Hydrologic response to prescribed fire in a central Nevada pinyon-juniper (*Pinus monophylla-Juniperus osteosperma*) woodland

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Abstract

This study was conducted to further explore and document the effect of prescribed fire on surface hydrology in Great Basin Pinyon-juniper woodlands. The study was conducted 35 miles south of Austin, Nev. in the Shoshone mountain range. Infiltration rates were measured using a single ring infiltrometer over an elevation (low, mid, and high) gradient, at three microsites (under tree, under shrub, and interspace) before a prescribed burn in Aug. 2001 and then following the prescribed burn in Aug. 2002. Data collected from infiltration experiments was used to calculate saturated hydraulic conductivity ($K(\theta_s)$). Soil was collected from the burn location and water drop penetration times were performed in order to determine the development of water repellent soils. Final infiltration rates before the burn were higher at the low elevation than at the mid and high elevation sites although the data could not be numerically analyzed due to the inability to pond water on the soil surface at the low elevation. At the mid elevation interspace and under shrub microsites did not differ before the burn in regards to final infiltration rate or $K(\theta_s)$, but were lower than under tree microsites. After the burn no significant differences were found between microsites for final infiltration rate or $K(\theta_s)$. At the high elevation before the burn interspace and under shrub microsites had lower final infiltration rates than under tree microsites, and burning caused no significant deviation in this trend. Saturated hydraulic conductivity at the high elevation did not differ by microsite before the burn, however, after burning interspace microsites had lower $K(\theta_s)$ than under tree microsites. Burning increased water repellency of surface soils (0-3 cm) by 300% under shrubs and 196% under trees.

Introduction

Pinyon-juniper woodlands in the Great Basin currently occupy about 18 million ha (Miller and Tausch 2001), an increase of roughly 60-94% from the area occupied prior to European settlement of the Great Basin approximately 140 years ago (Gruell 1999). Although pinyon-juniper woodlands have expanded and receded several times over the last 5,000 years, the rate of expansion over the last 140 years is unprecedented, and $\leq$ 10% of current woodlands are of age classes exceeding 140 years (Miller and Tausch 2001). Prior to European settlement, wildfire return intervals were 25-130 years restricting woodlands to steep rocky terrain with limited understory vegetation. These fire resistant sites currently retain woodlands of age class > 140 years (Miller and Tausch 2001). Domestic livestock grazing, climate change, and fire suppression explain current woodland expansion (Miller and Wigand 1994; Miller and Rose 1995, 1999).

Increasing tree dominance and crown cover eliminates understory vegetation, and increases crown fuel continuity across the landscape (Tausch 1999a, b). Crown cover exceeding 50% is sufficient to carry high intensity fire during dry or windy periods. Woodlands with this coverage now occupy 25% of the current range, and the area is expected to double over the next 50 years (Miller and Tasusch 2001).

High severity wildfire combined with reduced understory vegetation has been reported to produce detrimental hydrologic responses in arid and semi-arid woodland ecosystems (Covington and Debano 1988). Illg and Illg (1997) and Cannon and Savage (1998) have reported increased water repellency, catastrophic flooding, and debris flows following wildfire in ponderosa pine (*Pinus ponderosa*) forest. Poff (1989) has found severe water repellency in white fir (*Abies concolor*) forest. Pierson et al. (2001, 2002) described decreased infiltration and increased sediment yield in sagebrush-steppe, and Brock and DeBano (1988) reported severe water repellency in Arizona chaparral. Little information regarding post wildfire surface hydrology has been reported in pinyon-juniper woodlands where landscape response to fire is highly dependent on the timing of precipitation. In the Southwest, for example, a late spring fire season is followed by the summer monsoon characterized by short duration high intensity rainfall. By contrast, in the Great Basin most fires occur in late summer, and precipitation comes mostly as winter snow and spring rains.

Prescribed fire has been suggested as a management tool to decrease the trend of pinyon-juniper expansion and reduce the risk of high severity wildfire. It is prudent, therefore, to increase our understanding of prescribed fire and how it affects the hydrology of pinyon-juniper woodlands in the Great Basin.

Infiltration rates are often high in mature pinyon-juniper woodlands, but prescribed burning can reduce infiltration and increase sediment yield (Buckhouse and Gifford 1978). The effects of prescribed fire on infiltration and runoff are much less pronounced in pinyon-juniper than in other cover types such as oak (*Quercus virginiana*), bunchgrass, and shortgrass (Hester et al. 1997). Burning can have variable effects on soil hydrologic response based on fire severity and antecedent soil and fuel moisture content (DeBano 2000). Pinyon-juniper woodlands are spatially heterogeneous, and under shrub and under tree microsites tend to have more litter and soil organic carbon than interspace microsites (Davenport et al 1998, Chambers 2001). Burning volatilizes organic compounds, which are often drawn into the soil profile due to steep temperature gradients. Condensation of organic distillates onto soil particles creates a water repellent layer (DeBano 1970). The depth and extent to which water repellent layers develop is determined by soil moisture and soil specific surface (DeBano 1970, 1976). Pinyon-juniper woodlands occur in areas of variable particle size dependent on landscape position and relief (Davenport et al 1998) (D. Zamudio, pers. com. 2001; USDA Soil Scientist Lakeview, OR). Burning may also alter soil hydrologic properties by the addition of ash to the soil. Ash may plug smaller soil pores, or cause dispersion of expandable clays (Durgin 1985). Intense burning may reduce soil elasticity and plasticity by consumption of organic matter and formation of coarse-grained silica aggregates (Ulry and Graham 1993, 1996). One or a combination of these effects have been shown to produce detrimental hydrologic responses such as reduced infiltration, increased runoff, increased sediment yield, and catastrophic flooding and debris flows (Pierson et al. 2001, 2002; Illg and Illg 1987; Cannon and Savage 1998). In this study we document the hydrologic response (water repellency, final infiltration rate, and saturated hydraulic conductivity) in a pinyon-juniper woodland to a prescribed burn. Our null research hypotheses were: 1) Hydrologic response does not change over the elevation gradient typical of pinyon-juniper woodlands; and 2) Spatial variability and cover type do not affect the hydrologic response to burning.

Materials Methods

Study Area

The study area is located in the Shoshone Mountain Range on the Humboldt-Toiyabe National Forest (Austin Ranger District) in Nye and Lander Counties, Nevada. Underdown Canyon (39.1511°N 117.3583°W) is oriented east to west and contains infrequent springs and an ephemeral stream near the top of the drainage. Average annual precipitation ranges from 23 cm at the bottom to 50 cm at the top of the drainage mostly in winter as snow and spring rains. Average annual temperature recorded in Austin, NV ranges from –7.2 in

January to 29.4°C in July. Lithology of the Shoshone range consists of welded and non-welded silica ash flow tuff. Soils developed on alluvial fans in this study are classified as Coarse loamy mixed frigid Typic Haploxerolls. Coarse fragment and particle size change with increasing elevation (Table 1).

Vegetation is dominated by single leaf pinyon (*Pinus monophyllla*), and has considerable cover of Utah juniper (*Juniperus osteosperma*), and associated *Artemisia tridentata* communities. *Artemisia tridentata wyomingensis*, *Poa secunda secunda*, *Eeleymus elymoides*, and *Stipa comata* dominate lower elevations. *Artemisia tridentata vaseyana* occurs at mid to high elevations, as does *Festuca idahoensis* and *Pseudoroegneria spicata.* Forbs in the study area include *Erioginum* species, *Crepis accuminata*, *Phlox longifolia*, *Agoseris glauca*, *Lupinus sericeus*, *Penstemon* species, and others in lower abundance. *Bromus tectorum*, an invasive annual grass is not a large component of the study area. The vegetation occurs in patches of variable tree dominance and is classified as low (12% cover, 2152 kg/ ha), intermediate (38% cover, 6722 kg/ ha), and high tree dominance (74% cover, 14213 kg/ ha) (Reiner 2004).

Study Design

The study was a split plot design with sub-sampling. The study sites were located on north-east facing alluvial fans at elevations 2103 , 2225 , and 2347 m. Three plots were sampled at each elevation. Plots were characterized by intermediate tree dominance at all elevations (n=9) with three additional late tree dominance plots occurring at the 2225 m site. All plots measured approximately 1000 m^2 and contained a mixture of trees, shrubs, and interspaces. Two sub-samples were located in each of these three microsites (under shrub, under tree, and interspace) on all plots except for the late tree dominance plots where only the under tree microsite was sampled (n=60). USDA Forest Service fire personnel burned the study plots on 11-14 May 2002 under favorable weather conditions. Soil temperatures were recorded during the fire using heat sensitive paints on metal strips. Strips were placed at 0, 2, and 5 cm soil depths at all microsites (Korfmacher 2002) (Table 2).

Data Collection

To characterize the sites, soil pits were dug at all three elevations to a minimum depth of 100 cm. Soil horizons were identified and samples were collected for particle size analyses (Table 1). Samples were sieved to 2 mm, organic matter was removed with H_2O_2, and particle size distribution determined by the centrifuge method (Jackson 1956).

Infiltration experiments were conducted using a 345 mm diameter Single Ring Infiltrometer (SRI) before the burn in Aug. 2001 and again in Aug. 2002 following the prescribed burn (n=120). The ring was placed at each microsite (under tree, under shrub, and interspace) so that the soil surface was not disturbed. The ring was inserted into the mineral soil surface to a depth of approximately 50 mm. A Scotch™ pad was placed in the center of the ring and 2 liters of water were poured onto the pad in order to pre-wet the soil and prevent dispersion at the soil surface. Water was then ponded to a depth of 20 mm and volume measurements of water added were taken every two minutes for thirty minutes (Bouwer 1986). Cumulative infiltration ($I = mm^3\ mm^{-2}$) was plotted against time (t). After the first year it was determined from data analyses that the slope of I vs. t rapidly reached a constant value such that it could be accurately obtained by shortening the total test length from 30 to 16 minutes. By plotting the slope ($\Delta I/\Delta t$) between each measurement interval over time ($mm\ min^{-1}$ vs. time) a standard infiltration curve (i vs. t) was obtained. Because i was not constant, final infiltration rates for each experiment were obtained by taking the mean value of the 10-16 minute intervals (Pierson et al. 2002).

Saturated hydraulic conductivity ($K(\theta_s)$) was estimated (mm min^{-1}) using the data from each individual infiltration experiment. When there was no further change in the volume infiltration over time, the following relationship for 1-dimensional saturated infiltration in the vertical direction was applied:

$$Q/At = -K(\theta_s)[(\Delta z+\Delta p)/L] \qquad [1]$$

where Q/At (mm^3 mm^{-2}) is the measured parameter, A is the cross sectional area (mm^2) of the SRI, $K(\theta_s)$ is the estimated saturated hydraulic conductivity (mm min^{-1}), z is the gravitational potential (mm), p is the pressure potential (mm), L is the column length (mm), and the change of z and p over depth $[(\Delta z+\Delta p)/L]$ is the hydraulic gradient. For vertical infiltration the gravitational gradient $\Delta z/L = 1$ and as L approaches infinity the pressure gradient ($\Delta p/L$) approaches zero. For long-term saturated vertical infiltration Eq. [1] may then be reduced to

$$Q/At = -K(\theta_s)\ (1) \qquad [2]$$

A sub-set of soil samples was collected from the 2225 m site in order to assess the development of water repellency. Soils were collected two days before the burn from all plots and microsites at depths of 0-3 and 3-8 cm (n=24). Collection sites were marked with a metal stake so that they were easily located after the prescribed burn. Samples were again collected two days after the burn from the same locations (n=48). Soils were brought back to the lab, air dried, and sieved to 2 mm. Water Drop Penetration Times (WDPT) were performed by pipetting one drop of water onto each soil sample's surface (Letey 1968). The time for each drop to be absorbed onto the soil was recorded with a minimum and maximum value of 1 and 180 s, respectively. Three replicates were performed on each sample (n=144).

Data Analyses

Differences in infiltration rate and estimated saturated hydraulic conductivity among elevation, microsites, and dates were evaluated by SAS™ using mixed effects models. Elevation was treated as a main effect, microsite was a split-plot within elevation, and treatment was a split-split-plot within elevations and microsite. Differences in water drop penetration times among microsites, depth, and dates were also evaluated by SAS™ using mixed effects models. Microsite was treated as a main effect, depth was a split-plot within microsite, and treatment was a split-split-plot within depths and microsites.

Results

Final Infiltration Rate

Pre-burn soil final infiltration rates were highest on the 2103 m site. Extremely coarse soil prevented ponding of water on the soil surface in most cases and for this reason, site 2103 m was not included in the statistical analyses. After the burn, soils in all microsites displayed reduced infiltration rates. However, because there was little pre-burn numeric data for comparison the results are strictly observational.

Results of the ANOVA show that final infiltration rates are affected by microsite, treatment, treatment-microsite interactions, and treatment-elevation-microsite interactions (Table 3). Final infiltration rates on the 2225 m site were affected by microsite and treatment. Before the burn, interspace and under shrub microsites had lower average infiltration rates than under tree microsites. After the burn, under shrub and interspace microsites retained comparably low infiltration rates. High tree dominance under tree microsites, however were no longer statistically different than any other microsite, and intermediate tree dominance under tree microsites were similar to under shrub microsites (Table 4, Figure 1).

At the 2347 m site final infiltration rate was affected by microsite but not treatment. (Table 4, Figure 1). Interspace microsites had the lowest final infiltration rate before and after the burn, but were only found to be significantly different than under tree microsites.

Saturated Hydraulic Conductivity

Estimated $K(\theta_s)$ was similar to the mean final infiltration rates in most cases. Because $K(\theta_s)$ values are not a direct transformation of the final infiltration rates i_f, but are instead based on I_f a separate comparative analyses was warranted

The low number of data points on the 2103 m site again rendered statistical comparisons impossible. However the observations suggest that large decreases in $K(\theta_s)$ occurred after the fire in all microsites (Table 4).

Results of the ANOVA show that $K(\theta_s)$ is affected by microsite, treatment, and treatment-microsite interactions (Table 3). At the 2225 m site $K(\theta_s)$ was affected by microsite and treatment. Interspace and under shrub microsites were not significantly different before or after the burn. Under tree microsites had significantly higher $K(\theta_s)$ before the burn, but became similar to interspace and under shrub microsites after the burn (Table 4).

For the 2347 m site, all microsites were similar before the burn, but only the interspace microsite had reduced $K(\theta_s)$ after the burn (Table 4).

Water Drop Penetration Times

Water drop penetration times were affected by depth, treatment, treatment-microsite interactions, treatment-depth interactions, and treatment-microsite-depth interactions (Table 5). Soils were not statistically different for any microsite or depth two days before the prescribed burn. After the prescribed burn the surface soil (0-3 cm) at all microsites exhibited significant increases in water drop penetration time; i.e., soil water repellency (Figure 2). There were no significant differences among microsites. Sub-surface soil (3-8 cm) remained unchanged by fire in all but the under shrub microsite. Soil at this depth and microsite was found to be statistically similar to surface soils after the burn (Figure 2).

Discussion

Burn temperature was highest in under shrub microsites at the soil surface and 2 cm depth, under tree sites had slightly lower temperatures, and interspace soils were only heated on the surface (Table 2). Sagebrush burn at higher temperatures than understory vegetation, but lack the thick litter mats of pinyon. Because the burn was conducted when fuel moisture in the litter was high, the mats were not completely consumed, and insulated soil from intense heating.

The differences in particle size distribution over the elevational gradient are most likely a result of localized variation in climate. Although only 244 m separate the lower and upper elevation site, the temperature and precipitation regimes are dramatically different. Average annual precipitation ranges from 23 at the bottom to 50 cm at the top of the drainage, and snow accumulations are much higher near the top of the drainage due to colder temperatures. Over time these diffences have resulted in differential soil development. Variation in course fragment and soil specific surface affects the development of water repellency (DeBano 1970).

The low elevation site (2103 m) contained a very coarse particle size distribution with > 2 mm fraction of 76% at the surface. This made ponded infiltration on the soil surface nearly impossible before the burn occurred. The few infiltration tests that were completed were in interspace and under shrub microsites. No tests could be successfully completed in under tree microsites before the burn. After the burn tests were easily performed on all microsites. Final infiltration rates and $K(\theta_s)$ for all microsites were reduced due to burning.

The intermediate elevation site (2225 m) is also coarse grained with the > 2 mm fraction exceeding 60% at the surface. Infiltration tests were completed on all microsites before the burn with the lowest rates again occurring at interspace and under shrub microsites. Infiltration rates and $K(\theta_s)$ in under tree microsites were significantly higher and quite variable. High spatial variability in infiltration rates and $K(\theta_s)$ has been observed in other studies (Parks and Cundy 1989; Hester et al. 1997; Pierson et al. 2002) and is especially evident on under tree sites in this study. High heterogeneity could be a result of variable soil organic matter and root density (Hester et al. 1997; Davenport et al. 1999; Chambers 2001). After the burn, intermediate tree dominance under tree microsites retained higher final infiltration rates than all other microsites, but all other microsite differences were eliminated. No microsite differences were found for $K(\theta_s)$ after the burn, and the heterogeneity in the system was greatly reduced similar to that reported by Parks and Cundy (1989). Because infiltration rates can not equal zero or be negative during vertical infiltration, the apparent reduction in landscape heterogeneity may be explained by the asymptotic final infiltration rate and $K(\theta_s)$ as they approach zero. Thus, the lowering of infiltration rates reduces the heterogeneity by effectively reducing the upper limits of final infiltration and $K(\theta_s)$. Sealing the soil surface with burn induced water repellent organics produces reduced conductivity and decreased heterogeneity. The water repellent layer inhibits other soil characteristics from dominating surface infiltration, i.e. particle size, porosity, and organic matter.

The lower coarse fragment content of 42% at the surface on the high elevation site (2347 m) may explain the minimal response to burn treatment (DeBano 1970; Brock and DeBano 1988). Smaller pore spaces and higher specific surface do not allow organic distillates to permeate as well or as deeply into the soil profile. Infiltration rates were not affected by burning, but varied by microsite. Interspace microsites did exhibit a significant decrease in $K(\theta_s)$, but the rate reduction was small in comparison to lower elevation sites.

Soil in arid regions is often found to be water repellent due to excessively dry conditions and organic compounds leached from litter (Parks and Cundy 1989; Brock and DeBano 1988; Covington and DeBano 1988). Soil collected from the mid-elevation site (2225 m) immediately before the burn was found to be water repellent under shrubs and under trees at the soil surface (0-3 cm). Soil from interspace microsites was not water repellent. After the burn, the surface soil at all microsites was found to be water repellent. Surface soil at under tree and under shrub microsites were 196% and 300%, respectively, more water repellent than before the burn. The only sub-surface soil (3-8 cm) affected by fire induced water repellency was found under shrubs. Steep temperature gradients are required for the development of heat-induced water repellency (DeBano 1976, 2000). Temperature strip data collected from the burn indicate that soil heating was limited to < 5 cm depth, but that soils at 2 cm were heated to the highest temperatures under shrubs (Table 1).

Conclusions

This study and others (Hester et al. 1997) indicate that prescribed burning in pinyon-juniper woodlands can affect soil hydrologic characteristics. We have shown that fire induced water repellency can be spatially variable after prescribed burning, and it is therefore important that managers consider the soil characteristics, cover type, % cover, and climate of the woodland with which they are dealing. Development of water repellent soils is affected by an elevation gradient due to differences in surface soil particle size distribution, especially coarse fragment. Water repellency is also affected by spatial variability in surface and soil organic matter based on surface vegetation and % cover. Burning in sagebrush-steppe dominated systems may have little or no effect on surface soil hydrology if the surface soil coarse fragment is < 70%. However, burning in pinyon-juniper dominated systems may cause significant decreases in infiltration and $K(\theta_s)$ if the surface soil coarse fragment is > 40%. Furthermore, the effects of reduced infiltration, $K(\theta_s)$, and the development of water repellency must be considered in the context within which they occur. Soil with coarse fragment > 40% will most likely have high infiltration rates and $K(\theta_s)$. The probability of a precipitation event exceeding $K(\theta_s)$ decreases as $K(\theta_s)$ increases within a climatic region. It must also be noted that heat induced water repellency can be short lived, and broken down by light intensity precipitation and spring wetting (Morris 1987; McNabb 1989).

Alluvial fans of Underdown canyon in central Nevada are high in coarse fragment, and precipitation occurs dominantly as winter snow and spring rain. High intensity summer monsoon events are infrequent in contrast to areas in Colorado, Arizona, and New Mexico. Saturated hydraulic conductivity data collected from this site and data from NOAA indicates that a five-minute storm event intense enough to exceed the lowest levels of conductivity occurs on an interval greater than one thousand years (Table 6). It is therefore unlikely that prescribed fire in an area similar to Underdown Canyon will cause detrimental hydrologic response.

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Table 1. Soil particle size analyses of soils at elevations 2103 m, 2225 m, and 2347 m.

depth	**>2mm%**	**sand%**	**silt%**	**clay%**
---------- 2103 m ----------				
0-15 A	76.2	53.2	44.1	2.7
15-50 AB	72.0	52.3	43.3	4.4
50-70 B_w	81.7	63.6	31.0	5.4
70-100 BC	75.0	64.4	33.5	2.1
---------- 2225 m ----------				
0-16 A_1	60.5	67.6	23.9	8.5
16-28 A_2	55.3	59.3	33.5	7.2
28-40 BA	47.8	65.9	27.1	7.1
40-70 B_w	47.0	53.9	21.4	24.6
70-100 BC	31.1	64.5	24.8	10.7
---------- 2347 m ----------				
0-15 A_1	41.6	67.6	24.9	7.5
15-38 A_2	35.3	62.9	30.9	6.2
38-65 B_w	53.7	63.2	29.0	7.8
65-100 BC	55.9	65.1	29.8	5.1

Table 2. Mean soil temperatures for surface, 2, and 5 cm soil depths at all microsites.

Microsite	**Avg. temperature (°C)**
------------------surface--------------------	
Interspace	206.1
Under shrub	369.4
Under tree	303.9
--------------------2 cm---------------------	
Interspace	39.5
Under shrub	86
Under tree	76.8
--------------------5 cm---------------------	
Interspace	39.5
Under Shrub	39.5
Under Tree	43.9

Table 3. Results of the ANOVA for final infiltration rate and saturated hydraulic conductivity.

	final infiltration rate			saturated hydraulic conductivity		
Factor	**DF**	**F**	***P* > F**	**DF**	**F**	***P* > F**
elevation	1	3.22	0.1471	1	5.02	0.0887
replicate(elevation)	4					
microsite	3	10.10	0.0023	3	8.9	0.0036
elevation*microsite	2	0.52	0.6104	2	0.78	0.4857
microsite*replicate(elevation)	10					
treatment	1	38.45	<0.0001	1	8.19	0.0061
treatment*microsite	3	14.96	<0.0001	3	3.31	0.0272
treatment*elevation	1	1.81	0.1797	1	0.38	0.5383
treatment*elevation*microsite	2	7.20	0.0009	2	1.15	0.3243
treatment*microsite*replicate(elevation)	51					

Table 4. The mean final infiltration rate and estimated saturated hydraulic conductivity (mm minute^{-1}) for different elevations and microsites prior to burn (2001) and after the burn (2002). Means followed by the same letter do not differ. (LSM; $P \leq 0.05$).

Elevation	**2103m**		**2225m**		**2347m**	
Year	**2001**	**2002**	**2001**	**2002**	**2001**	**2002**
---Mean Final Infiltration Rate (mm minute^{-1})---						
Intermediate						
Interspace	34.98	15.51	4.21 CD	4.49 CD	4.39 CD	3.02 D
Under shrub	65.12	18.82	8.00 BC	8.8 BC	6.89 BCD	5.63 BCD
Under tree	∞	21.13	17.67 A	9.90 B	9.25 B	10.07 B
High						
Under tree	x	x	20.03 A	6.08 BCD	x	x
---Estimated Saturated Hydraulic Conductivity (mm minute^{-1})---						
Intermediate						
Interspace	75.34	16.62	4.54 BC	4.92 BC	4.53 BC	3.56 C
Under shrub	74.68	26.02	8.27 BC	9.35 BC	7.09 BC	6.0 BC
Under tree	∞	25.08	18.21 A	10.63 B	8.34 BC	11.03 B
High						
Under tree	x	x	20.18 A	6.87 BC	x	x

Table 5. Results for the ANOVA for water drop penetration time.

Factor	DF	F	*P* > F
microsite	2	1.48	0.2785
replicate*microsite	9		
depth	1	18.79	0.0019
microsite*depth	2	1.01	0.4007
replicate*microsite*depth	9		
treatment	1	96.28	<.0001
treatment*microsite	2	4.68	0.0112
treatment*depth	1	37.06	<.0001
treatment*microsite*depth	2	7.14	0.0012
treatment*replicate*microsite*depth	111		

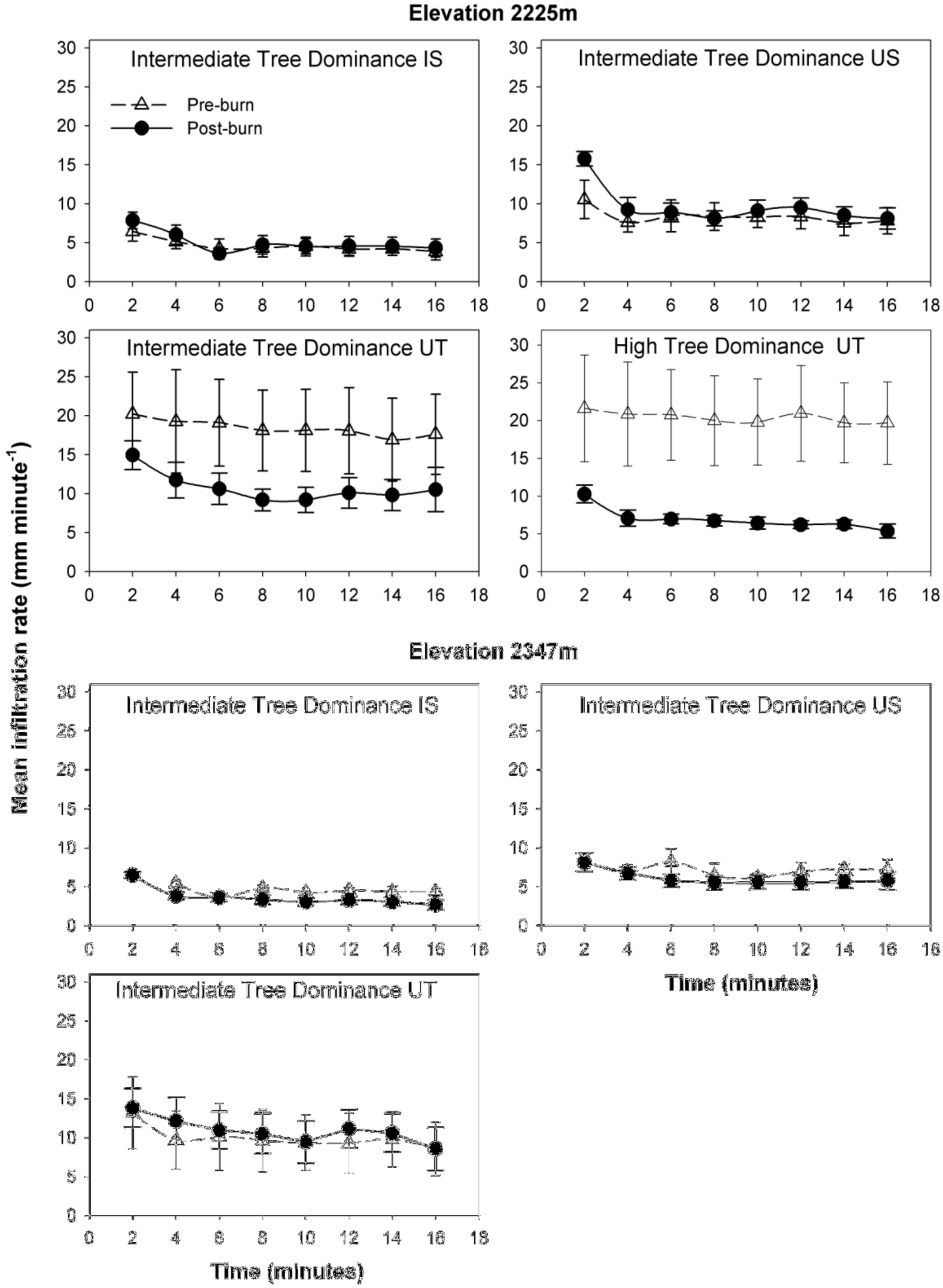
Table 6. Precipitation frequency estimates (mm minute^{-1}). Modified from: (http://dipper.nws.noaa.gov/hdsc/pfds/)

Duration	**5 min**	**10 min**	**15 min**	**30 min**	**1 hr**
Freq (yrs)					
----------Nevada 39.022ºN 117.488ºW 2055 m----------					
10	1.02	0.76	0.63	0.42	0.26
100	1.98	1.50	1.24	0.83	0.51
1000	3.56	2.72	2.24	1.51	0.94
----------Nevada 39.426ºN 117.085ºW 2413 m----------					
10	1.07	0.84	0.69	0.47	0.29
100	2.13	1.63	1.35	0.91	0.56
1000	3.96	3.00	2.47	1.67	1.03

Fig 1. Mean infiltration rates (mm minute-1) over time for interspace (IS), under shrub (US), and under tree (UT) microsites on intermediate tree dominance plots at 2225m and 2347m, and for under tree microsites on high tree dominance plots at 2225m.

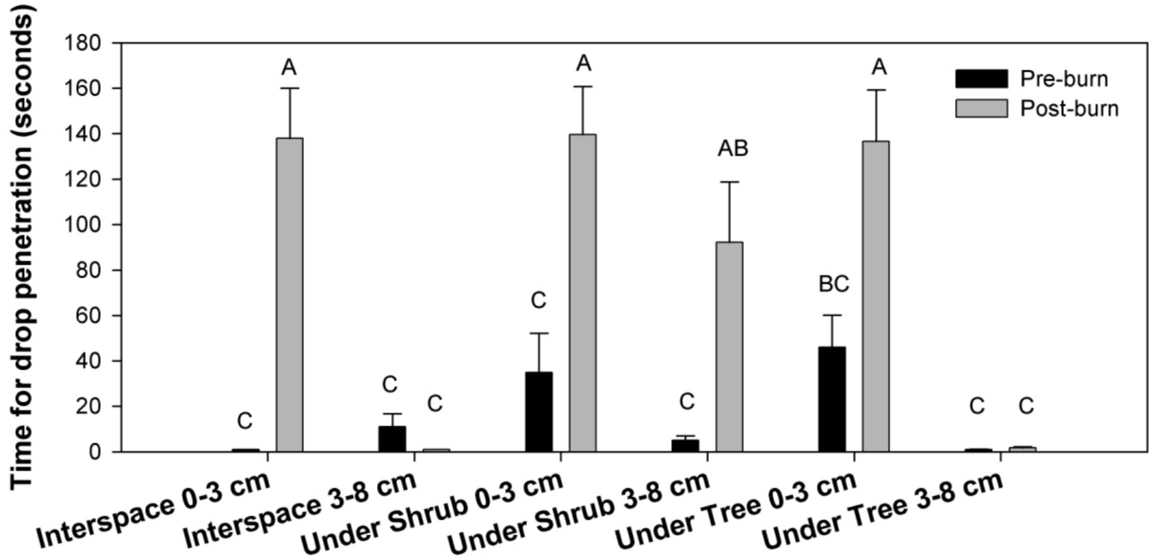
Fig 2. Mean drop penetration times and standard errors before and after prescribed fire for interspace, under shrub, and under tree microsites at 0-3 cm and 3-8 cm. Different letters indicate differences among treatment, microsites, and depths (LSM; $P < 0.05$).

Figure 1.



Elevation 2225m
Intermediate Tree Dominance IS
Pre-burn
Post-burn
Intermediate Tree Dominance US
Intermediate Tree Dominance UT
High Tree Dominance UT
Mean infiltration rate (mm minute^{-1})
Elevation 2347m
Intermediate Tree Dominance IS
Intermediate Tree Dominance US
Intermediate Tree Dominance UT
Time (minutes)
Time (minutes)

Figure 2.


Time for drop penetration (seconds)
180
160
140
120
100
80
60
40
20
0
Pre-burn
Post-burn
A
A
A
AB
BC
C
C
C
C
C
C
C
Interspace 0-3 cm
Interspace 3-8 cm
Under Shrub 0-3 cm
Under Shrub 3-8 cm
Under Tree 0-3 cm
Under Tree 3-8 cm