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Effects of conifer treatments on soil nutrient availability and plant composition in sagebrush steppe

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ABSTRACT

Piñon-juniper woodlands of the western United States have expanded 2 to 10-fold since the late 1800's. Tree control measures using chainsaws, heavy equipment and prescribed fire have been used to reduce woodlands and restore big sagebrush steppe and decrease woody fuel loading. We evaluated nutrient availability and herbaceous recovery following various cutting and prescribed fire treatments in late succession western juniper woodlands on two sites in southeast Oregon from 2007 to 2012. Sites were a cool, wet big sagebrush-Idaho fescue association (FESCUE), highly resistant to exotic annual grasses and a warm dry big sagebrush-bluebunch wheatgrass association (BLUEBUNCH), moderately resistant to annual grass invasion. Treatments were untreated controls, partial cutting followed by fall broadcast burning (SEP), cut and leave (CUT), and cut and burn in winter (JAN) and spring (APR). Soil inorganic N (NO_3^-, NH_4^+), phosphorus ($H_2PO_4^-$), potassium (K^+), and cover of herbaceous species were measured in three zones; interspace, litter mats around the tree canopy (canopy), and beneath felled trees (debris). Following woodland cutting, the results of the various slash treatments measured significant differences through time in the availability of inorganic N, P, and K and vegetation composition. Peak nutrient availability tended to occur within the first two years after treatment. The increases in N, P, and K were greatest in severely burned debris and canopy zones of the SEP and APR treatments. Invasive annual grass cover was positively correlated to soil inorganic N concentrations. Herbaceous composition at the FESCUE site was generally resistant to annual grasses after juniper treatments and native plants dominating post-treatment even in highly impacted debris and canopy zones of the SEP treatment. The BLUEBUNCH site was less resistance and resilient, thus, exotic annual grasses were a major component of the understory especially when tree and slash burning was of high fire severity. To lessen these impacts requires slash burning be applied from late fall to early spring, when fuel moisture and relative humidity are higher, to maintain an adequate perennial herbaceous composition for recovery.

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1. Introduction

In the past 150 years, juniper (*Juniperus* spp.) and piñon (*Pinus* spp.) coniferous woodlands have increased 2 to 10-fold across 9 ecoregions of the Intermountain area of the western United States (Omernik, 1987; Romme et al., 2009). Woodland expansion is well documented in semi-arid regions of the inland northwest where western juniper (*Juniperus occidentalis* spp. *occidentalis* Hook.) is estimated to occupy about 4 million hectares. About 95% of woodland expansion has occurred in sagebrush (*Artemisia* spp.) steppe communities (Miller et al., 2011). Woodland dominance results in lower diversity and production of herbaceous and shrub layers, loss of habitat for shrub obligate wildlife, altered soil and litter nutrient distribution, and may cause negative impacts to watershed processes (Doescher et al., 1987; Klemmedson and Tiedemann, 2000; Miller et al., 2005; Pierson et al., 2010).

To reverse these impacts, control of conifer woodlands by mechanical treatments and prescribed fire has been applied since the 1950's. The recovery of plant communities after treatment of conifers is well documented and is influenced by a number of factors including phase of woodland treated, type of treatment, disturbance severity, residual plant composition following treatment, and site resilience and resistance to invasion by exotic annual grasses (Miller et al., 2014; Roundy et al., 2014). Low and moderate severity fires often cause only nominal damage to herbaceous understories and recovery is dominated by native plant communities (Bates et al., 2006, 2014; Miller et al., 2014; Roundy et al., 2014). Severe fires that cause high levels of native plant mortality often result in post-fire weed dominance (Bates et al., 2006, 2013, 2014; Condon et al., 2011). A key determinant for recovery immediately after woodland treatment is initial plant composition. Sites

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with relatively intact residual understories recover within 5 years' post-treatment while sites with less intact understories require longer recovery periods, achieve only partial recovery with a mix of native and exotic species, or become dominated by invasive weeds. The lower a plant community's resistance and resilience the higher risk of conversion to invasive annual grass dominance after disturbance (Chambers et al., 2007, 2014).

Management treatments and natural disturbances in conifer woodlands and other semi-arid systems effect soil physical, chemical, and biological properties and processes which feedback to influence spatial, temporal, and compositional recovery of plant communities (DeBano et al., 1998; Neary et al., 1999). Fire and mechanical treatments increase short-term available soil water, N, P, and other nutrients in semiarid woodlands and shrublands (DeBano and Klopatek, 1988; Blank et al., 1994; Bates et al., 2000, 2002; Davies et al., 2007; Rau et al., 2007; Roundy et al., 2014). Available soil nutrients may remain elevated from 1 to 5 years depending on type of woodland treatment, although peak increases typically occur within the first two years after treatment (Covington et al., 1991; DeBano et al., 1998). However, greater resource availability caused by woodland treatment can increase invasibility and may promote dominance by exotic weeds (Blank, 2008; Rau et al., 2014; Chambers et al., 2014). How completely weeds occupy areas after conifer control is primarily determined by site characteristics, disturbance severity, and residual composition of native herbaceous species (Davies and Bates, 2017; Bates et al., 2014). Concurrent evaluation of soil resource pools and vegetation dynamics are lacking in sagebrush steppe, particularly after woodland treatments. It is important to improve our understanding of the effects of pinon-juniper control to ecological processes and assess linkage between soil resource availability and plant community recovery because large scale woodland reduction treatments are likely to continue into the future.

We evaluated the impact of cutting and prescribed fire on soil nutrient availability (N, P, K) and herbaceous composition for 6 years after western juniper control. Our objectives were to: (1) assess the effects of juniper removal on growing season (April-July) soil nutrient availability in juniper canopy areas, under cut juniper trees, and interspaces; (2) determine the duration and temporal variability of treatment effects on growing season soil nutrient availability; and (3) evaluate treatment impacts on composition of native and exotic species. We hypothesized that available nutrient pools would increase after conifer reduction because nutrient availability often increases following mechanical and fire treatments in pinon-juniper woodlands. We further hypothesized that elevated nutrient pools among the treatments would be greatest within the first 2–3 years following conifer control, which has typically been reported following woodland control. We hypothesized that treatments of lesser disturbance severity would be dominated by native herbaceous species and treatments with greater disturbance severity would result in dominance by invasive weeds; these conditions that have been frequently reported following woodland and forest treatments. Greater disturbance may result in higher soil nutrient availabilities, thus, we hypothesized that greater soil inorganic N levels would be positively correlated to greater invasive weed cover.

2. Methods and materials

2.1. Study sites

Two different plant associations were located on Steens Mountain, southeast Oregon, 80–90 km south of Burns. The two sites were basin big sagebrush/bluebunch wheatgrass-Thurber's needlegrass (*Artemisia tridentata* Nutt. spp. *tridentata* (Rydb.) Beetle/*Pseudoroegneria spicata* (Pursh) A. Löve - *Achnatherum thurberianum* (Piper) Barkworth) [BLUEBUNCH] and mountain big sagebrush/Idaho fescue (*Artemisia tridentata* Nutt. spp. *vaseyana* (Rydb.) Beetle/*Festuca idahoensis* Elmer) [FESCUE] plant associations. The BLUEBUNCH and FESCUE sites were classified as Phase 3 woodlands as juniper presence had eliminated the shrub layer and depleted the understory (Miller et al., 2005; Bates et al., 2014).

The BLUEBUNCH site (42° 56′ 10″ N, 118° 36′ 30″ W) was located on a west aspect (slope 15–22%) at 1550 to 1600 m elevation. The ecological site is a Droughty Loam (280–330 mm) PZ (precipitation zone) (NRCS, 2017). Soils are a clayey-skeletal, frigid, Lithic Argixerolls (NRCS, 2006). Soil pH (0–10 cm) was 7.5 in interspace soils and 7.6 under tree canopies. Soil textures (0–10 cm) were a silt-loam in the interspaces and a loam under tree canopies. Bulk density of the soils was 1.2 g cm^{-3} in the interspace and canopy zones. Prior to treatment, juniper canopy cover averaged 26%, the interspace was 95% bare ground and Sandberg's bluegrass (*Poa secunda* J Pres.), a shallow rooted perennial grass, was the main understory species. Invasiveness of annual grasses in the Great Basin may be enhanced on sites with warmer temperatures, higher soil water variability, and lower ecological condition (Koniak, 1985; Chambers et al., 2007; Davies, 2008; Condon et al., 2011). These characteristics apply to the BLUEBUNCH site and previous low disturbance conifer removal on this site indicate it is only moderately resistant to annual grass invasion (Bates et al., 2005; Bates and Svejcar, 2009).

The FESCUE site (42° 53′ 25″ N, 118° 34′ 18″ W) was on an east facing slope (20–45%) at 1650–1730 m elevation. The ecological site was a North Slope (304–406 mm) PZ (NRCS, 2017). Prior to treatment, juniper canopy cover averaged 35%, the interspace was 60% bare ground and Idaho fescue and perennial forbs dominated the understory. Soils are a loamy-skeletal, mixed, frigid Pachic Haploxerolls (NRCS, 2006). Soil pH (0–10 cm) was 6.9 ± 0.1 in interspaces and 7.2 ± 0.2 in tree canopy zones. Soil textures (0–10 cm) were loams and soil bulk density was 1.1 ± 0.1 g cm^{-3} in interspace and canopy zones.

Precipitation in the northern Great Basin occurs mostly from late fall into late spring. Water year precipitation (October 1 – September. 30) at the Steens Mountain BLUEBUNCH site averaged 352 ± 20 mm the past 12 years and ranged from 275 to 543 mm during the study (Bates and Davies, 2016). Precipitation is likely to be greater at the FESCUE site as it is 8 km further up the mountain and 100 m higher than the BLUEBUNCH site.

2.2. Experimental design and treatment application

The experimental design at each site was a randomized complete block (Peterson, 1985) with three cut-and-burn treatments, a cut-and-leave (CUT) treatment, and untreated woodlands (control). There were five treatment replicates at each site. Cut-and-burn treatments included fires applied in September (SEP), January (JAN), and April (APR). All juniper in the JAN, APR, and CUT treatments were felled in July 2006. JAN fires were applied on 17 and 19 Jan 2007, on the BLUEBUNCH, and FESCUE sites, respectively. These fires were of low severity (Bates et al., 2014). APR fires were applied on 6 Apr 2007 at both sites and fires were of low (interspace) to high (beneath cut trees) severity. JAN and APR burns required igniting individual or clusters of trees as snow or green herbaceous vegetation prevented fire from carrying in the interspaces. On SEP treatments, one-third of the juniper were cut in June 2006 and these were used to carry strip-head fires to kill remaining live trees. The SEP fires were of moderate to high severity and were applied on 25 and 26 Sep 2006, at the BLUEBUNCH and FESCUE sites, respectively. Burn conditions were typical for applications used to broadcast burn (SEP) and reduce western juniper fuel loads in winter and spring (Bates et al., 2014).