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The purpose of this study was to determine if amount and kind of thinning had an effect on wood specific gravity, modulus of rupture, modulus of elasticity, growth rate, or pulp yield and kappa number. The study involved 24 1/5-acre plots, three plots in each of eight thinning treatments. The treatments were in three groups; constant cutting intensities, increasing cutting intensities, and decreasing cutting intensities. The stand was cut four times from 1963 to 1980. Static bending tests were done on juvenile and mature wood from trees on all plots. Also specific gravities and number of rings per inch were determined. Pulp yields and kappa numbers were also calculated. Statistical analyses showed differences between thinning treatments in specific gravity values of juvenile and mature wood, and in mature wood modulus of rupture. No differences were shown in pulp yield or kappa number due to thinning treatment. Specific gravity and growth rate seemed to influence strength property regressions more than stand density. Growth rate seemed most influential to pulp yield and kappa number regressions. Average MOR

and MOE values for the samples tested were 14% and 28% respectively below the Wood Handbook values for coast range Douglas-fir.

The Effect of Forest Stand Thinning on Selected Strength and Pulping Characteristics of Douglas-fir

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INTRODUCTION

Forest stands can and have been managed in many ways to enhance productivity above that of natural, unmanaged stands. Thinning is a proven way of increasing overall useable volume production in a forest stand. Several advantages of thinned stands are the utilization of trees that would have died of suppression, increasing the growth rate of the selected remaining trees, improving product quality, and receiving an income during the rotation of the stand (22, 24).

Much research has been done on the effects of thinning on wood yield but less work has been directed at the effect of forest stand thinning on wood properties. This study has investigated the effects of different thinning regimes on wood strength and pulping properties of Douglas-fir [*Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco].

OBJECTIVES

The objectives of this study can be summarized as follows:

1) To determine if individual thinning treatments (amount of thinning) have an effect on wood specific gravity, modulus of rupture, modulus of elasticity, pulp yield, or kappa number.
2) To determine if thinning regime (method of thinning) has an effect on wood specific gravity, modulus of rupture, modulus of elasticity, pulp yield, or kappa number.
3) To determine which variables (specific gravity, number of trees per treatment, basal area per treatment, volume of tree, dbh, rings per inch) best predict strength values, and pulp yield and kappa number.

LITERATURE REVIEW

Effect of Thinning on Stand Yield

A forest stand is thinned to redistribute growth potential to the best trees in the stand and to utilize all the merchantable material produced during the rotation (24). Wahlenberg (27) found that in white pine, diameter was the first tree dimension to respond to the additional growing space provided by thinning and that the thinned stands had better volume growth. Reukema and Pienaar (23) also reported that in Douglas-fir thinning caused increased growth rate on the remaining trees, although removal of larger than average trees from the thinned stands resulted in tree diameters of approximately the same size in the thinned and unthinned stands. This growth pattern was also shown by Reukema and Bruce (22) and Reukema (21).

Reukema (21) studied a 38-year-old Douglas-fir stand thinned at several intervals and intensities. He found all plots had virtually the same total cubic volume as before thinning, about 65 percent of what they would have had without thinning, and gross volume growth was about 20 percent less in thinned plots when compared to unthinned plots . However, there was half as much mortality in the thinned stands and enough wood was salvaged to offset the growth loss. Therefore, Reukema concluded that the primary benefit from commercial thinning was the earlier harvest of the product, not an increase in volume growth. While working with Pienaar on another study, Reukema (23) concluded that there was a slight gain in useable volume in thinned stands, but, again, the main benefit of commercial thinning was from earlier harvest. Reukema and Bruce (22) found commercial thinnings to reduce cubic volume growth per acre because the trees did not completely occupy the area after thinning, but precommercial thinning increased growth by eliminating excess competition and concentrating all growth on trees that became merchantable.

A study by Myers (15) included three Douglas-fir stands of different ages with three thinning intensities per stand. He also found that thinning stimulated diameter growth, especially in the younger stands. Growth of the 100 largest trees per acre increased with the intensity of thinning in each stand. In the younger stands, basal area growth increased with stand density. In this study thinning did not reduce the periodic annual increment of cubic foot volume. Growth did not differ much among any of the thinned stands.

Yerkes (32) determined that released Douglas-fir trees grow faster along the lower ten percent of the bole, most likely to counteract wind action. However, no difference in form class between treatments could be seen, since the increase in lower stem growth was not expected to last very long. Zahner and Whitmore (33) noted reaction wood bands forming in some loblolly pine trees after thinning, but after three years the amount of reaction wood being formed in thinned trees was no greater than in unthinned trees. Reukema (20) studied Douglas-fir at Wind River Experimental Forest, and found that dominants showed the greatest response to release and that both the crown class and the number of competitors removed from around the tree had highly significant effects on diameter growth.

Effect of Accelerated Growth on Wood Properties

It is widely accepted that thinning will increase the growth rate of remaining trees. The question remains as to whether or not this increased growth rate affects the properties of the wood. Parker *et al.* (17) reported on the effect of fertilization and thinning of Douglas-fir. They analyzed trees showing a pronounced radial increment response to fertilization and thinning. Their findings indicated that thinning promoted higher latewood density and significantly increased ring width at breast height. They also found that thinning contributed significantly to improved weights of pulp obtained, since there was an increase in volume production but no reduction in wood density. In comparing the effect of thinning and fertilizing treatments on growth rates, this study suggested that thinning had a more sustained or continued increase than fertilizing. Erickson and Lambert (9) also conducted a fertilizer/thinning study on Douglas-fir. They found that specific gravity was the same in thinned and control plots and that there was a relationship between specific gravity and summerwood percentage in the rings. When the wood was analyzed for lignin, holocellulose, alpha-cellulose, ash, and extractives, little or no significant difference was found between wood formed before or after treatment. Thinning did cause some tendency toward reduced cellulose content compared to the wood formed before thinning on the same trees.

In another fertilizer/thinning study by Megraw and Nearn (13), thinning was found to affect the within-ring, individual fiber densities. More intermediate-density type fiber resulted because of lowered latewood density and increased earlywood density conditions which should contribute favorably to pulping characteristics. Overall ring specific gravity was not significantly changed by the fertilizer/thinning treatments. The principle effect was a prolongation of the lower average density across a growth ring typical of the juvenile growth period.

Bendtsen (3) wrote a review of literature covering wood properties of improved stands grown under intensive management. He concluded that the major difference between managed and virgin forests is that accelerated growth led to earlier harvest and a greater proportion of juvenile wood. He does not agree with the conclusions that rapid-grown wood is inherently low in specific gravity, has short fibers, a large fibril angle, and other undesirable characteristics. Low specific gravity and poor fibril angle are mostly related to the age of the wood from the tree center, not growth rate. Bendtsen further concludes that at the same age or number of growth rings from the pith, trees of the same species tend to have similar specific gravities independent of growth rate. The juvenile wood of most conifers is found to have lower specific gravity, shorter tracheids, larger fibril angle, higher moisture content, thinner cell walls, larger lumen diameters, lower strength, lower latewood percentage, less cellulose, and more lignin than mature wood. Specific gravity was considered by most researchers in this review to be the best single index of intrinsic wood quality.

Erickson and Harrison (8) found that the most significant factor associated with percentage latewood was either age of wood or the width of the earlywood. Specific gravity was found to increase with age to an approximate age class of 16 to 18 years. Accelerated growth of the trees lowered specific gravity, although it tended to return to original levels several years after treatment even though the growth rate increased or remained at the same level. They found that a ring width of one millimeter may be the critical value above which an increase in growth rate has only a minimal effect on specific gravity. The study indicated that thinning by itself did not cause changes in the wood characteristics, but suddenly accelerated growth rates did.

Cown (6) found that in young radiata pine the wood properties were not markedly altered by thinning. The density was not changed, and the tracheid length was very slightly reduced. These effects were more apparent at breast height than elsewhere up the stem.

Chalk (5) looked at a disk of fast-grown Douglas-fir and found no close relation between ring-width and specific gravity. Further, he found no evidence of a relationship between specific gravity and number of rings from the pith. This indicated that the tree could be grown very rapidly without decreasing the wood density. In a review, Rendle (19) explains that softwoods with wide annual rings are not necessarily inferior, but rather it is the juvenile core with wide rings that is structurally weak.

Specific gravity is a good index of wood quality (14, 27, 29) and it decreases with height in conifers which have fairly distinct bands of summerwood and are characterized by low taper. At a given height, specific gravity generally increases from the pith outward until trees are about 100 years old, and afterward may decrease with greater age. Spurr and Hsuing (25), in their review on growth rate and specific gravity in conifers, found as other researchers had that there was little or no correlation between ring width and specific gravity when position in the tree was held constant. Fast growing trees produced a large amount of low-density juvenile wood. In general they found that most of the variation in specific gravity in wood samples was due to position in tree, age of wood, and structural design of the stem. They recommended that conifers be grown at the fastest rate commensurable with good form, small knot size, natural pruning, and other silvicultural considerations. Mitchell and Wheeler (14) found tree age to be the strongest factor influencing specific gravity in southern pines. Larson (12) also found that in slash pine rate of growth exerted a negligible influence on both specific gravity and percentages of summerwood. Summerwood percent proved to be the best single criterion for estimating specific gravity.

Keith (11) observed little correlation between specific gravity and distance from pith in white spruce veneer logs. He did find that ring width accounted for over 40 percent of the variation in specific gravity. Harris and Orman (10) showed that the percentage and density of latewood are the factors through which age and rate of growth react to regulate the density of Douglas-fir in New Zealand.

Strength and Specific Gravity Values of Douglas-fir

Some properties of wood increase directly with an increase in specific gravity, other properties increase more rapidly. Specific gravity also affords an index of strength for different pieces of the same species. Specific gravity is an excellent index of the amount of wood substance present since the specific gravity of the wood substance is about the same for all wood (27).

Paul (18) found the specific gravity of coast-type virgin Douglas-fir to be 0.45. In many trees the average specific gravity was not reached until the width of growth rings narrowed to about ten rings or more per inch. Second growth Douglas-fir follows the same relationship for material below 15 rings per inch. Thus, as growth decreases from 15 to 35 rings per inch the specific gravity tends to increase. Sometimes young-growth specific gravity exceeded the old-growth values for comparable growth rates. Young-growth with wide growth rings of three to five rings per inch had specific gravities which ranged from 0.35 up, with an average of 0.38. Trees from site II averaged 0.43 and site IV trees averaged 0.47 in specific gravity. Trees of smaller diameter contained the more dense wood.

Drow (7) found that second growth, coast-type Douglas-fir had an average specific gravity of 0.428. The strength properties tended to increase with specific gravity. The modulus of rupture ranged from 4,500 to 10,000 psi and modulus of elasticity ranged from 900,000 to 2,000,000 psi over a specific gravity range of 0.32 to 0.54. When the number of rings per inch changed from 2 to 35, modulus of rupture increased from 6,250 to 8,750 psi and modulus of elasticity from 1,200,000 to 2,000,000 psi.

THE HOSKINS STUDY

The Hoskins Study is part of a levels-of-growing-stock study in young growth Douglas-fir coordinated by the Pacific Northwest Forest and Range Experiment Station. It is a joint effort by Oregon State University, the Oregon Forest Research Laboratory, and by Starker Forests, Corvallis, Oregon through provision of forest land. The study area is located just west of the Coast Range summit near Hoskins, Oregon, about 25 miles northwest of Corvallis. The land has a southerly aspect with slopes from 15 to 25 percent.

This experiment consists of eight thinning regimes plus unthinned control plots. Basal area change (growth) in the unthinned plots was the basis for treatment (amount of thinning) in the thinned plots. Three one-fifth acre plots per treatment were arranged in a completely randomized design (Figure 1). All 24 treatment plots were thinned to the same density (calibration thinning) before treatments began to minimize the effect of variations in original density on stand growth, and also to leave the stand as uniform and evenly spaced as possible.

The thinning regimes differed in the amount of basal area allowed to accumulate in growing stock. The amount of growth retained was a predetermined percentage of the gross basal area increase found in the unthinned plots since the last thinning (Table 1). Thinning regimes were being tested, rather than a single thinning treatment. Treatments 1, 3, 5, and 7 were of approximately constant cutting intensities (the same percentage of control plot basal area increase was retained at each thinning), differing only

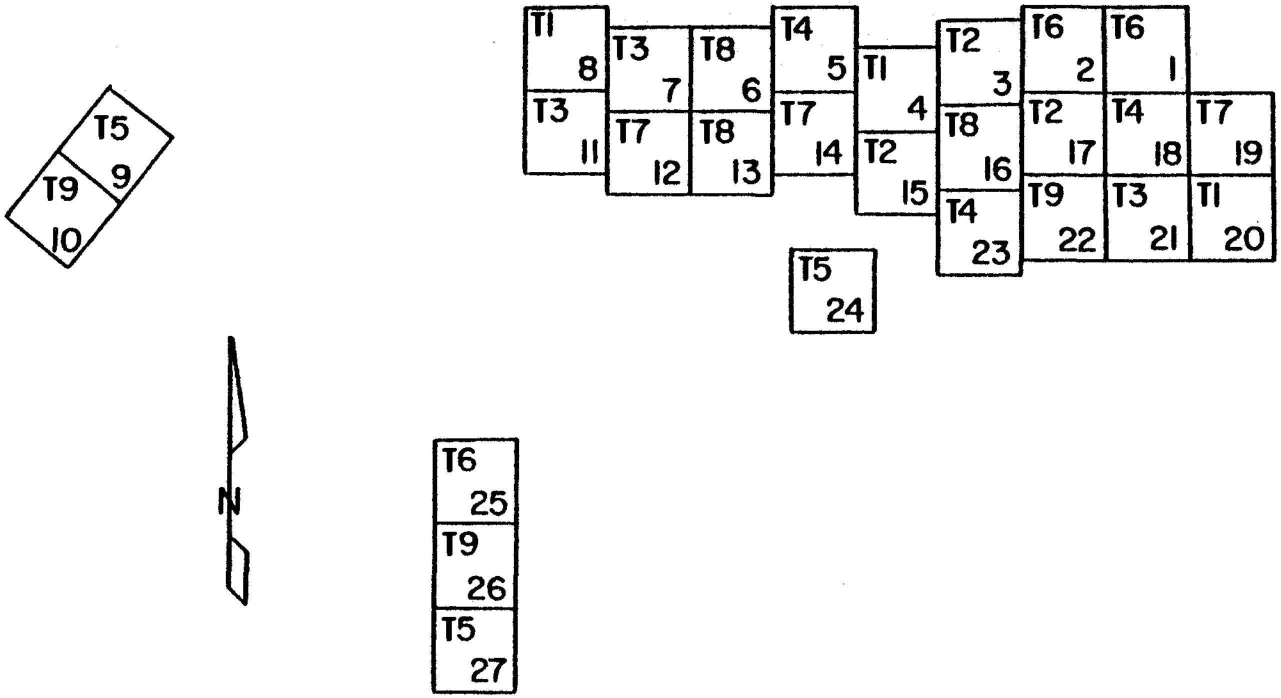

Figure 1. Plot location in Hoskins levels-of-growing-stock study.

Thinning	Treatment 1	2	3	4	5	6	7	8
First	10	10	30	30	50	50	70	70
Second	10	20	30	40	50	40	70	60
Third	10	30	30	50	50	30	70	50
Fourth	10	40	30	60	50	20	70	40

Table 1. Levels-of-growing-stock study treatment schedule, showing percent of gross basal area increment of control plot to be retained in growing stock (31).

in percentage of control plot basal area increase remaining. Treatments 2 and 4 varied in percentage of control plot basal area increase retained at each thinning from less basal area increase remaining to more basal area increase remaining (progressively lighter thinnings at each thinning). Treatments 6 and 8 varied in percentage retained from higher percentage retained to lower percentage retained (progressively heavier thinnings at each thinning).

Thinnings were made whenever the average height growth of the crop trees following the year of calibration thinning came closest to each multiple of ten feet. The stand was thinned in 1967, 1971, 1974, and 1980.

Details of the existing study can be found in the Levels-of-growing stock reports (2, 4, 30, 31).

PROCEDURE

The Hoskins plantation was thinned for the fourth time in the spring of 1980. Thinned trees were left on the ground, and samples for this study were taken from the felled trees. Bolts approximately two feet long were selected from above the butt swell of the trees. Cross-sectional disks were cut out at about dbh. All samples were labeled and taken to the Forest Research Laboratory at Oregon State University for preparation and testing.

Static Bending Sample Preparation and Testing

The bolts from each tree supplied samples for static bending tests and chips for pulping. Two or three static bending samples were cut from each bolt along an 'average' radius of the bolt. Each bending sample was cut to a one inch by one inch by 16 inch size, attempting to keep the growth rings parallel to one edge, while avoiding knots, compression wood, and irregular grain. The first bending sample from each bolt was cut one half inch from the pith of the bolt, representing juvenile wood. The second sample was cut one to one and one half inches from the first. If the bolt was large enough, a third sample was cut at one to one and one half inches from the second. The outermost sample, whether the second or third, represented mature wood. In the instances where there were three samples the middle sample was not considered in the results. The cut samples were then labeled and placed in a standard room (temperature 70°F; relative humidity 70%) for three weeks to equilibrate before testing.

These bending specimens were tested on the Instron Universal Testing Machine following as closely as possible ASTM secondary procedures D-141 for solid wood testing under the following conditions:

sample size	1" x 1" x 16"
span	14"
crosshead speed	0.1 cm/min.
loading block diameter	3 inches

Before testing, the height and width of all samples were measured to the nearest thousandth of an inch. They were then placed in the machine and loaded until maximum load (rupture) was reached. The slope of the elastic portion of the load-deflection curve, the maximum load, and the load at proportional limit were obtained from the Instron charts. From these values the modulus of elasticity (MOE), modulus of rupture (MOR), and fiber stress at proportional limit (FSPL), respectively, were calculated, using the following formulae:

$$\text{MOE} = \frac{(\text{load at proportional limit})(\text{length}^3)}{4\ (\text{deflection})(\text{width})(\text{depth}^3)}$$

$$\text{MOR} = \frac{1.5\ (\text{maximum load})(\text{length})}{(\text{width})(\text{depth}^2)}$$

$$\text{FSPL} = \frac{1.5\ (\text{load at proportional limit})(\text{length})}{(\text{width})(\text{depth}^2)}$$

Chip Preparation and Pulping

One tree from each treated plot was randomly chosen to be pulped. A wedge from each of the chosen bolts was split out and debarked. The wedge was split into smaller pieces and chipped in a two knife, 24 inch, #48 Appleton Machine Works Chipper. The chips were then processed through a John Deere No. 6 hammermill and air dried for two days. After drying, the chips were screened on a Williams Chip Classifier and the chip sizes (-5/8 to +3/16) were stored in plastic bags. The chips were pulped by the Kraft process in small tube digesters heated by a rocking oil bath. Ten tubes (samples) were cooked at once. Each tube held the equivalent of 15 grams of oven dry chips, along with 105 grams of the pulping liquor. The chips were cooked under the following conditions:

Active Alkali	22.4% on wood
Sulfidity	25%
Liquor/wood ratio	7/1
Time to 338°C	60 minutes
Time at 338°C	90 minutes
Target H factor	1,440

These conditions were selected to be as close to standard procedures as practicable. Two chip samples were cooked from each tree being pulped.

After cooking, the chips and spent cooking liquor were emptied from the digester tubes with water, blended in a Waring blender for approximately one minute to defiber the chips and then thoroughly washed to remove the spent cooking liquor. The pulp was vacuum dried on a piece of filter paper in a filter funnel over a flask and then partially dried on the filter paper in a press drier. The pulp was placed overnight in an oven at 105°C. The filter paper was removed, and the pulp mat was weighed. Pulp yield was calculated as follows:

$$\%\ \text{yield} = \frac{\text{oven dry weight of pulp out of digester}}{\text{original weight of chips into digester (15 grams)}}$$

Kappa number was also calculated on each cook, using methods described in TAPPI standard T-236 os-76 and was calculated by the following formula:

$$\log K = \log \left[\frac{\frac{(b-a)\ N}{0.1}}{W} \right] + 0.00093 \left[\frac{(b-a)\ N}{0.1} - 50 \right]$$

K = Kappa number
b = blank titration of 100 ml $KMnO_4$
a = actual titration value (ml of thiosulfate)
N = normality of thiosulfate
W = oven dry weight of pulp (g)

Specific Gravity Calculations

After the static bending tests, a one inch cube of wood was cut from each bending sample as close to the point of rupture as possible. The length and weight of the piece were measured. The cube was then put in an oven at 105°C to dry for 24 hours before being weighed again. These data were used to calculate moisture content percentage (% MC) and specific gravity (SG) of the samples using the following methods:

$$\%\ MC = \frac{(\text{green weight of block}) - (\text{ovendry weight of block})}{(\text{green weight of block})} \times 100$$

$$SG = \frac{\text{ovendry weight of block}}{\text{weight of water in equivalent volume of green wood}}$$

The number of growth rings on the end of each block was also counted.

The disks cut from the trees were used to obtain specific gravity measurements. A wedge was cut from each disk and then was cut again into three radial segments. The first segment included the first ten growth rings nearest the pith (juvenile wood segment). The remaining piece was cut approximately in half, the outer piece represented the mature wood segment. All segments were soaked overnight. Green volume of all segments was measured by water displacement, and oven dry weights were obtained. From this information the specific gravity was calculated for each segment and for the wedges as a whole (average immersion specific gravity).

The data obtained from the trees were averaged for each plot making a total of 24 observations on each of the measured variables in Table 2.

Statistical Analyses

The data were statistically analyzed using the SIPS program at Oregon State University. An analysis of variance was performed on variables SGBJ (bending sample specific gravity for juvenile wood), SGBM (bending sample specific gravity for mature wood), SGIJ (wedge specific gravity for juvenile wood), SGIM (wedge specific gravity for mature wood), MOEJ (modulus of elasticity for juvenile wood), MOEM (modulus of elasticity for mature wood), MORJ (modulus of rupture for juvenile wood), MORM (modulus of rupture for mature wood), FSPLJ (fiber stress at proportional limit for juvenile wood), FSPLM (fiber stress at proportional limit for mature wood), RIJ (number of rings per inch for juvenile wood), RIM (number of rings per inch for mature wood), XSGI (average wedge specific gravity), DBH (diameter breast height), VOL (volume), NOTR (number of trees per plot), BA (basal area per plot), YLD (pulp yield), and KAPPA (kappa number of pulp), using TTMT (treatment) as the

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TTMT: Treatment

SGBJ: Specific gravity from static bending sample, juvenile wood
SGBM: Specific gravity from static bending sample, mature wood
SGIJ: Specific gravity from wedge, juvenile wood
SGIM: Specific gravity from wedge, mature wood
MOEJ: Modulus of elasticity, juvenile wood, psi
MOEM: Modulus of elasticity, mature wood, psi
MORJ: Modulus of rupture, juvenile wood, psi
MORM: Modulus of rupture, mature wood, psi
FSPLJ: Fiber stress at proportional limit, juvenile wood, psi
FSPLM: Fiber stress at proportional limit, mature wood, psi
RIJ: Number of rings per inch from static bending sample, juvenile wood
RIM: Number of rings per inch from static bending sample, mature wood
XSGI: Average specific gravity from immersion method
DBH: Diameter breast height, inches
VOL: Volume, cubic feet
NOTR: Number of trees per plot
BA: Basal area per plot, square feet
YLD: Pulp yield, percent
KAPPA: Kappa number

Moisture contents, specific gravities, strength values, rings per inch, diameters and volumes are plot averages of all trees sampled on each plot. Yield and kappa values are from one randomly selected tree per plot.

Table 2. Variables used in one-way classification analyses of variance, regressions, HSD analyses, and contrasts.

classification variable (Table 2 gives a key to variable abbreviations). The F values obtained in this analysis tested whether the variable in question differed significantly between treatments.

Another analysis of variance was conducted using a split-plot design. The data were manipulated so that the juvenile and mature wood value for each plot, along with the whole tree values (DBH, VOL, XSGI, NOTR, BA) were separate observations making a total of 48 observations (variables explained in Table 3). This analysis tested the differences of variables SGB (bending sample specific gravity), SGI (wedge specific gravity), MOE (modulus of elasticity), MOR (modulus of rupture), FSPL (fiber stress at proportional limit), and RPI (rings per inch) due to TTMT (thinning treatment) and JM (wood type, juvenile or mature). Three tests were involved in this analysis to answer these three questions; (1) was there a difference between juvenile and mature wood over all treatments, (2) were the differences between juvenile and mature wood values consistent for all treatments, (3) did treatments have an effect on the juvenile and mature wood values (Appendix E).

In the instances where one-way classifications or split-plot design analysis of variance proved significant for differences between treatments, a test of Honestly Significant Differences (HSD) was carried out for the separate juvenile and mature treatment means. This test compares all possible pairs of treatment means of the variable involved, and by comparing the differences between means with the computed HSD value, the test determines which pairs of values differ (Appendix F).

TTMT:	Treatment
JM:	Juvenile/mature wood indicator variable
MOE:	Modulus of elasticity, psi
MOR:	Modulus of rupture, psi
FSPL:	Fiber stress at proportional limit, psi
RPI:	Number of rings per inch on bending samples
SGB:	Bending sample specific gravity
SGI:	Wedge specific gravity

Table 3. Variables used in split-plot design analyses of variance.

A set of contrasts was also performed on the variables that proved different in the analyses of variance. The contrasts tested for differences between the three groups of treatments, constant cutting intensities, increasing cutting intensities, and decreasing cutting intensities with each thinning treatment. As previously explained, treatments 1, 3, 5, and 7 were cut leaving a constant amount of the added basal area of the unthinned plots (constant cutting intensities), treatments 2 and 4 were cut leaving decreasing amounts of the added basal area of the control plots (increasing cutting intensities), and treatments 6 and 8 were cut leaving increasing amounts of the added basal area of the control plots (decreasing cutting intensities)(Appendix G).

Regressions were conducted using each strength value as a dependent variable and SGBJ or SGM, SGIJ or SGIM, RIJ or RIM, XSGI, DBH, VOL, NOTR, and BA as independent variables. Regressions were also carried out using KAPPA and YLD individually as dependent variables, with XSGI, DBH, VOL, NOTR, BA, and YLD or KAPPA as independent variables. All regressions were conducted by using the computer command STEPWISE, which adds variables one at a time, according to which variable has the best F value until all variables are incorporated into the model. At each addition the F value was tested to see if the variable just added was significant to the regression. The order in which the variables entered was also noted for comparison with the other regression analyses (Appendix H).

RESULTS

The F-values for the one-way classification analyses of variance are shown in Table 4. The split-plot design analysis of variance F-values are given in Table 5. The F-values of the one-way analyses of variance test whether there is a difference in the means of at least one of the treatments when compared to the others. These F-values show a significant difference in at least one of the treatment means for mature wood MOR (modulus of rupture) and highly significant differences in at least one of the treatment means in both juvenile (SGIJ) and mature (SGIM) wood wedge specific gravity, number of trees per plot (NOTR) and basal area per plot (BA). The split-plot design analyses of variance also show a significant difference (at the 0.05 level) between one or more of the treatments for wedge specific gravity (F-value associated with TTMT in Table 5) but not for MOR. This could be due to the non-significance of juvenile wood MOR in the one-way analysis of variance so when both juvenile and mature wood MOR values were considered together in the split-plot design analysis of variance no significant difference in the MOR values was found.

The split-plot analysis also tested for differences between juvenile and mature wood values over all treatment means (F-value associated with JM in Table 5). There was a highly significant difference (0.01 level) in the variables SGB, SGI, MOE, FSPL, and RPI between juvenile and mature wood and a significant difference (0.05 level) in MOR between juvenile and mature wood. The split plot design analysis of variance also tested for the consistency of

Variable	F-value
SGBJ	1.6267
SGBM	2.1584
SGIJ	4.3207**
SGIM	6.3342**
MOEJ	2.2690
MOEM	0.8087
MORJ	0.2658
MORM	2.7113*
FSPLJ	1.1037
FSPLM	0.8894
RIJ	0.3923
RIM	1.9610
XSGI	2.4676
DBH	0.6942
VOL	0.5171
NOTR	46.7282**
BA	7.2587**
YLD	1.1469
KAPPA	1.5766

*Significant (at 0.05 level)

**Highly significant (at 0.01 level)

Table 4. F-values associated with one-way classification analyses of variance (complete analyses in Appendix D).

Variable	Source of Variation	F-value
SGB		
	TTMT	1.8511
	JM	42.8252**
	TTMT * JM	2.0407
SGI		
	TTMT	5.3369**
	JM	29.7311**
	TTMT * JM	3.2972*
MOE		
	TTMT	1.1095
	JM	315.6902**
	TTMT * JM	4.6399*
MOR		
	TTMT	1.0197
	JM	26.1419*
	TTMT * JM	2.1355
FSPL		
	TTMT	0.7517
	JM	36.9473**
	TTMT * JM	1.8152
RPI		
	TTMT	0.7033
	JM	23.0333
	TTMT * JM	3.0675

*Significant (at 0.05 level)

**Highly significant (at 0.01 level)

Table 5. F-values associated with split-plot design analyses of variance (complete analyses in Appendix E).

differences between juvenile and mature wood over all treatments (interaction term F-value, JM*TTMT in Table 5). The F-values for this test were significant for the variables SGI (wedge specific gravity), MOE (modulus of elasticity), and RPI (number of rings per inch), indicating that the differences between juvenile and mature wood varied with treatment. The differences between juvenile and mature wood for variables SGB (bending sample specific gravity) and MOR (modulus of rupture) were not statistically different for all treatments.

Appendix F shows the HSDs (Honestly Significant Differences) of mature wood modulus of rupture (MORM), and of both juvenile and mature wood wedge specific gravities (SGBJ and SGBI), and for number of trees per plot (NOTR) and basal area per plot (BA). The juvenile wood wedge specific gravity means were significantly different between treatments 1 and 2, 1 and 5, and 1 and 7. The mature wood wedge specific gravity means were significantly different between treatments 1 and 2, 1 and 4, 1 and 7, and 3 and 4, and highly significantly different between treatments 1 and 4. Mature wood MOR treatment means were significantly different between treatments 1 and 4.

The treatment means for number of trees per plot and basal area per plot were almost all highly significantly different since they were more a function of the experimental plan than of treatment effects.

Contrasts were performed on the variables that were significantly different in the one-way analysis of variance. These contrasts tested differences between the groups of treatments, constant cutting intensities (treatments 1, 3, 5, and 7), decreasing cutting intensities (treatments 2 and 4), and increasing cutting intensities (treatments 6 and 8). Appendix G shows the contrasts performed, and Table 6 summarizes the results. Contrast 1 tested for a difference between constant cutting intensities and varying cutting intensities (both increasing and decreasing cutting intensities), contrast 2 tested for a difference between decreasing cutting intensities and increasing cutting intensities, contrast 3 tested for differences between constant cutting intensities and decreasing cutting intensities, and contrast 4 tested for the difference between constant cutting intensities and increasing cutting intensities.

A significant difference between the varying intensity thinning treatments was shown for juvenile wood wedge specific gravity. Mature wood wedge specific gravity means varied highly significantly between constant intensities and all of the varied thinning intensities, between constant cutting intensities and decreasing cutting intensities, and between increasing cutting intensities and decreasing cutting intensities. Mature wood MOR values show highly significant differences between constant cutting intensities and decreasing cutting intensities, and constant and decreasing cutting intensities and a significant difference between low to high and high to low cutting intensities.

There was no difference between constant intensities and all varying cutting intensities for both NOTR (number of trees per plot) and BA (basal area per plot). All other contrasts with these two variables showed highly significant differences.

Variable	Contrast: 1	2	3	4
	Contrast t-values			
SGIJ	0.891	2.316*	2.065	0.610
SGIM	3.657**	-3.012**	4.725**	1.246
MORM	3.245**	-2.399*	4.034**	1.264
NOTR	1.138	-7.197**	5.085**	-3.226**
BA	-0.601	-24.833**	12.839**	-14.820**

*Significant (at 0.05 level)

**Highly significant (at 0.01 level)

Table 6. t-values associated with contrasts (complete analyses in Appendix G)

The results of the stepwise regression analysis are in Table 7 (regressions in Appendix H). The table shows the order in which the variables entered the models, even if the entering variable was not significant. In most cases involving the strength value variables (MOR, MOE, FSPL), a specific gravity variable entered into the regression first, followed by a growth rate variable (number of rings per inch, volume, or dbh).

The pulp yield regression added first the variable volume, and then number of trees per plot, the only significant regression variables. The kappa number regression had no significant variables, but the first variable to enter was volume.

Dependent Variable	Independent Variables in Entering Order F-value								R^2 at Last Significant Entering Variable
YLD	VOL 6.59*	NOTR 3.93*	KAPPA 2.79	DBH 2.07	BA 1.63	XSGI 1.37			0.2724
KAPPA	VOL 4.29	YLD 2.60	DBH 1.84	XSGI 1.34	NOTR 1.02	BA 0.83			
MOEJ	SGBJ 4.53*	VOL 7.05**	SGIJ 5.04**	RIJ 3.66*	NOTR 2.81**	BA 2.25	DBH 1.85	XSGI 1.52	0.4385
MOEM	SGBM 19.28**	DBH 25.09**	SGIM 17.40**	RIM 12.31**	NOTR 9.37**	BA 7.50**	XSGI 6.12**	VOL 5.02**	0.7282
MORJ	RIJ 16.13**	SGBJ 15.34**	BA 12.76**	XSGI 9.80**	DBH 7.63**	NOTR 6.15**	SGIJ 5.01**	VOL 4.12**	0.6871
MORM	SGIM 13.65**	VOL 14.83**	NOTR 9.51**	BA 7.27**	DBH 5.57**	SGBM 4.41**	XSGI 3.56*	RIM 2.93*	0.6095
FSPLJ	RIJ 6.57*	SGBJ 4.18*	VOL 3.00	SGIJ 2.22	DBH 1.72	XSGI 1.39	BA 1.12	NOTR 1.41	0.2849
FSPLM	SGIM 13.12**	VOL 10.04**	RIM 9.47**	BA 7.40**	NOTR 7.84**	DBH 7.77**	SGBM 6.38**	XSGI 5.24**	0.7366

*Significant (at 0.05 level)

**Highly significant (at 0.01 level)

Table 7. Order variables entered into regression models, and associated f-values. R^2 values at last significant entering variable (complete analyses in Appendix H)

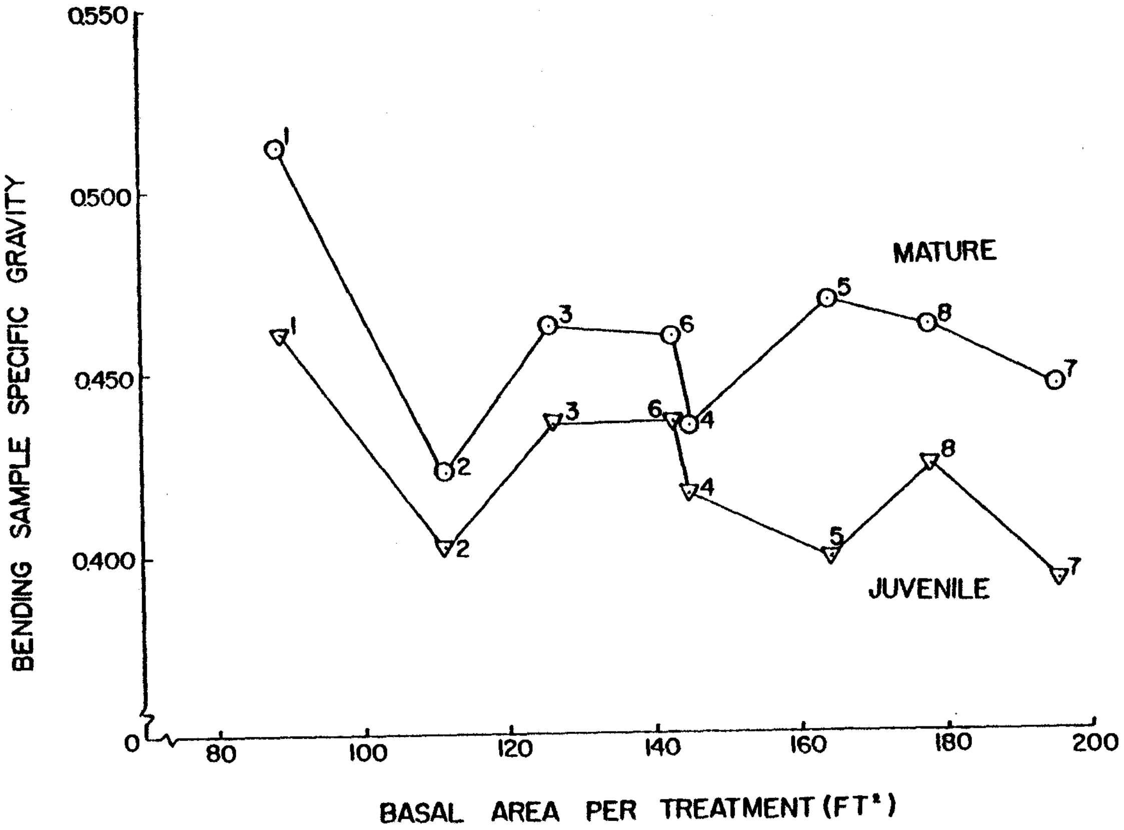
DISCUSSION

Treatment Effects on Specific Gravity

Specific gravity appeared to be affected by thinning treatment. The wedge specific gravity differed significantly among thinning treatments in juvenile and mature woods although the bending sample specific gravity did not vary significantly among thinning treatments. The wedge specific gravity means might be considered more representative of the true sample means because the samples used to obtain these measures included wood volumes that were proportional to the actual volume of wood with different specific gravities in the stem cross-section the samples were taken from.

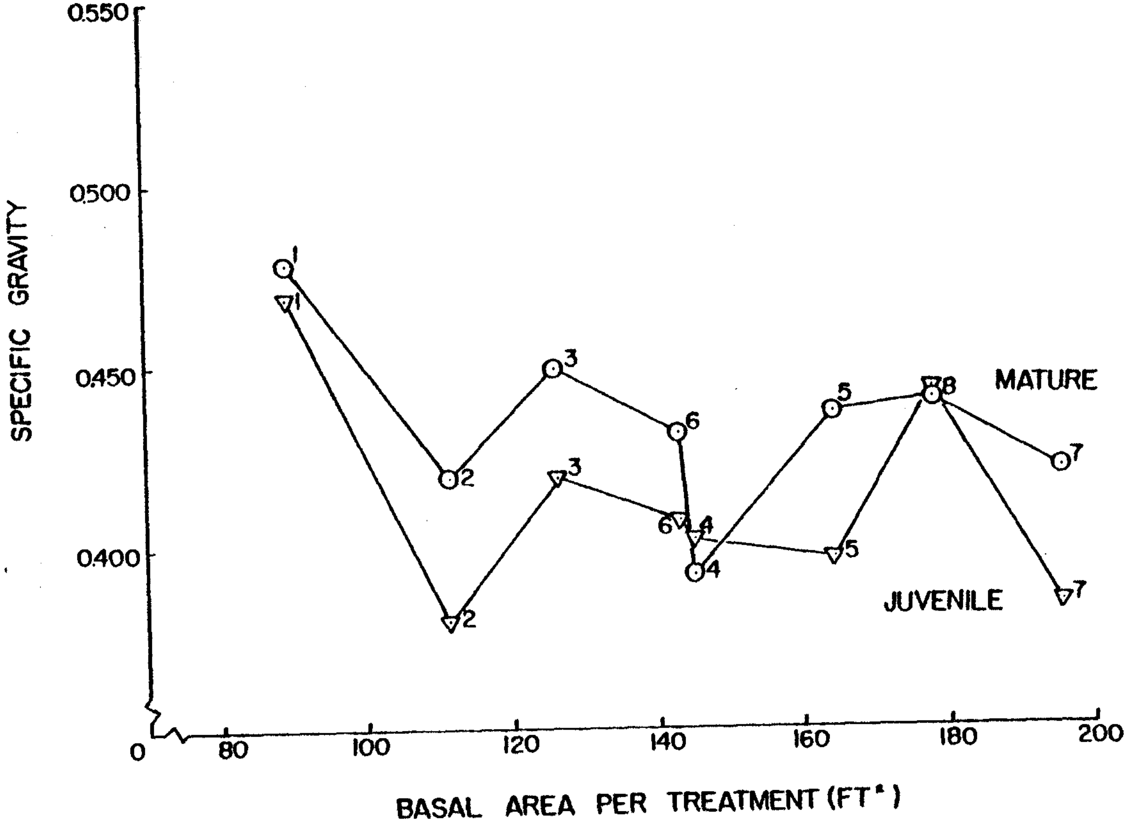
The trend (without statistical significance) for both the bending sample and wedge specific gravities (Figures 2 and 3 respectively) was generally to be lower as the amount of basal area per plot increased (intensity of thinning decreased). This trend was more pronounced when only treatments 1, 3, 5, and 7 were considered (treatments cut at constant thinning intensities). The average wedge specific gravity also followed this general trend (Figure 4) although again there was no statistically significant difference among thinning treatments.

The correlation coefficients for basal area per plot and bending sample specific gravity are -0.389 for juvenile wood and -0.219 for mature wood. For the wedge specific gravity and basal area the r values were -0.306 for juvenile wood and -0.355 for mature wood. Average wedge specific gravity and basal area per plot had an r value of -0.439. These values all indicate a downward trend in



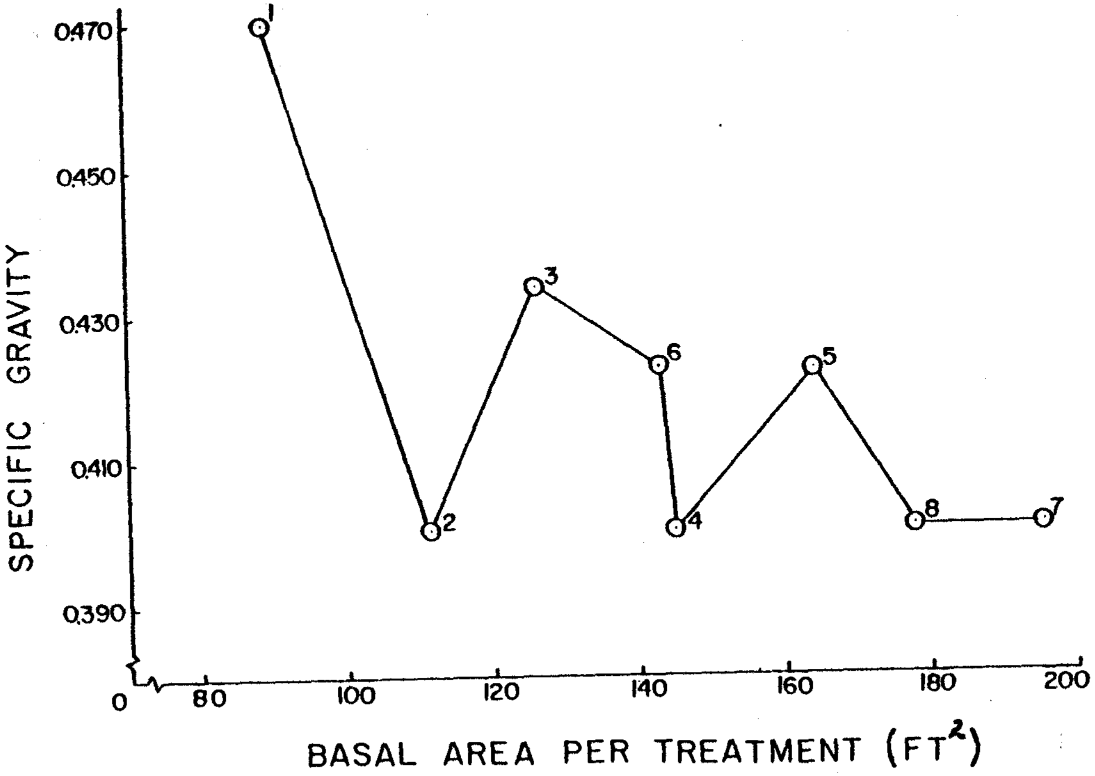
Note: Numbers beside data points represent treatment number.

Figure 2. Bending sample specific gravity versus basal area per treatment for juvenile and mature wood.



Note: Numbers beside data points represent treatment number.

Figure 3. Wedge specific gravity versus basal area per treatment for juvenile and mature wood.



Note: Numbers beside data points represent treatment number.

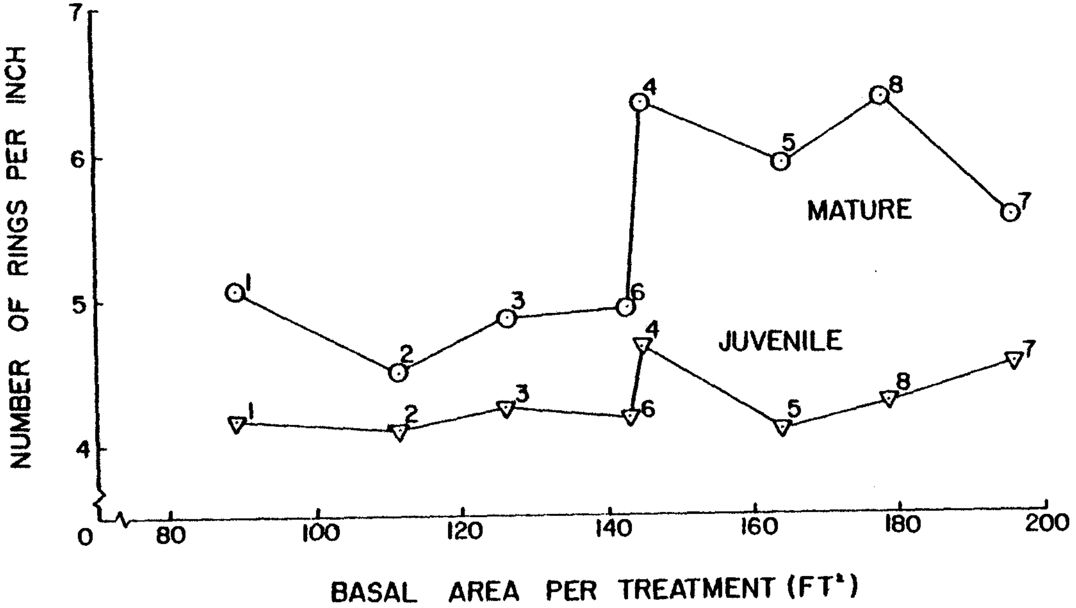
Figure 4. Average wedge specific gravity versus basal area per treatment.

specific gravity with increasing basal area per plot (less thinning). This trend seems opposite to what might be expected, that is, specific gravity would be greater when the stand was thinned less, and therefore growing more slowly. However, several researchers have found that thinning did not reduce wood density (9, 13, 17). Parker et al. (17) found that thinning promoted higher latewood density.

Growth Rate

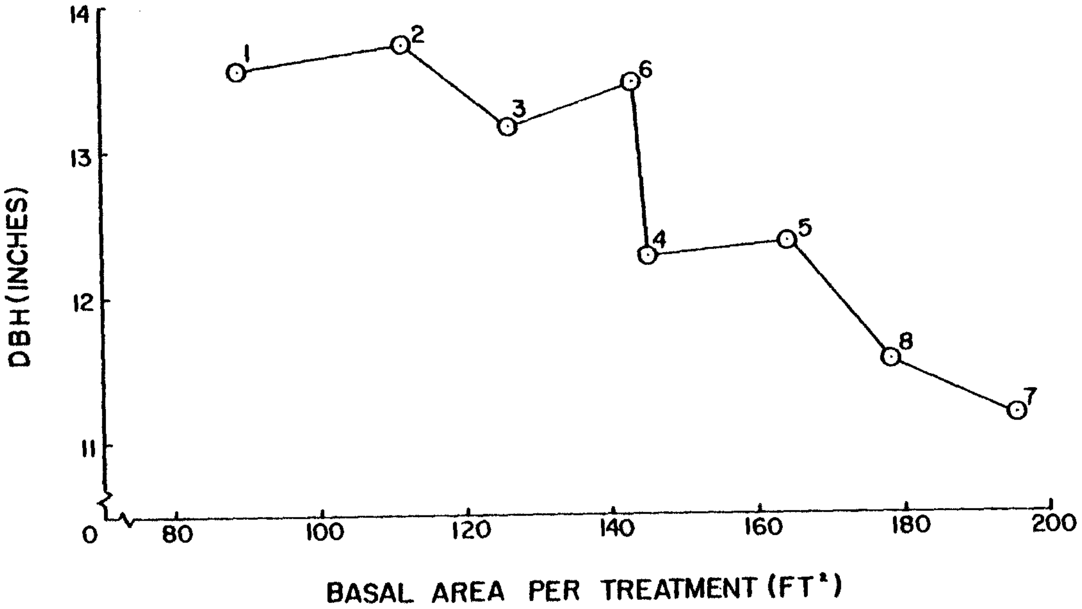
The number of rings per inch in the bending samples did not differ significantly by treatment. Figure 5 shows how growth rate varied over the range of basal area. The correlation coefficient for juvenile wood rings per inch with basal area per plot was 0.127 and for mature wood number of rings per inch with basal area per plot the r was 0.529. The juvenile wood correlation would be expected to be low since the trees were not given the first thinning treatment until they reached 20 years of age. This would indicate that the juvenile wood material most likely was not affected by thinning treatment.

The higher correlation between mature wood rate of growth and basal area is supported by other research showing an increase in growth rate due to thinning (10, 21, 22, 23, 32). A somewhat high correlation was also found between dbh (Figure 6) and basal area per plot (r value of -0.441), which would be expected since diameter growth is also a growth rate variable. Volume per tree is highly correlated with dbh (an r value of 0.975) so volume (Figure 7) would also follow the trend of increasing growth rate with decreasing basal area per plot (increased thinning).



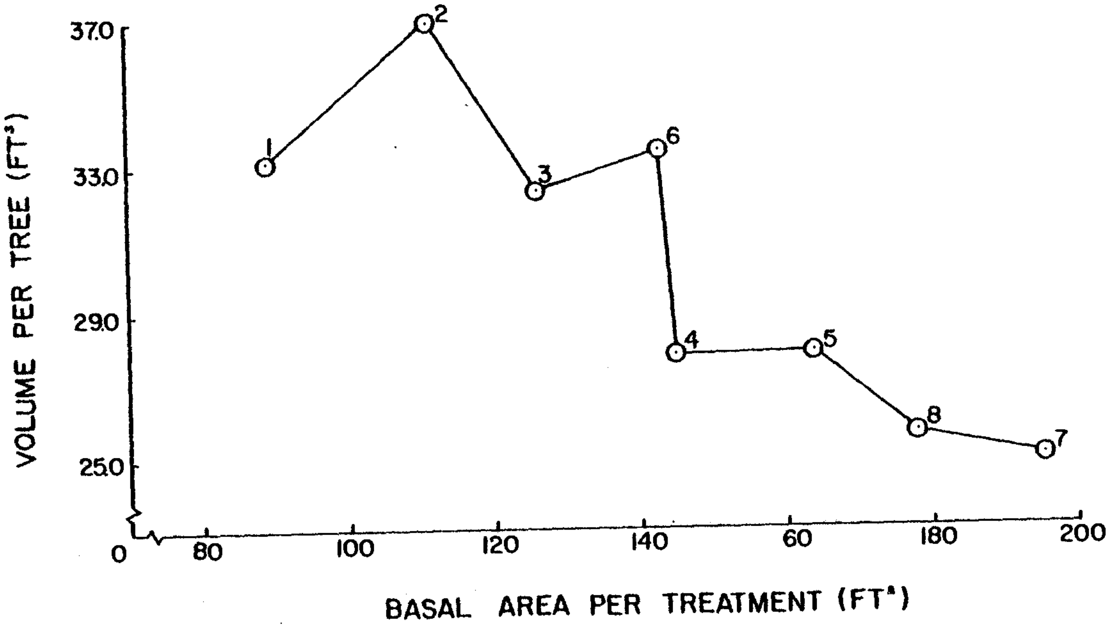
Note: Numbers beside data points represent treatment number.

Figure 5. Number of rings per inch versus basal area per treatment for juvenile and mature wood.



Note: Numbers beside data points represent treatment number.

Figure 6. Diameter breast height versus basal area per treatment.



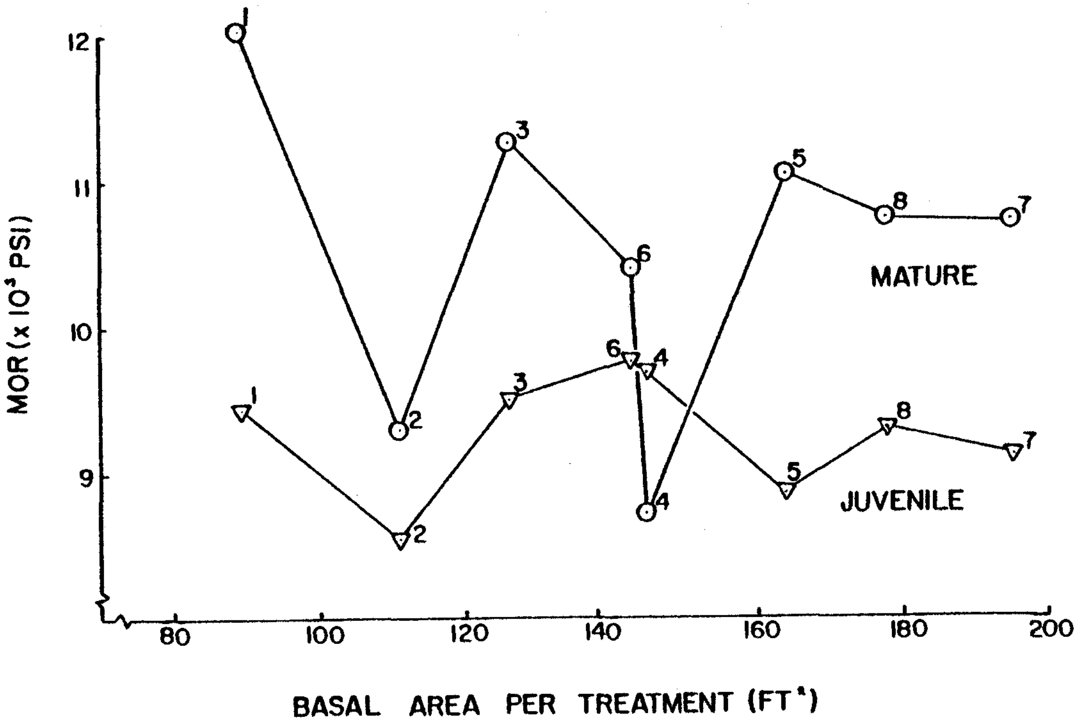
Note: Numbers beside data points represent treatment number.

Figure 7. Average tree volume per treatment versus basal area per treatment.

Modulus of Rupture

The modulus of rupture, MOR, does not appear to vary consistently with basal area per plot (Figure 8). The r values are 0.007 for juvenile wood MOR with basal area per plot and -0.069 for mature wood MOR. MOR values correlate much better with specific gravity values than with the basal area values. The correlation coefficients between juvenile wood MOR and specific gravity are 0.486 for bending sample specific gravity and 0.385 for wedge specific gravity. For mature wood the MOR correlation coefficients with specific gravities are 0.564 for bending sample specific gravity and 0.619 for wedge specific gravity. Specific gravity has been found to be a good predictor of strength values in wood because it gives a good indication of the amount of solid wood substance present.

There was a significant difference between the effect of one or more of the thinning treatments on MOR values in the mature wood samples. In the HSD (Honestly Significant Difference) analysis (Appendix F) this difference appears to be between treatments 1 and 4. Since there was also a difference between these two thinning treatments with the wedge specific gravity data for mature wood the difference in MOR appears to be due to variation in specific gravity. Treatment 1 was thinned at a constant cutting intensity and treatment 4 was thinned at decreasing cutting intensity. The contrast analysis (Table 6) indicates a difference between the two groups (constant cutting intensities and decreasing cutting intensities). The average MOR for the mature wood samples was



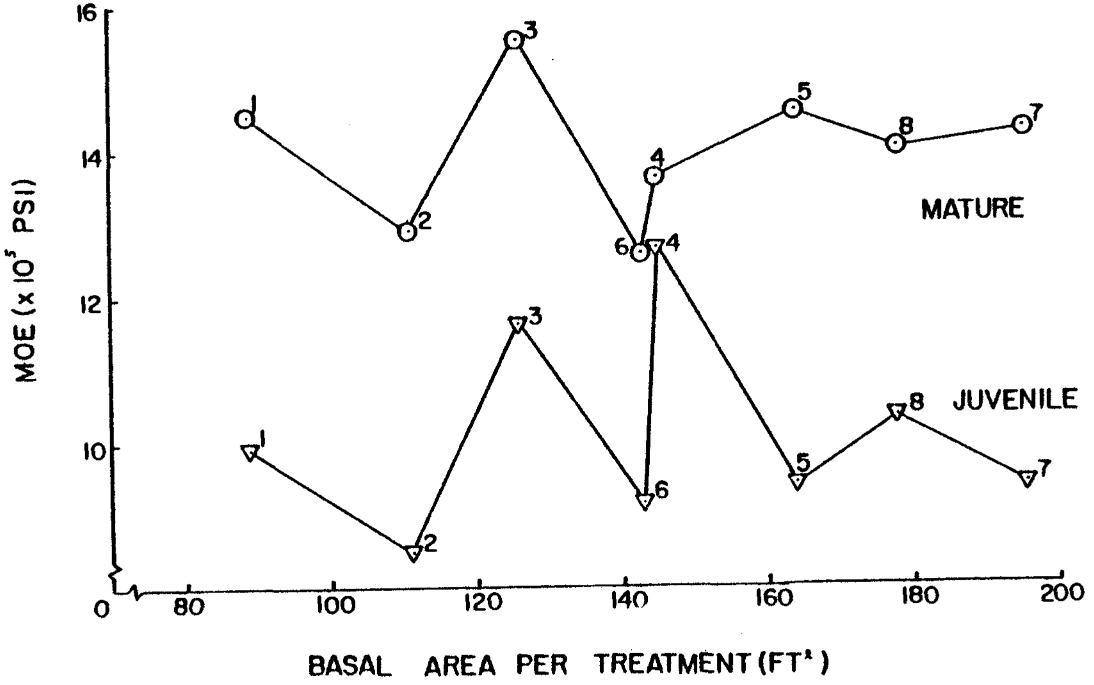
Note: Numbers beside data points represent treatment number.

Figure 8. Modulus of rupture versus basal area per treatment for juvenile and mature wood.

10,000 psi, 14.5% below the Wood Handbook value of 12,400 psi for coast range Douglas-fir.

Modulus of Elasticity

Modulus of elasticity (MOE) values showed no significant differences among thinning treatments (Table 4). They also showed little consistent upward or downward trend with change in basal area (Figure 9). This observation is further verified by the correlation coefficients of MOE values and basal area per plot values. The r value for juvenile wood MOE and basal area per plot was 0.014, and 0.036 for mature wood MOE and basal area per plot. As with MOR, MOE correlates much better with the specific gravity values. Mature wood MOE and bending sample specific gravity had an r value of 0.683, mature wood MOE and wedge specific gravity had an r value of 0.539. Juvenile wood MOE correlates with bending sample specific gravity with an r of 0.413 and with wedge specific gravity with an r of 0.210. Average wedge specific gravity and mature wood MOE have a correlation coefficient of 0.305 and average wedge specific gravity with juvenile wood have an r value of 0.481. The correlations for mature wood MOR values are not what would be expected, since the MOR values correlate better with wedge specific gravity than with the bending sample specific gravity from which the strengths were determined. The average MOE for the mature wood samples was 1.40 million psi, 28.2% less than the Wood Handbook value of 1.95 million psi for coast range Douglas-fir.



Note: Numbers beside data points represent treatment number.

Figure 9. Modulus of elasticity versus basal area per treatment for juvenile and mature wood.

Fiber Stress at Proportional Limit

Although values for fiber stress at proportional limit (FSPL) were obtained and an analysis of variance was run on these values they were not considered in this discussion. However, analyses of variance and regressions for FSPL are in the Appendices.

Juvenile and Mature Wood Differences

In all the correlations between specific gravity and strength values the mature wood values correlated more highly than the juvenile wood values. Juvenile wood tends to be less consistent in anatomical characteristics and varies from tree to tree more than does mature wood. Such wood is also lower in strength than mature wood and most of the specific gravity values are lower than the mature wood values. In the instance where juvenile wood was stronger than mature wood (MOR, treatment 4) the wedge specific gravity was also higher for the juvenile wood. The juvenile wood MOE values are lower than the mature wood values for treatment 4 as was expected but they were more similar in that treatment than in the others.

When strength values were analyzed using the split-plot design analyses of variance, the differences between juvenile and mature wood strength values were always significant. These differences were not always the same over the range of treatments. The differences between juvenile and mature wood varied between treatments for immersion specific gravity, MOE, and number of rings per inch. The differences between juvenile and mature wood remained statistically constant for bending sample specific gravity and MOR.

Regression of Strength Values

Specific gravity would seem to be the most important strength value predictor except in the case of juvenile wood MOR where specific gravity was the second variable into the regression. The first variable into the juvenile wood MOR regression was number of rings per inch, a growth rate variable. Volume and dbh were also considered growth rate variables since the stand is even-aged. The second variable entered into most of the regressions was one of the growth rate variables. Basal area and number of trees per plot, both stand density variables, were entered third in the MOR regressions, but further along in the regressions of the other dependent variables.

Many of the R^2 values reached a fairly high value, but only when all eight independent variables were entered in the model. Since many of the variables are similar to other variables, it would be impractical to use all of them to predict a desired value.

Pulping Study

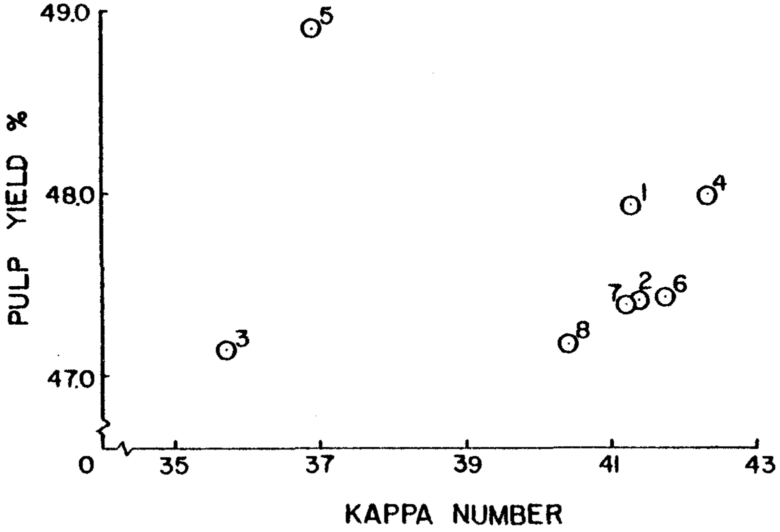
There was no statistical difference in kappa number or yield between any treatments and neither correlated well with average wedge specific gravity (kappa r value with average wedge specific gravity -0.028, yield r value of 0.002). Kappa and yield correlated somewhat more highly with each other, with an r value of -0.358 but the usual trend in kappa/yield relationships was positive in that increasing yield also gave an increasing kappa number. Figure 10 shows that the negative correlation might be due mostly to treatments 3 and 5 being separated from the grouping of the remaining treatment points. Figure 11 shows the relationship of average wedge specific gravity with kappa number and with yield. No clear trends are apparent.

The regressions of both kappa and yield did not provide much information. None of the independent variables used were helpful in predicting kappa number and although the yield regression showed volume per tree and number of trees per plot as being significantly helpful for predicting yield, the R^2 value was only 0.272. Volume was the first significant variable added in the regression and the first variable entered into the kappa number regression was also volume, although it had no significance in the regression.

The correlation coefficient between pulp yield and volume was -0.430, and 0.404 between kappa number and volume. Dbh showed similar but slightly lower correlations. Since both volume and dbh are growth rate variables (the stand being even-aged) these relationships would indicate that as the growth rate increased, pulp yield decreased and kappa increased under the same pulping conditions.

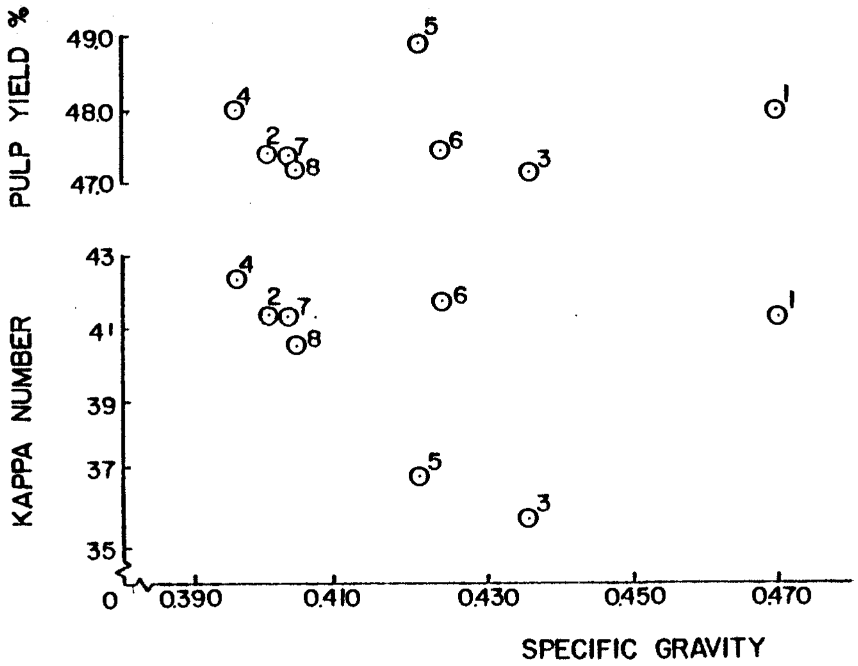
Recommendations

The bending strength and specific gravity portion of the study might have been improved in several ways. The statistical inference would have been of greater value if there had been more than three



Note: Numbers beside data points represent treatment number.

Figure 10. Pulp yield versus kappa number for samples pulped by Kraft process.



Note: Numbers beside data points represent treatment number.

Figure 11. Pulp yield and kappa number versus average wedge specific gravity for pulped samples.

observations per treatment. This could have been accomplished by sampling the same number of trees in each plot. It would then have been possible to analyze the data and obtain the within as well as between treatment variations. It was not possible to determine such data when the plot values were averaged.

When selecting samples for strength tests and specific gravity specimens, the number of rings from the pith, or age, might have been noted, or samples of the same age and from each thinning period might have been selected. This would have made it possible to compare strengths and specific gravities on the basis of age, rather than just on the basis of juvenile and mature wood.

The pulping portion of the study might have been improved by pulping juvenile and mature wood separately and by pulping a larger number of trees per plot. The randomly selected trees might have been better selected as being 'representative' of the plot. Another possible approach would have been to choose several trees of similar growth rate, the average for the treatment, then pulp yield and kappa number would have been better related to growth rate due to treatment.

CONCLUSIONS

A summary of the conclusions that can be drawn from the data obtained in this study are as follows:

1) The overall average mature wood MOR and MOE values in this study were 10,600 psi and (for mature wood MOE) 1.40 million psi respectively. These values were lower than the Wood Handbook values of 12,400 psi and 1.95 million psi for MOR and MOE.

2) Individual thinning treatment (see Table 1) statistically affected mature wood specific gravity and mature wood MOR values as follows:

   A. Treatments 1 and 3 had significantly higher mature wood specific gravities than treatment 4.

   B. Treatment 1 had significantly higher mature wood specific gravity than treatment 5.

   C. Treatments 2 and 7 had significantly lower juvenile and mature wood specific gravities than treatment 1.

   D. Treatment 1 mature wood MOR values were significantly higher than treatment 4 values.

3) Treatment regime (constant, increasing or decreasing cutting intensities) affected mature and juvenile wood specific gravity and mature wood modulus of rupture values in the following way:

   A. Mature wood specific gravity from plots thinned at constant cutting intensity values was significantly higher than from sample plots thinned at varying cutting intensities. Specific gravity of such wood from plots thinned with increasing cutting intensities was higher than from plots thinned with decreasing cutting intensities.

B. Juvenile wood specific gravity from plots thinned at increasing cutting intensities was higher than from plots thinned at constant and decreasing cutting intensities.

C. Mature wood MOR (as mature wood specific gravity) from plots thinned at constant cutting intensities was higher than from sample plots thinned at varying cutting intensities.

4) Juvenile and mature wood strength and specific gravity values were significantly different over all thinning treatments.

5) Specific gravity and growth rate were the most important independent variables in MOR and MOE regressions.

6) Treatment did not affect pulp yield or kappa number.

7) Growth rate was the most important independent variable in the kappa and yield regressions.

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APPENDICES

Appendix A
Hoskins Study Data

TTMT	PLOT	XSGI	DBH	VOL	NOTR	BA	YLD %	KAPPA
1	3	.492	12.6	27.233	70	88.825	48.70	40.3
1	8	.471	12.6	28.702	70	89.383	48.50	39.1
1	20	.447	15.5	43.419	70	90.106	46.60	44.5
2	4	.418	12.0	26.818	95	112.333	47.14	39.5
2	15	.400	18.9	65.840	70	111.766	46.20	45.5
2	17	.386	10.3	18.019	105	110.137	48.87	39.2
3	7	.453	12.6	28.751	145	127.318	47.73	32.0
3	11	.426	13.6	33.278	105	127.910	46.60	35.8
3	21	.428	13.3	34.874	120	123.396	47.10	39.4
4	5	.366	13.5	30.839	160	145.568	47.63	43.1
4	18	.433	13.5	33.478	150	145.424	48.20	45.5
4	23	.390	9.8	19.108	125	144.653	48.14	38.4
5	9	.432	12.6	29.729	195	163.568	48.73	40.4
5	24	.395	12.5	28.062	180	160.833	48.57	32.6
5	27	.435	12.0	25.962	205	168.627	49.44	37.7
6	1	.429	12.8	30.548	145	141.575	47.07	43.5
6	2	.427	13.4	32.985	150	144.684	48.43	41.9
6	25	.415	14.2	36.823	130	143.013	46.77	39.9
7	12	.419	11.1	24.019	255	196.454	47.03	37.4
7	14	.409	9.6	20.914	230	198.123	48.07	43.0
7	19	.381	12.8	29.839	230	192.352	47.07	43.3
8	6	.442	11.1	23.738	240	178.850	45.73	43.6
8	13	.344	12.6	30.359	215	175.441	47.00	41.2
8	16	.426	11.0	22.817	205	180.085	48.80	36.5

TTMT	PLOT	MCBJ %	SGBJ	SGIJ	MOEJ psi	MORJ psi	FSPLJ psi	RIJ	MCBM %	SGBM	SGIM	MOEM psi	MORM psi	FSPLM psi	RIM
1	3	12.6	.483	.485	981087	11563	5574	6.5	13.8	.489	.492	1433797	12215	6387	4.5
1	8	13.7	.449	.486	1074622	9654	4531	5.0	14.6	.528	.478	1604139	12839	5329	4.3
1	20	12.7	.453	.437	916838	7154	3821	3.7	13.1	.523	.465	1307281	11055	5340	3.7
2	4	13.5	.428	.393	1076069	9232	4521	4.5	14.6	.469	.439	1575256	10999	6251	3.5
2	15	13.9	.410	.388	614934	7505	3706	2.5	14.4	.385	.408	926870	7384	3787	4.0
2	17	11.3	.371	.358	856813	8933	4146	5.3	12.0	.417	.409	1376780	9592	4673	6.0
3	7	13.4	.450	.425	1364531	11121	5338	5.5	14.4	.493	.466	1708656	11755	6100	5.0
3	11	13.7	.417	.422	1017205	8386	4927	3.8	13.8	.451	.435	1528846	11426	6044	4.8
3	21	13.6	.445	.411	1108766	9065	4746	3.5	14.1	.449	.447	1422576	10668	5092	4.8
4	5	13.9	.367	.367	1067929	8057	4415	4.0	14.3	.393	.371	1139346	8936	4062	5.5
4	18	12.3	.473	.433	1469443	10762	4964	4.0	14.2	.491	.427	1545546	6714	5531	5.0
4	23	11.9	.415	.406	1275883	10323	5661	6.0	13.5	.424	.379	1406231	10567	4774	8.5
5	9	13.8	.444	.413	1050710	9909	4390	4.0	14.5	.501	.450	1561006	11755	5485	5.7
5	24	13.5	.348	.359	782391	7650	4118	4.5	14.1	.426	.413	1242141	9957	4907	5.3
5	27	13.5	.409	.419	988871	9102	4748	3.8	14.2	.482	.449	1555429	11474	5348	6.7
6	1	12.7	.418	.416	872629	9591	3434	4.1	13.1	.455	.436	1321694	10517	5338	5.3
6	2	13.7	.433	.409	933624	8996	4633	4.4	14.5	.451	.435	1336121	10424	4858	4.2
6	25	13.8	.490	.396	941632	8647	4109	4.0	14.3	.448	.423	1115789	10278	5217	5.3
7	12	12.9	.402	.406	861341	8675	3898	4.8	13.3	.458	.429	1456596	10842	5286	6.8
7	14	12.1	.399	.389	1009615	9563	4152	4.8	12.3	.454	.429	1526830	10896	5249	5.8
7	19	13.4	.376	.356	950874	9131	4611	4.0	14.4	.426	.405	1299325	10544	6052	4.0
8	6	13.3	.444	.455	1043726	9706	4393	4.6	13.6	.487	.435	1387167	10555	4894	6.3
8	13	12.3	.403	.468	812712	8156	3902	4.0	13.0	.429	.439	1331794	9971	5064	6.6
8	16	13.8	.427	.407	1250577	10099	5932	4.2	14.4	.472	.447	1489608	11734	5625	6.2

Appendix B
Class Means

```
? CLASSDESC.TTMT,JM.SGB


 TTMT
   JM

   VALUE          FREQ  MEAN OF   SGB        STD
     1.000
        1.000       3           .462        .019
        2.000       3           .513        .021
     2.000
        1.000       3           .403        .029
        2.000       3           .424        .042
     3.000
        1.000       3           .437        .018
        2.000       3           .464        .025
     4.000
        1.000       3           .418        .053
        2.000       3           .436        .050
     5.000
        1.000       3           .400        .049
        2.000       3           .470        .039
     6.000
        1.000       3           .447        .038
        2.000       3           .451        .004
     7.000
        1.000       3           .392        .014
        2.000       3           .446        .017
     8.000
        1.000       3           .425        .021
        2.000       3           .463        .030
? CLASSDESC,TTMT,JM,SGI


 TTMT
   JM

   VALUE          FREQ  MEAN OF   SGI        STD
     1.000
        1.000       3           .469        .028
        2.000       3           .478        .014
     2.000
        1.000       3           .380        .019
        2.000       3           .419        .018
     3.000
        1.000       3           .419        .007
        2.000       3           .449        .016
     4.000
        1.000       3           .402        .033
        2.000       3           .392        .030
     5.000
        1.000       3           .397        .033
        2.000       3           .437        .021
     6.000
        1.000       3           .407        .010
        2.000       3           .431        .007
     7.000
        1.000       3           .384        .025
        2.000       3           .421        .014
     8.000
        1.000       3           .443        .032
        2.000       3           .440        .006
? CLASSDESC.TTMT,JM.MOE
```

```
 TTMT
   JM

   VALUE          FREQ  MEAN OF  MOE        STD
     1.000
        1.000       3   990849.000  79343.684
        2.000       3  1448405.667 148967.204
     2.000
        1.000       3   849272.000 230659.971
        2.000       3  1292968.667 332218.837
     3.000
        1.000       3  1163500.667 180015.973
        2.000       3  1553359.333 144606.775
     4.000
        1.000       3  1271085.000 200799.997
        2.000       3  1363707.667 206411.689
     5.000
        1.000       3   940657.333 140506.903
        2.000       3  1452858.667 182508.156
     6.000
        1.000       3   915961.667  37740.191
        2.000       3  1257868.000 123255.289
     7.000
        1.000       3   940610.000  74667.979
        2.000       3  1427583.667 116494.283
     8.000
        1.000       3  1035671.667 219043.589
        2.000       3  1402856.333  80068.290


 TTMT
   JM

   VALUE          FREQ  MEAN OF   MOR        STD
     1.000
        1.000       3     9457.000   2211.092
        2.000       3    12036.333    905.321
     2.000
        1.000       3     8556.667    922.958
        2.000       3     9325.000   1822.230
     3.000
        1.000       3     9524.000   1424.102
        2.000       3    11283.000    557.431
     4.000
        1.000       3     9714.000   1451.695
        2.000       3     8739.000   1934.040
     5.000
        1.000       3     8887.000   1144.744
        2.000       3    11062.000    967.217
     6.000
        1.000       3     9078.000    477.312
        2.000       3    10406.333    120.475
     7.000
        1.000       3     9123.000    444.054
        2.000       3    10760.667    189.571
     8.000
        1.000       3     9320.333   1027.310
        2.000       3    10753.333    898.078
? CLASSDESC.TTMT.JM.FSPL
```

Appendix B, Continued

```
TTMT
  JM

  VALUE         FREQ  MEAN OF  FSPL      STD
    1.000
      1.000       3      4642.000    881.756
      2.000       3      5685.333    607.686
    2.000
      1.000       3      4124.333    407.932
      2.000       3      4903.667   1248.090
    3.000
      1.000       3      5003.667    303.355
      2.000       3      5745.333    566.496
    4.000
      1.000       3      5013.333    624.463
      2.000       3      4789.000    734.615
    5.000
      1.000       3      4418.667    315.977
      2.000       3      5246.667    302.030
    6.000
      1.000       3      4058.667    601.083
      2.000       3      5137.667    249.640
    7.000
      1.000       3      4220.333    361.378
      2.000       3      5529.000    453.309
    8.000
      1.000       3      4742.333   1059.127
      2.000       3      5194.333    382.531
CLASSDESC.TTMT,JM.RPI
```

```
TTMT
  JM

  VALUE         FREQ  MEAN OF  RPI       STD
    1.000
      1.000       3         5.067      1.401
      2.000       3         4.167       .416
    2.000
      1.000       3         4.100      1.442
      2.000       3         4.500      1.323
    3.000
      1.000       3         4.267      1.079
      2.000       3         4.867       .115
    4.000
      1.000       3         4.667      1.155
      2.000       3         6.333      1.893
    5.000
      1.000       3         4.100       .361
      2.000       3         5.900       .721
    6.000
      1.000       3         4.167       .208
      2.000       3         4.933       .635
    7.000
      1.000       3         4.533       .462
      2.000       3         5.533      1.419
    8.000
      1.000       3         4.267       .306
      2.000       3         6.367       .208
```

```
CLASSDESC.TTMT.XSGI


TTMT

  VALUE         FREQ  MEAN OF  XSGI      STD
    1.000         3          .479       .023
    2.000         3          .401       .016
    3.000         3          .436       .015
    4.000         3          .396       .034
    5.000         3          .421       .022
    6.000         3          .424       .008
    7.000         3          .403       .020
    8.000         3          .404       .053
```

```
CLASSDESC.TTMT.DBH


TTMT

  VALUE         FREQ  MEAN OF  DBH       STD
    1.000         3        13.567      1.674
    2.000         3        13.733      4.554
    3.000         3        13.167       .513
    4.000         3        12.267      2.136
    5.000         3        12.367       .321
    6.000         3        13.467       .702
    7.000         3        11.167      1.601
    8.000         3        11.567       .896
```

```
CLASSDESC.TTMT.VOL


TTMT

  VALUE         FREQ  MEAN OF  VOL       STD
    1.000         3        33.118      8.951
    2.000         3        36.892     25.453
    3.000         3        32.301      3.176
    4.000         3        27.808      7.649
    5.000         3        27.918      1.888
    6.000         3        33.452      3.163
    7.000         3        24.924      4.531
    8.000         3        25.638      4.114
```

Appendix B, Continued

```
CLASSDESC.TTMT.NOTR


TTMT

   VALUE       FREQ  MEAN OF   NOTR      STD
     1.000        3       70.000       0.000
     2.000        3       90.000      18.028
     3.000        3      123.333      20.207
     4.000        3      145.000      18.028
     5.000        3      193.333      12.583
     6.000        3      141.667      10.408
     7.000        3      238.333      14.434
     8.000        3      220.000      18.028
?
```

```
CLABSDESC.TTMT.YLD


TTMT

   VALUE       FREQ  MEAN OF   YLD       STD
     1.000        3        47.933      1.159
     2.000        3        47.403      1.354
     3.000        3        47.143       .566
     4.000        3        47.990       .313
     5.000        3        48.913       .463
     6.000        3        47.423       .885
     7.000        3        47.390       .589
     8.000        3        47.177      1.543
?
```

```
CLASSDESC.TTMT.BA


TTMT

   VALUE       FREQ  MEAN OF   BA        STD
     1.000        3       89.438        .642
     2.000        3      111.412       1.140
     3.000        3      126.208       2.453
     4.000        3      145.215        .492
     5.000        3      164.343       3.954
     6.000        3      143.091       1.556
     7.000        3      195.643       2.970
     8.000        3      178.125       2.405
?
```

```
CLASSDESC.TTMT.KAPPA


TTMT

   VALUE       FREQ  MEAN OF   KAPPA     STD
     1.000        3        41.300      2.835
     2.000        3        41.400      3.554
     3.000        3        35.733      3.700
     4.000        3        42.333      3.612
     5.000        3        36.900      3.961
     6.000        3        41.767      1.804
     7.000        3        41.233      3.323
     8.000        3        40.433      3.612
?
```

Appendix C
Overall Means

Means of variables from all treatments

```
SGBJ      =   .423083
SGBM      =   .458375
SGIJ      =   .412667
SGIM      =   .433583
MOEJ      =   .101345E+07
MOEM      =   .139995E+07
MORJ      =   9207.50
MORM      =   10545.7
FSPLJ     =   4527.92
FSPLM     =   5278.88
RIJ       =   4.39583
RIM       =   5.32500
XSGI      =   .419333
DBH       =   12.6625
VOL       =   30.2564
NOTR      =   152.708
BA        =   144.184
YLD       =   47.6717
KAPPA     =   40.1375
```

Means of variables from treatments 1, 3, 5, and 7

```
SGBJ      =   .422917
SGBM      =   .473333
SGIJ      =   .417333
SGIM      =   .446500
MOEJ      =   .100890E+07
MOEM      =   .147055E+07
MORJ      =   9247.75
MORM      =   11285.5
FSPLJ     =   4571.17
FSPLM     =   5551.58
RIJ       =   4.49167
RIM       =   5.11667
XSGI      =   .432333
DBH       =   12.5667
VOL       =   29.5652
NOTR      =   156.250
BA        =   143.908
YLD       =   47.8450
KAPPA     =   38.7917
```

Means of variables from treatments 2 and 4

```
SGBJ      =   .410667
SGBM      =   .429833
SGIJ      =   .390833
SGIM      =   .405500
RIJ       =   4.38333
RIM       =   5.41667
MOEJ      =   .106018E+07
MOEM      =   .132834E+07
MORJ      =   9135.33
MORM      =   9032.00
FSPLJ     =   4568.83
FSPLM     =   4846.33
XSGI      =   .398833
DBH       =   13.0000
VOL       =   32.3503
NOTR      =   117.500
BA        =   128.314
```

Means of variables from treatments 6 and 8

```
SGBJ      =   .435833
SGBM      =   .457000
SGIJ      =   .425167
SGIM      =   .435833
RIJ       =   4.21667
RIM       =   5.65000
MOEJ      =   975817.
MOEM      =   .133036E+07
MORJ      =   9199.17
MORM      =   10579.8
FSPLJ     =   4400.50
FSPLM     =   5166.00
XSGI      =   .413833
DBH       =   12.5167
VOL       =   29.5450
NOTR      =   180.833
BA        =   160.608
```

Appendix D
One-way Classification Analysis of Variance

```
ANALYSIS OF VARIANCE FOR SGBJ
 LINE  SOURCE OF VARIATION            DF  MEAN SQUARE
(    1) TTMT                           7  .178083E-02

(    2) ERROR                         16  .109475E-02

        TOTAL                         23
?

 AVTABLE.SGIJ


ANALYSIS OF VARIANCE FOR SGIJ
 LINE  SOURCE OF VARIATION            DF  MEAN SQUARE
(    1) TTMT                           7  .279314E-02

(    2) ERROR                         16  .646458E-03

        TOTAL                         23
?

 AVTABLE.MOEJ


ANALYSIS OF VARIANCE FOR MOEJ
 LINE  SOURCE OF VARIATION            DF  MEAN SQUARE
(    1) TTMT                           7  .386965E+11

(    2) ERROR                         16  .258685E+11

        TOTAL                         23
?
 AVTABLE.MORJ


ANALYSIS OF VARIANCE FOR MORJ
 LINE  SOURCE OF VARIATION            DF  MEAN SQUARE
(    1) TTMT                           7  .420819E+06

(    2) ERROR                         16  .158338E+07

        TOTAL                         23
?

 AVTABLE.FSPLJ


ANALYSIS OF VARIANCE FOR FSPLJ
 LINE  SOURCE OF VARIATION            DF  MEAN SQUARE
(    1) TTMT                           7  .433104E+06

(    2) ERROR                         16  .392421E+06

        TOTAL                         23
```

```
ANALYSIS OF VARIANCE FOR SGBM
 LINE  SOURCE OF VARIATION            DF  MEAN SQUARE
(    1) TTMT                           7  .218995E-02

(    2) ERROR                         16  .101463E-02

        TOTAL                         23
?

 AVTABLE.SGIM


ANALYSIS OF VARIANCE FOR SGIM
 LINE  SOURCE OF VARIATION            DF  MEAN SQUARE
(    1) TTMT                           7  .188474E-02

(    2) ERROR                         16  .297542E-03

        TOTAL                         23
?


 AVTABLE.MOEM


ANALYSIS OF VARIANCE FOR MOEM
 LINE  SOURCE OF VARIATION            DF  MEAN SQUARE
(    1) TTMT                           7  .267427E+11

(    2) ERROR                         16  .330701E+11

        TOTAL                         23
?

 AVTABLE.MORM


ANALYSIS OF VARIANCE FOR MORM
 LINE  SOURCE OF VARIATION            DF  MEAN SQUARE
(    1) TTMT                           7  .338365E+07

(    2) ERROR                         16  .124798E+07

        TOTAL                         23
?

 AVTABLE.FSPLM


ANALYSIS OF VARIANCE FOR FSPLM
 LINE  SOURCE OF VARIATION            DF  MEAN SQUARE
(    1) TTMT                           7  .366102E+06

(    2) ERROR                         16  .411619E+06

        TOTAL                         23
```

Appendix D, Continued

```
ANALYSIS OF VARIANCE FOR RIM
 LINE  SOURCE OF VARIATION                DF  MEAN SQUARE
(    1) TTMT                               7  .208357E+01

(    2) ERROR                             16  .106250E+01

        TOTAL                             23
?

 AVTABLE.RIJ


ANALYSIS OF VARIANCE FOR RIJ
 LINE  SOURCE OF VARIATION                DF  MEAN SQUARE
(    1) TTMT                               7  .344226E+00

(    2) ERROR                             16  .877500E+00

        TOTAL                             23
?

 AVTABLE.XSGI


ANALYSIS OF VARIANCE FOR XSGI
 LINE  SOURCE OF VARIATION                DF  MEAN SQUARE
(    1) TTMT                               7  .180400E-02

(    2) ERROR                             16  .731083E-03

        TOTAL                             23
?

 AVTABLE.DBH


ANALYSIS OF VARIANCE FOR DBH
 LINE  SOURCE OF VARIATION                DF  MEAN SQUARE
(    1) TTMT                               7  .280613E+01

(    2) ERROR                             16  .404208E+01

        TOTAL                             23
?
 AVTABLE.

         VOL
```

```
ANALYSIS OF VARIANCE FOR VOL
 LINE  SOURCE OF VARIATION                DF  MEAN SQUARE
(    1) TTMT                               7  .547900E+02

(    2) ERROR                             16  .105948E+03

        TOTAL                             23
?

 AVTABLE.NOTR


ANALYSIS OF VARIANCE FOR NOTR
 LINE  SOURCE OF VARIATION                DF  MEAN SQUARE
(    1) TTMT                               7  .108546E+05

(    2) ERROR                             16  .232292E+03

        TOTAL                             23
?

 AVTABLE.BA


ANALYSIS OF VARIANCE FOR BA
 LINE  SOURCE OF VARIATION                DF  MEAN SQUARE
(    1) TTMT                               7  .368697E+04

(    2) ERROR                             16  .507936E+01

        TOTAL                             23
?

 AVTABLE.YLD


ANALYSIS OF VARIANCE FOR YLD
 LINE  SOURCE OF VARIATION                DF  MEAN SQUARE
(    1) TTMT                               7  .104945E+01

(    2) ERROR                             16  .915012E+00

        TOTAL                             23
?

 AVTABLE.KAPPA


ANALYSIS OF VARIANCE FOR KAPPA
 LINE  SOURCE OF VARIATION                DF  MEAN SQUARE
(    1) TTMT                               7  .178233E+02

(    2) ERROR                             16  .113046E+02

        TOTAL                             23
?
```

Appendix E
Split-plot Design Analysis of Variance

```
 ANALYSIS OF VARIANCE FOR SGB
  LINE  SOURCE OF VARIATION              DF  MEAN SQUARE
 (    1) TTMT                             7  .325857E-02
 (    2) JM                               1  .149460E-01
 (    3) TTMT*JM                          7  .712211E-03
 (    4  REP
 +    5) TTMT*REP                        16  .176038E-02

 (    8) ERROR                           16  .349000E-03

         TOTAL                           47
? AVTABLE.SGI


 ANALYSIS OF VARIANCE FOR SGI
  LINE  SOURCE OF VARIATION              DF  MEAN SQUARE
 (    1) TTMT                             7  .409565E-02
 (    2) JM                               1  .525008E-02
 (    3) TTMT*JM                          7  .582226E-03
 (    4  REP
 +    5) TTMT*REP                        16  .767417E-03

 (    8) ERROR                           16  .176583E-03

         TOTAL                           47
? AVTABLE,MOE


 ANALYSIS OF VARIANCE FOR MOE
  LINE  SOURCE OF VARIATION              DF  MEAN SQUARE
 (    1) TTMT                             7  .590920E+11
 (    2) JM                               1  .179259E+13
 (    3) TTMT*JM                          7  .263471E+11
 (    4  REP
 +    5) TTMT*REP                        16  .532602E+11

 (    8) ERROR                           16  .567832E+10

         TOTAL                           47
? AVTABLE,MOR
```

```
 ANALYSIS OF VARIANCE FOR MOR
  LINE  SOURCE OF VARIATION              DF  MEAN SQUARE
 (    1) TTMT                             7  .204901E+07
 (    2) JM                               1  .214896E+08
 (    3) TTMT*JM                          7  .175546E+07
 (    4  REP
 +    5) TTMT*REP                        16  .200933E+07

 (    8) ERROR                           16  .822036E+06

         TOTAL                           47
? AVTABLE.FSPL


 ANALYSIS OF VARIANCE FOR FSPL
  LINE  SOURCE OF VARIATION              DF  MEAN SQUARE
 (    1) TTMT                             7  .466735E+06
 (    2) JM                               1  .676726E+07
 (    3) TTMT*JM                          7  .332471E+06
 (    4  REP
 +    5) TTMT*REP                        16  .620880E+06

 (    8) ERROR                           16  .183160E+06

         TOTAL                           47
? AVTABLE,RPI


 ANALYSIS OF VARIANCE FOR RPI
  LINE  SOURCE OF VARIATION              DF  MEAN SQUARE
 (    1) TTMT                             7  .104807E+01
 (    2) JM                               1  .103602E+02
 (    3) TTMT*JM                          7  .137973E+01
 (    4  REP
 +    5) TTMT*REP                        16  .149021E+01

 (    8) ERROR                           16  .449792E+00

         TOTAL                           47
? END
```

Appendix F
Honestly Significant Differences Analyses

$$\mathrm{HSD} = Q_x\sqrt{\frac{\mathrm{MSE}}{R}}$$

SGIJ

		2	3	4	5	6	7	8
	Mean	.380	.419	.402	.397	.407	.384	.443
1	.469	.089*	.050	.067	.072*	.062	.085*	.026
2	.380		.039	.022	.017	.027	.004	.063
3	.419			.017	.022	.012	.035	.024
4	.402				.005	.005	.018	.041
5	.397					.010	.013	.046
6	.407						.023	.036
7	.384							.059

$$\mathrm{HSD} = \begin{matrix}4.90\\6.08\end{matrix}\sqrt{\frac{.646458\ \mathrm{E}\text{-}3}{3}} = \begin{matrix}.0719\\.0893\end{matrix}$$

*Significant (at .05 α level)

**Highly significant (at .01 α level)

Appendix F, Continued

SGIM

	Mean	2 .419	3 .449	4 .392	5 .437	6 .431	7 .421	8 .440
1	.478	.059*	.029	.086**	.041	.047	.057*	.038
2	.419		.030	.027	.018	.012	.002	.021
3	.449			.057*	.012	.018	.028	.009
4	.392				.045	.039	.029	.048
5	.437					.006	.016	.003
6	.431						.010	.009
7	.421							.019

$$\text{HSD} = \begin{matrix} 4.90 \\ 6.08 \end{matrix} \sqrt{\frac{.297542\ \text{E-3}}{3}} = \begin{matrix} .0488 \\ .0606 \end{matrix}$$

MORM

		2 9,325	3 11,283	4 8,739	5 11,062	6 10,406	7 10,760.667	8 10,753.333
1	12,036.333	2,711.33	753.33	3,297.33*	974.33	1,630.33	1,275.67	1,283
2	9,326		1,958	586.0	1,737	1,081	1,435.67	1,428.33
3	11,283			2,544	221	877	522.33	529.67
4	8,739				2,323	1,667	2,021.67	2,014.33
5	11,062					656	301.33	308.67
6	10,406.333						354.33	347
7	10,760.667							7.33

$$\text{HSD} = \begin{matrix} 4.90 \\ 6.08 \end{matrix} \sqrt{\frac{.124798\ \text{E7}}{3}} = \begin{matrix} 3{,}160.38 \\ 3{,}921.45 \end{matrix}$$

Appendix F, Continued

NOTR

		2	3	4	5	6	7	8
		90	123.33	145	193.33	141.67	238.33	220
1	70	20	53.33*	75**	123.33**	71.67**	168.33**	156**
2	90		33.33	55**	103.33**	51.67*	148.33**	130**
3	123.33			21.67	70**	18.34	115.00**	96.67**
4	145				48.33*	3.33	93.33**	75.00**
5	193.33					51.66*	45.0*	26.67
6	141.67						96.66**	78.33**
7	238.33							18.33

$$HSD = \begin{matrix}4.90\\6.08\end{matrix}\sqrt{\frac{.232292\ E3}{3}} = \begin{matrix}43.12\\53.50\end{matrix}$$

BA

		2	3	4	5	6	7	8
		111.412	126.208	145.215	164.343	143.091	195.643	178.125
1	89.438	21.97**	36.77**	55.78**	74.91**	53.65**	106.21**	88.69**
2	111.412		14.80**	33.80**	52.93**	31.68**	84.23**	66.71**
3	126.208			19.01**	38.14**	16.88**	69.44**	51.92**
4	145.215				19.13**	2.12	50.43**	32.91**
5	164.343					21.25**	31.30**	13.78**
6	143.091						52.55**	35.03**
7	195.643							17.52**

$$HSD = \begin{matrix}4.90\\6.08\end{matrix}\sqrt{\frac{.507936\ E1}{3}} = \begin{matrix}6.38\\7.91\end{matrix}$$

Appendix G
Contrast Analyses

$$t = \frac{1}{\sqrt{v(1)}} \quad s^2 df \qquad\qquad v(1) = [\frac{k_1^2}{r_1} + \frac{k_2^2}{r_2} + \frac{k_p^2}{r_p}]\ s^2 \quad (MSE)$$

$$1 = k_1\bar{y}_1 + k_2\bar{y}_2 + k_p\bar{y}_p$$

SGIJ

1) $1 = .469 - .380 + .419 - .402 + .397 - .407 + .384 - .443$

$v(1) = [8/3]\ .646458\ E-3$

$$t = \frac{.037}{\sqrt{.002}} = .891$$

2) $1 = .380 + .402 - .407 - .443$

$v(1) = [4/3]\ .646458\ E-3$

$$t = \frac{-.068}{\sqrt{.001}} = 2.316*$$

3) $1 = .469 + .419 + .397 + .384 - 2(.380) - 2(.402)$

$v(1) = [12/3]\ .646458\ E-3$

$t = 2.065$

4) $1 = .469 + .419 + .397 + .384 - 2(.407) - 2(.443)$

$v(1) = [12/3]\ .646458\ E-3$

$t = -.610$

SGIM

1) $1 = .478 - .419 + .449 - .392 + .437 - .431 + .421 - .440$

$v(1) = [8/3]\ .297542\ E-3$

$$t = \frac{.103}{\sqrt{.001}} = 3.657**$$

Appendix G, Continued

SGIM, Continued

2) $1 = .419 + .392 - .431 - .440$

$v(1) = [4/3]\ .297542\ E-3$

$$t = \frac{-.060}{\sqrt{.020}} = -3.012^{**}$$

3) $1 = .478 + .449 + .437 + .421 - 2(.419) - 2(.392)$

$v(1) = [12/3]\ .297542\ E-3$

$$t = \frac{.163}{\sqrt{.001}} = 4.725^{**}$$

4) $1 = .478 + .449 + .437 + .421 - 2(.431) - 2(.440)$

$v(1) = [12/3]\ .297542\ E-3$

$$t = \frac{.043}{\sqrt{.001}} = 1.246$$

MORM

1) $1 = 12{,}036 - 9{,}325 + 11{,}283 - 8{,}739 + 11{,}062 - 10{,}406 + 10{,}761 - 10{,}753$

$v(1) = [8/3]\ .124798\ E7$

$$t = \frac{5{,}919}{\sqrt{3{,}327{,}946.667}} = 3.245^{**}$$

2) $1 = 932.5 + 8{,}739 - 10{,}406 - 10{,}753$

$v(1) = [4/3]\ .1247980$

$$t = \frac{-3{,}095}{\sqrt{1{,}663{,}973.333}} = -2.399^{*}$$

3) $1 = 12{,}036 + 11{,}283 + 11{,}062 + 10{,}761 - 2(9{,}325) - 2(8{,}739)$

$v(1) = [12/3]\ .124798\ E7$

$t = 4.034^{**}$

Appendix G, Continued

MORM, Continued

4) 1 = 12,036 + 11,283 + 11,062 + 10,761 - 2(10,406) - 2(10,753)

v(1) = [12/3] .124798 E7

t = 1.264

NOTR

1) 1 = 70 - 90 + 123.333 - 145 + 193.333 - 141.667 + 238.333 - 220

v(1) = [8/3] 232.292

$$t = \frac{28.332}{\sqrt{619.445}} = 1.138$$

2) 1 = 90 + 145 - 141.667 - 220

v(1) = [4/3] 232.292

$$t = \frac{-126.667}{\sqrt{309.723}} = -7.197^{**}$$

3) 1 = 70 + 123.333 + 193.333 + 238.333 - 2(90) - 2(145)

v(1) = [12/3] 232.292

t = 5.085**

4) 1 = 70 + 123.333 + 193.333 + 238.333 - 2(141.667) - 2(220)

v(1) = [12/3] 232.292

t = -3.226**

BA

1) 1 = 89.438 - 111.412 + 126.208 - 145.215 + 164.343 - 143.091 + 195.643 - 178.125

v(1) = [8/3] 5.07936

$$t = \frac{-2.211}{\sqrt{13.545}} = -.601$$

Appendix G, Continued

BA, Continued

2) $1 = 111.412 + 145.215 - 143.091 - 178.125$

$v(1) = [4/3]\ 5.0736$

$$t = \frac{-64.589}{\sqrt{6.765}} = -24.833^{**}$$

3) $1 = 89.438 + 126.208 + 164.343 + 195.643 - 2(111.412)$
$-2(145.215)$

$v(1) = [12/3]\ 5.07936$

$$t = 13.839^{**}$$

4) $1 = 89.438 + 126.208 + 164.343 + 195.643 - 2(143.091) - 2(178.125)$

$v(1) = [12/3]\ 5.07936$

$$t = -14.820^{**}$$

---

[*] Significant (at .05 α level)

[**] Highly significant (at .01 α level)

Appendix H
Regression Analyses

```
 REGRESS.MOEJ.SGBJ.SGIJ.RIJ.XSGI.DBH.VOL.NOTR.BA
**ENTERING REGRESS SUBSYSTEM**

MOEJ    = .10135E+07
? STEPWISE


VARIABLE ENTERING= SGBJ


MOEJ    =
  96656.3      (CONSTANT)
  .216694E+07 SGBJ


          ANALYSIS OF VARIANCE TABLE

SOURCE       DF   SUM OF SQUARES         MEAN SQUARE
TOTAL        23      .824771E+12         .358596E+11
REGRESSION    1      .140783E+12         .140783E+12
RESIDUAL     22      .683988E+12         .310903E+11

            R SQUARED =  .1707


VAR        S.E. OF REGR. COEF.         T
CONSTANT          .43233E+06          .224
SGBJ              .10183E+07         2.128


VARIABLE ENTERING= VOL


MOEJ    =
  186620.      (CONSTANT)
  .264674E+07 SGBJ
 -9748.64      VOL


          ANALYSIS OF VARIANCE TABLE

SOURCE       DF   SUM OF SQUARES         MEAN SQUARE
TOTAL        23      .824771E+12         .358596E+11
REGRESSION    2      .331432E+12         .165716E+12
RESIDUAL     21      .493339E+12         .234923E+11

            R SQUARED =  .4018


VAR        S.E. OF REGR. COEF.         T
CONSTANT          .37720E+06          .500
SGBJ              .90107E+06         2.937
VOL               3422.1            -2.849


VARIABLE ENTERING= SGIJ


MOEJ    =
  352717.      (CONSTANT)
  .346804E+07 SGBJ
 -.119902E+07 SGIJ
 -10336.4      VOL


          ANALYSIS OF VARIANCE TABLE

SOURCE       DF   SUM OF SQUARES         MEAN SQUARE
TOTAL        23      .824771E+12         .358596E+11
REGRESSION    3      .354893E+12         .118298E+12
RESIDUAL     20      .469878E+12         .234939E+11

            R SQUARED =  .4303
```

```
VAR        S.E. OF REGR. COEF.         T
CONSTANT          .41180E+06          .859
SGBJ              .12196E+07         2.944
SGIJ              .11998E+07         -.999
VOL               3472.4            -2.977


VARIABLE ENTERING= RIJ


MOEJ    =
  435341.      (CONSTANT)
  .355260E+07 SGBJ
 -.111141E+07 SGIJ
 -24215.6      RIJ
 -11893.2      VOL


          ANALYSIS OF VARIANCE TABLE

SOURCE       DF   SUM OF SQUARES         MEAN SQUARE
TOTAL        23      .824771E+12         .358596E+11
REGRESSION    4      .359150E+12         .897875E+11
RESIDUAL     19      .465621E+12         .245064E+11

            R SQUARED =  .4355


VAR        S.E. OF REGR. COEF.         T
CONSTANT          .46394E+06          .938
SGBJ              .12620E+07         2.815
SGIJ              .12433E+07         -.894
RIJ               58101.             -.417
VOL               5150.6            -2.309


VARIABLE ENTERING= NOTR


MOEJ    =
  576361.      (CONSTANT)
  .348350E+07 SGBJ
 -.107922E+07 SGIJ
 -35310.6      RIJ
 -13190.4      VOL
 -242.588      NOTR


          ANALYSIS OF VARIANCE TABLE

SOURCE       DF   SUM OF SQUARES         MEAN SQUARE
TOTAL        23      .824771E+12         .358596E+11
REGRESSION    5      .361667E+12         .723334E+11
RESIDUAL     18      .463104E+12         .257280E+11

            R SQUARED =  .4385


VAR        S.E. OF REGR. COEF.         T
CONSTANT          .65515E+06          .880
SGBJ              .13118E+07         2.655
SGIJ              .12781E+07         -.844
RIJ               69297.             -.510
VOL               6711.9            -1.965
NOTR              775.53             -.313
```

Appendix H, Continued

```
VARIABLE ENTERING= VOL


FSPLJ   =
  1846.48     (CONSTANT)
  5294.46     SGBJ
  210.076     RIJ
 -15.9312     VOL


           ANALYSIS OF VARIANCE TABLE

SOURCE       DF   SUM OF SQUARES        MEAN SQUARE
TOTAL        23       .931046E+07       404803.
REGRESSION    3       .288656E+07       962188.
RESIDUAL     20       .642389E+07       321195.

            R SQUARED =  .3100


VAR         S.E. OF REGR. COEF.        T
CONSTANT          1608.9             1.148
SGBJ              3554.2             1.490
RIJ               207.32             1.013
VOL               18.646             -.854


VARIABLE ENTERING= SGIJ


FSPLJ   =
  2091.21     (CONSTANT)
  6751.52     SGBJ
 -2284.43     SGIJ
  228.123     RIJ
 -15.8589     VOL


           ANALYSIS OF VARIANCE TABLE

SOURCE       DF   SUM OF SQUARES        MEAN SQUARE
TOTAL        23       .931046E+07       404803.
REGRESSION    4       .296929E+07       742323.
RESIDUAL     19       .634116E+07       333745.

            R SQUARED =  .3189


VAR         S.E. OF REGR. COEF.        T
CONSTANT          1712.1             1.221
SGBJ              4657.3             1.450
SGIJ              4588.3             -.498
RIJ               214.41             1.064
VOL               19.008             -.834


VARIABLE ENTERING= DBH


FSPLJ   =
  1469.31     (CONSTANT)
  6664.94     SGBJ
 -2378.03     SGIJ
  226.154     RIJ
  105.239     DBH
 -36.5741     VOL


           ANALYSIS OF VARIANCE TABLE

SOURCE       DF   SUM OF SQUARES        MEAN SQUARE
TOTAL        23       .931046E+07       404803.
REGRESSION    5       .301535E+07       603070.
RESIDUAL     18       .629511E+07       349728.

            R SQUARED =  .3239
```

```
VAR         S.E. OF REGR. COEF.        T
CONSTANT          2451.2              .599
SGBJ              4773.5             1.396
SGIJ              4704.0             -.506
RIJ               219.56             1.030
DBH               289.99              .363
VOL               60.308             -.606


VARIABLE ENTERING= XSGI


FSPLJ   =
  1391.67     (CONSTANT)
  5945.79     SGBJ
 -2582.29     SGIJ
  212.881     RIJ
  1443.39     XSGI
  94.7028     DBH
 -34.8328     VOL


           ANALYSIS OF VARIANCE TABLE

SOURCE       DF   SUM OF SQUARES        MEAN SQUARE
TOTAL        23       .931046E+07       404803.
REGRESSION    6       .303676E+07       506127.
RESIDUAL     17       .627370E+07       369041.

            R SQUARED =  .3262


VAR         S.E. OF REGR. COEF.        T
CONSTANT          2538.5              .548
SGBJ              5741.0             1.036
SGIJ              4906.0             -.526
RIJ               232.17              .917
XSGI              5992.4              .241
DBH               301.09              .315
VOL               62.371             -.558


VARIABLE ENTERING= BA


FSPLJ   =
  599.845     (CONSTANT)
  5933.08     SGBJ
 -2578.63     SGIJ
  245.588     RIJ
  1735.96     XSGI
  126.365     DBH
 -37.2113     VOL
  1.38899     BA


           ANALYSIS OF VARIANCE TABLE

SOURCE       DF   SUM OF SQUARES        MEAN SQUARE
TOTAL        23       .931046E+07       404803.
REGRESSION    7       .305889E+07       436984.
RESIDUAL     16       .625157E+07       390723.

            R SQUARED =  .3285


VAR         S.E. OF REGR. COEF.        T
CONSTANT          4230.2              .142
SGBJ              5907.5             1.004
SGIJ              5048.0             -.511
RIJ               275.61              .891
XSGI              6287.3              .276
DBH               337.17              .375
VOL               64.950             -.573
BA                5.8368              .238
```

Appendix H, Continued

```
VARIABLE ENTERING= NOTR


FSPLJ   =
 -3814.93      (CONSTANT)
  2709.25      SGBJ
  1037.56      SGIJ
  214.921      RIJ
  4807.29      XSGI
  342.536      DBH
 -87.1501      VOL
 -18.6747      NOTR
  34.3942      BA


           ANALYSIS OF VARIANCE TABLE

SOURCE       DF   SUM OF SQUARES         MEAN SQUARE
TOTAL        23      .931046E+07         404803.
REGRESSION    8      .400340E+07         500425.
RESIDUAL     15      .530706E+07         353804.

            R SQUARED =  .4300


VAR         S.E. OF REGR. COEF.          T
CONSTANT            4848.1             -.787
SGBJ                5957.7              .455
SGIJ                5289.0              .196
RIJ                 262.94              .817
XSGI                6271.3              .767
DBH                 347.05              .987
VOL                 68.950            -1.264
NOTR                11.430            -1.634
BA                  20.950             1.642
? END
 **LEAVING REGRESS SUBSYSTEM**
```

```
? REGRESS,FSPLM,SGBM,SGIM,RIM,XSGI,DBH,VOL,NOTR,BA
 **ENTERING REGRESS SUBSYSTEM**

 FSPLM   = 5278.9
? STEPWISE


 VARIABLE ENTERING= SGIM


 FSPLM   =
  -703.098     (CONSTANT)
   13796.6     SGIM


            ANALYSIS OF VARIANCE TABLE

 SOURCE       DF   SUM OF SQUARES         MEAN SQUARE
 TOTAL        23      .914861E+07         397766.
 REGRESSION    1      .341744E+07         .341744E+07
 RESIDUAL     22      .573117E+07         260508.

             R SQUARED =  .3735


 VAR         S.E. OF REGR. COEF.          T
 CONSTANT            1654.9             -.425
 SGIM                3809.2             3.622
```

```
VARIABLE ENTERING= VOL


FSPLM   =
 -14.9973      (CONSTANT)
  13781.8      SGIM
 -22.5308      VOL


           ANALYSIS OF VARIANCE TABLE

SOURCE       DF   SUM OF SQUARES         MEAN SQUARE
TOTAL        23      .914861E+07         397766.
REGRESSION    2      .447266E+07         .223633E+07
RESIDUAL     21      .467596E+07         222665.

            R SQUARED =  .4889


VAR         S.E. OF REGR. COEF.          T
CONSTANT            1562.3             -.010
SGIM                3521.7             3.913
VOL                 10.350            -2.177


VARIABLE ENTERING= RIM


FSPLM   =
  3042.29      (CONSTANT)
  10520.7      SGIM
 -222.497      RIM
 -37.6848      VOL


           ANALYSIS OF VARIANCE TABLE

SOURCE       DF   SUM OF SQUARES         MEAN SQUARE
TOTAL        23      .914861E+07         397766.
REGRESSION    3      .536913E+07         .178971E+07
RESIDUAL     20      .377949E+07         188974.

            R SQUARED =  .5869


VAR         S.E. OF REGR. COEF.          T
CONSTANT            2010.4              1.513
SGIM                3573.2              2.944
RIM                 102.15             -2.178
VOL                 11.803             -3.193


VARIABLE ENTERING= BA


FSPLM   =
  2253.67      (CONSTANT)
  11476.3      SGIM
 -256.780      RIM
 -35.5643      VOL
  3.41684      BA


           ANALYSIS OF VARIANCE TABLE

SOURCE       DF   SUM OF SQUARES         MEAN SQUARE
TOTAL        23      .914861E+07         397766.
REGRESSION    4      .557082E+07         .139270E+07
RESIDUAL     19      .357779E+07         188305.

            R SQUARED =  .6089

 VAR         S.E. OF REGR. COEF.          T
 CONSTANT            2146.6              1.050
 SGIM                3684.4              3.115
 RIM                 107.22             -2.395
 VOL                 11.959             -2.974
 BA                  3.3015              1.035
```

Appendix H, Continued

```
VARIABLE ENTERING= NOTR


FSPLM   =
 -515.193      (CONSTANT)
  15201.1      SGIM
 -264.579      RIM
 -42.9275      VOL
 -14.6235      NOTR
  28.7409      BA


          ANALYSIS OF VARIANCE TABLE

SOURCE      DF   SUM OF SQUARES          MEAN SQUARE
TOTAL       23      .914861E+07          397766.
REGRESSION   5      .626971E+07          .125394E+07
RESIDUAL    18      .287890E+07          159939.

           R SQUARED =  .6853


VAR        S.E. OF REGR. COEF.            T
CONSTANT          2380.8               -.216
SGIM              3834.7               3.964
RIM               98.884              -2.676
VOL               11.571              -3.710
NOTR              6.9956              -2.090
BA                12.491               2.301


VARIABLE ENTERING= DBH


FSPLM   =
 -4929.96      (CONSTANT)
  16689.3      SGIM
 -206.930      RIM
  398.485      DBH
 -117.569      VOL
 -19.4277      NOTR
  38.5112      BA


          ANALYSIS OF VARIANCE TABLE

SOURCE      DF   SUM OF SQUARES          MEAN SQUARE
TOTAL       23      .914861E+07          397766.
REGRESSION   6      .670330E+07          .111722E+07
RESIDUAL    17      .244531E+07          143842.

           R SQUARED =  .7327


VAR        S.E. OF REGR. COEF.            T
CONSTANT          3400.5              -1.450
SGIM              3736.3               4.467
RIM               99.481              -2.080
DBH               229.52               1.736
VOL               44.370              -2.650
NOTR              7.1881              -2.703
BA                13.114               2.937


VARIABLE ENTERING= SGBM


FSPLM   =
 -4944.10      (CONSTANT)
  1879.10      SGBM
  14715.0      SGIM
 -207.452      RIM
  392.194      DBH
 -115.142      VOL
 -19.6579      NOTR
  38.8786      BA
```

```
          ANALYSIS OF VARIANCE TABLE

SOURCE      DF   SUM OF SQUARES          MEAN SQUARE
TOTAL       23      .914861E+07          397766.
REGRESSION   7      .673610E+07          962301.
RESIDUAL    16      .241251E+07          150782.

           R SQUARED =  .7363


VAR        S.E. OF REGR. COEF.            T
CONSTANT          3481.7              -1.420
SGBM              4028.7                .466
SGIM              5705.3               2.579
RIM               101.86              -2.037
DBH               235.38               1.666
VOL               45.725              -2.518
NOTR              7.3760              -2.665
BA                13.450               2.891


VARIABLE ENTERING= XSGI


FSPLM   =
 -4906.48      (CONSTANT)
  2179.13      SGBM
  14967.5      SGIM
 -207.623      RIM
 -642.211      XSGI
  391.010      DBH
 -114.936      VOL
 -19.8013      NOTR
  38.9911      BA


          ANALYSIS OF VARIANCE TABLE

SOURCE      DF   SUM OF SQUARES          MEAN SQUARE
TOTAL       23      .914861E+07          397766.
REGRESSION   8      .673855E+07          842319.
RESIDUAL    15      .241006E+07          160671.

           R SQUARED =  .7366


VAR        S.E. OF REGR. COEF.            T
CONSTANT          3607.0              -1.360
SGBM              4816.6                .452
SBIM              6234.3               2.401
RIM               105.15              -1.974
XSGI              5201.3               -.123
DBH               243.16               1.608
VOL               47.230              -2.434
NOTR              7.7021              -2.571
BA                13.914               2.802
? END
 **LEAVING REGRESS SUBSYSTEM**
```

Appendix H, Continued

```
VARIABLE ENTERING= SGBJ


FSPLJ   =
  1273.93     (CONSTANT)
  4156.68     SGBJ
  340.178     RIJ


         ANALYSIS OF VARIANCE TABLE

SOURCE        DF   SUM OF SQUARES        MEAN SQUARE
TOTAL         23      .931046E+07        404803.
REGRESSION     2      .265210E+07        .132605E+07
RESIDUAL      21      .665836E+07        317065.

          R SQUARED =  .2849


VAR          S.E. OF REGR. COEF.          T
CONSTANT          1453.3                .877
SGBJ              3274.1               1.270
RIJ               139.78               2.434
```

```
? REGRESS,KAPPA,NOTR,BA,VOL,DBH,XSGI,YLD
 **ENTERING REGRESS SUBSYSTEM**

 KAPPA    = 40.137
? STEPWISE


 VARIABLE ENTERING= VOL


 KAPPA    =
   35.4529     (CONSTANT)
   .154831     VOL


          ANALYSIS OF VARIANCE TABLE

 SOURCE        DF   SUM OF SQUARES        MEAN SQUARE
 TOTAL         23      305.636            13.2885
 REGRESSION     1      49.8320            49.8320
 RESIDUAL      22      255.804            11.6275

          R SQUARED =  .1630


 VAR          S.E. OF REGR. COEF.          T
 CONSTANT          2.3675              14.975
 VOL                .74791E-01          2.070


 VARIABLE ENTERING= YLD


 KAPPA    =
   74.6371     (CONSTANT)
   .115479     VOL
  -.796985     YLD
```

```
            ANALYSIS OF VARIANCE TABLE

SOURCE        DF   SUM OF SQUARES        MEAN SQUARE
TOTAL         23      305.636            13.2885
REGRESSION     2      60.5782            30.2891
RESIDUAL      21      245.058            11.6694

          R SQUARED =  .1982


VAR          S.E. OF REGR. COEF.          T
CONSTANT          40.902               1.825
VOL               .85414E-01           1.352
YLD               .83051               -.960


VARIABLE ENTERING= DBH


KAPPA    =
  76.9187     (CONSTANT)
 -1.14831     DBH
  .346315     VOL
 -.686339     YLD


           ANALYSIS OF VARIANCE TABLE

SOURCE        DF   SUM OF SQUARES        MEAN SQUARE
TOTAL         23      305.636            13.2885
REGRESSION     3      65.9688            21.9896
RESIDUAL      20      239.667            11.9834

          R SQUARED =  .2158


VAR          S.E. OF REGR. COEF.          T
CONSTANT          41.587               1.850
DBH               1.7121               -.671
VOL               .35489                .976
YLD               .85763               -.800


VARIABLE ENTERING= XSGI


KAPPA    =
  77.2355     (CONSTANT)
 -7.16200     XSGI
 -1.05648     DBH
  .330444     VOL
 -.644306     YLD


           ANALYSIS OF VARIANCE TABLE

SOURCE        DF   SUM OF SQUARES        MEAN SQUARE
TOTAL         23      305.636            13.2885
REGRESSION     4      67.1383            16.7846
RESIDUAL      19      238.498            12.5525

          R SQUARED =  .2197


VAR          S.E. OF REGR. COEF.          T
CONSTANT          42.576               1.814
XSGI              23.464               -.305
DBH               1.7779               -.594
VOL               .36692                .901
YLD               .88850               -.725
```

Appendix H, Continued

```
VARIABLE ENTERING= NOTR


KAPPA   =
  73.9041      (CONSTANT)
 -5.48638      XSGI
 -.975060      DBH
  .324593      VOL
  .323976E-02 NOTR
 -.617453      YLD


          ANALYSIS OF VARIANCE TABLE

SOURCE       DF    SUM OF SQUARES         MEAN SQUARE
TOTAL        23       305.636             13.2885
REGRESSION    5       67.6690             13.5338
RESIDUAL     18       237.967             13.2204

           R SQUARED =  .2214


VAR         S.E. OF REGR. COEF.          T
CONSTANT           46.751              1.581
XSGI               25.491              -.215
DBH                1.8693              -.522
VOL                .37769               .859
NOTR               .16169E-01           .200
YLD                .92162              -.670

VARIABLE ENTERING= BA


KAPPA   =
  77.4178      (CONSTANT)
 -9.54953      XSGI
 -1.29125      DBH
  .394749      VOL
  .236154E-01 NOTR
 -.384229E-01 BA
 -.565019      YLD


          ANALYSIS OF VARIANCE TABLE

SOURCE       DF    SUM OF SQUARES         MEAN SQUARE
TOTAL        23       305.636             13.2885
REGRESSION    6       69.0998             11.5166
RESIDUAL     17       236.536             13.9139

           R SQUARED =  .2261


VAR         S.E. OF REGR. COEF.          T
CONSTANT           49.197              1.574
XSGI               29.059              -.329
DBH                2.1564              -.599
VOL                .44496               .887
NOTR               .65669E-01           .360
BA                 .11982              -.321
YLD                .95952              -.589
? END
 **LEAVING REGRESS SUBSYSTEM**
?
```