Final Report to California Department of Forestry & Fire Protection:

Simulated Results of a Thinning Study on Coast Redwood (*Sequoia sempervirens*) Using a Newly Developed Triangular Thinning Method

by
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INTRODUCTION

A new method of thinning--the triangular thinning method--(Stone and Cavallaro, in prep) was developed to take advantage of growing space-stand growth relationships established for 140' codominant coast redwoods growing on north slopes of the Caspar Creek watershed on the Jackson State Forest (Cavallaro 1989) that have been incorporated into a stand simulator--GSPACE (Cavallaro and Krumland in prep). This method makes it possible to maximize the stand growth obtainable from any particular distribution of trees in even-aged stands. Furthermore, stand growth may actually be increased as a result of using this method of thinning: Growth will not necessarily just be transferred to the remaining trees nor will mortality simply be captured.

The method was used to thin fourteen .2 acre groups of coast redwoods that are spread out over a twenty acre area. Another fourteen groups were not cut and served as controls to determine the effect this method of thinning has on tree and stand growth[2]. Although growth responses will be followed for ten to twenty years after thinning, an immediate comparison of the expected tree and stand growth responses to thinning was simulated with a rudimentary

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[2]Use of the term group rather than plot is discussed in Appendix A.

version of the stand simulator GSPACE (Cavallaro and Krumland, in prep.). Since it currently does not include the relationships needed for predicting tree growth during the time that trees are releasing and taking over new growing space, the simulation was made for the time period between fifteen and twenty years into the future when the trees are expected to be completely released and fully occupy their new growing spaces.

STUDY AREA

The twenty acre study area is made up of even-aged second-growth redwood and is located on the Jackson State Forest east of Parlin Fork. Scattered amongst the redwood are a few Douglas-fir (*Pseudotsuga menziesii*), madrone (*Arbutus menziesii*), and tanoak (*Lithocarpos densiflora*). The area was originally cut around 1920 after which the redwood sprouted back. The lower part of the area, however, was converted to pastoral and/or agricultural use in scattered locations for various lengths of time and the redwoods vary a bit more in age.

Site quality is highly variable over the area. Generally, the site index (Krumland and Wensel 1977) ranges from 80 to 115 (base age 50) but exceeds 130 in localized areas. Consequently, the heights of the codominants vary from 95 to 145'.

The density of the codominant redwoods also varies greatly across the area because of their sprouting nature and because of scattered small grass openings.

METHODS

Experimental Design

Since site quality and density both affect stand growth and both vary greatly across the area, a randomized block design was selected as the appropriate one to use in this thinning experiment. With it, the effect that thinning has on tree and stand growth can be estimated much more precisely. Each block consists of paired .2 acre groups with similar sites and densities[3].

Identification of .2 Acre Groups with Similar Densities. All the clumps of redwoods and hardwoods and single redwood, douglas-fir, and hardwood trees in the area were mapped in order to make a three-dimensional model. With it, we searched for pairs of .2 acre groups that had similar patterns both inside and outside the groups. To assist in the mapping, a two chain by two chain string grid was laid out across the area. For each clump, the location on the grid, species, number of trees, and the range of diameters at breast height were recorded. For single trees, their location on the grid, species, and diameter at breast height were recorded. Thereafter, the three-dimensional model was constructed out of dowelling and eighteen pairs of .2 acre groups were identified. The groups in each pair had similar densities both internally

[3]More precisely, the pattern of trees (i.e., distribution of trees in an area) was used in assigning two groups to the same block. Although pattern and density are related, pattern is more specific. Two different patterns can have the same density, but two different densities cannot have the same identical pattern. Furthermore, the growing spaces of the trees is more closely related to pattern than density and we wanted the growing spaces of trees in the groups to be as similar as possible. Given the common use of the term density and the infrequent use of the term pattern by foresters, however, we have used the term density to facilitate the reading of this paper. Pattern, however, can usually be substituted for it and would be more precise.

and on their outside borders and constituted one of the blocks in the experiment (Fig. 1).

Identification of .2 Acre Groups with Similar Sites. After the blocks containing .2 acre groups with similar densities were identified from the three-dimensional stand model, the site index was determined for each .2 acre group. If the site indices of the two .2 acre groups in a block differed by more than fifteen feet at fifty years, the block was rejected. According to this criterion, four blocks were rejected leaving fourteen for the thinning experiment[4].

Randomization of the Thinning-No Thinning Treatments Applied to the Experimental Units in Each Block. To the extent possible, the thinning and no thinning treatments were randomly assigned to the experimental units (i.e., .2 acre groups) within a block. When groups from different blocks were in close proximity without adequate space between them to allow for a buffer, random assignment of the thinning-no thinning treatments was not possible. In such cases, the treatment randomly assigned to a group belonging to one block was assigned to adjacent groups belonging to different blocks. Consequently, the randomization was constrained (Fig. 2). This was the case for groups in six out of the fourteen blocks. By chance, however, some of the groups in these blocks received the treatment they would have received through a completely random assignment. Thus, the constrained random assignment of the

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[4]For clarity, it is worth noting that the two .2 acre groups in a block are often not contiguous. This is not required in a block design although schematic drawings of experimental designs containing blocks conventionally show them as contiguous. If this experiment had been designed to block out microsite variation across the study area, much like bench effects are blocked in greenhouse experiments, then the experimental units in each block would most certainly be contiguous and blocks would be distributed across the study area. In this study, however, site variation had to be blocked jointly with variation in density and since groups with similar densities usually did not lie side by side, the groups in a block were not contiguous.

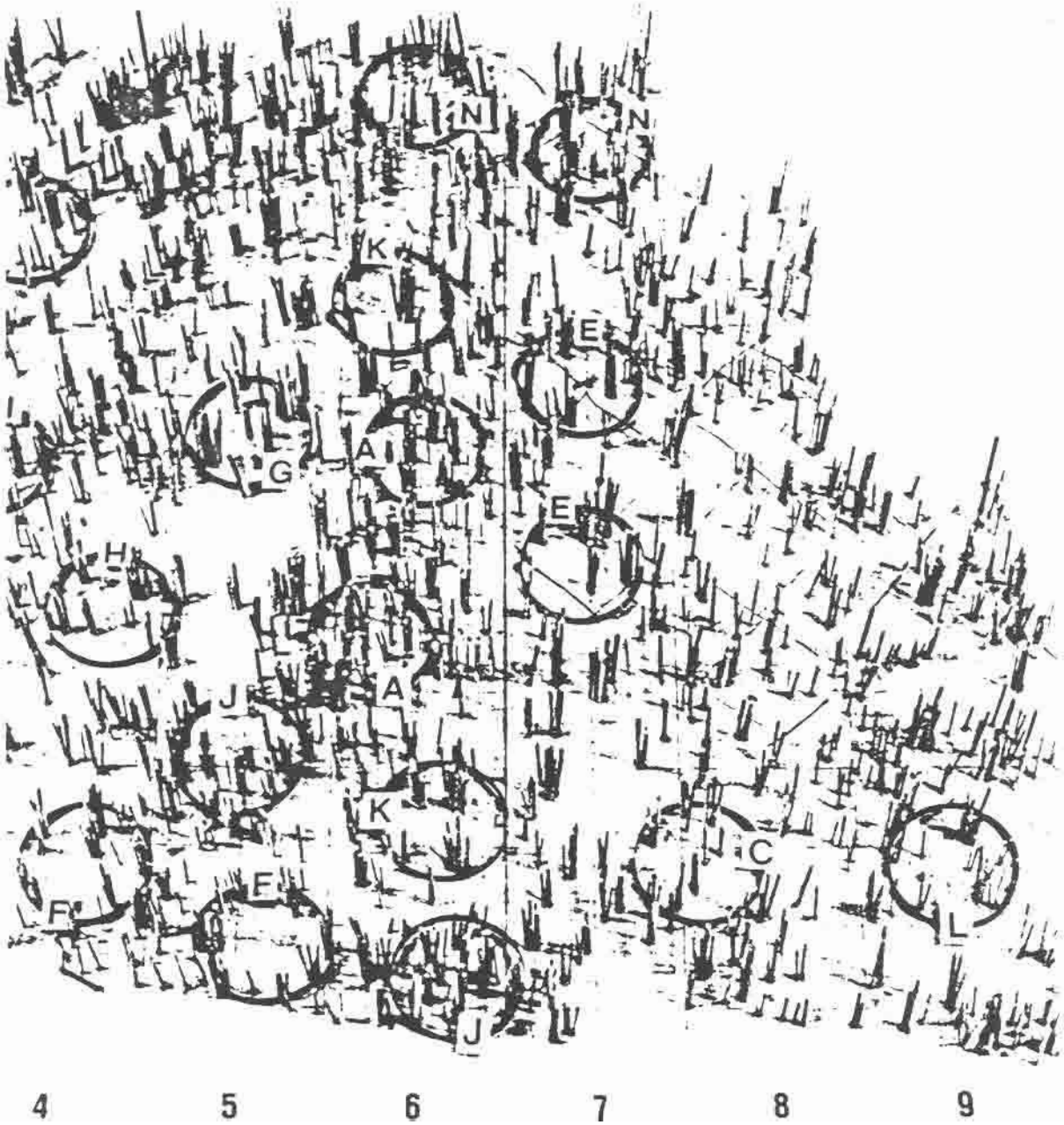

Figure 1. A portion of the three-dimensional dowelling model of the twenty acre study area showing the location of sixteen of the twenty-eight .2 acre groups. The block identification is shown with each group. The two groups in block K have widely scattered clumps of redwoods and/or single redwoods located on the inside border of the group and sizeable openings in the central part. Outside the two groups, the redwood clumps are also widely scattered. In contrast, the two groups in block A have dense clumps of redwood over the entire area and the distribution of clumps continues in much the same pattern outside the groups.

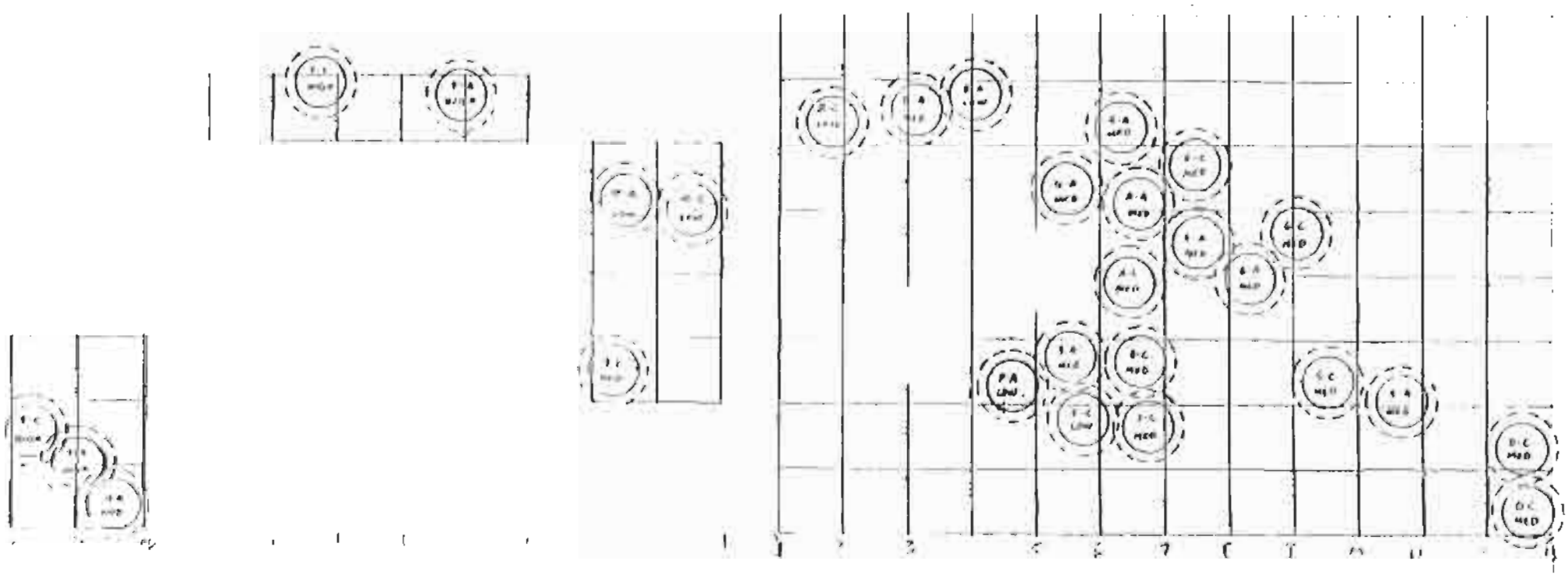

Figure 2. Layout of the .2 acre groups in the study area. The thinned group in each block is designated with an A and the unthinned group with a C.

treatments was equivalent to about a seventy-five percent completely random assignment.

Inventory Data

In the unthinned .2 acre groups, all the trees with diameters ≥4" at breast height were permanently tagged and their dbhs measured to the nearest .1" with a diameter tape. The basal area of each tree was then calculated. Thereafter, the basal areas per .2 acre and per acre were calculated. In the thinned .2 acre groups, the heights and dbhs were measured on both the harvested and residual trees. Dbhs were measured as described for trees in the unthinned groups. Heights of the residual trees were measured with an abney after the thinned trees were harvested. Heights of the harvested trees were measured with a logger's tape after they were felled. The residual trees were permanently tagged. The basal area and board foot volume of each tree were calculated from the dbh and height measurements. Thereafter, the harvested and residual basal areas and board foot volumes per .2 acre and per acre were calculated.

Stem Mapping of Thinned Groups for Simulating Future Tree and Stand Growth Responses to Thinning

A transit and 100' tape were used to establish the locations of both the harvested and residual dominant, codominant, and intermediate trees in the thinned .2 acre groups. In addition, they were used to locate similar trees outside the groups that were within fifty feet of trees inside the groups. The transit gave the azimuth and slope to the trees and the tape, the distance. When all trees could not be seen from one transit station, one or more additional stations were used and tied in to the first by azimuth and distance.

Subsequently, the data was run through a program[5] that generates x-y coordinates for each of the trees.

RESULTS

Group Inventories

A list of all the trees with diameters ≥4" at breast height in each of the unthinned .2 acre groups is given in Appendix B. The trees are separated according to growth-form (i.e., conifers or hardwoods). Their dbhs and basal areas are listed along with their identification numbers. The basal areas of all the conifers and all the hardwoods are summed at the bottom of the tree list for each unthinned .2 acre group.

A list of all the residual and harvested trees with diameters ≥4" at breast height in each of the thinned .2 acre groups is given in Appendix C. Again, the trees are separated according to growth-form. Their dbhs, basal areas, heights, and board foot volumes are listed along with their identification numbers. The harvested, residual and total basal areas in each thinned .2 acre group are summed at the bottom of each tree list. In addition, the percent of the basal area harvested is indicated. Similarly, the harvested, residual, and total board foot volumes in each .2 acre group are summed at the bottom of each tree list. Again, the percent of the board foot volume harvested is indicated.

The ninety-five percent confidence interval for the average basal area in the unthinned .2 acre groups was 536 ± 78 sq. ft./acre. For the thinned .2 acre groups prior to thinning it was 476 ± 54 sq. ft./acre. Thus, initially, the thinned

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[5]The program was written by Bruce Krumland, Ph.D. in conjunction with the development of GSPACE.

and unthinned groups had similar average basal areas. Both the thinned and unthinned groups had appreciable variability as indicated by the width of the confidence intervals and the coefficients of variation of twenty-one and twenty-seven percent for the thinned and unthinned groups. Even though significant variation existed in the basal areas of the thinned groups (334-657 sq. ft.) and the unthinned groups (362-803 sq. ft.), the basal areas of the groups in each block were strongly correlated prior to thinning (r=.7). This suggests that the blocking should be fairly effective, especially considering that both the density inside and outside the .2 acre groups were considered in the identification of the blocks while only the density inside the groups was considered in the correlation analysis.

Summary Data for Thinned Groups

The average residual basal area in the thinned .2 acre groups and the average basal area and percent basal area removed are listed in Table 1. Similarly, the average residual volume and the average volume and percent volume removed are listed. The standard deviation, coefficient of variation and range for each variable are also given.

Stem Maps and Descriptions of the Thinned Groups

Stem maps and descriptions of the thinned .2 acre groups are given in Appendix D. They show the location of the dominant and codominant trees in each group. Trees at the apices of triangles or the end points of lines are the residual dominants and codominants; the others are the harvested dominants and codominants. The marking rules used for the thinning are presented in an earlier report (Cavallaro and Stone 1990). Included with each map is a general description which includes: site index, basal area prior to thinning, basal area

Table 1. Description of the thinned .2 acre groups.

Variable	$\bar{x}$	S.D.	C.V.	Range
Basal area removed (sq.ft./ac.)	197	66.8	34%	106-320
Residual basal area (sq.ft./ac.)	282	52.3	19%	197-381
Percent basal area harvested	41	7.1	18%	26.8-51.0
Volume removed (bd.ft./ac)	29178	16327	56%	10850-60251
Residual volume (bd.ft./ac.)	51609	17340	34%	24737-80324
Percent volume harvested	32	11.6	37%	18.4-45.8%
Projected stand growth rate had plots not been thinned (cu.ft./ac./5 yr.)	1446	.321	22%	1087-2049
Projected stand growth rate after thinning once codominants occupy their growing space (cu.ft./ac./5 yr.)	1500	331	22%	1104-2078
Percent increase in stand growth rate as a result of thinning	4	.16	4%	0-15
Projected tree growth rate had plots not been thinned (cu.ft./5 yr)	9	2	23%	5.5-11.9
Projected tree growth rate after thinning once residual trees occupy their growing space (cu.ft./5yr.)	17	5	29%	10.5-26.0
Percent increase in tree growth rate as a result of thinning	95	18	19%	45-163

harvested, residual basal area, percent of the basal area removed, and various projections of stand and average tree growth rates, with and without thinning.

Simulated Thinning Response

Instead of waiting ten to twenty years to measure the tree and stand growth rates in the thinned and unthinned groups, GSPACE was used to simulate the growth responses to thinning. The stem maps for the thinned .2 acre groups were used to simulate tree and stand growth between fifteen and twenty years in the future, both with and without thinning. In the simulations of thinning, growth projections were made using only the residual dominants and codominants. In the simulations of no thinning, growth projections were made using all the dominants and codominants. The simulations were made for the time period between fifteen and twenty years in the future to be certain that all the residual trees in the simulated thinning would fully occupy the new growing space made available to them.

The data generated by the simulations were then analyzed according to the randomized block design which clearly indicated that thinning has a significant effect on average stand growth rates as well as average tree growth rates (Tables 2 and 3). The average stand growth rate of the thinned .2 acre groups was projected to be four percent higher than that of the unthinned groups (p=.007) and average tree growth rates were projected to be ninety-five percent higher (p=.000) (Table 1).

In using strictly the thinned groups to simulate stand growth responses with and without thinning, no variation existed in site and density between "thinned" and "unthinned" groups in each "block". Consequently, this

Table 2. Analysis of variance of the average stand growth rates of thinned and unthinned .2 acre groups belonging to different density-site class blocks.

Source	df	Sums of Squares	Mean Square	F-test	P-value
Thinning Treatment	1	20358.0	20358.0	10.70	.007
Blocks	13	27386803.2	210661.8	110.73	.000
Error	13	24731.5	1902.4		

Table 3. Analysis of variance of the average growth rates of trees in the thinned and unthinned .2 acre groups belonging to the different density-site class blocks.

Source	df	Sums of Squares	Mean Square	F-test	P-value
Thinning Treatment	1	492.3	492.3	69.53	.000
Blocks	13	289.2	22.3	3.14	.025
Error	13	92.1	7.08		

simulation was the most sensitive test possible for detecting thinning effects on average stand and average tree growth rates. Whether or not the thinning effect on average stand growth will be detectable in the actual experiment depends on whether or not the thinning effect is still masked by the residual variability in density between the two .2 acre groups assigned to each block. *If it is, the only way to detect differences in stand growth following thinning will be through simulation.*

DISCUSSION

Simulated Results of the Thinning Experiment Had Other Experimental Designs Been Used

Completely Randomized Design. If the design of this thinning experiment had been a completely randomized design, the thinning-no thinning treatments would have been assigned randomly to the groups irrespective of their density and site index. With such a design, no difference in the average stand growth rate resulting from the thinning treatment would have been detectable (p=.6652) although a difference in average tree growth rates would have been (p=.0001). Detection of differences in average tree growth rates is possible in this simple design because tree growth rates were projected to nearly double as a result of thinning. Detection of differences in the average stand growth rate, however, is impossible when initial densities and site indices vary because of the relatively smaller changes that occur in stand growth as a result of thinning. *Consequently, without an experimental design which blocks for density and site differences, detection of these changes is highly unlikely; and even with a design that does so, it might not be possible. Then simulation of the thinning effect would be the only alternative.*

sufficient for detecting differences in average stand growth rates in the thinned

Two Factor Design. Since stand growth varies with site quality and site quality varies considerably across the area, a two factor experimental design in which site class and thinning treatment are the two factors could be expected to be more appropriate than the completely randomized design. With this design, the variation in stand growth caused by site quality is removed from the experimental error, and, therefore, detection of the thinning treatment effect is potentially easier. If successful, blocking by density would not be required. Specifically the two factors used with this experimental design were thinning treatment and site class (<95' at fifty years and ≥95' at fifty years). With it, average stand growth rates could be shown to vary with the broad categories of site quality (p=.0001), but not with thinning treatment (p=.1840). Consequently, even by removing the effect that site quality has on average stand growth, the effect that thinning has could not be detected. *This again demonstrates the need for an experimental design that accounts for variation in initial density. Only then, if the initial density can be adequately blocked would it be possible to detect the effect of thinning. Otherwise, again, simulation would be the only answer*.

Conclusions. Detection of different average stand growth rates in the thinned and unthinned groups was considerably closer with the two factor design than with the completely randomized design. The probability that the average stand growth rates of the thinned and unthinned groups are the same dropped from sixty-seven to eighteen percent. *With this relatively low probability of the average stand growth rates in the thinned and unthinned groups being the same, the blocking we did for density differences may well be sufficient for detecting differences in average stand growth rates in the thinned*

and unthinned groups fifteen to twenty years after the thinning when all the trees are fully released.

Comparison of Average Stand and Average Tree Growth Responses to Different Kinds of Prescriptions

Although this study was not designed to compare different approaches to thinning, the data from the simulations can be used to compare triangular thinning prescriptions with prescriptions that specify the percent of the basal area removed or a target residual basal area. In addition, we have compared the triangular thinning prescriptions developed with the distance dependent simulator GSPACE with prescriptions one might generate with the distance independent simulator CRYPTOS (Krumland and Wensel 1987) assuming the objective is to maximize stand growth.

Removal of a Percent of the Existing Basal Area. Since different percentages of the basal area were harvested from the .2 acre groups used in the thinning experiment, we were able to analyze whether or not a relationship existed between the percent of the basal area removed and stand growth. No statistically significant regression could be established (p=.2114). In a further effort to find such a relationship, we ran a multiple regression with both the percent of the basal area removed and site index as independent variables since site quality also contributes to the variability in stand growth and it may, therefore, mask the relationship between the percent of the basal area removed and stand growth. Although a significant multiple regression was established (R^2=.59, p=,0074), the regression coefficient for the percent of the basal area removed did not differ from zero (p=.9998) and, thus, no relationship was found to exist between the percent basal area removed and stand growth.

A regression, however, did exist between the percent basal area removed and the percent increase in average tree growth rates (R^2=.64, p=.0006). The ninety-five percent confidence intervals for the true mean of percent increases in average tree growth rates are shown in Figure 3. Adding in site index improved the regression somewhat (R^2=.72), but the regression coefficient for site index did not differ from zero (p=.1077). Consequently, the simple regression between percent basal area removed and percent increas in average tree growth rates is more appropriate. In contrast, no statistically significant regression existed between percent basal area removed and average tree growth rates (p=.1176), but one did exist between site index and average tree growth rates (R^2=.45, p=.009) (Fig. 4).

In summary, removing a particular percentage of the basal area resulted in a predictable percent increase in average tree growth rates but not in a predictable average tree growth rate. The average depended more on site index than on the percent of the basal area removed. Removing a particular percentage of the basal area did not result in a predictable stand growth rate. Consequently, foresters could achieve greater and more predictable tree and stand growth responses by using triangular thinning prescriptions; but tradition dies hard, and we fear it may take a considerable period of time for them to change the kind of prescription they use.

Reduction of the Basal Area to a Target Residual Basal Area. Since different residual basal areas were left in the .2 acre groups used in the thinning experiment, we were able to analyze whether or not a relationship existed between the residual basal area in a group and stand growth. In this case, a regression was established between residual basal area and stand growth (R^2=.41, p=.0142) (Fig. 5). However, a regression between site index and

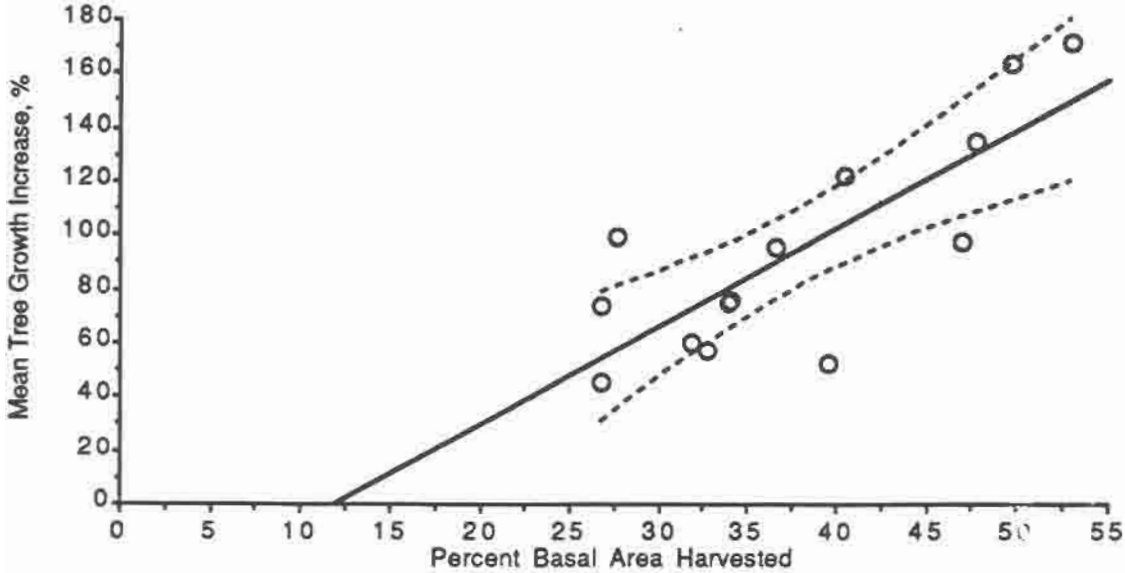

Figure 3. Percent increase in average tree growth rates as a function of the percent of the basal area removed. Ninety-five percent confidence intervals for the true mean of percent increases in average tree growth rates are shown R^2=.64, y = 43.56 + 3.66 x.

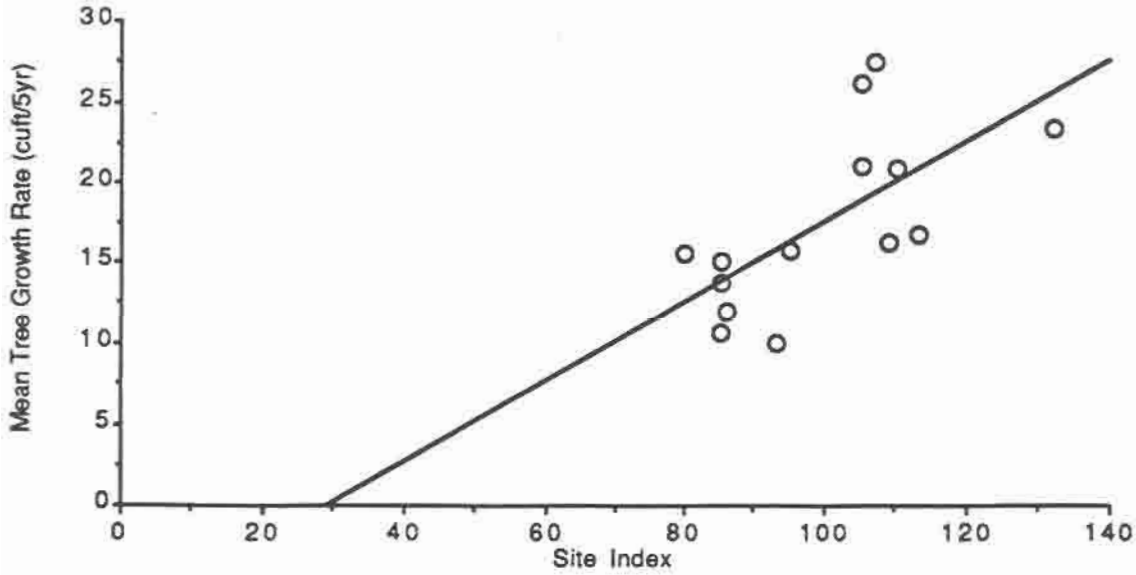

Figure 4. Average tree growth rates as a function of site index. R^2 = .45, y = -7.17 + .25 x

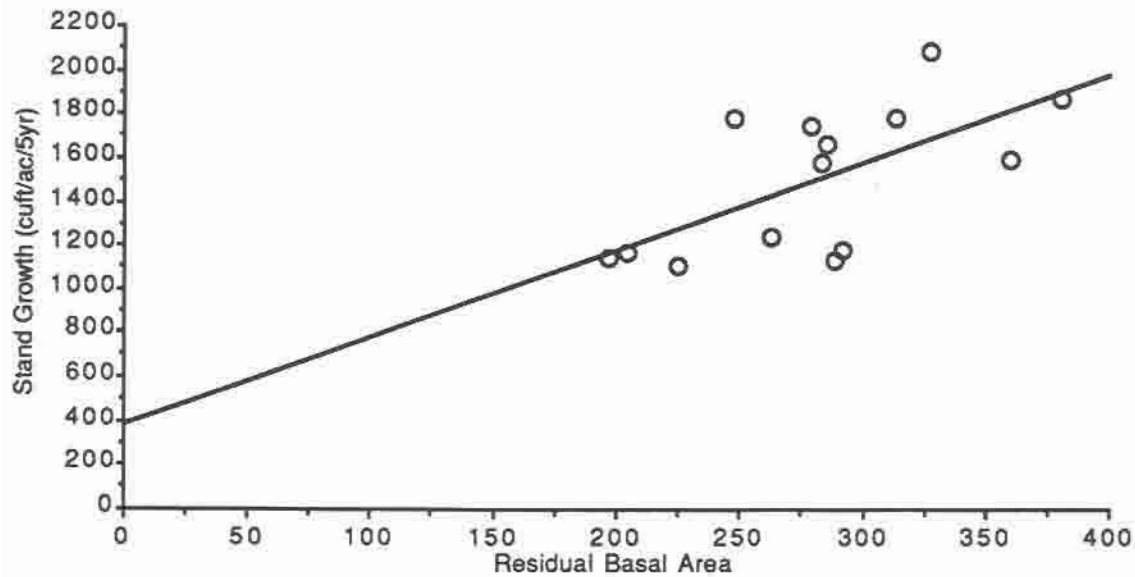

Figure 5. Stand growth as a function of residual basal area. R^2=.41, y = 385.36 + 3.96 x.

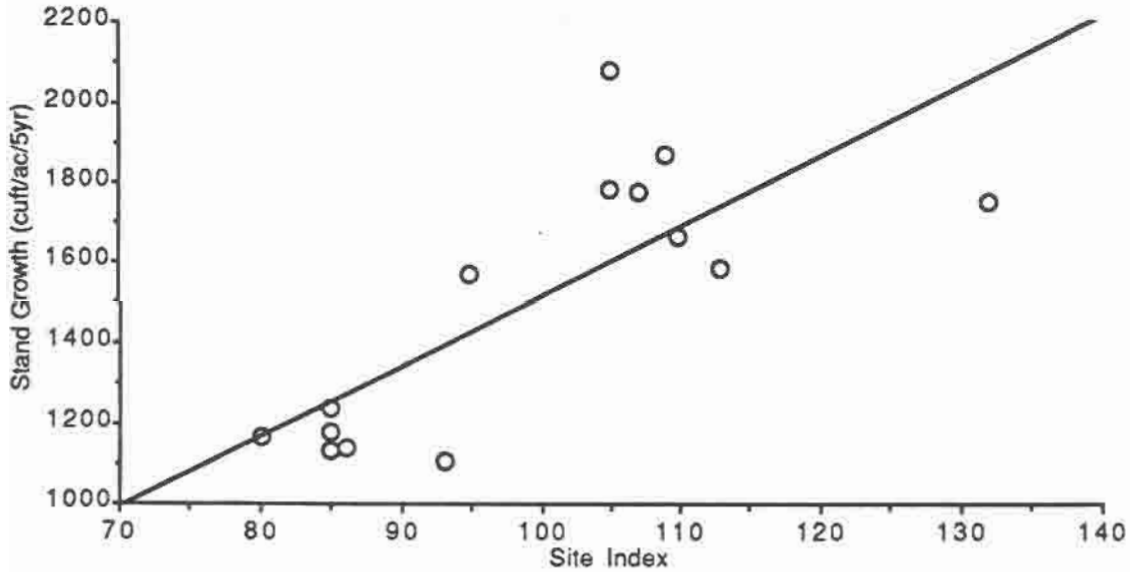

Figure 6. Stand growth as a function of site index. R^2 = .59, y = -221.44 + 17.35 x.

stand growth was considerably stronger (R^2=.59, p=.0013) (Fig. 6); and, therefore, the regression between residual basal area and stand growth may to a large extent be due to a correlation between residual basal area and site index (r=.51). Three different analyses were carried out to ascertain the degree to which residual basal area itself and not its correlation with site index affects stand growth: a partial correlation analysis, multiple regression analysis, and analysis of covariance. All three indicate that the correlation between site index and residual basal area contributes greatly to the apparent relationship between residual basal area and stand growth.

A partial correlation analysis determines the correlation between two variables when one or more other variables are fixed. This type of analysis revealed that the partial correlation between residual basal area and stand growth is only .49 with site index fixed. This is considerably lower than the simple correlation coefficient between these two variables (r=.64) and indicates the degree to which the correlation is an artifact of the correlation between site index and stand growth. For comparative purposes, the partial correlation between site index and stand growth with basal area fixed is considerably higher--r=.66 (as high as the simple correlation between residual basal area and stand growth). It too, however, is lower than the simple correlation coefficient between site index and stand growth (r=.77), although it did not decrease to the same extent.

When site index and residual basal area were used as two independent variables for predicting stand growth in a multiple regression, the regression coefficient for residual basal area came close but did not differ from zero (p=.1212) whereas the coefficient for site index did (p=.0120). Thus, the simple regression model where site index alone predicts stand growth is more

appropriate. This again indicates the lack of a strong relationship between residual basal area and stand growth.

Lastly, a covariance analysis was carried out to see if a regression exists between residual basal area and stand growth when site index was broken into two broad classes (<95' at fifty years and ≥95' at fifty years). Again, in this analysis, the regression coefficient for the residual basal area did not differ from zero (p=.4893) so residual basal area had no effect on stand growth (Fig. 7).

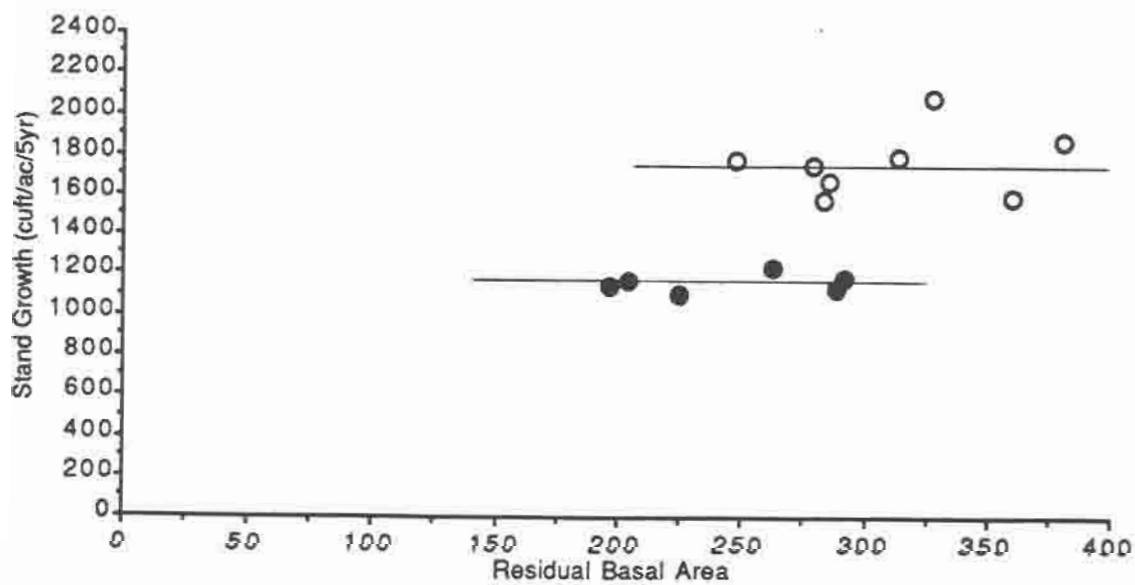

Figure 7. Stand growth as a function of residual basal area with site class (<95' at 50 years--solid circles and >95' at 50 years--open circles) used as a covariate. The regression coefficient for residual basal area does not differ significantly from zero (p=.4893) so y = 1181 for site classes <95 and 1741 for site classes >95, R^2=.87.

No regression could be established between residual basal area and average tree growth rates or percent increases in average tree growth rates (p=.3613 and .7640). Average tree growth rates, like stand growth rates, however, were linearly related to site index (R^2=.45, p=.009) and the regression coefficient did not equal zero (Fig. 4).

In summary, reducing the stand to a target residual basal area is not expected to result in a predictable stand growth rate. Furthermore, it is not expected to result in predictable average tree growth rates or predictable increases in average tree growth rates. Consequently, again, foresters could achieve greater and more predictable tree and stand growth responses by using triangular thinning prescriptions; but, as mentioned, tradition dies hard and we fear it may take a considerable period of time for them to change the kind of prescription they use.

Distant Independent Stand Simulators. Distance independent stand simulators have become increasingly available for developing stand specific thinning prescriptions. With this approach to the development of prescriptions, inventorial data is collected for a given stand after which tree and stand growth simulations are made for a variety of treatments including no thinning. Since such a simulator--CRYPTOS (Krumand and Wensel 1987)--is available for coast redwood growing in the Fort Bragg area, we were able to compare the kinds of prescriptions that might be developed with that type of simulator with the triangular thinning prescriptions developed with GSPACE.

In developing the prescription with CRYPTOS, the twenty acre study area was viewed as a stand, as would generally be done, and a set of ten randomly located .2 acre plots were established. The data collected in them

was used to determine if the growth rate of the twenty acre stand could be increased by any thinning treatment or if no thinning would result in the highest stand growth rate. For each plot, the dbh, height, and live crown ratio were determined for all trees ≥4" at dbh. Stand growth was then projected for each plot without thinning and with the removal of fifteen percent of the basal area from below and from above, removal of twenty-five percent of the basal area from below and from above, and removal of all trees with live crown ratios less than twenty percent.

CRYPTOS projected that if the stand was left unthinned, the average stand growth rate fifteen to twenty years in the future would be 7.3, 10.4, 11.5, 19.0, and 8.9 percent higher than if the stand was given the above treatments. Clearly, then, simulations with CRYPTOS indicate that the best treatment for the Parlin stand is no thinning if one wants to maximize stand growth. This differs dramatically from simulations with GSPACE. It projects the same or as much as fifteen percent higher stand growth in the .2 acre groups fifteen to twenty years after thinning if they are thinned according to the triangular thinning method. The difference in these two simulators is even more dramatic in that considerably more of the basal area was removed as a result of the triangular thinning prescription--27 to 53%--than was ever taken out in any of the simulations with CRYPTOS.

Which simulator gives the more accurate estimate, of course, remains to be seen when the Parlin thinning experiment is terminated; but we expect that GSPACE will prove far superior. CRYPTOS was built with purely statistical models that lack a data base on thinned stands. Consequently, to use it to project growth responses to conditions or situations outside its data base is

very risky and could prove to be totally unreliable[6]. Evidence suggesting that this is the case is presented in the next section.

Summary. Triangular thinning prescriptions based on the growing space-growth rate relationships incorporated in GSPACE should be far superior to prescriptions based on the percent of the basal area removed or the residual basal area or to prescriptions developed from a distant independent stand simulator such as CRYPTOS that is built on a data base that includes few, if any, observations on thinned stands. *With the former prescriptions, the variables to be modified by thinning are not strongly related to stand growth, and thus, one must question why these variables are used. In contrast, the variables in GSPACE are strongly related to both stand and tree growth rates and the triangular thinning prescriptions developed from GSPACE make use of one of these variables--a tree's growing space*.

Results of the Thinning Experiment as Simulated with CRYPTOS

We used CRYPTOS as well as GSPACE to simulate the stand and average tree growth rates expected in each of the thinned .2 acre groups assuming they were and were not thinned. We wanted to evaluate the behavior of CRYPTOS with and without thinning and to compare it to GSPACE.

Assuming the .2 acre thinned groups are not thinned, the stand growth projections made by CRYPTOS and GSPACE do not differ significantly and their stand growth projections are highly correlated (r=.76) (Fig. 8). Thus, the two simulators make similar projections in the absence of thinning; and, in this sense, validate each other.

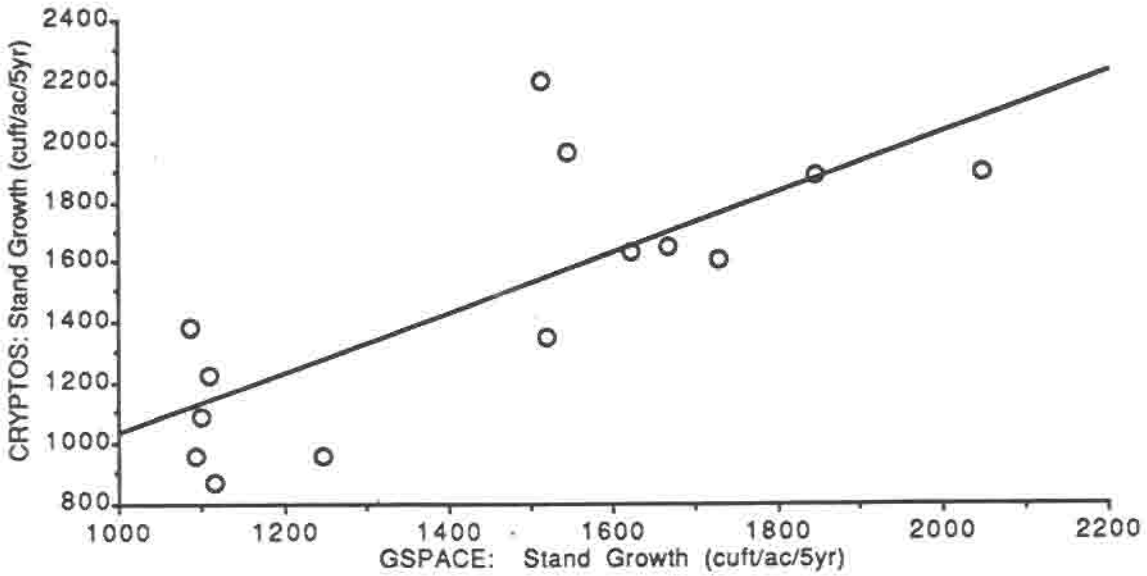

Figure 8. Stand growth projected by CRYPTOS predicted from stand growth projected by GSPACE, R^2=.58, y = 36.72 + .995 x.

In contrast, assuming that the .2 acre thinned groups are, in fact, thinned, CRYPTOS projects their average stand growth fifteen to twenty years in the future to be seventeen percent lower than if they were not thinned. GSPACE, on the other hand, projects it to be four percent higher. The projections made by CRYPTOS are contrary to the results of a vast number of thinning studies where stand growth following thinning is shown to return to the level of the unthinned stands once the residual trees take over their new growing space (Smith 1962, Daniel, Helms and Baker 1979). Consequently, CRYPTOS does not appear to make reasonable projections of the response of stands to thinning.

Associated with these lower stand growth rates for thinned stands are smaller increases in average tree growth rates during the period fifteen to

twenty years after thinning. CRYPTOS projects the average tree growth rates to be only sixty percent higher whereas GSPACE projects them to be ninety-five percent higher. Since increases of one hundred to two hundred percent in tree growth rates are common in thinning studies (Smith 1962, Daniel, Helms, and Baker 1979), the sixty percent average increase projected by CRYPTOS is relatively low and is probably inaccurate whereas the ninety-five percent average increase projected by GSPACE is in line with what can be expected and is probably considerably more accurate. Since the data base for CRYPTOS includes little, if any, data on thinned stands, the models in it cannot be expected to change the crown dimensions of trees accurately after a stand is thinned. Furthermore, the ways in which a tree's growth rate, height, diameter, and crown dimensions vary with each other in unthinned stands are not expected to apply to trees in thinned stands yet these patterns of variation are implicit in all the models in CRYPTOS. In contrast, the model in GSPACE which uses a codominant's height and growing space to predict its leaf surface area can be expected to apply about equally as well to trees in thinned stands once they fully occupy their growing spaces as it does to trees in unthinned stands. In both cases, a given size growing space will have a similar effect on the amount of light a crown receives and hence the amount of leaf surface area it has.

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basis of visual discontinuities in vegetation attributes. Smaller units may be bounded similarly although the visual discontinuities are seldom as prominent and therefore more equivocal, or the units may be bounded in another way such as arbitrary lines (e.g., a circle, square, or rectangle .2 acres in size) set

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[1]To include a wider range of initial conditions in such studies, a split-plot design would probably be the choice.

[2]Without a conscious perception of vegetation units or terrestrial ecosystems, the landscape is simply made up of organisms that are interacting and, thereby, exchanging matter, energy, or in the case of animals information with objects in their environment.

determines the number of replications in the experiment. The only limitation with such studies is that the treatment responses apply to only one or at most a few initial conditions[1].

Since the .2 acre forest units we used as experimental units had their own integrity and were not used to estimate stand growth for the larger twenty acre area within which they are located, we did not refer to them as plots. These experimental units were used to determine if thinning effects the amount of stand growth produced by groups of trees growing in different densities and not to determine the change thinning causes in stand growth over a relatively large area that is highly variable in terms of density. The latter change depends on both the amount of area covered by groups of different densities and the degree to which stand growth changes in the groups with different densities.

This confusion between sampling units and small forest units that serve as experimental units arises from the fact that the existence of entities containing a collection of organisms is far from unequivocal and depends on some conscious perception of them[2] and from the fact that these smaller units are often bounded differently than are stands. Stands are bounded on the basis of visual discontinuities in vegetation attributes. Smaller units may be bounded similarly although the visual discontinuities are seldom as prominent and therefore more equivocal, or the units may be bounded in another way such as arbitrary lines (e.g., a circle, square, or rectangle .2 acres in size) set

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around an area where one or more vegetation attributes is homogeneous. In the latter case, the arbitrary lines make these units begin to "feel" like plots even though they have their own integrity, are homogeneous in one or more vegetation attributes, and are viewed as the experimental unit instead of the stand or plantation being viewed as the experimental unit. In the end, whether the "plots" are experimental units or sampling units depends on the very specific hypothesis being tested.