Modeling approach to analyzing ecological condition as a result of alternative fuel treatment strategies

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A MODELING APPROACH TO ANALYZING ECOLOGICAL CONDITION AS A RESULT OF ALTERNATIVE FUEL TREATMENT STRATEGIES

By

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Approved by:

Committee Chair

Dean, Graduate School

Date
A Modeling Approach to Analyzing Ecological Condition as a Result of Alternative Fuel Treatment Strategies

Fire exclusion has altered fire regimes and the composition and structure of vegetation in many Northern Rocky Mountain ecosystems. These changes in vegetation may increase the risk of losing key ecological components in the event of a wildland fire today. Current fire management policy recognizes these risks and aims to restore the natural role of fire by means of various fuel treatment strategies. The objective of this study was to apply a modeling approach toward analyzing the impacts of fuel treatment strategies from an ecological perspective at the landscape scale.

A set of rules was applied to a Geographic Information System (GIS) to model the historical fire regimes and the departure of those regimes or “condition class” for the 467,375-acre Bitterroot Front in western Montana. The condition class ruleset was then integrated into the spatially explicit simulation model, SIMPPLLE, in order to assign treatment strategies based upon the dynamic changes to condition class on a decadal basis. Finally, the response of condition class to each of eight, 100-year treatment strategies was compared to the original modeled conditions.

The fire regime and condition class modeling revealed departure from historical conditions on the Bitterroot Front. Many areas that historically experienced low severity fire regimes are now expected to experience high severity fires. Simulation results suggest that treating areas of moderate departure from historical conditions and allowing wildland fire use in wilderness were the most efficient restoration strategies. However, difficulties with integrating different modeling approaches limited comparison between strategies.
ACKNOWLEDGEMENTS

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INTRODUCTION

Wildland fire plays an important role in many forested ecosystems by means of its influence on vegetative composition and structure, landscape patterns, and ecological functioning (Brown and Smith 2000). In the northern Rocky Mountains, many of these ecosystems and their associated species are considered to be fire-adapted, meaning that they have the ability to survive and regenerate in a fire-prone environment. Historically, fire has maintained the characteristics that define these ecosystems. Land managers and researchers have begun to acknowledge that many of the past century’s land management policies and practices that have excluded fire, have led to major changes in how fire influences fire-adapted forest ecosystems.

In the absence of fire, forest succession leads to the replacement of fire-resistant tree species with less fire-resistant species and increases in tree density and fuel loading. These changes are most apparent within short-interval, fire-adapted systems, which historically experienced frequent, low intensity fire events. but have also occurred in ecosystems that historically experienced less frequent, high intensity events (Brown and Smith 2000). Over time, this transformation has directly affected the systems’ natural fire regime (Morgan et al. 1996, Barrett 2002, Hardy et al. 2001) resulting in uncharacteristic fire frequency, severity, and/or spatial extent.

Fire regimes refer to “the nature of fire occurring over long periods and the prominent immediate effects of fire that generally characterize an ecosystem” (Brown and Smith 2000). The fire process, however, is not uniform in either time or space. The frequency, intensity, seasonality, extent, and other characteristics of fire, which
collectively make up the fire regime, vary considerably across the landscape (Agee 1993) thus making it difficult to evaluate the impacts of altered fire regimes.

Natural variability is defined as “the ecological conditions, and the spatial and temporal variation in these conditions, that are relatively unaffected by people, within a period of time and geographical area appropriate to an expressed goal” (Landres et al. 1999). The concept is based on two premises: 1) past conditions and processes provide context and guidance for managing ecological systems today, and 2) that disturbance-driven spatial and temporal variability is a vital attribute of nearly all ecological systems. In using the historical fire regime as a reference condition, the natural variability concept provides a framework with which to evaluate the impacts of altered fire regimes and the consequences of future management actions (Landres et al. 1999).

Wildland fire managers acknowledge the importance of restoring the natural ecological role of fire. In fact, the 2001 Federal Wildland Fire Management Policy states as a guiding principle that “The role of wildland fire as an essential ecological process and natural change agent will be incorporated into the planning process.” (U.S. Department of the Interior and U.S. Department of Agriculture 2001). Information on the effects of restoration-based fuel treatment strategies can aid in the success of future fuel management programs.

The objective of this study was to apply a modeling approach toward analyzing the impacts of alternative fuel treatment strategies from an ecological perspective. First, the historical fire regimes and the departure of those regimes were modeled for a 467,375-acre landscape in western Montana. The methodology of the fire regime models was then integrated into a spatially explicit simulation model in order to assign treatment
strategies based on the dynamic changes occurring across the landscape. Finally, the response of ecological condition to alternative treatment strategies was compared to the original modeled conditions.

**Background**

*Fire Regimes and Condition Class*

Knowledge of fire regimes can provide a broad context for fuels and fire management decisions (Morgan et al. 2001). Fire regimes are often classified according to the characteristics of the fire itself or the effects produced by the fire (Brown and Smith 2000). Many classifications exist and vary in their level of detail, area of interest, or application. Fire regime information has been used to evaluate ecosystem change (Brown et al. 1994, Morgan et al. 1996), estimate the ecological need for (Keifer et al. 2000) or benefits of fire (Miller et al. 2000), assess management plans (Cissel et al. 1999), and suggest appropriate levels of management for fire regime restoration (Hardy et al. 1999, Schmidt et al. 2002).

Approaches to mapping fire regimes in geographic space vary with the type and amount of data available as well as with the scale and context in which they will be used. At fine scales, fire-scarred trees have been used to estimate historical fire frequencies (Arno and Sneck 1977, Arno and Petersen 1983, Barrett and Arno 1988). Statistical models can be used to extrapolate from fine scale data to larger spatial extents (Long 1998, McKenzie et al. 2000) by correlating fire regime classes with biophysical and environmental variables. Rule-based approaches, most commonly used at mid to coarse scales, are typically informed by, but not directly based on, fire history data (Morgan et al. 2001) and are usually derived by combinations of vegetative and biophysical variables.
together with expert knowledge. Rule-based approaches have been used to map historical fire regimes (e.g., Hardy et al. 1998) and compare past and present fire regimes (e.g., Morgan et al. 1996, Jones et al. 2002).

Departure from historical fire regimes may serve as a proxy with which to assess risk to key ecological components (Keifer et al. 2000, Miller et al. 2000, Hardy et al. 2001, Jones et al. 2002). Hardy et al. (2001) applied a rule-based approach in developing an index of condition class by integrating biophysical data with disturbance and vegetative succession logic. Condition classes are a function of the degree of departure from historical fire regimes resulting in alteration of key ecosystem components such as species composition, structural stage, stand age, and canopy closure (Hardy et al. 2001). The index is categorized on a scale of 1 – 3, where condition class 1 represents fire regimes within their historical range of variability and condition class 3 represents fire regimes that have been significantly altered from their historical range (Table 1).

Table 1. Fire regime condition classes\(^1\) for the Northern Region, U.S. Forest Service (Jones et al. 2002).

<table>
<thead>
<tr>
<th>Condition Class</th>
<th>Condition Class Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC1</td>
<td>Fire regimes are within their historical range and the risk of losing key ecosystem components as a result of wildfire is low. Vegetation attributes (species composition and structure) are intact and functioning within an historical range. Fire effects would be similar to those expected during historical times.</td>
</tr>
<tr>
<td>CC2</td>
<td>Fire regimes have been moderately altered from their historical range. The risk of losing key ecosystem components as a result of wildfire is moderate. Fire frequencies have changed by one or more fire-return intervals (either increased or decreased). Vegetation attributes have been moderately altered from their historical range. Consequently, wildfires would likely be larger, more intense, more severe, and have altered burn patterns than that expected during historical times.</td>
</tr>
<tr>
<td>CC3</td>
<td>Fire regimes have changed substantially from their historical range. The risk of losing key ecosystem components is high. Fire frequencies have changed by two or more fire-return intervals. Vegetation attributes have been significantly altered from their historical range. Consequently, wildfires would likely be larger, more intense, more severe, and have altered burn patterns than that expected during historical times.</td>
</tr>
</tbody>
</table>

\(^1\)Condition classes were adapted from Schmidt et al. (2002).
It is assumed that if a fire were to occur in a community that has experienced significant alteration to these components that the type of fire and its subsequent effects would be uncharacteristic of those which the community had adapted to under the historical fire regime. Therefore, it is inferred that the greater the departure the greater the probability of losing key ecosystem components and concomitant attributes such as soil productivity, water quality, wildlife species, etc., should a fire occur. Current condition classes of the conterminous United States were mapped at a spatial resolution of 1km² (Schmidt et al. 2002). This effort, however, was intended for coarse scale planning and therefore is not appropriate at scales finer than the regional level.

Jones et al. (2002) adopted the condition class concept to develop spatial data layers of historical fire regimes and departure of historical fire regimes (condition class) for northern Idaho and western Montana. Their methodology differs from that of Schmidt et al. (2002) in that it uses an empirically based fire regime classification developed specifically for the northern Rocky Mountains (Barrett 2002) and 30m² spatial resolution data to develop modeling rules. Jones et al. (2002) developed models using variables describing the inherent productivity of a site in conjunction with variables that influence fire behavior to predict the historical fire regime, expected fire severity, and subsequent condition class. The resulting data layers were integrated into a USDA Forest Service, Northern Region database project called “FIRERISK” (WSAL 2000) which was developed for use at the regional, sub-regional, and landscape levels.

**SIMPPLLE – SIMulating Patterns and Processes at Landscape scaLEs**

There are many contributing factors that lead to the alteration of historical fire regimes. In addition to vegetative changes resulting from successional processes in the
absence of fire, the spatial and temporal variation of natural disturbance processes and the interaction among these processes can have a profound effect. Often, the disturbance processes with a low probability of occurrence, such as a stand-replacement wildfire or severe bark beetle outbreak, determine the pattern of a landscape and future events for extended periods of time (Chew et al. 2002). Even similar landscapes have unique combinations of vegetative conditions and spatial attributes that will affect the probability of occurrence and spread of ecological processes. Thus, to effectively analyze the effects of multiple fuel treatments on fire regimes and condition class over long periods of time, the spatial pattern of the landscape, interactions among various natural processes, and the impacts of human intervention must all be accounted for. Simulation models are useful tools for addressing this task.

Model Overview

SIMPPLLE is a knowledge-based, spatially explicit modeling system for simulating vegetative change at landscape scales (Chew 1995). Changes in vegetative composition, structure, and density are simulated as a result of stochastic disturbance processes, succession, and management. The model is not designed to predict the precise location, timing, or extent of processes but rather to provide a range of possible outcomes and general trends on a specific landscape. The modeling logic within SIMPPLLE is compartmentalized into individual data structures that allow flexibility when adapting the system to new areas and making updates. The data structures are collectively referred to as system knowledge.
System knowledge

An individual community (unit) is represented in SIMPPLLE as a discrete vegetative state characterized by a unique grouping of dominant species composition, size class-structure combination, and canopy density. Vegetative pathways are developed by stratifying all possible states within a given habitat type group by dominant species composition (Figure 1). The individual pathways contain the logic for how a particular state changes as the result of natural processes (i.e., succession, fire, insects, or disease). In addition, separate system knowledge is present for simulating regeneration (e.g., vegetative establishment after a stand replacing event or encroachment of shade-tolerant species) (Chew et al. 2002).

Figure 1. Example of pathway diagram for ponderosa pine-Douglas-fir composition on B2 habitat type group.
The probability of a disturbance process occurring is not associated with the pathway knowledge but rather with the individual process itself. Because SIMPPLLE is spatially explicit, whereby each unit is unique and includes information about its neighboring units, the probability of occurrence is adjusted based on the past processes and management treatments of a unit, conditions and processes that are occurring in neighboring units, and the spatial relationships among units (Chew et al. 2002). This provides an effective mean for simulating the natural variability of processes and patterns within landscapes. Additional system knowledge represents the conditions and spatial relationships that result in the spread of some processes.

Knowledge of the impacts of management treatments is also held in a separate data structure. Treatments are applied at the beginning of a time step thereby allowing natural processes to subsequently occur within the time step. As mentioned above, an applied treatment impacts the probability of a process occurring or spreading. There are three ways in which treatments can be scheduled in SIMPPLLE: specifying individual units by treatment and time step, specifying an acreage goal for a combination of special area, habitat type groups, species, size class-structure, density, and previous process occurrence, or specifying units with a minimum probability level for a process occurring (Chew et al. 2002).

Three types of fire are simulated in SIMPPLLE: light severity fire, mixed severity fire, and stand-replacing fire. In the event of a light or mixed-severity fire, the degree of tree mortality is based on the fire tolerance, size class-structure, and density of the community. Stand-replacing fire results in the complete mortality of the trees in the
stand (Chew et al. 2002). Figure 2 illustrates how SIMPPLLE models the fire process and identifies where the user can adjust the process logic.

Figure 2. Diagram of the steps used by SIMPPLLE in modeling the fire process (Chew et al. 2002).

The probability of ignition is based on the fire history of the landscape. This probability can vary for a given landscape by dividing it geographically into fire management zones (FMZ). SIMPPLLE uses the number of fires for a past ten-year period divided by the total acres on which the fires occurred. Separate logic is used to determine the probability of suppressing a fire event based on whether the fire is at the class A level (0-0.25 acres) or larger. The suppression probability of a class A fire is determined by the size class-structure, ownership, and road status of the community it is occurring on, where as, the probability of suppressing fires larger than the class A level (these fires now have a “type of fire” assigned to them) is determined by the type of fire,
ownership, and road status of the community. If a fire is determined to be only class A (0-0.25 acres), no fire effects are calculated.

**Synopsis**

Current wildland fire management policy aims to restore the integrity and sustainability of fire-adapted ecosystems and in doing so has adopted concepts that incorporate the ecological role of fire, such as natural variability and condition class. It is not well understood, however, what effect the application of these concepts to management will have on ecological condition at broad temporal and spatial scales.

In the context of wildland fire, risk assessments and studies that evaluate ecosystem change generally provide a snapshot in time of the current conditions or the departure from a historical baseline (Jones et al. 1999, Harkins et al., Keifer et al., Miller et al., Sampson et al. 2000). Natural processes will continue to occur and recur simultaneously with management, however, and the interactions of succession, disturbance, and treatment will result in varied trajectories of vegetative change. It is therefore untested whether managers can realistically treat enough acres to reverse the effects of altered fire regimes and restore conditions to within their natural range of variability. For example, the amount of land moving to a state outside of its natural range of variability, as a result of succession and/or lack of natural disturbance processes, may be equal to or greater than the amount of land being restored. It is also unknown whether certain restoration strategies are more effective than others or what effect current fire suppression policy has on restoration goals. For instance, is it more effective to treat areas that have been severely altered from their historical conditions or to maintain those
that are currently within their natural range of variability? Furthermore, could the use of wildland fire in wilderness bolster restoration accomplishments?

In this project the condition class concept was applied to a spatially explicit simulation model (SIMPPLLE) in order to account for the contagion or "spatial dependence" of natural processes and treatments. Using this approach, the effects of alternative fuel treatment strategies were analyzed together with the variability and interactions of natural processes at the landscape scale and over multiple time steps.
METHODS

Study Area

The Bitterroot Mountains are located along the Montana/Idaho border and run south of Missoula, Montana for approximately 60 miles. The 467,375-acre Bitterroot Front (east side of the Bitterroot Range) was chosen as the study area for this project. The USDA Forest Service manages Seventy-five percent (352,143 acres) of the land within the study area while the remaining 25 percent (115,232) is of private or state ownership. Forty-five percent (211,540 acres) of the study area is within the Selway-Bitterroot Wilderness.

The Front comprises approximately 260,000 acres of forested land upon which a variety of forest types are represented along an elevational gradient ranging from approximately 4500 to 9200 feet. The forest types can be compiled into three general forest zones identified by seral species: ponderosa pine, lodgepole pine, and whitebark pine (Hartwell 1997). The ponderosa pine zone is primarily composed of ponderosa pine, western larch, and Douglas-fir with subalpine and grand fir also present in the more mesic areas of the zone. Within the mid-elevation lodgepole pine zone, ponderosa pine becomes scarce and lodgepole co-dominates with Douglas-fir and subalpine fir. The whitebark pine zone is dominated by the presence of whitebark pine, subalpine fir, lodgepole pine, and alpine larch.

Evidence of fire in the study area is well represented by a number of fire history studies (Barrett and Arno 1982; Arno and Petersen 1983; Arno et al. 1993, 1995; Hartwell 1997). A variety of fire regimes exist, ranging from those characterized by non-lethal understory fires to stand-replacement fires. Evidence of ecosystem change due to
fire exclusion during the 20th century is also prevalent. Using quantitative techniques to reconstruct historic forests for three forested faces on the Bitterroot Front, Hartwell (1997) measured landscape changes in forest structures between 1900 and 1995. His results show dramatic decreases in fire-dependent species such as ponderosa pine, western larch, and whitebark pine and increases in fire-intolerant species such as Douglas-fir and lodgepole pine throughout all elevation zones.

In analyzing the effectiveness of the prescribed natural fire program1 within the Selway-Bitterroot Wilderness, Brown et al. (1994) estimated that the pre-settlement (before 1935) area burned was 1.7 times greater than that burned during the recent period (1979-90). When stratified by fire severity classes, they estimated that stand-replacement fire was 1.5 times greater and non-lethal understory fire 1.9 times greater during the pre-settlement period.

**Fire Regime & Condition Class**

An ArcInfo polygon coverage of the study area was acquired from the USFS RMRS Forest Sciences Lab. Polygons depict individual forest stands defined by unique combinations of habitat type group, cover type, size class-structure, and canopy density and were derived primarily from air photo interpretation (Chew pers. comm. 2002). The average stand (polygon) size is 51 acres, with a standard deviation of 276 acres. Median stand size is 16 acres.

The modeling rules developed by Jones et al. (2002) for estimating historical fire regime, current fire severity, and the concomitant condition class are the basis for

---

1 The USDA Forest Service and the USDI National Park Service initiated the prescribed natural fire program around 1970 in an effort to reintroduce fire into some large park and wilderness areas.
analyzing departure from historical conditions in this project. Furthermore, the condition class ruleset is later used to differentiate between and assign treatment strategies (e.g., treat condition class 1 areas) during simulation modeling. These rulesets incorporate commonly used ecological descriptors – ecological subregions (McNab and Avers 1994), potential vegetation type (PVT), topographic variables (slope & aspect), and current vegetation (cover type, size class, & canopy density) – into a rule-based modeling approach.

A Geographic Information System (GIS) was used to apply the modeling rules to the study area coverage and thereby map the historical fire regime, current fire severity, and condition class of the study area (Appendix A). Differences in the way the study area coverage and modeling rules describe biophysical and vegetative attributes, however, required the development of crosswalks. The following sections describe the methods used to develop these crosswalks and the application of the rulesets to the study area data.

**Historical Fire Regime**

A fire regime classification developed for northern Rocky Mountain forests was used for this project (Barrett 2002) (Table 2). Six categories of fire regimes are defined by fire frequency (i.e., mean fire interval) and severity (% of overstory replacement) (Barrett 2002).
Table 2. Characterization of historical fire regimes\textsuperscript{1}.

<table>
<thead>
<tr>
<th>Fire Regime Class</th>
<th>Fire Regime</th>
<th>Severity (% Overstory Replacement)</th>
<th>Fire Interval (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS1</td>
<td>Short-Interval Mixed-Severity</td>
<td>Low - 20-30%</td>
<td>20 to 40</td>
</tr>
<tr>
<td>MS2</td>
<td>Long-Interval Mixed-Severity</td>
<td>Moderate - 30 - 80%</td>
<td>40 to 120</td>
</tr>
<tr>
<td>MS3</td>
<td>Variable-Interval Mixed-Severity</td>
<td>Variable - 10 - 90%</td>
<td>45 to 275</td>
</tr>
<tr>
<td>NL</td>
<td>Non-Lethal</td>
<td>Low - &lt; 20%</td>
<td>10 to 25</td>
</tr>
<tr>
<td>SR1</td>
<td>Short-Interval Stand Replacement</td>
<td>High - &gt; 80%</td>
<td>95 to 180</td>
</tr>
<tr>
<td>SR2</td>
<td>Long-Interval Stand Replacement</td>
<td>High - &gt; 80%</td>
<td>200 to 325</td>
</tr>
</tbody>
</table>

\textsuperscript{1}The characterization of fire regimes was adapted from Barrett (2002).

The modeling rules (Appendix B) required PVT, slope class, aspect class, and cover type as input variables to estimate historical fire regimes. The historical fire regime was modeled and added as an attribute to the study area coverage using a series of queries in ArcMap (ESRI 2001). However, the input variables required some development, which is described next.

Potential Vegetation Type

PVTs represent discrete biophysical environments defined by climax vegetation in the absence of disturbance. As mentioned above, the ruleset developed to model the historical fire regime required PVT as an input variable. The SIMPPLLE model, however, represents biophysical settings as habitat type groups (HTG) and therefore a translation was required. SIMPPLLE HTGs are groups of similar habitat types (Pfister et al. 1977) developed by regional experts (Chew 2002) to provide a comprehensive classification for the entire Northern Region of the Forest Service. Using Pfister’s Habitat Types of Montana (Pfister et al. 1977) a crosswalk between PVT and HTG was developed (Table 3). A PVT attribute was assigned to each polygon in the study area coverage.
Table 3. Crosswalk between SIMPPLLE habitat type groups\(^1\) and potential vegetation types.

<table>
<thead>
<tr>
<th>Habitat Type Group</th>
<th>Potential Vegetation Type</th>
<th>PVT Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2</td>
<td>PSME1</td>
<td>31</td>
</tr>
<tr>
<td>B2</td>
<td>PSME2</td>
<td>31</td>
</tr>
<tr>
<td>C1</td>
<td>PSME2</td>
<td>31</td>
</tr>
<tr>
<td>C2</td>
<td>ABGR2</td>
<td>31</td>
</tr>
<tr>
<td>D3</td>
<td>ABLA1</td>
<td>1</td>
</tr>
<tr>
<td>E2</td>
<td>ABLA1</td>
<td>1</td>
</tr>
<tr>
<td>F1</td>
<td>ABLA1</td>
<td>1</td>
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<tr>
<td>F2</td>
<td>ABLA1</td>
<td>1</td>
</tr>
<tr>
<td>G1</td>
<td>ABLA2</td>
<td>2</td>
</tr>
<tr>
<td>G2</td>
<td>PIAL</td>
<td>33</td>
</tr>
</tbody>
</table>

\(^1\)Crosswalks were developed only for habitat type groups in the study area coverage.

**Topographic Variables**

A 30m\(^3\) USGS DEM and the ARC/INFO GRID module (ESRI 2001) were used to generate the topographic variables of slope and aspect class. First, a percent slope and aspect grid were built using the SLOPE and ASPECT functions in GRID respectively. Next, the ZONALSTATS function was applied to the grids to derive the mean slope and majority aspect for each polygon in the study area coverage. These attributes were then classified into slope and aspect classes as defined in the ruleset (Tables 4 & 5) and added to the study area coverage.

Table 4. Slope classes used to model historical fire regimes (Jones et al. 2002).

<table>
<thead>
<tr>
<th>Slope Class</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-10%</td>
</tr>
<tr>
<td>2</td>
<td>11-30%</td>
</tr>
<tr>
<td>3</td>
<td>31-45%</td>
</tr>
<tr>
<td>4</td>
<td>46-60%</td>
</tr>
<tr>
<td>5</td>
<td>&gt; 60%</td>
</tr>
</tbody>
</table>

Table 5. Aspect classes used to model historical fire regimes (Jones et al. 2002).

<table>
<thead>
<tr>
<th>Aspect Class</th>
<th>Aspect</th>
<th>Energy Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (North)</td>
<td>Flat. 1-112°, 293-360°</td>
<td>Low</td>
</tr>
<tr>
<td>2 (South)</td>
<td>113-292°</td>
<td>High</td>
</tr>
</tbody>
</table>
**Current Fire Severity & Condition Class**

Current fire severity as used by Jones et al. (2002) estimates the amount of overstory removal if a fire were to burn under current vegetative conditions (Table 6).

### Table 6. Description of current fire severity classes (Jones et al. 2002).

<table>
<thead>
<tr>
<th>Current Fire Severity Class</th>
<th>Severity (%) Overstory Replacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS1</td>
<td>Low – 20-30%</td>
</tr>
<tr>
<td>MS2</td>
<td>Moderate – 30 – 80%</td>
</tr>
<tr>
<td>MS3</td>
<td>Variable – 10 – 90%</td>
</tr>
<tr>
<td>NL</td>
<td>Low - &lt; 20%</td>
</tr>
<tr>
<td>SR1</td>
<td>High - &gt; 80%</td>
</tr>
</tbody>
</table>

Comparing the current fire severity to an estimate of the historical fire regime then derives condition class. A single ruleset was used to model the current fire severity and condition class simultaneously (Appendix C). The current fire severity/condition class (CFS/CC) ruleset required historical fire regime, fire tolerance of the cover type, size class, canopy density, and slope class as input variables. The study area coverage and the modeling rules describe vegetation classes differently and therefore crosswalks were required. These crosswalks are described next.

The modeling rules developed by Jones et al. (2002) incorporated vegetation layers derived from 30m² LANDSAT Thematic Mapper data (Redmond and others 1998) to classify cover type, size class, and canopy density. A qualitative rating of fire tolerance was then assigned to each cover type to represent the degree of tree mortality if a fire were to occur in that type (Jones et al. 2002). Alternatively, the study area coverage classifies cover type by species compositions used within the SIMPPLLE model. The fire tolerance of each of these compositions is built into the SIMPPLLE system knowledge (Table 7).
Table 7. Fire tolerance of cover types\(^1\) used in the study area coverage.

<table>
<thead>
<tr>
<th>1 – Fire-Tolerant</th>
<th>2 – Moderately Tolerant</th>
<th>3 – Fire-Intolerant</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF</td>
<td>AF-ES-MH</td>
<td>AF</td>
</tr>
<tr>
<td>DF-PP-LP</td>
<td>AL</td>
<td>AF-MH</td>
</tr>
<tr>
<td>L</td>
<td>AL-AF</td>
<td>CW</td>
</tr>
<tr>
<td>L-DF</td>
<td>AL-WB-AF</td>
<td>CW-MC</td>
</tr>
<tr>
<td>L-DF-LP</td>
<td>C</td>
<td>Early-Seral</td>
</tr>
<tr>
<td>L-DF-PP</td>
<td>DF-AF</td>
<td>ES</td>
</tr>
<tr>
<td>L-LP</td>
<td>DF-GF</td>
<td>ES-AF</td>
</tr>
<tr>
<td>L-PP</td>
<td>DF-LP</td>
<td>Late-Seral</td>
</tr>
<tr>
<td>L-PP-LP</td>
<td>DF-LP-AF</td>
<td>ES</td>
</tr>
<tr>
<td>PP</td>
<td>DF-PP-GF</td>
<td>MH</td>
</tr>
<tr>
<td>PP-DF</td>
<td>DF-RRWP</td>
<td>QA</td>
</tr>
<tr>
<td>DF-RRWP-GF</td>
<td>QA-MC</td>
<td>WH</td>
</tr>
<tr>
<td>DF-WP</td>
<td>DF-WP-GF</td>
<td>WH-C</td>
</tr>
<tr>
<td>GF</td>
<td></td>
<td>WH-C-GF</td>
</tr>
<tr>
<td>L-DF-AF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L-DF-GF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L-DF-RRWP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L-DF-WP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L-ES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L-ES-AF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L-GF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L-LP-GF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L-RRWP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L-RRWP-GF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L-WP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L-WP-GF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LP-AF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RRWP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WB-ES-AF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WP</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Cover types: DF = Douglas fir, PP = ponderosa pine, LP = lodgepole pine, L = western larch, AF = subalpine fir, ES = Engelmann spruce, MH = mixed-hardwood, AL = subalpine larch, WB = whitebark pine, C = western red cedar, GF = grand fir, RRWP = rust resistant white pine, WP = white pine, CW = cottonwood, MC = mixed-conifer, QA = quaking aspen, WH = western hemlock

The cover type and associated fire tolerances from SIMPPLLE were used in this project.

Additional crosswalks were developed to account for differences in size class and canopy density classifications between the study area coverage and modeling rules (Tables 8 & 9).
Table 8. Crosswalk between size classes used to model current fire severity/condition class.

<table>
<thead>
<tr>
<th>Size Class</th>
<th>SIMPPLLE¹</th>
<th>Modeling Rules²</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SS</td>
<td>Seedling/sapling</td>
<td>&lt; 5” DBH</td>
</tr>
<tr>
<td>2</td>
<td>Pole, PMU, PTS</td>
<td>Pole</td>
<td>5.0-8.9”</td>
</tr>
<tr>
<td>3</td>
<td>Medium, MTS, MMU</td>
<td>Medium</td>
<td>9.0-14.9”</td>
</tr>
<tr>
<td>4</td>
<td>Large, LTS, LMU</td>
<td>Large</td>
<td>15-20.9”</td>
</tr>
<tr>
<td>6</td>
<td>Very-Large, VLTS, VLMU</td>
<td>Very-Large</td>
<td>&gt;21”</td>
</tr>
</tbody>
</table>

¹PTS = Pole Two-Story, PMU = Pole Multi-Unit, LTS = Large Two-Story, LMU = Large Multi-Unit, VLTS = Very-Large Two-Story, VLMU = Very-Large Multi-Unit.
²Adapted from Jones et al. (2002).

Table 9. Crosswalk between canopy density classes used to model current fire severity/condition class.

<table>
<thead>
<tr>
<th>Density Class</th>
<th>SIMPPLLE¹</th>
<th>Modeling Rules²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 – 14%</td>
<td>≤24%</td>
</tr>
<tr>
<td>2</td>
<td>15 – 39%</td>
<td>25 – 44%</td>
</tr>
<tr>
<td>3</td>
<td>40 – 69%</td>
<td>45 – 64%</td>
</tr>
<tr>
<td>4</td>
<td>70 – 100%</td>
<td>&gt;64%</td>
</tr>
</tbody>
</table>

¹The SIMPPLLE model does not assign a density class < 2 to forested vegetative states (Chew 2002).
²Adapted from Jones et al. (2002).

The CFS/CC ruleset was then applied to the study area coverage through a series of queries to the attribute table in ArcMap (ESRI 2001). Some communities (1% land area) were classified as non-stocked (NS) in the study area coverage and therefore it was not possible to apply a current fire severity classification to them. Attributes for the current fire severity and condition class of the study area (before simulations) were added to the study area coverage. These results were used to analyze departure from historical conditions on the Bitterroot Front and to provide a baseline for comparison of the simulation modeling results.

Simulation Modeling

Twenty-five 10-decade SIMPPLLE simulations were run for each of eight treatment strategies discussed below. Chew (pers. comm.) recommended this as an adequate time frame and number of simulations to capture the natural variability present on the Bitterroot Front.
Treatment Strategies

Landscape scale fuel management tends to be limited in the amount, location, and kind of treatment permitted. In this project, treatment strategies were defined by condition class and whether or not suppression was applied to wilderness (suppression was always applied in non-wilderness areas). Treatments were further constrained to roaded areas and to non-lethal (NL), short-interval mixed-severity (MS1), and long-interval mixed-severity (MS2) historical fire regimes. It was decided not to treat areas within variable-interval mixed-severity (MS3) and short-interval stand-replacement (SRI) historical fire regimes because the CFS/CC modeling rules assume that fire exclusion has not measurably changed the expected fire severity of vegetative communities within these regimes (Jones et al. 2002). None of the study area was classified as having a long-interval stand-replacement (SR2) historical fire regime, which generally occurs on highly productive sites rare to the study area, such as those in the western hemlock/red cedar or moist subalpine fir PVTs (Barrett 2002).

The eight treatment strategies applied were:

1. Treat condition class 1 areas. Apply suppression in Wilderness.
2. Treat condition class 1 areas. No suppression in Wilderness (Wildland Fire Use).
3. Treat condition class 2 areas. Apply suppression in Wilderness.
4. Treat condition class 2 areas. No suppression in Wilderness (Wildland Fire Use).
5. Treat condition class 3 areas. Apply suppression in Wilderness.
6. Treat condition class 3 areas. No suppression in Wilderness (Wildland Fire Use).
8. No treatment. No suppression in Wilderness (Wildland Fire Use).

Treatment Schedules

The intent of strategies 1 – 6 was to restore vegetative conditions, through the application of treatments, to a state considered to be within a natural range of variability (i.e., condition class 1). Therefore, the treatments within each strategy modify a stratum
of species composition, size class-structure, and density to represent condition class 1
(Figure 3). The intent of strategies 7 and 8 was to simulate the response of condition
class to no management action other than suppression. It should be noted that in addition
to management activities (treatment and suppression) natural disturbance and succession
continued to influence vegetative change under each treatment strategy.

![Diagram](image)

**Figure 3. Example of restoration treatment effects.**

The treatment schedule interface in SIMPPLLE was used to assign treatments in
accordance with the strategy being modeled. The criteria (combinations of special area\(^2\),
species, size class-structure, and canopy density) used within the CFS/CC ruleset to
model a specific condition class were defined within the treatment schedule interface for
each strategy (Figure 4).

---

\(^2\) ‘Special area’ is an optional attribute available in SIMPPLLE used to designate spatially distinct areas of
interest (e.g., watersheds, wildlife management areas) not already captured in the default attributes. In this
project the special area attribute was derived by combining the static attributes of historical fire regime and
slope class, which is referred to as the ‘modified historical fire regime’ in the CFS/CC modeling rules
(Appendix C).
In using this method, a treatment schedule is dynamically built at the beginning of each time step by selecting vegetative communities (polygons) that meet the defined criteria. Treatments are therefore applied based on the dynamic changes to condition class that SIMPPLLE simulates (Figure 5).

**Figure 4.** Example of SIMPPLLE treatment schedule interface used to dynamically build treatment schedules at the beginning of each time step by defining the vegetative criteria (right column) that represent the condition class being treated.
Pathway Modifications

Preliminary tests revealed two issues that required modification to the vegetative pathways logic in SIMPPLLE. First, when a treatment was applied to the same community repeatedly over multiple time steps, a cycle would occur in which the community did not “grow” into the next larger size class (e.g., pole to medium). The treatment logic being applied in this project converts a community classified as a two- or multi-story structure to a single-story structure. In most of the vegetative pathways, succession occurring within the same time step as the treatment results in a return to a two- or multi-story structure but with no change in the size class (e.g., pole to pole two-story) (Figure 6).
Figure 6. Example of succession cycle problem before modification of vegetative pathway logic.

A second treatment would then start the cycle over therefore giving the impression that the “leave” trees (larger cohort) within the treated community are not growing. This issue was addressed by adding additional logic to the model that checks for the cycle and, if found, projects the community to a corrected state\(^3\) (Appendix D).

The second issue is closely related to the first. Because treatments are applied at the beginning of a time step, succession occurring in that same time step oftentimes negates the restoration effects of the treatment (Figure 7).

Figure 7. Example of how a treatment is negated by the establishment of a second cohort in the same time step. In this instance, succession, as represented by the vegetative pathway in SIMPPLLE results in the establishment of Douglas-fir and subsequent increase in structure, density, and condition class.

\(^3\) Jimmie Chew and Kirk Moeller of the USFS, RMRS Forestry Sciences Lab performed this modification to the model logic.
This occurs because the logic for establishing a second cohort of trees and the consequent two- or multi-story structure and density increase is built into many of the vegetative pathway diagrams. On the drier habitat types of the Bitterroot Face, however, the establishment of understory trees is more realistically the result of a suite of environmental conditions (e.g., good seed year and favorable moisture conditions) leading to a “regeneration pulse,” which may be best modeled as a stochastic event (Chew pers. comm.). Therefore, the vegetative pathways for habitat types A2 (warm & very dry), B2 (moderately warm & dry), C1 (moderately warm & moderately moist), and C2 (moderately warm & moist) and the model logic were modified to allow the use of a regeneration pulse function. Within these habitat types the establishment of understory tree species no longer automatically occurs with succession. Rather, it is a stochastic event linked to the probability of a "regeneration pulse" occurring along with a disturbance within a given plant community.

Analysis

The results of the treatment strategy simulations were imported into a Microsoft Access database (Microsoft, 2000). Queries were developed to recalculate the current fire severity and condition class of each vegetative community at the end of time step 10, for each of the 25 simulations. Additional queries were then developed to determine the average acres (n=25) within each current fire severity and condition class, the results of which were stratified by historical fire regime.

---

4 Jimmie Chew and Kirk Moeller of the USFS, RMRS Forestry Sciences Lab, performed these modifications.
A graphical analysis was used to compare the response of current fire severity and condition class to each treatment strategy. The current fire severity and condition class modeled before simulations (time step zero) was used as a baseline to determine positive or negative change from an ecological restoration perspective.
RESULTS

The results of this study are organized into two sections. The first section presents the results of the rule-based approach to modeling the historical fire regime, current fire severity, and condition class of the Bitterroot Front. Within this section the results are first given for the entire landscape and then stratified by historical fire regime. The second section presents changes in vegetative condition as a result of alternative treatment strategies as projected by multiple 100-year (10-decade) simulations using the SIMPPLLE model. The current conditions modeled in the first section were used as a baseline with which to compare the simulated current fire severity and condition class of each treatment strategy. The results of the second section are stratified by historical fire regime.

Fire Regime and Condition Class Modeling

Applying the historical fire regime and current fire severity models to the study area coverage suggests that historical conditions on the Bitterroot Front have been altered. The current fire severity model predicts the expected fire severity if a fire were to burn under the current state of vegetative conditions (Jones et al. 2002). When comparing historical fire regimes with current fire severity of the entire landscape, more area is predicted to burn with higher severity under current conditions than did historically (Figure 8).
Table 10 provides a summary of current fire severity by historical fire regime.

Table 10. Modeled current fire severity by historical fire regime.

<table>
<thead>
<tr>
<th>Historical Fire Regime&lt;sup&gt;1&lt;/sup&gt;</th>
<th>NL</th>
<th>MS1</th>
<th>MS2</th>
<th>SR</th>
<th>NS</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent of Land Area (Acres)</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
<td>---------------</td>
</tr>
<tr>
<td>NL</td>
<td>42 (24,922)</td>
<td>18 (10,742)</td>
<td>17 (9,956)</td>
<td>22 (13,335)</td>
<td>1 (381)</td>
<td>100 (59,336)</td>
</tr>
<tr>
<td>MS1</td>
<td>46 (24,424)</td>
<td>49 (26,043)</td>
<td>3 (1,360)</td>
<td>2 (851)</td>
<td>100 (52,678)</td>
<td></td>
</tr>
<tr>
<td>MS2</td>
<td>77 (43,140)</td>
<td>21 (11,489)</td>
<td>2 (1,316)</td>
<td>100 (55,945)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup>Historical fire regimes: NL = non-lethal, MS1 = short-interval mixed-severity, MS2 = long-interval mixed-severity.

<sup>2</sup>Current fire severity: NL = non-lethal, MS1 = low mortality mixed-severity, MS2 = high mortality mixed-severity, SR = stand-replacement, NS = non-stocked.

Within the NL historical fire regime only 42% of the area is predicted to burn in a non-lethal manner under current conditions. Twenty-two percent of the area is predicted to burn in a stand-replacement and 35% in a mixed-severity manner, suggesting significant vegetative change due to fire exclusion. The MSI regime was also modeled to have more severe fires than it would have under historical conditions. Only 46% of the area was predicted to burn in the characteristic low mortality mixed-severity manner. Forty-nine percent of the area predicted to burn in a moderate mortality mixed-severity and 3% in a stand-replacement manner. The MS2 historical fire regime shows the least alteration with 21% of its area predicted to burn as stand-replacement fire.

The condition class model estimated 72% of the study area as condition class 1 (CC1), indicating that the majority of the study area has not departed from its historical fire regime. The remaining 27% of the area (1% was non-stocked) was almost evenly split between condition class 2 (CC2) (12%) and condition class 3 (CC3) (15%) (Figure 8). It should be noted that 40% of the forested land in the study area was modeled to have an SRI or MS3 historical fire regime and therefore by definition was classified as CC1 (Appendix E). Similarly, 20% of the forested land was modeled to have an MS2
historical fire regime, which by definition can only be classified as $CC_1$ or $CC_2$. Due to these modeling limitations, viewing condition class over the entire study area may mask trends in departure seen in the short-interval low-severity regimes (i.e., $NL$ or $MSI$).

Table 11 provides a summary of condition class by historical fire regime.

### Table 11. Modeled condition class by historical fire regime.

<table>
<thead>
<tr>
<th>Historical Fire Regime</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>NS</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent of Land Area (Acres)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NL</td>
<td>42 (24,922)</td>
<td>18 (10,742)</td>
<td>39 (23,291)</td>
<td>1 (381)</td>
<td>100 (59,336)</td>
</tr>
<tr>
<td>MSI</td>
<td>46 (24,424)</td>
<td>19 (10,204)</td>
<td>33 (17,199)</td>
<td>2 (851)</td>
<td>100 (52,678)</td>
</tr>
<tr>
<td>MS2</td>
<td>77 (43,140)</td>
<td>21 (11,489)</td>
<td>--</td>
<td>2 (1,316)</td>
<td>100 (55,945)</td>
</tr>
</tbody>
</table>

1Historical fire regimes: NL = non-lethal, MSI = short-interval mixed-severity, MS2 = long-interval mixed-severity. 2Condition class: 1 = low departure from historical conditions, 2 = moderate departure from historical conditions, 3 = high departure from historical conditions, NS = non-stocked.

Stratifying condition class by historical fire regime shows that within the $NL$ and $MSI$ regimes, nearly half (42% and 46% respectively) of the area in each regime was modeled to be within its historical range ($CC_1$) while a majority of the remaining area had substantially departed ($CC_3$). Within the $MS2$ regime 77% of the area remained within its historical range ($CC_1$) and 21% had moderately departed ($CC_2$).

### Treatment Strategy Simulation Modeling

The response of current fire severity and condition class to each of the eight treatment strategies was analyzed for the $NL$, $MSI$, and $MS2$ historical fire regimes (Tables 12 and 13, Figures 9 11). Again, because changes in current fire severity and condition class are not detectable within the $MS3$ and $SRI$ regimes (Jones et al. 2002) they were omitted from this analysis.
Table 12. Change in percent area of current fire severity classes stratified by historical fire regime and 100 year treatment strategy. Averages of 25 simulations.

<table>
<thead>
<tr>
<th>HFR/CFS²</th>
<th>Original¹</th>
<th>CC1-S</th>
<th>CC1-NWS</th>
<th>CC2-S</th>
<th>CC2-NWS</th>
<th>CC3-S</th>
<th>CC3-NWS</th>
<th>NT-S</th>
<th>NT-NWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS1</td>
<td>18</td>
<td>+17</td>
<td>+14</td>
<td>+9</td>
<td>+5</td>
<td>+19</td>
<td>+17</td>
<td>+21</td>
<td>+20</td>
</tr>
<tr>
<td>MS2</td>
<td>17</td>
<td>+7</td>
<td>+7</td>
<td>+5</td>
<td>+5</td>
<td>-14</td>
<td>-14</td>
<td>+8</td>
<td>+8</td>
</tr>
<tr>
<td>NL</td>
<td>12</td>
<td>-6</td>
<td>-3</td>
<td>+4</td>
<td>+8</td>
<td>-9</td>
<td>-7</td>
<td>-11</td>
<td>-10</td>
</tr>
<tr>
<td>SR</td>
<td>22</td>
<td>-17</td>
<td>-17</td>
<td>-17</td>
<td>-18</td>
<td>+4</td>
<td>+5</td>
<td>-17</td>
<td>-17</td>
</tr>
<tr>
<td>NS</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>MS1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS1</td>
<td>46</td>
<td>-6</td>
<td>-3</td>
<td>+4</td>
<td>+8</td>
<td>-9</td>
<td>-6</td>
<td>-11</td>
<td>-10</td>
</tr>
<tr>
<td>MS2</td>
<td>49</td>
<td>+9</td>
<td>+6</td>
<td>-1</td>
<td>-5</td>
<td>+11</td>
<td>+8</td>
<td>+14</td>
<td>+12</td>
</tr>
<tr>
<td>SR</td>
<td>3</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
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<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-1</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
</tr>
<tr>
<td>MS2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS2</td>
<td>77</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>-2</td>
<td>-2</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>SR</td>
<td>21</td>
<td>-2</td>
<td>-4</td>
<td>-3</td>
<td>-5</td>
<td>-2</td>
<td>-4</td>
<td>-2</td>
<td>-4</td>
</tr>
<tr>
<td>NS</td>
<td>2</td>
<td>+3</td>
<td>+5</td>
<td>+3</td>
<td>+5</td>
<td>+4</td>
<td>+5</td>
<td>+3</td>
<td>+5</td>
</tr>
</tbody>
</table>

¹Strategies: CC = condition class, S = apply suppression in Wilderness, NWS = no suppression in Wilderness. Average of 25 simulations.
²Historical fire regimes: NL = non-lethal, MS1 = short-interval mixed-severity, MS2 = long-interval mixed-severity. ³Condition class: 1 = low departure from historical conditions, 2 = moderate departure from historical conditions, 3 = high departure from historical conditions, NS = non-stocked.
Current fire severity: NL = non-lethal, MS1 = low mortality mixed-severity, MS2 = high mortality mixed-severity, SR = stand-replacement, NS = non-stocked.
³Original = before simulations (time step 0).
Table 13. Change in percent area of condition classes stratified by historical fire regime and 100 year treatment strategy. Averages of 25 simulations.

<table>
<thead>
<tr>
<th>HFR/CC</th>
<th>Original(^1)</th>
<th>CC1-S</th>
<th>CC1-NWS</th>
<th>CC2-S</th>
<th>CC2-NWS</th>
<th>CC3-S</th>
<th>CC3-NWS</th>
<th>NT-S</th>
<th>NT-NWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC1</td>
<td>42</td>
<td>-6</td>
<td>-3</td>
<td>+4</td>
<td>+8</td>
<td>-9</td>
<td>-7</td>
<td>-11</td>
<td>-10</td>
</tr>
<tr>
<td>CC2</td>
<td>18</td>
<td>+17</td>
<td>+14</td>
<td>+9</td>
<td>+5</td>
<td>+19</td>
<td>+17</td>
<td>+21</td>
<td>+20</td>
</tr>
<tr>
<td>CC3</td>
<td>39</td>
<td>-10</td>
<td>-10</td>
<td>-13</td>
<td>-13</td>
<td>-9</td>
<td>-9</td>
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<tr>
<td>NS</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>MS1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CC1</td>
<td>46</td>
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<td>-10</td>
</tr>
<tr>
<td>CC2</td>
<td>19</td>
<td>+9</td>
<td>+8</td>
<td>+1</td>
<td>-2</td>
<td>+14</td>
<td>+12</td>
<td>+13</td>
<td>+12</td>
</tr>
<tr>
<td>CC3</td>
<td>33</td>
<td>-1</td>
<td>-3</td>
<td>-3</td>
<td>-4</td>
<td>-3</td>
<td>-4</td>
<td>-1</td>
<td>-1</td>
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<tr>
<td>NS</td>
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<td>-2</td>
<td>-2</td>
<td>-1</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
</tr>
<tr>
<td>MS2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC1</td>
<td>77</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>-2</td>
<td>-2</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>CC2</td>
<td>21</td>
<td>-2</td>
<td>-4</td>
<td>-3</td>
<td>-5</td>
<td>-2</td>
<td>-4</td>
<td>-2</td>
<td>-4</td>
</tr>
<tr>
<td>NS</td>
<td>2</td>
<td>+3</td>
<td>+5</td>
<td>+3</td>
<td>+5</td>
<td>+4</td>
<td>+5</td>
<td>+3</td>
<td>+5</td>
</tr>
</tbody>
</table>

\(^1\)Strategies: CC = condition class, S = apply suppression in Wilderness, NWS = no suppression in Wilderness. Average of 25 simulations.

Within the NL historical fire regime, both strategies that treated CC2, CC2 with wilderness suppression (CC2-S) and CC2 without wilderness suppression (CC2-NWS), increased the amount of area classified as having a fire severity characteristic of the historical regime (i.e., non-lethal). Accordingly, the amount of area classified as CC1 was also increased by these two strategies. All strategies, with the exception of those that treated CC3 with and without wilderness suppression (CC3-S and CC3-NWS respectively), resulted in a considerable decrease in the amount of area expected to burn...
with stand-replacement severity while increasing the amount of area in a mixed-severity classification. Likewise, all strategies were shown to increase the amount of area classified as CC2 while decreasing CC3 (Figure 9).

Within the MSI historical fire regime, the amount of area classified with a stand-replacement fire severity and subsequent CC3 remained relatively unchanged compared to the original conditions. The CC2-S and CC2-NWS strategies resulted in an increase in the amount of area expected to receive a characteristic fire severity and subsequent CC1 classification. Conversely, all other strategies showed an increase in MS2 and decrease in MSI severity. Likewise, all strategies, with the exception of the CC2-NWS, were shown to increase the amount of area classified as CC2 while decreasing CC3 (Figure 10).

Within both the NL and MSI regimes, the simulation model results indicated that for any given condition class prioritization (i.e.: CC1, CC2, CC3, or no treatment), the no wilderness suppression (NWS) strategy resulted in more land being restored to a CC1 state than did the suppression strategy (Figures 9 and 10).
DISCUSSION

As with any modeling exercise one must interpret these results with an understanding of the assumptions in the models. Moreover, integrating the rule-based fire regime models with the SIMPPLLE model required additional assumptions to address the differences between them. In some cases, these assumptions heavily influenced the results of this study. Nevertheless, this study provides insight into changes in vegetative condition in response to the spatial and temporal interactions of natural processes and fuel treatments.

Fire Regime and Condition Class Modeling

The current high severity fire potential in forests that historically have experienced low-severity fire regimes (Figure 8) is consistent with the findings of other fire history research within the study area (Arno et al. 1993, 1995, Hartwell 1997). A number of factors may be associated with this change including extensive livestock grazing, cessation of Native American burning, and decades of successful fire suppression (Brown and Smith 2000). The distribution of current fire severity and condition class modeled on the landscape is largely influenced by the vegetative attributes used in the modeling rules. The need to develop crosswalks that define a common vegetative classification system was essential in integrating the CFS/CC models with the SIMPPLLE model, however, differences in how the models describe the fire tolerance of cover types had a significant influence on the current fire severity and condition class modeling results. Although the CFS/CC models are very sensitive to the fire tolerance of cover types, the fire tolerance classifications of the SIMPPLLE model were used since they are germane to the cover types used in the Bitterroot Front dataset.
as well as to the type of fire and fire spread logic used in the subsequent simulation modeling. However, the original condition class distribution would have been different had the fire tolerance classifications of the CFS/CC modeling rules been used.

Discrepancies are particularly noticeable for the Douglas-fir (DF) and Cottonwood/mixed-conifer (CW-MC) cover types. For example, the DF cover type is assigned to 15%, 33%, and 47% of the NL, MSI, and MS2 historical fire regimes, respectively. SIMPPLLE classifies DF as a fire tolerant cover type while the CFS/CC models classify it as moderately tolerant. If the CFS/CC tolerances had been used, less area in CCS and more area in CC3 would have resulted (Table 14).

Table 14. Comparison of condition class distribution within non-lethal, short-interval mixed-severity, and long-interval mixed-severity historical fire regimes using different fire tolerance classifications for Douglas-fir cover type.

<table>
<thead>
<tr>
<th>Historical Fire Regime / Fire Tolerance</th>
<th>Condition Class</th>
<th>Percent of Land Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>NL Intolerant (SIMPPLLE)</td>
<td>42</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>18</td>
</tr>
<tr>
<td>MS1 Intolerant (SIMPPLLE)</td>
<td>46</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>MS2 Intolerant (SIMPPLLE)</td>
<td>77</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>72</td>
<td>26</td>
</tr>
</tbody>
</table>

1Historical fire regimes: NL = non-lethal, MS1 = short interval mixed severity, MS2 = long interval mixed severity. 2Condition class: 1 = low departure from historical conditions, 2 = moderate departure from historical conditions, 3 = high departure from historical conditions, NS = non-stocked.

Discrepancies also exist for the grand fir and western larch cover types. However, these cover types are assigned to less than 0.001% of the NL, MSI, and MS2 historical fire regimes combined.
The CW-MC cover type mainly influences the NL historical fire regime because it is assigned to 29% of the land area within the regime. Although differences in how the models define the fire tolerance of this cover type influenced the resulting condition class distribution (Table 15), the more pertinent issue is that a conflict exists between the cover type and the historical fire regime in which it is established.

Table 15. Comparison of condition class distribution within non-lethal historical fire regime using different fire tolerance classifications for cottonwood-mixed conifer cover type.

<table>
<thead>
<tr>
<th>Fire Tolerance</th>
<th>Condition Class 1</th>
<th>Condition Class 2</th>
<th>Condition Class 3</th>
<th>NS</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>Percent of Land Area</td>
<td>---------------</td>
<td>---------------</td>
<td>---------------</td>
<td>----</td>
<td>-------</td>
</tr>
<tr>
<td>Intolerant (SIMPPLLE)</td>
<td>42</td>
<td>18</td>
<td>39</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Moderately Tolerant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(CFS/CC ruleset)</td>
<td>42</td>
<td>42</td>
<td>15</td>
<td>1</td>
<td>100</td>
</tr>
</tbody>
</table>

1Condition class: 1 = low departure from historical conditions, 2 = moderate departure from historical conditions, 3 = high departure from historical conditions, NS = non-stocked.

Within the CFS/CC modeling rules (Appendix C) neither an intolerant nor moderately tolerant cover type can be classified as CCl within an NL historical fire regime, suggesting that coniferous riparian cover types, such as CW-MC, historically did not exist within this regime. In developing the modeling rules, Jones et al. (2002) assumed that the historical fire regime of coniferous riparian areas would be the same as adjacent upland areas (Jones et al. 2002). Although historically CW-MC communities most likely experienced frequent fire as did their adjacent counterparts of Douglas-fir and ponderosa pine, (USDA Fire Effects Information System 2002), the fire severity would likely be one of high mortality (Brown 1996, Gom and Rood 1999) suggesting a mixed-severity regime. Future applications of this modeling approach should therefore consider making refinements to historical fire regimes based on the presence of riparian cover types.
A third assumption influencing how one interprets the CFS/CC modeling results is that fire exclusion has not measurably changed the expected fire severity of vegetative communities within the MS3 and SRI historical fire regimes (Jones et al. 2002). Acknowledgement of this assumption is particularly important when interpreting the results at different observational scales. For instance, although from a management perspective 72% of the entire landscape being classified as CCl (Figure 8) may appear desirable, 39% of the non-lethal historical fire regime classified as CC3 (Table 11) would not. The high percentage of CCl at the landscape scale is attributed to 40% of the landscape being characterized by an MS3 or SRI historical fire regime (Figure 8), which based on this assumption can be classified only as CCl (Appendix E). Jones et al. (2002) attribute the inability of the CFS/CC models to detect change in fire severity potential within these regimes to the resolution of the data used to define modeling rules rather than actual ground conditions. For instance, it has been suggested that fire exclusion can affect stand-replacement fire regimes, (Arno et al. 1993, Baker 1993, Hessburg et al. 1999, Arno 2000, Barrett 2002) where changes are revealed in landscape scale patterns and processes such as increased continuity of fuels and spatial extent of stand-replacement fires. However, accumulations of duff and down woody fuels play a major role in limiting the spread of fire in stand-replacement fire regimes (Arno 2000); attributes not incorporated in the modeling rules.

**Treatment Strategy Simulation Modeling**

These simulations depict the spatial and temporal interactions of natural disturbance processes and succession occurring simultaneously with fuel treatment. The resulting distribution of condition class represents the effect of these interactions on
vegetative conditions over a ten-decade period. It was not possible to track change in condition class over time and therefore the actual path of any given community is uncertain, however, inferences are made by comparing original and decade ten conditions. This discussion will focus on the NL and MSI historical fire regimes.

The CCl strategies (CC1-S and CCl-NWS) can be thought of as “maintenance” approaches to fuel treatment. The intent of simulating these strategies was to gain an understanding of the effect that natural disturbance processes and succession have on vegetative conditions under current fire suppression policies, while maintaining (via treatment) areas that have not yet departed from their historical fire regime (i.e., CCl). For example, would natural disturbances convert CC2 and CC3 areas to CCl thereby increasing the total amount of area in CCl, or would the interaction of natural disturbances and succession have relatively no effect on CCl but influence the current distribution of CC2 and CC3? The simulations, however, resulted in a decrease in the amount of area in CCl from original conditions. The ineffectiveness of these strategies is an artifact of an assumption made in the modeling approach. In developing pathway modifications to the SIMPPLLLE model (see methods) it was assumed that the establishment of understory tree species on drier habitat types of the Bitterroot Front is the result of a suite of stochastic environmental conditions leading to a regeneration pulse. Because treatments are modeled at the beginning of a time step, the maintenance of a CCl community is actually dependent on the probability of a regeneration pulse rather than the actual treatment being applied (Figure 12). For example, if a regeneration pulse (stochastic event) were predicted to occur, the stratum of vegetative attributes
could, depending on the specific habitat and cover type, be altered to that of $CC_2$ thereby discontinuing treatment in the next time step.

![Diagram A]

**A**

<table>
<thead>
<tr>
<th>PP/Large/2</th>
<th>Treatment</th>
<th>PP/Large/2</th>
<th>Succession</th>
<th>No &quot;regen pulse&quot;</th>
<th>PP/Large/2</th>
<th>CC1</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Diagram B]

**B**

<table>
<thead>
<tr>
<th>PP/Large/2</th>
<th>Treatment</th>
<th>PP/Large/2</th>
<th>Succession</th>
<th>With &quot;regen pulse&quot;</th>
<th>PP/LTS/3</th>
<th>CC2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 12. Effect of regeneration pulse on CC1 treatment strategies. A: no regeneration pulse results in maintenance of CC1 state. B: Regeneration pulse results in an increase of density and subsequent CC2 state.**

The only way the community would ever be re-treated is if a natural disturbance process occurred and restored the community to a $CC_1$ stratum. Due to the influence of this assumption on the CC1 strategy results comparison to other strategies is limited. In future applications, alternative methods should be developed to represent the maintenance of $CC_1$ communities.

The CC2 strategies ($CC_2$-S and $CC_2$-NWS) restore areas that have moderately departed from their historical fire regime (i.e., $CC_2$), through the application of treatment, at the beginning of each time step. The treatment logic restores the community to a stratum of composition, size class-structure, and density required for a $CC_1$ classification. These communities may eventually reach $CC_2$ again as a result of forest succession in which case they would be re-treated. The CC2 strategies resulted in an

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6 By definition, there are a few cases in which the treatment logic does not restore $CC_1$ but maintains the $CC_2$ stratum. These cases are unique, however, in that within these communities an increase in size class will eventually reduce the expected fire severity therefore restoring $CC_1$ (Appendix C).
increase of $CC_1$ and reduction of $CC_3$ within both the $NL$ and $MSI$ historical fire regimes (Figures 9 and 10). As previously mentioned, it was not possible to track the actual history of any one community or group of communities over time. Therefore, it is unclear what proportion of the total acreage of $CC_1$ in decade ten is a result of treatments targeting $CC_2$, natural processes maintaining $CC_1$, or natural disturbances converting $CC_3$ to $CC_1$ (Figures 9 and 10). Furthermore, it is counterintuitive that the $CC_2$ strategies would result in an increase in the area in $CC_2$ (Figure 9). This occurs, however, because treatments are not the only processes occurring in the simulation. Natural disturbances can convert $CC_3$ to $CC_2$, and successional processes can convert $CC_1$ to $CC_2$. It could be hypothesized therefore that within both the $NL$ and $MSI$ regimes, treatment was converting $CC_2$ to $CC_1$ at a rate slightly greater than that in which it was succeeding from $CC_1$ to $CC_2$, and within the $NL$ regime the significantly larger reduction of $CC_3$ and increase in $CC_2$ was the result of natural disturbances converting $CC_3$ to $CC_2$. In reality, it would be expected to have more frequent fire in the non-lethal regime than in the mixed-severity. Simulation results further support this hypothesis where significantly more stand-replacement fire (the type of fire most likely to occur in $CC_3$ communities) events occurred within the $NL$ regime compared to the $MSI$ regime over the simulation period ($CC_2$-NWS strategy, Figure 13).

The $CC_3$ strategies ($CC_3$-S and $CC_3$-NWS) target areas that have significantly departed from their historical fire regime and are therefore at the greatest risk of losing key ecological components in the event of a fire. Although it may have been expected that these would be effective restoration strategies, a decrease in $CC_1$ from original
conditions resulted, suggesting an increasing rate of departure due to succession (Figures 9 and 10).

Within the NL historical regime, modeling assumptions had a large influence on the CC3 strategy results thereby limiting comparison to other strategies. As discussed above, it was assumed that coniferous riparian areas would be characterized by the historical fire regime of their adjacent upland counterparts, thereby classifying all CW-MC communities with an NL historical fire regime. Given this assumption, treatment of the CW-MC communities had no effect on condition class (Figure 14). For example, according to the treatment logic of the SIMPPLLE model, treating a CW-MC cover type results in removal of the MC component thus re-coding the community as CW, also an intolerant cover type. Therefore, because the CFS/CC models assign CC3 whenever a fire-intolerant cover type is established on a NL historical fire regime, SIMPPLLE applies treatment to the resulting CW communities at the beginning of each time step for the remainder of the simulation, but with no effect on condition class.

Figure 14. Effects of treating coniferous riparian cover types on NL historical fire regime using two separate fire tolerance classifications.
Furthermore, unlike the CW-MC cover type, both models consider CW as intolerant. Therefore, even if a moderate fire tolerance had been assigned to CW-MC, treatment in the first time step would convert the community to a fire intolerant, CW cover type and subsequent CC3 classification for the remainder of the simulation (Figure 14). If instead a moderate fire tolerance had been used, 24% of the CW-MC would have been classified as CC2 and 5% as CC3. Therefore, the difference would be that the majority of the CW-MC would have been treated under the CC2 strategies rather than the CC3.

Within the MSI regime interpretation of the CC3 strategies is not limited by the assumptions discussed above. Coniferous riparian cover types make up only 3% of the communities within this regime. Nevertheless, CC3 strategies were still less effective than the CC2 strategies at restoring CC1 (Figures 9 and 10). The following factors offer explanation to why. In comparing the CC3 strategy results to the NT results, little difference is observed within CC3 communities, suggesting that neither natural disturbance nor treatment of CC3 was effective at reducing CC3 within this regime. Although it is unclear how much of the original CC3 was retained through the entire simulation, less than 0.25% of the land area within the regime experienced stand-replacement fire in any time step (CC3-NWS strategy, Figure 15). Stand-replacement fire would be the most likely type of fire in CC3. Therefore, this suggests that CC3 communities did not experience fire events very often and therefore natural disturbance was unable to accomplish the restoration of CC3 communities within the time frame modeled. Furthermore, 24% of the area within the MSI regime is not roaded and therefore unavailable for treatment. Finally, by definition, treatment of CC3 communities does not always result in restoration to a lower condition class (Appendix C).
In the NT strategies (NT-S and NT-NWS), no treatments are applied and therefore the effects of natural disturbances and succession simulated by the SIMPPLLE model dictate the condition class distribution within all fire regimes. The NT strategies resulted in a reduction of $CC_1$ and increase of $CC_2$ within both the $NL$ and $MSI$ historical fire regimes (Figures 9 and 10). These results suggest that in the absence of treatment, communities are continuing to depart from historical conditions at a rate greater than that which is being maintained or restored by natural processes on these regimes.

Comparison among treatment strategies is limited due to assumptions made in the modeling process explained above. However, in analyzing individual strategies, some inferences can be made. For instance, a trend observed across all strategy couplets (e.g., $CC_1$-S and $CC_1$-NWS) is that $CC_1$ increased and $CC_2$ decreased when no suppression was applied to wilderness (Figures 9 and 10). This result suggests that wildland fire use in wilderness may be an effective restoration strategy. Furthermore, these simulations suggest that the balance between rates of natural disturbance and succession has a significant influence on the resultant vegetative conditions regardless of where treatment is applied.

Finally, because the trajectory of any given community is unique, the applicability of these results to different landscapes is limited. For instance, the factors that influence model results (e.g., biophysical variables, probability of disturbance processes, suppression effectiveness) can vary considerably between landscapes.
CONCLUSIONS

Managing ecological systems today involves a broad spatial and temporal perspective. Resource management has shifted focus from the stand level to that of watersheds and entire landscapes and recognizes the importance of disturbance regimes on past, present, and future conditions. The interrelations of fire and vegetative succession are perhaps the greatest influence on the landscape dynamics of Northern Rocky Mountain ecosystems. Combining the condition class concept with the SIMPPLLE model provided a means with which to evaluate the impacts of fuel treatment strategies in the context of this disturbance-driven spatial and temporal variability.

The historical fire regime and current fire severity/condition class models suggest that fire exclusion has led to departure from historical conditions on the Bitterroot Front. Much of the area that was historically characterized by low mortality fire regimes (NL and MSI) is now expected to experience moderate to high mortality fires (MS2 and SRI). In the present simulations, fuel treatment strategies that targeted CC2 were the most effective at restoring CCl. Results also suggest that in the absence of treatment, communities will continue to depart from historical conditions at a rate greater than that which is being maintained or restored by natural disturbances. Furthermore, simulation results suggest that wildland fire use in wilderness may be an effective restoration strategy. Finally, natural disturbance appears to have a greater ability to reduce CC3 within the NL historical fire regime than the MSI regime. Comparing the results of different strategies is limited, however, due to the effect of assumptions made in the modeling approach. Nevertheless, this study provides insight as to changes in vegetative
condition in response to the spatial and temporal interactions of natural processes and fuel treatments.

While the treatment strategies simulated in this study are simplified from a management perspective, the modeling approach identifies key issues to resolve, thus providing a first step toward examining a more complex set of fire management problems. Future applications would benefit by resolving conflicts between initial and derived data layers (e.g., current vegetation and historical fire regime), developing an alternative method for simulating the maintenance of condition class 1 (given the influence of a regeneration pulse and the timing of treatments within a time step), and developing methods with which to track condition class over time.
REFERENCES


Figure 8. Area distribution of Historical Fire Regime, Current Fire Severity, and Condition Classes for forested land on Bitterroot Front.
Figure 9. Results of treatment strategy modeling within non-lethal historical fire regime. Averages of 25 simulations. (Error bars represent percent standard deviation)
Figure 10. Results of treatment strategy modeling within short-interval mixed-severity historical fire regime. Averages of 25 simulations. (Error bars represent percent standard deviation)
Figure 11. Results of treatment strategy modeling within long-interval mixed-severity historical fire regime. Averages of 25 simulations. (Error bars represent percent standard deviation)
Figure 13. Simulated wildland fire under CC2-NWS strategy within non-lethal and short-interval mixed-severity historical fire regimes. Points represent averages of 25 simulations. (LSF = Light-Severity Fire, MSF = Mixed-Severity Fire, SRF = Stand-Replacement Fire)
Figure 15. Simulated wildland fire under CC3-NWS strategy within non-lethal and short-interval mixed-severity historical fire regimes. Points represent averages of 25 simulations. (LSF = Light-Severity Fire, MSF = Mixed-Severity Fire, SRF = Stand-Replacement Fire)
Appendix A: Historical Fire Regime, Current Fire Severity, and Condition Class of Bitterroot Front. Modeling rules adapted from Jones et al. (2002) and applied to Bitterroot Front polygon coverage (acquired from RMRS Forestry Sciences Lab 2002)
APPENDIX B: Historical Fire Regime Modeling Rules
Adapted from Jones et al. (2002) for Bitterroot Front polygon coverage (acquired from RMRS Forestry Sciences Lab 2002)

Attributes used:
Potential Vegetation Type (PVT):
1-abla1, 2-abla2, 11-psemen, 31-abgr2/psme2/psme1, 33-pial/laly

Aspect Direction (ASPDIR):
1-north, 2-south

Slope Class (SLPCLASS):
1 (0-10%), 2 (11-30%), 3 (31-45%), 4 (46-60%), 5 (>60%)

Cover Type (SPECIES):
GF-grand fir, PP-ponderosa pine, DF-Douglas fir, LP-lodgepole pine, L-western larch, AGR-agriculture, NF-non-forest

Attributes labeled:
Historical Fire Regime (HFR):
4-NL (non-lethal), 1-MS1 (short-interval mixed-severity), 2-MS2 (long-interval mixed-severity), 3-MS3 (variable-interval mixed-severity), 5-SR1 (short-interval stand-replacement), None

NL:
PVT = 11 and ASPDIR = 1 and SLPCLASS = 1
PVT = 11 and ASPDIR = 2 and SLPCLASS <= 3
PVT = 31 and ASPDIR = 1 and SLPCLASS = 1
PVT = 31 and ASPDIR = 2 and SLPCLASS <= 3

MS1:
PVT = 1 and SLPCLASS = 1
PVT = 11 and ASPDIR = 1 and (SLPCLASS = 2 or SLPCLASS = 3)
PVT = 11 and ASPDIR = 2 and SLPCLASS = 4
PVT = 31 and ASPDIR = 2 and SLPCLASS = 4
PVT = 31 and ASPDIR = 1 and (SLPCLASS = 2 or SLPCLASS = 3)
SPECIES = GF and PVT = 31 and ASPDIR = 1 and SLPCLASS <= 2
SPECIES = GF and PVT = 31 and ASPDIR = 2 and SLPCLASS <= 3

MS2:
PVT = 1 and SLPCLASS = 2
PVT = 2 and ASPDIR = 1 and SLPCLASS <= 1
PVT = 2 and ASPDIR = 2 and SLPCLASS <= 2
PVT = 11 and ASPDIR = 1 and SLPCLASS >= 4
PVT = 11 and ASPDIR = 2 and SLPCLASS = 5
PVT = 31 and ASPDIR = 1 and SLPCLASS >= 4
PVT = 31 and ASPDIR = 2 and SLPCLASS = 5
SPECIES = GF and PVT = 31 and ASPDIR = 1 and SLPCLASS = 3
SPECIES = GF and PVT = 31 and ASPDIR = 2 and SLPCLASS = 4

**MS3:**
PVT = 33

**SR1:**
PVT = 1 and SLPCLASS >= 3
PVT = 2 and ASPDIR = 1 and SLPCLASS >= 2
PVT = 2 and ASPDIR = 2 and SLPCLASS >= 3
SPECIES = GF and PVT = 31 and ASPDIR = 1 and SLPCLASS >= 4
SPECIES = GF and PVT = 31 and ASPDIR = 2 and SLPCLASS = 5

Covertype and PVT Modifications:

**MS1:**
SPECIES = PP and HFR = 5
SPECIES = LP and HFR = 4
SPECIES = L and HFR = 4

**MS2:**
SPECIES = DF and HFR = 5 and (PVT <> 35 or PVT <> 36)
SPECIES = GF and SIZECLASS = 4 and PVT = 31 and (HFR = 4 or HFR = 1) and SLPCLASS = 1

**SR1:**
SPECIES = GF and SIZECLASS = 4 and PVT = 31 and (HFR = 4 or HFR = 1) and SLPCLASS >= 2

**None:**
Species = AGR or Species = NF
APPENDIX B: Current Fire Severity and Condition Class Modeling Rules

Adapted from Jones et al. (2002) for Bitterroot Front polygon coverage (acquired from RMRS Forestry Sciences Lab 2002)

Attributes used:
Modified Historical Fire Regime (MHFR):
   First digit = HFR:
       4-NL (non-lethal), 1-MS1 (short-interval mixed-severity), 2-MS2 (long-interval mixed-severity), 3-MS3 (variable-interval mixed-severity), 5-SR1 (short-interval stand-replacement)
   Second digit = Current Fire Severity (CFS) slope class:
       2 (≤ 30%), 3 (>30%)

Fire Tolerance (FIRETOL):
   1-Tolerant, 2-Moderately Tolerant, 3-Intolerant

Size Class (SIZECODE):
   1-Seedling/sapling (<5”dbh), 2-pole (5-8.9”), 3-medium (9-14.9”), 4-large (15-20.9”), 5-very large (>21”)

Canopy Density (DENSITY):
   1 (0-14%), 2 (15-39%), 3 (40-69%), 4 (70-100%)

Attributes labeled:
Current Fire Severity (CFS):
   NL (non-lethal), MS1 (low mortality mixed-severity), MS2 (high mortality mixed-severity), MS3 (variable mortality mixed-severity), 5-SR1 (stand-replacement)

Condition Class (CC):
   CC1 (low departure from historical conditions), CC2 (moderate departure from historical conditions), CC3 (high departure from historical conditions)

CC1:
CFS = NL
   MHFR = 42 AND FIRETOL = 1 AND SIZECODE >= 2 AND DENSITY <= 2
   MHFR = 43 AND FIRETOL = 1 AND SIZECODE >= 4 AND DENSITY <= 2

CFS = MS1
   MHFR = 12 AND FIRETOL = 1 AND DENSITY <=2
   MHFR = 12 AND FIRETOL = 2 AND SIZECODE >= 2 AND DENSITY <= 2
   MHFR = 13 AND FIRETOL = 1 AND SIZECODE >= 4 AND DENSITY <= 2

CFS = MS2
   MHFR = 22 AND FIRETOL = 1 AND SIZECODE <> 2
   MHFR = 22 AND FIRETOL = 1 AND SIZECODE = 2 AND DENSITY <= 2
   MHFR = 22 AND FIRETOL = 2
MHFR = 22 AND FIRETOL = 3 AND SIZECODE >= 3 AND DENSITY <= 2
MHFR = 23 AND FIRETOL = (1 OR 2) AND DENSITY <= 2
MHFR = 23 AND FIRETOL = 1 AND SIZECODE >= 4 AND DENSITY >= 3

CFS = MS3
MHFR = 3

CFS = SR
MHFR = 5

CC2:
CFS = MS1
MHFR = 42 AND FIRETOL = 1 AND SIZECODE = 1 AND DENSITY <= 2
MHFR = 42 AND FIRETOL = 1 AND SIZECODE >= 4 AND DENSITY >= 3
MHFR = 42 AND FIRETOL = 2 AND SIZECODE >= 2 AND DENSITY <= 2
MHFR = 43 AND FIRETOL = 1 AND SIZECODE = (2 OR 3) AND DENSITY <= 2
MHFR = 43 AND FIRETOL = 1 AND SIZECODE >= 4 AND DENSITY >= 3

CFS = MS2
MHFR = 12 AND FIRETOL = 1 AND SIZECODE >= 4 AND DENSITY >= 3
MHFR = 13 AND FIRETOL = 1 AND SIZECODE >= 4 AND DENSITY >= 3

CFS = SR
MHFR = 22 AND FIRETOL = 1 AND SIZECODE = 2 AND DENSITY >= 3
MHFR = 22 AND FIRETOL = 3 AND SIZECODE <= 2
MHFR = 22 AND FIRETOL = 3 AND SIZECODE >= 3 AND DENSITY >= 3
MHFR = 23 AND FIRETOL = (1 OR 2) AND SIZECODE <= 3 AND DENSITY <= 2
MHFR = 23 AND FIRETOL = 2 AND SIZECODE >= 4 AND DENSITY >= 3
MHFR = 23 AND FIRETOL = 3

CC3:
CFS = MS2
MHFR = 42 AND FIRETOL = 1 AND SIZECODE <= 3 AND DENSITY >= 3
MHFR = 42 AND FIRETOL = 2 AND SIZECODE = 1
MHFR = 42 AND FIRETOL = 2 AND SIZECODE >= 2 AND DENSITY >= 3
MHFR = 42 AND FIRETOL = 3 AND SIZECODE >= 3 AND DENSITY <= 2
MHFR = 43 AND FIRETOL = (1 OR 2) AND SIZECODE = 1 AND DENSITY <= 2
MHFR = 43 AND FIRETOL = 1 AND SIZECODE <= 3 AND DENSITY >= 3
MHFR = 43 AND FIRETOL = 2 AND SIZECODE >= 2 AND DENSITY = 2
MHFR = 12 AND FIRETOL = 1 AND SIZECODE <= 3 AND DENSITY >= 3
MHFR = 12 AND FIRETOL = 2 AND SIZECODE = 1
MHFR = 12 AND FIRETOL = 2 AND SIZECODE >= 2 AND DENSITY >= 3
MHFR = 12 AND FIRETOL = 3 AND SIZECODE >= 3 AND DENSITY <= 2
MHFR = 13 AND FIRETOL = (1 OR 2) AND SIZECODE = 1 AND DENSITY <= 2
MHFR = 13 AND FIRETOL = 1 AND SIZECODE = (2 OR 3)
MHFR = 13 AND FIRETOL = 2 AND SIZECODE >= 2 AND DENSITY = 2

CFS = SR
MHFR = 42 AND FIRETOL = 3 AND SIZECODE <= 2
MHFR = 42 AND FIRETOL = 3 AND SIZECODE >= 3 AND DENSITY >= 3
MHFR = 43 AND FIRETOL = 2 AND DENSITY >= 3
MHFR = 43 AND FIRETOL = 3 AND SIZECODE <= 2
MHFR = 43 AND FIRETOL = 3 AND SIZECODE >= 3
MHFR = 12 AND FIRETOL = 3 AND SIZECODE <= 2
MHFR = 12 AND FIRETOL = 3 AND SIZECODE >= 3 AND DENSITY >= 3
MHFR = 13 AND FIRETOL = 1 AND SIZECODE = 1 AND DENSITY >= 3
MHFR = 13 AND FIRETOL = 2 AND DENSITY >= 3
MHFR = 13 AND FIRETOL = 3 AND SIZECODE <= 2
MHFR = 13 AND FIRETOL = 3 AND SIZECODE >= 3
The treatment cycle code will be called if Succession Regen and Fire regen fail to create a new state.

The code does the following:

1. Determine if we have the appropriate conditions.
   Check last 3 veg states for one of:
   a. a Treatment that changes the structure but not the size class.
   b. A Light or Mixed Severity fire

2. If we don't have a correct condition return.

3. Go backward through the veg states until we find a change in size class, or we reach the beginning.
   Make a note of how many states we search back.

4. Take the unit's current state and project it forward through succession n times. Where n is the count we found in step 3.

5. Remove one level of structure from the resulting size class. (i.e. LMU --> LTS)

6. Create a new state:
   Current Species/ New Size Class/ Current Density

7. If this creates a valid Vegetative Type then use this as the new state for the unit.