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Forest Fire Severity Patterns of Resource Objective Wildfires in the Southern Sierra Nevada

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Distinguishing favorable versus undesirable outcomes of wildland fires in coniferous forest ecosystems is challenging and requires a clear and objective approach. I applied the natural range of variation (NRV) concept and used fire severity indicators to evaluate the possible effects of wildfires managed for resource benefits (hereafter "resource objective wildfires") in four national forests of the southern Sierra Nevada, California. Results indicated that resource objective wildfires in coniferous forests were overwhelmingly within the NRV with respect to fire severity proportions and mean and maximum high-severity patch size. These results suggest that the continued and expanded use of resource objective wildfires, including the establishment of "demonstration firesheds" within and across administrative boundaries, has the potential to vastly increase the scale of regional forest restoration efforts in the western United States.

Keywords: resource objective wildfire, natural range of variation, fire severity, fire benefits, Sierra Nevada

Fire has a variety of ecological benefits for coniferous forests, including reducing fuel loading, enhancing structural heterogeneity, promoting biodiversity, and facilitating regeneration of shade-intolerant tree species (Agee 1993, Sugihara et al. 2006, North et al. 2009). Current US federal fire management policy defines these and other benefits (i.e., resource benefits and fire benefits) as "fire effects with positive value or that contribute to the attainment of organizational goals" (US Department of Agriculture and US Department of the Interior 2009, p. 2). However, objectively defining these resource or ecological benefits can be challenging for national forests and other federal land management agencies, because of the absence of clear approaches or procedures for evaluating the long-term ecological benefits of fires in forest plans and associated fire management plans. For example, although current fire management plans provide goals that outline desirable ecological and other resource benefits, such goals may be too broadly defined, focused on more immediate resource issues (e.g., soil stabilization), or lacking an appropriate scientific evaluation framework (Aplet and Wilmer 2010).

Several conceptual frameworks are useful for evaluating whether resource goals and objectives are met for the national forests of the Sierra Nevada. One of these approaches is the natural range of variation (NRV) concept advocated under the new US Department of Agriculture (USDA) Forest Service planning rule (USDA 2012). With a combination of historic information, modeling, and contemporary reference landscape information, the NRV concept seeks to identify those "natural" or historic reference conditions that are indicative of a healthy, functional, and resilient ecosystem inclusive of historic (before widespread Euro-American settlement) human influence and future stressors (Romme et al. 2012, Safford et al. 2012). Ecosystem indicators that fall within the NRV, including fire regime characteristics, probably signify ecosystem integrity and sustainability (Morgan et al. 2001, Padgett et al. 2012). Landscape-scale fire indicators (e.g., high-severity patch size) are especially suitable for this application because of the availability of both NRV information (e.g., Meyer 2013, Safford 2013) and remote-sensed fire severity data to monitor trends in these indicators across a variety of spatial and temporal scales (e.g., Miller et al. 2009a, 2012, Dillon et al. 2011).

The southern Sierra Nevada is an ideal study area for the examination of the long-term ecological benefits of wildland fire in western US forest ecosystems. First, the neighboring national parks (i.e., Yosemite National Park and Sequoia and Kings Canyon National Parks) are unique in having a significant pro-

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portion of unlogged forest landscapes that have been extensively managed with prescribed fire and "wildland fire use" (Collins and Stephens 2007, van Wagtendonk 2007). These contemporary reference landscapes have been the focus of numerous studies that inform the NRV of Sierra Nevada forests (Meyer 2013, Safford 2013). Second, the national forests and national parks of the southern Sierra Nevada have more resource objective wildfires (e.g., wildfires managed for resource benefits) per unit area than any other part of the Sierra Nevada (van Wagtendonk 2007, Miller and Safford 2008), and most parts of the western United States with few exceptions (e.g., Teske et al. 2012). This is due, in part, to the extensive continuity of federal lands, vigorous land management and science partnerships, and active fire management efforts in the ecoregion. Lastly, the national forests of the southern Sierra Nevada, including the Sierra, Sequoia, and Inyo national forests, are currently revising their land and resource management plans under the new USDA Forest Service planning rule. Therefore, an evaluation of ecoregional wildland fire effects is timely.

The goal of this study was to evaluate whether resource objective wildfires (e.g., wildland fire use) in the national forests of the southern Sierra Nevada were within the NRV based on landscape-scale fire severity indicators. This evaluation is intended to ascertain whether resource objective wildfires provide favorable outcomes for forested landscapes in the ecoregion.

Methods

Study Area and Fire Selection

I focused my study on the national forests of the southern Sierra Nevada, including the Sequoia, Sierra, Inyo, and Stanislaus (Groveland Ranger District only) national forests, and Giant Sequoia National Monument. This study area, totaling approximately 6.0 million acres, included the neighboring national parks as reference sites to define the NRV (i.e., Yosemite National Park and Sequoia and Kings Canyon National Parks). I selected fires for fire severity analyses based on the following criteria: (1) recent incidents (2000–2011); (2) larger fire size with at least 1,000 acres located on national forestlands; (3) domination (≥50% of total area) by midelevation coniferous forest types, especially mixed conifer, yellow pine (ponderosa pine [*Pinus ponderosa*] or Jeffrey pine [*P. jeffreyi*]), and red fir (*Abies magnifica*); (4) available fire severity data based on a 1-year postfire assessment; and (5) location within the study area. I chose more recent fires, because these spanned the period during which wildland fire use fires were first introduced at a significant spatial scale in the national forests of the southern Sierra Nevada. In addition, I wished to constrain the effect of longer time periods on fire severity patterns, because there is a trend for increasing high-severity fire over time in mixed conifer and yellow pine forests of the national forests of the Sierra Nevada (Miller et al. 2009a, Miller and Safford 2012). I also selected larger wildland fires, because these were indicative of the larger spatial scale needed to effectively restore fire regimes across landscapes in the national forests of the region (Stephens et al. 2010, North et al. 2012). In a few cases, individual fires were combined (i.e., Albanita-Hooker, Broder-Beck, and Mountain-Box) when they shared fire perimeters, burned in the same year, and were considered jointly managed incidents in one or more USDA Forest Service regional databases.

I identified a total of 17 resource objective wildfires (95,296 acres total) for fire severity analysis based on the established selection criteria (Table 1). All fires burned on the west slope of the Sierra Nevada, and most fires (71%) burned in or adjacent to the Kern Plateau or neighboring Golden Trout Wilderness in the southern part of the study area. The majority of resource objective wildfires (76%) occurred on some part of the Sequoia National Forest and Giant Sequoia National Monument, and the remainder were evenly distributed among the Sierra, Inyo, and southern Stanislaus national forests (Table 1).

NRV and Current Data Sources

I extracted NRV reference information for Sierra Nevada midelevation forests using contemporary reference landscape information, LANDFIRE Biophysical Setting models, and historic field inventories (Table 2). These diverse information sources were used in combination to provide a more robust estimate of the NRV that was less prone to conceptual issues than any singular source (e.g., historic data) and consistent with current approaches for the application of NRV in natural resource management (Romme et al. 2012, Safford et al. 2012, USDA Forest Service 2012). However, individual NRV estimates may contain methodological limitations and geographic constraints, resulting in variable degrees of uncertainty. I calculated the mean and SD for each fire severity variable using values provided in each reference. I did not use recent NRV information related to studies that relied exclusively or predominantly on tree size distribution data to reconstruct historic fire severity patterns (e.g., General Land Office data in Williams and Baker 2012 or Baker 2014 or Forest Inventory and Analysis data in Odion et al. 2014), because these estimates contain substantial methodological errors, unsupported assumptions, confounding factors, misclassified vegetation types, and biased and low sampling density (Fulé et al. 2013).

I used the USDA Forest Service Region 5 vegetation burn severity and existing vegetation geospatial databases to estimate current fire severity metrics based on 1-year postfire (matching pre- and postfire image dates to minimize seasonal phenology, surface moisture, and solar zenith angle differences; Miller et al. 2009a) derived from Landsat Thematic Mapper imagery using the relative differenced normalized burn ratio (RdNBR) (Miller and Thode 2007). The dNBR values for each pixel were calculated by subtracting the postfire NBR from the prefire NBR, and RdNBR val-

Management and Policy Implications

Unplanned ignitions burning in favorable weather conditions and terrain offer unique opportunities to restore and maintain the resilience of forest ecosystems. These wildfires managed for resource objectives are ideally suited to large wilderness or inventoried roadless areas but may also include self-contained "firesheds" outside the wildland urban interface. In the national forests of the southern Sierra Nevada, 17 wildfires between 1,000 and 20,000 acres in size have been successfully managed for natural resource objectives, despite decades of fire exclusion in these topographically complex, fire-adapted forest landscapes. Fire severity patterns within these areas were overwhelmingly within the natural range of variation, and in many cases greater fire severity effects (e.g., greater proportions of moderate severity fire) could be desirable to advance structural restoration and other objectives. Collaborative efforts, "all lands" partnerships, and the use of demonstration landscapes or "firesheds" can assist managers in achieving forest restoration across large and complex landscapes.

ues are calculated by calibrating severity measurements for variation in prefire vegetation using the square root of the prefire NBR. Satellite-derived RdNBR values were classified into standard burn severity classes originally calibrated with field-based composite burn index plots (unchanged = 0–0.1, low = 0.1–1.24, moderate = 1.25–2.24, and high = 2.25–3.0) (Key and Benson 2006, Miller and Thode 2007, Miller et al. 2009b). Unchanged represents areas unburned or areas where burn severity was so low that a change could not be detected in the comparison of prefire and 1-year postfire satellite images (Miller and Thode 2007). Low fire severity generally indicates areas lightly burned, resulting in the partial combustion of surface fuels and understory vegetation and little mortality of structurally dominant vegetation. Moderate fire severity results in a mixture of fire effects, including variable tree mortality of medium- and large-sized trees (typically 25–95% mortality). High fire severity areas are characterized by complete or near-complete combustion of surface and ladder fuels and high to complete mortality of the tree canopy (usually >95%) (Miller et al. 2009b).

At the time of the study, contiguous, 1-year postfire imagery data were not available for the 2011 Lion Fire because of a sensor problem with Landsat 5. To address this data gap, I overlaid 1-year postfire National Agriculture Imagery Program aerial imagery (~1 m resolution) on the striped (i.e., fragmented) monitoring trends in burn severity 1-year postfire vegetation burn severity data to estimate mean and maximum high-severity patch size in the 2011 Lion Fire. The high-severity threshold value for monitoring trends in burn severity data was based on RdNBR. Although this approach lacks the consistency of analyses derived exclusively from Landsat imagery and should be interpreted with caution, it nevertheless provides a reasonable estimate of high-severity patch size by combining complementary imagery useful in the detection of a forest canopy change after disturbance (e.g., Prichard and Kennedy 2014, Schroeder et al. 2014).

Table 1. Characteristics of resource objective wildfires (17 total) selected for study in the national forests of the southern Sierra Nevada.

Fire name	Year	Location[a]	Size (ac)	Forest (%)[b]
Albanita-Hooker Fire	2003	Sequoia NF	4,599	80
Broder-Beck Fire	2006	Sequoia NF	3,492	84
Comb Fire	2005	Sequoia NF, SEKI	9,746	73
Cooney Fire	2003	Sequoia NF	1,928	61
Crag Fire	2005	Sequoia NF	1,185	66
Granite Fire	2009	Sequoia NF	1,397	94
Kibbie Complex	2003	Stanislaus NF, YNP	5,570	72
Lion Complex	2009	Sequoia NF	2,577	89
Lion Fire	2011	Sequoia NF, SEKI	20,681	90
Maggie Fire	2006	Sequoia NF	2,098	99
Mountain-Box Fire	2003	Stanislaus NF	2,633	67
Sheep Fire	2010	Sequoia NF, SEKI	9,021	89
Shotgun Fire	2009	Sequoia NF	1,333	80
Summit Complex	2003	Inyo NF	4,761	62
Tamarack Fire	2006	Sequoia NF	4,656	98
Tehipite Fire	2008	Sierra NF, SEKI	11,648	94
West Kern Fire	2003	Sequoia, NF, Inyo NF, SEKI	7,971	88

[a] Indicates the primary location of the fire area, excluding smaller portions of state and private lands, that includes Sequoia and Kings Canyon National Parks (SEKI), Yosemite National Park (YNP), and Bureau of Land Management-administered lands. NF, National Forest.
[b] Percentage of area within the fire perimeter that contained coniferous forest vegetation during prefire conditions.

Fire Categorization

Although a primary objective of this study was to evaluate resource objective wildfires using fire severity indicators, the current national fire management policy direction does not recognize a simple dichotomy in fire type and management response, namely "suppression" versus "wildland fire use." This is be-

Table 2. Methods and literature sources used in the estimation of the NRV for fire severity variables in midelevation coniferous forests of the Sierra Nevada.

Variable	Estimation method[a]	Study area[b]	Literature source(s)	Fire severity index	Low severity	Moderate severity	High severity[c]
					............(%)............		
Fire severity proportion	Satellite-derived	YNP	Collins et al. (2009)	2.3	42	24	13
		YNP	Kane et al. (2013)	2.3	48	24	12
		YNP	Miller et al. (2012)				11
		YNP	Thode et al. (2011)	2.4	42	37	7
		YNP	van Wagtendonk et al. (2012)	2.2	38	31	8
		SEKI	Collins et al. (2007)	1.7	44	9	4
	LANDFIRE Biophysical Models	SN	Mallek et al. (2013)	2.5	70	18	12
	Aerial photo reconstruction	SSPM	Minnich et al. (2000)	2.4	54	31	8
	Historic field estimation	SN	Leiberg (1902)	2.4	71	21	8
		SN	Show and Kotok (1925)				5
High-severity patch size	Satellite-derived	YNP	Collins and Stephens (2010)				13.8 (222) ac
		YNP	Miller et al. (2012)				10.4 (183) ac
		YNP	van Wagtendonk et al. (2012)				5.7 (—) ac
	Aerial photo reconstruction	SSPM	Minnich et al. (2000)				4.2 (133) ac
	Literature review	SN	Safford (2013)				— (247) ac

[a] All satellite-derived fire severity estimates are based on the RdNBR, with the exception that Collins et al. (2007) is based on the dNBR.
[b] Studied areas include Yosemite National Park (YNP), Sequoia and Kings Canyon National Parks (SEKI), Sierra Nevada bioregion (SN), and Sierra San Pedro Mártir in Baja California, Mexico (SSPM). Leiberg (1902) is based on the northern and central Sierra Nevada.
[c] Study estimate of high severity proportion (%) or mean (and maximum) high-severity patch size (acres). Estimates are based on the average of all mixed conifer, yellow pine, and red fir forest types. The mean high-severity patch size estimate for Collins and Stephens (2010) is based on all vegetation types excluding those containing lodgepole pine (*Pinus contorta*). The Safford (2013) high-severity patch size estimate is based on the conclusion that these patches "were rarely more than 100 ha (247 ac) in size."

cause current federal policy acknowledges that "no single term can convey the full scope or degree of management options used" for the management of wildland fires (US Department of Agriculture and US Department of the Interior 2009, p. 2). Accordingly, a single wildland fire may be concurrently managed for one or more objectives, including both protection (i.e., limit adverse fire effects to valued resources) and resource benefit objectives. Although such policy guidance provides greater flexibility to fire managers in incident management, it does present challenges for evaluating the effectiveness of fire use for achieving resource benefits after unplanned ignitions. In this study, I recognize this current terminology but have adopted a dichotomous approach, because most of the fires I analyzed burned during the period that preceded the current wildland fire federal policy direction (i.e., 2000–2009 fire seasons). In addition, more recent wildfires analyzed in this study (i.e., 2010 Sheep Fire and 2011 Lion Fire) were largely managed for resource benefits (Ewell et al. 2013) and hence provided examples of resource objective wildfires that could be grouped with wildland fire use fires of the 2000–2009 period.

Data Analysis

I used the USDA Forest Service geospatial data to estimate the percentage of forest vegetation types within individual fire perimeters. For each fire, I calculated the fire severity index as the sum of the proportional areas of each fire severity class multiplied by their fire severity value (i.e., unchanged = 1, low = 2, moderate = 3, and high = 4) (Roberts et al. 2008). Lower index values indicated fires that burned at reduced severity with more frequent unburned patches, and higher values indicated increasing fire effects and tree canopy loss. Patch Analyst 5 in ArcGIS 10 was used to estimate the mean and maximum high-severity patch size. Data were evaluated for normality with the Kolmogorov-Smirnov test and for homoscedasticity with Levene's test. I used a multivariate analysis of variance (ANOVA) to evaluate whether the NRVs in fire severity proportions (i.e., percentage of area burned at unchanged, low, moderate, or high severity) were similar between yellow pine-mixed conifer and red fir forest types. I used a one-factor model II ANOVA to evaluate whether fire severity variables (i.e., fire severity index; proportion of area burned at unchanged, low, moderate, or high severity; mean high-severity patch size; and maximum high-severity patch size) were significantly different between resource objective wildfires and NRV. I used model II linear regression to examine the relationship between fire size and fire severity proportions, fire severity index, and mean and maximum high-severity patch sizes in resource objective wildfires; Model II regression was most appropriate for fire severity and size data that were subject to natural variation and measurement error. I log-transformed fire size and mean and maximum high-severity patch size to meet parametric assumptions of normality and homoscedasticity. I conducted all analyses with Statistica 6.0 using an α level of 0.05.

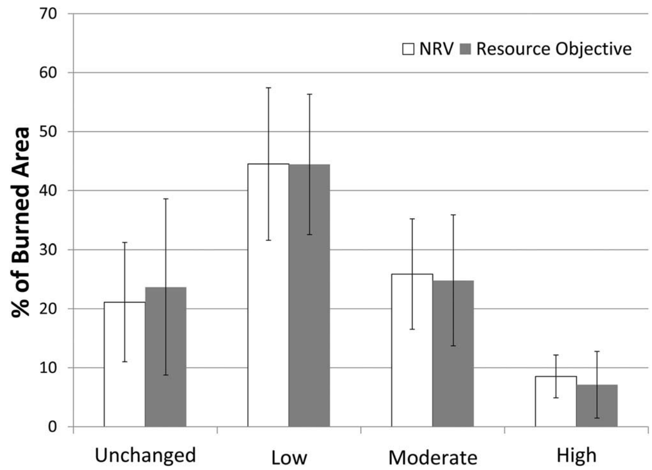

Figure 1. Mean (± SD) fire severity proportions in each severity class based on NRV and resource objective wildfires in the national forests of the southern Sierra Nevada.

Results

Across all fires, the mean ± SD percentage of prefire area dominated by coniferous forest vegetation was 82 ± 13%, and the primary forest types were mixed conifer, red fir, and Jeffrey pine forests. Six fires totaling 64,638 acres (68% of the burned acres analyzed) burned across USDA Forest Service and National Park Service boundaries. Overall, the NRV proportions of unchanged, low-, moderate-, and high-severity fire classes were generally similar between yellow pine, mixed conifer, and red fir forest types (Wilks' λ = 0.908, $F_{4,10}$ = 0.123, P = 0.966), although the proportion of high-severity fire was marginally greater in red fir (9.5 ± 4.9%) than in yellow pine or mixed conifer (8.7 ± 3.2%) forests. The proportions of unchanged ($F_{1,21}$ = 0.142, P = 0.710), low-severity fire ($F_{1,23}$ = 0.312, P = 0.582), moderate-severity fire ($F_{1,23}$ = 0.001, P = 0.973), and high-severity fire ($F_{1,25}$ = 0.644, P = 0.430) were similar between NRV and resource objective wildfires (Figure 1). Similarly, the mean ± SD fire severity index was similar between NRV (2.25 ± 0.22) and resource objective wildfires (2.15 ± 0.33; $F_{1,23}$ = 0.786, P = 0.385). There was no significant relationship between fire size and fire severity proportions or fire severity index (Table 3). The mean high-severity patch size was similar between NRV (8.5 ± 4.4 acres) and resource objective wildfires (7.0 ± 4.3 acres; $F_{1,20}$ = 0.428, P = 0.520). The maximum high-severity patch size was also similar between NRV (196 ± 50 acres) and resource objective wildfires (89 ± 75 acres; $F_{1,20}$ = 2.874, P = 0.106). The maximum high-severity patch size in resource objective wildfires was positively related to fire size based on a power relationship (log_{10} scales) (Table 3; Figure 2). Only 1 of 17 resource objective wildfires (2011 Lion Fire) had a single maximum high-severity patch size (286 acres) that approached the upper NRV value (296 acres). There was no significant relationship between mean high-severity patch size and fire size for resource objective wildfires (Table 3), although there was a tendency for larger fires to produce larger high-severity patches.

Discussion

Over the past decade, virtually all wildfires managed for resource benefit in the national forests of the southern Sierra Nevada were within the NRV with respect to fire severity proportions and mean and maximum high-severity patch size. These results suggest that resource objective wildfires in the ecoregion have been effective for achieving natural resource benefits in fire-adapted forest landscapes based on the NRV concept. Resource objective fires also have the potential to significantly increase the scale of restoration treatments currently backlogged in the mideleva-

Table 3. Summary of linear regression results for fire severity proportion, fire severity index, and high-severity patch size.

Dependent variable	Predictor	*df*	r^2_{adj}	*F* ratio	*P* value	Coefficient ± SE
Fire severity proportion and fire severity index						
Unchanged	Fire size	1,15	−0.041	0.366	0.554	
% low severity	Fire size	1,15	−0.034	0.477	0.500	
% moderate severity	Fire size	1,15	−0.066	0.003	0.955	
% high severity	Fire size	1,15	−0.067	0.001	0.979	
Fire severity index	Fire size	1,15	−0.050	0.236	0.364	
High-severity patch size						
Maximum size	Fire size	1,16	0.250	6.658	**0.020**[a]	0.78 ± 0.30
Mean size	Fire size	1,16	0.132	3.576	0.078	

All fire size predictors and maximum fire size were $\log_{10}$-transformed.
[a] *P* value for significant regression ($P < 0.05$).

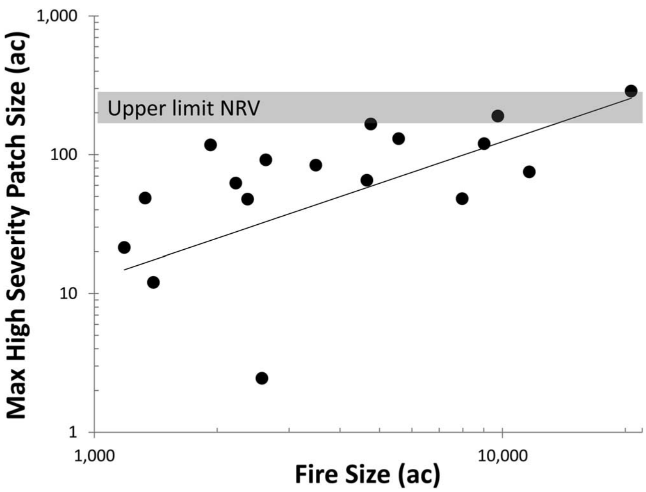

Figure 2. Relationship ($\log_{10}$ scale) between fire size and maximum high-severity patch size based on resource objective wildfires in the national forests of the southern Sierra Nevada. The upper limit in NRV for maximum high-severity patch size is denoted by the transparent gray bar between 196 (mean) and 296 acres (2 SD above the mean), indicating that values within or less than this range are likely within NRV.

tion forests of the Sierra Nevada (North et al. 2012). Six of the fires were cooperatively managed incidents that burned across USDA Forest Service and National Park Service boundaries, resulting in a combined 64,638 acres of federal lands achieving resource objectives by the standards used in this study. Resource objective wildfires in the southern Sierra Nevada and elsewhere are broadly supportive of the USDA Forest Service "all lands approach" to ecological restoration that focuses in part on building effective partnerships for the protection and enhancement of natural resources that span administrative boundaries.

Several studies of fire severity patterns in the Sierra Nevada indicate that wildfires managed under suppression objectives ("suppression wildfires") contrast greatly with resource objective wildfires or the NRV. In Yosemite National Park, suppression wildfires produced high-severity proportions and mean high-severity patch sizes that were approximately three times greater than those from wildland fire use (van Wagtendonk and Lutz 2007). Similarly, suppression fires in the midelevation forest types of the Sierra Nevada national forests generated high-severity fire proportions and mean high-severity patch sizes that were roughly twice those of wildfires managed primarily for resource benefit in Yosemite National Park (Miller et al. 2012). In the Sierra Nevada and southern Cascades, modern burned area estimates of high-severity fire proportion exceeded presettlement (NRV) estimates by a factor of 4–8 in all midelevation forest types except red fir (Mallek et al. 2013). In addition, these estimates indicate a current deficit of low- and moderate-fire severity classes in midelevation forests of the Sierra Nevada and no notable departure in high-severity fire between the modern and presettlement periods. Extreme weather conditions, challenging topography, hazardous fuel loading, high fuel continuity, and long-term fire exclusion often result in the greater fire severity effects within the footprint of suppression wildfires relative to resource objective wildfires (van Wagtendonk and Lutz 2007, Dillon et al. 2011). Interestingly, high-severity fire proportion and mean and maximum high-severity patch size are increasing in many suppression wildfires of the Sierra Nevada, a pattern that is potentially linked to changing climate in the region (Miller et al. 2009, Miller and Safford 2012).

Limitations and Additional Approaches

There are several limitations of the NRV concept and fire severity indicators used in this study. First, the evaluation of resource objectives was based exclusively on landscape-scale vegetation burn severity indicators and did not consider other natural resources or metrics. A more comprehensive assessment would include the incorporation of additional natural resources or "high valued resources and assets" (Scott et al. 2013), such as wildlife habitat, air quality, watershed function, cultural resources, biodiversity, forest carbon, and socioeconomic values and costs (Gebert and Black 2012, Hayward et al. 2012, Romme et al. 2012). Second, the practicality and scope of the NRV conceptual approach is limited by the amount and quality of NRV data available, especially for indicators that are difficult to measure in the past (e.g., historic estimates of high-severity patch size). Third, climate change and other stressors are altering background reference conditions, and these ecological changes could limit the relevance of historic data in resource management. This is especially concerning for historic data based exclusively on pre-European conditions during the relatively wetter and cooler Little Ice Age (approximately 100–650 years ago) (Stephens et al. 2010, Romme et al. 2012). However, the NRV estimates used in this study incorporate a combination of historic, contemporary reference, and model-derived information sources that provide more robust estimates of the NRV than historic data alone. Accordingly, use of diverse NRV information is desirable to reduce uncertainty and define the bounds in which fire will function as a key ecological process and maintain long-term ecosystem integrity, especially in the absence of robust projections of future fire severity in the western United States (Romme et al. 2012, Safford et al. 2012).

Implications of Fire Severity Patterns and NRV

Fire severity patterns of resource objective wildfires in the national forests of the southern Sierra Nevada suggest that greater latitude may be warranted for the reintroduction of fire into many fire-adapted forest landscapes of the western United States. This is especially the case for fires that are located outside the wildland urban interface in self-contained firesheds. For instance, some resource objective wildfires (e.g., 2006 Maggie Fire and 2010 Sheep Fire) burned primarily at lower severity, such that the proportions of moderate- and high-severity fire were typically at the lower end of the NRV. Resource objective wildfires with relatively greater or even proportions of moderate-severity fire (i.e., where low- and moderate-severity fire is in roughly equal proportion) may be considered particularly desirable, as moderate-severity fire may be more effective for achieving ecological restoration objectives (e.g., structural restoration and increased understory diversity) in fire-excluded Sierra Nevada mixed conifer and yellow pine forests (Webster and Halpern 2010, Collins et al. 2011, Kane et al. 2013) and similar frequent-fire forests in the western United States (e.g., Stevens-Rumann et al. 2012). In contrast, greater proportions of low-severity fire may have greater benefit for the maintenance of key ecological processes in mixed conifer and yellow pine forests within active fire regime landscapes (North et al. 2009, Collins and Stephens 2012) or restoring structural heterogeneity in fire-excluded red fir and other upper montane forests (Kane et al. 2013). Patches of moderate- and high-severity fire within the NRV with respect to patch size and landscape proportion are beneficial for fire-dependent species in the southern Sierra Nevada, such as giant sequoia (*Sequoiadendron giganteum*; Meyer and Safford 2011), Piute cypress (*Cupressus arizonica* ssp. *nevadensis*; Stuart and Sawyer 2001), and black-backed woodpecker (*Picoides arcticus*; Saracco et al. 2011). In comparison, patches of unburned refugia within fire perimeters (e.g., Kolden et al. 2012) would greatly benefit fire-sensitive or "fire-avoider" species such as the northern flying squirrel (*Glaucomys sabrinus*; Meyer et al. 2007, Roberts et al. 2015), hermit thrush (*Catharus guttatus*) and yellow-rumped warbler (*Setophaga coronata*; Fontaine and Kennedy 2012), foxtail pine (*Pinus balfouriana*; Keeley 2012), and an assemblage of shade-dependent understory plant species (Wayman and North 2007, Webster and Halpern 2010). Burned landscapes containing a heterogeneous mixture of fire severity classes not dominated by large high-severity or unburned patches appear to benefit fire-dependent, fire-sensitive, and fire-tolerant species alike in forests of the Sierra Nevada (e.g., Roberts et al. 2011, Saracco et al. 2011, North 2012) and western United States (Fontaine and Kennedy 2012, Stephens et al. 2012, Ryan et al. 2013). Despite recent debates over the historic importance of different fire severity classes in fire-adapted forests of western North America (e.g., Franklin and Johnson 2012, Williams and Baker 2012, DellaSala et al. 2013, Fulé et al. 2013, Henson et al. 2013, Odion et al. 2014), the management of fire in both contemporary and future forest landscapes in the region will clearly require greater management flexibility, use of wildland fire, interagency collaboration, and recognition of the uncertainty of future fire regimes and climates (Fulé 2008, Stephens et al. 2010, 2013, North et al. 2012, Hurteau et al. 2014).

Large resource objective wildfires can substantially increase the scale of forest restoration efforts, but fire managers may wish to exercise caution in landscapes with heavy and continuous fuel loading and drought-stressed vegetation (North et al. 2012, van Mantgem et al. 2013). Rapid fire spread rates in these landscapes during less favorable weather conditions may be especially concerning if they result in undesirable negative impacts on watersheds, air quality, wildlife habitat, and other natural resources. For example, fire spread rates in the 2011 Lion Fire that exceed roughly 740 acres per day resulted in localized smoke impacts that were considered unhealthy to smoke-sensitive groups (e.g., elderly individuals and individuals with asthma; Schweizer and Cisneros 2014). Arguably, such rapid fire spread rates may sometimes be necessary for increasing the scale of resource objective wildfires in topographically complex forested landscapes, especially during the initial entry phase. However, the use of such an approach would need careful weighing of the full costs and benefits of increased fire effects across the larger landscape to maximize natural resource benefits and minimize losses resulting from resource objective wildfires.

Ecological Restoration and "Demonstration Firesheds"

Wildland fire is an essential management tool for achieving ecological restoration across large forest landscapes of the western United States (Ryan et al. 2013). However, achieving this scale of fire use for resource benefits in the region requires identifying suitable areas for the restoration and long-term maintenance of fire and other key ecological processes (North et al. 2012). Ideally, these suitable areas are relatively remote or largely outside the wildland urban interface and dominated by forests characterized with historically frequent, low- to moderate-severity fire regimes (e.g., Collins and Stephens 2007). These areas, identified as "experimental landscape laboratories" or "demonstration firesheds," could serve not only as future areas of ecological research but also as contemporary reference landscapes with the effective reintroduction of fire (North et al. 2014). Large forest landscapes predominantly within federal ownership, such as the southern Sierra Nevada, are highly suitable for the future restoration, maintenance, and study of wildland fire both within and across agency boundaries. In addition, strong interagency partnerships and active collaborations with stakeholders, nongovernmental organizations, and local tribes are essential to building mutual support for these demonstration firesheds that can facilitate shared learning and trust. The establishment of these demonstration landscapes in appropriate areas of the western United States could significantly advance fire and natural resource management objectives focused on enhancing the resilience of forest ecosystems throughout the region, especially in an era of rapidly changing climate (Stephens et al. 2010, 2013).

Conclusions

Resource objective wildfires have achieved broad-scale natural resource benefits in the national forests of the southern Sierra Nevada, based on an application of the NRV concept using several fire severity metrics. These patterns contrast with wildfires managed under suppression objectives, which, based on several previous studies in the ecoregion, indicate that most suppression wildfires fall outside the NRV with respect to high fire severity proportion and patch size. There are several limitations in the use of NRV information to define resource benefits of wildland fires, including conceptual and practical issues. However, this approach can be suitable for evaluating the initial effects of large wildland fires on forest landscapes, especially when coupled with other conceptual methods and considering fire effects on additional focal resources (e.g., air quality).

Fire severity patterns of resource objective wildfires in the southern Sierra Nevada suggest that greater flexibility may be warranted for the reintroduction of fire into many fire-adapted forest landscapes of the western United States, including national forestlands. This can substantially increase the scale of forest restoration efforts in the region. In most instances, a heterogeneous mixture of fire severity classes not dominated by large high-severity or perennially unburned patches is beneficial to a diverse array of flora and fauna in the ecoregion. However, each forest landscape would present a unique challenge to fire managers attempting to consider the cumulative effects of multiple, intersecting wildland fires. For instance, greater proportions of low-severity fire may be broadly desirable for the maintenance of key ecological processes in active fire regime landscapes or for the promotion of structural heterogeneity in specific forest types. Drought-stressed landscapes with excessive fuel loading or invasive species concerns may present additional constraints in the use of wildland fire. Remote fire-adapted landscapes outside the wildland urban interface are ideal for the reintroduction and long-term maintenance of wildland fire. In conjunction with advance planning and collaborative efforts, these demonstration firesheds will greatly enhance natural resource benefits and minimize losses associated with resource objective wildfires in the region.

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