THE EFFECT OF ANNUAL RING MICRO-CHARACTERISTICS ON WOOD PROPERTIES

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Wood technologists have known for a long time that variations in wood anatomy and wood structure have a significant influence on the strength of wood and on other important wood properties such as shrinkage, etc. Until the present time, very tedious and time consuming techniques have been employed to measure wood quality characteristics within the annual ring.

X-ray densitometry is a convenient and rapid technique enabling wood technologists to measure specific gravity variation within each annual ring. In this report, X-ray densitometry was used to measure 10 annual ring micro-characteristics. The influence of forest management on these annual ring micro-characteristics is discussed and the relationships between strength properties of wood and annual ring micro-characteristics are analyzed. Data presented in this report were taken from a Master of Science thesis written by Josef Bodner (3).

X-RAY DENSITOMETRY

In the technique employed, a small cross-sectional strip of wood 2 cm wide from the pith to the bark and 4.45 mm along the grain was exposed to X-rays with X-ray film placed below the wood sample. The latewood will absorb more X-rays so after film development that portion of the negative will be less dense than the earlywood portion of the annual ring. A calibration section composed of several species of wood of known specific gravities was exposed along with each sample.

The developed film was placed in a densitometer to measure the differing density of the film which is calibrated to the specific gravity of the wood. The output of the densitometer was fed to a mini-computer and placed on floppy disks for subsequent statistical analyses by a main frame computer.

ANNUAL RING MICRO-CHARACTERISTICS

A total of ten annual ring micro-characteristics were analyzed for this project (Figure 1). They were: 1. ring width (RW), 2. earlywood width (EW), 3. latewood width (LW), 4. percent latewood (PL), 5. ring specific gravity (RS), 6. earlywood specific gravity (ES), 7. latewood specific gravity (LS), 8. minimum earlywood specific gravity (MES),

9. maximum latewood specific gravity (MLS), and 10. specific gravity range (SR). Prior to computerized data acquisition techniques the above annual ring micro-characteristics were calculated according to a preselected earlywood-latewood boundary level based on the average specific gravity of the whole tree radius (Figure 1).

PROCEDURE

Material

Material for this study consisted of seven trees randomly selected from each of two thinning treatments and a control (unthinned) stand (a total of 21 trees). Unthinned control trees and trees from a thinned/fertilized plot (14 trees) were obtained near Sweet Home, Oregon, while 7 trees were obtained from Oregon StateUniversity (OSU) School Forest (Dunn Forest) near Corvallis, Oregon. The control stand (C) and the fertilized and thinned stand (F) in the Sweet Home area (Hill Forest) were 42 years-old while the thinned stand in the OSU Dunn Forest(s) was 48 years-old.

Further information on the stands sampled are summarized as follows:

1. C = Control stand, 42 years old, Sweet Home area, no thinning treatment
2. F = Fertilized and thinned, 42 years old, Sweet Home area
   Treatments: 1959 - precommercial thinning to 10 x 10 spacing
   1959 - fertilized, 200 lbs/acre, 40% U.B.N.
   1966 - fertilized, 200 lbs/acre, 45% U.B.N.
   1978 - individual light thinning, 500 BF/acre removed
   1979 - fertilized, 200 lbs/acre, 45% U.B.N.
3. S = Thinned stand, 48 years old, OSU School Forest
   Treatments: 1960 - thinned from 700 trees/acre to 330 trees/acre
   1970 - thinned from 330 trees/acre to 300 trees/acre
   1975 - thinned from 300 trees/acre to 160 trees/acre

Because of the different years of thinning the analysis of variance analyses compared control (C) and Hill Forest (F) plots and then compared C with OSU forest (S) plots.

Statis Bending and X-ray Samples

Bolts approximately two-feet long were selected at the butt and at 16-18 feet above the stump from each of the 21 trees felled. Twelve static bending samples (1" x 1" x 16") were cut from each bolt, six from juvenile wood and six from mature wood.

The modulus of elasticity (MOE), and modulus of rupture (MOR) at 12 percent moisture content were obtained from these bending samples.

A radial strip of wood about 2 cm wide and 4.45 mm along the grain from the pith to the bark was sawn from each bolt for X-ray analyses.

RESULTS

Effect of Stand Treatment on Annual Ring Characteristics

Table 1 shows analysis of variance results comparing the control (C) and the thinned and fertilized (F) plots. In each of seven annual ring micro-characteristics analyzed a highly significant difference was found between C and F (TRMT). This table clearly illustrated the tendency for annual ring micro-characteristics to change with forest stand thinning and fertilization in these two stands.

Thinning and fertilization tended to cause a reduction in annual ring specific gravity micro-characteristics. Two examples of this relationship are given in Figure 2 and Figure 3. Figure 2 shows that average earlywood specific gravity was lower in the thinned stand. Note that this took a few years to develop after the original thinning treatment. Figure 3 shows maximum latewood specific gravity for the control and treatment F. The response of latewood specific gravity to the thinning and fertilization treatment seems more obvious than that of the earlywood.

The above statistical analyses and charts illustrate that annual ring micro-characteristics are affected by forest stand manipulation.

Effect of Stand Treatment on Wood Mechanical Properties

Logs from young Douglas-fir stands such as these produce lumber containing a much higher proportion of juvenile wood than lumber from larger, older trees. Juvenile wood has usually been considered the first 10 or 20 growth rings from the pith. Although no one has defined juvenile wood as a specific number of annual rings, Senft and Bendtson (6) have analyzed strength properties of individual annual rings from juvenile through to mature wood in loblolly pine and found that the maximum rate of change in strength properties occurred at about 15 rings from the pith.

Sawmills are presently cutting a much higher percentage of small logs and several reports Bendtsen (2), Bodner (3), Johnson (4), Lulay and Galligan (5), and Senft, Bendtsen and Galligan (7) have discussed problems created by producing greater proportion of juvenile wood. All of these researchers report that juvenile wood has lower strength properties and exhibits greater longitudinal shrinkage than mature wood. A recent publication by Barrett and Kellogg (1) test full sized structural members composed of mostly juvenile wood and other members composed of mostly mature wood. The results showed that the lower strength values of juvenile wood members were enough to consider evaluating the possibility of reducing stress values for Douglas-fir.

Table 2 shows that F values for mechanical properties resulting from analysis of variance of the bending samples collected for this project. The modulus of elasticity (MOE) of juvenile wood (MOEJ) was significantly different at the 18-ft height level than at the butt. Further, MOEJ differed significantly with thinning treatment and this was an interaction between thinning treatment and MOEJ. This means that MOEJ did not always behave the same with different heights and thinning treatments. The MOE of mature wood (MOEM) differed only with thinning treatment.

Although MORM showed a statistical difference for height, the average MORM at the butt (13,200 p.s.i.) was only slightly (3.1%) greater than average MORM at the 18-ft height level (12,790 p.s.i.). This small difference in average MORM values is clearly within the natural variation range for wood.

Figures 4 and 5 give butt and 18-ft height MOR and MOE values for the three treatments studied. These figures clearly demonstrated the two basic populations of mechanical properties established by juvenile and mature wood.

Table 3 shows some differences between strength values found in this project and the established values from the Wood Handbook (7). The results shown in Table 4 revealed how much the MOE and MOR of juvenile wood differed from mature wood. In the butt region MOE of juvenile wood averaged 36.5% less than mature wood. The average MOE value of juvenile wood samples from the Dunn Forest (S) were over 50% less than the Wood Handbook value.

At the bottom of Table 3, the overall MOE and MOR of juvenile wood samples are compared to the established values used for Douglas-fir (8). As the Douglas-fir region shifts more to small log production the proportion of juvenile wood will increase in production resulting in a tendency to yield pieces with lower strength values. This study further verifies the discussions in reports by Bendtsen (2), Senft, Bendtsen and Galligan (7), and Lulay and Galligan (5).

Effect of Annual Ring Characteristics on Wood Mechanical Properties

A multiple linear regression calculation was prepared in which juvenile wood MOR and MOE, mature wood MOR and MOE, and ring specific gravity (RS) were the five dependent variables and early wood specific gravity (ES), earlywood width (EW), latewood width (LW), ring width (RW), latewood specific gravity (LS), minimum earlywood specific gravity (MES) and maximum latewood specific gravity (MLS) were the seven independent variables.

Table 4 shows the order in which independent variables entered the regression model for each forest stand studied.

The variables entered first on the left of Table 4 had most influence on mechanical properties and variables on the right side had least influence. For example, in the control stand MES had the most influence on strength properties while EW had the least influence. Even so, the influence of EW was highly significant.

Careful observation of Table 4 reveals that the seven independent variables (all within ring micro-characteristics) differ mostly between the control and the two thinning treatments. For example, only two variables, maximum latewood specific gravity (MLS) and latewood specific gravity (LS) differ by more than one entering position in the table and the other five variables differ by no more than one entering position between the two managed stands. Thus, the order of variables entering the model was quite different between the thinned stands and unthinned stand.

If a value is assigned to each micro-characteristic proportional to influence on the dependent variables, ES and MLS rate No. 1 and No. 2 respectively when all three stands are combined. Those same two annual ring micro-characteristics are also No. 1 and No. 2 in the managed (thinned and thinned + fertilization) stands although EW tied with MLS for No. 2 ranking. MLS rated No. 1 in the McDonald Forest stand and was fifth in the thinned + fertilized Hill Forest stand while LS ranked second in stand F and fifth in stand S. It appears that fertilization as occurred in stand F had a significant influence on latewood density.

RELATIONSHIP TO KILN DRYING

As previously mentioned, several articles (2) (5) (7) generally discuss the influence of greater proportion of juvenile wood on conversion and utilization. Lulay and Galligan (5) point out how the impact of juvenile and compression wood in lumber from small logs will cause seasoning and kiln drying problems.

On of the characteristics studied in this project was range in specific gravity (SR) within annual rings. This is the difference between the specific gravity of the last formed latewood and first formed earlywood. Figure 6 shows SR between the Hill Forest (F) and the control plot (C). Note that SR is less in the thinned plot. This characteristic of wood is important to dry kiln operators because of the tendency of Douglas-fir with a high density range to have raised grain and shelling from seasoning and machining.

One objective of this project was to better define juvenile wood. As most dry kiln operators know, juvenile wood tends to shrink excessively in the longitudinal direction and will cause bowing and/or crook if placed on one side of a piece. Since boxing the pith is really no longer a viable option for many lumber producers, research is needed on diminishing the influence of the juvenility through both processing and forest management.

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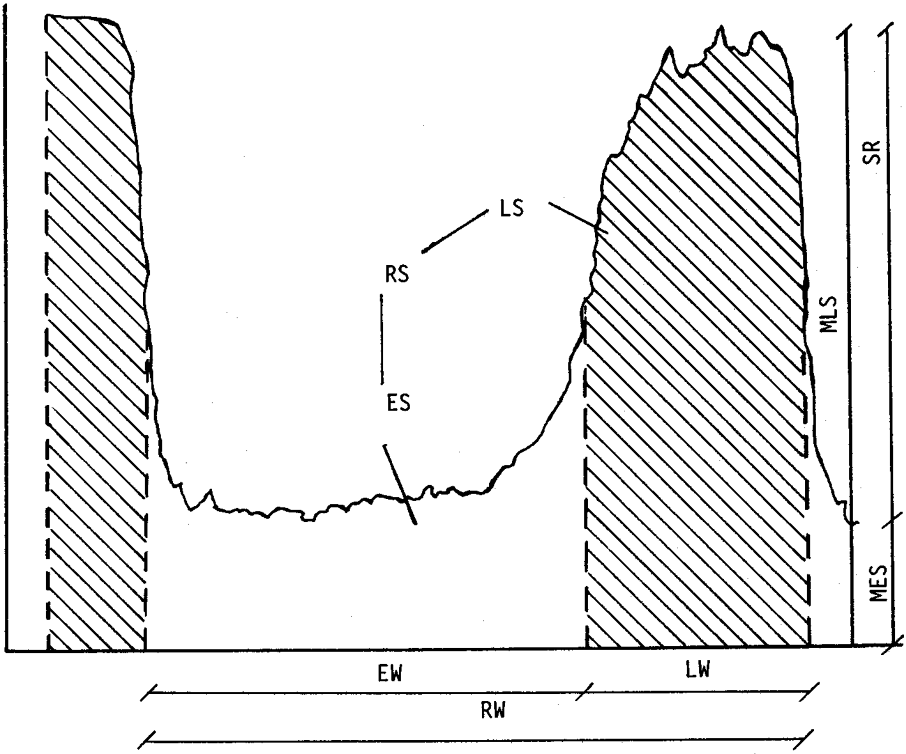

Variables

RW -- Ring width
EW -- Earlywood width
LW -- Latewood width
RS -- Ring specific gravity
ES -- Earlywood specific gravity
LDS-- Matewood specific gravity
MLS-- Maximum latewood specific gravity
MES-- Minimum earlywood specific gravity
SR -- Specific gravity range

Figure 1. Specific gravity variation across an annual ring and some intra-ring parameters.

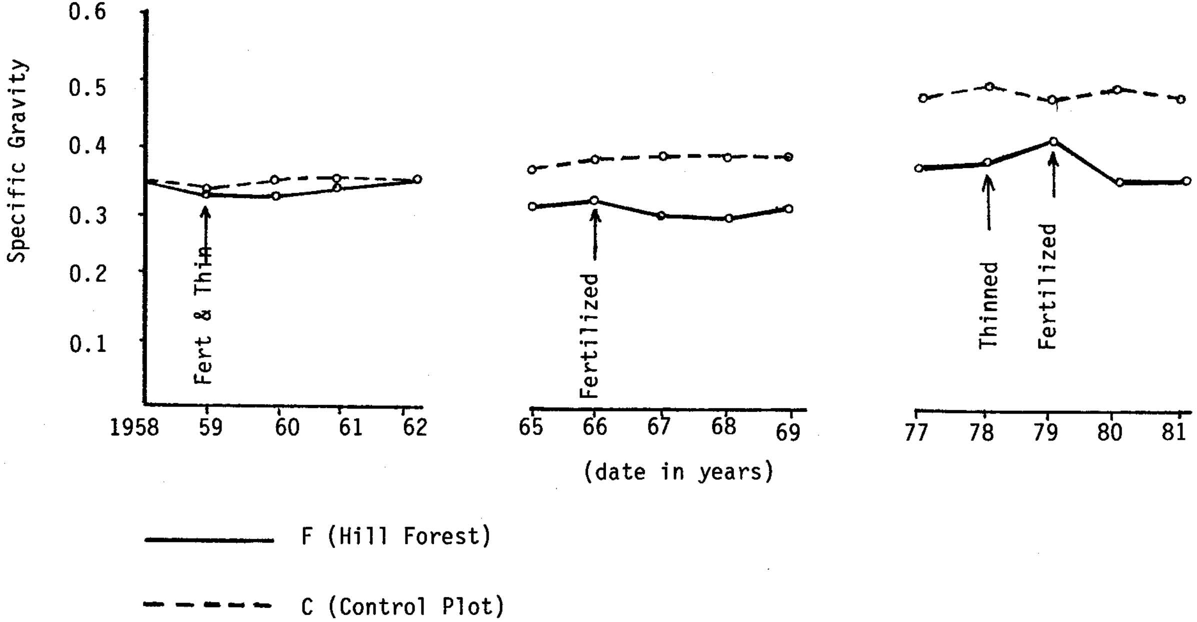

Figure 2. Earlywood specific gravity of treatment F (Hill Forest) and Control Plot C.

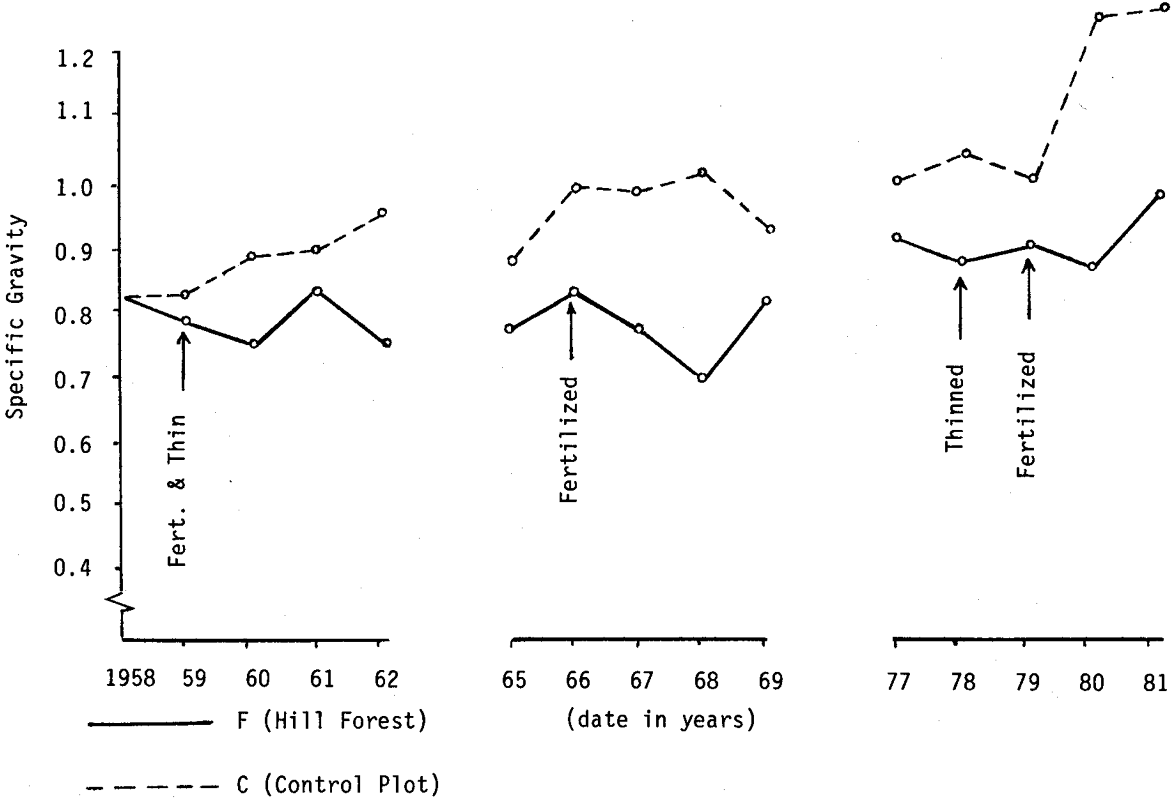

Figure 3. Maximum latewood specific gravity of treatment F (Hill Forest) and Control Plot C.

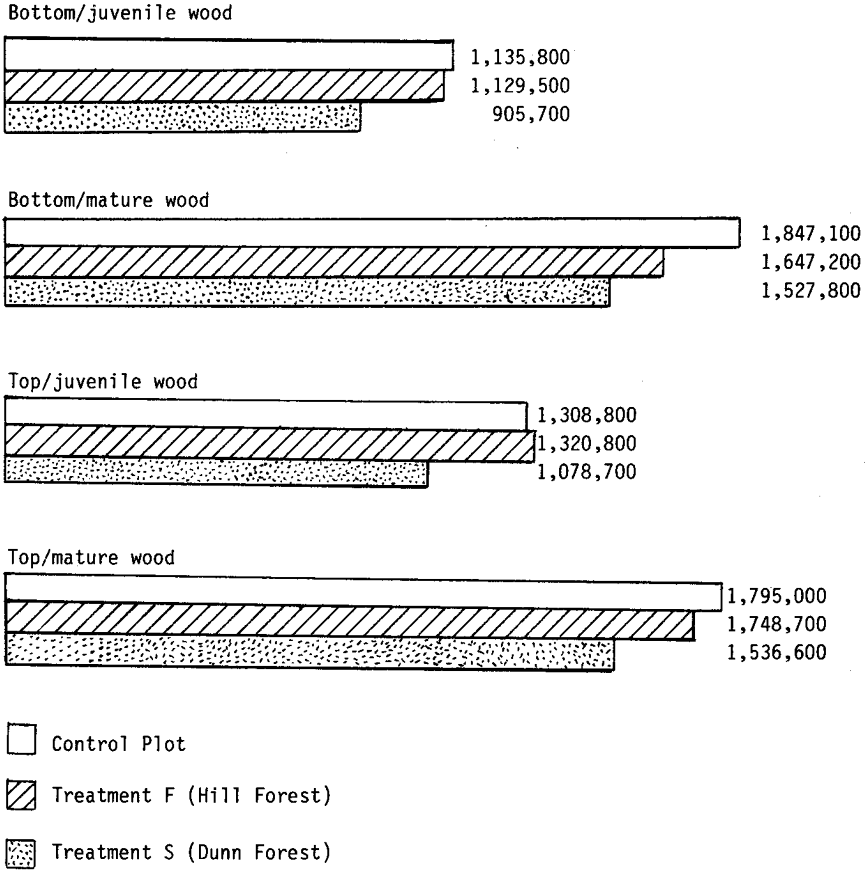

Figure 4. Modulus of elasticity values for treatments C (control), F (Hill Forest) and S (Dunn Forest) in lbs/in².

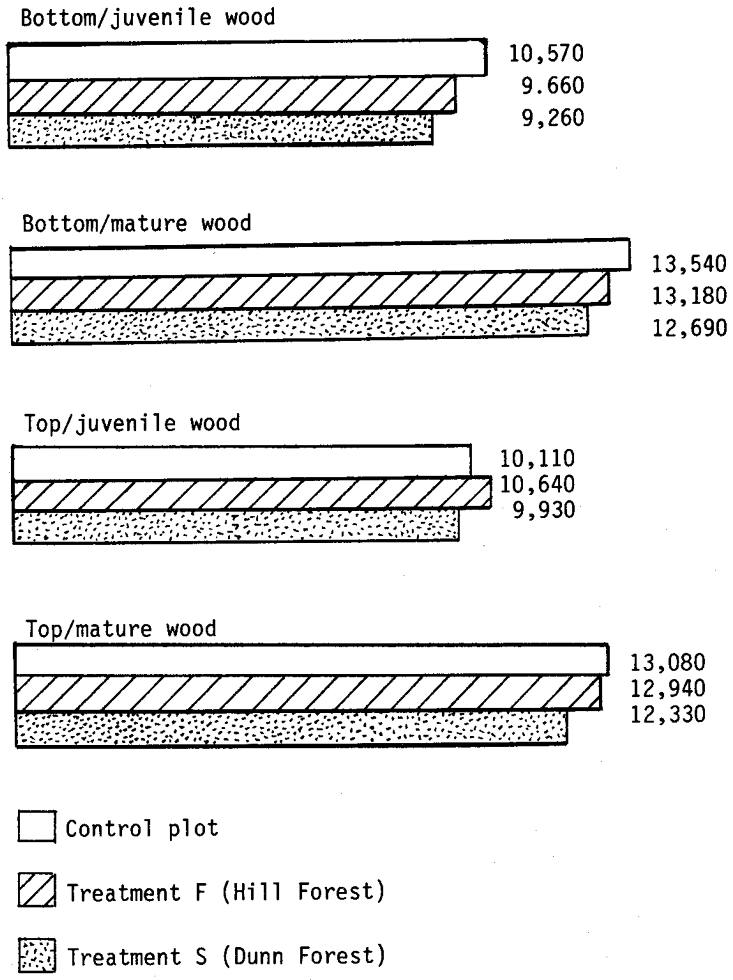

Figure 5. Modulus of rupture values for treatments C (control), F (Hill Forest) and S (Dunn Forest) (lbs/in^2)

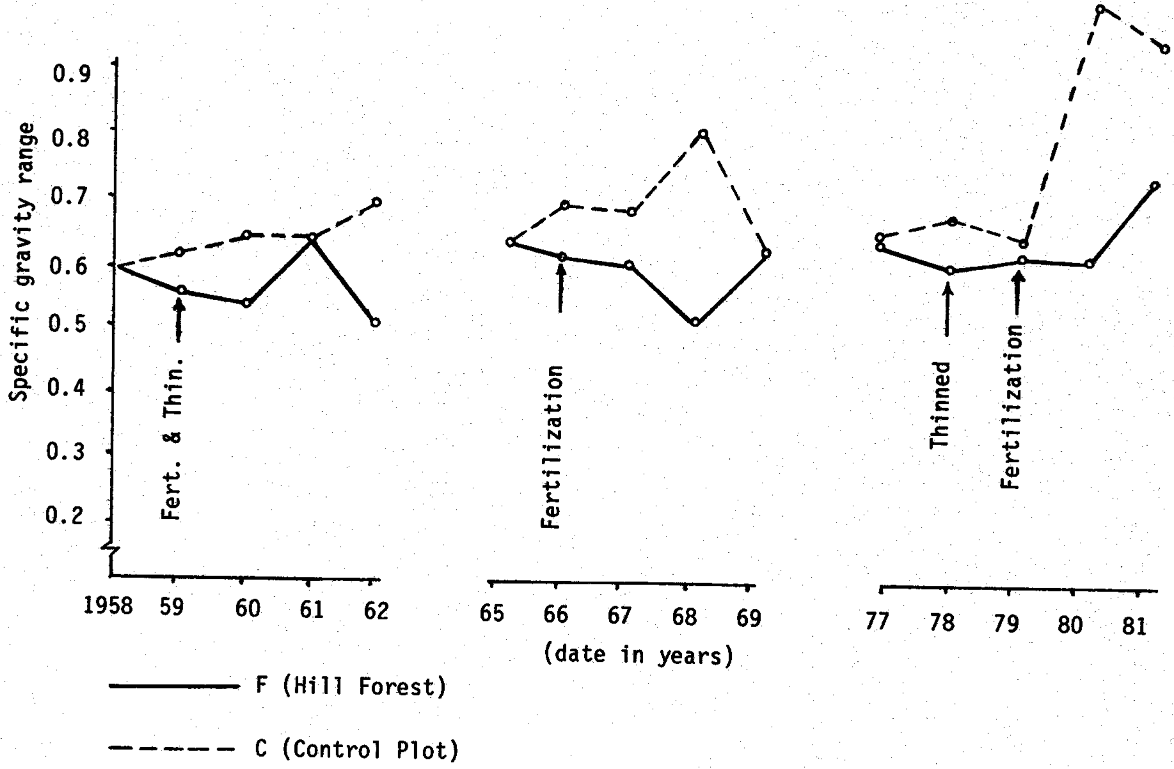

Figure 6. Specific gravity range of treatment F (Hill Forest) and control plot C.

Table 1 F-values for intra-ring parameters associated with analysis of variance (randomized block design). C vs. F.

Variable	Source of variation	F-value
RW1:[1]	KNDT	17.97**
	TRMT	66.79**
	KNDT*TRMT	4.18*
ED1:	KNDT	107.16**
	TRMT	98.93**
	KNDT*TRMT	26.37**
LD1:	KNDT	30.27**
	TRMT	17.90**
	KNDT*TRMT	4.14*
RD1:	KNDT	29.44**
	TRMT	71.86**
	KNDT*TRMT	11.61**
MED1:	KNDT	142.22**
	TRMT	84.81**
	KNDT*TRMT	18.27**
MLD1:	KNDT	26.07**
	TRMT	12.51**
	KNDT*TRMT	9.11**
PL1:	KNDT	3.19
	TRMT	43.14**
	KNDT*TRMT	4.20*

[1] See Figure 1for description of variable. (KNDT --treatment indicator variable)

*Significant (at 0.05 level).

**Significant (at 0.01 level).

Table 2 F-values for mechanical properties associated with analysis of variance (randomized design).

Variable	Source of variation	F-value
OSG:	POS	23.03**
	TRM	1.60
	POS*TRM	0.40
MOEJ:	POS	28.17**
	TRM	21.89**
	POS*TRM	3.33*
MOEM:	POS	0.43
	TRM	25.11**
	POS*TRM	1.38
MORJ:	POS	2.98
	TRM	2.62
	POS*TRM	2.51
MORM:	POS	3.90*
	TRM	4.39**
	POS*TRM	0.39

POS -- Butt vs 18 ft. level; TRM -- Thinning treatment

*Significant (at 0.05 level).

**Significant (at 0.01 level).

Table 3. Mechanical Strength Properties of Samples (kg/cm^2)

MOE

	Butt		18-ft	
	Juvenile	Mature	Juvenile	Mature
Control	79856[1]	129876	92028	126190
Hill (F)	80699	115808	90964	122947
Dunn (S)	63676	107419	75837	108031
Average	74744 ---	117701	86276 ---	119056
	36.5% increase		27.5% increase	

MOR

	Butt		18-ft	
	Juvenile	Mature	Juvenile	Mature
Control	744	952	711	919
Hill (F)	679	928	748	911
Dunn (S)	650	903	699	868
Average	691 ---	928	718 ---	899
	25.5% increase		20.1% increase	

[1] Each value is the mean of 49 samples tested

MOE for No. 2 structural light framing (9) = 1,700,000 psi
overall MOE for mature wood = 1,709,400 psi
overall MOE for juvenile wood = 1,162,600 psi
31.6% less than grading rules

MOR value from Wood Handbook (8) for D. fir = 12,200 psi
overall MOR for mature wood = 13,190 psi
overall MOR for juvenile wood = 10,172 psi
16.6% less than the standard

Table 4. Order of variables entered into regression model and associated F-values.

Dependent variable ring density	Independent Variables in Entering Order[1] F-value							R^2 at last significant entering order[2]
Control	MED 281.72**	MLD 176.22**	LW 122.60**	ED 91.21**	LD 67.41**	RW 51.50**	EW 47.80**	0.965
Hill Forest	ED 56.17**	LD 83.72**	EW 72.97**	LW 185.84**	MLD 221.61**	MED 261.41**	RW 89.30**	0.9948
Dunn Forest	MLD 268.97**	ED 324.62**	EW 242.58**	LW 253.11**	LD 229.68**	RW 193.17**	MED 157.06**	0.9910

[1] See Tables 6 and 7 for explanation of variables.

[2] R^2 values at last significant entering variable.

*Significant (at 0.05 level).

**Highly significant (at 0.01 level).