Forest Ecology and Management 287 (2013) 103–112

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Post-fire regeneration across a fire severity gradient in the southern Cascades

Justin S. Crotteau [a,b,*], J. Morgan Varner III [b], Martin W. Ritchie [b]

[a] Department of Forestry & Wildland Resources, Humboldt State University, 1 Harpst Street, Arcata, CA 95521, USA
[b] USDA, Forest Service Pacific Southwest Research Station, 3644 Avtech Parkway, Redding, CA 96002, USA

ARTICLE INFO

Article history:
Received 9 March 2012
Received in revised form 7 September 2012
Accepted 13 September 2012
Available online 13 October 2012

Keywords:
Regeneration
Seedlings
Vegetation dynamics
Lassen National Forest
Storrie Fire

ABSTRACT

Large scale, high-severity fires are increasing in the western United States. Despite this trend, there have been few studies investigating post-fire tree regeneration. We established a study in the footprint of the 2000 Storrie Fire, a 23,000 ha wildfire that occurred in northern California, USA. We used a stratified sampling design to quantify post-fire vegetation dynamics across four levels of burn severity and three forest types on the Lassen National Forest nine and ten years following fire. Within each sampled stand, we recorded tree seedlings, forest overstory, shrub cover, and abiotic factors hypothesized to influence growth and establishment.

Median conifer seedling densities varied substantially by burn severity: 1918 seedlings ha^{-1} in the Unchanged units; 4838 seedlings ha^{-1} in the Low-severity units; 6484 seedlings ha^{-1} in the Medium-severity units; and 710 seedlings ha^{-1} in the High-severity units. Increased burn severity was associated with greater shrub coverage: shrub cover in High-severity burns was more than three times those of lower burn severities. We calculated Shannon's Species Diversity (H') and Pielou's Evenness (E_H) indices to examine woody shrub and tree diversity. *Abies* spp. were by far the most abundant regenerating conifer species, which may be a concern for land managers; shrub cover after High-severity burns was dominated by *Ceanothus* spp. Although fir regeneration was prolific, the Storrie Fire generated diverse vegetative responses, potentially aiding in the reintroduction of the diverse landscape mosaic homogenized by a century of landscape-scale fire exclusion.

1. Introduction

Roughly a century of fire exclusion in the western USA has led to alterations in surface and canopy fuels and increased densities of forests due to the protracted fire-return intervals (McKenzie et al., 2004). Recent evidence points to an increase in large fires (Westerling et al., 2005) and the frequency of high burn severities in large patches (Miller et al., 2009; Fried et al., 2008), resulting in structurally coarse-grained landscapes. These altered fire regimes directly affect landscape vegetation dynamics, influencing both forest structure and composition (Turner et al., 1997; Broncano et al., 2005; McIntire et al., 2005; Odion et al., 2010), yet studies examining the resultant forest legacies after mixed-severity fire are few.

Natural forest regeneration gains importance as scale of disturbance increases. High-severity burns may be less likely to naturally reforest if the scale is sufficient to preclude seed-tree adjacency (Turner et al., 1999; Sessions et al., 2004). Coniferous species rely on wind and rodents for seed dispersal, therefore spatial distribution of regeneration is limited by distance to nearest seed-bearing tree or stand (Bonnet et al., 2005; Donato et al., 2009). Current research in post-fire natural regeneration reveals desirable natural regeneration may be inhibited by dominance of woody shrubs (e.g., Gray et al., 2005; Hogg and Wein, 2005; Moghaddas et al., 2008) and suggests high spatial variability in the regenerating cohort (e.g., Turner et al., 1997; Shatford et al., 2007). Monitoring shifting trends on the landscape can provide valuable insight into post-fire vegetation dynamics (Stuart et al., 1993; Odion et al., 2010; Freeman and Kobziar, 2011) and informing forest managers about the extent and condition of mature natural regeneration.

Montane ecosystems in California have adapted to a range of historic fire frequencies and severities (Agee, 1993; Skinner and Taylor, 2006). The Mediterranean climate maintains fire-prone ecosystems, resulting in a variety of species assemblages across a topographically heterogeneous landscape (Sugihara and Barbour, 2006). Land managers in California are subject to a number of pressures in the aftermath of a wildfire event, many of which hinge on the ability of the diverse forested landscape to not only regenerate, but reestablish dominance on the landscape. Although a number of studies have examined natural regeneration immediately following fire (2–5 years; e.g., Turner et al., 1997; Donato et al., 2006, 2009; Moghaddas et al., 2008), trees may require a longer period

* Corresponding author. Address: USDA, Forest Service Pacific Southwest Research Station, 3644 Avtech Parkway, Redding, CA 96002, USA. Tel.: +1 530 226 2547; fax: +1 530 226 5091.
E-mail address: jscrotteau@fs.fed.gov (J.S. Crotteau).

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http://dx.doi.org/10.1016/j.foreco.2012.09.022

to establish, therefore a long term study of regeneration and shrub dynamics is essential for improved ecosystem understanding and long term forest management decision making.

The 2000 Storrie Fire in northern California presented an opportunity to investigate post-fire regeneration patterns across the landscape after a 9–10 year period of natural recovery. The Storrie Fire was a large (23,000 ha), mixed-severity burn, and provided occasion to study a variety of landscape conditions. The objectives of this study were to: (1) quantify post-fire tree seedling and woody shrub response; and (2) examine seedling and shrub species trends on the landscape. The latter objective addresses woody shrub and tree seedling species diversity and the relative balance between pine and fir. This study was designed to aid our understanding of tree recovery and shrub competition after mixed-severity fire in northern California. Our study presents distinct post-fire vegetation trends across a burn severity gradient that may be carefully extrapolated to a variety of fire-prone western landscapes with similar climate, fire, and management regimes.

2. Methods

2.1. Study site

The study site was a 9371 ha portion of Lassen National Forest (LNF), California, where the 2000 Storrie Fire burned. Historically, fires were observed a minimum of 9 years apart in mid-montane forests to 110 years apart in the upper montane forests of this bioregion (Skinner and Chang, 1996; Beaty and Taylor, 2001; Skinner and Taylor, 2006). USFS R5 historical burn polygons reveal that the majority of our study area (98.4%), however, had experienced approximately a century without fire preceding the 2000 event.

The Storrie Fire was characterized by high spatial complexity with varying levels of low- to high-severity burns (Table A1) on the predominantly forested landscape. The fire burned areas within the Plumas and Lassen National Forests; this study was funded by the latter and therefore focuses only on the forested portion of the LNF, ca. 41% of the total footprint of the fire. The fire was ignited on 17 August 2000 after which it rapidly spread north and then slowly fanned outward and created a burned region of approximately 24 km from north to south in Plumas County. After a period of slow fire growth in the northwestern quarter, the fire was fully contained by 27 September 2000. The most northerly edge of the burn was located at approximately 121.32°W and 40.17°N, just over 16 km southwest of Lake Almanor (Fig. 1). The 4 days prior to the fire were characterized by low minimum relative humidity (5–15%), high maximum daily temperatures (greater than 30 °C), and low mean wind speeds with gusts no greater than 32 km/h (PRISM Climate Group, 2011). Following ignition, temperatures became slightly cooler and relative humidity increased.

Elevation of the study area ranged from ca. 900 m to 2100 m above MSL. Climate for the study site is typified as Mediterranean with warm, dry summers (mean max. temperature, June–September: 21–26 °C) with precipitation less than 42 mm each summer month and wet, cool winters (mean max. temperature, November–March: 6–9 °C) with precipitation greater than 248 mm each winter month; the area receives less than 5% of annual precipitation in summer months (PRISM Climate Group, 2011). Palmer Drought Severity Index (PDSI) for the year 2000 in the encompassing Sacramento Drainage region was 0.15, a neutral year after one neutral and four very wet to extremely wet years since 1995 (National Climatic Data Center, 2011). This region is in close proximity (ca. 45 km) to Mount Lassen, the southernmost volcanic peak in the Cascades, abutting the northern edge of the Sierra Nevada. The soil-vegetation map of the area reports both volcanic and granitic parent material, a product of the two adjacent mountain ranges (Soil Survey Staff, 2011). The soils are therefore highly variable, ranging from rocky outcroppings with little or no topsoil to deep (1.5 m) loams overlying bedrock. Overstory characteristics, slope, aspect, and vegetative cover were variable across the study area, as is typical of the region (Skinner and Taylor, 2006). The Lassen NF burned area was dominated by forests of white fir (*Abies concolor* (Gordon & Glend.) Lindley), California red fir (*A. magnifica* var. *magnifica* Andr. Murray), incense-cedar (*Calocedrus decurrens* (Torrey) Florin), Sierra lodgepole pine (*Pinus contorta* Louden var. *murrayana* (Grev. & Balf.) Critchf.), Jeffrey pine (*P. jeffreyi* Grev. & Balf.), sugar pine (*P. lambertiana* Douglas), western white pine (*P. monticola* Douglas), ponderosa pine (*P. ponderosa* Laws.), Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco), and California black oak (*Quercus kelloggii* Newb.). The most prevalent shrub species included deer brush (*Ceanothus integerrimus* Hook. & Arn.), snowbrush (*C. velutinus* Dougl.), huckleberry oak (*Q. vaccinifolia* Kellogg), pinemat manzanita (*Arctostaphylos nevadensis* A. Gray), greenleaf manzanita (*A. patula* E. Greene), mountain whitethorn (*C. cordulatus* Kellogg), and bush chinquapin (*Chrysolepis sempervirens* (Kellogg) Hjelmq.).

Dominant forest types were Sierra Nevada Mixed Conifer, White fir, and Red fir, following the elevation gradient of the region (Eyre, 1980). The Mixed Conifer type of the mid-montane westside zone of the southern Cascades historically experienced frequent (every 9–42.5 years), small to medium surface fires that burned with low to moderate severity, creating open stands of large diameter trees (Beaty and Taylor, 2001; Skinner and Taylor, 2006). Although each of the coniferous species in this zone (*A. concolor*, *C. decurrens*, *Pseudotsuga menziesii*, *Pinus lambertiana*, and *P. ponderosa*) are resistant to fire when mature, the fire stimulated germination of *P. ponderosa* and the ability to withstand fire at a young age suggests that *P. ponderosa* may most suitably interact with the historic fire regime. Yet, twentieth century fire suppression has resulted in a drastic inflation in fire rotation for the mid-montane westside zone, resulting in uncharacteristically high densities of the shade-tolerant *A. concolor* (Beaty and Taylor, 2001). At slightly higher elevations, the White fir forest type in this region is situated such that it occupies both mid-montane westside and the upper-montane ecological zones, while the Red fir type is most commonly associated with the upper-montane zone. These forest types often form nearly pure stands of true fir (*A. concolor* and *A. magnifica*), particularly as elevation increases. Historically, the fire regime for the White and Red fir types ranged from frequent to infrequent fire (25–110 years) that burned small to medium patches in a variety of severities, resulting in relatively high spatial stand complexities (Skinner and Taylor, 2006). Fire suppression has allowed for denser forests in these forest types as well, yet current fire return intervals may not be outside of natural variation.

2.2. Sampling methods

The Lassen NF landscape within the perimeter of the Storrie Fire was divided into 12 strata: four levels of fire-severity across three levels of forest type. Fire severity was determined remotely by using the Relative differenced Normalized Burn Ratio (RdNBR), which has been reported to approximate the Composite Burn Index (CBI; Miller et al., 2008), a field-based assessment of burn severity. The RdNBR is created from bands 4 and 7 from two LANDSAT Thematic Mapper images (pre-fire and 1 year post-fire) and is subsequently transformed to four nominal CBI categories: (1) Unchanged (minimal or no visible effect of fire), (2) Low-severity, (2) Medium-severity, and (4) High-severity (Table 1). Forest type was determined according to Eyre (1980) in conjunction with a digital elevation model (DEM) to guide elevation thresholds. The forested landscape was segregated into "Mixed Conifer" (dominant type: Sierra Nevada Mixed Conifer), "Low-elevation Fir" (dominant