SOIL DISTURBANCE IN SIERRA NEVADA MONTANE MEADOW FOLLOWING LODGEPOLE PINE REMOVAL

A Project

presented to

the Faculty of California Polytechnic State University,

San Luis Obispo

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Environmental Sciences and Management

by

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August 2021

COMMITTEE MEMBERSHIP

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ABSTRACT

Soil Disturbance in Sierra Nevada Montane Meadows Following Lodgepole Pine Removal

Climate change and other anthropogenic stressors are driving conifer encroachment into meadow habitat. Encroachment, if ignored, can revert meadows back into dense forested habitat, negating meadow's ecologic services (Durak et al. 2014). This research attempts to measure soil and stream habitat disturbances in Rock Creek meadow, located with Collins Pine Company land in Plumas County, California after clear-cut removal of encroaching lodgepole pine with mechanical machinery. Soil bulk density, ground cover transect data, and stream habitat conditions were monitored before (July 2019) and after (June 2021) restoration to measure changes in soil compaction, stream temperature, and surface disturbance (rutting/ tracks). Statistically significant differences were recorded in overall soil bulk density increasing from 0.75 g/cm^3 prior to lodgepole pine removal to 0.87 g/cm^3 following removal. Comparison between disturbed and undisturbed samples, identified at time of measurement, did not yield a statistically significant difference. Ground cover experienced major decreases in vegetation cover and increases in woody debris, rutting, and skidder tracks. When comparing soil bulk density by cover designation, disturbed sample sites were similar to undisturbed samples. Rock Creek had no streamflow in Summer 2021, making stream habitat interpretations inconclusive following lodgepole pine removal. Continuous monitoring is needed to understand the long-term recovery of compacted meadow soils and develop effective future management of these fragile ecosystems.

Keywords: [soil bulk density, soil compaction, Sierra Nevada, meadow restoration, encroachment, lodgepole pine, logging]

ACKNOWLEDGMENTS

I would like to give a huge thank you to my graduate major advisor Dr. Surfleet for his guidance over the past year. This research would not have been possible without his education and commitment of time. And thank you to The Collins Pine Company for providing housing in Chester, CA during field work and permitting us to conduct the following research on your land. Funding for this project was provided by grants from the Sierra Institute for the Community and Environment and the California Board of Forestry's Monitoring Effectiveness Committee.

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Chapter 1

INTRODUCTION

The numerous threats to Sierra Nevada montane meadows (encroachment, climate change, grazing, and fire suppression) can alter their hydrologic properties, negating their ecologic benefits/ services to local wildlife and humans (Viers et al. 2013). Early detection and land management intervention is pivotal in restoring meadows towards a functional and productive state. This can be done using common restoration techniques including mechanical removal, controlled burn, restoring hydrologic functions, or selective livestock grazing (Ratliff 1985). Lodgepole pine meadow encroachment in the Sierra Nevada range can be treated with any of these techniques given appropriate circumstances, all of which aim to maintain hydrologic function.

The hydrologic impacts from mechanical forest removal in the Sierra Nevada and Cascade ranges have been researched (Busse et al. 2021). However, no research exists that assesses the impacts from the machinery itself during conifer removal. How much compaction and disturbance does machinery inflict on a montane meadow's soil and vegetation? Does the disturbance from mechanical removal recover quickly or outweigh the restorative benefits?

To answer these questions, an encroached meadow along Rock Creek within land owned by Collins Pine Company in Northern California's Plumas County was studied to contribute new data on mechanical disturbances and montane meadow restoration efficacy in the Sierra Nevada range. The encroached trees along Rock Creek were mechanically removed by logging machinery in 2020 and 2021. Prior to removal, four 500-foot study areas were established and measured. Ground cover types were recorded at every one-foot increment, soil bulk density was sampled within designated transects. Approximately one year after the restoration during the summer of 2021, measurements were recorded again to assess mechanical disturbances and compare Rock Creek's soil bulk density after the removal of encroaching lodgepole pine.

Stream habitat metrics of residual pool depths, pool rifle ratio, stream bed particle size, and cobble embeddedness were measured at the downstream end of the Rock Creek treatment area. Stream temperature sensors were placed upstream and downstream of the encroached area to record weekly stream metrics. No post-restoration stream habitat or stream temperature were measured due to no streamflow in 2021 water year.

It is hypothesized that 1) heavy machinery, such as tree harvesters and ground-based yarding equipment, during lodgepole pine removal will create soil compaction as measured by an increase in soil bulk density. 2) Soil disturbance, measured percent of ground cover remaining, will increase following the first year of lodgepole pine removal due to mechanical disturbance. 3) Reduction of stream shading from the removal of near stream lodgepole pine will create increased maximum and mean daily stream temperatures impacting stream habitat. 4) An increase in soil compaction and decrease in ground cover will result in increased erosion and sediment delivery to the watercourse affecting stream habitat. 5) The disturbances from the forest removal operation will be short-term with soil compaction, ground cover, and stream habitat disturbances recovering over time.

The goal of this study is to evaluate the first year of soil disturbances and stream habitat conditions associated with the Rock Creek Meadow restoration from removal of encroached lodgepole pine. Specific objectives are: 1) Evaluate the change in soil bulk density, as measure of soil compaction in the watercourse and lake protection zone (WLPZ) the first year after the removal of encroached lodgepole pine (associated with hypothesis 1). 2) Evaluate the amount of soil disturbance following harvest operations in the WLPZ the first year after the removal of encroached lodgepole pine (associated with hypothesis 2). 3) Present the pre-restoration stream habitat metrics associated with hypothesis 3 and 4. Due to a dry winter no streamflow occurred in the first-year post-restoration. Hypotheses 3-5 should be evaluated in the future.

Chapter 2

LITERATURE REVIEW

The following literature review will help inform the reader on current meadow information including meadow types and characteristics, ecosystem services, their importance to humans, restoration techniques, drivers of meadow degradation, and the complexity with assessing restoration success.

2.1.0 Meadow Types

Meadows are groundwater-dependent open field habitats consisting of grass, herbs, and other non-woody plants (Weixelman 2011). There are many different types of meadows including agricultural, transitional, perpetual, and urban meadows. Agricultural meadows are characterized by the lack of grazing in order to produce hay and other agricultural products. Transitional meadows occur when grazing and farming is halted allowing self-seeding woody trees to establish themselves in the open field. If left unchecked, these meadows will eventually return to a fully wooded state (Durak et al. 2014). Perpetual meadows are naturally occurring and possess climatic and soil conditions that discourage woody intrusion and allow perennial grasses to flourish. Different types of perpetual meadows include alpine, coastal, desert, prairie, and semi-wetland areas.

2.2.0 Meadow Ecosystem Services

Meadows serve as an important resource for both humans and environment. Their ecologic benefits range from reducing downstream floods, providing natural fire breaks, organic carbon storage, providing crucial riparian habitat for herbaceous species (McIlroy & Allen-Diaz 2012), purifying water, and reducing erosion (Norton et al. 2014).

As humans, we are dependent on the health of meadows just as much as the fauna and flora that occupy them. Almost two-thirds of municipalities in North America receive their drinking water from forested areas (Bladon 2018). Meadows control flooding and provide a clean, reliable water supply which reduces wastewater treatment costs for urban downstream use (Lubetkin et al. 2017). Meadows can be used for agricultural purposes such as grazing and/or farming in lowland or upland fields. Summer grazing of meadows can act as a form of meadow maintenance. Meadows can store and source huge amounts of organic carbon in soil, which fluctuates with seasonal variation (Zhao et al. 2010). The degradation of meadows is associated with soil carbon loss which releases more carbon dioxide into the atmosphere, emphasizing the role of meadow preservation in the context of climate change (Zhao et al. 2010).

2.3.0 Montane Meadows in Sierra Nevada

Montane meadows in the Sierra Nevada mountains compromise less than 10% of the range but still hold great importance (Viers et al. 2013). An assemblage of all known GIS data layers for meadows estimated there are approximately 17,039 meadows among the Sierra Nevada range covering 191,900 acres (Viers et al. 2013). These wet, or semi-wetlands, support a variety of hydrophytes (plants that grow on or in water) and mesophytes (adapted to neither aquatic nor dry conditions) (Ratliff 1982). Snowmelt provides a consistent water supply for surface runoff and groundwater storage (Viers et al. 2013). Sierra Nevada montane meadows harbor high biodiversity and provide habitat for numerous protected species such as the *Empidonax traillii* (Willow Flycatcher) and *Bufo canorus* (Yosemite Toad) (Ratliff 1985). 50% of California domestic water supply comes from Sierra Nevada watersheds. For over 150 years, these meadows have produced forage and water for grazing and domestic livestock (Ratliff 1985). Native grazing animals that utilize meadow habitats include deer, bighorn sheep, and small mammals (Ratliff 1985).

2.3.1 Hydrology, Soils, and Vegetation

Classifications of montane meadows consider the wetness, range type, altitude, physiography, vegetation, and sites. No two meadows are identical in this sense. Typically, a single classification is applied to a whole meadow based on a combination of its herbaceous vegetation, hydrology, and geomorphology (Ratliff 1985). Sierra Nevada montane meadows are characterized by a shallow water table less than 1 meter in depth (Viers et al. 2013). Trees and meadows show surface flow is a minor contributor to healthy meadows while groundwater metrics were more appropriate for assessing meadow health (Davis et al. 2020). Data gathered by piezometers found certain plant community types were related to locations with low and high varying water table patterns, demonstrating how the complexity of physical and biological inhabitants can be predicted through water table monitoring (Allen-Diaz 1991).

Based off its setting, hydrology, and vegetation, Rock Creek meadow is classified as a dry meadow. Dry meadows can occur at a variety of elevations and landforms. At higher elevations, the main water source for dry meadows is derived from precipitation or snow melt (Weixelman 2011). In meadows, water is lost by evapotranspiration, overland flow, and seepage into the groundwater below (Weixelman 2011).

2.4.0 Threats to Montane Meadows in Sierra Nevada

There are four major threats to meadows which include livestock grazing, encroachment, fire, and stream incision (deepening of stream bed). Montane meadows are located in mountainous regions far from the urban setting, yet anthropogenic activities and climate change are driving huge ecological consequences that threaten the existence and functions of these delicate ecosystems all around the Sierra Nevada range (Benedict 1982).

2.4.1 Encroachment Threats

Encroachment is defined as the intrusion of woody trees beyond their known territory into open meadow grasslands (Van Auken 2009). *Pinus contorta* (lodgepole pine) is highly adaptable to a wide range of mountainous conditions making it a species of concern to land management (Ratliff 1985). Lodgepole pine grows in the Sierra Nevada and Cascade Ranges at elevations ranging from approximately 5,000 to 11,000 feet and grow from 50 to 130 feet tall with seed production starting at 4 to 8 years of age (Ratliff 1985). Lodgepole pine regenerates best in mineral soil fully exposed to light to increase reproductive success (Tackle 1959). Lodgepole pine encroachment causes unfavorable changes in species composition and productivity primarily because lodgepole pine reduces open field area, available light to native meadow herbs, and soil moisture (Taylor 1990). Meadows are naturally capable maintaining their open field and preventing invasive woody establishment through their unique characteristics including sod, dense meadow vegetation, and/or dense organic surface material, and saturated soils (Leonard et al. 1969). Saturated soils discourage lodgepole pine seedlings from taking root and are at constant risk of being trampled by local grazing (Leonard et al.1969). However, once a seedling has been established in meadow habitat, it will follow a normal growth rate even in saturated soil. (Leonard et al. 1969). This highlights the importance of understanding the encroaching tree's germination requirements and how land managers can modify the hydrologic regime to prevent favorable encroachment conditions. Research has found lodgepole pine establishment to be most successful in years with low snowpack and early melting (Wood 1975).

These various threats are especially noticeable among meadows in California's mountain ranges. Numerous studies in the Sierra Nevada and Cascades have revealed climate change, land management practices, and unnatural fire occurrences are driving large woody trees, primarily lodgepole pine, to encroach towards the center of meadows (Lubetkin et al. 2017). Encroaching conifers shade out native flora and possess deep roots which alter the shallow water table, leaving native meadow species without adequate water (Kauffman et al. 1984). Encroachment into meadow habitats replaces native meadow food sources with woody trees which stresses local wildlife. The strong positive feedbacks between a meadow's hydrologic properties and invasive trees only causes further encroachment (Archer et al. 1994). Climate change enhances this problem as warmer conditions, strong soil drying, and longer growing seasons favor encroaching tree establishment with temporal models suggesting the average meadow will shift to forest by the end of the 21st century (Lubetkin et al. 2017).

2.4.2 Livestock and Grazing Threats

Grazing is a common reason for lodgepole pine encroachment. Heavy sheep grazing by ranchers in the late 19th and early 20th century influenced vegetation and soil characteristics which created a suitable niche for lodgepole pine to fill. However, some evidence suggests sheepherders set fires to direct flock movement which unintentionally discouraged lodgepole pine encroachment (Vankat 1971). Livestock, if not applied correctly, can create problems when defoliation, selective grazing, trampling, and mineral redistribution disrupt the natural growth and reproductive needs of meadow plants which creates favorable conditions for lodgepole pine invasion, altered meadow-fire relationships, and accelerate erosion (Ratliff 1985). Meadows with stable hydrologic and vegetative properties reduce opportunities for invasion (Benedict 1982).

2.4.3 Unnatural Fire Regime

Prior to anthropogenic influence, fires occurred naturally in the Sierra Nevada range. When ranchers settled in the range, they adopted regular burning practices from indigenous people (Sterling 1904). Wildfires naturally regulate the tree line along meadow edges (Cocking et al. 2012). When fire suppression became a priority in the 20th century, it shielded encroaching trees from regulatory wildfire processes that originally kept encroaching trees in check (Cocking et al. 2012), resulting in more woody fuel accumulation and higher burn severity. Severe fire-induced changes to soil hydrology causes profound impacts on runoff and sediment loads, more so in larger fires, affecting gully formation (Ratliff 1985).

2.4.4 Climate Change

Climate change is driving the Earth's temperature to increase, leading to drier conditions and changes in meadow hydrology, sediment, erosion, filtration, water table levels, vegetation, and biodiversity. Unfavorable changes in these fields can negate their ecological services to both humans and local fauna/flora (Lubetkin et al. 2017). The impacts of climate change on the Sierra Nevada range have been studied extensively due to the range's role in California's water supply. Future climate models consistently forecast a substantial increase in air temperature and decrease in precipitation for nearly all of California (Franco et al. 2011). State-wide increases in temperature by the end of the 21st century forecast a warming of 1.5 to 6 degrees Celsius above the 1961-1990 summer month mean temperature (Franco et al. 2011). Previous climactic studies have already observed less precipitation as snow, earlier snowmelt and onset of spring, and earlier runoff in the Western portion of the United States (Barnett et al. 2008). These climactic changes imply numerous consequences to the functionality of Sierra Nevada meadows.

2.4.5 Stream Incision

Degradation of montane meadows often occurs in the stream channel (Purdy et al. 2012) as erosion alters bank stability and vegetative cover, inducing erosion and a widening of the stream's channel. Streams can become incised to the point where peak runoff is incapable of overtopping the stream banks, concentrating erosive energy inside the stream bank which cuts deeper into the stream bed (Viers et al. 2013). Stream incision lowers the water table, creating suitable conditions for woody encroachment near the stream while conditions continued to support wet meadow vegetation away from the stream (Loheide et al. 2009). Woody encroachment modifies streamflow, runoff, recharge, evaporative leaf area, root system volume (Huxman et al. 2005). Stream incision in montane meadows can be incited by a few activities, primarily grazing, logging, and road construction (Loheide et al. 2009). Comparing the hydrologic implications from incised and natural montane meadows is difficult due to many temporal and spatial factors that differ between meadows and stream reaches (Essaid et al. 2014).

2.5.0 Restoration Methods

This section will discuss various land management techniques are implemented to rehabilitate meadow ecosystems experiencing woody encroachment.

2.5.1 Mechanical Removal

One short term but highly effective method to rehabilitate an encroached meadow is to mechanically remove encroaching woody trees (Adams et al. 1991; Surfleet et al., 2020). Research in Cascade Range meadows found that mechanical removal increased the meadow's herbaceous cover by 47% and species richness by 38% (Halpern et al. 2012). Similar research found significant increases in subsurface water storage following lodgepole pine removal during summer months when transpiration would be highest (Lesh et al. 2010). Four years after mechanical removal of lodgepole pine in Marian Meadow (Surfleet et al., 2020), an average decrease in depth to groundwater of 0.15 meters was measured. Marian Meadow's water budget indicated that lodgepole pine removal decreased evapotranspiration and interception, raising the water table closer to the surface promoting the growth of native meadow vegetation.

2.5.2 Controlled Burn

Controlled burning can be an effective restoration method if used in the right context. Prior to modern fire suppression and land management, wildfire disturbances naturally consumed residual woody fuels which maintained forested ecosystems. But the intricacies of pre-colonial wildfire disturbances and their contribution to meadow ecosystems are poorly understood (Kremer et al. 2014).

2014). Controlled burning in areas with highly accumulated woody fuels can lead to severe vegetation and soil damage, further altering ground water conditions and assisting in encroachment reinvasion (Mooney et al. 2000). The introduction of controlled burning in encroached grasslands found woody encroachment stayed constant, but did not reverse, while untreated plots experienced continued encroachment (Miller et al. 2017). However, studies comparing the response of cutting and burning effectiveness found no difference in resprouting encroaching trees regardless of burn or mechanical removal while encroachment was more driven by woody species composition and tree age. This demonstrates the importance of early restoration intervention as younger trees have less resprouting ability (Michielsen et al. 2017).

2.5.3 Grazing

Grazing, while unintentionally damaging at times, can also be used to control encroachment but requires a better understanding of the relationship between site-specific vegetative communities and grazing levels. Studies on grazing impacts have found correlations between grazing levels among certain plant communities in wet and mesic meadows in the Sierra Nevada range (McIlroy & Allen-Diaz 2012). Other livestock management research used GIS and multiple regression equations to estimate livestock's role in soil carbon and nitrogen storage but found subtle impacts (Norton et al. 2014). In one instance, late season cattle grazing assisted in conifer encroachment and decreased meadow vegetation. This suggests land managers should set stocking rates and install fencing to target certain vegetation. (Jones et al. 2011). Other research on tree age and fire history in Mt. Lassen National Forest found conifer encroachment spiked when livestock grazing and burning was halted between 1905 and 1933 (Taylor 1990).

2.5.4 Other Methods

Other less-used mechanical restoration techniques include annual mowing of grasslands which was found to be beneficial for native species but neutral for exotics (Smith et al. 2018). Another technique, referred to as "pond and plug", takes an incised (deep) stream channel and redirects the flow to stable channels which is connected to a broader floodplain. This can be done with stream structures such as beaver dam analogs which raise the incised streambed. This allows a more broad and spread-out flow which, in turn, reduces erosion and allows riparian vegetation establishment. A study on pond and plug restorations in a Sierra Nevada meadow found the technique increased the water table and its ability to store water in both wet and dry seasons (Brown et al. 2013).

2.6.0 Soil Disturbance from Mechanical Operations

Minimizing soil compaction during logging operations is vital for maintaining healthy and productive soils. Little research exists on mechanical soil disturbance in the context of meadow restorations. However, research following forest harvest found clear cutting and tree yarding caused compaction on the soil surface and organic layer, limiting root growth and forest regeneration (DeArmond et al. 2020). Research in meadow grass cultivation reveals increasing the passes of heavy machinery increased compaction leading to soil structure degradation through changes in the size and shape of pores, ultimately reducing plant yield (Glab 2013). Root systems respond to increases in soil bulk density by decreasing root length, concentrating them in upper soils (Lipiec et al., 2003). Other negative impacts include restricting oxygen, water, and nutrient supply (Chen and Weil, 2010). In severely compacted soils, microbial soil conditions were unfavorable leading to lower microbial biomass C from slow drainage and gas permeability (Frey et al. 2009).

Soil compaction can also encourage erosion, which delivers increased sediment loads to nearby streams with consequent impacts to downstream aquatic ecosystems (Litschert and MacDonald, 2009). For this reason, many state forest best management practices (BMPs) aim to protect water resources from forestry operations by limiting ground-based machinery activity near waterways (Washington Forest Practices Board, 2001). However, it should be noted that there are many site-specific conditions that may contribute to increases in sediment erosion such as soil type, climate, rainfall, and slope (Grigal, 2000). Minimizing compaction involves prohibiting logging operations when soil moisture levels are above a certain threshold (Froehlich 1983).

Compaction can have profound long-term effects on forest soils. A 20-year study on post-harvest compaction in mixed Sierra Nevada conifer forests found soil physical properties remained altered for 20 years following harvest (Busse et al. 2021). Average bulk densities were 10-29% greater and total porosity was lost by 9-11% (Busse et al. 2021). The results were consistent across a variety of sites with differing soil OM and clay content (Busse et al. 2021). Despite these sustained changes in soil physical properties, no adverse effects were observed on soil C and N content (Busse et al. 2021).

2.7.0 Restoration Efficacy

Erosion is the transportation of sediment to lower elevations through processes such as wind or water movement. Erosion prevention and control is key to restoring and maintaining a meadow's hydrology and overall health. This is attributed to erosion which removes protective sod and productive topsoil which lowers the water table (Ratliff 1985). It is these types of hydrologic change that can alter vegetation composition, creating invasive opportunity for lodgepole pine (Ratliff 1985).

Previous studies have found the negative effects of conifer encroachment in meadows can be combated by common land management practices including mechanical removal of trees, controlled burning, and prescribed livestock (Adams 1991). The effectiveness and application of these land management practices should be dependent upon the context of a meadow. Not all meadows are created equally as their setting can range anywhere from the high alpine to the coastal ranges and desert (Ratliff 1985), each with intricate characteristics that make their respective meadow ecosystem unique. Meadow restoration studies have tested and compared how various land management practices in different settings produce different efficacy results in halting or reversing encroachment. For example, grazing ungulates in one meadow could target encroached saplings before they establish. However, in a different setting, the same application could target native meadow species, encouraging even more encroachment (Keely et al. 2003). The natural complexity involved with prescribing meadow restoration treatments calls for extensive experimentation in quantifying the changes in the hydrology, soil, and vegetative conditions after treatment as these variables have the most influence on a meadow’s vegetative composition (Mitsch et al. 2000).

Understanding the effectiveness of restoration methods on meadow hydrology allows land managers to make better informed decisions as to what, how, and when a certain treatment should be implemented. With more research in this field, well-established patterns could be synthesized to add additional information to guides on meadow restoration techniques which better inform land managers on conservation and restoration practices.

Chapter 3

METHODS

3.1 Study Area

Rock Creek Meadow is a historic montane meadow located within land owned by the Collins Pine Company in Plumas County just East of Lake Almanor and the town of Chester, CA. The study area is within the eastern portion of the South Cascades Bioregion (SCB). This region is characterized by a Mediterranean climate with hot/ dry summers and wet/ cold winters. The forest surrounding Rock Creek is a subalpine zone compromised of mixed conifers. Common flora in the area includes *Pinus jefferyi* (Jeffrey Pine), *Pinus jeffreyi* (Jeffrey pine), *Calocedrus decurrans* (incense cedar), *Abies concolor* (white fir), and *Pinus contorta* (lodgepole pine). Rock Creek Meadow's elevation is 4,980 ft. Mean summer air temperatures collected by the National Oceanic and Atmospheric Administration (NOAA) at Chester, CA between 1981-2010 recorded a mean summer air temperature high of 27.4 degrees Celsius and mean winter lows of -5.9 degrees Celsius. The average annual precipitation measured at Chester, California is 872.5mm.

3.2 Study Design

The removal of encroached conifers from Rock Creek Meadow began at the end of summer of 2020. Removal was done by a mechanical harvester with felled trees forwarded by a ground-based rubber tire skidder to a central location to be transported, chipped, or burned. Most of Rock Creek Meadow had encroached conifer removal completed by fall 2020. Many of the felled conifers were not removed from the site in 2020, this final work extended into 2021. The narrow corridor of encroached conifers that extends adjacent to Rock Creek toward State Route 36 was removed in late spring 2021.

To examine soil and stream disturbances from the removal of trees in the Watercourse and Lake Protection Zone (WLPZ) along Rock Creek, before and after measurements of soil bulk density and ground cover designation were completed. For indication of stream habitat changes, stream temperature, particle size distribution of the stream bed, residual pool depths, and pool to riffle ratio were collected. The extremely dry winter of 2020-2021 resulted in no springtime streamflow in Rock Creek. There were no post restoration water quality measurements for comparison done in 2021.

3.3 Soil Disturbance within Watercourse and Lake Protection Zone (WLPZ)

Soil disturbance was examined along four 500-foot lengths of the WLPZ. At each of the 500-foot sections, four transects were used to measure soil disturbance and ground cover at 30, 50, or 70 feet from the watercourse transition line defined by the California Forest Practice Rules (Cal Fire 2020). A measure of ground cover was used to compare before and after WLPZ ground disturbance. Pre-restoration (July 2019), each transect was walked at 30, 50, and 70 feet parallel to the transect and the length of different ground cover designations were recorded to the nearest 1-foot increment (Table 1). Post-restoration (June 2021), the ground cover survey recorded only the 30-foot distance of each 500-foot transect.

Table 1. Ground cover designations. Bare soil equipment (BSE) describes an exposed and disturbed sample site with no type of vegetative cover while covered soil equipment (CSE) are disturbed sites with persisting live vegetation.

Undisturbed Soil Designations	**Disturbed Soil Designations**
Vegetation	Bare soil, disturbed from harvest equipment (BSE)
Litter/ Limbs	Covered soil, disturbed from harvest equipment (CSE)
Logging Slash	Roads
Rock or Gravel	
Large Wood	

To determine the amount of soil compaction, soil bulk density samples were taken using a soil bulk density sampler manufactured by Arts Machine Shop (AMS). Bulk density is the mass of dry soil per unit volume (Froehlich 1983). The soil bulk density core sampler cap features a built-in waste barrel that offers 2 inches of relief and helps to eliminate both compaction from overdriving the sampler. Organic matter was removed from the soil surface to expose the A horizon. The sample core was hammered into the soil until a 2 inch by 2 inch (5.08 cm by 5.08 cm) ring was filled with soil. The ring was removed from the sampler, with excess soil trimmed from the sample ring then capped. The sampled soil is put in a 105 degrees Celsius oven for 24 hours then weighed. The resulting oven dry weight in grams is divided by the volume of the sample cylinder, 90.57 cm^3, to provide soil bulk density (g/cm^3).

In July 2019, before restoration, two soil bulk density samples were collected along each transect (30, 50, and 70 foot) for each 500-foot section of the WLPZ. This resulted in 6 soil bulk density samples for each of the four 500-foot sections for a total of 24 soil bulk density measurements. In November 2020 and July 2021, following restoration, there were four bulk density samples randomly sampled along each transect (30, 50, and 70 foot) for each 500-foot section. The four soil bulk density samples, on each transect, comprised of two samples from undisturbed ground and two from disturbed ground, as determined by visual inspection. The exact sample was collected at the closest undisturbed or disturbed soil location to the randomly selected point. A total of 12 samples were collected at each 500-foot transect.

During soil core sampling, bark, roots, and other types of ground litter would sometimes be included in our soil cores. For soil bulk density accuracy, it's important that soil core samples do not have large chunks of debris in them. It should be noted that this inevitably happened to some degree within our samples from time to time, these samples were excluded from the analysis when this occurred.

Statistical analysis of soil bulk density samples was done with a two-sample t-test assuming unequal variance with a standard Alpha level of 0.05. Two groups were compared: 1) overall pre-restoration vs. post-restoration soil bulk density and 2) post-restoration overall undisturbed vs. disturbed soil bulk density.

3.4 Rock Creek Stream Data

For evaluation of disturbances to stream habitat associated with the meadow restoration, before and after measurements for stream temperature, pebble counts, particle size distribution of the streambed, residual pool depth, and pool to riffle ratio were planned. Pre-restoration stream habitat metric measurements were taken in July 2019. Stream temperature was monitored annually from 2017-2020. Due to an extremely dry winter no post restoration stream measurements could be taken in 2021. Only pre-restoration results are presented.

3.4.1. Stream Temperature and Streamflow Measurements

Stream temperature sensors were placed upstream, downstream, and within Rock Creek restoration area, provided by Plumas Corp, for the years 2017 to 2021 (Figure 1). One streamflow gauge was used to record flow (cfs). Stream temperature and flow was recorded during Spring when the stream is fed from snow melt. Stream temperature was recorded until the Rock Creek stream ran dry. This would vary from year to year with differing snowpack.

Stream data was used to calculate seven-day rolling average for the daily average temperature (MWAT) and the maximum daily (MWMT) stream temperatures for all stations for each year (2017-2020).

3.4.2. Stream Habitat Metrics

3.4.2.1 Particle Size Distribution

For a representation of streambed particle size distribution, five particle size measurements of 100 pebbles from the streambed occurred along a 2,215-foot reach of Rock Creek. The sample site start points were determined using a random number table to select the first start point within 0-500 feet, with each after 500 feet apart Site #1 was located 103 feet above start, 397 feet below streamflow gage (Figure 1). The particle size distribution was collected by breaking a 100-foot section of stream into 10 - 10 foot transects. Each transects had

10 pebbles measured using a random walk method for a total of 100 particles measured from each of the five sites. When a cobble sized particle was selected (64-256 mm), the degree of embeddedness was estimated in 10% increments. The particle size distributions were graphed as cumulative distribution curves and the median particle size determined from each site.

3.4.2.2. Pool habitat

Pool-to-riffle ratio data was measured on the same span of 2,125 feet, beginning 500 feet downstream of the Streamflow Gauge. The length of pools and riffles and the maximum depths of pools and pool tail-outs were measured. Pools were identified by increased depth from the water to streambed and slower moving water, whereas riffles were identified by shallow faster moving water. Each pool encounter had the maximum depth measured and the deepest depth at the crest of the downstream riffle, or spill point of the pool. A residual pool depth was determined by subtracting the riffle crest depth from the maximum pool depth. The average and standard deviation of residual pool depths were calculated.

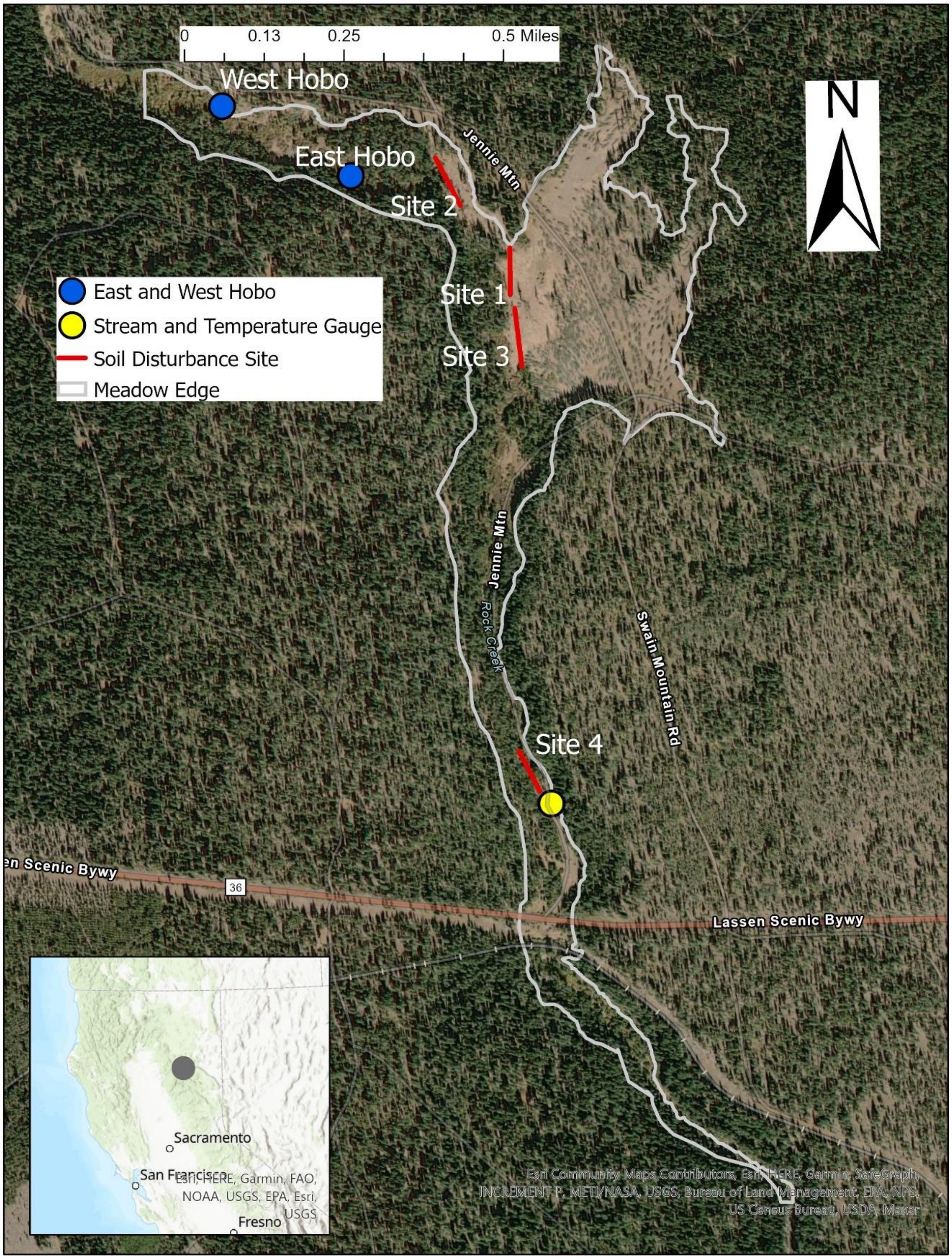


Figure 1. Rock Creek meadow map. Displays meadow boundary with soil disturbance site locations (1-4) and stream temperature gauges.

Chapter 4

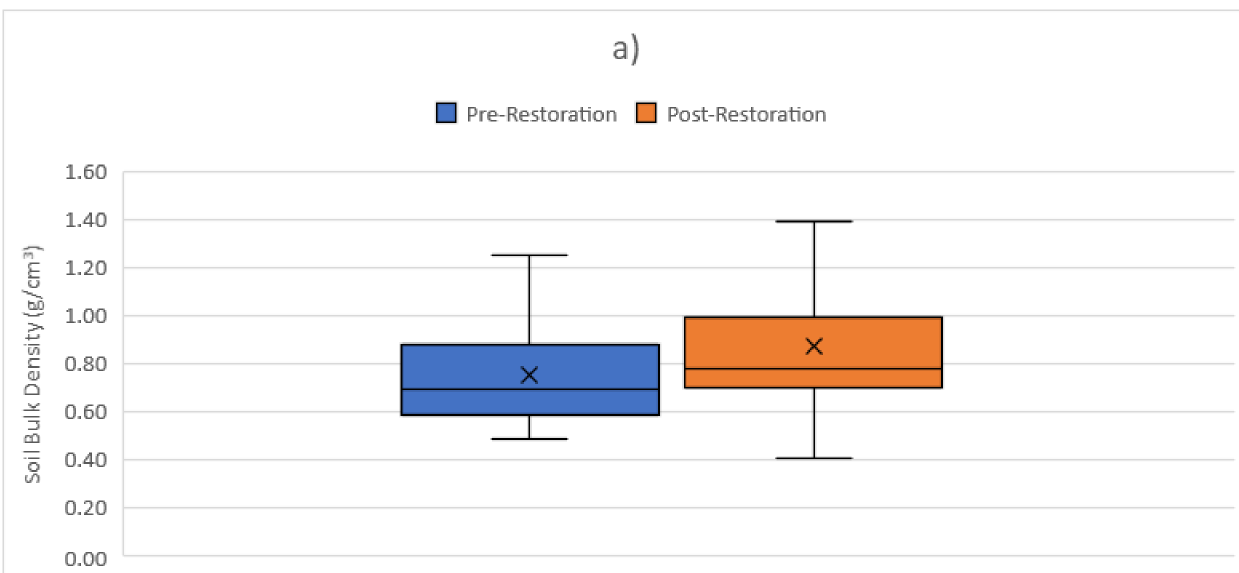
RESULTS

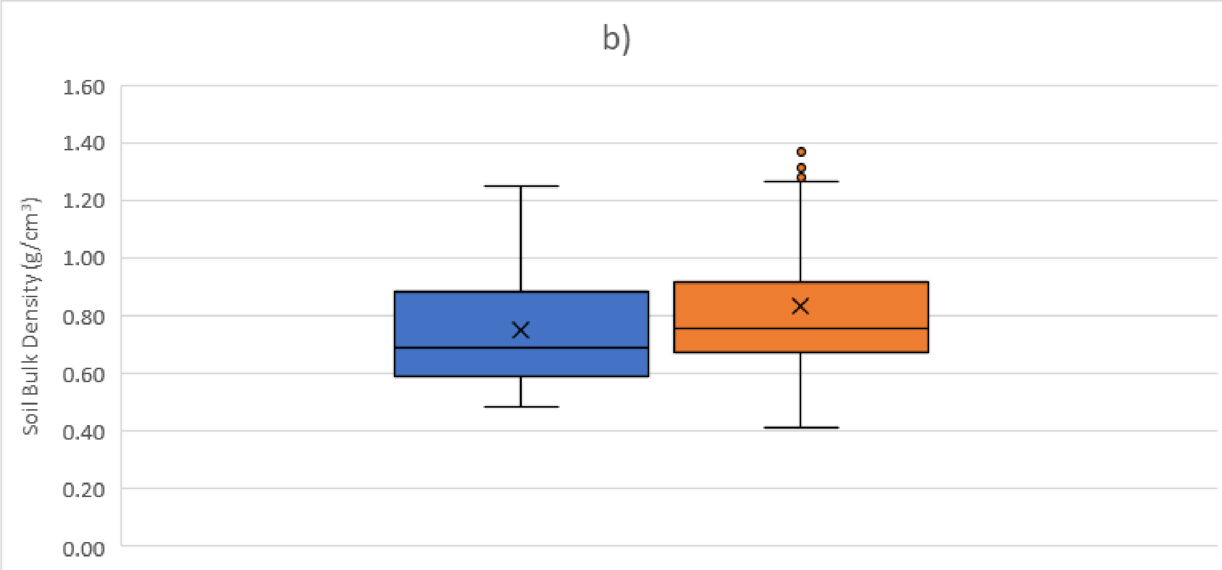
4.1 Soil Bulk Density Measurements

The mean, standard deviation and box plots of the soil bulk density samples collected prior to the removal of encroached lodgepole pine, July 2019, and post restoration, November of 2020, and June 2021, are shown (Table 2; Figure 2).

Table 2. Soil bulk density (g/cm^3) and standard deviation ( ) , from pre- and post-restoration.

Date of Collection	Soil Bulk Density (g/cm^3)	Disturbed Soil Bulk Density (g/cm^3)	Undisturbed Soil Bulk Density (g/cm^3)
Pre-restoration July 2019	0.75 (0.21)	N/A	0.75 (0.21)
Post-restoration November 2020 – June 2021	0.87 (0.26)	0.91 (0.26)	0.83 (0.26)





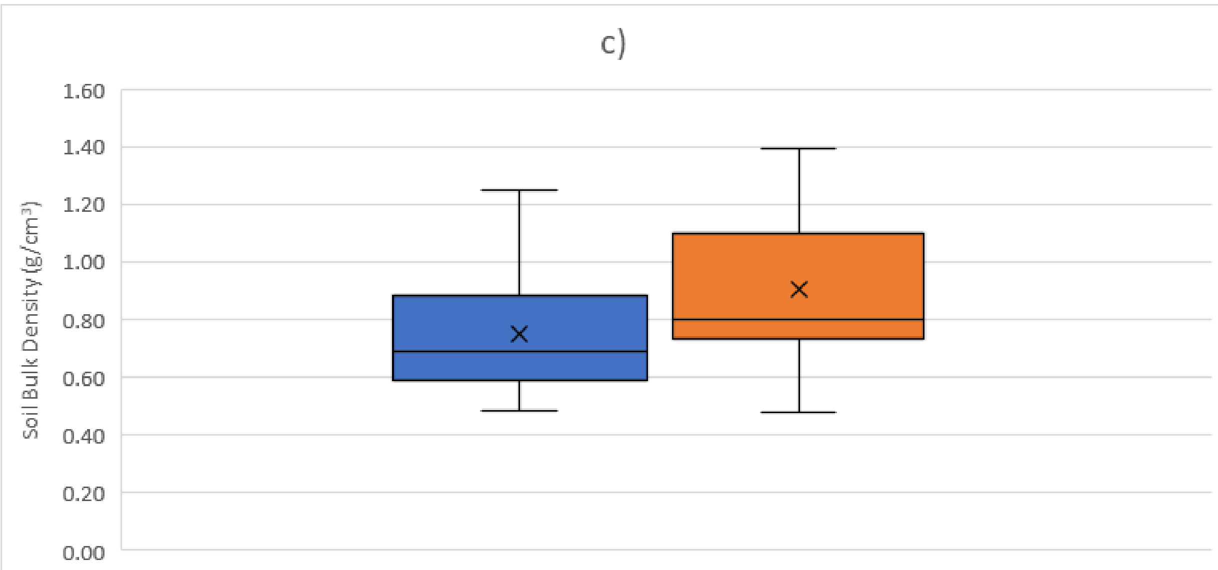


Figure 2. (a) Soil bulk density (g/cm^3) of undisturbed and disturbed samples for pre and post restoration. (b) Pre- and post-restoration overall undisturbed soil bulk density and (c) undisturbed vs. disturbed average soil bulk density (c) which compares the overall pre-restoration with post-restoration soil bulk density samples.

Table 3. Two-sample T-Test comparing a) pre- and post-restoration soil bulk density and b) post-restoration undisturbed vs. disturbed soil bulk density. Alpha level was set at 0.05.

a) Pre- vs. Post-Restoration Overall Soil Bulk Density		
t-Test: Two-Sample Assuming Unequal Variances		
	Pre-Restoration	*Post-Restoration*
Mean	**0.75**	**0.87**
Variance	**0.05**	**0.07**

Observations	22	83
Hypothesized Mean Difference	0	
df	39	
t Stat	-2.226	
P(T<=t) one-tail	0.016	
t Critical one-tail	1.685	
P(T<=t) two-tail	0.032	
t Critical two-tail	2.0227	

b) Post-Restoration Undisturbed vs. Disturbed Soil Bulk Density		
t-Test: Two-Sample Assuming Unequal Variances		
	Post-Undisturbed	*Post-Disturbed*
Mean	0.83	0.91
Variance	0.07	0.07
Observations	38	45
Hypothesized Mean Difference	0	
df	79	
t Stat	-1.307	
P(T<=t) one-tail	0.097	
t Critical one-tail	1.664	
P(T<=t) two-tail	0.194	
t Critical two-tail	1.990	

The average soil bulk density (g/cm^3), comprised of all samples regardless of disturbed or undisturbed status, is 0.75 g/cm^{-3} prior to restoration in July 2019. Post restoration had a higher average soil bulk density of 0.87 g/cm^3, an increase of 0.12 g/cm^3 (Table 2). Standard deviation was slightly higher (0.26 g/cm^3) in post-restoration samples compared to pre-restoration samples (0.21 g/cm^3). Comparing post-restoration overall disturbed soil bulk density (0.91 g/cm^3) with undisturbed soil bulk density (0.83 g/cm^3) reveals a difference of 0.08 g/cm^3. Each post restoration soil bulk density shared the same standard deviation at 0.26 g/cm^3. In Figure 2a-c, the data range is noticeably larger in post-restoration box plots. The undisturbed data in Figure 2b is the only figure of the three that exhibits extreme outliers.

A two-sample t-test, assuming unequal variance, was used to determine significant differences between the overall pre and post restoration soil bulk density (Table 3a) and post-restoration undisturbed vs. disturbed soil bulk density (Table 3b). It should be noted that post-restoration data consists of November 2020 and June 2021 data sets. The t-test reveals a statistically significant difference between pre- and post-restoration bulk density (p-value = 0.032) (Table 3a) and no statistically significant difference between soil bulk density for disturbed and undisturbed sites (p value = 0.194) (Table 3b)

4.2 Transect Cover Designations

Each 500-foot transect was surveyed for ground cover data pre and post restoration to determine increases or decreases for each cover designation. Each cover designation was given a percent value to represent changes of the meadow ground cover.

Table 4. Ground cover percentage before pre-restoration (July 2019) and post-restoration (June 2021).

Post-Restoration	
Average Cover by type	
Undisturbed	
Vegetation	**29.3%**
Litter/ Limbs	**41.1%**
Rock or Gravel	**0.0%**
Large Wood	**4.8%**
Logging Slash	**9.6%**
Disturbed	
B.S.E	**8.1%**
C.S.E	**7.1%**
Road	**0.0%**

Pre-Restoration	
Average Cover by type	
Undisturbed	
Vegetation	**69.9%**
Litter/ Limbs	**23.0%**
Rock or Gravel	**0.3%**
Large Wood	**6.8%**
Logging Slash	**0%**
Disturbed	
B.S.E	**0.0%**
C.S.E	**0.0%**
Road	**0.0%**

Prior to removal of encroached conifers, disturbed sites and logging slash are expected to remain at 0%. Notable changes in cover types were recorded following logging operations. Approximately 15.2% of ground cover became disturbed from equipment on bare or covered soil. Undisturbed vegetation decreased following logging operations by 40.6% and litter/limbs increased by 18.1%. No forest roads were counted in both pre-logging and post-logging transect surveys. Logging slash remains at 9.6% from left over woody debris.

Post-restoration, soil bulk density (g/cm^3) respective to cover type was relatively similar despite the presence of both disturbed (B.S.E and C.S.E) and undisturbed (Vegetation and

Litter/Limbs) cover types (Figure 3). The average soil bulk density of vegetation samples was 1.02 and 0.92 for litter/limbs. BSE was 0.97 and CSE was 1.06 (Table 5, Figure 3). The extreme lows came from B.S.E. sample sites. None of the cover types produced any noticeable extreme highs or lows (Table 5, Figure 3).

Table 5. Soil bulk density (g/cm^3) average, 25th percentile (Q1), 75th percentile (Q3), median, highest, and lowest measurements for soil sample site cover designation, June 2021.

	Vegetation	Litter/ Limbs	BSE	CSE
Average	1.02	0.92	0.97	1.06
Q1	0.79	0.68	0.77	0.77
Q3	1.27	1.27	1.20	1.36
Median	1.04	0.84	0.95	0.99
Highest	1.37	1.33	1.36	1.39
Lowest	0.66	0.59	0.48	0.65

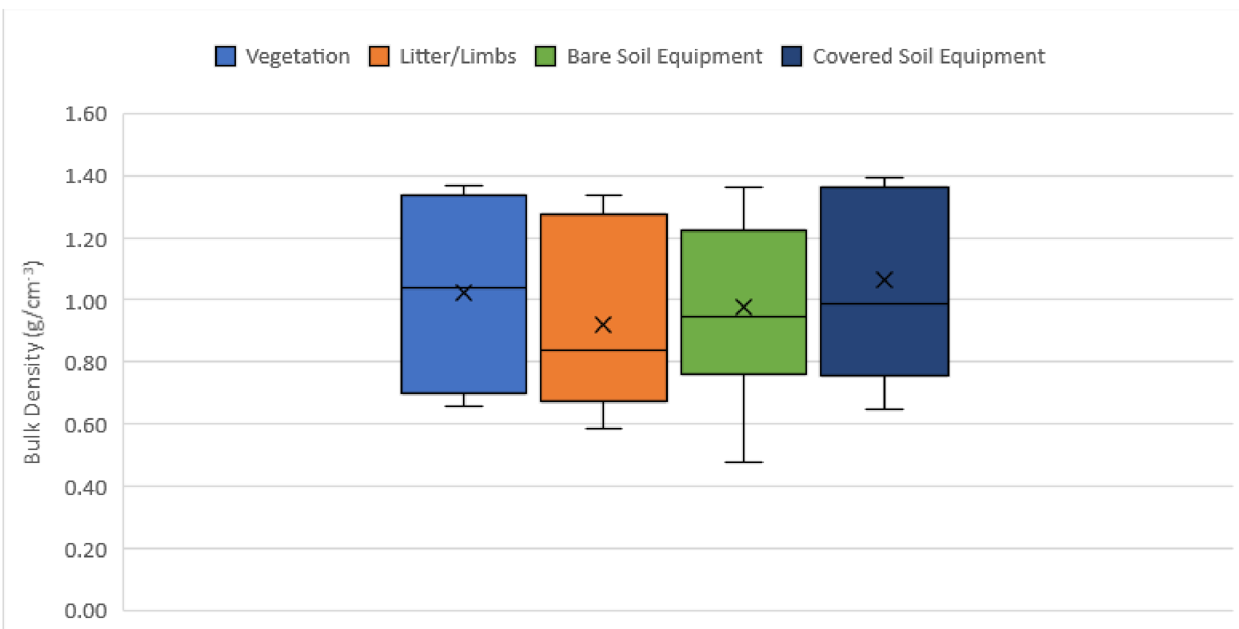
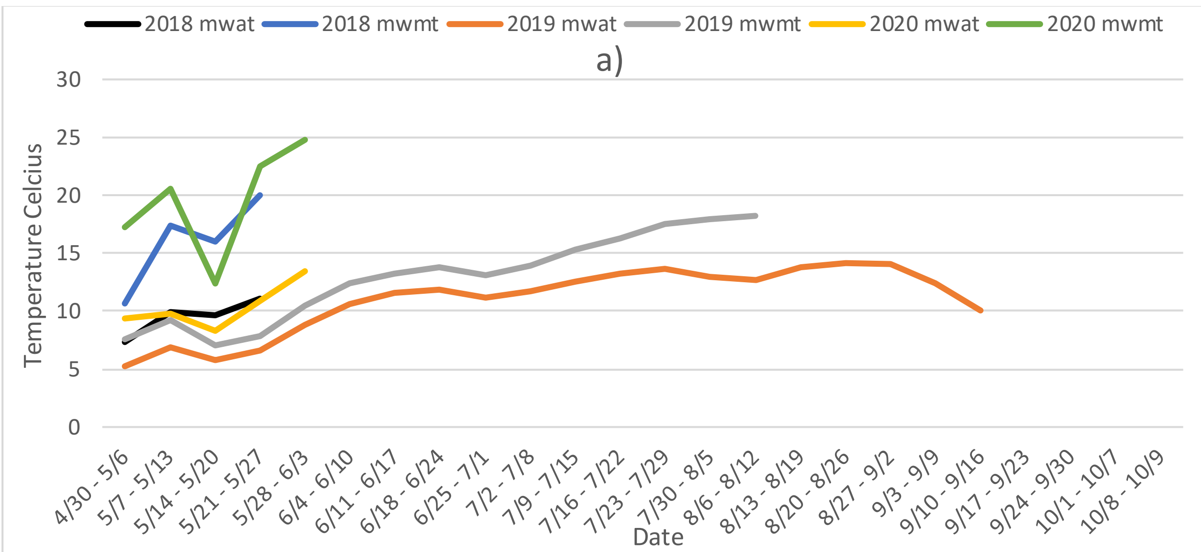
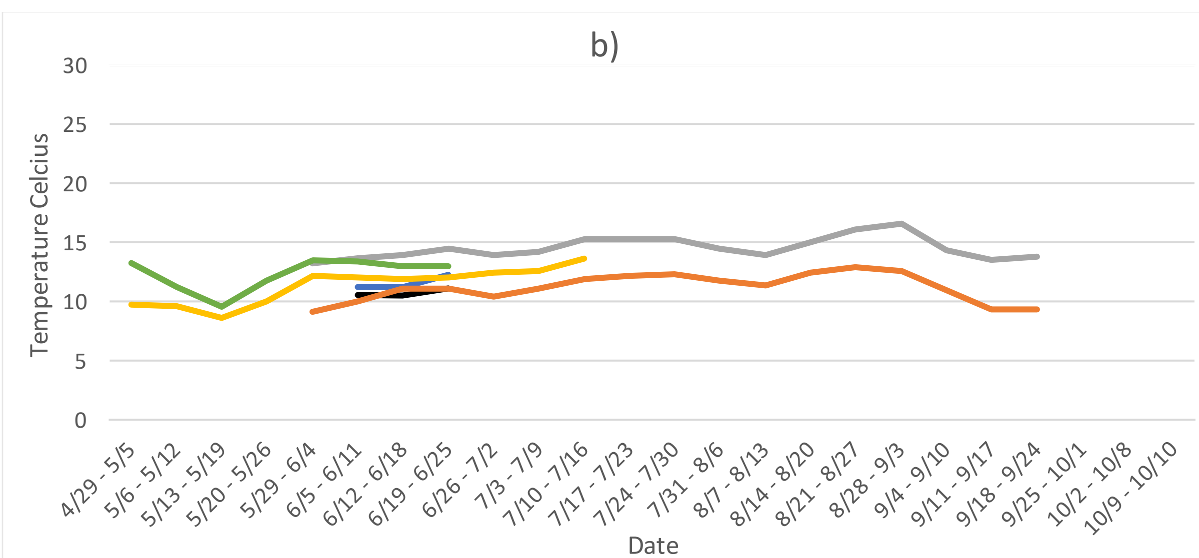


Figure 3. Box plots of post-restoration soil bulk density (g/cm^3) categorized by sample site ground cover designation, June 2021. The mean is marked by an (x).

4.3 Stream Habitat Conditions

The spring and summer stream temperature (Celsius) of Rock Creek was monitored at three gauges (Figure 4) since 2017. Stream temperature data was collected until Rock Creek ran dry in summer. This cutoff would vary depending on the previous winter's precipitation. The winter of 2020-2021 was characterized by historically low precipitation which led to dry creek conditions by Spring. For future comparison, data from 2017 - 2020 provides insight into Rock Creek's highest seven day rolling average of maximum daily temperatures (MWMT) and highest seven day rolling average daily temperature (MWAT) (Figure 4).





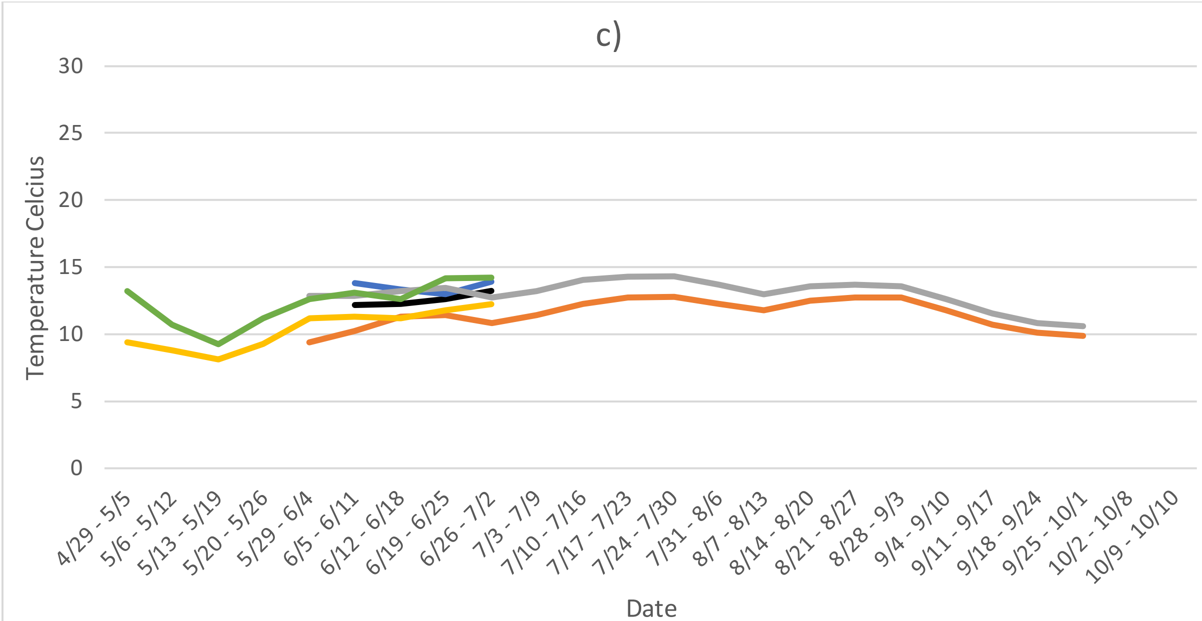


Figure 4. Seven day rolling average of maximum daily temperatures (MWMT) and seven day rolling average daily temperature (MWAT) 2017 – 2020 at a) Streamflow Gauge, b) West Hobo, and c) East Hobo. Temperature measurements continued until Rock Creek ran dry in summer.

Table 6. Particle size distribution by 100 count method. Standard deviation is presented in parenthesis.

Site #	% Slope	Class	100 D50 (mm)	100 Cobble Emb.
Site #2 – 603	**2 – 5%**	**VC Gravel**	**56**	**11.5% (19.7)**
Site #3 – 1,103	**2 – 5%**	**VC Gravel**	**50**	**17.7% (24.9)**
Site #4 – 1,603	**0.5 – 3%**	**Med. Gravel**	**11**	**21.7% (23.3)**
Site #5 – 2,103	**0.5 – 3%**	**Coarse Gravel**	**18**	**10.8% (16.2)**

Table 7. Pool-to-Riffle ratio.

Feature	Length (ft)	% by Length
Riffles	**931**	**43%**
Pools	**1,236**	**57%**

Table 8. Residual Pool Depth.

Feature	Average	Minimum	Maximum	Standard Deviation	Range

Residual Pool Depth	**1.0**	**0.7**	**1.4**	**0.21**	**0.7**

The pool-to-riffle ratio was calculated at 57:43. This indicates that the pool percentage by stream length is 57% (Table 7). The residual pool depth values are indicative of a normalized pool depths eliminating the variability in stream water depth (Table 8). Particle size distribution was approximately 56 and 50mm on a 2-5% slope (Table 6) while lower gradient sample sites at 0.5-3% had smaller particles around 11 and 18 mm.

Chapter 5

DISCUSSION

5.1 Discussion Overview

The main goal of this study was to assess changes in soil compaction, surface disturbance, and stream habitat conditions in Rock Creek meadow following the the removal of encroached lodgepole pine. This study offers new insight into the disturbance associated with mechanical removal of encroached meadows within the Sierra Nevada and Cascade ranges. The results suggest there was a statistically significant difference in overall soil compaction and noticeable change in ground cover following restoration. The following discussion provides interpretations of these results, including findings that may have been affected by our methodology, how our results compare to similar studies, and the implications our study may have for future meadow restorations.

5.2 Changes in Overall Soil Bulk Density

Prior to restoration, the overall soil bulk density was 0.75 g/cm^3 (July 2019). Post-restoration, overall soil bulk density was significantly different at 0.87 g/cm^3. This result was expected and aligns with other soil compaction studies using similar methodology which found the average soil bulk density was significantly greater within the tracks of machine skid trails compared to undisturbed sites (Jamshidi et al. 2008). The same study found increasing the number of skidding cycles beyond 12 resulted in highly significant differences in soil compaction ($p < 0.01$). Other compaction studies saw an increase from undisturbed 0.93 g/cm^3 to 1.09 g/cm^3 after 3 skidder passes, 1.26 g/cm^3 at 8, 1.31 g/cm^3 at 13, and 1.33 g/cm^3 greater than 13 passes. In Rock Creek meadow, the number of skidding cycles/ passes was not recorded, however the skidding pattern observed at the site suggested little repeated patterns or designated skid trails where multiple passes were likely. This inconsistency may have attributed to the large data ranges in overall soil bulk density.

5.3 Changes in Disturbed and Undisturbed Soil Bulk Density

To further investigate soil bulk density changes in Rock Creek, soil compaction data was gathered from both disturbed and undisturbed sites during the post-restoration data collection trips (November 2020 and June 2021). Pre-restoration, undisturbed soil bulk density was 0.75 g/cm^3 while post-restoration undisturbed soil bulk density was 0.83 g/cm^3, an increase of 0.08 g/cm^3. This was a greater difference than expected because regardless of a post-restoration sample, an undisturbed post-restoration site should exhibit similar pre-restoration compaction levels. At the first post-restoration visit in November 2020 Rock Creek meadow had a layer of snow during this time which made cover designations less obvious. At times, determining whether vegetation was alive, dead, or in winter dormancy may have yielded inaccurate designations. The high soil organic matter, typical in meadow soils, should also be considered as previous studies have shown high organic matter soils are less susceptible to compaction (Zhang et al. 1997), but this impact is less studied among varying types of meadow soils and water content (Ekwue et al. 1995) in the Sierra Nevada range.

Figure 5. November 2020 conditions. Note the obvious rutting/ track disturbance and remaining logging slash.

Pre-restoration soil bulk density samples were compared with disturbed post-restoration samples. Unlike the previously discussed changes in undisturbed samples, we expected to see the biggest contrast between these two groups. The results reflected these expectations with disturbed post-restoration samples yielding the highest overall soil bulk density of 0.91 g/cm^3, a difference of 0.16 g/cm^3, when compared to pre-restoration compaction levels (0.75 g/cm^3).

Aside from the previously mentioned impacts snow may have had on our cover designations, frozen topsoil and heightened soil moisture made the November 2020 data set unlike the other two data collection trips, which took place in drier conditions (July 2019 & June 2020). Soil compaction studies have found that soil water content, at the time of sampling, plays a role in the soil bulk density and porosity of soils such that increasing soil water content decreased the aggregate soil bulk density (Nemček et al. 2012).

Other sources of methodological errors in measurement could derive from the soil sample itself. Samples that were clearly loaded with rocky/ rooted material were disposed of, but this could not be mitigated entirely. Some sections of our transects were characterized by soils with alluvial deposits. Pieces of gravel and small rocks were inevitably present in a few of our samples. However, extreme samples with heavy debris were excluded from overall soil bulk density calculations.

Figure 6. Soil bulk density sample processing. Note the large rock in the middle sample. Samples with high amounts of roots, pebbles, and rocks were not included in calculating overall soil compaction.

5.4 Changes in Ground Cover Type

Prior to restoration, Rock Creek meadow was encroached by lodgepole pine. Transect ground cover surveys were primarily vegetation (69.9%) and litter/limbs (23%) with few large woody pieces (6.8%) and rock/gravel (0.3%). Post-restoration, Rock Creek meadow experienced noticeable changes in ground cover. Vegetation comprised 29.3% of our transects, a 40.6% decrease from pre-restoration surveys. Litter and limbs increased from 18.1% pre-restoration to 41.1% post restoration due to residual logging debris of branches and felled leaves. Total ground cover was reduced by approximately 15.2% due to rutting and skidding tracks. Vegetative recovery will be inhibited by the increased resistance to root penetration in these disturbed areas (Vora 1988).

The largest trunks and woody debris were removed from the site resulting in rutting and exposed bare soil disturbances (8.1%). Covered soil disturbed sites were not as severely rutted which may be attributed to fewer machine passes, these sites were capable of harboring newly recovered vegetation (7.1%). Overall, the transect survey revealed approximately 15.2% of Rock Creek meadow remains disturbed in the WLPZ as of June 2021. Other studies measuring areal disturbance from clear cutting operations recorded higher disturbance percentages at 23.1% (Jusoff and Majid 1992), 25% (Jackson et al. 2002), and 30% (Solgi 2014). Minimizing the areal impact of soil compaction has been accomplished by concentrating machine operations (Jamshidi et al. 2008). However, this study found only minimal change in soil bulk density in the dry meadow soils and designated skid trails were not utilized.

5.5 Soil Bulk Density by Cover Designation

The final June 2021 post-restoration soil bulk density of each sample site's respective cover designation was isolated to further compare soil compaction among disturbed and undisturbed sites. Four soil cover designations were compared (Vegetation, Litter/ Limbs, Bare Soil Equipment, and Covered Soil Equipment). To our surprise, each soil cover designation had average soil bulk densities between the 0.92 – 1.06 g/cm^3 range. It was anticipated that the undisturbed soil bulk density samples (Vegetation & Litter/ Limbs) would have soil bulk densities significantly less than the disturbed samples (B.S.E and C.S.E). This distinguishment is important because the overall disturbed average suggests disturbed samples experienced greater soil compaction. Oddly, B.S.E, which is characterized by rutting and a lack of living vegetation, yielded a soil bulk density of 0.97 g/cm^3 while vegetated sample sites had a soil bulk density of 1.02 g/cm^3. One could hypothesize Rock Creek meadow may have experienced some degree of recovery from the initial compaction. Other compaction recovery studies in forest range soils have found soil bulk density values did not return to undisturbed levels below the 5cm depth 23 years post logging (Froehlich et al. 1985), and in other studies, 14 years (von Wilpert and Schaffer 2006). However, significant recovery was recorded in the top 5cm of soil within disturbed areas (DeArmond et al. 2020). The depth of the cylinder (5.08cm) used in this research to sample soil bulk density was alike, meaning our post-restoration samples, coupled with high organic matter soil, could be exhibiting a similar recovery trajectory.

Chapter 6

CONCLUSION

Following removal of encroached lodgepole pine from Rock Creek meadow ground cover within the WLPZ was altered. Post-restoration the amount of herbaceous vegetation covering the ground was reduced by 40.6%, litter/limbs increased by 18.1% and bare soil from rutting and skidding tracks was 15.2%. This areal disturbance was kept at percentages much lower than other clear cut logging operations (Jusoff and Majid 1992 & Jackson et al. 2002). Soil bulk density increased in the WLPZ following removal of encroached lodgepole pine, but the difference between disturbed and undisturbed post-restoration soil bulk densities were not statistically different. This could be attributed to recovery in the top 5cm of soil where soils tend to recover faster compared to deeper depths (DeArmond et al. 2020). The high organic matter soils could have an impact in resisting compaction and accelerating recovery (Zhang et al. 1997). Sampling during winter conditions in November 2020 may have also played a role as heightened soil moisture levels can increase volume and decrease soil bulk density values through swelling processes (Nemček et al. 2012). Hydrologic interpretations remain inconclusive due to the lack of flow in Rock Creek since restoration. Ultimately, disturbance was recorded on the surface and in the soil of Rock Creek meadow, but Rock Creek will require continuous monitoring to truly grasp the long-term impacts and recovery. With a better understanding of logging disturbances in Sierra Nevada meadows, similar restorations can be effectively used in other encroached sites and develop best management practices.

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APPENDIX

A. Bulk Density Samples

Appendix (A) will provide all the soil bulk density sample measurements from each data collection trip throughout the research project. “Status” will distinguish disturbed (D) and undisturbed (U) samples.

Soil Bulk Density (g/cm3)	Status	Year
0.88	D	20
0.81	D	20
0.70	D	20
0.77	D	20
0.72	D	20
0.77	D	20
0.80	D	20
0.80	D	20
0.86	D	20
0.83	D	20
0.78	D	20
0.55	D	20
0.76	D	20
0.75	D	20
0.72	D	20
0.60	D	20
0.68	D	20
0.67	D	20
0.86	U	20
0.80	U	20
0.84	U	20
0.84	U	20
0.75	U	20
0.81	U	20
0.65	U	20
0.73	U	20
0.70	U	20
0.71	U	20
0.70	U	20
0.41	U	20
0.85	U	20
0.77	U	20
0.71	U	20

0.47	U	20
0.54	U	20
0.56	U	20
0.76	U	19
1.25	U	19
0.69	U	19
1.20	U	19
0.56	U	19
0.60	U	19
0.70	U	19
0.60	U	19
0.54	U	19
0.58	U	19
0.60	U	19
0.57	U	19
0.69	U	19
0.59	U	19
0.49	U	19
0.64	U	19
0.85	U	19
0.88	U	19
1.09	U	19
0.84	U	19
0.91	U	19
0.88	U	19
1.37	D	21
1.31	D	21
1.27	D	21
1.28	D	21
1.33	D	21
1.24	D	21
0.66	D	21
0.70	D	21
0.67	D	21
0.83	D	21
0.71	D	21
0.60	D	21
0.67	D	21
0.68	D	21
1.32	D	21
0.93	D	21
0.91	D	21
0.76	D	21
0.59	D	21
1.02	D	21

1.36	U	21
1.33	U	21
1.36	U	21
0.99	U	21
1.39	U	21
1.39	U	21
0.68	U	21
0.78	U	21
0.75	U	21
0.48	U	21
0.65	U	21
0.79	U	21
0.78	U	21
0.69	U	21
0.76	U	21
1.24	U	21
1.35	U	21
1.18	U	21
1.36	U	21
1.35	U	21
0.75	U	21
0.99	U	21
0.90	U	21
0.86	U	21
0.92	U	21
1.05	U	21
1.14	U	21

B. Transect Cover Surveys

Appendix (B) displays the transect cover surveys from July 2019 (pre-restoration) and June 2021 (post-restoration).

Soil Disturbance/ Cover Designations Data Entry

Segment ID: GPS: Length: 500ft

Location: Date: Jun-21

Transect ID: T1

	Designation Length (ft)																					
Undisturbed	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Totals	% of Cover
Vegetation	23	49	58	70																	200	40.0%
Litter	25	48	68	24	50																215	43.0%
Rock or Gravel																					0	0%
Large Wood	17																				17	3.4%
Other: Woody Litter	45																				45	9.0%
Distubed																						
Bare Soil Equipment	6	7	10																		23	4.6%
Covered Soil Equipment																					0	0%
Road																					0	0%
																					0	0%
																			Totals		500	100%

Transect ID: T2

	Designation Length (ft)																					
Undisturbed	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Totals	% of Cover
Vegetation	15	40	18	9	40	29	34														185	37.0%
Litter	11	27	34	11	36	39															158	31.6%
Rock or Gravel																					0	0%
Large Wood																					0	0%
Other: Woody Litter	31																				31	6.2%
Distubed																						
Bare Soil Equipment	11	11																			22	4.4%
Covered Soil Equipment	18	21	10	16	14	16	9														104	20.8%
Road																					0	0%
																					0	0%
																			Totals		500	100%

Transect ID: T3

	Designation Length (ft)																					
Undisturbed	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Totals	% of Cover
Vegetation	53	86																			139	27.8%
Litter	50	49	96	10																	205	41.0%
Rock or Gravel																					0	0%
Large Wood	32	8	29																		69	13.8%
Other: Woody Litter	37	22																			59	11.8%
Distubed																						
Bare Soil Equipment	28																				28	5.6%
Covered Soil Equipment																					0	0%
Road																					0	0%
																					0	0%
																			Totals		500	100%

Transect ID: T4

	Designation Length (ft)																					
Undisturbed	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Totals	% of Cover
Vegetation	5	27	5	28																	65	13.0%
Litter	24	12	28	18	64	30	47	21													244	48.8%
Rock or Gravel																					0	0%
Large Wood	4	5																			9	1.8%
Other: Woody Litter	16	22	19																		57	11.4%
Distubed																						
Bare Soil Equipment	10	17	23	30	8																88	17.6%
Covered Soil Equipment	15	22																			37	7.4%
Road																					0	0%
																					0	0%
																			Totals		500	100%

Segment ID:	Transect 1	GPS:		Length:	500 ft
Location:	Rock Creek	Date:	2019		

Transect ID: T1- 30 ft

	Designation Length (ft)																					
Cover Designations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	**Totals**	**% of Cover**
Vegetation	13	9	10	16	8	19	4	42	17	20	38	5	9	5							215	43.0%
Litter	41	15	29	16	4	24	62	6	67	3											267	53.4%
Rock or Gravel	2	2																			4	0.8%
Large Wood	1	1	7	4	1																14	2.8%
Other: Woody Litter																					0	0%
Bare Soil Designations																						
Undisturbed																					0	0%
Road																					0	0%
Tree Yarding																					0	0%
Rutting																					0	0%
																				Totals	500	100%

Transect ID: T1- 50 ft

	Designation Length (ft)																					
Cover Designations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	**Totals**	**% of Cover**
Vegetation	2	4	8	11	111	5	37	4	45	146	7	7	17								404	80.8%
Litter	6	11	5	11																	33	6.6%
Rock or Gravel																					0	0%
Large Wood	32	3																			35	7.0%
Other: Woody Litter	3	4	16																		23	4.6%
Bare Soil Designations																						
Undisturbed																					0	0%
Road																					0	0%
Tree Yarding																					0	0%
Rutting	3	2																			5	1.0%
																				Totals	500	100%

Transect ID: T1- 75 ft

	Designation Length (ft)																					
Cover Designations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	**Totals**	**% of Cover**
Vegetation	8	16	4	11	144	40	16	13	19	13	5	8									297	59.4%
Litter	9	10	11	24	16	21	13	45	17	17											183	36.6%
Rock or Gravel	4																				4	0.8%
Large Wood	4	9																			13	2.6%
Other: Woody Litter																					0	0%
Bare Soil Designations																						
Undisturbed																					0	0%
Road																					0	0%
Tree Yarding																					0	0%
Rutting	3																				3	0.6%
																				Totals	500	100%

Segment ID:	Transect 2	GPS:		Length:	500 ft
Location:	Rock Creek	Date:			

Transect ID: T2- 30 ft

	Designation Length (ft)																					
Cover Designations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	**Totals**	**% of Cover**
Vegetation	5	10	39	31	5	17	19	64	37	9	112	60	4								412	82.6%
Litter	8	28	23	2	9																70	14.0%
Rock or Gravel																					0	0%
Large Wood	1	2	3	3	2	2	4														17	3.4%
Other: Woody Litter																					0	0%
Bare Soil Designations																						
Undisturbed																					0	0%
Road																					0	0%
Tree Yarding																					0	0%
Rutting																					0	0%
																				Totals	499	100%

Transect ID: T2- 50 ft

	Designation Length (ft)																					
Cover Designations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	**Totals**	**% of Cover**
Vegetation	2	4	8	11	111	5	37	4	45	146	7	7	17								404	80.8%
Litter	6	11	5	11																	33	6.6%
Rock or Gravel																					0	0%
Large Wood	32	3																			35	7.0%
Other: Woody Litter	3	4	16																		23	4.6%
Bare Soil Designations																						
Undisturbed																					0	0%
Road																					0	0%
Tree Yarding																					0	0%
Rutting	3	2																			5	1.0%
																				Totals	500	100%

Transect ID: T2- 75 ft

	Designation Length (ft)																					
Cover Designations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	**Totals**	**% of Cover**
Vegetation	11	54	36	27	17	32	12	3	17	25	10	5	9	3							261	52.2%
Litter	1	18	17	9	20	12	35	33	24	12											181	36.2%
Rock or Gravel																					0	0%
Large Wood	1	3	2	9	2	6	11	7													41	8.2%
Other: Woody Litter	6	11																			17	3.4%
Bare Soil Designations																						
Undisturbed																					0	0%
Road																					0	0%
Tree Yarding																					0	0%
Rutting																					0	0%
																				Totals	500	100%

Segment ID:	Transect 3	GPS:		Length:	500 ft
Location:	Rock Creek	Date:			

Transect ID: T3- 30 ft

	Designation Length (ft)																					
Cover Designations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	**Totals**	**% of Cover**
Vegetation	22	13	2	2	24	57	40	60	19	26	46	16	17	6	16						366	73.2%
Litter	1	2	2	7	17	7	44	7	8												95	19.0%
Rock or Gravel																					0	0%
Large Wood	1	34	2	2																	39	7.8%
Other: Woody Litter																					0	0%
Bare Soil Designations																						
Undisturbed																					0	0%
Road																					0	0%
Tree Yarding																					0	0%
Rutting																					0	0%
																				Totals	500	100%

Transect ID: T3- 50 ft

	Designation Length (ft)																					
Cover Designations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	**Totals**	**% of Cover**
Vegetation	39	7	83	39	27	10	8	4	9	9	28	21	3	16							303	60.6%
Litter	3	5	12	43	11	13	10	15	27	8											147	29.4%
Rock or Gravel																					0	0%
Large Wood	2	9	15	22	2																50	10.0%
Other: Woody Litter																					0	0%
Bare Soil Designations																						
Undisturbed																					0	0%
Road																					0	0%
Tree Yarding																					0	0%
Rutting																					0	0%
																				Totals	500	100%

Transect ID: T3- 75 ft

	Designation Length (ft)																					
Cover Designations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	**Totals**	**% of Cover**
Vegetation	8	40	72	3	7	5	3	25	10	17	12	55	18	61							336	67.2%
Litter	21	12	4	23	2	15	29	10	6	14	9										145	29.0%
Rock or Gravel																					0	0%
Large Wood	1	7	2	5	2	1															18	3.6%
Other: Woody Litter																					0	0%
Bare Soil Designations																						
Undisturbed	1																				1	0.2%
Road																					0	0%
Tree Yarding																					0	0%
Rutting																					0	0%
																				Totals	500	100%

Segment ID:	Transect 4	GPS:		Length:	500 ft
Location:	Rock Creek	Date:			

Transect ID: T4- 30 ft

Cover Designations	Designation Length (ft) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Totals	% of Cover
Vegetation	60	27	16	22	10	17	63	23	2	6	71	26	18	13							374	74.8%
Litter	9	14	53	9																	85	17.0%
Rock or Gravel																					0	0%
Large Wood	1	3	5	6	16	5	1	3													40	8.0%
Other: Woody Litter																					0	0%
Bare Soil Designations																						
Undisturbed	1																				1	0.2%
Road																					0	0%
Tree Yarding																					0	0%
Rutting																					0	0%
																				Totals	500	100%

Transect ID: T4- 50 ft

Cover Designations	Designation Length (ft) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Totals	% of Cover
Vegetation	78	22	14	31	80	50	90	32													397	79.4%
Litter	2	52	25																		79	15.8%
Rock or Gravel	2																				2	0.4%
Large Wood	19	3																			22	4.4%
Other: Woody Litter																					0	0%
Bare Soil Designations																						
Undisturbed																					0	0%
Road																					0	0%
Tree Yarding																					0	0%
Rutting																					0	0%
																				Totals	500	100%

Transect ID: T4- 75 ft

Cover Designations	Designation Length (ft) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Totals	% of Cover
Vegetation	45	24	121	7	12	4	32	140	27	12											424	84.8%
Litter	12	2	11	3	13	18															59	11.8%
Rock or Gravel																					0	0%
Large Wood	14	3																			17	3.4%
Other: Woody Litter																					0	0%
Bare Soil Designations																						
Undisturbed																					0	0%
Road																					0	0%
Tree Yarding																					0	0%
Rutting																					0	0%
																				Totals	500	100%