1 0))
 (POSITIONS
  (DF 436 28)
  (PP-DF 378 79)))
```

(VEGETATIVE-TYPE DF/LARGE3/2
(SPECIES DF)
(SIZE-CLASS LARGE)
(CANOPY-COVERAGE 2)
(NEXT-STATE
(SUCCESSION DF/LARGE4/2 96)
(LIGHT-SEVERITY-FIRE DF/LARGE4/1 2)
(**MIXED-SEVERITY-FIRE DF/LARGE3/1 2**)
(STAND-REPLACING-FIRE NS/NS/0 0)
(ROOT-DISEASE DF/LMU/1 0)
(LIGHT-WSBW DF/LARGE4/2 0)
(SEVERE-WSBW DF/LARGE3/1 0))
(POSITIONS
(DF 437 125)))

(VEGETATIVE-TYPE DF/LARGE3/3
(SPECIES DF)
(SIZE-CLASS LARGE)
(CANOPY-COVERAGE 3)
(NEXT-STATE
(SUCCESSION DF/LARGE4/3 97)
(LIGHT-SEVERITY-FIRE DF/LARGE4/1 1)
(**MIXED-SEVERITY-FIRE DF/LARGE3/1 1**)
(STAND-REPLACING-FIRE NS/NS/0 1)
(ROOT-DISEASE DF/LMU/1 0)
(LIGHT-WSBW DF/LARGE4/3 0)
(SEVERE-WSBW DF/LARGE3/1 0))
(POSITIONS
(DF 432 232)))

(VEGETATIVE-TYPE DF/LARGE4/1
(SPECIES DF)
(SIZE-CLASS LARGE)
(CANOPY-COVERAGE 1)
(NEXT-STATE
(SUCCESSION DF/VERY-LARGE/1 96)
(LIGHT-SEVERITY-FIRE DF/VERY-LARGE/1 2)
(**MIXED-SEVERITY-FIRE DF/LARGE4/1 2**)
(STAND-REPLACING-FIRE NS/NS/0 0)
(ROOT-DISEASE DF/LMU/1 0)
(LIGHT-WSBW DF/VERY-LARGE/1 0)
(SEVERE-WSBW DF/LARGE4/1 0))
(POSITIONS

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  (DF 447 36)
  (PP-DF 388 87)))

(VEGETATIVE-TYPE DF/LARGE4/2
 (SPECIES DF)
 (SIZE-CLASS LARGE)
 (CANOPY-COVERAGE 2)
 (NEXT-STATE
  (SUCCESSION DF/VERY-LARGE/2 96)
  (LIGHT-SEVERITY-FIRE DF/VERY-LARGE/1 2)
  (MIXED-SEVERITY-FIRE DF/LARGE4/1 2)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/LMU/1 0)
  (LIGHT-WSBW DF/VERY-LARGE/2 0)
  (SEVERE-WSBW DF/LARGE4/1 0))
 (POSITIONS
  (DF 445 134)))

(VEGETATIVE-TYPE DF/LARGE4/3
 (SPECIES DF)
 (SIZE-CLASS LARGE)
 (CANOPY-COVERAGE 3)
 (NEXT-STATE
  (SUCCESSION DF/VERY-LARGE/3 97)
  (LIGHT-SEVERITY-FIRE DF/VERY-LARGE/2 1)
  (MIXED-SEVERITY-FIRE DF/LARGE4/1 1)
  (STAND-REPLACING-FIRE NS/NS/0 1)
  (ROOT-DISEASE DF/LMU/1 0)
  (LIGHT-WSBW DF/VERY-LARGE/3 0)
  (SEVERE-WSBW DF/LARGE4/1 0))
 (POSITIONS
  (DF 442 239)))

(VEGETATIVE-TYPE DF/LMU/1
 (SPECIES DF)
 (SIZE-CLASS LMU)
 (CANOPY-COVERAGE 1)
 (NEXT-STATE
  (SUCCESSION DF/MU/3 97)
  (LIGHT-SEVERITY-FIRE DF/MU/1 0)
  (MIXED-SEVERITY-FIRE DF/LARGE4/1 1)
  (STAND-REPLACING-FIRE NS/NS/0 2)
  (ROOT-DISEASE DF/MMU/1 0)
```

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  (LIGHT-WSBW DF/MU/2 0)
  (SEVERE-WSBW DF/LARGE4/1 0))
 (POSITIONS
  (DF 500 8)))

(VEGETATIVE-TYPE DF/MEDIUM/1
 (SPECIES DF)
 (SIZE-CLASS MEDIUM)
 (CANOPY-COVERAGE 1)
 (NEXT-STATE
  (SUCCESSION DF/MEDIUM2/1 98)
  (LIGHT-SEVERITY-FIRE DF/MEDIUM2/1 1)
  (MIXED-SEVERITY-FIRE DF/MEDIUM/1 1)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/MMU/1 0))
 (POSITIONS
  (DF 259 9)
  (PP-DF 270 43)))

(VEGETATIVE-TYPE DF/MEDIUM/2
 (SPECIES DF)
 (SIZE-CLASS MEDIUM)
 (CANOPY-COVERAGE 2)
 (NEXT-STATE
  (SUCCESSION DF/MEDIUM2/2 98)
  (LIGHT-SEVERITY-FIRE DF/MEDIUM2/1 1)
  (MIXED-SEVERITY-FIRE DF/MEDIUM/1 1)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/MMU/1 0))
 (POSITIONS
  (DF 256 109)))

(VEGETATIVE-TYPE DF/MEDIUM/3
 (SPECIES DF)
 (SIZE-CLASS MEDIUM)
 (CANOPY-COVERAGE 3)
 (NEXT-STATE
  (SUCCESSION DF/MEDIUM2/3 98)
  (LIGHT-SEVERITY-FIRE DF/MEDIUM2/1 0)
  (MIXED-SEVERITY-FIRE DF/MEDIUM/1 0)
  (STAND-REPLACING-FIRE NS/NS/0 2)
  (ROOT-DISEASE DF/MMU/1 0))
 (POSITIONS
```

```
(DF 270 221)))

(VEGETATIVE-TYPE DF/MEDIUM2/1
 (SPECIES DF)
 (SIZE-CLASS MEDIUM)
 (CANOPY-COVERAGE 1)
 (NEXT-STATE
  (SUCCESSION DF/LARGE/1 98)
  (LIGHT-SEVERITY-FIRE DF/LARGE/1 1)
  (MIXED-SEVERITY-FIRE DF/MEDIUM2/1 1)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/MMU/1 0))
 (POSITIONS
  (DF 269 22)))

(VEGETATIVE-TYPE DF/MEDIUM2/2
 (SPECIES DF)
 (SIZE-CLASS MEDIUM)
 (CANOPY-COVERAGE 2)
 (NEXT-STATE
  (SUCCESSION DF/LARGE/2 98)
  (LIGHT-SEVERITY-FIRE DF/LARGE/1 1)
  (MIXED-SEVERITY-FIRE DF/MEDIUM2/1 1)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/MMU/1 0))
 (POSITIONS
  (DF 265 119)))

(VEGETATIVE-TYPE DF/MEDIUM2/3
 (SPECIES DF)
 (SIZE-CLASS MEDIUM)
 (CANOPY-COVERAGE 3)
 (NEXT-STATE
  (SUCCESSION DF/LARGE/3 98)
  (LIGHT-SEVERITY-FIRE DF/LARGE/2 0)
  (MIXED-SEVERITY-FIRE DF/MEDIUM2/2 0)
  (STAND-REPLACING-FIRE NS/NS/0 2)
  (ROOT-DISEASE DF/MMU/1 0))
 (POSITIONS
  (DF 281 232)))

(VEGETATIVE-TYPE DF/MMU/1
 (SPECIES DF)
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 (SIZE-CLASS MMU)
 (CANOPY-COVERAGE 1)
 (NEXT-STATE
  (SUCCESSION DF/MMU/1 0)
  (LIGHT-SEVERITY-FIRE DF/MMU/1 0)
  (MIXED-SEVERITY-FIRE DF/PMU/1 0)
  (STAND-REPLACING-FIRE NS/NS/0 2)
  (ROOT-DISEASE DF/PMU/1 98))
 (POSITIONS
  (DF 332 38)))

(VEGETATIVE-TYPE DF/MU/1
 (SPECIES DF)
 (SIZE-CLASS MU)
 (CANOPY-COVERAGE 1)
 (NEXT-STATE
  (SUCCESSION DF/MU/2 94)
  (LIGHT-SEVERITY-FIRE DF/MU/1 3)
  (MIXED-SEVERITY-FIRE DF/VERY-LARGE/1 3)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/LMU/1 0)
  (LIGHT-WSBW DF/VERY-LARGE/1 0)
  (SEVERE-WSBW DF/VERY-LARGE/1 0))
 (POSITIONS
  (DF 700 6)
  (PP-DF 837 40)))

(VEGETATIVE-TYPE DF/MU/2
 (SPECIES DF)
 (SIZE-CLASS MU)
 (CANOPY-COVERAGE 2)
 (NEXT-STATE
  (SUCCESSION DF/MU/3 95)
  (LIGHT-SEVERITY-FIRE DF/MU/2 2)
  (MIXED-SEVERITY-FIRE DF/VERY-LARGE/1 2)
  (STAND-REPLACING-FIRE NS/NS/0 1)
  (ROOT-DISEASE DF/LMU/1 0)
  (LIGHT-WSBW DF/VERY-LARGE/1 0)
  (SEVERE-WSBW DF/VERY-LARGE/1 0))
 (POSITIONS
  (DF 706 113)
  (PP-DF 856 234)))
```

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(VEGETATIVE-TYPE DF/MU/3
 (SPECIES DF)
 (SIZE-CLASS MU)
 (CANOPY-COVERAGE 3)
 (NEXT-STATE
  (SUCCESSION DF/MU/3 95)
  (LIGHT-SEVERITY-FIRE DF/MU/2 1)
  (MIXED-SEVERITY-FIRE DF/VERY-LARGE/1 2)
  (STAND-REPLACING-FIRE NS/NS/0 2)
  (ROOT-DISEASE DF/LMU/1 0)
  (LIGHT-WSBW DF/VERY-LARGE/1 0)
  (SEVERE-WSBW DF/VERY-LARGE/1 0))
 (POSITIONS
  (DF 704 231)
  (PP-DF 844 416)))

(VEGETATIVE-TYPE DF/PMU/1
 (SPECIES DF)
 (SIZE-CLASS PMU)
 (CANOPY-COVERAGE 1)
 (NEXT-STATE
  (SUCCESSION DF/MMU/1 0)
  (LIGHT-SEVERITY-FIRE DF/PMU/1 0)
  (MIXED-SEVERITY-FIRE DF/PMU/1 0)
  (STAND-REPLACING-FIRE NS/NS/0 2)
  (ROOT-DISEASE DF/PMU/1 98))
 (POSITIONS
  (DF 219 33)))

(VEGETATIVE-TYPE DF/POLE/1
 (SPECIES DF)
 (SIZE-CLASS POLE)
 (CANOPY-COVERAGE 1)
 (NEXT-STATE
  (SUCCESSION DF/POLE2/1 99)
  (LIGHT-SEVERITY-FIRE DF/POLE2/1 1)
  (MIXED-SEVERITY-FIRE DF/POLE/1 0)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/PMU/1 0))
 (POSITIONS
  (DF 157 7)))

(VEGETATIVE-TYPE DF/POLE/2
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```
 (SPECIES DF)
 (SIZE-CLASS POLE)
 (CANOPY-COVERAGE 2)
 (NEXT-STATE
  (SUCCESSION DF/POLE2/2 99)
  (LIGHT-SEVERITY-FIRE DF/POLE2/1 1)
  (MIXED-SEVERITY-FIRE DF/POLE/1 0)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/PMU/1 0))
 (POSITIONS
  (DF 168 107)))

(VEGETATIVE-TYPE DF/POLE/3
 (SPECIES DF)
 (SIZE-CLASS POLE)
 (CANOPY-COVERAGE 3)
 (NEXT-STATE
  (SUCCESSION DF/POLE2/3 100)
  (LIGHT-SEVERITY-FIRE DF/POLE2/2 0)
  (MIXED-SEVERITY-FIRE DF/POLE/2 0)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/PMU/1 0))
 (POSITIONS
  (DF 163 219)))

(VEGETATIVE-TYPE DF/POLE2/1
 (SPECIES DF)
 (SIZE-CLASS POLE)
 (CANOPY-COVERAGE 1)
 (NEXT-STATE
  (SUCCESSION DF/MEDIUM/1 99)
  (LIGHT-SEVERITY-FIRE DF/MEDIUM/1 1)
  (MIXED-SEVERITY-FIRE DF/POLE2/1 0)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/PMU/1 0))
 (POSITIONS
  (DF 164 14)))

(VEGETATIVE-TYPE DF/POLE2/2
 (SPECIES DF)
 (SIZE-CLASS POLE)
 (CANOPY-COVERAGE 2)
 (NEXT-STATE
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```
  (SUCCESSION DF/MEDIUM/2 99)
  (LIGHT-SEVERITY-FIRE DF/MEDIUM/1 1)
  (MIXED-SEVERITY-FIRE DF/POLE2/1 0)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/PMU/1 0))
 (POSITIONS
  (DF 181 118)))

(VEGETATIVE-TYPE DF/POLE2/3
 (SPECIES DF)
 (SIZE-CLASS POLE)
 (CANOPY-COVERAGE 3)
 (NEXT-STATE
  (SUCCESSION DF/MEDIUM/3 100)
  (LIGHT-SEVERITY-FIRE DF/MEDIUM/2 0)
  (MIXED-SEVERITY-FIRE DF/POLE2/2 0)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/PMU/1 0))
 (POSITIONS
  (DF 172 228)))

(VEGETATIVE-TYPE DF/SS/1
 (SPECIES DF)
 (SIZE-CLASS SS)
 (CANOPY-COVERAGE 1)
 (NEXT-STATE
  (SUCCESSION DF/SS2/1 100)
  (LIGHT-SEVERITY-FIRE NS/NS/0 0)
  (MIXED-SEVERITY-FIRE NS/NS/0 0)
  (STAND-REPLACING-FIRE NS/NS/0 0))
 (POSITIONS
  (DF 62 1)))

(VEGETATIVE-TYPE DF/SS/2
 (SPECIES DF)
 (SIZE-CLASS SS)
 (CANOPY-COVERAGE 2)
 (NEXT-STATE
  (SUCCESSION DF/SS2/2 100)
  (LIGHT-SEVERITY-FIRE NS/NS/0 0)
  (MIXED-SEVERITY-FIRE NS/NS/0 0)
  (STAND-REPLACING-FIRE NS/NS/0 0))
 (POSITIONS
```

```
 (DF 59 95)))

(VEGETATIVE-TYPE DF/SS/3
 (SPECIES DF)
 (SIZE-CLASS SS)
 (CANOPY-COVERAGE 3)
 (NEXT-STATE
  (SUCCESSION DF/SS2/3 100)
  (LIGHT-SEVERITY-FIRE NS/NS/0 0)
  (MIXED-SEVERITY-FIRE NS/NS/0 0)
  (STAND-REPLACING-FIRE NS/NS/0 0))
 (POSITIONS
  (DF 54 225)))

(VEGETATIVE-TYPE DF/SS2/1
 (SPECIES DF)
 (SIZE-CLASS SS)
 (CANOPY-COVERAGE 1)
 (NEXT-STATE
  (SUCCESSION DF/SS3/1 100)
  (LIGHT-SEVERITY-FIRE NS/NS/0 0)
  (MIXED-SEVERITY-FIRE NS/NS/0 0)
  (STAND-REPLACING-FIRE NS/NS/0 0))
 (POSITIONS
  (DF 70 9)))

(VEGETATIVE-TYPE DF/SS2/2
 (SPECIES DF)
 (SIZE-CLASS SS)
 (CANOPY-COVERAGE 2)
 (NEXT-STATE
  (SUCCESSION DF/SS3/2 100)
  (LIGHT-SEVERITY-FIRE NS/NS/0 0)
  (MIXED-SEVERITY-FIRE NS/NS/0 0)
  (STAND-REPLACING-FIRE NS/NS/0 0))
 (POSITIONS
  (DF 67 101)))

(VEGETATIVE-TYPE DF/SS2/3
 (SPECIES DF)
 (SIZE-CLASS SS)
 (CANOPY-COVERAGE 3)
 (NEXT-STATE
```

```
  (SUCCESSION DF/SS3/3 100)
  (LIGHT-SEVERITY-FIRE NS/NS/0 0)
  (MIXED-SEVERITY-FIRE NS/NS/0 0)
  (STAND-REPLACING-FIRE NS/NS/0 0))
 (POSITIONS
  (DF 71 238)))

(VEGETATIVE-TYPE DF/SS3/1
 (SPECIES DF)
 (SIZE-CLASS SS)
 (CANOPY-COVERAGE 1)
 (NEXT-STATE
  (SUCCESSION DF/SS4/1 100)
  (LIGHT-SEVERITY-FIRE DF/SS4/1 0)
  (MIXED-SEVERITY-FIRE DF/SS4/1 0)
  (STAND-REPLACING-FIRE NS/NS/0 0))
 (POSITIONS
  (DF 82 19)))

(VEGETATIVE-TYPE DF/SS3/2
 (SPECIES DF)
 (SIZE-CLASS SS)
 (CANOPY-COVERAGE 2)
 (NEXT-STATE
  (SUCCESSION DF/SS4/2 100)
  (LIGHT-SEVERITY-FIRE DF/SS4/1 0)
  (MIXED-SEVERITY-FIRE DF/SS4/1 0)
  (STAND-REPLACING-FIRE NS/NS/0 0))
 (POSITIONS
  (DF 77 108)))

(VEGETATIVE-TYPE DF/SS3/3
 (SPECIES DF)
 (SIZE-CLASS SS)
 (CANOPY-COVERAGE 3)
 (NEXT-STATE
  (SUCCESSION DF/SS4/3 100)
  (LIGHT-SEVERITY-FIRE DF/SS4/2 0)
  (MIXED-SEVERITY-FIRE DF/SS4/1 0)
  (STAND-REPLACING-FIRE NS/NS/0 0))
 (POSITIONS
  (DF 80 244)))
```

(VEGETATIVE-TYPE DF/SS4/1
 (SPECIES DF)
 (SIZE-CLASS SS)
 (CANOPY-COVERAGE 1)
 (NEXT-STATE
  (SUCCESSION DF/POLE/1 100)
  (LIGHT-SEVERITY-FIRE DF/POLE/1 0)
  (**MIXED-SEVERITY-FIRE DF/POLE/1 0**)
  (STAND-REPLACING-FIRE NS/NS/0 0))
 (POSITIONS
  (DF 93 28)))

(VEGETATIVE-TYPE DF/SS4/2
 (SPECIES DF)
 (SIZE-CLASS SS)
 (CANOPY-COVERAGE 2)
 (NEXT-STATE
  (SUCCESSION DF/POLE/2 100)
  (LIGHT-SEVERITY-FIRE DF/POLE/1 0)
  (**MIXED-SEVERITY-FIRE DF/POLE/1 0**)
  (STAND-REPLACING-FIRE NS/NS/0 0))
 (POSITIONS
  (DF 84 119)))

(VEGETATIVE-TYPE DF/SS4/3
 (SPECIES DF)
 (SIZE-CLASS SS)
 (CANOPY-COVERAGE 3)
 (NEXT-STATE
  (SUCCESSION DF/POLE/3 100)
  (LIGHT-SEVERITY-FIRE DF/POLE/2 0)
  (**MIXED-SEVERITY-FIRE DF/POLE/2 0**)
  (STAND-REPLACING-FIRE NS/NS/0 0))
 (POSITIONS
  (DF 92 252)))

(VEGETATIVE-TYPE DF/TS/1
 (SPECIES DF)
 (SIZE-CLASS TS)
 (CANOPY-COVERAGE 1)
 (NEXT-STATE
  (SUCCESSION DF/TS2/1 96)
  (LIGHT-SEVERITY-FIRE DF/TS/1 2)

```
 (MIXED-SEVERITY-FIRE DF/VERY-LARGE/1 2)
 (STAND-REPLACING-FIRE NS/NS/0 0)
 (ROOT-DISEASE DF/LMU/1 0)
 (LIGHT-WSBW DF/TS/1 0)
 (SEVERE-WSBW DF/VERY-LARGE/1 0))
(POSITIONS
 (DF 626 7)))

(VEGETATIVE-TYPE DF/TS/2
(SPECIES DF)
(SIZE-CLASS TS)
(CANOPY-COVERAGE 2)
(NEXT-STATE
 (SUCCESSION DF/TS2/2 96)
 (LIGHT-SEVERITY-FIRE DF/TS/1 2)
 (MIXED-SEVERITY-FIRE DF/VERY-LARGE/1 2)
 (STAND-REPLACING-FIRE NS/NS/0 0)
 (ROOT-DISEASE DF/LMU/1 0)
 (LIGHT-WSBW DF/TS/1 0)
 (SEVERE-WSBW DF/VERY-LARGE/2 0))
(POSITIONS
 (DF 629 114)))

(VEGETATIVE-TYPE DF/TS/3
(SPECIES DF)
(SIZE-CLASS TS)
(CANOPY-COVERAGE 3)
(NEXT-STATE
 (SUCCESSION DF/TS2/3 96)
 (LIGHT-SEVERITY-FIRE DF/TS/1 2)
 (MIXED-SEVERITY-FIRE DF/VERY-LARGE/1 2)
 (STAND-REPLACING-FIRE NS/NS/0 0)
 (ROOT-DISEASE DF/LMU/1 0)
 (LIGHT-WSBW DF/TS/1 0)
 (SEVERE-WSBW DF/VERY-LARGE/3 0))
(POSITIONS
 (DF 632 220)))

(VEGETATIVE-TYPE DF/TS2/1
(SPECIES DF)
(SIZE-CLASS TS)
(CANOPY-COVERAGE 1)
(NEXT-STATE
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```
  (SUCCESSION DF/MU/1 96)
  (LIGHT-SEVERITY-FIRE DF/TS2/1 2)
  (MIXED-SEVERITY-FIRE DF/VERY-LARGE/1 2)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/LMU/1 0)
  (LIGHT-WSBW DF/MU/1 0)
  (SEVERE-WSBW DF/VERY-LARGE/1 0))
 (POSITIONS
  (DF 641 20)))

(VEGETATIVE-TYPE DF/TS2/2
 (SPECIES DF)
 (SIZE-CLASS TS)
 (CANOPY-COVERAGE 2)
 (NEXT-STATE
  (SUCCESSION DF/MU/2 96)
  (LIGHT-SEVERITY-FIRE DF/TS2/1 2)
  (MIXED-SEVERITY-FIRE DF/VERY-LARGE/1 2)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/LMU/1 0)
  (LIGHT-WSBW DF/MU/2 0)
  (SEVERE-WSBW DF/VERY-LARGE/2 0))
 (POSITIONS
  (DF 642 129)))

(VEGETATIVE-TYPE DF/TS2/3
 (SPECIES DF)
 (SIZE-CLASS TS)
 (CANOPY-COVERAGE 3)
 (NEXT-STATE
  (SUCCESSION DF/MU/3 96)
  (LIGHT-SEVERITY-FIRE DF/TS2/1 2)
  (MIXED-SEVERITY-FIRE DF/VERY-LARGE/1 2)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/LMU/1 0)
  (LIGHT-WSBW DF/MU/3 0)
  (SEVERE-WSBW DF/VERY-LARGE/3 0))
 (POSITIONS
  (DF 651 241)))

(VEGETATIVE-TYPE DF/VERY-LARGE/1
 (SPECIES DF)
 (SIZE-CLASS VERY-LARGE)
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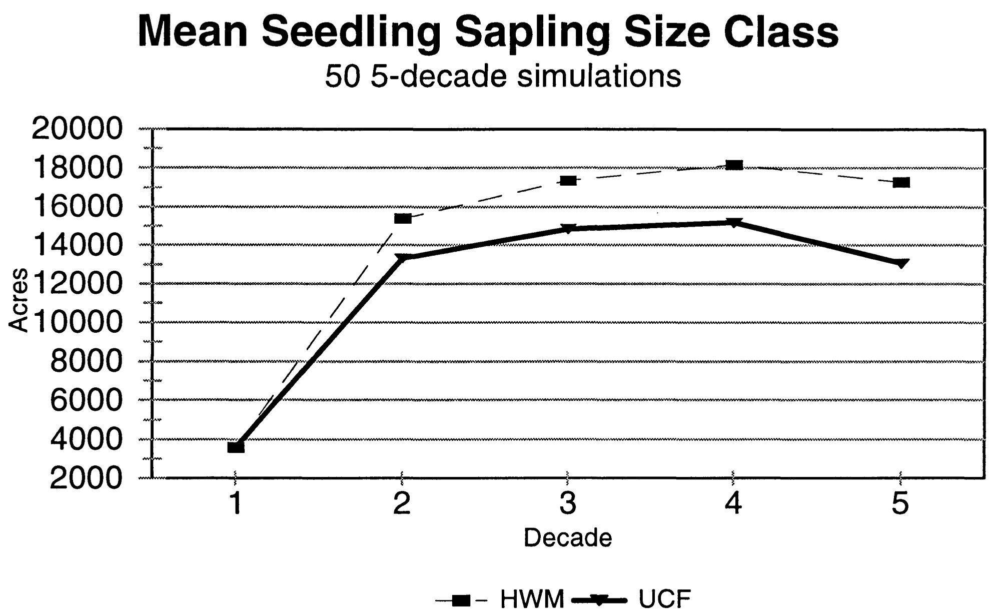
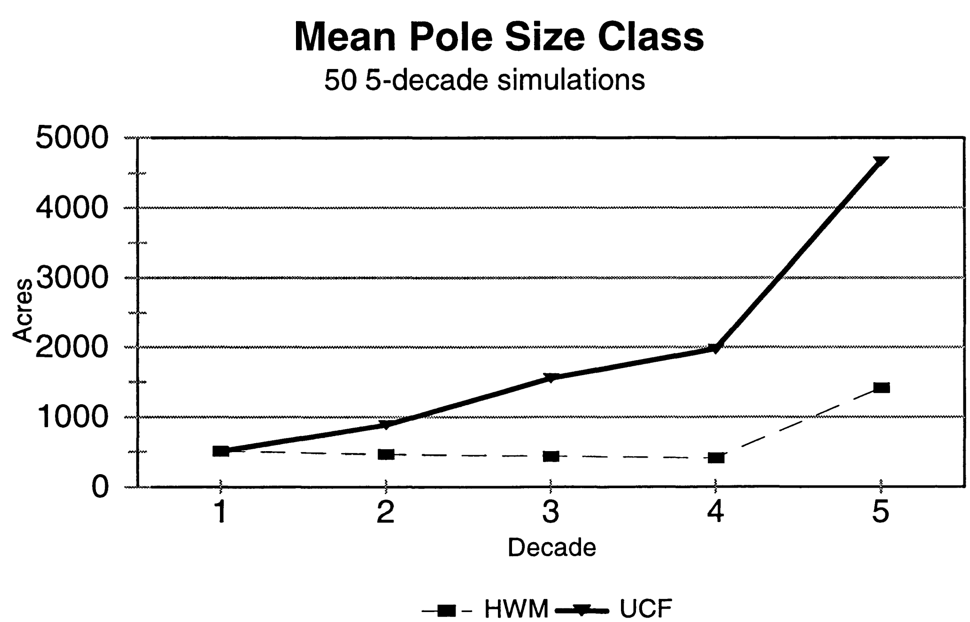
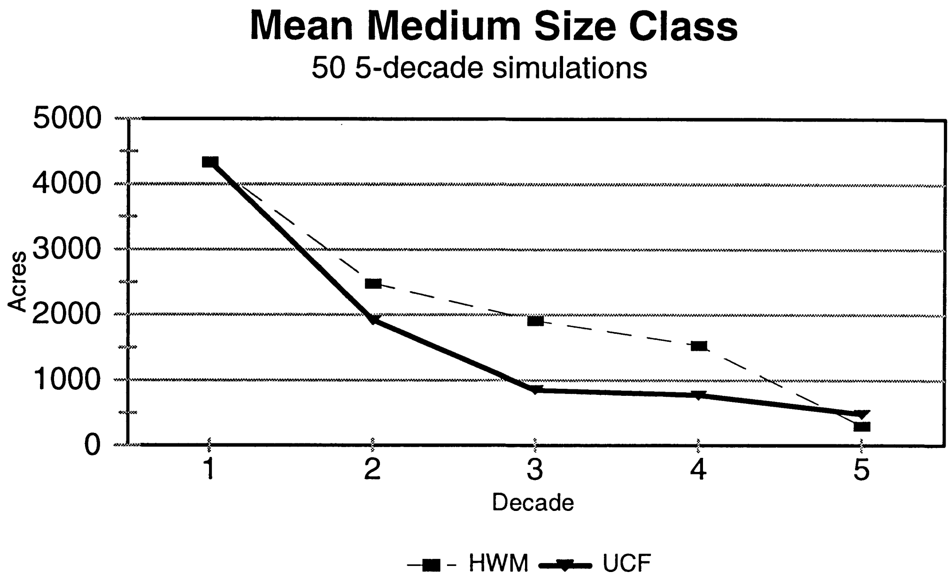
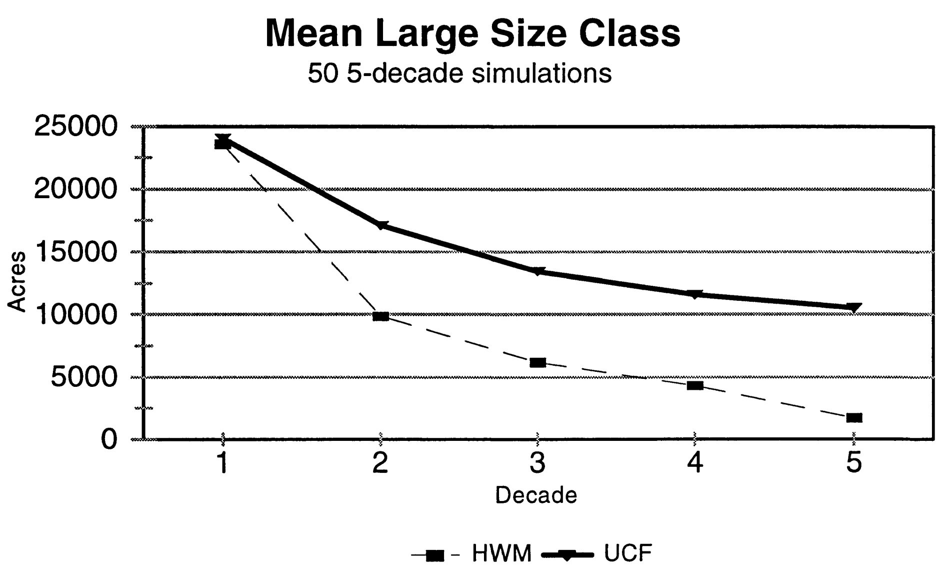
```
 (CANOPY-COVERAGE 1)
 (NEXT-STATE
  (SUCCESSION DF/TS/1 96)
  (LIGHT-SEVERITY-FIRE DF/MU/1 2)
  (MIXED-SEVERITY-FIRE DF/VERY-LARGE/1 2)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/LMU/1 0)
  (LIGHT-WSBW DF/VERY-LARGE/1 0)
  (SEVERE-WSBW DF/VERY-LARGE/1 0))
 (POSITIONS
  (DF 576 10)))

(VEGETATIVE-TYPE DF/VERY-LARGE/2
 (SPECIES DF)
 (SIZE-CLASS VERY-LARGE)
 (CANOPY-COVERAGE 2)
 (NEXT-STATE
  (SUCCESSION DF/TS/2 96)
  (LIGHT-SEVERITY-FIRE DF/VERY-LARGE/2 2)
  (MIXED-SEVERITY-FIRE DF/VERY-LARGE/1 2)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/LMU/1 0)
  (LIGHT-WSBW DF/VERY-LARGE/1 0)
  (SEVERE-WSBW DF/VERY-LARGE/1 0))
 (POSITIONS
  (DF 575 112)))

(VEGETATIVE-TYPE DF/VERY-LARGE/3
 (SPECIES DF)
 (SIZE-CLASS VERY-LARGE)
 (CANOPY-COVERAGE 3)
 (NEXT-STATE
  (SUCCESSION DF/TS/3 96)
  (LIGHT-SEVERITY-FIRE DF/VERY-LARGE/2 2)
  (MIXED-SEVERITY-FIRE DF/VERY-LARGE/1 2)
  (STAND-REPLACING-FIRE NS/NS/0 0)
  (ROOT-DISEASE DF/LMU/1 0)
  (LIGHT-WSBW DF/VERY-LARGE/1 0)
  (SEVERE-WSBW DF/VERY-LARGE/1 0))
 (POSITIONS
  (DF 580 219)))
```

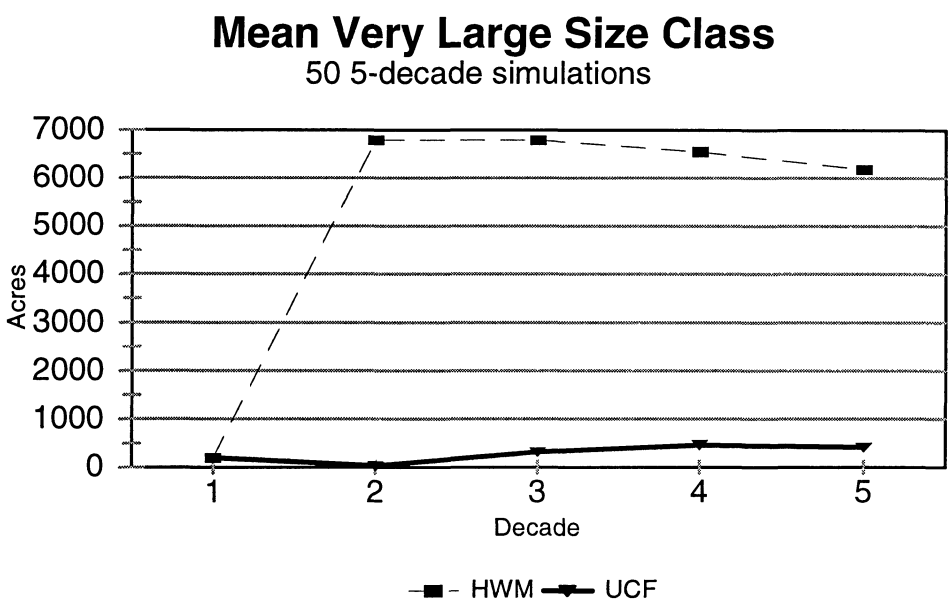
Appendix E1. Mean acreage distributions of size classes for the HWM and UCF regional variants using output from SIMPPLLE simulations run for 50, 5-decade simulations.



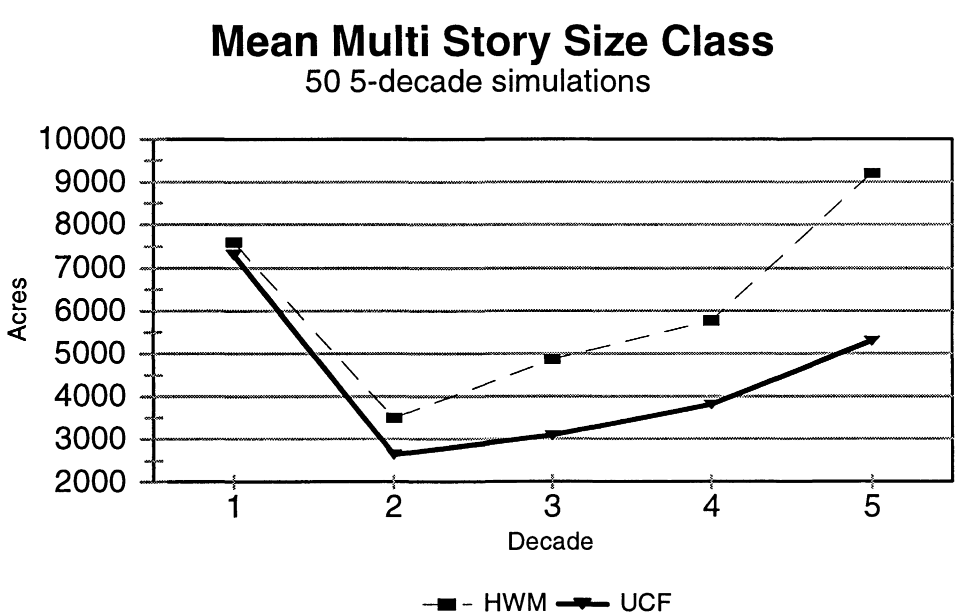



Mean Medium Size Class
50 5-decade simulations
5000
4000
3000
2000
1000
0
Acres
1
2
3
4
5
Decade
HWM
UCF

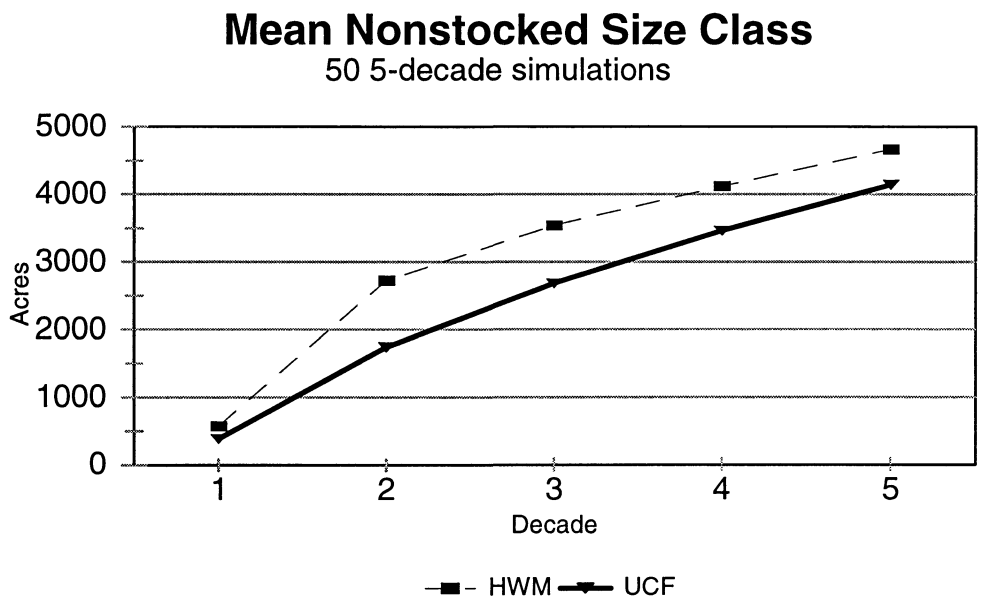

Mean Large Size Class
50 5-decade simulations
25000
20000
15000
10000
5000
0
Acres
1
2
3
4
5
Decade
HWM
UCF



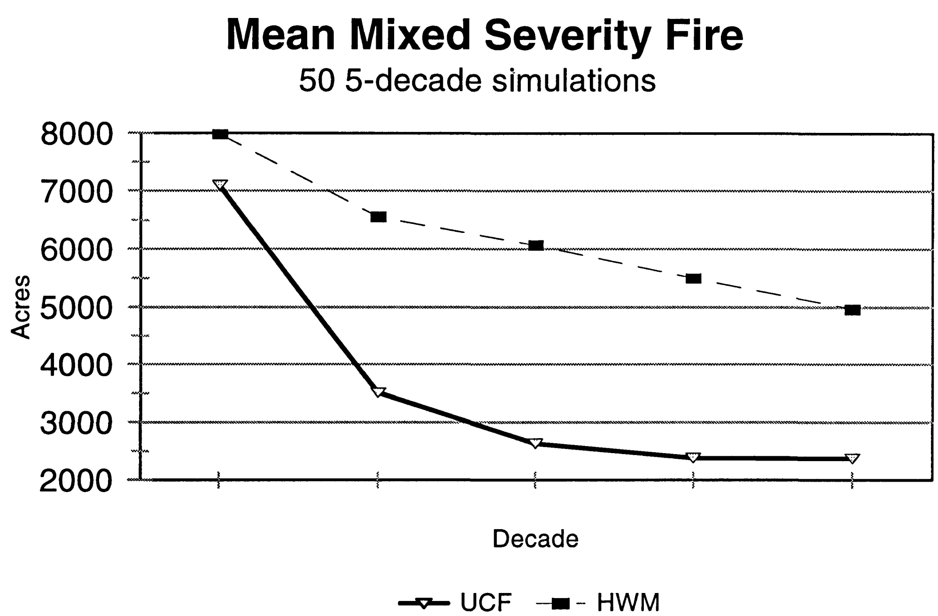
Mean Very Large Size Class
50 5-decade simulations
7000
6000
5000
4000
3000
2000
1000
0
Acres
1
2
3
4
5
Decade
HWM
UCF

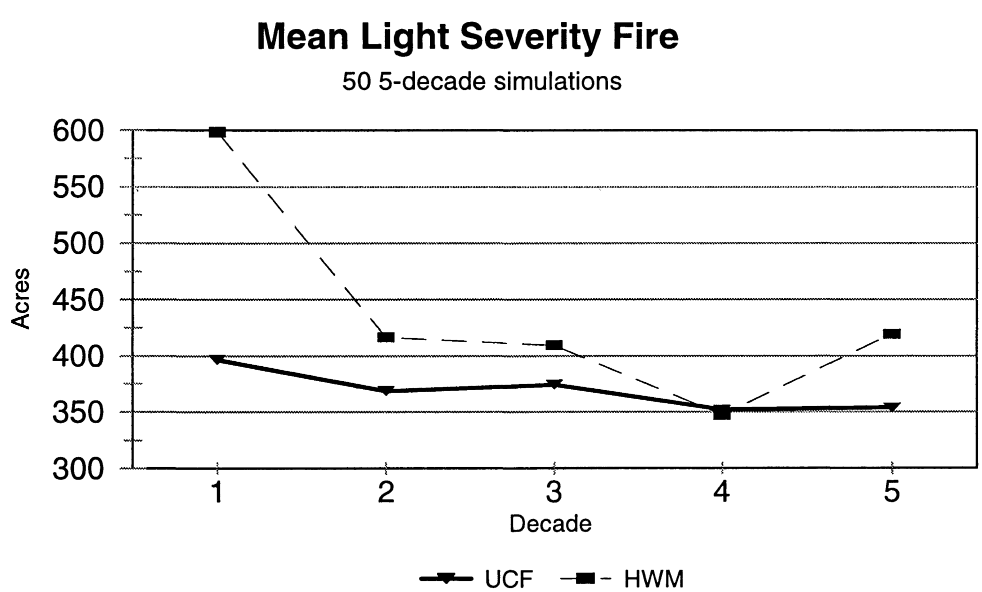


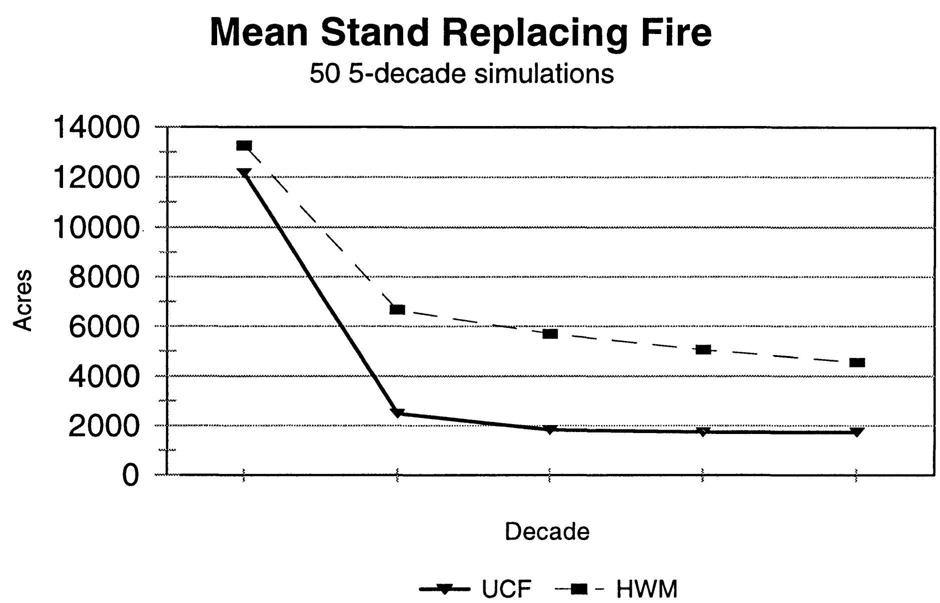
Mean Multi Story Size Class
50 5-decade simulations
10000
9000
8000
7000
6000
5000
4000
3000
2000
Acres
1
2
3
4
5
Decade
HWM
UCF

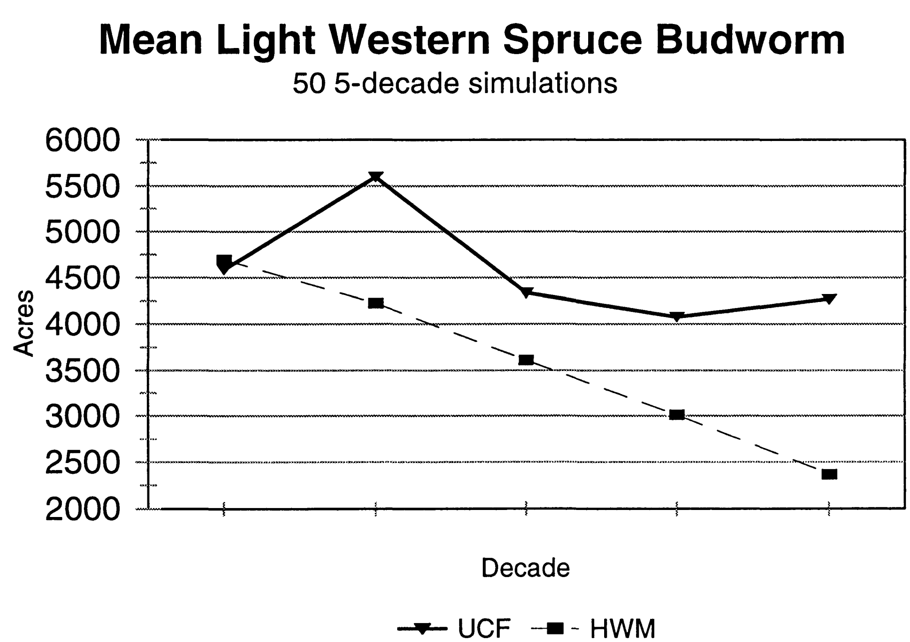

Mean Nonstocked Size Class
50 5-decade simulations
5000
4000
3000
2000
1000
0
Acres
1
2
3
4
5
Decade
HWM
UCF

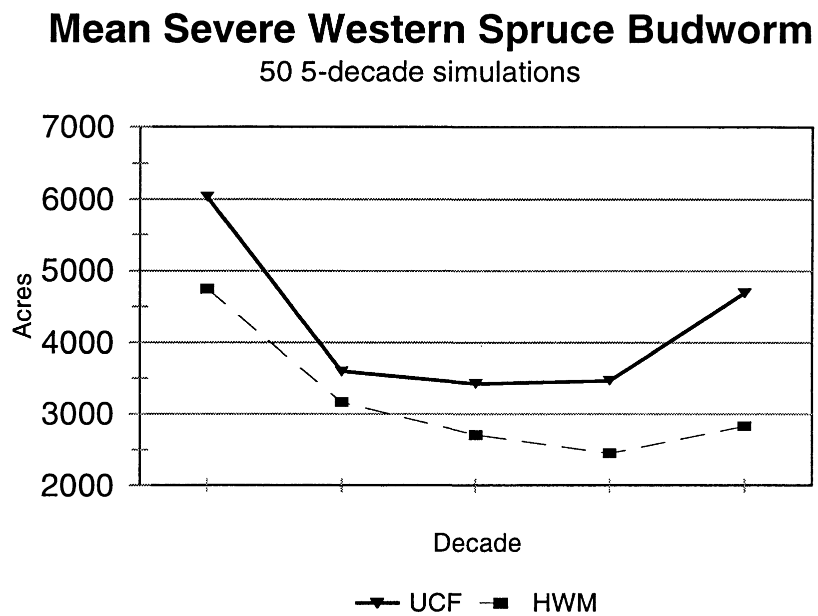
Appendix E2. Mean acreage distributions of disturbance processes for the HWM and UCF regional variants using output from SIMPPLLE simulations run for 50, 5-decade simulations.

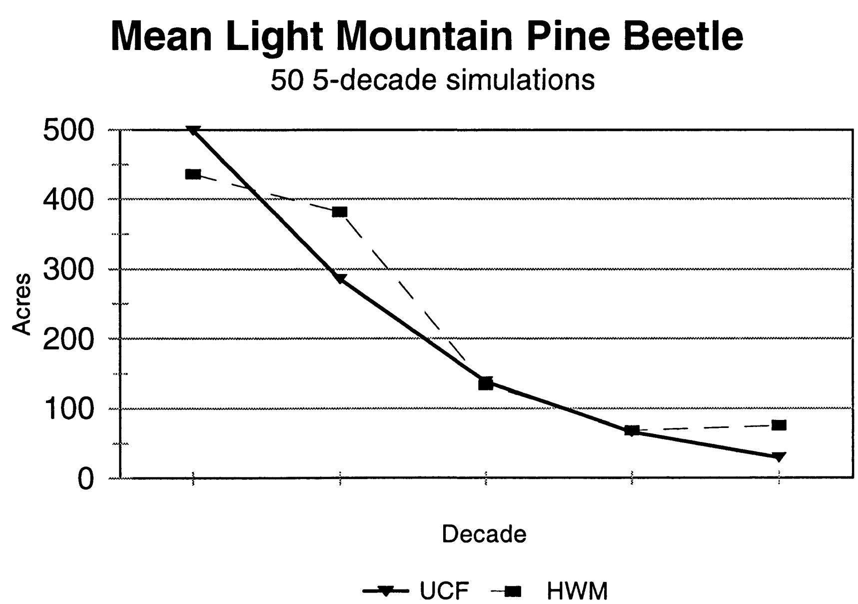


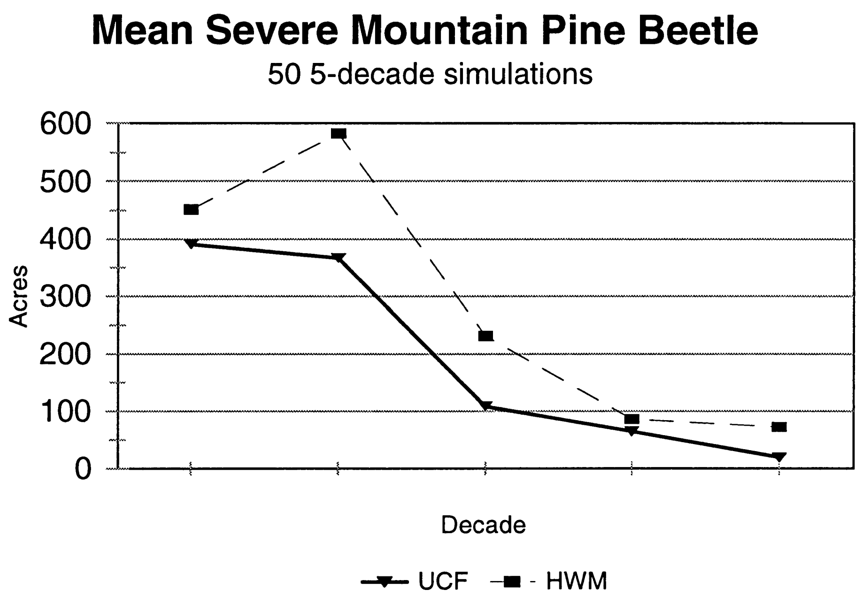



Mean Stand Replacing Fire
50 5-decade simulations
14000
12000
10000
8000
6000
4000
2000
0
Acres
Decade
UCF
HWM


Mean Light Western Spruce Budworm
50 5-decade simulations
6000
5500
5000
4500
4000
3500
3000
2500
2000
Acres
Decade
UCF
HWM


Mean Severe Western Spruce Budworm
50 5-decade simulations
7000
6000
5000
4000
3000
2000
Acres
Decade
UCF
HWM


Mean Light Mountain Pine Beetle
50 5-decade simulations
500
400
300
200
100
0
Acres
Decade
UCF
HWM


Mean Severe Mountain Pine Beetle
50 5-decade simulations
600
500
400
300
200
100
0
Acres
Decade
UCF
HWM