Chapter 14. Understanding the Effects of Fire Management Practices on Forest Health: Implications for Weeds and Vegetation Structure

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Introduction

Current fire policy to restore ecosystem function and resiliency and reduce buildup of hazardous fuels implies a larger future role for fire (both natural and human ignitions) (USDA Forest Service and U.S. Department of the Interior 2000). Yet some fire management (such as building fire line, spike camps, or heli-spots) potentially causes both short- and long-term impacts to forest health. In the short run, these practices may increase soil disturbance, thereby promoting post-fire weed establishment (Keeley 2005, Merriam and others 2006). Fire management practices also may initiate long-term changes to aspects of landscape structure (such as patch connectivity, size, and shape) that may exacerbate future fire, insect, or disease risk, or jeopardize wildlife habitat (Backer and others 2004). Quantification of these effects can provide important information to guide fire strategy, tactics, and restoration decisionmaking (Sugihara and others 2006).

We sought to determine whether fire management tactics undertaken across a strategic continuum from aggressive suppression to minimum impact create substantially different post-fire conditions as measured by nonnative weeds and landscape patch structure. To do so, we investigated the potential to associate current fire incident data, along with grid locations from the Forest Inventory and Analysis (FIA) of the Forest Service, U.S. Department of Agriculture, to extend the ability of the network to monitor ecological conditions and assess trends.

Objectives

Specifically, we considered the following questions for weeds:

1. Do fire management tactics increase short-term post-fire weed establishment?
2. Do FIA data assist in monitoring short- and long-term weed establishment?

For landscape structure:

3. Do fire records capture and report management tactics in sufficient detail and consistency to answer extensive research questions?
4. Are digital images of fires (fire line, perimeters, and burn severity) collected in a consistent manner and archived in a central location, thus allowing for programmatic assessment of fire management?
5. Does satellite imagery such as Landsat Thematic Mapper (TM) imagery capture sufficient edge detail to allow identification of ecologically significant edge characteristics and comparison of sharp vs. diffuse burned area edges?

If sufficient landscape data exist, then:

6. Do suppressed fires have a simpler shape than natural fires?
7. Is there less internal heterogeneity in suppressed fires than natural fires?
8. Are the data in such a format (spatial, digital) that they can be associated and stored with FIA data?

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Methods

The active fire seasons of 2000, 2003, and 2005 within and surrounding the Selway-Bitterroot Wilderness (northern Rocky Mountains of Idaho and Montana) offer an intriguing natural experiment with potential for statistically comparing the effects of fire management strategies and tactics on resulting forest health, here defined as impact on nonnative plant species at a fine scale and landscape patch structure at the broad scale.

FIA data captures common species well, yet weed infestations begin as small, rare, often low density occurrences. Theoretically, a more extensive sampling methodology would be more likely to detect infestations early, as compared to the relatively fine-scale standard FIA Phase 2 sampling design. To test this (Objective 2), in 2004 and 2005 we draped an extensive sampling design over nine approximate FIA plots in areas burned in 2000 or 2003 in the Anaconda-Pintlar and Selway-Bitterroot Wilderness areas. At each FIA plot location, we sampled a total area of 40 m^2 randomly within a 500-m^2 area centered on the approximate location of an FIA plot. We established four 250-m long randomly oriented transects originating at the approximate center of an FIA plot, one in each quadrant, with quadrants delineated by the main cardinal directions. One 1-m^2 sample was located at random along each 25-m interval of each transect for a total of 40 1-m^2 samples. This design ensures extensive sampling with plots randomly spread throughout the entire sampling area. We then set up a standard FIA phase 2 sampling plot design following the Forest Inventory and Analysis National Core Field Guide (Volume 1: Field Data Collection Procedures for Phase 2 Plots, Version 2.0, January 2004) using the same center point as was used for the extensive sampling. We then recorded all herbaceous weeds within the four sampling subplots of this phase 2 design.

To test whether constructed fire-lines (including dozer, n = 8 and hand-line, n = 11) increase the likelihood of weed species becoming established in wilderness (Objective 1), we randomly sampled for weeds at prescribed distances from a 150-m transect laid down the center of the fire-line. We divided each 150-m transect into 3-m segments and at a random point in each segment, a 20-m transect was established perpendicular to and centered on the main transect (10 m on each side). Along each of these 50 perpendicular transects, all plant species were recorded within a 0.5-m^2 sampling frame at 0.5-m, 3-m, and 10-m distances from each side of the center. Thus, a total of 150 m^2 (300 0.5-m^2 samples) were sampled along the fire-line. The sampling frame 10 m from the fire-line was considered as the control because in all cases these sample points were within forest undisturbed by the fire-line by a distance of at least 3 m.

To test whether areas of high impact, such as back-country camps (spike camps, n = 2) and helicopter pads (heli-spots) have a greater presence of weeds than surrounding areas (Objective 1), 50 m^2 was sampled at various distances from a randomly orientated, 50-m

transect placed in the approximate center of the disturbed area. This transect was divided into 10-m segments, a random point chosen within each segment, and at this point a 100-m perpendicular transect bisected the main transect. A 0.5-m^2 sampling frame was placed at 5-m intervals along the 100-m transect. This led to 5 segments each with 20 sampling frames for a total of 100 * 0.5 m^2 = 50 m^2. The area surrounding the spike camp or heli-spot and in the same vegetation type and physiographic conditions was thoroughly searched for the occurrence of weed species to serve as a control.

To address our landscape structure questions (Objectives 3–8) we collected and analyzed archived incident records (daily incident activity forms and GIS files) and digital imagery (30 m Landsat) for 96 fires (ranging in size from 3 ha to 8079 ha) that burned in 2003 and 2005. For fires occurring within similar biophysical conditions (n = 49 in subalpine Potential Vegetation Types), we calculated area and cover-type specific (landscape and class) metrics using FRAGSTATS (McGarigal and Marks 1995) and assessed patterns in burn severity and edge characteristics across the spectrum of fire management strategies reflecting management goals: aggressive suppression (suppress), minimal suppression (contain), and for resource benefits (at the time, called Wildland Fire Use [WFU], fire use). Data were analyzed using a variety of methods due to the messiness of the data—no containment fires in 2005, relatively small sample sizes, very different climatic years in 2003 from 2005. We report results from univariate analysis of variance and GLIMMIX, because our dataset, though the largest known, is still somewhat limited and unbalanced.

Results

Objective 1—*Do fire management tactics increase short-term post-fire weed establishment?* Yes, our data showed a marked increase of nonnative invasive plant species on the 11 hand-lines measured (73 percent of occurrences) compared to control plots (27 percent of occurrences). This increase was most notable near the "anchor-point" (where the hand-line is anchored to another feature that prevents fire movement) most likely because of the proximity of this location to previously disturbed areas. Over time, the hand-line may serve as a corridor for the dispersal and establishment of nonnative invasive plants as they move along the length of the hand-line.

Objective 2—*Do FIA data assist in monitoring short- and long-term weed establishment?* Yes, FIA data did detect several nonnative invasive plant species following fire. However, FIA methods appeared useful only in terrain that is not very complex. In contrast, a less intensive sampling procedure that covers a greater area appeared to be more useful in complex terrain, likely because this method sampled a greater variety of habitats that occur in complex terrain. However, neither method detected all the nonnative invasive plant species that were seen in the area surrounding the sampling plots.

Objective 3—*Do fire incident records capture and report management tactics in sufficient detail and consistency to answer landscape-level research questions?* No. Fire records collected for incident management purposes in and around the Selway-Bitterroot Wilderness in western Montana and northern Idaho in 2000, 2003, and 2005 inconsistently captured planned and implemented tactics and were inconsistently archived, resulting in limited utility for post-fire analyses. To conduct such assessments, records would need to note whether and where planned tactics were implemented.

Objective 4—*Are digital images of fires (fire line, perimeters, and burn severity) collected in a consistent manner and archived in a central location to allow for programmatic assessment of fire management?* High potential. To date, as noted above, there is no central location where fire information (hard copy or electronic) generated on an incident is consistently archived. Fire perimeters were mapped using a variety of techniques; fire-line tactics were not consistently digitized. Moreover, archived data rarely include actual GIS data. This situation inhibits all but local efforts to assess potential ecological impacts of various fire tactics. However, the Forest Service's Remote Sensing Applications Center (RSAC) produces initial burn severity data for all suppression (suppression and containment) fires over 100 acres [Burned Area Reflectance Classification (BARC); Key and Benson 2002, 2006] and was willing to generate similar information for WFU events. These satellite-derived data are sufficient to address landscape ecological questions at a minimum spatial resolution above several ha (O'Neill and others 1999).

Objective 5—*Does Landsat TM imagery capture sufficient edge detail to allow for identification of ecologically significant edge characteristics and comparison of sharp vs. diffuse edges?* No. TM data were not sufficient for a number of reasons: (1) temporal differences between date of imagery and final fire perimeter (up to 16 days between over-flights plus additional time if smoke obscures the scene); (2) variations in methods used to generate final fire perimeters across and within incidents (varying from hand-held ground-based GPS units, to hand-held air-based GPS units, to digitizing from 30-m resolution satellite imagery); and (3) a mismatch in scale between TM data and that at which edge effects occur (30 m for satellite imagery and sub-units of meters for ecological effects) result in an inability to use TM data for considerations of edge characteristics such as sharpness of edge and sinuosity. Changes in how perimeters are derived for purposes of BARC calculation, and storage of these perimeters confounded year effects for patches and area of unburned vegetation within the final fire perimeter. If this could be standardized, the data would be even more useful.

Objective 6—*Do suppressed fires have a simpler shape than natural fires?* No. We analyzed the BARC data for our 49 sub-alpine fires at two scales: by entire fire and by severity class.

Looking at the final fire perimeter, we find larger fires are significantly more complex (as measured by Area Weighted Mean Patch Fractal Dimension) even after controlling for total fire size ($F_{1, 39} = 29.93$, $P \leq 0.000$). Using a randomized complete block design with year as a random effect, a GLIMMIX model indicates there is no significant difference in perimeter shape by strategy or by year once size and year are controlled. However, there appear to be differences between suppression fires in warm, dry years (2003) and wildfire use fires (2003, 2005) as indicated by significant p-values in least squares means tests for year*firetype after adjusting for multiple comparisons (Tukey-Kramer).

In the absence of year and size considerations, high severity patches are *less* complex than other severities (fig. 14.1). Univariate analysis of variance shows patches of all severities within a suppression fire are significantly *more* complex than either WFU or containment fires ($F_{2, 36} = 4.113$, $P \leq 0.025$ high severity; $F_{2, 46} = 14.352$, $P \leq 0.000$ moderate; $F_{2, 46} = 5.26$, $P \leq 0.009$ low severity; $F_{2, 45} = 5.838$, $P \leq 0.006$ unburned). These statistical differences disappear when controlling for year and size effects, although the resulting models have low power. Patches do become somewhat more complex with increasing size, and 2005 was a less severe season than 2003, as measured by number of days above 80th percent

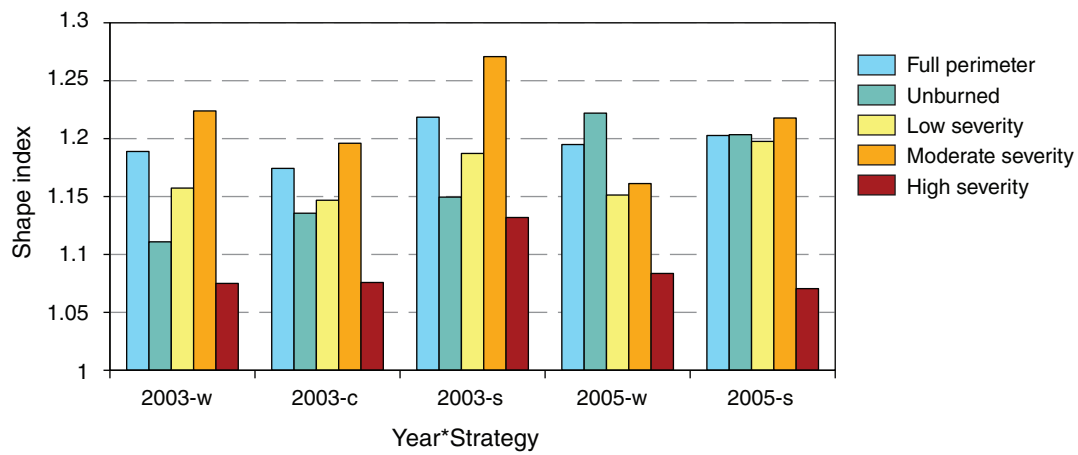

Figure 14.1—Comparison of fire and internal patch shape (defined by severity class and measured by Area Weighted Mean Shape Index) for wildland fire use (w), confinement (c), and suppression (s) fires in 2003 and 2005. Note: there were no confinement fires in 2005.

Energy Release Component. Overall, the trend appears to be that complexity increases with size and decreases with increasing fire severity and fire weather conditions.

Objective 7—*Is internal heterogeneity lower in suppressed fires than natural fires?* In some respects, yes. We measured heterogeneity several ways—patch density, mean patch size, interspersion, aggregation, contagion, and percent area—at both scales: entire fire and by severity class. Comparison among strategies indicates that patch density in fire use events is higher than in suppression events for unburned, low, and moderate severity classes and the entire fire (fig. 14.2A). Overall, density was higher in cooler 2005 and decreased for larger fires. We used several FRAGSTATS metrics to assess interspersion, aggregation, and contagion. As with other metrics, when considered irrespective of year and size, fire use events were more disaggregated (lower contagion, aggregation) and heterogeneous (variability in patch size, higher interspersion) than suppression events at both the fire scale and by fire severity class (fig. 14.2B through 14.2E). Once again, these differences were over-shadowed by year and size effects. Degree of aggregation differs with size of fire regardless of year, but was significantly lower in the cooler 2005.

Objective 8—*Are the data in such a format (spatial and digital) that they can be associated and stored with FIA data?* Possible, not currently. As noted earlier, data are not currently consistently or accessibly archived. If tactical-level GIS data, and associated BARC imagery, were to be consistently generated and centrally stored, it would be quite possible to tag with FIA plot numbers to create a national network for monitoring trends in ecological effects of fire management.

Discussion

Landscape results are consistent across a variety of different models based on one-way and multi-way analyses of variance. The emerging picture is a trend toward greater heterogeneity in internal post-fire patch structure during cooler years, and a pattern of smaller, more dispersed patches on WFU and containment as opposed to suppression events, particularly when considering patches of high severity burns. Warmer years appear to result in more homogeneous patches of high severity burn. If this trend plays out statistically, the implication for future forest health has more to do with timing of choice of fire management strategy and overall climate than with the strategy *per se*. This assumes that heterogeneity post-fire translates into more diverse future vegetative succession, and patchier fuels (more heterogeneity in cover type and structure), which is likely to influence future fire behavior through patchier fuel moisture. The robustness of significant differences in this study, and the low power of non-significant results, combined with policy and demographic changes that will undoubtedly affect strategic decisions for fire management, suggest that it would be useful to pay closer attention to this issue. Consistently associating and storing BARC data with FIA plots could be one way to build a sufficient database for more robust analyses.

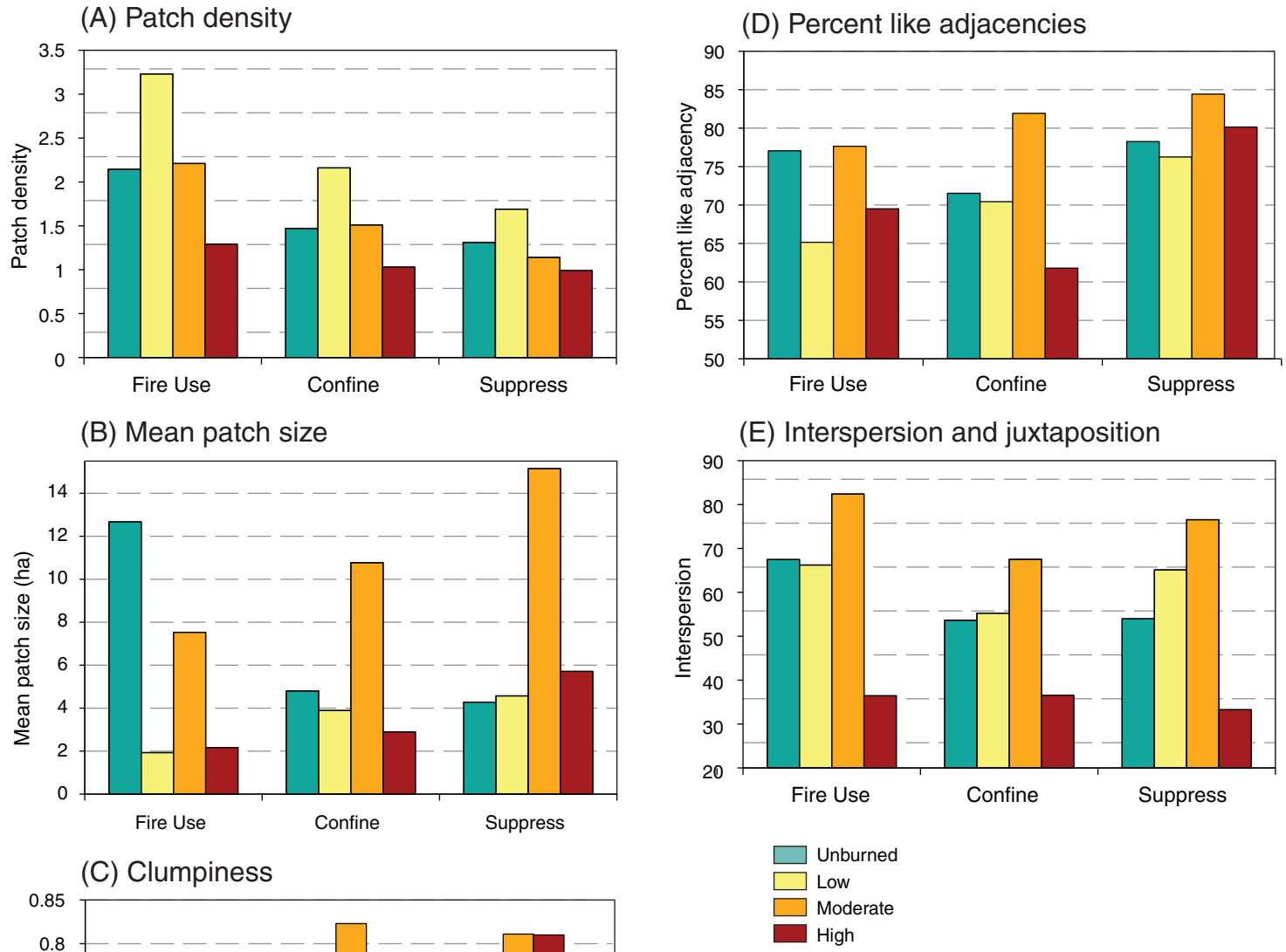

Figure 14.2—Class metrics, defined by severity class, for wildland fire use, confinement, and suppression strategies for subalpine fires > 3 ha in and around the Selway-Bitterroot Wilderness in 2003 and 2005.

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