Rangeland Ecology & Management 71 (2018) 345–355

Contents lists available at ScienceDirect

Rangeland Ecology & Management

journal homepage: http://www.elsevier.com/locate/rama

Factors Affecting Efficacy of Prescribed Fire for Western Juniper Control☆

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ARTICLE INFO

Article history:
Received 29 September 2017
Received in revised form 1 February 2018
Accepted 7 February 2018

Key Words:
bare ground
encroachment
fire type
mortality rate
vegetation type
tree height

ABSTRACT

Western juniper (*Juniperus occidentalis* Hook.) is a tree species occurring on 3.6 million ha in the northern Great Basin. This native species can be quite invasive, encroaching into sagebrush-grassland vegetation, forming woodlands, and dominating extensive landscapes. Control of encroaching juniper is often necessary and important. Efficacy of prescribed fire for western juniper control depends on many factors for which our understanding is still quite incomplete. This knowledge gap makes fire management planning for western juniper control more difficult and imprecise. Natural resource managers require a fire efficacy model that accurately predicts juniper mortality rates and is based entirely on predictors that are measurable prefire. We evaluated efficacy models using data from a fall prescribed fire conducted during 2002 in southwestern Idaho on mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* [Rydb.] Beetle) rangelands with early to midsuccessional juniper encroachment. A logistic regression model, which included vegetation cover type, tree height, fire type, and bare ground as predictors, accurately predicted (area under the receiver operating characteristic [ROC] curve [AUC] $= 0.881 \pm 0.128$ standard deviation [SD]) the mortality rate for a random sample of western juniper trees marked and assessed prefire and 5 yr post fire. Trees occurring in an antelope bitterbrush (*Purshia tridentata* [Pursh] DC.) type, which had a heavy fuel load, were 8 times more likely to be killed by fire than trees in a mountain big sagebrush type, where loading was typically lighter. Probability of mortality decreased by 28.8% for each 1-meter increase in tree height. Trees exposed to head fire were 3 times as likely to be killed as those exposed to backing fire. Findings from this case study suggest that with just four factors which are readily quantifiable prefire, managers can accurately predict juniper mortality rate and thus make better informed decisions when planning prescribed fire treatments.

Introduction

Western juniper (*Juniperus occidentalis* Hook.) is a tree species that occurs on about 3.6 million ha in the northern Great Basin (Miller et al., 2005). Although it is a native species, western juniper can be quite invasive, encroaching into sagebrush-grassland vegetation, eventually forming woodlands, and functionally dominating extensive landscapes. However, western juniper, a nonsprouting species, can be killed by fire. Local distribution of western juniper can thus be strongly influenced by the periodic occurrence of wildfire. Before European settlement (i.e., before 1870), western juniper in the northern Great Basin was primarily confined to rocky ridgetops, shallow soils, and other areas with sparse fuels (Cottam and Stewart, 1940; Burkhardt and Tisdale, 1976; West, 1984; Miller et al., 1999). Juniper trees encroaching on shrub- and grass-dominated rangelands, where soils were deeper and fuels more abundant, were probably killed by periodic wildfires. However, during the nearly 150 yr since European settlement, western juniper populations have increased exponentially (Miller and Wigand, 1994; Miller et al., 2005). Climatic changes may account for some of this increase (Knapp and Soule, 1996), but anthropogenic reductions of wildfire occurrence and/or extent, through heavy livestock grazing and active fire suppression, are believed to be the principal cause of this dramatic growth in western juniper populations (Burkhardt and Tisdale, 1976; Miller and Rose, 1995, 1999).

Juniper encroachment and transition of shrub-grasslands into western juniper woodlands reduce shrubs and, in some cases, herbaceous plant cover (Burkhardt and Tisdale, 1969; Bunting et al., 1999; Miller et al., 2000), increase risk of soil nutrient loss (Miller et al., 2005), reduce effective precipitation through canopy interception (Young et al., 1984; Larsen, 1993), decrease site capacity to capture and store water (Bates et al., 2000; Roundy et al., 2014b; Kormos et al., 2017), increase the potential for runoff and erosion (Pierson et al., 2013; Williams et al., 2014), decrease the quality and/or diversity of habitat for some wildlife species

☆ This study was funded by the USDA-ARS. Mention of a proprietary product does not constitute a guarantee or warranty of the product by the USDA or the authors and does not imply its approval to the exclusion of other products that may also be suitable.

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https://doi.org/10.1016/j.rama.2018.02.002
1550-7424/Published by Elsevier Inc. on behalf of The Society for Range Management.

(Willis and Miller, 1999; Noson, 2000; Schaefer et al., 2003; Baruch-Mordo et al., 2013; Coates et al., 2017); and adversely impact forage quantity and quality, livestock grazing opportunities, and ranch-level economics (Young et al., 1982, 1985; Bates et al., 2000; Aldrich et al., 2005; McClain, 2013). Juniper encroachment and woodland development on shrub-grasslands have been classified into three phases (Miller et al., 2005). Juniper trees are sparsely scattered, small in size, and subdominate to shrubs in phase I; more common and codominate with shrubs in phase II and dominate the site in phase III or woodland phase. Juniper control in phases I and II can prevent advancement of a site into phase III and avoid the adverse consequences of woodland development (Bates et al., 2014). Restoring phase III juniper sites back to a preinvasion shrub-grassland state is difficult, costly, and, often, not entirely possible (Young et al., 1982; Miller et al., 2005; Bates et al., 2017). Control of encroaching western juniper is, therefore, often necessary and important.

Approaches to juniper control generally include mechanical (e.g., chaining, cutting/felling, and mastication), chemical (e.g., tebuthiuron and picloram herbicides), and prescribed fire (Miller et al., 2005; Bates and Svejcar, 2009; Bates and Davies, 2016; Bates et al., 2017). All have their merits and drawbacks (Miller et al., 2013; Roundy et al., 2014a; Bates and Davies, 2016), but prescribed fire is often the most efficient and cost-effective approach, particularly for phase I encroachments into mountain big sagebrush associations when trees are smaller, less densely clustered, and ample shrubs are present as ladder fuels (Miller et al., 2000, 2014). Efficacy of prescribed fire for western juniper control, however, depends on many factors. Yet our understanding of the influence and ranked importance of these factors is still incomplete. This knowledge gap makes fire management planning for western juniper control more difficult and imprecise.

Factors affecting the efficacy of prescribed fire have been evaluated for other juniper and rangeland tree species. Tree size, wind speed, relative humidity, and total fuel load affect fire-induced mortality rates of honey mesquite (*Prosopis glandulosa* Torr. var. *grandulosa*) (Britton and Wright, 1971). Tree size is a factor in alligator juniper (*Juniper deppeana* Steud.) killed by fire (Johnson et al., 1962). Mortality rate of redberry juniper (*Juniperus pinchotii* Sudw.) decreases with increased tree height and burial of the bud zone (Steuter and Britton, 1983). Tree height also affects fire-induced mortality rate of Ashe juniper (*Juniperus ashei* J. Buchholz) (Noel and Fowler, 2007). Leaf moisture content and seasonal climatic conditions influence the flammability of redberry juniper (Bunting et al., 1983). Fuel load under and adjacent to the crown contribute to crown scorch severity in redberry and Ashe juniper (Twidwell et al., 2009). Factors affecting prescribed fire-mortality rates in western juniper, however, have received less research attention.

Fire efficacy and conifer mortality models commonly include tree-injury variables (e.g., crown volume scorched, bore char), which are measured following the fire (Ryan and Reinhardt, 1988; McHugh and Kolb, 2003; Thies et al., 2006; Hood et al., 2007). For planning prescribed fires, models dependent on tree-injury predictor variables would have much less utility than a model based on predictors that can be readily assessed in the field and/or at the geographic information system (GIS) workstation before burning operations. Natural resource managers planning prescribed fires for control of western juniper need a fire-efficacy model that accurately predicts juniper mortality rates and is based entirely on predictors that are measurable prefire. Consequently, the goal of this research was to develop and evaluate a preliminary version of this kind of fire-efficacy model based on data acquired from a prescribed fire conducted on sagebrush rangeland in phase I of western juniper encroachment. Specific objectives of this research included 1) determine the principal factors affecting the efficacy of fall prescribed fire for killing western juniper trees on sagebrush steppe landscapes and 2) evaluate the accuracy and predictive performance of simple, fire-efficacy models based only on predictors readily assessable in the field or with GIS before fire application.

Materials and Methods

Study Area

The study was conducted at the Breaks prescribed-fire study area (81.1 ha), which comprises private lands located within the Reynolds Creek Experimental Watershed (43°6′29″N, 116°46′37″W) and about 80 km south of Boise in southwestern Idaho (Fig. 1). This research centers around a prescribed fire conducted in the study area during fall 2002. Climate at the study area is continental with maritime influences. Winters are cold and wet, while summers are warm and dry. Long-term (1966 − 1975, 2002 − 2016) mean water-yr precipitation at the Breaks gauges (site ID 145) was 571 mm (NWRC, 2017), about one-third of which falls as snow (Hanson, 2001). Annual precipitation during the 2002 water yr was 525 mm and thus quite close to average. The growing season is about 100 d, but frost can occur during any month of the year. Long-term (2001 − 2016) mean daily maximum, minimum, and mean air temperatures at Breaks were 8.3°C, 3.8°C, and 7.8°C, respectively (NWRC, 2017). The daily mean air temperature during the 2002 study yr was 7.9°C.

Topography of the study area is an east-facing hillslope ranging from 1 542 to 1 763 m in elevation. Slope ranges from flat to steep (78% or 38° maximum). Aspects in all four cardinal directions are well represented. Four hillslope positions are present in the study area: summit, shoulder, backslope, and footslope. The toeslope on this landscape was below and outside the bounds of the study area. Soils are primarily derived from granitic parent materials and composed of a complex of Takeuchi (coarse, loamy, mixed, frigid Typic Haploxerolls) and Kanlee (fine, loamy, mixed, frigid Typic Argixerolls) soil series (Seyfried et al., 2001).

Three vegetation cover types dominate this landscape: 1) mountain big sagebrush–mountain snowberry (*Artemisia tridentata* Nutt. ssp. *vaseyana* [Rydb.] Beetle–*Symphoricarpus oreophilus* A. Gray), 2) antelope bitterbrush (*Purshia tridentata* [Pursh] DC.)–mountain big sagebrush, and 3) native bunchgrass grassland. This vegetation composition is typical of the mid- and higher-elevation portions of the sagebrush steppe throughout the northern Great Basin (see Fig. 1). All three of these vegetation types would be classified to the Loamy 16-22 Ecological Site with the two shrub-dominated types representing state 1, phase 1.5 and the bunchgrass type, state 1, phase 1.4 (R025XY022ID). In addition to the two codominant shrub species, the mountain big sagebrush − mountain snowberry type includes yellow rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt.), Saskatoon serviceberry (*Amelanchier alnifolia* [Nutt.] Nutt. ex M. Roem. *alnifolia*), bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Love), Sandberg bluegrass (*Poa secunda* J. Presl.), squirreltail (*Elymus elymoides* [Raf.] Swezey), Idaho fescue (*Festuca idahoensis* Elmer), basin wildrye (*Leymus cinereus* [Scribn. & Merr.] A. Love), mountain brome (*Bromus marginatus* Nees ex Steud.), silvery lupine (*Lupinus argenteus* Pursh), tapertip hawksbeard (*Crepis acuminata* Nutt.), western stoneseed (*Lithospermum ruderale* Douglas ex Lehm.), and western aster (*Symphyotrichum ascendens* [Lindl.] Nesom). Graminoid components of the antelope bitterbrush − mountain big sagebrush type include bluebunch wheatgrass, Sandberg bluegrass, and squirreltail. Arrowleaf balsamroot (*Balsamorhiza sagittata* [Pursh] Nutt.), western yarrow (*Achillea millefolium* L. var. *occidentalis* DC.), buckwheats (*Eriogonum spp.* Michx.), biscuitroots (*Lomatium spp.* Raf.), and tapertip hawkbeard are the principal forbs in this type. Bluebunch wheatgrass, Sandberg bluegrass, squirreltail, Idaho fescue, and needlegrasses (*Achnatherum* spp. Beauv.) dominate the native bunchgrass cover type. Cheatgrass (*Bromus tectorum* L.) has a minor to common presence in all three of these dominant vegetation types.

Two additional vegetation types occur in minor extents within the study area. Dry meadow grassland occurs in some swales on the footslope. Western rush (*Juncus occidentalis* Wiegand) and bluegrasses (*Poa* ssp. L.) are the principal vegetation in this type. Several small stands (< 1 ha) of quaking aspen (*Populus tremuloides* Michx.) occupy