Ozarks Environmental and Water Resources Institute (OEWRI)
Missouri State University (MSU)

FINAL REPORT

SOIL AND VEGETATION MONITORING TO EVALUATE HYDROLOGICAL EFFECTS OF PRESCRIBED BURNING IN BIG BARREN CREEK WATERSHED, MARK TWAIN NATIONAL FOREST, SE MISSOURI

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SCOPE AND OBJECTIVES

Fire is a major component of forest disturbance that plays an important role in the management and maintenance of forest ecosystems. Prescribed burning, as opposed to wildfire, is a forest management practice that is used to reduce understory growth, eradicate invasive species and create clear-open stands. Prescribed fires are used to meet objectives that have social, cultural, ecological, and economic benefits that often include stand structure improvement, habitat restoration, enhancing biodiversity, and reducing the risk of wildfires, pathogens and pests (Gray et al. 2013). Prescribed burns are also commonly used to promote the restoration of dominant vegetation through eradication of invasive species and by returning forests with shade-tolerant shrubs to their original clear-open stands (Certini, 2005; Gurbir et al., 2017; Tiedemann et al., 1998).

Forest fires can change conditions at the vegetation and soil interface, which can have a direct effect on hydrologic processes leading to increased runoff and leaching (Elliot and Vose, 2006). Increased runoff and erosion can ultimately degrade forest productivity and water quality by removing leaf litter and duff layers exposing the soil surface. Unlike wildfires, prescribed fires have fewer negative effects on forest and soil characteristics and can improve soil productivity and infiltration (Certini, 2005). However, there are concerns about the effects of prescribed fire on forest conditions that effect vegetation cover and local hydrology that can ultimately effect water quality.

The Mark Twain National Forest (MTNF) is located in the Ozark Highlands region of southern Missouri. The Eleven Point Ranger District (EPRD) of the MTNF is located in southeast Missouri and was identified in 2006 as an Ozark landscape with significant pine-oak woodland restoration potential. In 2012, the Collaborative Forest Landscape Restoration Project (CFLRP) was implemented in the EPRD to restore the forest to its original shortleaf pine-oak stands. The CFLRP uses a combination of prescribed burning practices and silvicultural management to restore the forest. Big Barren Creek watershed within the EPRD has experienced increased flooding, stream bank erosion, and gravel deposition in local streams over the last decade during the implementation of the CFLRP. Precipitation analysis in the Big Barren Creek watershed found that over the last decade extreme rainfall events have become more frequent (Pavlowsky et al., 2016). However, the role prescribed burns have on hydrology, such as infiltration and runoff, which may be contributing to increases in flooding within the watershed, is still not fully understood.

From 2015 to 2016, Hente (2017) assessed the influence of prescribed burning on upland forest and soil physical properties that could influence erosion processes across sites with varying

prescribed burn histories. This study evaluated 30 sites within Big Barren Creek watershed and found significant differences between burned and unburned sites as well as differences in stand types (pine, oak, and mixed). Significant differences between vegetation variables including basal area and coarse woody debris (CWD) were attributed to stand type differences. Other ground cover variables including leaf litter and duff depths were significantly lower in burned sites compared to unburned sites. However, recovery trend analysis showed leaf litter and duff layers recover within one year following a prescribed burn. Soil organic matter was higher and soil bulk density was lower in burned sites compared to unburned sites within the top 5 cm of the soil profile. Additionally, soil bulk density and organic matter were found to have an inverse relationship which has been found in other studies (Chaudhari et al., 2013). No significant differences were found in seedling and sampling densities, soil texture, and soil properties below 5 cm between burned and unburned sites as well as between different stand types.

The purpose of this study is to continue forest soil and vegetation monitoring in the Big Barren Creek watershed to better understand the influences of prescribe burning on forest soil characteristics and ground cover in MTNF. The United States Forest Service (USFS) contracted the Ozarks Environmental and Water Resources Institute (OEWRI) at Missouri State University to conduct a Forest Watershed Monitoring Study under Agreement No. 5-CS-11090500-036. The goal of this study is to assess changes in forest soil and vegetation characteristics based on prescribed burn history to infer changes in forest hydrology in MTNF.

The specific objectives of this assessment are to:

1. Implement a monitoring network to determine baseline conditions for unburned forest sites in Big Barren Creek which can be compared to burned sites of varying frequency;
2. Assess spatial soil and vegetation cover differences between burned and unburned sites by stand types and using statistical tests and;
3. Discuss the implications of these findings.

STUDY AREA

Big Barren Creek is a tributary of the Current River Basin (8-digit Hydrological Unit Code (HUC) #11010008) located in portions of Ripley, Oregon and Carter Counties in southeast Missouri (Figure 1). The Big Barren Creek watershed (190.6 km^2 (73.6 mi^2)) is made up of two 12-digit HUCs, #110100080606 (Headwaters Big Barren Creek) and #110100080611 (Big Barren Creek). The watershed is located in the Salem Plateau physiographic subdivision of the Ozarks Highlands, which is underlain by flat, Paleozoic age sedimentary rock underlain by a structural

dome that is part of a series uplifts about 150 m (492 ft) higher in elevation than the Mississippi Alluvial Plain located just to the southeast (Adamski et. al 1995). Southeast Missouri has a temperate climate with a mean annual temperature of 14.4⁰ C (58°F) and mean annual precipitation around 112 cm (44 in) (Adamski et. al 1995). Land cover within the watershed is about 92% forested, with around 78% being National forest lands (Figure 1). The majority of the remainder is pasture and hay, along with small areas of developed open space.

METHODS

Geospatial & Site Selection

Geospatial databases and ArcGIS maps were used to store forest and soil characteristics data and for randomized site selection. Sources of this data include MSDIS, USDA-NRCS geospatial data gateway, and the USFS Geodata Clearinghouse. Soil data were obtained from the USDA-NRCS geospatial data gateway for Carter, Oregon and Ripley counties (USDA-NRCS, 2017). Burn unit polygons were obtained from the USFS Geodata Clearinghouse (USDA-FS, 2017). Burn frequency was compiled using these burn units and USFS records to identify specific areas influenced by prescribed fires (Figure 2).

Hente (2017) used a stratified random sampling method to locate monitoring sites. Random points were generated by adding transect points every 200 meters along roads that intersected the Macedonia soil series polygons in both burned and unburned areas. The Macedonia soil series was selected as the control soil for both burned and unburned sites because it occurred most frequently on upland sites with the least amount of rock fragments. The Macedonia soil series has slopes ranging from 2 to 15 percent and consist of deep, well drained soils on ridgetops and uplands that consist of thin layers of loess or silty slope alluvium underlain by residuum from clayey shales and cherty dolomite and limestone (USDA-NCSS, 2005). Points located within burned areas of different years, and unburned areas were assigned a set of numbers. A random number generator was used to eliminate sampling bias by generating 3-7 points for each burned area and unburned area to create a total of 30 sampling sites across the watershed (Figure 2). A total of 26 of the original 30 sites were used for this study. Sites were removed due to either canopy consumption during a previous prescribed burn, an excess of brambles due to lack of canopy cover, or timber harvesting activities.

Field Setup & Sampling

Sampling sites were organized into subplots in accordance with the USFS Forest Soil Inventory and Analysis subplot sampling layout (FIA, 2014). Subplots were located between 50 to 200 m from the forest roads to the center of the Macedonia soil series area. A GPS location was

collected at each site and imported into ArcMap to ensure accuracy of the sampling location. These GPS points were taken in the center of subplot one which was labeled by hammering a stake into the ground (Photo 1 & 2). Centers for the other 3 subplots were then measured 37 m from the stake at subplot 1 following azimuths of 0/360° for subplot 2, 120° for subplot 3 and 240° for subplot 4 (Figure 3). A white wooden sign with the subplot number was attached to a witness tree at each subplot for easy identification (Photo 3).

Soil and vegetation information was collected at each subplot in order to describe overall site ground cover, soil health, and vegetation cover. Leaf litter and duff depth measurements were collected using a one meter diameter sampling frame (Photo 4). Five measurements were taken within the frame at three different points within a subplot to create a subplot average. This was done at three of the four subplots to determine an overall site average for leaf litter and duff depths. Soil samples were collected at each site and taken from the first 5 cm of soil using a 5 cm by 5 cm steel bulk density sampling ring (Photo 5 & 6). Slope was also measured at each subplot using a clinometer. Finally, vegetation cover was estimated by using DBH measurements and by collecting standing tree and CWD inventories.

Laboratory

Soil samples were processed in the OEWRI geomorphology laboratory at Missouri State University. Samples were dried in an oven at 60° C for 24 to 48 hours, or until all moisture had been removed. Once samples were dried they were disaggregated and passed through a 2 mm sieve to remove rocks and larger particles. Bulk density was calculated as the dry soil mass (< 2 mm) divided by soil volume (USDA Kellogg Soil Survey, 2014). Soil volume was estimated using water displacement methods to estimate root and rock fragment bulk density which was then subtracted from the total known volume of the bulk density ring. The mass of each soil sample was then divided by the sample volume to obtain soil bulk density. Organic matter content in the soil was analyzed by using the loss on ignition technique (LOI) following procedures defined in the Soil Science Society of America Methods of Soil Analysis (Sparks, 1996, p. 1004), and the OEWRI standard operating procedure (OEWRI, 2007).

Statistical

Descriptive statistics and one-way ANOVA were used to analyze statistical significance using Microsoft Excel and IBM SPSS Statistical software. Descriptive statistics include measures of central tendency (mean), and measures of dispersion (standard deviation, standard error, variance, minimum and maximum). One-way ANOVA was used to determine if there were any statistically significant differences between the means of two or more independent groups. The independent groups for this study were burned versus unburned sites in the first round of ANOVA testing, and burned and unburned stand types (burned pine, burned oak/mixed,

unburned pine, unburned oak/mixed) in the second round of testing. A homogeneity of variance test was used to examine the assumptions of ANOVA in SPSS. A Least Significance Difference post-hoc test was used to specify statistically significant differences between groups in the second round of ANOVA testing.

RESULTS

General Characteristics

A total of 19 sites were classified as being burned and the remaining 7 sites were classified as unburned. Of the 19 sites that were burned, 4 were categorized as pine stand type and 15 as oak/mixed stand type. Of the 7 unburned sites 3 were categorized as pine and 4 as oak/mixed. Percent slope of burned pine sites ranged from 1.57-5.03% while burned oak/mixed sites ranged from 0.43-7.87%. Percent slope of unburned sites were similar in that unburned pine sites ranged from 1.00-6.80% and unburned oak/mixed ranged from 0.70-3.30%. Approximately half of these sites have also experienced some sort of past timber harvest activity such as commercial thinning or improvement cutting (Table 1).

Vegetation Cover

Vegetation cover is important in protecting soils from raindrop impact and subsequent erosion and includes mature trees as well as woody and herbaceous understory flora. In general, for both burned and unburned sites, basal area increases with percent pine (Figure 4). Basal area, however, is not statistically different between burned and unburned sites (Table 2). When differences between stand types were examined it was found that burned and unburned pine sites had significantly higher basal area than burned and unburned oak/mixed sites (Table 3, Figure 5). Overall, unburned sites tended to have greater volumes of CWD than burned sites (Figure 6). However, ANOVA testing showed that differences in CWD volumes between burned and unburned sites as well as stand types were not statistically significant (Tables 4 & 5). These results are similar to the 2015-2016 results in that they indicate that differences in basal area and CWD amongst sites is due to differences in stand type and possibly the management practices associated with those stand types.

Ground Cover

Ground cover is a function of forest canopy and vegetation cover and acts as a secondary barrier of protection to prevent soil erosion. Leaf litter and duff are two major components of ground cover. Leaf litter can be defined as the layer of freshly fallen leaves, needles, twigs and loose plant material that can still be easily identified. Whereas duff is defined as the mat-like

layer below litter and above the A-horizon that consists of decomposed litter components, which are not easily identified. Similar to the 2015-2016 results, leaf litter depths were significantly smaller in burned compared to unburned sites (Table 2). This trend was also present among the different stand types, but was only significantly different between burned and unburned pines (Table 3, Figure 7). Burned and unburned sites showed no significant difference in duff depths (Table 2). Burned pine sights experienced larger duff depths than unburned pine sights, however this was not statistically significant (Table 3, Figure 8). Burned and unburned oak sites had very similar duff depths, and overall pine duff depths were significantly larger than overall oak/mixed duff depths.

Soil Condition

Soil physical properties such as organic matter and bulk density are important indicators of soil health. Between burned and unburned sites, organic matter was found to be significantly different, in that burned sites have significantly larger percentages of soil organic matter than unburned sites (Table 2). This trend was also significantly different among stand types in that burned pine and oak/mixed sites had larger amounts of soil organic matter than unburned pine and oak/mixed sites (Table 3, Figure 9). Average bulk density values indicate that unburned sites tend to have larger bulk density values (Table 2). However, this trend was not statistically significant between burned and unburned sites nor between stand types (Table 3, Figure 10). When plotted against each other it appears that for burned sites organic matter and bulk density have an inverse relationship, similar to the one found in the 2015-2016 results (Chaudhari et al., 2013) (Figure 11). In contrast, the relationship between bulk density and organic matter is inconclusive for unburned sites. This trend persists when stand type is considered in that burned pine and oak/mixed sites show an inverse relationship and there is no clear trend between bulk density and organic matter in unburned pine and unburned oak/mixed sites (Figure 11).

DISCUSSION

Overall the 2015-2016 and 2018 monitoring results were fairly similar. For only three variables were there differences in the outcomes of the statistical analysis. These variables included CWD, duff depth, and soil bulk density.

CWD differences between sites were determined to be dissimilar between the two monitoring periods. The 2015-2016 monitoring results indicate that CWD volumes were significantly higher in burned pine sites versus burned oak/mixed. However, the 2018 monitoring results found no significant differences between burned and unburned sites as well as between stand types.

Other studies have found that CWD varies naturally by stand type, season, and with varying management practices such as timber stand improvement (Tiedemann et al., 1998; Wang et al., 2005). Overall, both basal area and CWD appear to be generally unaffected by prescribed burning and are more dependent on stand type differences and the management practices implemented based on those differences.

Duff depth was another variable that was dissimilar between monitoring results. The 2015-2016 monitoring showed that duff depths were significantly smaller in burned sites compared to unburned sites. The 2018 monitoring results showed that duff depths were significantly larger in pine sites compared to oak/mixed sites. Duff depths can vary naturally by stand type and time since leaf fall as well as season sampled, as warmer temperatures promote decomposition and accumulation of duff (Sierra et al., 2016). The variability in these results demonstrates that prescribed burning has the potential to decrease duff depths. Prescribed fire's effects on duff is limited by fire severity which can vary burn to burn, and even vary locally during the same burn event (Parr and Brockett, 1999; Johansen et al., 2001). Like litter, the removal of the protective duff layer has a negative effect on soil condition as it leaves soils vulnerable to rain and wind erosion.

Bulk density was the last variable with dissimilar outcomes for the two monitoring periods. The 2015-2016 monitoring periods showed that bulk density was significantly lower in burned sites than in unburned sites. However, the 2018 monitoring determined that there were no significant difference in bulk density between burned or unburned sites nor stand type. Other studies have also documented that prescribed burns do not have a significant effect on soil bulk density (Hester et al., 1997, Massman and Frank, 2006). Bulk density is also known to be affected by anthropogenic influences that remove vegetation cover and cause soil compaction which can cause variation in soil bulk densities. It is unclear whether prescribed burns have the potential to affect bulk density, and further monitoring is needed to determine if fire has an affect and if it is significant. However, if prescribe fires are influencing soil bulk density, in that prescribed burning reduces bulk density creating less dense soils, this would improve soil conditions and allow for increased rates of infiltration.

Differences between the 2015 to 2016 monitoring and the 2018 monitoring could also potentially be due to the removal of four sites that misrepresent forest conditions and prescribed fire intensity. Three of the four sites that were removed between the 2015-2016 and the 2018 monitoring were removed due to canopy consumption during a previous prescribed burn and excess of brambles due to lack of canopy cover. Canopy consumption is not a typical characteristic of prescribed fires that are typically low intensity and can be indicative of areas where prescribed fires burned too hot. Canopy consumption can also increase the amount of

sunlight that reaches the ground which can cause shade-intolerant invasive species to thrive. Sites with these characteristics were excluded in 2018 and may be the reason for discrepancies between the two different monitoring periods. Including sites that represent more severe burning could have caused there to be significant differences in CWD, duff depth, and soil bulk density. When these sites were excluded, no significant differences were found between burned and unburned sites for these variables.

CONCLUSION

There are four main conclusion from this study:

1. **Sites managed with prescribed burns had significantly less leaf litter but can recover to pre-burn conditions within one growing season.** These results were consistent across the two monitoring periods and have been well documented in other studies. Decreases in leaf litter were shown by Hente (2017) to be a short term effect of prescribed burns in that leaf litter depths recover to pre-burn conditions within one season. Considering decreased litter depth from prescribed burns is a short term trend, increased erosion potential due to decreased litter is limited to the time it takes for surface cover to be re-established. Removing the protective litter layer and exposing soils to runoff and erosion in early spring when rainfall events are more frequent and intense could be a factor contributing to an increase in flooding in the watershed. With that being said, precipitation analysis for the Big Barren Creek watershed has also indicated that more extreme rainfall events have become more common over the past decade which could also be leading to increased flooding events. Overall, more seasonal monitoring of leaf litter is needed to understand its temporal variability and how prescribed burns effect leaf litter variability.

2. **Basal area and duff thickness were significantly different among stand types regardless of burn history.** The forest monitoring done in spring of 2018 showed that sites that are dominated by pines tend to have higher basal area and duff thickness compared to oak dominated or mixed hardwood stand types. Significant differences in basal area based on stand type may be due to natural variations among stand types as well as differences in land management practices that are dependent on stand type. For instance, sites that are dominated by oaks and other hardwood species may be targeted for timber harvesting or improvement which could then reduce basal area for those stand types. Pines and oak/mixed dominated sites also have different leaf litter and duff composition that could contribute to differences in duff depths. Pine trees are also coniferous in that they never lose all their needles and can continually contribute to increased litter, and therein duff, all

year long. As it seems, natural forest variability, as opposed to burn management variability, has a bigger influence on differences seen between site basal area and duff thickness.

3. **Prescribed fires can improve soil physical properties such as increasing soil organic matter and lowering bulk density in the upper 5 cm of the soil profile.** Soil organic matter was found to be significantly higher in burned sites compared to unburned sites. While burned sites had lower bulk densities compared to unburned sites, this trend was not statistically significant. However, burned sites show an inverse relationship between organic matter and bulk density. Considering organic matter's significant difference between sites, this relationship may be indicating that bulk density is slowly being decreased by prescribed burning. Unlike burned sites, unburned sites do not appear to have a correlation between organic matter and bulk density. While differences in bulk density between burned and unburned sites were not statistically significant, the strong inverse relationship between bulk density and organic matter in burned sites suggests fire may be slowly improving infiltration rates by lowering bulk density in the upper layers of the soil profile. Hente (2017) also found no significant effects of prescribed burns on soil properties below 5 cm.

4. **The 2015 to 2016 monitoring and the 2018 monitoring show no clear negative effects of prescribed burning.** Overall, results of the two studies support the same conclusion that prescribed fire does not negatively affect soil and vegetation characteristics that affect runoff rates. In some cases, burned areas had soil organic matter and bulk density values that would be expected to lead to slightly higher rates of infiltration than unburned forest soils. Of course, litter thickness is also expected to decrease after a burn in comparison to an unburned site and can help reduce forest fuel loads. Removal of litter, however, is a short-lived effect and duff and A-horizon integrity tend to remain intact following a prescribed burn. More short-term monitoring of the seasonal changes in litter and duff thickness in burned and unburned sites is needed to better understand the recovery times of burned soils and associated ground cover.

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TABLES

Table 1. General site characteristics for the 26 sites assessed for the 2018 monitoring.

Site	Stand Type	Number of Times Burned	Years Burned	USFS Timber Harvest Activity
1	Oak/Mixed	0	Never	Commercial thinning- 2011
2	Oak/Mixed	4	2007, 2009, 2013, 2016	Sanitation Cut- 1981
3	Oak/Mixed	4	2007, 2009, 2013, 2016	Salvage Cut- 1997
4	Oak/Mixed	0	Never	None
5	Oak/Mixed	0	Never	Commercial thinning- 2008
6	Pine	0	Never	Commercial thinning- 2009
7	Oak/Mixed	2	2012, 2016	None
8	Oak/Mixed	2	2012, 2016	None
9	Oak/Mixed	2	2012, 2016	None
10	Oak/Mixed	1	2011	Stand clear-cut- 1987
11	Oak/Mixed	1	2011	Salvage Cut- 1991
12	Pine	3	2011, 2012, 2015	None
13	Oak/Mixed	2	2012, 2015	None
14	Oak/Mixed	2	2012, 2015	None
15	Pine	3	2009, 2012, 2015	Sanitation Cut- 1981
16	Oak/Mixed	2	2012, 2015	Sanitation Cut- 1985
17	Oak/Mixed	4	2012, 2014, 2016, 2018	Stand clear-cut- 1984
18	Pine	5	2009, 2012, 2014, 2016, 2018	None
19	Oak/Mixed	4	2012, 2014, 2016, 2018	Improvement cut- 1997
20	Oak/Mixed	5	2009, 2012, 2014, 2016, 2018	Stand clear-cut- 1985
21	Pine	5	2009, 2012, 2014, 2016, 2018	Commercial thinning- 1994
22	Oak/Mixed	0	Never	Stand clear-cut- 1991
23	Pine	0	Never	None
24	Pine	0	Never	None
28	Oak/Mixed	4	2008, 2009, 2012, 2015	Stand clear-cut- 1982
29	Oak/Mixed	1	2007, 2009, 2013, 2016	Commercial thinning- 2014

Table 2. 2018 monitoring burned vs. unburned statistical test results for.

	Burned Mean ± SD	**Unburned Mean ± SD**	p (**α = 0.05**)*
Basal Area (m^2/ha)	94.79 ± 40.57	109.28 ± 51.82	0.138
CWD (m^3/ha)	54.71 ± 74.47	72.60 ± 130.52	0.385
Standing Trees (#)	7.76 ± 3.33	8.75 ± 4.92	0.245
Litter depth (mm)	24.30 ± 13.62	39.67 ± 14.17	**3.47E-06**
Duff depth (mm)	16.67 ± 7.13	16.82 ± 5.45	0.924
OM (%)	6.74 ± 2.51	4.76 ± 0.80	**5.12E-05**
BD (g/cm^3)	1.05 ± 0.23	1.07 ± 0.13	0.664

*Significant values are in bold as determined by one-way ANOVA.

Table 3. 2018 monitoring burned vs. unburned by stand type statistical test results.

		Burned Mean ± SD	**Unburned Mean ± SD**	p (**α = 0.05**)*
Basal Area (m^2/ha)	Pine	130.93 ± 44.78	130.77 ± 57.33	**4.68E-05**
	Oak/Mixed	85.15 ± 33.66	93.17 ± 42.16	
CWD (m^3/ha)	Pine	74.46 ± 70.89	86.57 ± 171.65	0.545
	Oak/Mixed	49.44 ± 75.09	62.12 ± 93.72	
Standing Trees (#)	Pine	20.47 ± 11.92	49.27 ± 12.98	**1.64E-07**
	Oak/Mixed	25.33 ± 13.95	31.43 ± 9.24	
Litter depth (mm)	Pine	9.00 ± 3.56	11.33 ± 5.73	**0.0034**
	Oak/Mixed	7.43 ± 3.22	6.81 ± 3.19	
Duff depth (mm)	Pine	23.38 ± 7.17	19.44 ± 3.77	**8.46E-06**
	Oak/Mixed	14.88 ± 6.01	14.57 ± 5.77	
OM (%)	Pine	7.22 ± 2.47	4.89 ± 0.79	**0.0006**
	Oak/Mixed	6.62 ± 2.53	4.66 ± 0.81	
BD (g/cm^3)	Pine	1.00 ± 0.17	1.06 ± 0.13	0.779
	Oak/Mixed	1.05 ± 0.22	1.07 ± 0.14	

*Significant values are in bold as determined by one-way ANOVA.

FIGURES

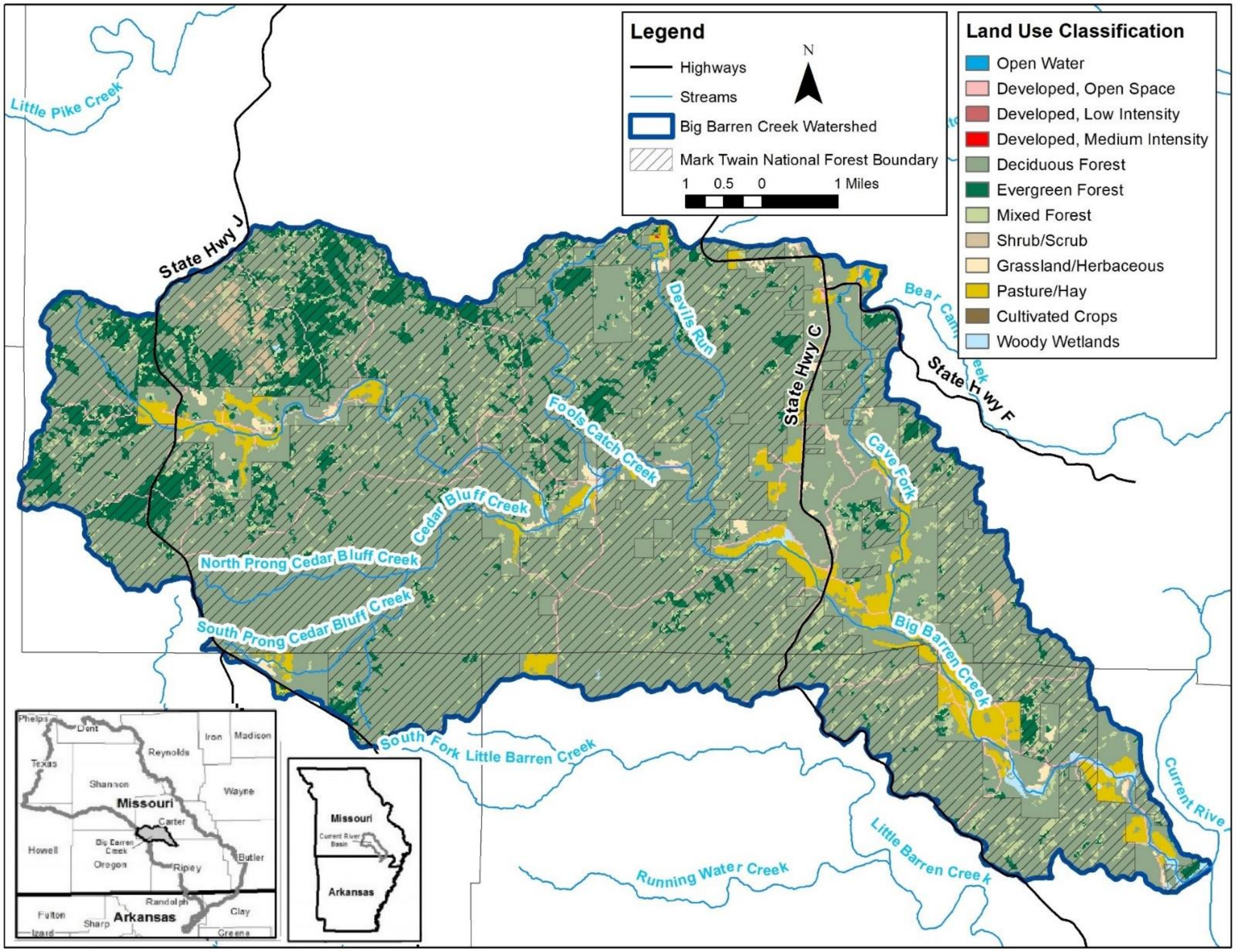

Figure 1. Location and land use of the Big Barren Creek Watershed in Southeast Missouri.

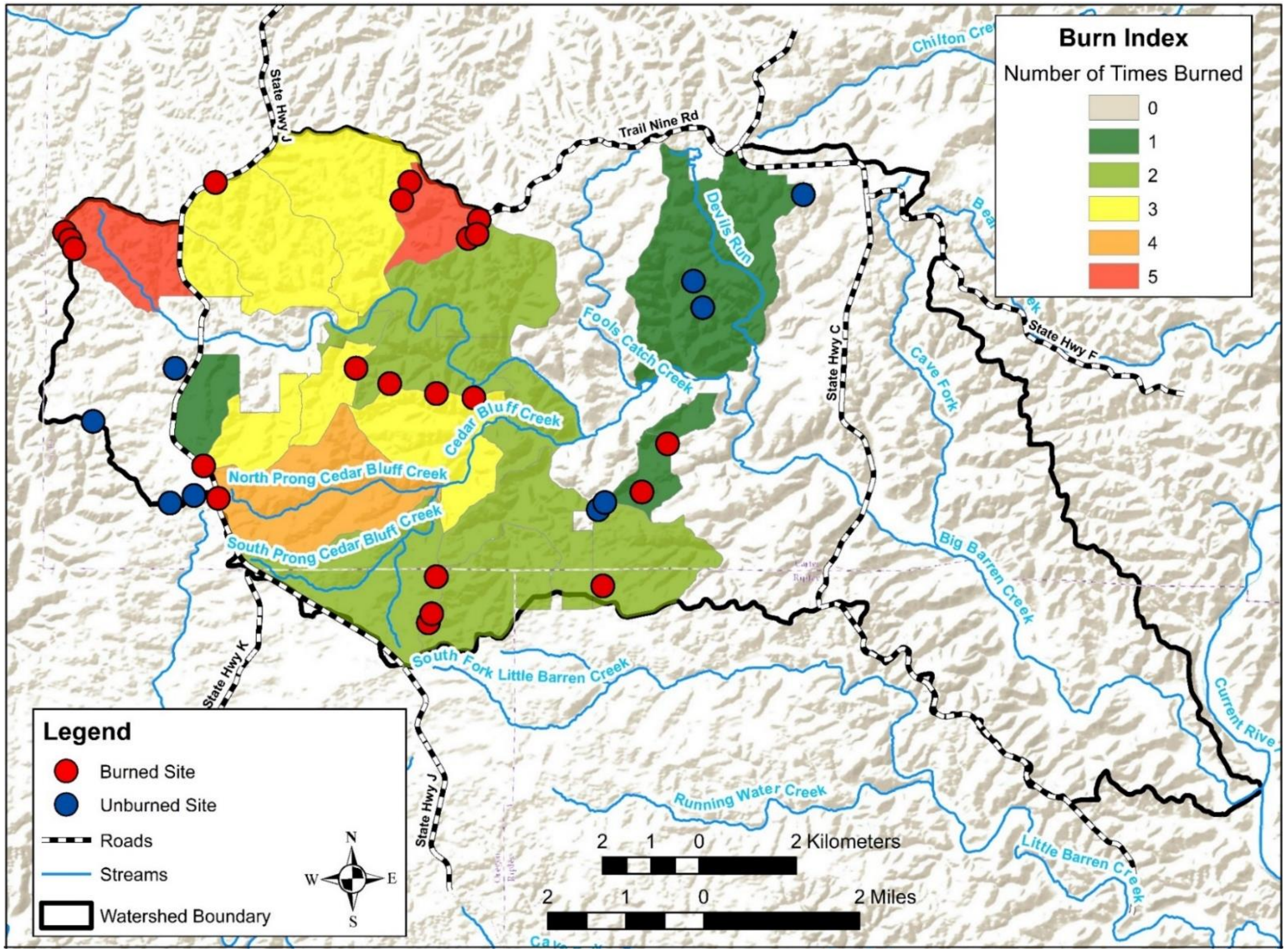

Figure 2. Burn history and of the Big Barren Creek Watershed and study site locations.

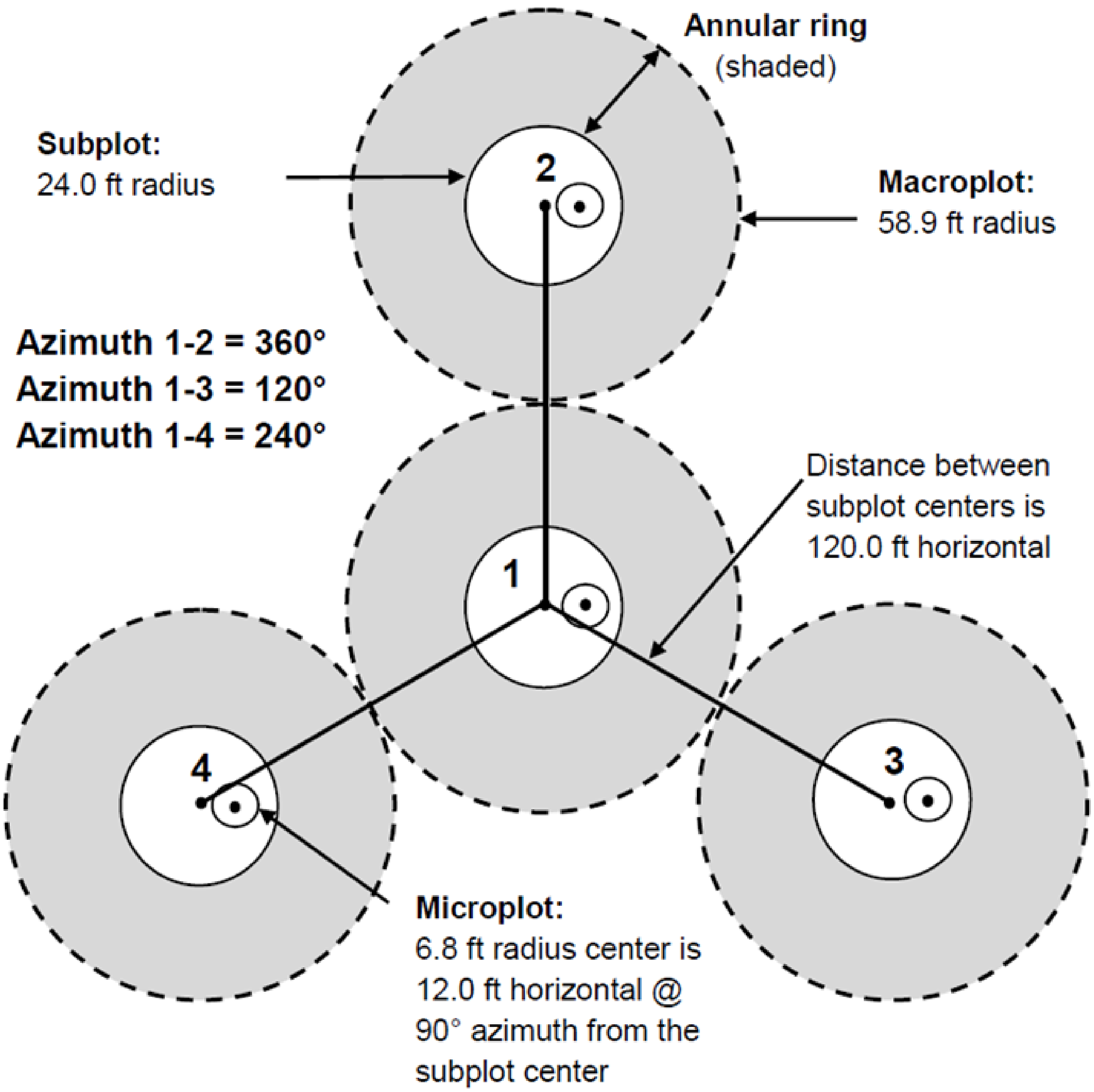

Figure 3. USFS Forest Inventory and Analysis subplot sampling layout.

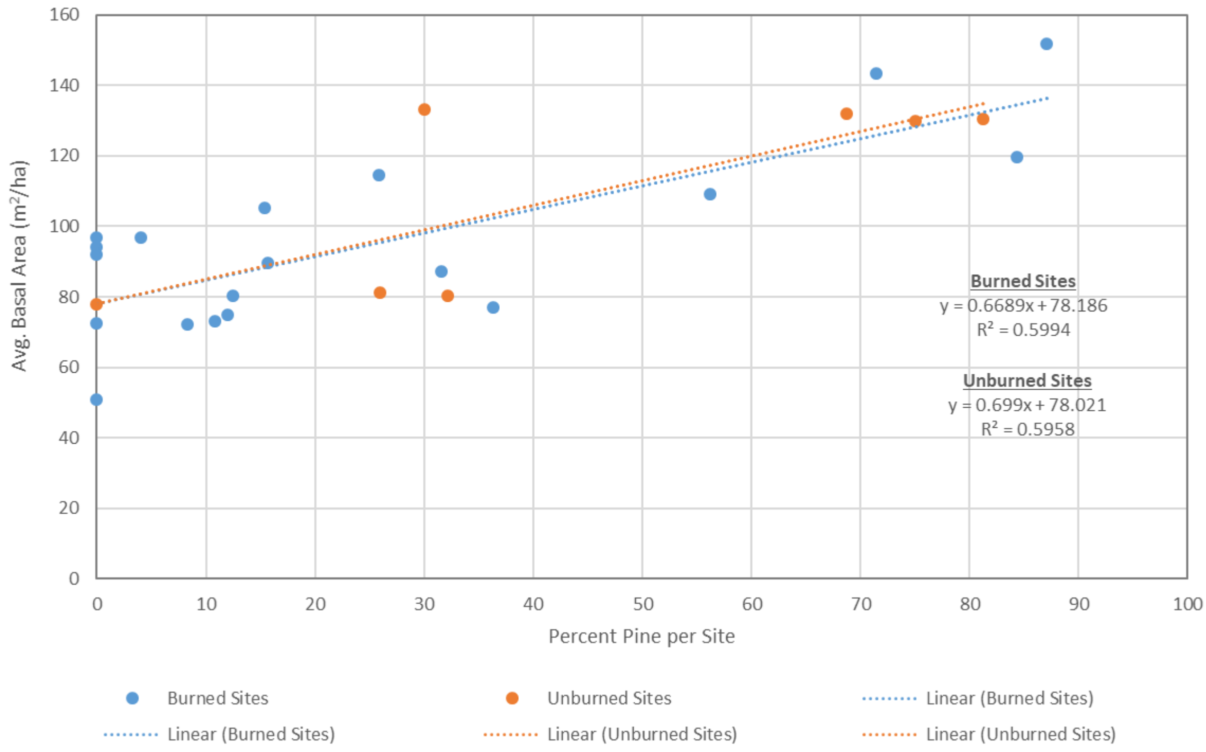

Figure 4. Percent pine vs. basal area for burned and unburned sites.

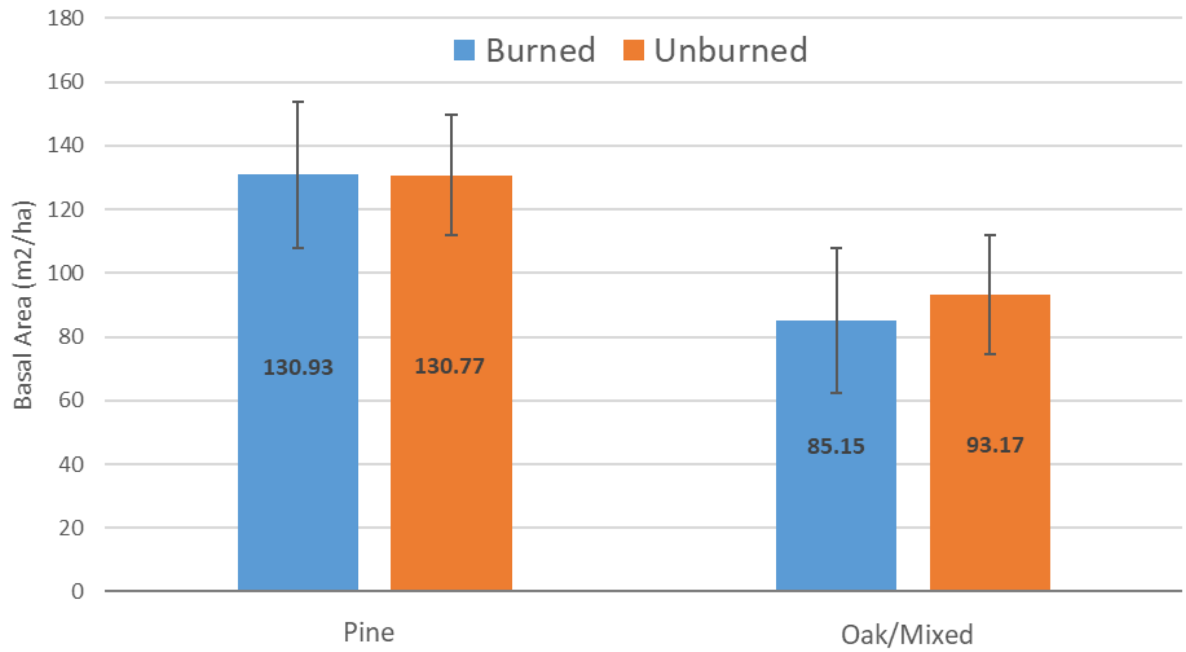

Figure 5. Basal area among stand types.

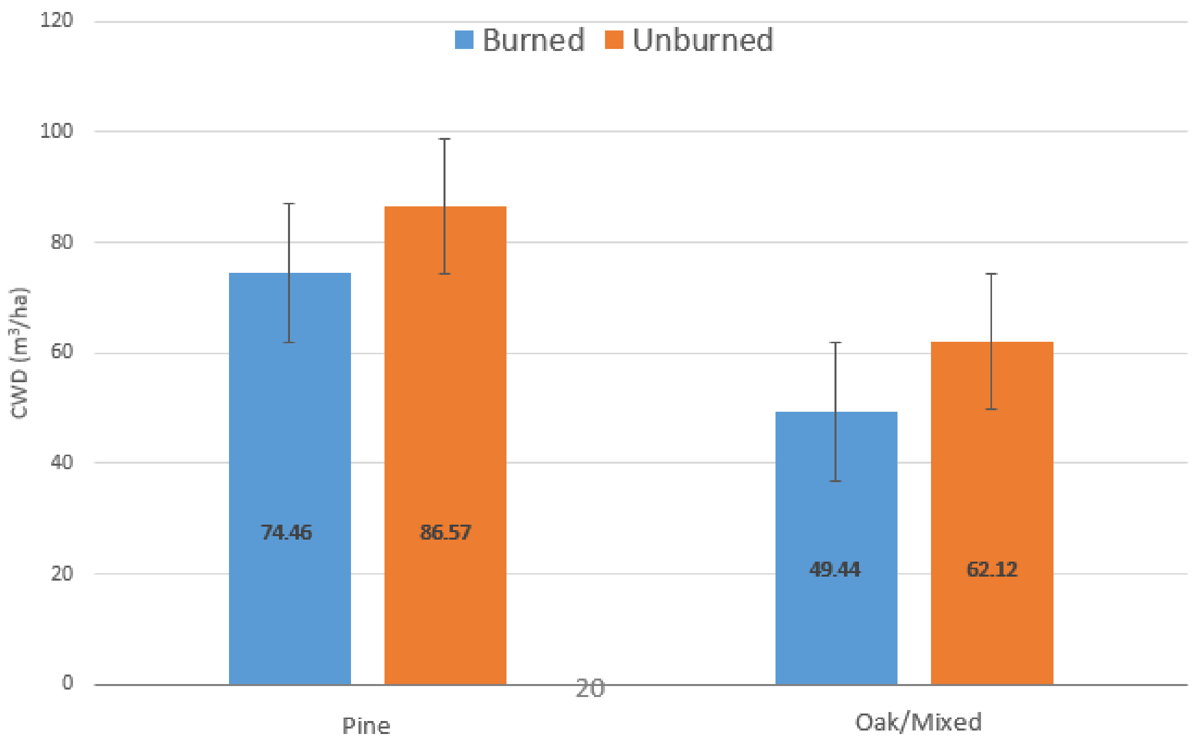

Figure 6. Coarse woody debris volumes by stand type.

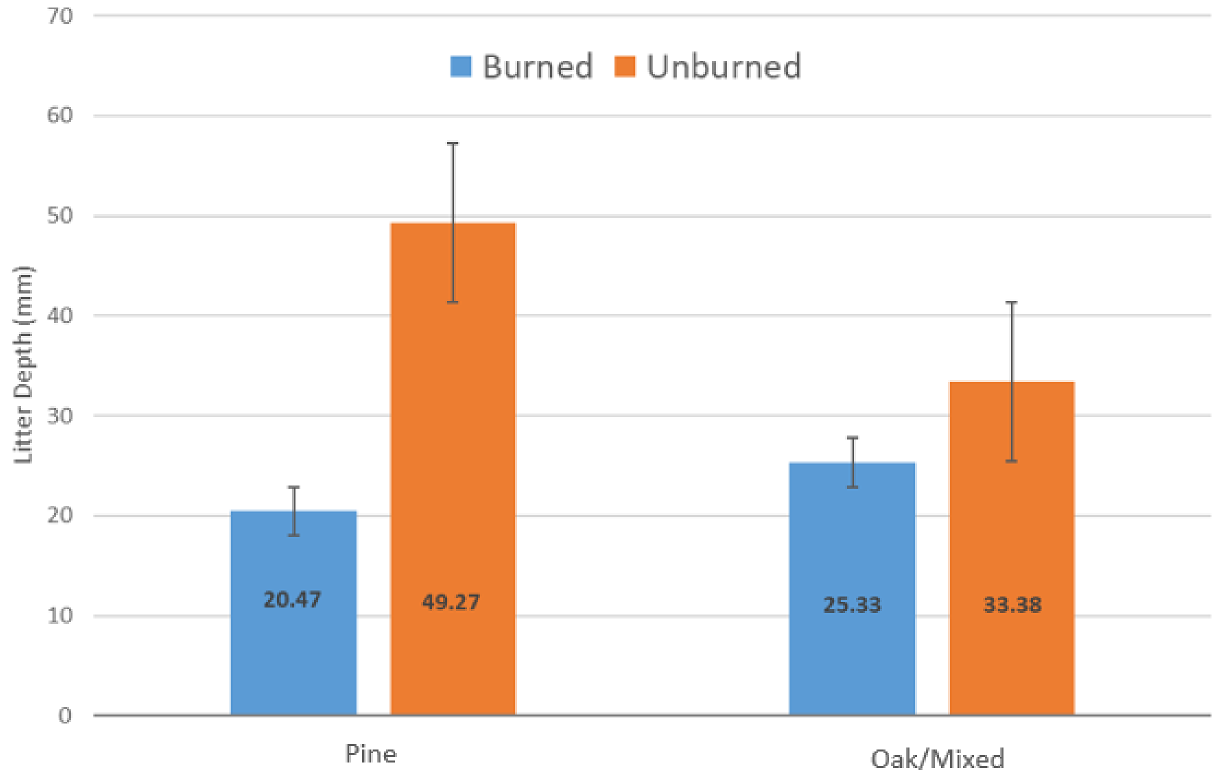

Figure 7. Leaf litter depths by stand type.

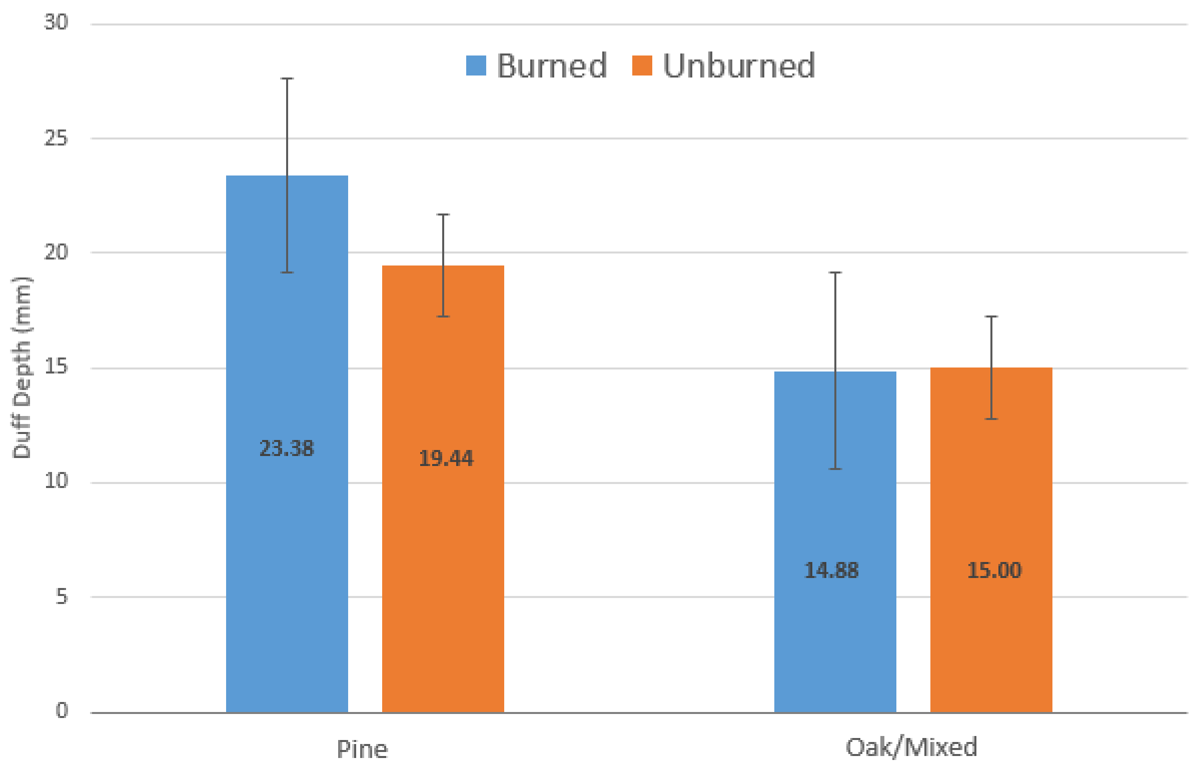

Figure 8. Duff depths by stand type.

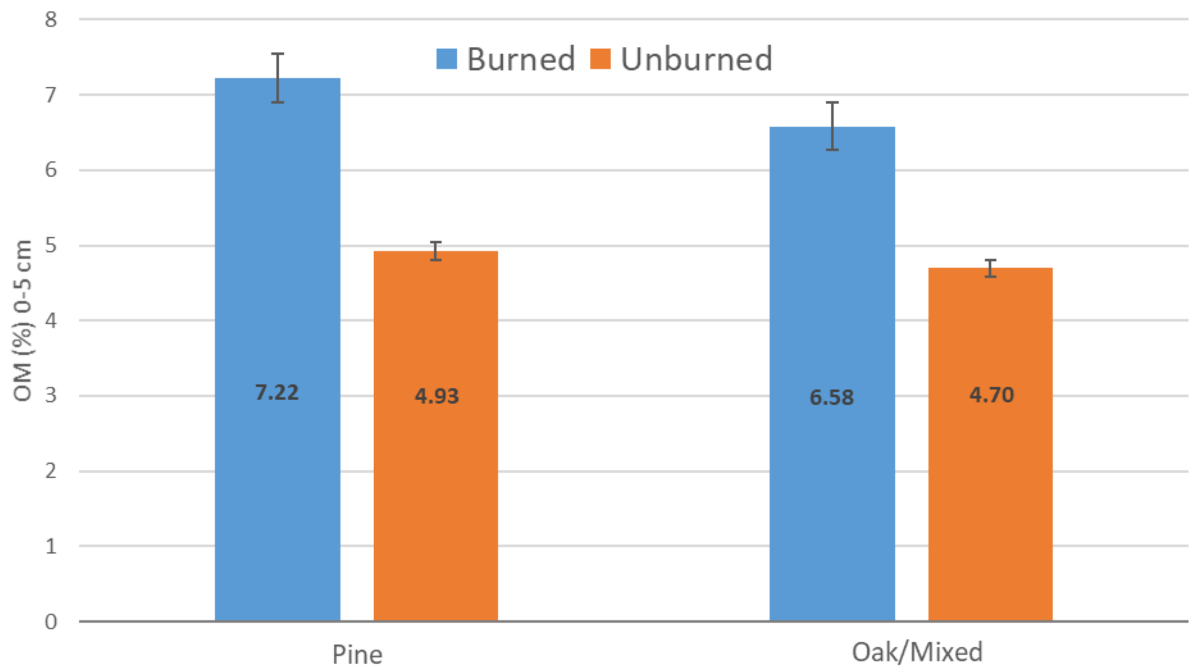

Figure 9. Soil organic matter by stand type.

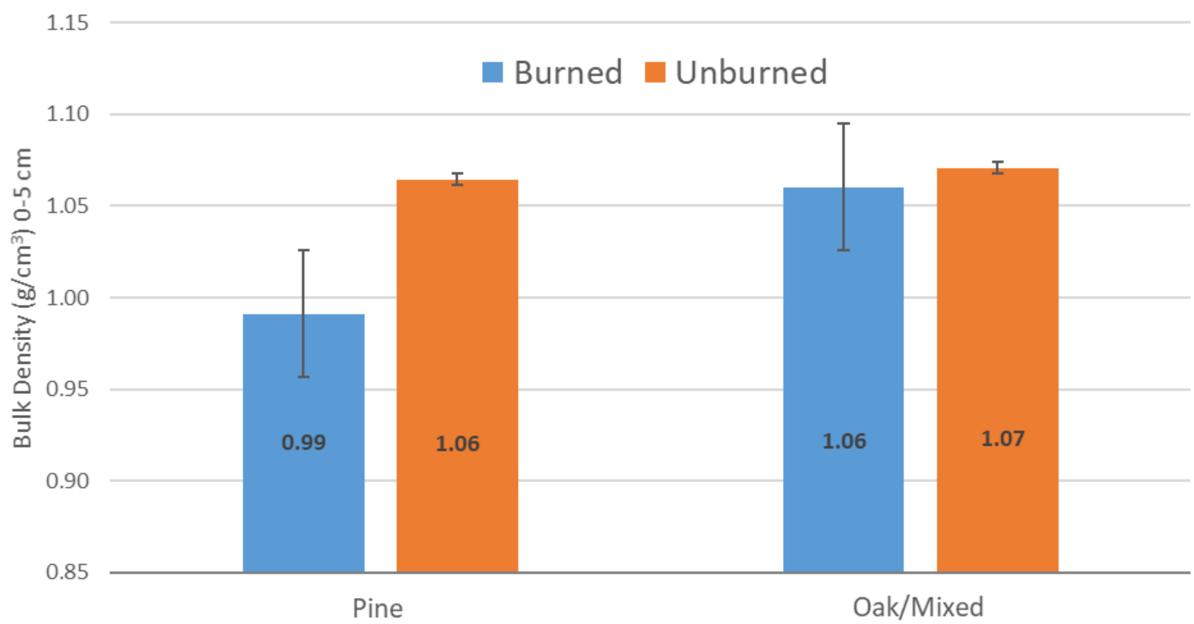

Figure 10. Soil bulk density by stand type.

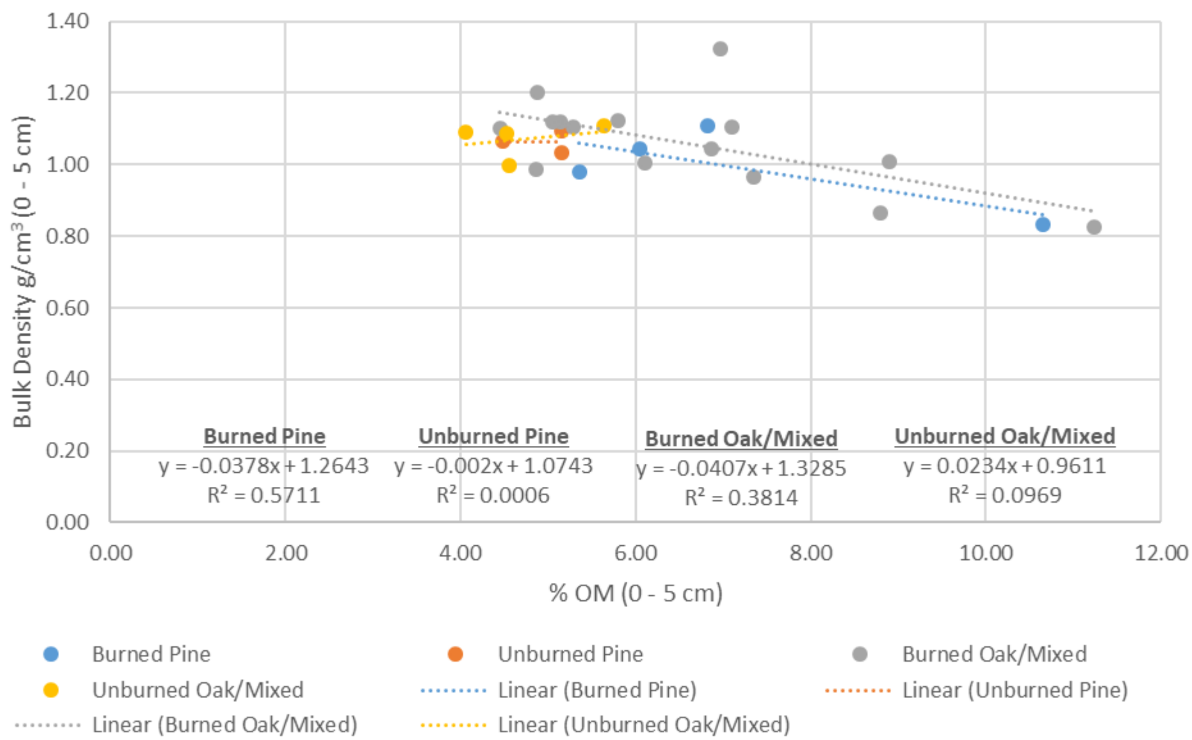

Figure 11. Soil organic matter vs. soil bulk density for burned and unburned sites by stand type.

PHOTOGRAPHS

Photo 1. Site 1, subplot 1 with stake at center.

Photo 2. Center stake and transect being used to establish other subplots, device in center is the RTK used to obtain GPS data.

Photo 3. Site 14, subplot 4 designated by white sign on adjacent witness tree.

Photo 4. An example of a soil pit dug for soil sampling and sampling frame at site 1, subplot 3.

Photo 5. Preparing an area to take a soil bulk density sample with the bulk density ring.

Photo 6. Measuring soil depth to collect soil samples.

Photo 7. Site 3 has been frequently burned and most trees show remnant fire scares at the base.

Photo 8. In comparison to photo 4, site 1 has never been burned.

Photo 9. Site 30, subplot 3 shows signs of canopy consumption and was one of the sites excluded from 2018 monitoring.