Range and Variation in Landscape Patch Dynamics: Implications for Ecosystem Management

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Abstract—Northern Rocky Mountain landscape patterns are shaped primarily by fire and succession, and conversely, these vegetation patterns influence burning patterns and plant colonization processes. Historical range and variability (HRV) of landscape pattern can be quantified from three sources: (1) historical chronosequences, (2) spatial series, and (3) simulated chronosequences. The last two sources were used to compute HRV for this study. Spatial series were characterized from aerial photographs of 10 similar landscapes on the Bitterroot National Forest, Montana. The LANDSUM model was used to simulate landscape patterns for three landscapes on the Flathead National Forest. Landscape metrics were computed using FRAGSTATS. Results can be used (1) to describe landscape characteristics, (2) to develop baseline threshold values, and (3) to design treatment guidelines for ecosystem management.

Introduction

Vegetation patch dynamics reflect the cumulative effects of disturbance regimes and successional processes on the landscape (Baker 1989; Bormann and Likens 1979; Crutzen and Goldammer 1993; Pickett and White 1985; Wright 1974). Northern Rocky Mountain landscape patterns are primarily shaped by fire and succession, and conversely, these patterns will invariably influence future burning patterns, plant colonization and development processes (Keane and others 1998; Hessburg and others 1999b; Turner and others 1994; Veblen and others 1994). It follows, then, that some general characteristics of disturbance regimes may be described from landscape patch characteristics and dynamics (Hessburg and others 1999b; Forman 1995; Swanson and others 1990). For example, large, severe fires will probably create large patches and these patches on a landscape may indicate stand-replacement fire regimes (Baker 1989; Keane and others 1999). Using this inference, patch and landscape characteristics could be used to assess, plan, and design ecosystem management activities. For example, the range of patch sizes on a landscape over time could be used to design the size of a prescribed fire so that it is not bigger, or smaller, than what would have occurred historically (Cissel and others 1999; Swetnam and others 1999; Mladenoff and others 1993). Current landscape conditions could also be compared with summarized historical landscape conditions to detect ecologically significant change, such as that brought on by fire exclusion and timber harvesting (Baker 1992, 1995; Cissel and others 1999; Hessburg and others 1999b; Landres and others 1999).

Landscape structure and composition are usually characterized from the spatial distribution of patches—a term synonymous with stands or polygons. Many types of spatial statistics, often called landscape metrics, are used to quantitatively describe patch dynamics of landscapes (Turner and Gardner 1991; McGarigal and Marks 1995). Landscape metrics statistically portray distributions of patch shape, size, and adjacency by patch class (in other words, label or name) across many scales (for example, patch, class, to landscape) (Cain and others 1997; Hargis and others 1998). These metrics are important because they allow a consistent, comprehensive, and objective comparison among and across landscapes, even though many metrics cannot be tested for statistical significance as yet (Turner and Gardner 1991). Landscape metrics are calculated by importing spatial data layers, usually from a Geographic Information System (GIS), into any of the many landscape metrics programs available (for example, FRAGSTATS; McGarigal and Marks 1995; r.le, Baker and Cai 1990).

Landscapes are usually described by a digital thematic layer in raster (for example, grid or pixel map) or vector (for example, line maps) format. The layer contains geo-referenced polygons (in other words, patches) often described by dominant species cover type, but any theme can be used to label patches, providing there is an existing classification (Hessburg and others 1999a). The selection and categories of the mapped theme are important to interpreting landscape patch dynamics (Keane and others 1999). Different categories or themes (for example, cover type and structural stage) will generate entirely different sets of landscape metrics for the same area. So, the detail inherent in the theme design can have a significant influence on the landscape metrics analysis. Thematic layers are usually created from a spectral classification of satellite imagery (Verbyla 1995) or an interpretation of aerial photography (Hessburg and others 1999b).

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A useful concept for planning and designing landscape treatments is historical range and variability (HRV) (Parsons and others 1999, Landres and others 1999). We define HRV as the quantification of temporal fluctuations in ecological processes and characteristics prior to European settlement (in other words, before 1900). Naturally, HRV is highly scale-dependent. Fluctuations at the stand-level might be characterized by changes in the stand basal area or snag density, whereas at the landscape-level, HRV might refer to the fluctuation of patch size, cover type area, or fractal dimension. The HRV concept is invaluable to ecosystem management because it defines threshold boundaries of acceptable change (Swetnam and others 1999). For example, management activities can be designed to create patch distributions that are within the HRV to ensure ecologically sound treatments (Hessburg and others 1999b). Moreover, HRV can be used to assess the condition of a landscape or stand to prioritize or select for proactive management such as restoration (Hessburg and others 1999b).

The range and variation of historical patch dynamics can be quantified from three main sources. First, a chronosequence (in other words, a sequence of maps of one landscape from many time periods) can be input to landscape metric programs and the results summarized across the time span. This is the best source for computing HRV, but unfortunately, chronosequences of historical landscape conditions are absent for many western landscapes because aerial photography or satellite imagery are rare or nonexistent prior to 1930.

Second, a spatial collection of maps from many similar landscapes taken from one or more time periods can be gathered across a geographic region and input to landscape metric programs (Hessburg and others 1999b). This spatial series essentially substitutes space for time (Hessburg and others 1999a) and assumes that landscapes in the series have similar environmental conditions, such that all mapped entities have the same probability of occurrence across all watersheds. Since aerial photography is absent prior to 1900, historical spatial series can be created from similar remote, unsettled watersheds mapped with the earliest imagery possible (Hessburg and others 1999b). One of the biggest limitations of this source is that landscapes are rarely similar in their potential to support similar vegetation. Landform, relief, soils, and climate play major roles in dictating the distribution of vegetation communities across a landscape. However, landscapes can be grouped according to the processes that govern vegetation, such as climate, disturbance, and species succession (Hessburg and others 1999b).

The third method of quantifying HRV involves simulating a landscape to produce a chronosequence of simulated maps to compute landscape metrics. This approach assumes that both succession and disturbance are simulated accurately in space and time, and that the spatial properties of the disturbance simulation are reflected in the patch dynamics (Keane and others 1999). Unfortunately, most landscape fire succession models are overly simplified representations of complex ecological processes, and, as such, they are probably more valuable for comparison than prediction (Keane and others 1999).

This paper presents two approaches for estimating landscape patch metric HRV. First, a spatial series was created for 10 Bitterroot National Forest (BNF) watersheds to assess HRV for lodgepole pine landscapes. Then, the LANDscape Succession Model (LANDSUM) model was used to spatially simulate historical processes on three Flathead National Forest (FNF) landscapes to create simulated chronosequences to calculate patch metric HRV for these areas. Results from this effort can be used to plan and implement landscape ecosystem management activities.

Methods

Spatial Series

Seven BNF landscapes, composed primarily of lodgepole pine (*Pinus contorta*) of about 600 ha in size, were mapped from 1996 aerial photos using the methodology described by Hessburg and others (1999a) (table 1). All landscapes were assumed to represent historical conditions and have the potential to support high coverage of lodgepole pine. Polygons were delineated by BNF personnel based on textural differences in the dominant vegetation stratum. Many attributes were assigned to each delineated polygon, but we only selected the attributes of cover type and structural stage as key polygon descriptors for this project (table 1). Cover type was assigned as the tree species having the plurality of vertically projected canopy cover; non-forest cover types were lumped together. Structural stages were defined by tree diameter size classes associated with stand developmental processes (table 1).

We augmented these seven small landscapes with three larger landscapes (4,000 to 15,000 ha), also found on the BNF (table 1). Polygons on these large landscapes were delineated using the same methodology, but as part of the Interior Columbia Basin Ecosystem Management Project (ICBEMP) in 1995. The three ICBEMP landscapes were mapped from aerial photographs taken in the mid 1930s to describe historical conditions.

Simulated Chronosequences

The LANDSUM is a spatially explicit, deterministic vegetation dynamics simulation model with disturbance treated as a stochastic process (Keane and others 1997). LANDSUM is a polygon-based model, unlike its pixel-based parent CRBSUM, which was developed for coarse scale applications (Keane and others 1996). LANDSUM is based on the conceptual multiple pathway fire succession-modeling approach presented by Kessell and Fischer (1981). This approach assumes all pathways of successional development will eventually converge to a stable or climax plant community called a Potential Vegetation Type (PVT). A PVT identifies a biophysical setting that supports a unique and stable climax plant community. There is a unique set of successional pathways for each PVT present on the landscape (Arno and others 1985). Successional development of a polygon is simulated as a change in structural stage and cover type (in other words, succession class) simulated at an annual time step. Disturbances disrupt successional

Table 1—General descriptions of landscapes used in this study. BNF is the Bitterroot National Forest, ICBEMP is BNF watersheds digitized for Interior Columbia Basin Ecosystem Management Project, FNF-LANDSUM is the Flathead National Forest LANDSUM watersheds.

Landscape	Project	Size	Dominant cover type	Dominant stage
		ha		
Beaverwoods	BNF	766	Lodgepole pine	Pole
Cow Creek	BNF	334	Douglas-fir	Pole
Gibbons	BNF	593	Douglas-fir	Small
Lick Creek	BNF	667	Douglas-fir	Pole
St. Joe	BNF	476	Subalpine fir	Pole
Sawmill	BNF	276	Subalpine fir	Small
Sweeney	BNF	248	Douglas-fir	Small
Sweeney-Joe	BNF-ICBEMP	4,300	Subalpine fir	Small
Roaring Lion	BNF-ICBEMP	6,573	Subalpine fir	Nonforest
Sleeping Child	BNF-ICBEMP	14,398	Subalpine fir	Small
Stillwater	FNF-LANDSUM	14,182	Subalpine fir	Pole
North Fork	FNF-LANDSUM	8,945	Subalpine fir	Pole
South Fork	FNF-LANDSUM	18,038	Subalpine fir	Small

Mapping entity	Map categories or classes
Cover type	1-Pipo, 2-Pico, 3-Psme, 4-Abla, 5-Abla/Pien, 6-Pial, 7-Laoc, 8-Laly, 9-Pial/Pico, 10-Wet meadow, 11-Alpine meadow, 12-Rock, 13-Pial/Laly, 14-Aspen/Cottonwood, 15-Water, 16-Shrubland, 17-Cropland, 18-Tsme, 19-Grass/Forb, 20-Burned over, 21-Nonforest
Structural stage	1-Nonforest, 2-Seedling/sapling trees (0-4 in DBH), 3-Pole tree (4-9 in DBH), 4-Small tree (9-20 in DBH), 5-Medium tree (20-40 in DBH), 6-Large tree (40+ in DBH)
CT-SS combinations	Every logical Cover type/Structural stage combination from the first two entities. For example, a CT = Pial, and SS = nonforest would NOT be a logical cover type.

Note: Pipo-ponderosa pine, Pico-lodgepole pine, Psme-Douglas-fir, Abla-subalpine fir, Pien-spruce, Pial-whitebark pine, Laly-alpine larch, Tsme-mountain hemlock, Laoc-western larch, Nonforest-Includes several categories of nonforest that differ in tree seedling sapling cover.

development and can delay or advance the time spent in a succession class, or cause an abrupt change to another succession class. Occurrences of human-caused and natural disturbances are stochastically modeled from probabilities based on historical frequencies.

Three FNF landscapes were simulated for 1,000 years using the LANDSUM model (table 1). Initial input maps for each landscape were created by delineating and digitizing polygons from historical aerial photography (circa 1930s) by FNF personnel. Landscapes were defined by watershed boundaries. Successional pathway and disturbance parameters were taken from the CRBSUM effort and modified to represent local conditions (Keane and others 1996). LANDSUM output statistics and maps were generated every 20 years for cover type, structural stage, and cover type, structural stage, and cover type-structural type (CT-SS) combination.

Landscape Metric Analysis

We selected cover type, structural stage, and cover type-structural stage combination (CT-SS) maps for landscape metric evaluation. Cover types were selected because they describe species compositional patch dynamics. Structural stages are used as surrogates to describe size and age class. Lastly, CT-SS maps describe patch dynamics in classes most meaningful to management, which most closely describes a stand, best indicates successional status, and matches those results and analyses done by Hessburg and others (1999a). Spatial data layers were imported into the FRAGSTATS spatial pattern analysis program to compute landscape metrics that was then summarized and analyzed with SAS statistical software.

We computed landscape metrics at two levels. At the landscape-level, metrics were summarized for the entire landscape without stratification by other mapped categories (Hessburg and others 1999b). At the class level, metrics were summarized across the landscape but stratified by classification category to provide detail and context for interpretation of landscape level results (Forman 1995; Chen and others 1996; Hargis and others 1998).

We selected a set of landscape metrics that may be useful in ecosystem management for comparing, prioritizing, and restoring landscapes. Hargis and others (1998) found that only a small set of indices was needed because of redundancy and dependency between metrics (Turner and Gardner 1991). It is also important to match the landscape metric with the biological processes that influence landscape structure (Chen and others 1996). Patch density (PD, patches per

100 ha), mean patch size (MPS, ha), and patch size coefficient of variation (PSCV, percent) were selected because they represent the direct effect of disturbance processes. The landscape patch index (LPI) is maximum percent of the landscape occupied by one patch. It was selected because it represents the upward bounds of patch or burn size. Because edge, shape, and fractal dimension metrics are highly correlated and quite similar in these landscapes, they were not included in this study. Diversity indices, such as Simpson's (SIDI) and Shannon's indices, are descriptive but they are not very informative for management decisions because they combine elements of patch richness and evenness (McGarigal and Marks 1995). Relative patch richness (RPR) rates the richness in patch classes on a scale of zero to 100 (100 have all patch types possible). Evenness, expressed as computed level of diversity divided by the maximum possible diversity for a given patch richness, describes the degree to which the landscape is composed of one patch class. We selected the modified Simpson's evenness index (MSIEI) on the scale of 0–100 percent to evaluate evenness. Mean nearest neighbor (MNN) describes the average distance to the nearest polygon of a different class. Lastly, contagion (CONTAG), a number between 0–100, measures the interspersion and dispersion of patches across a landscape. Landscapes with clumped or aggregated patch types have high contagion values (Li and Reynolds 1994).

We selected four statistics to describe each metric. The average across all landscapes is used as a target or reference metric and the standard error indicate the level of variability in that metric. The maximum and minimum values of that metric across landscapes are used as boundary or absolute threshold constraints.

Results and Discussion

Spatial Series

Landscape-level FRAGSTATS output is summarized in table 2 for the three mapping classifications across the 10 BNF landscapes. Nearly every landscape from the BNF data set (excluding ICBEMP landscapes) had low patch density, moderate patch sizes, and large variation in patch sizes. These landscapes were similar in patch size (LPI, MPS, PSCV) and contagion (CONTAG). However, individual BNF landscapes had patches that were highly variable in size, shape, and contagion with coefficient of variations often exceeding 200 percent. Douglas-fir and subalpine fir patches were often the largest in size and had the greatest variation, perhaps indicating some lasting effects of fire exclusion. However, the largest structural stage patches were not in the older, large size classes. Cover type metrics were quite similar to structural stage metrics because of the small number of patches on the landscapes.

The Bitterroot National Forest ICBEMP landscapes were quite different in composition and structure when compared

Table 2—Landscape metric statistics for spatial series of BNF lodgepole pine landscapes. The Sawmill landscape is included for comparison purposes. . LPI-landscape patch index, PD-patch density, MPS-mean patch size, PSCV-patch size coefficient of variation, RPR-relative patch richness, MSIEI-modified Simpson's evenness index, CONTAG-contagion.

Landscape metric	Sawmill	Average	Standard error	Minimum value	Maximum value
Cover type					
LPI (%)	41.1	31.8	4.0	14.1	50.3
PD (100 ha^{-1})	8.0	4.6	1.1	0.7	10.5
MPS (ha)	12.6	42.7	13.3	9.6	146.9
PSCV (%)	200.4	209.6	18.0	101.1	335.4
RPR (%)	46.2	50.2	2.9	36.0	64.0
MSIEI (%)	69.0	62.7	3.8	45.0	85.0
CONTAG (%)	47.0	54.8	2.4	41.1	65.2
Structural stage					
LPI (%)	43.4	30.5	3.9	16.2	57.7
PD (100 ha^{-1})	11.2	6.1	1.4	0.6	11.7
MPS (ha)	8.9	42.1	16.1	8.6	169.4
PSCV (%)	236.2	227.0	36.9	153.3	544.1
RPR (%)	67.7	81.7	1.7	66.7	83.3
MSIEI (%)	79.0	70.7	4.0	48.0	87.0
CONTAG (%)	38.5	47.6	2.5	36.5	66.0
Cover type/Structural stage (CT-SS) combination					
LPI (%)	20.3	12.7	1.8	5.6	24.6
PD (100 ha^{-1})	14.1	9.2	2.0	1.5	17.7
MPS (ha)	7.1	21.4	6.5	5.7	66.6
PSCV (%)	142.5	148.7	11.4	110.1	236.8
RPR (%)	18.9	30.9	3.2	18.9	49.1
MSIEI (%)	87.0	71.8	2.7	59.0	87.0
CONTAG (%)	39.1	49.7	1.9	39.1	58.3

with the other seven BNF landscapes. Mean ICBEMP patch size (MPS) ranged from 61 to 147 ha while patch density (PD) went from 0.68 patches per 100 ha to 1.65 per 100 ha. Surprisingly, the coefficient of variation (PSCV) was around 200 percent, similar to that of the small BNF landscapes. ICBEMP landscapes tended to (1) be higher in elevation (in other words, composed of higher amounts of subalpine fir, whitebark pine), (2) contain higher amounts of non-forest and rock cover types, (3) have higher proportions in early seral stages (except for Sleeping Child), and (4) be created from earlier photography. As a result, ICBEMP patches were larger with higher variation and higher contagion. Patch shapes were more irregular, being controlled by topography and the large size of these landscapes (Chen and others 1996). Large ICBEMP landscapes tend to have more diverse biophysical settings, which increase the number of possible cover types and topographical constraints (Swanson and others 1990). And, ICBEMP landscapes were created from photography more representative of historical conditions since 1930s aerial photography was used.

It was interesting that results from Hessburg and others (1999a) were similar to those computed for the 10 BNF landscapes, considering they used 132 watersheds from a region quite distant from the Bitterroot valley. This may indicate that fire processes are similar on landscapes that support lodgepole pine (Heinselman 1981; Peet 1988; Wright 1974). The small number of historical landscapes present in the BNF-ICBEMP sample (n = 3) may limit the applicability of these results to management planning.

Simulated Chronosequences

Landscape metric statistics are summarized for the South Fork FNF landscape in table 3, with the 500-year averages of metrics computed from the North Fork FNF landscape included as reference. Patch sizes (MPS) are roughly comparable between the BNF and FNF landscapes, but patch densities (PD) and patch size variations (PSCV) were quite different due to the simulation of fire. South Fork cover type patches were larger than the structural stage and CT-SS patches (table 3) because simulated fires created many patches on the landscape, but most progressed along similar successional pathways composed of the same cover type (Keane and others 1997). Mean nearest neighbor (MNN) was substituted for RPR to illustrate that it could be a useful metric for landscape management. Simulated Stillwater landscape results are not presented due to lack of space.

The FNF landscapes had much higher patch densities than BNF landscapes because the spatial simulation of fire created many smaller patches by the end of the simulation. This effect is also evident by the large PSCV values in the structural stage and CT-SS classifications (table 3). Initial input FNF landscapes, like the BNF landscapes, were mapped with minimum polygon sizes around 5 ha, but simulated

Table 3—Landscape metric statistics for simulated chronsequence of South Fork FNF landscape. Ave 500 yr simulated conditions of FNF North Fork landscape is for reference. LPI-landscape patch index, PD-patch density, MPS-mean patch size, PSCV-patch size coefficient of variation, MNN-mean nearest neighbor, MSIEI-modified Simpson's evenness index, CONTAG-contagion.

Landscape metric	North Fork	Average	Standard error	Minimum value	Maximum value
Cover type					
LPI (%)	49.6	33.1	0.5	29.0	36.2
PD (100 ha^{-1})	27.5	19.7	3.3	0.3	48.9
MPS (ha)	21.8	36.8	16.6	2.0	368.1
PSCV (%)	270.0	220.1	41.58	83.6	918.4
MNN (m)	177.9	220.1	58.5	58.1	1208.0
MSIEI (%)	39.6	44.9	1.3	37.0	60.0
CONTAG (%)	60.4	59.7	0.55	55.9	64.7
Structural stage					
LPI (%)	62.7	24.4	1.0	13.4	36.2
PD(100ha^{-1})	22.2	58.4	6.0	0.6	117.5
MPS (ha)	20.7	15.4	6.1	0.9	176.2
PSCV (%)	2537.0	2874.0	189.1	210.2	4603.0
MNN (m)	173.0	125.2	31.8	44.1	1175.7
MSIEI (%)	31.8	56.0	1.2	43.0	79.0
CONTAG (%)	66.5	50.9	0.8	42.7	59.5
Cover type/Structural stage (CT-SS) combination					
LPI(%)	31.3	17.0	0.8	12.5	29.5
PD (100 ha$^{-1)}$	52.9	129.6	12.7	0.7	271.9
MPS (ha)	10.5	7.8	3.5	0.4	146.7
PSCV (%)	2371.3	3263.0	194.4	200.8	5441.0
MNN (%)	235.0	173.5	38.9	65.6	1519.5
MSIEI (%)	42.3	48.4	0.9	39.0	73.0
CONTAG (%)	51.1	52.0	0.85	42.4	62.2

fires continually sliced polygons so that, by the end of the simulation, the minimum polygon size was less than 1 ha. We are developing GIS techniques to modify simulated layers to make them comparable through time using GIS techniques of smoothing and nibbling.

Management Implications

An interesting finding is the apparent dissimilarity in landscape metrics across mapping classifications. Metrics computed from cover type patches are somewhat different for the same landscape described by structural stage or CT-SS combinations (tables 2 and 3). There were approximately twice as many CT/SS combination patches as there were cover type patches or structural stage patches. This then halved the size (MPS), increased the density (PD), and increased the variation (PSCV). Interestingly, some metrics computed for CT-SS combination maps were very similar to those computed for all other maps (see CONTAG, MSIEI, RPR). This illustrates the importance of matching of management objectives to map design and construction to facilitate planning and ensure the appropriate ecological attribute is being assessed.

The Sawmill and North Fork landscapes are presented as *target landscapes* in tables 2 and 3 to compare spatial patch characteristics to HRV and to determine patch parameters for treatment design. Four patch metrics (PD, MPS, MSIEI, and CONTAG) for the Sawmill landscape were consistently outside the standard error bounds for the HRV of BNF landscapes, yet within the minimum and maximum values for cover type, structural stage, and CT-SS. This might indicate that the landscape is outside historical conditions. The North Fork 500-year average landscape metrics were not within any standard error bounds, and outside of most maximum-minimum ranges, for almost all metrics and for all classifications (table 3). Unlike the Sawmill watershed, this is because the topography, potential vegetation, and fire regime of the North Fork watershed is quite different from the South Fork drainage, even though the two are in the same geographical region. This illustrates the importance of clustering landscapes in a spatial series based on landscape processes rather than composition or structure.

We can roughly estimate the target size and maximum allowable boundaries of possible restoration treatments from mean patch size (MPS) or LPI statistics (tables 2 and 3). The maximum and minimum patch size can be assessed from four statistics at four levels of confidence. The standard error can be used as the most conservative estimation of patch variability. The next confidence level would be to apply the maximum and minimum range of patch size coefficient of variation (PSCV) to the mean patch size. A more lenient alternative to this approach is to use the maximum PSCV instead of the mean PSCV. The next most liberal level estimation of range of variability uses the minimum and maximum values. Hessburg and others (1999b) recommend the 80th percentile of mean patch size as a more realistic maximum patch size. Lastly, the largest patch can be bounded from the largest patch index (LPI).

Summary and Conclusions

This paper demonstrates how the historical range and variability (HRV) of landscape composition and structure can be described from landscape metrics computed from two sources, spatial series and simulated chronosequences, using the FRAGSTATS program. Landscape metric statistics quantifying HRV can then be used to assess, prioritize, compare, and design landscapes for possible restoration treatments. Spatial series and simulated chronosequences are suitable sources to compute landscape structure, but each has major limitations. Spatial series assume that all landscapes are similar in environmental conditions, which is often not the case. Simulations of chronosequences rely on inexact computer models that often contain oversimplifications of disturbance and succession processes. However, since historical chronosequences are essentially unavailable, these two sources currently provide the best data sets for quantification of HRV.

These spatial metric analyses illustrate the importance of assessing landscape structure and composition of individual watersheds prior to treatment to determine management and planning parameters. The high variability between and across landscapes makes a "one-size-fits-all" set of recommendations difficult. Landscapes are shaped by the timing and severity of past disturbances, such as fire, and, fire spread and intensity are influenced by topography and vegetation, which are extremely variable across landscapes (Hessburg and others 1999a; Swanson and others 1994). Therefore, it is essential that landscapes be mapped using appropriate vegetation classifications so that patch dynamics can be quantified to provide a guide for design and assessment of treatment opportunities.

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