Hydrologic and erosional impacts of pinyon and juniper encroachment into sagebrush steppe communities of the Great Basin, USA

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1. Abstract

The conversion of sagebrush steppe to pinyon and juniper woodlands has been linked to changes in plant community structure and composition, reduced forage production, altered wildlife habitat, and increased runoff and erosion. The Sagebrush Steppe Treatment Evaluation Project (SageSTEP, *www.sagestep.org*) was implemented in 2005 as a 5 year interdisciplinary research study to evaluate restoration methodologies for sagebrush rangelands degraded by woodland and annual grassland encroachment over a six state area of the Great Basin, USA. The hydrology component of SageSTEP focuses on the relationships between changes in vegetation and ground cover and runoff/erosion processes. Rainfall simulation over small (0.5 m^2) and large (13 m^2) plot scales and concentrated flow experiments were applied across a ground cover gradient to determine whether critical thresholds exist in ground cover that significantly influence infiltration, runoff, and erosion in pinyon and juniper woodlands. Water drop penetration times were used to investigate the influence of soil water repellency on infiltration. Preliminary results indicate runoff and erosion from pinyon and juniper woodlands are greater from interspace than vegetated areas and that impacts of woodland encroachment on runoff and erosion likely depend on the influence it has on interspace extent and connectivity. Furthermore, static (soil properties, hillslope angle) and variable (soil water repellency) site characteristics may mitigate or enhance hydrologic impacts of woodland encroachment.

2. **Introduction**

Pinyon and juniper (*Pinus* spp. and *Juniperus* spp.) woodlands have expanded 10-fold in the past 130 years and now occupy over 30 million ha of the western United States (Miller and Tausch, 2001). Warmer and wetter winter climate conditions from 1850 to 1916 favored establishment and growth of pinyon and juniper species and correspond with peak periods of woodland expansion. A reduction in fine fuels and an increase in the mean fire return interval since the late 1880's are attributed to intensive livestock grazing and fire suppression. Reductions in the number and size of fires and favorable climate conditions facilitated establishment and expansion of woodland communities. Miller and Tausch (2001) and others (see Miller et al., 2005) suggest elevated atmospheric CO^2 may have facilitated increased water use efficiency and canopy expansion by pinyon and juniper species.

Woodland encroachment into sagebrush (*Artemisia* spp.) steppe systems alters the structural complexity of plant communities, decreases seed pools of pre-invasion species, reduces fuels and the role of fire (favoring tree recruitment), and increases surface runoff and erosion (see Miller at al., 2005). Woodland encroachment typically reduces shrub and herbaceous cover and species diversity. Bare-interspace zones between tree/shrub canopies increase in size and connectedness as woodland trees out-compete shrub and herbaceous understories. Surface runoff and erosion rates are highest from these interspace zones and lowest near bases of shrubs and trees protected by canopy and litter (Reid et al., 1999). These vegetative and ground cover alterations and changes to hydrologic cycles negatively affect wildlife habitat, decrease soil productivity, and affect local economies (Miller et al., 2005).

The Sagebrush Steppe Treatment Evaluation Project (SageSTEP, *www.sagestep.org*) was implemented in 2005 as a 5 year interdisciplinary research study to evaluate restoration methodologies for sagebrush rangelands degraded by woodland and grassland encroachment. Researchers from six federal government entities and five major universities are collaborating on the project. Eighteen research sites were established within a six state area of the Great Basin Region, USA, to investigate encroachment impacts on vegetation and fuels, soils, hydrology, wildlife, entomology, economics, and sociopolitical disciplines. The project will evaluate prescribed fire, mechanical thinning, and herbicide treatments to sagebrush steppe invaded by exotic grasses, and prescribed fire and mechanical thinning treatments to sagebrush steppe invaded by woodland conifers. Pre-treatment data were collected from the study sites prior to restoration applications. Monitoring data will be collected post-treatment to determine the impacts of the treatments relative to each study discipline.

In this paper we present preliminary results from the pre-treatment hydrology component of the SageSTEP study. The purpose of collecting pre-treatment hydrologic data was to quantify runoff and erosion contributions of tree coppice (areas underneath tree canopy), shrub coppice (areas underneath shrub canopy), and interspace (areas between tree and shrub canopies) microsites in a Utah juniper [*Juniperus osteosperma* (Torr.) Little] and in a single leaf pinyon-juniper woodland (*Pinus monophylla-Juniperus osteosperma*). Artificial rainfall and concentrated flow simulations were conducted across small and large plot scales to investigate rainsplash, sheet, and concentrated flow processes on the respective microsites (Pierson et al., 2007, 2008). Soil water repellency and ground cover factors that influence runoff and erosion were quantified. These data were established as a baseline data set for future evaluation of the hydrologic effects of woodland control treatments and to investigate hydrologic and erosional impacts of woodland encroachment into sagebrush steppe.

3. Study Sites

One Utah juniper site (Onaqui, UT, USA) and one single leaf pinyon-juniper (Marking Corral, Nevada, USA) site were selected for the hydrology study within the SageSTEP site network. The Onaqui site is located at 40°12'42" latitude 112°28'24" longitude. Elevation of the hydrology study site at Onaqui is approximately 1720 m and slopes range from 10 to 20%. The site averages 268 mm of precipitation annually and average annual air temperature is approximately 8.6°C. Soils are derived from sandstone and limestone and are classified as gravelly loam. Soil depth ranges from 1.0 to 1.5 m, with petrocalcic restrictive layers 0.25 to 0.50 m below the surface. Common vegetation at the site includes Utah juniper, Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young), bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) A. Löve], Sandberg bluegrass (*Poa secunda* J. Presl), and various forbs and native wildflowers.

The Marking Corral site is located at 39°27'17" latitude 115°06'51" longitude. Site elevation is 2250 m and slopes range from 5 to 15%. Average annual precipitation at the site is approximately 300 mm and mean annual air temperature is approximately 6.8°C. Parent rock material is predominately rhyolite and andesite. Soils are of the Segura-Upatad-Cropper association and are classified as gravelly clay to clay loam, with depths ranging from 0.35 to 0.50 m to lithic bedrock. Common vegetation at the site consists of Utah juniper, single leaf pinyon pine, Wyoming big sagebrush, black sagebrush (*Artemisia nova* A. Nelson), bitterbrush (*Purshia* spp.), bluebunch wheatgrass, Sandberg bluegrass, and various forbs and native wildflowers.

4. Methods

Rainfall simulation experiments were conducted at the small (0.7 m × 0.7 m) and large (2 m × 7 m) plot scales (Pierson et al., 2007, 2008). Small plot simulations were used to quantify runoff and erosion from rainsplash and sheet flow processes and large plot simulations were used to quantify runoff and erosion from rainsplash, sheet flow, and concentrated flow processes. Each small plot was placed on either a shrub coppice (n = 34), tree coppice (n = 47), or interspace (n = 59) microsite. Large plots were installed on either shrub-interspace patches (varying amounts of shrub and interspace, n = 30) or tree patches (juniper or pinyon coppice with varying interspace, n = 30) using methodology described in Pierson et al. (2007). Trees were removed by chainsaw from all tree coppice plots. Canopy and ground cover were characterized for each small plot at 105 points using point frame procedures. Litter depths were measured at four evenly spaced points along each small plot border parallel to the slope. Canopy and ground cover on large plots were characterized using line-point intercept methodology. Soil water repellency was measured before rainfall simulation immediately adjacent to each small plot using the water drop penetration time (WDPT) procedure (see Pierson et al., 2008).

Rainfall was applied to small and large plots at rainfall rates of 64 mm hr^{-1} (dry run) and 102 mm hr^{-1} (wet run) for 45 minutes. The dry run was applied under uniformly dry antecedent soil moisture conditions, and the wet run was applied immediately following the dry run. The dry run application intensity is approximately equal to 5-, 10-, and 15-min duration storms with respective return intervals of 7, 15, and 25 years. The wet run application intensity is approximately equal to 5-, 10-, and 15-min duration storms with respective return intervals of 25, 60, and 120 years. Rainfall on small plots was applied using portable oscillating-arm rainfall simulators (Pierson et al., 2008). Rainfall was applied to large rainfall simulation plots using a Colorado State University (CSU) type rainfall simulator (see Pierson et al., 2007) with stationary sprinklers elevated 3.05 m above the soil surface. Runoff samples from small and large rainfall simulations were collected on 1- to 3- minute intervals throughout simulation. Samples were weighed, oven-dried at 105°C, then re-weighed to determine runoff and sediment yield. Concentrated flow simulations were conducted within each large plot approximately 2-3 hours following rainfall simulation. Computer controlled flow regulators were used to apply concentrated flow rates of 15, 30, and 45 L min^{-1} to large plots using methodology described by Pierson et al. (2008). Flow velocity at each concentrated flow plot was determined by releasing a concentrated salt solution into the dominate flow path and measuring the mean travel time of the salt solution over a 2 m flow length.

Table 1. Small plot (0.5 m^2) surface descriptions and hydrology and erosion response variables

Microsite	Percent Bare Ground	Litter Depth (cm)	Soil Water Repellency (sec)	Dry Run Cumulative Runoff (mm)	Wet Run Cumulative Runoff (mm)	Dry Run Cumulative Sediment (g m^{-2})	Wet Run Cumulative Sediment (g m^{-2})
Interspace	41	0.0	<5	12.4	38.2	32.6	138.0
Shrub Coppice	27	0.2	<5	2.2	8.2	3.0	28.0
Tree Coppice	4	6.4	101	9.8	17.0	16.0	28.0

5. Results

Runoff and erosion at the small plot scale was greater from interspaces than shrub and tree coppice microsites (Table 1). Greater runoff and erosion on interspaces is attributed to higher percent bare ground and absence of litter between shrub and tree areas. Rainfall interception and storage in the canopy (shrub coppices) and litter (shrub and tree coppices) are assumed to decrease the amount of water available for runoff and provide soil protection from rainsplash effects. Trees removed from tree coppice plots in this study would offer further storage of rainfall, reducing runoff below measured levels. Strongly water repellent soils (WDPT > 60 sec) were observed on tree coppices, but the influence of soil water repellency on runoff generation was mitigated by storage of rainfall in the thick litter layers (Table 1). Increased storage time likely facilitated infiltration through macropores or wettable portions of the soil surface. Soil water repellency was largely non-existent on shrub and interspace plots. These data suggest the storage of rainfall in the canopy and litter material on coppices may exert a greater influence on infiltration and runoff processes than antecedent water repellent soil conditions.

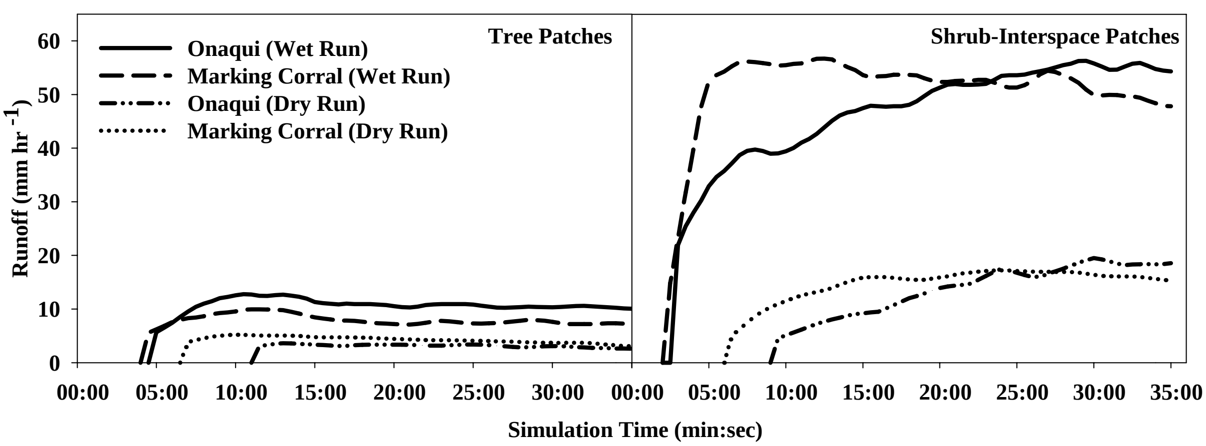

Figure 1. Runoff (mm hr^{-1}) from dry (64 mm hr^{-1}) and wet (102 mm hr^{-1}) run rainfall applications on tree and shrub-interspace large plots (13 m^2)

Runoff and erosion at the large plot scale were greater from shrub-interspace than tree patches. Figure 1 shows average runoff curves from all large plot rainfall simulations that began runoff within the first 15 min of simulation. Greater runoff from shrub-interspace versus tree patches is related to respective greater proportions of interspace to coppice area within shrub-interspace patches. Tree coppice mounds typically covered a larger surface area than did shrub coppices and had greater litter depths (Table 1). These data indicate tree patches have a greater rainfall storage and/or infiltration capacity than canopy and ground cover in shrub-interspace patches at the large plot scale, even in the absence of the tree canopy. Cumulative sediment yields from large plot rainfall simulations were greater from shrub-interspace than tree patches during the dry (23.7 and 13.0 g m^{-2}) and wet (56.1 and 38.3 g m^{-2}) runs. Sediment yield from shrub-interspace patches (72.3 g m^{-2}) at the Onaqui site was significantly greater than measured on treed plots (44.0 g m^{-2}) during the wet run. Differences in erosion between shrub-interspace (26.9 g m^{-2}) and tree (29.3 g m^{-2}) patches during the wet run at Marking Corral were minor, indicating a site difference in erodibility. Additionally, concentrated flow velocities were greater at the Onaqui site and were generally greater in shrub-interspace patches (Table 2). Differing erosion rates between the two sites are likely related to the site differences in soil properties and hillslope angles. Surface soils at Marking Corral contain more gravel sized soil thought to protect underlying fine soils from erosion and to reduce the velocity and erosive energy of overland flow. Hillslope angles were lower at Marking Corral (9%) than Onaqui (14%), implicating greater resistance to overland flow velocity and erosive energy at the Marking Corral site.

Table 2. Overland flow velocities measured on concentrated flow plots

	Concentrated Flow Velocity (m sec^{-1})			
Inflow Rate (L min^{-1})	Onaqui Shrub-Interspace Patch	Onaqui Tree Patch	Marking Corral Shrub-Interspace Patch	Marking Corral Tree Patch
15	0.07	0.05	0.06	-
30	0.11	0.13	0.08	0.04
45	0.17	0.14	0.12	0.05

6. Implications

The results presented here are preliminary, but indicate different portions of the landscape in pinyon and juniper woodlands exhibit different responses to convective rainfall events. Storage and infiltration of rainfall are greater in tree than in shrub-interspace patches and the differences are largely dependent on the amount of cover present. Reid et al. (1999) reported similar results from a pinyon-juniper woodland in southwestern United States and indicated convective storms accounted for most of the runoff and sediment yield. Rainfall intensities applied in this study represent convective storm events and when analyzed over the first 15 minutes are representative of storms with 25 to 120 year return intervals. The results from this study when combined with those of Reid et al. (1999) and other woodland studies (Roundy et al., 1978; Pierson et al., 2007) indicate summer convective rain events may contribute to significant soil loss from interspace areas of pinyon and juniper woodlands. The impact of woodland encroachment on runoff and soil loss on invaded sagebrush steppe sites likely depends on the woodland encroachment affects on the spatial extent and continuity of interspace areas. Furthermore, more static site characteristics like soil properties and hillslope angle and spatially and temporally variable influences like soil water repellency may mitigate or accelerate the influence of woodland encroachment on runoff and erosion processes.

7. References

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