

An Examination of Stand Attributes and the Presence of English holly in a Pacific Northwest
Forest, Grays Harbor County, Wash.

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Glossary of Forestry Terms

barochory. A method of seed dispersal that uses solely gravity, i.e., falling beneath the mother tree.

basal area. A measurement expressed in relation to a tree's diameter at breast height. An increase in tree size or the number of trees found on an acre translates into an increase of basal area. Expressed as ft^2 .

CVTS. A tree's cubic volume including top and stump.

downed woody debris (DWD). Woody debris, such as branches or logs, found on the forest floor.

endozoochory. A method of seed dispersal that has animals such as birds, rodents, or ungulates consuming the seeds and depositing them elsewhere.

primary control. A known fixed point on the landscape that can be identified using an aerial map. Used as the starting location for placing plots using secondary control.

quadratic mean diameter (QMD). - A measurement of the average tree size within the stand.

secondary control. The use of tape measurements, compass headings, GPS, or pacing to place plots.

stand density index (SDI). - A measurement of the number of trees per acre and QMD. A high SDI indicates a crowded stand.

relative density (RD). - A measurement of the number of trees per acre and the average tree size expressed in volume.

volume. A measurement expressed in relation to a tree's height and diameter. Expressed as ft^3 .

Plants referenced in paper

For a complete list of plants observed in the research area, see Appendix 4.

Scientific Name	Common Name
<i>Acer circinatum</i>	vine maple
<i>Alnus rubra</i>	red alder
<i>Gaultheria shallon</i>	salal
<i>Ilex aquifolium</i>	English holly
<i>Lysichiton americanum</i>	skunk cabbage
<i>Metasequoia glyptostroboides</i>	dawn redwood* tree was planted on research area by a property owner
<i>Oplopanax horridum</i>	Devil's club
<i>Phalaris arundinacea</i>	reed canary grass
<i>Pinus contorta</i>	lodgepole pine tree was planted by a property owner
<i>Pinus ponderosa</i>	ponderosa pine tree was planted by a property owner
<i>Polystichum munitum</i>	sword fern
<i>Populus balsamifera</i>	black cottonwood
<i>Pseudotsuga menziesii</i>	Douglas-fir
<i>Rhamnus purshiana</i>	casara
<i>Rubus armeniacus</i>	Himalayan blackberry
<i>Rubus laciniatus</i>	evergreen blackberry
<i>Rubus spectabilis</i>	salmonberry

Salix

willow

Thuja plicata

western red cedar

Tsuga heterophylla

western hemlock

Abstract

English holly (*Ilex aquifolium*) is an ornamental favored by people who appreciate its wildlife benefits and traditional significance. Since its introduction into the Pacific Northwest over one hundred years ago, *Ilex* has escaped from cultivation and is increasingly found in natural areas such as national parks and forests that are far from an urban-rural interface. The presence of *Ilex* within these natural areas is disconcerting to natural resource managers and organizations because the plant is observed to out-compete native vegetation and resists attempts at its removal. While there are piecemeal efforts of identifying *Ilex*'s habitat, there has not been a systematic collection of data focused on that purpose. The purpose of this study was to identify the forest conditions under which *Ilex* is found and to determine if there are significant differences between plots where *Ilex* is present (*Ilex*-present plots) and where it is absent (*Ilex*-absent plots). The research site is located in Grays Harbor County in Washington State, and data collection occurred from June 2011–November 2012, on 200 plots placed throughout the stand stages found on the landscape. The results yielded a significant difference in basal area and the number of shrubby understory vegetation species between the *Ilex*-absent and *Ilex*-present plots. Downed woody debris (DWD) (0.5-1.9" in diameter) also proved significantly different between the two conditions, and the stand stages identified as being significant DWD were Understory Reinitiation and Late Initiation. The presence of reed canary grass and native grass could serve as an indicator for the absence of *Ilex* while other common PNW species such as sword fern or cascara serve as indicators of a favorable habitat. *Ilex*'s growth pattern of upright single stalk and multiple stalks upright and lying down was also found to be affected by SDI. While was found to *Ilex* appear in any stand stage, being linked with a high basal area this means that mature forests are particularly vulnerable to *Ilex* entering the stand and becoming established because this stage

has combination of a high SDI and light-rich conditions capable of supporting diverse understory vegetative species.

Introduction

Of the well-known introduced plant species from the English Isles, English holly (*Ilex aquifolium*) is likely the first species introduced to the western Pacific Northwest (PNW) (Washington, Oregon, northern California, and southern British Columbia); its introduction dates to 1874 (Brownell 1970). Though western PNW forests are quite unlike the European pine and deciduous forests of beech, oak, or alder where *Ilex* is native and found as an understory species (Peterken and Lloyd 1967; Arrieta and Suarez 2005), this plant readily adapted to the PNW's climate of mild winter and summer temperatures. *Ilex* is a dioecious evergreen plant (Figure 1) with a height reaching 25 m (75 ft) (Galle 1997). Just as western red cedar sprouts new shoots from branches lying on the ground, *Ilex* is also capable of sprouting from branches, creating a multi-stalked plant and suckering from its roots (Peterken and Lloyd 1967). Each plant has fibrous, deep roots, enabling the plant to obtain the nutrients and water necessary for survival in any growing condition (Figure 2). Peterken and Lloyd (1967) reported that “[i]n a closed, understory stand the horizontal spread of roots from an individual appeared approximately equal to the horizontal extent of its canopy.”

What is known about *Ilex*'s germination and growth rates is courtesy of orchardists, which may not translate to the growing conditions of a forest. Though Galle reports this plant is not adapted to poorly drained sites in the PNW (Galle 1997), Peterken and Lloyd (1967) reported *Ilex* growing in permanently water logged soils in England, and during the course of this study, *Ilex* plants are observed in areas classified as forested wetlands and riparian areas. This plant can grow in soils with a pH range of 5.5 to 7.0 (Galle 1997), which matches the range of soil pH of Pacific Northwest forests.

The primary dispersal methods of the seeds are through barochory, and endozoochory by birds and cattle but rodents have also been identified, though their frequency of predation is less

frequent compared to birds (Olmsted 2006; Zika 2010; Arrieta and Suarez 2005). Germination of seeds takes one to two years, and when deliberately planted, the seeds should be covered with a fine layer of peat or fine pine bark (Galle 1997). Under natural conditions, Peterken (1966) found that the mortality of seedlings was higher on sites containing a high litter fall, as litter was found to smother the seedlings. Other contributors to seedling death included browse, insufficient soil moisture, and deep shade (Peterken 1966). Deep shade leading to seedling mortality was also noted by Arrieta and Suarez's (2006) research in Spain.

Ilex does not readily establish but does become vigorous under the proper cultivated conditions (Galle 1997). Its average growth is 5-15 cm (2-6 in.) per year (Galle 1997). Under nursery conditions, young plants are planted outside when they reach 0.9-1.2 m (3-4 ft.), around three to four years old (Galle 1997). Though *Ilex* blooms in the springtime, the plants can also produce fall fruits (Figure 3, Galle 1997). Male seedlings produce flowers at three to four years old, while females reach maturation at six to eight years old. The ratio of male to female plants is observed to be about equal during the course of long-term studies (Galle 1997).

Today more than 90% of *Ilex* sold across the United States is grown in the PNW, and Washington State farms generate \$5 million dollars annually, providing employment and tax revenue. The trade group, the Northwest Holly Growers Association, promotes the holly industry within the PNW.

But *Ilex* also thrives outside of human cultivation and naturally-seeded plants are found in backyards, city parks, and natural areas. The *Ilex*'s success in naturally propagating on the landscape is unusual given that establishment and dispersion of a plant species outside of its native habitat usually ends in failure; of plants that immigrate into a new landscape, only a small fraction become a naturalized species, much less an invader (Mack et al. 2000). *Ilex* fits the

definition of a naturalized plant of the PNW by independently reproducing without assistance from humans (Pysek and Richardson 2006). Figure 4 shows the current distribution of *Ilex* within the Pacific Northwest.

Ilex's widespread dispersal, its competition with native vegetation, and the difficulties of eradicating the plant from a site once established (Figure 5 and 6) has prompted natural resource managers throughout the region to classify the plant as an invasive species. This plant is considered an invasive alien species in Canada (Hendrickson 2002), the State of California classifies the plant as "Moderate, Alert" (Cal-IPC 2006), and *Invasive Species in the Pacific Northwest* gives *Ilex* a "High" invasive threat (Olmsted 2006). However, the classification of *Ilex* as an invasive species is not without its controversy. *Ilex* growers challenge classifying this plant as invasive, because there is little scientific research justifying the label – a finding echoed by Aslan and Rejmanek (2010).

Removal of this plant from city forests, parks, and rural areas is the focus of many local government and nonprofit organizations and is not without a high cost. Seattle Public Utilities spent \$89,299 during 2007 – 2009 to eradicate *Ilex* at Lake Youngs (King County Proposal 2010).

While there are efforts to map the current distribution of *Ilex* in the region (King County Proposal 2010) or anticipate future spread (Jones et al 2010, Jones and Reichard 2009), these data do not fully document the stand conditions where *Ilex* is found or in the case of the dataset used in Jones and Reichard (2009), data collection occurred in areas readily accessible, i.e. near trails, rivers, or roads.

The purpose of this study is to compare the forest composition on plots where *Ilex* is absent with those where *Ilex* is present to determine if there are statistically significant

differences in forest condition. If it can be determined that certain stand stages or forest compositions are more conducive to *Ilex* germination, then these areas can be monitored as future germination sites and reduce the cost of eliminating the plant once it becomes established.

Methods

Study Site

Under normal circumstances, it is difficult to study an invasive species from the moment of its introduction due to technical and ethical reasons (Pysek and Richardson 2006); however, this study is located in an area when the planting of the first and only female *Ilex* is known. The disturbance history, such as logging, is also documented, and a variety of land uses are taking place on the landscape so data can be collected under a range of circumstances where *Ilex* is present (Mack et al 2000).

The research area is located in eastern Grays Harbor County, just outside the city limits of McCleary, Wash., within the *Tsuga heterophylla* zone (Franklin and Dyrness 1988) of Washington State and encompasses 344.90 acres (Figure 7). This acreage is owned by five private property owners: Port Blakely Tree Farms LP and four non-industrial private forest landowners (Figure 8).

The landscape contains stands in varying succession stages (Figure 9) – from Seeding/Grass to Late Initiation to Understory Reinitiation (Smith et al. 1997). These stands have differing species compositions of red alder (*Alnus rubra*), western red cedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), and Douglas-fir (*Pseudotsuga menziesii*) and age classes (Table 1). Other landscape features include a year-round fish-bearing stream and a sizable forested wetland.

During a preliminary study in 2009--2010, a survey of the research area located the *Ilex* on the landscape. Additional *Ilex* plants were found during this study (Figure 10).

Sample Size and Plot Placement

The plot sample size was originally set at 336, as this amount would detect a change of 40 ba ft²/acre at a significance level of 0.10 and with a power of 80%. Proportional allocation [$n_j = (N_j/N)n$, where N_j is the stand stage's acreage, N is total acreage and n is total number of plots] determined the number of plots assigned to each stand stage and unit (Figure 11). In most stand stages, it was possible to have an equal representation of *Ilex*-absent and *Ilex* plots.

The location of the *Ilex* plots was determined by assigning each known *Ilex* an ID and using a random number generator (Randomizer.org) to determine which plants would be used as plot centers. *Ilex*-absent plots were based upon earlier calculations used to calculate the acreage within each unit. Simple random sampling was used to place the *Ilex*-absent plots using the following process. First, to calculate a unit's acreage, a square grid (scaled so that one dot represented 4,316.5 ft²) was randomly dropped three times on an aerial photograph (scale factor 1:3943, source: Washington State NAIP 2009 Imagery), and the number of dots counted. For example, the Understory Reinitiation Unit 2 was found to contain 242 dots, which translated into 23.98 acres. The number of dots contained within each unit was entered into Randomizer.org, and the selected numbers became plot locations. The square grid was placed over the aerial photograph, and the dots that corresponded to the randomly generated number were plot centers. The numbering of the dots always started in the northern most point of the unit.

All plots were 1/20 acre, and the starting plots of each unit were located using a primary control of measuring via a 300-ft tape and a Silva compass. However, when ground conditions hindered the use of measuring with a tape, such as a high flowing stream, pacing was used.

Secondary controls were pacing and a Silva compass. If the location of an *Ilex*-absent plot was found to contain *Ilex*, the plot center was randomly moved until the *Ilex* fell outside of the plot's radius.

After a preliminary analysis was run on 158 plots, testing whether there is a significant difference in the basal area on *Ilex*-absent and *Ilex*-present plots, the result yielded a p-value of $<9.90E-04$. Because of this significant p-value, it was determined that the number of plots could be reduced to 200 and that Stem Exclusion Unit 1 did not need to be sampled since it did not share similar overstory species composition as the other two stem exclusion units (western hemlock instead of red alder) and was quite small (less than two acres). The number of plots assigned to the remaining units (six each) was based upon the minimum required to have three pairs. To determine the location of these plots, their numbers were randomly chosen from the original set of plots.

Table 2 lists the final number of plots assigned to each stand stage and unit. Figure 12 shows the location of the plots across the research area.

Data Collection

Data collection began in June 2011 and continued through November 2012. On each plot, the diameter of trees with a 1" dbh or greater were measured; although some understory species such as willow or vine maple did have trunks greater than 1" dbh, these species were not counted as trees. Of the trees measured, the smallest, average, and largest trees of each species were measured for height. In Understory Reinitiation Unit 1, *Ilex* entered the stand prior to the 2008 clear cut so to represent the conditions accurately when *Ilex* entered the stand, the stand had to be recreated. Within each plot, the diameter outside bark (DOB) and height of the stump were

measured; with these measurements, it is possible to recreate the tree's dbh using the equation found in Curtis and Arney (May 1977):

$$DBH = .8522 * (H^{0.1063}) * DOB$$

where H = Height of stump', DOB = Diameter outside bark"

Although the majority of the stand was composed of second-growth Douglas fir, there were other species present in the stand, such as big leaf maple and western red cedar. Because there are no equations available to recreate the heights of these species based upon the stump height, this equation was used for these species too. With these reconstructed DBHs, the known age of the stand, and site index, the stand inventory was rebuilt using the Landscape Management System (Landscape Management System 2006) employing the PN variant of FVS (Forest Vegetation Simulator). The heights estimated by the system were then used to generate CVTS for each of the trees.

Downed woody debris (DWD) was measured along three radially oriented 66' transects with origin at plot center. The first transect was based upon a randomly selected compass heading, and the subsequent two transects were based upon a randomly selected number between 1-360° added to the initial compass heading. Along the transect different-sized pieces were measured: from 0-6' along the transect pieces 0-0.4" diameter were measured; from 6-12', pieces 0.5-1.9" diameter were measured; and from 0-66", pieces 2"+ were measured. Where a piece of downed woody debris crossed the transect, its diameter and length were measured. For pieces where the tape could not be wrapped around the piece, in the case of large logs, half of the piece's diameter was measured and that number was doubled to calculate its total diameter. The DWD was not measured on the Understory Reinitiation Unit 1 and Seedling Grass Unit, because the DWD was present due to recent logging and therefore did not represent the condition under which *Ilex* entered the stand. Two plots (*Ilex*-absent and *Ilex*) in the Stem Exclusion Unit 2 did

not have the DWD measured, because there were several large beaver-felled black cottonwood DWD pieces that made the operation too hazardous.

The understory species within the plot were identified by observation, and the species noted were those that did not die during the winter, such as herbaceous plants.

Another measurement taken was identifying the tree with the lowest branch over plot center and measuring the distance from plot center to its base. This measurement was not done on the Understory Reinitiation Unit 1 and Seedling Grass stand stage, as it was not possible to reconstruct from the stumps which tree had a branch over plot center. Other measurements included slope and aspect. The growth type of the *Ilex* plant was also noted: single stalk upright, single stalk lying down, multiple stalks upright, multiple stalks lying down, or multiple stalks upright and lying down.

Data analyses

For each plot, stand summary statistics, such as volume, basal area, stand density index, relative density, quadratic mean diameter, and number of measured trees, were calculated to a per acre basis. For the trees whose heights were measured, volume was calculated using the British Columbia cubic volume equation coefficients (Browne 1962). However, because cascara or *Ilex* does not have cubic volume equation coefficients, the coefficients for red alder were used instead. The coefficients for the dawn redwood were based upon Griffen (1986).

To determine the volume of those trees whose heights were not measured, on each plot, a species-specific Volume:Basal Area Ratio (VBAR) was calculated based upon the trees whose heights were measured. This VBAR was then multiplied by the tree's basal area to estimate its volume.

For the DWD, the number of pieces in each diameter class and the total DWD per acre were calculated. Each understory vegetation species was assigned an absence or present value.

An Analysis of Deviance (Type II) was used to determine if statistically significant differences existed between the *Ilex*-absent and *Ilex*-present plots. The ANOVA was run on generalized linear models that used the binomial (logit), as the linked error function:

$$P_i = \frac{e^{\dot{x}\beta}}{1 + e^{\dot{x}\beta}}$$

where P = is the probability of *Ilex* presence,

X is a vector of predictor variables,

β is a vector of fitted model coefficients

The R statistical language (R Development Core Team 2010) was used to conduct the analysis.

Results

The explanatory variable being tested limited the number of plots within the dataset; as was mentioned earlier, measurements of all variables did not occur on every plot. Table 3 is a summary of the explanatory variables being tested, and the number of plots available for each variable. Because of the number of variables involved, the single-factor models will be addressed first, followed by the multi-factor models.

Single-factor Models

Stand Density Variables and Stand Stage

During the course of a prior study that involved surveying the research area for *Ilex*, I noticed that certain portions of a forest seemed more likely to contain *Ilex* due to the spacing of the surrounding trees; in unscientific terms, the area felt “right” that *Ilex* would be there. *Ilex* was also observed to grow in proximity to a nearby tree. To determine whether there was such a pattern existed, I tested stand density variables that relate to spacing and tree size.

The stand density explanatory variables that were tested include basal area, volume, relative density, quadratic mean diameter, trees per acre, and stand density index. (For list of forestry mensuration terms, see Glossary.) All of these variables proved statistically significant, ($p < 0.10$). Stand stage resulted in the lowest residual deviance (246.89, null deviance 270.74) though its p-value was not the most significant. All the stand stages, except for open grassland, had an association with presence of *Ilex*. This matches my observation of finding very few *Ilex* in the open grassland stage unless there were trees nearby.

While SDI does not relate to spacing across the landscape, this variable accounts for a tree's size and the number distributed across an acre. An increase in SDI is associated with a stand having few but large trees or being dense with smaller-sized trees. SDI had the second-lowest residual deviance value and lowest p-value ($p < 2.536e-05$) while basal area (ft^2 per acre) resulted in a p-value of ($p < 4.676e-05$) and a residual deviance of (254.17). Figure 13 is a boxplot of the SDI values per acre of each condition. The stand stages associated with the highest SDI values are the Riparian and Understory Reinitiation stages (Figure 14). This is due to large trees being left along the stream after the 1992 logging, and the Understory Reinitiation stage having not been clear cut since the turn of the century.

Because Douglas-fir and western red cedar are the dominate overstory species across the research area and appear in many of the plots, I did not expect to find these species significant in relation to *Ilex*-presence. With basal area proving more significant than volume, I used this measurement when testing the significance of an individual tree species basal area. The basal area of western red cedar and Douglas- fir did prove significantly different between the *Ilex*-absent and *Ilex* plots ($p < 0.001968$ and $p < 0.001816$), respectively and there is an association of *Ilex* with these two tree species. However, the basal area of western hemlock and red alder, also

common across the research area, did not explain the presence or absence of *Ilex* ($p > 0.9822$ and $p > 0.6518$, respectively). Even cascara proved significant though its p-value was not as low ($p < 0.01247$). Testing the significance of the rarer species planted on the research area, such as ponderosa pine (only found on 3 plots of the 200 in the grassland and seedling/grass stages) and lodgepole pine (only found on 2 out of 200 in the grassland stage) found that ponderosa pine was significant but has a disassociation with *Ilex* ($p < 0.07375$) while lodgepole pine was not significant.

Downed Woody Debris

During my earlier observations, I did not observe DWD, as I was focused on the trees. However, knowing that smaller pieces could prevent germination by smothering the seedlings, I expected to find smaller-sized DWD significant with the absence of *Ilex* or that the Stem Exclusion stand stage would prove to be the most significant, as the stands are composed of red alder and are undergoing competition.

Of the downed woody debris measurements, only one proved significant: DWD with diameter of 0.5-1.9" ($p < 2.114e-06$). Total DWD debris ($p > 0.429$), DWD with diameter of 0-0.4" ($p > 0.7083$), and DWD with a diameter of 2+" ($p > 0.5952$) were not significant. This size-class still resulted in a substantial residual deviance: null deviance 233.71, with a residual deviance of 211.22. A boxplot of the DWD with a diameter of 0.5-1.9" shows *Ilex* plots with more downed woody debris present than *Ilex*-absent plots (Figure 15). When this variable is graphed over the stand stages (Figure 16), the highest CWD totals of this diameter class are associated with stand stages experiencing competition or transitioning into another stage, i.e. late initiation, stem exclusion, and Understory Reinitiation. This is also matched the ANOVA linear model run on stand stage and its effect upon this size class of DWD. While all the stand stages resulted with an

association, Understory Reinitation, Late Initiation, and Stem Exclusion proved significant ($p < 0.000577$, $p < 0.001265$, and $p < 0.010508$, respectively). That the highest number of pieces per acre was found on a plot in the Late Initiation Unit 2 is unexpected, as this plot had a low SDI (67.9) created by 15 trees. However, the DWD was lengthier than other pieces in that size class measured across the research area and could possibly been knocked down by the cattle as they rubbed against the tree or been scatted into the plot area as they grazed.

Understory Vegetation

With most of the stands having a similar composition of sword fern, salmonberry, salal, etc., except for stem exclusion where red alder's dense canopy limited the amount of light, I did not expect the number of species present on a plot to have any bearing on presence or absence of *Ilex*.

Of the 49 understory vegetation species that were observed across the landscape (Appendix 4), I first tested whether the overall number of understory species is significant. This explanatory variable was significant ($p < 1.169e-08$) and resulted in the lowest residual deviance of 238.21, surpassing even stand stage's 246.89. The fewest number of species were found on *Ilex*-absent plots, with one plot having only one species while the fewest species observed on an *Ilex* plot was three (Figure 17). Of the stand stages, open grassland was observed to have the fewest understory species, and the riparian stage had the highest number of observed species (Figure 18).

I also tested if individual species exerted influence upon the microhabitat by providing extensive ground cover, possibly preventing *Ilex* seeds from settling into the soil and prevent germination, or could serve as habitat proxies for *Ilex*'s presence or absence. Species such as salmonberry, the naturalized evergreen and Himalayan blackberries, or reed canary grass are

relatively shade-intolerant and since *Ilex* is a shade-tolerant species, these species could indicate a disassociation with *Ilex*.

When an analysis is run on vegetation that could prevent the *Ilex* germination, several species were found to have an effect. Native grass, browsed grass, reed canary grass were found to be significant with p-values of ($p < 0.001633$), ($p < 0.07332$), and ($p < 0.005874$), respectively and their negative coefficients indicate a disassociation. Of the 34 plots that contained reed canary grass, 7 contained *Ilex*. However, these variables resulted in a higher residual deviance than the stand measurement variables: native grass (260.82) and reed canary grass (263.15). Evergreen blackberry, also a groundcover, was not a significant explanatory variable ($p > 0.6135$).

Sword fern had a positive association with *Ilex*, resulting in a lower p-value than any over the grass groundcovers ($p < 4.581e-05$) and having a lower residual deviance (254.13) than the other understory vegetation species. This association is unexpected given that sword fern was observed to extensively cover the forest floor in the Understory Reinitiation stand stage, and this coverage would have been assumed to be a barrier to seeds reaching the ground. This positive association was also found in species whose growth patterns wouldn't be a barrier to *Ilex* germination: cascara ($p < 5.187e-05$), hazelnut ($p < 0.004091$), or Oregon grape ($p < 0.007443$).

Understory species that occupy certain habitats could serve as indicators of *Ilex*'s inability to grow on that site. Yet even species that appear specialized, such as devil's club, which prefers moist microsites in a riparian or forest setting, was found in conjunction with *Ilex*; of the seven plots that contained Devil's club, five were *Ilex* plots. The p-value for this species also proved significant ($p < 0.09736$) and its positive coefficient indicating an association. This demonstrates that *Ilex* is capable of growing in riparian and forested wetland sites as has been observed. When testing *Ilex*-presence with horsetail and skunk cabbage, these two riparian-

specific species were found not to be significant: horsetail ($p > 0.4811$) and skunk cabbage ($p > 0.1235$). The only understory species found on *Ilex*-present plots that wasn't noted on *Ilex*-absent plots was understory black cottonwood; however, as this species was planted on this landscape, it is not useful as an indicator species.

Aspect and Slope

Because I observed the research area to be relatively flat during my survey work, I did not expect slope to be significant. Yet after having to view the research area from a microsite perspective, I realized that there is more variation in topography with localized hills and valleys on each plot. Slope and aspect had p-values of ($p < 0.00215$) and ($p > 0.5523$), respectively. The residual deviance of slope resulted in 261.33 (null deviance 270.74), Figure 19 is a boxplot of the slope values for the condition types. The lowest slope value for *Ilex*-present plots was 0.5 degrees while *Ilex*-absent plots were located on flat topography or also reported a 0.5 degree slope.

Ilex Growth Type

Ilex plants were observed to have different growing patterns across the landscape: single stalk upright (Figure 20), multiple stalks upright (Figure 21), multiple stalks lying down, and multiple stalks upright and lying down (Figure 22), and I was interested in determining whether stand density variables influenced these growth patterns. Because SDI was the most significant variable for *Ilex*-presence, I used this variable. The upright single stalk and multiple stalks upright and lying down both had significant p-values ($p < 0.02064$) ($p < 0.0265$), respectively and an association with SDI. The multiple stalks upright growth pattern resulted in a significant p-value ($p < 0.00100$), but there is a disassociation with SDI. The multiple stalks lying down resulted with a p-value that was not significant. I also tested whether the number of understory vegetation species or basal area affected growth type, and these variables were not significant.

Distance and DBH of Tree with Branch over Plot Center

The reason for measuring these variables was to determine if a perch site was associated with an *Ilex*, as I assumed that birds were the primary disperser of *Ilex* seeds which has been noted in previous studies. And if there was a perch size present, I assumed that the tree would be larger to support branches capable of being a suitable perch site. The dbh of the tree with branch over plot center proved significant ($p < 0.01540$) while the distance of the tree from plot center did not ($p > 0.6047$). This matches observations of there not being an observable pattern of where *Ilex* is found beneath a tree: *Ilex* was found right at a tree's base or several feet away from the trunk. There were 11 *Ilex*-present plots versus 47 *Ilex*-absent plots that did not have a branch over plot center. Figure 25 shows the tree's dbh on *Ilex* plots is on average larger than *Ilex*-absent plots, and the *Ilex* plots are associated with the largest measured trees. Figure 26 also shows that the Understory Reinitiation stage has a higher average dbh than the other stand stages, which is to be expected, as this stand stage is associated with larger trees and is transitioning into old growth.

Multi Factor Model

Stand Density Measurements, etc.

To determine if there was an interaction or cumulative effects of these variables on whether the area of the forest felt "right" for *Ilex*-presence, I ran a multi-factor model on a subsample of plots that had all the measurements taken (Table 3). The significant explanatory factors found in the single-factor models were tested, as with several variables that were not significant singly but could have an interaction.

Beginning with the most significant variable, number of understory vegetation species, this variable was combined with stand stage, DWD (0.5-1.9" diameter), SDI, slope, and dbh of tree with branch over plot center to determine the most parsimonious model. The resulting model

contained the variables in the following order: number of understory vegetation ($p < 9.13e-06$), DWD (0.5-1.9" diameter) ($p < 0.00379$), and SDI ($p < 0.00487$), and the residual deviance is 175.56 (null deviance 233.71). The interactions between these variables all resulted in p-values greater than 0.10, and these were not significant. Figure 27 is a scatterplot matrix of these three variables. While there is an overlap in the number of understory vegetation species, DWD amounts, and SDI index values, *Ilex*-absent plots were located on sites that are characterized by SDI values of 0 and few understory species.

Discussion

That *Ilex* plants are associated with an increase in basal area within a forest is expected of its being an understory species in European forests. Andrew Gray (2002) found that on sites inventoried in Oregon, *Ilex* was only found in stands with a larger dbh size class. At the 2011 ESA Conference, scientists familiar with *Ilex* on Vancouver Island commented to me about *Ilex* being found in mature forests. The presence of *Ilex* in areas with high basal area contradicts the the Northwest Holly Growers Association's claim on their website that "holly cannot thrive in our native forests because it is shade intolerant and cannot compete in a dense forest environment." From my years of observing *Ilex*, I have only found one example where an *Ilex* plant died because of shady due to overstory canopy created by bracken fern. David Stokes, an associate professor at UW Bothell who is studying *Ilex* at St. Edwards State Park, also reported not seeing a dead *Ilex* during the course of his research (personal communication).

However, what is noteworthy is the association of all stand stages, except for open grassland, to the presence of *Ilex*. This means that every stand stage is suitable habitat for *Ilex* once a certain SDI threshold has been met. The lowest plot SDI value associated with *Ilex* was 6.26, which was two Douglas-fir trees that had 41.5 and 39.9 dbhs, respectively. As the smallest

tree serving as a perch site was 1.7 dbh, even trees over 10 years old can create forest conditions where *Ilex* can be found, which means from the Sapling/Shrub stage onward is ideal *Ilex* habitat.

Though a high basal area could indicate shady conditions, it can also correspond to an increased level of light reaching the forest floor; as a stand transitions into Understory Reinitiation, the trees become more widely spaced, allowing more light to reach the forest floor and stimulate understory vegetation's growth. Because *Ilex* is found in stands still undergoing stand competition which creates shady conditions, i.e. late initiation and stem exclusion, *Ilex* can adapt to growing in shady or light-rich conditions and will remain a constant presence in a forest regardless whether the forest is thinned, untouched, or clear cut. The study by Scarnati et al. (2009) noted that regeneration of *Ilex* can be encouraged by frequent cuts, and while seedlings may be vulnerable to high light levels, mature *Ilex* plants do not appear affected. I observed that following the 2008 clear cut of Understory Reinitiation Unit 1, the surviving *Ilex* was one of the first species to recover in spite of logging damage and being exposed to the sun. This adaptability to light-filled or deep shade habitats means *Ilex* will survive a clear cut and remain a permanent fixture within the forest as they grow alongside regeneration.

The significance of the DWD is also likely associated with the stand transitioning into the next stand stage, as the diameter class of the significant-sized DWD included larger branches or smaller trees that died due to overstory competition, and the stand stages where this competition is occurring proved significant, i.e., Late Initiation, Stem Exclusion, and Understory Reinitiation. What is unexpected is in spite of this overstory competition that would limit the light reaching the forest floor, there is still a high number of understory vegetation species associated with relatively large amounts of DWD. However, since different sized DWD were measured at

different intervals along the transect, this significance needs further exploration to determine whether DWD is related to *Ilex* presence.

How slope relates to presence or absence of *Ilex* could be tied to better germination sites; sloping ground will accumulate more water and debris from above, conditions that would negatively impact the seedlings' survival. And since *Ilex* is found in association with larger dbh trees, these trees could have built up the microsite through years of branch and needle deposition.

On this research area, birds are the likeliest dispersal method of *Ilex* berries, and it can be assumed that the presence of the natural *Ilex* plants is because a bird visited the area; only the original mother *Ilex* tree was planted. As birds require perch sites, it would be expected that *Ilex*-present plots are more likely to be associated with a branch over plot center than *Ilex*-absent plots. What should be explored further is whether there is a bird species adapted to a variety of forest conditions or whether multiple bird species eat the *Ilex* berries. Zika (2010) noted seven species of birds swallowing *Ilex* fruits in an observational study conducted in the city of Seattle, and the species that was observed most frequently doing so was the American robin. The increased presence of shrubby understory vegetation species would also be expected to be related to presence of *Ilex*, as these shrubs would provide habitat for birds. However, given that *Ilex* is found in at least two different types of wildlife habitats, forest edge and forest interior (Figure 7), it is possible that several bird species are responsible for spreading *Ilex* throughout a forest.

That *Ilex* plants are located near a tree can also be linked back to a branch providing a perch site but also shade providing suitable growing conditions for *Ilex* seedlings. With shade, the risk of desiccation during the summer is reduced, as Peterken (1966) observed. Though the proximity to an overstory tree could reduce the moisture received by the seedling, as it has been observed that the canopy prevents rainfall from reaching the forest floor, this might be beneficial

for *Ilex*; Scarnati et al. (2009) found that *Ilex* regeneration is negatively influenced by annual precipitation.

What hasn't been addressed is whether these are the stand conditions under which *Ilex* germinated. Seeds can remain dormant for three years before germination so it is possible for seeds to be deposited after the forest has experienced a disturbance. This was observed in the 2008 clear cut of Understory Reinitiation Unit 1; a sweep in 2009 did not find a seedling, but in 2011, a seedling was found. An *Ilex* tree cut in 2007 in Stem Exclusion Unit 2 was 13 years, which meant it was deposited when the stand was in the Understory Reinitiation stage and germinated after the 1992 logging. And while I cannot confirm whether the *Ilex* plants found in the Seedling Grass stage were present before the stand was clear cut, I suspect they were based upon the height of the *Ilex* plants and the lack of perch sites overhead.

Given that *Ilex* can survive in multiple stand stages, is it possible to identify the forests that are more vulnerable to *Ilex* incursion? Since *Ilex* is predominately found in areas associated with a higher SDI, DWD, and understory vegetation species presence, the stand stages which have these conditions and proved to be the most significant are the Late Initiation, Understory Reinitiation, and Riparian. These variables could be a starting point for natural resource managers wanting to determine whether *Ilex* is likely to be found on their forestland. Using native and reed canary grass as representation of habitat where *Ilex* will not be found is useful, but because these species are not associated with forestland, other species are needed to serve as indicators for ideal *Ilex*-absent conditions. This might be difficult due to *Ilex* being associated with many ubiquitous PNW species, such as sword fern. Instead, what could be used is a combination of species to identify the habitat where *Ilex* will likely be found. Species such as hazel nut, devil's club, and cascara require light-rich conditions within a forest so *Ilex* is likeliest

to be found in stands with light-rich conditions capable of supporting species that are relatively shade intolerant. This requirement can be associated with any stand stage whose tree spacing allows for light to reach the forest floor.

If land managers or property owners are intent on preventing *Ilex* from becoming established in a forest or on their property, then constant vigilance is required, as it can take three years for a seedling to germinate, and if mother trees are anywhere in the area, there will remain a constant source of seedlings.

Though other forest products are used in floral arrangements, such as salal, and harvesting *Ilex* from the forest could be a way of controlling its spread, it is unlikely that the demand for *Ilex* will surpass what can be supplied by the PNW *Ilex* growers, as *Ilex* is a seasonal crop. This raises the question of whether *Ilex* will affect the long-term health of PNW forests. Peterken and Lloyd (1967) note that *Ilex* litter forms alkaline mull humus. This pH change could potentially affect the health of vegetation that is adapted to acidic soil conditions and should be studied further.

And does the spread of *Ilex* pose a threat to understory vegetation or Douglas-fir seedlings? As has been observed (Figure 5), *Ilex* forms an ever-expanding, dense clump after being cut. Its extensive root system also means it will have access to water both at the surface and deep beneath the soil. This access to water stores could mean the difference of survival in summer when conifer seedlings are vulnerable to water shortages on drier sites.

While there is an association between *Ilex* growth type and SDI, further study is needed to determine if another variable, such as light, precipitation levels, or temperature, is responsible for different growth types. We also do not know the affect each growth type has upon the microhabitat, but what is known is *Ilex* clumps are caused by layering and suckering, and this

growth type could be detrimental within a microhabitat; therefore, understanding what influences its growth type could be useful.

Even though the model contains values that are well below the $p < .10$ significance level, there is still a substantial residual deviance unexplained by the variables (null 233.71, residual 175.56). This suggests that there are likely other environmental conditions related to the presence and absence of *Ilex*. Scarnati et al. (2009) found that while basal area and annual precipitation negatively influences *Ilex* regeneration, in addition to annual precipitation, the maximum temperature positively influences growth. These are two measurements that should be explored further in to determine if they are factors affecting growth as was found in the Apennines.

This study demonstrates more research is needed to assess whether the observations made in Grays Harbor County hold true in other forests across the PNW and if stand attributes such as SDI or the number of understory vegetation species could be used as indicators of *Ilex*'s presence or absence within a forest. Given *Ilex*'s hardiness and spread throughout the PNW, we are still faced with many questions of how to manage this naturalized plant.

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Appendix 1 Photographs and Figures



Figure 1 An 11-year-old *Ilex* tree (1.6" DBH 15') growing amidst Douglas fir and red alder. This plant's distinctive green and shape are different than the native evergreen trees in the Pacific Northwest.



Figure 2 The root system of an *Ilex* tree. The main stalk descended more than three feet into the ground and not all the side roots could be dug out. This tree is estimated to be seven years old.



Figure 3 The *Ilex*'s fruit is called a berry or drupe by horticulturists. These red berries are another distinctive feature that set *Ilex* trees apart from other PNW evergreen trees.

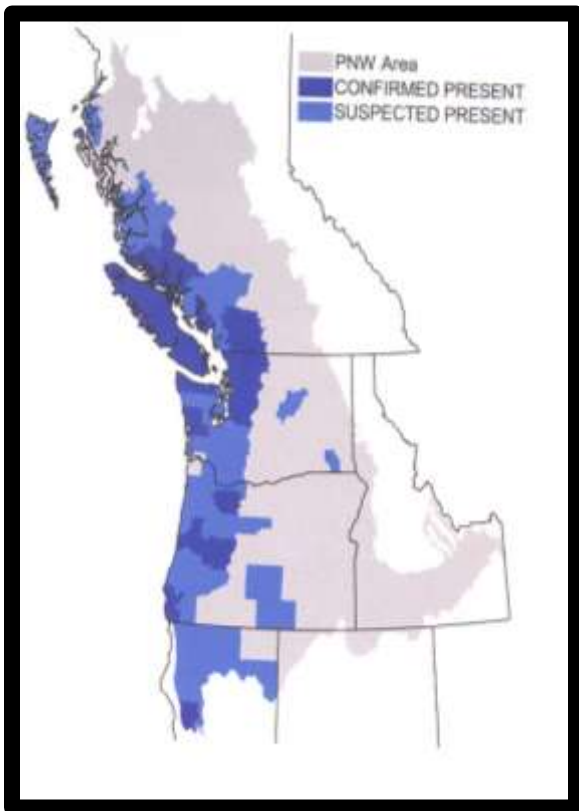


Figure 4 Distribution of *Ilex* within the Pacific Northwest. Map from Olmsted, Dawn. 2006. *Invasive Species in the Pacific Northwest*. (ed by P. D. Boersma, Sarah H. Reichard, A. N. Van Buren). University of Washington Press, Seattle.



Figure 5 An example of *Ilex* growth after being cut. What used to be a single-stalked *Ilex* tree is now a clump spanning over six feet in diameter. This plant, found in Understory Reinitiation Unit 1, was cut in 2008 when the area was logged by Port Blakely.



Figure 6 A close-up of an *Ilex* tree's trunk, the same tree as in Fig. 1. With a thick root stalk and expansive root system that penetrates deep into the soil, mature *Ilex* plants are difficult to remove without greatly disturbing the soil or nearby plants.

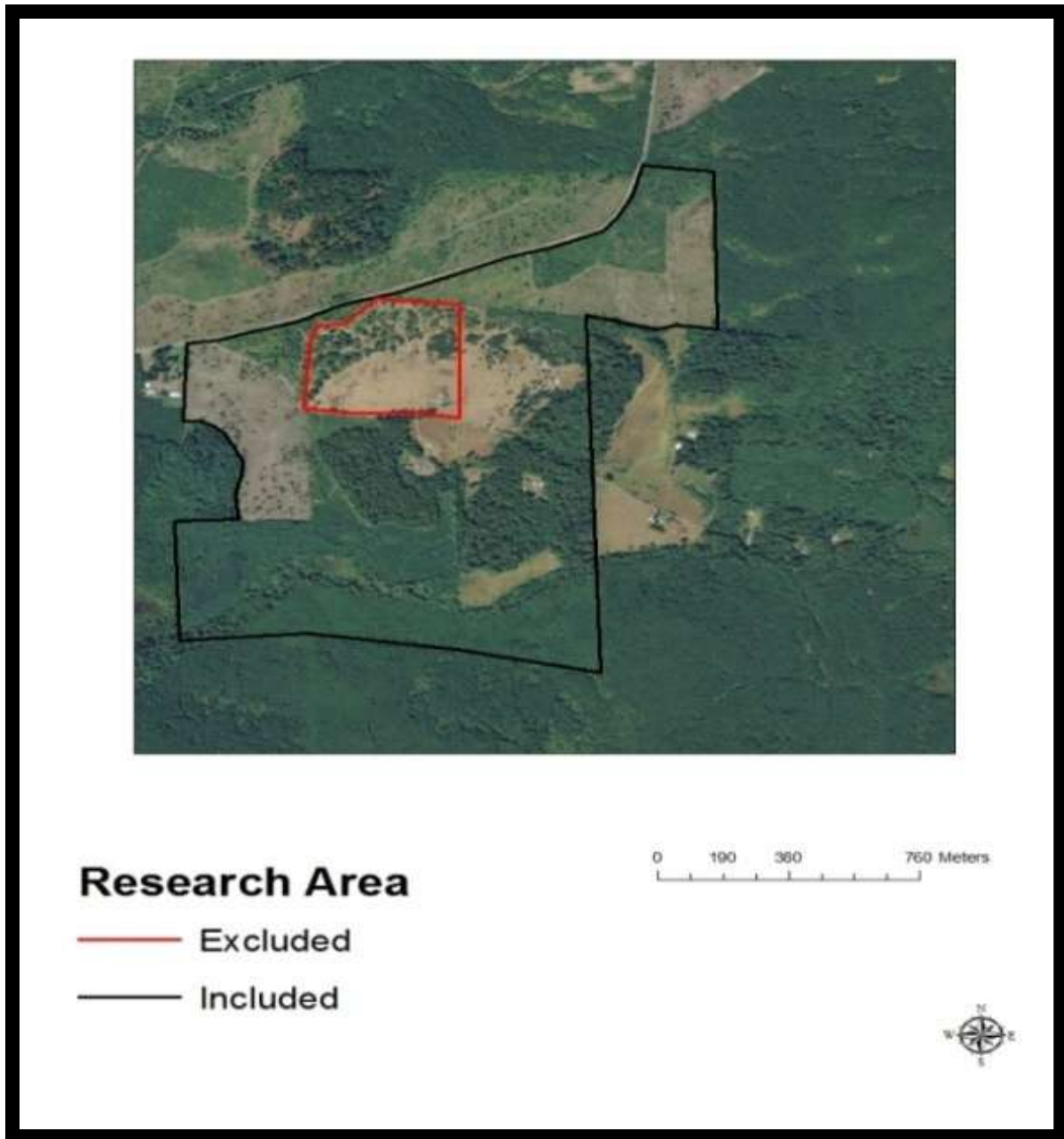


Figure 7 An aerial overview of research area.
The excluded area (red polygon) was converted to livestock grazing after being logged in 1992.

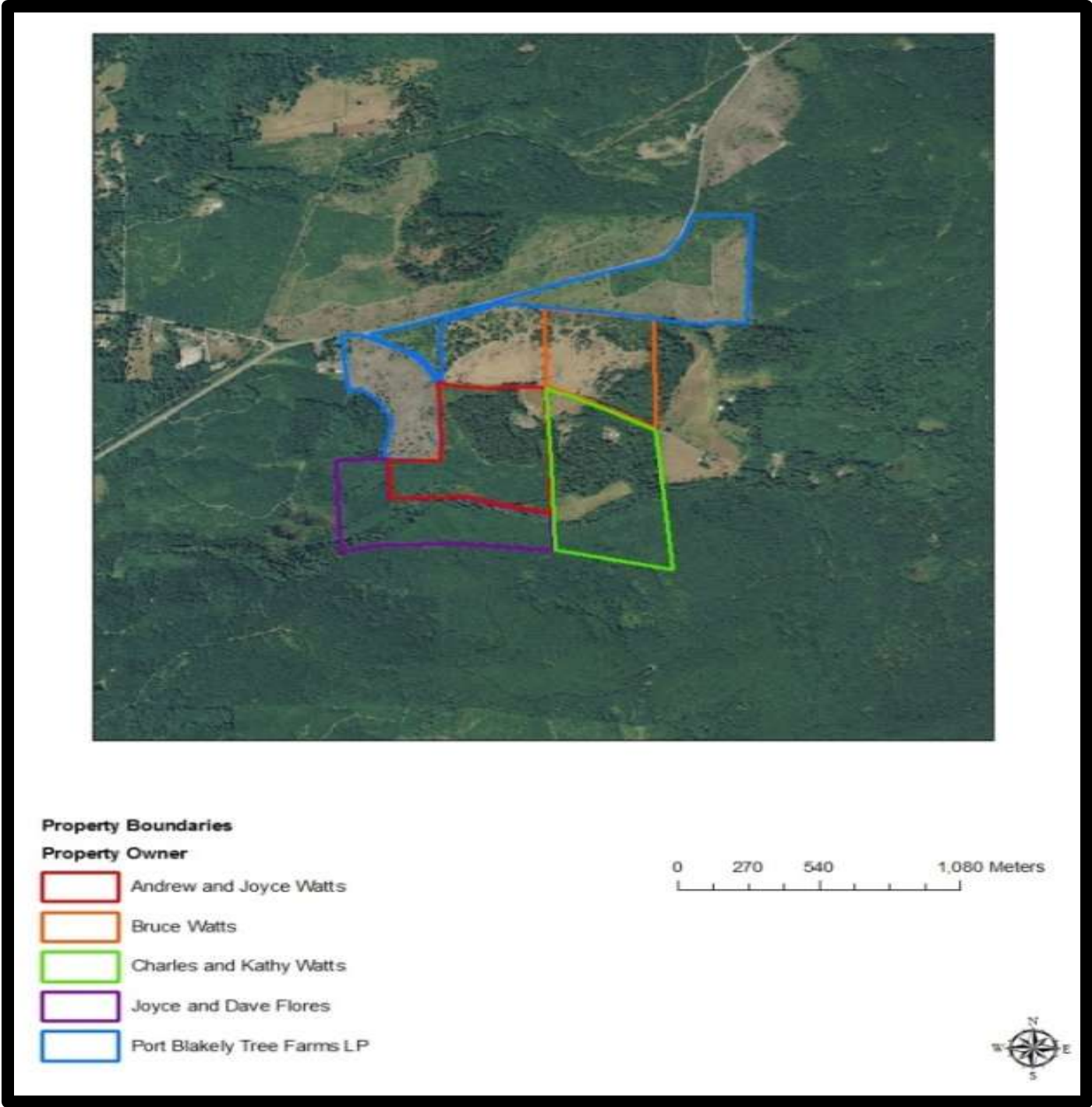


Figure 8 An aerial overview of research area with an overlay of the property boundaries.

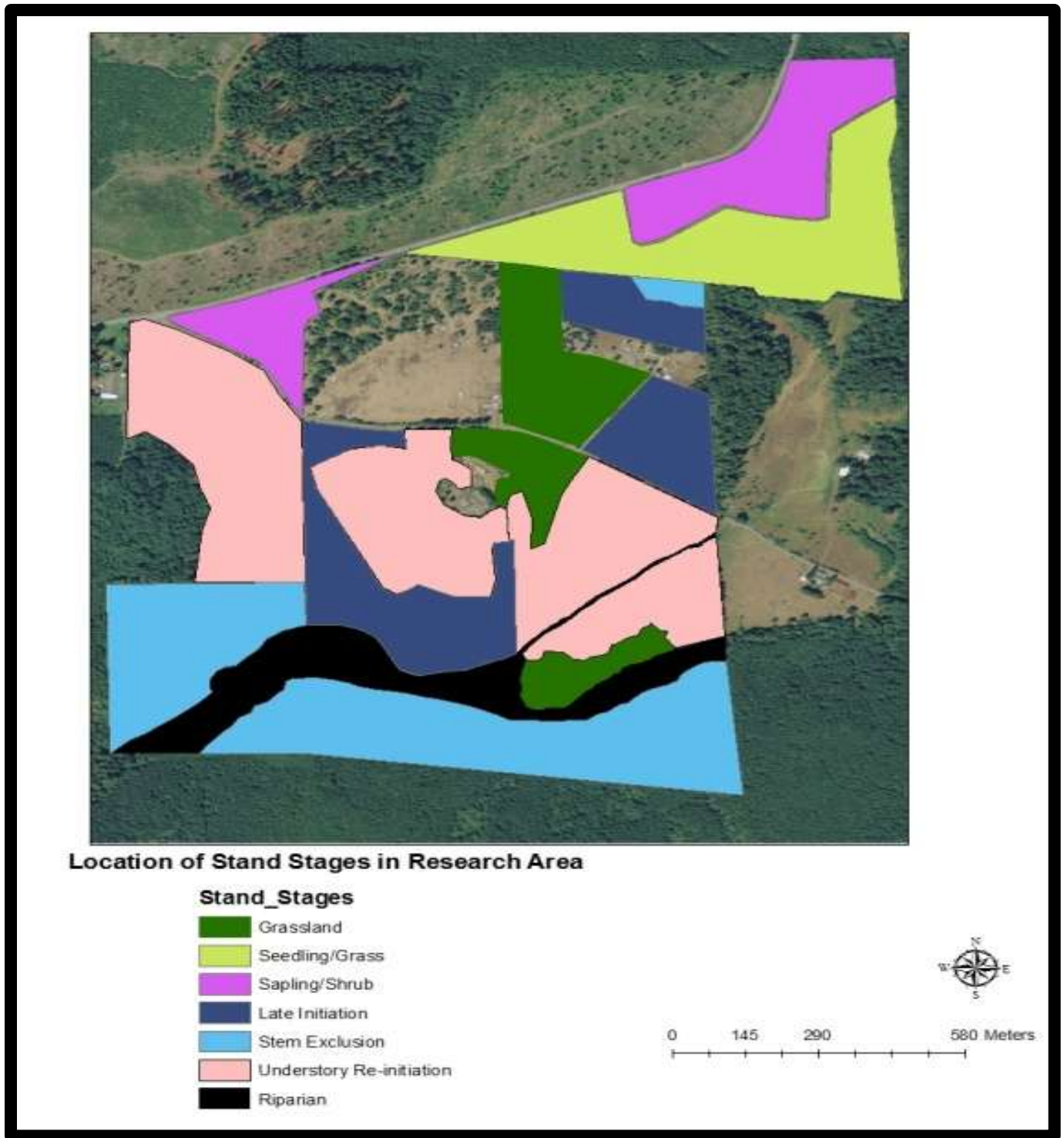


Figure 9 The research area with an overlay of the stand stages. Although the Understory Reinitiation stand stage on Port Blakely is clear-cut in the photograph (Fig. 7), *Ilex* entered the stand before the clear cut so the unit is being classified as the Understory Reinitiation stage after appropriate reconstruction of prevailing stand conditions immediately prior to harvest.

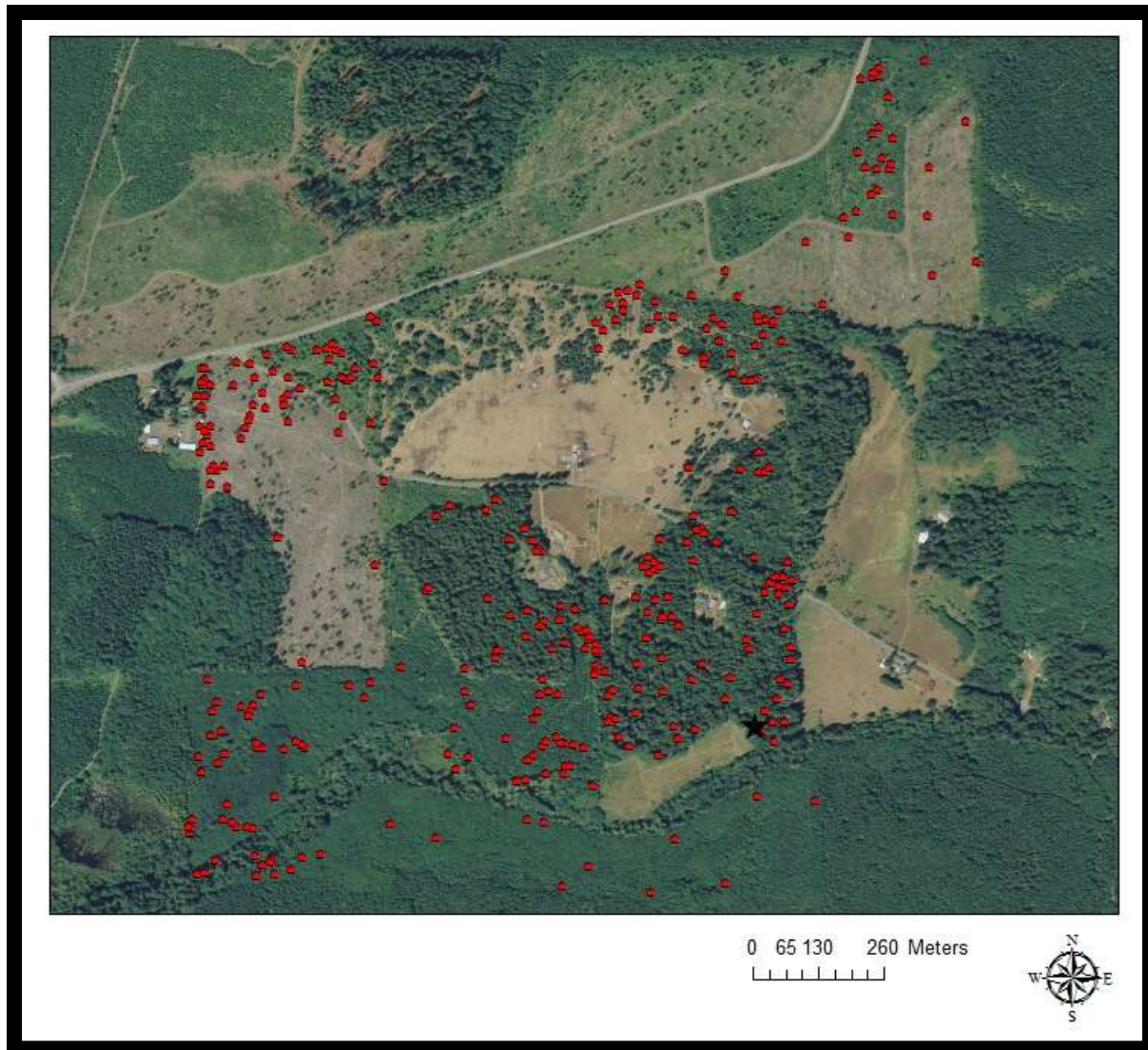



Figure 10 The location of *Ilex* within the research area. A dot may represent a single plant or a clump of plants. The  is the location of the only planted *Ilex*. *Ilex* plants were also observed outside the research area but do not appear on this map. It took a little over 20 years for this spread to occur. There is speculation that there were planted *Ilex* near the former Port Blakely field office (the buildings located on the left portion of the map) but this has never been confirmed.

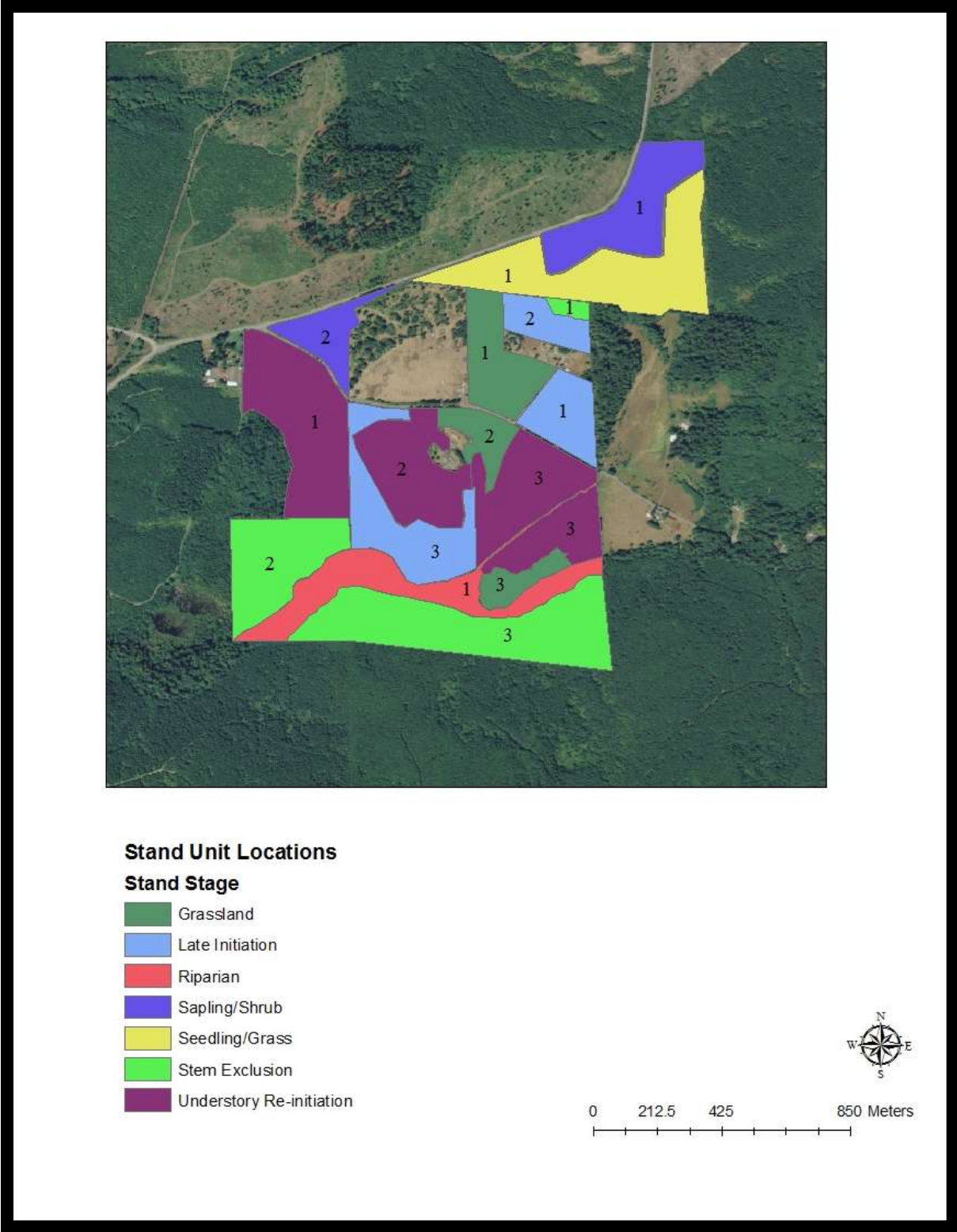


Figure 11 Location of stand stages' units on the landscape.

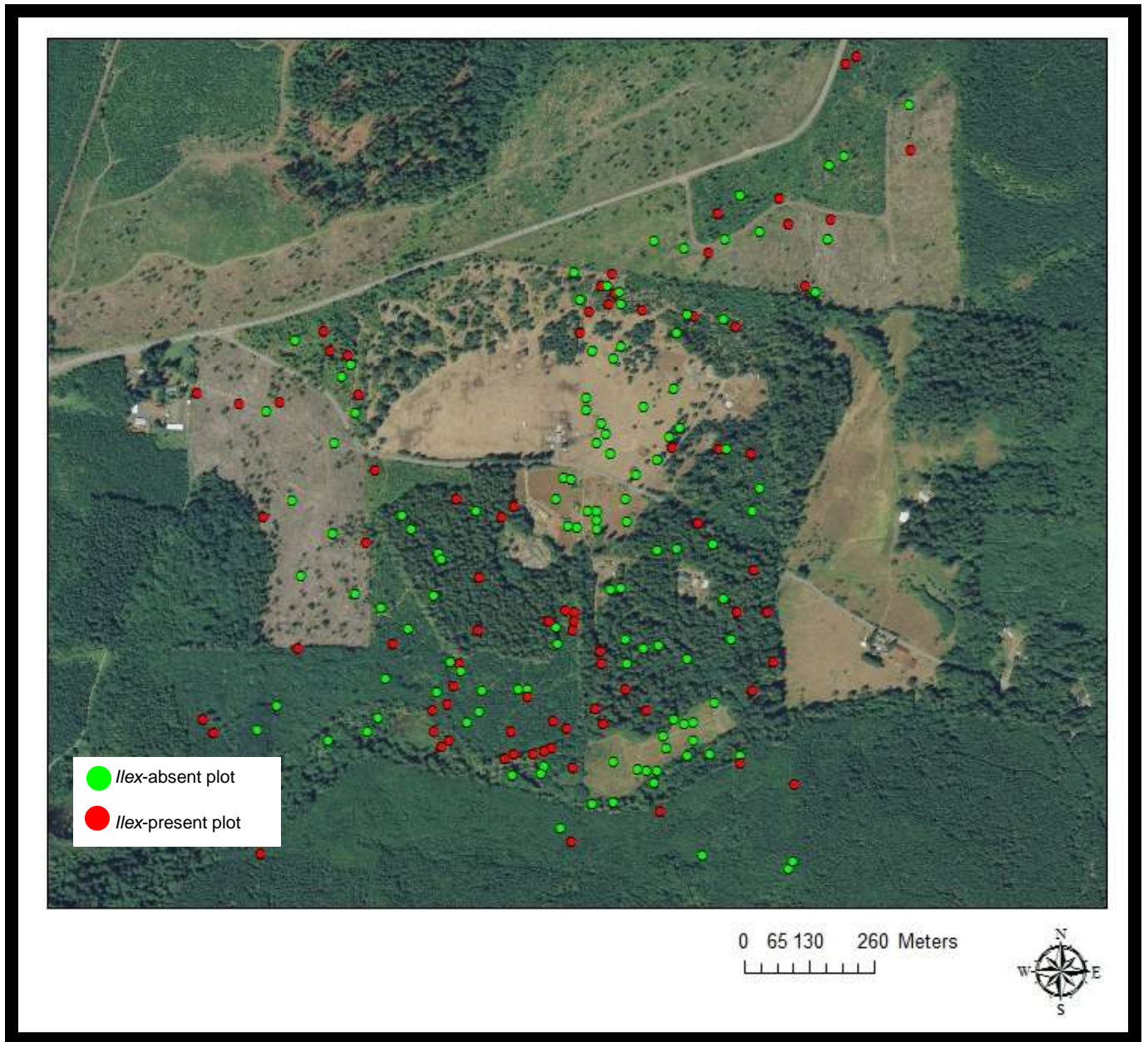


Figure 12 The location of plots across the research area.
Due to the variability of the GPS unit, some of the plots may be a few feet from their actual location on the landscape.

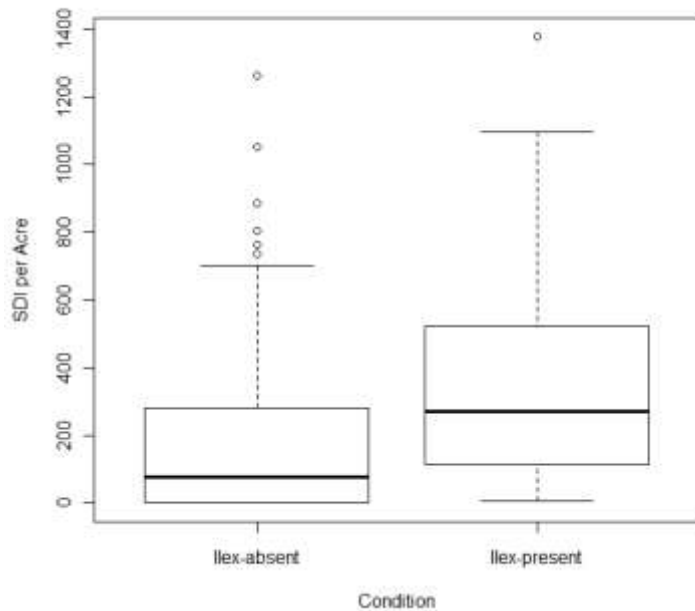


Figure 13 The SDI values of *Ilex*-absent and *Ilex*-present plots, The reason for the outlier point under the *Ilex*-present is because that plot had 81.4", 53.9", and 50.1" dbh western red cedars. Also see Figure 29 for its basal area per acre table.

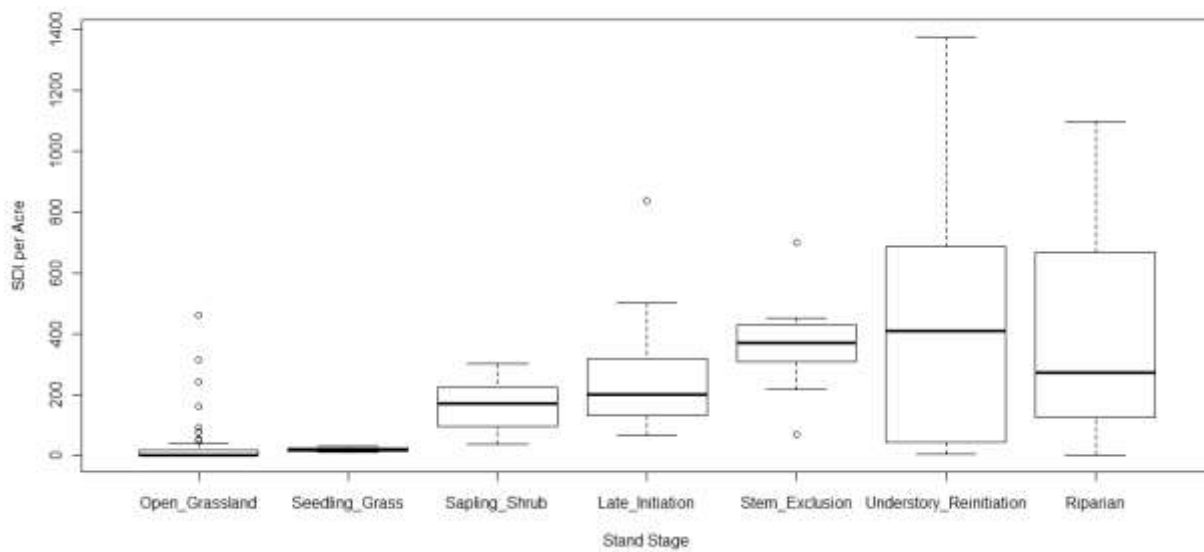


Figure 14 The SDI per acre values across the research area follow the stand stages, i.e., larger trees are to be expected as the stand matures. The outlier values are associated with remnant trees that were not logged or unusually large trees in the research area.

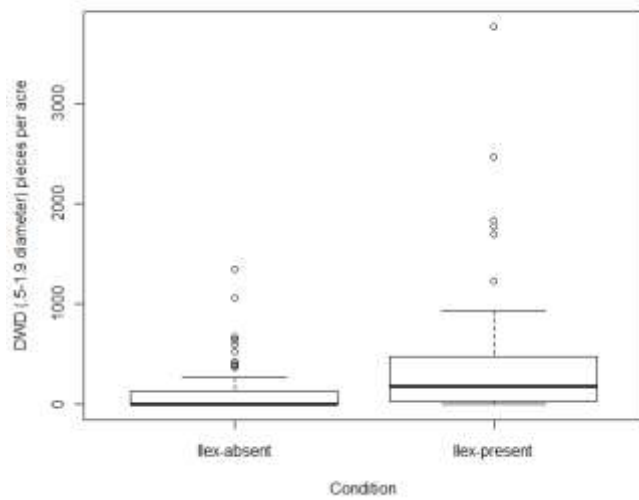


Figure 15 The amount of DWD with a diameter class of 0.5-1.9” is on average higher on *Ilex*-present plots than *Ilex*-absent plots. This size of DWD observed consisted of larger branches or small trees that died due to competition.

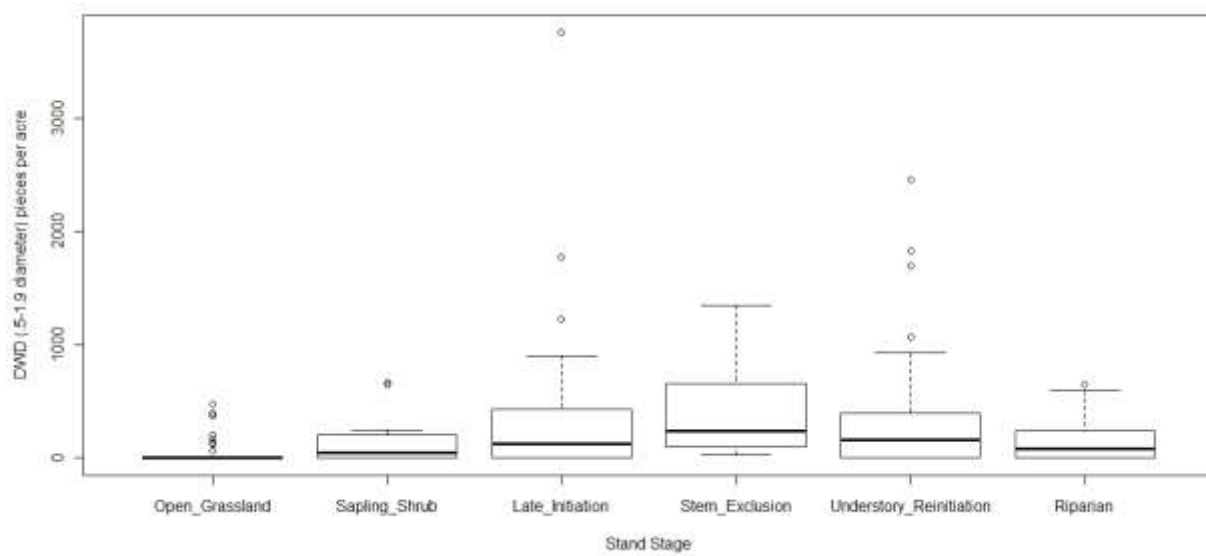


Figure 16 The distribution of DWD with a diameter class of 0.5-1.9” across the stand stages. The plot containing the highest number of DWD in this diameter class is found in Late Initiation Unit 2.

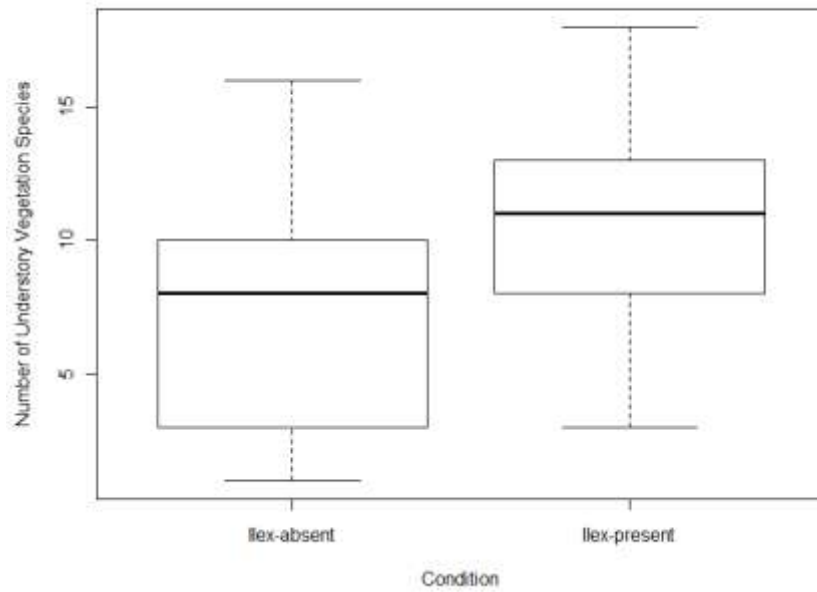


Figure 17 *Ilex*-present plots had on average more observed understory species than *Ilex*-absent plots.

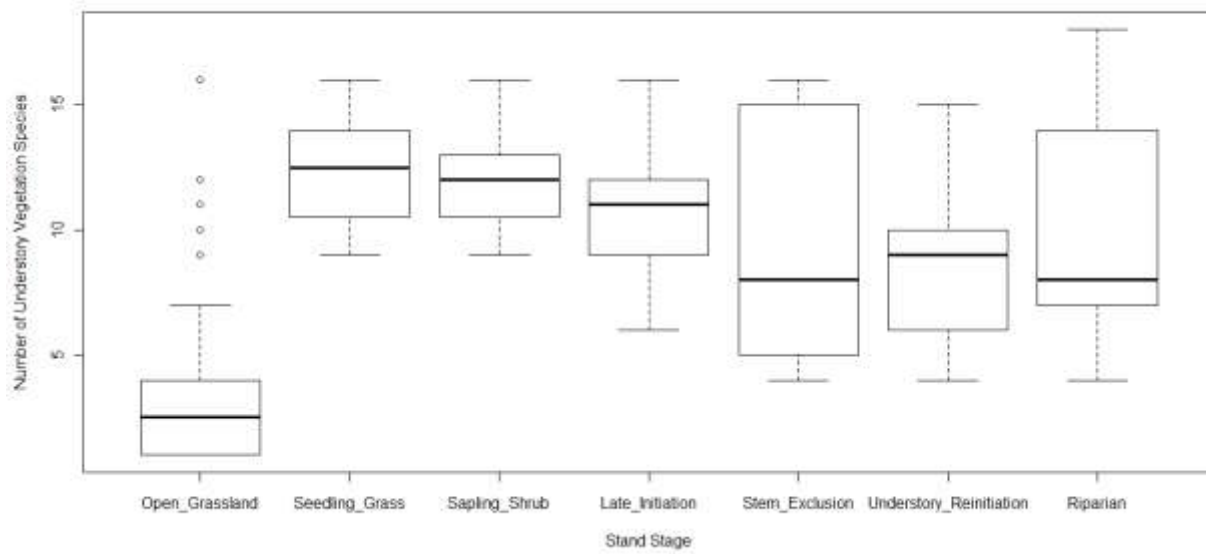


Figure 18 As only shrubby understory species or those that persisted during the winter were counted, there is likely a higher number of understory vegetation species if the herbaceous species are included.

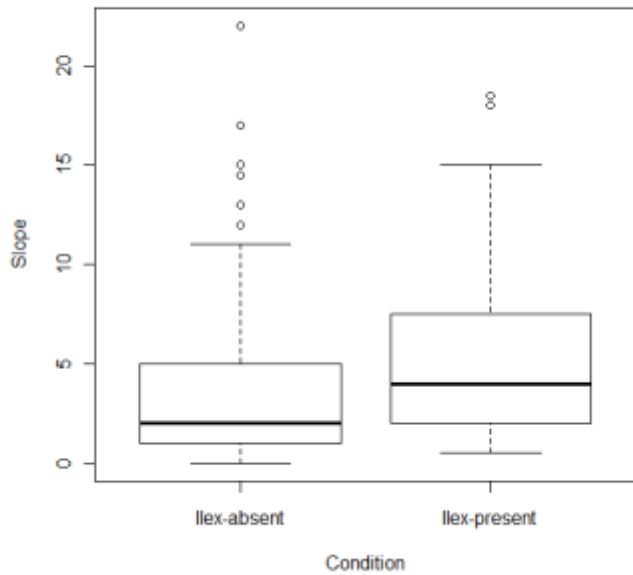


Figure 19 A boxplot of the slope values for the *Ilex*-absent and *Ilex* plots. Though there is an overlap of values between the conditions, the average slope value is higher for *Ilex*-present plots.



Figure 20 An example of a single stalked, upright *Ilex* holly. This tree was the planted mother and has a DBH of 8.2.”



Figure 21 An example of a multiple stalked and upright *Ilex* tree.



Figure 22 An example of a multiple stalked *Ilex* plant that has stalks lying down and upright. A plant that was classified as lying down would have all its stalks lying on the ground.

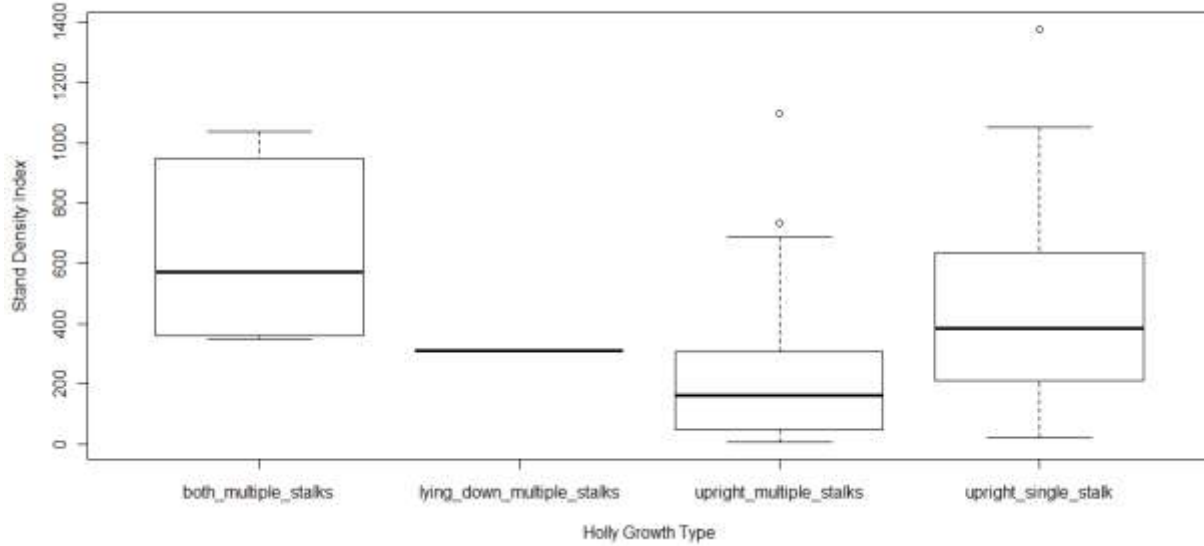


Figure 23 A boxplot of the SDI values associated with the observed *Ilex* growth types. While stand stage is a significant explanatory variable, several stand stages were associated (open grassland and seedling grass) and disassociated (Riparian, Sapling Shrub, Stem Exclusion, and Understory Reinitiation) with growth type. This can be seen by the overlap of growth types with the same SDI value.

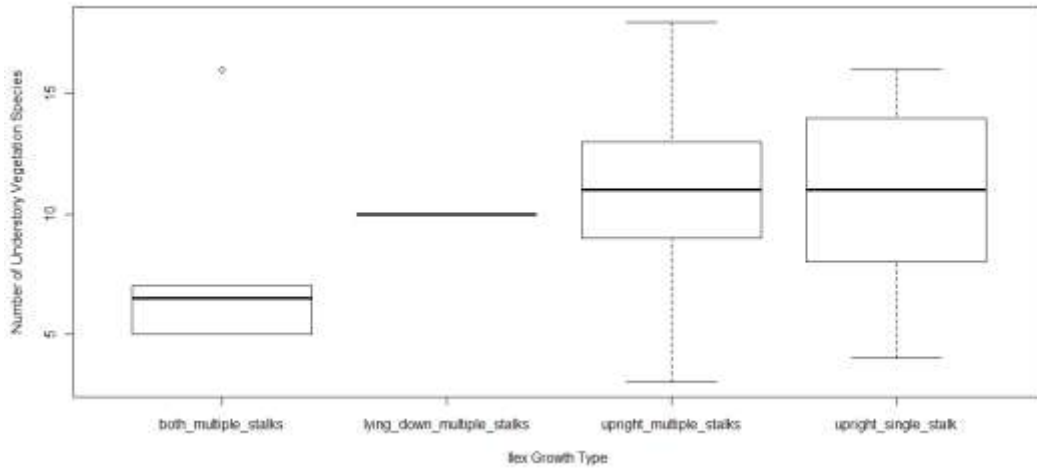


Figure 24 Though the upright multiple stalks and single stalk growth types overlap in the number of understory vegetation species present, upright multiple stalks are associated with the fewest and most understory vegetation species.

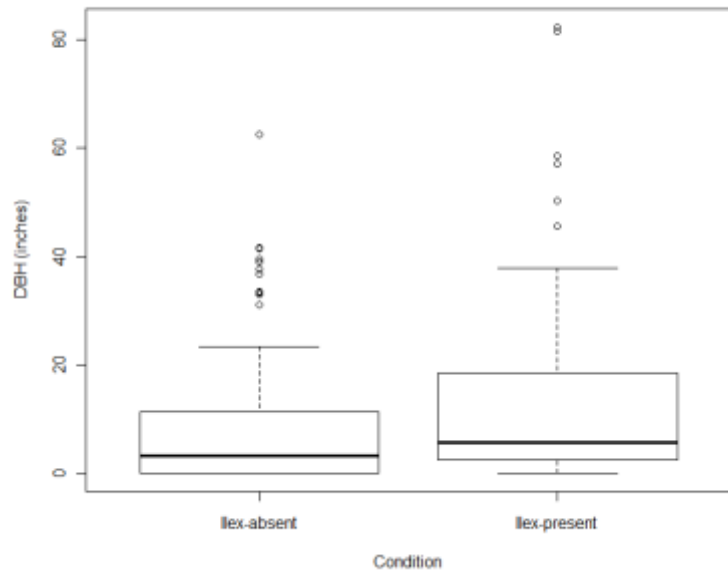


Figure 25 The average dbh of trees found on *Ilex* plots is larger or the plots are more likely to have a branch over plot center when compared to *Ilex*-absent plots.

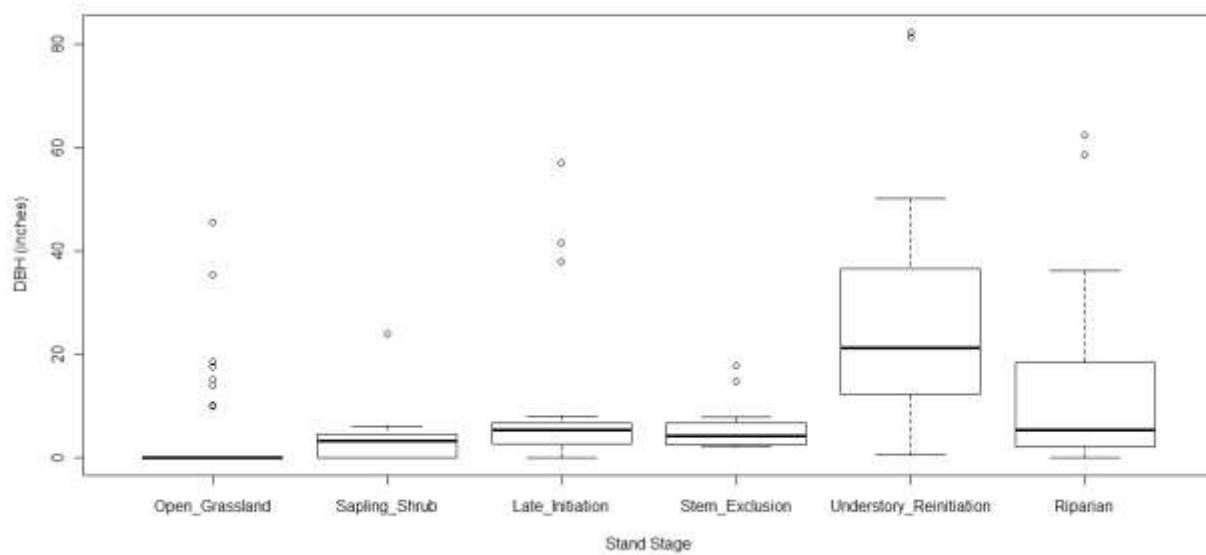


Figure 26 The DBH distribution by stand stage. The Understory Reinitiation stage has on average larger trees because it is a mature stand and the presence of small-diameter trees also indicates Understory R einitiation is occurring.

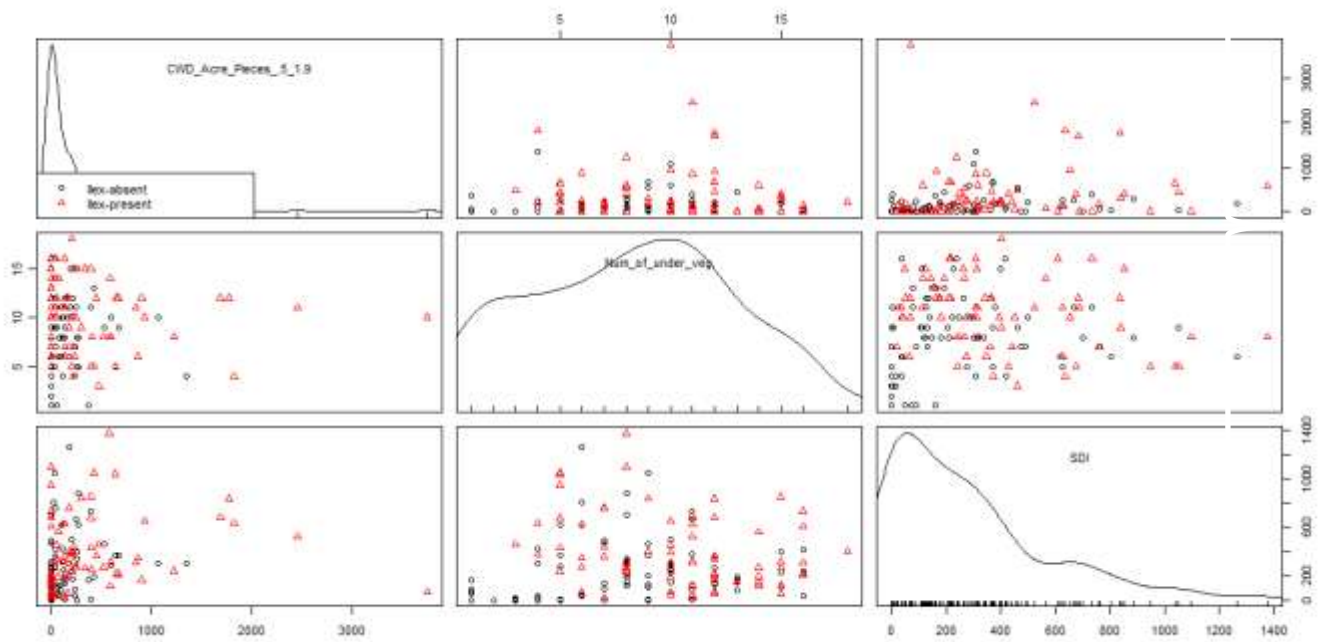


Figure 27 A scatterplot matrix of the significant explanatory factors in the multi-factor model. *Ilex*-present plots are associated with the highest extreme values of the variables.

Appendix 2 Tables

Table 1 Summary of stand stages within the research area. Throughout the stand stages are trees left behind from earlier logging, and the youngest age of these trees is noted in ().

Stand Stage	Dominant overstory species composition	Average Stand Age (yrs)	Disturbance history	Number of units	Average Trees/Acre (SD)	Average Basal Area ft ² /Acre (SD)	Acreage
Open Grassland/Savannah	Douglas fir, western red cedar	< 30 (50)+	Two units are still native prairie while the third unit is used for cattle grazing. Sporadic replanting has occurred.	3	28 (55)	23 (68)	32.89
Seedling/Grass	Douglas fir, red alder	< 11	This stage was clear cut in 2005 and replanted with Douglas fir.	1	300 (113)	5 (2)	43.2
Sapling/Shrub	Douglas fir, western red cedar	< 12 (69+)	This stage was clear cut in 2001 and replanted with Douglas fir.	2	595 (380)	69 (38)	31.22
Late Initiation	Douglas fir, western red cedar	< 20 (82+)	This stage was clear cut in 1992 and replanted with Douglas fir.	3	879 (647)	113 (115)	45.51
Stem Exclusion	cascara, red alder	< 20	This stage was clear cut in 1992 and replanted with Douglas fir and black cottonwood. However, the red alder and cascara became the dominant tree species.	3	1780 (813)	140 (64)	65.30
Understory Reinitiation	Douglas fir, western red cedar	<125	This stage experienced repeated thinning since its establishment in 1883.	3	191 (131)	416 (263)	98.01
Riparian	cascara, red alder, western red cedar	< (79+)	Some areas were altered by the clear cut in 1992; others have remained untouched since the purchase of the property in 1959.	1	453 (537)	255 (251)	26.89

Table 2 A summary of the number of plots placed in each stand stage and unit and distribution between *Ilex*-absent and *Ilex* plots.

Stand Stage	Unit	Acreage of Unit	Number of plots for each condition (<i>Ilex-absent</i> / <i>Ilex-present</i>)
Open Grassland	1	18.13	20/6
	2	8.62	12/0
	3	6.14	10/0
			48
Seedling/Grass	1	43.2	6/6
			12
Sapling/Shrub	1	22.1	4/4
	2	9.12	4/4
			16
Late Initiation	1	11.89	3/3
	2	9.25	3/3
	3	24.37	13/13
			38
Stem Exclusion	2	23.68	3/3
	3	41.62	4/4
			14
Understory Reinitiation	1	37.56	6/6
	2	23.98	6/6
	3	36.47	9/9
			42
Riparian	1	26.89	15/15
			30
Total		343.02	200

Table 3 A summary of the number of plots forming the explanatory variable dataset.

The reason there is not an equal number of *Ilex* and *Ilex* absent plots is because two units within the open grassland stand stage did not have *Ilex* present. Because not all the measurements were taken on all the plots, the data was parsed into multiple datasets to test as many variables as possible, resulting in explanatory variables being tested with varying sample sizes.

Model Type	Major Explanatory Variables	Number of Plots	Min/Max (Standard Deviation) Values	Number of plots for each condition (<i>Ilex-absent</i> / <i>Ilex-present</i>)
Single Factor	Aspect	200	1.5/359 (95.96)	(118/82)
	Basal Area ft ² per Acre	200	0/1,318.98 (222.54)	(118/82)
	Number of Understory Vegetation Species	200	0/18 (4.4)	(118/82)
	Relative Density per Acre	200	0/955.38 (120.62)	(118/82)
	SDI	200	0/1,377.64 (282.81)	(118/82)
	Slope	200	0/22 (3.98)	(118/82)
	Stand Stage	200	N/A	(118/82)
	Trees per Acre	200	0/3660 (630.85)	(118/82)
	Volume ft ³ per Acre	200	0/52,635.49 (8,515.82)	(118/82)
	DBH of tree with branch over plot center	176	0/82.3 (15.30)	(106/70)
	Distance from plot center of tree with branch over plot center	176	0/19 (4.57)	(106/70)
	Downed Woody Debris (.5-1.9" diameter) Pieces per Acre	174	0/3,754.79 (456.63)	(105/69)
	Downed Woody Debris (0-.4" diameter) Pieces per Acre	174	0/25,114.62 (2470.49)	(105/69)
	Downed Woody Debris (2+" diameter) Pieces per Acre	174	0/25,111.80 (1912.18)	(105/69)
	Downed Woody Debris (Total) Pieces per Acre	174	0/25545.91 (3226.28)	(105/69)
	Basal Area ft ² per Acre	82	2.61/1,318.98 (261.97)	(0/82)
	<i>Ilex</i> Growth Type	82	N/A	(0/82)

Multi Factor	Downed Woody Debris (.5-1.9" diameter) Pieces per Acre	174	0, 25,114.62 (2470.49)	(105/69)
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DBH of tree with branch over plot center	174	0, 82.3 (15.37)	(106/70)
Distance from plot center of tree with branch over plot center	174	0, 19 (4.60)	(106/70)
Number of Understory Vegetation Species	174	0, 18 (4.45)	(105/69)
SDI	174	0, 1377.64 (287.67)	(105/69)
DBH of tree with branch over plot center	70	0, 82.3 (18.56)	
Distance from plot center of tree with branch over plot center	70	0, 16.08 (3.51)	
<i>Ilex</i> Growth Type	70	N/A	(0/70)
Number of Understory Vegetation Species	70	3, 18 (3.68)	(0/70)
SDI	70	20.14, 1377.64 (298.78)	(0/70)

Appendix 3 DBH and Basal Area per Acre Distributions for Stand Stages and Units

Open Grassland

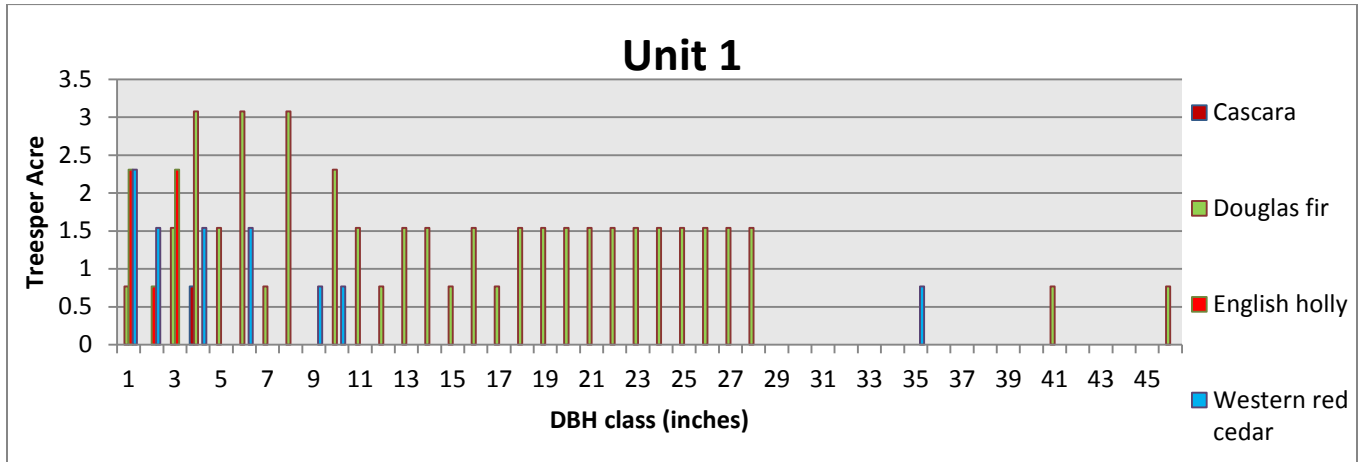


Figure 28 DBH distribution of Open Grassland Unit 1 is based on 26 plots across 18.13 acres. This unit has (21, 66) trees per acre, unless a 10% chance occurred.

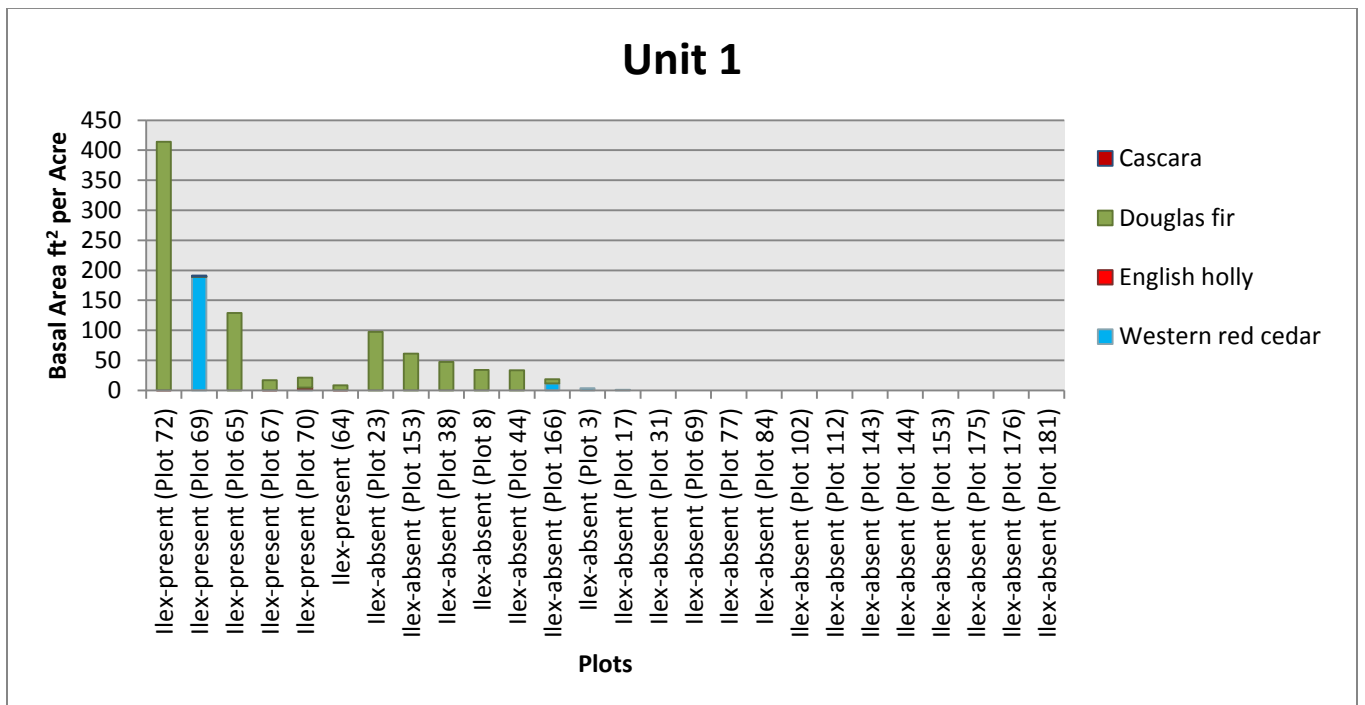


Figure 29 The basal area composition of Open Grassland Unit 1. This area is browsed by cattle. Douglas fir basal area on the plot is high, because a plot contained one of several wolf trees scattered throughout the open grassland units.

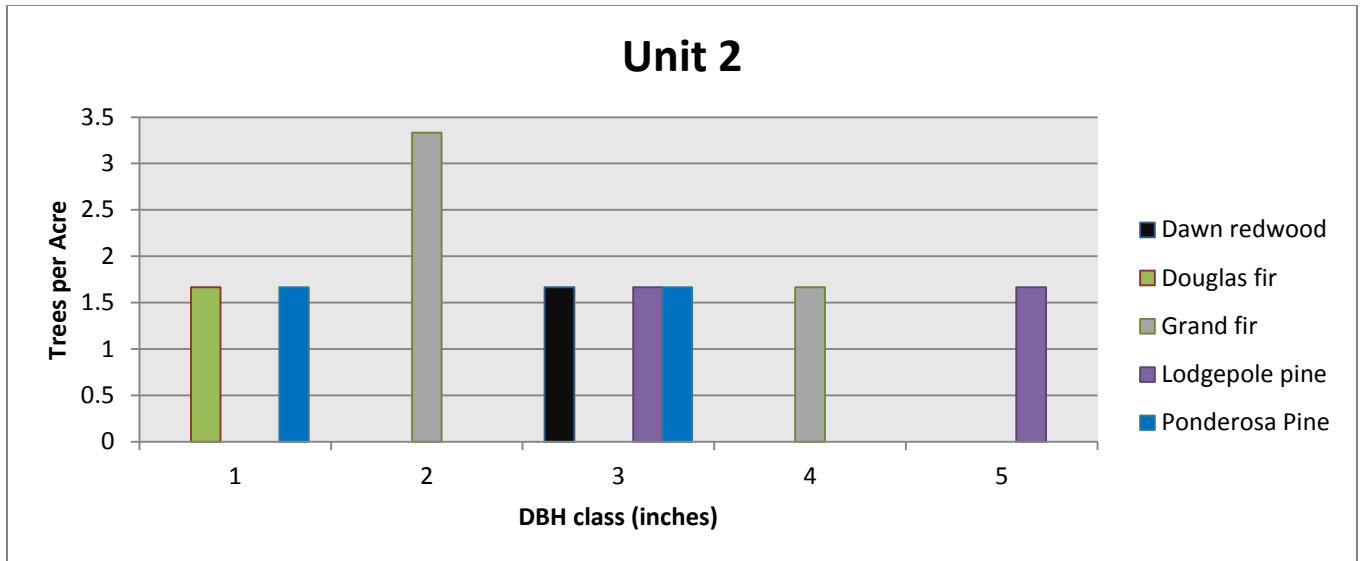


Figure 30 DBH distribution for Open Grassland Unit 2 is based on 12 plots across 8.62 acres. This unit has (0, 37) trees per acre, unless a 10% chance occurred. These trees were all planted.

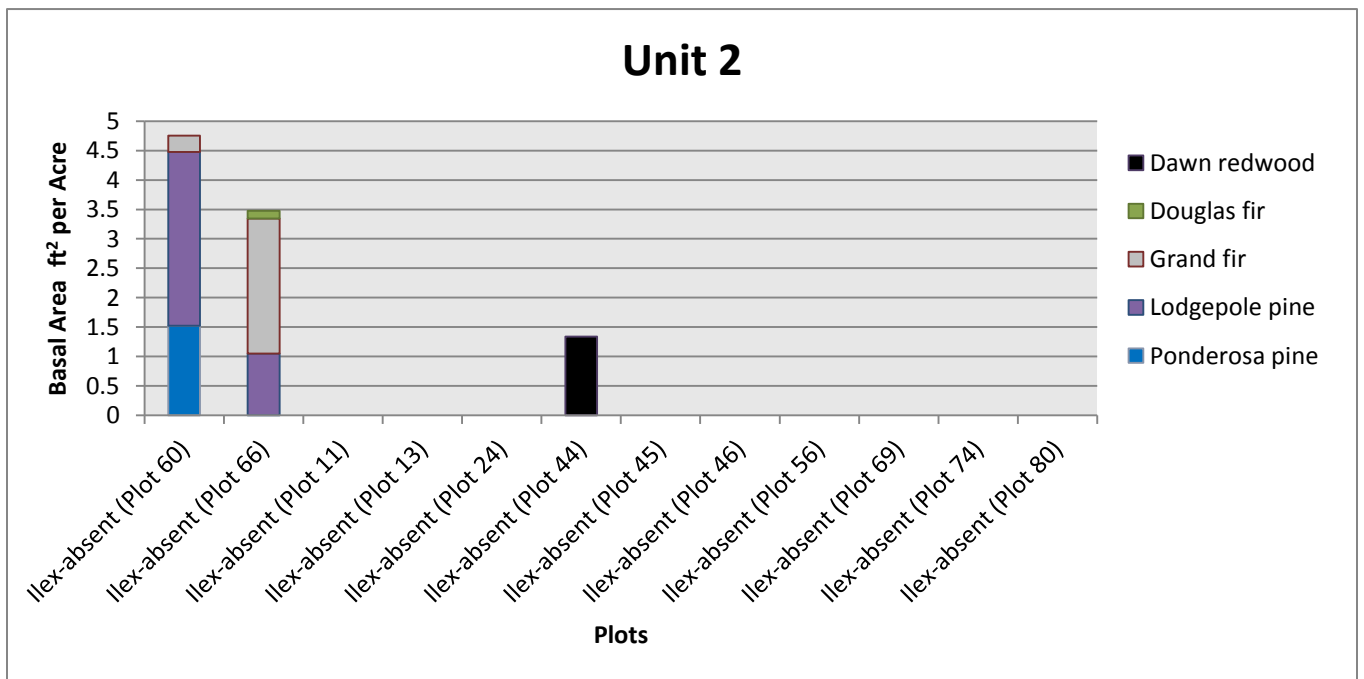


Figure 31 The basal area composition of Open Grassland Unit 2. This area is not browsed by cattle. The trees present in this unit were planted

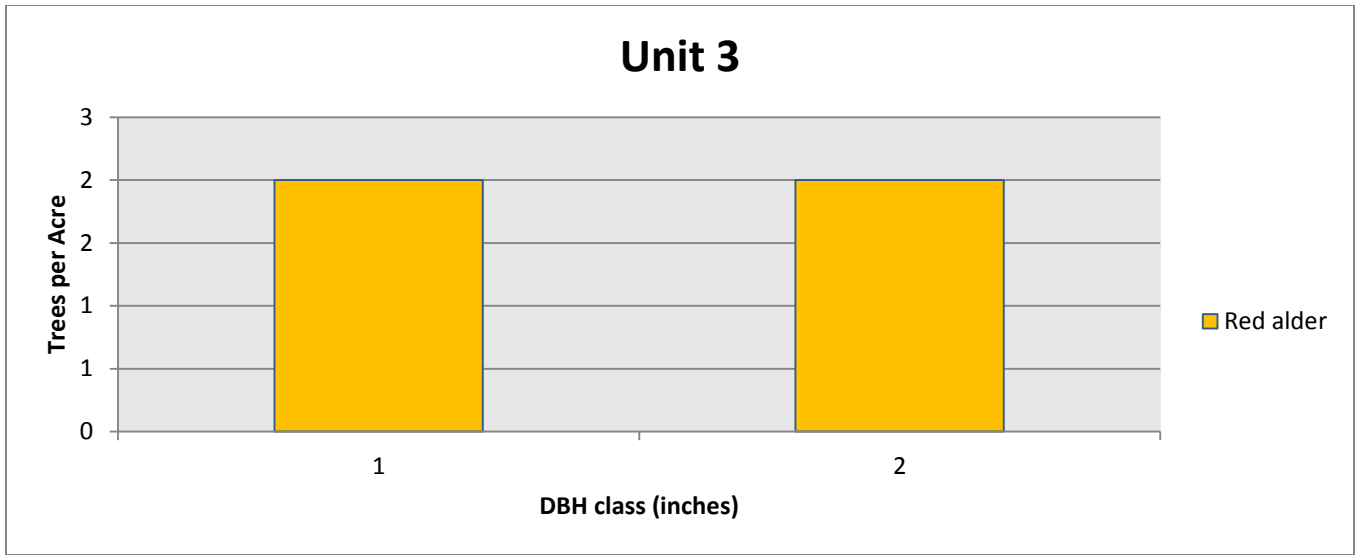


Figure 32 DBH distribution for Open Grassland Unit 3 is based on 10 plots across 6.14 acres. This unit has (1, 9) trees per acre, unless a 10% chance occurred.

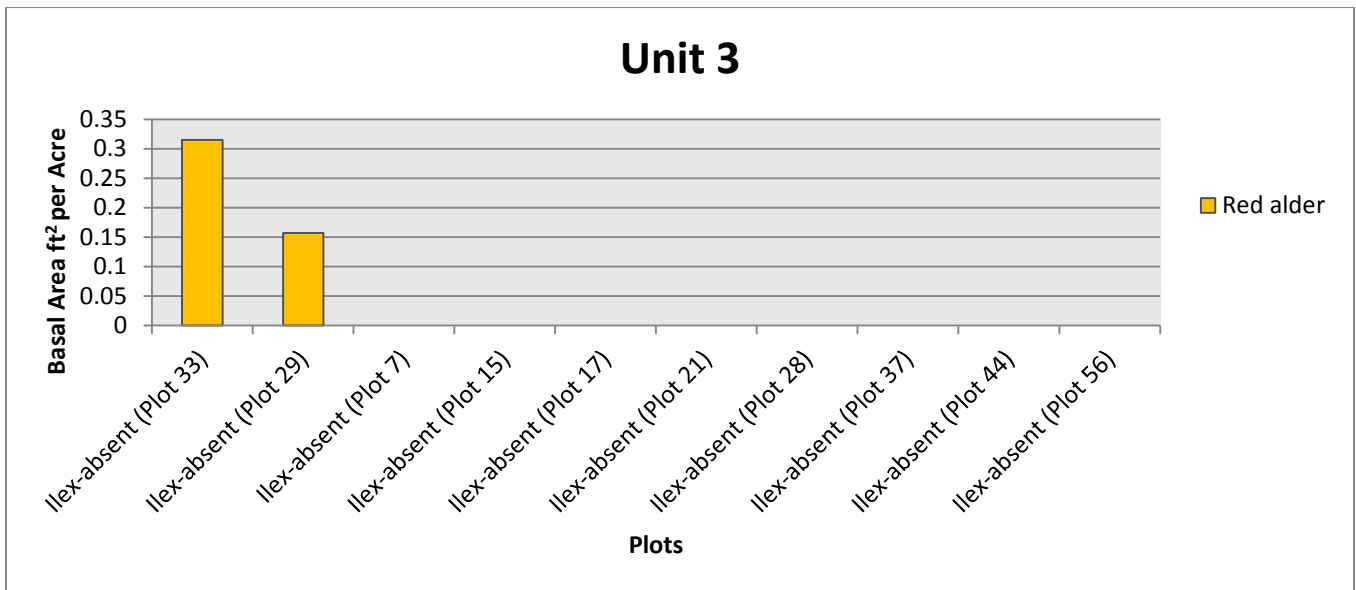


Figure 33 The basal area composition of Open Grassland Unit 3. This area is not browsed by cattle.

Seedling Grass

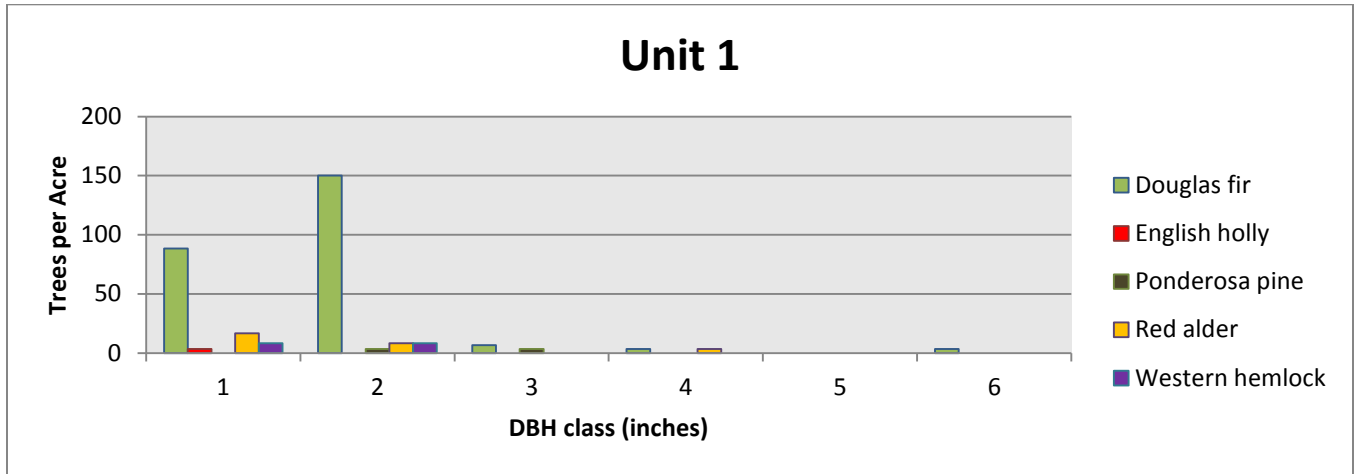


Figure 34 DBH distribution for Seedling Grass is based on 12 plots across 43.2 acres. This unit has (241, 358) trees per acre, unless a 10% chance occurred.

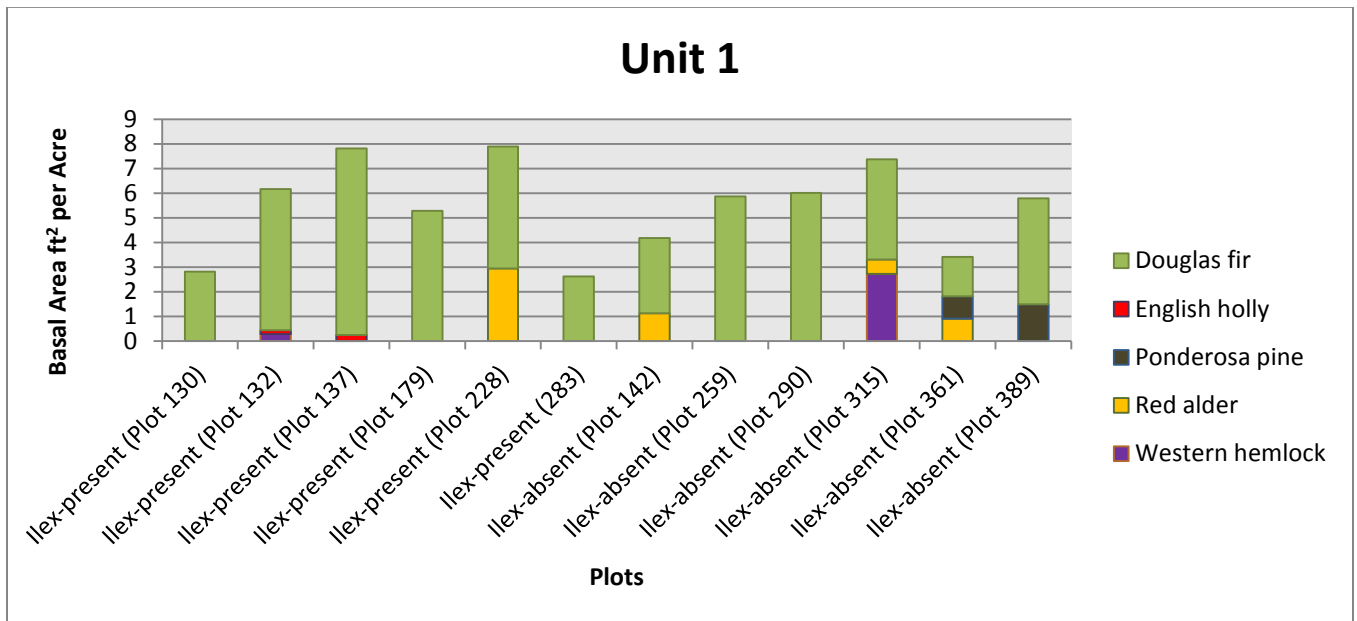


Figure 35 The basal area composition of Seedling Grass.

Sapling Shrub

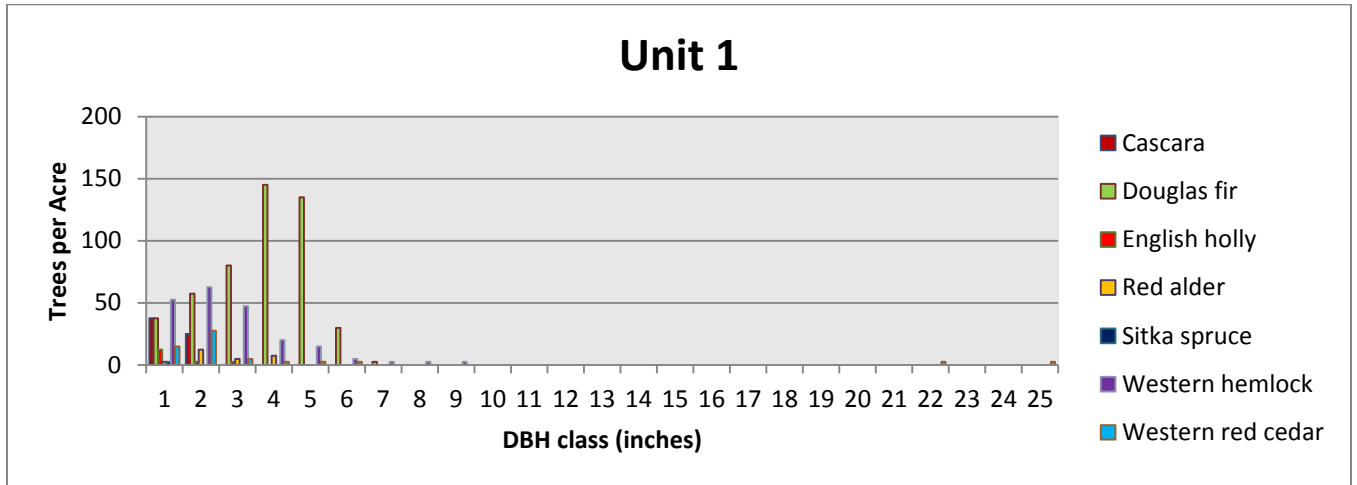


Figure 36 DBH distribution for Sapling Shrub Unit 1 is based on 8 plots across 22.1 acres. This unit has (630, 1105) trees per acre, unless a 10% chance occurred.

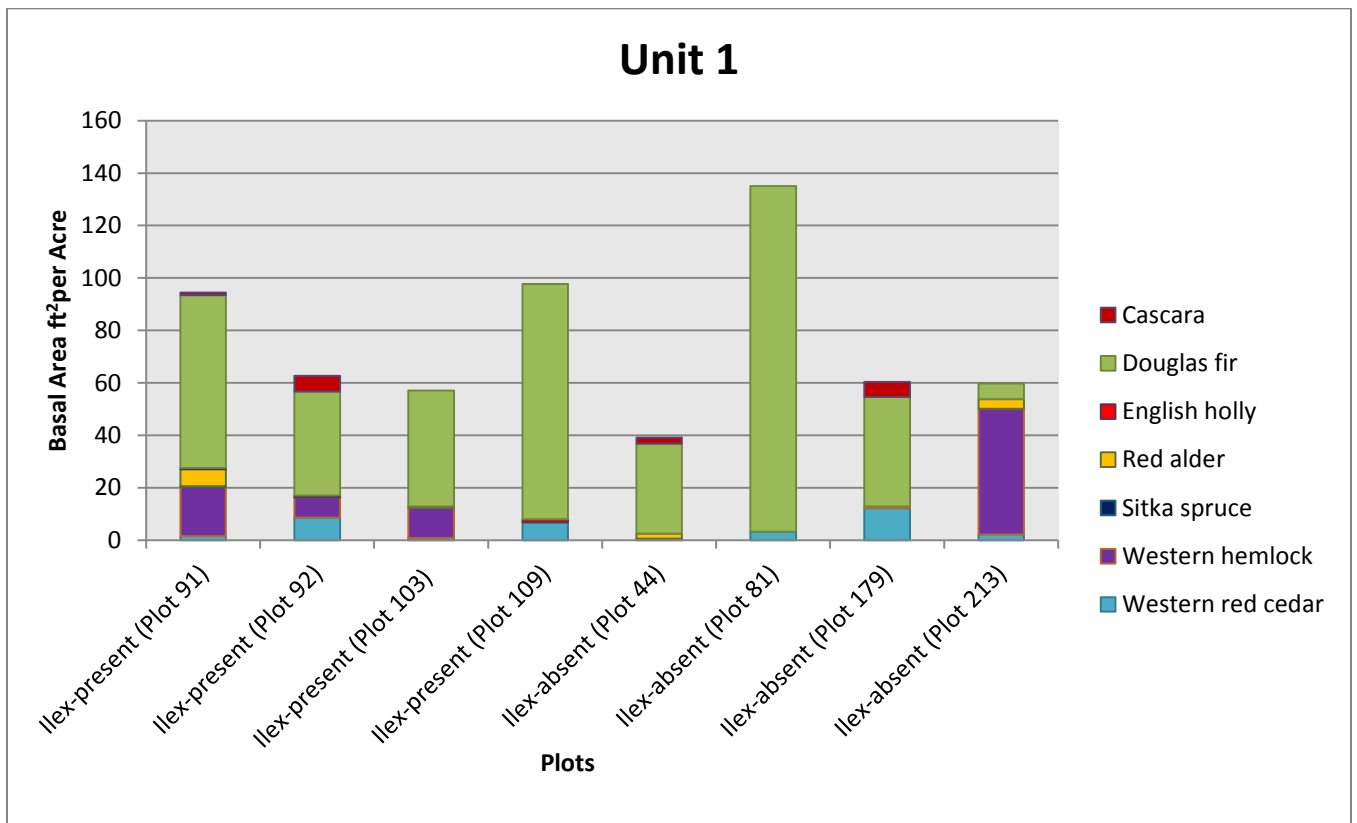


Figure 37 The basal area composition of Sapling Shrub Unit 1.

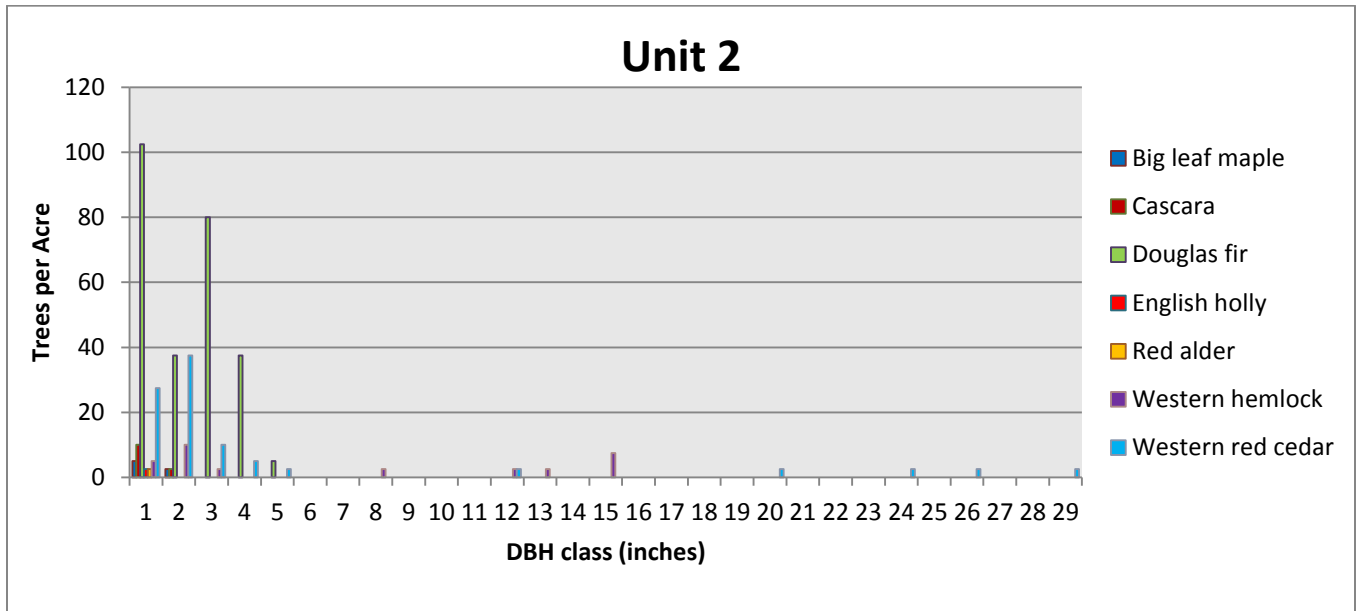


Figure 38 DBH distribution for Sapling Shrub Unit 2 is based on 8 plots across 9.12 acres. This unit has (243, 402) trees per acre, unless a 10% chance occurred.

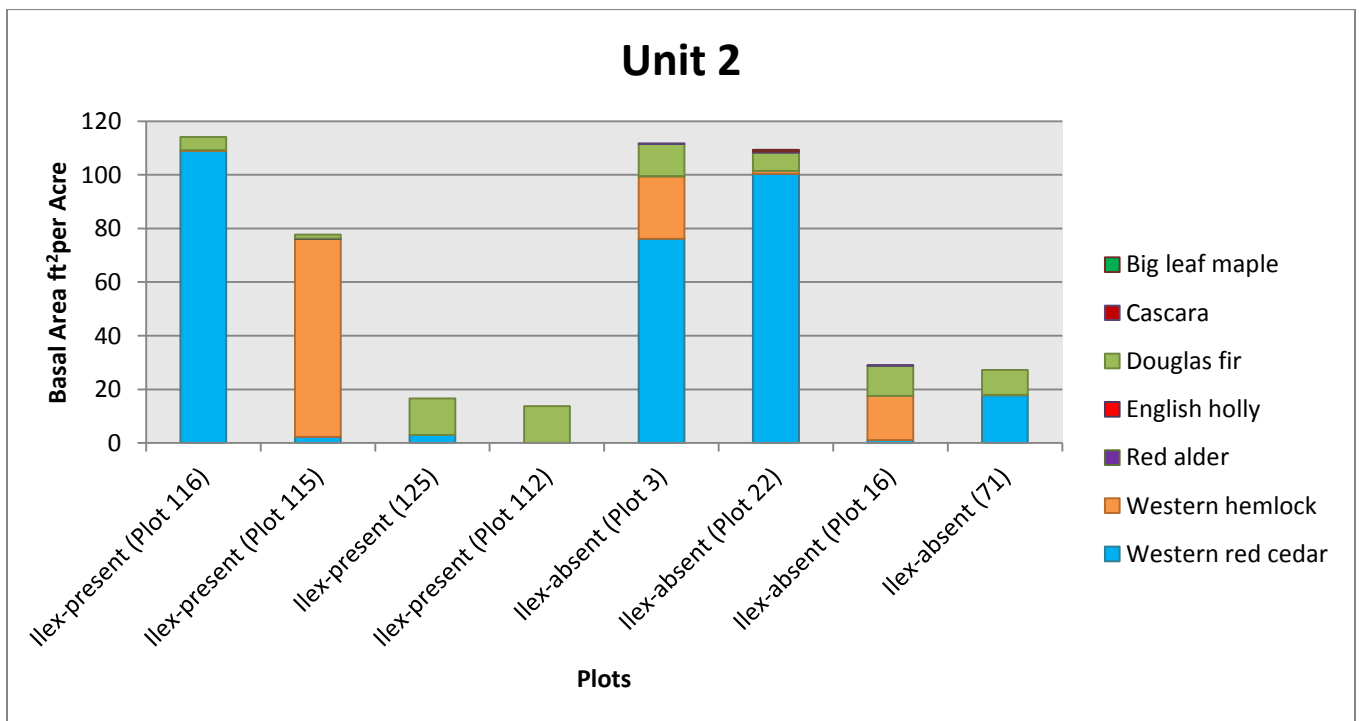


Figure 39 The basal area composition of Sapling Shrub Unit 2. The high basal area totals of western hemlock and western red cedar are because they were wildlife trees left behind after the clear cut.

Late Initiation

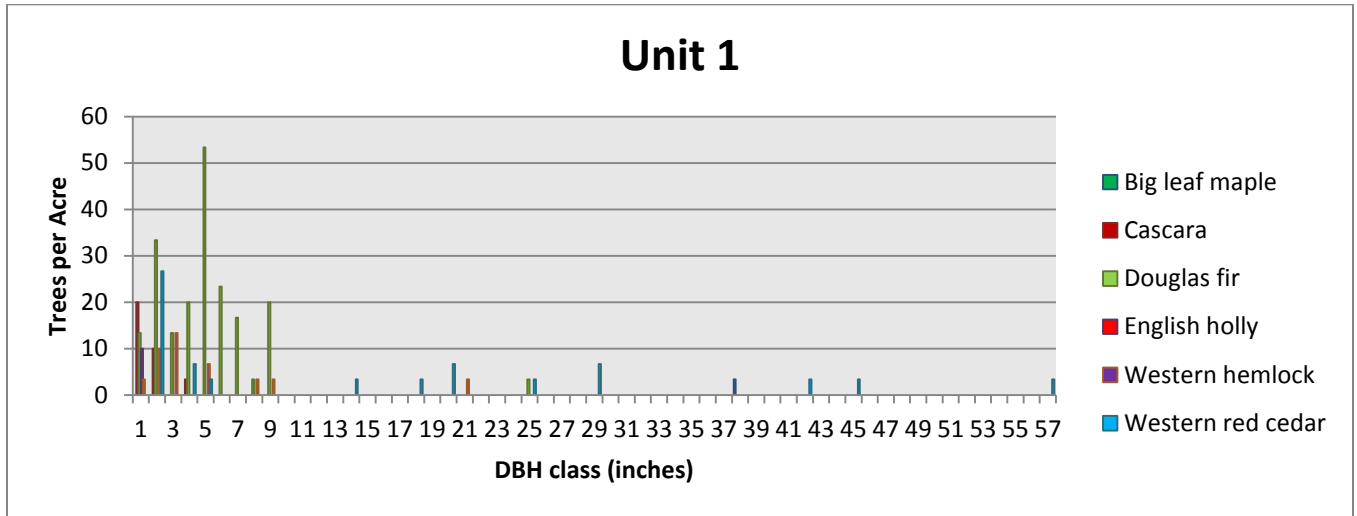


Figure 40 DBH distribution for Late Initiation Unit 1 is based on 6 plots across 11.89 acres. This unit has (174, 546) trees per acre, unless a 10% chance occurred.

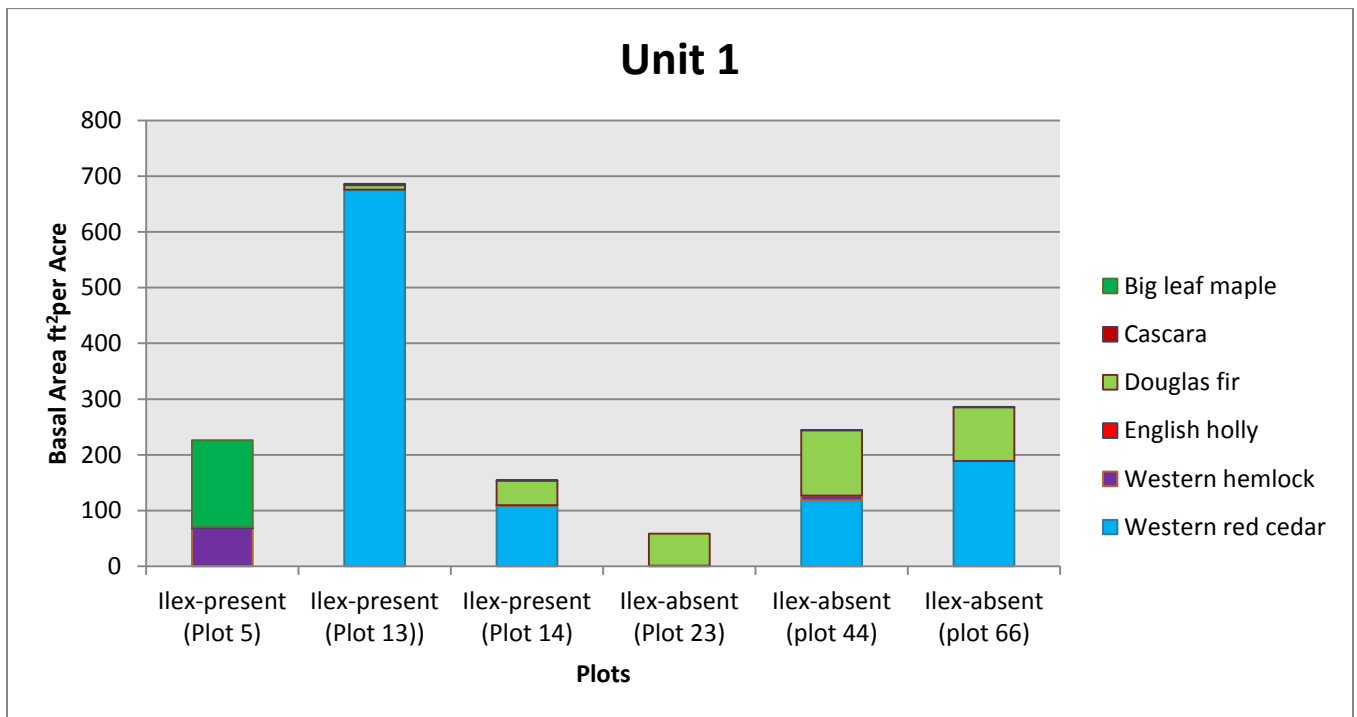


Figure 41 The basal area composition of Late Initiation Unit 1.

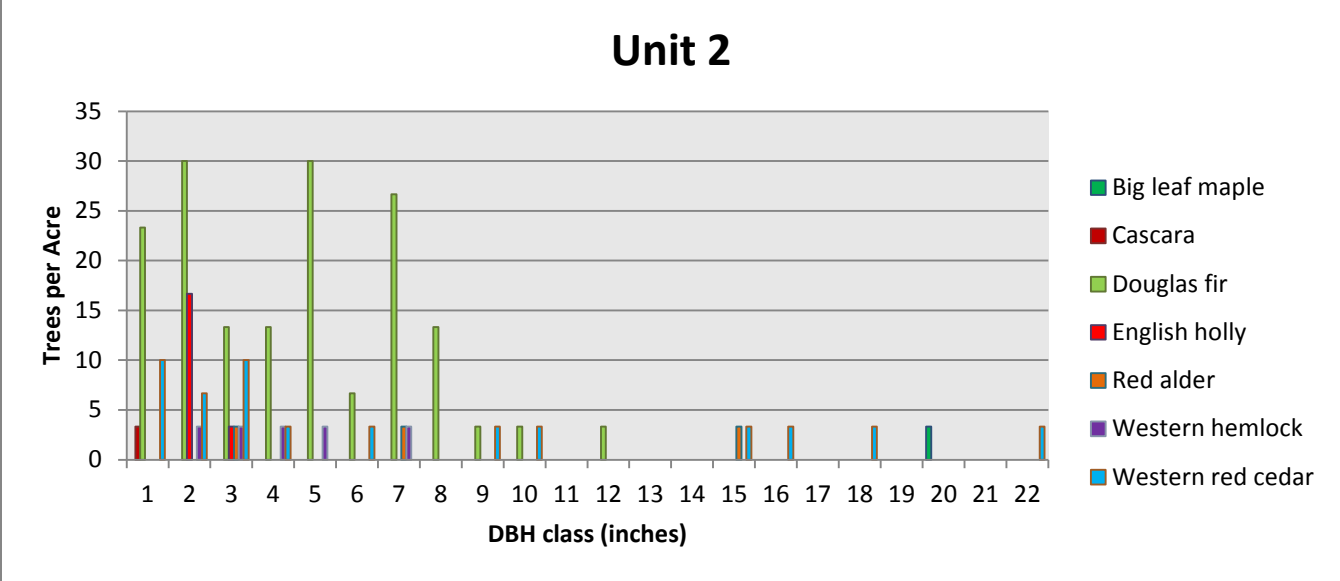


Figure 42 DBH distribution for Late Initiation Unit 2 is based on 6 plots across 9.25 acres. This unit has (160, 393) trees per acre, unless a 10% chance occurred.

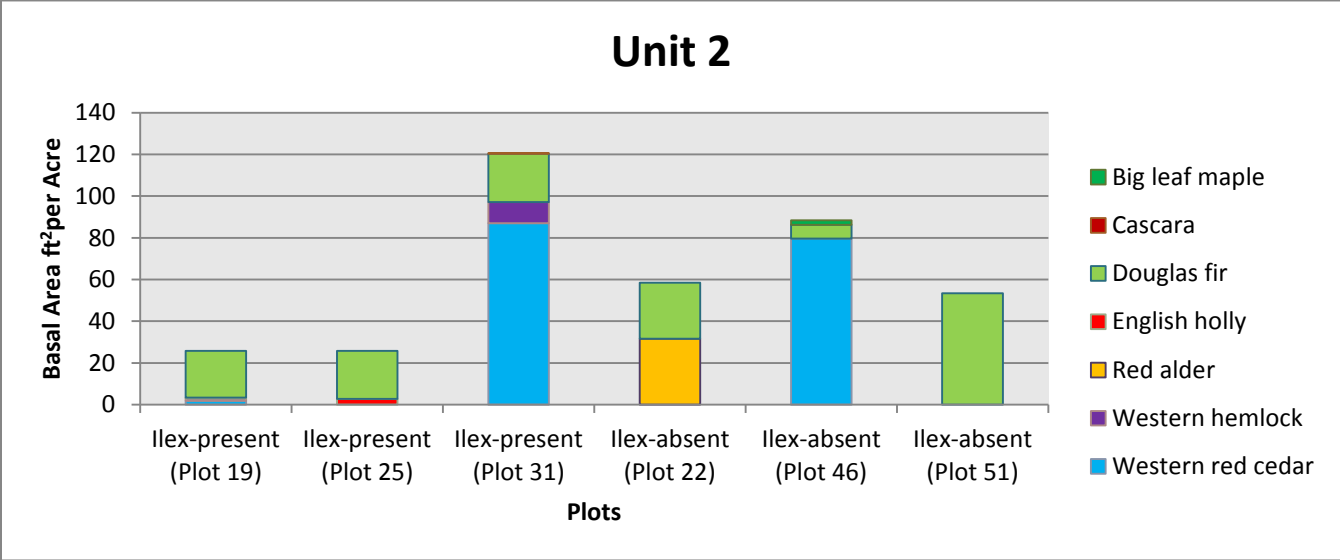


Figure 43 The basal area composition of Late Initiation Unit 2.

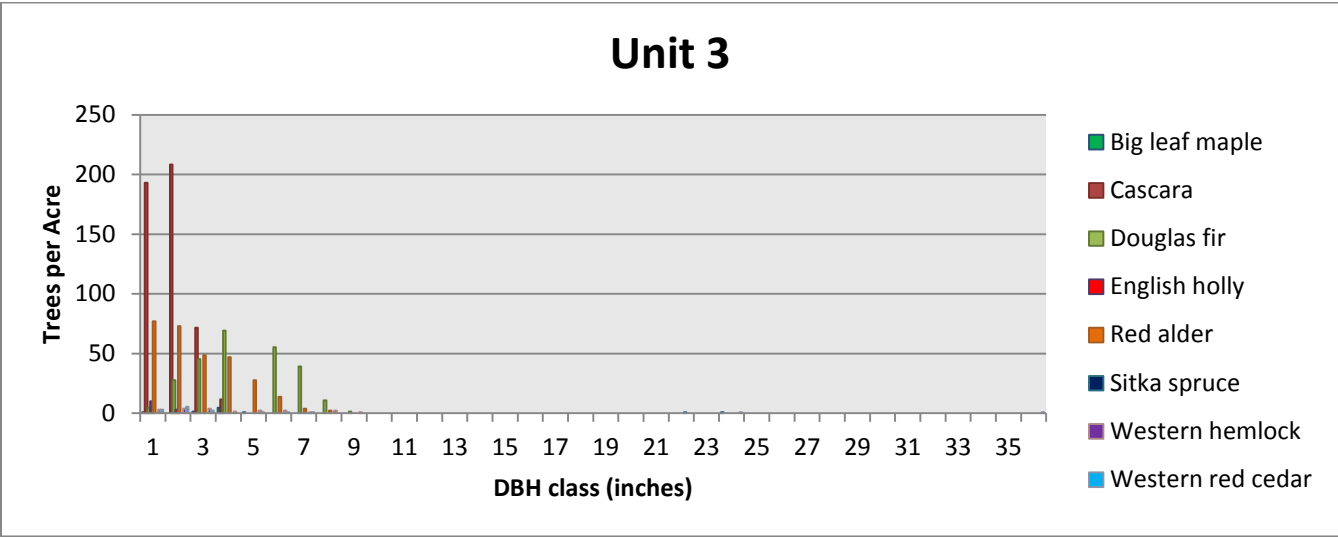


Figure 44 DBH distribution for Late Initiation Unit 3 is based on 26 plots across 24.37 acres. This unit has (930, 1345) trees per acre, unless a 10% chance occurred.

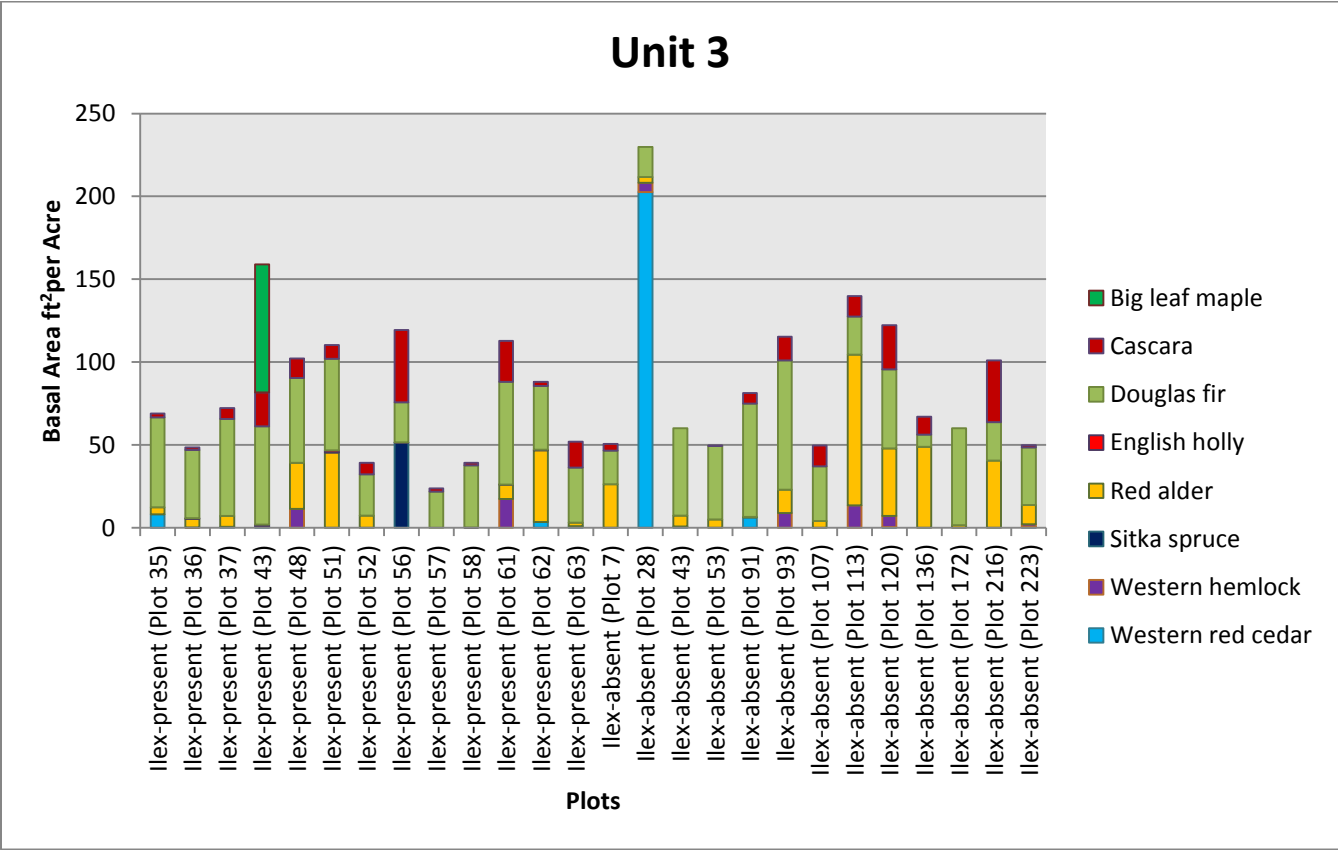


Figure 45 The basal area composition of Late Initiation Unit 3.

Stem Exclusion

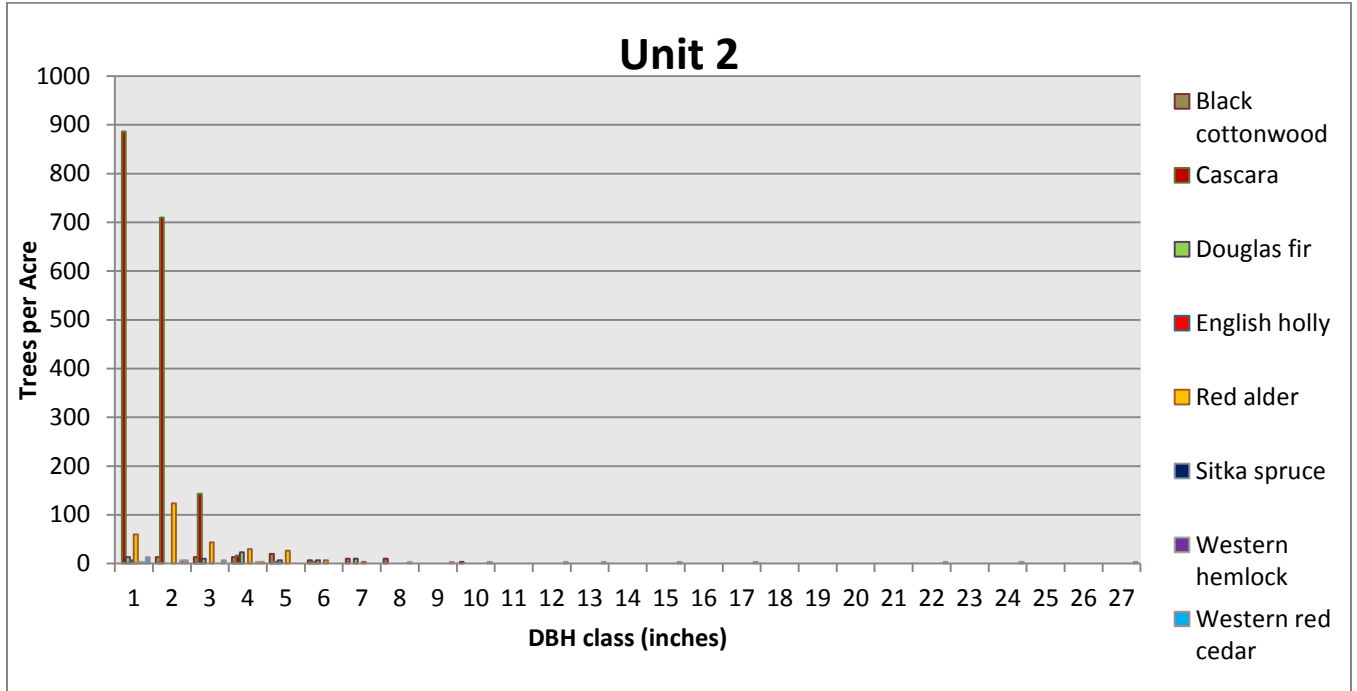


Figure 46 DBH distribution for Stem Exclusion Unit 2 is based on 8 plots across 23.68 acres. This unit has (1517, 3096) trees per acre, unless a 10% chance occurred.

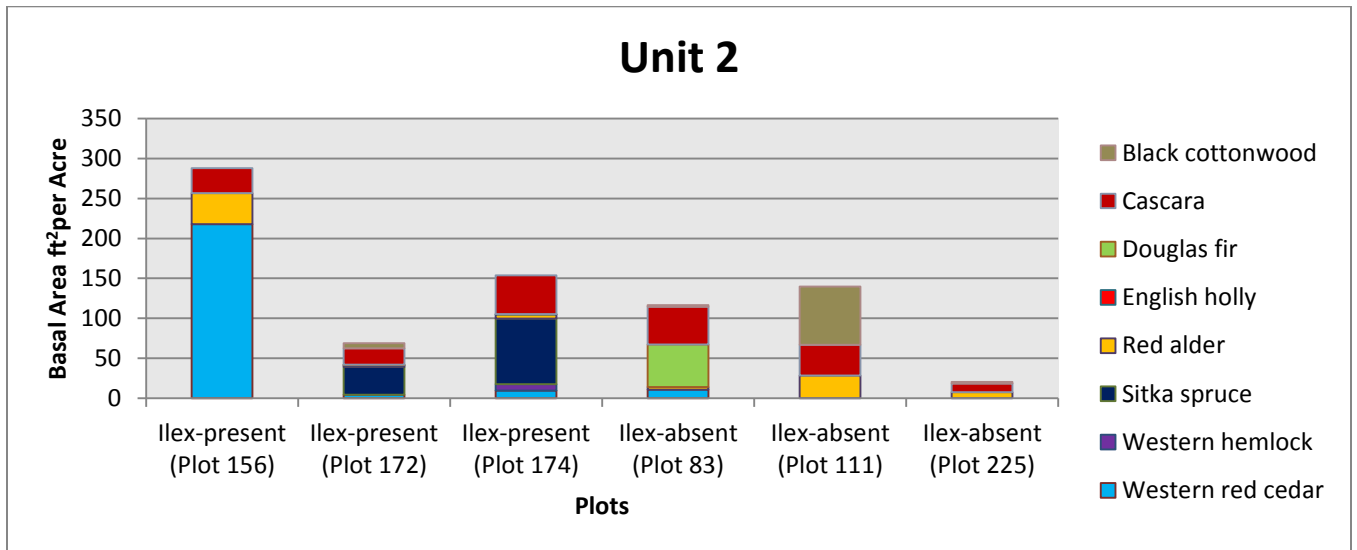


Figure 47 The basal area composition of Stem Exclusion Unit 2.

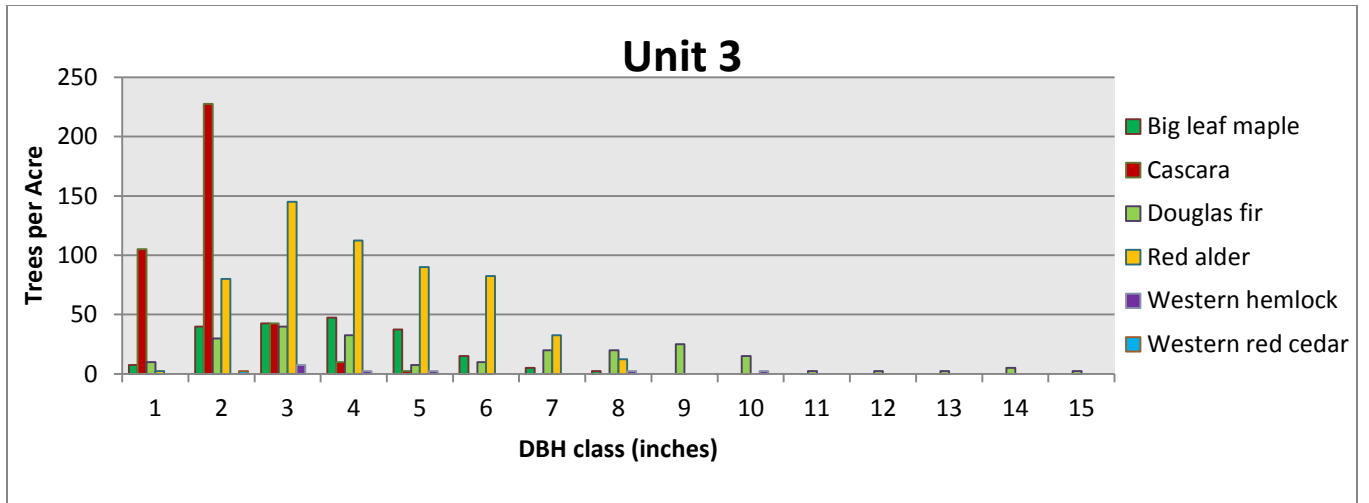


Figure 48 DBH distribution for Stem Exclusion Unit 3 is based on 8 plots across 41.62 acres. This unit has (1123, 1646) trees per acre, unless a 10% chance occurred.

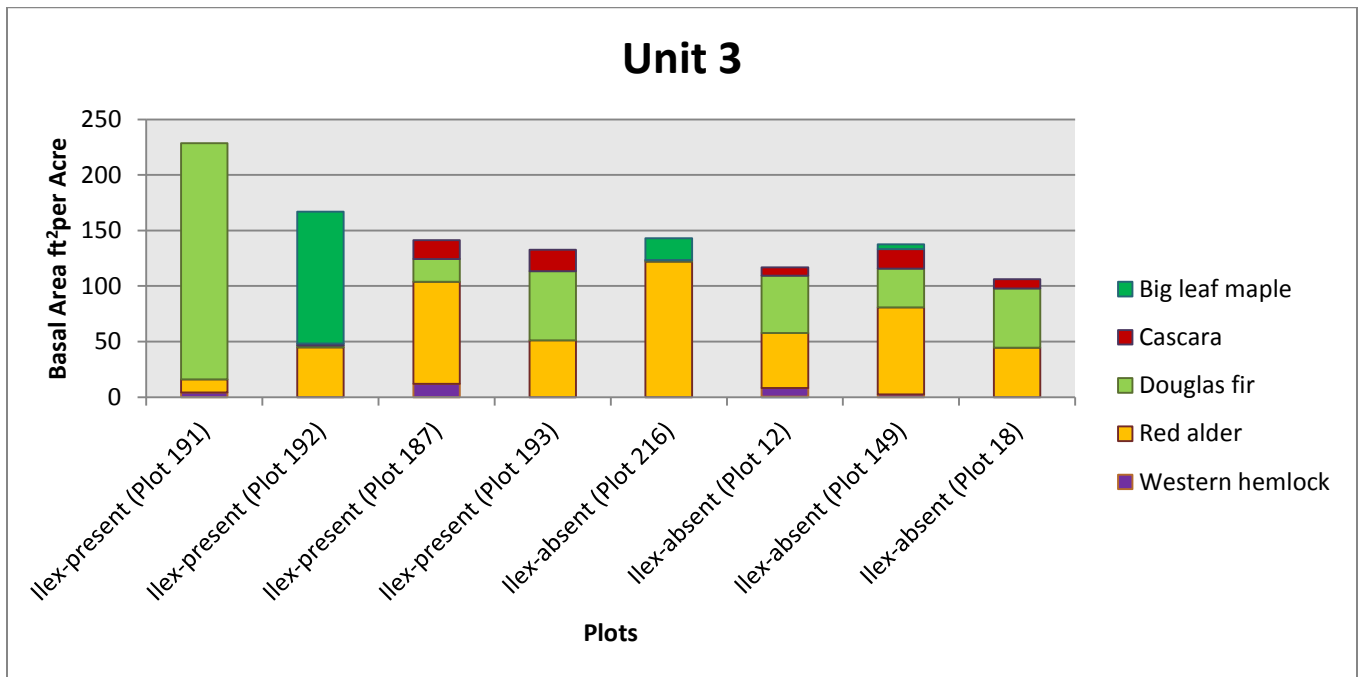


Figure 49 The basal area composition of Stem Exclusion Unit 3.

Understory Reinitiation

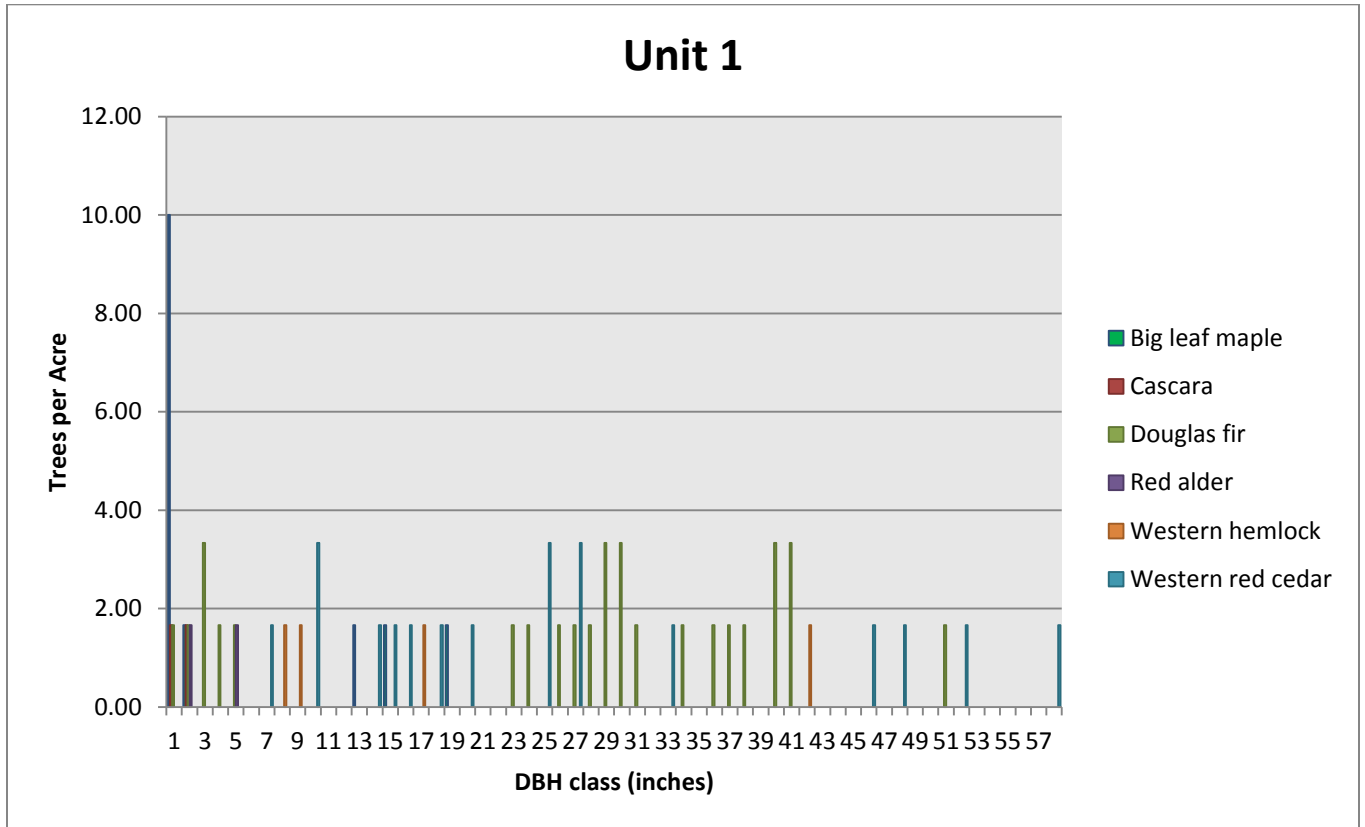


Figure 50 DBH distribution for Understory Reinitiation Unit 1 is based on 12 plots across 37.56 acres. This unit has (154, 516) trees per acre, unless a 10% chance occurred.

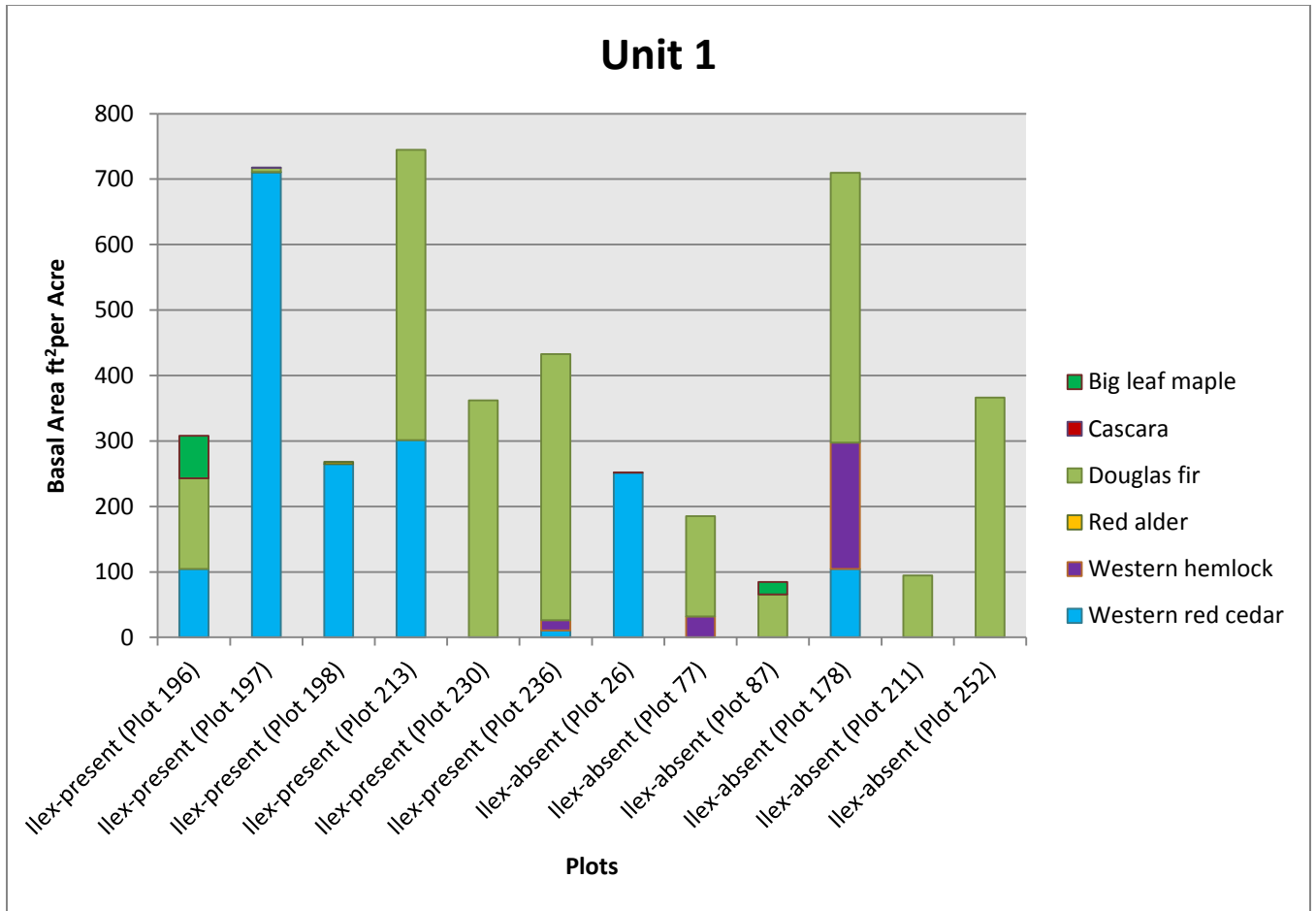


Figure 51 The basal area composition of Understory Reinitiation Unit 1.

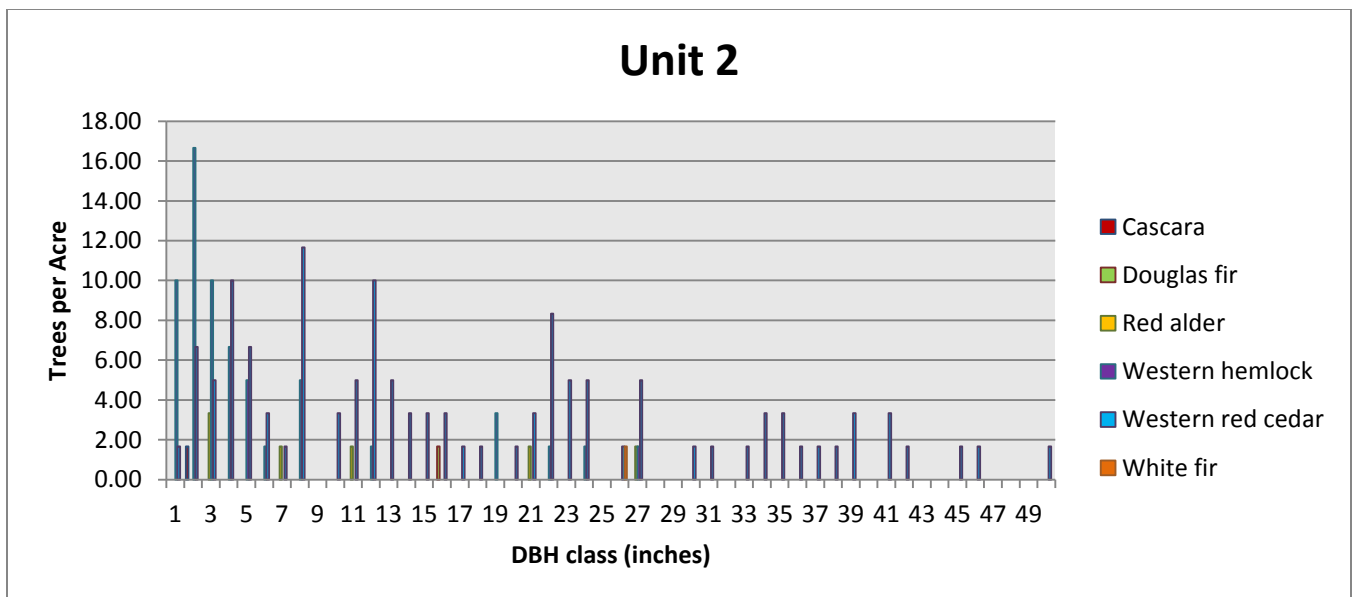


Figure 52 DBH distribution for Understory Reinitiation Unit 2 is based on 12 plots across 23.98 acres. This unit has (158, 289) trees per acre, unless a 10% chance occurred.

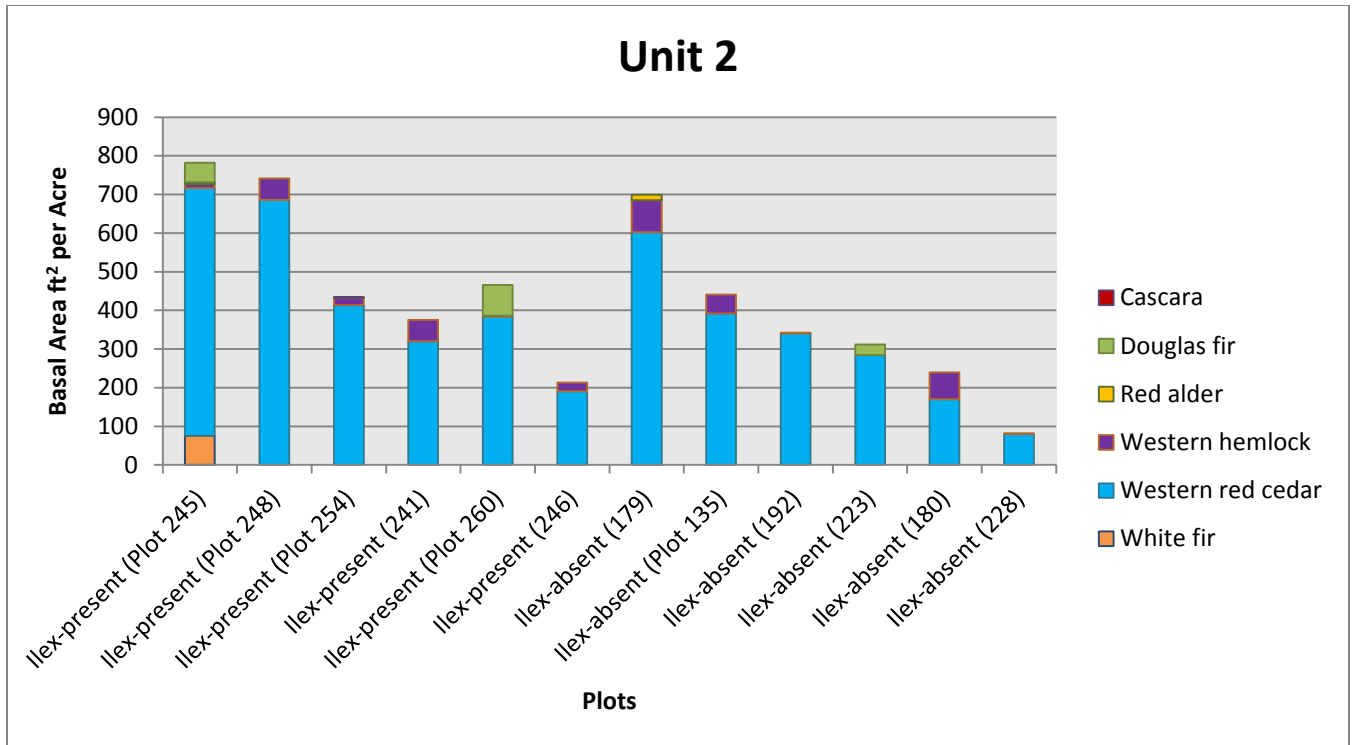


Figure 53 The basal area composition of Understory Reinitiation Unit 2.

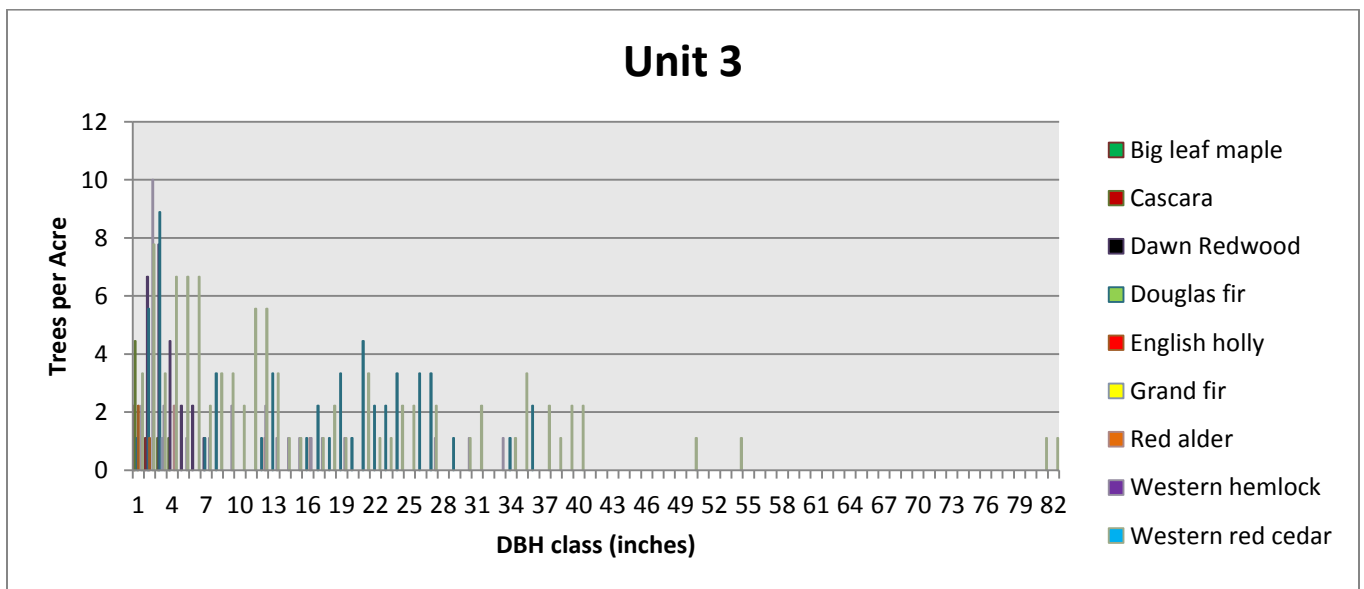


Figure 54 DBH distribution for Understory Reinitiation Unit 3 is based on 18 plots across 36.47 acres. This unit has (173, 287) trees per acre, unless a 10% chance occurred.

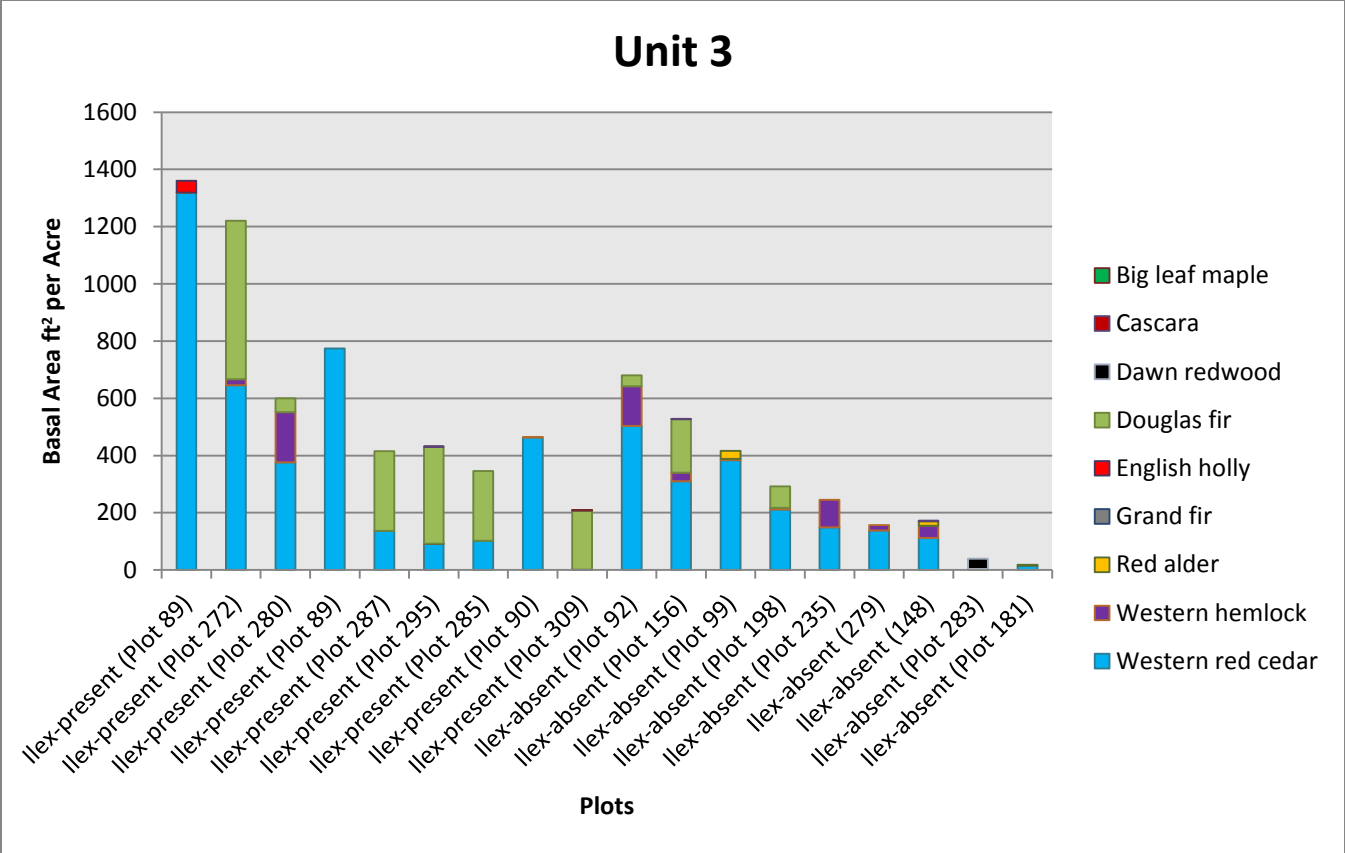


Figure 55 The basal area composition of Understory Reinitiation Unit3. The *Ilex* plot with the highest basal area is due to 81.4", 53.9", and 50.1" dbh western red cedars on that plot. The second highest plot had an 82.3" dbh western red cedar.

Riparian

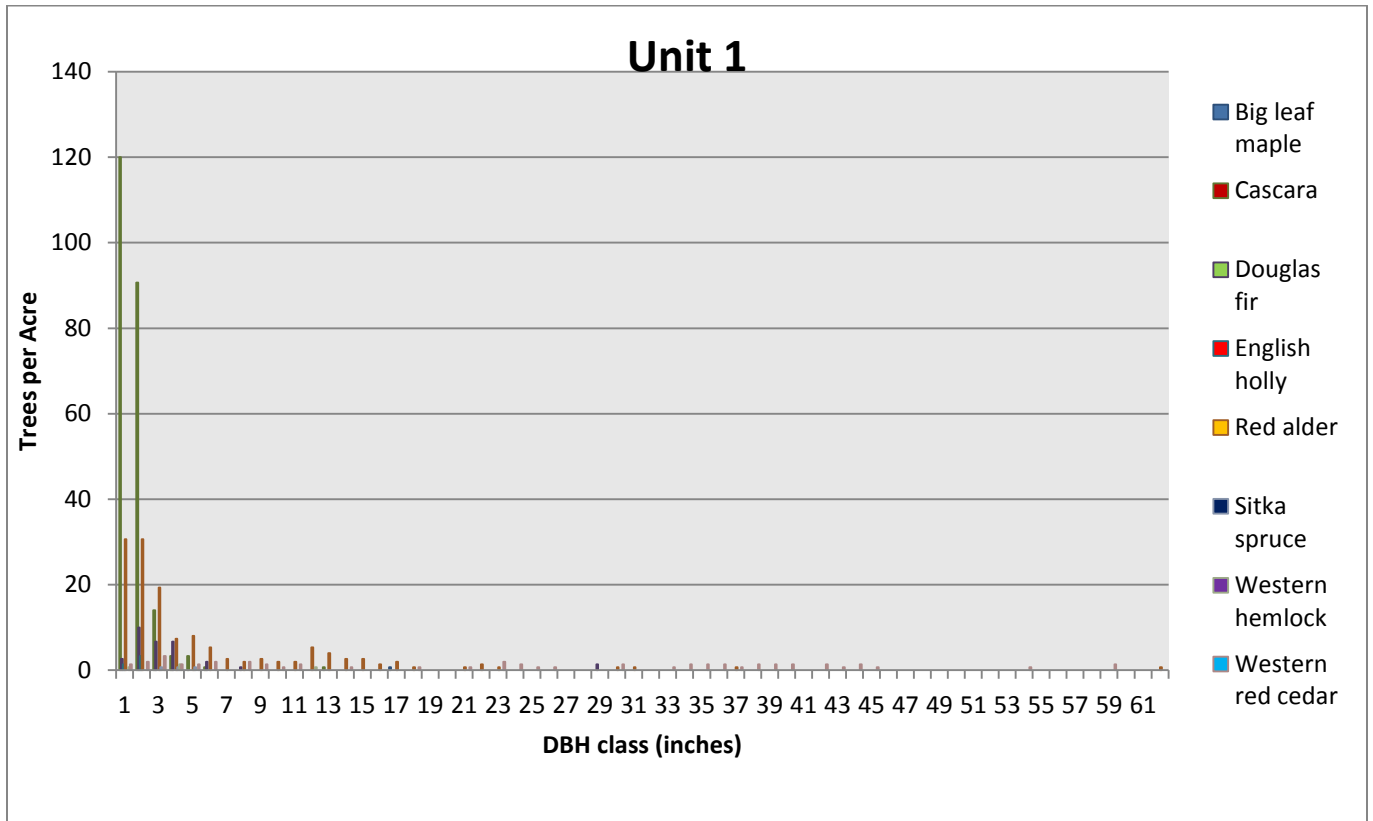


Figure 56 DBH distribution for Riparian is based on 30 plots across 26.89 acres. This unit has (286, 619) trees per acre, unless a 10% chance occurred.

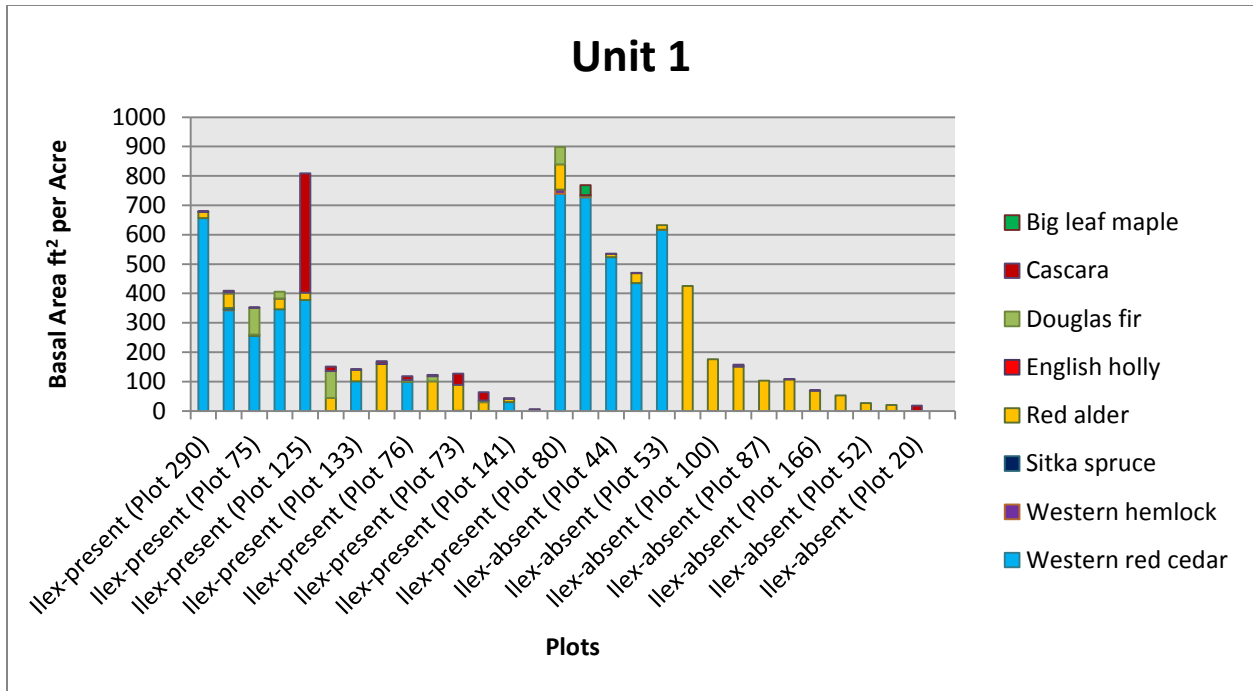


Figure 57 The basal area composition of Riparian area. The plot with the highest basal area has a 58.6", 39.5", and 38.3" dbh western red cedars, a 23.1" dbh Douglas fir, and a 23.5" dbh red alder.

Appendix 4 Trees and Plants Identified in the Research Area

This is a listing of plants observed on plots in the research area. If the exact variety is unknown, the species name is given. Note that herbaceous plants are not included.

Scientific Name	Common Name	Comments
	native grass	
<i>Abies grandis</i>	grand fir	
<i>Acer circinatum</i>	vine maple	
<i>Acer macrophyllum</i>	big leaf maple	
<i>Alnus rubra</i>	red alder	
<i>Athyrium filix-femina</i>	lady fern	
<i>Blechnum spicant</i>	deer fern	
<i>Carex lyngbyei</i>	Lyngbye's sedge	
<i>Cornus nuttallii</i>	flowering dogwood	
<i>Corylus cornuta var. californica</i>	beaked hazelnut	
<i>Crataegus douglasii</i>	black hawthorn	
<i>Cytisus scoparius</i>	Scotchbroom	
<i>Equisetum fluviatile</i>	horsetail	
<i>Gaultheria shallon</i>	salal	
<i>Holodiscus discolor</i>	ocean spray	
<i>Ilex aquifolium</i>	English holly	
<i>Lysichiton americanum</i>	skunk cabbage	
<i>Mahonia nervosa</i>	low Oregon grape	

<i>Metasequoia glyptostroboides</i>	dawn redwood	planted by property owner, date unknown
<i>Oemlaria cerasiformis</i>	Indian plum	
<i>Oplopanax horridus</i>	devil's club	
<i>Phalaris arundinacea</i>	reed canary grass	
<i>Philadelphus lewisii</i>	mock orange	
<i>Picea sitchensis</i>	Sitka spruce	
<i>Pinus contorta</i>	lodgepole pine	planted by property owner, date unknown
<i>Pinus ponderosa</i>	ponderosa pine	planted by property owner, date unknown
<i>Polystichum munitum</i>	swordfern	
<i>Populus balsamifera</i>	black cottonwood	planted in 1992
<i>Prunus emarginata</i>	bitter cherry	
<i>Pseudotsuga menziesii</i>	Douglas-fir	
<i>Pteridium aquilinum</i>	bracken fern	
<i>Pyrus</i>	wild apple	
<i>Rhamnus purshiana</i>	cascara	
<i>Ribes</i>	flowering currant	
<i>Ribes lacustre</i>	black gooseberry	
<i>Rosa gymnocarpa</i>	bald hip rose	
<i>Rubus armeniacus</i>	Himalayan blackberry	
<i>Rubus laciniatus</i>	evergreen blackberry	
<i>Rubus parviflorus</i>	thimbleberry	

<i>Rubus spectabilis</i>	salmonberry
<i>Rubus ursinus</i>	trailing blackberry
<i>Salix</i>	willow
<i>Sambucus caerulea</i>	blue elderberry
<i>Sorbus americana</i>	mountain ash
<i>Spiraea douglasii</i>	spirea
<i>Symphoricarpos albus</i>	snowberry
<i>Thuja plicata</i>	western red cedar
<i>Tsuga heterophylla</i>	western hemlock
<i>Urtica dioica</i>	stinging nettle
<i>Vaccinium ovatum</i>	evergreen huckleberry
