Headwaters Forest Reserve: Growth Model Development for Northern California Second and Old Growth Redwood Stands

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ENVS410, Fall 2011
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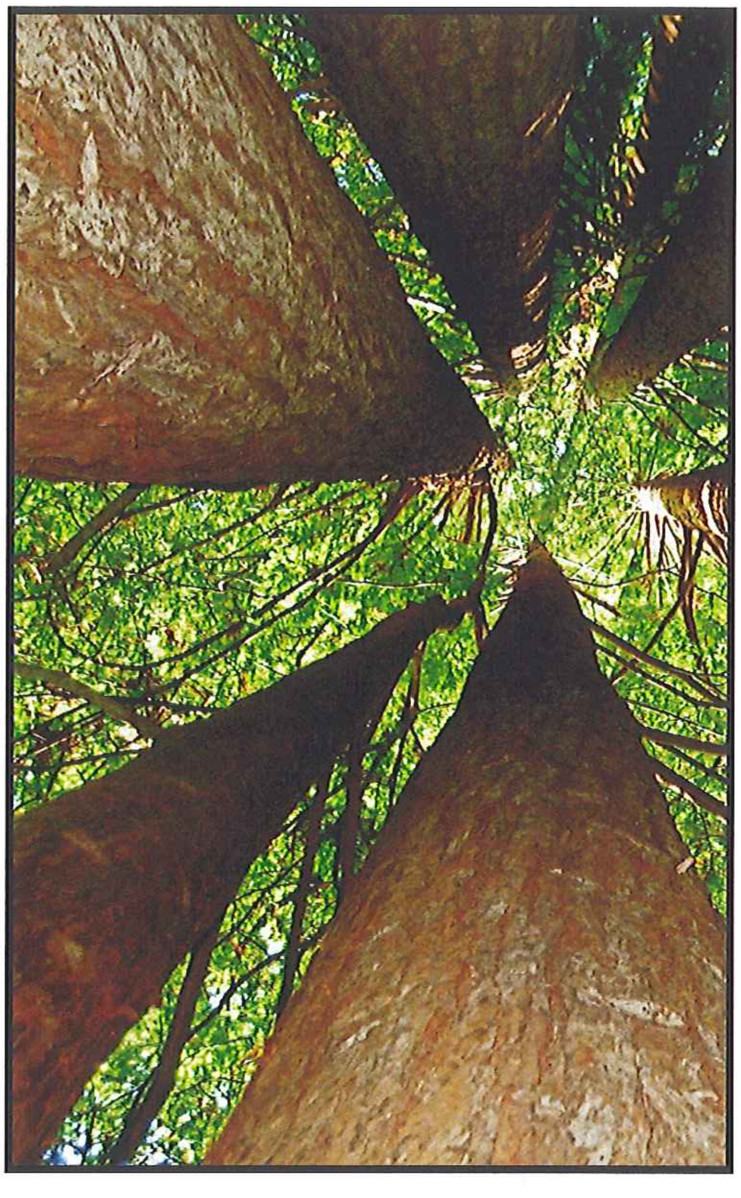


Introduction

Thinning of timber stands can have a large positive impact on the stand if done correctly. This method has been used in many applications ranging from fuels management to pre-commercial harvesting. In the context of managing for wild flora and fauna, thinning can be utilized as a mechanism in creating old growth characteristics faster than natural processes allow (Dagley, 2007).

Located within the north coast region of California, land now designated as the Headwaters Forest Reserve was previously owned by Pacific Lumber Company (PALCO). In 1986, the property was bought out by Charles Hurwitz of Maxxam Corp. (Bay Area Coalition, 2009). However, not all of the land purchased contained untouched forest. Several acres of land on the preserve were logged and are regenerating as second growth forest (Figure3). The removal of some second growth trees has been shown to reduce competition and therefore encourage fewer, larger stems, to grow within a dominant overstory (Albrecht et. al., 2006).

Headwaters Forest Reserve shares many similarities with other local restoration projects such as Redwood National Park. For Redwood National Park, two different thinning prescriptions were used depending on slope steepness and road access. These thins were of moderate and low intensity. Forty-percent of the moderate thin of merchantable size would be sold (after removal) to the contractor for sale off-site (Teraoka, 2010). Despite similar thinning regimes, Headwaters differs in that it will not be selling felled timber. As part of restoration efforts, the reserve will be utilizing felled timber for attempting to return second growth to old growth conditions (BLM: Priorities for the Reserve, 2008).

Utilizing field data collected on both old growth (Figure2) and second growth stands, can be analyzed to develop a correlation between tree growth and neighboring competition. Correlations can then be made into active models useful for sustainable management practices. Models take visual and biological correlations and translate them into demonstrating the mathematical and statistical aspects of data (Hasenauer, 2006).

Problem Statement

Headwaters Forest Reserve has several stands of second growth trees that are too dense. By having an excess of trees closely spaced, stands become overly competitive therefore limiting growth. This process is called the "Stem Exclusion Phase" of tree stand development where competition excludes weaker trees. Although this stage is a natural process, it can drastically reduce or even stop the growth of certain trees. The thicker the stand becomes, the greater the fire risk. Consequently, this contributes to even less understory vegetative growth.

Geographic Project Location

The project was located in Headwaters Forest Reserve near the town of Fortuna, CA. Plot sampling occurred within the 7,472 acres of forested land and was taken from both old growth (undisturbed) and second growth (disturbed) stands. Geographically, the plots are nestled within the coastal mountain redwood region.

Specific Project Location

The primary location of sampling occurred within the Governor's Grove section of Headwaters Forest Reserve. Areas included plots of uncut mixed old growth as well as plots of regenerating second growth.

- **Vegetation**

Old growth areas contain a large over story of Coast Redwood. These stands encompass a multi age stand structure with trees of varying ages at different heights. Douglas-Fir (Psuedotsuga menziesii) is scattered amongst the Redwoods. Understory vegetation consists of Sword Fern (Polystichum munitum), Deer Fern (Blechnum spicant), Sorrel (Oxalis spp.), Evergreen Huckleberry (Vaccinum spp.).

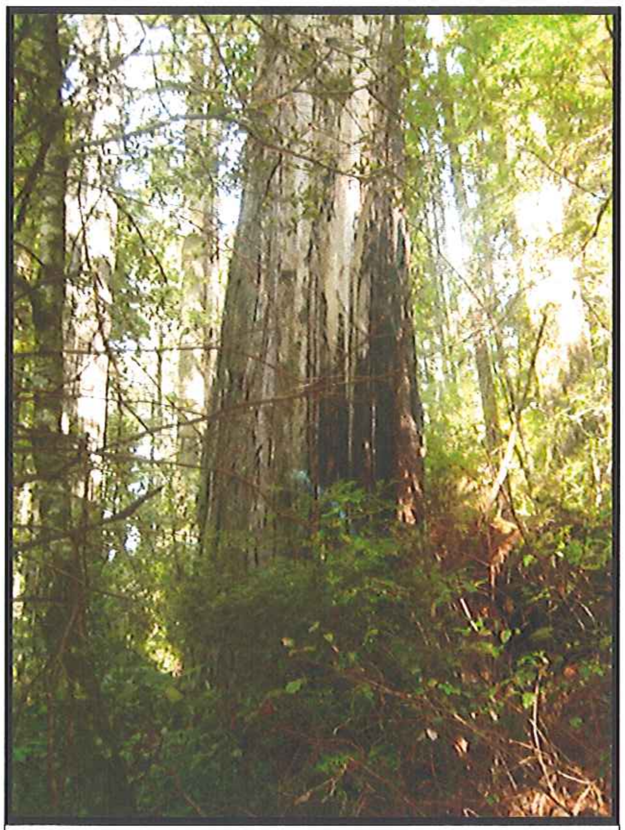


Figure 1. Old growth redwood tree.

The logged areas of Headwaters Forest Reserve have a dense thicket-like atmosphere. Coast Redwood (Sequoia sempervirens) tends to grow closer together in even-aged stands with Tanoak (Lithocarpus spp.) as well. Understory vegetation in many areas, is suppressed due to the intense shading by the canopy.

Specific Project

This project encompasses developing a growth model using gathered tree data. By creating a model, foresters and restoration specialists can use it to produce and carry out potential thinning recommendations for second growth forest stands within Headwaters Forest Reserve (BLM: Proposed Resource Management Plan, 2002).

Objectives

- Determine the growth rate of trees in relation to competition within second growth and old growth forest stands in Headwaters Forest Reserve.

- Use collected data to help determine other useful correlations within stands for restoration specialists and foresters to use in the future.
- Develop a methodology of tree sampling for this study.

Questions

- Is growth impeded by competition in second growth forest stands?
- Is growth based on crown class type?
- Does competition relate to basal area?

Problem Background

Purchased in 1986 by Charles Hurwitz and Maxxam Corp., PALCO's debts continued to haunt its new owner. Despite efforts to preserve the remaining old growth and second growth redwoods by EPIC, or Environmental Protection Information Center, Maxxam proceeded to mark Headwaters Grove for felling in order to pay off remaining debts. However, once the community caught wind of Maxxam's purposed timber liquidation, this sparked an anti-logging movement, better known as Redwood Summer.

During the summer of 1990, environmentalists and EPIC members began to protest the highly anticipated logging planned by Maxxam. Some even went so far as to set up camp in the tree itself, hoping loggers would be discouraged. Despite their extensive efforts, logging went ahead as planned (Bonanno et. al., 2001). Between 1987 and 1996, over 3.3 billion board feet were taken from the forest. By liquidating their forest, Maxxam's clearcut averaged $3.6 billion. Yet, this amount was still not enough to pay back Pacific Lumber Company's remaining debt of $700 million.

In light of the newly acquired debt, in September 1996, the state and federal governments including U.S. Senator Dianne Feinstein, agreed to purchase the property resulting in a $380 million settlement (BLM: Priorities for Headwaters Forest Reserve, 2008). The state agreed on $130 million while the federal government appropriated $250 million. The outstanding amount was paid to Pacific Lumber Company (including adjoining landowners, Elk River Timber Company).

The establishment was meant to "...preserve the last unprotected large stand of old growth redwood forest" (BLM: Manager's Report, 2007). Agreement stipulations required a comprehensive agreement between the State of California, USDA (United States Department of Agriculture), and PALCO declaring the area protected under a 50-year Habitat Conservation Plan. By adhering to the plan, 200,000 acres of nearby land would protect wildlife including the Marbled Murrelet and Northern Spotted Owl. These plan measures also included a 50-year ban on logging within 12 groves covering 8,000 acres of old growth redwood trees. Within the parcel, Pacific Lumber was also restricted from logging within a 100-foot buffer area adjacent to fish-bearing streams and erosion prone slopes (BLM: Proposed Resource Management Plan, 2002). Today, the Bureau of Land Management (BLM) manages the multi-age forest (see Figure3.) while the State of California manages state interest through a conservation plan. In total, the reserve consists of 7,472 acres including 3,088 acres of virgin redwood groves within 4,384 acres of second growth forest (BLM: Manager's Report, 2007).

In order to adhere to plan stipulations, restoration specialists must find ways to restore an ecosystem back to its original state. Thinning for restoration purposes plays a major part in the variable retention technique currently utilized by restoration specialists and foresters at Headwaters. Felled trees are used for restoration purposes such as large and coarse woody debris found and used in streams and forests. This recreates conditions that were prevalent before logging operations took place.

- **Redwood National Park**

  Redwood National Park is comprised of roughly 50,000 acres of second-growth forest. Between the years of 1968 and 1978, these were left unmanaged and soon became too dense. In 2009, the first "successful attempt at programmatic forest restoration" was completed on 1,700 acres of the South Fork of Lost Man Creek (*Forest Restoration, 2010*). The plan calls for implementing five silvicultural prescriptions throughout the 1,700 acres. The two most prominent prescriptions included "(1) a crown thinning on steep slopes, reducing the stand basal area by 25-percent, lopping-and-scattering woody biomass and (2) a low thinning on gentle slopes, reducing the stand basal area by 40-percent, removing woody biomass from the site to be utilized as different forest products" (*Forest Restoration, 2010*). Essentially, the focus was to reduce stand density in order to promote growth and maintain vigor of the remaining trees all while "...protecting adjacent old growth stands; maintaining water quality in riparian habitats; minimizing tanoak tree disturbance; and minimizing excessive fuel build-up on the forest floor" (*Second Growth Forest Restoration Environmental Assessment, 2009*).

  When it came to thinning, experiments were originally conducted on 200 acres along the Holter Ridge road in 1978, 40 acres on Bald Hills Road in 1995, again on Bald Hills road in 2005, and 45 acres along A972 Road along the west side of Redwood Creek in 2007. These small-scale thinning projects were intended to demonstrate how thinning promotes growth in remaining trees as well encourages the development of new understory vegetation and tree cohorts (*Second Growth Forest Restoration Environmental Assessment, 2009).*

  In 2003, the South Fork of the Lost Man Creek was selected as the first area to undergo large-scale thinning treatments. Two different thinning prescriptions were used depending on slope steepness and road access: moderate and low intensity thins. 40% of the moderate thin of merchantable size would be sold (after removal) to the contractor for sale offsite. Low intensity was used for slopes greater than 30%. However, felled trees were not removed on slopes greater than 30% as skidding removal would cause too much soil disturbance.

For low intensity thinning, 90 trees per acre were removed (8-20" dbh) while 247 trees per acre (5-20" dbh) were removed in areas of moderate thinning. Due to the high percentage of Douglas-fir and tanoak in these stands, redwood was not to be removed. It should also be noted that all felled trees up to 8" dbh not viable for sale, were lopped, bucked, and scattered amongst the forest floor throughout the project area. Felled trees of merchantable size were also removed via skidders on previously created haul roads. It should also be noted an Environmental Impact Assessment was created but a Timber Harvest Plan was not.

- **Arcata Community Forest**

Originally logged in 1890 with the use of handsaws, slash burning, and log-bark peeling, the logs were transported by oxen and the area was left to regenerate. Dedicated in 1955, the Arcata Community Forest was the first municipally owned forest in the State of California (*Arcata Community Forest Management Plan, 1994*). Now flourishing, the forest contains species of redwood, Douglas-fir, grand fir, western hemlock, and sitka spruce. Despite suffering yearly windstorms, the last known severe storm occurred in 1981. Aside from the wind, the largest disturbance comes from human-made recreational use destruction (*Chapter 8: Managing Redwoods, 2008*).

From 1965 to 1971, over 16.7 million board feet of timber was thinned from the Community forest via high lead cable yarding. The Arcata Community Forest/Jacoby Creek Multiple-Use Management Plan was adopted. Guidelines stipulated for management encompassed "sound principles of ecological forestry and perpetual sustained-yield". In 1980, uniform thinning of 30% of a particular stand was initiated. Revenue produced from harvesting covered forest management costs. All areas cut were specified within a Timber Harvest Plan (THP). Once covered, the remaining balance was spent as determined by the City of Arcata. Due to a fluctuating market and high interest prices, the harvest was suspended in 1989 (*Arcata Community Forest Plan, 1994*).

With respect to restoration, after each harvest, two-year seedlings were planted to replace what was harvested. Seedlings were estimated as having a 90% survival rate. The seedlings used in restoration were grown in a greenhouse. However, seed origin is currently unknown.

Figure 3. Photo taken of primary old growth forest (undisturbed) located in Headwaters Forest Reserve.

Figure 4. Photo taken of second-growth forest (disturbed) in Headwaters Forest Reserve. Notice the visual change in stand density compared to Figure 3.

Solution

From the perspective of a restoration specialist, it is vital to return logged old growth, back to its original reference conditions. In order to do this, a great amount of research and data collection must be taken. This data includes diameter at breast height (dbh), tree height, and the diameter of sapwood via core sampling. These samples are collected in hopes of developing a model to create an old growth structure representing reference conditions. By creating model correlations within a forest stand in order to develop thinning recommendations for Headwaters Forest Reserve and the greater restoration community.

Although the growth rate has been widely studied within old growth stands (more specifically, redwoods), our goal pertains to developing a model utilizing the rate of growth in relation to tree competition. This model of redwood growth will inevitably become a guide for a mathematical thinning prescription useful for not only foresters and arborists, but more specifically, for forest restoration specialists.

Alternative Solutions

1. **Alternative Solution #1- Data Collection and Model Development**

   In order to solve the problem of not having the proper model for thinning recommendations, it is possible to contract out a third party arborist or forester to create a prescription and an arborist for thinning. Data collection would be continued preferably by interested researchers of students of Humboldt State University. By eliminating multiple sources of researchers and their methods, collected data would have a higher probability of being more consistent. Essentially, the more variance between collection techniques, the greater the potential for a larger margin of error.

   Aside from sampling errors, this solution may be more expensive than if it was conducted by students or reserve employees. In other words, utilizing the services of a highly skilled researcher may produce more accurate results but also may end up becoming more expensive. However, once the data is collected, Headwaters staff has the option of analyzing the data themselves or continuing to fund another researcher.

   Although this solution is a viable option, it also provides another researcher with work a graduate or undergraduate student could complete. If the work were left to a student, then the project becomes a "win-win" situation: the student gains knowledge by putting his/her skills to use in the field while Headwaters Forest Reserve receives a useful analysis that will cost them very little.

2. **Alternative Solution #2- Previously Collected Data**

   The second viable option might be to take data collected from another project (i.e. Arcata Community Forest, Redwood National Park) and utilize their thinning recommendations within Headwaters. By doing so, this would eliminate the time and cost of hiring employees or other researchers, to collect the data, analyze it, and eventually develop their own model and interpretations. Since Headwaters is primarily comprised of second-growth redwoods, it tends to be very similar (in tree composition) to that of the stands within Redwood National Park and the Arcata Community Forest.

   Although this solution appears to be relatively flawless in theory, it fails to acknowledge the failed thinning regimes occurring after implementation of past projects. Despite final solutions succeeding in Redwood National

Park and the Arcata Community Forest, each forest is different, no matter how ecologically related they may appear to be. In other words, utilizing past data and restoration or thinning techniques for one area, may not work for another.

3. **Alternative Solution #3- No Action**

The third and most controversial solution would be to avoid taking data and consequently, avoid thinning altogether. This solution is essentially allowing nature to do the thinning. A benefit in implementing this solution would be the low cost of payment to employees or third party arborists who might have been hired to conduct thinning operations. Without the use of human involvement to reduce tree density, the process would in fact, be cheaper but might also take much longer to succeed. Depending on the storm severity, age of the tree (and current damage) as well as its decomposition rate once fallen, time to succeed may take several decades.

One of the primary issues concerning this solution relates to the time between when the forest begins to thin itself and the fire return interval. With an estimated interval (in redwoods) of 11-44 years, the fire may return faster than the forest has time to thin and decompose itself (*Presettlement and Modern Disturbance Regimes, 2009*). Therefore, the probability of fire tearing through this forest is much higher than if it had been thinned early on.

- **Weighing Alternatives**

Table1. Weighted Alternatives	Alt. #1	Alt. #2	Alt. #3
Implementation Time	5	4	1
Planning Time	5	3	1
Materials Cost	3	5	1
Employment Cost	2	2	1
Long-term Effectiveness	5	2	1
Professional Usefulness	5	3	2
Total	25	17	7
*Based on a 1 to 5 rating: 1 is least and 5 is greatest			

- **Alternative #1- Data Collection and Model Development**

When rating this alternative, implementation was rated as a 5 as this alternative takes a great deal of time in collecting data, analyzing data, developing a model, and the eventual implementation of the created model. Planning time was also rated a 5 as this alternative takes the most time to develop various plans for data collection, data analysis, model development, and implementation. For materials cost, the rating was determined to be a 3 as the majority of this project is to be carried out by volunteer students. The only possible materials cost could potentially be the hiring of a professional arborist or timber operator to conduct thinning if Headwaters Reserve staff decide to utilize the created model. Employment cost is listed low as well (2) as it pertains to the materials cost. The majority of this project is to done by student volunteers. The only possible employment cost may be a third party forester or at the very least, paid staff members at Headwaters hired to implement this model. When it comes to long-term effectiveness, this solution should be the most effective of all three possible solutions. It should be noted long-term effectiveness also includes long-term monitoring. In doing so, this alternative would require them most monitoring via research. By doing research, this model should be able to be used by foresters, restoration specialists, and land managers. Nonetheless, research could last a few years to several decades depending on the source of funding. It has a wide range of use and will be customized to fit this specific stand of trees. Finally, professional usefulness is also rating a 5 due to the specificity of the model. By using specific data collected within Headwaters, any conclusive model created will be useful to professionals studying old growth and second-growth forests in Headwaters Forest Reserve.

- **Alternative #2- Previously Collected Data**

Although this alternative was a viable option, it was not chosen as the final solution. For implementation time, this alternative was rated as a 4. Although this solution's restoration plan would take a great deal of time to carry out, it would inevitably take less time as the plan would have been already prepared and written for another (past) project. Planning time was rated as a 3 as, once again, the time to plan would take less time as the plan would have already been written and prepared from a past project. For materials cost, this was rated as having a 3. The rating for this alternative is the same as in alternative #1 as materials costs for both of these alternatives are projected to be the same. The majority of labor will be volunteer-based with the exception of Headwaters' staff and a possible arborist. Materials costs would also include tools and equipment used to carry out the project. Employment costs (2) are very similar to materials cost as they encompass the cost of minimal Headwater's staff. With long-term effectiveness, this alternative is not projected to be as effective in the future. Essentially, although monitoring may be as conclusive as Alternative #1, the effectiveness of such monitoring and implementation would be less as the plan used for restoration was not customized. In the future, this may cause added monitoring or an additional project to fix associated problems. As far as professional usefulness is concerned, this was rated with a 3 as once again, a model created for another project and used for a different project, is not as useful in the professional realm. This strategy is not representative of the data and therefore is not as useful when it comes to research and development within the project area.

- **Alternative #3- No Action**

For the final viable alternative, the implementation time was rated as a 1 as there would be no action. The planning time and materials costs are also rated a 1 due to the lack of project. Employment cost is listed as a 2 due to the nature of still having to hire staff personnel at Headwaters Forest Reserve. As far as long-term effectiveness is concerned, no implementation of any such project will only allow the problem to deteriorate. These factors are also going to be irrelevant as no action would prove monitoring and overall effectiveness to be obsolete. A model will not be created and therefore, thinning will most likely not occur. Without thinning, the area will be more susceptible to forest fire meaning the second-growth portion will not easily be able to return to old growth reference conditions. Professionally, not having a project might become a catalyst for studying the effects of not having a project. However, in the long run, implementation would not be effective in the professional realm of restoration or forestry as nothing is available to study.

Methods

- **Site Description**

Sampling sites were located within the Governor's Grove of Headwaters Forest Reserve just outside of Fortuna, CA. This is an upland redwood area with both second and old growth stands of redwood. Both varieties of sites were sampled including edges of second growth bordering old growth. Topographically, these sample locations were along ridges and ridge shoulders.

This particular site ranged from 25-50 percent slopes under a dominant redwood canopy. However, there are occasional Douglas fir trees in the overstory as well. Tanoak is present in the understory along with evergreen huckleberry, sword fern, and deer fern. The mean annual temperature of the site is around 52°F with an average rainfall of 75 inches per year.

There are two main geological formations present in Headwaters: the Wildcat and the Yager formations. Both are composed of uplifted marine sediments and are very prone to erosion, especially after a logging operation.

The soil mapping of the reserve is incomplete. However, examining nearby sites with similar parent material and site conditions have the Coppercreek series. This series is a fine, semiactive, isomesic typic, Palehumult.

- **Vegetation**

Old growth sites tend to encompass a large overstory of coast redwood. These stands contain a multi-age stand structure with trees of varying ages at different heights. Douglas fir *(Psuedotsuga menziesii)* is scattered amongst the redwoods including understory vegetation of sword fern (*Polystichum munitum*), deer fern *(Blechnum spicant*), sorrel (*Oxalis spp.*) and evergreen huckleberry *(Vaccinum spp.*).

The logged areas (second growth) of Headwaters Forest Reserve are significantly thicker in vegetative cover as compared to old growth sections. Coast redwood *(Sequoia sempervirens*) grows close together in even-aged stands with tanoak (*Lithocarpus spp.)* as well. Once growing space opens, fast-growing species inundate the area and tend to choke off small saplings, pushing many into an unfortunate stem exclusion stage (Oliver, 1996).

- **Experimental Methods**

Data (tree selection) was based on two factors: the density of competition and the dbh (diameter at breast height) of the tree. Collecting a range of data in relation to competition was completed upon choosing trees that fit into a defined size class. This range extended from 5-35cm in 5cm increments as well as if the tree was old or second growth. Growth determination was based on if the area within the grove was previously cut or a pure stand (Figure5.). This was ultimately determined on a tree by tree basis as these two types were often close to each other. It should also be noted that collection was also based on gathering equal amounts of trees fitting into both the dbh size class and tree density competition. Competition measurements were based on four crown classes: dominant, co-dominant, intermediate, and suppressed. All crown classifications were determined visually (Figure2.) and recorded according to their associated species. Dominant and co-dominant trees are competing with one another crowding out other potential saplings. However, once canopy layers become dense enough to shade out light, most saplings are excluded. If trees do not experience this stage of exclusion, they will reach the intermediate growth stage. At this point, trees cannot fully obtain the ideal growing conditions as dominant trees, but have not yet been shaded out. If time to germinate or the rate of growth is somehow reduced, trees may be classified as suppressed. Although smaller, suppressed trees may be of equal age or older than surrounding dominant trees, their height was limited at some point along the way. This may occur naturally or after some disturbance such as logging or fire (Lorimer et. al., 2009). This classification is most commonly found after thinning in a second growth stand whereas intermediate and dominant typically occur in old growth stands (Oliver, 1996).

Overall measurements taken included bark density, tree height, diameter (dbh), basal area tally, a tree core of 5-year (calculated cross-sectional) growth and distance to sapwood, as well as height of the live crown. Diameter was measured using a “d-tape” also known as a logger’s tape with a built-in factor of pi. The core samples were taken via tree corer and measured with a small ruler. Using the same ruler, bark thickness was determined by a thickness gauge by pressing the instrument into ridges on the bark. Since plot sampling was variable, basal area was determined via prism (also known as a “cruz-all” or “church key”) and heights were measured using a laser. Since each tree was considered its

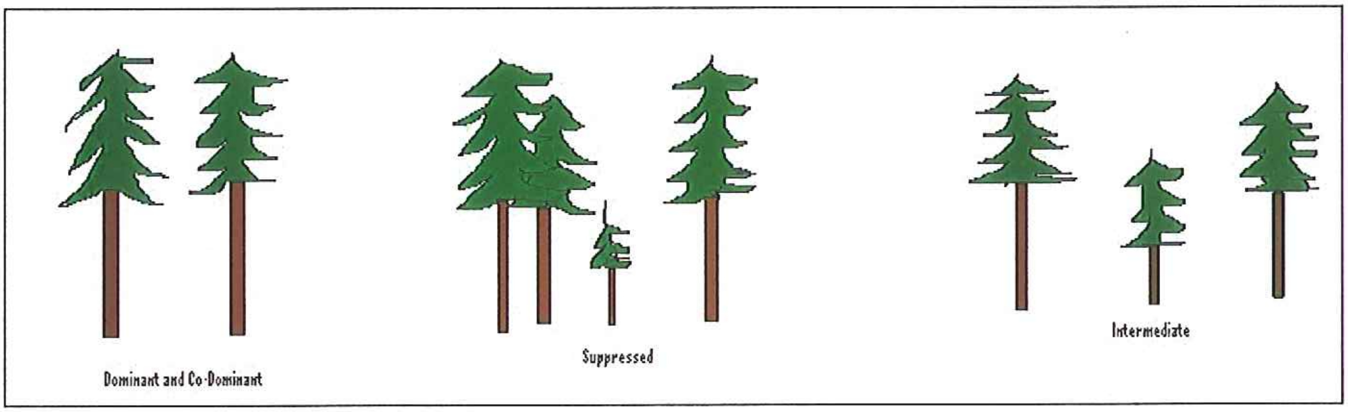


Figure2. Crown classifications.

only individual plot center, a prism was used to calculate total basal area surrounding each center. The prism is essentially a calibrated glass eyepiece that is to be held out at arms length. When looking through the glass, if a tree in the background fits inside (aligns) the foreground of the glass, it is considered “in”. Since the prism glass is in the shape of a wedge, refraction will offset trees of a certain size. A 360-degree rotation of this is done around plot center (or the tree in this case). All trees are tallied and multiplied by the prism factor. For this study, the factor was 40. Therefore, the ending sum is representative of surrounding stand density (basal area) (University of Vermont, 2011).

Tree height and live crown were measured using a laser. This device took three readings to calculate tree height and live crown including tree height at the base, breast height, and the very top. With live crown, readings included height at dbh, base of tree and base or start, of the live crown. Using this calculated height can then be subtracted from calculated tree height in order to determine height of the live crown. Live crown was not measured outright as the margin of error may have exceeded that of the subtraction method.

Data readings for cores and bark thickness were taken twice only if tree diameters met or exceeded 20cm. These readings included one reading on the uphill slope and one reading parallel to the slope. If a tree diameter was less than 20cm, only one reading would be taken into account (preferably on the uphill slope). It should be noted all data collected in the field were put into tables (Table1) for easier processing and analyzing.

- **Data Analysis Methods**

After the data were collected, all were placed into excel for sorting and calculating. Calculated data included averages of dbh, height, crown height, and basal area. Aside from Excel, Minitab and R programs were used in this analysis in order to answer the aforementioned questions.

Although several comparisons were made, few were significant. Significance was based on "P-value" where significant relationships were less than 0.05 or 5% probability. For instance, a co-variance analysis in Minitab made between the growth-rate (5-yr.) and total basal area calculated a p-value of 0.00. This value describes a relation but does not dictate how strong it may be or what kind of effect this relation has on other variables.

Other statistical observations made with this general linear model (GLM) using a covariance analysis were the t-value (statistical hypothesis), and a plot of each relation. Plots and the use of a GLM were tabulated in Minitab (version 16) along with basic statistics done in R (version 2.12.1). Within a general linear regression (Minitab), a covariance analysis (ANOVA) produced statistical results showing relationships between basal area and tree growth derived from core samples.

Figure 4. Photo taken of second-growth forest (disturbed) in Headwaters Forest Reserve. Notice the visual change in stand density compared to Figure 3.

Results

Utilizing a GLM, covariance analysis results yielded several strong relationships between variables. A comparison between overall growth-rate (5yr.) and total basal area is shown below in Table2.

Table2. Growth-rate vs. Total Basal Area comparison.

Analysis of Variance for grwthrate, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
BAtotal	1	7.1792	7.1792	7.1792	14.80	0.000
Error	58	28.1443	28.1443	0.4852		
Total	59	35.3235				

S = 0.696596   R-Sq = 20.32%   R-Sq(adj) = 18.95%

Term	Coef	SE Coef	T	P
Constant	1.6842	0.2122	7.94	0.000

BAtotal	-0.002561	0.000666	-3.85	0.000

As shown above, the p-value is zero (p<0.05; showing a relation) meaning we reject the null hypothesis. In this case, the null hypothesis would be that there is no relation between growth and basal area. So, therefore by the p-value, there is a relation. This pattern (relation) can be seen below in Figure5.

In order to answer the question of if growth is based on stratum, a comparison was made between cross sectional 5yr. growth and three different basal area measurements. Basal area included any tree below, above, or at level with the height of the tree currently being measured (based on factor 40 prism). Results showed only above-tree (overstory canopy) basal area having a strong relation to cross sectional 5yr. growth (Table3.). So, competition was found to be significant but only for dominant trees not at equal level or below the tree in question.

Finally, a model representing the annual average growth rate and basal area (above) was developed for both second and old growth redwood stands. Data used for average annual growth was derived from 5yr. cross-sectional (core samples that were divided by the current 5yr. cross-sectional growth. Equations used to calculate values are as follows:

5yr._DIB (Diameter Inside Bark)= DBH-AverageBarkThickness-(5yr.*2)
5yr._CrossSectArea= [{((5yr._DIB+(AvgBarkThick*2))/2]^2}*Pi
CrossSectCurrent=Pi*(DBH/2)^2
Current_5yr.= CrossSectCurrent-5yr._CrossSectArea
Average_Yearly_Growth= Current_5yr./5

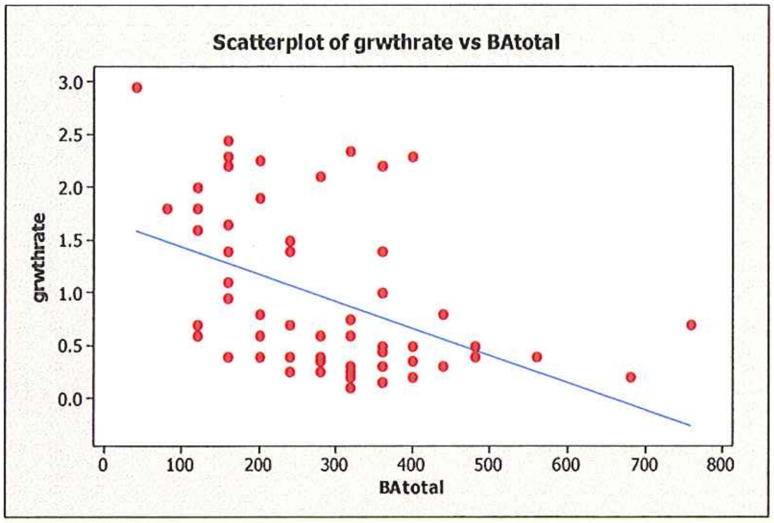
Table3. Basal Area compared to basal area above (a), at level (s), and below (b) the tree being measured.

Term	Coef	SE Coef	T	P
Constant	1.7165	0.2151	7.98	0.000
BAa	-0.004260	0.000699	-6.09	0.000
BAs	-0.001305	0.001456	-0.90	0.374
BAb	-0.000033	0.000886	-0.04	0.970

Distinctive relations not found included the comparison between lower crown ratio and height (p=0.483) as well as cross sectional 5yr. growth are not related to stratum (p=0.690). Despite the relation of overstory competition, it doesn't matter how large the tree is in the understory, the tree is still subject to the same competition factors.

- **Overall Growth-Rate Model**

Figure5. Graph showing relation between 5yr. growth and total basal area for all trees.



- **Second growth vs. Old growth Model**

The rate of growth calculated for both old growth and second growth redwood stands is represented (Figure6) by the total basal area of trees above individual plots (trees) and the annual average of cross-sectional growth (from 5yr.). Trend lines demonstrate the model's equations. These are as follows:

Old growth: $y = 16.748 - 0.03957x$
Second growth: $y = 22.507 - 0.05895x$

Ex: A forester calculates 220sq.meters. of (second growth) total basal area for an overstory in a stand of trees. He desires to know the average annual cross-sectional growth rate for the past five years. To calculate this, plug in 220 as the "x-variable".

$Y=22.507 - 0.05895(220)$ $\quad$ $Y= 9.538$
$Y=22.507 - 12.96$

So, this means that the rate of growth for the past five years has been roughly 9.538 cm or 1.9076 cm/yr. If a restoration specialist desires his trees to be less than 10cm in diameter (larger than 10 may be considered timber harvest) before they are felled and taken to be used as large woody debris in a creek, he can figure out roughly how many years it might take him. However, it should be kept in mind that the rate of growth is dependent on the basal area. So, although it may be simple to calculate the growth rate for one tree at a given point in time, this rate will not stay constant over a longer period. Despite this fact, if he wanted a rough estimate of a certain stand of trees, at this rate, the tree will growth to just under 10cm (9.538) in about 5 years. So, it might be recommended the trees of this stand be cut five years from the date of initial measurements.

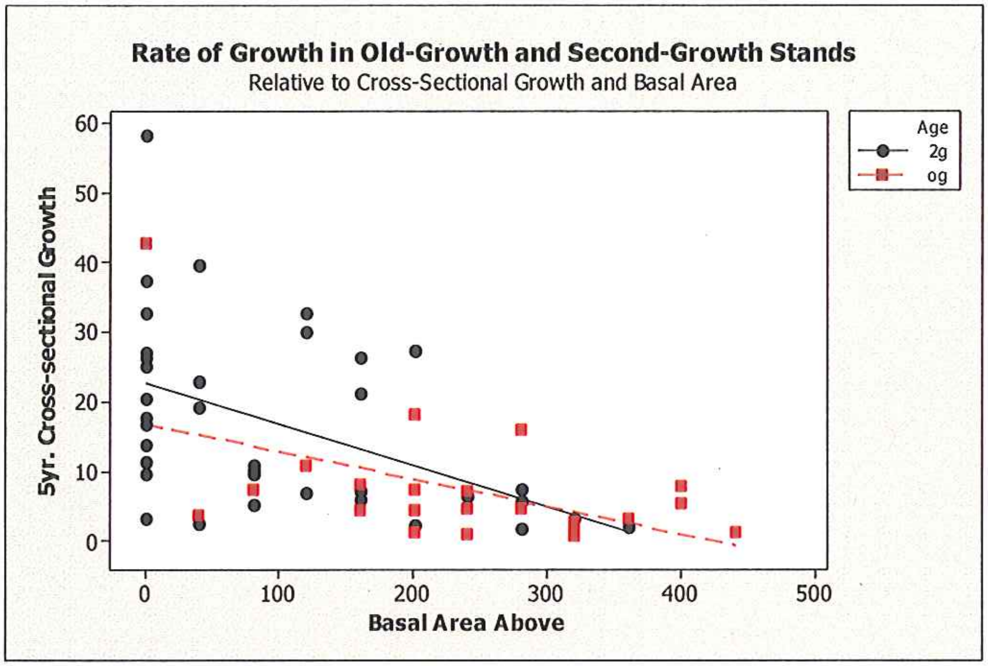


Figure6. Growth-rate model for old growth (og) and second growth (2g) redwood stands in Governor's Grove, Headwaters Forest Reserve.

Discussion

Within the forest restoration community, thinning must be understood and taken into account as a tool of the trade. When second growth stands have suffered a major disturbance, areas typically become inundated with thick layers of vegetation. In order to suppress this occurrence, discourage excessive competition, and encourage growth in previously established trees, silvicultural thinnings are used quite often (Albrecht et. al., 2006). "Stand development following human induced stand-replacing events such as those caused by the repeated use of seed tree or clear cut silviculture therefore establish artificial growth trajectories that are rarely found in the natural ecosystem"(Porter et. al. 2007).

The results produced in this study were significant in proving competition is not necessarily a factor of understory size, but becomes a factor when the tree is dominating the overstory. Findings also support the notion that as total basal area increases, the rate of growth decreases. When comparing the two trend lines (and equations) of the model (Figure6), it is clear as basal area increases, the rate of growth decreases. Second growth data suggest the rate of growth is faster when the tree is younger. The opposite is true for old growth. This model not only proves our hypothesis true (that growth is impeded by competition) but also confirms that as trees grow older, their growth slows.

- **Applications**

The model created utilizing collected field data within Headwaters Forest Reserve is useful for restoration specialists and foresters alike. The data is mathematically represented in order to show how fast trees are growing in relation to their height and amount of wood put on within the last 5 years. For instance, if the reserve wants to thin when a particular stand reaches a certain basal area, the desired basal area can be plugged into the equation to find the amount of years it will take to grow. This information can be applied toward developing a restoration (by using a predictive model) plan for thinning second growth stands in order to return to these reference conditions. Foresters might utilize this model to calculate the desired density and spatial pattern for a second growth stand (x=basal area and y=cross-sectional growth). By doing so, thinning operations can be carried out therefore begin the process of restoration.

- **Vegetation Correlation**

Originally, it was presumed data collected and quantified as understory vegetation, would in fact be modeled in order to aide the growth-rate competition model. Upon further inspection, the sampling method conducted allowed for minimal correlations to be made. In fact, the selective sampling produced data not relevant to growth rates among an old growth or second growth stand. Sampled trees were not only picked selectively, but also assumed to be their own plot. In agreeing with this assumption, several different species (including their diameters) were part of the overall data collection. Despite species variance, in order to answer the underlying question of if there is in fact a correlation between understory vegetation and a tree's rate of growth, an entirely new experiment would have needed to be created in order to focus all efforts entirely on the question at hand.

With limited tree data and multiple sites of interest, it was very difficult to quantify changes in understory growth in relation to nearby trees. The only observations made were loosely observed vegetative trends. Essentially, the larger the tree, the more overstory cover. With this is mind, there tended to be less deciduous plants and more shade-tolerant hearty ones (i.e. sword fern). These observations were purely based on the coverage factor and appeared to be completely unrelated to any type of growth-rate factor.

If understory vegetation were to be studied more carefully, sampling techniques would need to be altered in order to focus on primarily vegetation and not so much on trees. Due to the specific nature of this experiment, limited data does not provide a strong correlation of vegetation to the growth rates of trees at this present time.

- **Implementation**

As far as implementation, thinning is to be conducted at the discretion of a forester or land manager. Once a desired stand density (reference conditions) is calculated (using this projects developed and predictive models), the area can be restored (thinned) by a professional arborist. At this point, a restoration specialist can create a plan instituting the pattern and number of trees to be removed (determined by forester). For this particular project, implementation should be continued via strategies mentioned in methods (see above). Future implementation of this project should be carried out by another restoration researcher. This is to be done at the discretion of both this report, and Headwaters staff. Sampling methods are inclusive and any variation may compromise continued project results.

A timeline for implementation is dependent upon the point at which the desired tree density within the second-growth stand is calculated and trees have been felled. Due to permitting, funding, availability, and resources, this restoration research process could take anywhere from a few weeks to several years. This study is meant to be a continued project as the more data collected, the more useful the model becomes in helping to determine thinning recommendations.

- **Monitoring & Evaluation**

In monitoring and evaluating this area's tree growth, it is recommended the same procedures are carried out as mentioned previously. Ultimately, the objectives of this study were to use collected data to determine growth rates of second and old growth forest stands. So, the more data collected from trees within a respective stand, the more accurate the model becomes and the more accurate thinning recommendations will be. This gathered data can then be added in order to enhance the overall competition correlation and growth model. Monitoring and evaluation could take the form of bi-monthly to half-yearly tree and vegetation health checks. Over time, these evaluations may produce results that could show a pattern as to the effects of competition. However, projected time for overall monitoring is pending as research is dependent upon funding as well as the accuracy and rate of collection.

Aside from collection-based monitoring, there should also be light pruning or eradication of unwanted vegetation. This selection might include tanoak, pampas grass and any other species known for intruding growing space after an area has been disturbed (thinned). Eradication monitoring should be monthly or bi-monthly during the year. However, the summer season may require monitoring every 2-4 weeks. Likewise, with winter, monitoring will most likely be unnecessary as vegetation will be a minimum.

Timeline

- **Project**

Although this study was conducted over a period of 5 weeks, it should be continued until Headwaters staff specifies otherwise. Depending on

- **Volunteers/Workers**

  Any volunteers or workers hired to conduct research contributing to this model should follow the same methods described above (for collection). The more precise the replication is of data collection, the less chance of error there is in the data being recorded.

- **Cost Analysis**

This model is meant to be free of cost to Headwaters Forest Reserve as well as the public. Its intended purpose is to be educational and a learning experience in how forestry data is collected and processed. However, despite free labor, the materials can be relatively expensive.

Table4. Cost analysis for conducting project. *Based on prices from Forestry Suppliers Inc.

Materials Cost Analysis	
Material	Price
Ruler	$1.50
DBH Tape	$47.95
Bark Gauge	$77.50
Impulse 200 Laser	$2,495.00
Tree Increment Borer	$171.00
Rite In The Rain Pad	$16.95
40 BAF Prism	$49.95
TOTAL:	$2,859.85

Recommendations

- **Thinning**

It should be noted any thinning conducted in the area is subject to rules and guidelines set forth by the U.S. Fish and Wildlife Service in the case of protecting the Marbled Murrelet during mating season. Therefore, thinning and machine-intensive restoration can only occur during a specified window. According to the EIR/EIS report by Headwaters Forest Reserve "To the extent practicable all recreation access, restoration activities, trail construction or maintenance activities, or other work requiring use of motorized equipment will be buffered from Marbled Murrelet nesting habitat during the period March 24–September 15 by using vegetative screening or topographic screening and establishing seasonal operating periods or a distance buffer of up to 0.25 mile, as determined in consultation with USFWS to balance protection needs with recovery actions for threatened fish species" (*Headwaters Forest Reserve EIR, 4-8, 2002*). Restoration or mechanical disturbance is also not to occur between January 15-August 15 for Bald Eagle breeding season and February 1- August 1 for Osprey (*Headwaters Forest Reserve, 4-9, 2002*).

This report also recommends (along with the Headwaters' Management Plan) that currently, only Douglas-fir trees (12" dbh restriction) should be cut, not redwood. In order to encourage old growth redwood, competing species (Douglas-fir) should be removed.

- **Tree Species Mixture**

  Although old growth stands along the north coast are predominately thought of as redwood, Douglas-fir, grand fir, and tanoak also make up the tree community within Headwaters Forest Reserve. It is important to have multiple species within each stand as it provides habitat and vegetative variability. Monoculture avoidance also reduces the probability of massive stand destruction due to disease. Since the old growth redwood stands are primarily found with a co-dominant species of Douglas-fir, it is recommended these two species work well together and should continue to be planted alongside of each other. Plants such as Tanoak should not. This tree is almost always suppressed and typically crowds out smaller saplings. Its fast and hearty growth in disturbed areas tends to dominate native species therefore creating a dense, over-crowded stand.

- **Availability to the Public (Information access)**

  - **Growth-Rate Model**

    The growth model is meant to pertain to scientific researchers and natural resources based scientists alike. However, it is crucial to maintain public awareness as the majority of this property was saved from logging by the community only a few decades ago. It is to be recommended the public have access to all records of thinning operations as well as the growth model. In order to gain more support and understanding within the project, public education may be a viable option. This education may take the form of guided walks (to see thinning in action and the difference in old growth vs. second-growth stands), community outreach (presentations in restoration and forestry classes), and possibly developing an interactive website or interpretive center for the community to interact and learn from.

Although the growth model is intended for professional use, its general trend line and overall ideas are ones to be shared and explained to the neighboring community. Perhaps an interactive website and/or interpretive center might allow for the community to view current data trends in stands and how they might change over-time for both old growth and second-growth areas in the reserve. By presenting data in a general populous-friendly way, the model would be able to connect people with restoration using a pathway that is understood by all and not just the scientific community. After all, restoration is much more than replanting or removing trees; it is a process based heavily on research collection and natural resource-based correlations.

Special Thanks

Chris Beale, Brian Anderson, David LaFever, Pascal Berrill

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Appendix

Headwaters Forest Reserve Map

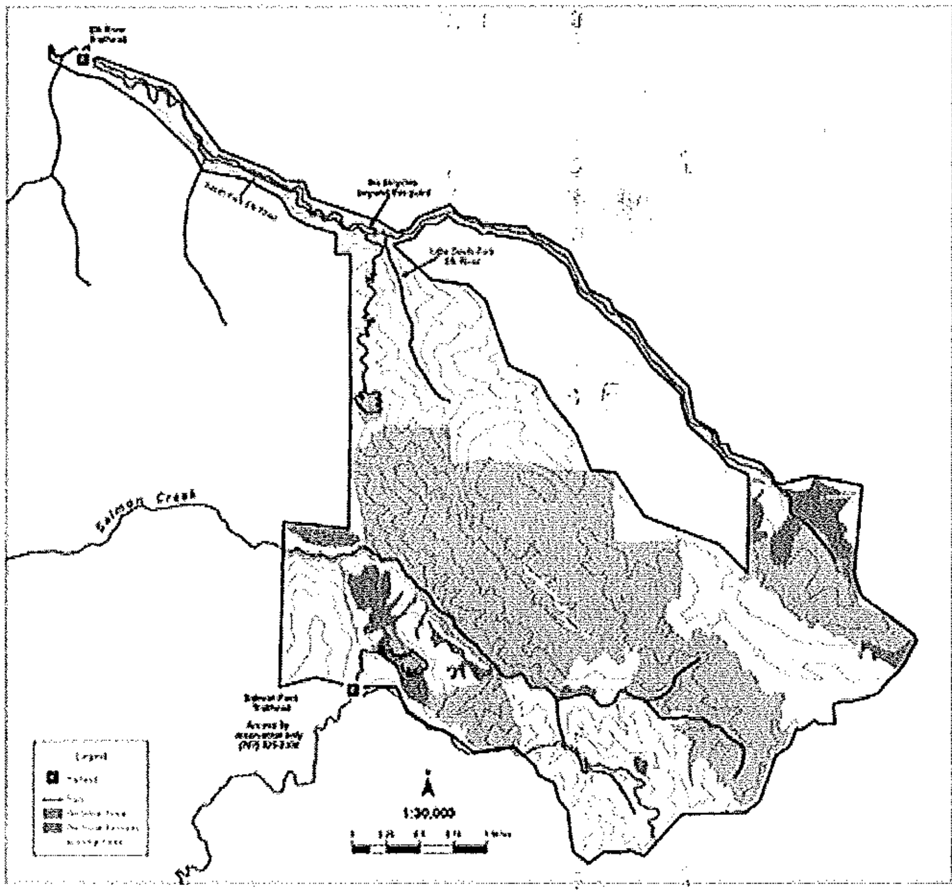

Figure 1. Map of Headwaters Forest Reserve. Bureau of Land Management, 2007.

Time Log

Date	Hours	Notes	SUM:	82.25
9/11/11	0.5	E-mailed community partners, set up Google doc		
9/13/11	1	Discussion of project		
9/14/11	1	Meeting with Pascal; project overview		

9/15/11	1.5	Background Research		
9/20/11	3	Research/writing		
9/23/11	0.5	Meeting with Chris Beale		
9/24/11	3.5	Research/writing, intro		
9/25/11	3.75	Research/writing, Redwood National Park		
9/27/11	1	Research/writing, Redwood National Park		
10/2/11	7	Field Collection with Chris Beale		
10/2/11	1.5	Research/writing		
10/4/11	3	Research/Objectives		
10/5/11	2	Research/writing, background		
10/6/11	2.5	Research/writing, site description/objectives		
10/7/11	1	Research/writing		
10/9/11	7	Field Collection with Chris Beale		
10/11/11	3	Research, Arcata Community Forest		
10/15/11	7	Field Collection with Chris Beale		
10/19/11	3	Weighing Alternatives		
10/23/11	2	Methods/Discussion		
10/27/11	1	Intro		
10/30/11	7	Field Research		
10/31/11	1	Paper revisions		
11/1/11	1	Methods addition		
11/3/11	3	Edits to paper and writing implementation		
11/7/11	2.25	Edits to methods and appendix		
11/9/11	3	Analysis		
11/10/11	3.25	Analysis		
11/11/11	4	Analysis and finishing of 2nd draft		
11/27/11	2	Final Paper edits		