THE EFFECTS OF POST-HARVEST RESIDUE ON PLANTATION FOREST SOILS AND EARLY GROWTH OF REDWOOD AND DOUGLAS-FIR SEEDLINGS IN HUMBOLDT COUNTY CALIFORNIA

By

Robert Raibley

A Thesis Presented to
The Faculty of California State Polytechnic University, Humboldt
In Partial Fulfillment of the Requirements for the Degree
Master of Science in Natural Resources: Forestry, Watershed, & Wildland Sciences

Committee Membership

Dr. Melanie McCavour, Committee Chair

Dr. John-Pascal Berrill, Committee Member

Dr. Hunter Harrill, Committee Member

Dr. Andrew Stubblefield, Graduate Program Coordinator

May 2023

ABSTRACT

THE EFFECTS OF POST-HARVEST RESIDUE ON PLANTATION FOREST SOILS AND EARLY GROWTH OF REDWOOD AND DOUGLAS-FIR SEEDLINGS IN HUMBOLDT COUNTY CALIFORNIA

Robert Raibley

Forest harvest residue (slash) usefulness has been up for debate among private timberland owners, public land managers, and the timber industry for decades. The disposal of slash, viewed as having low ecological value, has received considerable attention as wildfire risk has made burning it harder. In recent years, forest scientists and ecologists have recognized the importance of decaying wood and its relationship to forest growth and regeneration. At this site in Northern California, we looked at whether forest harvest residue enriches soil near slash windrows through soils coring and lab analyses, looking for primary limited nutrients nitrate (NO_3-N) and ammonium (NH_4-N). This study looks at the growth responses of newly planted Douglas-fir seedlings and clonal redwood nursery stock, with respect to their distance to slash piles. In our findings, there was no clear relationship to distance to piles in terms of soil nutrients, however there was an increase in basal area of planted Douglas-fir and redwood farther away from slash piles. Soil analyses showed no clear relationship to early slash decay and soil nutrient replenishment, however this study only looked at the early stages between one year after harvest and the second year. Further research is needed over a longer timeframe to determine if and when slash piles might affect soil chemistry, and we recommend including a range of sites to expand the scope of inference beyond our two study sites that were close together and located outside redwood's natural range.

ACKNOWLEDGEMENTS

A special thanks for helping with this project: Cal Poly Humboldt, Pascal Berrill, Hunter Harrill, Kim Lamphear, Andrew Stubblefield, Erin Kelly, Susan Cashman, and Melanie McCavour. Green Diamond Resource Company, Elicia Goldsworthy, Stacy McNeil, Mitch Hunt, Reid Cody, Tony Whitehead, David Lamphear, Jayce Burniske, Christopher Hale, and all of Intensive Forest Management Team (IFM). Family Richard Raibley, Anne Hubbs, Caitlin Giddings, Anna (service dog) and in memory of Shasta (previous service dog).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

For decades, management of post-logging forest harvest residue (slash), comprised of coarse and fine woody debris (CWD and FWD), has been the subject of considerable discussion. It has been viewed as a problematic waste product of the logging industry and as having little to no value. How or what methods to best manage it after logging have also been up for debate (Boyle & Powers, 2013). Until recently, few studies had been done on the effects of forest harvest residue on tree growth, forest ecosystem services such as soil fertility or biodiversity, and provision of habitat and food to animals or detrivorous bacteria and fungi responsible for woody debris decomposition (McCavour et al., 2014).

In the historical context of how slash was managed, one primary factor limiting the processing and management of forest harvest residue after logging had been equipment availability (Melanie McCavour, zoom discussion, 2020). In the 19th century, tree felling and delimbing was mainly done by hand. As the timber industry entered the early 20th century, the introduction of better equipment allowed the process to move more efficiently and at a much faster pace. In the 1960s, slash piles were created after logging operations, and then the piles were bladed over with machinery covering them with soil. This aided in the decomposition of forest harvest residue, but also was highly disruptive and destructive for the forest floor, which was not considered an important part of the ecosystem at that time (Melanie McCavour, zoom discussion, 2020). In the 1980s, regulations were enacted that prohibited this style of damaging post-harvest management, and this in turn caused the timber industry to look into implementing alternative slash disposal processes (Melanie McCavour, zoom discussion, 2020).

Popular options for slash disposal include burning the slash piles on site or chipping and transporting the woody debris to mills to be used for energy in cogen power plants (Zabowski et al., 2000; Dahlberg et al., 2011; Richard Raibley, in-person discussion, September 2, 2020). The chipping option is an especially common practice in Scandinavia, led by an increase in the price of energy, and is possible to implement in other nations such as Canada, Finland, Russia, and Sweden with some infrastructure and investment (Lattimore et al., 2009). Recently, it has become increasingly difficult for timber industries in the Pacific Northwest to obtain the proper permitting to burn on-site due to the fire danger and potential emissions from burning and their effects on air quality (Zabowski et al., 2000). Transporting slash or chips has also become more cost-prohibitive due to increased fuel costs and greenhouse gas emission considerations (Boyle & Powers, 2013). As predicted by Ambrose et al. (2015), the increased frequency and severity of drought is not only stressing trees, but increasing fire risk and occurrence. The constraints of obtaining burn permits due to our current fire conditions for slash pile management, as well as an increased understanding of forest management and ecosystem function, have led the timber industry to consider alternatives to forest harvest residue disposal.

Forest managers over the years have also realized that many slash management practices of the past were problematic for forest ecosystems by disrupting soil processes and decay of wood that led to nutrient deposit in the environment (Attiwill, 1994). These issues have led to the investigation of alternative ways to manage harvest residue, as well as maintain forest ecosystems in healthier ways. One of the ways forest managers have changed management techniques are to attempt to emulate natural processes. Practices of alternative treatment of forest harvest residue have actually drawn on results from studies of natural disturbance on forests (Attiwill, 1994). Natural disturbance is important because scientists have shown that imitation of natural disturbance is a possible way to maintain ecosystem integrity and diversity (Attiwill, 1994). Foresters have modified forest management practices by comparing and contrasting forest operation practices with the natural disturbance patterns in the region to better fit what the land's best practices may be (Attiwill, 1994).

One example of a natural disturbance type is wind disturbance. When trees are blown over, they usually fall downslope, in an orientation perpendicular to the terrain. Foresters mimic wind disturbance with partial harvests, as they do not remove all the trees but instead leave patches of trees as wind would do (Hagemann et al., 2010). Another technique that foresters use is clear-cutting, which is emulating a stand-replacing forest fire (Hagemann et al., 2010). When a fire breaks out in a forest, it can completely clear an area of trees which is what foresters are trying to mirror. While there are differences in how woody debris is created and the amount of downed woody debris originating from forest fires compared to clearcutting, this method is still used widely and thought to emulate most closely a stand-replacing natural disturbance model for regions (Hagemann et al., 2010).

Historically, slash had commonly been burned on site after logging, however this is not always a viable option for the Pacific Northwest due to current global and local droughts (Boyle & Powers, 2013; Ambrose et al., 2015). Forest fires in the region of Northwestern California have started to become one of the more common types of natural disturbances due to their reoccurrence interval being more frequent as the forest becomes drier with the changing climate (McCavour, 2016).

McCavour et al. (2014) and McCavour (2016) were among the first researchers that examined the value of forest harvest residue for forest regeneration, health, and as a contributor of soil nitrogen, a key element in the forest ecosystem. McCavour’s 2016 study, conducted in a *Populus maximowiczii x P.balsamifera* (hybrid poplar) plantation in the Haute Mauricie region of Quebec, found that forest harvest residue enhanced tree growth due to slash piles more than enough to offset the lower stocking. Results showed increased soil ammonium, nitrate, cation exchange capacity, and phosphorous around decomposing slash piles. In addition, the slash piles provided habitat for pollinators, thereby increasing fruit/seeds available to a variety of forest animals. Another study that specifically looked at the effect of slash on *Pinus radiata* (Monterey pine) plantation tree growth was Ballard (1978). He looked at the effects of windrowed slash piles and their ability to replenish soil nutrients in a sandy pumice soil in New Zealand. Ballard’s (1978) study found that there was decreased tree growth in the inter-windrow sites (between slash piles), and he discussed the need for more study. Second, he speculated that the reason for the decreased growth of trees was either due to the topsoil removal (meaning nitrogen and magnesium were very disrupted, which are key soil nutrients) or that the removal of slash itself was disruptive to the site and therefore recommended that perhaps only the CWD should be removed, or the inter-windrow areas reduced.

Timber companies are increasingly interested in a possible solution of aggregating forest harvest residue into nutrient producing piles in order to positively impact their rotation time and forest ecosystems (Hacker, 2005; Boyle & Powers, 2013). There can be many forest ecosystem benefits to this approach. Slash can provide habitat for animals that aid in the decomposition processes (Farve and Napper, 2009). Slash piles also allow for fungal and bacterial breakdown of the forest harvest residue debris, which gives food and nutrients to other types of organisms. These processes subsequently allow for greater soil nutrient replenishment of key minerals necessary to plant growth, especially nitrogen (McCavour et al., 2014).

Nitrogen enrichment through decomposition is one of the most important parts of tree and plant growth, as it is one of the key nutrients needed, along with potassium, phosphorus, and calcium (Farve and Napper, 2009). Although nitrogen is abundant in gas form as N_2, it is not available for organic use until it is converted to ammonium NH_4-N or nitrate NO_3-. This process is done through microbial processing of N_2, a site-specific process that starts to produce a net nitrogen balance after two to three years (McCavour et al., 2014). Once converted, trees and plants can utilize nitrogen and have access to other nutrients released through decomposition as well as through other biogeochemical processes of wood decay (van der Wal et al., 2007). This is why the initial research in Ballard (1978), McCavour et al.’s (2014), and McCavour’s (2016) studies are interesting to the timber industry and forestry scientists both. If slash is piled in specific ways that mean that there is a greater nitrogen enrichment to the soil, it could mean that slash is no longer a useless byproduct of the timber industry.

In the Northern California county of Humboldt, forestry is an important industry, and much slash is produced when low-value hardwoods that are intermingled with merchantable conifers are felled, ending up wasted. Therefore slash disposal is an important part of forest management, as well as promoting successful regeneration of merchantable conifers while limiting hardwood regeneration where possible. The two main commercial timber species are *Pseudotsuga menziesii* (Douglas-fir) and *Sequoia sempervirens* (coastal redwood). Douglas-firs are often utilized for structural lumber, and the variety in this study is the coast Douglas-fir (*P. menziesii* var *menziesii*) rather than the Rocky Mountain Douglas-fir which does not grow in north coastal California (Hermann & Lavender, 1990). Douglas-fir trees thrive in deep soils that drain, and this often means that coastal Douglas-firs exist in weathered marine sandstone and shale. Fire disturbance can favor Douglas-fir by eliminating fire-sensitive species that compete for resources. Douglas-firs often grow in association with redwood and grow rapidly once they have become established and have grown above deer or elk browse height (Hermann & Lavender, 1990). Lack of nitrogen is one of the main issues limiting Douglas-fir growth, meaning it is of interest in any studies around soil on timberland, and the importance of this nutrient is why nitrogen-rich fertilizer is sometimes used in timberlands to increase growth (Hermann & Lavender, 1990).

Coastal redwoods have a geographically smaller range, seemingly due more to summer fog rather than rainfall totals as one might expect. They have a unique ability to generate their own fog because of their transpiration rates (Olson et al., 1990). Redwood trees grow mainly on ancient oceanic soil that comes from sandstone, limestone, slate, chert, and shist, and in steep terrain they can grow in deep soil similar to Douglas-fir. Redwood can grow in soil with moisture that measures 18%-86%, but the ideal measure is soil no less moist than 60%, reinforcing their high need for moisture content. Coastal redwood can form pure stands but is commonly found in association in Douglas-fir and other conifer and hardwood species (Olson et al., 1990).

Studies of forest soil chemistry often focus on nitrogen, specifically, ammonium NH_4-N and nitrate NO_3-N, in addition to studying non-nutrients such as cation exchange capacity (CEC), and percent soil water concentration (θg) (Farve & Napper, 2009). Other soil nutrients that are also important for forest growth and seedling uptake include: soil pH, carbon (C), hydrogen (H), sulfur (S), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). These nutrients can all be measured, but may not the focus of studies where nitrogen, CEC, and soil moisture are key factors known to limit tree growth (Hermann & Lavender, 1990; Olson et al., 1990).

The goal of this thesis research was to study relationships between slash piles and soil properties as well as early growth of trees planted near piles. Such information could help forest managers to include considerations of tree growth and ecosystem services in forest and slash management plans. The first part of this study examined the short-term effects of slash as a source of soil nitrogen and nutrition. We sought to address the following questions: 1st What are the average slash pile areas (m^2) and volumes (m^3) present at each study site? 2nd What is the total area (percent of the harvest site) occupied by slash left after trees were planted? 3rd Over a one-year growth period, do seedlings and clones grow larger in: height (m), diameter (mm), volume (cm^3), and basal area (mm^2) closer to piles of slash? 4th Approximately three years after piles were formed, will cation exchange capacity (CEC), bulk density (Db), percent soil water concentration (θg), and soil nutrients ammonium (NH_4-N) and nitrate (NO_3-) be elevated closer to slash piles?

The second part of the study tested the degree to which trees responded with heightened growth near windrows, represented as increased tree size or stemwood biomass, relative to trees that were planted far from windrows. The hypothesis was that forest harvest residue would cause soil enrichment over time at this site in Northern California, and that in turn will improve the growth rate of planted stems. If found, benefits of slash pile retention could include an increase in economic value to timberland owners and managers, as well as benefits in maintenance or enhancement of forest ecosystems.

MATERIALS & METHODS

Site Description

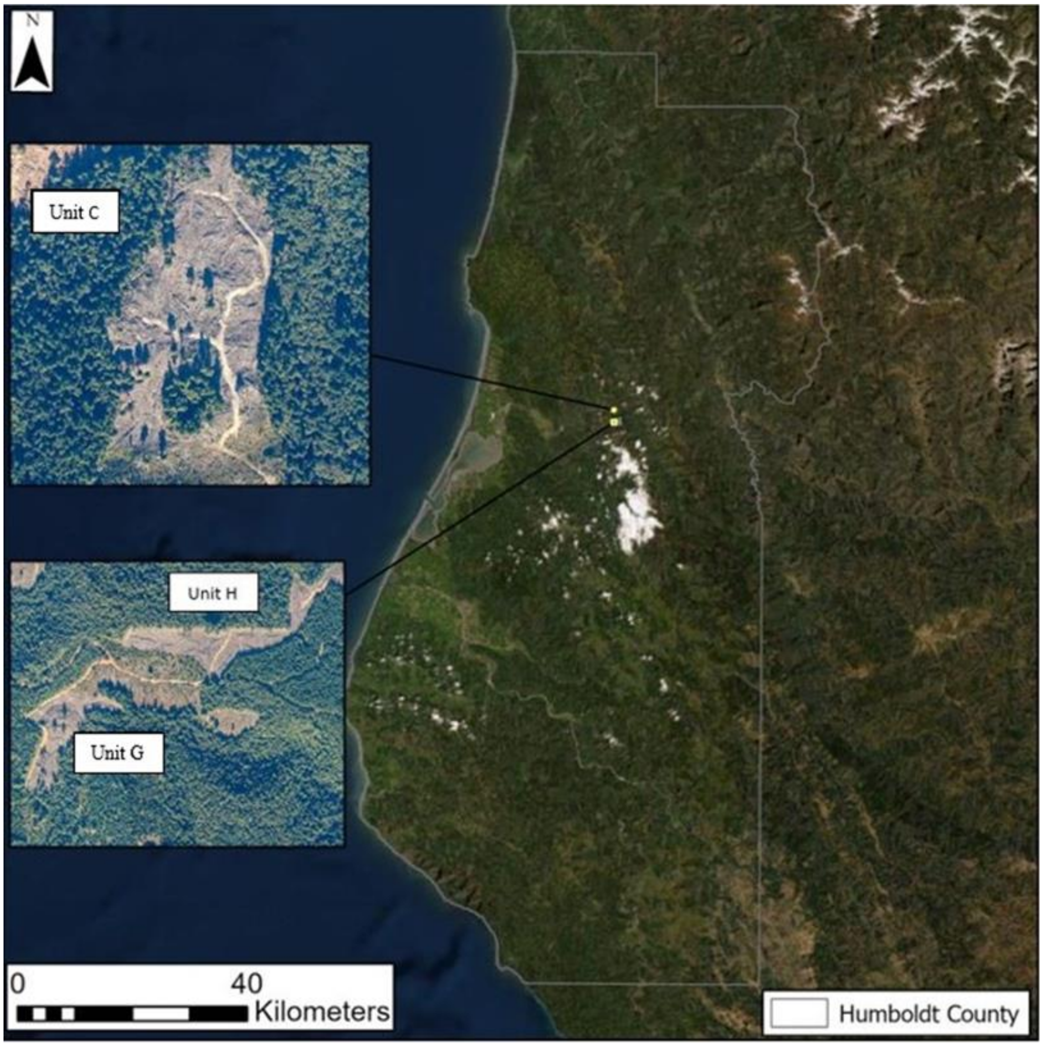


Figure 1: Location of study area for Units C, G and H in relation to Humboldt Bay

The study area is located in Humboldt County, California. The climate is temperate coastal conditions in the lower Pacific Northwest with a considerable amount of fog and moisture content in the air. After clearcutting and piling of harvest residues and non-merchantable hardwoods, the study sites were planted with redwood clones propagated by tissue culture in the Green Diamond laboratory along with Douglas-fir seedlings that were grown in styro-15 containers for one season in the Korbel Green Diamond nursery.

The three harvest blocks in the study were located near Lord Ellis Summit outside of Korbel, CA on Green Diamond Resource Company land (Figure 1). The harvest blocks were Units C, G, and H, off of cutoff road 271801, and they all required driving at least 20 minutes into redwood and Douglas-fir forests south of Highway 299. The elevation at Lord Ellis Summit is 2,267 feet or 691 meters, and the study sites were located at slightly higher elevation ranging from 1800 to 2600 feet. The harvest blocks studied received snow in the winter, rain in fall and spring, and coastal fog, in addition to temperatures of up to approximately 90 degrees in summer during the period of study. The slash piles on each unit that were the focus of the study were woody debris produced from clear-cutting specifically. The slash pile locations were carefully created on top of coastal inland rolling hills, known as anticlinal and synclinal folds due to faulting (Appendix A). The locations were picked for least amount of slope possible in order to have an even distribution of soil nutrients. The generic composition of all the slash piles was graded CWD from the bottom to FWD at the top, with leaves and small branches intermixed in the CWD.

In each of the units, redwood plus-tree clones and seed orchard-origin Douglas-fir seedlings had been planted in spring of 2020 parallel to the piles at approximately 1-3 m intervals in a grid like pattern out to approximately 10 m radially from the piles. None of the bark, leaves, and branches making up the fine woody debris exhibited signs of decomposition yet, as they were only harvested in the spring of 2020, and the cut *Notholithocarpus densiflorus* (tanoak) and *Quercus muehlenbergii* (chinkapin) trees making up much of the piled wood pieces were distinguishable. The piles were approximately 10-20 meters at the upslope side in width and tapered to 5-10 meters at the downslope, approximately 30-60 meters long, and 5-10 meters tall.

Unit C: Harvest ID 631610 located at 427,930.73E and 4,526,239.45N was a net 19.63 ha unit, with a clearcut of 12.14 ha. This unit, categorized as Site Class II with 357 trees per acre (TPA), contained approximately 9 piles of downed woody debris. The piles were oriented perpendicular to the topography and roads, in a downslope direction to emulate natural wind disturbance as a forest management technique. Their orientation was northeast at the upslope side of the piles to southwest at the downslope side of the piles. The slope for these piles started at a gradual incline of approximately 10° on the northeast side and generally steepened to 22° at the southwest. Cloned redwoods (RB1 & RB3) were planted in spring of 2020 oriented parallel to the piles.

Unit G: Harvest ID 632013 located at 428,111.06E and 4,528,591.12N was a net 4.05 ha unit, with a clearcut of 3.24 ha. This unit, was categorized as a Site Class II with 172 TPA, and contained 9 piles of downed woody debris. The piles were oriented perpendicular to the terrain and roads in a downslope direction. The piles were similar to unit C and H as they were approximately 5-10 meters in width and 30-60 meters in length. Cloned redwoods (RB1) had been planted in spring of 2020.

Unit H: Harvest ID 632109 located at 428,344.37E and 4,526,438.42N was a net 16.19 ha unit, with a clearcut of 11.94 ha, however this study only looked at 3.0 ha of that clearcut. This unit, was categorized as Site Class II with a 188 TPA with a replant TPA of 131, contained approximately 12 piles of downed woody debris that were comprised of a mix of CWD and FWD, most with larger amounts of CWD near the base of the piles. Some piles contained greater amounts of FWD, with lesser amounts of CWD. The piles were oriented parallel to the terrain and roads in a gentle downslope direction. Their general orientation was west to east at the east side of the cut block, and north to south at the west side of the cut block. The slope for the west to east piles was approximately 5-10°. The piles oriented north to south had a gentle slope of approximately 10-12°. Cloned redwoods (RB1 originally, then RB3 due to mortality of first-year planting) were planted in Unit H in spring of 2020 after harvest parallel to the piles.

Data Collection

In addition to the assessments of soil properties and the growth of planted stock, geospatial data was processed to give harvest unit area, pile size, and pile volume at Unit C and also nearby in the adjoining Units G and H. The following sections describe data collection, beginning with sources of geospatial data, followed by soil properties data collection along transects adjacent to piles, and finally the measurement of growth rates of planted redwood clones and Douglas-fir seedlings between the summers of 2021 and 2022, beginning one year after piles were constructed, with the objective of correlating seedling growth with their proximity to slash piles.

Geospatial Data

The GIS data was acquired from the Green Diamond Resource Company in 2020. The data included aerial photography of the study sites, as well as freshly taken submeter digital elevation modeling imagery (DEM). Geospatial data was gathered on slopes using LiDAR, which was then analyzed in ArcGIS Pro along with the imagery. Ground truthing was also done by collecting waypoints of piles at the three study sites (Units C, G, and H). This was all used to construct models for analyzing terrain to give a visual representation of the site slash piles as well as the slope, which was important to analyze because the slope needed to be less than 12° to verify there was an even distribution of nutrients as the piles underwent their decay process.

When the data was obtained from Green Diamond Research Company, it was loaded into ArcGIS Pro. The geospatial reference was set to World Geodetic System

1984 (WGS84), Universal Transverse Mercator (UTM), Zone 10 North. The raster information showed it was 32 bit, the cell size was 0.25m both in the x and y direction, and it was not set to nearest neighbor. The images were taken pre-pile development and did not give a good visual representation of the slash piles.

Waypoints were taken in the field by using a Garmin GPS Map64 SC set to WGS84 and Universal Transverse Mercator (UTM). On November 6th 2020 the waypoints data collection started. Benchmarks were established by taking 3 to 4 waypoints at the same location, using the average location function of the GPS and setting it on the ground for 1 to 2 minutes for each waypoint. After benchmarks were established, footprints of each of the piles for Units C, G and H were walked which gathered waypoints of the footprints. There was careful consideration of each slash pile in terms of woody debris and its gradient between CWD and FWD, as well as an approximate slope estimate using a Brunton Geo Transit compass. The field measurement data was recorded in a field book. The data points were plotted on the aerial photography that was provided, which was then digitized using polygons, and resulted in calculating their areas. Microsoft Excel was used to compute the root mean square error and standard deviation of the benchmark's waypoints.

After collecting the data from Green Diamond Resource Company and waypoints, the next step was to create models to include hillshade, hillslope and determine the slope gradient for Units C, G, and H of the project area. The first step was creating a hillshade model by using the raster projection tool in ArcGIS Pro. Then, using the hillshade tool, hillshade models were created (Appendix B-D) for Units C, G, and H. The hillshade models were of excellent quality as seen in the Appendix B-D sections, as they show roads and even tracks of logging equipment that were used during harvesting operations.

The next step was to create a series of hillslope models (Appendix E-G) using the hillslope 3D analyst tool in ArcGIS Pro to create a geospatial representation of the hillslope using the 0.25 meter DEM provided by the Green Diamond Resource Company. The last and final step was creating hillslope gradient diagrams using the raster calculator and setting the hillslope to less than or equal to 1° and greater than and equal to 25° (Appendix H-J). For the most part, the hillslope is less than or equal to 1° and greater than or equal to 12°, however there is a section in the southeast corner in Unit C that dips to 25° and a section in Unit H to the north and Unit G to the west that also had a slope equal to or greater than 25°. These sections with a slope greater that 12° are not included in data collection as the study is looking at nutrient retention, and slopes with greater than 12° will not retain nutrients at similar rates compared to more gentle slopes, due to runoff.

Soil Collection and Analysis

Transects for soil sampling were laid out perpendicular to the slash pile’s length at a minimum distance of 10 meters between transects. Using a 50-meter engineering tape, each transect was laid out to extend at maximum 20 meters. After transects were laid out, pin flags were spaced along each transect lines length at the specific intervals of 0, 2.5, 5, 7.5, 9, 14, and 20 meters.

Using a hammer soil corer with a 93 cm^3 collar, soil samples were collected at the intervals predesignated where pin flags had been placed. Each soils collection was conducted where the mineral soil started, meaning in most cases duff had to be removed before each sample was collected. The duff depth was measured using a metric tape measure in centimeters. Once at mineral soil, the hammer corer was then pounded into the soil until resistance was met. Each sample extracted was carefully scraped into a bag recording the unit, pile number, transect number, and sample number. Once bagged, they were all placed into a cooler and kept there through transport to the Cal Poly Humboldt soil laboratory fridge, until it was time for sifting and drying (which happened only after the soil samples from all three units had been collected).

Serialized cans and lids for gathering soil weight pre and post drying in an oven were weighed empty first, using a digital laboratory scale capable of measuring to the ten-thousandths place in grams. Each can and lid serial number were assigned to a specific soil sample. The soil samples were then placed into their specific cans carefully making sure to place the correct sample with the correct lid and can. The can and soil were then weighed to get wet soil weight in grams before being placed into the oven to be dried. All data was recorded directly into Microsoft Excel during all soil laboratory work.

Once enough samples filled up the oven (approximately 25 cans), the oven was started with the temperature set to 39°C. The samples were left overnight for approximately 12 hours, but not exceeding 24 hours, before being taken out to collect the dry soil weight. Once the cans had cooled, they were then placed back on the digital scale, while recording their dry weight in grams. The soil water concentration (Θg) was calculated using the equation:

$$\Theta g\ = \frac{(Can\ weight +\ wet\ soil\ grams - Can\ weight +\ dry\ soil\ grams)}{(Can\ weight +\ dry\ soil\ grams\ - Can\ weight\ empty\ grams)}$$

Sieving of soil was conducted to reduce the particle size down to less than two millimeters in order to send to A&L Western Agricultural Laboratories in Modesto, California for further analyses of nutrients. All particles greater than two millimeters were retained in their appropriate sample collection bags to complete the bulk density (Db) measurements. The remaining samples with particle size greater than two millimeters were weighed in grams. Volume was then measured by water displacement, using an appropriately sized graduated cylinder depending on rock size and recording the cylinder with water level in milliliters first, then adding the particles and recording water level plus added sample particles in milliliters. Using the standard conversion, one milliliter is equal to one cubic centimeter, all of the sample volumes were converted to cubic centimeters. Using the same values from the top part of the soil moisture concentration Θg (Can weight + wet soil grams-Can weight + dry soil grams), rock weight (particles greater than 2mm) was then subtracted from (Can weight + wet soil grams-Can weight + dry soil grams). This was then divided by the standard soil sample collection cylinder volume of 93 cm^3 and subtracting the rock volume that was measured using the graduated cylinder.

$$Db = \frac{(Can\ weight +\ wet\ soil\ grams - Can\ weight +\ dry\ soil\ grams) - (Rock\ Weight\ grams)}{(Cylindar\ Volume = 93cm^3) - (Rock\ Volume\ cm^3)}$$

Cation exchange of the samples was analyzed by mass spectrometry before sending the samples to be analyzed by the external lab in Modesto for moisture content and key element concentrations of ammonium NH_4-N, nitrate NO_3-, cation exchange capacity (CEC), and phosphorus (P). The samples throughout the entire process were kept with their appropriate collection bags with the sample ID written on the bag to not confuse the samples. A&L required all samples be sieved down to less than two millimeters which was completed. All samples were packaged and sent off with their appropriate chain of custody forms that were provided on the A&L website.

Pile Measurements

The pile volumes were measured using a 50-meter engineering tape for every pile that was studied. Each pile was measured every 5 meters along its length to determine the width and height. When calculating the total pile volumes, each 5-meter increment of volume was calculated separately. Once all the 5-meter sections were calculated, they were then summed to give a more accurate total volume for each pile. Pile dimensions and volume were calculated in order to determine the total volume that was occupied by slash.

To compare the growth of planted redwood and Douglas-fir, both their total height and basal diameter (i.e., caliper), along with their distance to the nearest windrowed slash piles were measured. Basal diameter of seedlings and clones were measured using a digital micrometer as close to the tree base near soil as possible. Tree height was measured using a metric tape measure from the ground to the top of the newly sprouted leading stem of each tree. Using a metric 50-meter engineering tape, the tree’s distance to the nearest slash pile was measured. Trees were measured a minimum of 0 meters from pile to a maximum of 20 meters from each pile. The exception to this was if an adjacent slash pile was in close proximity to the pile being studied. Then trees would only be measured to the midpoint between the two piles in order to avoid measuring trees that could potentially be influenced by the other pile.

Data Analysis

Data was first analyzed in Microsoft Excel for general regressions and data processing. Tree measurements and distance to pile measurements were uploaded into Microsoft Excel, and conversions were made into the metric system. Then the dead tree data was eliminated from the data to prevent skewing the data towards the smaller dead trees. Then the regression function inside Excel was run. Once the data was ready for mixed effects modeling, it was uploaded into Minitab. The data was separated into three main groups for mixed effects modeling: year one tree data, the change between years one and two, and soils data. Pile size data, in terms of pile area or pile volume collected in year one, was tested as candidate independent (predictor) variables in the regression analyses. Another candidate predictor variable was initial size of planted stock. Random effects of pile number nested within harvest unit accounted for the nesting of piles within each unit. Logarithmic transformation of dependent variables was performed using the natural log for data sets with non-normal distribution.

To analyze the data gathered, generalized linear mixed-effects models were developed with dependent variables seedling diameter, basal diameter, & volume.

Independent variables referred to as ‘fixed effects’ included distance-to-pile (continuous variable), pile volume (continuous variable), seedling species (categorical variable), and their interaction (distance x species). The random effects were assigned to site ID (categorical variable) and slash pile ID (categorical variable) to account for the lack of independence among seedlings planted in the same unit and in the vicinity of the same pile.

RESULTS

Study Unit Area and Pile Size

The result of the digitized pile analysis done in Microsoft Excel yielded the following results (Table 1). GPS data had a standard deviation northing (STDN) of 1.25 meters (Table 1), standard deviation easting (STDE) was 0.17 meters, root mean square error northing (RMSEN) was 1.45 meters, root mean square error easting (RMSEE) was 0.20 meters, and the GPS horizontal dilution of precision (HDOP) was plus or minus 3.00 meters. These results indicate that the data is within one to two standard deviations of the mean, which shows the GPS data is valid and relatively normal. The root mean square error is the measure of closeness of fit to the mean and the value for these indicate that the datasets are accurate as well.

Table 1: Standard deviation, Root Mean Square Error, & HDOP for GPS waypoints data.

Standard Deviation Northing	Standard Devotion Easting	Root Mean Square Error Northing	Root Mean Square Error Easting	GPS Horizontal Dilution of Precision
1.24722	0.16996	1.44721	0.19794	HDOP =_-^+3 meters

Unit C

This unit contained four piles of downed woody debris that were primarily comprised of CWD at the base of the piles and graded upward to FWD at the top of the piles. There was also FWD throughout CWD. This aids in decomposition of the piles in every unit. The piles were oriented perpendicular to the terrain and roads in a downslope orientation (Figure 2).

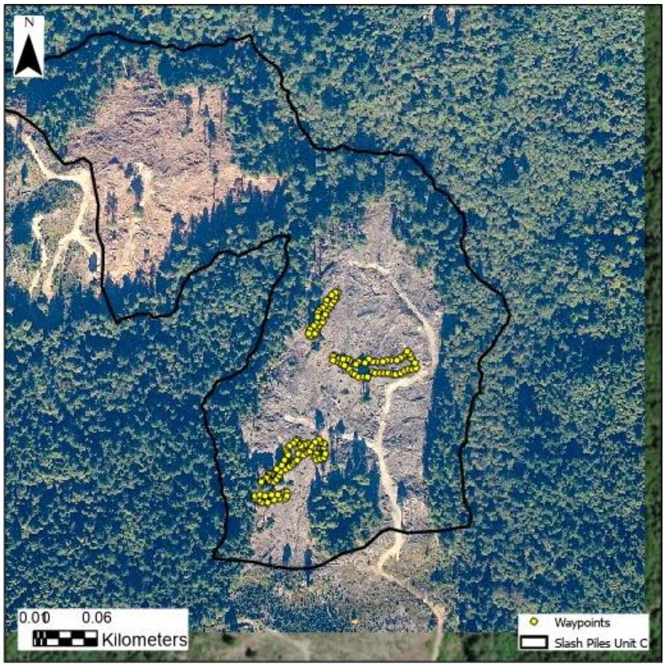


Figure 2: Aerial photography and Unit C slash pile polygons using waypoints

The area values for the piles in Unit C ranged in sizes, for example the smallest pile was 357.45 m² and the largest pile was 1347.05 m² (Table 2). The total area that was calculated from the piles for Unit C was 2905.16 m², while the average area was approximately 726.29 m².

Table 2: Unit C area calculations per pile in meters squared.

FID	Shape*	ID	Area (m²)
0	Polygon	1	1347.05
1	Polygon	4	240.35
2	Polygon	3	960.31
3	Polygon	2	357.45
Total Area=	2605.16 m^2	Average Area=	726.29 m^2

Unit H

This unit contained approximately twelve piles of downed woody debris that were comprised of a mix of CWD and FWD, most with larger amounts of CWD near the base of the piles (Figure 3). The piles were oriented parallel to the terrain and roads in a gentle downslope orientation. This allows for nutrients to disburse more evenly as the decomposition process takes place.

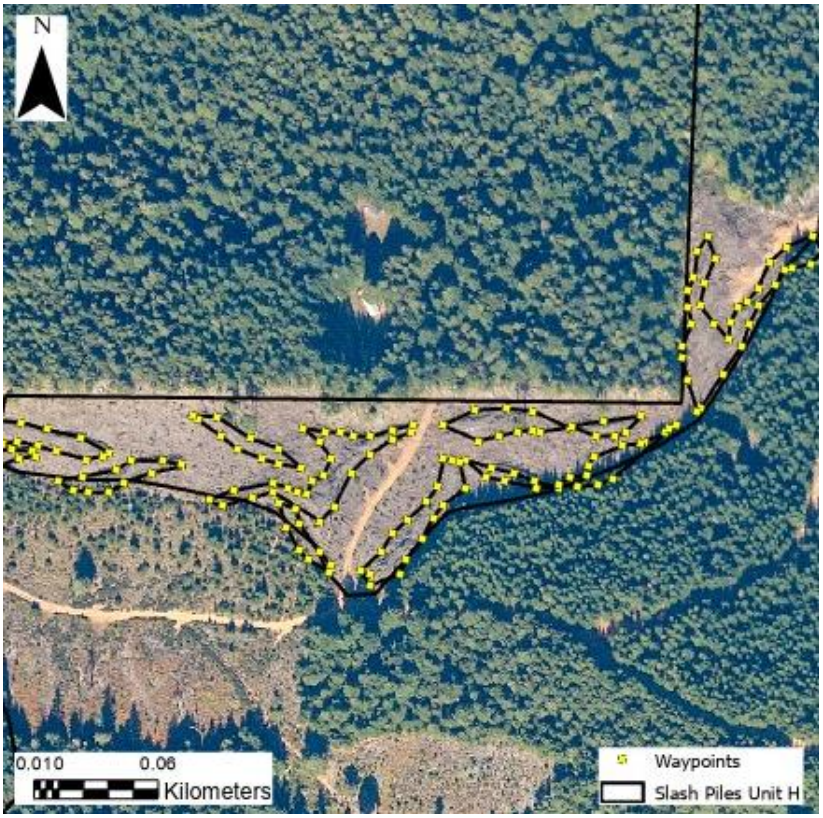


Figure 3: Aerial photography and Unit H slash pile polygons using waypoints

The total area that was calculated from the piles for Unit H was 9,790.07 m². The average area was approximately 754.77 m² (Table 3).

Table 3: Unit H area calculations per pile in meters squared.

FID	Shape*	ID	Area (m^2)
11	Polygon	1	2377.52
6	Polygon	2	1662.13
0	Polygon	3	1214.25
1	Polygon	4	851.00
4	Polygon	5	623.31
9	Polygon	6	606.76
5	Polygon	7	515.90
10	Polygon	8	372.42
7	Polygon	9	270.94
2	Polygon	10	136.70
8	Polygon	11	236.70
3	Polygon	12	189.59
Total Area =	9057.22 m^2	Average Area =	754.77 m^2

Unit G

This unit contained approximately nine piles of downed woody debris that were primarily comprised of coarse woody debris at the base of the piles that graded upward to fine woody debris at the top of the piles (Figure 4). There was also fine woody debris throughout the coarse woody debris. The slope for the piles started at a gradual incline of approximately 10° on the northeast side and generally steepened to 22° at the southwest.

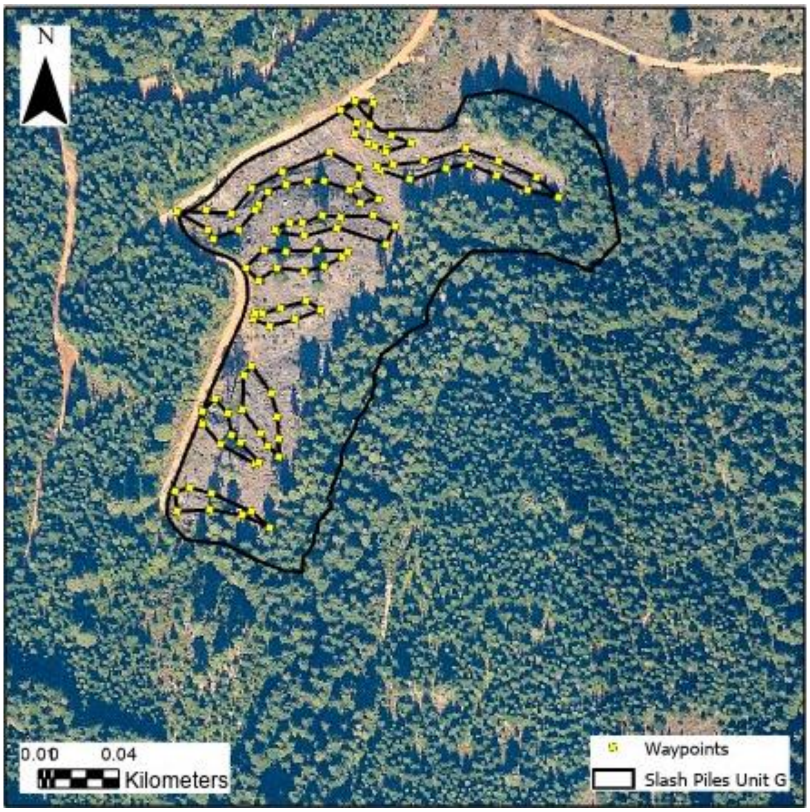


Figure 4: Aerial photography and Unit G slash pile polygons using waypoints

The total area that was calculated from the piles for Unit G was 6,125.51 m². The average pile area was approximately 680.61 m² (Table 4).

Table 4: Unit G area calculations per pile in meters squared.

FID	Shape*	ID	Area (m^2)
8	Polygon	1	1462.37
5	Polygon	2	916.3
2	Polygon	3	704.42
7	Polygon	4	665.12
4	Polygon	5	648.63
0	Polygon	6	478.96
6	Polygon	7	476.11
1	Polygon	8	459.92
3	Polygon	9	313.68
Total Area =	6123.51 m^2	Average Area =	680.61 m^2

Pile Area

Unit G had a total of 0.61 ha taken up by slash. The total area studied for Unit G was 3.2 ha with a percent slash left on site after harvest of 19.14%, leaving approximately 80.86% plantable space for Unit G. Unit H had a total of 0.97 ha taken up by slash. The total area studied for Unit H was 3.0 ha with a percent slash left on site after harvest of 32.36%, leaving approximately 67.64% plantable space for unit H. Due to limited time and accessibility for Unit C, there was not enough data collected to make a prediction for percent space taken up by slash and plantable percent space.

Pile Volume

Pile volume was calculated using the standard volume equation of length times width times height (Table 5). The average pile volumes were: 1105.63 m^3 (Unit C), 1306.343 m^3 (Unit G), and 1321.82 m^3 (Unit H). Unit G and H had larger pile volumes due to them being much taller than Unit C piles. The smallest pile volume studied was 440.50 m^3 and the largest volume was 2,761.05 m^3. The variation in pile volumes was probably due to equipment and the fact that less hardwood material was being sent to the chip dock for export due to the re-dredging of Humboldt Bay harbor which limited the amount of ships who could take chips, which then resulted in larger amounts of hardwood not being hauled off site.

Table 5: Volume for only piles studied in terms of soil nutrient sampling.

Unit	Pile	Area (m^2)	Volume (m^3)
C	1	1347.05	1486.18
C	2	357.45	440.50
C	3	960.31	1388.70
C	4	240.31	1107.15
H	1	1214.25	2761.05
H	2	236.70	692.00
H	3	515.90	512.40
G	1	916.30	1823.73
G	2	474.96	894.05
G	3	459.92	1201.25
Unit C Avg Volume =	1105.63 m^3		
Unit G Avg Volume =	1306.34 m^3		
Unit H Avg Volume =	1321.82 m^3		

Size and Growth of Planted Stock

Year One Descriptive Statistics

The average seedling tree diameter at year one (D1) for Units C, G and H were as follows, C: 7.06 mm, G: 6.43 mm, and H: 5.69 mm (Table 6). The average seedling tree height at year one (H1) for Units C, G and H were as follows, C: 0.33 m, G: 0.31 m, and H: 0.27 m. The average seedling stemwood volume at year one (V1) for Units C, G and H were as follows, C: 5.89 cm^3, G: 4.15 cm^3, and H: 2.69 cm^3. The average seedling basal area at year one (BA1) for Units C, G and H were as follows, C: 45.52, G: 36.09, and H: 27.50. Variances in seedling response between Units C, G and H could have been because of soil nutrient levels, soil water abundance, thermal heat, and distance to piles.

Table 6: Descriptive statistics for year one variables for predicting tree growth measurement by harvest unit.

Variable	Unit	N	Mean	SE Mean	StDev	Min.	Max.
Pile Area (m²)	C	4	948.30	19.90	418.10	240.30	1347.00
	G	3	716.80	12.20	223.70	459.90	916.30
	H	3	756.30	21.70	411.40	236.70	1214.30
	All	**10**	**819.00**	**11.40**	**382.90**	**236.70**	**1347.00**
Pile Volume (m³)	C	4	1253.60	17.30	362.40	440.50	1486.20
	G	3	1485.70	21.30	392.50	894.00	1823.70
	H	3	1518.30	57.30	1083.30	512.40	2761.10
	All	**10**	**1405.90**	**20.60**	**693.00**	**440.50**	**2761.10**
D1 (mm)	C	441	7.06	0.14	2.86	1.05	15.99
	G	338	6.43	0.12	2.17	1.34	12.37
	H	358	5.69	0.09	1.61	2.05	11.40
	All	**1137**	**6.44**	**0.07**	**2.39**	**1.05**	**15.99**
HT1 (m)	C	441	0.33	0.01	0.12	0.05	0.83
	G	338	0.31	0.00	0.09	0.10	0.54
	H	358	0.27	0.00	0.07	0.11	0.53
	All	**1137**	**0.31**	**0.00**	**0.10**	**0.05**	**0.83**
V1 (cm³)	C	441	5.89	0.30	6.25	0.05	35.48
	G	338	4.15	0.18	3.37	0.13	16.83
	H	358	2.69	0.10	1.92	0.17	13.27
	All	**1137**	**4.37**	**0.14**	**4.63**	**0.05**	**35.48**
BA1 (mm²)	C	441	45.52	1.74	36.48	0.87	200.81
	G	338	36.09	1.26	23.24	1.41	120.18
	H	358	27.50	0.79	14.98	3.30	102.07
	All	**1137**	**37.04**	**0.84**	**28.34**	**0.87**	**200.81**
Dist. to Pile (m)	C	441	7.73	0.25	5.28	0.20	20.60
	G	338	7.80	0.27	5.03	0.30	20.90
	H	358	7.93	0.29	5.46	0.00	20.90
	All	**1137**	**7.816**	**0.156**	**5.261**	**0.00**	**20.9**

Note: D1 = Diameter at year one, HT1 = Seedling height at year one, V1 = Stemwood volume at year one, BA1 = Basal area at year one. N ample size, SE Mean = Standard error of the mean, StDev = Standard deviation of the mean

Year One Candidate Models

Sixty-four models were run in Minitab using the mixed effects modeling tool looking at the size data for planted redwood and Douglas-fir from data collection in summer 2021. The models included stemwood volume at year one (V1), diameter at groundline (caliper) at year one (D1), height at year one (HT1), and groundline basal area at year one (BA1) (Table 7). Logarithmic transformations were necessary using natural log for the following variables with non-normal distribution, natural log of diameter increment at year one (Ln D1), natural log of volume increment at year one (Ln V1), natural log of basal area increment (Ln BA1), and natural log of height increment at year one (Ln HT1).

Table 7: Candidate models for predicting tree size at year one.

Response	Variables	R squared	AIC	ΔAIC
V1 (cm³)	Spc	36.28%	6247.46	
	Dp+Spc+(Dp*Spc)	36.42%	6256.87	9.41
	Null	46.54%	6549.14	301.68
Ln V1 (cm³)	**PV+Spc**	**44.70%**	**2624.71**	
	Spc	44.69%	2609.08	-15.63
	Null	11.12%	3138.37	513.66
D1 (mm)	**Spc**	**46.02%**	**4554.78**	
	Dp+Spc	46.03%	4562.02	7.24
	Null	13.46%	5083.07	528.29
Ln D1 (mm)	Dp+PV+Spc	44.96%	402	
	Spc	44.94%	373.56	-28.44
	Null	10.00%	920.25	518.25
HT1 (m)	**Spc**	**25.90%**	**-2308.68**	
	Dp+Spc	26.03%	-2297.29	11.39
	Null	10.63	-2107.71	200.97
Ln HT1 (m)	Dp+Sp+(Dp*Sp)	25.68%	486.54	
	Spc	25.61%	465.6	-20.94
	Null	9.08%	684.45	197.91
BA1 (mm²)	Spc	41.77%	10257.59	
	Dp+Spc	41.77%	10259.91	2.32
	Null	15.60%	10677.00	419.41
Ln BA1 (mm²)	**Dp+Spc**	**44.96%**	**1956.32**	
	Spc	44.94%	1947.00	-9.32
	Null	10.00%	2495.08	538.76

Note: D1 = Diameter at year one, Ln D1 = natural log of diameter at year one, HT1 = Seedling height at year one, Ln HT1 = natural log of height at year one, V1 = Stemwood volume at year one, Ln V1 = natural log of stemwood volume at year one, BA1 = Basal area at year one, Ln B1 = natural log of basal area at year one, Variables: Spc = species, Dp = distance to pile, PV = pile volume, Statistics: R squared = a measure of the closeness of fit to the linear regression line looking at the variation in the dependent variable, AIC = Akaike information criterion, ΔAIC = change in Akaike information criterion

For the mixed effects models pre-natural log transformation, Akaike Information Criterion (AIC) was used to narrow down the best models with the lowest AIC values. For the models that were transformed using natural log, R^2 was evaluated for the best models with the highest R^2 value. In Table 7, the best models have been bolded due to either their AIC, R^2, or a combination of the two being the best models that were run out of the sixty-four models that were evaluated. In each category there are three models with two of them being the best models that were run, and the null model. Four models were chosen between untransformed and transformed data.

For volume at year one, the natural log model was selected due to its R^2 value being highest at 44.70% and the AIC being lowest at 2624.71. The variables with significance were pile volume and species. Diameter at year one was evaluated and the best model had an AIC value of 4554.78 with species being the only variable of significance. Height at year one's best model had an AIC of -2308.68. The variable with the most significance was species for height at year one. Basal area at year one's best model was the natural log of basal area at year one with an R^2 value of 44.96% and an AIC of 1956.32. The significant variables were distance to pile and species.

Year One Best Models Selected

For the natural log of volume at year one, the P value for species was a strong predictor 0.0030 but pile volume was not a strong predictor at 0.93 when breaking down species between Douglas-fir and redwood (Table 8). At the beginning of the study, Douglas-fir seedlings were larger than redwood seedlings (Table 8). In addition, at the beginning of the study, seedlings around larger piles were slightly larger which was indicated by the positive coefficient. Most of the variation among seedling volumes was random error as opposed to variation between piles and units. This study's model predicted that the average Douglas-fir seedling volume at Unit C would be 4.82 cm^3 at year one, as opposed to redwood which was predicted to be 1.48 cm^3. For Unit G, Douglas-fir predicted volume was 4.80 cm^3 and redwood was 1.48 cm^3. Unit H's predicted volume for Douglas-fir was 4.84 cm^3 and redwood was 1.49 cm^3.

Table 8: Best statistical model for predicting tree growth at year one.

Response	Effect	Term	Coef	SE Coef	DF	T-Value	P-Value
Ln V1 (cm^3)	Fixed	Constant	1.00	0.23	8.16	4.28	0.0030
		Pile Volume (m^3)	-0.000014	0.00017	7.96	-0.09	0.93
		Species					
		Douglas-fir (Df)	0.59	0.02	1128.37	26.14	0.00
	Random	Source	Var	% of Total	SE Var	Z-Value	P-Value
		Pile	0	0.00%	*	*	*
		Unit (Pile)	0.11	16.99%	0.06	1.92	0.03
		Error	0.56	83.01%	0.02	23.73	0.00
		Total	0.67				
D1 (mm)	Fixed	Term	Coef	SE Coef	DF	T-Value	P-Value
		Constant	6.31	0.27	9.17	23.67	0.00
		Species					
		DF	1.38	0.05	1128.31	26.06	0.00
	Random	Source	Var	% of Total	SE Var	Z-Value	P-Value
		Pile	0.00	0.00	*	*	*
		Unit (Pile)	0.68	0.18	0.33	2.04	0.02
		Error	3.10	0.82	0.13	23.73	0.00
		Total	3.78				

Note: Ln V1 = natural log of volume at year one, D1 = diameter at year one, Df = Douglas-fir, Statistics: Coef = coefficients, SE Coef = standard error of coefficients, DF =Degrees of freedom, Var = variation, SE Var = standard error of variation

Table 9: Best statistical models for predicting tree growth at year one.

HT1 (m)	Fixed	Term	Coef	SE Coef	DF	T-Value	P-Value
		Constant	0.31	0.01	9.08	28.41	0.0000
		Species					
		DF	0.04	0.00	1129.14	15.22	0.00
	Random	Source	Var	% of Total	SE Var	Z-Value	P-Value
		Pile	0.00	0.00%	*	*	*
		Unit (Pile)	0.00	0.13	0.00	1.99	0.02
		Error	0.01	0.87	0.00	23.73	0.00
		Total	0.01				
Ln BA1 (mm²)	Fixed	Term	Coef	SE Coef	DF	T-Value	P-Value
		Constant	3.30	0.08	11.44	43.25	0.0000
		Distance to Pile (m)	0.0018	0.00	1129.22	0.57	0.57
		Species					
		DF	0.45	0.02	1128.06	26.72	0.00
	Random	Source	Var	% of Total	SE Var	Z-Value	P-Value
		Pile	0.00	0.00%	*	*	*
		Unit (Pile)	0.05	0.14	0.02	2.01	0.02
		Error	0.31	0.86	0.01	23.72	0.00
		Total	0.36				

Note: HT1 = height at year one, Ln BA1 = natural log of basal area at year one, Df = Douglas-fir, Statistics: Coef = coefficients, SE Coef = standard error of coefficients, DF =Degrees of freedom, Var = variation, SE Var = standard error of variation

For diameter at year one, the P value for species was a strong predictor at 0.00 when breaking down species between Douglas-fir and redwood. At the beginning of the study, Douglas-fir seedlings had a larger diameter than redwood seedlings. Also at the beginning of the study, distance to pile was not a strong predictor of seedling diameter and was not significant enough to be included in the model. Some of the variation among seedling diameter was between piles and units as opposed to most of the variation being due to random error. The model predicted that the average Douglas-fir seedling diameter at all units would be 7.69 mm at year one, as opposed to redwood seedlings which were predicted to be 4.93 mm.

For height at year one, the P value for species was a strong predictor at 0.00 when breaking down species between Douglas-fir and redwood (Table 9). At the beginning of the study, Douglas-fir seedlings were slightly taller than redwood seedlings by approximately 8 cm. At year one, pile size and distance to pile were not significant enough to be included in the model. Furthermore, units and piles within units did not explain much of the variation between seedling height. Most of the variation among seedling height was due to random error, not piles and units. Upon observation of the units, there was heavy browsing from deer, elk and rodents, especially for Douglas-fir seedlings. This could explain the minimal height variation between species.

For the natural log of basal area at year one, the P value for species was a strong predictor at 0.00. Distance to pile, however, was not as strong of a predictor, with a P value of 0.57. While distance to pile is not significant at an alpha level of 0.05, including it in the model resulted in a slightly higher R^2 value when compared to the null model.

With there being a positive coefficient for distance to pile, it is expected that seedlings would have greater basal area further from piles. When breaking down species, Douglas-fir had a larger basal area at year one compared to redwood. The variability between seedling basal area can be partially explained by piles nested within units, but most of the variation is due to random error. Our model predicted that the basal area at Unit C had an average distance to pile of 7.73 m, the average Douglas-fir would be 43.12 mm^2 and redwood would be 17.53 mm^2. Unit G's average distance was 7.80m, and the average Douglas-fir would be 43.12 mm^2 with redwood being 17.53 mm^2. Unit H average distance was 7.9 3m, so the average Douglas-fir would be 43.13 mm^2 and redwood would be 17.54 mm^2.

Growth of Planted Stock

Fewer data were available for year two size of planted stock, and the associated calculation of change in size (i.e., growth) occurring between year one to year two in seedling volume (ΔV), seedling basal area (ΔBA), and seedling height (ΔHT) (Table 10). The mean ΔV for Unit C was 30.41 cm^3 with a minimum of -2.14 cm^3 and a maximum of 153.34 cm^3. The mean ΔV for Unit G was 12.44 cm^3 with a minimum of -4.47 cm^3 and a maximum of 61.24 cm^3. The mean ΔV for Unit H was 4.96 cm^3 with a minimum of -2.29 cm^3 and a maximum of 37.06 cm^3. In observation, Unit C had larger trees than G and H. The data shows that the trees at Unit C had grown significantly more over a one-year period than Units G and H.

Table 10: Combined year one and two descriptive statistics of variables for predicting tree growth measurements by harvest unit.

Variable	Unit	N	Mean	SE Mean	StDev	Minimum	Maximum
Pile Area	C	4.00	1274.20	18.30	152.30	960.30	1347.00
(m^2)	G	3.00	646.00	19.50	220.90	459.90	916.30
	H	3.00	708.30	41.50	410.70	236.70	1214.30
	All	**10**	**813.60**	**22.40**	**384.50**	**236.70**	**1347.00**
Pile Volume	C	4.00	1467.80	4.62	38.40	1388.70	1486.20
(m^3)	G	3.00	1362.90	34.90	395.00	894.00	1823.70
	H	3.00	1407.00	107.00	1062.00	512.00	2761.00
	All	**10**	**1402.10**	**38.70**	**664.60**	**512.40**	**2761.10**
ΔV (cm^3)	C	69.00	30.41	4.33	35.94	-2.14	153.34
	G	128.00	12.44	1.34	15.19	-4.47	61.24
	H	98.00	4.96	0.70	6.90	-2.29	37.06
	All	**295**	**14.16**	**1.31**	**22.48**	**-4.47**	**153.34**
ΔD (mm)	C	69.00	7.55	0.78	6.48	-1.98	30.30
	G	128.00	5.04	0.42	4.70	-1.67	18.17
	H	98.00	3.41	0.34	3.33	-1.24	14.43
	All	**295**	**5.08**	**0.29**	**5.03**	**-1.98**	**30.30**
ΔBA (mm)	C	69.00	77.30	14.60	121.00	0.00	722.10
	G	128.00	37.24	4.51	50.98	0.00	259.65
	H	98.00	17.76	3.22	31.85	0.00	163.76
	All	**295**	**40.14**	**4.25**	**73.07**	**0.00**	**722.05**
ΔHT (m)	C	69.00	0.14	0.02	0.18	-0.21	0.68
	G	128.00	0.07	0.01	0.13	-0.21	0.45
	H	98.00	0.02	0.01	0.10	-0.23	0.28
	All	**295**	**0.07**	**0.01**	**0.14**	**-0.23**	**0.68**

Note: ΔV (cm^3) = change in volume from year one to year two, ΔD (mm) = change in diameter from year one to year two, ΔBA (mm) = change in baseal area from year one to year two, ΔHT (m) = change in height from year one to year two, N = sample size, SE mean = standard error of the mean

The mean ΔD for Unit C was 7.55 mm with a minimum of -1.98 mm and a maximum of 30.30 mm (Table 10). The mean ΔD for Unit G was 5.04 mm with a minimum of -1.67 mm and a maximum of 18.17 mm. The mean ΔD for Unit H was 3.41 mm with a minimum of -1.24 mm and a maximum of 14.43 mm. The variation between ΔD for Units C, G and H could possibly be due to the microsite conditions of each unit.

The mean ΔBA for Unit C was 77.30 mm^2 with a minimum of 0.00 mm^2 and a maximum of 722.10 mm^2. The mean ΔBA for Unit G was 37.24 mm^2 with a minimum of 0.00 mm^2 and a maximum of 259.65 mm^2. The mean ΔBA for Unit H was 17.76 mm^2 with a minimum of 0.00 mm^2 and a maximum of 163.76 mm^2. The variation between ΔBA for Units C, G and H could possibly be due to variations in plantable space between the units. Piles at Unit C were much longer than G and H, possibly due to terrain restrictions in slope. Unit G also had terrain restrictions but not as much as Unit C, and H had relatively none.

The mean ΔHT for Unit C was 0.14 m with a minimum of -0.2 m and a maximum of 0.68 m. The mean ΔHT for Unit G was 0.07 m with a minimum of -0.21 m and a maximum of 0.45 m. The mean ΔHT for Unit H was 0.02 m with a minimum of -0.23 m and a maximum of 0.28 m. The mean variation in height between Units C, G, and H were very similar, probably due to heavy browsing seen in field observations at all three units. Unit C did have slightly more growth over the one-year period than that of Unit H. Besides browsing, variations in soil could also be a factor in ΔV and ΔHT.

Candidate Models for Growth of Planted Stock

One hundred sixteen models were run in Minitab using the mixed effects modeling tool, looking at the tree growth data from summer data collection in both 2021 and 2022 (Table 11). More specifically, the models focused on the change from 2021 to 2022 in volume increment (ΔV), diameter increment (ΔD), height increment (ΔHT), and basal area increment (ΔBA). After reviewing the statistical data, it was determined that logarithmic transformations were necessary, which used natural log for the following variables with non-normal distribution: natural log of diameter increment (Ln ΔD), natural log of volume increment (Ln ΔV), and natural log of basal area increment (Ln ΔBA).

Table 11: Combined year one and two candidate models for predicting growth between year one and two.

Response	Variables	R squared	AIC	ΔAIC
ΔV (cm^3)	**Dp+Spc+V1**	**23.04%**	**2618.53**	
	Dp+Spc+V1+(Dp*Spc)	23.28%	2618.72	0.19
	Null	22.23%	2624.14	5.61
Ln ΔV	Dp	22.54%	865.07	
(cm^3)	Spc	21.51%	867.69	2.62
	Null	20.99%	866.38	1.31
ΔD (mm)	D1+Spc	14.9	1767.49	
	DI	14.88	1767.83	0.34
	Null	12.35%	1773.51	6.02
Ln ΔD	**DI**	**63.80%**	**542.98**	
(mm)	Dp	9.08%	785.82	242.84
	Null	8.20%	782.08	**239.10**
ΔHT (m)	**HT1**	**19.21%**	**-372.89**	
	HT1+PA	29.15%	-359.17	13.72
	Null	11.02	-314.1	58.79
ΔBA	**Dp+BA1+Spc+(Dp*Spc)+(Ba1*Spc)**	**15.22%**	**3333.21**	
(mm^2)	Dp+BA1+Spc+(Dp*Spc)	14.57%	3334.39	1.18
	Null	11.52%	3349.51	16.30
Ln ΔBA	Dp+Spc	12.09%	1395.47	
(mm^2)	Spc	11.62%	1392.26	-3.21
	Null	9.81%	1396.24	0.77

Note: ΔD = change in diameter between years one and two, Ln ΔD = natural log of change in diameter between years one and two, ΔHT = the change in seedling height between years one and two, Ln ΔHT = natural log of the change in seedling height between years one and two, ΔV = change in stemwood volume between yeas one and two, Ln ΔV = change in natural log of stemwood volume between years one and two, ΔBA = change in basal area between years one and two, Ln ΔB = change in natural log of basal area between years one and two, Variables: Spc = species, D1 = distance to pile at year one, Dp = distance to pile, PV = pile volume, PA = pile area, HT1 = height at year one, BA1 = basal area at year one, Statistics: R squared = a measure of the closeness of fit to the linear regression line looking at the variation in the dependent variable, AIC = Akaike information criterion, ΔAIC = change in Akaike information criterion

For the mixed effects models pre-natural log transformation, Akaike Information Criterion (AIC) was used to narrow down the best models with the lowest AIC values. For the models that were transformed using natural log, R^2 was evaluated for the best models with the highest R^2 value. In Table 11, the best models have been bolded due to either their AIC, R^2, or a combination of the two being the best models that were developed out of the 116 models that were evaluated. In each category there are three models, with two of them being the best models that were run, and the null model.

For ΔV, the candidate model selected was the untransformed model due to its R^2 value being highest at 23.04% and the AIC being lowest at 2618.53. The significant variables were distance to pile, species, and volume at year one. The best model for ΔD was Ln ΔD. The R^2 value was 63.80% and an AIC of 542.98. The only significant variable was diameter at year one. The best model for the ΔHT had an R^2 value of 19.21% and an AIC of -372.89. The only significant variable was height at year one. The best model for ΔBA had an R^2 value of 15.22% and an AIC of 3333.21. This model was one of the best models that was developed during this study. The variables that were found to be significant were distance to pile, basal area at year one, species, the interaction between distance to pile and species, and the interaction between basal area at year one and species.

Best Models for Growth of Planted Stock

For the change in seedling stemwood volume (ΔV) between summer field research 2021 and 2022, the P value for distance to pile was a slight predictor at 0.10 and stemwood volume at year one was also a slight predictor at 0.12 (Table 12). Seedlings further from piles were slightly larger, indicated by the positive 0.38 coefficient. Species also had a strong influence in growth, where redwood grew more over the one-year period than Douglas-fir, as noted by the negative coefficient for Douglas-fir.

Most of the variation among seedling volumes was random error as opposed to variation between piles and units. Our model predicted that the average Douglas-fir seedling change in volume would be 11.02 cm^3, as opposed to a redwood which would be predicted to be 13.77 cm^3. Redwoods grew at a faster rate over a one-year period, however, Douglas-fir was still a larger tree at this time by approximately 5 cm^3.

Table 12: Best models for growth of redwood and Douglas-fir planted stock from year one to year two.

Response	Effect	Term	Coef	SE Coef	DF	T-Value	P-Value
ΔV (cm³)	Fixed	Constant	7.71	3.97	4.15	1.95	0.12
		Distance to Pile (m)	0.38	0.23	288.09	1.64	0.10
		V1 (cm3)	0.52	0.33	290.57	1.57	0.12
		Species					
		Douglas-fir (DF)	-1.37	1.38	288.16	-0.99	0.33
	Random	Source	Var	% of Total	SE Var	Z-Value	P-Value
		Pile	1.15	0.00	35.28	0.03	0.49
		Unit (Pile)	70.20	0.15	50.41	1.39	0.08
		Error	401.26	0.85	33.65	11.92	0.00
		Total	472.61				
Ln ΔD (mm)	Effect	Term	Coef	SE Coef	DF	T-Value	P-Value
	Fixed	Constant	0.24	0.07	33.77	3.37	0.00
		DI (mm/yr)	0.19	0.01	144.97	19.91	0.00
	Random	Source	Var	% of Total	SE Var	Z-Value	P-Value
		Pile	0.00	0.00	*	*	*
		Unit (Pile)	0.00	0.00	0.01	0.22	0.41
		Error	0.46	1.00	0.04	11.10	0.00
		Total	0.47				

Note: ΔV = change in volume between years one and two, Ln ΔD = natural log of change in diameter between years one and two, Term: V1 = volume at year one, D1 = diameter at year one, Statistics: Coef = coefficients, SE Coef = standard error of coefficients, DF =Degrees of freedom, Var = variation, SE Var = standard error of variation

Table 13: Best models for change in growth from year one to year two.

ΔH (m)	Effect	Term	Coef	SE Coef	DF	T-Value	P-Value
	Fixed	Constant	0.26	0.03	29.77	7.99	0.00
		HT1 (m)	-0.67	0.08	291.44	-8.35	0.00
	Random	Source	Var	% of Total	SE Var	Z-Value	P-Value
		Pile	0.00	0.00	*	*	*
		Unit (Pile)	0.00	0.19	0.00	1.67	0.05
		Error	0.01	0.81	0.00	11.96	0.00
		Total	0.02				
ΔBA (mm^2)	Effect	Term	Coef	SE Coef	DF	T-Value	P-Value
	Fixed	Constant	29.47	13.50	6.01	2.18	0.07
		Distance to Pile (m)	1.38	0.80	286.57	1.73	0.08
		BA1	0.01	0.26	288.90	0.05	0.96
		Species					
		DF	9.56	9.10	285.93	1.05	0.30
		Distance to Pile (m)*Species					
		DF	-0.66	0.78	283.71	-0.85	0.40
		BA1*Species					
		DF	-0.36	0.24	283.87	-1.48	0.14
	Random	Source	Var	% of Total	SE Var	Z-Value	P-Value
		Pile	64.75	0.01	327.95	0.20	0.42
		Unit (Pile)	518.11	0.10	401.85	1.29	0.10
		Error	4694.05	0.89	395.06	11.88	0.00
		Total	5276.90				

Note: Note: ΔH = change in height between years one and two, ΔBA = change in basal area between years one and two, Term: HT1 = height at year one, BA1 = basal area at year one, Statistics: Coef = coefficients, SE Coef = standard error of coefficients, DF =Degrees of freedom, Var = variation, SE Var = standard error of variation

For the model predicting change in diameter between years one and two, the only variable that was significant was the initial diameter at year one with a P value at 0.00. Most of the variation among change in seedling diameter was due to random error. The model predicted that the average change in seedling diameter at all units would be 4.01 mm. For the model predicting change in height from year one to year two, the only significant variable included was height at year one with a P value of 0.00 (Table 13). Height at year one had a negative coefficient, which means the larger the seedling height was at year one, the less the seedling would be expected to grow in height between years one and two. The model predicted that the average change in seedling height would be 0.06 m.

For the model predicting change in basal area between years one and two, the P value for distance to pile was a strong predictor at 0.08 (Table 13). The basal area at year one however was not as strong of a predictor, with a P value of 0.96. While basal area at year one is not significant at an alpha level of 0.05, including it in the model resulted in a slightly lower AIC value when compared to the null model. Species was not a strong predictor either with a P value of 0.30 when compared to the alpha level of 0.05, however it was important to keep in the model when comparing AIC to the null model. The interaction between basal area at year one and species was a stronger predictor with a P value of 0.14.

The interaction between distance to pile and species was not significant with a P value of 0.40 but when compared to the alpha level of 0.05, it was important to keep in the model when comparing AIC to the null model. With there being positive coefficients for distance to pile, basal area at year one, and species, it would be expected that seedlings would have greater basal area further from piles. When breaking down species, Douglas-fir had a larger average basal area at years one and two compared to redwood. The variability between seedling basal area can be somewhat explained by piles nested within units, but most of the variation was due to random error.

Our model would predict that for the change in average basal area between years one and two (BAI) for all units, Douglas-fir would be 27.50 mm² and redwood would be 42.49 mm². This means that redwood grew more in basal area over the one-year increment. Both species had greater basal area growth the further they were away from the piles. However, redwood was more affected by distance to pile, meaning they grew better further away. For example, every meter away from a pile, redwood would be expected to have a BAI increase of 2.03 mm², where Douglas-fir would only be expected to increase by 0.72 mm².

Influence of Pile Size and Distance on Soil Nutrients

The average distance to pile for Unit C was 7.79 m, Unit G was 7.14 m and Unit H was 6.93 meters in regards to soils coring and collection along transects (Table 14). The minimum distance for all piles was 0.00 m and maximum was 20.00 m. The average pile area for Unit C was 11.90 m² with a minimum of 960.30 m² and a maximum of 13.47 m². The average pile area for Unit G was 705.10 m² with a minimum of 459.90 m² and a maximum of 916.30 m². The average pile area for Unit H was 593.20 m² with a minimum of 236.70 m² and a maximum of 1,214.30 m². The average pile volume for Unit C was

1446.80 m³ with a minimum of 1,388.70 m³ and a maximum of 1,486.20 m³. The average pile volume for Unit G was 1,458.50 m³ with a minimum of 894.00 m³ and a maximum of 1823.70 m³. The average pile volume for Unit H was 993.00 m³ with a minimum of 512.00 m³ and a maximum of 2,761.00 m³.

Table 14: Soils descriptive statistics for predicting soil nutrient replenishment in relation with distance to slash pile.

Variable	Unit	N	Mean	SE Mean	StDev	Minimum	Maximum
Distance to pile	C	47.00	7.79	0.89	6.08	0.00	20.00
(m)	G	51.00	7.14	0.77	5.51	0.00	20.00
	H	56.00	6.93	0.72	5.39	0.00	20.00
	All	**154**	**7.26**	**0.45**	**5.62**	**0.00**	**20.00**
Pile Area	C	4.00	1190.70	28.00	191.80	960.30	1347.00
(m^2)	G	3.00	705.10	31.70	226.30	459.90	916.30
	H	3.00	593.20	44.00	329.30	236.70	1214.30
	All	**10.00**	**812.60**	**29.30**	**363.60**	**236.70**	**1347.00**
Pile Volume	C	4.00	1446.80	7.05	48.40	1388.70	1486.20
(m^3)	G	3.00	1458.50	56.80	405.40	894.00	1823.70
	H	3.00	993.00	118.00	885.00	512.00	2761.00
	All	**10.00**	**1285.50**	**50.00**	**620.90**	**512.40**	**2761.10**
Θg	C	47.00	0.27	0.01	0.08	0.14	0.61
(%Soil Water)	G	51.00	0.32	0.03	0.19	0.11	1.56
	H	56.00	0.24	0.01	0.05	0.13	0.37
	All	**154**	**0.28**	**0.01**	**0.13**	**0.11**	**1.56**
Bulk Density	C	47.00	0.87	0.03	0.22	0.35	1.49
(Db, g/cm^3)	G	51.00	0.90	0.03	0.24	-0.33	1.33
	H	56.00	0.95	0.02	0.12	0.67	1.35
	All	**154**	**0.91**	**0.02**	**0.20**	**-0.33**	**1.49**
CEC	C	47.00	2.23	0.21	1.43	0.40	7.20
(meq/100g)	G	51.00	1.17	0.12	0.88	0.40	5.40
	H	56.00	0.74	0.04	0.30	0.30	1.70
	All	**154**	**1.34**	**0.09**	**1.14**	**0.30**	**7.20**
Nitrate	C	47.00	1.40	0.14	0.95	1.00	5.00
(NO3-N, ppm)	G	51.00	1.84	0.21	1.49	1.00	8.00
	H	56.00	1.41	0.13	0.95	1.00	6.00
	All	**154**	**1.55**	**0.09**	**1.17**	**1.00**	**8.00**
Ammonium	C	47.00	4.85	0.26	1.76	1.70	9.70
(NH4-N, ppm)	G	51.00	6.19	0.15	1.10	4.50	9.10
	H	56.00	7.17	0.30	2.25	4.70	15.40
	All	**154**	**6.14**	**0.16**	**2.01**	**1.70**	**15.40**

Note: Θg= Percent soil moisture/water concentration, Db= Bulk Density, CEC= Cation exchange capacity, NO3-N=Nitrate Nitrogen, NH4-N=Ammonium Nitrogen, Units: Meq/100g = milliequivalents per 100 grams of soil. 1 meq/100 = 1 cmol(+)/kg, where cmol(+)/kg is the abbreviation for centimoles per kilogram, ppm = parts per million, Statistics: N = sample size, SE mean = standard error of the mean, StDev = standard deviation from the mean

Soil moisture concentration (Θg) was measured in percent soil moisture (Table 14). The mean Θg for Unit C was 0.27% with a minimum of 0.14% and maximum of 0.61%. The mean Θg for Unit G was 0.32% with a minimum of 0.11% and maximum of 1.56%. The mean Θg for Unit H was 0.0.24% with a minimum of 0.13% and maximum of 0.37%. The variation in soil moisture Θg could be due to microsite and thermal heat in relation to sun exposure, as well as slash matting around piles. Pile area and volume could also be factors in soil moisture concentrations. Units C and G had less sun exposure through the day in observation than Unit H. They also had larger values in relation to pile area and volume as opposed to Unit H.

Bulk density (Db) was measured in g/cm^3 and the average Db measured for Unit C was 0.87 g/cm^3 with a minimum of 0.35 g/cm^3 and a maximum or 1.49 g/cm^3 (Table 14). Unit G's average Db was 0.90 g/cm^3 with a minimum of -0.33 g/cm^3 and a maximum or 1.33 g/cm^3. Unit H's average Db was 0.95 g/cm^3 with a minimum of 0.67 g/cm^3 and a maximum or 1.35 g/cm^3. The variation between units could be due to impact from equipment that was used during harvest.

Cation Exchange Capacity (CEC) was measured in meq/100g. The average CEC for Unit C was 2.23 meq/100g with a minimum 0.40 meq/100g and a maximum 7.20 meq/100g (Table 14). The average CEC for Unit G was 1.17 meq/100g with a minimum 0.40 meq/100g and a maximum 5.40 meq/100g. The average CEC for Unit H was 0.74 meq/100g with a minimum 0.30 meq/100g and a maximum 1.70 meq/100g. Units G and C had a lower average CEC in comparison to the Unit H average at 5.40 meq/100g. This means that ability for cations to bind was much lower for Units G and C as opposed to Unit H.

Nitrate-nitrogen (NO_3-N) was measured in ppm. The average NO_3-N for Unit C was 1.40 ppm with a minimum 1.00 ppm and a maximum 5.00 ppm (Table 14). The average NO_3-N for Unit G was 1.84 ppm with a minimum 1.00 ppm and a maximum 8.00 ppm. The average NO_3-N for Unit H was 1.41 ppm with a minimum 1.00 ppm and a maximum 6.00 ppm. Units C and H were lower than Unit G.

Ammonium nitrogen (NH_4-N) was measured in ppm. The average NH_4-N for Unit C was 4.85 ppm with a minimum 1.70 ppm and a maximum 9.70 ppm (Table 14). The average NH_4-N for Unit G was 6.19 ppm with a minimum 4.50 ppm and a maximum 9.10 ppm. The average NH_4-N for Unit H was 7.17 ppm with a minimum 4.70 ppm and a maximum 15.40 ppm.

Soils Candidate Models

Ninety-six models were run in Minitab using the mixed effects modeling tool to investigate the soils data that was collected in the summer of 2021 (Table 15). The purpose was to determine soil nutrient levels in relationship to distance to slash piles and the size of piles (i.e., volume and area). The primary nutrients that were evaluated included soil moisture percent (%) concentration (Θg), bulk density (Db), cation exchange capacity (CEC), ammonium nitrogen (NO_3-N), and nitrate nitrogen (NH_4-N). After reviewing the statistical data, it was determined that logarithmic transformations of dependent variables were not necessary, due to normal distribution of the data.

Table 15: Candidate models for predicting soil nutrient levels.

Response	Variables	R squared	AIC	ΔAIC
Soil Water Concentration	Null	9.11%	-188.13	
(Θg)	PV	7.89%	-171.22	16.91
	Dp+PV	10.96%	-142.05	46.08
Bulk Density (Db)	Null	1.07%	-47.15	
	PA	2.80%	-32.95	14.20
	PV	1.41%	-29.71	17.44
Cation Exchange Capacity	**Dp**	**42.67%**	**435.85**	
(CEC, meq/100g)	Null	38.78%	435.89	0.04
	DP+PV	42.66%	449.59	13.74
Nitrate Nitrogen	Null	15.28%	482.42	
(NO3-N, ppm)	Dp	19.66%	483.13	0.71
	Dp+PA	19.54%	495.38	12.96
Ammonium Nitrogen	**Dp**	**34.89%**	**624.62**	
(NH4-N' ppm)	Null	31.41%	628.72	4.10
	Dp+PA	34.30%	634.03	9.41

Note: Terms: PV = pile volume, PA = pile area, Dp = distance to pile, Statistics: R squared = a measure of the closeness of fit to the linear regression line looking at the variation in the dependent variable, AIC = Akaike information criterion, ΔAIC = change in Akaike information criterion, Units: Meq/100g = milliequivalents per 100 grams of soil. 1 meq/100 = 1 cmol(+)/kg, where cmol(+)/kg is the abbreviation for centimoles per kilogram, ppm = parts per million, Mixed effects models Akaike Information Criterion (AIC) were used to narrow down the best models with the lowest AIC values. In Table 15, the best models have been bolded due to their AIC being the best out of the ninety-six models that were evaluated. In each category there are three models, with two of them being the best models that were run and the null model. In the event that the null model was the best model, it was placed at the top of the three models for that particular nutrient that was evaluated. If the null model was the best model, there was no relationship between (response variable) and any candidate predictor variables, which concluded that the null model was the best model.

For Θg, it was determined that the null model was the best model with an AIC of -188.13 and an R^2 9.11 %. For Db, it was determined that the null model was the best model with an AIC of -47.15 and an R^2 1.07 %. For $N0_3$-N, it was determined that the null model was the best model with an AIC 482.52 and an R^2 value of 15.28%. For the above models with the null model being deemed the best model, the data would suggest that there was no relationship between the (response variable) and any candidate predictor variables such as distance to pile.

For CEC, it was determined that the best model had an AIC of 435.85 and an R^2 of 42.67%. The candidate predictor for this model was distance to pile, meaning that there was a relationship between CEC and the predictor variable distance to pile. For NH_4-N, it was determined that the best model had an AIC of 624.62 and an R^2 of 34.89%. The candidate predictor for this model was distance to pile, meaning that there was a relationship between NH_4-N and the predictor variable distance to pile.

Best Soils Models

CEC of the soil samples that were taken during the summer of 2021 field research were analyzed. The P value for distance to pile at all units for zero through fourteen meters were not strong predictors as they did not meet the alpha level of 0.05 or lower (Table 16). CEC was greater closer to the piles, indicated by the negative coefficients for the distances between zero through nine meters, which ranged from -0.08 to -0.31 meq/100g. Interestingly, CEC at fourteen meters was 0.19 meq/100g above average for the transects. Most of the variation (two thirds) in CEC was random error as opposed to variation between transects and piles nested within units. Overall, CEC was highly variable along transect lines. There is not a clear relationship between distance to pile and CEC values.

Table 16: Soils mixed effects modeling showing best models for predicting soil nutrient levels.

Response	Effect	Term	Coef	SE Coef	DF	T-Value	P-Value
Cation Exchange Capacity	Fixed	Constant	1.27	0.25	7.64	5.09	0.00
(CEC, meq/100g)		Dp (m)					
		0.00	-0.08	0.17	137.02	-0.46	0.64
		2.50	-0.25	0.17	137.02	-1.45	0.15
		5.00	-0.07	0.17	137.02	-0.39	0.70
		7.50	-0.31	0.17	137.02	-1.79	0.08
		9.00	-0.10	0.17	137.02	-0.56	0.58
		14.00	0.19	0.18	137.31	1.07	0.29
	Random	Source	Var	% of Total	SE Var	Z-Value	P-Value
		Pile	0.00	0.00	*	*	*
		Transect	0.00	0.00	0.03	0.16	0.43
		Unit (Pile)	0.41	0.34	0.24	1.68	0.05
		Error	0.81	0.66	0.10	8.27	0.00
		Total	1.22				

Note: Dp = distance to pile, Statistics: Coef = coefficients, SE Coef = standard error of coefficients, DF =Degrees of freedom, Var = variation, SE Var = standard error of variation, Meq/100g = milliequivalents per 100 grams of soil. 1 meq/100 = 1 cmol(+)/kg, where cmol(+)/kg is the abbreviation for centimoles per kilogram, ppm = parts per million,

Table 17: Soils mixed effects modeling showing best models for predicting soil nutrient levels.

Response	Effect	Term	Coef	SE Coef	DF	T-Value	P-Value
Ammonium Nitrogen	Fixed	Constant	6.05	0.47	6.97	12.79	0.00
(NH4-N, ppm)		Dp (m)					
		0.00	-0.34	0.33	133.35	-1.04	0.30
		2.50	-0.26	0.33	133.35	-0.78	0.43
		5.00	-0.39	0.33	133.35	-1.20	0.23
		7.50	-0.10	0.33	133.35	-0.31	0.76
		9.00	0.17	0.33	133.35	0.53	0.60
		14.00	0.68	0.33	133.55	2.05	0.04
	Random	Source	Var	% of Total	SE Var	Z-Value	P-Value
		Pile	0	0.00%	*	*	*
		Transect	0.09	0.02	0.19	0.47	0.32
		Unit (Pile)	1.31	0.30	0.79	1.65	0.05
		Error	2.90	0.67	0.35	8.16	0.00
		Total	4.30				

Note: Dp = distance to pile, Statistics: Coef = coefficients, SE Coef = standard error of coefficients, DF =Degrees of freedom, Var = variation, SE Var = standard error of variation, Units: PPM = parts per million, For NH_4-N of the soil samples that were taken during the summer of 2021 field research, the P value for distance to pile at all units for zero to nine meters was not significant due to the values being above the alpha level of 0.05 (Table 17). However, 14 m was a strong predictor of 0.04 when compared to the alpha level of 0.05. NH_4-N had a lower concentration closer to the piles, indicated by the negative coefficients for the following distances: 0 m was -0.34, 2.5 m was -0.26, 5 m was -0.39, and 7.5 m was -0.10 ppm below the average. NH_4-N was greater than average further away from the piles, indicated by the positive coefficients for the following distances: 9 m was 0.17 and 14 m was 0.68.

Most of the variation in NH_4-N was random error as opposed to variation between soil sampling transects and piles nested within units. Overall NH_4-N is highly variable along transect lines. There is not a clear relationship between distance to pile and NH_4-N values. For the other variables that were studied during soils analyses, soil moisture percent concentration (Θg), bulk density (Db), and nitrate nitrogen (NH_4-N), there was no relationship between the (response variable) and any candidate predictor variables, which concluded that the null models were the best models.

DISCUSSION

This study aimed to answer the following questions. 1st What are the average slash pile areas (m^2) and volumes (m^3) present at each study site? 2nd What is the total area (percent of harvest site) occupied by slash left after trees were planted? 3rd Over a one-year growth period do seedlings and clones grow larger in: height (m), diameter (mm), volume (cm^3), and basal area (mm^2) closer to piles of slash? 4th Approximately one year after piles were formed, will cation exchange capacity (CEC), bulk density (Db), percent soil water concentration (θg) and soil nutrients: ammonium (NH_4-N), nitrate (NO_3-), be elevated closer to slash piles?

The large average slash pile volume in this study was comparable to or larger than piles in other studies in the field. In Units C, G, and H, the average slash pile areas for the units were as follows: C: 726.29 m^2, G: 680.61 m^2, and H: 754.77 m^2. The average slash volumes for units were C: 1105.63 m^3, G: 1306.343 m^3, and H: 1321.82 m^3. In comparison, McCavour's (2016) piles of slash were 200-500 m^3, which are much smaller than the piles in this study. While the pile sizes in our study were much larger than McCavour's (2016) study, they were very comparable in site H to Ballard's (1978) study, indicating these sizes were not necessarily out of the norm. That being said, the piles at Units C, G and H were considerably larger than Green Diamond Resource Company would like. This was due to export restrictions because the mouth of Humboldt Bay needed to be re-dredged, which reduced the number of ships that could dock that could take the chips for export (Mitch Hunt, in-person communication, March 15, 2023). The implications of the inability to export as much hardwood as planned meant that the unit would have less plantable space, and it would be harder for Green Diamond’s Intensive Forest Management (IFM) department to meet their planting goals for trees per acre. As a result, they had to replant one of the sites because initially they only planted 100 trees per acre, as compared to 150 trees per acre at minimum.

Another aspect of the study addressed the percentage of slash left behind on sites. The total area studied for Unit G was 3.2 ha with a percent slash left on site after harvest of 19.14% (0.61 ha of the area), leaving approximately 80.86% plantable space for Unit G. The total area studied for Unit H was 3.0 ha with a percent slash left on site after harvest of 32.36% (0.97 ha of the area), leaving approximately 67.64% plantable space for Unit H. This is contrast to the Ballard (1978) study of windrows in New Zealand on timberland, where the windrows in their study site took up around 30% of the area. This means that they would have had 70% of their site left for planting if they desired. This was very similar to study site H where approximately 67% of the area was available to plant for units H, which was less than Unit G’s plantable space. One cause of this difference between the windrows in New Zealand and our study besides the inability to export chips as much could be that our large machine-constructed piles were taller and therefore carried more slash volume per unit of ground area than typical long narrow windrows that we speculate were much shorter in stature than our large oval piles.

In general, the IFM department generally tries to have the least amount of slash left on site as possible after harvest. This is done to maximize plantable space like many timber companies, and IFM generally wants piles to take up less than 10-15% of the overall clearcut harvest area. Depending on site class and designation by the California Forest Practice rules, silvicultural foresters designate the spacing of planted seedlings and clones to meet the desired TPA for that specific harvest unit (Mitch Hunt, in-person communication, March 15, 2023). This is similar to the 1980s, when piles often covered only 10-15% of areas that had been selectively cut (Rosén and Lundmark-Thelin, 1987). This seems to have stayed consistent throughout the decades as Green Diamond's standard today is right around that same guideline.

Growth after one year was the next metric measured in this study. One year is a limited amount of time to complete a study within, especially in Northern California where droughts are common, and climate and tree growth fluctuates annually (Dagley et al. 2023). Studies of seedling growth usually span several years to average out these fluctuations. For example, field studies by Berrill et al. (2018, 2020), Zabowski et al. (2000), McCavour (2016), Jameson & Robard (2007), and Preston et al. (2011) all ranged between 3-10 years long. Over a one-year growth period, Douglas-fir seedlings and redwood clones grew slightly more stem basal area further from piles, while distance from pile did not significantly affect stem diameter growth or volume growth. In terms of stem basal area and volume, redwood grew more over the one-year period than Douglas-fir. It was predicted that the average Douglas-fir seedling change in volume at all units would be 11.02 cm^3, as opposed to redwood which was predicted to be 13.77 cm^3. Redwood clones grew at a faster rate over a one-year period and Douglas-fir was still a larger tree at that time by approximately 5 cm^3. Change in diameter between years one and two would predict that the average change in seedling and clone diameter at all units would be 4.01 mm. These findings are consistent with Berrill et al. (2018) who also compared redwood and Douglas-fir seedlings planted outside redwood's range at Maple Creek, at a similar site roughly 15 miles farther south than our study site. They reported that redwood was slower to become established and grow, but then accelerated and began to catch up with Douglas-fir after three years (Berrill et al. 2018).

Change in height from year one to year two indicated the larger the seedling height was at year one, the less the seedling would be expected to grow in height between years one and two. Similar to the Jameson & Robard (2007) study where they looked at redwood seedlings from plug stage (right out of the Styrofoam) to two years after plug stage and found that there were no significant differences in seedling height between their units, our model similarly predicted that the average change in seedling height would be only 0.06 m between years one and two.

In regards to the change in basal area, the data suggested that it would be expected that seedlings would have greater basal area further from piles. Douglas-fir had a larger basal area at years one and two compared to redwood. Our model predicted that the change in average basal area between years one and two (BAI) for all units for Douglas-fir would be 27.50 mm² and redwood would be 42.49 mm². The result for Douglas-fir is comparable to the Berrill et al. (2018) study which looked at variable density retention rates and found a mean basal area of 22.03 mm², which is very similar to ours. Redwood, however, grew more in basal area over the one-year increment and was more affected by distance to pile, growing better further away. For example, for every meter away from a pile, redwood would be expected to have a BAI increase of 2.03 mm², whereas Douglas-fir would only be expected to increase by 0.72 mm².

McCavour (2016) reported that trees grew better near piles rather than far from piles when studying a 6-year-old hybrid poplar plantation in Canada. That study stated that tree volume decreased exponentially as the distance from the piles increased. McCavour (2016) stated that because the trees within the surrounding four meters of the piles showed increased soil nutrients, that the rotation time of harvest could reduce by 8% or more because of the pile area's reach. The data from our study does not match that conclusion, as trees farther away from the piles had a greater increase in basal area and stemwood volume when compared to the trees close the piles. Additionally, redwood grew more than Douglas-fir the farther away from the pile the seedlings were, potentially indicating they were affected even more by their proximity to piles than the Douglas-firs. Perhaps, as Berrill et al.'s (2018) study suggests, overstory, above-ground competition, or below-ground competition is playing a role that we have not yet established.

Soil cation exchange capacity and distance to pile did not have a strong correlation. CEC was greater closer to the piles for the distances between zero through nine meters, which ranged from -0.08 meq/100g to -0.31 meq/100g. CEC at fourteen meters was 0.19 meq/100g above average for the transects. For our study there was not a clear and consistent relationship between distance to pile and CEC values. This is not consistent with DeByle's (1980) study, which measured the cation exchange capacity of the surface through 15cm deep, with the surface result measuring average 18.63 meq/100 g and 5-15cm measuring average 15.27 meq/100g of soil. We suspect that the CEC in our study was significantly lower due to the soil being analyzed for CEC in the lab instead of in the natural environment, where it isn't separated and dried. We also suspect that the CEC nearer to the piles had not yet been influenced by the pile decay, as there was not yet visible decay when surveyed.

NH_4-N from zero to nine meters was not significant due to the values being above the alpha level of 0.05. However, at 14 m NH_4-N was significant when compared to the alpha level of 0.05. It was found that NH_4-N had a lower concentration closer to the piles for the following distances: 0 m was -0.34, 2.5 m was -0.26, 5 m was -0.39, 7.5 m was -0.10 ppm below the average. NH_4-N was found to have greater influence at the following distances: 9 m was 0.17, and 14 m was 0.68. Overall, NH_4-N was highly variable along transect lines. There is not a clear relationship between distance to pile and NH_4-N values.

In contrast, McCavour et al. (2014) and McCavour's (2016) study seemed to find a negative correlation with NH_4-N, meaning that the value was high near the piles. This is similar to Rosén & Lundmark-Thelin's (1987) and Preston et al.'s (2011) results. Rosén & Lundmark-Thelin (1987) found that there was an increased amount of nitrogen found in the soil underneath their slash piles whereas Preston et al.'s (2011) study indicated higher levels of N within chipped piles of slash after a 10-year period, with positive seedling growth the nearer to the piles they were. Rosén & Lundmark-Thelin (1987) attributed that to increasing mineralization, in addition to roots having a reduction in the uptake of nitrogen. There has likely not been enough time for these factors to have impacted the soil in our study yet because the Preston et al. (2011) study measured at years 6 and 10, but found the higher N level in soil only after year 10, indicating it took a period of time to impact the soil nutrient levels.

Again, our study seems to contradict the McCavour (2016) and Rosén & Lundmark-Thelin (1987) studies as our study found no significant correlation with close distance to pile and positive tree growth. This could be due to the fact that we were looking at much younger trees than McCavour et al. (2014), McCavour (2016), and Rosén & Lundmark-Thelin's (1987) studies did. While our study looked at trees just one to two years after planting took place in 2020, McCavour's (2016) study took place in 2012 after the planting had taken place in 2006. This is a much longer span of time for nutrients to leach into soil as a result of slash piles and for nutrient levels to be meaningfully affected by the slash piles. For the other variables that were studied during soils analyses, soil moisture (Θg), bulk density (Db), and nitrate nitrogen (NH_4-N), there was no relationship between the (response variable) and any candidate predictor variables which concluded that the null models were the best models. Bulk density in Graham et al.'s (1989) study looked in part at soil moisture and bulk density using a soil corer and then drying to calculate. They were able to find a relationship between growing their Douglas-fir in beds with chemically controlled competition removal and being the tallest and heaviest. Their result indicated that the soil they had in the beds was full of organic matter (we would suggest similar to fine woody debris) that had a higher capacity to hold moisture and keep a lower bulk density. This would have been more like the result expected to be seen in our study, but we suspect our soil simply did not have enough time to develop any kind of relationship yet.

A similar study that looked at treatment of post-harvest residue’s effect on soil and seedlings was completed in eastern Washington over four study sites that had been clearcut and then planted with Douglas-fir (*Pseudotsuga menziesii*) and lodgepole pine (*Pinus contorta*) (Zabowski et al., 2000). The Washington sites were 5-12 ha, similarly, our study’s sites were between 3-12 ha. The results in Zabowski et al.’s (2000) study found that burning the slash piles specifically in spring led to the highest average height growth for Douglas-fir and lodgepole pine after five years and it was not windrows that produced the most height gain. The length of the study in Washington most likely assisted in such clear results about which method resulted in the most cm of growth. Since that study was effective in detecting treatment effects on growth rates after just five years, it’s possible that our study in Northern California could show more conclusive results in 2025.

As our study and the Zabowski et al. (2000) study suggest, Douglas-fir seem to do better farther from piles (if they exist) or with no piles, which would happen as a result of burning or of leaving slash where it falls without disturbing it. Perhaps Douglas-fir has a preference for a type of land with fire as natural disturbance because they can compete well in that environment and grow quickly, and that is why the Douglas-fir in this study grew quicker the farther away from the piles they were.

Hardy’s (1996) guidelines for calculating the combustion efficiency of burning slash piles demonstrate how much burning was relied on to eliminate slash. The authors studied packing of piles, classifications of sizes of CWD and FWD with their effect on burning, and what percentage of piles must burn to give the most precise recommendations to timber companies for slash elimination via burning. The in-depth guidelines from Hardy’s study indicate how commonplace it was to use burning as a way to eliminate slash, and the hope is that with more time studying alternative slash disposal methods such as windrowing that there could be this type of extensive slash pile research in future. Our study hopes to contribute to the start of a large body of research on this topic to inform best practices for forest managers in future.

SUMMARY & RECOMMENDATIONS

In conclusion, there was no evidence to correlate increased seedling and clone growth near slash piles, and in fact the opposite was found. There was also no evidence of increased nitrogen levels in soil near slash piles. This study did find that redwood grew better further away from the piles, even outpacing Douglas-fir growth. The growth rates indicated that both species grew better farther away from the piles.

Our study is valuable in that it tries to address alternative uses of post-harvest residue and determine if the methods from both McCavour et al.'s 2014 and McCavour's 2016 studies could be replicated with success in the United States. While the results did not back up McCavour's (2016) study, our study would most likely show more results were it to take place six to seven years after planting such as Ballard (1978) and McCavour's (2016) studies did, instead of between one to two years after planting. That is one of the major limitations of this study.

Plants evolve in and adapt to pH ranges over time, and although soil conditions are still under-studied, redwoods are understood to prefer slightly acidic soil with pH perhaps falling between 5.5 and 6.0 (Redwood Park Association, 2002). Douglas-fir have a broader optimal range that may extend to a wider pH range of 4.5-7.2 (Eckhart et al., 2019). Species that have lower optimal pH ranges have been found to have the ability to better utilize NH_4 as a N source than species with a higher optimal pH range (McCavour et al., 2014; Hahne & Schuch, 2004). NH_4 is available earlier in the N cycle and excluding other factors, NH_4 adapted species can utilize nitrogen following decomposition before it is converted to NO_3, leaving less nitrogen available to plants adapted to utilize NO_3 over NH_4 (McCavour et al., 2014; Hahne & Schuch, 2004). At the same time, optimal pH ranges are in part driven by or interact with the microbial communities that live in those ranges (McCavour et al., 2014). Therefore, a limitation of this study is the lack of data on soil pH, and similarly, microbial analyses because optimal pH range varies by species, and the optimal pH ranges cited in the literature for redwoods and Douglas-fir are influenced and driven by microbial community differences. Berrill & O'Hara (2016) found that soil pH was positively correlated with redwood productivity in Mendocino County further south than our study site and closer to the Pacific coast, and that pH (which averaged 5.1 but was highly variable) was more strongly associated with redwood productivity than nitrogen content or the carbon: nitrogen ratio (Berrill & O'Hara 2016).

Limitations affecting the study also included restricted geographic extent, limited sample size, and statistical power. While all studies have limitations, our study had enough limiting factors to caution against drawing any conclusions based on this study alone from any of the findings. Specifically, the close proximity of harvest units restricts the scope of inference of our findings to the area adjacent to Lord Ellis Summit, California. Furthermore, two units were immediately adjacent to one another and harvested in the same year, suggesting that they may not actually represent independent sample units. Assessing soil chemistry so soon after harvest and pile building risked missing the detection of pile effects that may develop over time but may not be detectable within one year of pile construction. The sampling of multiple piles nested within each unit was time-efficient but necessitated mixed-effects analysis with an associated loss of statistical power due to the lack of statistical independence among piles sharing the same unit. This meant that effectively the study only had two to three replicates, which is unlikely to give sufficient power to allow for detection of finer differences or effects of pile size and distance.

Therefore, we recommend future studies sample fewer piles per unit across many more units covering a broader geographic area. The depth and scope of this project was also highly involved with all three units for one to two researchers to cover within two short summer seasons, and ideally could have had better results if sample areas were smaller and more time was available to collect field data. We also recommend assessing soil properties before pile construction, and again some years later to give time for pile effects to manifest themselves and simultaneously delay remeasurement of planted stock to give a longer growth period for analysis. While we do not have data on pH, a future study could also include an examination of pH, nitrate, and ammonium values. Douglas-fir has an optimal pH range that is higher than that of redwood, and in this study, both species are planted in an area that may be more suited to Douglas-fir pH preferences than to redwood, as the study area is in a geographical location near the edge of the range understood to be native for redwoods.

There could be a fear that the inconclusive results of this study could deter future study or timber company interest in this topic. However, we would argue that studying alternative slash disposal, especially disposal that has such a possibility to benefit company and forest ecosystems alike, wasn’t wasted time. Something to study in future could be revisiting the sites after 5-15 years, in order to see if the findings in this study are sustained or in fact reverse and start to mirror closer to McCavour (2016) and others.

LITERATURE CITED

Aalto, K. R., Kathy Moley, and Linda Stone. 1995. "Neogene paleogeography and tectonics of northwestern California." In *Cenozoic Paleogeography of the Western United States: II*, edited by A. Eugene Fritsche: 162-180. No city, Pacific Section, SEPM (Society for Sedimentary Geology).

Ambrose, Anthony R., Baxter, Wendy L., Wong, Christopher S., Næsborg, Rikke R., Williams, Cameron B., and Dawson, Todd E. 2010. "Contrasting drought-response strategies in California redwoods." *Tree Physiology* 35, no. 5: 453-469. https://doi.org/10.1093/treephys/tpv016

Attiwill, Peter M., 1994. “The disturbance of forest ecosystems: the ecological basis for conservative management.” *Forest Ecology and Management*, 63 (2-3): 247-300. https://doi.org/10.1016/0378-1127(94)90114-7

Ballard, Russ. 1978. "Effect of slash and soil removal on the productivity of second rotation radiata pine on a pumice soil." Accessed March 27, 2023. *New Zealand Journal of Forestry Science* 8, no. 2: 248-258. https://www.scionresearch.com/__data/assets/pdf_file/0004/59008/NZJFS821978BALLARD248_258.pdf

Berrill, John-Pascal, O’Hara, and Kevin L. 2016. “How do biophysical factors contribute to height and basal area development in a mixed multiaged coast redwood stand?” *Forestry* 89: 170–181. https://doi.org/10.1093/forestry/cpv049

Berrill John-Pascal, Dagley Christa M., Gorman Alexander J.,Obeidy Chelsea S., Powell Holly K., and Wright Joseph C. 2018. “Variable-density Retention Promotes Spatial Heterogeneity and Structural Complexity in a Douglas-fir/Tanoak Stand.” Accessed March 26, 2023. *Current Trends Forest Research*: CTFR-108. https://www.gavinpublishers.com/article/view/variabledensity-retention-promotes-spatial-heterogeneity-and-structural-complexity-in-a-douglas-fir-tanoak-stand

Berrill, John-Pascal, Webb, Lynn A., DeYoung, Kristy L., Dagley, Christa M.; Bodle, Christopher G., and Simpson, Sean M. 2020. “Development of redwood regeneration after conifer partial harvest and hardwood management.” *Forest Science* 67(1): 72-82. https://doi.org/10.1093/forsci/fxaa031

Boyle, James R. and Powers, Robert F. 2013. "Forest Soils.” In Reference Model in Earth Systems and Environmental Sciences, compiled by Elsevier: 73-79. https://doi.org/10.1016/B978-0-12-409548-9.05169-1

Dagley, Christa M., Berrill, John-Pascal, and Fraver, Shawn. 2023. “Forest restoration mitigates drought vulnerability of coast Douglas-fir in a Mediterranean climate.” *Canadian Journal of Forest Research* 53: 1–7. https://doi.org/10.1139/cjfr-2022-0119

Dahlberg, Anders, Göran Thor, Johan Allmér, Mats Jonsell, Mattias Jonsson, and Thomas Ranius. 2011. "Modelled impact of Norway spruce logging residue extraction on biodiversity in Sweden." *Canadian Journal of Forest Research* 41, no. 6): 1220-1232. https://doi.org/10.1139/x11-034

DeBye, Norbert. 1980. "Harvesting and Site Treatment Influences on the Nutrient Status of Lodgepole Pine Forest in Western Wyoming." In *Volume 90 of USDA Forest Service general technical report INT, United States Intermountain Forest and Range Experiment Station, Ogden, Utah*, edited by Intermountain Forest and Range Experiment Station (Ogden, Utah): 137-155. University of Michigan: The Station.

Earthstar Geographics, ESDA FSA, GeoEye, Maxar. ArcGIS Pro.

Eckhart, Tamra, Pötzelsberger, Elisabeth, Koeck, Roland, Thom, Dominik, Lair, Georg J., van Loo, Marcela, and Hasenauer, Hubert. 2019. "Forest stand productivity derived from site conditions: an assessment of old Douglas-fir stands (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) in Central Europe." *Annals of Forest Science* 76, 19: 1-11. https://doi.org/10.1007/s13595-019-0805-3

Farve, Reynaud and Napper, Carolyn. 2009. *Biomass Fuels & Whole Tree Harvesting Impacts on Soil Productivity review of Literature.* Accessed October 25, 2022. US Department of Agriculture, Forest Service, San Dimas Technology and Development Center. https://www.fs.usda.gov/t-d/pubs/pdf/hi_res/09201803hi.pdf

Graham, Russell T., Harvey, Alan E. and Jurgensen, Martin F. 1989. "Effect of site preparation on survival and growth of Douglas-fir (Pseudotsuga menziessi Mirb. Franco.) seedlings." *New Forests*, 3: 89-98. https://doi.org/10.1007/BF00128903

Green Diamond Timber Resource Company Digital Elevation Modeling data, accessed December 16 2020.

Gulick, Sean P., Meltzer, Anne S., and Clarke Jr, Samuel H. 2002. "Effect of the northward-migrating Mendocino triple junction on the Eel River forearc basin, California: Stratigraphic development." *Geological Society of America Bulletin*, 114(2): 178-191. https://doi.org/10.1130/0016-7606(2002)114<0178:EOTNMM>2.0.CO;2

Hacker, Jan J. 2005. "Effects of Logging Residue Removal on Forest Sites A Literature Review." Accessed March 26, 2023. West Central Wisconsin Regional Planning Commission. https://dnr.wisconsin.gov/sites/default/files/topic/ForestBusinesses/LoggingResidueReport.pdf

Hagemann, Ulrike, Moroni, Martin T., Gleißner, Johanna, and Makeschin, Franz. 2010. "Disturbance history influences downed woody debris and soil respiration." *Forest Ecology and Management* 260, 10: 1762-1772. https://doi.org/10.1016/j.foreco.2010.08.018

Hahne, Kathryn S. and Schuch, Ursula K. 2004. "Response of Nitrate and Ammonium on Growth of *Prosopis Velutina* and *Simmondsia Chinensis* Seedlings." University of Arizona College of Agriculture Turfgrass and Ornamental Research Report.

Accessed May 3, 2023. https://cals.arizona.edu/extension/ornamentalhort/nurseryprod/nitrogenresponse.pdf

Hardy, Colin C. 1996. *Guidelines for Estimating Volume, Biomass, and Smoke Production for Piled Slash.* US Department of Agriculture, Forest Service, Pacific Northwest Research Station. https://doi.org/10.2737/PNW-GTR-364

Hermann, Richard K. and Lavender, Denis P. 1990. Pseudotsuga menziesii (Mirb.) Franco, Douglas-fir. In Burns and Honkala (Editors) 1990. "Silvics of North America: 1. Conifers." *Agriculture Handbook 654*, 1, 675. U.S. Department of Agriculture, Forest Service, Washington, DC. https://www.srs.fs.usda.gov/pubs/misc/ag_654_vol1.pdf

Jameson, Marc J. and Robards, Timothy A. 2007. "Coast Redwood Regeneration Survival and Growth in Mendocino County, California." *Western Journal of Applied Forestry*, 22(3):171–175. https://doi.org/10.1093/wjaf/22.3.171

Lattimore, Brenna, Smith, C.T., Titus, Brian T., Stupak, Inge, and Egnell, Gustaf. 2009. "Environmental factors in woodfuel production: Opportunities, risks, and criteria and indicators for sustainable practices." *Biomass and Bioenergy*, 33(10): 1321-1342. https://doi.org/10.1016/j.biombioe.2009.06.005

Lock, Jane, Kelsey, Harvey, Furlong, Kevin, and Woolace, Adam. 2006. "Late Neogene and Quaternary landscape evolution of the northern California Coast Ranges: Evidence for Mendocino triple junction tectonics." *Geological Society of America Bulletin*, 118(9-10): 1232-1246. https://doi.org/10.1130/B25885.1

McCavour, Melanie J. 2016. "The Role Of Spatially Aggregated Post-Harvest Woody Residue in Soil Fertility and the Establishment, Growth, and Flowering of Plants." Ph.D. Thesis, University of Quebec in Montreal, Canada. http://archipel.uqam.ca/id/eprint/9276

McCavour, Melanie J., Paré, David, Messier, Christian, Thiffault, Nelson, and Thiffault, Evelyne. 2014. "The role of aggregated forest harvest residue in soil fertility, plant growth, and pollination services." *Soil Science Society of America Journal*, 78(S1): S196-S207. https://doi.org/10.2136/sssaj2013.08.0373nafsc

Olson, David F. Jr., Roy, Douglass F., and Walters, Gerald A. "Sequoia sempervirens (D. Don) Endl. Redwood." In Burns and Honkala (Editors) 1990. "Silvics of North America: 1. Conifers." *Agriculture Handbook 654*, 1, 675. U.S. Department of Agriculture, Forest Service, Washington, DC. https://www.srs.fs.usda.gov/pubs/misc/ag_654_vol1.pdf

Preston, Caroline M., Smernik, Ronald J., Powers, Robert F., McColl, John G., and McBeath, Therese M. 2011. "The decomposition of windrowed, chipped logging slash and tree seedling response: A plant growth and nuclear magnetic resonance spectroscopy study." *Organic Geochemistry* 42, no.8: 936-946. https://doi.org/10.1016/j.orggeochem.2011.03.026

Raibley, Robert. 2018. “Evolution and migration of Northern California fluvial estuary sediment depositional systems due to the northern movement of the Mendocino Triple Junction.” Geology 332 Research Paper, Cal Poly Humboldt.

Redwood Park Association. 2002. “How to Help Your Redwood Seedling Survive.” National Park Service Educational Publication. Accessed May 3, 2023. https://www.nps.gov/redw/planyourvisit/upload/redw-seedlings-2012-508.pdf

Rose, Cathy L., Marcot, Bruce G., Mellen, T. Kim, Ohmann, Janet L., Waddell, Karen L., Lindley, Deborah L. and Schreiber, Barry. 2001. “Decaying Wood in Pacific Northwest Forests: Concepts and Tools for Habitat Management.” Accessed October 30, 2022. In *Wildlife-Habitat Relationships in Oregon and Washington*: 580-623. Oregon State University Press, Corvallis. https://apps.fs.usda.gov/r6_decaid/legacy/decaid/pages/documents/Rose-et-al-2001.pdf

Rosén, Kaj and Lundmark-Thelin, Anita.1987. “Increased nitrogen leaching under piles of slash— a consequence of modern forest harvesting techniques.” *Scandinavian Journal of Forest Research*, 2(21-29): 1-4. https://doi.org/10.1080/02827588709382443

van der Wal, Annemieke, de Boer, Wietse, Smant, Wiecher, and van Veen, Johannes A. 2007. “Initial decay of woody fragments in soil is influenced by size, vertical position, nitrogen availability and soil origin.” *Plant and Soil*, 301(1-2): 189-201. https://doi.org/10.1007/s11104-007-9437-8

Zabowski, Darlene, Java, B., Scherer, George, Everett, R.L., and Ottmar, Roger. 2000. “Timber harvesting residue treatment: Part 1. Responses of conifer seedlings, soils and microclimate.” *Forest Ecology and Management* 126, no. 1: 25-34. https://doi.org/10.1016/S0378-1127(99)00081-X

APPENDICES

Appendix A: Geomorphology

The source of the following information is an unpublished report that had previously been prepared by the author (Raibley, 2018).

Geologic processes are a major part of our study region; however, they do not play as much of a role as fire and wind do in terms of natural disturbance reoccurrence rates (Raibley, 2018). The primary type of geomorphologic disturbance in the study area is sliding and slumping of the coastal thrust belt system. Due to this constant motion, loosely unconsolidated soils are constantly in motion at a rate of approximately 2-5mm/year. This does have a natural disturbance effect but differs from fire and wind, where one tends to see more trees downed in a single event.

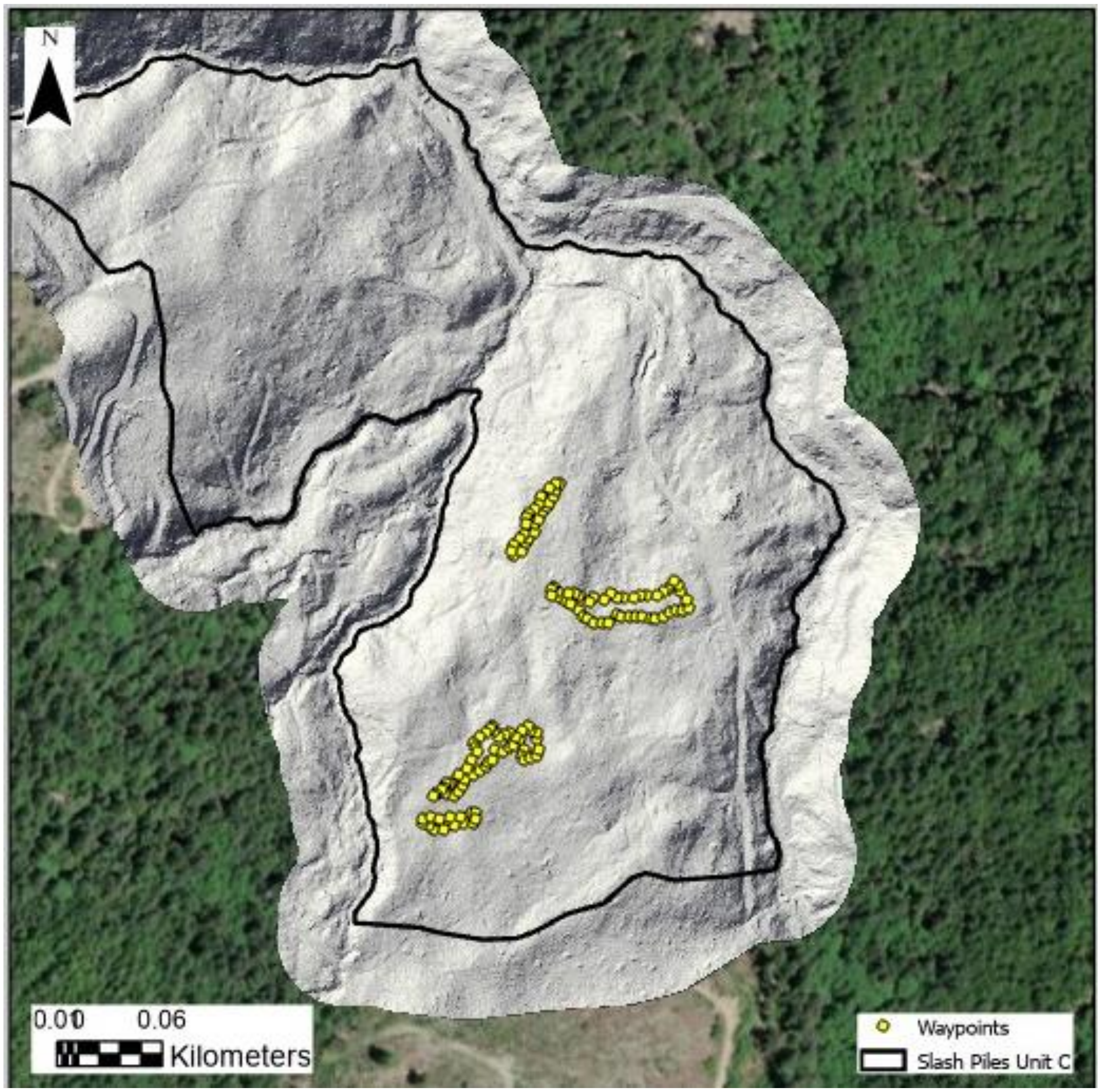
The Mendocino Triple Junction’s central point is located at approximately Humboldt Hill (Lock et al., 2006: Gulick et al., 2002). At this point there are two oceanic plates being separated by the Mendocino fracture zone coming in from the west of Humboldt Hill. The plate to the south of the Mendocino fracture zone is the Pacific Plate and the plate to the north is the Gorda Plate (Lock et al., 2006: Gulick et al., 2002). Both the Pacific and Gorda plates are in collision with the North American Continental Plate to the east (Lock et al., 2006: Rose et al., 2001: Raibley, 2018).

The Gorda Plate is actively subducting under the North American Plate, creating the Cascadian Arc to the northeast of Humboldt Hill (Lock et al., 2006: Gulick et al., 2002: Raibley, 2018). The Pacific Plate is being carried northward by a right lateral strike slip system known as the San Andreas Fault, and is in collision with the Mendocino Fracture Zone, as well as the Gorda and North American plates (Lock et al., 2006: Gulick et al., 2002). This collision is causing the Mendocino Triple Junction to transition laterally northward along the Mendocino Crustal Conveyor (Lock et al., 2006: Gulick et al., 2002). As the Mendocino Triple Junction shifts northward, a series of anticlines and synclines (rolling inland hills) have developed, known as a thrust belt system, north of the Mendocino Fracture Zone (Lock et al., 2006: Gulick et al., 2002).

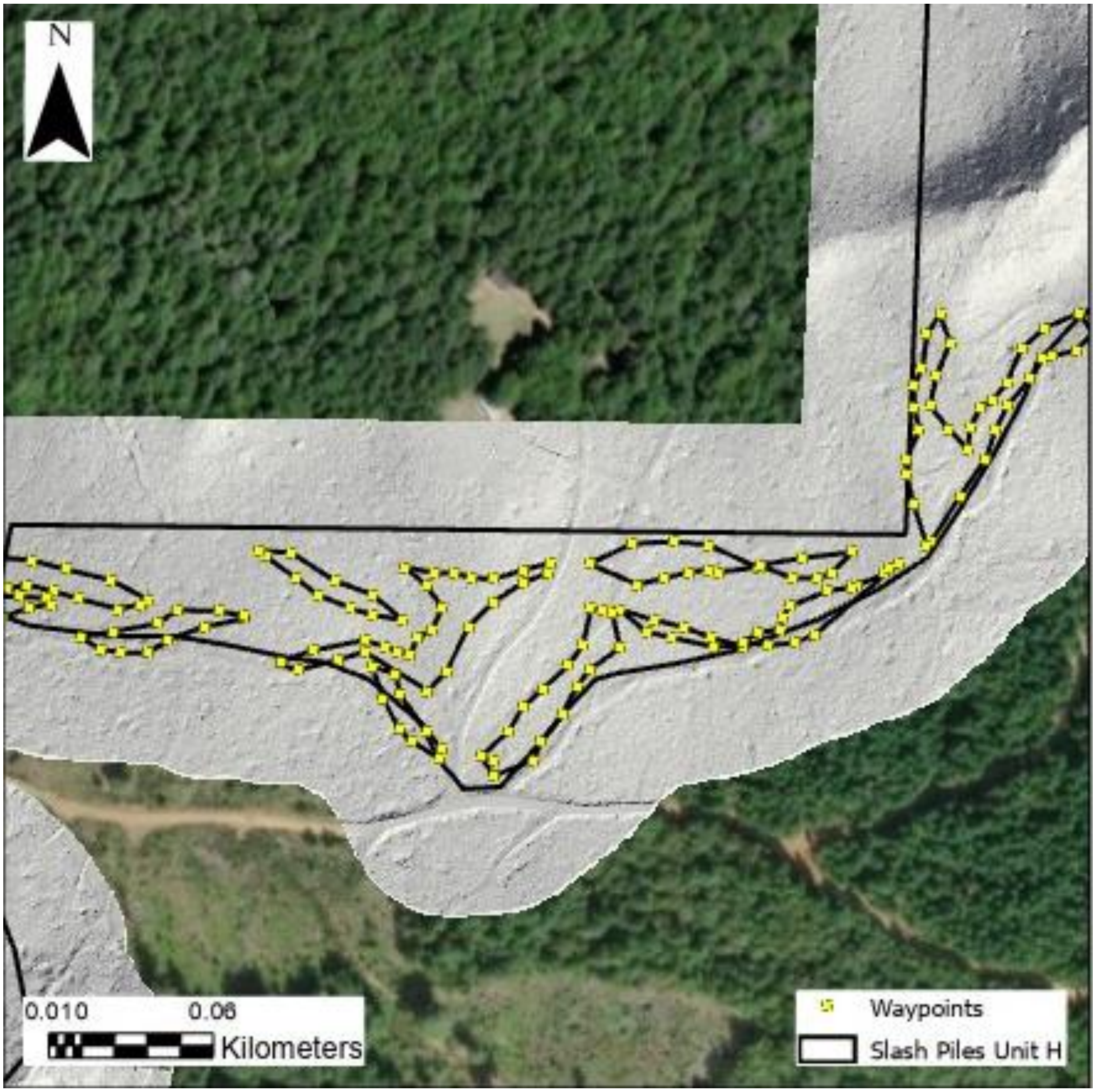
The study location is located in this thrust belt system. The slash pile locations were specifically placed on top of the anticlines to have the least slope angle as possible for an even distribution of soil nutrients. Special attention had to be focused on the slope gradient and angle, as the ideal slope angle for even nutrient disbursement is less than 12°. A gradient greater than 12° in the loosely unconsolidated soils would mean that the nutrients would leach downslope before being able to be taken up by the redwood trees around the piles, due to slumping and sliding of the Franciscan Mélange (Aalto et al., 1995: Raibley, 2018).

Appendix B-D: Hillshade Diagrams

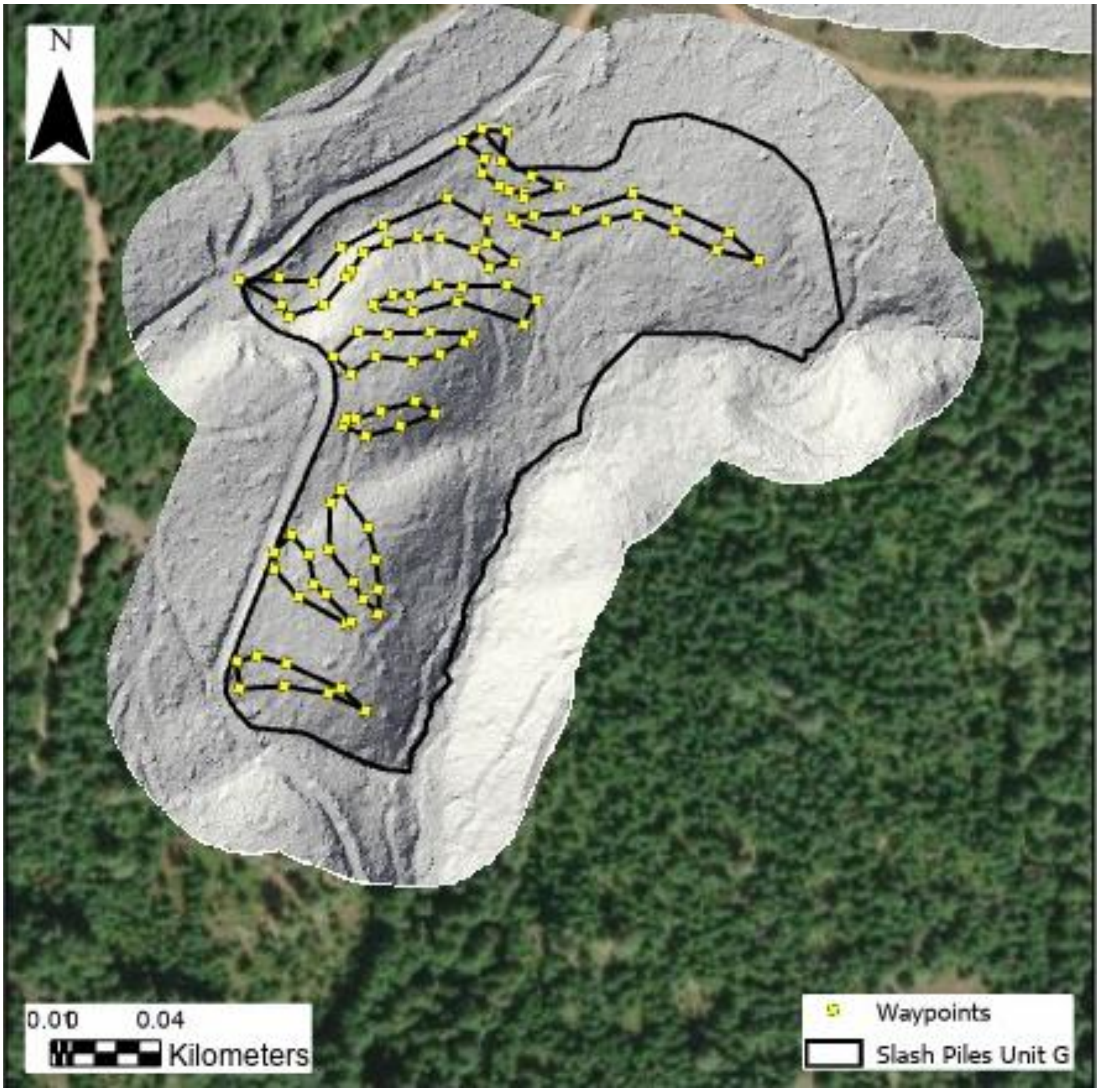
Appendix B: Hillshade Model for Unit C



Appendix C: Hillshade Model for Unit H

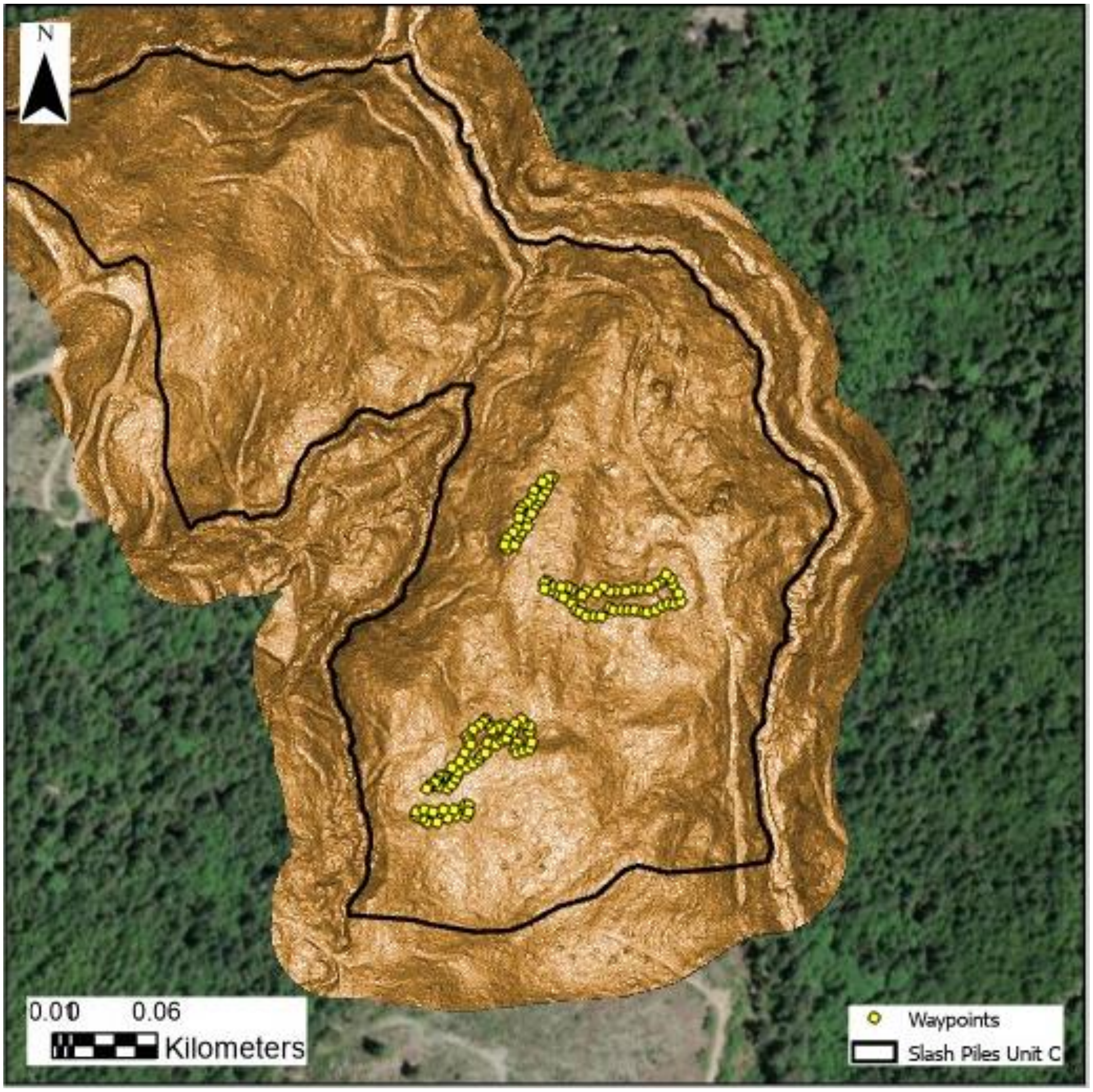


Appendix D: Hillshade Model for Unit G

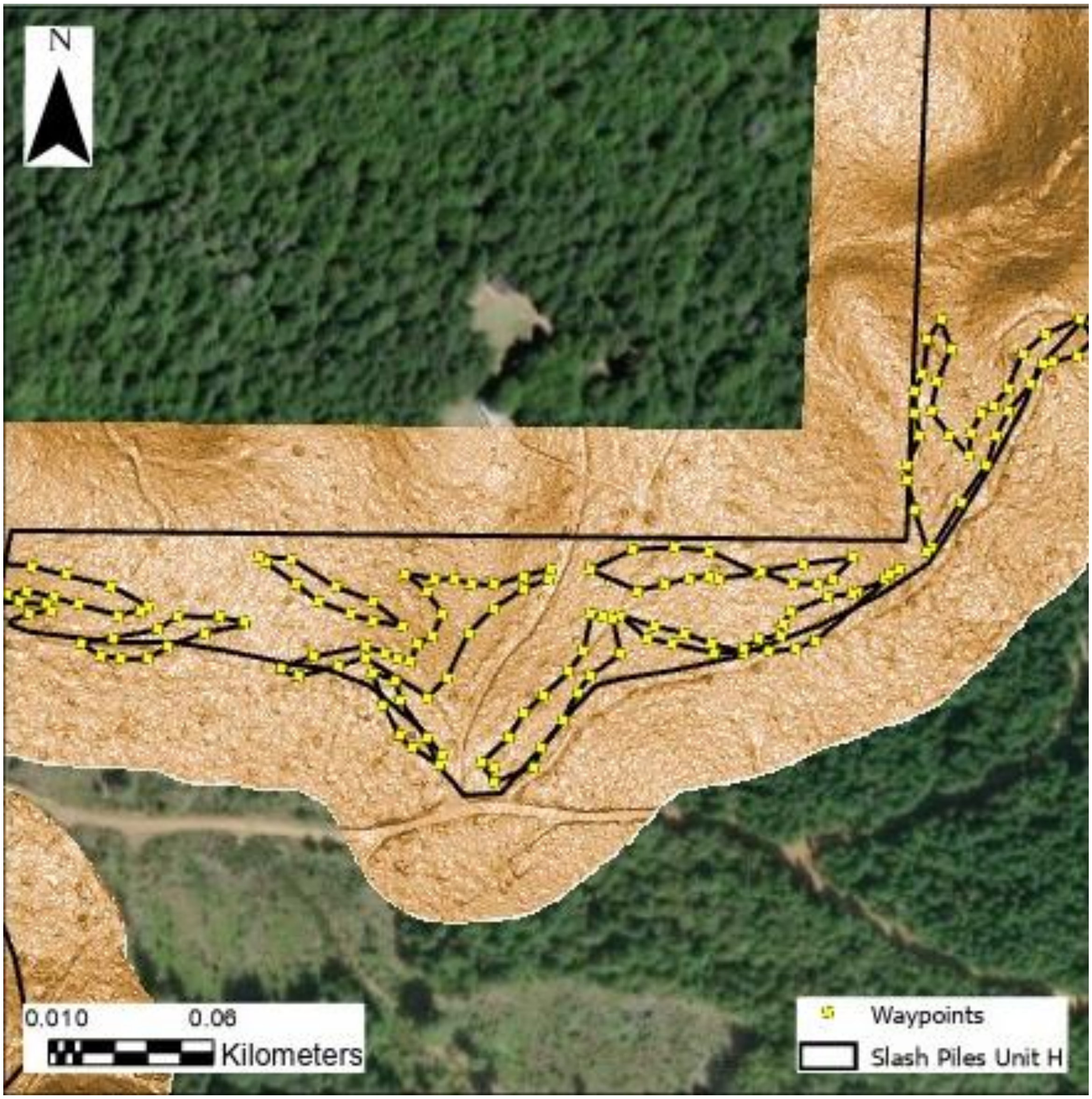


Appendix E-G: Hillslope Diagrams

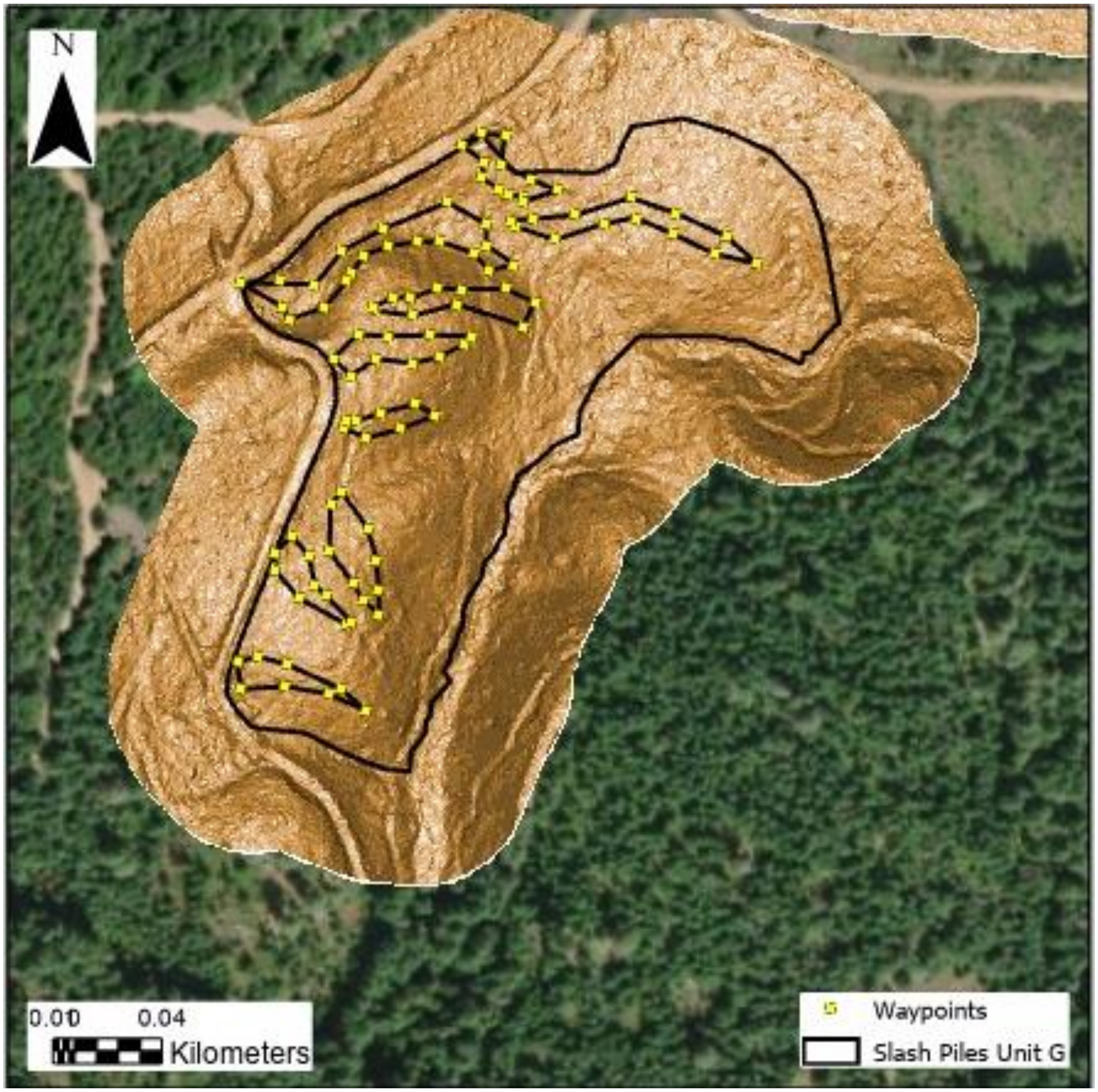
Appendix E: Hillslope Model for Unit C



Appendix F: Hillslope Model for Unit H

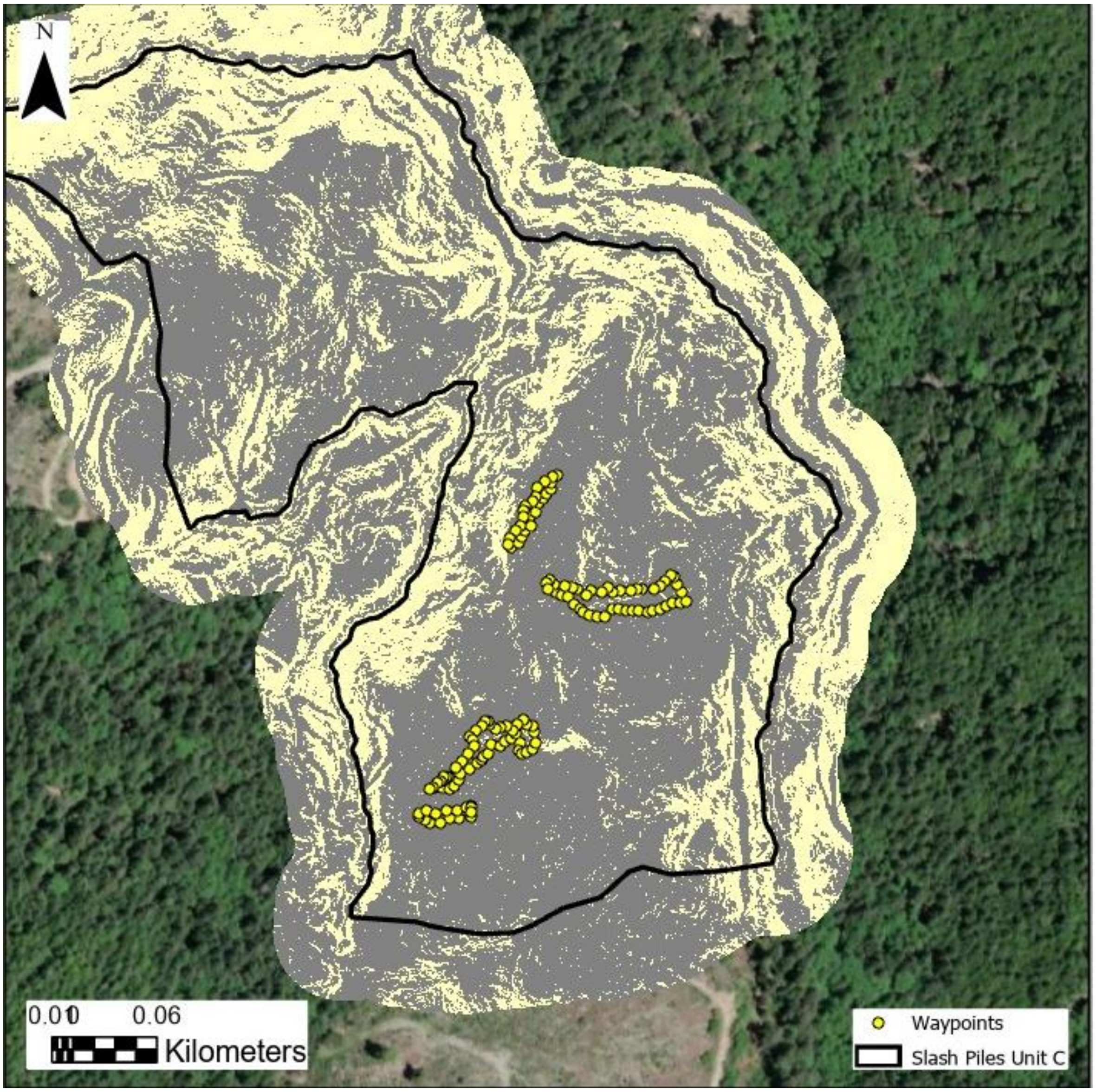


Appendix G: Hillslope Model for Unit G

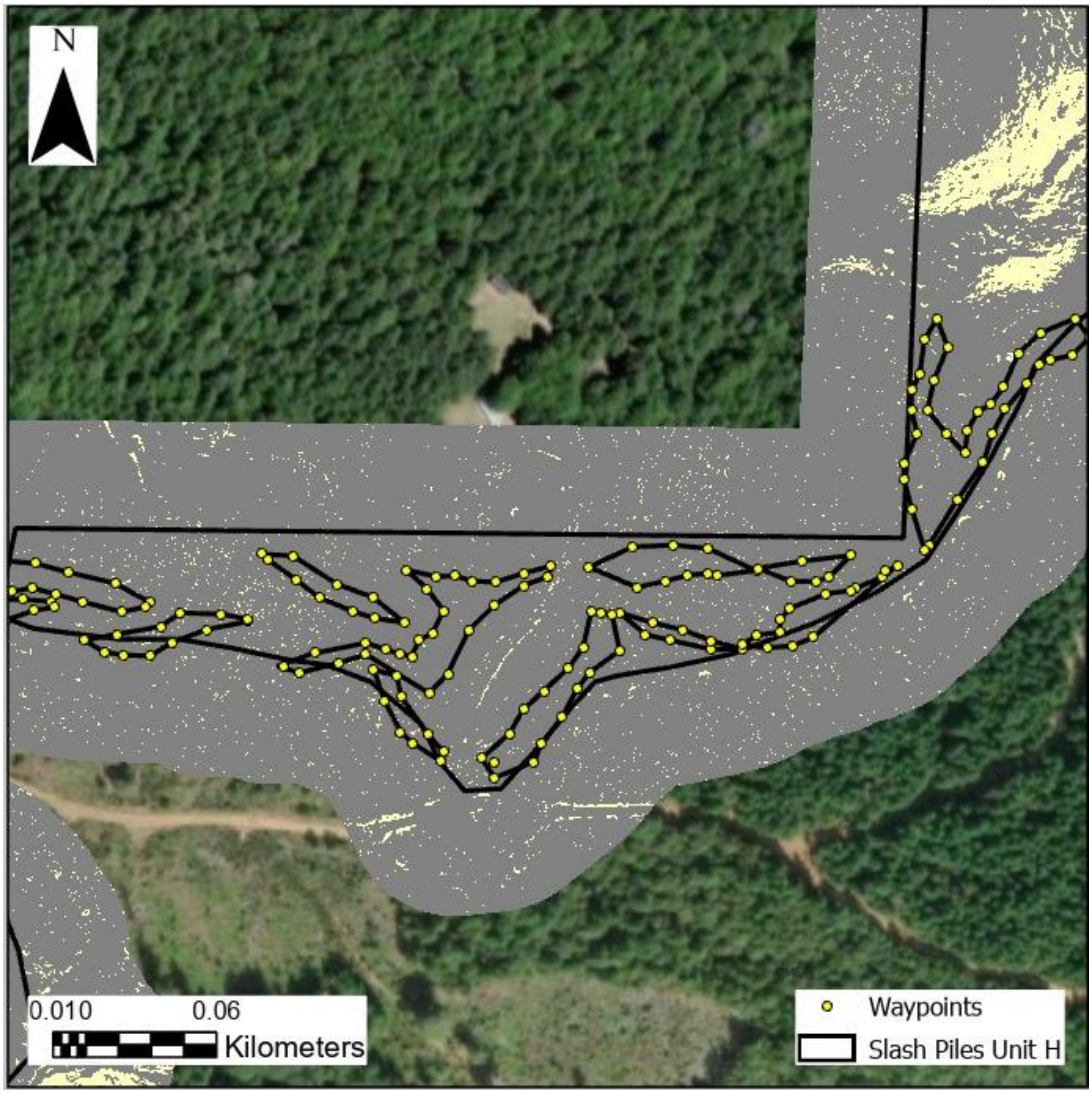


Appendix H-J: Slope Gradient 1° to 25° Diagrams

Appendix H: Slope Gradient for Model for Unit C



Appendix I: Slope Gradient for Model for Unit H



Appendix J: Slope Gradient for Model for Unit G