Universidad de Valladolid
Campus de Palencia

ESCUELA TÉCNICA SUPERIOR
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QUANTIFYING DIFFERENTIAL GROWTH RATES AMONG UNDERSTORY TREE SPECIES IN COMPLEX STANDS RESULTING FROM SHELTERWOOD-WITH-RESERVES ON FEDERAL LAND IN SOUTHWESTERN OREGON (USA).

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INGENIERÍA TÉCNICA FORESTAL
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Ramiro Oliveri Martinez-Pardo

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Table of contents

ABSTRACT

0. RESUMEN

En la década de 1980 la oficina de manejo del paisaje del departamento de estado de los EE.UU implanto uma serie de parcelas para el estudio de aclareos sucesivos en el suroeste de Oregón, en el distrito de Melford.
Los aclareos sucesivos se propusieron para procurar una adecuada regeneración en esta zona, la cual está caracterizada por tener un verano con clima muy seco y con suelos rocosos poco profundos. Los bosques de coníferas del suroeste de Oregón se encuentran entre los más complejos del oeste de Norteamérica, debido al terreno escarpado, las pendientes, la elevación y al tipo de suelo y roca madre (Whittaker 1960).

Una estrategia clave en el diseño de un aclareo sucesivo es encontrar la estructura adecuada que proporciona la condición deseada en el estrato superior y el crecimiento adecuado del sotobosque. El número apropiado de árboles del dosel depende de los objetivos de gestión, así como de la especie y el sitio. Siempre es recomendable el mantenimiento de la cubierta del dosel mínima necesaria para cumplir los objetivos de reforestación.

El objetivo de este estúdio fue mejorar nuestro conocimiento de las dinamicas de las masas a largo plazo en estos sistemas. Entender las dinámicas a largo plazo es un requisito previo para una silvicultura efectiva en masas complejas.

Se realizó un modelo de árbol individual para el crecimiento en diámetro de los árboles del sotobosque en función de variables a nivel de parcela y árbol. El modelo incial se tomó de un modelo previo desarrollado para los bosques de coníferas mixtos del suroeste de Oregón (Hann *et al.,* 2002). El modelo se simplificó por eliminación backward para asegurarse que todas las variables eran estadisticamente significantes y que el comportamiento biológico del crecimiento del diámetro sobre las variables retenidas era realista.

Se obtuvieron ecuaciones de crecimiento para el *Pseudotsuga menziensii*, *Pinus ponderosa* and *Calocedrus decurrens*. En todos los casos la variable más importante fue el ratio de copa. Tambien se obtuvo un efecto negativo del CCFL y del área basal de la masa. El *Pinus ponderosa* casi desaparecía cuando el CCF superaba el 50%, corraborandose su menor tolarencia a la sombra.

1. ABSTRACT

In the 1980s and 1990s the USDI Bureau of Land Management implemented a number of shelterwood studies in their southwestern Oregon Medford District. Shelterwood regeneration cuts were proposed as one way to procure adequate regeneration on harsh sites characterized by a hot dry summer climate and shallow rocky soils. The mixed coniferous forests of the Klamath-Siskiyou Mountains of southwestern Oregon and northern California are among the most complex forests found in western North America due to steep gradients in slope, aspect, elevation, and soil parent material (Whittaker 1960).

A key strategy for designing a successful shelterwood-with-reserves system is finding the appropriate stand structure that provides the desired overstory condition and adequate growth of the understory. The appropriate number of overstory trees depends on management objectives, as well as on the species and the site. Retaining the minimum canopy cover necessary to meet reforestation objectives is always recommended, especially if the overstory trees will be retained.

The objective of this research was to improve our knowledge of the long-term stand dynamics in potential shelterwood-with-reserves systems. Understanding long-term stand dynamics is a prerequisite for effective silvicultural planning in complex stands. The growth analysis should consider the effects of gradients in overstory density, species composition and relative height.

Diameter growth of individual understory trees was modeled as a function of tree-level and stand-level variables.The initial model form was borrowed from a previous diameter growth model developed for southwestern Oregon mixed conifer forests (Hann et al. 2002).). The model was simplified in a backward elimination approach to ensure that all variables were statistically significant and that the biological behavior of diameter growth over the retained predictor variables was realistic.

We have obtained equations for Douglas fir, Ponderosa pine and Incense cedar. In all cases the most important variable was crown ratio. We also obtaineda negative effect of crown competition factor inlarger trees (CCFL) and totalbasal area. Ponderosa pine almost disappears when CCF exceeds 50 per cent, because of its lower shade-tolerance.

INTRODUCTION

2. INTRODUCTION

Regeneration methods are defined as timber harvesting strategies designed to promote and to ensure reforestation. They may involve one to several harvesting cuttings designed to control species composition and stand structureand are based on recognition of the microenvironment needed to establish desired species on a site. All regeneration methods are situation-specific and their applicability varies according to ecological, managerial and social factors.

The environment created by each regeneration method depends on the climate, topography, and soil of the site. The most extreem environmental modification occurs with the clearcut method because it exposes the ground completely in one cutting. The single tree selection method results in the least disturbance and creates an environment very similar to that of an undusturbed stand.

In the 1980s and 1990s the USDI Bureau of Land Management implemented a number of shelterwood studies in their southwestern Oregon Medford District. Shelterwood regeneration cuts were proposed as one way to procure adequate regeneration on harsh sites characterized by a hot dry summer climate and shallow rocky soils. The mixed coniferous forests of the Klamath-Siskiyou Mountains of southwestern Oregon and northern California are among the most complex forests found in western North America due to steep gradients in slope, aspect, elevation, and soil parent material (Whittaker 1960).

The shelterwood regeneration method is designed to remove an existing stand in two or more harvests, providing a shaded microsite during establishment of regeneration. This shading may be helpful on hot, dry sites, for frost-prone species on frosty sites, or for more shade-tolerant species such as true firs on more moderate sites. While the shelterwood method is more complex from the viewpoint of timber production, the shelterwood trees are more aestheically pleasing at least until the overstory is removed, and the method offers greater structural diversity for wildlife habitat than the clearcut method.

A key strategy for designing a successful shelterwood-with-reserves system is finding the appropriate stand structure that provides the desired overstory condition and adequate growth of the understory. The appropriate number of overstory trees depends on management objectives, as well as on the species and the site. Retaining the minimum canopy cover necessary to meet reforestation objectives is always recommended, especially with the shelterwood system.

Density of the canopy can be varied widely to create the microclimatic conditions necessary for establishment of the target species and propagule type. Overstory trees compete for soil water and other site resources (Childs 1985) and will probably reduce growth of seedling if not removed prompty after regeneration is established (McDonald 1976). The presence of shelterwood canopy will also reduce the growth of understory vegetation compared to that in fully exposed environments.

Physiologically, shade tolerance is the result of relative light compensation points for different species. The light compensation point is the light intensity at which respiration and photosynthesis are equal (O´Hara, 2014). Virtually all seedlings benefit from shade for the first year or two, but the light intensity required for continued seedling survival and development varies by species, with white fir requiring less than 2 percent of full sunlight, Douglas fir 2-10 percent, and ponderosa pine 20-30 percent (Alzet and Waring, 1970). Once they become established, both shadetolerant and intolerant seedlings increase in growth as light intensity increase to full sunlight.

The light available to the understory trees has an important influence on their growth and form. Most vascular plants increase their growth with increasing light intensity until they are saturated with respect to light utilization (O´Hara 2014). The light avaible in the stands depends of the stand density and composition. Not all species have the same crown width and the same leaf area.

The interaction of greater light intensity with greater soil moisture availability is probably also important, particularly on hot, dry sites. Regeneration methods affect air and soil temperature, wind speed, competing vegetation, and the amount of avaible soil water. The water used by overstory trees can be important. If overstory trees are present, the soil water utilized by them becomes unavailable for seedlings. The ameliorative temperature benefits provided by the canopy may be offset by the amount of water large trees consume.

Species of trees and other vegetation present in the existing stand, and their distribution vertically and horizontally, may provide important clues to the local environment and perhaps to the tree species best adapted to the site. Differences in species composition between the overstory canopy and the understory, if present, reflect changes in species dominance that are likely to occur if shaded conditions in the understory are maintained. For example, if the overstory is dominatedby shade-intolerant species but the advance regeneration in the understory is of more shade-tolerant species, a regeneration method that creates a more open forest floor is probably neccesary to regenerate shade-intolerant species in the future stand.

In 2004, a project was initiated to monitor stand dynamics in stands that had an established mix of natural and planted understory regeneration beneath a retained residual overstory, resulting in a two-storied structure consistent with a shelterwood-with-reserves silvicultural system, either by design or by default.

The objective of this research was to improve our knowledge of the long-term stand dynamics in potential shelterwood-with-reserves systems. Understanding long-term stand dynamics is a prerequisite for effective silvicultural planning in complex stands. The growth analysis should consider the effects of gradients in overstory density, species composition and relative height.

OBJECTIVES

3. OBJECTIVES

The goal of this research was to improve our knowledge of long-term stand dynamics in mixed-conifer stands that had receivedregeneration cuts under a system best described as ashelterwood-with-reserves. The specific objectives of this analysis were:

1) to quantify the growth response of two understory treespecies with different silvical characteristicsto varying levels of overstory competition; and

2) to quantify competition from other individuals in the regeneration cohort that established after the shelterwood regeneration cut.

MATERIAL AND METHODS

4- MATERIAL AND METHODS

4.1. Study area

All plots are located in southwestern Oregon and are considered to fall within the mixed conifer zone of the Klamath Mountains (Whittaker 1960; Tesch1994). The twoprincipal locations of the sampled stand are northeastern Josephine County and southeastern Jackson County (Figure 1).

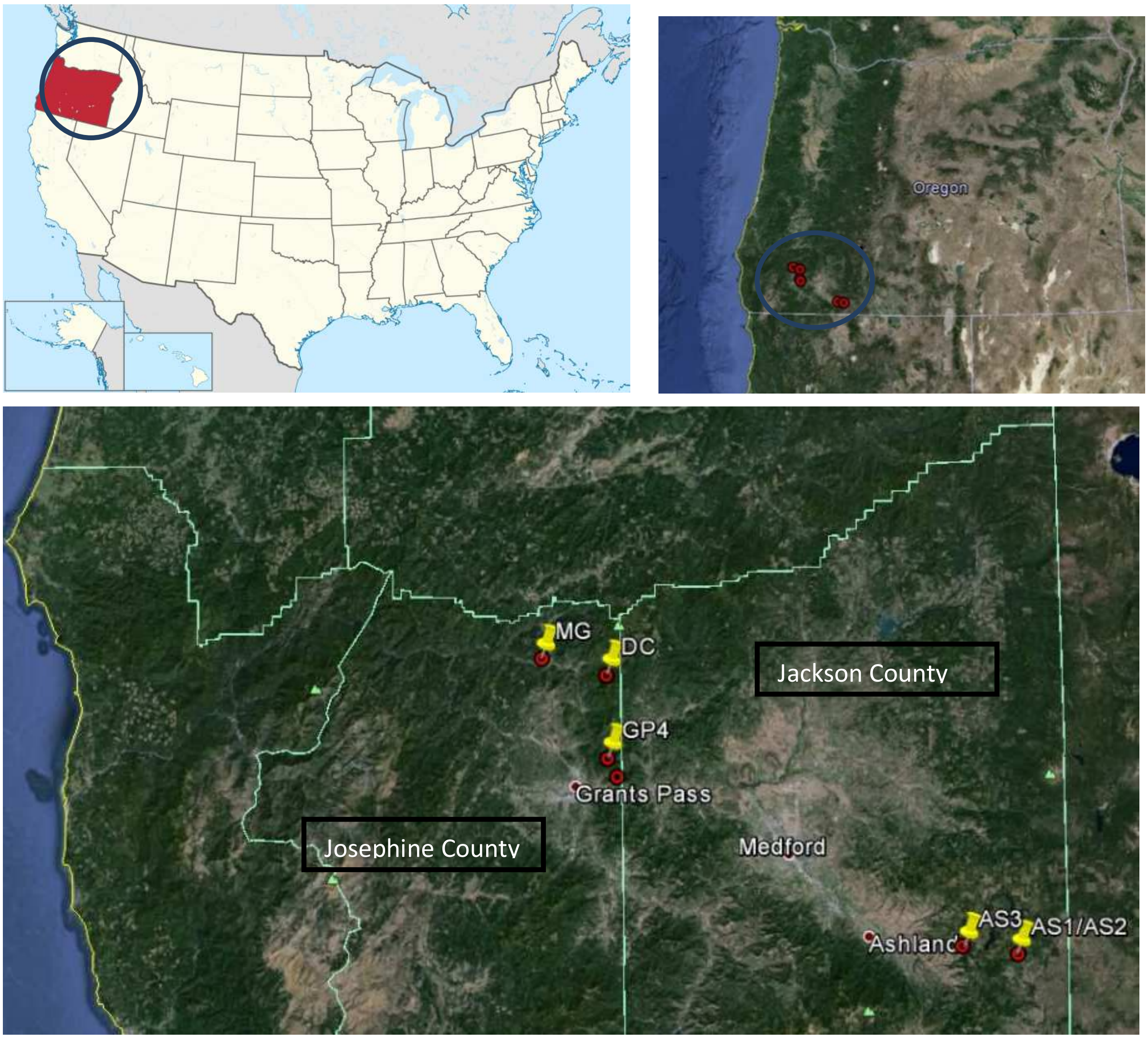

Figure 1: plots location

4.1.1 Geological area

The state of Oregon has been separated into nine physiographic provinces (Figure 2). The stands are located inside the Klamath Mountains Province. This Province encompasses a complex of ranges in southwestern Oregon (the portion of Oregon is commonly identified as Siskiyou Mountains) and in northern California.

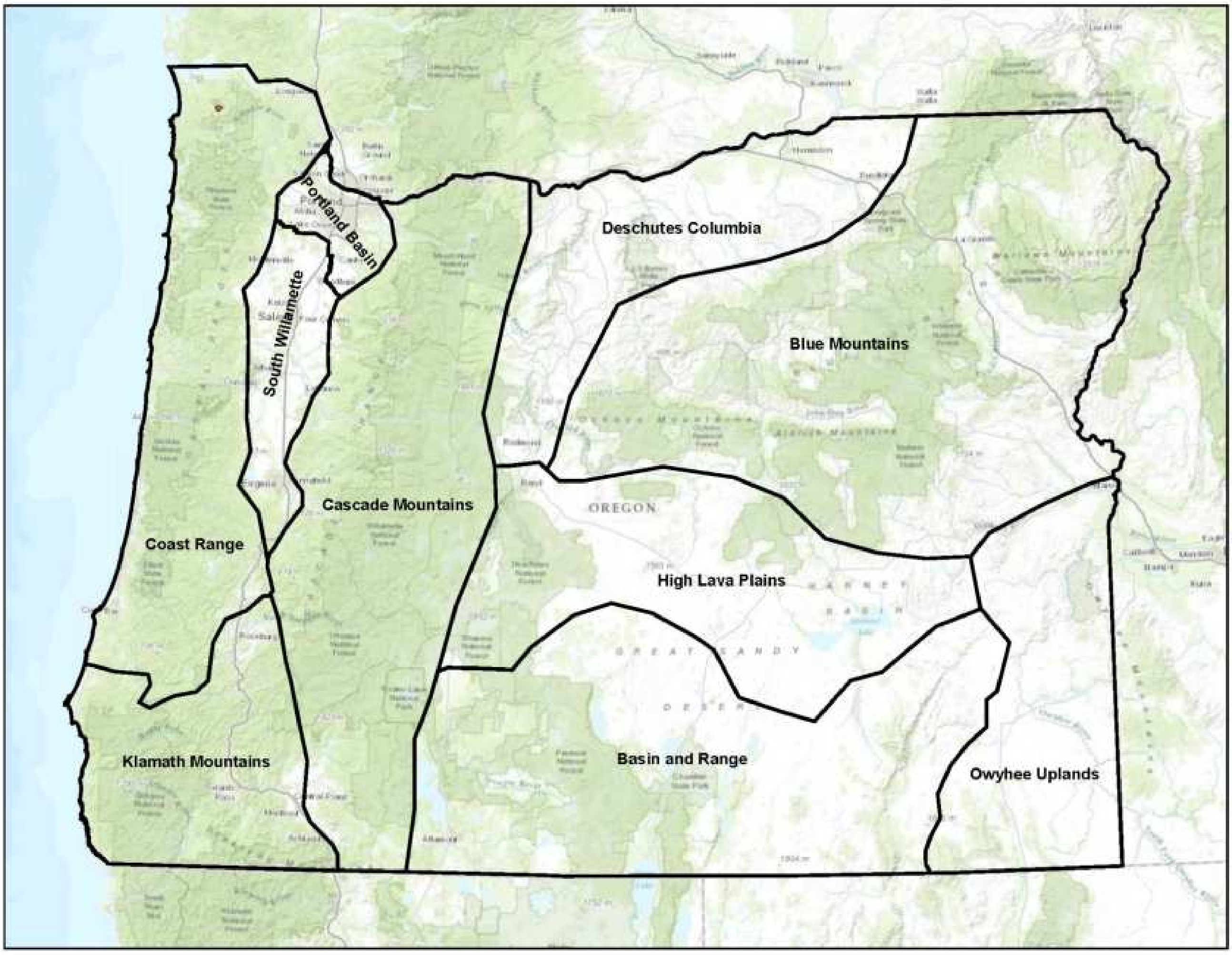

Figure 2. Physiographic Provinces of Oregon

This region is characterized by rugged terrain with some evidence of glaciation at high elevations and deeply dissected with V-shaped canyons at lower elevations. Steeply folded and faulted pre-Tertiary stratacomprise the mountain ranges and elevation varies from 1200 meters in the east to approximately 600 meters near the Pacific Coast.

The soils in this zone are extremely varied due to the complex geological history, topography, and steep gradients in climatic factors imposed by topography and distance from the coast (Whittaker 1960; Franklin et al. 1988). Table 1 shows the principal great soil groups in the area, following the National Cooperative Soil Survey Classification of 1967.

Table 1: Principal great soil groups within the Klamath Mountains physiografic province. (Franklin *et al*. 1988)

Province	**Widespread great soil groups**	**Less abundant great soil groups**
Klamath Mountains	Haplohumults Haploxerults	Haplumbrepts Haploxeralfs Xerochrepts Dystrochrepts Hapludalfs Haploxerolls Cromoxererts

4.1.2 Climatology

The complex interplay between maritime and continental airmasses and the mountain ranges causes the varied climate in Oregon and Washington. Specifically, the interior valleys of southwestern Oregon are influenced by the coastal mountains. The maritime airmasses are blocked from these areas to varying degrees, and precipitation declines markedly in resultant rain shadows. At the same time, there is a general latitudinal increase in precipitation from south to north. Consequently, the interior valleys of southwestern Oregon typically have hot and dry summers, as it is shown in Figure 3. Table 2 is a summary of the annual precipitation and the annual temperature for the city of Medford, centralto the sampled stand locations.

Table 2:Summary of weather averages in Medford, Oregon. From US climate data.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Average high in °C:	8.2	11.7	14.4	17.9	22.2	26.6	31.1	30.6	26.6	19.4	10.7	7.3	18.9°C
Average low in °C:	-0.8	0.2	1.4	3.1	5.6	8.6	10.8	10.4	6.9	2.9	1.2	-0.7	4.1°C
Av. precipitation in mm:	70	59	57	41	36	20	13	14	24	38	81	83	536 mm

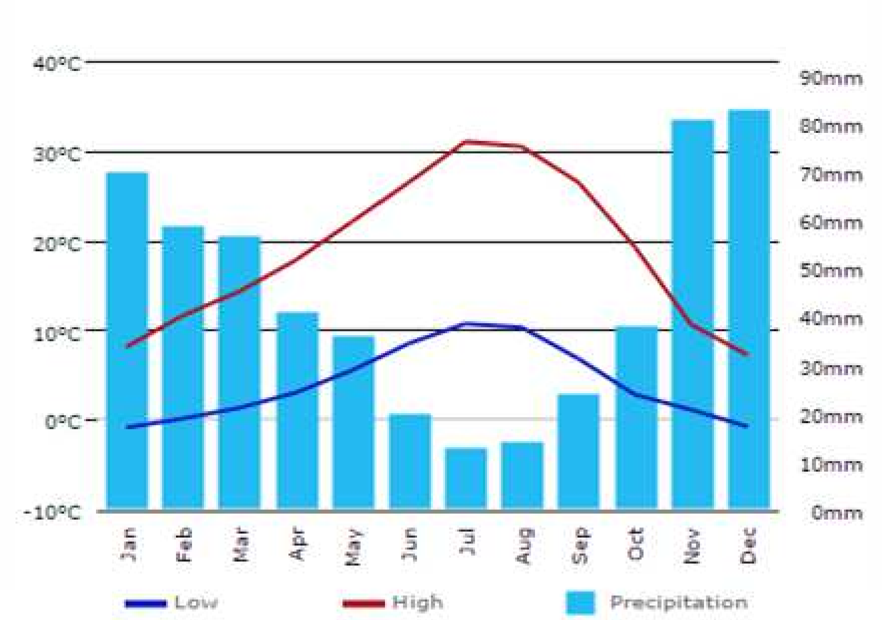

Figure 3: Ombrothermic diagram of Medford. (From:http://www.usclimatedata.com)

4.1.3 Vegetation

The overstories of these forests are dominated by five major coniferous species. These species include Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco*),* ponderosa pine *(Pinus ponderosa* Dougl. ex Laws*),* grand/white fir *(Abies grandis* (Dougl. ex D. Don) Lindl.*x Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.*),* sugar pine *(Pinus lambertiana,* Douglas*),* and incense cedar *(Calocedrus decurrens,* Pursh*),* with only occasional presence of lodgepole pine (*Pinus contorta,* Douglas). In addition, several hardwood species are common, including madrone *(Arbutus menziesii,* Pursh*)* and Oregon white oak *(Quercus garryana,* Douglas, ex Hook*).* The sampled plots were dominated by one of the three principal species, specifically Douglas-fir, grand/white fir, and ponderosa pine, in order of abundance. This study covers a zone of genetic intergrade between grand and white fir, with DNA studies suggesting that hybridization between the two species precludes their distinction (Meyers 2015). Silvicultural prescriptions and treatments are therefore typically applied as if they were one species.

Abies concolor/Abies grandis seems the major climax species over the entire Mixed-Conifer Zone. However, on dry habitats *Pseudotsuga* appears to be the major climax primarily because *Abies* is unable to establish inthese stressful environments, to compete successfully, and/or to survive the historicaly frequent ground fires in these systems. *Pinus ponderosa* and *Pinus lambertiana* are considered to be early seral species, although *P. ponderosa* may achieve climax status at the extremes of the moisture gradient, i.e., on harsh dry sites or on poorly drained andswampy sites. “Gap-phase” disturbances provide favorable environments for regeneration of *P. ponderosa*, an early seral species that is generally intolerant of shade. Small openings are a pervasive feature of mixed-conifer forest throughout much of the Siskiyou Mountains.

4.2. Sampling design.

The study was initiated by establishing eight square 0.4-ha plots (63.61 x 63.61 m; 208.7 x 208.7 ft) to characterize the overstory structure. Each 0.4-ha plot contained nine nested 81-m^2 circular subplots (5.07-m radius) to characterize the understory trees, established ona systematic 3x3 grid of plots. The selection of the sample plots bythis method maintained fixed distances between the plots (Figure 4).

All overstory trees with diameter at breast height (DBH) >12.7 cm (5.0 inches) were measured within the square 0.4-ha plot. All trees with total height (HT) >1.37 m (4.5 feet) and with DBH ≤12.7 cm (5.0 inches) were measured on the nine subplots. Table 3 shows the location of each plot, along with its elevation, slope, and aspect.

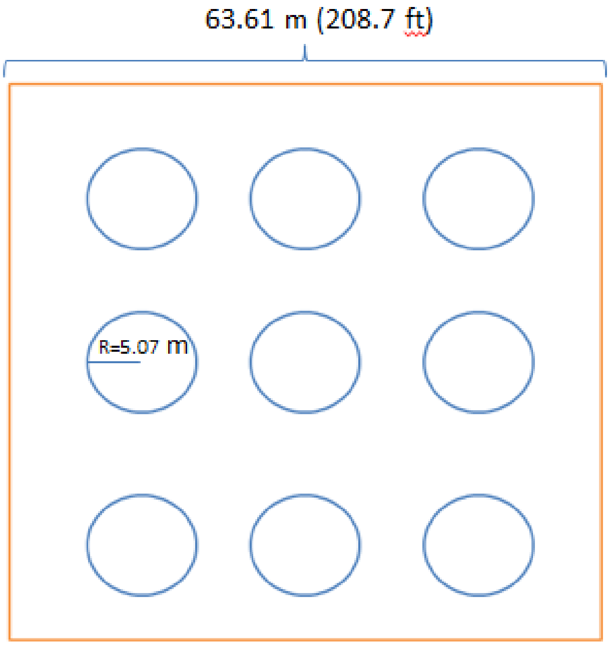

Figure 4: Plot design for the southwestern Oregon shelterwood-with-reserves study.

Trees were measured twice, initially in late summer 2005 and again in late summer 2014 (near the end of the corresponding growing season). Each tree was measured for DBH, total height (Ht), height to lowest live branch (Hllb), and the height to compacted crown base (HCB) (Monleon et al. 2004). Some trees were missed during the initial 2005 measurement. The 2005 DBH of any missed tree was estimated by coring the tree in 2015, measuring 9-yr radial growth, and computing the corresponding 9-yr diameter growth inside bark as 2x this radial growth. Diameter inside bark at breast height in 2015 was estimated from DBH using equations developed by Larsen and Hann (1985). Diameter inside bark at breast height in 2005 was the estimated from the diameter growth measured on the increment core, and the 2015 DBH was estimated by inverting the equations developed by Larsen and Hann (1985). Tree attributes are listed in Table 4.

Table 3: Location and physiographic attributes of 0.4-ha plots in two-storied mixed conifer stands in southwestern Oregon.

Plot label	Latitude	Longitude	Elevation (m)	Slope (%)	Aspect (°)
MG/MG2	42.6438	-123.3947	417	49	274
GP4	42.4837	-123.2568	1003	59	122
AS3	42.1784	-122.5108	1430	27	214
AS1/AS2	42.1639	-122.3931	1530	10	225
DC	42.6146	-123.2568	1147	17	309

Mensurational attributes of the 0.4-ha plots for overstory, understory, and all trees together were computed assuming expansion factors of 2.5 trees per hectare for overstory trees, 13.72 trees per hectare for understory trees when the analysis was at the level of a plot, and 123.trees per hectare when the analysis was at the level of a subplot.

Table 4: Dimensions of the sample trees by species in the southwestern Oregon shelterwood-with-reserves study.

Species	**Common Name**	**Code SPP**	**Dbh Max (cm)**	**Dbh min (cm)**	**H max (m)**	**H min (m)**	**Hllb max (m)**	**Hllbmin (m)**
Coniferous								
Pseudotsugamenziesii	Douglas-fir	PSME	131.1	0.3	53.8	1.3	33.3	0.1
Pinus ponderosa	Ponderosa pine	PIPO	132.1	0.5	58.9	1.4	21.5	0.1
Abiesconcolor x Abiesgrandis	Grand/White fir	ABGR	84.6	0.8	36.5	1.6	23.7	0.5
Calocedrusdecurrens	Incense cedar	CADE	71.9	0.5	24.9	1.3	11.8	0.1
Pinuslambertiana	Sugar pine	PILA	97.8	0.5	41.8	1.3	28.3	0.1
Pinuscontorta	Lodgepole pine	PICO	16.6	0.8	7.0	1.5	0.9	0.1
Hardwood								
Arbutus menziesii	Madrone	ARME	48.5	10.0	20.49	6.36	-	-
Quercusgarryana	Oregon white oak	QUGA	43.9	43.9	12.70	12.7	-	-

4.3 Calculated variables.

Several variables were calculated from DBH (Diameter at breast Height), Ht (Total Height) and HCB (height to live crown). All variables could be divided in two groups:

Tree-level variables:

- Initial DBH [cm]
- Initial HT [m]
- Crown ratio:

$$\mathrm{CR} = \frac{\mathrm{Ht} - \mathrm{hcb}}{\mathrm{Ht}}$$

- DBH/HT [cm/m]
- BAL [m^2/ha] (basal area in trees with larger DBH than the subject tree; sum of BA ofall trees whose DBHis greater than the subjecti tree).
- CCFL(crown competition factor in trees with larger DBH than the subject tree).

Stand level predictors:

- Initial basal area
- Initial CCF

4.3.1 CCF (Crown Competition Factor):

Crown competition factor (CCF) is defined as the percentage of the plot area that would covered by the crown projection areas of all the trees on the plot if they had been open grown and hence with live crowns to the base of the tree.

Crown competition factor (Krajieck et al. 1961) was computed from maximum crown width (MCW) equations developed by Paine and Hann (1982). Because these equations assumed Dbh was measured in inches and predicted crown width in feet, the measured DBHs were converted to inches and MCWs were converted to meters. The original MCW equations (Paine and Hann 1982) were:

- PSME, mcw=4.6336+1.6078*Dbh14-9.6250^-3*Dbh14^2)
- ABGR, mcw=6.1880+1.0069*Dbh14)
- PIPO, mcw=3.4835+ 1.3430*Dbh14-8.2544^-3*Dbh14^2)
- CADE, mcw=3.2837+ 1.2031*Dbh14-7.1858^-3*Dbh14^2)
- PILA, mcw=4.6601+ 1.0702*Dbh14)
- QUGA, mcw=3.0786+ 1.9242*Dbh14)
- ARME, mcw=3.4299+ 1.3532*Dbh14)
- CACH, mcw=2.9794+1.5512*Dbh-0.14161*Dbh^2 (from Paine and Hann)
- PICO, mcw=2.4132*Dbh^0.6403 (from FVS Region 6)

The MCW predictions for each tree were applied to compute the potential crown projection area (CPA) of each tree assuming a circular projection, and total crown projection areas of all trees converted to total m^2 per ha was then computed by multiplying each CPA by its expansion factor and summing these products for the plot. CCF was expressed as a % of a hectare that would be covered by potential CPAs of the sampled trees on the plot. The key equations for these computations were:

- **cpa:** maximum crown area (m^2). $CPA = \frac{\pi}{4} MCW^2$

- **CCF**: Crown competition factor (%) = $\frac{100 \times ef \times CPA}{10^4}$

4.4 Stand description.

Table 5 is a summary of the number of trees per hectare (Tph), the Basal area (BA; m^2/ha) and the crown competition factor (CCF) for theoverstory and understory of each stand, as well as the total for the understory and overstory. Stand densities differed dramatically between plots. Total trees per hectare varied from 1073-3434, stand basal area from 20.3-54.3 m^2/ha, and crown competition factor (CCF) from 110-327% (Table 5). Overstory trees were retained at densities ranging from 148 to 395 trees per hectare and at basal areas ranging from 11.6 to 45.0 m^2/ha (Table 2).

The diameter distribution by diameter class in each plot and the BA (m^2/ha) distribution per species in each plot are shown in the next page.

Table 5: .Mensurational attributes of 0.4-ha plots in two-storied mixed conifer stands in southwestern Oregon

Stand	layer	Trees per ha	BA (m^2/ha)	CCF (%)
AS1	Overstory	353	29.2	94
	Understory	1084	5.7	46
	Total	1437	35	141
AS2	Overstory	395	11.6	45
	Understory	1633	8.8	66
	Total	2028	20.3	111
AS3	Overstory	346	25.6	114
	Understory	727	6.5	46
	Total	1073	32.2	161
DC	Overstory	368	45	204
	Understory	2676	9.3	124
	Total	3044	54.3	327
GP4	Overstory	264	31.2	121
	Understory	3170	6.9	110
	Total	3434	38.1	231

MG	Overstory	193	28.7	122
	Understory	961	3.4	43
	Total	1153	32.1	165
MG2	Overstory	148	22.5	98
	Understory	1139	4	50
	Total	1287	26.5	148

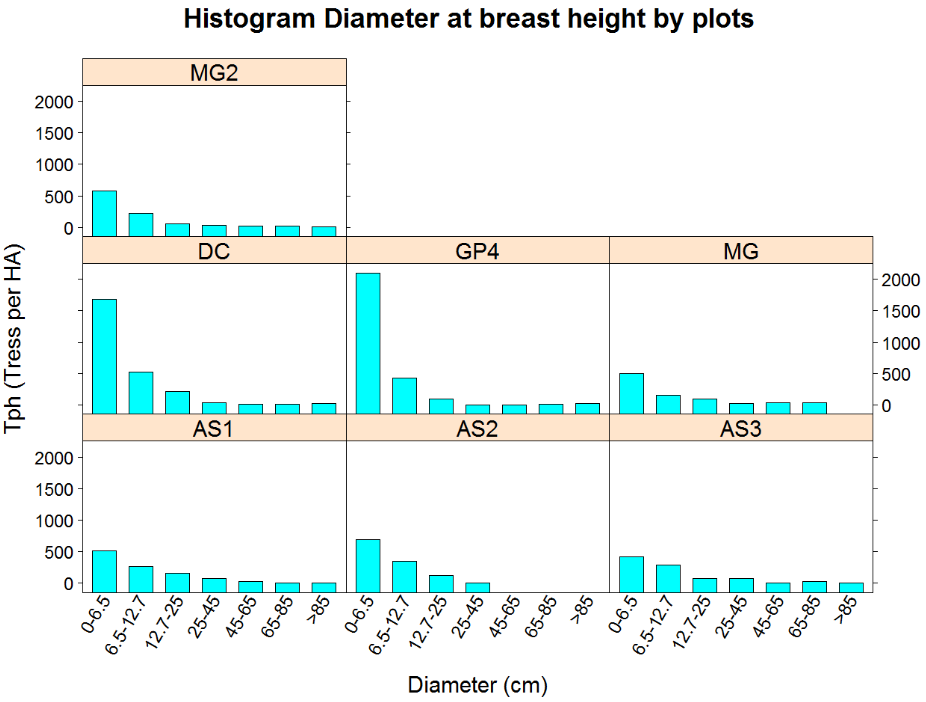

Figure 5: Diameter distribution for each plotin 2014 from the southwestern Oregon shelterwood-with-reserves study.

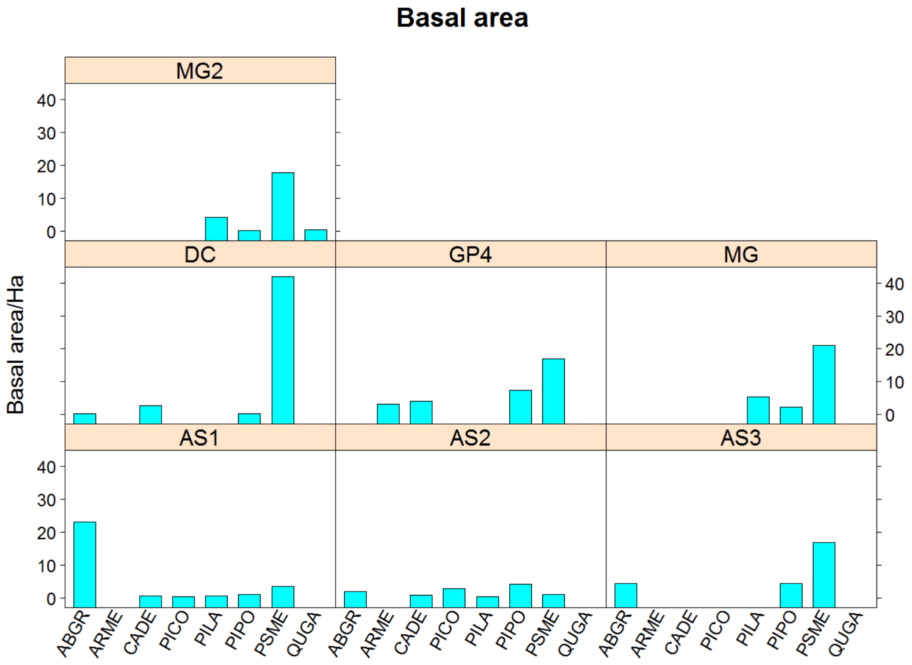

Figure 6: Basal area (m^2/ha) distribution by species for each plot in 2014 from the southwestern Oregon shelterwood-with-reserves study.

4.5 Statistical analysis:

Diameter growth of individual understory trees was modeled as a function of tree-level and stand-level variables. The latter stand-level variables were based on trees within the subject tree subplot rather than the entire 0.4-ha plot after screening suggested that trees were responding much more strongly to local stand structure on the subplots. The following tree-level variables were tested as predictors of periodic annual diameter growth: initial DBH, initial HT, crown ratio (CR), DBH/HT, BAL (basal area in trees with larger DBH than the subject tree) and CCFL (crown competition factor in trees with larger DBH than the subject tree). Both basal area and CCF were tested as stand-level predictors of periodic annual diameter growth. A summary of variables ofthe two most common species is shown in Table 6.

Table 6: Summary of predictors and response variables for each species.

Pinus ponderosa	**n**	**Units**	**Mean**	**sd**	**min**	**Max**
Annual DBH growth	82	cm	0.6	0.4	0	1.3
Intial DBH	86	cm	3.9	2.9	0.5	12.4
Initial Ht	86	m	3.1	2	1.4	15.4
Crown ratio	93	Proportion	0.6	0.3	0.04	1.0
H_D05	86	m/cm	1.1	0.5	0.4	3
CCFL05	86	%	115.1	45.8	33.5	275.7
BAL05	86	m^2/ha	23.1	7.9	5.8	46.3
Pseudotsuga menziesii	**n**	**Units**	**Mean**	**sd**	**min**	**Max**
Annual DBH growth	344	cm	0.3	0.3	0	2.4
Intial DBH	393	cm	4.1	3.2	0.5	12.7
Initial Ht	391	m	4.1	2.4	0	13.6
Crown ratio	474	Proportion	0.5	0.2	0.02	1.0
H_D05	390	m/cm	1.4	0.9	0.2	5.3
CCFL05	393	%	175.3	64.2	19.6	277.5
BAL05	393	m^2/ha	33.3	10.5	4.3	46.3
Calocedrusdecurrens	**n**	**Units**	**Mean**	**sd**	**min**	**Max**
Annual DBH growth	50	cm	0.4	0.3	0.0	1.1
Initial DBH	53	cm	3.1	2.7	0.5	10.9
Initial Ht	53	m	2.8	1.6	1.3	9.1
Crown Ratio	53	Proportion	0.7	0.2	0.1	0.95
H_D05	53	m/cm	1.2	0.7	0.3	3.6
CCFL05	53	%	111.5	75.4	34.6	271.0
BAL05	53	m^2/ha	20.4	13.9	5.9	46.3

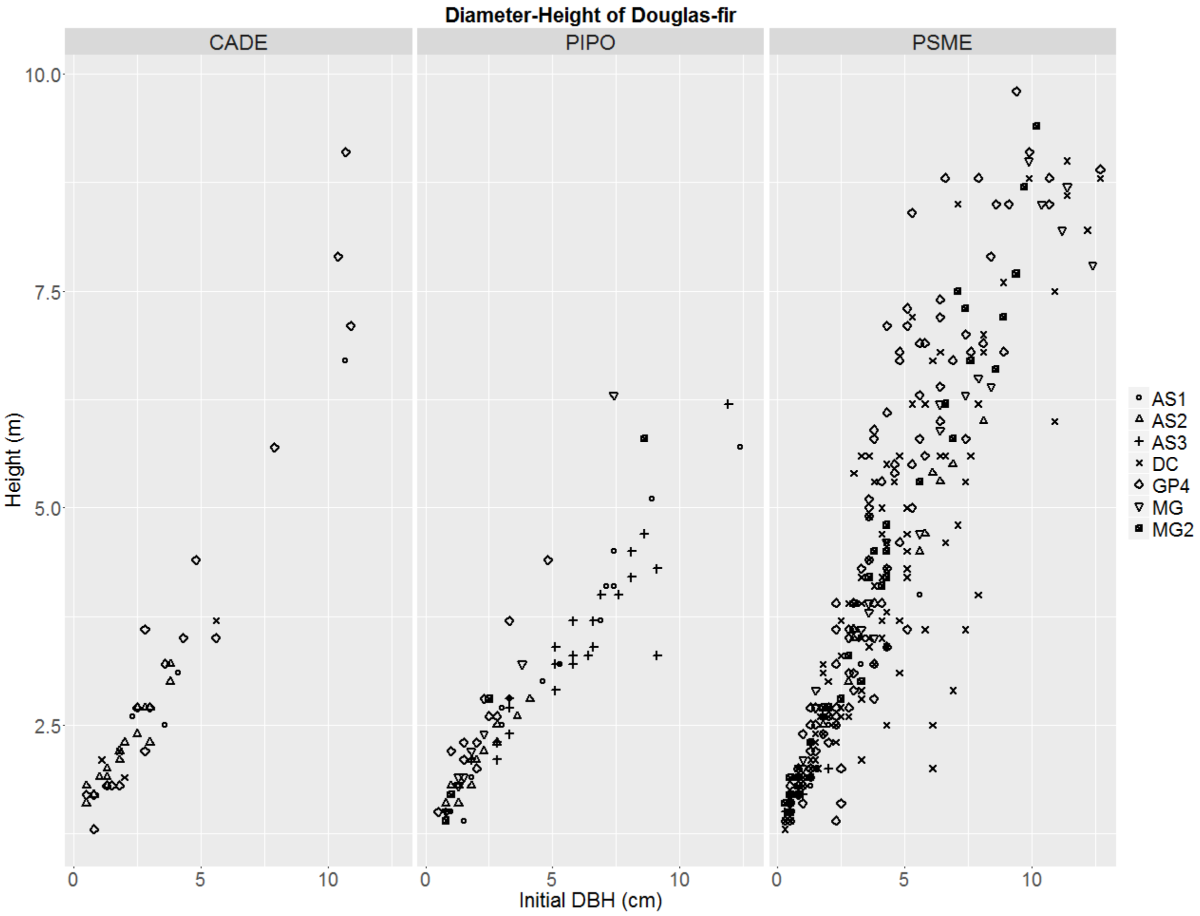

Figure 7: Height relationship todiameter for the three main species.

The initial model form was borrowed from a previous diameter growth model developed for southwestern Oregon mixed conifer forests (Hann et al. 2002).

$$[1]\Delta D = e^{\sum_{i=0}^{7} a_i + X_i} + \varepsilon$$

Where:
$X_0 = 1.0$
$X_1 = Ln(D+1)$
$X_2 = D^2$
$X_3 = Ln[\left(CR + \frac{0.2}{1.2}\right)]$
$X_4 = Ln(SI - 4.5)$
$X_5 = BAL^2/Ln(D+5)$
$X_6 = BA^{1/2}$
$a_i = regression\ parameters$
$\epsilon = Random\ error$ with $\epsilon \sim N(0,\sigma_1^2)$

Initial parameter estimates were obtained by linearization of model [1]. Because the eight two-storied stands covered a much narrower range in conditions than the 529 stands sampled by Hann et al. (2002), the model was simplified in a backward elimination approach to ensure that all variables were statistically significant and that the biological behavior of diameter growth over the retained predictor variables was realistic. To check for unique plot-specific behaviors, indicator variables were also assessed in the preliminary models that were reduced forms of model [1].

RESULTS AND DISCUSSION

5 Results and discussion

5.1 Analysis of diameter growth:

Assessment of plot GP4 effects in preliminary models :

The two following models for Douglas-fir (model [2]) and ponderosa pine (model 3]) describe the effects of initial tree and stand attributes on diameter growth of these two respective species:

$$[2]\ ln(\Delta Dbh) = -0.52553 + 0.00562 \cdot D05^2 - 0.17658 \cdot I_{GP4} + 1.98365 \cdot ln\big((CR + 0.2)/1.2\big)$$

$$[3]\ ln(\Delta Dbh) = -43103 + 0.45623 \cdot ln(D05 + 1) - 0.80408 \cdot I_{GP4} + 1.68322 \cdot ln\left(\frac{(CR+0.2)}{1.2}\right) - 0.00103 \cdot BAL^2/ln(D05 + 5.0)$$

Where ΔDbh was periodic annual diameter increment (cm/yr), D05 was initial diameter in 2005 (cm), I_{GP4} was an indicator variable for stand GP4 (Tables 1 and 2), CR was live crown ratio (proportion), and BAL was basal area in trees with larger D05 than the subject tree (m^2/ha).

The best predictor variable in both models was crown ratio (Figure 8) and initial diameter had a positive effect on diameter increment in both species.The first model accounted for 65% of the variation in diameter growth of understory Douglas fir trees (R^2=0.65) and the second model accounted for 89% of the variation in understory ponderosa pine (R^2=0.89). BAL had a negative effect on diameter growth in ponderosa pine (Figure 9), which appeared more sensitive to competition from residual overstory trees probably due to its low tolerance of shade.

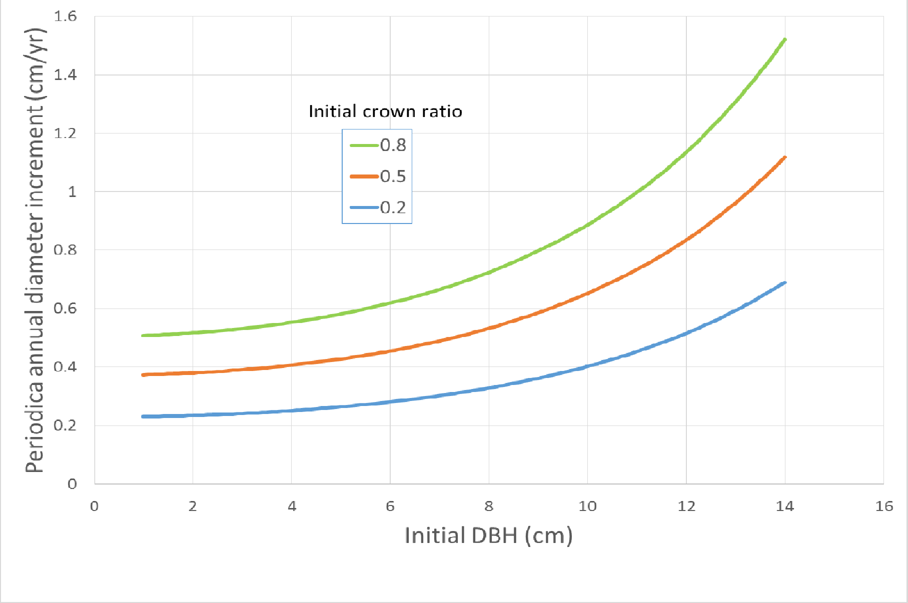

Figure 8: Trend in periodic annual diameter increment of Douglas-fir over initial tree diameter for three different initial crown ratios, 0.2, 0.5 and 0.8.

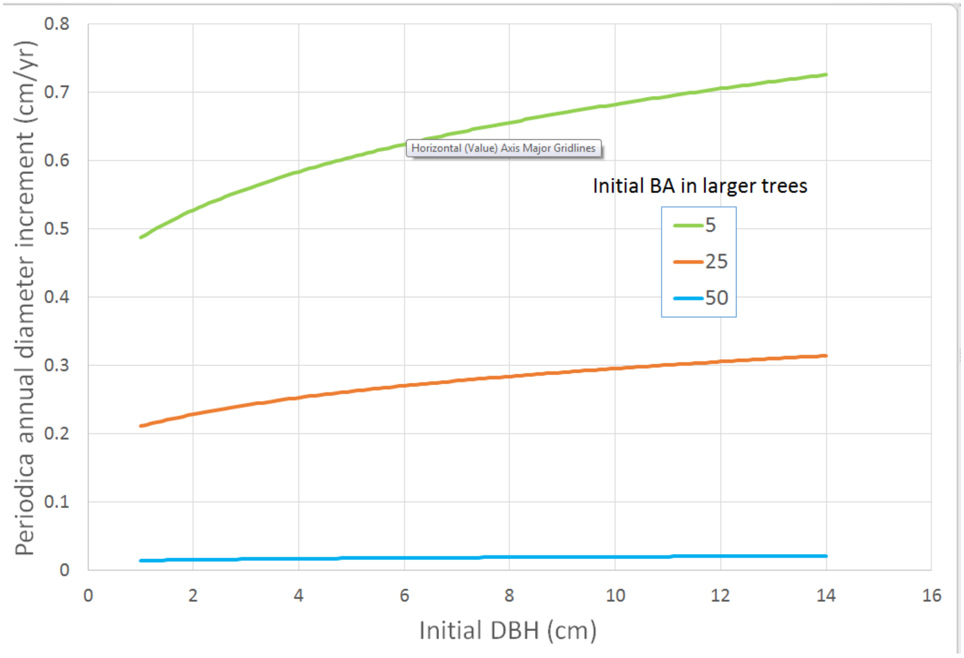

Figure 9: Trend in periodic annual diameter increment of ponderosa pine understory trees over initial diameter for three different levels of basal area in trees larger than the subject tree, 5, 25, and 50 m^2/ha.

In both models, an indicator variable for stand GP4 was included because that site (plot) consistently emerged as having significantly lower growth rates. These lower diameter increments could be caused by one or both of two factors:

The first possible influential factor was the high slope and southeasterly aspect of this plot (Table 3). To check this possibility, the influence of both aspect and slope were investigated further, and their potential influence on site index, were tested in the model (see Appendix A for estimation of site index implied from initial height and subsequent 9-yr height growth of individual trees).

To incorporate the influence of aspect and the slope in the model, the following variables were calculated to derive variables that were continuous with aspect, allowed the peak to be defined by the data, and allowed for the expected interaction between slope and aspect (Stage 1976).

$$[4]\ aspect\ in\ radians = aspect * PI/180$$

$$[5]\ Slope.cos.aspect = \frac{slope(\%)}{100} * \cos\left(aspect\ [rad]\right)$$

$$[6] Slope.sin.aspect = \frac{slope(\%)}{100} * \sin(aspect\ [rad])$$

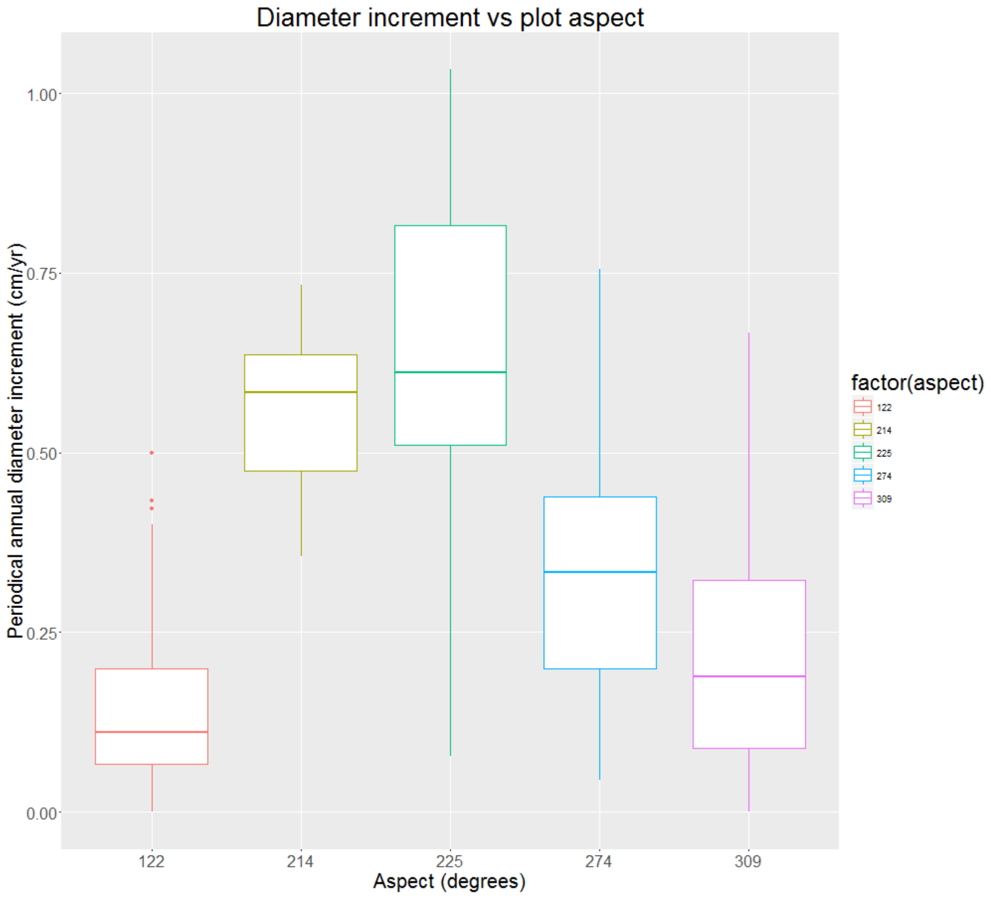

Figure 10: Boxplot of the diameter year-growth in relation to aspect.

The second possible factor is the abundance of madrone on plot GP4. As we can see in the pictures (AppendixV) the MG plots and GP4 presented an abundance of understory madrone, but only GP4 included madrone overstory trees.

Unfortunately, madrone trees were only measured in 2014, and the limited data therefore do not make possible an adequate analysis. However, other studies suggest that madrone is an intense competitor for Douglas-fir. Newton *et al.* (2008) noticed that the high density of madrone caused a significant reduction in Douglas-fir height, but intermediate densities of madrone reduced both diameter and volume. In short, increasing madrone density was correlated with decreasing Douglas fir size. The other possibility is that madrone indicates a poorer site quality.

Hughes *et .al* (1990) found that diameter and height growth of Douglas fir were negatively related to increasing LAI and cover of madrone and that height-to-diameter ratios increased. Radosevich *et al.* (1976) observed that Pacific madrone and tanoak reduced basal area growth between 20-40% in Douglas fir.

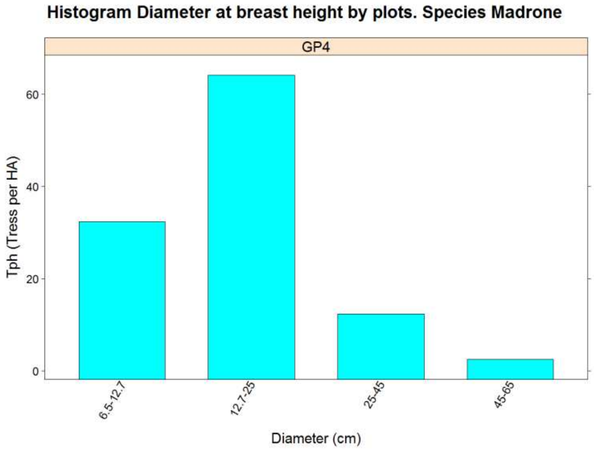

Figure 11: Madrone diameter distribution for plot GP4 in 2014.

Final models:

Based on the first models, supplementary models were developed to study the effects of different variables in the principal species. Also, a different model was developed forincense cedar because sufficient data were available to provide reasonable statistical power for an analysis.

In the first model for Douglas-fir the indicator variable was replaced by the estimated site index (Appendix I), in order to observe if it is possible to replace the indicator variable by a continuous environmental variable. Site index had a more negative effect on diameter growth than $I_{GP4,}$ but both models were very similar to each other. However, the plot GP4 has one of the highest site indices, while showing the lowest diameter increment. Most likely the presence of larger madrone stimulated the growth in height relative to diameter, resulting in a large height-diameter ratio. Site index did not have the same effect in ponderosa pine, with the indicator variable providing much better explanatory power than site index. The larger diameter growth difference between stands for Ponderosa pine than Douglas-fir may also affect this relationship.

MODEL 1DF:

	Estimate	STD error	T value	P- value	Vif
Intercept	4.1202	1.4765	2.79	0.00559 **	
Ln ((CR+0.2)/1.2)	1.8288	0.0968	18.89	< 2e-16 ***	1.25
Dbh^2	0.0062	0.0009	7.26	3.21e-12 ***	1.03
Ln (SI – 4.5)	-0.9931	0.4310	-2.30	0.02188 *	1.22

Residual standard error	0.5377
Degrees of freedom	307
F-statistic	198.2
R^2**Adjusted**	0.66
MSE	0.28542

The CCFL variable was added to the preliminary models, giving a negative effect in both species. The next graph shows the influence of CCFL in the 5-year diameter growth by species. The behavior was very similar in all three species, but the Douglas-fir is distributed more evenly across the range in CCFL. Ponderosa pine has a normal distribution up to the CCFL value of 50%. Above 50% ponderosa pine is almost absent. Its lower shade tolerance is quite evident from this trend. Atzet (1981) suggested that shelterwood canopies with 50-60 percent crown cover can still provide 20 percent of full sunlight and that perhaps only ponderosa pine will have trouble surviving. This variable provides a different value between species that did BA.

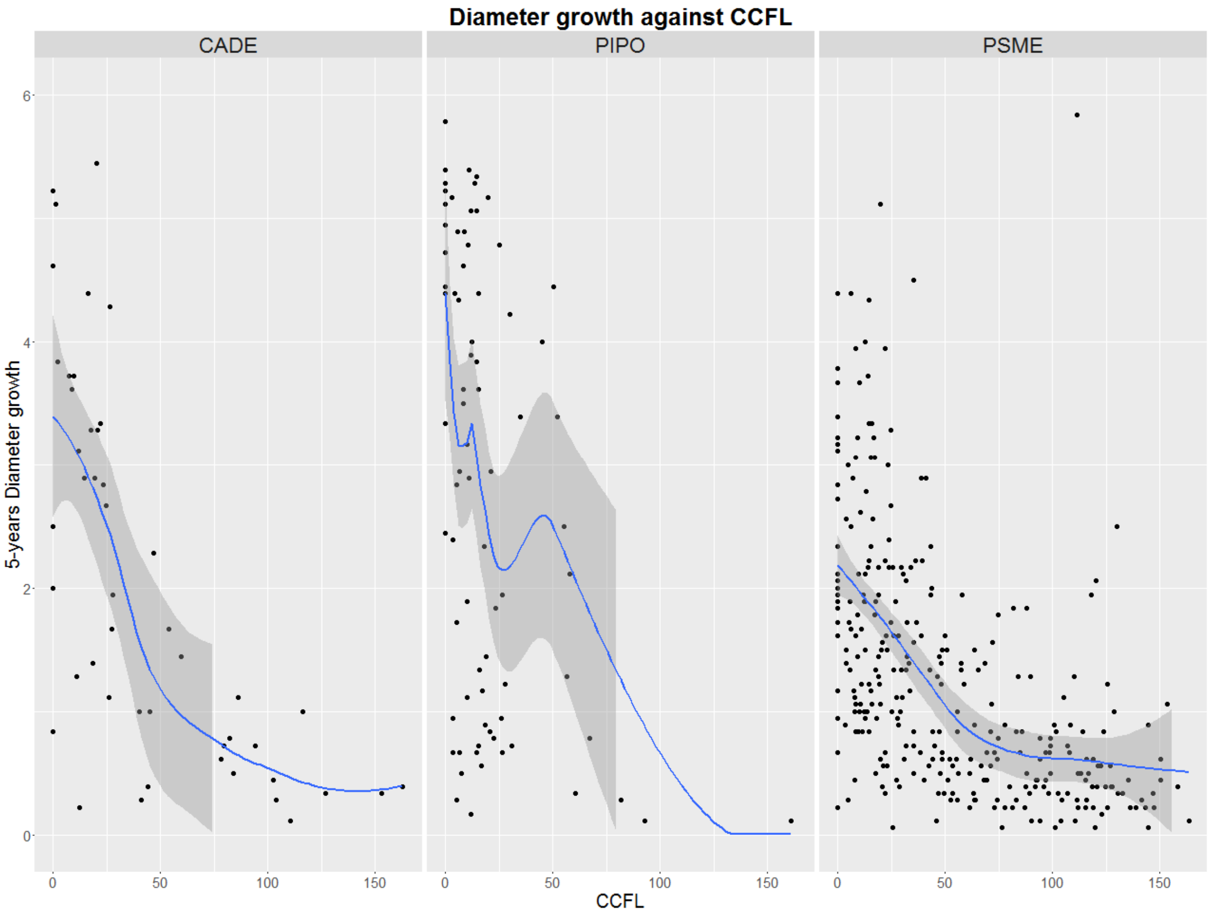

Figure 12: Diameter growth against the CCFL for the tree major species.

MODEL 2DF:

	Estimate	**STD error**	**T value**	**P- value**	**Vif**
Intercept	4.1790	1.4468	2.89	0.004147	
Ln ((CR+0.2)/1.2)	1.6170	0.1107	14.61	< 2e-16 ***	1.69
Dbh^2	0.0048	0.0009	5.28	2.5e-107***	1.24
Ln (SI – 4.5)	-0.9799	0.4223	-2.32	0.0298	1.22
CCFL	-0.0033	0.0009	-3.71	0.000245	1.74

Residual standard error	0.5269
Degrees of freedom	306
F-statistic	158.3
R^2**Adjusted**	0.67
MSE	0.273125

MODEL 1PP:

	Estimate	**STD error**	**T value**	**P- value**	**Vif**
Intercept	1.0350	0.1403	7.38	2.53e-10 ***	
Ln ((CR+0.2)/1.2)	1.8791	0.1338	14.04	< 2e-16 ***	1.59
Ln(Dbh+1)	0.3238	0.0721	4.49	2.72e-05 ***	1.4
GP4	-0.7035	0.1258	-5.59	4.03e-07 ***	1.45
CCFL	-0.0035	0.00169	-2.04	0.0447 *	1.23

Residual standard error	0.2955
Degrees of freedom	70
F-statistic	174.5
R^2Adjusted	**0.90**
MSE	0.08

In model [3DF] BAL was added to the model, with a negative effect on the diameter growth. Model [4DF] shows the effect of simultaneous addition of CCFL and the BAL. Because the two variables are strongly correlated, only one or the other variable adds predicted power to the model. The model with CCFL has a smaller mean squared error than the model with BAL, but the difference between the two models was small.

MODEL 3DF:

	Estimate	**STD error**	**T value**	**P- value**	**Vif**
Intercept	4.307818	1.4557135	2.959	0.00332	
Ln ((CR+0.2)/1.2)	1.6784	0.1062	15.80	< 2e-16 ***	1.54
Dbh^2	0.0056	0.0009	5.28	3.4e-16 ***	1.08
Ln (SI – 4.5)	-1.0398	0.4248	-2.45	0.01495***	1.22
$BAL^2/Ln(Dbh+5)$	-0.0082	0.0026	-3.21	0.00145	1.37

Residual standard error	0.5297
Degrees of freedom	306
F-statistic	155.7
R^2**Adjusted**	0.67
MSE	0.276105

MODEL 4DF:

	Estimate	**STD error**	**T value**	**P- value**	**Vif**
Intercept	3.534416	1.534426	2.303	0.022	
Ln ((CR+0.2)/1.2)	1.6744	0.1138	14.71	< 2e-16 ***	1.63
Dbh^2	0.0065	0.0012	5.26	2.9e-10***	1.19
Ln (SI – 4.5)	-0.7911	0.4482	-1.77	0.0787$^{.}$	1.22
$BAL^2/Ln(Dbh+5)$	-0.0035	0.0018	-1.88	0.061$^{.}$	6.27
CCFL	0.0005	0.0051	0.10	0.9177	5.23

Residual standard error	0.5254
Degrees of freedom	275
F-statistic	112.2
R^2**Adjusted**	0.67
MSE	0.270119

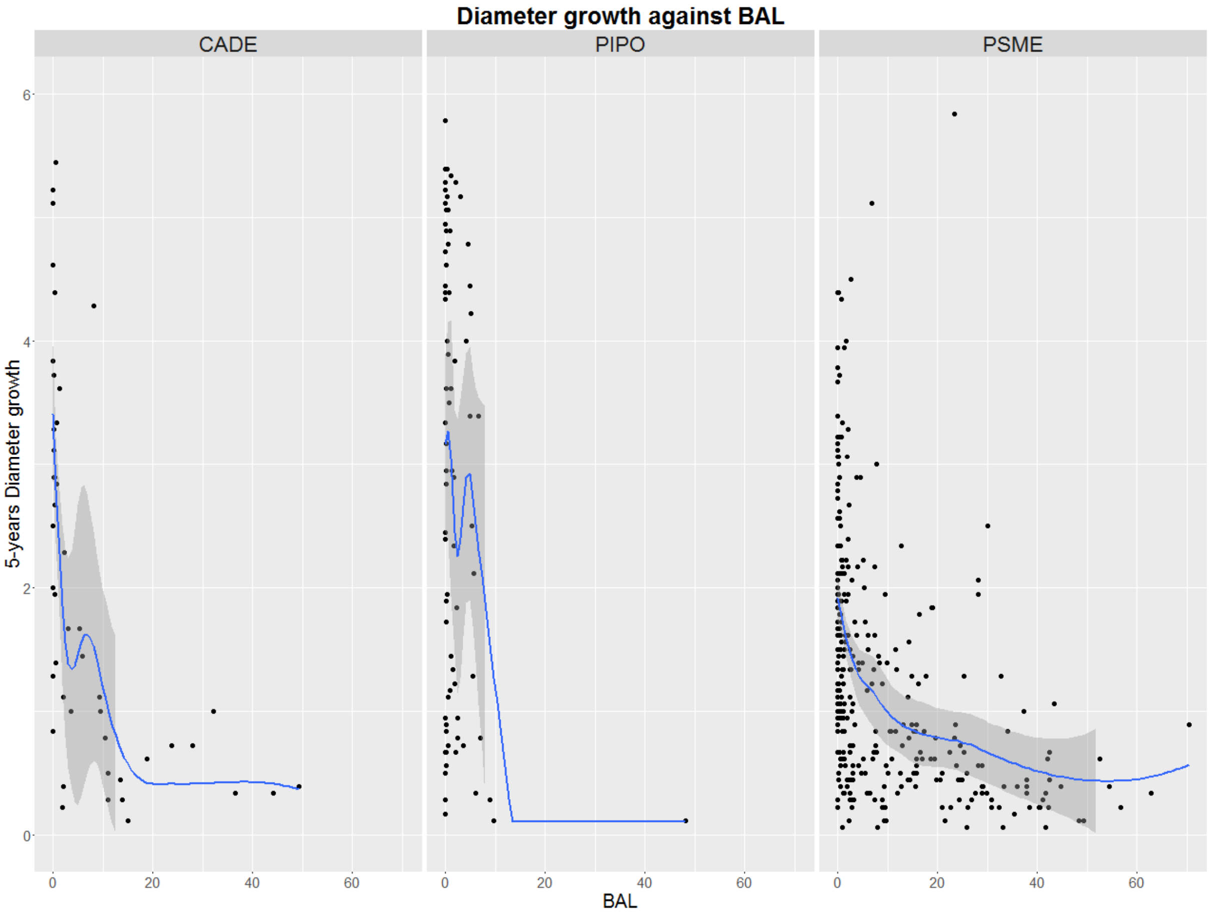

Figure 13: Diameter growth against the BAL for the tree species.

Finally, total basal area per subplot was added to study the effect of local stand density in the two species, resulting in a negative effect from both, but with a p-value>0.05.

MODEL 5DF:

	Estimate	**STD error**	**T value**	**P- value**	**Vif**
Intercept	4.351745	1.4767101	2.947	0.00346	
Ln ((CR+0.2)/1.2)	1.7213	0.1134	15.18	< 2e-16 ***	1.72
Dbh^{2}	0.0068	0.0009	7.46	8.78e-13***	1.17
Ln (SI – 4.5)	-1.0340	0.4300	-2.40	0.01679*	1.22
BAsubplot^0.5	-0.0755	0.0419	-1801.00	0.07272$^{\cdot}$	1.5

Residual standard error	0.5358

Degrees of freedom	306
F-statistic	150.5
R^{2}**Adjusted**	0.66
MSE	0.282427

MODEL 1PP:

	Estimate	**STD error**	**T value**	**P- value**	**Vif**
Intercept	0.9730	0.1227	7.97	2.72e-11 ***	
Ln ((CR+0.2)/1.2)	1.8537	0.1299	14.27	< 2e-16 ***	1.59
Ln(Dbh+1)	0.3742	0.0688	5.44	7.65e-07 ***	1.4
GP4	-0.7209	0.1171	-6.15	4.37e-08 ***	1.45
BAL^{2}*/Ln(Dbh+5)*	-0.0068	0.002486	-2.73	0.0081 **	1.23
BAsubplot^0.5	-0.020533	0.014059	-1.461	0.1487	1.1

Residual standard error	0.2857
Degrees of freedom	70
F-statistic	150.7
R^{2}Adjusted	**0.90**
MSE	0.0751

The last two models were developed for Incense cedar. Crown ratio and CCFL were the most important variables. Total basal area and site index imposed a negative on diameter increment, as was the case in the other species.

MODEL 1/C:

	Estimate	**STD error**	**T value**	**P- value**	**Vif**
Intercept	6.6338	2.6338	2.51	0.0160 *	
LnCR	1.3803	0.2872	4.81	2.09e-05 ***	3.00
Dln	0.5778	0.1284	4.50	5.49e-05 ***	1.21
Basub^0.5	-0.2595	0.1098	-2.36	0.0229 *	2.91
Ln SI	-1.7755	0.8005	-2.22	0.0321 *	2.29

Residual standar error	0.4436
Degrees of freedom	41

F-statistic	44.05
R^2**Adjusted**	0.80
MSE	0.175

MODEL 2/C:

	Estimate	**STD error**	**T value**	**P- value**	**Vif**
Intercept	9.3135	2.8343	4.27	0.000119 ***	
CCFL	-0.0084	0.0017	-5.08	9.05e-06 ***	1.8372
LnCR	0.6353	0.2187	2.91	0.005954 **	2.62
LnSI	-2.4317	0.6573	-3.70	0.000649 ***	2.37

Residual standar error	0.3486
Degrees of freedom	40
F-statistic	77.3
R^2**Adjusted**	0.84
MSE	0.179

This study has helped improve knowledge about the growth dynamics of these forest types. Although the attempt to include the aspect and slope in the model was not successful, we could observe certain trends. The presence of madrone was greater than it was believed at first. The madrone that regenerates well in these sites could help regeneration of both shade tolerant and intolerant species. Rodriguez García *et al.* (2011) studied the seedling emergence, survival and early growth of the Mediterranean conifer Maritine pine (*Pinus pinaster* Ait.) under different canopy cover conditions. Their results suggested that seedling of shade-intolerant species may require overstory cover to establish succesfully. The seedling mortality under open canopy conditions was greater than under close canopy. In our case, the greater leaf area index of madrone could help seedlings survive in these harsh sites more efficently than the conifer overstory. Amaranthus and Perry (1989) researched the influence of madrone on soil and Douglas-fir seedling growth. Their results suggest that the madrone imposes a biological pattern on soils that stimulates Douglas-fir growth and survival.The effect of madrone could be a good topic for future research, to development a special mixed species silviculture for these sites. `

CONCLUSION

6. CONCLUSION

- The crown ratio variable was the best predictor for diameter increment in all species examined. Crown ratio can represent vigor, photosynthetic capacity, and and local social status of the tree.

- The crown competition factor could be a very good variable to implement in subsequent models as expression of competition in the plots, because it includes the unique crown dimensions of species.

- The schlerophyllous madrone tree, with its everygreen leaves and moderaterly dense leaf area could provide very good protection in the early phase of tree establishment and growth on this sites. However, continued retention of this species in the stand results in an unfavorable H/D ratio because of its light interception.

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APPENDIX I

SITE INDEX IMPLIED BY INITIAL HEIGHT IN 2005

AND SUBSEQUENT 9-YR HEIGHT GROWTH

This APPENDIX documents the procedure taken to estimate potential height growth for understory trees on the southwestern Oregon shelterwood-with-reserves stands that were sampled in 2005 and re-sampled in 2014.

The fundamental problem is that the residual trees do not represent true site trees, and therefore none of the overstory sample trees were cored to determine total age in 2005. However, some effective approaches for modeling height growth start with the potential height growth of site trees and then scale down this expected maximum height growth based on stand density and relative position of the tree in the stand. For this reason, we decided to proceed with estimating site index from the data available, realizing that it will almost certainly be an underestimate. However, the primary objective is to test how the understory trees respond to local (plot-level) and wider (stand-level) stand structure.

Because observed height growth (9-yr growth period in this study) and the initial height of the tree in 2005 imply a site index, the site index or height growth curves of choice can be solved numerically to estimate this site index. For the purposes of this study, we chose to use Bruce's (1981) top height growth curves.

The SAS code below provides the general approach of starting with a relatively low site index (30 feet at 50 years), solves for implied age for that site index and tree height in 2005, and then compares the implied height growth to observed height growth iteratively until a match is arrived at between the estimated site index, height in 2005, and observed 9-yr height growth.

The site index of each of the six stands was computed in three alternative ways: 1) based on the highest estimated site index; 2) based on the average of the TWO highest estimated site indices; and 3) based on the average of the THREE highest estimated site indices. In stand AS1, the trees with the two highest site indices were *Abiesgrandis* and the tree with the third highest site index was *Pinuslambertiana*. In all other plots except MG, where the tree with the third largest site index was *Pinus ponderosa*, the trees with the three highest site indices were *Pseudotsugamenziesii*. The intent is to reference potential height growth of all species to *Pseudotsugamenziesii*. This potential provides a uniform basis to compare the species, and is justified in part by the fact that the potential height growth of the two most common understory species, *Pseudotsugamenziesii* and*Pinusponderosa* is quite similar (Hann and Scrivani 1987).

Core SAS code

```
datashelt_site;
set shelter;
/*  Designate the length of the growth period as 9 years  */
```

```
y=9;
/*  Solve for Bruce's site index that implies the observed 9-yr growth rate  */
itera=0;
ksi = 30.0;;
doi=1to4;
        dowhile(bruce<0);
                itera=itera+1;
ksi = ksi + 100.0/10.0**i;
 b3=-0.447762 - 0.894427*(ksi/100) + 0.793548*(ksi/100)**2- 0.171666*(ksi/100)**3;
b2=log(4.5/ksi)/((13.25-ksi/20)**b3 - (63.25-ksi/20)**b3);
                z1a=log(h05/ksi)/b2;
                 z1b=(63.25-ksi/20)**b3;
                 z1=z1a+z1b;
                 z2a=log(h14/ksi)/b2;
                 z2b=(63.25-ksi/20)**b3;
                 z2=z2a+z2b;
                if z1>0 and z2>0thendo;
a1=z1**(1/b3);
                  a2=z2**(1/b3);
bruce = y - (a2-a1);
end;
end;
ksi = ksi - 100.0/10.0**i;
bruce=-1;
end;
Bruce_si=round(ksi,0.1);
/* Compute growth effective age */
b3=-0.447762 - 0.894427*(Bruce_si/100) + 0.793548*(Bruce_si/100)**2- 0.171666*(Bruce_si/100)**3;
b2=log(4.5/Bruce_si)/((13.25-Bruce_si/20)**b3 - (63.25-Bruce_si/20)**b3);
gea = Bruce_si/20 - 13.25 + ( log(h05/Bruce_si)/b2 + (63.25-Bruce_si/20)**b3 )**(1/b3);
/* Compute top height growth (potential height growth) */
     h=h05;
do j=1to9;
        dhtop = h*(b2*b3)*(gea + 13.25 - Bruce_si/20)**(b2-1);
          h=h+dhtop;
        gea=gea+1;
end;
ph14=h;
keep stand tree sppspncchcr d05 d14 h05 h14 ph14 dh relhtgrgeaiteraBruce_si ;
run;
```

Resulting site indices (feet at 50 years)

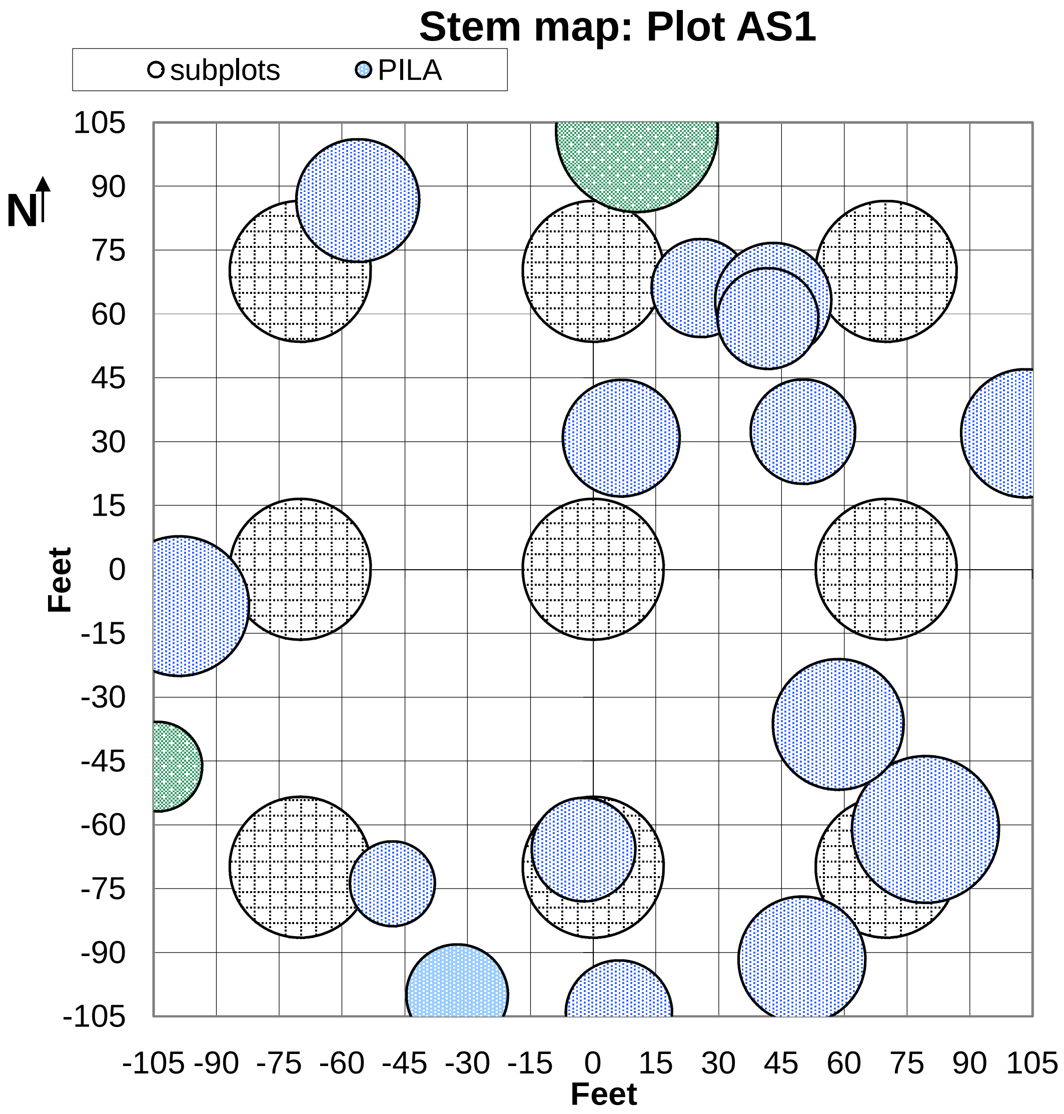
Stand	site1	sp1	site2	site3
AS1	110	ABGR	103	100
AS3	154	PSME	128	118
DC	123	PSME	117	115
GP4	138	PSME	129	121
MG	135	PSME	131	126

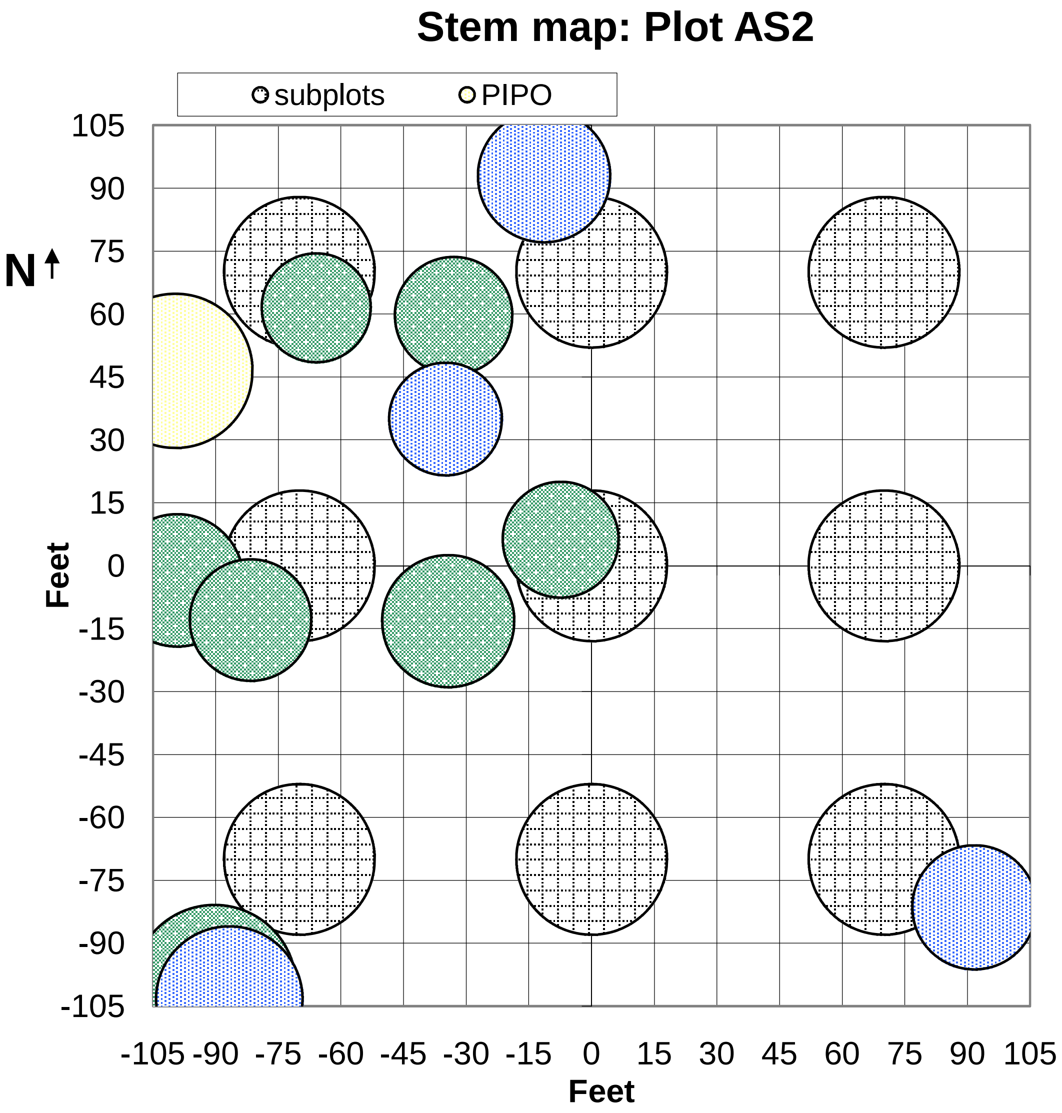
MG2	124	PSME	114	110

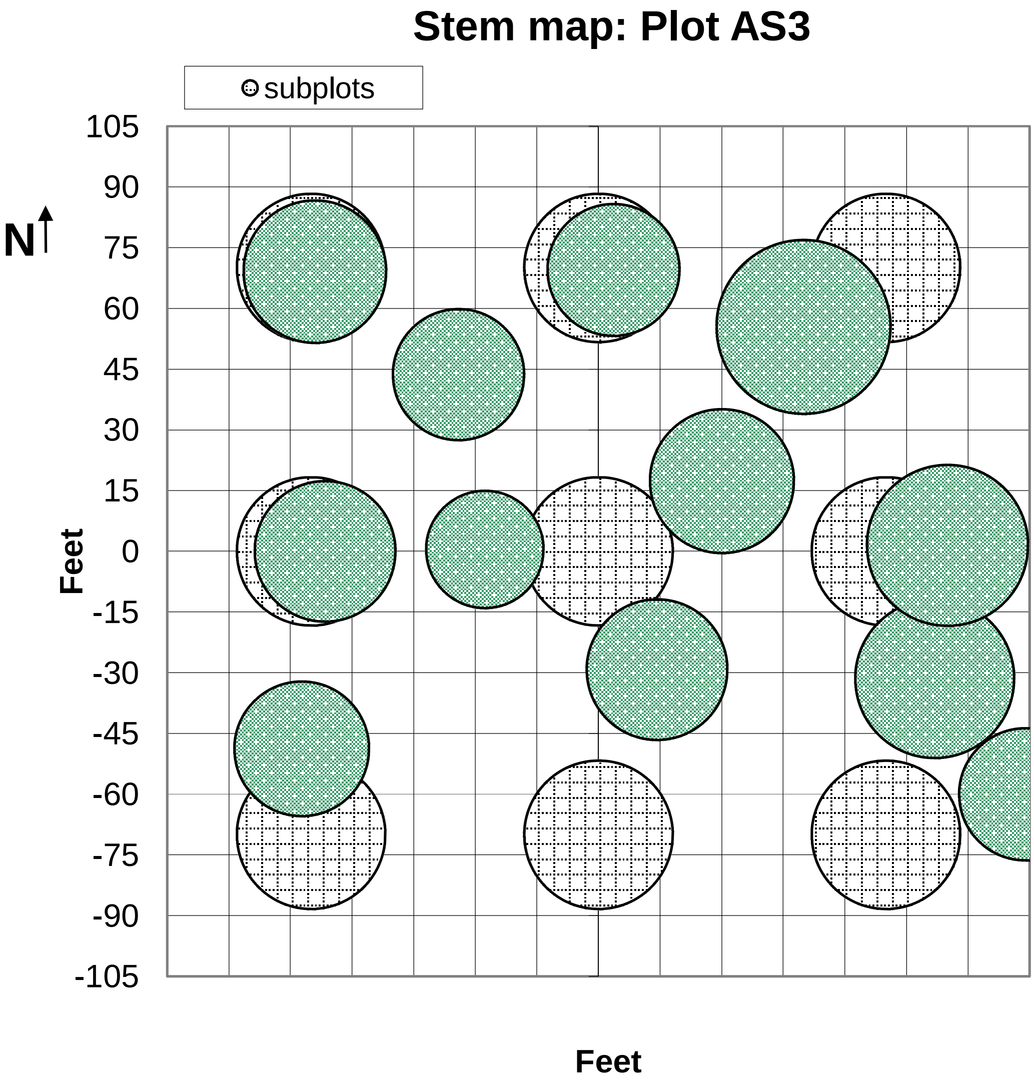
All three site trees per stand (Bruce's site index, feet at 50 years)

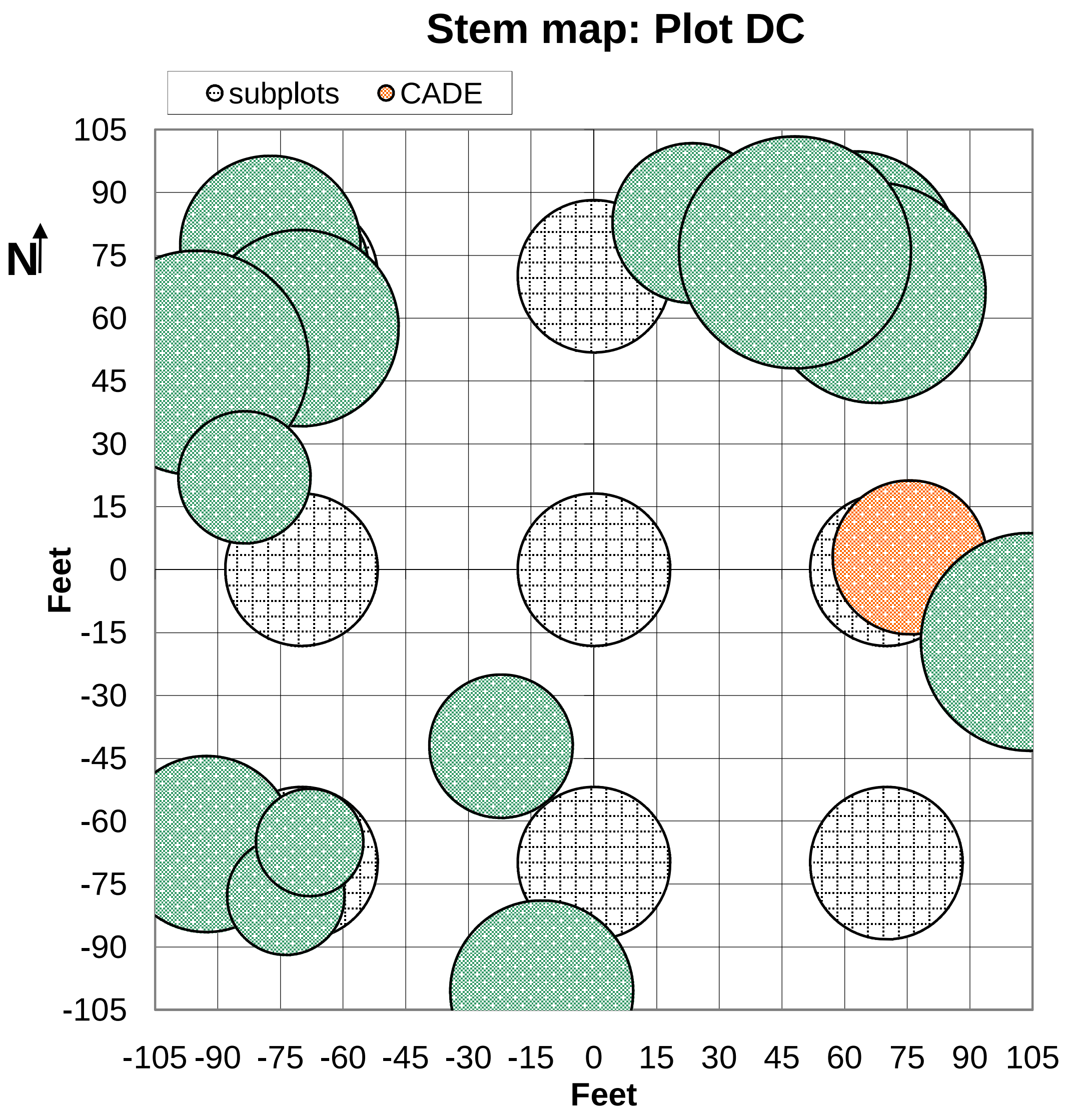
Stand	Tree	Spp	Bruce_si	siterank
AS1	8	ABGR	110	1
AS1	23	ABGR	96	2
AS1	27	PILA	95	3
AS3	39	PSME	154	1
AS3	35	PSME	103	2
AS3	40	PSME	97	3
DC	53	PSME	123	1
DC	49	PSME	112	2
DC	50	PSME	111	3
GP4	61	PSME	138	1
GP4	60	PSME	120	2
GP4	55	PSME	106	3
MG	80	PSME	135	1
MG	76	PSME	127	2
MG	65	PIPO	115	3
MG2	100	PSME	124	1
MG2	109	PSME	104	2
MG2	95	PSME	102	3

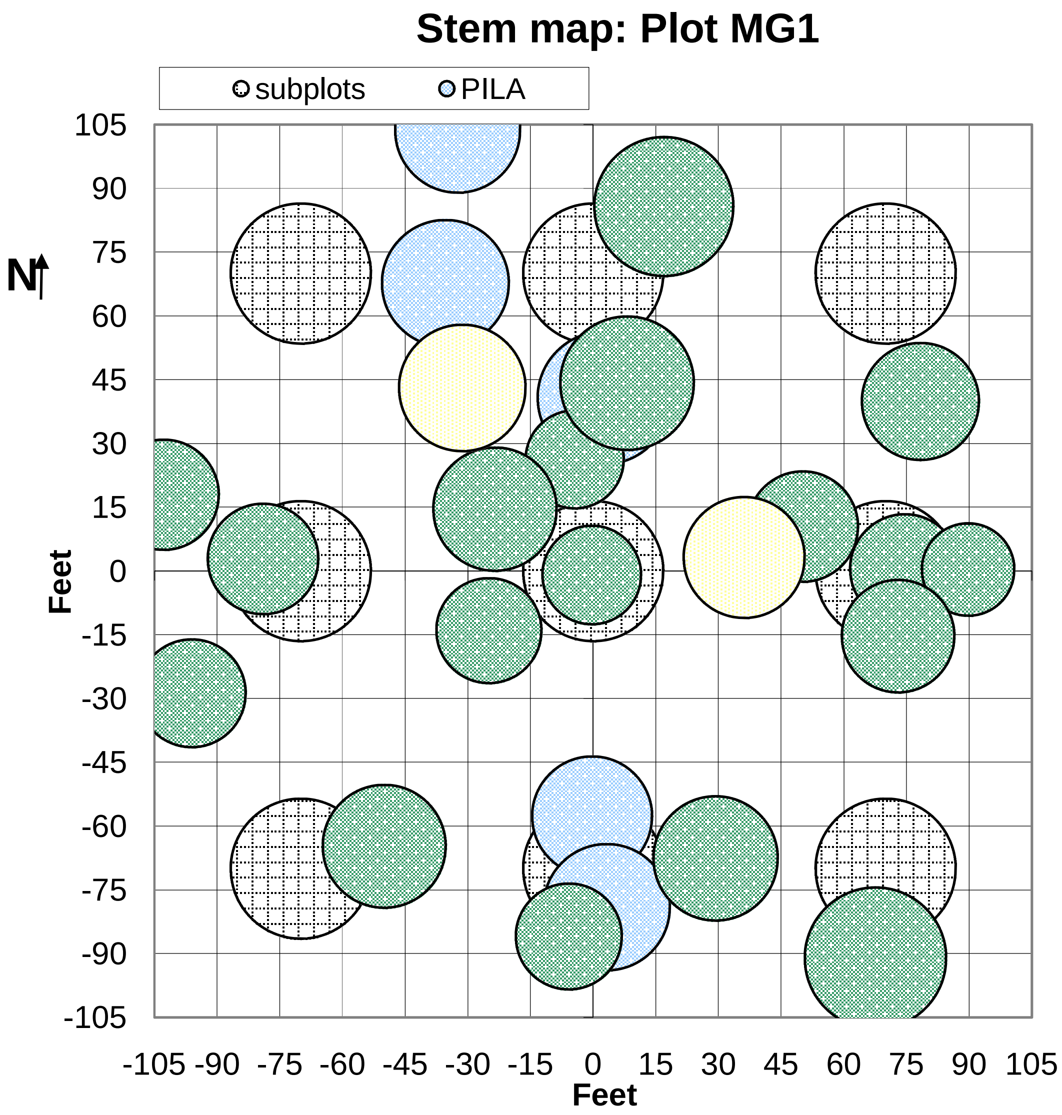
APPENDIX II: LARGE CROWN WIDHT MAPPING

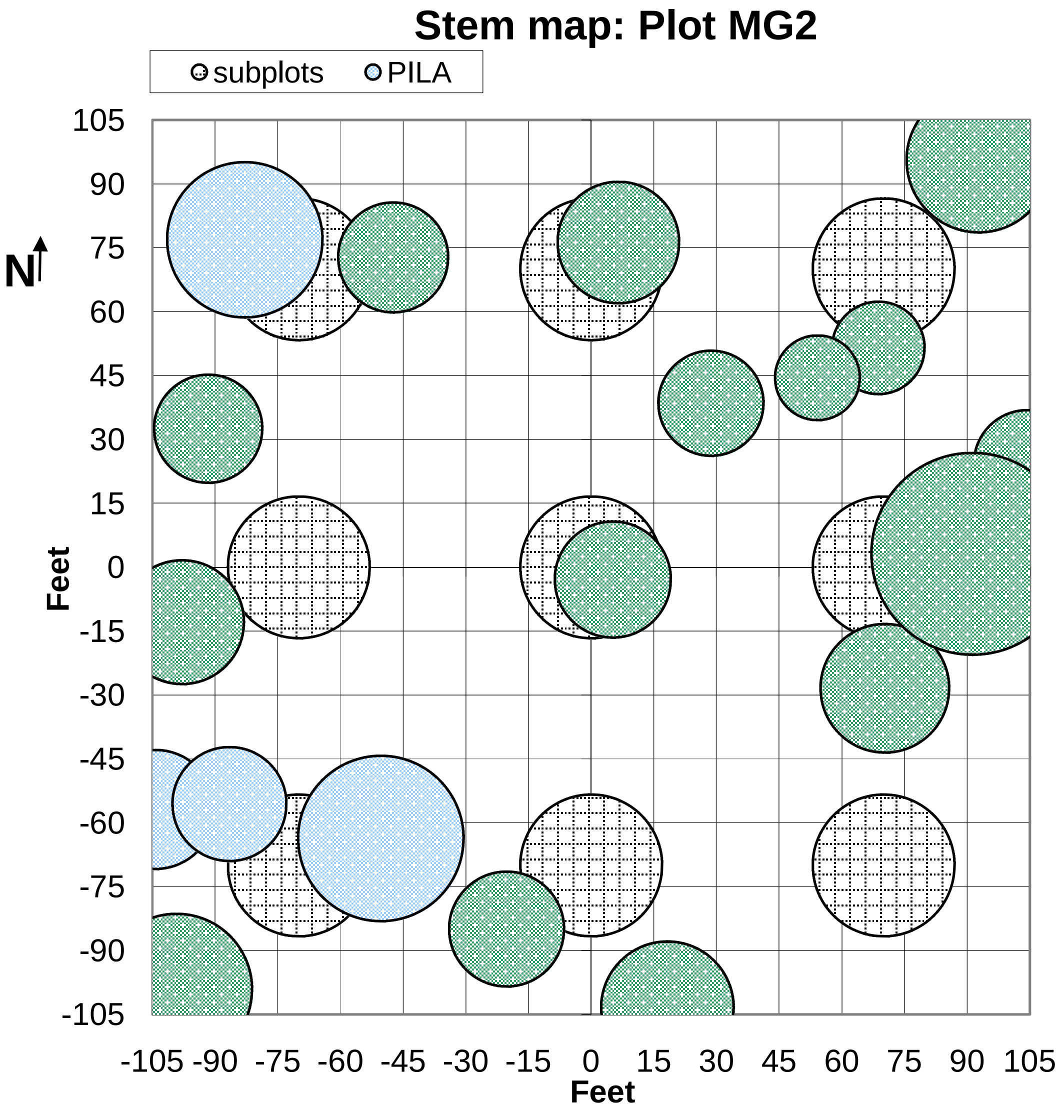


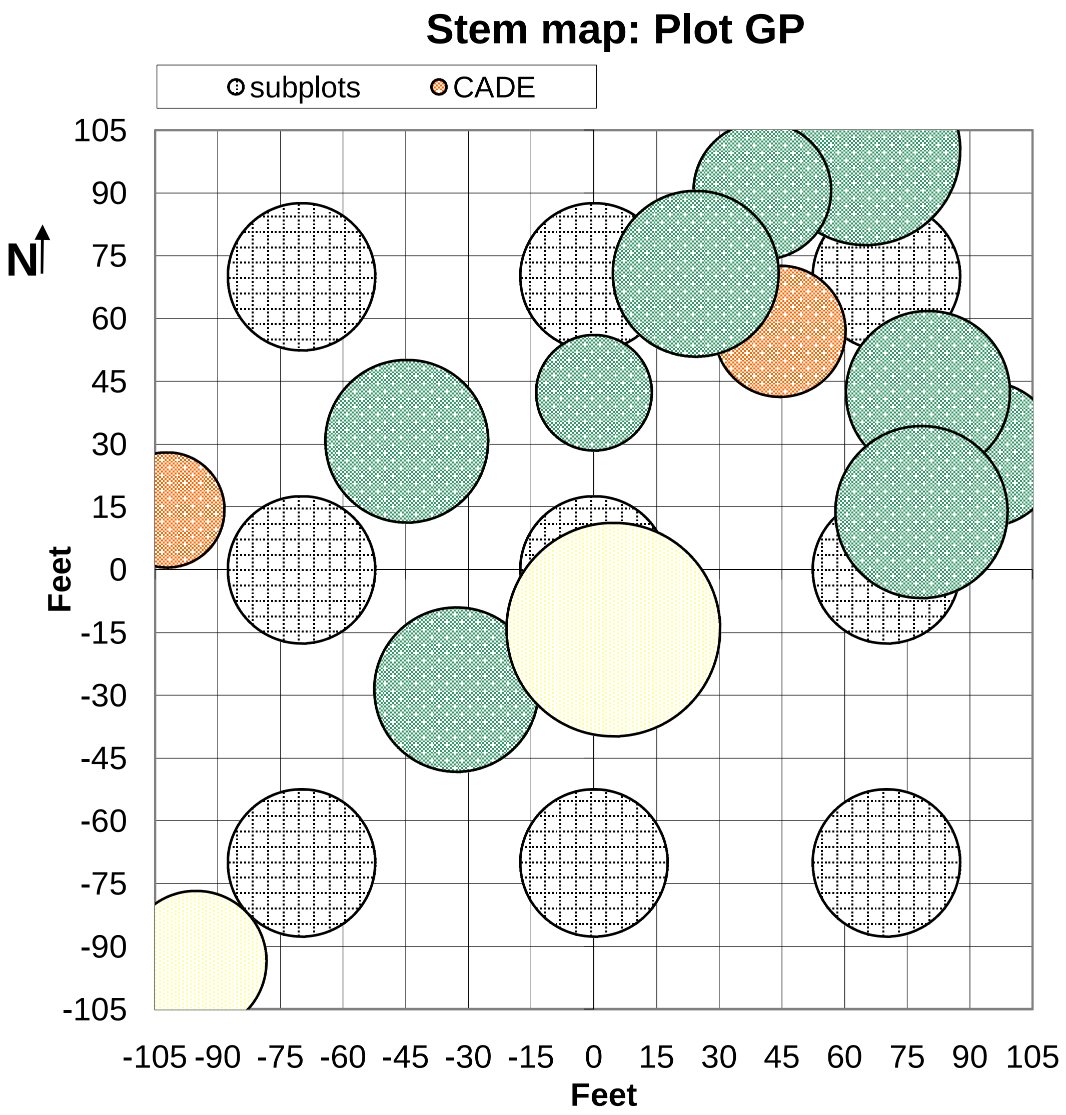

Stem map: Plot AS2
subplots
PIPO
N
Feet
105
90
75
60
45
30
15
0
-15
-30
-45
-60
-75
-90
-105
-105
-90
-75
-60
-45
-30
-15
0
15
30
45
60
75
90
105
Feet


Stem map: Plot AS3
subplots
N
105
90
75
60
45
30
15
0
-15
-30
-45
-60
-75
-90
-105
Feet
Feet


Stem map: Plot DC
subplots
CADE
N
105
90
75
60
45
30
15
0
-15
-30
-45
-60
-75
-90
-105
Feet
-105 -90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90 105
Feet


Stem map: Plot MG1
subplots
PILA
N
Feet
105
90
75
60
45
30
15
0
-15
-30
-45
-60
-75
-90
-105
-105 -90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90 105
Feet

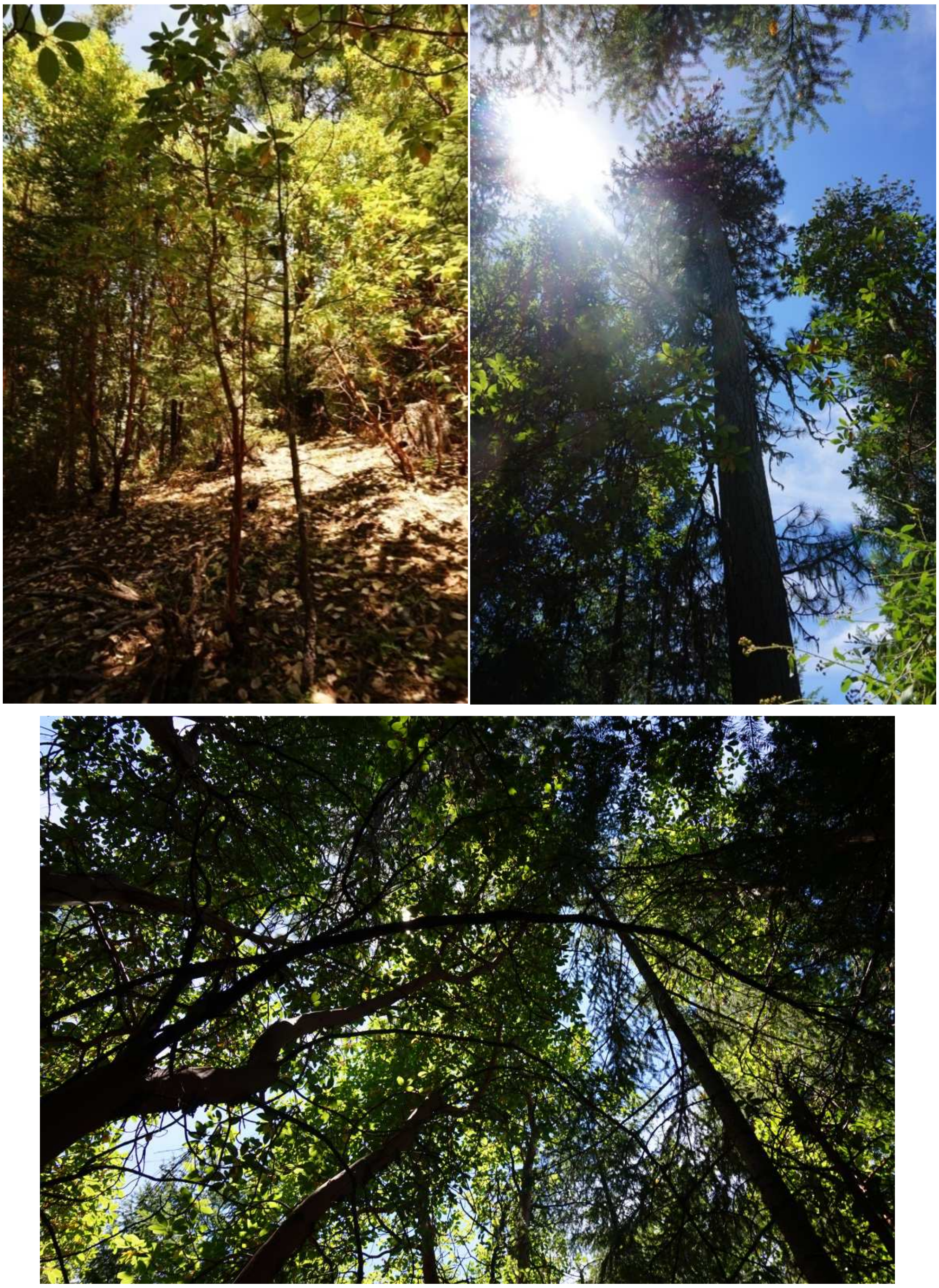

Stem map: Plot MG2
subplots
PILA
N
Feet
105
90
75
60
45
30
15
0
-15
-30
-45
-60
-75
-90
-105
-105 -90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90 105
Feet


Stem map: Plot GP
subplots
CADE
N
105
90
75
60
45
30
15
0
-15
-30
-45
-60
-75
-90
-105
Feet
-105 -90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90 105
Feet

APPENDIX III: PICTURES

Picture 1: Plot MG. Understory composed of madrone, Douglas fir, and ponderosa pine.

Picture 2: Plot MG.



Picture 3: Plot GP. The madrone cover captures a large portion of incident light.

Picture 4: Plot GP. Overstory trees of Douglas-fir.

Picture 5: Plot GP. Subplot example withDouglas-fir regeneration.

Picture 6: Plot GP. Another example of a subplot with high density.

APPENDIX IV: R code

```
#### Estimate variables ####
data2<-read.csv("shelterwood.csv", header=TRUE, dec=".")
setwd('C:/Users/RAMIRO/Documents')

##Basal area
data2$G.05<-data2$Dbh05^2/4*pi*data2$ef/10000
data2$G.05sub<-data2$Dbh05^2/4*pi*data2$efsub/10000

###Variables level tree ###
require(dplyr)
data2<-mutate(data2, crown_lenght=Ht14-hcb, crown_ratio= crown_lenght/100)
data2<-mutate(data2, D_H05=Dbh05/Ht05, H_D05=Ht05/Dbh05)

## Variable Maximun Crown Widht ##
dataPSME<- filter(data2, Spp=="PSME")
dataPSME<-mutate(dataPSME, mcw05=4.6336+1.6078*Dbh05-9.6250^-3*Dbh05^2)
dataABGR<- filter(data2, Spp=="ABGR")
dataABGR<-mutate(dataABGR, mcw05=6.1880+1.0069*Dbh05)
dataPIPO<-filter(data2, Spp=="PIPO")
dataPIPO<-mutate(dataPIPO, mcw05=3.4835+ 1.3430*Dbh05-8.2544^-3*Dbh05^2)
dataCADE<-filter(data2, Spp=="CADE")
dataCADE<-mutate(dataCADE, mcw05=3.2837+ 1.2031*Dbh05-7.1858^-3*Dbh05^2)
dataPILA<-filter(data2, Spp=="PILA")
dataPILA<-mutate(dataPILA, mcw05=4.6601+ 1.0702*Dbh05)
dataQUGA<-filter(data2, Spp=="QUGA")
dataQUGA<-mutate(dataQUGA, mcw05=3.0786+ 1.9242*Dbh05)
dataARME<-filter(data2, Spp=="ARME")
dataARME<-mutate(dataARME, mcw05=3.4299+ 1.3532*Dbh05)
dataCACH<-filter(data2, Spp=="CACH")
dataCACH<-mutate(dataCACH, mcw05=0)
dataPICO<-filter(data2, Spp=="PICO")
dataPICO<-mutate(dataPICO, mcw05=0)
data2<-rbind(dataABGR, dataPSME, dataPIPO, dataPILA, dataCADE, dataARME, dataQUGA,
dataPICO, dataCACH)
### Maximun Crown Area ###
data2<-mutate(data2, cpa05=pi/4*mcw05^2)

### Crown competition factor ###
data2<-mutate(data2, ccf05=100*ef*cpa05/10000)
data2<-mutate(data2, ccf05sub=100*efsub*cpa05/10000)

### Calcular BAL ###
data2<-arrange(data2, desc(Stand,Sub,Dbh14))
data2<- data2 %>% arrange(Stand, desc(Dbh05)) %>% group_by(Stand) %>%
        mutate(BAL05 = cumsum(G.05) - G.05)
data2<- data2 %>% arrange(Stand, desc(Dbh05)) %>% group_by(Stand,Sub) %>%
        mutate(BAL05sub = cumsum(G.05) - G.05)
## Calcular CCFL ###
```

```
data2<- data2 %>% arrange(Stand, desc(Dbh05)) %>% group_by(Stand) %>% mutate(CCFL05 =
cumsum(ccf05) - ccf05)
data2<-   data2   %>%   arrange(Stand,   desc(Dbh05))   %>%   group_by(Stand,Sub)   %>%
mutate(CCFL05sub = cumsum(ccf05) - ccf05)

#### Variables level plot ####
datos_Stand05<-  summarise(group_by(data3, Stand),
                         BA_plot05 = sum(G.05,na.rm = T),
                         CCF_plot05= sum(ccf05,na.rm = T))
#### Variables level subplot ####
sub05<-  summarise(group_by(data4, Stand, Sub),#perfecto
                 BA_subplot05 = sum(G.05,na.rm = T),
                 CCF_subplot05= sum(ccf05,na.rm = T))
tabla_unida<-merge(sub05, datos_Stand05, by=c('Stand'))
data2<-merge(tabla_unida, data2, by=c('Stand','Sub'))

##Elevation
data<-mutate(data, elevation=0)
elevation<-vector(length=length(data$Stand))
for(i in 1:length(data$Stand)) {
  data$elevation[i] <- if (data$Stand[i] == "AS1"|data$Stand[i] == "AS2") 1530
  else if (data$Stand[i] == "AS3") 1430
  else if (data$Stand[i] == "DC") 1147
  else if (data$Stand[i] == "GP4") 1003
  else if (data$Stand[i] == "MG"|data$Stand[i] == "MG2") 417
  else 0 }
summary(data$elevation)

##Aspect
data<-mutate(data, aspect=0)
aspect<-vector(length=length(data$Stand))
for(i in 1:length(data$Stand)) {
  data$aspect[i] <- if (data$Stand[i] == "AS1"|data$Stand[i] == "AS2") 225
  else if (data$Stand[i] == "AS3") 214
  else if (data$Stand[i] == "DC") 309
  else if (data$Stand[i] == "GP4") 122
  else if (data$Stand[i] == "MG"|data$Stand[i] == "MG2") 274
  else 3}

##Slope
data<-mutate(data, slope=0)
slope<-vector(length=length(data$Stand))
for(i in 1:length(data$Stand)) {
  data$slope[i] <- if (data$Stand[i] == "AS1"|data$Stand[i] == "AS2") 10
  else if (data$Stand[i] == "AS3") 27
  else if (data$Stand[i] == "DC") 17
  else if (data$Stand[i] == "GP4") 59
  else if (data$Stand[i] == "MG"|data$Stand[i] == "MG2") 49
  else 3}
data<-mutate(data, rad.asp=aspect*pi/180)
data<-mutate(data, slope.cos.aspect=slope/100*cos(rad.asp))
data<-mutate(data, slope.sen.aspect=slope/100*sin(rad.asp))
```

```
#####Example Analisis#####
library(psych)
pairs.panels(PSME[c(4,5,6,7,8,9,10)],main="PSME understory")
library(leaps)
lm1 <- regsubsets(X.DBH ~ ., data = PSME1,  nvmax = 5, nbest = 2,
           method = "backward")
fit <- lm(log(dgr ~ ., data=mydata)
summary(fit) # show results
coefficients(fit) # model coefficients
confint(fit, level=0.95) # CIs for model parameters
fitted(fit) # predicted values
residuals(fit) # residuals
anova(fit) # anova table
vcov(fit) # covariance matrix for model parameters
influence(fit) # regression diagnostics
# diagnostic plots
layout(matrix(c(1,2,3,4),2,2)) # optional 4 graphs/page
plot(fit)
# compare models
fit1 <- lm(y ~ x1 + x2 + x3 + x4, data=mydata)
fit2 <- lm(y ~ x1 + x2)
anova(fit1, fit2)

#####Exemple graphics#####
require(ggplot2)
ggplot(data_modelo)+aes(x=ccflsub_over,y=dgr)+facet_grid(. ~ Spp)+
  geom_point(size=2)+
  geom_smooth(method='loess',se=T,size=0.9,na.rm=T)+ylim(y=c(0,6))+
  labs   (title   =   "Diameter   growth   against   CCFL",y=   "5-years   Diameter
growth",x="CCFL",legend.title="Stand")
```