SOIL INFLUENCE ON FOREST VEGETATION PRODUCTIVITY AND PATTERNS IN THE EASTERN CASCADES OF SOUTHERN OREGON

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Abstract

Soil Influence on Forest Vegetation Productivity and Patterns in the Eastern Cascades of Southern Oregon
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Soils influence vegetation and can critically affect forest restoration results. Areas with similar parent materials can have changes in soil and vegetation across a slope, aspect, slope position, microtopography, and elevation. The objective of this project was to assess what soil characteristics influence vegetation productivity, patterns, and species. The study area for this project is located in the dry forests of the eastern slopes of the Cascade Mountains in the Fremont Winema National Forest of South Central Oregon and overlaps with a Forest Service NEPA project planning area called the Lobert Restoration project. Five major soil series, previously mapped by a collaborative effort between the USFS and NRCS, in the restoration study area were chosen to represent the variety of soil types in the NEPA project planning area. Within mapped areas of each of the soil series, four replicated sites were characterized for soil, vegetation, and landforms. Moisture loggers were placed to monitor soil water content. Soil moisture content throughout the year is a key factor of the productivity and patterns of the plant communities throughout the restoration area. Soil nitrogen and carbon in soil had little correlation with productivity or understory vegetation. Texture, rockiness of profile, buried horizons and slope position influenced vegetation by influencing soil moisture. Resource managers are challenged with the need to develop ecologically based treatment prescriptions that address all the various resource issues across large landscapes. Soil quality can be used as a tool to improve understanding and assessments for both land-use decisions and the sustainability of different land management practices.

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CHAPTER 1: INTRODUCTION

As scientific knowledge and experience in the field of forestry evolve, natural resource management programs continue to adapt. With this growing knowledge base, today's forest land management decisions are not related to just growing trees, but include other resource issues such as restoring resilient forest conditions, habitat enhancement, and improved water quality (Fisher et al. 2005). Resource managers are challenged with the need to develop ecologically based treatment prescriptions that address all the various resource concerns across large landscapes. Knowledge of the soil resource can assist this process by matching different land management objectives to soils that have the highest potential for meeting those objectives (Craigg et al. 2015). The result is management strategies that are both sustainable and better able to meet the intent of planners because management actions are occurring on soil types that have the highest potential for attaining resource objectives. Soil quality can be used as a tool to improve understanding and assessments for both land-use decisions and the sustainability of different land management practices (Craigg et al. 2015, Doran and Parker 1994, Karlen et al. 2001).

Soils are an important component of forest ecosystem sustainability as they provide the necessary support, nutrients, aeration and water quantity and quality for growth of plants and subsequently wildlife. Soils also maintain a healthy soil ecosystem to promote biogeochemical cycling. Soil is the product of the combination of variable amounts of minerals, organic matter, air, and water with a wide range of physical, chemical, and biological properties (Neary 2005). Soils provide the foundation for other resources that overlay large landscapes. Changes in soil types are due to the interaction of the soil parent material, climate, organisms, topography, and time that alter physical and morphological properties within the soils and in turn contributes to ecological patterns (Conacher and Darymple 1977). Varying soil types will provide different conditions for understory and overstory plant species. These growing conditions provided by soils are valuable information that forest managers should understand and consider for management.

Commonly in forestry there are competing objectives used to decide on the best management practices for a forest landscape restoration. The main goal of many management and research projects of the eastern Cascades in Oregon is to focus on old-growth ecosystem diversity (Spies et al. 2006). In general, the current conditions of mixed conifer forests in central Oregon are a result of a recent history of land management practices of fire exclusion and logging (Merschel 2014, Agee 2003). The historic range of variability has been used as a guideline to maintain ecosystem long-term sustainability and resiliency. To develop the old growth ecosystem diversity and sustainability, management practices such as thinning, mowing, and burning to restore historic range of variability are typically recommended. Historic range of variability consequently fulfills other resource concerns that can arise. For example, the Northern Spotted Owl (*Strix occidentalis caurina*) is a threatened species of concern and the Northwest Forest Plan provides protection for it. The spotted owl prefers dense, high basal area, multistoried canopy forests, which competes with the objective of having well-spaced old growth for fire resilience. On the other hand, other wildlife species such as the White-Headed Woodpecker (*Picoides albolarvatus*) favor open, old-growth ponderosa pine (Spies et al. 2006). These different management objectives can be met by matching soils that have the best inherent potential to support them over the long term.

Soil physical, chemical, and biological properties can influence productivity and vegetation patterns, therefore soils information can provide a baseline of information to fulfill forest management objectives Inherent soil properties of the soil and landscape influenced the presence of different plant types at a sub-alpine site in Northeastern Washington (Roche and Busacca 1987). Grasslands were on soils with high rock content and lower soil moisture content, while trees occurred on soils with less stone rock content and higher soil moisture content. Understory species including mountain sagebrush (*Artemisia tredentata* Nutt.) and bluebunch wheat grew on mounds with deep less-stony soil profiles. The differences in vegetation were the result of the inherent soil properties and landscape. Research by Xu et al. (2008) found that increased clay content and moisture content positively correlated with increased plant diversity. However, another study suggested that relationships between vegetation and soil are not always clear-cut. Brosofske et al. (2001) discovered little differences in understory patterns between sites when correlating subsurface E and B soil horizons. Nevertheless, understory species patterns did change with changes in moisture content, organic matter content, and N and C content in A horizons. Past management and site history could have affected soil characteristics and as a result may have affected the understory vegetation indirectly in this study. The correlation of soils and vegetation productivity and patterns is very complex as many studies have found contradictory and inconsistent results (Hironaka 1991). On broad landscape scales, habitat type can be associated with particular soil series; however at the smallest scale, there can be many soil-vegetation relationship variations with no direct applicable correlation due to site specific differences. Soils information can still provide a baseline for forest management decisions in conjunction with other resource information (Hironaka 1991).

In the Fremont-Winema National Forest in South central Oregon, United States of America, primary objectives for a large scale National Environmental Policy Act (NEPA) project called the Lobert Restoration project were to restore forest resiliency through the restoration of forest structure, pattern, composition, and diversity. The Forest Service has proposed activities in the project area that span a total of 97,500 National Forest System acres (USDA 2015). The restoration of existing stands to pre-settlement stand patterns can be a good option to manage ponderosa pine and mixed conifer forests (Churchill et al. 2013). Churchill argued that the spatial patterns of the past could vary by the soil type. The integration of soils information with other resource information (i.e. silviculture, wildlife biology, hydrology) early on in the NEPA planning process, instead of later during implementation, provides a more holistic view of existing conditions, and predictions of future conditions with activities. The Terrestrial Ecological Unit Inventory (TEUI) was used to identify the soil types in the Lobert Restoration Project and could possibly help assess and match vegetation productivity and patterns (USDA 2015).

The objective of this research project was to assess how several soil characteristics influence vegetation productivity, patterns, and species composition. Areas with similar parent materials can have changes in soil and vegetation across a slope, aspect, slope position, microtopography, and elevation. The study area for this project is located in the dry forests of the eastern slopes of the Cascade Mountains in the Fremont Winema National Forest of south central Oregon and overlaps with a Forest Service NEPA project planning area called the Lobert Restoration project. Five of the major soil series, previously mapped by a collaborative effort between the Forest Service and Natural Resource Conservation Service, were chosen to represent the variety of soil types in the project area. The soil properties and vegetation cover and composition for each site were compared to determine a causal relationship between soil characteristics and vegetation pattern, productivity and species. Soil texture, bulk density, organic matter, carbon and nitrogen content, and water holding capacity are all characteristics that could influence soil productivity and management decisions. This project will provide insight into soil characteristics and vegetation within the Lobert Restoration project area for the purpose of forest restoration planning.

CHAPTER 2: METHODS

Site Description

The study area for this project is located in the Fremont-Winema National Forest and lies within with the Lobert Restoration project (US Forest Service NEPA project planning area, Figure 1). The forest borders Crater Lake National park and stretches to the the Klamath River Basin in the state of Oregon in the United States of America. The average elevation of the area is between 1280 m-1590 m. The town closest within the project area is Chiloquin, Oregon.

The study area is influenced by deep pumice and volcanic ash caps that blanketed the area during the eruption of Mount Mazama approximately 7000 years ago (USDA 2015). Within the study area, five major soil series that well represented the project area were selected for sites. These soil series were mapped and classified by soil mappers in the project area and recorded in the Terrestrial Ecological Unit Inventory (TEUI) available through the United States Forest Service GIS database. The project area has a range of landform types; the major landforms include pumice-mantled tablelands, escarpments, small cinder cones and hills. The landforms are underlain by a large variety of geologic formations, the major ones being basalt, sedimentary rock, Mazama ash flows, and tuff capped with volcanic soils. Alluvial deposits and lacustrine sediments are present in the flood plains, and the soils in these areas are abundant in organic material. The overall landscape has an undulating topography with slight changes in elevation and aspect in most areas and abrupt changes in small areas.

The Lobert planning area has varying soil moisture regimes depending on location. Soil moisture regimes are defined based on the presence or absence of available water – all moisture are based on regional climate and soil texture. Within the project area the Xeric moisture regime is most common, which means the soil area have a Mediterranean climate with moist, cool winters and dry, warm summers. The other moisture regime present is Udic. The Udic moisture regime commonly occurs in humid or sub-humid climates with more persistent moisture availability. When a soil has a xeric moisture regime it has available moisture for 45 days or more after the winter solstice and is dry for 45 days or more after the summer solstice. The designation of the udic moisture regime means that a soil can not be dry for no more than 90 cumulative days. The average annual precipitation in the project area is 44 cm and the average annual snowfall totals 104 cm.

The primary forest types consist of dry ponderosa pine, dry mixed conifer, and moist mixed conifer. The dry ponderosa pine forest type is predominantly Ponderosa pine mixed with lodgepole pine. The understory species present in the dry ponderosa pine forest type is dominated by bitterbrush (*Purshia tridnetata)*, Greenleaf Manzanita (*Arctostaphylos patula*), and snowbrush ceonothus (*Ceanothus velutinus*). The dry mixed conifer forest consists of ponderosa pine, lodgepole pine, incense cedar and some Douglas-fir with an understory of mainly bitterbrush. The moist mixed conifer forest type is predominately Douglas-fir, ponderosa pine, white fir, incense cedar and sugar pine with a large variety of understory plants. Riparian areas within the study area (present in one of the soil series: Maresegg) have vegetation mainly of quaking aspen (*Populous tremuloides*) with conifer encroachment. The understory of the riparian areas were lush with many different understory plants i.e. *spirea spp.* Baldhip rose (*Rosa gymnocarpa*), Western Yarrow (*Achillea millefolium*), and Tuber starwort (*Stellaria jamesiana*).

Fire history in the study area is an important factor that influences the forest and soils. Wildfires had occurred in the past before fire suppression was practiced. The natural return intervals of wildfire in the study is frequent with low/mixed severity fires in the dry ponderosa pine and dry mixed conifer forest types while in the moist conifer stand fires are less frequent and more severe. Fire suppression began in the US in the 20th century, so whenever a fire occurred, whether natural or other from causes, managers would quickly suppress it fearing development of large catastrophic fires (US Forest Service). Although wildfires have occurred in the past in the study area, enough time has passed since their occurrence that existing vegetation and forest litter are providing adequate ground cover to protect and enhance mineral soils. The current forest composition and structure has been greatly influenced by forest management and fire suppression. Over the past century, many of the larger fire resistant trees were removed through harvest. Past harvest and fire suppression has resulted in an increase in stand densities of smaller trees in ponderosa pine forest types and both an increase in stand densities and an increase in shade tolerant species like grand fir in the mixed conifer forest types (Merschel et al. 2014).

Anthropogenic disturbance within the project area has been occurring since the 1800s with fire suppression, grazing, logging activities and prescribed burns. Prescribed under burning has been used to reduce hazardous fuels within the Wildland Urban Interface (USDA 2015, TEUI). Based on observations of burned units it appeared that burns were kept within a burn prescription and adequate soil duff remained to cover mineral soil. It was also noted that litter recruitment from residual trees was occurring thus providing additional surface organic matter on site. Observed soil disturbances included both residual soil compaction and soil displacement of surface soils. While some of these soil disturbances appear to be associated with harvest system trails and landings, there also appeared to be additional soil disturbances due to machine piling and burning of fuels following harvest.

Field Methods

Seventeen research sites were selected within the study area (Figure 1). A total of five of the major soil series were selected for analysis within the project area. Each soil series had 3-4 replicated sites to assess variability. These sites were chosen by their typical site characteristics such as slope and aspect to be representative of the land covered by the soil series. The soil series were Lapine (*Ashy-pumiceous, glassy Xeric* Vitri*cryands*), Maset (*Ashy over loamy-skeletal, glassy over isotic, frigid Alfic Vitrixerands)* , Yawhee (*Ashy-skeletal over loamy skeletal, glassy over isotic, frigid Alfic Udivitrand)*, Maresegg (*Fine, frigid Vitrandic Durixerolls*), and Smiling (*Ashy over loamy, glassy over isotic, frigid Alfic Vitrixerands*) soil series; these were previously mapped within the project area by a collaborative effort between the USFS and NRCS (USDA 2015). At each site a soil pit was dug to a depth between 70-140 cm. The soil horizons, depth, color, consistency, and structure were described at each site. Soil samples were taken from each horizon near the middle of each soil horizon range in depth. Samples were air-dried prior to analysis. Bulk density samples were collected using a soil corer from each horizon at each of the sites. Moisture data loggers (Decagon Em50) were placed at two sites of each soil type at depths of 10 and 50 cm in August of 2015. The moisture data loggers were removed in May of 2016.

To understand vegetation productivity and patterns, a stand exam was done to take a look at the current overstory conditions. The stand exam plots were variable-size plots determined by the use of a Spiegel Relaskop®. Trees were determined in or out of the variable-size plot referring to the relascope scale. The diameter at breast height

(DBH), crown height, total height, and species of each of the trees in the plots were noted. Basal area was calculated using the stand exam data through Forest Vegetation Simulator (FVS). A representative ponderosa pine (and Douglas-fir for the Yawhee soil series) tree was selected for each study site; this tree was cored for age and a height was taken to calculate site index (100 years). Understory species below five feet were measured by ocularly estimated percent cover along three randomized 10 m transects at each site. The three understory transect bearings were selected randomly and a meter tape was laid on the ground to measure distances of specific species on the tape and determine percent cover.

Lab Analyses

All soil samples were measured for pH using a 2:1 soil to water slurry and left to sit for at least 30 minutes. A pH probe was then inserted into the water/soil slurry soil samples to getting pH readings. To get the percent carbon and nitrogen, soil horizon samples were oven dried, sieved to 2mm, and ground. The prepared soil was then inserted into small aluminum sample tins, and weighed (mg). The aluminum soil sample tins were analyzed using into a Carbon-Hydrogen-Nitrogen Analyzer - 2400 CHN model (PERKIN ELMER Co.). Bulk density core samples were oven dried and weighed (g) to determine bulk density. Bulk density, horizon thickness, and carbon and nitrogen concentrations were used to calculate total soil profile carbon and nitrogen content for each soil profile which were then averaged for each soil series.

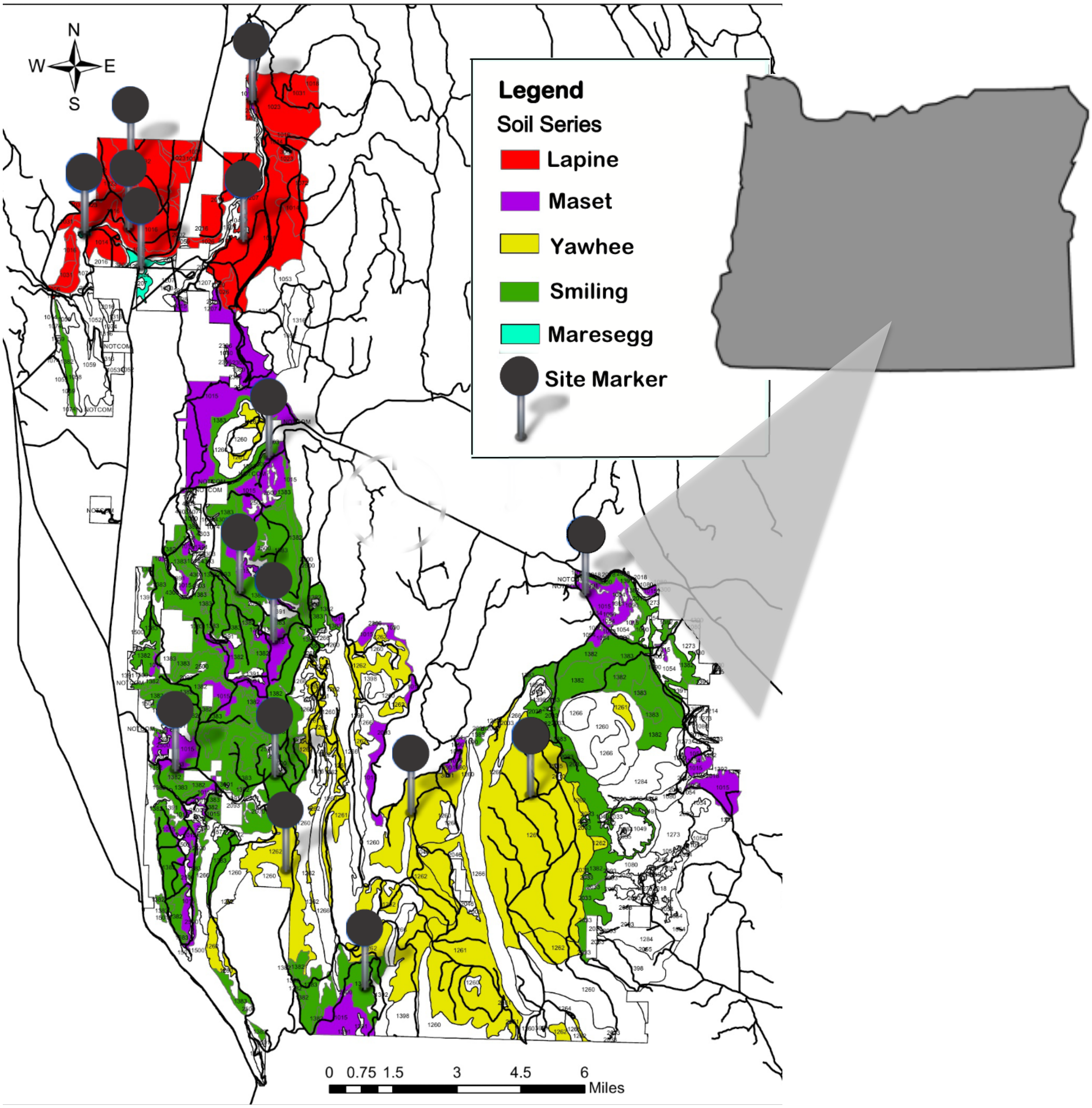

Figure 1. Lobert Restoration study area map with five soil series and site markers.

CHAPTER 3: RESULTS AND DISCUSSION

Soil profile and properties

The landscape of the study area is heavily influenced by past volcanic eruptions as confirmed by the parent material of volcanic ejecta and the high concentration of pumice, volcanic ash and other volcanic material (Peterson and Groh 1967). Stratigraphy of the study area is complex as there was widespread volcanic activity from the Cascades to the west and from the south in the Klamath Falls basin during the Pliocene and Pleistocene eras (Peterson and Groh 1967). Each of the soil series predominately occurred on different slope positions (Table 1). Overall, the field soil descriptions compared well with the corresponding TEUI (Terrestrial Ecological Unit Inventory) soil survey profiles (USDA 2015). The TEUI and the studied soil profiles in this restoration project had close to identical soil descriptions and horizonations. Soil horizonation with similar parent material can exhibit variability throughout the landscape (Table 2, Appendix, Figures 12-16). In particular, the Lapine soil series had horizons consisting of O, A, Bw1, Bw2, Bw3, C, and 2Ab in two of the four replicated sites. The other two sites, were missing the Bw2, C, and 2Ab horizons. This was similar with the four other soil series, where commonly the lower horizons were not present in some of the study replicates in the field. Due to field restrictions, the depth of the soil pits was no greater than an average of 87 cm, therefore no conclusions can be made about the depth to bedrock.

Horizons of all the study soil series are a result of weathering of volcanic parent materials (Peterson and Groh 1967). The organic horizons were very thin or discontinuous with some charcoal present and often mixed with the surface mineral soil therefore sampling of these horizons was difficult. When the O horizons were present, much of it was slightly decomposed pine needle litter. The A horizons in all the soil series are directly influenced by vegetation decomposing and mixing with the mineral horizons below. The Maresegg soil series had a thicker A horizon in comparison to the other soil series due the presence of Aspen and other riparian canopy vegetation litter being more readily decomposed (Table 2). Bw horizons were present in the Lapine, Maresegg, and Yawhee soil series. The Maset soil series had a Bt horizon rich in clay minerals possibly from a previous lacustrine parent material below the ash cap or from translocation of clays (Staples 1967). Andisols typically have buried horizons from previous volcanic activity. Buried horizons were found in the Lapine, Maresegg, and Maset soil series at the depths that were reached in the field (Table 1 and 2). These buried horizons were present through field observations likely because these soil series were in locations that received less ash with the more recent volcanic activity.

Soil texture can provide important information about influences on vegetation communities (Gilliam et al. 1993). A higher clay content soil can retain more moisture and nutrients although physical properties become poorer at high clay concentration. In the study area, most soil series have coarser volcanic ash and pumice, thus have coarser soil textures. The Lapine soil series had a paragravely ashy sand soil texture throughout the profile until reaching the buried 2Ab horizon where there was a finer texture of silty clay loam. This coarser texture could mean that infiltration of water and nutrients in the soil could be high in the upper horizons and retention of moisture could increase once in contact with the buried horizon. There was surficial erosion evident in the Lapine soil series through some exposed tree roots and evidence of displacement of organic horizons in some areas. This erosion could be correlated with the coarse-textured upper horizons and storm events. The Maresegg and Maset soil series had loamy ashy coarse sand textured surface soils with no evidence of erosion. The Smiling and Yawhee soil series had surface soil textures of sandy loam and had no evidence of erosion. During the dry season, there was moisture evident in the lower Smiling and Yawhee soil horizons.

Moisture Data

Soil moisture availability is important in semiarid forests like those of the Lobert restoration area where dry conditions persist through much of the growing season and there are large soil moisture deficits. According to the data collected from September 2015 to May 2016, the pattern of changing moisture content with wetting and drying pattern at 10 cm is comparable to that of soil at 50 cm although actual volumetric water content varies among the five soil profiles (Figures 2 and 3). At 10 cm, the moisture content for the Lapine, Maset, and Maresegg soil series has a negligible amount of moisture in the late summer season then increases in November, however volumetric moisture content never exceeded 30% in moisture. These three soil series also have coarse textures, which could contribute, to the minimal moisture content during summer months and rapid increase of moisture in the wet season. During the wet season all the soil series likely exceeded their respective field capacities based on soil texture. At the same depth, Smiling and Yawhee soil series start with 5-10% moisture and reach up to 50% moisture content in December. The Yawhee soil series had the highest moisture content on average throughout the year and the Smiling soil series was next highest. The Yawhee soil series has a udic moisture regime as the profile is dry less than 90 consecutive days throughout the year. The Lapine, Maset, Maresegg, and Smiling soil series were mapped with having xeric moisture regimes and this is consistent with the moisture data. These soil series are wet for more than 45 days after the winter solstice, December 22, 2015, and presumed to be dry for 45 days after the summer solstice. The fluctuation in water content at 10 cm depth of the soil profiles provides evidence that the upper soil horizons of all the soil series are directly influenced by environmental factors. Rapid changes in moisture content could be due to quick evaporation at the surface and rapid infiltration of rain and snowmelt as well as plant uptake. During late summer months, dry conditions lead to low water availability while starting in the winter, combined rain and snowmelt increased in soil water content.

In the lower horizons of all the soil series, there is a similar pattern of lower moisture content in late August then rapid increase in moisture content in November and December (Figure 3). At 50 cm depth, the Lapine, Smiling, and Marsegg soil series start with about 10% moisture content in August while the Maset and Yawhee soil series have between 15-20% moisture content. Increase in moisture occurs between December and January in all the soil series. The Smiling and Yawhee soil series have the most similar pattern of moisture content throughout the year at 10 and 50 cm. At the 50 cm depth, slower response to rain and snowmelt occurred. Soil water drying in summer would be expected to occur more quickly and rapidly at the 10 cm depth compared to the 50 cm depth.

Changes in topography can affect soil properties and therefore soil processes (Khalili-Rad et al. 2011). The Lapine and Maset soil series occur on shoulder and side slopes in which there was a small range of variability in carbon, nitrogen, and moisture. The Maresegg soil series located on foot and toe slopes did not have significantly greater soil moisture content, which is contradictory to expectations. However, the Maresegg soil series supported riparian species i.e. Aspen and white spirea with higher soil nitrogen and carbon (Figures 4, 5, and 6). The Khalili-Rad study (2011) also found that there was an increase of soil organic carbon and nitrogen with slope position from summit to toe slope.

The Yawhee soil series being at the summit had a lower soil carbon and nitrogen content, however there was a higher moisture content. Topography may have influenced some of the soil series properties to an extent, but there are other local factors as well such as depth to bedrock and buried horizons, which could influence soil moisture.

Carbon and Nitrogen

Carbon is an essential element for life. Within soil, organic matter from plant and animal litter decomposes and create the pool of soil organic carbon (SOC). Soil organic carbon is crucial for soil fertility as it promotes plant growth and soil health. The Lapine, Masest, Smiling, and Yawhee soil series are Andisols and the Maresegg soil series was classified as an andic Mollisol due to a presence of a mollic epipedon. Andisols are soils that have formed in volcanic material and are considered to hold the most soil carbon second only to Histosols (Tsui et al. 2013, Matus et al. 2014). Total average C content (C_{tot}) differed among the five soil series in the Lobert restoration study area and ranged from 31 to 680 Mg ha^{-1} (Figure 4). The series with the lowest total carbon (average of 31 Mg ha^{-1}) was within the Lapine soil series, most likely due to limited organic matter within the mineral horizons. The Yawhee soil series is located on the summit, which generally has the least carbon content due to erosion (Khalili-Rad et al. 2011); the carbon content in the Yawhee series was 80 Mg ha^{-1}. The highest total carbon was in the Maset soil series, in which most of the carbon came from the buried horizons 2Ab and 2AC (Figure 5). The total carbon content varied between sites, due to varying depths of horizons as well as varying carbon concentration.

Carbon concentrations typically decreased with depth with highest concentrations in the O horizons (Figure 5), as these horizons are composed mostly of decomposing pine needles. In some cases, the organic horizon concentrations were lower, less than 20%

carbon, as a pure O horizon could not be collected without mineral material due to thin O horizons and mixing, possibly from past fires or animals. The mineral horizons below the O horizons of all the soil series contained relatively less carbon. The Lapine and Smiling soil series have a similar pattern of decreasing %C with increasing depth. The O horizon in both the Lapine and Smiling soil series had an average percent carbon of 47% and 33%; the A horizons decreased to 3%.

The Maresegg, Maset and Lapine soil series all had deeper soil horizons that were buried soil horizons. The Lapine soil series had the least carbon within the deeper buried horizon (2Ab). Yoshida and Kumuda (1978) found low carbon content in buried horizons below volcanic ash caps. They inferred that the conditions in the past including climate and vegetation might not have been favorable for the accumulation of humus. Furthermore, the accumulation of humus could have been interrupted by a recent volcanic eruption. In this case, the Lapine 2Ab horizon had a fine texture with low organic matter concentration, so similar factors could have prevented humus formation. Another postulate could be that there was erosion of the organic horizon above the 2Ab buried horizon prior to burial with more recent volcanic material. The Maresegg and Maset buried soil horizons showed an increase in carbon due to the mixing of organic material that was once was at the surface with the above mineral horizons. In these two soil profiles, accumulation of organic matter before volcanic eruptions may have been more effective than in the Lapine soil series. Another possibility is that the degradation of humus could have been slower in the Maresegg and Maset soil profiles than in the Lapine soil series, which would be influenced more directly by increased volcanic ejecta.

The most common growth-limiting nutrient in the Pacific Northwest forests is nitrogen. Within the restoration study area nitrogen concentration within the five soil series was less than 1.2 percent (Figure 6). Nitrogen concentration corresponds with carbon concentrations of the horizons. The Lapine, Smiling and Yawhee soil series % N decrease as depth increases through the soil profile. The buried horizon of the Lapine series, 2Ab, has a low nitrogen concentration. Maresegg soil series had high concentrations of nitrogen in the lower two horizons and the O horizon; the high concentrations could be due to past vegetation such as aspen, grasses being more influential and the buried 2AC and 2Ab horizons. The Maset soil series buried horizon had a high amount of nitrogen, which could be a result of the presence of curlleaf mountain mahogany. A study in the San Bernardino Mountains of California found that total nitrogen was higher in soils with curlleaf mountain mahogany forest stands than without curlleaf mountain mahogany which indicating the presence of an N-fixing soil microbes (Lepper and Fleschner 1977).

The soil carbon and nitrogen concentration found in the soils of the study area are comparable to other studies in dry conifer forests. In a study (Zabowski et al. 2009) with 19 soil series sampled across Alaska, Puerto Rico, eastern and western Oregon and Washington, soil carbon percentages in soil mineral horizons did not exceed 4.2 %. The carbon concentrations of mineral horizons A, Bw, and C in study area of this project did not exceed 3.9 percent carbon. Bw horizons in this study had less than 1 percent carbon, which is similar to the carbon concentration in the Zabowski et al. (2009) study with an average of 0.7 percent carbon. The average of the carbon concentrations in Zabowski et al. (2009) study encompassed several different ecosystems, but the carbon values are similar nonetheless to carbon found in this restoration study area. Percent nitrogen within the restoration study area soil series is typical in comparison to literature of multiple forest soils. Total soil nitrogen present in Whitney and Zabowski (2004) in the A horizons and mineral horizons below did not exceed 1.7% which is close to this study's average nitrogen concentration not exceeding 1.2%. No valid conclusions can be made of the O horizon nitrogen concentration for the restoration soil series due to mineral mixing, however, typical nitrogen concentration is around 17 percent (Whitney and Zabowski 2004).

Bulk Density

Within the study area, the bulk density (Figure 7) of the soil horizons was low to moderate with the exception of the Bt horizon. Most of the soil series have less than a 1.0 g/cm^3 bulk density suggesting that the soils should be readily penetrable by plant roots. Minore et al. (1969) found that Douglas-fir, lodgepole pine, and red alder roots were limited at a bulk density of 1.59 g/cm^3 in sandy loam soils, while Veihmeyer and Hendrickson (1984) reported that a bulk density of 1.75 g/cm^3 stopped sunflower root growth. A lower bulk density is due to the volcanic material including ash and pumice from eruptions in the past. Volcanic material is less dense than most other parent materials. The low bulk densities could mean that although there is good root penetration and anchorage there is possible erosion as there may be less aggregation and binding by clay. Both the Smiling and Yawhee have higher bulk densities due to a higher clay content evident in their profiles. The Lapine and Maset soil series have relatively lower bulk density in the surface horizons, however, their buried horizons have higher bulk densities. The Maresegg soil series had the lowest bulk density, probably due to the higher amount of organic material from Aspen tree litter.

Understory Species

Across all sampled sites there were twenty-nine understory plant species identified (Table 3). The five understory species shown in Figure 8, are the five species of concern outlined in the Forest Service Lobert Restoration project based on how they provide forage, habitat, and species diversity to the ecosystem. None of these critical understory species are present in all the soil series study sites. The most prominent understory species was bitterbrush found with the Lapine, Maset, and Smiling soil series (Figure 8). Bitterbrush is adapted to moisture limited environments and is a nitrogen fixer, which could contribute nitrogen to the Lapine, Maset, and Smiling soil series. The Yawhee and Maresegg soil series had other understory species present and had the largest variety of species (Table 4). Mountain mahogany is a species of concern due to its rarity in the Lobert restoration landscape. Mountain mahogany was present only in the Maset and Smiling soil series – occurring on rockier soils. Serviceberry and squaw currant were present in four of the five soil series although with limited percent cover. Manzanita was the second most prominent understory species present in the study area in terms of percent cover. Variations in the understory species suggest that the soil series have characteristics that support different vegetation.

Each soil series had varying species richness (Table 4). The Lapine soil series had high bitterbrush cover of 80% and a few other understory species including Serviceberry, pinemat manzanita, Greenleaf manzanita, and Mountain Mahogany. Similarly, the Maset soil series had 80% bitterbrush cover, but had less variety in the remaining understory. Curlleaf Mountain mahogany was present primarily in the Maset soil series and is a species of concern. Management for curlleaf mountain mahagony could occur on the

Maset soil series. The Maresegg and Smiling soil series had moderately high species richness with 40 percent cover of white spirea and bitterbrush respectively in addition to a variety of smaller percentages of other understory species. The Yawhee soil series had the highest species diversity, as almost all the understory species in the restoration area were present. There was also a high percentage of bare ground within most of the soil series. The percent cover in Table 4 is a calculation of only the total understory cover, excluding bareground. The Lapine, Maset and Smiling soil series had a higher average bareground cover of 40%, while the Yawhee and Maresegg soil series had lower average bareground cover of 20%.

Overstory species

Overstory species identified in the study area include ponderosa pine, juniper, lodgepole pine, Douglas-fir, aspen, incense cedar and sugar pine. The Yawhee soil series had the highest average total basal area (Figure 9). The Lapine soil series had the second highest total basal area, particular due to many stands having old growth and dense clumps of trees. Overstory species diversity, percent of each overstory species within the context of the total basal area of each site was compared between the soil series. In Figure 10, there is a comparison of the percent of total basal area of each of the overstory species in the five soil series. In particular, the Lapine, Maset, and Smiling soil series had approximately 85-95% ponderosa pine of the entire basal area of each of the soil series plots. This is common in central Oregon forests, as ponderosa pine is a species most suitable for the climate and fire regime. The only soil series where ponderosa pine is not the most dominant overstory species is the Yawhee soil series which supports Douglas-fir more successfully due to the higher moisture availability and higher elevation. The Maresegg soil series is a riparian soil and supports aspen, however aspen is being encroached by conifers like ponderosa pine, juniper and lodgepole pine due to fire suppression and possible wildlife foraging on aspen.

The soil series were postulated to provide varying degrees of site productivity. This can be compared using site index, the measurement to describe productivity commonly used by foresters. The Smiling is the most productive soil series for ponderosa pine with a site index of 84 while the Yawhee is marginally less productive in terms of Douglas-fir growth with a site index of 82 (Figure 11). The least productive soil series according to this is the Maresegg soil series, possibly due to the presence of aspen and lodegpole pine competing with the ponderosa pine. The Lapine and Maset soil series support the growth of overstory species; however there are limitations in comparison to the Smiling soil series, particularly rockiness and moisture content. According to Figures 2 and 3, the moisture content is high in the wet season in the Smiling and Maset soil series in contrast to the Lapine soil series. This high saturation in the wet season could hinder growth of Ponderosa pine, as the species does best on coarse-textured soils when soil moisture is not too high (USDA NRCS 2011). A site index range of 70-85 is typical in many Eastern Oregon cascade forest stands and the site indexes found in the restoration area all fell within this range (Barrett 1978, Cochran 1979).

Table 1. Site characteristics for each soil series studied in the Lobert restoration area.

Soil Series		Lapine	Maresegg	Maset	Smiling	Yawhee
	Elevation Range (m)	1284-1400	1280-1304	1303-1375	1321-1397	1382-1562
	Maximum profile depth studied (cm)	107	132	89	81	89
	Average air temp (°C)	7	7	7	7	6
	Average annual precipitation (cm)	64	70	68	76	76
	Range of Slope (%)	0-10	0-10	0-15	0-40	0-20
	Slope position	Shoulder and side slope	Foot and toe slope	Shoulder and side slope	Shoulder and side slope	Summit and shoulder

Table 2. Soil horizons and average properties of the five soil series studied in the Lobert restoration area. Four profile descriptions of each soil series were combined to give typical characteristics

Soil Series	Horizon Type	Range in thickness (cm)	Parent Material	Moist Color	Texture	pH
Lapine	O	Discontinuous – 1.3	-	-	-	4.6
	A	2.5 – 8.6	Volcanic ejecta	10 YR 2/2	Paragravelly loamy ashy coarse sand	6.2
	Bw 1	10 – 25	Volcanic ejecta	10 YR 3/2	Paragravelly loamy ashy coarse sand	6.5
	Bw 2	9 – 23	Volcanic ejecta	10 YR 4/3	Paragravelly ashy coarse sand	6.6
	Bw 3	15 – 53	Volcanic ejecta	10 YR 5/3	Paragravelly ashy coarse sand	6.5
	C	20 – 28	Volcanic ejecta	2.5 YR 5/4	Paragravelly ashy coarse sand	6.7
	2Ab	10 – 23	Volcanic ejecta	5 YR 3/4	Silty clay loam	6.7
Maresegg	O	Discontinuous – 1.3	-	-	-	4.6
	A	2.5 – 20.3	Volcanic Ash	10 YR 2/2	Paragravelly ashy sandy loam	5.8
	Bw 1	10 – 25	Volcanic Ash	10 YR 3/2	Paragravelly ashy sandy loam	6.3
	Bw 2	9 – 38	Volcanic Ash	10 YR 4/3, 10 YR 4/6	Paragravelly ashy sandy loam	6.2
	2AC	15 – 53	Volcanic Ash	10 YR 5/6, 10 YR 5/3	Paragravelly ashy coarse sand	6.8

Maset	O	Discontinuous – 2.5	Volcanic ejecta	-	-	5
	A1	1 – 12.7	Volcanic ejecta	10 YR 3/3	Ashy coarse sandy loam	4.8
	A2	12.7 - 39.7	Volcanic ejecta	10 YR 3/3	Ashy coarse sandy loam	6.5
	AC	20.3 – 58.4	Volcanic ejecta	10 YR 3/4	Gravelly ashy sandy loam	6.6
	2Ab	0 – 35.6	Volcanic ejecta	10 YR 4/3	Gravelly sandy loam	6.4
Smiling	O	0.3 – 2.5	Volcanic ejecta	-	-	5.3
	A1	7.6 – 12.5	Volcanic ejecta	7.5 YR 2.5/2	Ashy sandy loam	6.1
	A2	15.2 – 28	Volcanic ejecta	7.5 YR 3/4	Ashy sandy loam	6.6
	2Bw1	20.3 – 40.6	Volcanic ejecta	7.5 YR 3/4	Very fine Sandy loam	6.7
	2Bw2	20.3	Volcanic ejecta	7.5 YR 3/4	Loam	6.8
Yawhee	O	1.3 – 2.5	Volcanic ejecta	-	-	5.7
	A1	3 - 12	Volcanic ejecta	10YR 3/3	Stony ashy coarse sandy loam	6.3
	A2	0- 25	Volcanic ejecta	7.5 YR 3/4	Very cobbly ashy coarse sandy loam	6.5
	Bw1	0 - 28	Volcanic ejecta	10 YR 3/4	Very cobbly ashy loamy coarse sand	6.4
	Bw2	0 - 23	Volcanic ejecta	10 YR 4/6	Very cobbly fine sandy loam	6.1

Table 3. Species list of all understory and overstory plants identified species present in the study area with common name and scientific name.

Shrubs

Common Name	**Scientific Name, author citation**
Vine Maple	*Acer circinatum* Pursh
Rockymountain Maple	*Acer glabrum* Torr.
Saskatoon Serviceberry	*Amelanchier alnifolia* Nutt.
Pinemat Manzanita	*Arctostaphylos nevadensis* A.Gray
Greenleaf Manzanita	*Arcostaphylos uva-ursi* (L.) Spreng.
Bearberry	*Artmisia arbuscula* Nutt.
Low Sagebrush	*Artemesia ridgida* (Nutt.) A.Gray
Ridged Sagebrush	*Artmesis tridentate* Nutt.
Subalpine Sagebrush	*Artemisia tridentate var. vaseyana* (Rydb.)
Golden Chinkapin	*Castanopsis chrysophylla* (Douglas ex Hook.) Hjelmq.
Snowbrush	*Ceanothus velutinus* Dougl. ex Hook.
Curlleaf Mountain-mahogony	*Cercocarpus ledifolius* Nutt.

Herbs

Prince's Pine	*Chimaphila umbelleta* (L.) Barton
Rabbitbrush Goldenweed	*Haplopappus bloomer* A. Gray
Bitterbrush	*Purshia tridentata (*Pursh) DC
Squaw Currant	*Ribes cereum* Douglas
Baldhip Rose	*Rosa gymnocarpa* Nutt.
White Spirea	*Spirea betulifolia* Pall.
Menzies Spirea	*Spiraea douglasil var. menziesii* Hook.
Snowberry	*Symphorcarpos albus* (L.) S.F.Blake
Western Yarrow	*Achillea millefollium* L.
King's Sandwort	*Arenaria kingly*
Bull Thistle	*Cirsium vulgare* (Savi) Ten.
Strawberry	*Fragaria virginiana* Duchesne
Yellow Hairy Hawkweed	*Hieracium albertinum* Farr
Pine Lupin	*Lupinus albicaulis* Dougl.
Tuber Starwort	*Stellaria jamesiana* (Torr.) W.A. Weber & R.L. Hartm.
Wooly Wyethia	*Wyethia mollis* A. Gray
Twinflower	*Linnaea borealis* L.

Overstory species

Ponderosa pine	*Pinus ponderosa* Douglas ex C.Lawson
Juniper	*Juniperus* L.
Lodgepole pine	*Pinus contorta* Douglas
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Aspen	*Populus tremuloides*
Incense Cedar	*Calocedrus* Kurz
Sugar Pine	*Pinus lambertiana* Douglas

Table 4. Average % cover of all understory species excluding bareground in the Lobert restoration study area for each of the five soil series.

	Common Name	Lapine – Avg % cover	Maresegg – Avg % cover	Maset – Avg % cover	Smiling – Avg % cover	Yawhee – Avg % cover
Shrubs	Vine Maple	0	4	0	0	2
	Rockymountain Maple	0	2	0	0	0
	Saskatoon Serviceberry	2	3	3	8	4
	Pinemat Manzanita	2	2	0	5	3
	Greenleaf Manzanita	5	4	0	8	3
	Bearberry	0	10	0	2	5
	Low Sagebrush	3	0	0	1	2
	Ridged Sagebrush	2	0	1	3	0
	Subalpine Sagebrush	2	0	0	0	5
	Golden Chinkapin	0	0	0	4	0
	Snowbrush	0	0	0	3	10
	Curlleaf Mountain-mahogony	4	0	10	5	0
Herbs	Prince's Pine	0	0	1	2	4
	Rabbitbrush Goldenweed	0	0	4	2	2
	Bitterbrush	80	3	80	40	6
	Squaw Currant	0		4	6	4
	Baldhip Rose	0	5	0	0	2
	White Spirea	0	40	0	0	7
	Menzies Spirea	0	5	0	0	1
	Snowberry	0	3	0	3	5
	Western Yarrow	0	4	2	0	2
	King's Sandwort	0	0	0	0	0
	Bull Thistle	0	2	0	0	0
	Strawberry	0	8	3	3	2
	Yellow Hairy Hawkweed	0	0	0	0	3
	Pine Lupin	0	0	0	0	8
	Tuber Starwort	0	2	0	0	0
	Wooly Wyethia	0	0	1	0	2
	Twinflower	0	3	0	0	2

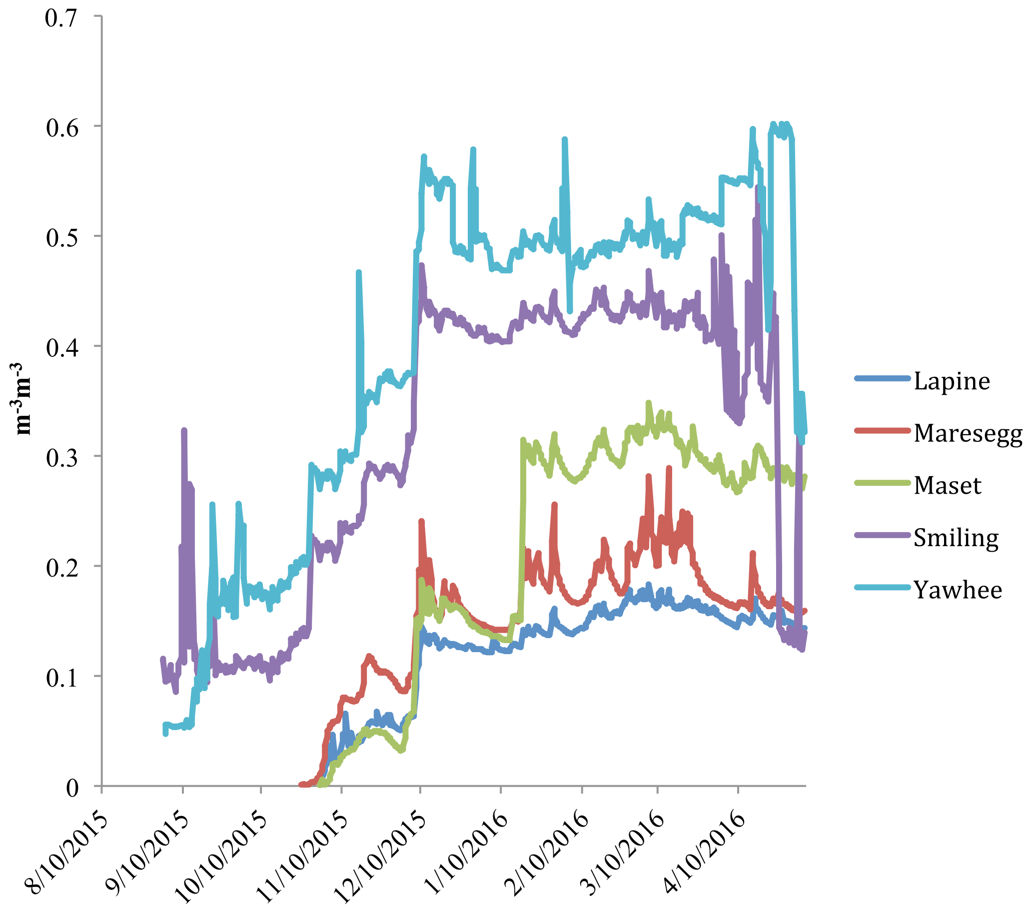

Figure 2. Average soil volumetric water content (m^3m^{-3}) by soil series at 10 cm depth below the mineral soil surface from September 2015 to May 2016.

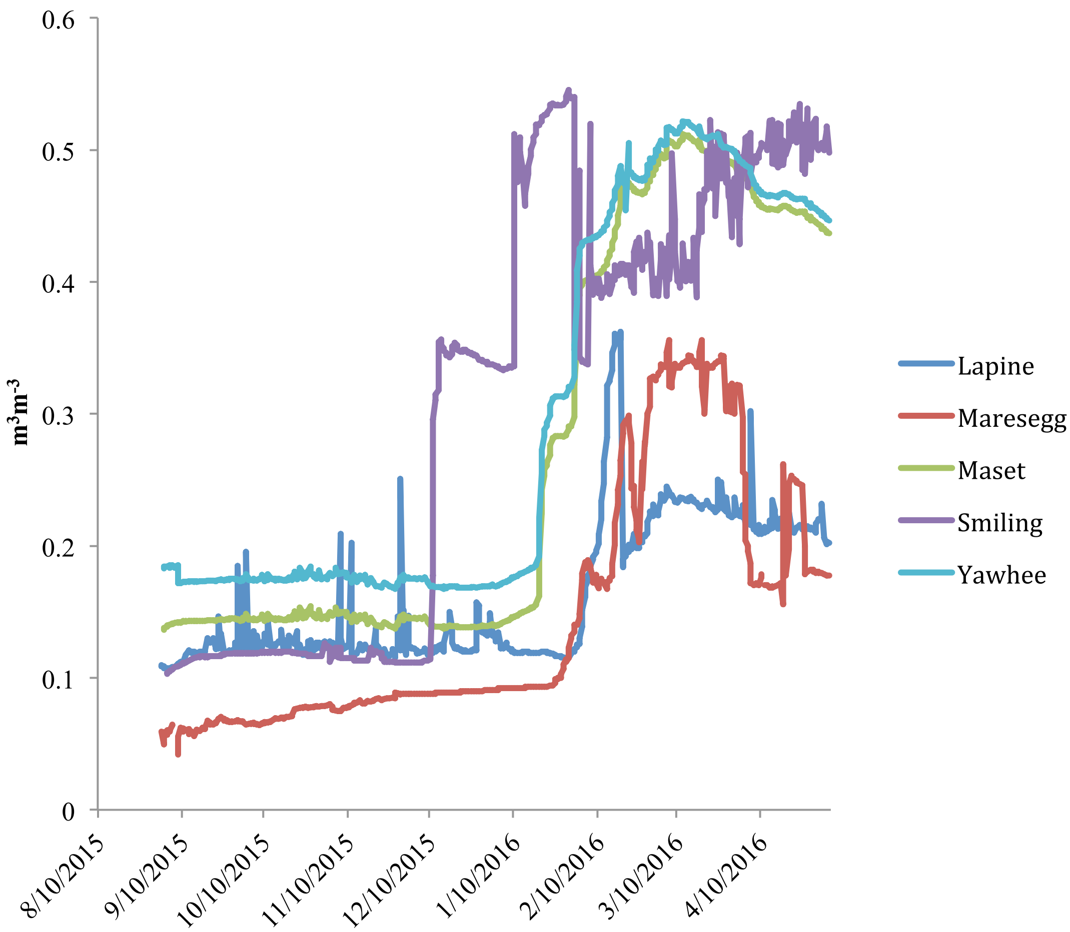

Figure 3. Average soil volumetric water content (m^3m^{-3}) by soil series at 50 cm depth below mineral soil surface from September 2015 to May 2016.

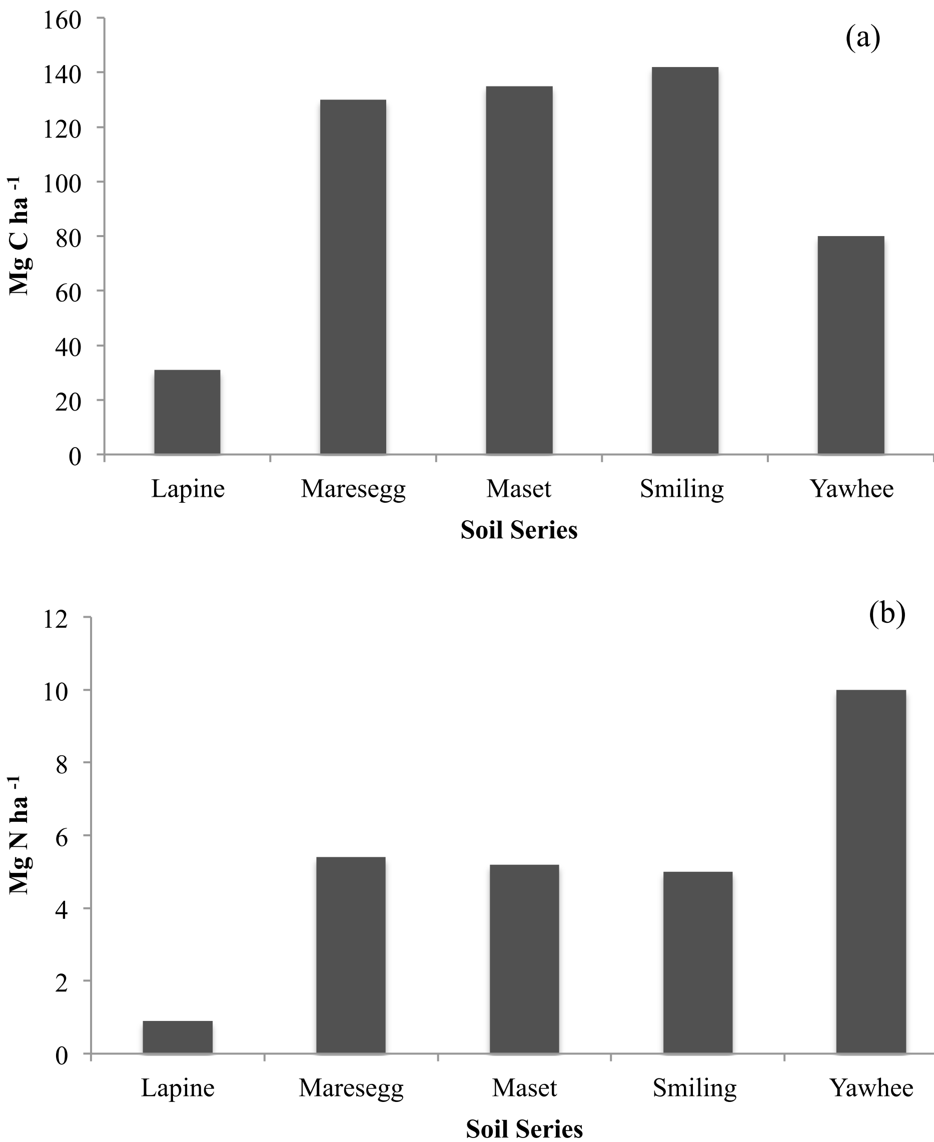

Figure 4. a. Average soil total C (Mg ha^{-1}) content profile to 80 cm depth of all five soil series examined in the Lobert restoration area. **b.** Average Soil total N (Mg ha^{-1}) content to 80 cm depth of all five soil series examined in the Lobert restoration area.

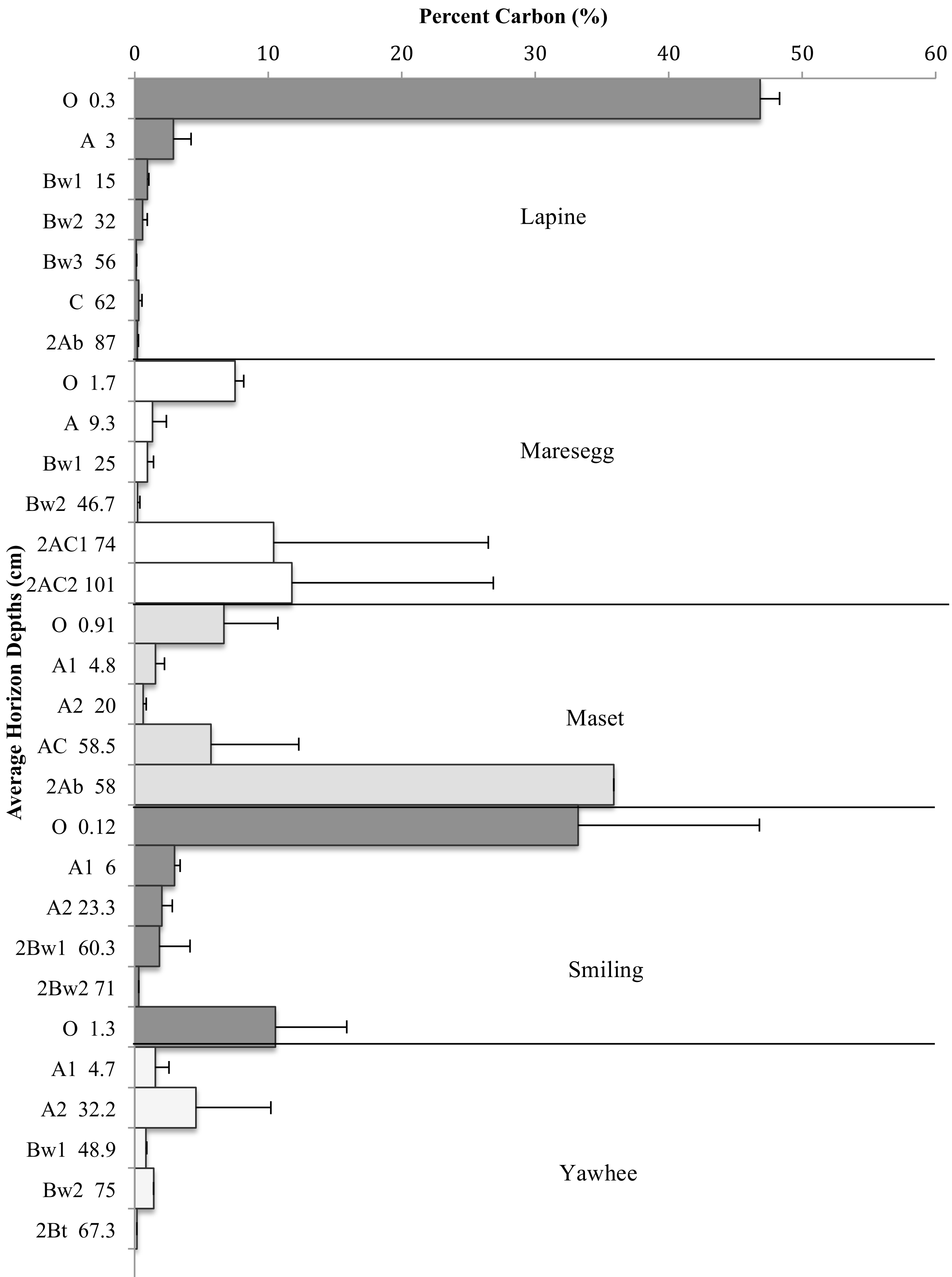

Figure 5. Average % C by horizon along with average horizon depth for the five soil series in the Lobert restoration area. Averages were taken from three to four replicated sites of each soil series. Note that there were some sites that did not have all the horizons present in their profiles, therefore depths are averages of depths where horizons were present.

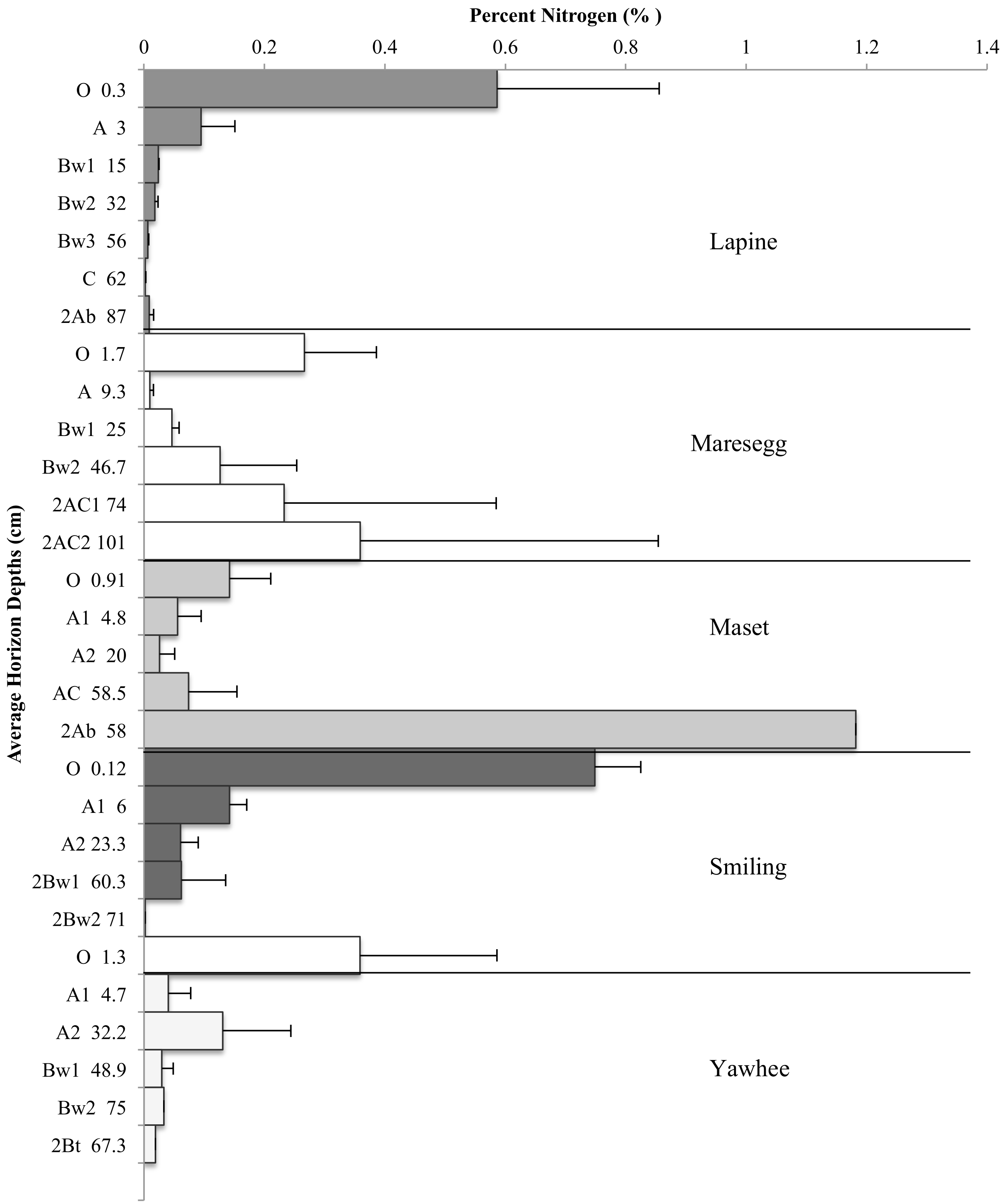

Figure 6. Average % by horizon along with average horizon depth for the five soil series in the Lobert restoration area. Averages were taken from three to four replicated sites of each soil series.

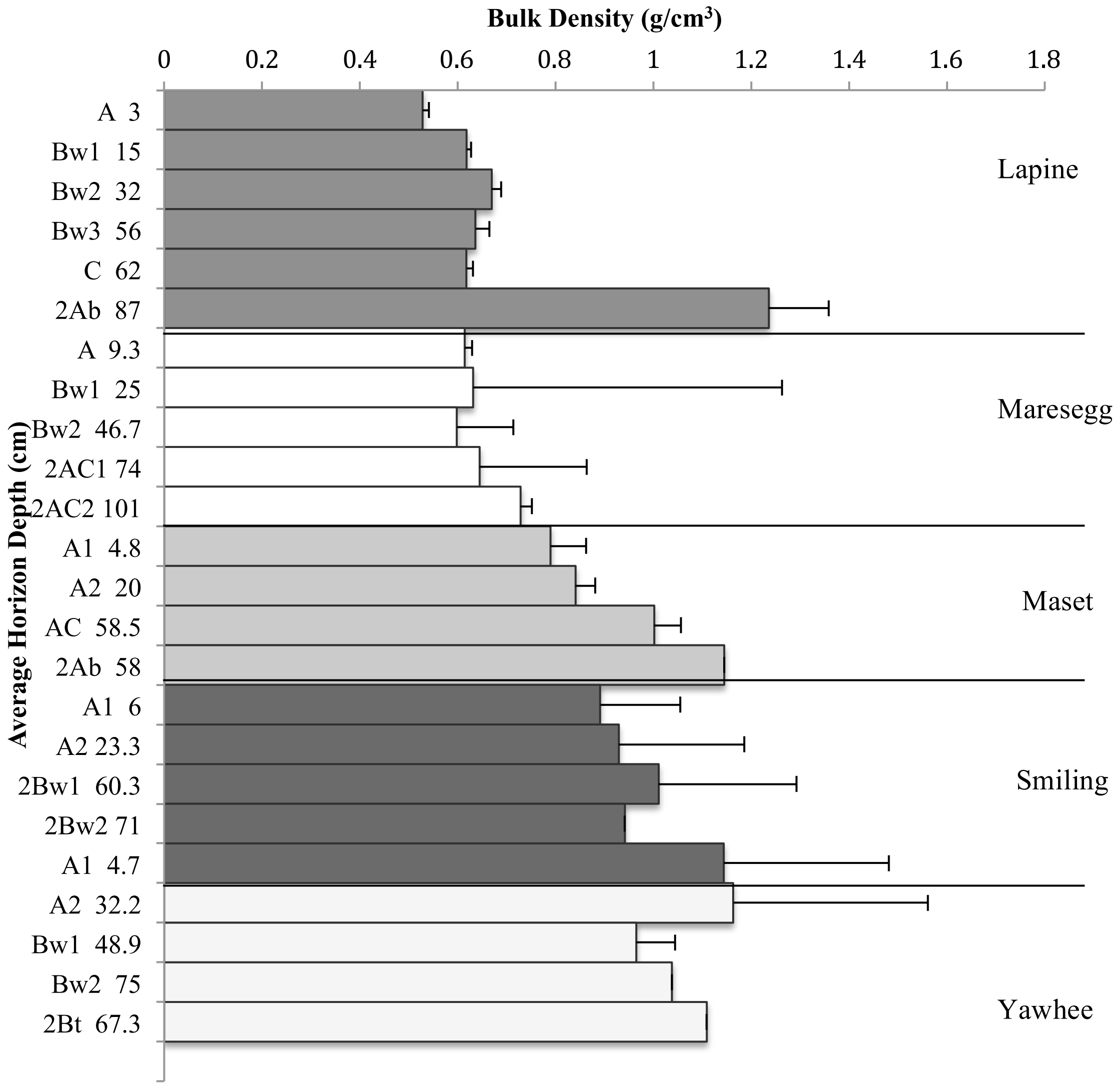

Figure 7. Average bulk density by horizon along with average horizon depth for the five soil series in the Lobert restoration area.

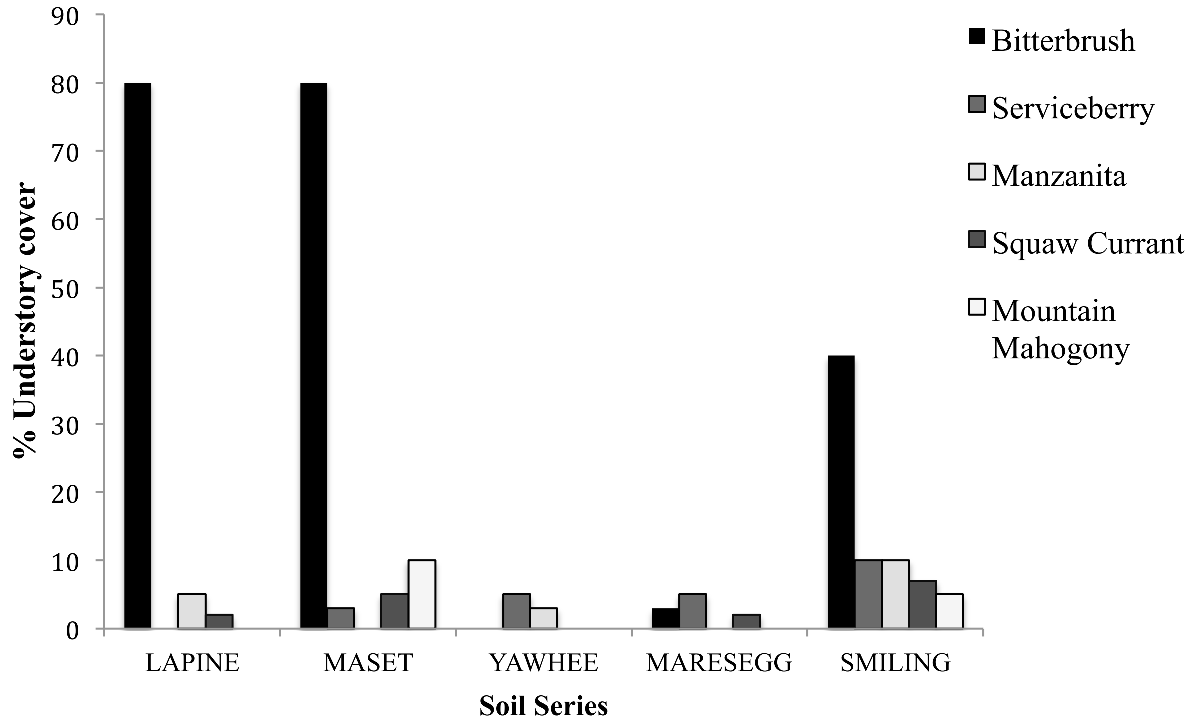

Figure 8. Average % cover understory cover of five understory species of concern at five soil series examined within the Lobert restoration area excluding bareground.

Figure 9. Average total basal area in each of the soil series in the restoration study area.

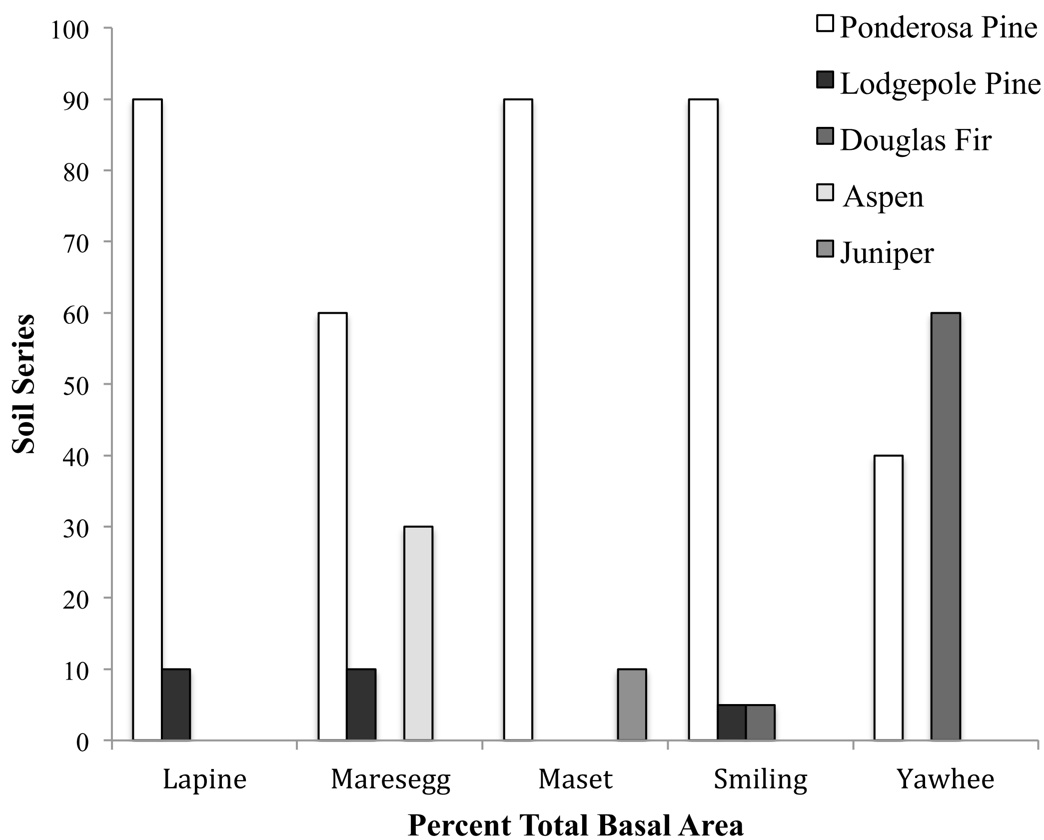

Figure 10. Percent of total basal area of each overstory species in the five soil series.

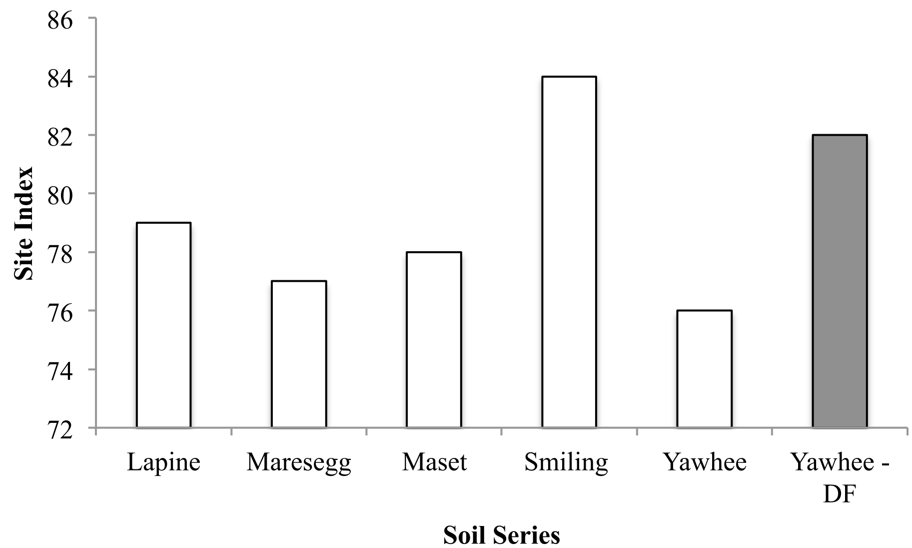

Figure 11. Average ponderosa pine site index with base age of 100 years for each of the soil series. The Yawhee soil series has site index based on 100 years Douglas-fir, the primary overstory species on the Yawhee soil series.

Figure 12. Example of Lapine soil series and associated landscape. The yellow and black bars indicate 10 cm increments.

Figure 13. Example of Maresegg soil series and associated landscape. The brown and white bars indicate 10 cm increments.

Figure 14. Example of Maset soil series and associated landscape. The brown and white bars indicate 10 cm increments.

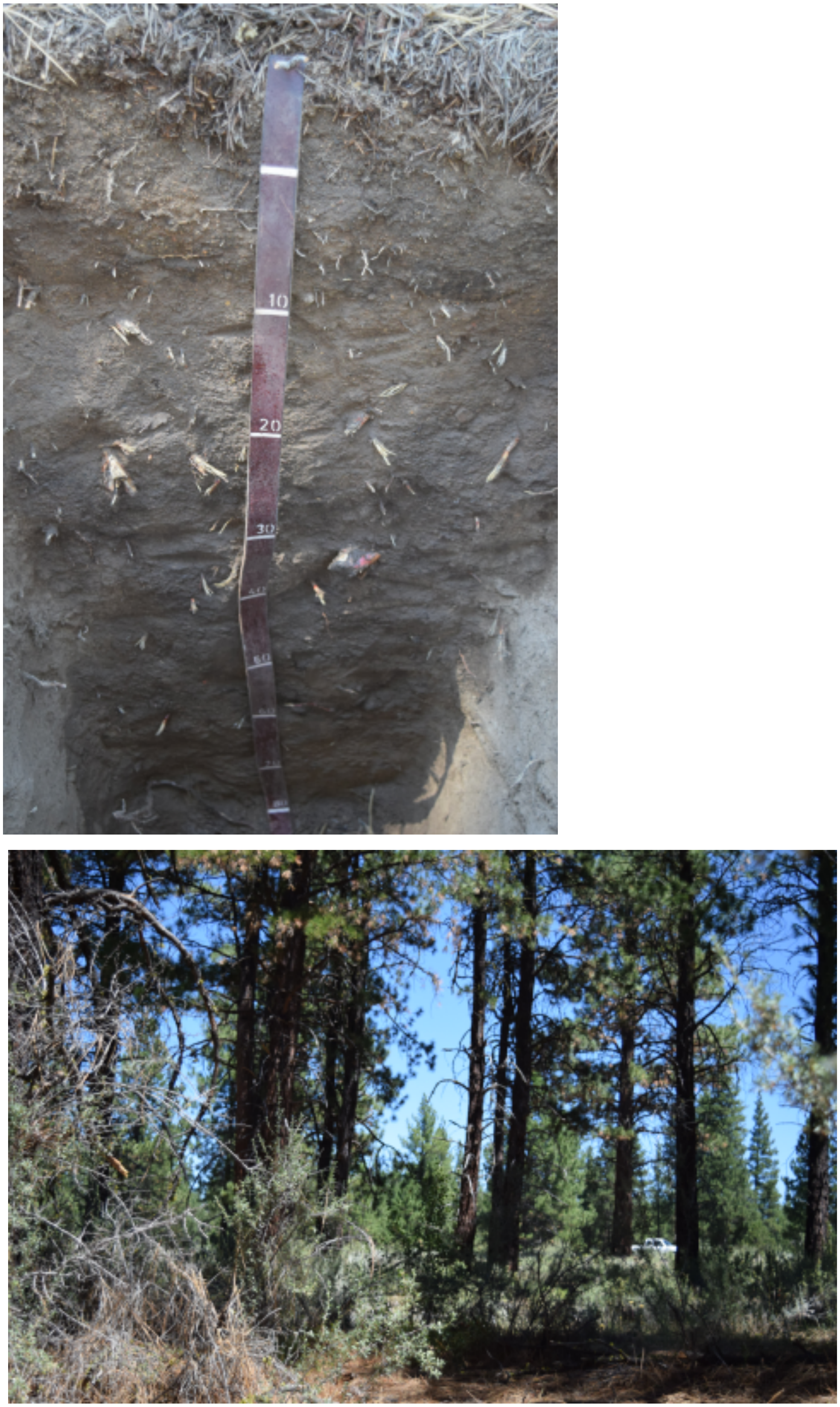

Figure 15. Example of Smiling soil series and associated landscape. The brown and white bars indicate 10 cm increments.

Figure 16. Example of Yawhee soil series and associated landscape. The brown and white bars indicate10 cm increments.

CHAPTER 4: MANAGEMENT IMPLICATIONS

Combined soil and vegetation information can create a base of information that enables land managers to understand the ecology of a landscape. In the Lobert restoration study area, there are multiple management objectives. The overall purpose of the US Forest Service Lobert Restoration NEPA Project was to restore forest resiliency by reestablishing forest structure and pattern, and vegetation composition and diversity to conditions that are more resilient to natural disturbance processes. The main management objectives in the restoration area include promoting old growth, creating vegetative conditions that are better prepared for fire events, conserving and restoring cultural plants, and maintaining and improving wildlife species habitat. Each of the five soil series studied in the Lobert restoration study area provide different conditions that support these range of objectives (Table 5, Figure 17). A tool for more effective forest management is soils information, linking inherent soil characteristics influences on vegetation.

Old growth and Fire resilience management

Fire resiliency is a characteristic of historic forest stands in the east cascades of Oregon. Due to fire suppression activities, the forest structure of the Lobert restoration area has been overstocked with increasing density of standing vegetation, surface fuels and ladder fuels (USDA 2015). These overstocked stands occur on all five soil series in the restoration study area. The Lapine, Maset, and Smiling soil series had the highest percent of ponderosa pine and were located on shoulder and side slopes (Figure 10). The Smiling soil series had the highest site index of 84, with old growth trees growing well, due to the buried horizon providing moisture and nutrition to the ponderosa pine roots (Figure 11). Similarly, the Maset soil series had buried horizons that provided plentiful moisture and nutrients to ponderosa roots, however due to the rockiness of the profile, less soil volume was available to the trees resulting in a lower site index of 79. The Lapine soil series had the highest basal area based on ponderosa pine, however due to the nutrient and moisture limitations the site productivity is lower than the Smiling soil series. The Lapine soil series was listed having a cryic temperature regime (USDA 2015) based on the thermal properties and low bulk density of the pumice, however it was found in low elevation in the restoration area. Cochran et al, (1967) found that exposed Lapine soils have low thermal conductivity which makes them more susceptible to changes in environmental factors. If the soil organic matter of these soils is removed, it is very difficult to reforest. Ponderosa pine growing on these soil series could be managed for by thinning the stands to reduce fire hazard and allowing trees left behind more access to soil moisture and nutrients, due to decreased in competition.

Northern Spotted Owl habitat management

Another overstory species of importance in the Lobert restoration area is Douglas-fir, which was found primarily on the Yawhee soil series. The Yawhee soil series supported Douglas-fir more successfully than the other soils due to the higher elevation, and slope position sandy loam texture, and higher moisture content. The Yawhee soil series were located on summit and shoulder slopes with elevations between 1382 to 1562 meters and had the highest annual precipitation of 76 cm in the study area. Texture in the upper part of the soil profile is ashy coarse sandy loam with the lower horizons loam and clay loam textures. The fine texture of the soil profile and local climate supported the highest moisture content at both the 10 and 50 cm depths (Figure 2 and 3). Due to these favorable soil conditions, the Yawhee soil series is the most productive soil series in the Lobert project area that supports moist mixed conifer species with a site index of 82. The characteristics of the mixed conifer stands on the Yawhee soil series support the habitat of the Northern Spotted Owl (NSO), a listed threatened species under the Endangered Species Act in 1990. To preserve owl habitat in nesting, roosting, and dispersal within these soil series there could be a designation of no treatment areas where stands are left as they are. The NSO habitat that already exists within the mixed conifer stands should be untouched to preserve NSO activity within the areas. The Yawhee soil series has a udic moisture regime which makes it the most resistant to wildfire in the restoration area. However, the Yawhee soil series also has a high basal area and thus still has the risk of fire destroying habitat. Hand cut thinning and brush removal in locations where it is most needed on the Yawhee soil series would be beneficial. Regeneration of NSO habitat in some areas with potential of providing nesting, roosting, and dispersal is another possibility. The soil complexes with the highest percentage of the Yawhee provide for the most suitable NSO habitat due to the higher moisture content throughout the year. The texture of sandy loam provides higher moisture retention available for the mixed conifer species. Treatments for regenerating habitat would include thinning young trees and mowing to increase understory growth and promote old growth.

Promoting Understory Plant Communities

The Lapine, Maset, and Smiling soil series had the highest bitterbrush understory percent covers, which could be due to the dry and nutrient limited conditions of the soil series surface horizons reducing competition (Figure 2). Bitterbrush is valuable forage for winter range mule deer (Burrell 1982), therefore the promotion of bitterbrush growth is recommended in these soil series. Mountain mahogany prefers the Maset soil series because of the tephra layer, mixed minerology, and rockiness of the soil profile. The mountain mahogany looked healthy but may benefit from juniper and or conifer removal from existing stands. The mountain mahogany could be a natural firebreak on the Maset soil series, therefore thinning specifically around them would be recommended. Recommended treatment in the Lapine, Maset and Smiling soil series is to prescribe thinning, mowing, and burning to result in an increase in understory response to increase species richness and decrease fire potential in the stands.

Riparian Restoration

The promotion of riparian vegetation and cultural plants is an objective that can be met by examining the soil series that are the most suitable for riparian vegetation. Aspen was found on the Maresegg soil series secondary to Ponderosa pine. The Maresegg ponderosa pine site index was one of the lowest of all the soil series, this could be due to the location on toe slopes, however it is difficult to fully understand why the Maresegg soil series is less productive then the Lapine soil series. This can be due to past treatments and site history that is unknown. The Maresegg soil series has higher annual moisture content, carbon, and nitrogen than the Lapine soil series. The aspen growing on the Maresegg soil series was found due to the slope position, increased moisture content, and a deeper organic-rich A horizon (Table 1 and 2, Figure 2 and 3). The understory diversity in the Maresegg soil series was higher due to these soil characteristics as well. The aspen and understory species in the Maresegg soil series can be restored to higher vigor by prescribed burning and thinning of encroaching conifers. Burning aspen stands promotes aspen regeneration (Cryer and Murray 1992). Planting aspen can be considered on the soil series too, however, there would need to be fencing to avoid wildlife consumption of seedlings.

Soil and forest vegetation relationships in the Lobert restoration area are complex, as there are many variations possible. Soil moisture content was the most apparent soil characteristic that could be associated with vegetation patterns and productivity. Soil texture and rockiness directly related to moisture content and also influenced the vegetation patterns. However, there were inconsistencies of correlating soils and productivity. The Lapine soil series, although lower in site index than the Smiling soil series, had a high basal area. Hironaka et al. (1991) noted that there were other studies that found inconsistencies correlating site productivity with soil characteristics. Some studies found that some of the highest site index trees were located on less productive soils. Other studies saw correlation of high site productivity with productive soils. The studies that had constrained independent variables found meaningful correlations (Hirnoka et al. 2001). Soils in the Lobert restoration area were constrained to volcanic parent material, however other factors were not held constant. The variability of soil and vegetation through the sites could be due to many factors not known such as site history. Nevertheless, soils information still provides a baseline of information for management decisions across broad landscapes. For the broad planning area, soils can be used as a baseline for management decisions. Specific sites may vary based on past management history and local soil/site conditions.

CONCLUSIONS

The soil series within the Lobert restoration area influenced the forest vegetation patterns and productivity to a certain extent. Soil characteristics and soils can clarify the relationship of soils with plant species. Factors that may have influenced the productivity of overstory species could be moisture content, texture, slope position, and rock content. Soil moisture content varied by the soil series and influenced support of specific species such as Ponderosa pine and Douglas-fir. The Smiling soil series supported the highest site index of Ponderosa pine, which could be due to the adequate moisture content available throughout the year. The Lapine soil series had the highest ponderosa pine basal area possibly due to the buried 2Ab horizon that provided ponderosa pine moisture. In contrast, the Yawhee soil series had the highest moisture content throughout the year and was shown to support Douglas-fir and mixed conifer stands.

Related to moisture content, soil texture explained differences between the vegetation in the restoration area. The Yawhee soil series had sandy loam to loam textures and the highest moisture content, which provided suitable conditions for Douglas-fir and the highest understory species richness. High bitterbrush cover was present in the Lapine, Maset, and Smiling soil series possibly due to the dry and nutrient limited conditions of the soil series surface horizons reducing competition. Slope position was another factor contributing to soil conditions that supported different vegetation. Aspen was found on the Maresegg soil series likely because of the toe slope position receiving moisture from upslope and development of deep A horizons. Rock content was high in the Maset soil series, which could explain the presence of curlleaf mountain-mahogany and lower site index. Soil carbon and nitrogen were factors that were examined in the study, however did not correlate with vegetation patterns and productivity.

The objective of this study was to assess several soil characteristics and their influence on vegetation productivity, patterns, and species richness. Of the soil characteristics examined, moisture content, texture, rockiness of soil profile, and slope position were determined to influence the vegetation productivity and patterns. On a broad scale, vegetation changed with soil type within the planning area and provides appropriate delineations that can be used to meet specific management objectives. Fuels treatment through thinning could be done to increase fire resiliency on the Lapine, Maset, and Smiling soil series. Promoting bitterbrush could be focused on the Lapine, Maset and Smiling soil series and curlleaf mountain mahagony can be restored by thinning on the Maset soil series. The Maresegg soil series can be restored to riparian ecosystems by thinning and prescribed burning. And the Yawhee soil series can be managed for habitat restoration of the Northern spotted owl. Using soils information as a baseline, management practices can be addressed using previously mapped soil series to fulfill management objectives.

Table 5. Management objectives with corresponding soil series and recommended treatment to fulfill management objective.

Management Objective	Soil Series	Recommended Treatment
Increase fire resilience	Lapine, Maset and Smiling	Thin existing forest stands, leaving old growth ponderosa pine
Promote Northern Spotted Owl habitat	Yawhee	Nesting, roosting, and dispersal habitat should be left untouched Hand cut thinning and brush removal in very dense patches Regenerating habitat would include thinning young trees and mowing to promote understory growth and old growth
Promote bitterbrush and mule deer forage	Lapine, Maset, and Smiling	Thinning, mowing, and burning to promote bitterbrush
Promote curlleaf mountain mahagony	Maset	Thinning conifers around the curlleaf mountain mahagony
Riparian restoration	Maresegg	Restore aspen and understory species vigor by prescribed burning and thinning of encroaching conifers

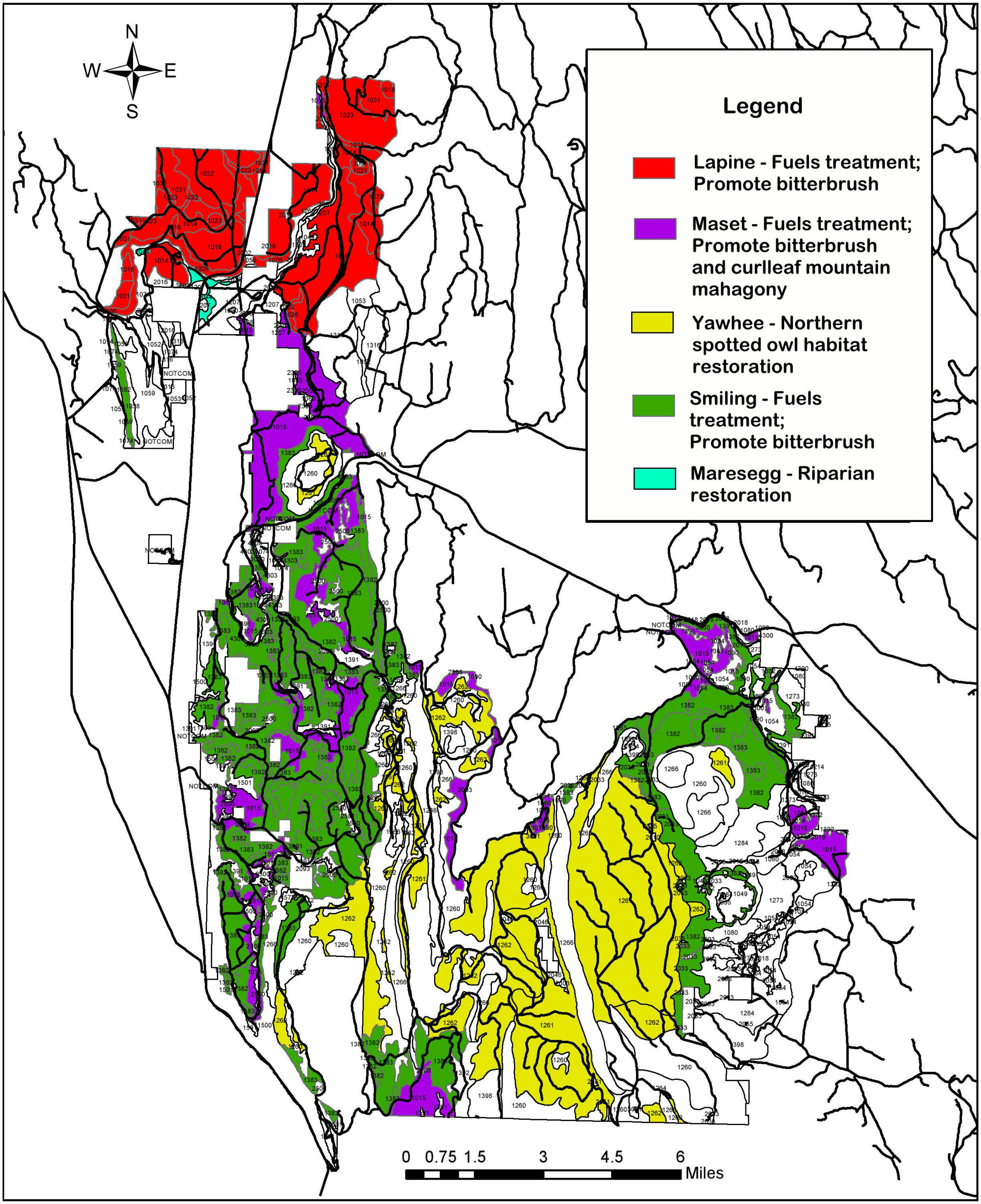

Figure 17. Lobert restoration area map with recommended management areas based on soil series

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APPENDIX: SOIL PROFILE DESCRIPTIONS

LAPINE SOIL SERIES

The Lapine series consists of deep, excessively drained soils that formed in air-laid caps of paragravel pumice and ash. The Lapine soils are located on flat upland pumice mantled lava plains and shoulder slopes. The Lapine series has a xeric moisture regime and has an average mean annual precipitation of about 25 inches (64 cm).Vegetation supported by this soil series ponderosa pine, lodgepole pine, antelope bitterbrush, manzanita, and snowbrush ceanothus.

All soil horizons color, texture, and consistence were examined when moist.

O -- 0 to 0.1 inch (0 to 0.25 cm); slightly decomposed litter of ponderosa pine needles and grasses; very stronhly acidic (pH 4.6).

A-- 1 to 4 inches (2.5 to 10.2 cm); very dark grayish brown (10YR 3/2) paragravelly ashy loamy coarse sand; weak fine granular structure; very friable consistence; many very fine and fine roots; many very fine pores; about 20 percent paragravel pumice fragments; slightly acid (pH 6.2); clear wavy boundary. (1 to 3.5 inches thick; 2.5 to 8.6 cm thick)

Bw1 -- 4 to 9 inches (10.2 to 22.9 cm); dark brown (10YR 3/3) paragravelly ashy loamy coarse sand; single grain; very friable consistence; many roots; many very fine pores; about 30 percent paragravel pumice fragments; slightly acid (pH 6.5); clear wavy boundary. (4 to 10 inches thick; 10 to 25 cm thick)

Bw2 -- 9 to 18 inches (22.9 to 45.7 cm); brown (10YR 4/3) very paragravelly ashy loamy coarse sand; single-grain very friable consistence; many roots; many fine pores; about 40 percent strong brown paragravel pumice fragments; slightly acid (pH 6.6); clear wavy boundary. (3.5 to 9 inches thick; 9 to 23 cm thick)

Bw3 -- 18 to 25 inches (45.7 to 63.5 cm); brown (10YR 5/3) very paragravelly ashy coarse sand; single-grain; very friable consistence; few roots; many very fine pores; about 50 percent strong brown paragravel pumice fragments; slightly acid (pH 6.5); clear wavy boundary. (6 to 21 inches thick; 14 to 53 cm thick)

C -- 25 to 36 inches (63.5 to 91.4 cm); light olive brown (2.5Y 5/4), extremely paragravelly ashy coarse sand; single grain; loose; few roots; many very fine pores; about 75 percent paragravel pumice fragments; neutral (pH 6.7); gradual wavy boundary. (8 to 11 inches thick; 20 to 28 cm)

2Ab -- 36 to 45 inches (91.4 to 114.3 cm); dark reddish brown (5YR 3/4) silty clay loam, weak fine subangular blocky structure; very friable consistence; common roots; many very fine pores; about 10 percent gravel; neutral (pH 6.7); clear smooth boundary. (4 to 9 inches thick, 10 to 23 cm thick)

MARESEGG SOIL SERIES

The Maresegg series is a deep moderately well drained soil located on toe slopes and within the vicinity of flood plains. The Maresegg series is influenced by air-laid pumice of past volcanic eruptions and deciduous forest litter decomposition. The soil moisture regime is xeric and has an mean annual precipitation of 28 inches (71 cm). Vegetation supported by this soil includes quaking aspen, ponderosa pine, juniper, lodgepole pine, white spirea, vine maple, Greenleaf Manzanita, strawberry, snowberry, and other riparian understory species.

All soil horizons color, texture, and consistence were examined when moist.

O -- 0 to 1 inch (0 to 2.5 cm); slightly decomposed litter of ponderosa pine needles, grasses, deciduous aspen litter; very strongly acidic (pH 4.6).

A -- 1 to 6 inches (2.5 to 15.2 cm); very dark brown (10 YR 2/2) paragravelly ashy sandy loam; weak to moderate granular structure; very friable consistence; many very fine and fine roots; many very fine pores; about 10 percent paragravel pumice fragments; medium acidic (pH 5.8); clear wavy boundary. (1 to 8 inches thick; 2.5 – 20.3 cm thick)

Bw1 -- 6 to 14 inches (15.2 to 35.6 cm); brown (10 YR 3/2) paragravelly ashy sandy loam; weak granular structure; very friable consistence; many very fine and fine roots; many very fine pores; about 15 percent paragravel pumice fragments; slightly acidic (pH 6.3); clear wavy boundary. (4 to 9.8 inches thick; 10 to 25 cm thick)

Bw2 -- 14 to 29 inches (35.6 to 73.7 cm); brown (10 YR 4/3) paragravelly ashy sandy loam; single grain; very friable consistence; many very fine and fine roots; many very fine pores; about 20 percent paragravel pumice fragments; slightly acidic (pH 6.2); gradual wavy boundary. (4 to 15 inches thick; 9 to 38 cm thick)

2AC -- 29-50 inches (73.7 to 127 cm); mottled brown and black (10 YR 5/3 and 10 YR 2/1) paragravelly ashy coarse sandy loam; single grain; loose; many very fine and fine roots; many very fine pores; about 30 percent paragravel pumice fragments; neutral (pH 6.8); gradual wavy boundary. (6 to 21 inches thick; 15 to 53 cm thick)

MASET SOIL SERIES

The Maset series consists of moderately deep, well drained soils that formed in a thin mantle of ash over buried loamy soils. Maset soils are on benches, escarpments, and shoulder slopes. The soil moisture regime is xeric and has an mean annual precipitation of about 18 inches (45.7 cm). Vegetation supported by this soil is ponderosa pine, bitterbrush, curlleaf mountain-mahgonay, strawberry, serviceberry and squaw currant.

All soil horizons color, texture, and consistence were examined when moist.

O -- 0 to 0.1 inch (0 to 0.25 cm); slightly decomposed litter of ponderosa pine needles, grasses; acidic (pH 5)

A1—0.1 to 4 inches (0.25 to 10.2 cm); dark brown (10YR 3/3) ashy coarse sandy loam; weak very fine granular structure; very friable consistence; many very fine roots; many very fine pores; about 10 percent gravel of hard lava; slightly acid (pH 6.3); clear wavy boundary. (2.5 to 5 inches; 1 to 12.7 cm thick)

A2--4 to 8 inches (10.2 to 20.3 cm); dark brown (10YR 3/3) ashy coarse sandy loam, weak massive structure; very friable consistence; many very fine pores; about 10 percent gravel of hard lava; slightly acid (pH 6.5); clear wavy boundary. (5 to 15.6 inches thick; 12.7 to 39.7 cm thick)

AC--8 to 16 inches (20.3 to 40.6 cm); dark yellowish brown (10YR 3/4) gravelly ashy coarse sandy loam; massive; very friable consistence; common fine and very fine roots; many very fine pores; about 15 percent gravel and 5 percent cobbles of hard lava; neutral (pH 6.6); gradual wavy boundary. (8 to 23 inches thick ;20.3 to 58.4 cm thick)

2Ab--16 to 30 inches (40.6 to 76.2 cm); brown (10YR 4/3) gravelly sandy loam; weak medium subangular blocky structure; very friable consistence; common fine and very fine roots; many very fine pores; about 15 percent gravel and 5 percent; common fine and very fine roots; common very fine tubular pores; about 20 percent gravel; 5 percent cobbles and 5 percent stones; slightly acid (pH 6.4); clear wavy boundary (0 to 8 inches thick; 0 to 20.3 cm thick)

SMILING SOIL SERIES

The Smiling series consists of deep well drained soils formed in ash over colluvium. The soils are located on mountains on shoulder and side slopes ranging from 0 to 40 percent. The soil moisture regime is xeric and has an mean annual of about 30 inches (76.2 cm). Common vegetation supported by the Smiling series includes ponderosa pine, lodgepole pine, Douglas-fir, bitterbrush, squaw currant, sagebrush and Manzanita.

All soil horizons color, texture, and consistence were examined when moist.

O--0 to 1 inch (0 to 2.5 cm); slightly decomposed litter of ponderosa pine needles and grasses; strongly acidic (pH 5.3).

A1--1 to 5 inches (2.5 to 12.7 cm); very dark brown (7.5YR 2.5/2) ashy sandy loam; moderate very fine granular structure; friable consistence; many very fine and fine and common medium roots; many very fine irregular pores; 10 percent pumice; slightly acidic (pH 6.1); clear smooth boundary (3 to 5 inches thick; 7.6 to 12.5 cm thick)

A2--5 to 14 inches (12.7 to 35.6 cm); dark brown (7.5YR 3/4) ashy sandy loam; moderate very fine granular structure; friable consistence; common very fine, fine, medium, and coarse roots; many very fine pores; 10 percent pumice; neutral (pH 6.6); clear wavy boundary. (6 to 11 inches thick; 15.2 to 28 cm thick)

2Bw1--14 to 24 inches (35.6 to 61 cm); dark brown (7.5YR 3/4) very fine sandy loam; weak medium subangular blocky structure; friable consistence; few fine and common medium and coarse roots; common very fine tubular pores; few faint clay films on peds and in pores; 5 percent gravel; neutral (pH 6.7); gradual wavy boundary. (8 inches thick; 20 cm thick)

2Bw2—24 to 32 inches (61 to 81.3 cm); dark brown (7.5YR 3/4) loam, brown (7.5YR 5/4) dry; weak medium subangular blocky structure; friable consistence; few fine and common medium and coarse roots; common very fine tubular pores; few faint clay films on peds and in pores; 5 percent gravel; neutral (pH 6.8); clear wavy boundary. (8 inches thick; 20 cm thick)

YAWHEE SERIES

The Yawhee series consists of deep well drained soils that formed in a mantle of volcanic ash over buried very gravelly loamy mixed material. Yawhee soils are on volcanic cones, escarpments, and cuestas on summit and shoulder slopes of 0 to 20 percent. The moisture regime is Udic and the mean annual precipitation is about 30 inches (76.2 cm). Vegetation supported by the Yawhee soil series includes Douglas-fir, ponderosa pine, sugar Pine, snowbrush, pine lupine, white spirea, bitterbrush, and subalpine sagebrush.

All soil horizons color, texture, and consistence were examined when moist.

Oi--0 to 1 inch; slightly decomposed plant material consisting of a loose mat of pine and fir needles; medium acid (pH 5.7)

A1--1 to 3 inches (2.5 to 7.6 cm); dark brown (10YR 3/3) stony ashy coarse sandy loam; weak very fine granular structure; very friable consistence; many fine pores; 15 percent gravel, 5 percent stones; slightly acid (pH 6.3); clear wavy boundary. (1.2 to 4.7 inches thick; 3 to 12 cm thick)

A2--3 to 15 inches (7.6 to 38.1 cm); dark brown (7.5 YR 3/4) very cobbly ashy coarse sandy loam; weak fine and medium subangular blocky structure; very friable consistence; many roots; many very fine pores; 20 percent gravel, 20 percent cobbles and stones; slightly acid (pH 6.5); clear wavy boundary. (0 to 9.8 inches thick; 0 to 25 cm thick)

Bw1--3 to 16 inches (7.6 to 40.6 cm); dark yellowish brown (10YR 3/4) very cobbly ashy loamy coarse sand; massive; very friable consistence; many roots; many very fine pores; 25 percent gravel, 25 percent cobbles and stones; slightly acid (pH 6.4); clear wavy boundary. (0 to 11 inches thick; 0 to 28 cm thick)

Bw2--16 to 25 inches (40.6 to 9.8 cm); dark yellowish brown (10YR 4/6) very cobbly fine sandy loam; weak subangular blocky structure; very friable consistence; many roots; many very fine pores; 25 percent gravel, 25 percent cobbles and stones; slightly acid (pH 6.1); clear wavy boundary. (0 to 9 inches thick; 0 to 23 cm thick)

2Bt--25 to 35 inches (40.6 to 88.9 cm); dark brown (7.5 3/3) very gravelly fine sandy loam; weak fine subangular blocky structure; very friable consistence; common rootsl many very fine pores; 35 percent gravel, 20 percent cobbles and stones; slighty acid (pH 6.5); clear wavy boundary. (0 to 10 inches thick; 0 to 25.4 cm thick)