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STATISTICAL EVALUATION OF THE EFFECT OF AGE ON SPECIFIC GRAVITY IN LOBLOLLY PINE

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STATISTICAL EVALUATION OF THE EFFECT OF AGE ON SPECIFIC GRAVITY IN LOBLOLLY PINE

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Introduction

Data on the specific gravity and width of annual rings for consecutive 10-year periods of growth were analyzed to determine the statistical significance of observed trends of increasing specific gravity from the pith outward. This study is an extension of cooperative research with the Southern Forest Experiment Station on the factors that affect the specific gravity, and hence the intrinsic wood quality, of loblolly pine grown on the Crossett Experimental Forest in southeastern Arkansas.

Although the primary objective of this study was an evaluation of the relationship of age to specific gravity, information was also obtained on the extent to which this relationship is influenced by the width of annual rings and other factors. A better understanding of the factors affecting specific gravity is needed to guide silvicultural research aimed at improving both the yield and quality of loblolly and other southern pines.

Source of Material and Procedures

The material used in this study consisted of a cross section, taken at 12 to 16 feet above the stump, from each of 30 loblolly pine trees that ranged in age from about 30 to 80 years. The trees grew in a natural forest stand of uneven age, consisting 75 percent of loblolly pine, 20 percent of shortleaf pine, and 5 percent of hardwoods.

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

All cross sections were sampled by consecutive 10-year periods from the pith along diametrically opposite radii, as shown in figures 1, 2, and 3. Specific gravity values for the samples were based on volume when green, as determined by buoyancy, and weight when ovendry. The average width of the annual rings was determined for each sample.

In order to minimize the effects of differences in total age among the cross sections, only the data for the first five 10-year periods were used in this study. Data for certain 10-year periods that were missing, because of defects in some samples or trees less than 31 or 41 years old, were supplied by values computed according to Yates' missing-data technique.[2] All data used in this study are shown in table 1, with the computed values identified. It should be pointed out that the Yates technique of filling in missing values is simply a device to simplify computation in the analysis of variance. The estimates of factor effects and the experimental error sum of squares obtained by using this technique are the same as would be obtained by solving the least squares normal equations.

Analysis of Variance of Specific Gravity

An analysis of variance was carried out to determine if there was a significant difference in the mean specific gravity of the five age groups. The analysis of variance was for a two-way classification based on a mixed model with age groups selected at equal intervals as one factor and trees selected at random as the other factor. The computed values are shown in table 2.

To test for differences in specific gravity between age groups, the hypothesis that mean specific gravity is equal for all age groups was tested against the alternate hypothesis of unequal mean specific gravities between age groups by using the *F* test.[3] The calculated *F* ratio was:

$$F = \frac{\text{Age group mean square}}{\text{Residual mean square}} = \frac{0.011084}{0.001034} = 10.72$$

This value ($F = 10.72$) for the *F* statistic with 4 and 107 degrees of freedom for the numerator and denominator, respectively, was significant at a probability level of 0.0005. The high significance of the *F* ratio resulted in rejection of the hypothesis of equal mean specific gravity for the five

[2] Yates, F. The Analysis of Replicated Experiments When the Field Results are Incomplete. Emp. Jour. Exp. Agr. 1, pp. 129-142. 1933.

[3] Dixon, W. J., and Massey, F. J., Jr. Introduction to Statistical Analysis. pp. 127-133. New York, 1951.

age groups. Accordingly, the age group means represent statistically significant differences in specific gravity.

The three components arising from the subdivision of the age groups sum of squares were also tested by means of an F test with the appropriate number of degrees of freedom. The component due to linear regression was found to be significant at the 0.0005 level, and the quadratic component was significant at the 0.05 level. Higher components were not significant.

Turnbull[4] has stated that the relationship of specific gravity to age is exponential. When the mean specific gravity for each of the five age groups was plotted against age (fig. 4), the relation appeared to be close to an exponential form. However, no attempt was made to determine from these data the exact form of the regression. This was not considered necessary for purposes of the present study.

In summary, the analysis of variance of specific gravity for age-group means showed a highly significant relationship between specific gravity and age for the consecutive 10-year periods. Such an analysis, however, does not show whether the increases in specific gravity with age are due to decreasing ring width or to other factors.

Analysis of Covariance of Specific Gravity and Ring Width

The analysis of covariance (table 3) was employed to determine whether the increase in specific gravity with age would be significant if the effect of growth rate was removed.

Since the covariance analysis is based on the assumption that the regression of specific gravity on ring width is the same for all age groups, the first step in the analysis was to test this assumption. Table 4 gives, for each of the individual regressions, the value of the slope b, the sum of squares for deviations from the regression $\Sigma(y - Y)^2$, and the reduction in the degrees of freedom due to estimating the slope. The individual regressions for the five age groups are shown in figure 5. The values used for making the test of significance of difference in slope are shown in table 5. The F ratio

$$F = \frac{0.0006812129}{0.0012337404} = 0.55$$

was formed from the values in table 5. This value of F was not significant and therefore the hypothesis of equality of slopes between age groups was not rejected.

[4] Turnbull, J. M. Some Factors Affecting Wood Density in Pine Stems. Jour. S. African For. Assoc., No. 16. 1948.

In the analysis of covariance, the same hypothesis was tested as for the analysis of variance for specific gravity. From the values in the analysis of covariance table, the following F ratio was formed:

$$F = \frac{0.00843225}{0.00094637} = 8.91$$

Comparing this with the standard value of F with 4 degrees of freedom in the numerator and 106 degrees of freedom in the denominator,

$$F_{0.0005}\ (4,106) \approx 5.4,$$

it is evident that, although the specific gravities for the age groups were adjusted by the mean regression of specific gravity on ring width, the calculated F was still considerably larger than the tabled F. Thus, even when the effect of growth rate is effectively removed from the test, there is still a significant difference in specific gravity between age groups.

Conclusions

Analysis of the data studied shows that there is a highly significant trend of increasing specific gravity in the radial direction from the pith outward. Although decreasing ring width accounts in part for the observed increase in specific gravity, the analysis of covariance shows that ring width does not nearly account for the total increment in specific gravity. Evidently there are some factors related to age, other than decreasing ring width, that influenced the formation of the wood in such a way as to cause specific gravity to increase with increasing age.

Table 1.--Specific gravity[1] and average ring width values by decades from the pith in loblolly pine trees (Shipment 1657)

Tree No.	Age groups by years									
	1 - 10		11 - 20		21 - 30		31 - 40		41 - 50	
	Average ring width	Specific gravity	Average ring width	Specific gravity	Average ring width	Specific gravity	Average ring width	Specific gravity	Average ring width	Specific gravity
	In.		In.		In.		In.		In.	
1	0.1429	0.393	0.1429	0.426	0.1250	0.445	0.1250	0.491	0.1250	0.448
2	.1667	.419	.1429	.521	.1250	.575	.1429	.539	.1429	.506
3	.1000	.446	.1111	.465	.1429	.488	.1667	.485	.1429	.462
4	.1429	.469	.0588	.593	.1000	.545	.1111	.555	.1667	.529
5	.1111	.466	.1667	.502	.1429	.469	.1111	.482	.1000	.551
6	.1111	.472	.1429	.486	.1111	.531	.1667	.471	.1667	.466
7	.1667	.485	.2500	.488	.2500	.426	.2500	.446	.2000	.484
8	.1429	.424	.1111	.477	.1000	.477	.1000	.521	.1111	.573
9	.1667	.416	.1000	.465	.1000	.479	.1429	.531	.1250	.593
10	.2000	.459	.0625	.565	.0435	.513	.0909	.526	.0833	.556
101	.1111	.487	.1429	.471	.1429	.456	.1429	.453	.1250	.480
102	.1250	.421	.0769	.469	.0769	.526	.0303	.484	.0556	.463
103	.1000	.514	.0500	.517	.0455	.530	.0250	.556	.0303	.487
104	.1000	.460	.0556	.489	.0556	.541	.0909	.524	.0769	.574
105	.2000	.466	.2500	.473	.2000	.512	[2].1667	[2].502	[2].2000	[2].509
106	.1429	.488	.1000	.530	.1111	.525	.1429	.533	.1250	.562
107	.1667	.422	.1667	.460	.1667	.469	.1429	.516	[2].1667	[2].488
108	.1667	.490	.0909	.516	.1429	.517	.1111	.477	.1000	.496
109	.1667	.423	.2000	.428	.2000	.452	[2].1429	[2].453	[2].1667	[2].460
110	.0714	.571	.1667	.480	.1667	.467	.1250	.468	.1250	.538

(Sheet 1 of 2)

Table 1.--Specific gravity[1] and average ring width values by decades from the pith in loblolly pine trees (Shipment 1657) (continued)

Tree No.	Age groups by years									
	1 - 10		11 - 20		21 - 30		31 - 40		41 - 50	
	Average ring width	Specific gravity	Average ring width	Specific gravity	Average ring width	Specific gravity	Average ring width	Specific gravity	Average ring width	Specific gravity
	In.		In.		In.		In.		In.	
111	0.1429	0.457	0.1111	0.510	0.0833	0.531	0.0769	0.493	0.0769	0.538
112	.1667	.460	.2000	.470	.1429	.486	[2].1250	[2].491	[2].1429	[2].498
113	.1000	.512	.2000	.470	.2000	.457	.1111	.466	.0714	.520
114	.1000	.565	.0500	.547	.0345	.531	.0303	.496	.1429	.525
115	.0909	.457	.0667	.489	.0833	.511	.1250	.559	.0909	.504
116	.1250	.444	.1000	.491	.0769	.542	.0769	.538	.1000	.531
117	.1429	[2].456	.1250	[2].486	.2000	.506	.1667	.499	.1667	.493
118	.2000	.461	.1429	.514	.1429	.515	.1250	.545	.0556	.500
119	.1111	.423	.0833	.484	.0588	.517	.0769	.500	.1429	.525
120	.1429	.470	.1250	.518	.1667	.552	.1111	.558	.1000	.506

[1] Based on weight when ovendry and volume when green.

[2] Values calculated by missing-data technique.

Table 2.--Analysis of variance of specific gravity

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F
Between age groups	4	0.044335	0.011084	[1]10.72
Linear component	1	.036212	.036212	35.02
Quadratic component	1	.006233	.006233	6.03
Higher order components	2	.001890	....	....
Between trees	29	.086720	.002990	2.89
Residual	[2]107	.110601	.001034	....
Total	140	.241656	....	....

[1]The calculated F ratio is not exact because of the method of inserting values for the missing data; however, it so greatly exceeds the tabled F that the exact computation was not considered necessary.

[2]The degrees of freedom for residual variation are reduced from 116 to 107 because of the 9 missing values.

Table 3.--Analysis of covariance of ring width ($\underline{x}$) and specific gravity ($\underline{y}$) between age groups

Source	Degrees of freedom	(x^2) $\Sigma(x_i - \bar{x})^2$	(xy) $\Sigma(x_i-\bar{x})(y_i-\bar{y})$	(y^2) $\Sigma(y_i-\bar{y})^2$	Regression coefficient b $\frac{(xy)}{(x^2)}$	Errors of estimate: Sum of squares $(y^2)-(xy)^2/(x^2)$	Errors of estimate: Degrees of freedom	Errors of estimate: Mean squares
Between trees	29	0.20583405	-0.06852060	0.086720	-0.33289244	0.063910		
Between age groups	4	.00649727	- .01626076	.044335	-2.50270652	.003639		
Error (116)	107	.11973603	- .03509346	.110601	- .29309023	.100315	106	0.00094637
Total (149)	140	.33206735	- .11987482	.241656				
Age groups + error	111	.12623330	- .05135422	.154936		.134044	110	
Adjusted age group means						.033729	4	.00843225

Table 4.--Values for the individual regressions of specific gravity (y) on ring width (x)

Age group	Degrees of freedom	(x^2)	(xy)	(y^2)	b	$\Sigma(y - Y)^2$	Degrees of freedom
5	28	0.0345636697	-0.01713618	0.0476868000	-0.496	0.0391909236	27
15	28	.0903071080	- .02936190	.037344667	- .325	.0277981184	27
25	29	.0859773000	- .03247050	.0387909667	- .378	.0265280395	28
35	26	.0620004387	- .0150123133	.0330838667	- .242	.0294488997	25
45	25	.0527215667	- .0096331667	.0404141667	- .183	.0386540160	24
Total	136	.3255700831	- .1036140600	.1973204668	....	.1616199972	131

Table 5.--Analysis of variance for deviation from regression

Source of estimate	Degrees of freedom	Sum of squares	Mean squares
Deviations for average within group regression	135	0.1643448527	
Deviations from individual group regressions	131	.1616199972	0.0012337404
Difference - contribution due to slopes	4	.0027248555	.0006812139

$$F = \frac{.0006812139}{.0012337404} = 0.55 \text{ N.S.} \quad F_{.05}\ (4 \text{ d.f.}, 131 \text{ d.f.}) = 2.44$$

Figure 1. --Cross sections of trees 1 to 10 from which specific gravity samples were taken.

Z M 90216 F

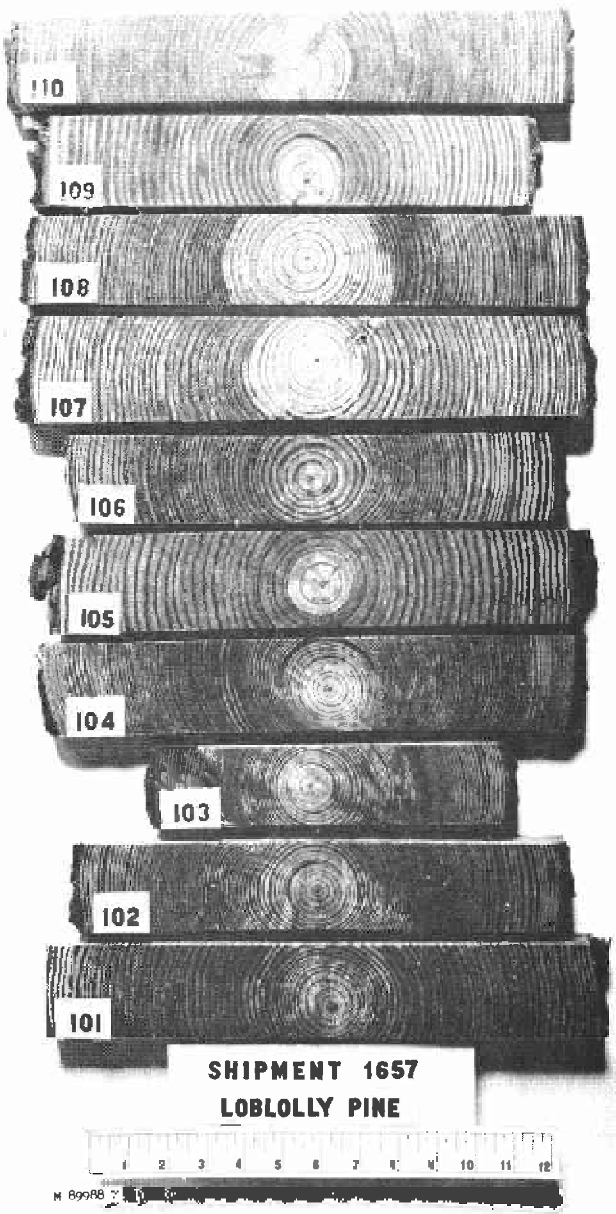

Figure 2. --Cross sections of trees 101 to 110 from which specific gravity samples were taken.

Z M 89988 F

Figure 3. --Cross sections of trees 111 to 120 from which specific gravity samples were taken.

Z M 89987 F

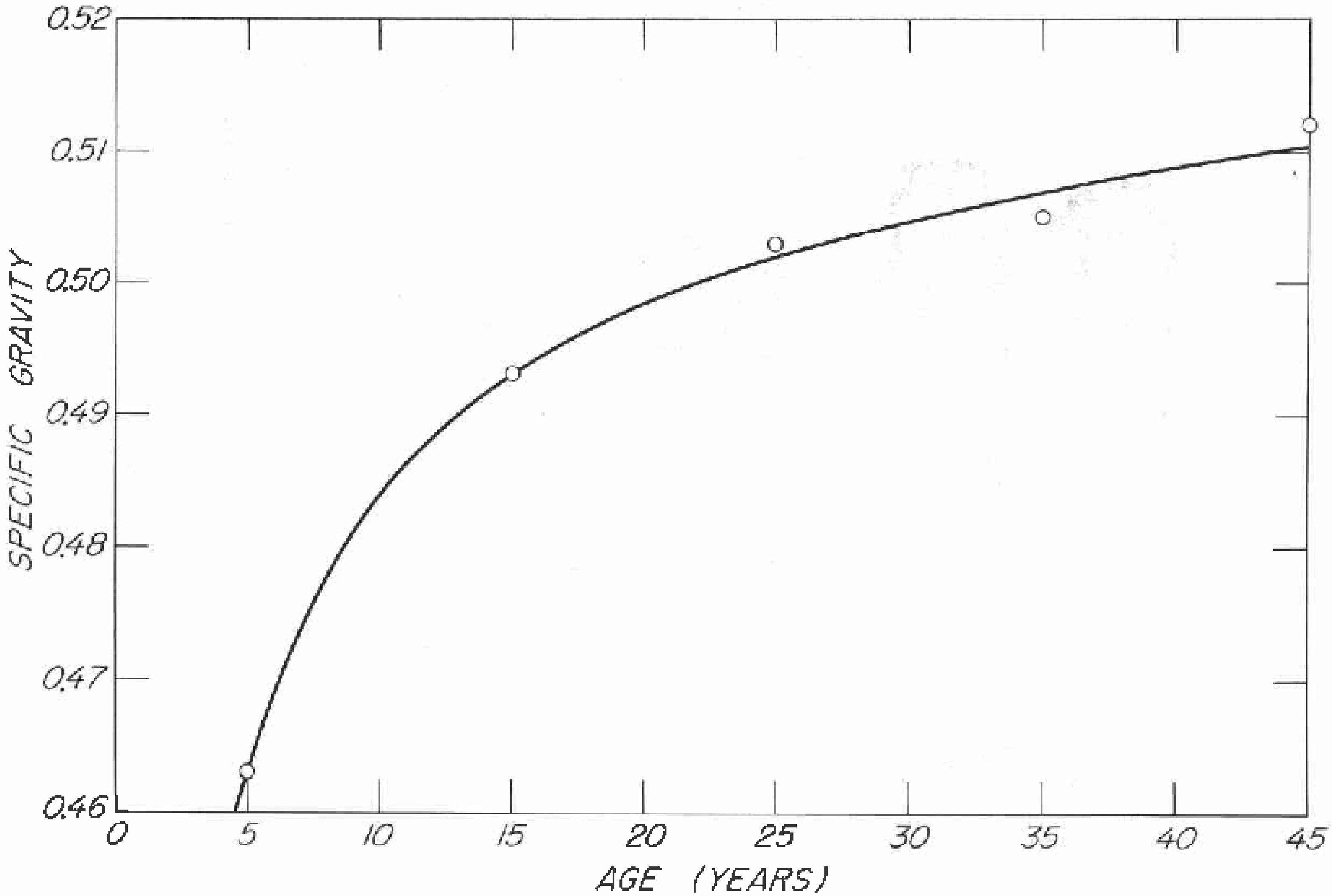

Figure 4. --Relationship between specific gravity and age in loblolly pine.

Z M 105 680

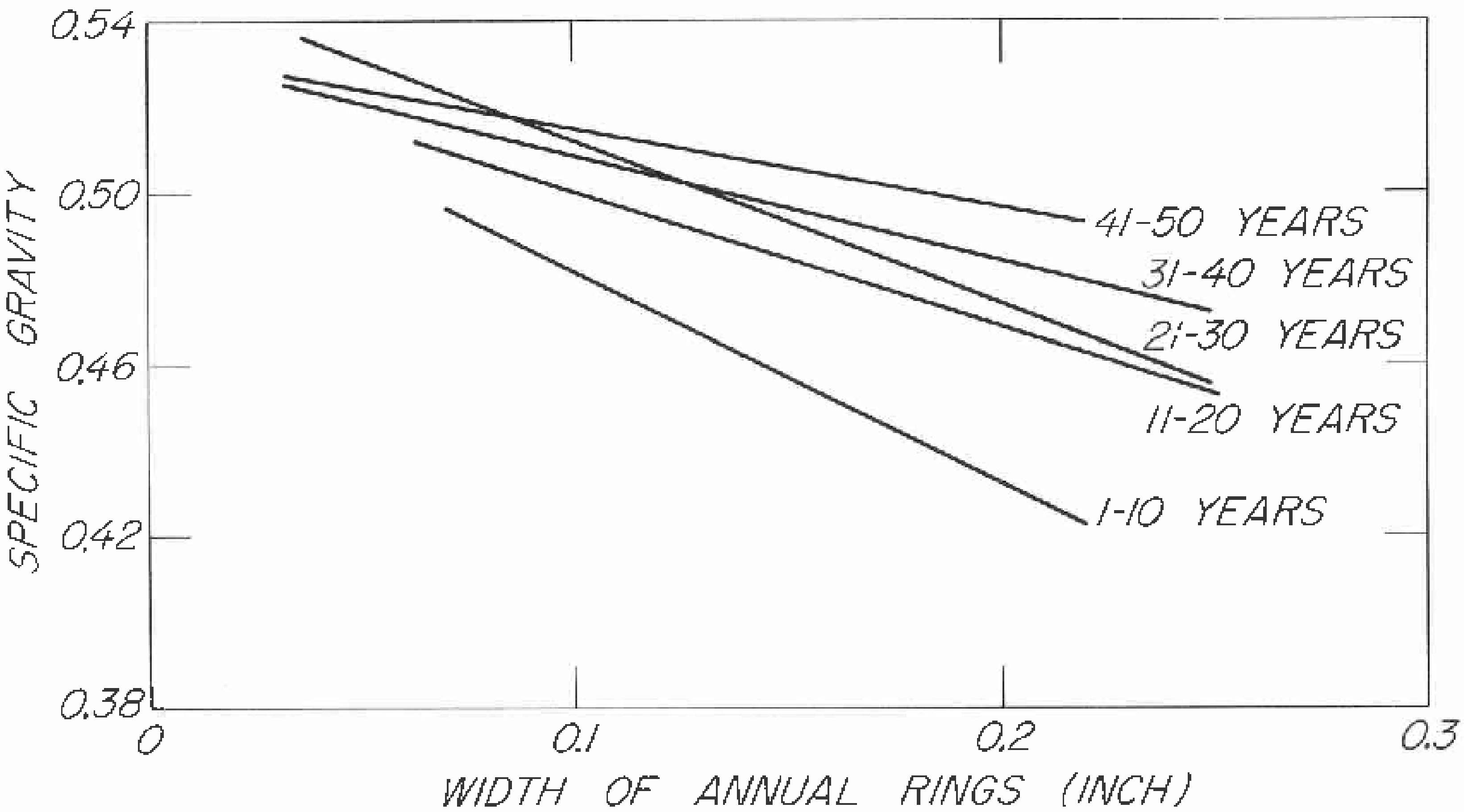

Figure 5.--Regressions of specific gravity on width of annual rings for 5 consecutive 10-year periods in loblolly pine.

Z M 105 679