MAPPING FIRE REGIME CONDITION CLASS: A METHOD FOR WATERSHED AND PROJECT SCALE ANALYSIS

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ABSTRACT

Fire regime and associated condition class mapping have provided key data for development of cohesive strategies for restoration of fire-adapted ecosystems and for the National Fire Plan within the U.S. Department of Agriculture, Forest Service and U.S. Department of Interior land management agencies. Fire regime condition class (FRCC) provides data that can be used to infer risk to ecosystem sustainability and risk of uncharacteristic wildland fire behavior and effects. These spatial data when combined with human community locations can be used to identify communities at risk from uncharacteristic wildland fire. When combined with spatial data on air, native species, and water, opportunities for fuel management and fire use can be identified that benefit local communities and minimize risk or potentially enhance resources and sustainability. Scenarios of spatial prioritization, fire use and fuel management levels, and associated resource and risk reduction effects can be evaluated by combining these data with tools to model future outcomes. In combination with vegetation composition and structure, understanding of FRCC provides the framework for design of projects on the ground.

A method for coarse-scale (1-km^2) mapping of FRCC and associated fire management data across the conterminous U.S. has been developed and applied. However, no method had been developed and applied for finer-scale (30-m) watershed and project mapping of FRCC and associated prioritization and planning data. The study described in this paper used data from selected landscapes in the western U.S. to develop a method for FRCC analysis at watershed and project scales. Results indicate that the definitions and methods for mapping and understanding fire regime condition classes should change with scale of application. At a coarse scale, such as that used for national, regional, and state levels of prioritization and planning, the variation of fire regime frequency and severity can be collapsed into broad categories, and condition class departure can be assigned via rule sets. The large pixel area accounts for natural variation within and between fire regimes and condition classes that occurs across multiple stands or patches. At the finer scales (<1 km^2) of watershed assessment and project analyses, any one of a number of the vegetation–fuel classes characteristic of the natural or historical system can occur. Methods at this finer-scale focus on determination of the composition of characteristic classes and the associated variation in fire interval and severity. Standardized steps were developed, which combine available information with ground reconnaissance, and integration with the "box model."

keywords: condition class, fire regimes, fuels, natural range of variability, planning, western United States.

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INTRODUCTION

Fire regime condition class (FRCC) is now a key variable for assessment of wildland fire risk to people (communities) and ecosystems in the United States. Condition classes, numbered from 1 to 3, represent increasing levels of risk from uncharacteristic wildland fire behavior and effects (Hann and Bunnell 2001, Hardy et al. 2001, Schmidt et al. 2002). Also, condition classes are generally equivalent to low, moderate, and high departure from the natural or historical range of variability (HRV), considered a baseline for coarse-filter assessment of risks to ecosystems, habitats, and social values (Morgan et al. 1994, Hann et al. 1998, Landres et al. 1999).

Hardy et al. (2001) and Schmidt et al. (2002) map FRCC and associated information to support national scale strategic fire and fuels planning using coarse-scale 1-km^2 data for the conterminous United States. They define and map five historical natural fire regimes using a rule set approach to unique combinations of biophysical data. The fire regimes, based on Heinselman (1981), Morgan et al. (1996), and Brown (1995), are 0- to 35-year frequency with low severity (I), 0- to 35-year frequency with stand-replacement severity (II), 35- to 100+-year frequency with mixed severity (III), 35- to 100+-year frequency with stand-replacement severity (IV), and 200+-year frequency with stand-replacement severity (V). They define fire frequency or interval as "the average number of years between fires" and severity as the "effect of the fire on the dominant overstory vegetation."

Hardy et al. (2001) and Schmidt et al. (2002) classify FRCCs according to the relative risk of losing key components that define an ecosystem. They determine relative risk by comparing the current to the historical or natural baseline. They describe condition classes qualitatively as alteration from the historical range and risk of loss of ecosystem components and assign them using a rule set approach to 1-km^2 pixels based on combination of fire regime, cover type, and forest density or non-forest for each potential natural vegetation group.

Primary objectives for this study were to develop methods that could be applied consistently at the watershed and project scale to assess: 1) departure from the central tendency of the historical range of variability (HRVD), 2) FRCC and associated departure variables, 3) the primary causes of departure, and 4) associated management implications. A standardized succession–disturbance state and transition model (called here the "box" model) also was developed to reduce differences in classifications among interdisciplinary teams (IDT), time necessary for each IDT to set up the model, and time necessary for each IDT to learn the simulation modeling component of the methods.

Confidence levels for watershed and project scale FRCC and HRVD determination vary depending on amount of sampling and analysis of information. This study focuses on reconnaissance-level on-the-ground sampling, use of scientific literature, and integration of this information through modeling. Results provide the basis for rapid determination of FRCC, associated departure variables, and management implications including risk.

FRCC and associated departure variables are multi-scale landscape variables (Morgan et al. 1994, 2001; Hann and Bunnell 2001; Hann et al. 2003). The departure or condition of a historical or natural fire regime can be determined for multiple scales of extent—as a summary across a landscape of large extent, such as a river subbasin or national forest, or as a summary across one or a group of different types of biophysical environments. Hardy et al. (2001) and Schmidt et al. (2002) used a potential natural vegetation group classification to classify biophysical environments. This was based on grouping Küchler's (1975) map of potential natural vegetation types. This classification stratified the land area based on site and disturbance conditions that supports a regime of natural vegetation, typically named by the predominant plant community for that vegetation regime. The natural vegetation regime results from the integrated vegetation relationship to terrain, soils, climate, and natural disturbance frequencies and severities. A somewhat different biophysical classification focuses on potential vegetation type (PVT) without the inference of the natural regime and stratifies the land (topography, soil, climate, and organisms) that supports a group of site indicator species that tend to dominate in the absence of disturbance (Hann et al. 1997, 1998).

Although FRCC and associated departure variables do not have a specific maximum area of extent, usefulness of the summary class or departure value becomes low when the dominant biophysical class makes up a small portion of the landscape such that the average across a number of biophysical classes reflects many interacting processes instead of a few dominant processes (Hann et al. 1997). This maximum extent usually occurs at a subbasin (4^{th} code) level of the hydrologic unit code hierarchy, province level of the ecoregion code hierarchy, and planning unit (national forest, park, refuge, reservation, county) of administrative levels (Hann and Bunnell 2001). These variables do have a minimum area of extent, in that they are not site variables (such as cover type or soil type) that can be determined for a sample point, plot, or stand. Because the fire regime and HRV are defined by transition and disturbance probabilities, percent replacement, and composition, structure, and mosaic of vegetation successional stages, sufficient area must be included to account for these processes (Keane et al. 1996, Hann et al. 1997, Keane and Long 1998, Hann and Bunnell 2001). For typical wildland landscapes this appears to be a minimum of about 1 km^2, but could be smaller for island wildlands that are scattered within waterscapes or agricultural or urban landscapes, or where polygon size of the dominant ecosystems are small (such as wetlands).

STUDY AREA

This development of a method for watershed and project scale FRCC mapping was conducted using selected landscapes in the eleven western U.S. states. The "ECORegion" of Hardy et al. (2001) and Schmidt et al. (2002) combined with ecoregion provinces (Bailey 1995) were used as a stratification to select wildland landscapes in the western U.S. where the author had data from previous field reconnaissance and project analysis (Table 1).

METHODS

Hardy et al. (2001) and Schmidt et al. (2002) developed their definitions and methods for coarse-scale, broad extent mapping of the conterminous U.S. to address the watershed and project scale; Hann and Bunnell (2001) defined fire regimes and condition classes based on concepts of multiple scales (Tables 2 and 3). For this study, the author further refined the definitions using reconnaissance information from the landscapes selected for study.

Hardy et al. (2001) and Schmidt et al. (2002) recognized a broad fire interval boundary between the infrequent (35–100+ years) and rare (200+ years) because of the lack of information for some types in the conterminous U.S. Consequently, they define an infrequent fire return interval as 35 to 100+ years with an upper limit of 200 years. At the watershed and project extent this broad boundary also appears to be necessary because of types that appear to have high variability through time (Keane et al. 2004; McNicoll and Hann, *this volume*). The boundary between frequent (0–35 years) and infrequent (35–100 years) should be broad for similar reasons. For this study the definition of the frequent fire interval was adjusted to be 0 to 35+ years (Table 2) with an upper limit of 50 years for systems with high temporal variation (Figure

1). Hardy et al. (2001) and Schmidt et al. (2002) do not specify a statistical measure for central tendency of the fire interval since their assignment was qualitative expert opinion. Although Hessburg et al. (1999) found that the median was the best measure of central tendency when assessing HRV with reference data from historical photography, Hann et al. (1997) and Keane et al. (1996, 1997, 2004) found that the mean and median produce similar estimates of central tendency when using simulation to integrate multiple sources of reference data for assessing HRV. For this study the mean was selected as the statistical measure of central tendency because simulation modeling was used to integrate multiple sources of reference data and the mean is more commonly understood by managers.

For this study the break between surface and mixed fire severities, and mixed and replacement fire severities, was assigned 25% and 75% replacement of the upper layer respectively (Figure 1). The five fire regime classification of Hardy et al. (2001) and Schmidt et al. (2002) does not include mixed severity in fire regime I nor in fire regime II. For this study the definition of fire regime I was expanded to include mixed fire severities (Figure 1). In a similar vein fire regime III was expanded from infrequent mixed to include infrequent mixed and surface. The infrequent replacement regime (IV) was defined similar to that of Hardy et al. (2001) and Schmidt et al. (2002), while the rare replacement regime (V) was expanded to include surface and mixed as well as replacement fire severities (Figure 1). Hardy et al. (2001) and Schmidt et al. (2002) did not specify the percent replacement for the different regimes or the statistical measure of central tendency because their assignments were based on qualitative expert opinion. For this study I specified the percent replacement and used the mean as the statistical measure of central tendency.

Hardy et al. (2001) and Schmidt et al. (2002) did not define a quantitative departure for FRCC. Because their methods assigned relative departure of HRV of 0 to 4, and condition class of 1 to 3 there was no need for this type of definition. At the watershed and project scale a quantitative definition of departure was necessary because a rule set assignment of a departure or condition class was not applicable to stand components. FRCC and associated departure variables were classified by calculating a percent departure with a maximum of 100% and using a simple division of this departure into thirds for FRCC 1, 2, 3, and for departure variables (FRD [Fire Regime Departure] and HRVD) of low, moderate, and high (Figure 2). The FRCC of 1 was considered by Hardy et al. (2001) and Schmidt et al. (2002) to be within the HRV, while FRCC 2 and 3 were considered to be outside of HRV. For this study I considered the FRCC of 1 or the low classes of departure variables to be within ±33% of the mean, or a range of 66%. This range was considered to be a compromise between the 80% median range recommended by Hessberg et al. (1999) from analysis of reference historical photography data for HRV, and the ±25% (range of 50%) recommended by Keane et al. (1997, 2002, 2004) for integration of reference data to assess HRV using simulation. In this study two FRCC departure variables (FRD, HRVD) were considered important inputs to determination of FRCC. These were departure from the natural or historical range of fire interval–severity and vegetation–fuel composition and structure departure. Preliminary review of the landscapes selected for study indicated that different ecosystems respond differently; loss of diversity in native species composition, loss of soil cover, simplification of patch mosaic cover, simplification of structure, and changes in fuel structure or loading can be substantial in association with fire interval–severity departure, but not detected in the cover type–structure classification used to measure vegetation–fuel composition–structure departure. In contrast, the same variables can be substantial in association with vegetation–fuel composition–structure departure, but not detected in the fire interval–severity measures.

As recommended by Keane et al. (1997, 2002, 2004), variables that classify fire regime or natural or historical range of variability (FRD, FRCC, and HRVD at watershed and project extents) should integrate ground reconnaissance data with information from historical, recent historical, and current records and literature with a simulation model. Because interdisciplinary team members and experts would use this model across the western U.S., it was desirable to develop a standard set of class states and succession and disturbance pathways, and use user-friendly modeling software.

One of the most extensive efforts at developing these types of state and transition models across a wide variety of ecosystems has been the Interior Columbia Basin Ecosystem Management Project (ICBEMP) (Keane et al. 1996, Quigley et al. 1996, Hann et al. 1997, Quigley and Arbelbide 1997). The software used to develop the ICBEMP models was the vegetation dynamics development tool (Beukema and Kurz 2000). Through review of the ICBEMP models and the succession pathways of Hardy et al. (2001) and Schmidt et al. (2002), a standardized set of classes characteristic of HRV in most ecosystems was developed (Table 4). Classes were also identified that were uncharacteristic or did not occur in HRV. After testing and revisions of different formats for locating classes in relation to each other, a pattern was selected that appeared to be effective in modeling succession and disturbance relationships characteristic of HRV and modeling succession and disturbance to classes uncharacteristic of HRV. This format, similar to a box, was called the box model (Figure 3).

The most important component of the methods was the use of simulation to integrate information from ground reconnaissance, review of local historic and current paired photographs, and local fire history and historical vegetation literature. Use of expert judgment or textbook generalities relative to natural (historical) fire and other disturbance regimes applied to vegetation types at watershed and project extents apparently results in a substantial error. For example, the lodgepole pine (*Pinus contorta*) type has typically been characterized as an infrequent stand-replacement regime, yet much of this type can have mixed or surface severity and frequent interval (Hann et al. 1994; McNicoll and Hann, *this volume*). Sagebrush (*Artemisia* spp.) has typically been characterized as a frequent-replacement regime, but commonly occurs with a mixed severity and infrequent interval. Similar errors occur when fire regime, FRCC, and HRV departure are estimated at watershed and project extents based on expert judgment or opinion without simulation testing. In almost all of the landscapes selected for this study the author's initial classification of the natural (historical) fire regime, FRCC, and HRV departure class was proven incorrect after conducting the ground reconnaissance and integration of information with simulation. These potential errors increase the importance of consistently modeling the interactions of fire frequency and severity with multiple pathways of succession and other disturbances. Lack of consideration of influences equally or more important than fire, such as succession, lack of seed source due to large patch size or repeated fire, and competition, can result in substantial misinterpretation.

Each landscape was selected based on the desire to have a range of ECOregions and potential vegetation groups (PVG) from Hardy et al. (2001) and Schmidt et al. (2002) (Table 1). In addition the author took advantage of interdisciplinary team projects (Box Creek, Missouri Breaks, and Trout West) where he could work with the interdisciplinary teams to assess the value and difficulties of the FRCC and HRV departure methods and use of the box model.

Each landscape selected for study was assessed using the following steps:

1) Review of information from Bailey (1995), Hardy et al. (2001), Schmidt et al. (2002), local literature, and local vegetation maps and data prior to visiting the

landscape. Preliminary classification of fire regime potential vegetation groups (FRPVG).
2) After arriving at the landscape select one or more viewpoints for landscape scale photographs based on achieving the best perspective of FRPVG variation across the landscape. Note dominant FRPVGs, associated terrain, local weather and climate influences, current vegetation–fuel composition, structure, patch mosaic, and recent historic anthropogenic disturbances, such as livestock grazing, logging, and wildland–urban interface.
3) Walk a gradient transect: across elevation and aspect changes for foothill and mountainous landscapes; across soil or other gradients for flat landscapes. Take notes on elevation, aspect, or soil breaks between different FRPVGs. Collect data on typical FRPVG conditions to record general location, vegetation, structure, fuels, ground cover, and site conditions. Write notes on recent historical anthropogenic disturbances, such as fire, fire exclusion, livestock grazing, logging, and development. Take photographs of typical stand-scale FRPVG conditions.
4) Utilize reconnaissance methods to characterize the historical fire interval, severity, and vegetation–fuel conditions. Formal cross-dated fire history or destructive fire-scar sampling is not necessary for this type of reconnaissance, but this information should be given more weight if available from previous work. Walk contour transects across each dominant FRPVG to find fire-scarred trees, stumps, logs, or snags. Core, count, or estimate the age of the trees, count scars, and divide age by number of counted scars plus two (one for fire prior to regeneration and one for fire prior to char) to estimate an approximate fire interval range (Arno and Sneck 1977, Barrett and Arno 1988). Collect data on associated stand conditions to record general location, vegetation, structure, fuels, ground cover, and site conditions. Write notes on associated HRV disturbance regime and recent historic anthropogenic disturbances, such as fire, fire exclusion, livestock grazing, logging, and the wildland–urban interface. Take photographs of evidence of typical disturbance regime conditions.
5) Return to the landscape viewpoints and estimateor determine from a map or aerial photo summary the box model class composition for historical regime and current conditions (Table 4).
6) Identify and review local historical oblique and aerial photo resources and maps. If possible identify location of historical oblique photos and shoot a comparative current photo. Identify and review historic maps from forest reserve, geological, agricultural, and military expeditions, if available. Use the changes interpreted from the photos to estimate succession times between early-, mid-, and late-successional (seral) stages and open and closed canopies. Review General Land Office survey notes if available. List dominant species of historical and current regimes. Use literature and the Fire Effects Information System (http://www.fs.fed.us/database/feis/index.html)to identify species growth rates following fire, regeneration strategies, and adaptations to fire and other disturbances. Use this interpreted information to estimate succession times from early- to mid- to late-seral structural stages, and to interpret frequency and severity of fire and other natural disturbances necessary to maintain these species as dominants in the landscape. Review literature and local history for evidence of Native American and prehistoric peoples' use of the area and of fire. Include these effects as

part of the natural (historical) regime in relation to 10 to 15 thousand years of fire adaptations of native species (Barrett and Arno 1982).
7) Load historical estimates for succession rates and disturbance probabilities into the vegetation dynamics development tool, the box model. Input initial conditions for HRV, and simulate 10 times to get averages for classes, surface fire, and replacement fire (such as examples in Figures 4 and 5). Conduct sensitivity testing and adjustment until comfortable with the outcomes in association with knowledge from ground reconnaissance, historical and current photos, literature, and interdisciplinary team interaction and review.
8) Calculate vegetation–fuel composition–structure departure based on HRV average (example in Figure 4) and current estimate by summing the percent from current up to the HRV amount for the characteristic classes to determine the similarity (Table 4). Departure is calculated by subtracting the similarity from 100% (Table 5). Vegetation–fuel composition–structure departure or condition class can then be classified using the defined breaks (Figure 6, Table 5).
9) Use expert judgment or analysis of local wildland fire occurrence data to estimate current fire interval or a fire occurrence probability. Calculate fire interval departure by dividing the smaller of the two by the larger (Figure 5 example of historical probability from box model, current from estimate or local data) and subtracting from 1. Use expert judgment from people with experience on wildland or prescribed fires and fire behavior modeling to estimate current fire severity (probability of replacement fire). Calculate the fire severity departure by dividing the smaller of the two by the larger (Figure 5 example of historical probability from box model, current from estimate or probability) and subtracting from 1. To combine into the fire interval–severity departure sum the two values, divide by 2, and multiply times 100 to get a percentage. The combined fire interval–severity departure or condition class can then be classified using the defined breaks (Figure 6, Table 5).
10) Classify the overall fire regime, FRCC, and associated departure variables (Figure 6, Table 5), and calculate a weighted average to landscape scale for multiple PVGs. Identify current vegetation classes with low (< ±25% difference from HRV average), moderate (≥25%, < ±75% difference from HRV average), and high (≥75% difference or uncharacteristic) contribution to fire regime and HRV departure from central tendency. Identify current vegetation classes with maintain management implication or similar abundance (< ±25% difference from HRV average), recruit management implication or rare abundance (≤ –25% difference from HRV average), and reduce management implication or high abundance (≥25% difference from HRV average). Identify current classes with specific fire behavior and effects risks to the wildland–urban interface and resources.

RESULTS

Assessment of the 10 different landscapes confirmed that watershed and project scale FRCC and HRVD were landscape variables that should be summarized at the FRPVG, watershed or project area, and management region (such as ownership and roadless combinations) scale because the natural (historical) regime includes some component of all of the five characteristic development stages. Even though the FRCC and associated departure variables should not be mapped to stand or patch scales, stand or patch level risk classes and management implications (such as reduce, recruit, or maintain or rare, similar, high abundance) can be mapped. Those characteristic stand or patch types that were substantially above or below the HRV range, and the uncharacteristic types, were categorized as to their low, moderate, or high risk (contribution) to the FRCC and associated departure variables and classified as to management implication (maintain, reduce, and recruit or rare, similar, and high abundance).

The standardized box model format and state and disturbance definitions substantially reduced both the time necessary for interdisciplinary members to become proficient in the analysis and the potential for miscommunication between members. The ground reconnaissance integrated with literature and office information and simulation versus use of office information and literature resulted in model outcomes with substantially improved confidence. Most differences between model outcomes were related to real differences between ecosystems and landscapes, rather than differences in complexity of classification and disturbances or lack of locally specific knowledge.

For the 10 different landscapes, a majority of the initial estimates based solely on expert judgment, literature, and available office information were found to be in error. Fire regime class errors using only the literature or available office data generally occurred because of a focus on the role of fire in the dominant PVG (e.g., lodgepole pine or sagebrush often classified as replacement regimes). However, the local terrain, climate, fire weather, ignition source, and juxtaposition (patch mosaic) of more and less flammable vegetation types, appear to be more important causal factors for determining the fire regime than the PVG. Errors in PVG assigned based on readily available office information occurred because such information was focused on the dominant upper layer species instead of site potential species (e.g., focus on ponderosa pine [*Pinus ponderosa*] in the overstory instead of Douglas-fir [*Pseudotsuga menziesii*] in the understory). Simulation modeling that integrated ground reconnaissance information and historical data with information readily available in office data files and existing literature to determine the FRPVG produced results with much higher confidence. Field reconnaissance was used to identify potential vegetation based on plant species indicators of the biophysical environment.

The pine–Douglas-fir landscape of the Box Creek area of Colorado is an example of a landscape that was classified very differently pre- and post-field reconnaissance. Initially, the fire regime was classified as infrequent replacement and the PVG as spruce–fir because of the predominance of lodgepole pine. Field reconnaissance, however, found ponderosa pine stumps, snags, and down logs with fire scars, fire-scarred lodgepole pine stumps, and evidence of Douglas-fir. This information, combined with the simulation modeling, caused the FRPVG to be classified as frequent, mixed conifer (ponderosa pine–Douglas-fir–lodgepole pine).

The area with the most frequent natural fire regime was the juniper woodland–pine forest landscape in the Pine Creek area of Arizona (Table 5), although the plains grassland (with conifer) in the Missouri Breaks area of Montana was also quite frequent. Primary causal factors for departure in the juniper woodland–pine forest landscape included fire exclusion and uncharacteristic historic grazing. Excessive livestock grazing during the late 1800s and early 1900s appeared to have substantially increased density of juniper and pine regeneration leading to more closed stands than would have occurred with fire exclusion alone. Although livestock numbers were reduced by the mid-1900s the effects of juniper and pine canopy closure on reduction of understory and seral grassland production later concentrated the remaining livestock in successively smaller areas, resulting in continued uncharacteristic effects.

Fire interval–severity departure calculations indicate that the juniper–desert shrub landscape of the Green River area of Utah had the highest change as compared with the HRV, probably a result of the combination of invasive species, long history of excessive livestock grazing combined with vulnerable semi-arid climate, and juniper canopy closure, resulting in a condition class 3 (Table 5, Figure 6). The borderline condition class 2, almost class 3, for vegetation–fuel composition and structure departure of this type (65) may have been low because of the lack of a refined classification of current vegetation–fuel types. A classification with higher resolution could result in calculation of a somewhat higher departure. The overall FRCC was a 3 since either fire interval–severity or vegetation–fuel composition–structure departure greater than or equal to 67 can result in an FRCC 3 (Figure 6). Primary causal factors for departure in the juniper–desert shrub landscape included a host of effects ranging from historical and current grazing and off-road-vehicle use, to fire exclusion in the juniper combined with a semi-desert droughty climate that is vulnerable to invasive plants that subsequently increase vulnerability to fire ignition and flammability (Table 6).

Vegetation–fuel composition–structure departure calculations were highest for the plains grassland with conifer landscape of the Missouri Breaks area of Montana (Table 5, Figure 6). Historically, trees were scattered in rock outcrops or across bare ridges in an otherwise contiguous grassy landscape with frequent replacement fires; however, the area is currently characterized by a large increase in relatively dense patches of trees that occur repeatedly across the landscape on any soil and aspect with adequate water for tree regeneration. Both of the pine–Douglas-fir landscapes of the Trout West and Box Creek areas of Colorado produced relatively high vegetation–fuel departures of 73% and 75%, respectively. The primary causes for departure in the warmer Trout West landscape included both fire exclusion and past harvest activities, while in the cooler Box Creek landscape the late 1800s mining-era timber harvest and excessive surface soil disturbance played the primary role (Table 6).

The spruce–fir (*Picea–Abies*) landscape of the Box Creek area of Colorado and the sagebrush cool landscape of the Upper Salmon River area of Idaho both had a moderate level of departure in both vegetation–fuel and fire interval–severity (Table 5, Figure 6). Although these landscapes classify as condition class 2 and moderate HRV departure, some risks were still found to be high (Table 7). Crown closure and density in the spruce–fir forests resulted in moderate risks to ecosystems. Although fire effects risks are low, the departure in habitat conditions for an area with high biodiversity and productivity potential resulted in high current risk to ecosystems. The landscape position of the sagebrush cool landscape which has rapid fire spread in surface grass fuels and relatively tall flame lengths in the sagebrush fuels, and is backed by fire-generated winds from adjacent forests, caused high risk to wildland–urban interface. Similar to the spruce–fir landscape, although risks of fire effects to ecosystems were only moderate, the risks of current departure in a productive system were high. The alpine meadow–upper subalpine forest landscape of the Box Creek area of Colorado had the lowest departure and was the only landscape to have a vegetation–fuel, fire interval–severity, and overall fire regime condition class of 1.

DISCUSSION

The classification process for FRPVG(s) was difficult for many interdisciplinary team members to grasp. A common error made by team members was to assume that the current dominant vegetation species (for example ponderosa pine in the upper layer) was an indicator of the biophysical environment instead of focusing on the true site indicators (for example, Douglas-fir in the understory). Once the PVG definition was understood, interdisciplinary team members found that local plant association (habitat type), landtype association, or soil maps were either too complex or too simplified to be well correlated with the desired scale of FRPVG stratification. Initial tendencies were to use the dominant vegetation as the proxy to fire regime. However, this usually led to a substantial error in fire regime determination (such as assigning infrequent replacement to lodgepole pine), and often resulted in too many types to effectively analyze or articulate either within the interdisciplinary team or between team members and external individuals and groups. Hann et al. (1997) recommend the "rule of six" to keep the classification and maps simple. The classification and mapping stratifications should be designed so that management interpretations and implications need to be discussed for no more than 6 (preferably only 3–4) different classes at any one time within the interdisciplinary team or with external individuals or groups.

The most useful process appears to be to classify the fire regimes first and only split PVG(s) within a fire regime when necessary to account for different management implications. Focus on dominant PVGs for classifying types of landscapes and then group types of landscapes according to similar landscape-scale fire regimes to keep the number of FRPVG stratifications to 6 or fewer. Key management implications for stratifying FRPVG based on reduction of risk to people and restoration of fire-adapted ecosystems are level of effects of 1) fire exclusion; 2) past uncharacteristic management (such as harvest and grazing); and 3) exotic invasions (such as cheatgrass [*Bromus tectorum*], knapweed [*Centaurea* spp.], and blister rust [*Cronatium ribicola*]). Useful criteria for PVG stratification include 1) upper layer lifeform (herbland, shrubland, woodland, forestland, barrenlands, and agricultural–urban); 2) dominant upper layer species complexity (one, two, and greater than two); 3) lower layer (understory) lifeform; 4) standing, surface, and duff–litter layer fuels and fuel model; 5) climate (temperature/moisture zones not associated with slope–aspect); and 6) slope–aspect (flat, cool-aspect slopes, and warm-aspect slopes).

Past assessments of fire regime and HRV departure, such as by Hann et al. (1994, 1997), have focused on the vegetation composition and structure as a proxy for overall landscape composition and process departure. The results from this evaluation of 10 different landscapes across the western U.S. indicate this may tell only half the story. Three of the landscapes (juniper–desert shrub of Utah, pine forest of Colorado, and juniper woodland–pine forest of Arizona would have been classified as FRCC 2, if only vegetation–fuel departure was considered (Figure 6). In contrast, four of the landscapes (plains grassland with conifer of Montana, pine–Douglas-fir cool and warm of Colorado, and sagebrush warm of Idaho) would have been classified as FRCC 2 if only fire interval–severity departure was considered. Three reasons for the need to use both the vegetation composition and the fire interval–severity departure measures have become apparent: 1) different landscape types may express departure from HRV more in one measure than another; 2) methods of vegetation–fuel classification and mapping may not be of sufficient resolution in some landscapes to detect the full differences between current and the HRV regime; and 3) similar to the second reason, methods of ground reconnaissance and measurement of historical and current fire interval and severity may not be of sufficient resolution. The most useful approach combines both types of measures for determination of overall fire regime and vegetation departure and associated condition classes.

The idea that a condition class 2 or moderate HRV departure necessarily has low risk to people and ecosystems was found to be a misconception. This classification occurs typically in landscapes with the less frequent fires or more productive vegetation regimes. In a relative sense the level of uncharacteristic conditions may be less, but when an uncharacteristic wildland fire (wildfire) occurs in these types, the risk to people and ecosystems can often be just as high as condition class 3 in shorter interval regimes because the fuel loading, amount of ladder fuels, and crown canopy closure and density may be much higher. This can result in higher probability of a running crown fire with severe surface soil heating (Reinhardt et al. 1997, Scott and Reinhardt 2001). This can also be the case with FRCC 1 within a landscape naturally dominated by a crown fire regime. Even though the fire interval–severity and vegetation–fuel departure are within the HRV the risks to people from wildland fire (wildfire) characteristic to that system can be substantial, but probably not as severe as risks from a landscape in this fire regime, but in FRCC 2 and 3. Additional risk variables, such as for crown fire and soil heating, should be used in addition to FRCC and associated departure variables for prioritization and effects analysis.

FRCC, FRD, and HRVD methods should change with scale. The rule set method can be used for coarse-scale mapping of pixels 1 km^2 or larger, but finer-scale methods should use composition of vegetation–fuel, fire interval, and fire severity classes across landscape extents. A useful stratification for summary of these variables appears to be a combination of watershed, FRPVG, and management region (such as ownership, roadless). Although FRCC, FRD, and HRVD variables should not be mapped to finer-scale pixels, stands, or patches, risk rating of pixels, stands, or patches can be used to identify contribution to these variables. The use of the box model provides a consistent and systematic process to integrate a broad array of information at the watershed and project scale. In addition this model provides standardized classes and succession–disturbance pathways that reduce the time of the learning curve for interdisciplinary team members.

Substantial errors and lack of confidence in the FRPVG classification and subsequent FRCC, FRD, and HRVD result from use of textbook fire regimes applied to broad vegetation types. Classification, mapping, analysis, and management implications for these variables should be based on landscape-specific vegetation and disturbance history reconnaissance combined with thorough evaluation of local literature and other information sources. The use of simulation modeling provides a tool to integrate ground reconnaissance with other available information.

Future studies of methods should evaluate the definitions for upper layer canopy replacement for this scale of mapping. The values used in this study (25% and 75%) for classification of surface (non-replacement), mixed, and replacement severity may result in too much being placed into the mixed class. A classification based on thirds of 0% to 100% replacement may be more useful.

Results from Hardy et al. (2001) and Schmidt et al. (2002) indicated substantial amounts of FRCC 1 in eastern Montana. Our landscape selected for study in that area indicated substantial amounts of FRCC 3. This may indicate that conifer invasion in prairie cannot be detected with coarse-scale 1-km^2 remote sensing information or the rule set may not be sensitive to conifer presence in these types. Further investigation at finer scales will likely improve understanding of differences between coarse-scale and finer-scale methods.

The importance of having common base data themes and classification definitions cannot be overemphasized. These base data can also be used for fuel model mapping, and fire effects, fire behavior, and wildlife habitat modeling. The basic process of FRCC and associated departure variable analysis and interpretation provides a valuable science-based and consistent reference for these additional analyses, and a rationale for prioritization and design of projects.

MANAGEMENT IMPLICATIONS

These methods for FRCC, FRD, and HRVD have a broad array of applications:

1) Variables that can be used to identify and prioritize watershed assessment and projects for the National Fire Plan and cohesive strategies.
2) An analysis process that can be used to better-fit restoration efforts to a natural or historical reference baseline and its associated variation, rather than using the typical one-size-fits-all mechanical or fire prescription.
3) An analysis process that can be used to determine desired conditions for vegetation and fuel composition and structure and design treatments that will produce that composition and structure. Subsequent prescribed fire or fire use can then be used to mimic HRV effects and produce a more natural range of variation in outcomes.
4) The fire interval and severity departure provides a way to conserve fire-adapted native species that are in decline because of a lack of fire effects, even though the vegetation composition–structure indicates low departure from HRV.
5) The box model classes allow a direct linkage to local classifications. The definition for open and closed varies depending on the local climate and disturbance regime.
6) Although the box model is relatively simple in complexity, this appears to be very similar to the level of knowledge that can be garnered for local landscapes using a reconnaissance-type approach.
7) Costs of rapid reconnaissance watershed and project scale mapping of FRCC, FRD, and HRVD, and associated management implications range from $0.01 to $0.17 per hectare depending on the complexity of GIS computer work. Given that implementation costs range from $50 per hectare for wildland fire use to $1,730 per hectare for mechanical restoration adjacent to wildland–urban interface areas this is a very inexpensive price to pay for consistent, science-based data that can be used to prioritize and plan projects.

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Table 1. Landscape areas selected for study in the development of a method for classification and mapping of fire regime condition class at watershed and project extents in the western U.S. ECORegion(s) shown were developed by Hardy et al. (2001) and Schmidt et al. (2002) for use in the development of coarse-scale fire regime condition class.

ECORegion	Type of landscape (Dominant Potential Natural Vegetation Group[s])	Area
4	Juniper–desert shrub	Green River, Utah
4	Sagebrush (warm)	Middle Salmon River, Idaho
4	Sagebrush (cool)	Upper Salmon River, Idaho
1	Plains grassland (with conifer)	Missouri Breaks, Montana
3	Juniper–pine (woodland–forest)	Pine Creek, Arizona
2	Pine forest	Trout West, Colorado
2	Pine–Douglas-fir (forest)	Trout West, Colorado
2	Pine–Douglas-fir (forest)	Box Creek, Colorado
2	Western spruce–fir (forest)	Box Creek, Colorado
2	Alpine meadow–upper subalpine forest	Box Creek, Colorado

Table 2. Natural (historical) fire regime classes from Hardy et al. (2001) and Schmidt et al. (2002) as interpreted by the author for modeling landscape dynamics at project and watershed scales.

Fire regime class	Frequency (mean fire return interval)	Severity	Modeling assumptions
I	0–35+ years, frequent	Surface and mixed	Open forest, woodland, shrub, and savannah structures maintained by frequent fire; also includes frequent mixed-severity fires that create a mosaic of different age post-fire open forest, woodland, shrub, or herb patches that make a mosaic of structural stages, with patches generally <40 ha. Mean fire interval can be greater than 35 years in systems with high temporal variation.
II	0–35+ years, frequent	Replacement	Shrub or grasslands maintained or cycled by frequent fire; fires kill non-sprouting shrubs which typically regenerate and become dominant within 10–15 years; fires remove tops of sprouting shrubs which typically resprout and dominate within 5 years; fires typically remove most tree regeneration.
III	35–100+ years, infrequent	Mixed and surface	Mosaic of different age post-fire open forest, early- to mid-seral forest structural stages, and shrub- or herb-dominated patches generally <40 ha, maintained or cycled by infrequent fire. Interval can range up to 200 years.
IV	35–100+ years, less infrequent	Replacement	Large patches generally >40 ha, of similar age post-fire shrub- or herb-dominated structures, or early- to mid-seral forest cycled by infrequent fire. Interval can range up to 200 years.
V	200+ years	Replacement, mixed, and surface	Variable sized patches of shrub- or herb-dominated structures, or early- to mid- to late-seral forest depending on the type of biophysical environment. Cycled by rare fire or other disturbance events. Often have complex structures influenced by small gap disturbances and understory regeneration.

Table 3. Condition classes from Hardy et al. (2001) and Schmidt et al. (2002) as interpreted by the author for modeling landscape dynamics and departure from historical or natural range of variability at project and watershed scales. Historical Range of Variability (HRV) is the variability of regional or landscape composition, structure, and disturbances, during a period of time of several cycles of the common disturbance intervals, and similar environmental gradients, referring, for the United States, to a period prior to extensive agricultural or industrial development (synthesized from Morgan et al.1994, Hann et al. 1997, Landres et al. 1999). Natural Range of Variability (NRV) is defined as the ecological conditions and processes within a specified area, period of time, and climate, and the variation in these conditions that would occur without substantial influence from mechanized equipment.

Condition class	NRV or HRV departure	Description
1	Low	Vegetation composition, structure, and fuels are similar to those of the natural regime and do not predispose the system to risk of loss of key ecosystem components. Wildland fires are characteristic of the natural fire regime behavior, severity, and patterns. Disturbance agents, native species habitats, and hydrologic functions are within the natural range of variability.
2	Moderate	Vegetation composition, structure, and fuels have moderate departure from the natural regime and predispose the system to risk of loss of key ecosystem components. Wildland fires are moderately uncharacteristic compared to the natural fire regime behaviors, severity, and patterns. Disturbance agents, native species habitats, and hydrologic functions are outside the natural range of variability.
3	High	Vegetation composition, structure, and fuels have high departure from the natural regime and predispose the system to high risk of loss of key ecosystem components. Wildland fires are highly uncharacteristic compared to the natural fire regime behaviors, severity, and patterns. Disturbance agents, native species habitats, and hydrologic functions are substantially outside the natural range of variability.

Table 4. Successional (seral) state classes and simulated average for each class are shown for an example fire regime potential vegetation group (FRPVG) of frequent surface ponderosa pine on gentle terrain in the Trout West watershed, Colorado. Successional classes are derived using a vegetation dynamics development tool format called the box model. Similarity is the comparison to historical range of variation (HRV) central tendency with values from 67% to 100% considered to be within HRV. Since the current can be higher or lower than the HRV measure of central tendency this allows for a range of ±33%.

Class	Historical character[a]	Class description[b]	Example FRPVG current vegetation class description	HRV % average	Current (%)	Similarity (%)
A	Characteristic	Early seral	Tree regeneration open/grassland	14	9	9
B	Characteristic	Mid seral closed	Closed canopy pole	4	5	4
C	Characteristic	Mid seral open	Open canopy pole	11	2	2
D	Characteristic	Late seral open	Open canopy mid-mature–mature	59	20	20
E	Characteristic	Late seral closed	Closed mid-mature–mature	12	31	12
F	Uncharacteristic	Invasive (exotic) plants				
G	Uncharacteristic	Harvest not mimicking HRV effects or regime	Harvest large trees and leave small trees		1	
H	Uncharacteristic	Grazing not mimicking HRV effects or regime				
I	Uncharacteristic	Succession beyond HRV maximum	Patch sizes of multi-layer trees and down fuels exceed HRV regime		29	
J	Uncharacteristic	Fire effects more severe than HRV or regime				
K	Uncharacteristic	Soil disturbance more severe than HRV				
L	Uncharacteristic	Insects–disease invasive (exotic) or more severe than HRV or regime	Patch sizes of mortality exceed HRV regime		2	
Total				100	100	47

[a] Characteristic, occurs within HRV regime; uncharacteristic, does not occur within HRV regime.
[b] Closed, vegetation and fuel structure closed for given ecosystem climate and disturbance regime; open, vegetation and fuel structure open for given ecosystem climate and disturbance regime.

Table 5. Results from calculation of fire regime condition class and associated departure variables for landscape areas selected for study in the development of a method for classification and mapping of fire regime condition class at watershed and project extents in the western U.S. Information in columns for natural (HRV [historical range of variability]) fire frequency (NFF) in years (rounded to closest 5) and fire frequency group (FFG: F. frequent; I, infrequent; R, rare), natural (HRV) fire severity (NFS) in percent and group (FSG: S, surface; M, mixed; R, replacement), fire interval–severity departure (FISD), fire interval–severity condition class (FIS), vegetation–fuel composition–structure departure (VFCSD), vegetation–fuel composition–structure condition class (VFCS), fire regime condition class (FRCC), and HRV departure class (HRVD): H, high; M, moderate; L, low). The departure measure is from the central tendency measure for HRV and condition class 1 or low departure is considered within the HRV.

	NFF		NFS							
Type of landscape (dominant potential natural vegetation group[s])	Years	FFG	%	FSG	FISD (%)	FIS class	VFCSD (%)	VFCS class	FRCC	HRVD class
Juniper–desert shrub, Utah	40	I	30	M	79	3	65	2	3	H
Sagebrush warm, Wyoming; big sage, basin big sage, Idaho	30	F	45	M	60	2	70	3	3	H
Sagebrush cool, Montana; big sage, Idaho	25	F	45	M	51	2	42	2	2	M
Plains grassland with conifer, Montana	15	F	50	M	51	2	83	3	3	H
Juniper woodland–pine forest, Arizona	5	F	45	M	73	3	47	2	3	H
Pine forest, Colorado	25	F	25	S	75	3	53	2	3	H
Pine–Douglas-fir forest, warm	30	F	65	M	48	2	73	3	3	H
Pine–Douglas-fir forest, cool	35	F	60	M	52	2	75	3	3	H
Western spruce–fir forest, Colorado	80	I	65	M	37	2	60	2	2	M
Alpine meadow, upper subalpine forest, Colorado	200	R	80	R	11	1	12	1	1	L

Table 6. Primary causal factors for fire regime and vegetation departure from historical range of variation (HRV) in landscapes selected for study in the western U.S. Causal factors are associated with departure in amounts greater than ±33% range around the measure of HRV central tendency.

Type of landscape (dominant potential natural vegetation group[s])	Area(s)	Primary causal agents of departure
Juniper–desert shrub	Green River, Utah	Uncharacteristic historic and current grazing, fire exclusion in juniper, semi-desert droughty climate, invasive plants, increased fire in invasive annual grass areas, off-road-vehicle use
Sagebrush , warm	Middle Salmon River, Idaho	Uncharacteristic historic grazing, semi-desert droughty climate, invasive plants, increased fire in invasive annual grass areas
Sagebrush , cool	Upper Salmon River, Idaho	Fire exclusion, uncharacteristic historic and current grazing
Plains grassland with conifer	Missouri Breaks, Montana	Fire exclusion, uncharacteristic historic grazing
Juniper–pine woodland–forest	Pine Creek, Arizona	Fire exclusion, uncharacteristic historic grazing
Pine forest	Trout West, Colorado	Fire exclusion, uncharacteristic historic grazing, and timber harvest not mimicking the natural regime
Pine–Douglas-fir forest	Trout West, Colorado	Fire exclusion, uncharacteristic historic grazing, timber harvest not mimicking the natural regime, and uncharacteristic insect–disease mortality
Pine–Douglas-fir forest	Box Creek, Colorado	Uncharacteristic late-1800s mining-era timber harvest and soil surface disturbance, uncharacteristic dwarf mistletoe–mountain pine beetle (***Dendroctonus ponderosae***), fire exclusion
Western spruce–fir forest	Box Creek, Colorado	Uncharacteristic late-1800s mining-era timber harvest and soil surface disturbance, fire exclusion
Alpine meadow, upper subalpine forest	Box Creek, Colorado	Limited uncharacteristic late-1800s mining-era timber harvest and soil surface disturbance, fire exclusion

Table 7. Associated level of effects of fire regime and vegetation departure from the historical range of variability (HRV) in landscapes selected for study in the western U.S. Level of effects ranked low (L), moderate (M), or high (H). Fire regime condition class (FRCC) 1 includes up to ±33% range around the measure of central tendency for HRV.

Type of landscape (dominant potential natural vegetation group[s])	Area(s)	FRCC	Risk to people of uncharacteristic wildland fire if near (less than 1.6 km) wildland–urban interface	Risk to ecosystems (air, water, soil, species habitats) of uncharacteristic wildland fire	Risk to ecosystems (water, soil, species habitats) of current departure
Juniper–desert Shrub	Green River, Utah	3	L	H	H
Sagebrush, warm	Middle Salmon River, Idaho	3	H	H	H
Sagebrush, cool	Upper Salmon River, Idaho	2	H	M	H
Plains grassland with conifer	Missouri Breaks, Montana	3	H	H	M
Juniper–Pine woodland forest	Pine Creek, Arizona	3	H	H	M
Pine forest	Trout West, Colorado	3	H	M	M
Pine–Douglas-fir forest	Trout West, Colorado	3	H	H	H
Pine–Douglas-fir forest	Box Creek, Colorado	3	H	M	H
Western spruce–fir forest	Box Creek, Colorado	2	L	M	H
Alpine meadow, upper subalpine forest	Box Creek, Colorado	1	L	L	L

Figure 1. Graphical representation of fire interval and severity (upper layer replacement) relationships used in defining the types of fire regime at the watershed and project scale. The frequent surface and mixed regime (I) typically has a mean fire interval ranging from 1 to 35 years, but in systems with high temporal variation where the median is a better measure of central tendency, the mean can range up to 50 years. The infrequent mixed and surface regime (III) has a mean fire interval ranging from greater than 35 years to 200 years although most systems in this regime only range up to 100 years. Mixed fire severity is the most common, but surface severity can also occur.

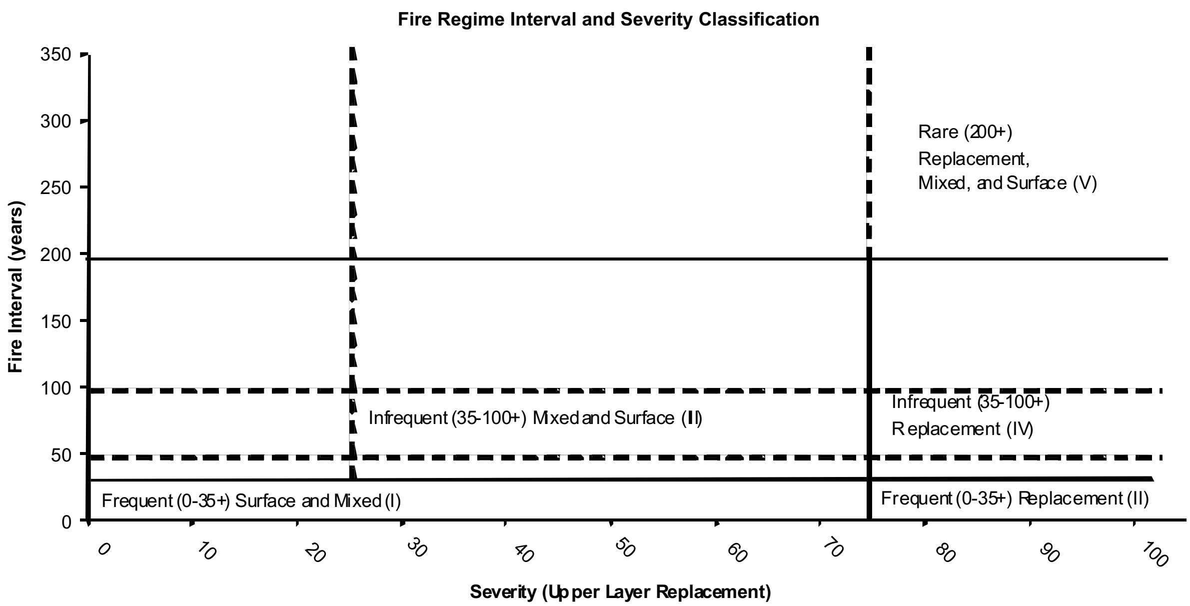

Figure 2. Graphical representation of fire interval–severity departure and vegetation composition–structure-fuel departure relationships for defining the fire regime condition classes and natural (historical) range of variability (HRV) departure classes at the watershed and project scale. Departure is determined in relation to the measure of central tendency for the HRV. Condition class 1 has low departure and is considered to be within the natural (historical) variation. Condition classes 2 and 3 are considered to be at moderate and high levels of departure outside the HRV. Restoration in landscapes that have high departure in fire interval–severity, but low departure in vegetation and fuel composition and structure would focus on returning natural fire effects to the system, while the reverse situation would require focus on vegetation type and fuel restoration to more natural conditions.

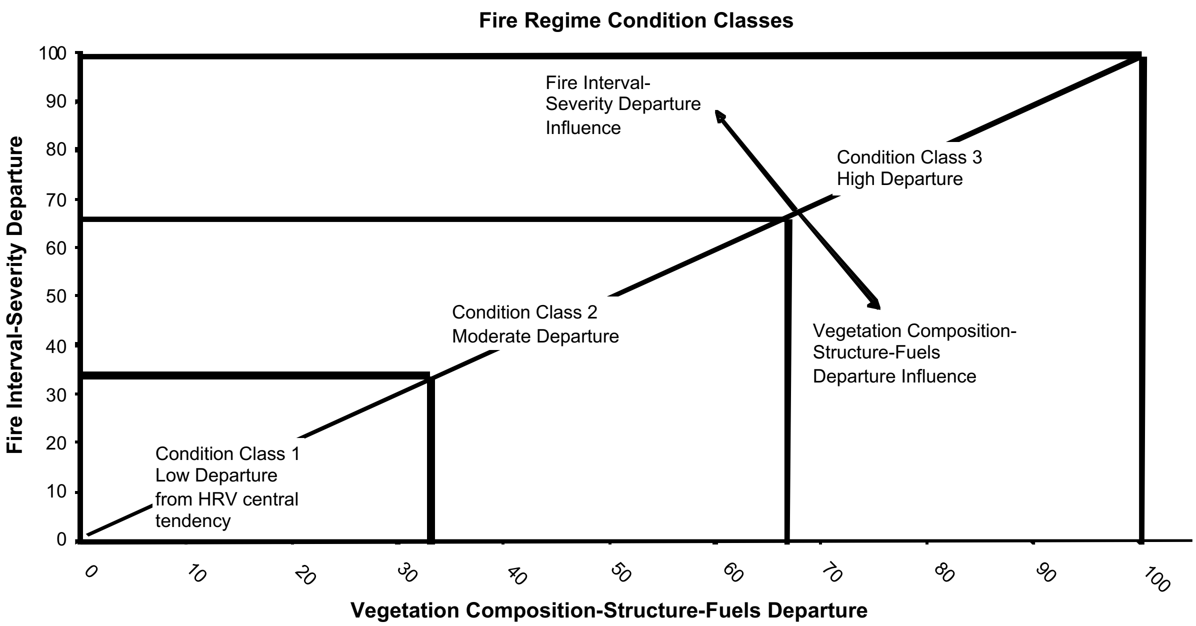

Figure 3. A standardized succession-disturbance state and transition model was developed to support the simulation component of the fire regime departure, fire regime condition class, and historical range of variability analysis. This standardized model was given the name "box model" because of the box-like format of the succession and disturbance diagram. Boxes show the characteristic seral structural stages, and arrows show typical direction of succession or disturbance change.

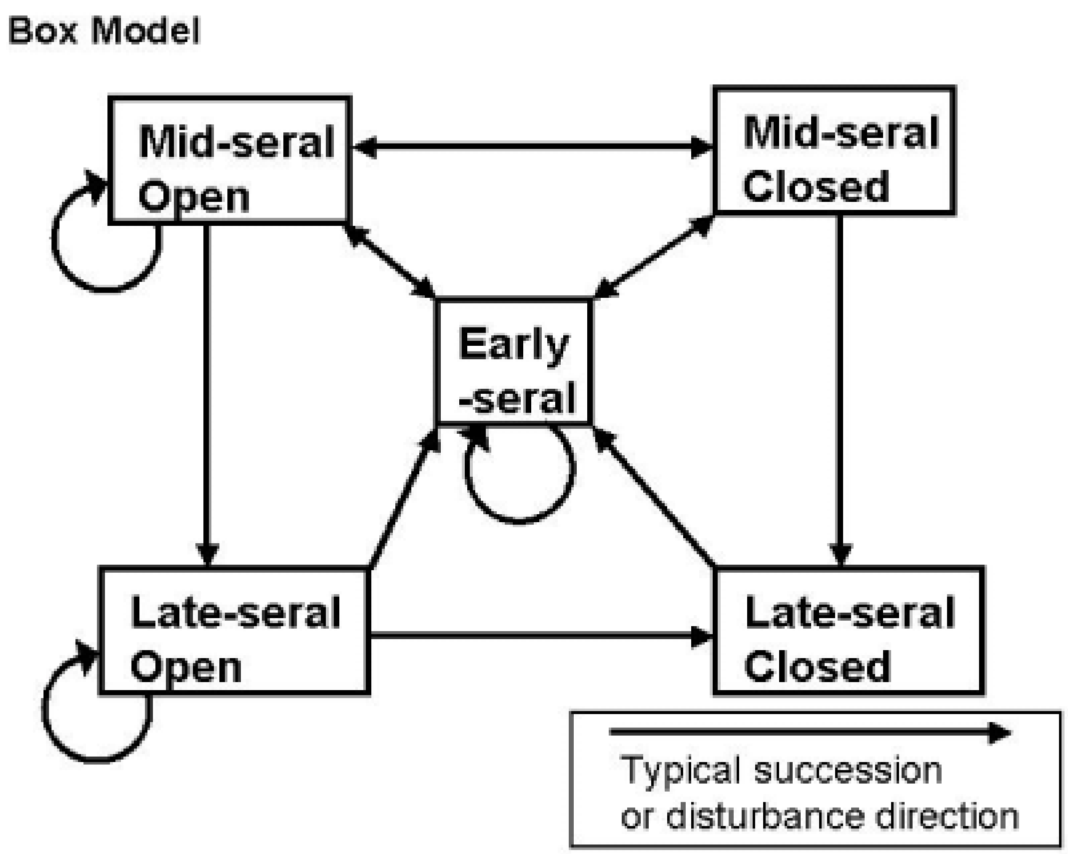

Figure 4. Example output from the box model of the late development open class. The average or central tendency of historical range of variability (HRV) was determined to be 59%. In this landscape the amount of the open late development class ranges from 52% to 67% with most of the variation ranging between 57% and 67%. Some landscapes have less variation and some have more. For classification of FRCC 1 and a rating of low for associated departure variables the HRV is assumed to include ±33% variation around the average.

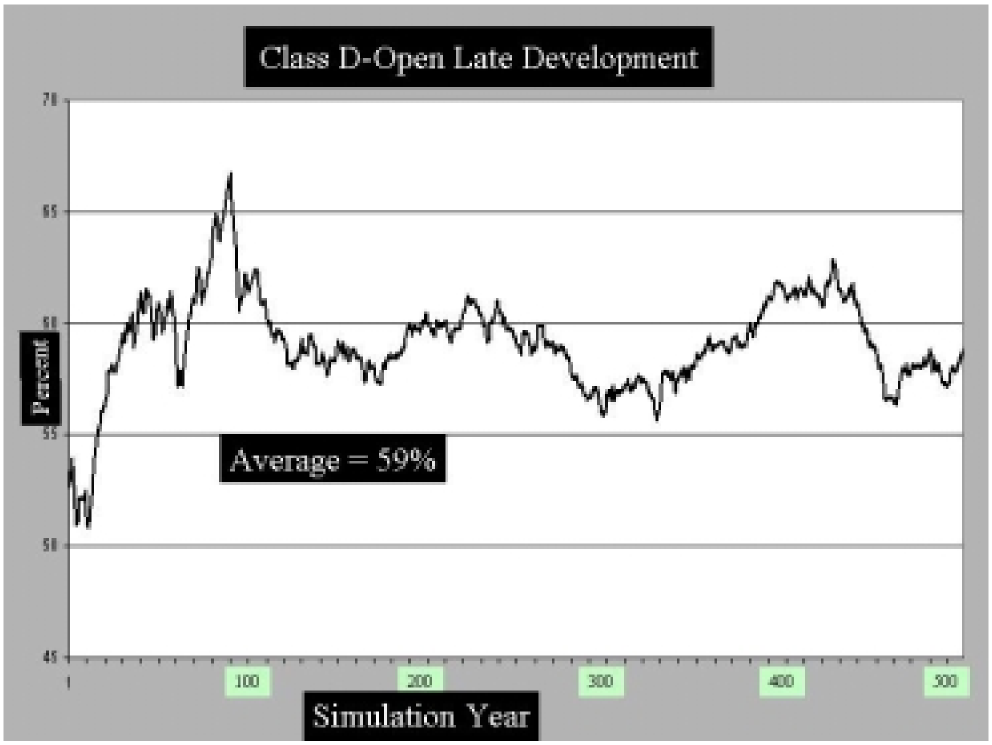

Figure 5. Example output of surface and replacement fire with calculations for fire regime and fire frequency. The solid upper line simulates amount of surface or understory fire while the dotted line below simulates the amount of upper layer or crown-replacement fire. The amount of replacement fire divided by the total amount of fire determines the severity, while the mean fire interval is used to classify frequency.

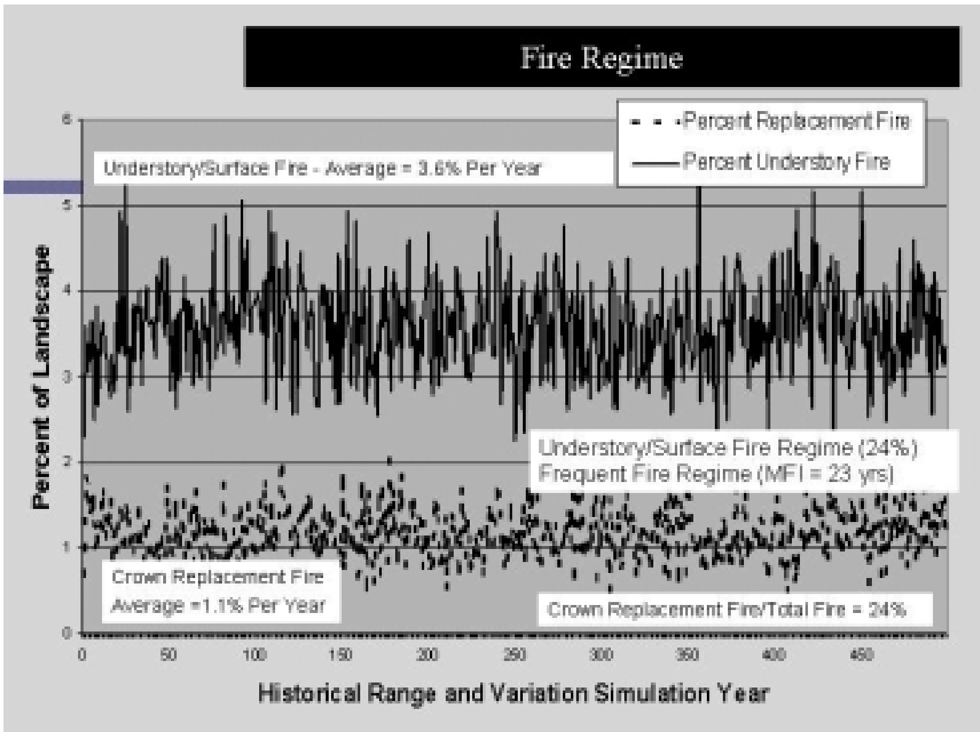

Figure 6. Fire regime condition class determined using vegetation–fuel composition–structure and fire interval–severity departure from the central tendency of historical range of variability for different types of landscapes in the western U.S. Assessment of departure depends on the response of different landscapes to the causal factors of departure, as well as resolution of the measures.