Rangeland Ecology & Management 68 (2015) 408–422

Contents lists available at ScienceDirect

Rangeland Ecology & Management

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

Short-Term Impacts of Tree Removal on Runoff and Erosion From Pinyon- and Juniper-Dominated Sagebrush Hillslopes☆,☆☆

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ARTICLE INFO

Article history:
Received 19 May 2014
Accepted 4 May 2015

Key words:
juniper
pinyon
prescribed fire
rangeland hydrology
restoration
tree mastication
woodland encroachment
infiltration
runoff
erosion
sagebrush steppe

ABSTRACT

Tree removal is often applied to woodland-encroached rangelands to restore vegetation and improve hydrologic function, but knowledge is limited regarding effects of tree removal on hydrologic response. This study used artificial rainfall and overland flow experiments (9–13 m^2) and measures of vegetation and ground cover to investigate short-term (1–2 yr) responses to tree removal at two woodland-encroached sites. Plots were located under trees (tree zone) and in the intercanopy (shrub-interspace zone, 75% of area). Before tree removal, vegetation and ground cover were degraded and intercanopy runoff and erosion rates were high. Cutting and placing trees into the intercanopy did not significantly affect vegetation, ground cover, runoff, or erosion 1 yr posttreatment. Whole-tree mastication as applied in this study did not redistribute tree mulch within the intercanopy, but the treatment did result in enhanced herbaceous cover and hydrologic function in the intercanopy. Fire removal of litter and herbaceous cover increased tree-zone runoff and erosion under high-intensity rainfall by 4- and 30-fold at one site but had minimal impact at the other site. Site response differences were attributed to variability in burn conditions and site-specific erodibility. Burning had minimal impact on shrub-interspace runoff and erosion from applied high-intensity rainfall. However, 1 yr postfire, erosion from concentrated overland flow experiments was 2- to 13-fold greater on burned than unburned tree-zone and shrub-interspace plots and erosion for burned tree zones was 3-fold greater for the more erodible site. Two yr postfire, overland flow erosion remained higher for burned versus unburned tree zones, but enhanced intercanopy herbaceous cover reduced erosion from shrub-interspace zones. The net impact of burning included an initial increase in erosion risk, particularly for tree zones, followed by enhanced herbaceous cover and improved hydrologic function within the intercanopy. The overall results suggest that erosion from late-succession woodlands is reduced primarily through recruitment of intercanopy herbaceous vegetation and ground cover.

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Introduction

The encroachment of pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.) species into sagebrush-steppe (*Artemisia* spp.) in the western United States has been associated with decreased shrub and herbaceous vegetation, amplified runoff and soil erosion, degraded wildlife habitat, and a reduced capacity to deliver various ecosystem goods and services (Knick et al., 2003; Aldrich et al., 2005; Miller et al., 2005; Pierson et al., 2010; Davies et al., 2011; Miller et al., 2011; Bates et al., 2014; Williams et al., 2014a). This woodland encroachment has been attributed to multiple factors including climate variability, land-use practices, decreased fire frequency, and CO_2 fertilization (Miller and Wigand, 1994; Miller and Rose, 1995; Knapp and Soulé, 1996; Miller and Tausch, 2001; Romme et al., 2009). Woodland development forms a continuum of increasing tree cover but has been categorized into three phases (Miller et al., 2000; Johnson and Miller, 2006; Miller et al., 2008; Roundy et al., 2014a). In phase I, tree cover increases for the 0- to 3-m height class, but shrubs and herbaceous species remain dominant. Phase II occurs once trees approach 10–50% of potential tree cover and understory shrub and herbaceous plants decline due to competition for limited water and soil resources. Phase III is reached when tree cover stabilizes as the dominant cover type and exerts primary control on key ecological

☆ This is Contribution Number 97 of the Sagebrush Steppe Treatment Evaluation Project (SageSTEP), funded by the U.S. Joint Fire Science Program, the Bureau of Land Management, and the National Interagency Fire Center.

☆☆ Mention of a proprietary product does not constitute endorsement by the U.S. Department of Agriculture (USDA) and does not imply its approval to the exclusion of the other products that may also be suitable. The USDA is an equal opportunity provider and employer.

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http://dx.doi.org/10.1016/j.rama.2015.07.004
1550-7424/Published by Elsevier Inc. On behalf of Society for Range Management.

processes. Declining understory cover in the later stages of phase II creates extensive and contiguous patches of bare ground within the intercanopy, reduces rainfall interception and infiltration, increases water available for runoff, and promotes overland flow (Pierson et al., 2007; Petersen and Stringham, 2008; Petersen et al., 2009; Pierson et al., 2010; Williams et al., 2014a). This encroachment-induced shift from a water- and soil-conserving sagebrush-steppe structure (Pierson et al., 1994, 2009) to a community of tree islands and bare intercanopy facilitates high rates of intercanopy runoff and erosion (Wilcox, 1994; Wilcox et al., 2003; Pierson et al., 2007, 2010, 2013; Williams et al., 2014a) and long-term loss of soil resources critical for plant productivity (Schlesinger et al., 1990; Davenport et al., 1998; Belnap et al., 2005; Ludwig et al., 2005; Turnbull et al., 2008, 2010, 2012). Tree removal is a common practice to rehabilitate or restore ecological structure and function of sagebrush-steppe rangelands (Miller et al., 2005; Pierson et al., 2007; Sheley and Bates, 2008; Bates and Svejcar, 2009; Pierson et al., 2013; Bates et al., 2014; McIver et al., 2014; Williams et al., 2014a).

Sagebrush-steppe vegetation response to tree removal can vary widely depending on the pretreatment plant community and site conditions, removal method, soil temperature and moisture regimens, and posttreatment weather patterns (Bates et al., 1998, 2000; Miller et al., 2005, 2013; Bates et al., 2014; Chambers et al., 2014; Miller et al., 2014). Restoration of sagebrush communities in late successional (late phase II–III) woodlands can be particularly challenging due to limited propagules and seed sources for perennial grasses and sagebrush reestablishment (Koniak and Everett, 1982; Miller et al., 2000, 2005; Bates et al., 2014; Miller et al., 2014; Roundy et al., 2014a). Bates et al. (2005, 2007, 2011, 2014) suggested that recruitment of sagebrush-steppe understory vegetation in heavily encroached systems requires pretreatment perennial grass and forb densities of at least 1–2 and 5 plants per square meter, respectively. Tree removal by prescribed burning can remove limited native perennial species and facilitate invasion by annual weeds, particularly on sites with mesic-aridic soil temperature-moisture regimens (>8°C annual temperature and < 305 mm annual precipitation) (Young and Evans, 1978; Melgoza et al., 1990; Koniak, 1985; Chambers et al., 2007; Condon et al., 2011; Bates et al., 2011, 2014; Miller et al., 2014; Roundy et al., 2014a). Prescribed fire can also reduce residual sagebrush cover (Chambers et al., 2014; Miller et al., 2014; Roundy et al., 2014a). Sagebrush does not resprout after fire and can require 15–50 yr for postfire recovery (Barney and Frischknecht, 1974; Miller and Heyerdahl, 2008; Ziegenliagen and Miller, 2009). Mechanical tree mastication and cutting can limit treatment-related shrub and herbaceous mortality (Chambers et al., 2014; Miller et al., 2014; Roundy et al., 2014a) but often leave residual juvenile pinyon and juniper seedlings to repopulate posttreatment (Bates et al., 2005; Miller et al., 2005, 2013; O'Connor et al., 2013). Vegetation response to any treatment is also influenced by precipitation in the years following treatment (Bates et al., 1998, 2000; West and Yorks, 2002; Bates et al., 2007). Successful restoration of woodland-encroached sagebrush-steppe is most likely on frigid-xeric sites and when tree removal is applied during phase I or early phase II encroachment (Miller et al., 2005, 2013; Chambers et al., 2014; Roundy et al., 2014a). Currently, much of the woodland-encroached domain across the western United States is approaching late succession (Miller and Tausch, 2001; Miller et al., 2008). The diverse conditions in which woodlands occur and the varying responses of vegetation to tree removal present major management challenges to land managers and agencies (Miller et al., 2005; McIver et al., 2010, 2014).

Knowledge is limited regarding linkages between sagebrush-steppe restoration and hydrologic function following tree removal treatments given the vast range of pinyon and juniper expansion. The generally accepted hypothesis is that favorable canopy and ground cover recovery following tree removal will improve infiltration, reduce runoff and soil loss, and enhance soil water recharge and vegetation productivity (Pierson et al., 2007, 2013; Young et al., 2013; Miller et al., 2014; Mollnau et al., 2014; Roundy et al., 2014a, 2014b; Williams et al., 2014a). Young et al. (2013) evaluated the effects of whole-tree mastication on soil water availability and found that tree removal by mastication created 44.5 additional wet-soil days (soil water potential at 13–30 cm soil depth > –1.5 MPa) during spring and summer growing seasons. Roundy et al. (2014b) evaluated the effects of prescribed fire, tree cutting, and tree mastication on available soil water (upper 30 cm of soil profile) at 13 pinyon- and/or juniper-encroached sagebrush sites in the Great Basin over a 4-yr period. That study found tree removal by each method increased the number of wet-soil days (soil water potential > –1.5 MPa) in the spring but also noted the additional number of wet-soil days declined as the understory plant cover increased. Four yr posttreatment, there were 8.6 and 18 more wet-soil days in treated areas than in untreated controls for mid and high tree dominance. Pierson et al. (2007) found that enhanced herbaceous cover significantly reduced intercanopy runoff and soil erosion from a simulated rainfall event 10 yr after tree cutting in a western juniper (*J. occidentalis* Hook.) woodland. Pierson et al. (2013) and Williams et al. (2014a) found that burning of a late-succession western juniper–dominated site enhanced intercanopy herbaceous cover and infiltration and reduced intercanopy erosion within two growing seasons postfire. At the small catchment scale (300–1100 m^2), Hastings et al. (2003) found that tree cut-and-slash treatments reduced soil erosion by nearly 100-fold relative to adjacent, untreated, pinyon-juniper–dominated sites. Hastings et al. (2003) attributed the reduced soil erosion to treatment-induced increases in surface cover of herbaceous plants and slash debris.

The goal of this study was to increase understanding of tree-removal effects on hillslope runoff and erosion processes on sagebrush rangelands dominated by single-leaf pinyon (*P. monophylla* Torr. and Frém) and Utah juniper (*J. osteosperma* [Torr.] Little). Specifically, we used rainfall simulation and overland flow experiments to evaluate the effects of tree cutting, mastication, and prescribed fire on runoff and erosion processes at the patch scale (10–40 m^2). The primary objectives were to quantify vegetation and ground cover characteristics and hillslope runoff and erosion underneath tree canopies (tree zones) and in the intercanopy (shrub-interspace zones) before tree removal, and 1 and 2 yr following tree removal. This research is part of the Sagebrush Steppe Treatment Evaluation Project (SageSTEP, www.sagestep.org) aimed at investigating the ecological impacts of invasive species and woodland encroachment into sagebrush-steppe ecosystems of the Great Basin cold desert, United States, and the effects of various sagebrush-steppe restoration methods (McIver et al., 2010; McIver and Brunson, 2014). The study areas were the subject of previous companion SageSTEP hydrologic studies by Pierson et al. (2010, 2014) and Cline et al. (2010). Pierson et al. (2010) evaluated runoff and erosion across small-plot (0.5 m^2) and patch scales at the two woodland sites before the tree removal. Cline et al. (2010) evaluated the impacts of tree mastication on small-plot scale infiltration, runoff, and erosion at one of the sites 1 yr following tree removal. Pierson et al. (2014) evaluated the effects of the whole-tree mastication and prescribed-fire tree-removal treatments on small-plot scale vegetation, soils, infiltration, runoff, and erosion at the sites 1 and 2 yr after tree removal. This study expands on the previous studies by Pierson et al. (2010, 2014) and Cline et al. (2010) through quantification of tree removal effects on patch-scale vegetation, soils, runoff, and erosion for the first 2 yr following the treatments. The larger-scale experiments (paired 13 m^2 plots) in this study relative to the smaller plots (0.5 m^2) in our previous post-treatment studies (Cline et al., 2010; Pierson et al., 2014) allow us to quantify treatment effects on runoff and erosion from combined rainsplash, sheetflow, and concentrated flow processes (Williams et al., 2014a).

Methods

Research Sites

This study was conducted on a single-leaf pinyon-Utah juniper site (Marking Corral—Nevada, United States) and a Utah juniper site