AN ABSTRACT OF THE THESIS OF

Andrew G. Merschel for the degree of Honors Baccalaureate of Science in Natural Resources presented on March 8, 2010. Title: Stand Structure of Old Growth Dry Mixed Conifer Forests in the Deschutes and Ochoco National Forests.

Abstract approved: ____

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Abstract Body

Old-growth dry-mixed conifer forests are valued as habitats for late seral forest species, for the ecosystem services and landscape diversity they provide, and for their aesthetic appeal. The structure of these forests has been heavily altered by historic logging of overstory ponderosa pine and Douglas-fir. Additionally, changes in fire regime have altered understory density in these forests to an unknown extent. Conserving remaining stands and facilitating old-growth development in disturbed stands are objectives of the Deschutes and Ochoco National Forests. This investigation addressed these objectives with two separate analyses. The first analysis was an accuracy assessment of the GNN forest vegetation map's ability to predict old-growth dry-mixed conifer structure at a site scale and at a landscape scale. This analysis determined that the GNN map is an adequate tool for identifying old-growth stands at a site scale, and was highly accurate at predicting dry-mixed conifer forest vegetation at a landscape scale. The second analysis characterized present day and historic stand structure of old-growth dry-mixed conifer forests, and described how stand structure varied across the Deschutes and Ochoco National Forests. The second analysis determined future research should investigate the growth rate of understory ponderosa pine and Douglas-fir under varying density levels.

Key Words: Dry Mixed Conifer, Old Growth, Stand Structure, Gradient Nearest Neighbor Method

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Stand Structure of Old Growth Dry Mixed Conifer Forests in the Deschutes and Ochoco National Forests.

By

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I understand that my project will become part of the permanent collection of Oregon State University Honors College. My signature below authorizes release of my project to any reader upon request.

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Andrew G. Merschel, Author

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Chapter 1: An Introduction to Dry-Mixed Conifer Forests

Introduction

The Dry-Mixed Conifer (DMC) forest type found in the Deschutes and Ochoco National Forests an important part of the Oregon landscape however, this forest type is inadequately understood by ecologists, land managers, and the general public. Specifically the historic and current stand structure of old growth DMC forest is not adequately described. DMC forests have been heavily altered since European settlement which has raised concerns about the long term resiliency of this ecosystem and the ecosystem services it provides. Of particular concern is the persistence and restoration of old-growth or mature DMC forest stands that have been heavily modified by grazing, logging, and fire regime alteration (Spies, Hemstrom, Youngblood, and Hummel 2006, and Fitzgerald 2005). Remaining old-growth trees and the stands they comprise are not threatened by logging, but are at risk from wildfire, insects, and disease. Youngblood, Metlen, and Coe (2006), reported that changes in fire regimes have altered stand structures, increasing the densities of shade tolerant understory species and the probability of high intensity stand-replacing wildfires. Furthermore, under increased densities, remnant stands face an increased risk of drought and insect related mortality (Hemstorm, 2001). There is a broad consensus that forest types with a historically mixed-severity fire regime now require active management through thinning and prescribed fire to maintain the resilience of these ecosystems (Brown, Agee, and Franklin 2004).

Understanding the current distribution and abundance of old-growth DMC forests and how stand structure varies in response to site characteristics and disturbance history are critical management objectives for the DMC forest type (personal communication, Tom Spies and Robin

Vora, 2010). This study furthers these goals with two separate and related investigations. In Chapter 2 I evaluate a vegetation map that is used to predict the structure and location of old-growth. In Chapter 3 I characterize the stand structure of old-growth DMC forests in the Deschutes and Ochoco National Forests. Both investigations were conducted using site data collected using the Forest Inventory and Analysis (FIA) sampling design. The accuracy assessment of the GNN mapping method was conducted by comparing site structural statistics reported by the GNN map to site data gathered during field sampling. Stand structure of older DMC forest was investigated by summarizing stand structure across geographic regions in the study area and by comparing stand structures to site conditions and disturbance histories. Sites sampled in this research also provide permanent plots that can be revisited to analyze changes in stand structure over time. Additionally, I collected data on site and stand characteristics that may be used for additional investigations. For purposes of this investigation all live trees with a diameter at breast height (DBH) >50cm are defined as old-growth trees, and all stands with a density of at least 25 old-growth trees per hectare (TPH) are defined as old-growth stands.

Study Area

DMC forests of the Deschutes National Forest are found on the eastern slopes of the Cascades and occupy a thin band of land running from north to south that features similar climatic conditions. The elevation range within the Deschutes is 1,100-1,500 meters (Franklin and Dyrness, 1973). DMC forests found in the Ochoco National Forest occupy mesic areas at upper elevations or valleys bottoms and are found within an elevation range of 1,500-2000 meters (Franklin and Dyrness, 1973). Figure 1 provides the location of the Deschutes and Ochoco National Forests in Oregon.

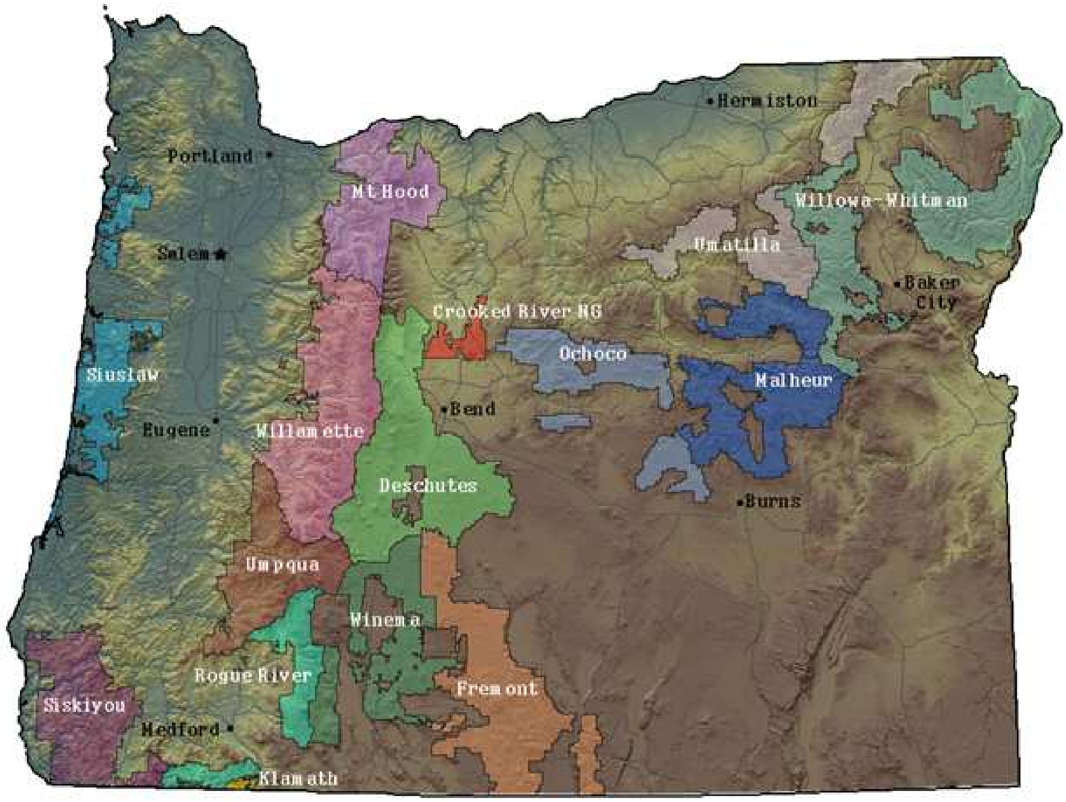

Figure 1- Map of Deschutes and Ochoco National Forest in Oregon

The DMC region is characterized by hot, dry summers with minimal precipitation, and cold winters with the vast majority of precipitation falling as snow. Climate records from the *Western Regional Climate Center* (http://www.wrcc.dri.edu/) for four climate stations found within the sampling are, and are provided in Table 1.

Station	Region	Elevation (m)	Latitude	Longitude	Temperature (Degrees C)			Precipitation (cm)		
					Average annual	Average January (min), (max)	Average July (min/max)	Annual Average	June-August	Average Snowfall
Sisters, Oregon	North Deschutes	969.3	4417.0	12132.0	16.0	(-6.1), (4.9)	(5.7), (29.2)	34.4	3.6	75.9
Wickiup Dam	South Deschutes	1320.7	4341.0	12142.0	14.2	(-8.5), (3.0)	(6.4), (27.0)	51.7	6.1	200.0
Rager Ranger Station	East Ochoco	1219.2	4414.0	11946.0	16.1	(-7.2), (3.6)	(7.6), (29.9)	43.1	6.1	97.5
Ochoco Ranger Station	West Ochoco	1216.1	4424.0	12026.0	14.4	(-9.2), (1.6)	(5.3), (27.7)	44.3	6.7	144.2

Table 1- Climate of the Deschutes and Ochoco National Forests

Soils generally exhibit minimal development in DMC forests but are relatively deep, due to accumulations of volcanic ash throughout much of the range. These soils are well drained to excessively drained and range from sandy to sandy clay loam in texture (NRCS, 1999). Soil processes are podzolic, and typical soil great groups are haplorthods, hamplumbrepts, and vitrandepts. "A" horizons average 30cm in thickness and are slightly acidic (6.2) with 8-9 percent organic matter. (Franklin and Dyrness 1973).

Franklin and Dyrness (1973) noted the major tree species in the forest type are grand fir/white fir *(Abies grandis/Abies concolor)*, ponderosa pine *(Pinus ponderosa)*, lodgepole pine *(Pinus contorta)*, western larch *(Larix occidentalis)*, and Douglas-fir *(Pseudotsuga menziesii)*. Minor species include Englemann spruce *(Picea englemannii)*, incense-cedar *(Calocedrus decurrens)*, sugar pine *(Pinus lambertiana)*, western white pine *(Pinus monticola)*, western hemlock *(Tsuga mertensiana)*, and Shasta red fir *(Abies magnifica var. shastensis)*. Because of their long lifespan and large size, both ponderosa pine and Douglas-fir are key structural components in old growth DMC forests (Spies et al., 2006). Lodgepole pine is a major early seral component of DMC forest at sites that have experienced high severity wildfires at an interval of less than 150 years (Agee, 1994). Additionally western larch is a seral dominant in the eastern portion of the Ochoco national forest (Franklin and Dyrness, 1973). Ponderosa pine, Douglas-fir, western larch, and lodgepole pine are replaced as shade tolerant grand fir becomes dominant in the absence of wildfire or other disturbance, making the majority DMC sites part of the grand fir/white fir plant association series developed by Simpson (2007). Several other climax plants series border the DMC zone. At upper elevations DMC forests gradually transition to the subalpine fir or western hemlock series and at lower elevations they transition to either the ponderosa pine or Douglas-fir series (Franklin and Dyrness, 1973; Spies *et al*., 2005).

DMC forests are typically characterized by a mixed-severity fire regime. Fires of variable severity create a mosaic of stand types by influencing species dominance (early seral vs. late seral) and structure (open vs. dense multilayered canopy). Hessburg, Agee, and Franklin (2003) provide the following summary of the mixed-severity fire regime, "Mixed-severity fire regimes exhibit intermediate fire return intervals, burn intensities that range from underburning to stand replacement, and create intermediate patches with significant edge." Agee (1993) reports that frequent low intensity fires create stands dominated by resistant species such as ponderosa pine, Douglas-fir, and western larch, and Spies et al., (2005) report that frequent fires result in open park-like stands with a single overstory layer. High frequency low-severity fires are characteristic of DMC forests on drier sites that produce lower fuel levels because of lower productivity and weather conditions that favor more frequent fires (Agee, 1994). In contrast more mesic sites that exhibit co-dominance of fire intolerant *Abies spp*. are characterized by moderate-severity to high-severity fires with longer return intervals. Moderate-severity to high-severity fires remove 75-100% percent of the basal area of fire intolerant species (Agee, 1993). The fire return interval for open DMC sites dominated by long lived early seral species is 7-20 years, (Fitzgerald, 2005; Agee, 1994), and the mean fire return interval for denser sites is 47 years in DMC forests (Agee, 1993). Presently, decades of fire suppression has led to an increased basal area and density, and a multilayered structure in DMC forests. These conditions have increased the proportion of stands that are burned by high-severity wildfires (Fitzgerald, 2005; Spies, 2006).

Chapter 2: Accuracy Assessment of the GNN Mapping Method for stand structure of the DMC Forest Type

Background and Rationale

The 1990 Land Management Resource Plan (LMRP) for the Deschutes and Ochoco National Forests states that old-growth stands should be maintained to preserve natural genetic pools, provide habitat for plant and wildlife species associated with mature stands, contribute to the landscape diversity spectrum, and to provide aesthetic appeal. A specific goal of the LMRP is that 21% of the national forest land base will be preserved or allowed to develop into an old growth condition. Accomplishing this management objective requires an understanding of how old growth stands are spatially arranged on the landscape. This knowledge will direct management activities designed to restore and preserve old-growth DMC forests in the Deschutes and Ochoco National Forests. A relatively new method of forest vegetation mapping, which provides the necessary spatial data, was developed by Ohmann and Gregory (2002) using the GNN method to predict and map forest vegetation across Oregon. The vegetation maps produced with this method will be used as a management tool for old growth DMC forests. The motivation for this analysis was to provide an independent assessment of the accuracy of GNN vegetation mapping where it is used to predict old growth forest characteristics for the DMC forest type (Personal Communication, Robin Vora 2009). Specific applications of the Deschutes and Ochoco National Forests for using the GNN map are to map where remaining old growth stands of DMC forests are, and to determine the spatial extent of old growth DMC forests. These needs provide the motivation for my research. Additionally, determining the accuracy of the GNN map will provide researchers with a framework of how the GNN map should be used to identify sample sites in study areas and how research using the GNN map should be designed.

GNN Background

To predict forest vegetation and stand structure across the landscape the GNN method uses a combination of Landsat imagery, Geographic Information Systems (GIS) layers, and field plots. GIS layers contain data of how climate, geology, topography, and ownership types vary across the landscape. The GNN method uses field data from sampled sites to assign stand structure to sites that have not been sampled through a process called imputation. In the GNN method, an un-sampled site is assigned the stand structure characteristics of its nearest neighbor in multivariate space that has similar characteristics in term of spectral reflectance (Landsat Imagery). Sites are represented spatially by pixels on the map, and each pixel has a 30m x 30m resolution. Essentially, GNN predictions use statistical relationships between satellite imagery, site characteristics, and known vegetation characteristics of similar sampled sites to estimate stand structure and vegetation type at un-sampled sites. For complete discussion of the GNN method see Ohmann and Gregory 2002.

Objectives

1. Determine the accuracy of GNN predictions for stand structure of DMC forest at specific site locations.
2. Determine the accuracy of the GNN mapping method for predicting the mean stand structure of DMC forests across the Deschutes and Ochoco National Forests. This objective is not site specific. It is intended to evaluate how accurate the inventory of DMC forests provided by the GNN map is on a landscape or regional scale.

Analysis Methods

Sample Site Selection

The GNN map evaluated was produced using Landsat images from 2000 and the GNN species-structure model from the Interagency Mapping and Assessment Project (IMAP). This data can be obtained from the Landscape Ecology, Modeling, Mapping, and Analysis (LEMMA) website at http://www.fsl.orst.edu/lemma/splash.php. Using the GNN *TPH_ge_50* variable which predicts the density of trees>50cm in diameter at breast height (DBH), the sample area was selected from all areas predicted to have >5TPH of any species >50cm DBH.

The following criteria were used to define the area where site samples would be randomly placed.

- Because the GNN data used were based on satellite imagery from 2000, areas affected by high-severity fire in the B&B and Davis fires were excluded from the sample area.
- All areas with less than 20% canopy cover were removed from the sample selection.
- Areas classified within the mixed conifer dry and ponderosa pine wet plant association groups (PAG) were included in the sample area. All other PAG were not included in the sample area.
- All areas within 60m of an existing road shown on the Deschutes and Ochoco National Forest transportation layer were eliminated and all areas within 55m from a patch edge were eliminated from the sample area. This was done to reduce the chance that sample sites would encompass multiple vegetation types or non forested areas.
- All areas not owned by the United States Forest Service were eliminated from the sample area.

After the sample area was defined, 75 sites were randomly selected. Equal proportions of sites were selected for sites predicted to have between 5-25TPH >50cm DBH and for sites predicted to have >25TPH >50cm DBH. Therefore this study applies to older DMC conifer sites that meet the structural requirements for old growth and to sites that may have been old growth but were modified by logging. Sites were at least 5,000m apart to create a well-distributed sample across the study area. The two maps in Figure 2 depict the study area of the Deschutes and Ochoco National Forests. Note that the Deschutes was separated into north and south zones, and the Ochoco was separated into an east and west zones.

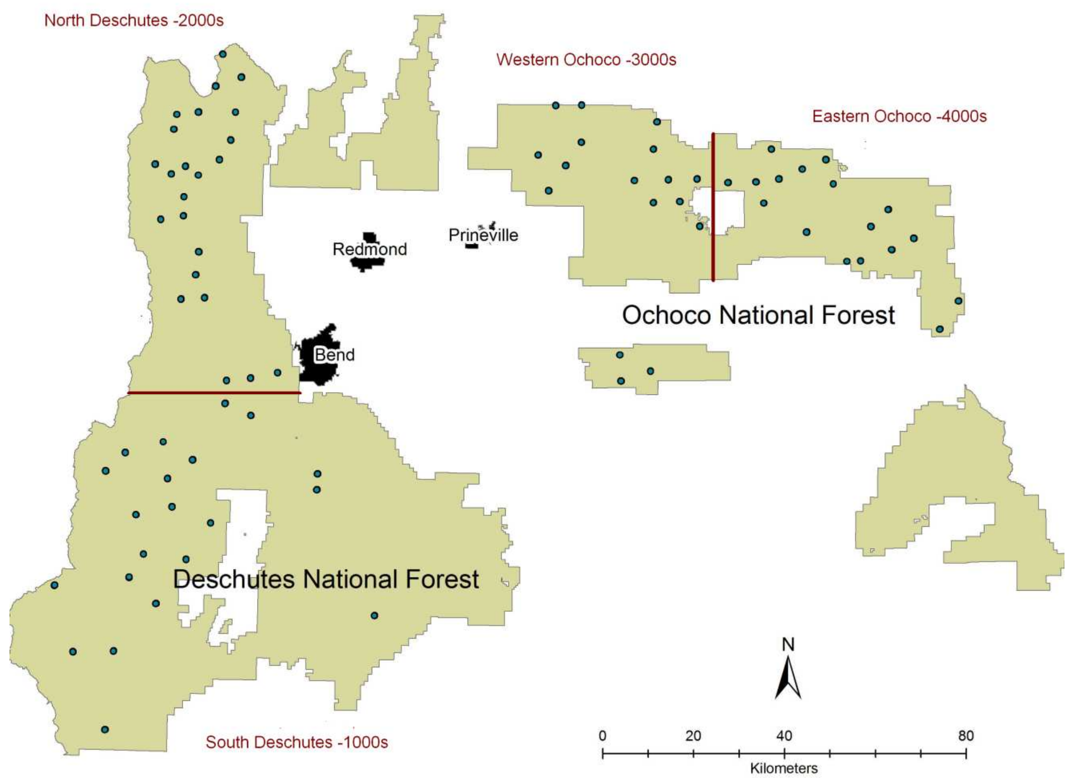

Figure 2 - Maps of study area and sample sites

A total of 43 sites were sampled in the Deschutes National Forest and 33 sites were sampled in the Ochoco National Forest. The sites selected in this procedure were also used to carry out the second analysis of this thesis described in Chapter 3. For both investigations the majority of site samples were recorded in the grand fir/white fir series, but because of small scale variability in elevation, aspect, and the spatial distribution of the grand fir/white fir series, some sites sampled were keyed as part of the ponderosa pine and Douglas-fir series. The field sampling procedure is detailed in Appendix A.

Analysis of GNN Accuracy

GNN predictions were compared to data collected at sample sites across the study area. Sites were sampled and stand structure metrics were calculated using the procedure outlined in Appendix A. The GNN predictions were evaluated based on the assumption that stand structure calculated from the sample sites was the best representation of actual stand structure. The following analysis steps were taken

1. Stand structure predictions were evaluated for density, basal area, and snags per hectare (SPH). Five stand structure attributes are reported in Table 2. These attributes were analyzed because the interim old growth definitions use the density of trees and snags greater than either 50cm or 75cm DBH to define old growth. The basal area attribute was included to analyze if GNN predictions were more accurate for density or basal area metrics.

Stand Structure Attributes Evaluated in GNN Analysis	
Attribute	**Attribute Abbreviation**
Density of trees (TPH) greater than 50cm in diameter at breast height	TPH> 50cm DBH
Density of trees (TPH) greater than 75cm in diameter at breast height	TPH>75cm DBH
Basal Area (BA) of all live trees	BA All Live
Basal Area (BA) of all live trees greater than 50cm in diameter at breast height	BA Live >50cm DBH
Density of snags (SPH) greater than 50cm in diameter at breast height	SPH> 50cm DBH
Density was measured in trees per hectare, basal area was measured in meters squared per hectare, and density of snags was measured in snags per hectare.	

Table 2 - Structural attributes evaluated in GNN analysis with attribute abbreviations

2. To compare stand structure attributes found at the sample sites, the GNN prediction for the same structural attributes was needed for an area that precisely matched the sample site. Using the GNN species structure model and Landsat imagery from 2000, zonal means for all attributes were obtained for all sites sampled. These zonal means were provided for all stand structure attributes used in the GNN Analysis and were generated within a circle with a 54.4m radius extending from the center of macroplot one at each site, which was defined as the zone. This zone encircling macroplot one from the field sample sites overlapped all four macroplots at each site, which were used to calculate stand structural attributes for a site.
3. All stand structure attributes measured at the sample sites were compared to the GNN predictions gathered from zonal stats in three ways.
    a. Each attribute was evaluated using an error matrix that determined the percent accuracy of GNN predictions, from a producer’s and user’s perspective. This assessment reports two types of accuracy including “dead on” accuracy, and a “fuzzy correct” accuracy used in previous evaluations of GNN accuracy by

Ohmann and Gregory (2002). Within each matrix, each of the attributes was divided into either density or basal area classes. These classes were created based on the frequency of sites, within a particular range for density or basal area, which were observed during sampling. Accuracy in the table was evaluated by calculating the proportion of sampled sites within each density or basal area class that were correctly predicted to be in that class by the GNN map.

b. Attributes were evaluated using XY scatter plots to determine the correlation between site values and predicted values. Values observed at sites were plotted along the x axis, and values predicted by the GNN map were predicted along the y axis on all scatter plots.

c. Attributes were additionally evaluated based on whether they were correct within site class range (SCR). SCR refers the density and basal areas classes described above and used in the error matrices. If a predicted attribute value was within the site class range for a stand attribute it was considered accurate. For example, the density of TPH >50cm was broken into 5 classes at intervals of 10TPH. The 10TPH interval is the site class range. If a site had a value of 5 TPH and the value predicted for the site was 15TPH then the site was considered accurate within SCR. However, if the prediction was >15TPH then the prediction was considered inaccurate. This evaluation was added because the fuzzy correct accuracy would indicate that a site with 1 TPH >50cm that was predicted to have 19 TPH>50cm was accurately predicted by the GNN map. Therefore site accuracy ratings for SCR analysis for each attribute, note how likely a GNN prediction will result in a site observation of approximately the same density or basal area. Overall the accuracy with SCR is more lenient than the requirements for dead on accuracy, and is stricter than the requirements for fuzzy correct accuracy report in the error matrices.

4. To analyze the accuracy of GNN predictions on a regional scale, the summary statistics for density and basal area of all attributes at all sites were calculated for GNN predictions and for site measurements. This enabled comparison of the inventory of stand structure across the study area taken during field sampling to the corresponding inventory estimated by the GNN map.

Results

Accuracy of the GNN map within Site Class Range (SCR)

A summary of GNN accuracy based on SCR is displayed in Table 3. Recall that accuracy within SCR is more strict than the "fuzzy correct" requirements and less strict the "dead on" correct requirements used in the error matrix tables. In general if a site was correct within SCR it had approximately the same structure predicted by the GNN. The accuracy of the GNN map at the site scale is dependent on both the attribute of interest and whether the predicted value of the attribute was relatively low, intermediate, or high in magnitude. Overall the GNN map is most accurate at the site scale for predicting the basal area in m^2/hectare of trees >50cm, and for predicting the density of trees >75cm DBH. Accuracy of predictions of density of trees > 50cm DBH accuracy within SCR decreased to fifty-three%, but was still sixty-three% for trees >75cmDBH. This indicates that GNN predictions of density of TPH >75 would be a more effective way to identify old-growth sites than using predictions based on the density of trees >50cm DBH.

Accuracy of GNN Predictions					
Density of TPH >50cm DBH					
TPH	Count	High	Low	Correct	Accuracy
(0-9.9)	9	0	2	7	78%
(10-19.9)	18	4	8	6	33%
(20-29.9)	20	4	4	12	60%
(30-39.9)	12	6	2	4	33%
(>40)	13	4	0	9	69%
Overall	72	18	16	38	53%
Density of TPH 75cm DBH					
TPH	Count	High	Low	Correct	Accuracy
0	4	0	1	3	75%
(0.1-5)	42	0	11	31	74%
(5.1-10)	19	9	3	7	37%
(10.1-15)	5	0	2	3	60%
(>15)	6	2	0	4	67%
Overall	72	11	17	48	63%

Accuracy of GNN Predictions (SCR)					
Basal Area of all live trees					
Basal Area (m2/H)	Count	High	Low	Correct	Accuracy
(0-9.9)	1	0	0	1	100%
(10-19.9)	16	1	3	12	75%
(20-29.9)	28	5	5	18	64%
(30-39.9)	16	3	7	6	38%
(>40)	11	3	0	8	73%
Overall	72	12	15	45	63%
Basal area of all trees >50cm DBH					
Basal Area (m2/H)	Count	High	Low	Correct	Accuracy
(0-4.9)	18	0	4	14	78%
(5.0-9.9)	26	3	9	14	54%
(10-14.9)	13	5	1	7	54%
(15-19.9)	9	2	3	4	44%
(>20)	6	2	0	4	67%
Overall	72	12	17	43	60%

Table 3 - Summary of SCR accuracy analysis

Producers and User's Accuracy of GNN Predictions

Error matrices provide both a user's accuracy and a producer's accuracy for GNN attribute predictions that are specific to ranges of density or basal area for each attribute. User's accuracy is based on the proportion of sites visited that were correctly predicted by the GNN maps. For example in Table 4, 13 of 29 sites were observed to have a basal area of trees >50cm DBH between 0-4.9 m^2/hectare, so the "dead on" user's accuracy is forty-five percent. In comparison, producer's accuracy is based upon the proportion of sites predicted that were determined to be correct upon visitation. For the same basal area class, table (XXX) shows the producers accuracy would be seventy-two percent as 13 of 18 predicted sites were predicted correctly. The basal area matrices determined the variability in accuracy of GNN predictions for different ranges of basal area illustrated in Table 4. In general low level and high level GNN predictions for basal area were most likely to be "fuzzy correct," "dead on" correct, and correct within site class range. Accuracy was lower for intermediate levels of basal area.

Comparison of Observed Site Classes to GNN Predicted Site Classes Basal Area of all Live Conifers >50cm - (m2/hectare)								
BA (m2/Hectare)	(0-4.9)	(5.0-9.9)	(10-14.9)	(15-19.9)	(>20)	Predicted	% Correct	% Fuzzy
(0-4.9)	13	2	2		1	18	72%	83%
(5.0-9.9)	8	5	8	2	3	26	19%	81%
(10-14.9)	5	3	2	2	1	13	15%	54%
(15-19.9)	2	0	3	0	4	9	0%	78%
(>20)	1	0	1	1	3	6	50%	67%
Observed	29	10	16	5	12	Overall	32%	69%
% Correct	45%	50%	13%	40%	25%	32%		
% Fuzzy	72%	100%	81%	60%	58%	75%		*n= 72*

Comparison of Observed Site Classes to GNN Predicted Site Classes (Basal Area of all Live Conifers - m2/hectare)								
BA (m2/Hectare)	(0-9.9)	(10-19.9)	(20-29.9)	(30-39.9)	(>40)	Predicted	% Correct	% Fuzzy
(0-9.9)	0	1	0	0	0	1	0%	100%
(10-19.9)	1	6	6	3	0	16	38%	81%
(20-29.9)	1	6	12	6	3	28	43%	86%
(30-39.9)	2	1	1	5	7	16	31%	81%
(>40)	0	0	2	4	5	11	45%	82%
Observed	4	14	21	18	15	Overall	39%	83%
% Correct	0%	43%	57%	28%	33%	39%		
Fuzzy	25%	93%	90%	83%	80%	86%		*n= 72*

Table 4 - Error matrix accuracy results for GNN basal area attributes

The accuracy of predictions for site density of trees >50cm DBH and for site density of trees >75cm DBH showed the following patterns displayed in the density error matrices. Low density predictions and moderately high density predictions for site density had the highest levels of accuracy, while intermediate density had lower levels of accuracy. However, sites that were observed with the highest densities for both TPH >50cm DBH and TPH >75cm DBH showed a decrease in prediction accuracy. This appears to be because the GNN predictions are conservative under-predict sites with the highest densities. For example, across the study area 16 sites had a density of more than 40 TPH >50cm DBH. Of these 16 sites, 8 were under predicted to have an intermediate density of less than 30TPH>50cm DBH. This tendency and others can be seen in error matrices for GNN predictions of density (Table 5).

Comparison of Observed Site Classes to GNN Predicted Site Classes Density of Trees per Hectare (TPH) >50cm DBH								
TPH	(0-9.9)	(10-19.9)	(20-29.9)	(30-39.9)	(>40)	Predicted	% Correct	% Fuzzy
(0-9.9)	5	2	1	0	1	9	56%	78%
(10-19.9)	5	3	2	4	4	18	17%	56%
(20-29.9)	3	6	4	4	3	20	20%	70%
(30-39.9)	3	3	3	2	1	12	17%	50%
(>40)	2	1	0	3	7	13	54%	77%
Observed	18	15	10	13	16	**Overall**	29%	65%
% Correct	28%	20%	40%	15%	44%	29%		
% Fuzzy	56%	73%	90%	69%	50%	65%		*n= 72*

Comparison of Observed Site Classes to GNN Predicted Site Classes (TPH >75cm DBH)							
TPH	(0.1-5)	(5.1-10)	(10.1-15)	(>15)	Predicted	% Correct	% Fuzzy
(0.1-5)	29	9	3	2	43	67%	88%
(5.1-10)	14	1	3	1	19	5%	95%
(10.1-15)	0	0	3	2	5	60%	100%
(>15)	1	0	0	4	5	80%	80%
Observed	44	10	9	9	Overall	28%	75%
% Correct	66%	10%	33%	44%	28%		
% Fuzzy	98%	100%	67%	67%	75%		*n=72*

Table 5 - Error matrix accuracy results for GNN density attributes.

Results of Scatter Plot Analyses

All scatter plots for density and basal area attributes are displayed in Figures 3 and 4.The scatter plots produced for all attributes analyzed indicate the tendencies of the GNN map when its predictions are too high or too low. At sites that had moderately high values for basal area of trees >50cm DBH, GNN predictions were generally too low. For sites with moderately low basal area GNN predictions were generally too high. This tendency was seen for all density and basal area attributes analyzed, and has been observed in GNN accuracy assessments for the GNN in other regions and forest types (Personal communication, Janet Ohmann, 2010).

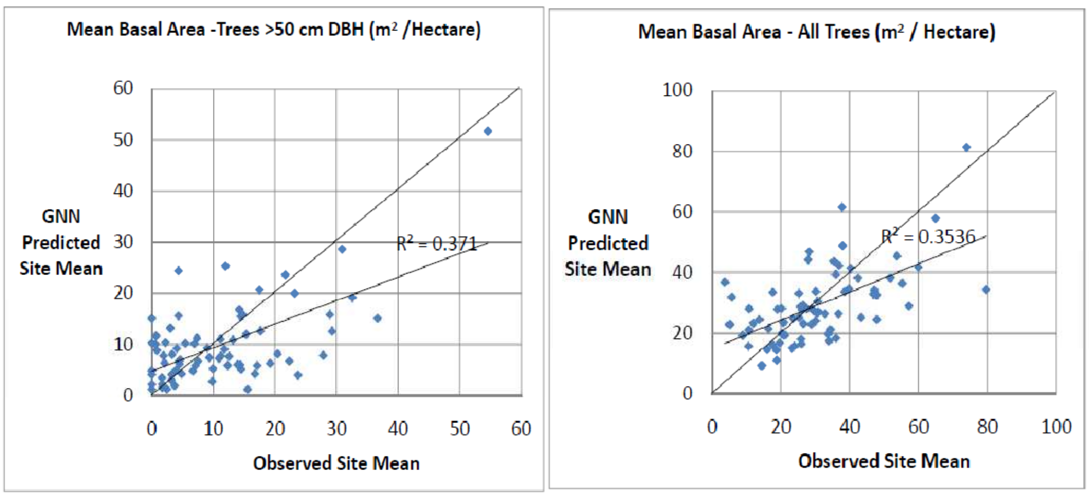

Figure 3 - Scatter plots comparing site basal area values to GNN predictions

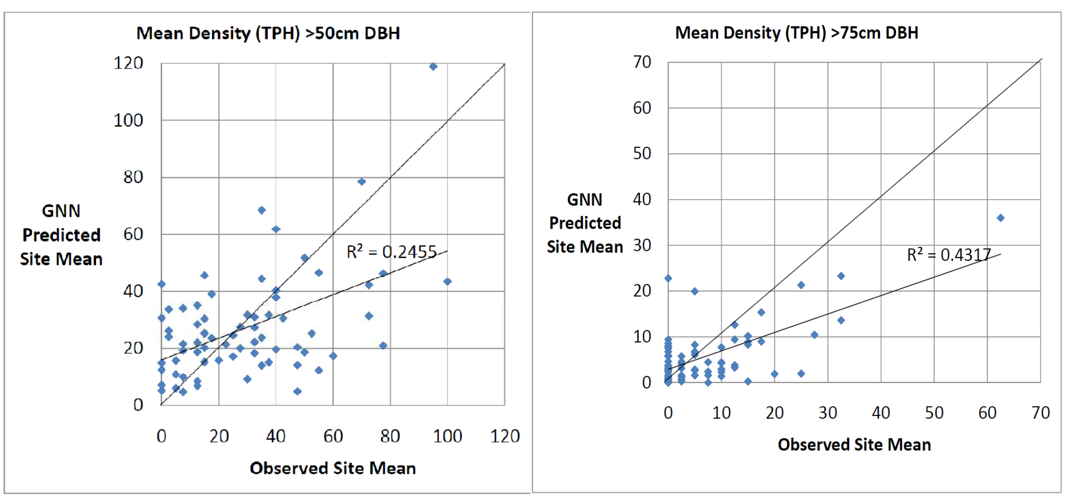

Figure 4 - Scatter plots comparing site density values to GNN predictions

Regional Accuracy of the GNN map for the DMC forest type

On a regional scale the GNN map was highly accurate at providing an inventory of stand structure across the study area. The mean values for all attributes measured at field sites were very similar to the mean values calculated for all attributes predicted by the GNN map as seen in Figures 15 and 16 in Appendix B. Additionally, the 95% confidence intervals for site attribute means and predicted site mean all overlapped (Figure 5). Based on results of this investigation the GNN map is a very effective tool for predicting the structure of DMC forest on a regional scale in the Deschutes and Ochoco National Forests. Summary statistics for field and GNN attributes can be viewed in Appendix B.

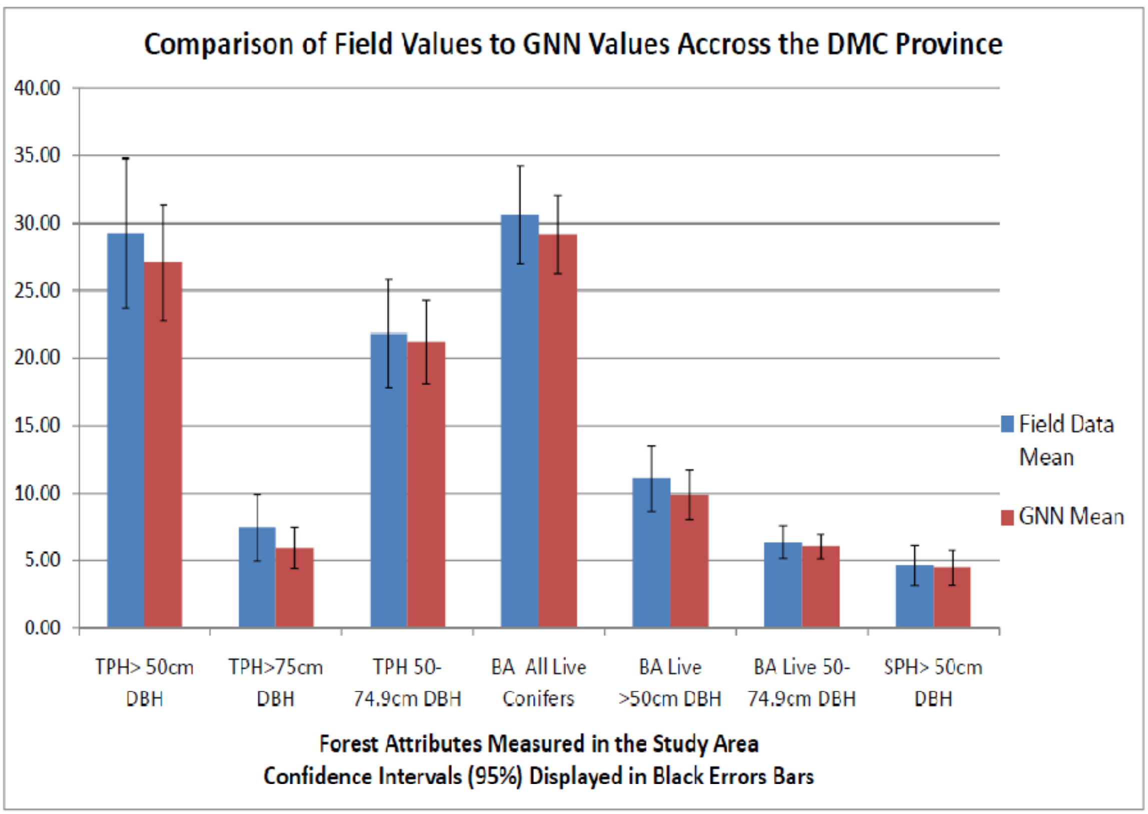

Figure 5 - Regional Accuracy of GNN Map.

Discussion and Conclusions

The GNN map of forest vegetation was effectively used to identify 39 old-growth sites out of 76 total sites. For purposes of this investigation, this was satisfactory because it was desired that approximately fifty percent of the sample sites met the characteristics for old-growth. When future investigations use the GNN map to locate sites of old-growth DMC forest they should consider the SCR accuracy of GNN predictions. If old-growth is defined by the density of trees >50cm DBH then the amount of potential sample sites should be doubled since fifty-three percent of predictions for old-growth density were correct within SCR. Sixty-three percent of predictions were correct within SCR for the density of trees>75cm DBH. Future investigations would benefit from using this GNN stand attribute because accuracy was significantly higher under the SCR analysis. From this investigation it is apparent that GNN attributes can be used to identify a sufficient sample of one hectare sites with varying densities of old-growth trees.

Examining the producer's and user's accuracy from the error matrices demonstrates under what density and basal area ranges the GNN is inaccurate at a site basis. For both basal and density of old-growth trees it is apparent that the GNN's inaccuracies are due to under-predicting the occurrence of sites on the extremely low range of density and basal area. For example 29 sites were observed to have a basal area of old-growth trees that was less than 5.0m^2/hectare when only 18 were predicted, and 18 sites were observed to have fewer than 10 old-growth TPH when only 9 were predicted. The producer's and user's accuracy illustrate that user's of the GNN map should expect to find more sites with low density ranges for old-growth trees than the GNN predicts. Scatter plots illustrate that when the GNN map is inaccurate at a site scale, predictions for high density or high basal area sites are generally under predicted and predictions for low density or low basal area sites are generally over predicted.

The regional inventory of DMC forests within the Deschutes and Ochoco National Forests provided by this investigation is nearly identical to the inventory predicted by the GNN map. The GNN map functions well for the purposes it was designed for, which was to predict vegetation on a landscape scale. Therefore regional inventories of DMC forests produced by the GNN should be used with a high level of confidence. This conflicts with the findings for site accuracy of GNN attributes, which were rarely higher than sixty percent. The regional accuracy could have achieved its accuracy because under predictions of high range values of basal area and density average with over predictions for low range values of density and basal area to match what is present on the landscape. Additionally, site sampling techniques that determined field values may have overestimated the occurrence of sites with the lowest values for density and basal area. For this to occur, only one old-growth tree per macroplot would have to be not recorded because it fell outside the sample area. As a result the density and basal area of old-growth trees at sites with low numbers of old-growth trees was likely to be underestimated.

Chapter 3: Stand Structure of Old-Growth Dry-Mixed Conifer Forests in the Deschutes and Ochoco National Forests

Background

Stand structure is a critical attribute of forest ecosystems because it can be used as a surrogate to measure and maintain biological diversity and overall ecosystem health (Franklin, Spies, Van Pelt, Carey, Thornburgh, Dean, Lindermayer, Harmon, Keeton, Shaw, Bible, and Chen 2002). Stand structure in old growth DMC forests has been difficult to quantify for multiple reasons. Stand structure of these forests is highly variable because DMC forests are found along a steep environmental gradient that is a transition zone between the relatively moist hemlock vegetation series and the relatively dry ponderosa pine or Juniper vegetation series (Franklin and Dyrness 1973). DMC stands are characterized by a complex species composition and wide range of site productivities (Hopkins, Simon, Schafer, and Lillybridge 1992). As a result, potential stand structure at an individual site is determined by site elevation, aspect, and precipitation. Additionally, stand structure is strongly influenced by a mixed severity fire regime that creates a diversity of stand structures and patch sizes across the landscape. Finally, anthropogenic disturbances since European settlement of the DMC forest region including logging, grazing, and fire suppression have heavily altered the historic stand structure of DMC forests (Fitzgerald, 2005). The combination of highly variable site conditions, a mixed severity fire regime, and clearcutting and logging of large overstory ponderosa pine and Douglas-fir has resulted in a poor understanding of the historic and present day structure of DMC forests (Spies *et al*. 2006).

Rationale and Significance

Potential restoration treatments that aim to restore historical stand structures across the landscape must be developed with an adequate understanding of what both present day and historical stand structures are. Knowledge of present day structures allows managers to evaluate options for creating more fire resistant forests that restore and maintain remaining old- growth ponderosa pine and Douglas-fir (Personal Communication, Tom Spies 2010). Currently two sets of interim definitions for old growth DMC have been developed by the Old-Growth Definition Task Group (1986) and the US Forest Service (Hopkins *et al*. 1992). These definitions describe the minimum structural requirements for large old growth trees, large snags, and coarse woody debris. This provides a baseline for minimum densities of large trees >50cm DBH per hectare, large snags >50cm DBH, and pieces of CWD per hectare. What these definitions lack is a description of how stand structure has been modified by anthropogenic disturbance and how stand structure varies with site conditions.

My investigation was used to improve the resolution of the interim structural definitions in two ways. First, variations in species composition, site density, and basal area across the Deschutes and Ochoco National Forests were captured. This is valuable data because species composition and site productivity are highly variable across the DMC province (Hopkins *et al*. 1992). Additionally these objectives link stand structural conditions that are prominent across the landscapes to both disturbance history and site conditions. How present day densities of old growth trees >50cm DBH compare to historical densities, and what density levels can be expected at a site under a given set of site conditions and disturbance history are questions that motivate this research.

Determining historical and current stand structure of old growth DMC forest is useful for several purposes. This analysis can be used to identify departure from historic stand structure, to predict future potential changes in forest structure, and to develop objectives for forest management and ecosystem restoration (Harrod, Bradner, and Hartl 1999). A similar exploratory study of current and pre-settlement structure of ponderosa pine was conducted by Harrod *et al*. (1999) in eastern Washington. Their investigation focused on ponderosa pine dominated forests with climax vegetation of ponderosa pine or Douglas-fir. My investigation of stand structure focused on ponderosa pine dominated forests with climax vegetation of grand fir. The analysis by Harrod *et al*., (1999) was used to develop silvicultural prescriptions for forest restoration in Washington. The results of my analysis could be used to develop management objectives for restoration, to highlight the current structural conditions of DMC forests across the landscape that are a concern to managers, and to identify where future research should be directed.

An example of one such structural condition would be elevated densities of shade tolerant species. This structural change increases the mortality risk for old ponderosa pines by increasing fire hazard and competitive stress. The risk of high severity fire is elevated as understory trees and shrubs provide accumulations of surface fuel loads and ladder fuels (Thompson, 2008). A long term goal of this inventory based research, is that ecosystem restoration, future research, and forest management objectives related to the DMC forest type will ensure the resiliency and conservation of this valued ecosystem. Successful restoration treatments and achievement of this goal will require a firm understanding of the historic and present composition of the ecosystem. Therefore this research presents a database of current density and basal area of understory and old growth trees and snags, and historical density of old growth trees.

Research Approach

The goal of this study was to characterize stand structure of older DMC forests found within the Deschutes and Ochoco National Forests. Stand structure can be quantitatively described and refers to the physical arrangement and characteristics of the forest (Stone and Porter 1998). I defined stand structure in terms of live trees, snags, and coarse woody debris (CWD). The measures for live trees included density for each species in trees per hectare (TPH), basal area of live trees by species, and the diameter distribution of live trees by species. Snags were measured by density in snags per hectare (SPH) and CWD was measured by total length (m) of all pieces >30cm in diameter per hectare and all pieces >60cm diameter per hectare. General trends or patterns of structure in relation to geographic regions, recent logging disturbance, and site conditions were identified. The effect of fire suppression was studied by measuring and reporting present day densities of understory trees, however this analysis was limited by the lack of historical data of the variability in understory density. Site conditions were plant association, elevation, aspect, and mean annual precipitation. **T**his research provided an expanded description of stand characteristics for old-growth DMC forests. A database of DMC stand structure metrics was made available ecologists and managers upon completion of this project.

This research was based on the determination by Spies et al. (2006) that conservation of the DMC forest type is complicated by a lack of adequate definitions that describe both present and historical conditions of this diverse ecosystem that has highly variable stand structure across its range. Ultimately, there was a need to conduct an inventory of the stand structure across the DMC province found in the Deschutes and Ochoco National Forests.

Hypotheses

The primary hypothesis for this investigation is that *stand structure of DMC forests varies with both site characteristics and site disturbance history*. This overall hypothesis has the following sub hypotheses reported below:

1. Sites with low, medium, high, and old growth classes densities of large old trees (>50cm DBH), will demonstrate differences in species composition and canopy structure.
2. The current composition and structure of sites will differ among regions, (North Deschutes, South Deschutes, West Ochoco, and East Ochoco) as site conditions are variable for DMC sites across the study region.
3. The historically reconstructed density of TPH >50cm DBH will differ among regions and site conditions.
4. The density for all trees with a DBH between 10-50cm at a site is positively correlated with mean annual precipitation.
5. The density of all trees >50cm DBH for sites that meet the minimum criteria for old growth DMC forest is correlated with mean annual precipitation and aspect.

Analysis Methods

1. The following procedure was used to create tables that summarize the stand structure of DMC forests for multiple density classes and for the different regions sampled
    a. Based on the density in TPH of old-growth trees >50cm DBH, sample sites were grouped into low, medium, high, and old growth *density classes*. The threshold for old growth is based on the interim old growth definitions by Hopkins *et al*. 1992.

b. Sites sampled were broken into four zones including the south Deschutes, north Deschutes, west Ochoco, and east Ochoco. To identify which zone a site was sampled in it was numbered with one of the series prefixes in Table 6 below. For example if site 37 was sampled in the north Deschutes National Forest it would be labeled site 2037.

Zone	Series
South Deschutes National Forest	1000s
North Deschutes National Forest	2000s
West Ochoco National Forest	3000s
East Ochoco National Forest	4000s

Table 6 - Classification of sites by sampling region

c. For all sites in each site density class, and for each site sampling zone, density and basal area was calculated for species groups including ponderosa pine, Douglas-fir, grand fir, and all "other" species lumped together.

d. Density and basal area were reported for each of the species groups above for the following five size classes: trees >10cm DBH, trees>50cm DBH, trees >75cm DBH, Trees 0-9.9 cm DBH, Trees 10-19.9cm DBH, and trees 20-49.9cm DBH.

2. How density for all trees 10-50cm DBH (understory trees) at a site is related to site characteristics was determined with the following procedure.

   a. All sites that were recently thinned or burned were eliminated from the analysis to focus on site characteristics as the explanatory variable for understory density.

   b. The average understory density was plotted vs. elevation and precipitation separately for sites in the Deschutes and Ochoco National Forests. This was done because mean site precipitation and density was significantly lower in the Ochoco National Forest in comparison to the Deschutes National Forest.

3. To determine how density of all live trees >50cm DBH varied with site characteristics the following procedure was used.
    a. The reconstructed value of TPH >50cm DBH was calculated using the procedure in Appendix A. This removed logging as an explanatory variable for the density of old-growth trees at a site enabling the investigation of site characteristics.
    b. The density of trees >50cm DBH was plotted vs. elevation and precipitation separately for sites in the Deschutes and Ochoco National Forests
    c. The mean density of trees >50cm was calculated for all sites group by aspect (N, S, E, W,).

Results and Discussion

Variation of Stand Structure by Density Class

The first analysis examined how stand structure varied for sites grouped by their density of old-growth trees (trees>50cm DBH). The complete results of this analysis are available in Appendix C. Old-growth density classes analyzed are displayed in Table 7, and abbreviations used in all results tables are displayed in Table 8.

Density Class- TPH >50cm DBH			
Low	Medium	High	Old Growth
5-15	15-30	>30	>25

Table 7 - Site Density Classes

Abbrevation	PP	PM	AB	OT	ALL
Species	ponderosa pine	Douglas-fir	grand fir	other	All Species
(R) notes values were calcuated with Reconstructed Stumps					

Table 8 - Species abbreviations used in results tables

Appendix C. can be used to determine how the species composition of section of the forest canopy varies for sites in various stages of successional development. For example, Table 9 clipped from these results demonstrates how understory grand fir becomes increasingly dominant in DMC stands as the density of old-growth trees increases. Understory trees are all trees <50cm DBH.

	Trees 10-19.9cmDBH				Trees 20-49.9cm DBH			
Category	PP	PM	AB	OT	PP	PM	AB	OT
Low	62.1	22.5	25.3	26.6	84.0	48.5	26.6	13.7
Med	18.8	18.8	78.8	35.0	62.6	48.8	78.8	20.0
High	57.2	21.7	93.9	22.3	46.5	34.9	91.1	24.2
Old Growth	49.7	23.5	98.6	33.1	44.3	39.7	95.5	23.9

Table 9 - Variation of density for understory trees grouped by old-growth density class

While the disproportional increase of grand fir in comparison to other trees is expected as it is the shade tolerant late seral stand species, the historic basal area and density of understory trees in old-growth DMC stands is not well described. Historically, a patchy distribution of relatively low to high densities of understory trees is predicted across the DMC province (Kennedy and Wimberly, 2009). Data from this investigation provides a current benchmark of understory density and basal area, which can be loosely compared to a limited amount of historic estimates by Munger (1917) for DMC stands. This data is not directly comparable to the data found in this investigation because the spatial distribution and number of sites it is based upon on is not known. Munger (1917) reported that sites dominated by ponderosa pine had a density of approximately 85TPH for all trees <53cm DBH. For all sites sampled that met the structural requirements for old growth from this study, the mean density of all understory trees was 408TPH (Table 9), with grand fir representing 50% of all understory trees. For all sites sampled that were part of the low density class the mean density of understory trees was 309TPH.

Regional Analysis

Overall the south Deschutes Region had the greatest species diversity in comparison to the other regions, and the Deschutes National Forest had significantly higher species richness than the Ochoco National Forest. All regions had ponderosa pine, Douglas-fir, grand fir, and lodgepole pine. The south Deschutes additionally included sugar pine, western white pine, Shasta red fir, Englemann spruce, mountain hemlock, western hemlock, and noble fir. However none of these species accounted for more than 5% of all live trees measured in the south Deschutes. Recall that all species besides ponderosa pine, Douglas-fir, grand fir were lumped into an “other” category. The species diversity of the south is apparent when the proportion of “other” trees in the south Deschutes is compared to all other zones. Twenty-one percent of all trees in the South Deschutes were part of the “other” category, in comparison to only thirteen percent in the north Deschutes and 4.5% for both the east and west Ochoco combined. The increase in this “other” category may be primarily due to the prominence of lodgepole pine in the pumice region of the south Deschutes. Both the historic and present day density of grand fir was also higher in the south Deschutes. Reconstruction of grand fir stumps indicated that the historic density of old-growth sized grand fir in the south Deschutes was 15.4 TPH (Table 11), while in the north Deschutes the density of old-growth sized grand was comparatively much lower at 8.6TPH. Additional species in the north Deschutes included Engelmann spruce, incense-cedar, and noble fir. Sites in the Ochoco National Forest did feature low densities of western juniper and western larch, which were not observed in the Deschutes National Forest.

Variation in species richness observed in different sampling regions can be tied to mean site conditions for precipitation and elevation for all sites within each region (Table 10).

Region	Deschutes	Ochoco	S. Deschutes	N. Deschutes	W. Ochoco	E. Ochoco
Sample Size	44	32	21	23	16	16
Elevation (meters)	1389	1497	1549	1235	1413	1580
Precipiation (cm/year)	86	54	93	80	46	62

Table 10 - Mean elevation and precipitation data for sites grouped by region

The increased species richness and density of grand fir of sites in the south Deschutes is tied to higher elevation and precipitation levels in comparison to the north Deschutes region. The elevated species richness may be an expression of the sites sampled where DMC forest was transitioning to relatively mesic forest types. Compared to the Ochoco National Forest, species richness is higher in the Deschutes National Forest because of increased precipitation and proximity to other forest types including climax western hemlock forests. Note in Table 10 that the mean precipitation for sites in the Ochoco National Forest was 32cm/year lower than the Deschutes National Forest indicating that DMC forests in the Ochoco are more limited by precipitation.

Historic vs. Present Day Density of Old-Growth Trees

The historic and present day density of old-growth trees and how these densities vary across the study area and with present day density classes are displayed in Table 11. Table 8 provides a description of abbreviation used for all tables in the results and appendix section pertaining to this analysis.

Present vs. Historic Density of Trees >50cm DBH									
		Trees per Hectare >50cm DBH							
Category	n	PP	PPR	PM	PMR	AB	ABR	ALL	ALLR
Low	22.0	5.8	28.1	3.0	4.9	1.8	3.9	10.6	36.8
Med	12.0	12.9	31.3	4.2	5.8	5.6	7.1	22.7	44.2
High	32.0	27.8	37.5	6.9	10.7	11.7	12.7	46.9	60.9
Old Growth	39.0	24.7	35.9	7.3	9.6	11.1	12.2	43.1	57.8
S. Deschutes	18.0	16.8	35.3	6.0	6.9	12.8	15.4	35.6	57.6
N. Deschutes	19.0	18.9	36.2	5.5	10.0	8.6	8.6	33.0	54.7
W. Ochoco	15.0	14.1	30.7	6.2	8.2	2.8	4.8	26.0	43.7
E. Ochoco	17.32	16.0	29.3	4.3	5.9	3.2	4.5	24.8	39.6
Deschutes	37.0	17.9	35.7	5.7	8.5	10.6	11.9	34.3	56.1
Ochoco	29.0	16.6	30.0	5.6	7.1	3.2	4.7	25.4	41.7

Table 11 - Present day vs. historic density of trees >50cm DBH

Regionally, current densities of old-growth trees at all sites in the Deschutes and Ochoco National Forests are approximately sixty percent of historic densities. Old-growth ponderosa pine was by far the prominent species removed, accounting for approximately eight percent of reconstructed stumps, but removal of Douglas-fir in the north Deschutes region is of similar magnitude, as forty-five percent of all old growth Douglas-fir were removed. These data illustrate the heavy modification of the overstory structure in DMC conifer forests across the study area. Before reconstruction fifty-nine percent of sample sites met the minimum requirements for old-growth of a density of greater than 25 old–growth TPH. After reconstruction eighty-nine percent of sample sites met the minimum requirements for old-growth

The mean density of old-growth trees per hectare calculated for all sites that met the structural definitions for old-growth is 43.1TPH, which is significantly higher than the minimum requirement of 25TPH provided by the interim old growth definitions. The density by species of all old-growth trees is displayed in Figure 6 and provides improved resolution of the current species composition of old-growth trees in stands that meet the criteria for old-growth.

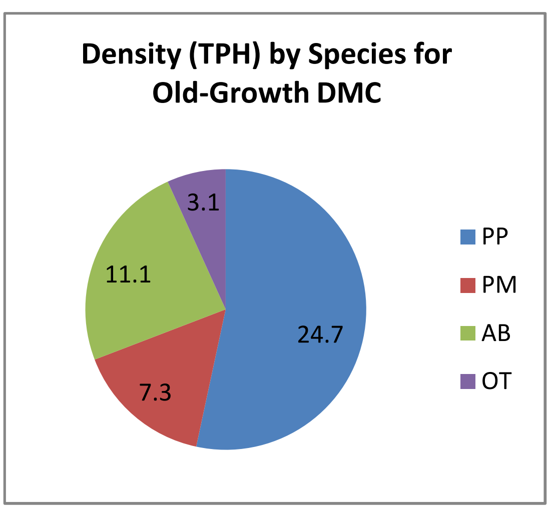

Figure 6 - Density by species for old-growth DMC

Variation of Density with Precipitation and Aspect

Mean annual precipitation is positively correlated with the density of understory trees (Figure 7). The general trend is that sites with higher mean annual precipitation, which are found at higher elevations, have an increased density of understory trees. However not all sites used in this analysis fit this relationship, indicated by the circled areas on Figure 7.

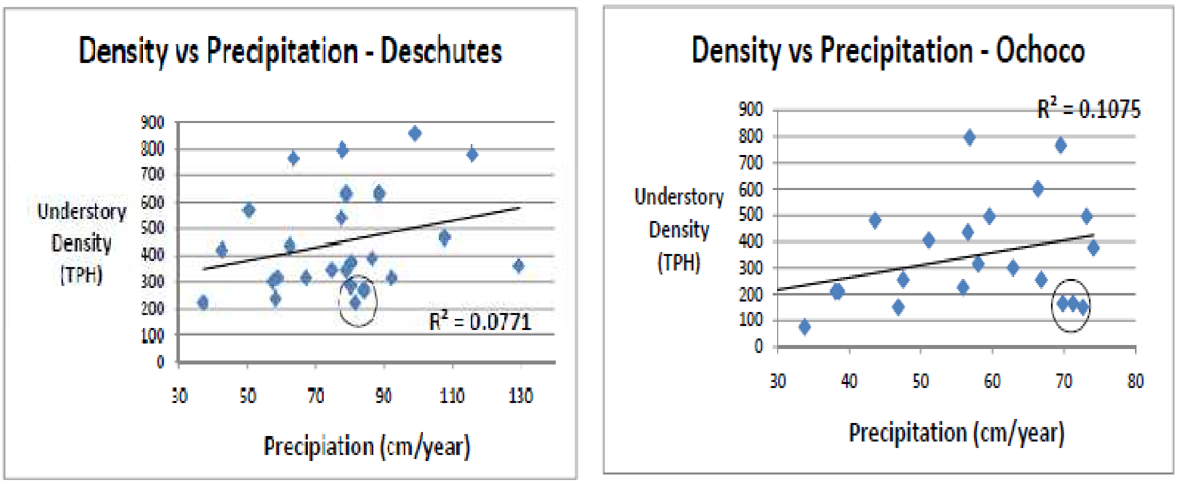

Figure 7 - Density of understory trees vs. precipitation

Some sites may not fit this trend because another site condition has a stronger influence on the density of understory trees, or because sampling techniques failed to capture the density of the understory at a site. By examining site photos of sites with relatively high mean annual precipitation and unexpectedly low density of understory trees I determined that the sampling procedure may have underestimated the density and basal area for understory trees at some sites for two reasons. The first is that photos taken through the plot center display thickets of saplings that are <10cm DBH and therefore would not have been recorded in the macroplot during sampling. The second reason is that by chance the majority of plot centers at a site could have landed in a portion of the stand that was not representation of its mean density.

If mean annual precipitation was not the limiting variable for regeneration and persistence of understory trees at a site then other site conditions such as aspect, soil depth, or recent disturbance history may be the primary site condition influencing the density of understory trees.

A similar relationship between the density of old-growth trees and mean annual precipitation was found for old growth trees in the Ochoco National Forest (Figure 8). However, this relationship was not found in the Deschutes National Forest. Because mean annual precipitation for sites in the Deschutes (86cm/year) was much higher than mean annual precipitation for sites in the Ochoco (54cm/year) it can be hypothesized that the density of old-growth in the Deschutes is not limited by precipitation, and that other sites characteristics play a more prominent role in determining density of old-growth trees. Conversely, mean annual precipitation is a more effective indicator of potential density of old-growth trees in the relatively arid Ochoco National Forest.

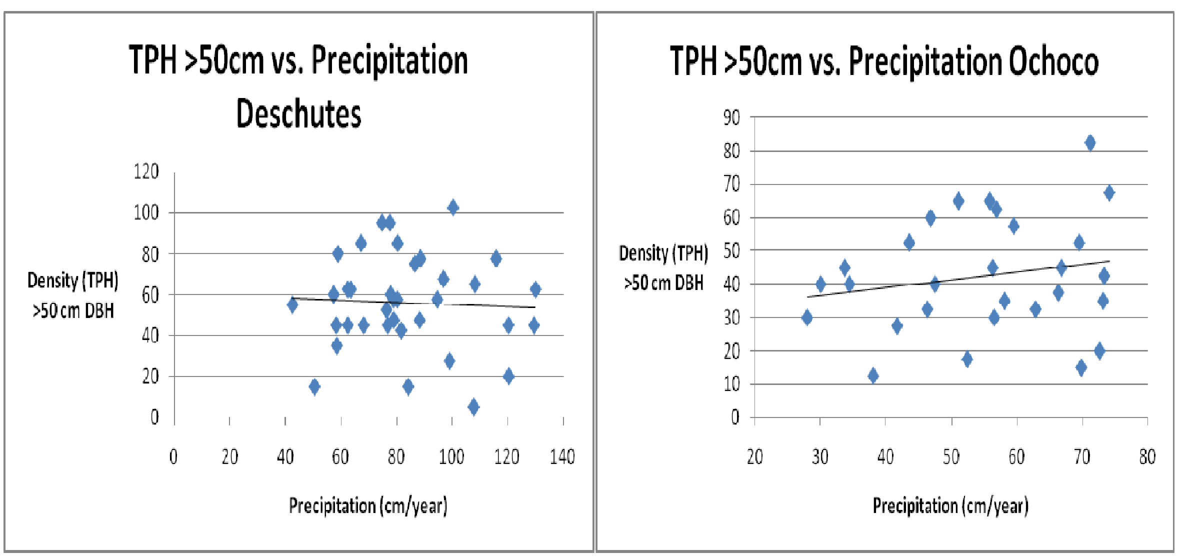

Figure 8 - Density of old-growth trees vs. precipitation

Density of old-growth trees also varied by aspect, as seen in Figure 9. Density of old-growth trees was highest on sites with a north aspect. These results illustrate how aspect influences density of old growth trees on DMC sites. Aspect is most likely altering density of old-growth trees by creating fire refugia, which enable the development of older forests stands within a younger forest matrix (Camp, Oliver, Hessburg, and Everett. 2006). Because sites on a north aspect receive more shade and less evaporation than sites on a south aspect, available moisture on north sites is higher. DMC forests receive the majority of their precipitation as snowfall (Table 1), which would remain longer on sites with a north aspect vs. south aspect meaning that there should be moisture available for growth for a longer period during the growing season. The increased amount of moisture on north aspects also serves to moderate the behavior of fires by increasing the moisture of live and dead fuels, and soil moisture. Increased soil moisture and fuel moisture would decrease the intensity and resulting severity of burns that took place at a site (Thompson, 2008). Ultimately a relatively moderate climate that provides increased moisture for plant growth and moderates fire intensity is a likely explanation for increased densities of old growth trees on sites with a north aspect.

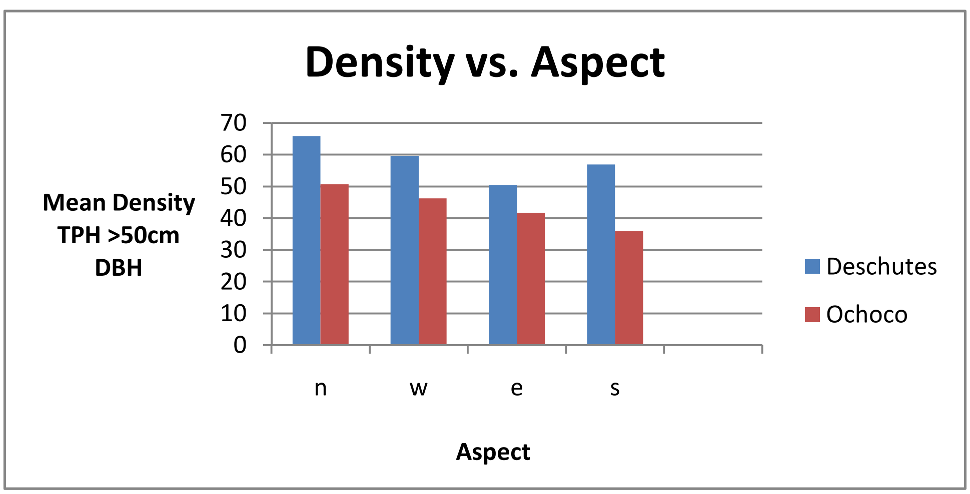

Figure 9 - Mean site density of old-growth vs. aspect

Conclusions

This investigation of the structure of old-growth DMC forests in the Deschutes and Ochoco National Forests provides a current field-based inventory of both the species composition and structural distribution of species in old-growth DMC forests. Additionally, it provides the same data for sites that have been modified and currently do not meet requirements for old DMC forest. The reconstruction analysis indicates how DMC forests have been heavily modified by logging. Reported densities of basal area for all understory trees provide a present day benchmark of understory density. This is valuable because many ecologists have theorized that mean basal area of understory trees in DMC stands is higher than expected under the historical range of variability.

The pitfalls of this investigation occurred when site conditions were used to determine site density of overstory and understory trees. Initially several site conditions were used separately to attempt to explain variations in density and basal area. Using individual site characteristics was an ineffective way to analyze how site conditions influence the density of both overstory and understory trees because site conditions were based on a combination of site conditions and particular site history. Future analysis should group site conditions and use multivariate analysis to develop a more complete picture of how density and basal area at a site are related to site conditions.

It is apparent from this inventory that the DMC forest type across the landscape has very few stands of open fire-resistant old-growth that are described by Spies 2006, Fitzgerald 2005, and others. However the historical variation in understory density in DMC is not understood. Maintaining the ecological services of old growth stands is a primary objective of the Deschutes and Ochoco National Forests. Therefore implementing management plans such as understory thinning and prescribed burning that improve the resiliency of present day old-growth stands, and managing regenerating stand of DMC forests so that succession leads to resilient old-growth stands should be management goals for the Deschutes and Ochoco National Forests. Designing effective management plans for these objectives will only be possible with future research that answers critical questions about the ecology and development of DMC forests. One potential investigation would be to analyze whether understory ponderosa pine and Douglas-fir will develop to historic old-growth sizes and densities that were determined in the reconstruction analysis of this report under current stand conditions in DMC forests. A potential way to answer this question would be to determine the growth rate of understory ponderosa pine and Douglas-fir for sites of varying understory densities. Alternatively, you could determine what the growth rate and variability in growth rate of existing old-growth trees was as they developed to the present size. These investigations would be essential in determining what the expected future condition of DMC forests will be, and would present alternatives for management activities designed to ensure the ecological and cultural values provided by DMC forests.

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Appendix A: Field Sampling and Stand Structure Calculation Methods

Site and Plot Layout

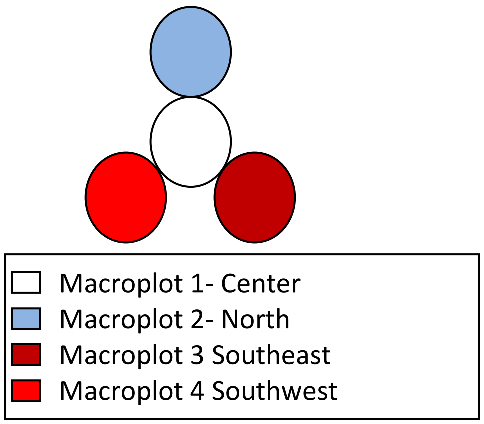

Figure 10 - Spatial layout of site macroplots

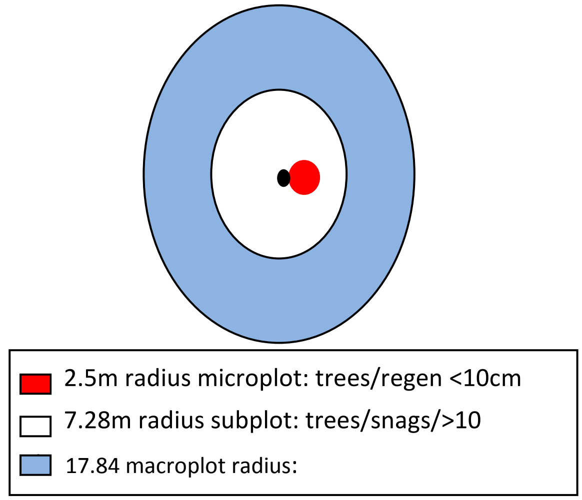

Figure 11 - Spatial layout of subplots and microplots

Field measurements were collected using a design based on the PNW-FIA Annual Plot Design. An entire site was sampled with 4 macroplots. GPS site coordinates were used to identify the site center, which was also used as the center point for macroplot one. Macroplot centers 2-4 were located 36.6m from plot 1, with plot 2 to the north, plot 3 to the southeast, and plot 4 to the southwest. Each plot had a 17.84m radius, a subplot with a radius of 7.28 meters, and a microplot with a radius of 2.5m. See figures 10 and 11 above for spatial distribution of macroplots, subplots, and microplots.

Macroplot Setup and Site Data Collection

The following procedure was used to establish each macroplot, record geographic location, and record site characteristics. All data from this procedure were recorded on data sheet CT1- Site and Subplot (See appendix D for example).

1. Centers of macroplots were marked with cedar stakes and tagged with macroplot number and site ID.
2. GPS coordinates were recorded at center stake.
3. Two witness trees were selected based on their conspicuous nature (size and distance from center).
    a. Each witness tree was tagged twice once at breast height and once below cut height facing the macroplot center. Tags recorded witness tree number, macroplot number and site ID.
    b. For witness trees DBH, distance to macroplot center, and bearing to macroplot center were recorded.
4. Boundaries of macroplots and subplots were found using a laser range finder and were flagged.
5. Boundaries of the microplots were found by marking a point 3.5m directly east from the enter of the macroplot and marking a 2.5m radius from this new point.
6. Slope, aspect, plant association were recorded at each macroplot.
7. From the macroplot center, 4 photos were taken one at each cardinal direction.
8. Notes about site conditions and disturbance were recorded at each macroplot.

Measurement of Trees, Snags, and Cuts

The following procedure was used to record data for trees, snags, and cuts found in the macroplot and the subplot. All data from this procedure were recorded on data sheet CT2-Trees and Snags (See appendix D for example).

Subplot Data Collection

1. For all trees within each subplot that were > 10cm DBH, the species type, the DBH, crown class, and the height to live branches were recorded. Keen class and any cat faces were recorded for PSME and PIPO specimens only.
    a. Tree Crown Classes: O=Open grown, S=Suppressed, I=Intermediate, C=Co dominant, D=Dominant, E=Emergent
    b. Height to live crown base, was estimated to the nearest half meter
    c. Keen Classes were used to record the health of mature early seral species PSME and PIPO. Keen classes were recorded for these species if specimens had at least an intermediate crown position and a DBH >20.0cm. Keen classes used for this study were adapted from Keen, (1936).
        i. Class A=an exceptional, full, vigorous crown extending>55% of tree height. Tree demonstrates full vigor
        ii. Class B=a full crown extending 30-55% of tree height somewhat narrow or short. Tree demonstrates fair to good vigor
        iii. Class C= a crown that extends ~30% of the tree length with some sides of crown missing. Tree demonstrates fair to poor vigor
        iv. Class D= a crown that is very short, patchy, sparse or ragged. Tree demonstrates very poor vigor
    d. The height and width of cat faces were recorded where present for PSME and PIPO.
2. For all snags >10cm found within each subplot, the species type, snag height to the nearest meter, and snag decay class were recorded. Snags less than 2.0m in height were

not recorded. Snag decay class was rated on a 1-5 scale with 1 being sound and five being rotten.

Macroplot Data Collection

1. The same procedure outlined above for the subplot was used to record all trees and snags > 50cm DBH.
2. For all cut stumps > 50cm at cut height the species type, diameter at cut height, cut height, and approximate cut age was recorded. Cut age was recorded as R=recent cut<20 years old or 0=old cut>20 years old.
3. Trees, snags, and cuts <50cm in diameter that were outside the subplot, but within the macroplot were not recorded.

Microplot Data Collection

Regeneration (trees <10cm DBH) were measured within the microplot at each macroplot. All data were recorded on data sheet CT3 Regeneration and Logs (See appendix D for example).

1. For regeneration <1.37m tall counts of regenerating trees in three size classes based on tree height were recorded for each species present. Size classes were (0.1-.0.5m), (0.5-1.0m), and (1.0-1.37m)
2. For regeneration >1.37m tall counts of regenerating trees in 5 classes based on DBH were recorded for each species present. DBH classes were (0.1-2cm), (2-4cm), (4-6cm), (6-8cm), and (8-10cm).

Measurement of Coarse Woody Debris (CWD)

CWD was recorded where present in the macroplot if it had a diameter >30cm at its large end and if the piece was >2.0m long. The species type of each piece was recorded along with its length to the nearest meter. Pieces found were broken into two categories, one for pieces >30cm and <60cm, and one category for pieces <60cm. All data were recorded on data sheet CT3 Regeneration and Logs (See appendix D for example).

Organization of Site Data

Sites sampled were broken into four zones including the south Deschutes, north Deschutes, west Ochoco, and east Ochoco. To identify which zone a site was sampled in it was numbered with one of the series prefixes in Table 12 below. For example if site 37 was sampled in the north Deschutes National Forest it would be labeled site 2037.

Zone	**Series**
South Deschutes National Forest	1000s
North Deschutes National Forest	2000s
West Ochoco National Forest	3000s
East Ochoco National Forest	4000s

Table 12 - Classification of sites by sampling region.

Calculation of Stand Structure

All variables measured such as trees per hectare (TPH), snags per hectare (SPH), cuts per hectare (CPH), and basal area were multiplied by an expansion factor linked to the size of the plot the variable was measured in. For example, the macroplot was a 1/10 of a hectare so all measurements recorded in the macroplot were multiplied by a factor of ten to produce a value expected at the expanded hectare scale. Table 13 lists the three expansion factors used and an example calculation is provided.

Plot Type	Area of plot	Area of Hectare	Expansion factor
Microplot	$19.63m^2$	$10,000m^2$	509.30
Subplot	$167.03m^2$	$10,000m^2$	60.06
Macroplot	$1000.00m^2$	$10,000m^2$	10.00

Table 13 Expansion factors for all plot sizes

If X number of trees/snags/cuts of a certain size and species class were found within the macroplot, then X would be multiplied by (10.00) to calculate the expected number of trees/snags/cuts per hectare.

Therefore if 8 PIPO with a DBH between 50-60cm were found in the macroplot the expected TPH value would be 80 PIPO/hectare. ***(8*10=80)***

Calculation of density of trees, snags, and cuts

TPH, SPH, and CPH densities were calculated individually for ponderosa pine, Douglas-fir, and grand fir. All other species were lumped into an "other" category. In order to calculate density, an estimate of density was first calculated for each of the four plots within a site. This was done by multiplying the count of a specific species recorded within a plot by the appropriate expansion factor (See Expansion Metrics). Once a value was calculated for each plot the mean value for all four plots at a site was used as a prediction of density for the site. All calculations were performed using R and Microsoft Excel Software.

Calculation of Basal Area

Basal area (BA) was calculated and reported in m^2/hectare. The measured DBH of each tree was input into the following equation to calculate basal area for that tree in square meters (m2).

Basal Area Equation -- (m2) = $(DBH/200)^2$ x 3.142.

After the BA area for each tree measured was calculated, this product was multiplied by the appropriate expansion factor to produce a basal area per hectare estimate based on the measurements taken inside a macroplot, subplot, or microplot. To produce a site basal area value, the values calculated for each corresponding plot type were averaged.

Reconstruction of Cuts

To reconstruct what the stand density of large trees ≥50cm DBH would be if logging had not occurred within a site, the diameter at cut height was reconstructed for all cuts ≥50cm at that were recorded. This reconstruction was done using one of three species specific 'taper' equations for ABGC, PIPO, and PSME species. This equation was empirically derived by measuring the DBH of 50 live ABGC, PIPO, and PSME trees at 10cm, 40cm, and 137cm (breast height). These measurements produced the average taper from 10cm to breast height and from 40cm to breast height. Therefore separate equations were used to reconstruct trees from cuts that were less than 40cm high, and for cuts that were taller than 40cm. See the Table 14 for the equations and how they were applied to cuts measured in the study.

Taper Equations			
Species	PIPO	PSME	ABGC
Cut Height			
<40	y = 0.8356x - 2.1322	y = 0.7103x + 5.3832	y = 0.6937x + 5.2034
>40	y = 0.9031x + 0.0151	y = 0.8086x + 4.4907	y = 0.842x + 2.5463

Table 14 Taper equations used for cut DBH reconstruction

Appendix B: Summary Statistics for Regional GNN Analysis

Summary Statistics for Stand Attributes Measured in Field Sample Sites							
	Density (Trees Per Hectare)			Basal Area (m2/Hectare)			Density Snags Per Hectare
	ALL> 50cm DBH	ALL>75cm DBH	ALL 50-74.9cm DBH	All Live Conifers	All Live >50cm DBH	ALL Live 50-74.9cm DBH	All Snags > 50cm DBH
Mean	29.24	7.43	21.81	30.63	11.10	6.35	4.62
Standard Error	2.79	1.24	2.01	1.83	1.23	0.60	0.74
Median	27.50	3.75	20.00	28.53	9.17	6.00	2.50
Standard Deviation	23.67	10.54	17.04	15.56	10.43	5.08	6.32
Sample Variance	560.32	111.09	290.36	242.05	108.76	25.84	39.90
Range	100.00	62.50	85.00	75.85	54.56	25.25	40.00
Minimum	0.00	0.00	0.00	3.75	0.00	0.00	0.00
Maximum	100.00	62.50	85.00	79.60	54.56	25.25	40.00
Sample Size (n)	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Confidence Level (95.0%)	5.56	2.48	4.00	3.66	2.45	1.19	1.48

Table 15 Summary of all stand attributes measured in sample sites

Summary Statistics for Stand Attributes Predicted by the GNN Map							
	Density (Trees Per Hectare)			Basal Area (m2/Hectare)			Density Snags Per Hectare
	ALL> 50cm DBH	ALL>75cm DBH	ALL 50 74.9cm DBH	All Live Conifers	All Live >50cm DBH	ALL Live 50 74.9cm DBH	All Snags > 50cm DBH
Mean	27.09	5.90	21.19	29.16	9.88	6.05	4.46
Standard Error	2.16	0.76	1.55	1.44	0.93	0.46	0.64
Median	22.86	3.96	19.10	27.35	7.77	5.71	2.76
Standard Deviation	18.31	6.46	13.17	12.19	7.88	3.90	5.45
Sample Variance	335.37	41.75	173.49	148.52	62.10	15.24	29.71
Range	114.08	36.00	78.32	72.17	50.48	22.27	32.85
Minimum	4.77	0.00	4.54	9.20	1.23	1.11	0.00
Maximum	118.86	36.00	82.86	81.37	51.70	23.38	32.85
Sample Size (n)	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Confidence Level(95.0%)	4.30	1.52	3.10	2.86	1.85	0.92	1.28

Table 16 Summary of all stand attributes predicted by the GNN map

Appendix C-1: Variation of DMC Stand Structure for Sites Grouped by Old-Growth Density

Variation of Stand Structure for all Sites Grouped by Density Class																									
		Absolute Density of Tree Species by Diameter Class (Trees Per Hectare)																							
		ALL Live Trees >10cm				Trees>50cm DBH				Trees>75cm DBH				Trees 0-9.9cmDBH				Trees 10-19.9cmDBH				Trees 20-49.9cm DBH			
Category	n	PP	PM	AB	OT	PP	PM	AB	OT	PP	PM	AB	OT	PP	PM	AB	OT	PP	PM	AB	OT	PP	PM	AB	OT
Low	22	151.9	73.4	53.7	40.5	5.8	3.0	1.8	0.2	0.7	0.2	0.5	0.0	839.2	127.3	619.3	410.9	62.1	22.5	25.3	26.6	84.0	48.5	26.6	13.7
Med	12	94.2	71.7	163.3	56.7	12.9	4.2	5.6	1.7	0.8	2.9	0.4	0.8	180.4	318.3	1421.8	169.8	18.8	18.8	78.8	35.0	62.6	48.8	78.8	20.0
High	32	131.5	63.6	196.0	48.9	27.8	6.9	11.7	2.4	9.4	1.8	1.4	0.1	587.0	336.8	1663.4	164.3	57.2	21.7	93.9	22.3	46.5	34.9	91.1	24.2
Old Growth	39	118.6	70.4	205.1	60.1	24.7	7.3	11.1	3.1	8.2	2.6	1.2	0.8	479.9	303.6	1652.0	202.4	49.7	23.5	98.6	33.1	44.3	39.7	95.5	23.9

Table 17- Density of tree species by diameter class for sites grouped by density of old-growth trees

Variation of Stand Structure for all Sites Grouped by Density Class																									
		Basal Area of Tree Species by Diameter Class (m2/hectare) for sites																							
		ALL Live Trees >10cm				Trees>50cm DBH				Trees>75cm DBH				Trees 0-9.9cmDBH				Trees 10-19.9cmDBH				Trees 20-49.9cm DBH			
Category	n	PP	PM	AB	OT	PP	PM	AB	OT	PP	PM	AB	OT	PP	PM	AB	OT	PP	PM	AB	OT	PP	PM	AB	OT
Low	22	10.0	5.6	4.0	1.5	1.8	0.8	0.8	0.0	0.3	0.1	0.4	0.0	0.4	0.1	0.2	0.3	1.0	0.5	0.4	0.4	6.8	4.2	2.6	0.7
Med	12	10.4	6.1	9.1	2.7	4.4	1.5	2.2	0.7	1.6	0.6	0.8	0.4	0.1	0.0	0.3	0.1	0.4	0.5	1.4	0.7	5.5	4.2	5.2	1.1
High	32	16.0	6.9	13.7	4.0	10.9	3.7	3.8	1.3	5.4	2.2	0.8	0.6	0.5	0.1	1.2	0.2	0.9	0.4	1.6	0.6	3.7	2.8	7.2	1.6
Old Growth	39	14.8	6.9	13.7	3.8	9.9	3.3	3.7	1.2	4.9	2.0	0.9	0.6	0.4	0.1	1.0	0.1	0.8	0.5	1.7	0.6	3.7	3.1	7.3	1.5

Table 18-Basal area of trees species by diameter class for sites grouped by density of old-growth trees

Appendix C-2: Variation of stand structure for sites grouped by study region

Variation of Stand Structure for all Sites Grouped by Study Region																									
		Absolute Density of Tree Species by Diameter Class (Trees Per Hectare)																							
		ALL Live Trees >10cm				Trees>50cm DBH				Trees>75cm DBH				Trees 0-9.9cmDBH				Trees 10-19.9cmDBH				Trees 20-49.9cm DBH			
Category	n	PP	PM	AB	OT	PP	PM	AB	OT	PP	PM	AB	OT	PP	PM	AB	OT	PP	PM	AB	OT	PP	PM	AB	OT
S. Deschutes	18	85.2	33.5	259.7	100.0	16.8	6.0	12.8	5.7	5.6	3.5	1.5	1.7	233	71	1684	368	25.9	10.8	126.8	49.2	42.5	16.7	120.1	45.0
N. Deschutes	19	177.8	81.4	119.2	54.4	18.9	5.5	8.6	0.7	6.3	0.9	0.8	0.0	643	194	1823	409	77.4	26.1	49.0	38.7	81.4	49.8	61.6	15.0
W. Ochoco	15	114.1	80.9	49.2	7.0	14.1	6.2	2.8	0.0	3.4	1.2	0.7	0.0	509	502	330	120	46.8	14.1	25.6	5.3	53.0	58.3	15.0	3.5
E. Ochoco	14	137.4	85.8	121.2	34.5	17.3	4.3	3.2	1.3	4.5	0.7	0.2	0.4	1045.9	272.8	854.9	136.4	48.3	36.5	57.9	20.4	71.9	45.0	60.1	12.9
Deschutes	37	132.7	58.1	187.5	76.6	17.9	5.7	10.6	3.1	5.9	2.2	1.1	0.8	444	134	1755	389	52.3	18.7	86.8	43.8	62.5	33.7	90.1	29.6
Ochoco	29	125.4	83.3	84.0	20.3	16.6	5.6	3.2	0.6	4.1	1.0	0.5	0.2	773	421	606	97	49.2	25.4	43.0	11.4	29.0	21.2	19.2	5.7

Table 19- Density of tree species by diameter class for sites grouped by sampling region

Variation of Stand Structure for all Sites Grouped by Study Region																									
		Basal Area of Tree Species by Diameter Class (m2/hectare)																							
		ALL Live Trees >10cm				Trees>50cm DBH				Trees>75cm DBH				Trees 0-9.9cmDBH				Trees 10-19.9cmDBH				Trees 20-49.9cm DBH			
Category	n	PP	PM	AB	OT	PP	PM	AB	OT	PP	PM	AB	OT	PP	PM	AB	OT	PP	PM	AB	OT	PP	PM	AB	OT
S. Deschutes*	18	10.8	4.9	16.7	6.5	6.4	3.4	4.5	2.3	3.0	2.7	1.3	1.1	0.4	0.0	1.2	0.1	0.5	0.2	2.3	1.0	6.5	7.8	6.4	8.3
N. Deschutes*	19	16.2	6.9	9.5	2.2	7.4	1.9	2.8	0.2	3.6	0.6	0.5	0.0	0.7	0.1	0.5	0.4	1.2	0.5	0.8	0.6	6.8	4.3	5.3	1.0
W. Ochoco*	15	11.1	8.3	3.5	0.3	6.0	2.5	1.3	0.0	2.3	1.0	0.6	0.0	0.1	0.0	0.0	0.0	0.8	0.3	0.5	0.1	4.2	5.5	1.7	0.3
E. Ochoco*	14	13.5	5.3	7.4	2.0	6.8	1.3	0.9	0.5	3.0	0.4	0.1	0.2	0.2	0.1	0.8	0.1	0.8	0.7	0.9	0.4	5.7	3.3	4.8	0.0
Deschutes	37	13.5	5.9	13.0	4.3	6.9	2.6	3.6	1.2	3.3	1.6	0.9	0.5	0.6	0.1	0.9	0.3	0.9	0.4	1.6	0.8	5.2	2.8	7.0	2.1
Ochoco	29	12.3	6.9	5.4	1.1	6.4	1.9	1.1	0.2	2.7	0.7	0.4	0.1	0.1	0.1	0.4	0.1	0.8	0.5	0.7	0.2	4.9	4.4	3.2	0.1

Table 20 – Density of tree species by diameter class for sites grouped by sampling region

Appendix D: Data Collection Sheets

CT3 - Regeneration and Logs

DRY OLD GROWTH PROJECT 2009 Date: ____/____/____ Obs: ________ Site:__________

SEEDLINGS, SAPLINGS, Sm TREES < 10 cm DBH in Micro Plot (2.5 m radius)

By Height Class if < 1.37 m tall or by Diameter Class if > 1.37 m tall and < 10 cm DBH

PLOT	SPP	Ht Cl (m) if < 1.37 m tall			DBH if ≥ 1.37 m tall and < 10 cm dbh				
		0.1-0.5	0.5-1.0	1.0-1.37	0.1-2 cm	2-4 cm	4-6 cm	6-8 cm	8-10 cm

SPP and LENGTH OF LOGS (> 2m long) by Large End Dia in 0.1 ha plot

Plot	SPP	> 30 cm D	>60 cm D		Plot	SPP	> 30 cm D	>60 cm D
		L (m)	L (m)				L (m)	L (m)

CT1 - Site and Subplot

DRY OLD GROWTH PROJECT 2009 Date: ____/____/____ Obs: ________ Site: ____________

SITE INFORMATION

GPS COORDINATES:	----- Target for Plot 1 -----	------- At road -------	Compass bearing from road
Datum: NAD83	Easting: ____________	Easting: ____________	to Plot 1: _______ deg
UTM zone:	Northing: ____________	Northing: ____________	

PLOT INFORMATION

Plot 1	Plot 2	Plot 3	Plot 4
Slope __________	Slope __________	Slope __________	Slope __________
Aspect __________	Aspect __________	Aspect __________	Aspect __________
PAss __________	PAss __________	PAss __________	PAss __________
GPS (UTM)	GPS (UTM)	GPS (UTM)	GPS (UTM)
Easting __________	__________	__________	__________
Northing __________	__________	__________	__________
File __________	__________	__________	__________
Photo ? N E S W	N E S W	N E S W	N E S W

Witness Trees-- 2 per plot

Plot	SPP	DBH cm	Distance (0.0 m)	Bearing tree to cntr	Notes
1					
1					
2					
2					
3					
3					
4					
4					

Observations, sketches, evidence of past human and natural disturbance, vegetation outside plots

DRY OLD GROWTH PROJECT 2009 **Date: ____/____/____ Obs: ________ Site:____________**

TREES + SNAGS
≥10 cm DBH/DCH in 7.28 m radius plot (*slope-corrected*)
> 50 cm DBH/DCH in 17.84 m radius plot (*slope-corrected*)

Plot	T,S,C	Spp*	DBH or DCH (0.1 cm)	Live trees only						Snags and Cut	
				Crown class*	Ht to Live		Keen class	CFHt (cm)	CFW (cm)	Height (m)	Decay class*

** Snag SppType = SPF. SPP TYPE PINE, FIR (ABIES), CONIFER, HARDWOOD, U (unknown)*

**Keen classes = A,B,C,D; CFH=catface height (cm); CFW=catface width cm*

** Tree crown class: O, S, I, C, D, E Snag decay class: 1 = sound to 5 = rotten*