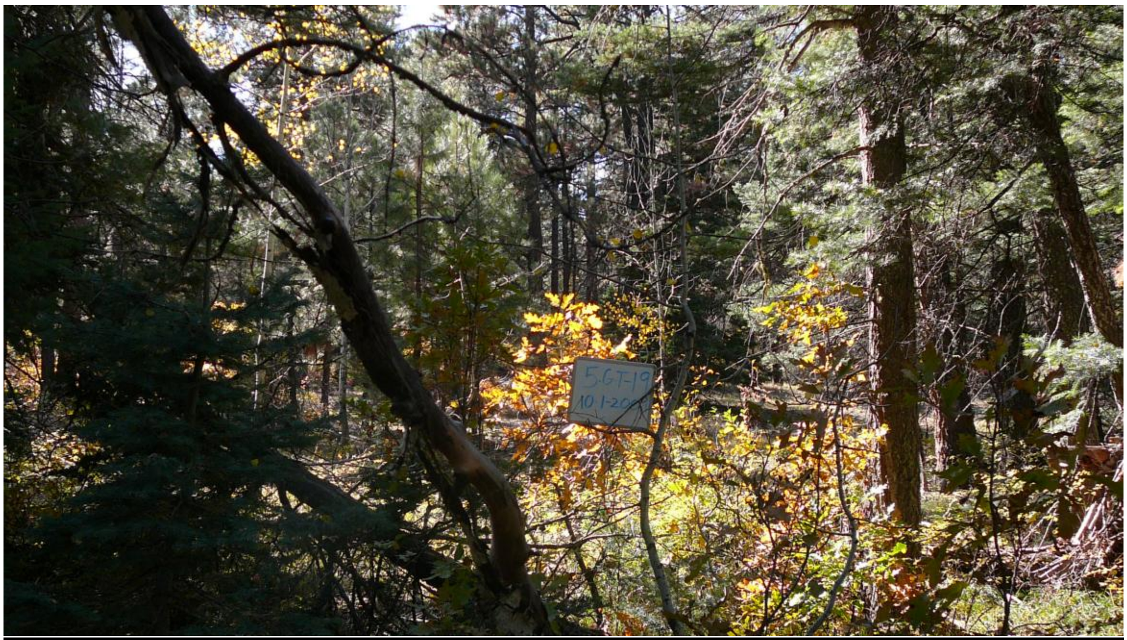
The Effect of Tree Harvesting on Soil Resistance to Penetration (Compaction): BioFuel Project, Pagosa Springs Ranger District, San Juan National Forest, Colorado

Pre-Treatment Report



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Executive Summary

There currently is a lack of research quantifying the effects of biofuel harvest treatments that utilize small diameter trees as fuel to produce electricity (biofuel) on soil structure and processes, soil biological activity, and tree and herbaceous productivity. The amount of soil disturbance associated with tree harvest often varies with the type of equipment used, the number of machine passes, soil moisture content at the timing of harvest, and site specific soil properties (e.g., texture, organic matter, etc.). The primary goals of this research project were to 1) quantify the intensity, extent, depth, and thickness of soil resistance to penetration using a soil penetrometer in harvest treatment areas, landings, and untreated controls, 2) quantify soil profile disturbance using a predetermined scale in the harvest treatment areas, landings and untreated controls, and 3) quantify forest floor substrate (rock, bare soil, wood, litter, plant, tree bole) cover along with noxious weed and a list of predetermined native plant species cover in harvest treatment areas, landings, and untreated controls. Numerous studies have emphasized the importance of pretreatment assessments of soil resistance to penetration measurements to provide baseline measurements to accurately quantify the impacts of harvesting on soil resistance to penetration and long-term forest stand productivity than simple control/treatment paired measurements. We designed our study following this protocol and established and sampled three biofuel harvest treatment units and three paired adjacent control units by similar soil type prior to any harvest treatments. Each treatment unit had 10 subsample plots and each control had 5 subsample plots. In addition, we also sampled five landing areas for harvested trees. Our pretreatment baseline assessment illustrated no significant differences in soil resistance to penetration, forest floor substrates or plant functional groups between our control and treatment units prior to treatment. As a result, any significant differences in post-treatment measurements within harvested stands will be able to be attributed to biofuel harvest treatments. Biofuel harvest treatments were initiated in the summer of 2010 and will be completed in 2011. A final report will be written following data collection in the summer of 2011.

Introduction

Hundreds of thousands of acres of ponderosa pine (*Pinus ponderosa*) and warm-dry mixed conifer forests [ponderosa pine, Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), and aspen (*Populus tremuloides*)] on federally owned public land in the southwestern United States currently consist of numerous small trees, with high fuel loads and low herbaceous understory diversity and productivity (Fulé et al. 2009). Two mechanisms to restore these forests include tree thinning and prescribed fire (Fulé et al. 1997). One use for the small diameter trees removed during forest restoration is to turn the trees into wood chips that can be used as fuel to produce electricity (biofuel). Unlike traditional tree thinning where branches and tree tops are left on the forest floor leaving 25-50 tons/acre of fuel, biofuel tree thinning removes the entire tree leaving significantly lower fuel loads, 3-5 tons/acre on average, on the forest floor. Subsequent reintroduction of prescribed burning is then easier because of lower fuel loads. As a result, a potential WIN-WIN situation is created when small diameter trees are either removed to restore forest ecological integrity or to decrease hazardous fuels and later utilized as fuel to produce electricity (biofuel). One possible caveat to this WIN-WIN situation is scientific research that has illustrated that tree thinning can significantly affect soil structure and processes, soil biological activity, and tree and herbaceous productivity through altering root growth potential, water infiltration and soil erosion due to soil profile disturbance and compaction (Froelich 1979, Jurgensen et al. 1997, McNabb et al. 2001, Page-Dumroese et al. 2006). The amount of soil disturbance associated with tree harvest often varies with the type of equipment used, the number of machine passes, soil moisture content at the timing of harvest, and site specific soil properties (e.g., texture, organic matter, etc.) (Greacen and Sands 1980, Howard et al. 1981, Rab 1996, Han et al. 2009). In general, soils in dry forests or overlaid on coarse, gravel parent material resistant soil compaction more than soils in wet forests or formed from fine-grained materials (Williamson and Neilsen 2000).

Jones and Kunze (2004) identified the following key issues regarding measurement and treatment of compaction (adapted from Rooney et al. (undated)):

• **Intensity –** How compacted is the soil relative to soils with no harvest treatment?
• **Extent –** Is the compaction across the entire area harvested or concentrated in specific areas?
• **Depth –** At what depth does the highest compaction occur?
• **Thickness –** How thick is the compacted layer, and does the thickness vary considerably across the site?

The specific objectives of this study were to: 1) quantify the intensity, extent, depth, and thickness of soil resistance to penetration using a soil penetrometer in harvest treatment areas, landings, and untreated controls, 2) quantify soil profile disturbance using a predetermined scale in the harvest treatment areas, landings and untreated controls, and 3) quantify substrate (rock, bare soil, wood, litter, plant, tree bole) cover along with noxious weed and a list of predetermined native plant species cover in harvest treatment areas, landings, and untreated controls.

We hypothesized that harvesting would have varying effects on the intensity, extent, depth, and thickness of soil compaction depending on soil type, soil moisture at the time of harvest, and the number of passes by mechanized harvesting equipment. Soil disturbance studies by Dickerson (1976) and Incerti and colleagues (1987) illustrated that significantly greater localized soil profile disturbance and compaction occurred in areas that were harvested using designated skid trails than in areas without designated skid trails. We hypothesized that harvest levels would not significantly affect soil disturbance unless in sif the harvest was conducted when the soil moisture content was appropriate for specific soil types based on studies by Gent and colleagues (1984) and Rab (1996) that showed the majority of soil profile disturbance and compaction occurring during the initial passes of mechanized harvesting equipment.

Methods

STUDY AREA

The study area is located in the San Juan Mountains in an area known as Turkey Springs near the town of Pagosa Springs, in southwest Colorado on the San Juan National Forest. The site has a relatively gentle and flat topography, with a few moderately steep mountain slopes (Chris Mountain), structural benches, and drainages. Soil types within the study units consisted of Pargin silt loam, the Brockover-Animas complex, and the Valto-Fosset complex. Average daily temperatures range from a maximum of 25.7ºC in July to a minimum of -17ºC in January. Average annual precipitation is 55.4 cm, with the greatest amounts occurring in July and August due to summer thunderstorm activity. Precipitation from November to March is dominated by snowfall, with an average annual total of 326 cm (Western Regional Climate Center, Pagosa Springs, 1906-1998, www.wrcc.dri.edu). Forest vegetation includes ponderosa pine, Douglas-fir, white fir, and aspen. The midstorey and understorey are dominated primarily by white fir and Douglas fir, with a variety of shrubs including Gambel oak (*Quercus gambelii*), snowberry (*Symphoricarpus rotundifolius*), and serviceberry (*Amelanchier alnifolia*). Past disturbance history includes sheep grazing beginning in the late 1800s and cattle grazing since the early 1900s along with timber harvesting during the same time period. Fire suppression has been management policy since the early twentieth century.

EXPERIMENTAL DESIGN

We quantified the effect of harvesting on soil compaction in three treatment units and three adjacent controls. Mark Roper, a GIS Analyst with the San Juan National Forest paired treatment and control units by similar soil type using ESRI ArcGIS (Appendix A). Within each treatment and control unit, we used a stratified, systematic sampling design. Each treatment unit had 10 subsample plots and each control had 5 subsample plots. In addition, we also sampled five landing areas for harvested trees. Stratified, systematic sampling allows us to understand if soil compaction varies among the harvesting areas and to get a better understanding of the spatial extent of soil compaction within the units (e.g., in the general harvested areas is soil compaction higher near the harvest entry point or is it evenly distributed throughout the entire unit?)

FIELD METHODS

In order to assess direct impacts of harvesting on soil compaction, we took pre-treatment measurements to quantify before/after differences in soil compaction and other variables. We sampled two randomly located 50 m transects in each of the five landing areas that were identified by the Pagosa Springs Ranger District staff. We sampled ten systematically located 50 m transects within each harvested unit and five systematically located 50 m transects in each paired control. The systematic grid had either 100 m or 200 m between transect center points depending on the size of the treatment or control unit. Mark Roper created all transect center points (latitude/longitude coordinates) using ERSI ArcGIS software (Appendix B). We navigated to each transect center point using a GPS Garmin. We permanently tagged a large ponderosa pine or Douglas-fir tree that would not be harvested to serve as a reference tree for future location of each transect center point in addition to GPS points. We recorded the distance to transect center point and azimuth from the reference tree on the tag (Appendix C). We ran all transects parallel to the steepest environmental gradient (up/down hill) and started each transect at 0 m from the GPS location center point.

Bulk density measures soil density (mass/unit volume) and is the most common technique used in soil compaction studies. Bulk density measurements quantify the relative air space or water retention capacity of soils (Nelson, 1994). Soil bulk density has been positively correlated with soil resistance, which can be measured using a soil penetrometer (Allbrook 1986 and Clayton 1990). A soil penetrometer measures soil resistance to penetration or the friction between the cone and soil particles when a cone penetrometer is pushed into the soil (Han et al. 2009). Soil penetrometers allow soil resistance to be measured at different soil depths up to 35 cm. Soil penetrometer measurements are easier to take in the field and do not require lab processing time as with bulk density measurements. Some soil compaction studies have shown that the cone penetrometer is more sensitive to quantifying soil compaction than bulk density measurements (Landsberg et al. 2003; Jones and Kunze 2004). Powers and others (1999) recommended that penetrometers should be the standardized national method for measuring soil compaction.

We took two soil resistance to penetration (compaction) measurements using a soil penetrometer every 15 m within 30 cm of the transect starting at 5 m for a total of four sampling points of eight measurements. At each location, we averaged the two readings to account for any variation. We recorded soil resistance to penetration every 1 inch to a depth of 12 inches at an insertion rate of 1 inch/second. The penetrometer gives a warning signal if the insertion rate exceeds this value. For this study, we used an electronic soil penetrometer (The Investigator Soil Compaction Meter; Spectrum Technologies, Inc.). Cone diameter was 0.505 in. We replaced the cone tip of the penetrometer when the tip had a wear factor of 3% or the cone diameter reached 0.490 in. Soil resistance to penetration was measured in pounds of force per square inch (psi or lbs/in^2). The metric equivalent is a kilopascal (1000 force of newton per square meter); 1 psi=6.89475729 kPa. Soil strength is strongly influenced by soil moisture with wet soils being more easily penetrated than dry soils; therefore we sampled within a concentrated time period to minimize potential effects of soil moisture influencing results. Ideally soils should be at or near field capacity when sampling across time (Miller et al. 2001) but this is difficult in a semi-arid environment and therefore we standardized sampling time to have no sampling occur 24 hours within a heavy (≥ 3 cm) rain event. We measured soil moisture using a standard soil moisture meter (TDR 100 Soil Moisture Probe by Spectrum Technologies, Inc.) with 7.9 inch rod lengths at the same 5 m intervals along a 50-m transect that were used to measure soil resistance to penetration to assist in quantifying standardization parameters. TDR stands for time-domain reflectometry, which allows for rapid and accurate measurement of volumetric water content (VWC) in soil, which is the ratio of the volume of water in a given volume of soil to the total soil volume expressed as a percentage.

We used the same 50 m transect for soil compaction to quantify substrate and plant cover. Along the 50 m transect, we placed a $1m^2$ (2m x 0.5m) quadrat parallel to the transect at 15 m and 35 m to record substrate (rock, bare soil, wood, litter, plant, tree bole) and plant cover. We placed the first plot at 15-17 m on the left side of the tape (standing at 0 m looking towards 50 m) and the second plot at 35-37 m on the right side of the tape (standing at 0m looking towards 50 m). We recorded plant and substrate data in percent with the lowest value of 0.25% (1/4 of 1%). Total values can exceed 100% due to overlapping vegetation layers. Plant cover was divided into general plant functional groups: native shrubs, native forbs, non-native forbs, native grasses and non-native grasses. We also recorded individual cover values for the following noxious weeds as identified by Sara Brinton, the district Ecologist for the Pagosa Springs Ranger District as species of concern: Canada thistle (*Cirsium arvense*), musk thistle (*Carduus nutans*), yellow toadflax (*Linaria vulgaris*), oxeye daisy (*Leucanthemum vulgare*), leafy spurge (*Euphorbia esula*), and spotted knapweed (*Centaurea maculosa*). In addition we recorded individual cover values for the following native grasses that were also identified by the district Ecologist: Parry's oatgrass (*Danthonia parryi*), Thurber's fescue (*Festuca thurberi*), and Arizona fescue (*Festuca arizonica*). This secondary data of plant and substrate responses to harvesting is important when trying to understand physical and biological changes in response to soil compaction (Jones and Kunze 2004). We took one permanent photo point from 0 m towards 50 m to create a photo time-series to visually assess harvest treatment impacts.

STATISTICAL ANALYSIS

We used the Shapiro Wilk test to test data for normality and Leven's test to test for homogeneity of the variance (Milliken and Johnson 1984). We used non-parametric Mann-Whitney U tests to quantify pre-treatment soil compaction, substrate, and plant cover differences for collected in 2009 in SPSS version 18 (SPSS 2010) and a non-parametric Wilcoxon matched pairs signed ranks test to quantify differences in soil compaction, substrate, and plant cover for control units sampled in 2009 (pre-treatment) and 2010 (post-treatment) (Zar 1984). Treatment harvesting was not completed in 2010 and therefore post-treatment analyses in treatment units and landings are not included in this analysis. These analyses will be completed in 2011 following post-harvesting data collection.

Results

Soil Moisture

Average soil moisture values (VWC%) were 14.38% in control units, 14.64% in treatment units and 17.5% in landing areas (Table 1). Average moisture period values were 0.87 m/s in control units, 1.03 m/s in treatment units and 1.62 m/s in landing areas (Table 2). There were no significant (U=5, p=0.827) differences in soil moisture values (VWC%) between control and treatment units pre-treatment in 2009 (Table 1). In addition, there were no significant (U=4.5, p=1) differences in moisture period values (m/s) between control and treatment units pre-treatment in 2009 (Table 1). Similarly, when just analyzing differences between the controls in 2009 and 2010, there were no significant (t=4.5, p=0.285) differences in soil moisture values (VWC%) or moisture period values (m/s) (t=6, p=0.109) (Table 2).

Soil Resistance (Compaction)

There were no significant differences in soil resistance to penetration values (soil compaction) between pre-treatment control and treatment units in 2009 along the 1 –12 inch soil profile: 1 inch (U=3, p=0.513), 2 inch (U=2, p=0.275), 3 inch (U=2, p=0.2.75), 4 inch (U=2, p=0.275), 5 inch (U=1, p=0.127), 6 inch (U=1, p=0.127), 7 inch (U=1, p=0.127), 8 inch (U=1, p=0.127), 9 inch (U=3, p=0.513), 10 inch (U=1, p=0.127), 11 inch (U=1, p=0.127) and 12 inch (U=2, p=0.275) (Table 3). Landing areas in 2009 (pre-treatment) had soil resistance to penetration values that were on average 1-1.5 times the values in control and treatment units (Table 3). Similarly, there were no significant differences in soil resistance to penetration values (soil compaction) between pre-treatment and post-treatment control units along the 1 –

12 inch soil profile: 1 inch (t=3, p=1.0), 2 inch (t=1, p=1.0), 3 inch (t=2, p=0.593), 4 inch (t=2, p=0.593), 5 inch (t=3, p=1.0), 6 inch (t=5, p=0.285), 7 inch (t=5, p=0.285), 8 inch (t=5, p=0.285), 9 inch (t=6, p=0.109), 10 inch (t=6, p=0.109), 11 inch (t=6, p=0.109) and 12 inch (t=1, p=0.109) (Table 4).

Forest Floor Substrates

There were no significant differences in forest floor substrates between control and treatment units in 2009 (pre-treament) (Table 5). Bare soil had 0.75% cover in control units compared to 5.14% cover in treatment units (U=2, p=0.275), rock had 0.43% cover in control units compared to 0.58% cover in treatment units (U=6, p=0.513), wood had 2.99% cover in control units compared to 2.65% cover in treatment units (U=5, p=0.827) and litter/duff had 57.36% cover in control units compared to 55.22% cover in treatment units (U=6, p=0.513) (Table 5). Landing areas had forest floor substrate values similar to control and treatment units in 2009 (Table 5). Likewise, there were no significant differences in forest floor substrates in control units between pre-treatment (2009) and post-treatment (2010): bare soil (t=3, p=0.109), rock (t=1, p=0.285), wood (t=4, p=0.593), and litter/duff (t=1, p=-0.285) (Table 6).

Plant Functional Groups

There were no significant differences in plant functional groups between pretreatment (2009) control and treatment units (Table 7). Average native shrub cover was 16.13% in control and 19.84% in treatment units (U=4, p=0.827), average native grass cover was 2.21% in control and 2.44% in treatment units (U=4, p=0.827), and average native forb cover was 18.08% in control and 14.28% in treatment units (U=5, p=0.827) (Table 7). Non-native plant cover overall was lower than native plant cover. Non-native grass cover was 0.84% in control and 0.93% in treatment units (U=4, p=0.827), non-native forb cover was 0.95% in control and 1.14% in treatment units (U=5, p=0.827), and noxious cover was 0% in control and 0.05% in treatment units (U=1.5, p=0.121) (Table 7). Native and non-native grass cover and non-native forb cover in landing areas was two times the cover values found in control and treatment units pre-treatment (2009) (Table 7). There was no significant difference between plant functional group cover in the control units between 2009 and 2010 (Table 8): native shrubs (t=5, p=0.285), native grasses (t=6, p=0.09), native forbs (t=5, p=0.285), non-native grasses (t=3, p=0.18), non-native forbs (t=6, p=0.1), and noxious weeds (t=.000, p=1) (Table 8).

Individual Plant Species

There were significant differences for three individual species between control and treatment units (Table 9): *Bromus ciliatus*, had 0.84% cover in control units versus 0.3% cover in treatment units (U=9, p=0.05), *Danthonia parryi*, had 0% cover in control units versus 0.89% cover in treatment units (U=.000, p=0.037) and *Phleum pratensis*, 0% cover in control units versus 0.35% cover in treatment units (U=.000, p=0.037) (Table 9). The remaining 11 species, had no significant differences between control and treatment units: *Bromus inermis* (U=6, p=0.317), *Centaurea maculosa* (U=3, p=0.317), *Elymus elymoides* (U=.5, p=0.072), *Elymus glaucus* (U=7.5, p=0.184), *Festuca thurberi* (U=2, p=0.268), *Koeleria macrantha* (U=3, p=0.317), *Lactuca serriola* (U=0.5, p=0.121), *Poa pratensis* (U=3.5 p=0.658), and *Taraxacum officinale* (U=5, p=0.827) (Table 9). Landing areas had similar cover values for individual species as in control and treatment units (2009) except for two native grasses, *Festuca thurberi* and *Danthonia parryi*, two non-native grasses, *Poa pratensis* and *Bromus inermis*, and one non-native forb, *Taraxacum officinale*; all these species had double plant cover values found in the control and treatment units (Table 9). There were no significant differences for individual species' cover values in the control units between 2009 and 2010: *Bromus ciliatus* (t=6, p=0.109), *Bromus inermis* (t=0.00, p=0.317), *Elymus elymoides* (t=5, p=0.285), *Festuca thurberi* (t=2, p=0.655), *Koeleria macrantha* (t=, p=0.317), *Poa pratensis* (t=5¸ p=0.285) and *Taraxacum officinale* (t=6, p=0.109) (Table 10).

Discussion

Soil resistance to penetration (soil compaction) in all pre-treatment units was greater deeper within the soil profile than at the soil surface as expected (Table 3).

Soil resistance increases with soil depth because soil weight above the depth of measurement increases and therefore increases the weight needed to penetrate soil (Sand et al. 1979). Soil resistance with greater depth can also be from changes in soil texture and gravel content (Landsberg et al. 2003). Resistance to penetration (soil compaction) was higher but not significantly different in landing areas (areas that were flat and open and have had mechanized equipment driven on in the past) than control or treatment units pre-treatment (Table 3). Numerous studies have illustrated that soils that have been previously compacted are often slow to recover (Tiarks and Haywood 1996). The rate of recovery is influenced by the number of harvests, soil moisture during harvests, soil texture and rock content (Williamson and Neilsen 2000; Liechty et al. 2002).

Soil strength or soil resistance to penetration influence numerous ecological processes, one of them being the energy root tips expend to penetrate soil. If a plant needs to put more energy into penetrating the soil because of small or rigid pores that prevent root growth, then less energy is available for plant growth (Landsberg et al. 2003). The USDA Forest Service Pacific Southwest Region (Region 5) recommends that a change of 500 kPA (72.5 lb/in^2) or more in soil resistance between 15-25 cm (5.9-9.84 in) in the soil profile following a management activity should be considered detrimental to soil structure and processes (Landsberg et al. 2003). Warkotsch and others (1994) found that soil resistance to penetration values exceeding 1000 kPa (145.05 lb/in^2) contributed to reduced growth in a pine plantation. Sands and others (1979) reported that radiata pine root penetration was severely restricted when resistance to penetration values exceeded a threshold level of about 3000 kPa (435.16 lb/in^2). Similarly, Taylor and others (1966) determined a level of 2500 kPa (362.63 lb/in^2) to restrict root growth on a variety of soil types from loamy fine sand to loam. In our study, within the 5.9-9.84 in soil profile, none of our values exceeded the resistance to penetration level of 2500 kPa (362.63 lb/in^2). It is important to note however, that there is no single threshold soil penetration value that exists for all plant species in all soil conditions and therefore site specific baseline soil penetration values are necessary to quantify the effects of harvest treatments on soil resistance to penetration (compaction). In addition, soil moisture values at the time of sampling have a large impact on soil resistance penetration which makes establishing threshold penetration values difficult to establish. Numerous studies have emphasized the importance of pretreatment assessments of soil resistance to penetration measurements to provide baseline measurements to accurately quantify the impacts of harvesting on soil resistance to penetration and long-term forest stand productivity than simple control/treatment paired measurements (Landsberg et al. 2003, Page-Dumroese et al. 2006). We designed our study following this protocol and did not find any significant differences in soil resistance to penetration between our control and treatment units prior to treatment (Table 3) or between our control units in 2009 and 2010 (Table 4).

IMPLICATIONS FOR MANAGEMENT IN A WARMER, DRIER CLIMATE

Numerous climate models have projected significant anthropogenic climate change by the end of the 21st century (IPCC 2007). In the southwestern United States, observations of historical data and climate models illustrate earlier spring snow melt, increased spring and summer temperatures, and drier summers (McCabe & Clark 2005; Westerling *et al.*2006; Seager *et al.*2007; Barnett *et al.* 2008). In addition, naturally occurring fluctuations in sea surface temperatures and atmospheric pressure in the Pacific and Atlantic Oceans play a role in interannual to multi-decadal moisture and temperature patterns in the Interior West, including patterns of warm, dry conditions that favor wildfire (Collins et al. 2006; Kitzberger *et al.* 2007). Fires are easier to ignite and spread, the fire season is longer, and extreme fire behavior is more common with warmer temperatures, drier soils and longer growing seasons (McKenzie *et al.* 2004; IPCC 2007; Lui et al. 2010). A study by Diggins and others (2010) illustrated however that while a warmer climate will increase fire frequency and intensity, a warmer climate may also reduce tree growth and increase tree mortality resulting in a decreased fuel load and thus decreased fire frequency and intensity. Given the uncertainty of potential projected changes, it is crucial to design forest biofuel and restoration treatments that incorporate these multifaceted and potentially counter-imposing ecosystem responses to climate change. Forest biofuel treatments and ecological restoration provide no guarantee that native forest ecosystems will survive a warmer, drier climate, but they do improve the likelihood of long-term conservation as long as fuel reduction treatments minimize negative impacts on other important biotic and abiotic ecosystem variables and processes.

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References

Allbrook, R.F. 1986. Effect of skid trail compaction on volcanic soil in central Oregon. Soil Science Society of America Journal 50: 1344–1346.

Barnett, T.P., Pierce, D.W., Hidalgo, H.G., Bonfils, C., Santer, B.D., Das, T., Bala, G., Wood, A.W., Nozawa, T., Mirin, A.A., Cayan, D.R.& Dettinger, M.D. 2008. Human-Induced Changes in the Hydrology of the Western United States. Science: 1080-1083.

Clayton, J.L. 1990. Soil disturbance resulting from skidding logs on granitic soils in central Idaho. Res. Pap. INT-436. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 8 p. Dickerson, B.P. 1976. Soil compaction after tree-length skidding in northern Mississippi. Soil Science Society of America Journal 40: 965-966.

Collins, B.M., Omi, P.N. & Chapman, P.L. 2006. Regional relationships between climate and wildfire-burn area in the Interior West, USA. Canadian Journal of Forest Research 36: 699-709.

Diggins, C., P.Z. Fulé, J.P. Kaye, & Covington, W.W. 2010. Future climate affects management strategies for maintaining forest restoration treatments. International Journal of Wildland Fire 19: 903-913.

Froehlich, H.A. 1979. Soil compaction from logging equipment: effects on growth of young ponderosa pine. Journal of Soil and Water Conservation. November–December: 276–278.

Fulé, P.Z., J.E. Korb, Wu, R. 2009. Changes in forest structure of a mixed conifer forest, southwestern Colorado, USA. Forest Ecology and Management 28: 1200-1210.

Fulé P.Z., W.W. Covington & Moore, M.M.. 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine forests. Ecological Applications 7:895-908.

Gent, J.A. Jr., R. Ballard, A.E. Hassan & Cassel, D.K. 1984. Impact of harvesting and site preparation on physical properties of piedmont forest soils. Soil Science Society of America Journal 48:173-177.

Greacen, E.L. & Sands, R. 1980. A review of compaction of forest soils. Australian Journal of Soil Research 18:163-189.

Han, S.K., Han, H.S., Page-Dumroese, D.S., & Johnson, L.R. 2009. Soil compaction associated with cut-to-length and whole-tree harvesting of a coniferous forest. Canadian Journal of Forest Research 39: 976-989.

Howard, R.F.,M.J. Singer & Frantz, G.A. 1981. Effects of soil physical properties, water content, and compactive effort on the compaction of selected California forest and range soils. Soil Science Society of America Journal 45: 231-236.
Kitzberger, T., Brown, P.M., Heyerdahl, E.K., Swetnam, T.W. & Veblen, T.T. 2007. Contingent Pacific-Atlantic Ocean influence on multicentury wildfire synchrony over western North America. Proceedings of the National Academy of Sciences 104: 543-548.

Incerti, M., P.F. Clinnick & Willatt, S.T. 1987. Changes in the physical properties of a forest soil following logging. Australian Forest Research 17: 91-98.

Intergovernmental Panel on Climate Change. 2007. Pachauri, R.K. and Reisinger, A. (Eds.) Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland. pp 104.

Jones, D. & Kunze, M. 2004. Guide to Sampling Soil Compaction Using Hand-Held Soil Penetrometers. Center for Environmental Management of Military Lands (CEMML), Colorado State University, Fort Collins, Colorado.

Jurgensen, M.F., A.E. Harvey, R.T. Graham, D.S. Page-Dumroese, J.R. Tonn, M.J. Larsen & Jain, T.B. 1997. Impacts of timber harvesting on soil organic matter, nitrogen, productivity, and health of inland northwest forests. Forest Science 43: 234-241.

Landsberg, J.D., R.E. Miller, H.W. Anderson & Tepp, J.S. 2003. Bulk density and soil resistance to penetration as affected by commercial thinning in Northeastern Washington. Unites States Department of Agriculture. Pacific Northwest Research Station. PW-RP-551.

Liechty, H.O., Shelton, M.G., Luckow, K.R., & Turton, D.J. 2002. Impacts of shortleaf pine-hardwood forest management on soils in the Ouachita Highlands: Southern Journal of Appalachian Forestry 26: 43-51.

Lui, Y., J. Stanturf & Goodrick, S. 2010. Trends in global wildfire potential in a changing climate. Forest Ecology and Management 259: 685-697.

McCabe, G. & Clark M. 2005. Trends and variability in snowmelt timing in the western United States. Journal of Hydrometeorology 6: 476-482.

McKenzie, D., Gedalof, Z., Peterson, D.L. & Mote, P. 2004. Climatic change, wildfire, and conservation. Conservation Biology 18: 890-902.

McNabb, D.H., A.D. Startsev & Nguyen, H. 2001. Soil wetness and traffic level effects on bulk density and airfilled porosity of compacted boreal forest soils. Soil Science Society of America Journal 65:1238-1247.

Landsberg, J.D., Miller, R.E., Anderson, H.W., & Tepp, J. S. 2003. Bulk density and soil resistance to penetration as affected by commercial thinning in northeastern Washington. Res. Pap. PNW-RP-551. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 35 p.

Miller, R.E., J. Hazard, & Howes, J. 2001. Precision, Accuracy, and Efficiency of Four Tools for Measuring Soil Bulk Density or Strength. USDA Forest Service Pacific Northwest Research Station Gen. Tech Report PNW-RP-532, April 2001.

Milliken, G.A. & Johnson, D.E. 1984. Analysis of messy date, Vol. I: Designed experiments. New York: Van Nostrand Reinhold.

Page-Dumroese, D.S., Jurgensen, M.F., Tiarks, A.E., Ponder, F.Jr., Sanchez, F.G., Fleming, R.L., Kranabetter, J.M., Powers, R.F., Stone, D.M., Elioff, J.D., & Scott, D.A. 2006. Soil physical property changes at the North American Long-Term Soil Productivity study sites: 1 and 5 years after compaction. Canadian Journal of Forest Research 36: 551–564.

Powers, O.F., A.E., Tiarks & Boyle, J.R. 1999. Assessing soil quality: practicable standards for sustainable forest productivity in the United States. In: Davidson, E., ed. The contribution of soil science to the development of and implementation of criteria and indicators of sustainable forest management. Soil Science Society of America Journal Special Publication 53: 53–80.

Rab, M.A. 1996. Soil physical and hydrological properties following logging and slash burning in the *Eucalyptus regnans* forest of southeastern Australia. Forest Ecology and Management 84:159-176.

Sands, R. Greacen, E.L., & Gerard, C.J. 1979. Compaction of sandy soils in radiata pine forests. I: A penetrometer study. Australian Journal of Soil Research 17: 101-103.

Seager, R., Ting, M. F., Held, I. M., Kushnir, Y., Lu, J. & Vecchi, G. 2007. Model projections of an imminent transition to a more arid climate in south-western North America. Science 316: 1181–1184.

SPSS. 2010. Base 18.0 for Windows user's guide and SPSS Base 18.0 applications guide package. Englewood Cliffs, NJ: Prentice Hall.

Taylor, H.M., Robertson, G.M., and Parker, J.J. Jr. 1966. Soil strength-root penetration relations for medium- to coarse-textured soil materials. Soil Science 102: 18-22.

Tiarks, A.E., & Haywood, J.D. 1996. Effects of site preparation and fertilization on growth of slash pine over two rotations. Soil Science Society of America Journal 60: 1654-1663.

Warkotsch, P.W., van Huyssteen, L., & Olsen, G.J. 1994. Identification and quantification of soil compaction due to various harvesting methods-a case study. Suid-Afrikaanse Bosboutydskrif nr. 170: 7-15.

Westerling, A.L., Hidalgo, H.G., Cayan, D.R. & Swetnam, T.W. 2006. Warming and earlier spring increase spring increase western U.S. forest wildfire activity. Science 313: 940–943.

Williamson, J.R. & Neilson, W.A. 2000. The influence of forest site on rate and extent of soil compaction and profile disturbance of skid trails during ground-based harvesting. Canadian Journal of Forest Research 30: 1196-1205.

Zar, J.H. 1984. Biostatistical analysis, 2nd ed. Englewood Cliffs, NJ: Prentice Hall.

Figure 1. Example of a landing site (landing 4-1) for biofuel thinning project, Turkey Springs, San Juan National Forest in 2009 prior to treatment.

Figure 2. Example of a landing site (landing 1-1) for biofuel thinning project, Turkey Springs, San Juan National Forest in 2009 prior to treatment

Figure 3. Example of a treatment site (1-G, T-24) for biofuel thinning project, Turkey Springs, San Juan National Forest in 2009 prior to treatment.

Figure 4. Example of a treatment site (4-G, T-1) for biofuel thinning project, Turkey Springs, San Juan National Forest in 2009 prior to treatment.

Figure 5. Example of a control plot (control C-1) for biofuel treatment, Turkey Springs, San Juan National Forest in 2009.

Figure 6. Example of a control plot (control C-7) for biofuel treatment, Turkey Springs, San Juan National Forest in 2009.

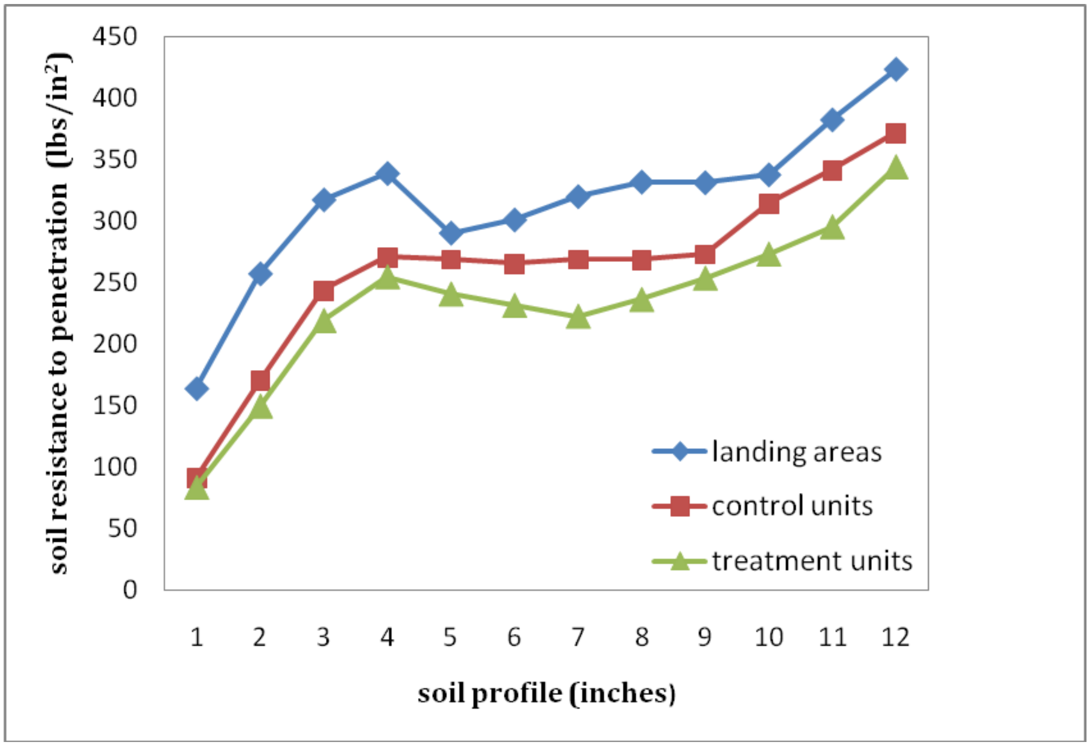


Figure 7. Soil resistant to penetration values (soil compaction) for pre-treatment (2009) control, treatment and landing area transects using a soil penetrometer from a 1-12 inch soil profile. Data is presented as mean (SEM) in pounds/inch^2. N=3 for control/treatment units. N=5 for landing units. There were no significant ($p \leq 0.05$) differences between control and treatment units for soil compaction along the soil profile using a Mann-Whitney U test.

Table 1. Soil moisture values (VWC)% and soil moisture period (m/s) for pre-treatment (2009) control, treatment and landing area transects. Data was collected to insure standardization of soil moisture values during soil compaction measurements using a soil penetrometer. N=3 for control/treatment units. N=5 for landing units. There were no significant ($p \leq 0.05$) differences between control and treatment units for moisture value or moisture period using a Mann-Whitney U test.

	Moisture Value (VWC%)	**SEM**	**Moisture Period (m/s)**	**SEM**
Control	14.38	1.64	0.87	0.009
Treatment	14.64	1.28	1.03	0.168
Landing	17.5	2.08	1.62	0.736

Table 2. Soil moisture values (VWC)% and soil moisture period (m/s) for pre-treatment (2009) and post-treatment year 1 (2010) control transects. Data was collected to insure standardization of soil moisture values during soil compaction measurements using a soil penetrometer. N=3 for control units. There were no significant ($p \leq 0.05$) differences between controls in 2009 and 2010 using a Wilcoxon matched pairs signed ranks test.

	Moisture Value (VWC%)	**SEM**	**Moisture Period (m/s)**	**SEM**
Control 2009	14.38	1.64	0.87	0.009
Control 2010	16.65	2.87	0.90	0.017

Table 3. Soil resistant to penetration values (soil compaction) for pre-treatment (2009) control, treatment and landing area transects using a soil penetrometer from a 1-12 inch soil profile. Data is presented as mean (SEM) in pounds/inch^2. N=3 for control/treatment units. N=5 for landing units. There were no significant ($p \leq 0.05$) differences between control and treatment units for soil compaction along the soil profile using a Mann-Whitney U test.

Soil Profile Location (inches)	**Control**	**Treatment**	**Landing**
1 inch	84.41 (17.3)	91.59 (6.66)	164.34 (38.65)
2 inch	150.28 (20.15	171.00 (7.11)	257.69 (35.67)
3 inch	219.47 (14.06)	244.03 (5.46)	317.72 (44.42)
4 inch	254.98 I10.39)	270.99 (6.87)	339.16 (52.96)
5 inch	241.01 (11.72)	269.21 (7.29)	290.69 (49.13)
6 inch	231.91 (10.56)	265.54 (7.29)	301.38 (51.60)
7 inch	223.04 (19.60)	269.17 (7.79)	320.38 (50.70)
8 inch	236.57 (17.71)	268.75 (11.39)	332.13 (38.85)
9 inch	253.93 (14.61)	273.92 (16.62)	331.63 (27.8)
10 inch	273.40 (8.75)	314.56 (21.87)	338.09 (23.63)
11 inch	295.5 (9.59)	341.45 (16.06)	382.72 (23.34)
12 inch	344.07 (6.01)	371.98 (13.77)	423.78 (23.68)

Table 4. Soil resistant to penetration values (soil compaction) for pre-treatment (2009) control and post-treatment year 1 (2010) using a soil penetrometer from a 1-12 inch soil profile. Data is presented as mean (SEM) in pounds/inch^2. N=3 for control units. There were no significant ($p \leq 0.05$) differences between controls in 2009 and 2010 using a Wilcoxon matched pairs signed ranks test.

Soil Profile Location (inches)	**Control 2009**	**Control 2010**
1 inch	84.41 (17.3)	95.37(30.82)
2 inch	150.28 (20.15	143.75 (30.83)
3 inch	219.47 (14.06)	197.5 (38.81)
4 inch	254.98 I10.39)	214.56 (41.24)
5 inch	241.01 (11.72)	239.07 (40.98)
6 inch	231.91 (10.56)	274.9 (35.48)
7 inch	223.04 (19.60)	303.87 (35.48)
8 inch	236.57 (17.71)	335.03 (37.29)
9 inch	253.93 (14.61)	362.65 (25.71)
10 inch	273.40 (8.75)	394.98 (41.59)
11 inch	295.5 (9.59)	420.50 (43.23)
12 inch	344.07 (6.01)	460.58 (23.59)

Table 5. Percent cover values for forest floor substrates for pre-treatment (2009) control, treatment and landing units from two 1 m^2 plots along each transect. Data is presented as mean (SEM) in percent. N=3 for control/treatment units. N=5 for landing units. There were no significant ($p \leq 0.05$) differences between control and treatment units for moisture value or moisture period using a Mann-Whitney U test.

Substrate	**Control**	**Treatment**	**Landing**
Bare soil	0.75 (0.33)	5.14 (2.51)	2.15 (1.01)
Rock	0.43 (0.20)	0.58 (0.55)	0.75 (0.075)
Wood	2.99 (0.92)	2.65 (0.96)	0.200 (0.20)
Litter/Duff	57.36 (18.51)	55.22 (3.36)	62.16 (3.83)

Table 6. Percent cover values for forest floor substrates for pre-treatment (2009) and post-treatment year 1 (2010) control units from two 1 m^2 plots along each transect. Data is presented as mean (SEM) in percent. N=3 for control units. There were no significant ($p \leq 0.05$) differences between controls in 2009 and 2010 using a Wilcoxon matched pairs signed ranks test.

Substrate	**Control 2009**	**Control 2010**
Bare soil	0.75 (0.33)	0.83 (0.43)
Rock	0.43 (0.20)	0.23 (0.05)
Wood	2.99 (0.92)	2.00 (0.84)
Litter/Duff	57.36 (18.51)	42.12 (9.51)

Table 7. Percent cover values for plant functional groups for pre-treatment (2009) control, treatment and landing units from two 1 m^2 plots along each transect. Data is presented as mean (SEM) in percent. N=3 for control/treatment units. N=5 for landing units. There were no significant ($p \leq 0.05$) differences between control and treatment units using a Mann-Whitney U test.

Plant Functional Group	**Control**	**Treatment**	**Landing**
Native Shrub	16.13 (2.69)	19.84 (5.65)	13.25 (8.15)
Native Grass	2.21 (0.63)	2.44 (0.43)	5.78 (1.56)
Native Forb	18.08 (5.59)	14.28 (1.98)	11.13 (2.24)
Non-native Grass	0.842 (0.48)	0.929 (0.38)	2.95 (1.26)
Non-native Forb	0.95 (0.14)	1.14 (0.51)	2.1 (0.97)
Noxious Weed	0 (0)	0.05 (0.29)	0.05 (0.31)

Table 8. Percent cover values for plant functional groups for pre-treatment (2009) control and post-treatment year 1 (2010) control units from two 1 m^2 plots along each transect. Data is presented as mean (SEM) in percent. N=3 for control units. There were no significant ($p \leq 0.05$) differences between controls in 2009 and 2010 using a Wilcoxon matched pairs signed ranks test.

Plant Functional Group	**Control 2009**	**Control 2010**
Native Shrub	16.13 (2.69)	23.35 (14.64)
Native Grass	2.21 (0.63)	5.36 (1.4)
Native Forb	18.08 (5.59)	26.13 (2.03)
Non-native Grass	0.842 (0.48)	0.33 (0.03)
Non-native Forb	0.95 (0.14)	1.32 (0.06)
Noxious Weed	0 (0)	0 (0)

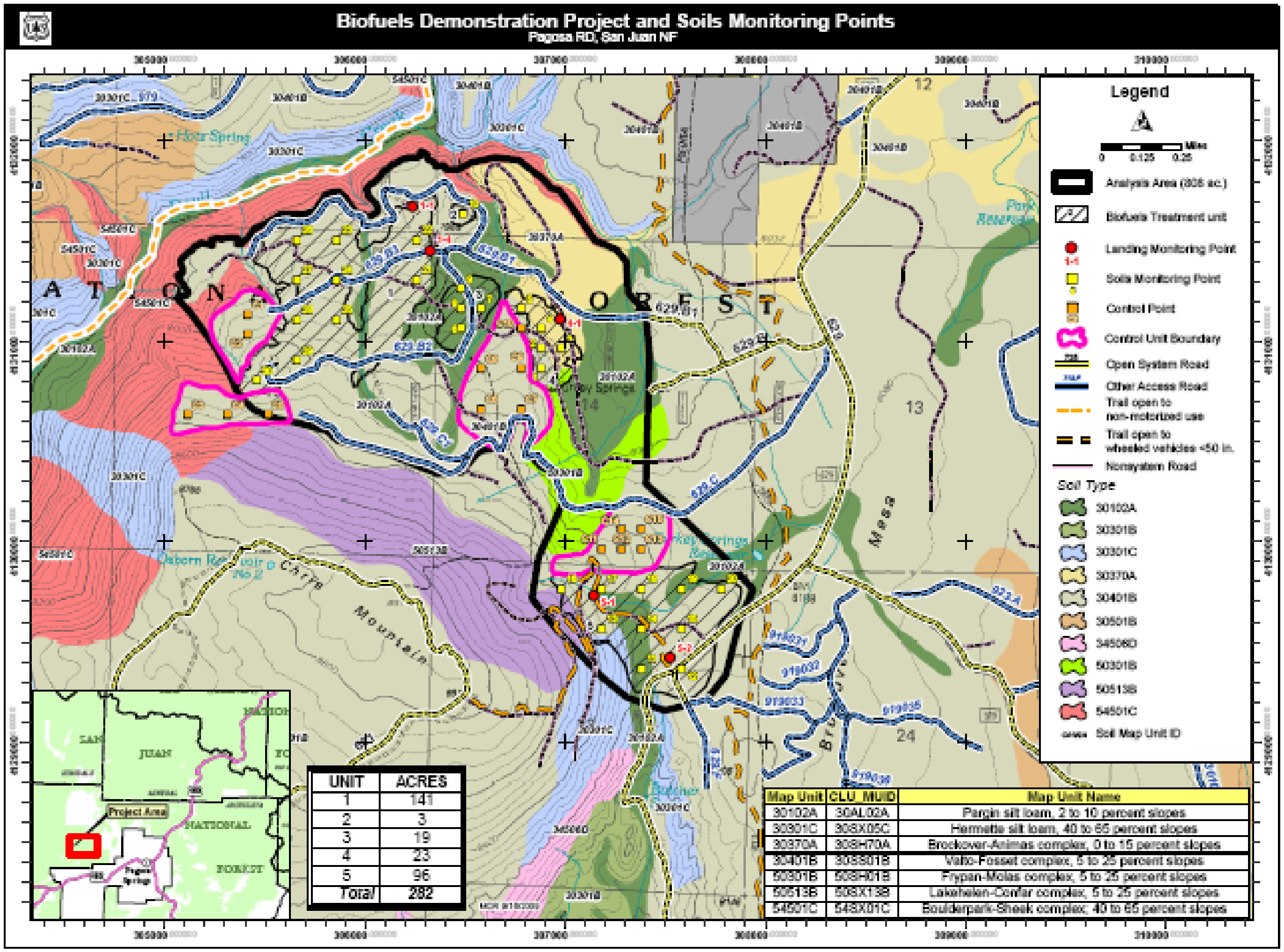
Table 9. Percent cover values for selective grasses and invasive species for pre-treatment (2009) control, treatment and landing units from two 1 m^2 plots along each transect. Data is presented as mean (SEM) in percent. N=3 for control/treatment units. N=5 for landing units. There were no significant ($p \leq 0.05$) differences between control and treatment units using a Mann-Whitney U test.

Species	**Control**	**Treatment**	**Landing**
Bromus ciliatus	0.84 (0.16)	0.3 (0.95)	0 (0)
Bromus inermis	0.47 (0.47)	0 (0)	1.5 (1.5)
Centaurea maculosa	0 (0)	0.47 (0.47)	0.4 (0.4)
***Cirsium* spp.**	0 (0)	0 (0)	0.35 (0.35)
Danthonia parryi	0 (0)	0.89 (0.51)	1.6 (0.82)
Elymus elymoides	0.083 (0.08)	0.43 (0.09)	0.13 (0.13)
Elymus glaucus	1.65 (1.04)	0.38 (0.14)	0.58 (0.58)
Festuca thurberi	0.2 (0.2)	1.13 (0.95)	4.8 (1.02)
Koeleria macrantha	0 (0)	0.32 (0.32)	0 (0)
Lactuca serriola	0 (0)	0.1 (0.05)	0 (0)
Phleum pretense	0 (0)	0.35 (0.08)	0.25 (0.25)
Poa pratensis	0.69 (0.48)	1.1 (0.60)	2.33 (0.98)
Taraxacum officinale	1.18 (0.18)	1.03 (0.26)	2.08 (0.87)
Trifolium repens	0 (0)	0 (0)	0.3 (0.3)

Table 10. Percent cover values for selective grasses and invasive species for pre-treatment (2009) control and post-treatment year 1 (2010) control units from two 1 m^2 plots along each transect. Data is presented as mean (SEM) in percent. N=3 for control units. There were no significant ($p \leq 0.05$) differences between controls in 2009 and 2010 using a Wilcoxon matched pairs signed ranks test.

Species	**Control 2009**	**Control 2010**
Bromus ciliatus	0.84 (0.16)	1.8 (0.56)
Bromus inermis	0.47 (0.47)	0 (0)
Elymus elymoides	0.083 (0.08)	1.07 (0.58)
Elymus glaucus	1.65 (1.04)	1.4 (0.61)
Festuca thurberi	0.2 (0.2)	0.53 (0.53)
Koeleria macrantha	0 (0)	0.2 (0.2)
Poa pratensis	0.69 (0.48)	2.93 (1.07)
Taraxacum officinale	1.18 (0.18)	2.63 (0.42)

Appendix A. Study site map with soil monitoring center points for control, treatment and landing area transects, Turkey Springs, San Juan National Forest, Colorado.



Apendix B. Soil monitoring transect center points for control, treatment and landing transects. Data presented in UTM and latitude/longitude coordinates.

			Treatment Points	
Id	**Easting**	**Northing**	**Latitude**	**Longitude**
T1	306880	4130864	37 18' 15.736" N	107 10' 44.582" W
T2	306880	4130964	37 18' 18.978" N	107 10' 44.675" W
T3	306980	4130964	37 18' 19.053" N	107 10' 40.616" W
T4	306880	4131064	37 18' 22.221" N	107 10' 44.769" W
T5	306780	4131164	37 18' 25.389" N	107 10' 48.922" W
T6	306480	4131064	37 18' 21.922" N	107 11' 1.007" W
T7	306580	4131164	37 18' 25.239" N	107 10' 57.041" W
T8	306480	4131164	37 18' 25.164" N	107 11' 1.100" W
T9	306480	4131264	37 18' 28.407" N	107 11' 1.194" W
T10	306490	4131638	37 18' 40.539" N	107 11' 1.148" W
T11	307380	4129364	37 17' 27.469" N	107 10' 22.885" W
T12	307580	4129364	37 17' 27.618" N	107 10' 14.768" W
T13	307180	4129564	37 17' 33.805" N	107 10' 31.189" W
T14	307380	4129564	37 17' 33.954" N	107 10' 23.072" W
T15	307580	4129564	37 17' 34.103" N	107 10' 14.954" W
T16	306980	4129764	37 17' 40.141" N	107 10' 39.494" W
T17	307180	4129764	37 17' 40.290" N	107 10' 31.376" W
T18	307380	4129764	37 17' 40.440" N	107 10' 23.258" W
T19	307580	4129764	37 17' 40.589" N	107 10' 15.141" W
T20	307780	4129764	37 17' 40.737" N	107 10' 7.023" W
T21	306258	4131307	37 18' 29.615" N	107 11' 10.235" W
T22	306258	4131507	37 18' 36.101" N	107 11' 10.423" W
T23	305858	4131507	37 18' 35.800" N	107 11' 26.662" W
T24	305858	4131307	37 18' 29.315" N	107 11' 26.473" W
T25	305858	4131107	37 18' 22.830" N	107 11' 26.285" W
T26	305658	4131507	37 18' 35.650" N	107 11' 34.781" W
T27	305658	4131307	37 18' 29.165" N	107 11' 34.592" W
T28	305658	4131107	37 18' 22.679" N	107 11' 34.404" W
T29	305658	4130907	37 18' 16.194" N	107 11' 34.216" W
T30	305458	4130807	37 18' 12.801" N	107 11' 42.240" W
		Control Points		
Control ID	**Easting**	**Northing**	**Latitude**	**Longitude**
C1	305314	4130636	37 18' 7.143" N	107 11' 47.924" W
C2	305414	4131136	37 18' 23.431" N	107 11' 44.337" W
C3	305514	4130636	37 18' 7.293" N	107 11' 39.806" W
C4	305414	4131036	37 18' 20.189" N	107 11' 44.243" W
C5	305114	4130636	37 18' 6.992" N	107 11' 56.043" W
C6	306580	4130664	37 18' 9.026" N	107 10' 56.572" W
C7	306780	4130664	37 18' 9.176" N	107 10' 48.454" W
C8	306580	4130864	37 18' 15.511" N	107 10' 56.760" W

			Control Points	
C9	306780	4130864	37 18' 15.661" N	107 10' 48.641" W
C10	306780	4131064	37 18' 22.146" N	107 10' 48.828" W
C11	307180	4129964	37 17' 46.776" N	107 10' 31.563" W
C12	307280	4129964	37 17' 46.850" N	107 10' 27.504" W
C13	307380	4129964	37 17' 46.925" N	107 10' 23.445" W
C14	307280	4130064	37 17' 50.093" N	107 10' 27.597" W
C15	307380	4130064	37 17' 50.168" N	107 10' 23.538" W
Landing Points				
Landing ID	**Easting**	**Northing**	**Latitude**	**Longitude**
1-1	306240	4131671	37 18' 41.400" N	107 11' 11.300" W
1-4	306326	4131450	37 18' 34.300" N	107 11' 7.600" W
4-1	306976	4131108	37 18' 23.700" N	107 10' 40.900" W
5-1	307144	4129728	37 17' 39.100" N	107 10' 32.800" W
5-2	307523	4129418	37 17' 29.300" N	107 10' 17.100" W

Appendix C. Reference tree information for transect center points and azimuth for direction of 50-m transect taken from 0-m for control, treatment and landing units.

Unit Number	Treatment	Reference Tree Info	Transect Azimuth	Comments
C1	Control	PIPO 5.8m at 340	190	
C2	Control	PIPO 3.5m at 81	179	
C3	Control	PIPO 17.3m at 88	156	
C4	Control	PIPO 8.3m at 296	157	
C5	Control	ABICON 5.9m at 88	159	
C6	Control	POPTRE 7.6m at 3	197	
C7	Control	PIPO 2.9m at 295	203	
C8	Control	PIPO 23m at 298	179	
C9	Control	PIPO 16.8m at 176	183	
C10	Control	PIPO 30.5 at 127	195	
C11	Control	POPTRE 3.4m at 1	116	
C12	Control	ABICON 4.2m at 354	183	
C13	Control	ABICON 3.5m at 238	190	
C14	Control	POPTRE 2.6m at 220	208	
C15	Control	ABICON 8.9m at 46	166	
T1	Treatment	PIPO 15.2m at 261	248	
T2	Treatment	PIPO 9.8m at 196	233	
T3	Treatment	PIPO 3.4m at 340	247	
T4	Treatment	PIPO 4.1m at 7	221	
T5	Treatment	PIPO 2.3 at 63	183	
T6	Treatment	PIPO 13.9m at 222	198	
T7	Treatment	PIPO 2m at 186	193	
T8	Treatment	PIPO 7.3m at 101	184	
T9	Treatment	PIPO 23.9m at 223	183	
T10	Treatment	PIPO 20.1m at 283	199	
T11	Treatment	PIPO 2.73m at 110	267	
T12	Treatment	PIPO 8.6m at 282	205	
T13	Treatment	PIPO 6.9m at	259	
T14	Treatment	PIPO 13m at 255	8	
T15	Treatment	PIPO 11.5 at 264	7	
T16	Treatment	ABICON 12.6m at 21	217	
T17	Treatment	PIPO 5m at 13	317	
T18	Treatment	PIPO 12.5m at 1	314	
T19	Treatment	ABICON 8.5m at 110	275	

Unit Number	Treatment	Reference Tree Info	Transect Azimuth	Comments
T20	Treatment	PIPO 7.1m at 224	168	
T21	Treatment	PIPO 5m at 303	237	
T22	Treatment	PIPO 13.6m at 289	143	
T23	Treatment	PIPO 7.2m at 331	186	
T24	Treatment	PIPO 8.6m at 322	156	
T25	Treatment	PIPO 6.4m at 257	192	
T26	Treatment	PIPO 6.6m at 31	193	
T27	Treatment	PIPO 4.6m at 158	91	
T28	Treatment	PIPO 6.6m at 352	186	
T29	Treatment	PIPO 6.1m at 53	288	
T30	Treatment	PIPO 3.1m at 92	133	
1-1 plot 2	Landing	PIPO 3.7m at 265	315	10m perpendicular (right) of plot 1
1-4 plot 1	Landing	PIPO 2.3m at 103	103	
1-4 plot 2	Landing	PIPO 2.3m at 103	103	10m perpendicular (right) of plot 1
4-1 plot 1	Landing	Pipo 5.3 m at 27	360	
4-1 plot 2	Landing	Pipo 5.3 m at 27	360	10m perpendicular (right) of plot 1
5-1 plot 1	Landing	PSEMEN	214	10m perpendicular (right) of plot 1
5-2 plot 1	Landing	PIPO	142	
5-2 plot 2	Landing	PIPO	142	10m perpendicular (right) of plot 1