1977

Variation of Selected Anatomical and Physical Properties in Sweetgum (Liquidambar Styraciflua L.) Grown on Upland and Bottomland Sites in Louisiana.

Andrew William Ezell
Louisiana State University and Agricultural & Mechanical College

78-7571

EZELL, Andrew William, 1950-
VARIATION OF SELECTED ANATOMICAL AND PHYSICAL PROPERTIES IN SWEETGUM (*LIQUIDAMBAR STYRACIFLUA* L.) GROWN ON UPLAND AND BOTTOMLAND SITES IN LOUISIANA.

The Louisiana State University and Agricultural and Mechanical College, Ph.D., 1977
Agriculture, forestry and wildlife

University Microfilms International, Ann Arbor, Michigan 48106

VARIATION OF SELECTED ANATOMICAL AND PHYSICAL PROPERTIES IN SWEETGUM (*LIQUIDAMBAR STYRACIFLUA* L.) GROWN ON UPLAND AND BOTTOMLAND SITES IN LOUISIANA

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The School of Forestry and Wildlife Management

by

Andrew William Ezell
B. S. F., University of Tennessee, 1972
M. F. S., Yale University, 1974
December, 1977

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to his major professor, Dr. Elvin T. Choong, for his guidance and supervision throughout the course of this work.

The author also wishes to express his appreciation to Dr. Peter J. Fogg, Dr. B. A. Thielges, Dr. S. C. Tucker, Dr. F. W. Manwiller, and Dr. N. E. Linnartz for their instruction and guidance.

The author wishes to express his sincere appreciation for the tireless efforts of Dr. P. E. Schilling and Mr. Larry Stewart in their statistical analysis and consultation work.

The author is appreciative of the efforts of all staff personnel who assisted him during the research.

The author wishes to express his sincere appreciation to Patsy A. Ezell, for it was her continual support and assistance that made this work possible.

TABLE OF CONTENTS

Page

Page

LIST OF TABLES

Table		Page

Table		Page

LIST OF FIGURES

Figure | Page

ABSTRACT

An intensive sampling study of sweetgum (Liquidambar styraciflua L.) was conducted to determine the amount and pattern of variation of selected anatomical and physical properties. Information on fiber length, specific gravity, tissue cell type proportions, and fiber cell wall diameter was obtained during the course of this research.

Samples were collected from 18 sweetgum trees selected for size and form in Louisiana. These trees were sampled on a radial and vertical basis, and sampling was designed to allow comparisons ranging from within the tree to among geographical areas. In addition, increment cores were collected from trees from an expanded geographical area in order to test the validity of intensive sampling results.

Fiber length(including bark fiber length) was found to vary significantly within the trees and between sites within an area. Generally, fiber length increased in later years of deposition and decreased with increasing height. Regression analysis indicated that age is not a major source of fiber length variation in the base section of sample trees. However, whole-tree averages may be predicted precisely from single samples taken at four feet above the ground.

Specific gravity was much less consistent than fiber length in its variation. Specific gravity varied significantly within the tree and between all upland and bottomland sites tested. This property fluctuated in both vertical and radial directions within the tree,

but patterns of variation are not consistent. Regression analysis indicated that age is not a major source of specific gravity variation, and prediction of average specific gravity for the whole tree from a sample taken four feet above the ground is much less precise than a similar prediction for fiber length.

Cellular element proportions and fiber wall thickness were both strongly related to specific gravity, but not to fiber length. Fiber proportions may even be used as a direct indicator of specific gravity and vice versa. The highest proportion of fibers and thickest cell walls were generally found in trees from upland sites.

Generally, sweetgum from upland sites was found to have longer fibers and higher specific gravity than sweetgum from bottomland sites. Results of this study indicate that variation in sweetgum is sufficient to warrant extensive future work.

Chapter I.

Introduction and General Literature Review

With the increased interest in hardwoods, especially southern hardwoods, that exists presently, it is important to expand the basic knowledge of desirable species to enhance existing or future work. Increased interest in southern hardwoods is a response to projected increases in wood and fiber demand. Of the 193 million acres of forest land in the South, 70 million acres are capable of growing high quality hardwoods rapidly (Briegleb and McKnight 1960). As most southern hardwoods have been cut over at least once and some twice, any further delay in expanding the knowledge of the hardwoods is detrimental, especially to tree improvement programs.

Sweetgum (Liquidambar styraciflua L.), in terms of where and how it grows, its uses, and the quantities utilized, is the most important single hardwood species in the United States (Perdue and Nieschlag 1961, Johnson and McElwee 1967, and Randel and Winstead 1976). The species is one of the most widely distributed hardwoods in the forests of the eastern United States, and it is found as far north as Connecticut, as far south as Florida, and as far west as Texas (Fowells 1965) (Figure 1). Within its native range, sweetgum occupies a wide variety of sites, as it occurs on all but the wettest bottomland sites and is absent only on the highest, driest upland sites (Putnam et al. 1960). There are apparently no altitudinal limitations to sweetgum's occurrence in the eastern United States with the exception of the Appalachians (Fowells 1965). The species attains admirable

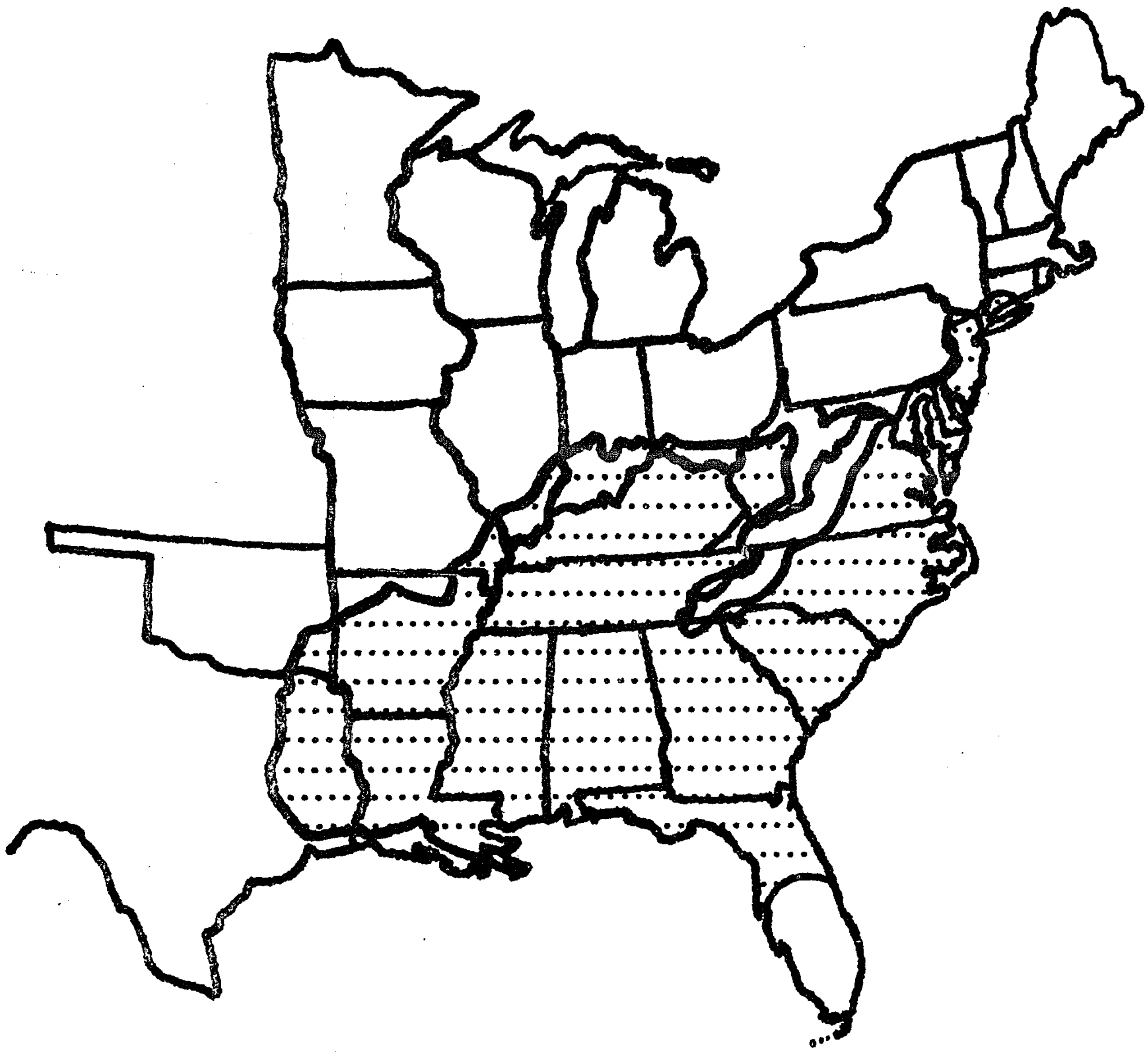


Figure 1. Native range of sweetgum within the United States.

proportions of up to 45 m in height and 1.5 m in diameter (Harlow and Harrar 1969).

Sweetgum is a major component of four forest cover types: (1) Northern Red Oak - Mockernut Hickory - Sweetgum, (2) Pin Oak - Sweetgum, (3) Sweetgum - Yellow Poplar, and (4) Sweetgum - Nuttall Oak - Willow Oak. In addition, it is an associated species in 24 other forest cover types.

Sweetgum is classed as intolerant with respect to its ability to withstand shading. This classification tends to be misleading as sweetgum is able to endure some shading in pure bottomland stands. The species is, however, unable to maintain itself in the understory of an older stand (Putnam et al. 1960). The shading which results as pure, even-aged stands of sweetgum develop serves as a natural thinning agent because the species exhibits a reduction in tolerance to overtopping with increased age (Winters and Osborne 1935).

Sweetgum reflects amenable capacities for management and manipulation, both genetically (Santamour 1972, Ferguson and Cooper 1977, and Wilcox 1970) and silviculturally (Johnson 1968, and Kaszkurewicz 1975). The species comprises 11.38 percent of the present hardwood volume in the South. This percentage represents 12,940 million cubic feet of standing sweetgum timber (Staff of Forest Resources Research Work Unit 1976).

Due to technological advances with concomitant improved utilization, the economic importance of sweetgum is ever-increasing. Utilization of the species has progressed from a status of general hardwood consumption to the present usage for face, box, and commercial

veneer, factory lumber, small dimension stock for furniture and interior trim, and hardwood pulp (Putnam et al. 1960).

There is presently a great demand for sweetgum. However, because the quality of growth may be as variable as the range of sites on which it occurs, the amount of basic information for the species must be increased. The knowledge of silvical characteristics is extensive, but there is a scarcity of information on wood properties of sweetgum. As demand for hardwood products increases, a need to obtain more basic information on wood properties becomes more acute, and this need must be satisfied to ensure optimal utilization of sweetgum.

Wood properties have been found to vary widely in nearly every species examined. The research is of sufficient volume to have warranted several reviews including those by Goggans (1961), who reviewed the interaction of environment and heredity and their effect upon specific gravity, Spurr and Hsiung (1954), who evaluated the relationships between growth rate and specific gravity and Spurr and Hyrvarinen (1954), who reported on the variation of fiber length as it related to the position in the tree and growth rates. In addition, the TAPPI Forest Biology Committee (1960 and 1962) compiled pertinent summaries including a summary of the use of small samples to characterize wood properties and a bibliography of over 800 references concerning the effects of heredity and environment on wood properties. Of major consideration is the fact that these reviews dealt primarily, if not entirely, with coniferous species. However, they stressed the following generalities which are a major consideration in any investigation of wood properties:

(1) There is a great deal of variation in the anatomical and physical properties of all commercially important species;

(2) Variation occurs within trees, among trees on the same site, and among trees from different sites;

(3) Most patterns of variation are reasonably consistent within a species, and various species may or may not exhibit similar patterns of variation;

(4) Patterns of variation affect sampling, and thus, variation patterns must be known to facilitate the construction of an efficient sampling scheme;

(5) Patterns of variation are affected by both heredity and environment, with the magnitude of the respective effects varying among species.

While these generalizations provide guidelines for research in wood properties, there presently exists only a framework for determining exactly what variation exists in sweetgum. There may be several sound research approaches to obtain the basic information needed for sweetgum. Modes of operation may vary from collecting a small amount of data from a large sample base to collecting a large amount of data from a small sample base. For reasons of efficiency, this research on sweetgum variation was structured on an intensive rather than extensive sampling format.

Variations between populations of sweetgum are multidimensional and extensive (Winstead 1968, 1971; Williams 1971 a,b; and Williams and McMillan 1971 a,b). Variation in anatomical properties of sweetgum includes differences among latitudinal origins (Hunter and

Goggans 1969, Johnson and McElwee 1967, Winstead 1972, and Randel and Winstead 1976), within-tree variation (Chow 1971, and Webb 1964), and variation from tree to tree on the same site (Webb 1964). Even with these sources of variation identified, a significant source for sweetgum growth, the upland site, has remained unexamined.

The primary objective of this research was to compare selected anatomical and physical properties of sweetgum growing on upland and bottomland sites. The sources of variation that were studied are:

(1) Variation of fiber length, specific gravity, proportions of fibers, vessels, and parenchyma, and cell wall thickness within trees;

(2) Variation of these properties among trees grown on the same site;

(3) Variation between sites within an area;

and

(4) Variation among trees grown on sites of the same topographic classification.

The first source of variation was evaluated by examining wood samples which were removed from trees in both radial and vertical directions. The second source of variation was studied by removing three trees from each site, in as close proximity to each other as possible. Evaluation of the third source of variation was facilitated by selection of comparative sample trees of approximately the same size on both upland and bottomland sites. The fourth source of variation was measured by comparing all trees which were sampled on either upland or bottomland sites. After evaluating the four

delineated sources of variation, a composite comparison of upland and bottomland sites was made.

A secondary objective of this research was to contribute information which can be combined with earlier reports in working toward a more complete characterization of the species. The volume of knowledge pertaining to most hardwoods is limited. By combining the results of this work with research on general silvical characteristics, physiological reactions, and wood chemistry, a much better comprehension of sweetgum may be obtained. More thorough information on sweetgum should contribute to better utilization of both growing site and fiber produced by the tree.

A series of experiments was designed and completed in logical sequence to achieve these objectives. The results of these experiments are reported in the following chapters (Chapters II - IV). An overall summation of comparative variation in sweetgum grown on upland and bottomland sites in Louisiana, with implications for future work, is presented in Chapter V.

Chapter II.

Fiber Length

Introduction and Literature Review

The scope of fiber length examination probably exceeds that of any other anatomical property of wood. However, much of this extensive fiber length research concerns coniferous species. Two reasons for the imbalance of efforts between conifers and hardwoods are (1) fiber length is critical in pulping properties and conifers represent the bulk of pulp production in this country, and (2) tree improvement programs which have utilized fiber length as a selection criterion have been almost exclusively concerned with conifers in the past.

The assessment of phenotype variation is essential to any genetic improvement program involving wood properties. With increased pulping of hardwoods and recent initiation of hardwood tree improvement programs, variation of fiber length is receiving more attention. While not of the magnitude of conifer data, the volume of fiber length research completed on hardwoods is still relatively large. However, relatively little is known about variation in sweetgum anatomical properties.

The fibers of sweetgum have been reported as being 1.47 to 2.13 mm in length (Forest Products Lab 1964, and Jett and Zobel 1975) with an average length of 1.82 $\pm$ 0.12 mm (Panshin and de Zeeuw 1970). Compared to conifers, sweetgum has relatively short fibers; therefore, variation in fiber length may be particularly important to breeding programs.

Since sweetgum occurs over such a wide range, major variation in fiber length might be expected. Winstead (1972) found the longest fibers of first-year seedlings in samples from Mexican populations, with Texas, North Carolina, and New Jersey populations displaying a trend of decreasing fiber length with higher latitudes. Winstead also reported that shorter fibers were produced when seedlings were subjected to shorter day-lengths, cooler temperatures, and lower light intensity under controlled conditions. In other work with first-year seedlings, Randel and Winstead (1976) found fiber length to be inversely proportional to latitude of origin in comparing sweetgum from United States and Central American populations.

Of greater importance to this study is the variation which exists in more mature stems. Thorbjornsen (1961), Taylor (1965), and Kellison (1966) studied the variation in the wood of yellow-poplar (Liriodendron tulipifera L.). All found extensive differences ranging from within-tree variation to variation among geographic source of the samples. Since yellow-poplar and sweetgum are both diffuse porous hardwoods, some similarities might be expected.

The variation of fiber length in sweetgum has been studied by a few investigators. Chow (1971) conducted a very intensive within-tree sampling study to test the effect of eccentric growth on fiber length in one tree. He noted that fiber length was significantly related to distance from the pith and that variation resulting from different sampling heights was small in comparison to that resulting from different radial positions. Overall, he reported a rapid increase in fiber length from the pith outward to a point 4 inches from the pith

followed by a slight decrease from this point to the bark.

Johnson and McElwee (1967) noted highly significant differences in mean fiber length among annual rings in increment cores taken from sweetgum on bottomland sites across the Southeast. They also reported highly significant differences in mean fiber length among trees in the same stand and among all stands within the same provenance.

Hunter and Goggans (1969) restricted their sampling to sweetgum growing in natural stands in Alabama. They found mean fiber length to vary significantly between quarter-degree latitude areas, whole-degree latitude areas, and physiographic and rainfall provinces. They also noted that longer fibers were found in trees growing in areas with longer growing seasons and more summer rainfall.

No study is more relevant to this work than that done by Webb (1964). He completed a study of sweetgum sampled from a large area of the Southeast and observed that fibers were shortest near the pith and increased in length in an outward radial direction to a point after which the increase was of a lesser magnitude or the fiber length decreased. These results are similar to findings of Chow (1971) reported above. Webb also found that sampling height had no effect on the variation of fiber length within an annual ring. In work with natural stands, differences between trees within stands was the most significant source of variation. Differences among stands were small, but the sites with more rapid growth had the longer fibers.

While the results of these previous efforts have been relatively uniform in some aspects, they do not describe the amount of variation which exists in sweetgum growing in upland and bottomland sites in

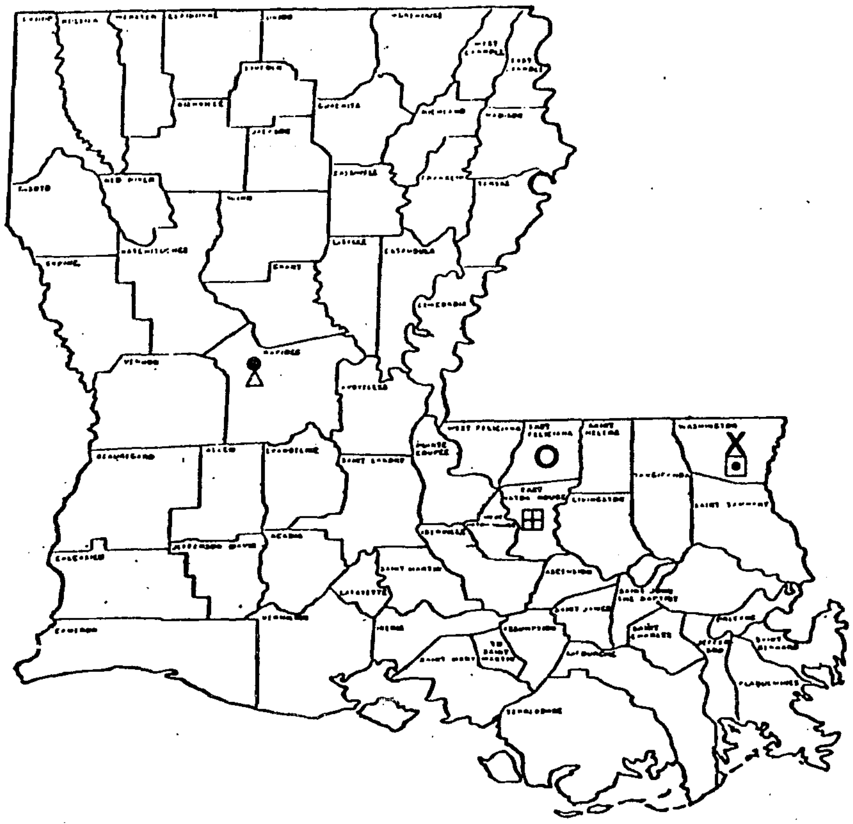
Louisiana. Other sources, as described in Chapter I, of fiber length variation were also examined, and the results are reported herein.

Materials and Methods

Field Sampling - The initial problem to be resolved was the designation and selection of sample areas. The term area is delineated herein as a geographic region which contained both bottomland and upland sites (sub-areas) in as close proximity as possible. All upland sites involved in the intensive sampling work were ridge tops. Bottomland sites used in intensive sampling research varied from a stream flat in Area 1 to a Mississippi River floodplain in Area 3 and a first bottom (along a stream) in Area 2. Three such areas were required, with one bottomland and one upland site sampled within each area (Figure 2). Sample sites were approximately 3 miles apart in Areas 1 and 2, but the upland site was approximately 38 miles from the bottomland site in Area 3. Sampling on this basis resulted in a total of six sample sites (three upland and three bottomland).

The stands on these sites were similar in that all grew from natural regeneration and were of moderate density. All stands on upland sites were of mixed pine and hardwood species composition. The stands on bottomland sites were generally comprised of mixed hardwoods with the one conifer, baldcypress (*Taxodium distichum* L.) being present on all bottomland sites used in intensive sampling.

On each of these sites, three dominant or co-dominant sweetgum trees were selected for analysis. Selection was based on the following criteria: (1) no visible defect in the bole (trees with wounds, scars,



● = Upland site in Kisatchie National Forest (Area 1)

△ = Bottomland site in Kisatchie National Forest (Area 1)

○ = Upland site in Idlewild Experiment Station (Area 3)

⊞ = Bottomland site in Idlewild Experiment Station (Area 3)

X = Upland site in Lee Memorial Forest (Area 2)

⊡ = Bottomland site in Lee Memorial Forest (Area 2)

Figure 2. Map of Louisiana illustrating the location of sample sites utilized in intensive sampling studies.

or hollow areas were omitted), (2) uniformity of the crown (trees with greatly unbalanced crown distribution were omitted), and (3) straightness of the bole (leaning trees were omitted). On each site, all sample trees were located within 20 m of each other. Information for individual trees is contained in Table 1, Appendix.

The diameter at breast height [4-½ ft. (1.37 m) above ground level] of each tree was measured. Diameter measurements facilitated the selection of three pairs of trees within each area which were of similar size, i.e., for each tree on an upland site, a tree within ± 0.5 inch of the same d.b.h. (diameter breast height) was selected from the bottomland site within that area. Also, before felling, the directional axes were determined with a compass and marked on each bole at a level 4-ft. above the ground. After felling, the total length (height) of each tree was measured.

The trees were felled in October 1974 and June and July 1975. Tags were attached along one directional axis at 4-ft. intervals along the stem starting at height of 4 ft. and proceeding to the top of the trees. In addition, a base section (6 inches above the ground) was tagged. A 3-inch wide disc was removed (Figures 3 and 4) at each tagged interval. For a conversion of sampling heights to metric units, see Table 2, Appendix. Three random branch samples were also removed from each tree, but no attempt was made to label a directional axis on branch samples.

Each disc was placed in a polyethylene bag after removal and sealed immediately. As soon as possible, the discs were refrigerated at approximately 2°C to restrict moisture loss, inhibit discoloration,

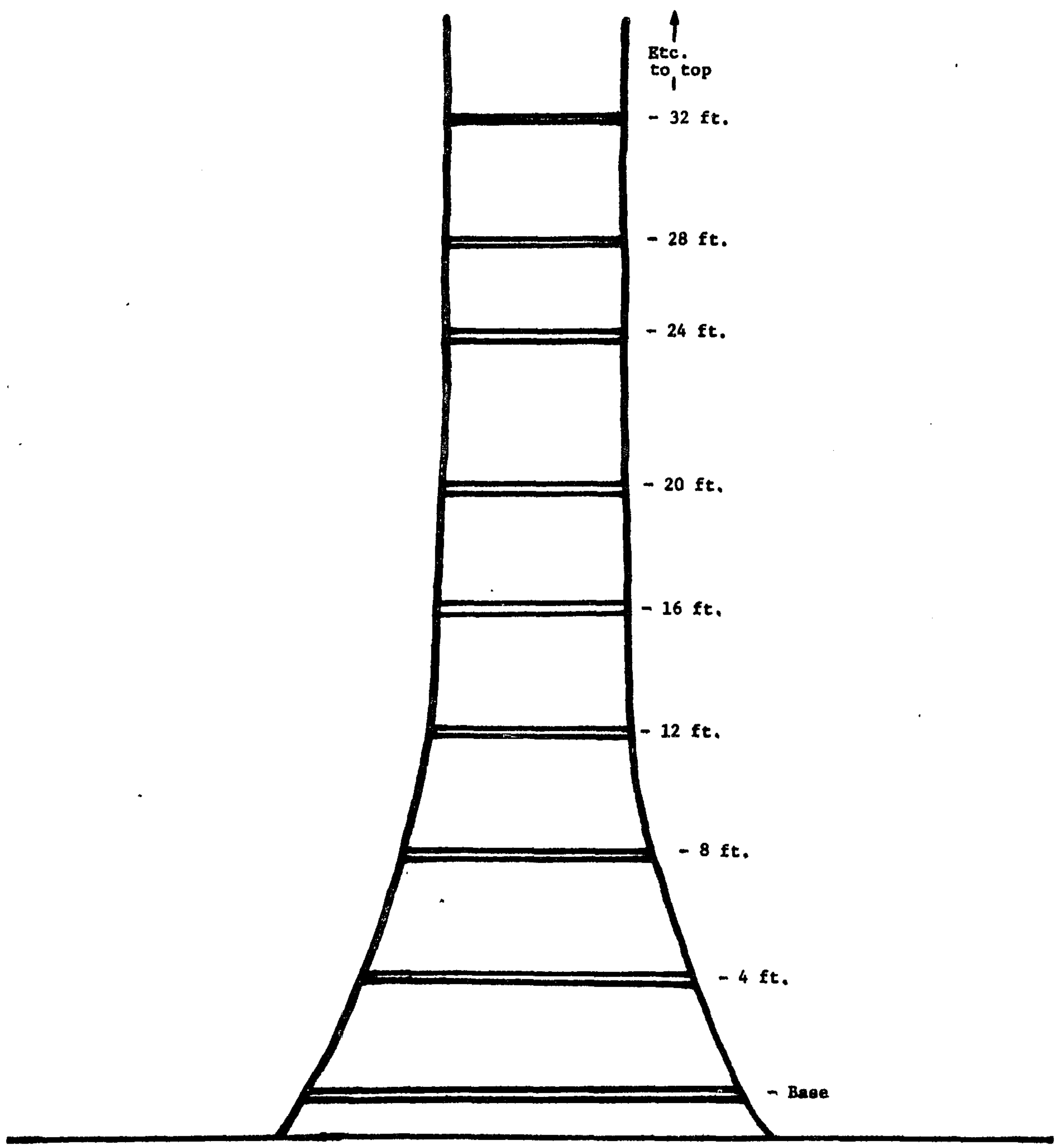


Figure 3. Schematic drawing illustrating the locations of sample disc removal from intensively sampled trees.

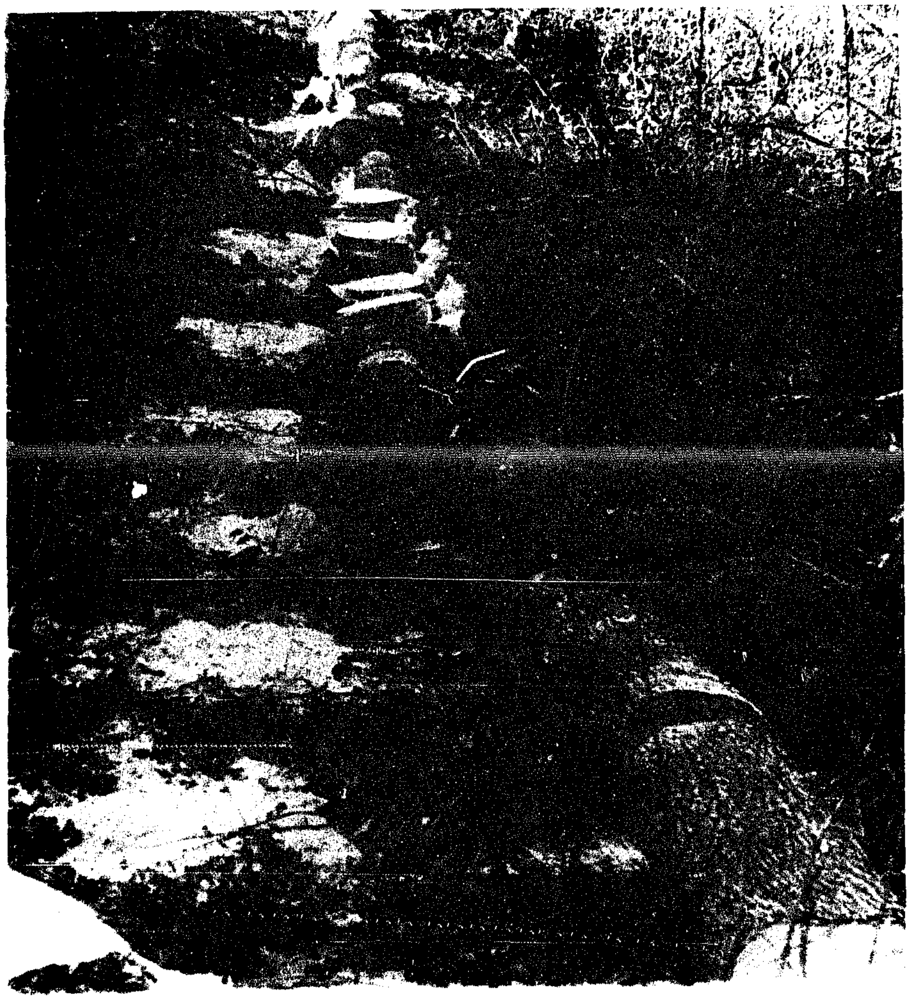


Figure 4. Illustration of sample disc removal for intensively sampled trees.

and prevent decay.

In addition to the intensively-sampled trees, increment cores of 12.1-mm diameter were taken from 50 dominant or co-dominant sweetgum trees on 25 additional sites, wherein 25 cores were taken from trees on upland sites, and 25 cores were taken from trees on bottomland sites. All cores were removed from the western directional axis of the trees at a level of 4 ft. above the ground. Core samples had a dual purpose: (1) to measure the effectiveness of the work on the intensively-sampled trees by comparing relevant results to the larger statistical base, and (2) to expand the geographical base of the research in an effort to be more representative of Louisiana (Figure 5).

Laboratory Sampling - All fiber length measurements were completed on sample sections taken from the western directional axis of each disc (Figure 6). By utilizing sections from the same location in each tree, potential error due to alteration of sample location around the stem was removed. The sample sections were removed by sawing with a radial arm saw or band saw and splitting the attachment at the pith with a chisel.

A fresh surface was prepared on the cross-sectional plane of each section with either a razor blade or sharp knife. A count of growth rings was made on each section. Differential staining with acridine orange and safranin-O was employed in conjunction with the use of a 14X hand lens when necessary for growth ring delineation. Any growth ring suspected of being a discontinuous ring was scrutinized for its presence around the entire disc to determine its validity.

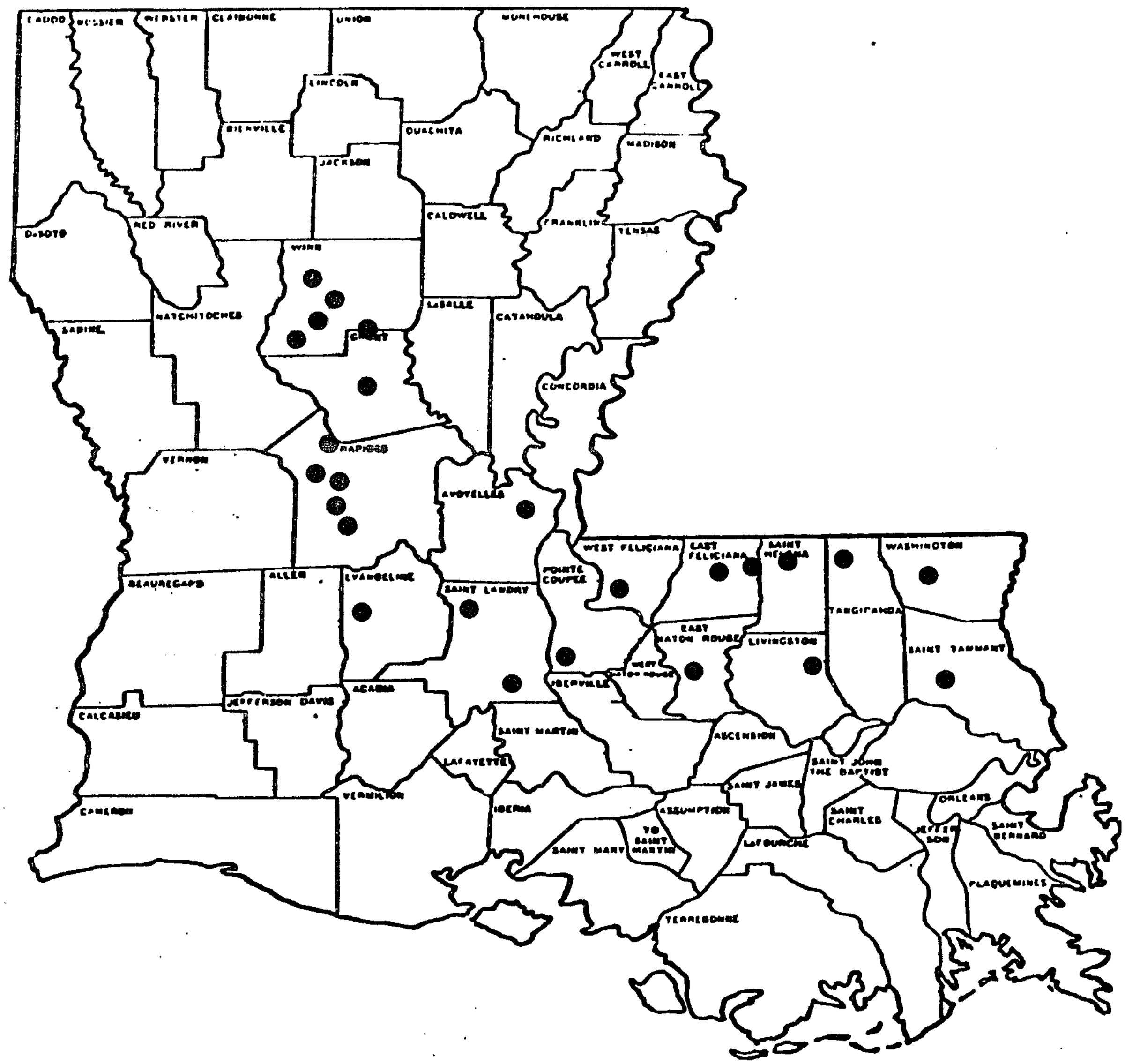


Figure 5. Map of Louisiana illustrating sites of increment core sampling.

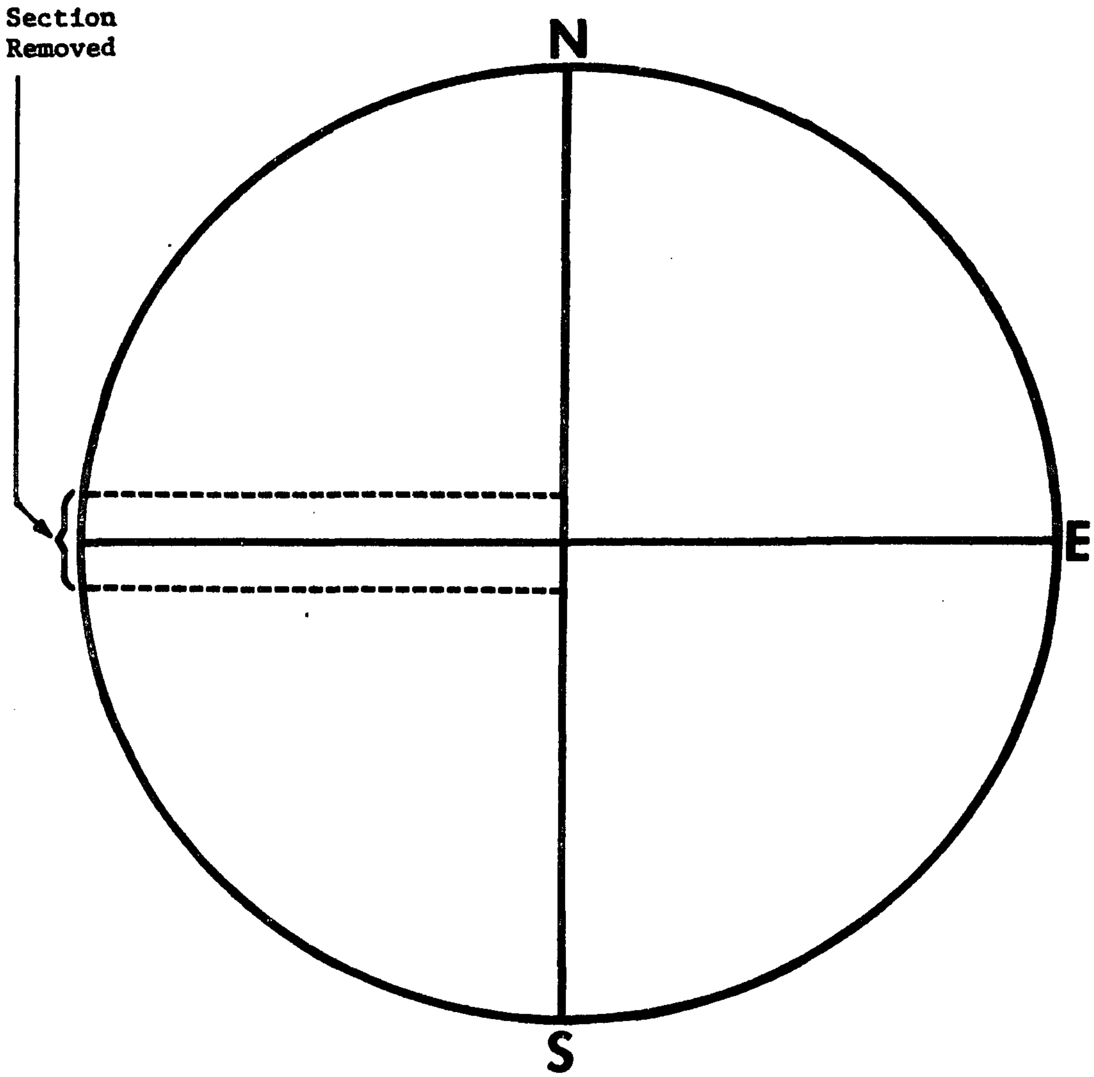


Figure 6. Schematic diagram of cross-sectional facet of sample disc illustrating the area removed for fiber length and specific gravity measurements.

The growth rings which had been deposited in the years 1974, 1970, 1965, 1960, and subsequent intervals of five years were used for all fiber length measurements (Figure 7). These growth rings were marked and removed by splitting them away with a large knife and hammer. Great care was taken to ensure that material from the growth ring on either side of the desired sample rings was not included.

Fiber length was measured in the bark of each sample section taken from the stem of the tree. Fiber lengths were not measured in the bark of branch samples or increment cores.

A portion of the isolated growth increment was sliced along the radial plane with a sharp knife. Each slice contained material from the entire width of the growth ring. By using this slicing method, the bias of differential sample points within the ring (Taylor 1963) was eliminated.

The slices were then macerated in Jeffrey's Solution (10 percent nitric acid and 10 percent chromic acid in a 1:1 ratio). Maceration was completed after 24 hours in the acid solution. The samples were then rinsed three times with distilled water. Shaking of the test tube ensured complete fiber separation.

A temporary slide was prepared for the fiber measurements of each sample ring. Two drops of the fiber-water slurry and one drop of safranin-0 stain were used for each slide.

A specially-etched glass slide was employed in all fiber length measurements. The bias of selecting longer fibers for measurements was eliminated by using delineated sample areas (areas between the three pairs of etched lines on each slide) and measuring only those

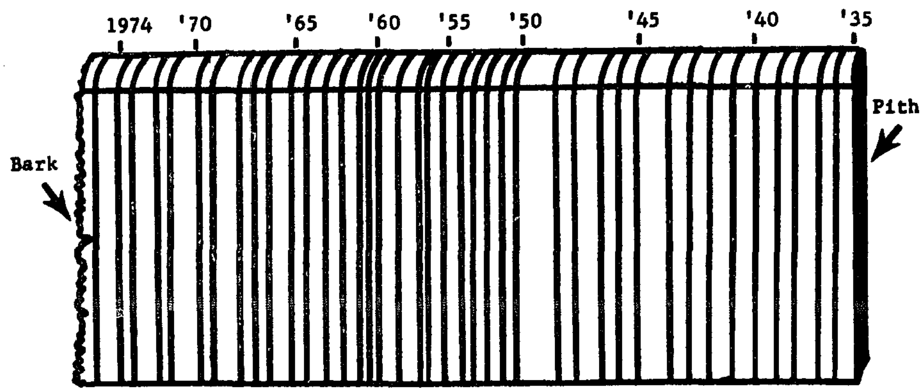


Figure 7. Schematic drawing representing radial view of sample removed from disc. Growth rings used for fiber length and specific gravity measurements indicated by year of deposition.

whole fibers that had one or both ends within the sample area (Figure 8). Selection of fibers on this basis was described in greater detail by Hart and Swindel (1967). Paired or bent fibers were measured if there was no doubt concerning their length.

Fiber length measurements were taken from fiber tracheids. These cells are distinguished in macerated material by their elongated shape and bordered pits. Fiber tracheids are longer than vessel segments and parenchyma cells, and the tapered ends of fiber tracheids render these cells easily identifiable when considered in conjunction with the length. Distinction between fiber tracheids and libriform fibers was unnecessary as sweetgum does not contain the latter (Panshin and de Zeeuw 1970).

Fiber lengths were determined by placing the temporary slide on a Rayoscope which had a 10X objective and measuring the projected images of the properly selected fibers with a centimeter scale. Image measurements were recorded in centimeters to the nearest 0.1 cm. Magnification of the instrument was 32.5X, and all image measurements were divided by a conversion factor of 3.25 to transpose the recordings to actual fiber lengths in millimeters.

A set of preliminary measurements based on random fiber selection from the total samples of each tree was first completed. The sample size required to ensure 95 percent confidence was then calculated by the formula (Avery 1967):

$$n \geq \frac{t^2 \ s^2}{E^2}$$

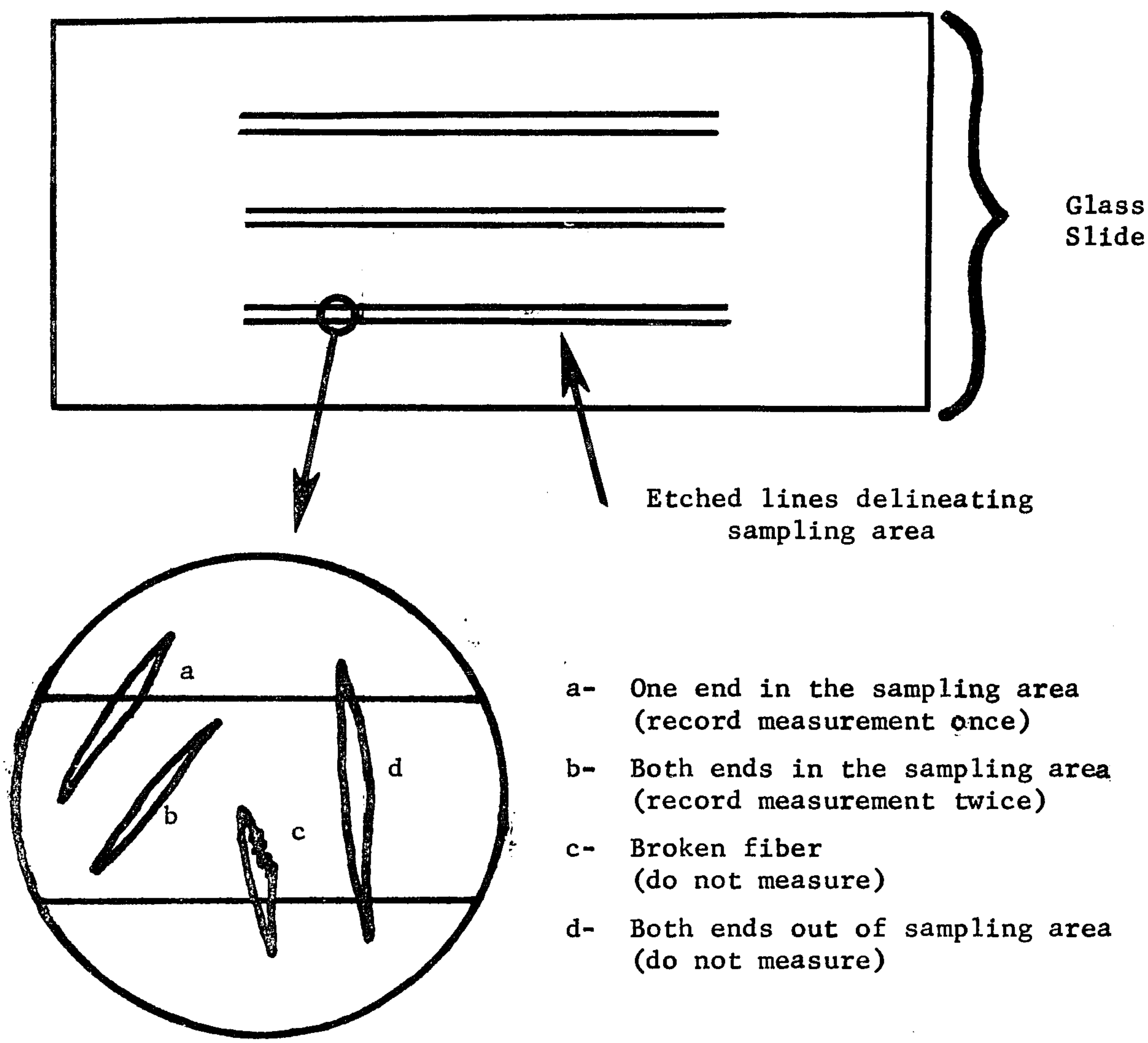


Figure 8. Schematic drawing illustrating the selection of fibers for measurement.

where,

n = number of samples required,

t = tabular t value from the t distribution at $p = .05$ using n-1 degrees of freedom,

s = standard deviation of the sample, and

E = the desired half width of the confidence interval.

A value of E=0.3 cm. was used as it was less than 5 percent of total length. Twenty-five fibers were measured from each ring and bark sample, and this number was always sufficient to ensure 95 percent confidence. A total of 79,550 fiber lengths were taken.

Three statistical procedures were used to analyze the data. These procedures are correlation analysis, least squares analysis of variance, and stepwise regression analysis.

Results and Discussion

In accordance with the objectives of this study, fiber length variation was analyzed and is presented along the following guidelines: (1) variation which occurs within the tree, (2) variation which occurs among trees from the same site, (3) variation which occurs between sites within an area, and (4) variation which occurs among similar sites (areas).

Within-tree variation - Average fiber length values for sample years and sample heights are presented in Tables 1 and 2. These values were reviewed to determine what, if any, patterns of variation existed within the tree. Inspection of Table 1 reveals that average fiber length decreased with increasing height, and subsequent correlation and

Table 1. Average fiber length for all sample heights in intensively sampled trees.

Area	Sub-Area	Tree	Height (ft.) Base	4.	8	12	16
			mm				
1[a]	U[1]	1	1.61	1.65	1.66	1.60	1.58
1	U	2	1.80	1.83	1.85	1.76	1.60
1	U	3	1.76	1.71	1.67	1.57	1.53
1	B[2]	1	1.77	1.81	1.73	1.73	1.65
1	B	2	1.67	1.63	1.72	1.63	1.62
1	B	3	1.77	1.62	1.70	1.65	1.62
2[b]	U	1	2.06	1.91	1.80	1.87	1.81
2	U	2	1.94	1.93	1.93	1.79	1.77
2	U	3	1.85	1.86	1.82	1.78	1.76
2	B	1	1.55	1.50	1.53	1.43	1.31
2	B	2	1.75	1.66	1.41	1.55	1.61
2	B	3	1.62	1.61	1.44	1.52	1.52
3[a]	U	1	1.28	1.26	1.20	0.97	1.28
3	U	2	1.75	1.74	1.72	1.57	1.61
3	U	3	1.61	1.77	1.69	1.77	1.62
3	U	1	1.71	1.65	1.57	1.78	1.78
3	U	2	1.80	1.85	1.82	1.77	1.79
3	U	3	1.71	1.77	1.72	1.78	1.76

Table 1, Continued

Height (ft.)										
20	24	28	32	36	40	44	48	52	56	60
mm										
1.58	1.46	1.58	1.52	1.43	1.42	1.38	1.28	1.19	1.17	1.27
1.62	1.56	1.60	1.55	1.50	1.50	1.39	1.43	1.46	1.45	1.28
1.61	1.54	1.52	1.36	1.36	1.27	1.20	1.27	1.19	1.16	1.07
1.64	1.69	1.67	1.68	1.53	1.57	1.52	1.45	1.54	1.44	1.43
1.60	1.57	1.58	1.46	1.49	1.49	1.48	1.45	1.43	1.33	1.43
1.58	1.65	1.55	1.49	1.47	1.46	1.37	1.48	1.56	1.45	1.46
1.71	1.69	1.70	1.61	1.69	1.65	1.68	1.60	1.63	1.55	1.78
1.74	1.77	1.77	1.71	1.76	1.77	1.73	1.69	1.69	1.77	1.61
1.73	1.76	1.69	1.63	1.68	1.61	1.61	1.48	1.47	1.42	1.35
1.27	1.24	1.24	1.25	1.24	1.29	1.26	1.09	1.10	1.07	1.12
1.54	1.56	1.48	1.46	1.41	1.42	1.42	1.35	1.36	1.32	1.25
1.49	1.47	1.38	1.35	1.31	1.27	1.33	1.25	1.30	1.28	1.22
1.11	1.12	0.99	1.14	1.25	1.18	1.12	1.01	1.14	1.14	1.08
1.57	1.50	1.47	1.45	1.45	1.40	1.41	1.29	1.25	1.15	1.10
1.50	1.60	1.62	1.60	1.58	1.57	1.45	1.34	1.24	1.11	1.04
1.67	1.66	1.70	1.64	1.51	1.48	1.59	1.41	1.44	1.40	1.36
1.75	1.82	1.78	1.76	1.79	1.76	1.74	1.72	1.73	1.62	1.60
1.78	1.79	1.74	1.72	1.69	1.66	1.65	1.63	1.53	1.54	

Table 1. Continued

Height (ft.)								
64	68	72	76	80	84	88	92	96
				mm				
1.11	1.15							
1.27	1.24							
1.01								
1.39	1.34	1.27	1.14	1.12	1.08			
1.26	1.37	1.33	1.27					
1.41	1.38	1.26	1.18	1.13				
1.80	1.80	1.78	1.76	1.73	1.69	1.67	1.54	
1.57	1.53	1.62	1.58	1.52	1.54	1.54	1.47	1.41
1.42	1.41	1.30	1.34	1.28				
0.99	0.85							
1.31	1.34	1.20	1.18	1.18	1.09			
1.25	1.27	1.19	1.16	1.12				
0.98								
1.01	0.92							
1.34	1.04							
1.49	1.18	1.33						

1/ Upland
2/ Bottomland

a/ Kisatchie
b/ Lee forest
c/ Idlewild-Ben Hur

Table 2. Average fiber length for all sample years in intensively sampled trees.

Area	Sub Area	Tree	Year of Deposition																
			Bark	1974	1970	1965	1960	1955	1950	1945	1940	1935	1930	1925	1920	1915	1910	1905	1900
			mm																
1[a]	U[1]	1	1.19	1.55	1.57	1.52	1.53	1.53	1.62	1.51	1.47	1.42							
1	U	2	1.24	1.69	1.67	1.64	1.66	1.63	1.54	1.58	1.58								
1	U	3	1.14	1.51	1.47	1.56	1.63	1.63	1.47	1.78	1.59								
1	B[2]	1	1.25	1.64	1.55	1.68	1.67	1.65	1.56	1.49	1.47	1.48	1.57	1.54					
1	B	2	1.10	1.65	1.64	1.56	1.56	1.53	1.49	1.48	1.47	1.62	1.61	1.66	1.88				
1	B	3	1.21	1.55	1.52	1.65	1.61	1.56	1.56	1.58	1.49	1.49	1.51						
2[b]	U	1	1.35	1.79	1.85	1.88	1.85	1.71	1.70	1.75	1.73	1.80	1.80	1.77	1.86	1.89	1.68		
2	U	2	1.44	1.73	1.80	1.77	1.76	1.76	1.78	1.80	1.70	1.75	1.82	1.77	1.75	1.77	1.76	1.83	
2	U	3	1.27	1.67	1.62	1.66	1.66	1.70	1.80	1.75	1.77	1.76	1.77	1.72					
2	B	1	1.06	1.24	1.27	1.30	1.31	1.35	1.35	1.28	1.43	1.52	1.46	1.48	1.34	1.52	1.52		
2	B	2	1.09	1.51	1.50	1.52	1.51	1.54	1.46	1.58	1.68	1.51							
2	B	3	1.13	1.45	1.41	1.49	1.41	1.44	1.32	1.22	1.51	1.55	1.65	1.46	1.69	1.52	1.59	1.42	1.27
3[c]	U	1	0.96	1.18	1.19	1.16	1.17	1.20	1.21	1.13	1.23	1.17							
3	U	2	1.13	1.51	1.46	1.58	1.60	1.52	1.54	1.52	1.52								
3	U	3	1.02	1.62	1.61	1.64	1.75	1.61	1.68	1.56	1.48								
3	B	1	1.19	1.57	1.63	1.69	1.73	1.64	1.76	1.66	1.66	1.52	1.41						
3	B	2	1.27	1.68	1.67	1.81	1.89	1.90	1.90	1.80	1.76	1.68							
3	B	3	1.28	1.73	1.75	1.79	1.80	1.85	1.90	1.89	1.69								

1/ Upland
2/ Bottomland

a/ Kisatchie
b/ Lee Forest
c/ Idlewild-Ben Hur

regression analyses substantiated the existence of this trend. Exceptions to this trend were the trees from the upland site in Area 2, as denoted in Table 1. These trees had an increase in average fiber length between the 64- and 80-foot levels which was sufficient to cause a discrepancy in the curves used to compare average fiber length in trees from upland and bottomland sites (Figure 9).

The minimum average fiber length value occurred in the uppermost four sample heights of 17 trees, and the maximum average fiber length occurred in the lowest three sample heights in 16 of the 18 trees (Table 1). Discussion of this variation is included with the results of the statistical analyses.

Review of the values in Table 2 failed to reveal any discernable trends in the variation of average fiber length with respect to year of deposition. Correlation and regression analyses supported the lack of consistent trends along this gradient. There are also no discernable trends in the occurrence of maximum or minimum average fiber lengths with respect to year of deposition (Table 2).

Fiber length values in this study are generally shorter than comparable values reported in earlier work on sweetgum. Though the difference is not great (approximately 0.2 to 0.4 mm shorter), it is notable. This discrepancy is possibly due to environmental factors, genotype-growth site interaction, or some other unmeasured factor, such as heritability (Smith 1967).

<u>Relation of fiber length to height</u>-Correlation analyses revealed a negative association between fiber length and height within the tree. Sixteen of the 18 intensively sampled trees produced significant

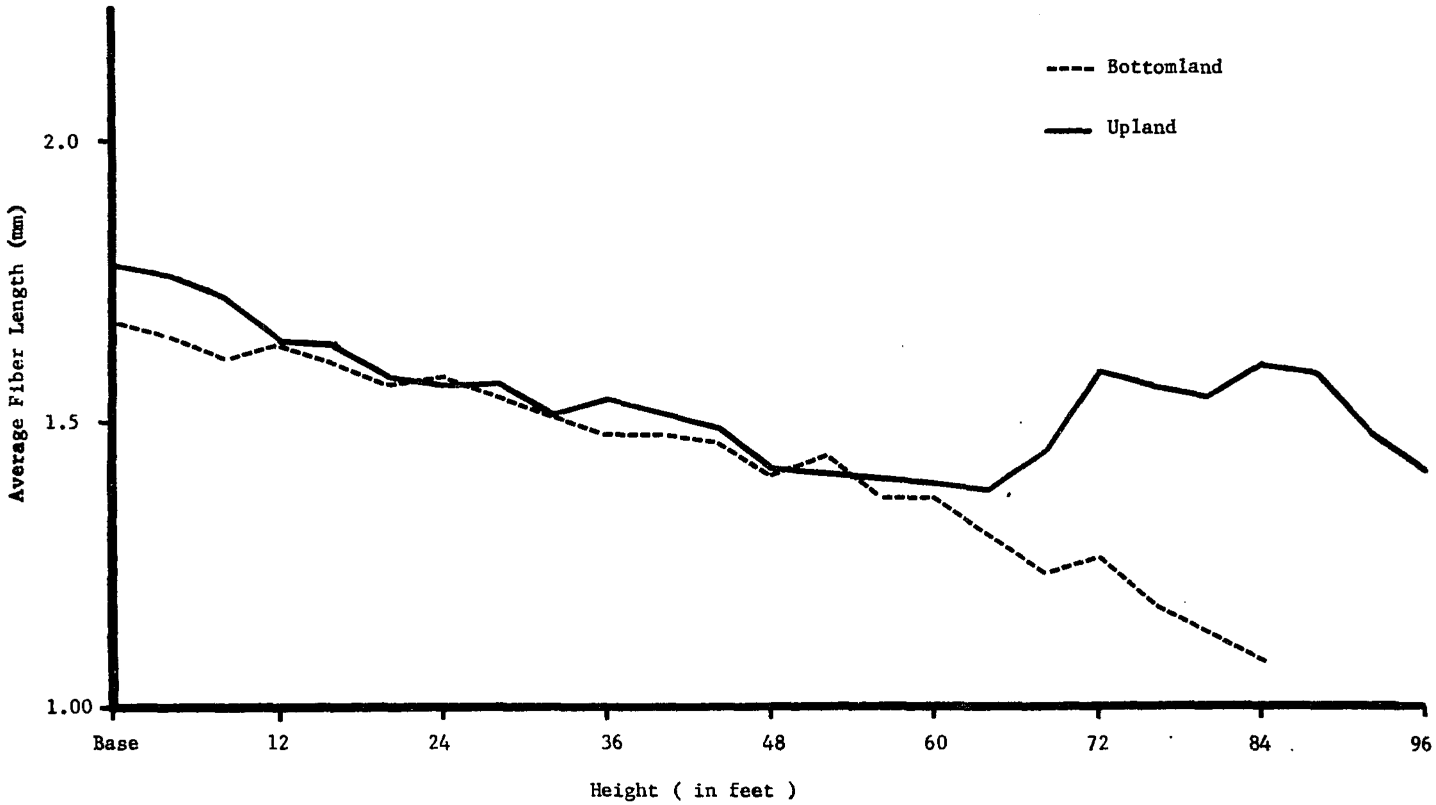


Figure 9. Variation of average sample fiber length with respect to height.

negative correlation coefficients ($p < .01$, Table 3). Both of the exceptions were from upland sites, where one had a negative coefficient ($p < .05$).

The data indicate that trees from bottomland sites have a much higher correlation coefficient (-.725, $p < .01$) than trees from upland sites (-.423, $p < .01$) or an evaluation of all trees (-.560, $p < .01$).

These results do not agree with those of Chow (1971) and Webb (1964). Both of these reports indicated that height was a negligible source of fiber length variation in sweetgum. However, Chow's results were based on the analysis of only one tree, and neither study involved as many vertical sampling points from each tree as this research. In comparison, if tree #1 from the upland site in Area 3 had been the only tree utilized in this study, a correlation between height and fiber length would not have been found. Also, if vertical sampling had been the same as Webb's, it is possible that the correlation coefficients might have been lower in this study. More importantly, evidence now exists which identifies height within the tree as a source of fiber length variation in sweetgum. While results of this study are limited to sweetgum growing in Louisiana, a new dimension has been added to the evaluation of the species.

Results from stepwise regression analyses of the effect of height in fiber length are presented in Table 4. The best model based on R^2 improvement at $p \leq .05$ was selected for each equation. All r^2 values are highly significant in this series, with the highest r^2 values obtained for trees from Area 1.

Results from grouping the data for regression analysis follow the

Table 3. Correlations between fiber length and sample height and between fiber length and year of deposition.

Area	Sub-Area	Tree	Fiber length X Ht.	Fiber length X Year
1[a]	U[1]	1	-.950**	.564
1	U	2	-.959**	.974**
1	U	3	-.982**	.639
1	B[2]	1	-.958**	.896**
1	B	2	-.953**	.365
1	B	3	-.908**	.909**
2[a]	U	1	-.483*	.540
2	U	2	-.940**	.416
2	U	3	-.980**	.497
2	B	1	-.938**	-.156
2	B	2	-.936**	.713*
2	B	3	-.948**	.120
3[c]	U	1	-.462	.743
3	U	2	-.976**	.908**
3	U	3	-.864**	.954**
3	B	1	-.850**	.797*
3	B	2	-.789**	.746
3	B	3	-.806**	.748*

1/ Upland

2/ Bottomland

a/ Kisatchie

b/ Lee Forest

c/ Idlewild - Ben Hur

*denotes significance at .05 level

**denotes significance at .01 level

Table 4. Regression equations for the regression of fiber length on height.

Area	Sub-Area	Equation	Coefficient of Determination (r^2)
1	Upland	$y = 1.76 - .0091\ (Ht.)$	.821**
1	Bottomland	$y = 1.67 - .00008\ (Ht.^2)$	.866**
2	Upland	$y = 1.92 - .0084\ (Ht.) + .00005\ (Ht.^2)$	.526**
2	Bottomland	$y = 1.56 - .0058\ (Ht.)$	.637**
3	Upland	$y = 1.52 - .00012\ (Ht.^2)$	.428**
3	Bottomland	$y = 1.76 - .0000015\ (Ht.^3)$	.696**
All	Upland	$y = 1.76 - .0085\ (Ht.) + .00000001\ (Ht.^4)$	.277**
All	Bottomland	$y = 1.69 - .0043\ (Ht.) - .0000004\ (Ht.^3)$	.534**
All	All	$y = 1.70 - .00543\ (Ht.)$	.313**

** denotes significance of the model at .01 level

same pattern established in correlation analysis in that trees from bottomland sites have a higher r^2 value (.534, $p < .01$) than trees from upland sites ($r^2 = .277$, $p < .01$).

Regression curves were plotted for each study area (Figures 10, 11, and 12). These curves offer high predictive capacities but have strong limitations in that individual sub-area curves are based on the data from only three trees. Even though all r^2 values are highly significant, their significance is limited by the sample base, which is small. Therefore, broad-spectrum application of these curves should be employed with caution.

No previous reports included regression equations for fiber length variation with respect to height in sweetgum. However, an overview of the present regression analyses yields notable inferences. Based on this study, almost one-third of fiber length variation in intensively-sampled sweetgum trees is due to vertical position. By applying these results, future research efforts may identify and quantify a source of variation in sweetgum fiber length which was heretofore discounted as being negligible (Chow 1971) for trees grown in Louisiana.

The discrepancy of the results concerning fiber length variation with respect to height between this study and previous reports is not surprising. Earlier reports (Hunter and Goggans 1969, Johnson and McElwee 1967, and Webb 1964) all reported variation in sweetgum fiber length when samples were taken from different geographic areas. While the nature of variation in those reports dealt primarily with overall tree averages or with variation in radial position, they established the perspective of geographic variation in the species. The results of this

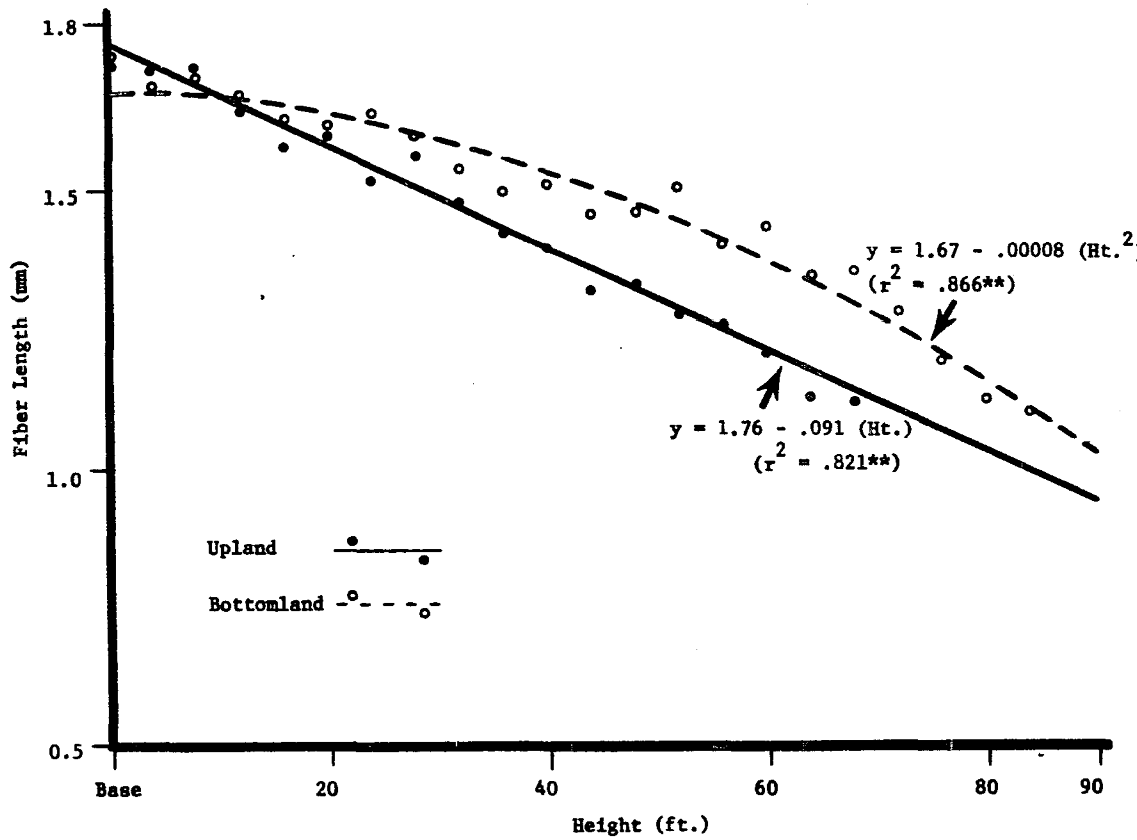


Figure 10. Regression curves for fiber length vs. height in Area 1.

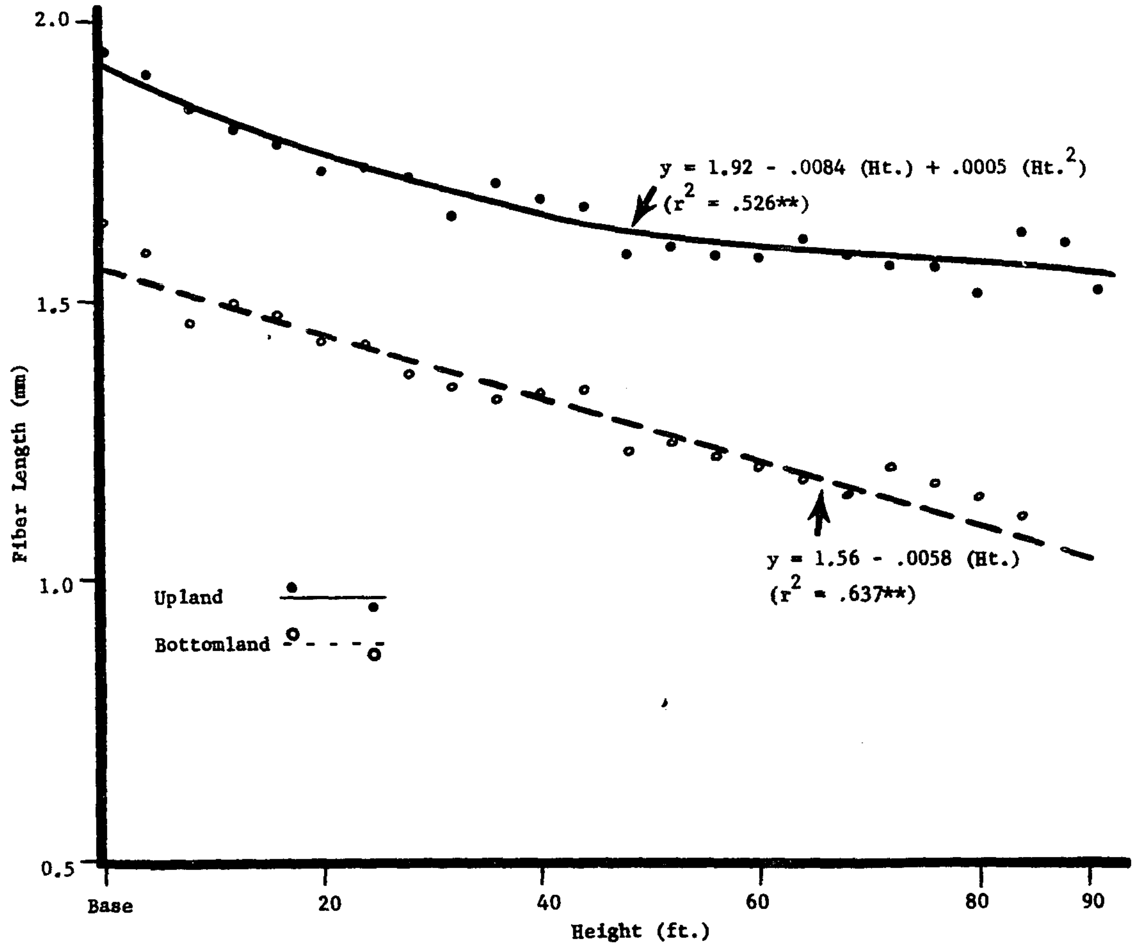


Figure 11. Regression curves for fiber length vs. height in Area 2.

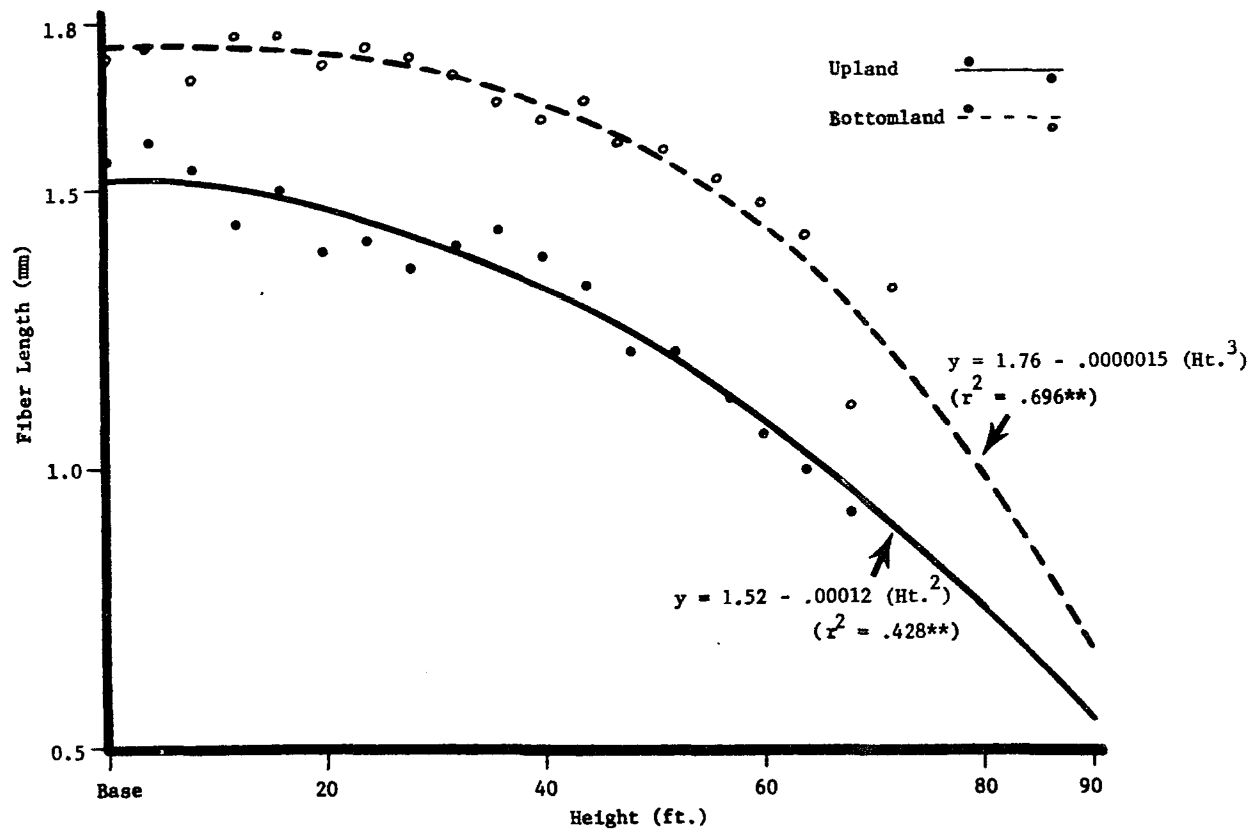


Figure 12. Regression curves for fiber length vs. height in Area 3.

research merely add a new dimension to that established source of variation, as none of the earlier work included extensive sampling in Louisiana.

Whether the discrepancy is due to differences in sampling procedure, sample site, genetic differences (Smith 1967), or some combination of these variables can not be ascertained by this study. The important aspect is not in the consideration of a discrepancy, but in the consideration of an added dimension in evaluating sweetgum.

Relationship of fiber length to year of deposition - Correlation analyses revealed that the effect of year of deposition (hereafter referred to as year) on fiber length was not as conclusive as that of height. Year correlations ranged from strongly positive (.974, $p < .01$) to slightly negative (-.156) for individual trees. Nine of the 18 trees displayed significant correlations ($p < .05$, Table 3). However, grouping the data by area for analysis yielded correlations which were all positive and significant at the .01 level. Again, trees from bottomland sites had a higher correlation coefficient (.491, $p < .01$) than trees from upland sites (.260, $p < .01$) or the correlation of all trees (.369, $p < .01$).

While year of deposition is not reflective of true age, both evaluations deal with variation along radial gradients. The results of this study dealing with year of deposition do not define variation in terms of age or distance from the pith. However, the lack of consistent trends in the data from individual trees and the low correlation coefficients from group analyses indicate the wide variability of fiber length in a radial direction in the sweetgum utilized in this study.

Results from regression analyses for fiber length with respect to year are presented in Table 5. All equations are nonlinear and have R^2 values which are significant at the .01 level. The results again followed a pattern displayed in correlation analysis, with trees from bottomland sites having a higher r^2 value (.395, $p<.01$) than trees from upland sites (r^2=.377, $p<.01$) or the evaluation of all trees (r^2=.345, $p<.01$).

Regression curves of fiber length on year are presented in Figure 13. Year of deposition is used herein to describe the wood formed during a given year, (note that the wood for a given year is not of a constant age or distance from the pith). The value of a prediction equation based on year is of questionable value and should be interpreted with extreme caution (see Figure 13).

The regression curves do serve a purpose in that they indicate the nature of fiber length variation which is attributable to calendar year in this study. These results might be applied to future studies of sweetgum grown in Louisiana if the exact same years were analyzed in subsequent work.

<u>Relationship of fiber length to age</u>-Age from the pith (referred to hereafter as age) was determined for the base section of all intensively-sampled trees, and average fiber length of these samples was analyzed to measure variation with increasing age. Results from this regression analysis are presented in Table 6. The r^2 values for all of the analyses are rather low.

Curves from this series of regression analyses are presented in Figure 14. These curves are of limited value as they account for such a small portion of fiber length variation. Extreme caution should be

Table 5. Regression equations for the variation of fiber length with respect to year of deposition.

Sub-Area	Equation	Coefficient of Determination (R^2)
Upland	$y = 1.21 + .0904\ (yr.) - .0043\ (yr.^2)$	
	$+ .00007\ (yr.^3) - .0000004\ (yr.^4)$	.377**
Bottomland	$y = 1.18 + .0488\ (yr.) - .0021\ (yr.^2)$	
	$+ .00004\ (yr.^3) - .0000002\ (yr.^4)$	.395**
All	$y = 1.19 + .068\ (yr.) - .0031\ (yr.^2)$	
	$+ .00005\ (yr.^3) - .0000003\ (yr.^4)$	.345**

** denotes significance of the model at .01 level

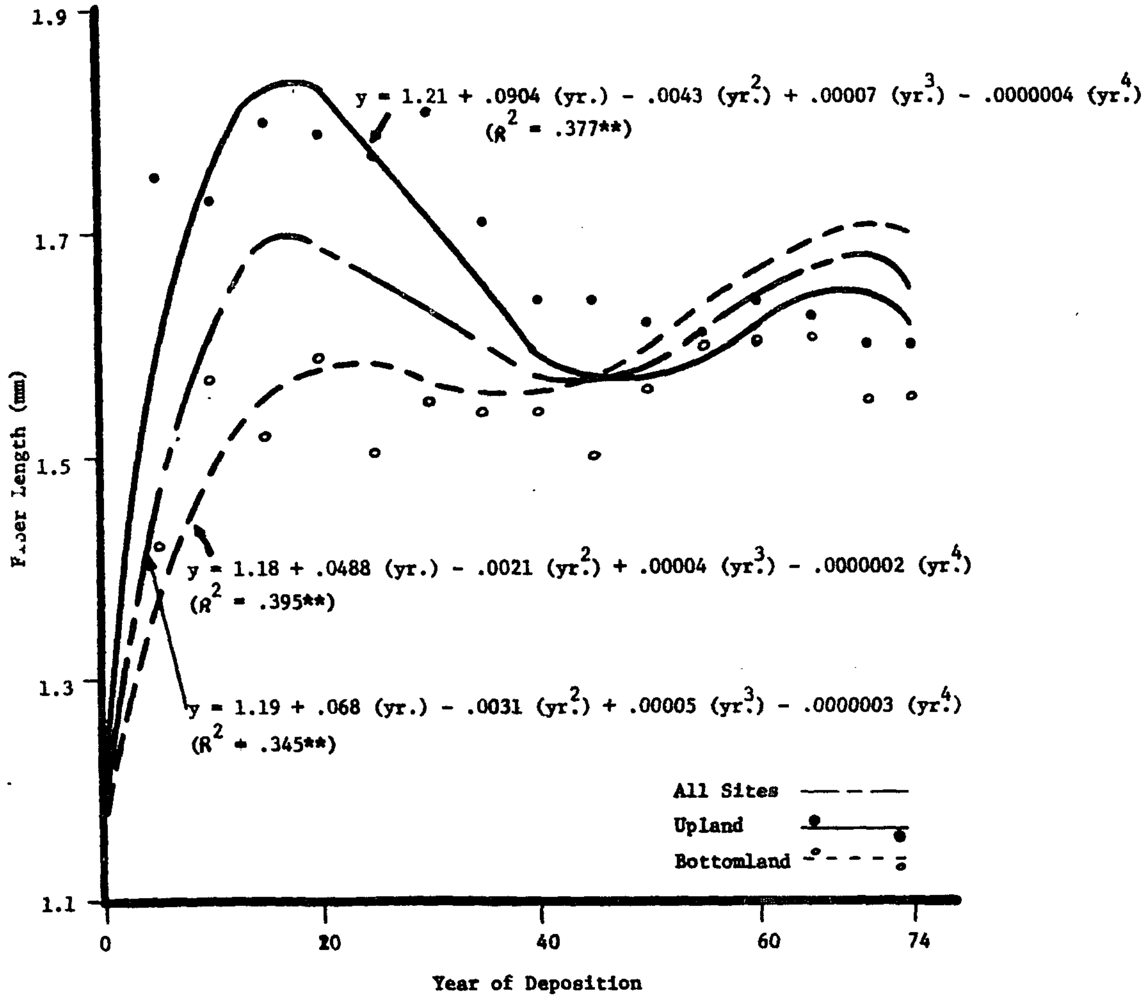


Figure 13. Regression curves for fiber length vs. year of deposition.

Table 6. Regression equations and coefficients of determination for fiber length vs. age.

Sub area	Equation	r^2
Upland	$y = 1.73 + .00554\,(Age)$	.024
Bottomland	$y = 1.57 + .01187(Age) - .00015(Age^2)$	.124**
All	$y = 1.60 + .01379(Age) - .00016(Age^2)$	.033*

*denotes significance at .05 level

**denotes significance at .01 level

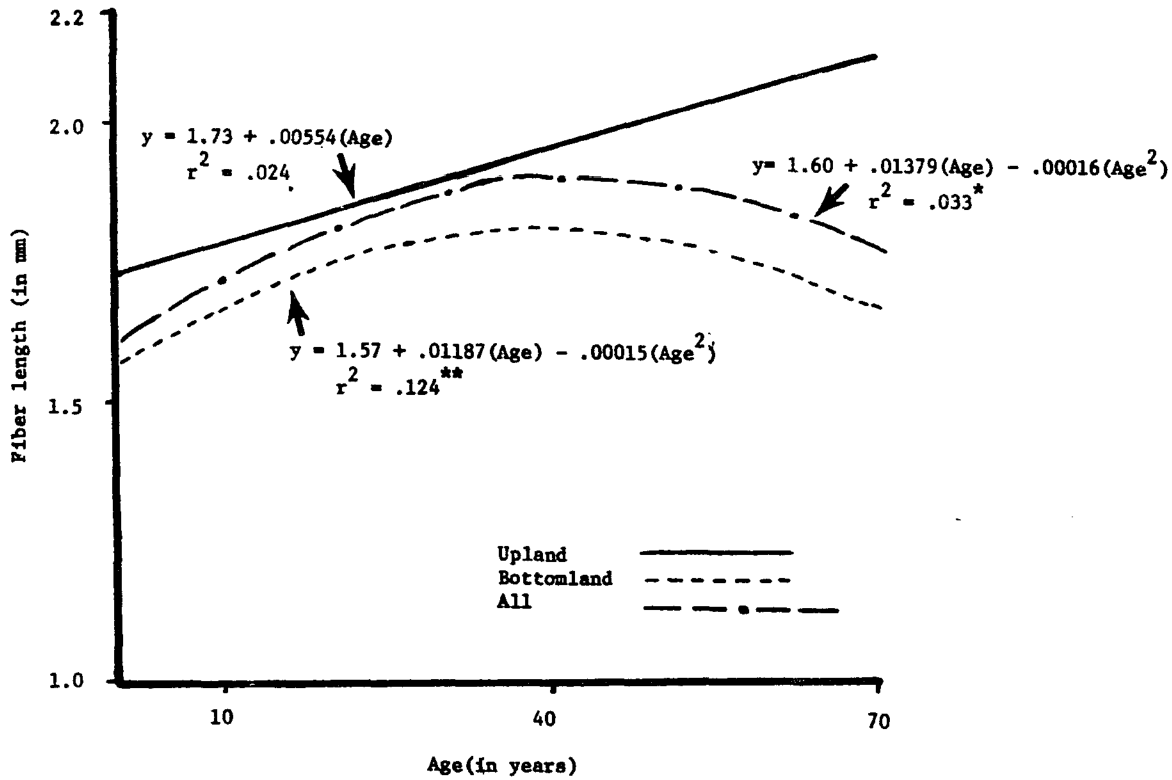


Figure 14. Regression curves for fiber length vs. age.

exercised in any projection of values based on these curves. Previous research on sweetgum has included a comparison of fiber length to age, but none involved regression analysis for this evaluation.

Johnson and McElwee (1967) found age to be a significant source of variation in sweetgum fiber length. Their work involved the fifteenth and thirtieth annual rings and corresponds to this study in that inspection of the curves in Figure 14 indicates an increase in fiber length between the fifteenth and thirtieth year of age. Webb (1964) also noted an initial increase in fiber length with increasing age before a period of stabilization or subsequent decrease. His extensive work was conducted on sweetgum from bottomland sites, and it is noteworthy that the curve for trees from bottomland sites (Figure 14) agrees with his results, while the curve for trees from upland sites indicates a linear increase with increasing age. Differences may be noted in sample location, with Webb's and Johnson and McElwee's work based on samples from 4½ ft. above ground level as compared to the base section in this work. Also, more annual rings were utilized in the present study. These differences may account for the fact that earlier reports found a much stronger relation between age and fiber length (r=.700 or higher) than could be found for groups in this study.

Overall, the data from age analysis in this study restates the results from year of deposition, and both indicate that fiber length is highly variable between sample years. There seems to be little doubt that age does have an effect on fiber length, but growth conditions for any given year may exert an equal amount of control. This study was not

designed to quantify the amount of control exerted by yearly fluctuations of conditions which control growth and cellular production, but the inferences are present.

Comparison of whole-tree averages to single samples-In an attempt to analyze the utility of a single sample height for evaluating whol-tree averages (average of all samples from the tree), the average fiber lengths from all samples from the 4-ft. level were correlated to respective averages for all other sample heights in the tree. Results indicated that whole-tree averages could be predicted effectively from the 4-ft. level samples. All coefficients are positive and highly significant ($p < .01$, Table 7). Webb (1964) found that average fiber length for sweetgum trees could be predicted from breast height measurements, but the correlation coefficients of his work ($r = .356$ to $.791$, $p < .01$) were not as high as those in this study ($r = .832$ to $.960$, $p < .01$). This is possibly due to the fact that no upland sites were included in his extensive work, whereas upland sites were the source of the highest coefficient ($r = .960$, $p < .01$) in this study.

Regression analysis substantiated the correlation analyses (see Table 8). From the curves in Figure 15, whole-tree average fiber length can be predicted from samples taken at the 4-ft. level. Prediction for trees growing on upland sites is more effective ($r^2 = .963$, $p < .01$) than for trees growing on bottomland sites ($r^2 = .723$, $p < .01$) or for an evaluation based on trees from all sites ($r^2 = .817$, $p < .01$).

No previous reports included regression analysis of single sample values to whole-tree average fiber length in sweetgum. Therefore, the

Table 7. Correlation of average fiber length at the 4-ft. level to the average fiber length of all samples from the tree.

	Upland sites	Bottomland sites	All sites
H4[1/] Fiber X Whole Tree	.960**	.832**	.889**

[1/] Average fiber length at 4-ft. level.

** Significant at .01 level

Table 8 . Regression equations for the prediction of whole-tree average fiber length from samples at the 4 - ft. level.

Sub-Area	Equation	Coefficient of Determination (R^2)
Upland	$y = .916 + .1122\ (F^3)$ 1/	.963**
Bottomland	$y = -.249 + 1.059\ (F^4)$	.723**
All	$y = .038 + .8716\ (F)$	.817**

1/ F = average fiber length at 4-ft. level

** denotes significance of the model at the .01 level

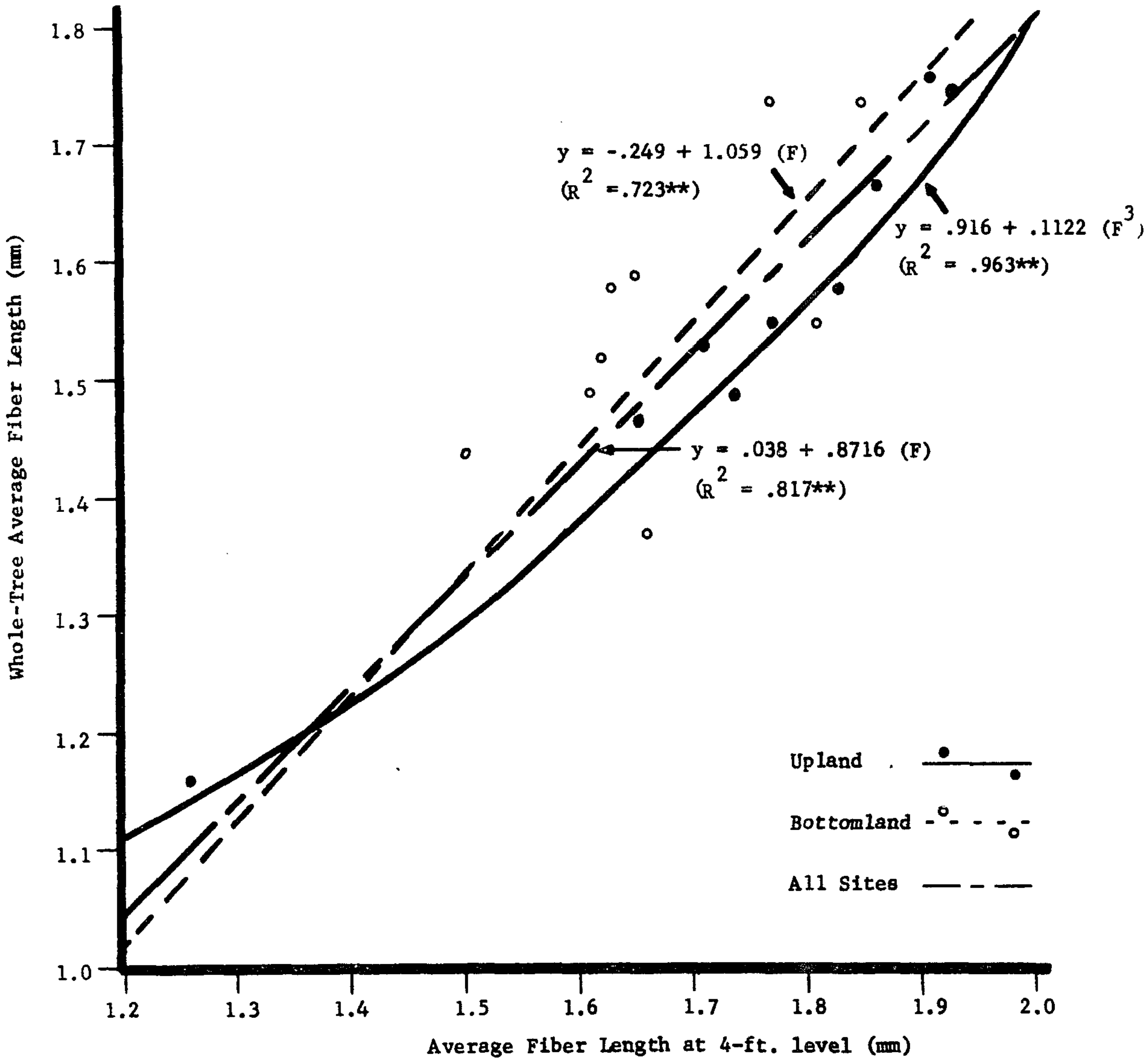


Figure 15. Regression curves for whole-tree averages on average fiber length at 4-ft. level.

results of this analysis are considered to be the strongest evidence to date that whole-tree average fiber length may be predicted effectively from single samples in sweetgum.

Comparison of branch samples to main stem samples - Branches were sampled according to the same format as the main stem, and average fiber length for sample years were compared in all possible years. In the three sample years compared, the comparisons for 1974 and 1970 had correlation coefficients which were significant ($r=.502$, $p<.01$ and $.579$, $p<.01$, respectively) while the comparison for the year 1965 yielded a correlation coefficient of $r=.313$.

If fiber length does increase with increasing age as indicated by the regression analysis, the later sample years would be expected to have fibers which are closer to the length of main stem samples. This is due to the fact that all branches sampled were relatively young in comparison to the main stem, and since all branches were of an age where fiber length should be increasing with increasing age, later sample years should contain fibers in the branches which are nearer the length of those in the stem.

Since whole-tree average fiber length can be predicted from 4-ft. level samples and whole-tree average fiber length is significantly correlated to average fiber length in two of three sample years, regression analyses were completed to test the ability to predict branch fiber length from 4-ft. level samples. The results of these analyses are presented in Table 9.

The only equation to display significance was for the year 1965 ($r^2=.425$, $p<.05$). These results are inconclusive in that they are

Table 9. Regression equations for prediction of branch fiber length from main stem samples at 4-ft. level.

Year of Deposition	Equation	Coefficient of Determination (R^2)
1965	$y = -.196 + .8857\ (A^3)$ 1/ $- .3529\ (A^4)$	.425*
1970	$y = -1.07 + 5.73\ (A^2) - 4.64\ (A^3) + 1.03\ (A^4)$	.085
1974	$y = -2.01 + 3.74\ (A) - 1.05\ (A^2)$	.106
All	$y = .892 + .2202\ (A^3) - .087\ (A^4)$	.041

1/ A = average fiber length of main stem samples

* denotes significance of model at .05 level

inversely related to correlation analysis which detected significance in the comparisons in 1970 and 1974, but not in 1965. However, the results are conclusive in that they indicate the low efficiency with which branch fiber length can be predicted from 4-ft. level samples.

Relationship of bark fiber length to height - In a final analysis of fiber length variation within the tree, fiber length in bark samples was evaluated. Because fibers in the annual growth rings are xylary fibers and those in the bark are phloem fibers, bark fiber lengths were analyzed separately. Individual tree examination was restricted to variation with respect to height as age of the bark could not be ascertained.

Correlation coefficients for individual trees ranged from highly significantly negative (-.906, $p < .01$) to highly significantly positive (.664, $p < .01$). However, 14 of the 18 trees had negative coefficients, one of which was significant and 11 which were highly significant (Table 10). Of the four positive coefficients, only one was significant ($p < .01$).

A better generalization of bark fiber length variation with respect to height may be obtained from analysis of groups of data. All correlations of this type resulted in highly significantly negative coefficients, and trees from bottomland sites had a higher coefficient (-.464, $p < .01$) than trees from upland sites (-.239, $p < .01$) or an evaluation of all trees (-.318, $p < .01$).

Regression analyses revealed that the best equation to explain fiber length variation in the bark with respect to height is $y = 1.28 - .0022$ (Ht.). However, the r^2 value for this equation is .101,

Table 10. Correlation coefficients for the comparison of bark fiber length to sample height.

Area	Sub-Area	Tree	Avg. fiber length X Ht.
1[a]	U[1]	1	-.792**
1	U	2	-.557*
1	U	3	-.889**
1	B[2]	1	-.860**
1	B	2	-.224
1	B	3	-.872**
2[b]	U	1	-.710**
2	U	2	-.884**
2	U	3	.086
2	B	1	-.722**
2	B	2	-.726**
2	B	3	-.877**
3[c]	U	1	.183
3	U	2	-.906**
3	U	3	-.857**
3	B	1	-.383
3	B	2	.259
3	B	3	.644**

[1]Upland
[2]Bottomland

[a]Kisatchie
[b]Lee Forest
[c]Idlewild - Ben Hur

*denotes significance at .05 level

**denotes significance at .01 level

$p < .01$, and even though highly significant, very little of the total variation is explained. Much of the total variation in bark fiber length appears to be a function of individual tree variation (Table 3).

The results of these analyses indicate that much more detailed examination is needed in order to properly identify the variation of fiber length in sweetgum bark. This work represents only the initial effort, as no past research has undertaken the analysis of bark fiber length in sweetgum. With the magnitude of variation in bark fiber length established, later research efforts will hopefully be better able to identify the source of variation in sweetgum.

Variation among trees within a site

Comparison of trees within a stand was accomplished with an evaluation of whole-tree average fiber lengths with their respective standard deviations (Figure 16). This method of comparison was best due to the variation in sample size incurred through use of trees of different heights and ages.

This analysis revealed that there is only one occurrence of significant difference between trees from the same site (Trees 1 and 3 from the upland site in Area 3). Using a significance level of .05, one would expect to find a difference at least 1 time in 20 by chance. Thus, with 18 samples examined, one significant difference is not surprising.

The tree which was significantly lower in upland Area 3 had an unusually low whole-tree average fiber length. Since the identical sampling scheme was applied to all trees, the shorter fibers in this

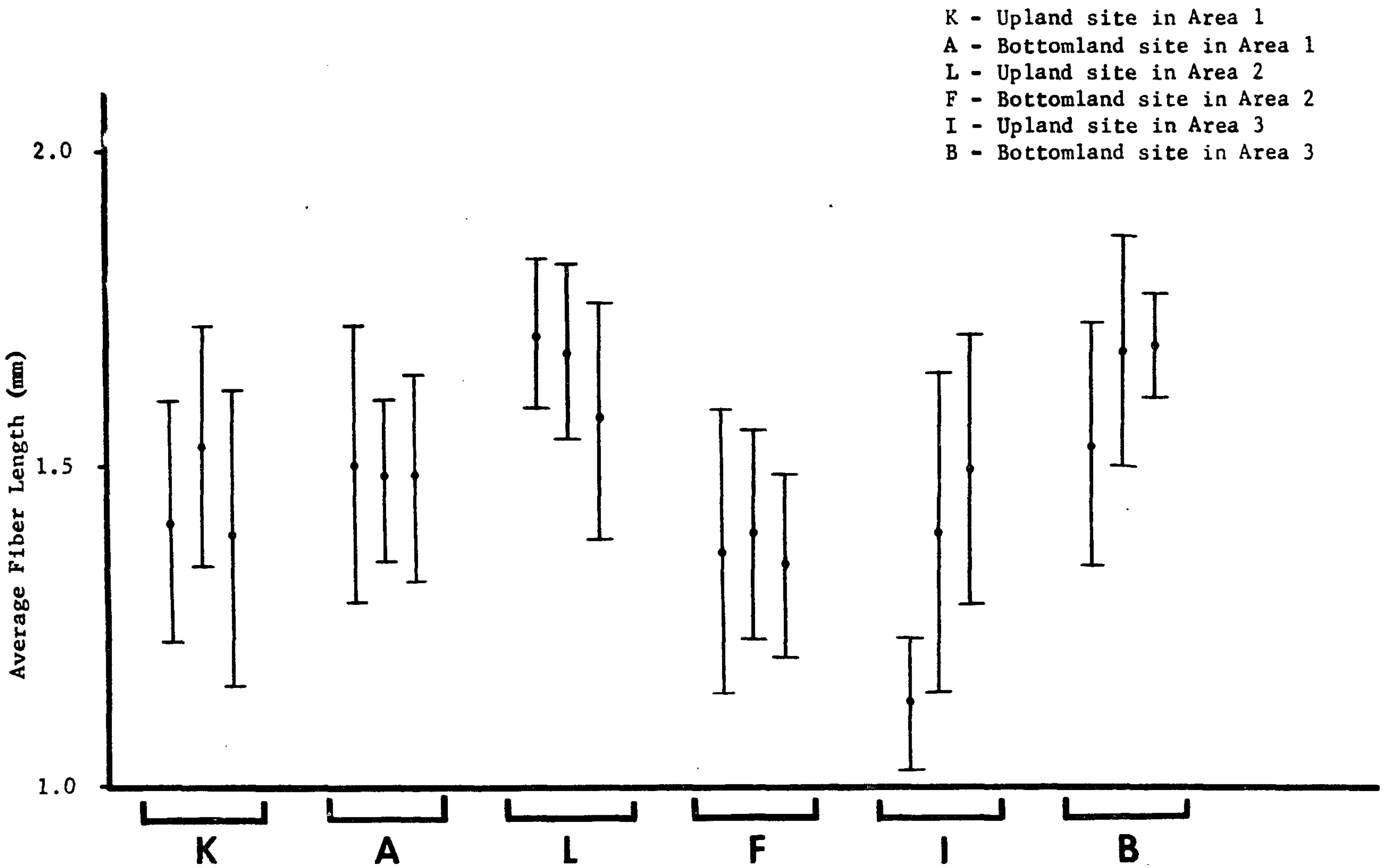


Figure 16. Average tree fiber length with one standard deviation for all trees.

tree appear to be a result of natural biological variation. This natural variation also seems to be a function of the individual tree rather than the site, since the other two trees from that site had means which are comparable to the means of the remainder of the intensively sampled trees. It is therefore possible to theorize that the shorter fibers of Tree 1 from the upland site in Area 3 are a result of a genotype/environment interaction as described by Smith (1967). Conversely, a genotype/environment interaction could result in a tree which has fibers which are significantly longer than other trees in the same stand, but no such case was found in the course of this research.

These results represent a deviation from previous reports, since variation between trees from the same stand has been reported as being a much more important source of variation. Johnson and McElwee (1967) and Webb (1964) both had highly significant differences between trees from the same stand in their studies involving sweetgum. Webb stated that this was the most important source of variation in his fiber length work which was also conducted to achieve 95 percent precision. Again, there arise differences in sampling which could account for discrepancies. First, this study utilized more samples from each tree than earlier efforts. Second, earlier efforts sampled more trees in each stand than this study. Third, earlier efforts sampled stands over a wider geographic area than the present study. Any of these differences or some combination of the three could give rise to discrepancies in results. In addition, it appears that the study area (i.e. Alabama or Georgia vs. Louisiana) could be as important as any differences in sampling scheme. If the latter is true, results of

this study indicate that fiber length in sweetgum varies along longitudinal in addition to latitudinal gradients. To discuss discrepancies along this basis is merely conjecture, but future research efforts should note the possibility of any of these thoughts being true when dealing with sweetgum fiber length.

Variation among sites within an area - Analysis of variance revealed that there are highly significant differences ($p < .01$) in average fiber length between upland and bottomland sites (sub-areas) within areas for every sample year of deposition examined (Table 11). This highly significant variation extended to include sampling heights for all but one sample year (1935). A series of specific comparisons revealed that fiber length was significantly different between sites within an area in only two of the three areas (Table 12). In all sample years, average fiber length was significantly longer in trees from upland sites in Area 2, significantly shorter in trees from upland sites from Area 3, but sites in Area 1 were significantly different in only two sample years. Even when differences were significant in Area 1, the magnitude of the differences was small in comparison to the differences in Areas 2 and 3.

An examination of reasons for differences of this nature reveals only that Area 1 is located further north than Areas 2 or 3, but this does not explain the reversal of values in Areas 2 and 3. While it is not a complete explanation, environmental differences between sites appear to be the explanation for this variation. To determine which differences in site are responsible for this variation is beyond the scope of this study.

Table 11. Analysis of variance of fiber length in intensively sampled trees.

	Bark			1935			1940		
	df	MS	F	df	MS	F	df	MS	F
Area	2	0.1736	1.70	2	0.0971	5.00	2	0.0599	4.76
Error (a)	6	0.1019		5	0.0194		6	0.0126	
Sub-Area	1	0.0298	2.74	1	0.0223		1	0.0405	3.72
A X SA [1]	2	1.5374	141.56**	2	0.2164	10.30**	2	0.4384	36.96**
H (A X SA) [2]	118	0.0243	2.24**	30	0.0298	1.42	41	0.0397	3.35**
Error (b)	220	0.0109		29	0.0210		48	0.0119	

	1945			1950			1955		
	df	MS	F	df	MS	F	df	MS	F
Area	2	0.0330	0.39	2	0.1322	1.13	2	0.0033	0.02
Error (a)	6	0.0845		6	0.1170		6	0.1606	
Sub-Area	1	0.0033	0.29	1	0.0017	0.08	1	0.0559	3.33
A X SA [1]	2	1.3831	119.52**	2	1.9188	88.40**	2	1.6626	99.08**
H (A X SA) [2]	59	0.0646	5.58**	69	0.0665	3.06**	82	0.0718	4.28**
Error (b)	67	0.0116		104	0.0217		138	0.0168	

Table 11. Cont.

	1960			1965			1970			1974		
	df	MS	F	df	MS	F	df	MS	F	df	MS	F
Area	2	0.0932	0.34	2	0.0130	0.04	2	0.0515	0.14	2	0.1150	0.29
Error (a)	6	0.2735		6	0.3549		6	0.3606		6	0.3973	
Sub-Area	1	0.0002	0.01	1	0.0005	0.02	1	0.1169	4.90*	1	0.0758	2.86
A X SA 1/	2	2.2463	100.81**	2	2.4955	111.57**	2	3.0969	129.74**	2	2.5138	94.79**
H (A X SA) 2/	93	0.0896	4.03**	116	0.1178	5.27**	132	0.1368	5.73**	136	0.1117	4.21**
Error (b)	172	0.0223		198	0.0224		247	0.0239		256	0.0265	

1/ Area X Sub-Area

2/ Height (Area X Sub-Area)

* Significant at .05 level

** Significant at .01 level

Table 12. Specific comparison of average fiber length between sites within an area.

Year	Area	Upland	Bottomland	LSD
		----------mm----------		
1935	1	1.42	1.53	.23
	2	1.77	1.53	.10*
	3	1.17	1.56	.24*
1940	1	1.51	1.48	.09
	2	1.72	1.50	.05*
	3	1.39	1.71	.08*
1945	1	1.55	1.51	.03*
	2	1.77	1.29	.02*
	3	1.33	1.76	.03*
1950	1	1.56	1.54	.07
	2	1.76	1.36	.06*
	3	1.42	1.85	.08*
1955	1	1.59	1.57	.05
	2	1.73	1.44	.04*
	3	1.41	1.79	.05*
1960	1	1.60	1.61	.05*
	2	1.76	1.40	.04*
	3	1.49	1.80	.05*
1965	1	1.57	1.63	.05*
	2	1.77	1.44	.05*
	3	1.46	1.76	.05*
1970	1	1.57	1.57	.05
	2	1.76	1.40	.04*
	3	1.42	1.68	.05*
1974	1	1.58	1.62	.05
	2	1.73	1.41	.04*
	3	1.43	1.65	.05*

* denotes significance at .05 level

Variation among similar sites - Analysis of variance among all similar sites (areas) failed to reveal any significant difference in any sample year examined (Table 11). Thus, the inference can be drawn that fiber length variation in this study is geographically isolated. This inference is further supported by the results from the specific comparisons (Table 12). No significant differences could be found in a comparison of all upland sites vs. all bottomland sites due to the fact that fiber length values did not fluctuate much in this respect. However, failure to detect significant differences between areas is due primarily to the nature of the variation displayed in the specific comparisons.

These results differ from Hunter and Goggans (1969), Johnson and McElwee (1967) and Webb (1964), all of whom noted significant differences between geographic areas in their work with sweetgum. The explanation for differences between this study and earlier efforts could lie within the results of earlier work. If sweetgum fiber length does vary between geographic regions, the lack of variation in Louisiana could be one more expression of total variation in the species (i.e. fiber length varies between areas in Alabama and Georgia, but not in Louisiana).

In a final test of differences among similar sites, data from the intensively-sampled trees were compared to increment core values. This analysis allowed evaluation of the effectiveness of the intensive sampling. While some significant and highly significant differences were found betweem sample bases (Table 13), subsequent analyses

Table 13. Analysis of variance of average fiber length between intensively sampled trees and increment cores.

	Year of Deposition											
	1940			1945			1950			1955		
	df	MS	F	df	MS	F	df	MS	F	df	MS	F
Group	1	0.0519	1.08	1	0.0529	1.63	1	0.1637	5.00*	1	0.1650	4.52*
Error	17	0.0483		26	0.0325		49	0.0327		61	0.0365	

	Year of Deposition											
	1960			1965			1970			1974		
	df	MS	F	df	MS	F	df	MS	F	df	MS	F
Group	1	0.2142	5.64*	1	0.1413	3.88	1	0.2687	6.99*	1	0.1664	3.31
Error	66	0.0380		66	0.0364		66	0.0384		66	0.0502	

* Significant at .05 level

revealed that the intensive sampling had accounted for the entire range of fiber length variation to be found in all sample years (Table 14). Therefore, the fiber length results from the intensively-sampled trees are considered to be representative for sweetgum growing in the sample area involved in this study.

In summary, fiber length in the wood and bark of sweetgum follows a general pattern of decrease with increasing height in trees from both upland and bottomland sites. Radial variation, with respect to both year of deposition and age, does not conform to any single consistent pattern, and modes of radial variation differ between upland and bottomland sites. Overall, sweetgum fiber length varies significantly within the tree and between some upland and bottomland sites in the same area. However, fiber length did not vary appreciably between trees in the same stand or between geographic areas used in this study.

Table 14. Range of fiber length and specific gravity values for intensively sampled trees and increment cores.

Year of Deposition	Avg. Fiber Length		Avg. Specific Gravity	
	Group 1*	Group 2**	Group 1	Group 2
	- - - - mm	- - - -		
1974	0.81 - 2.17	0.98 - 2.17	.333 - .652	.411 - .567
1970	0.87 - 2.23	1.22 - 2.05	.315 - .656	.416 - .551
1965	0.89 - 2.33	1.32 - 2.29	.378 - .635	.430 - .580
1960	0.93 - 2.30	1.36 - 2.11	.344 - .608	.434 - .561
1955	0.94 - 2.18	1.38 - 2.11	.325 - .627	.418 - .557
1950	0.86 - 2.27	1.31 - 2.05	.383 - .623	.419 - .620
1945	0.87 - 2.22	1.39 - 1.85	.333 - .597	.446 - .522
1940	0.99 - 2.16	1.38 - 1.66	.349 - .616	.473 - .520

Group 1* Intensively sampled trees

Group 2** Increment cores

Chapter III

Specific Gravity

Introduction and Literature Review

The specific gravity of wood is defined as "the decimal ratio of the ovendry weight of a piece of wood to the weight of the water displaced by the wood at a given moisture content" (Panshin and de Zeeuw 1970). Specific gravity is, in application, much more than that. Forest industries use this property as one of the direct measures of wood quality. One of the primary uses of specific gravity is as an intermediate value in correlating physical properties with growth or dimension measurements.

Specific gravity rivals fiber length as the most studied wood property. Generally, this property has been evaluated more extensively in conifers than in hardwoods. An inequity of this nature is understandable in view of the fact that specific gravity is highly heritable and is a direct indicator of pulp yields (Zobel 1977). Therefore, tree breeding programs seeking to improve pulp production and growth of a species should ascertain the variation of specific gravity.

Specific gravity of selected hardwood species has been receiving increased attention. However, the scope of basic data has not kept abreast of the increased need for a better understanding of wood properties of some species.

Sweetgum specific gravity ranges from 0.428 to 0.607 (Carpenter and Hopkins 1966). The average specific gravity of sweetgum is 0.496

for the "green" moisture content (Panshin and de Zeeuw 1970) and 0.530 for the oven-dry condition (Forest Products Lab 1974) and exhibits different sources of variation.

Two previous studies have evaluated the variation of sweetgum specific gravity in first-year seedlings. Winstead (1972) found that lower specific gravity was correlated with a decrease in latitude of origin. Samples with lowest specific gravity in this study were those from Mexico, while the highest values were recorded for the samples from New Jersey. This relation between specific gravity and latitude of origin was supported by Randel and Winstead (1976) who also reported that decreasing day and night temperatures resulted in increased specific gravity when comparing samples from Central America and the United States under controlled conditions.

The sweetgum research dealing with stems which are past sapling stage is not as conclusive with respect to specific gravity variation. Carpenter and Hopkins (1966) found significant differences in specific gravity due to sample height within the stem and stand location. Hunter and Goggans (1968) reported significant variation between points at the same sampling height, and Webb (1964) noted significant variation between growth rings within a single height. On the other hand, Jett and Zobel (1975) found no change in specific gravity between juvenile and mature wood.

Hunter and Goggans (1968) concluded that specific gravity and growth rate of wood formed during the first 20 years can be expected to vary with degrees of latitude, physiographic provinces, and rainfall

areas, but that wood formed outside the 20th growth ring did not vary greatly with general environmental factors. For all variables, variation in their study caused by differences between trees within plots formed the major portion of the total variation.

Webb (1964) reported specific gravities to be lowest near the pith and increase to a point 10 to 15 rings from the pith before leveling off. In his extensive study of sweetgum, sample height was not an important source of variation, but differences were significant between trees in the same stand and among stands. The major source of variation in Webb's study was between trees in the same stand.

Johnson and McElwee (1967) found significant differences between stands, but did not find significant variation between trees in the same stand.

The lack of agreement concerning most sources of variation in sweetgum specific gravity indicates the need to further measure this property. This experiment was designed to test specific gravity variation over a wide range of sources.

Materials and Methods

Field Sampling - Three separate geographic areas were identified for the collection of field samples. Two sites (one upland and one bottomland) were sampled within each area resulting in a total of six separate sites being utilized in the intensive specific gravity experiment. Field sampling for specific gravity work was identical to that of fiber length research as described in pages 11 through 16 of Chapter II.

Laboratory Sampling - Specific gravity was determined from sample sections taken from the western directional axis of each disc (Figure 6). By utilizing similar sections from uniform locations in each tree, potential error due to alteration of sample location around the stem was removed.

A fresh surface was prepared in the cross-sectional plane of each section with either a razor blade or sharp knife. An ocular count of growth rings was then made for each section with the use of stains and hand lens when necessary.

The growth rings which had been deposited in the years 1974, 1970, 1965, 1960, and subsequent intervals of five years were used for all specific gravity measurements (Figure 7). These growth rings were marked during the ocular count and removed by splitting with a large knife and hammer.

Specific gravity was measured according to the maximum moisture content method as described by Smith (1954). Samples were first dried for 96 hours in a 105^{o}C oven. Periods of time required for both drying and soaking were reduced by the small size of the samples. After drying, each sample was weighed to the nearest 0.1 mg. The oven-dry samples were then placed in a large desiccator and subjected to 28 inches of vacuum pressure. Before releasing the vacuum, the desiccator was filled with water with saturation of the samples being achieved rapidly. To ensure total saturation, the samples were allowed to soak for at least 96 hours with intermittent vacuum pressure. Excess moisture was removed from the sample by blotting as described in Smith's procedure. No final weight measurements were recorded until

fluctuations in sample weight were less than one percent as determined by weighings on successive days.

The ratio of maximum moisture weight: oven-dry weight was then calculated and specific gravity derived directly from the table constructed by Fogg (1967). This table is based on the following equation from Smith (1954):

$$G_f = \frac{1}{\frac{Mm - Mo}{Mo} + \frac{1}{G_{so}}}$$

wherein

Mm = the saturated weight of the wood sample

Mo = the oven-dry weight of the wood sample

G_{so} = the specific gravity of the wood substance

G_f = the specific gravity of the sample (wet volume, oven-dry weight basis)

If the Mm/Mo ratio is not within the realm of the table, the specific gravity can be calculated by the above formula, assuming $G_{so} = 1.53$. This assumption is valid according to the work of Choong and Fogg (1976).

Results and Discussion

Within-tree Variation - Average values for all sample years and sample heights are presented in Tables 15 and 16. There is no apparent trend in the occurrence of maximum or minimum average specific gravity with respect to sample heights. The only discernable trend is that 17 of 18 trees have a decrease in average specific gravity in the 4- to 16-ft. levels from the initial value at the base of the tree (Table 15).

There is no apparent trend in maximum or minimum average specific gravity with respect to year of deposition. Eight of 18 trees do display an increase in average specific gravity in four outermost sample years (Table 16).

Specific gravity in this study is generally in agreement with comparable values reported in earlier work on sweetgum. Deviations from previous reports are of individual sample nature, such as a single growth ring or sample height. When overall averages are considered, no great discrepancy can be detected.

Relationship of specific gravity to height - Correlation analyses of sample height with specific gravity produced varied results. Correlation coefficients ranged from strongly positive (.732, $p < .01$) to negative (-.441, $p > .05$) (Table 17). Five of the 18 intensively-sampled trees had correlation coefficients which were significant. Four trees, all from bottomland sites, had highly significant ($p < .01$) coefficients, and one tree from a bottomland site had a significant

Table 15. Average specific gravity for all sample heights in intensively sampled trees.

Area	Sub Area	Tree	Height (ft.) Base	4	8	12	16	20	24	28	32	36	40
1[a]	U[1]	1	0.511	0.480	0.478	0.481	0.496	0.491	0.535	0.504	0.469	0.483	0.557
1	U	2	0.518	0.478	0.476	0.464	0.474	0.473	0.492	0.497	0.524	0.489	0.480
1	U	3	0.495	0.524	0.492	0.488	0.486	0.502	0.536	0.422	0.476	0.484	0.528
1	B[2]	1	0.497	0.461	0.464	0.460	0.457	0.466	0.458	0.490	0.462	0.456	0.514
1	B	2	0.453	0.438	0.433	0.432	0.477	0.464	0.459	0.457	0.443	0.459	0.483
1	B	3	0.472	0.441	0.431	0.430	0.426	0.425	0.453	0.439	0.447	0.463	0.447
2[b]	U	1	0.515	0.480	0.450	0.451	0.449	0.457	0.470	0.458	0.458	0.491	0.477
2	U	2	0.499	0.458	0.457	0.436	0.414	0.443	0.457	0.449	0.477	0.465	0.465
2	U	3	0.496	0.466	0.454	0.453	0.483	0.456	0.492	0.470	0.570	0.488	0.496
2	B	1	0.482	0.465	0.461	0.440	0.490	0.449	0.467	0.450	0.446	0.448	0.453
2	B	2	0.485	0.474	0.453	0.466	0.448	0.477	0.471	0.477	0.495	0.480	0.484
2	B	3	0.451	0.442	0.433	0.421	0.463	0.460	0.442	0.431	0.435	0.529	0.545
3[c]	U	1	0.467	0.454	0.439	0.488	0.426	0.438	0.464	0.425	0.424	0.580	0.472
3	U	2	0.526	0.490	0.481	0.466	0.494	0.477	0.463	0.462	0.482	0.470	0.469
3	U	3	0.535	0.448	0.478	0.438	0.459	0.477	0.506	0.466	0.457	0.463	0.450
3	B	1	0.402	0.490	0.471	0.450	0.442	0.420	0.408	0.427	0.465	0.468	0.477
3	B	2	0.491	0.455	0.445	0.456	0.446	0.448	0.482	0.443	0.425	0.444	0.421
3	B	3	0.504	0.494	0.495	0.493	0.504	0.482	0.481	0.523	0.491	0.509	0.482

Table 15. continued.

Height (ft.)													
44	48	52	56	60	64	68	72	76	80	84	88	92	96
0.495	0.460	0.515	0.601	0.489	0.487	0.458							
0.602	0.477	0.481	0.485	0.464	0.459	0.466							
0.508	0.496	0.487	0.480	0.487	0.536								
0.467	0.483	0.484	0.483	0.490	0.493	0.547	0.498	0.499	0.501	0.489			
0.440	0.450	0.443	0.475	0.479	0.523	0.510	0.463	0.486					
0.434	0.432	0.435	0.431	0.449	0.424	0.456	0.448	0.392	0.477				
0.479	0.474	0.551	0.517	0.484	0.476	0.509	0.478	0.510	0.493	0.479	0.457	0.536	
0.447	0.503	0.505	0.494	0.480	0.534	0.533	0.495	0.481	0.469	0.459	0.492	0.495	0.534
0.485	0.487	0.483	0.559	0.510	0.504	0.567	0.522	0.510	0.466				
0.456	0.516	0.496	0.488	0.440	0.485	0.426							
0.496	0.524	0.502	0.498	0.512	0.490	0.487	0.492	0.536	0.492	0.531			
0.460	0.500	0.466	0.586	0.457	0.514	0.430	0.497	0.464	0.462				
0.488	0.432	0.482	0.479	0.451	0.464								
0.495	0.478	0.451	0.460	0.470	0.514	0.419							
0.455	0.469	0.462	0.460	0.460									
0.459	0.407	0.469	0.561	0.470	0.490								
0.441	0.492	0.473	0.481	0.466	0.448	0.415	0.524						
0.458	0.517	0.501	0.501										

1/ Upland 2/ Bottomland a/ Kisatchie b/ Lee forest c/ Idlewild-Ben Hur

Table 16. Average specific gravity for all sample years in intensively sampled trees.

Area	Sub Area	Tree	1974	1970	1965	1960	1955	1950	1945	1940
1	U[1/]	1	0.530	0.512	0.492	0.487	0.496	0.491	0.472	0.485
1	U	2	0.510	0.492	0.476	0.474	0.499	0.480	0.519	0.545
1	U	3	0.519	0.510	0.479	0.472	0.478	0.480	0.570	0.522
1	B[2/]	1	0.508	0.487	0.484	0.474	0.477	0.458	0.456	0.451
1	B	2	0.471	0.469	0.462	0.454	0.451	0.444	0.458	0.465
1	B	3	0.448	0.444	0.457	0.450	0.443	0.431	0.404	0.403
2	U	1	0.465	0.479	0.483	0.479	0.464	0.448	0.467	0.486
2	U	2	0.470	0.510	0.485	0.474	0.482	0.483	0.458	0.449
2	U	3	0.521	0.496	0.490	0.480	0.494	0.486	0.457	0.440
2	B	1	0.453	0.463	0.477	0.471	0.473	0.457	0.443	0.453
2	B	2	0.507	0.477	0.479	0.487	0.472	0.456	0.471	0.479
2	B	3	0.438	0.484	0.490	0.481	0.450	0.447	0.461	0.436
3	U	1	0.430	0.408	0.470	0.467	0.487	0.504	0.470	0.491
3	U	2	0.494	0.487	0.480	0.472	0.470	0.476	0.469	0.452
3	U	3	0.472	0.465	0.473	0.484	0.441	0.473	0.499	0.491
3	B	1	0.465	0.480	0.456	0.438	0.452	0.438	0.447	0.421
3	B	2	0.460	0.457	0.469	0.435	0.462	0.456	0.445	0.451
3	B	3	0.553	0.487	0.509	0.481	0.457	0.449	0.491	0.478

Table 16. continued.

Area	Sub Area	Tree	1935	1930	1925	1920	1915	1910	1905	1900
1	U[1/]	1	0.444							
1	U	2								
1	U	3								
1	B[2/]	1	0.451	0.464	0.462					
1	B	2	0.442	0.438	0.445	0.432				
1	B	3	0.412	0.464						
2	U	1	0.493	0.469	0.486	0.482	0.520	0.514		
2	U	2	0.448	0.422	0.437	0.432	0.441	0.454	0.502	
2	U	3	0.467	0.482	0.497					
2	B	1	0.465	0.458	0.461	0.475	0.528	0.554		
2	B	2	0.478							
2	B	3	0.419	0.446	0.416	0.459	0.485	0.462	0.484	0.448
3	U	1	0.499							
3	U	2								
3	U	3								
3	B	1	0.443							
3	B	2	0.461							
3	B	3								

1/ Upland
2/ Bottomland

a/ Kisatchic
b/ Lee forest

c/ Idlewild-Ben Hur

Table 17. Correlation coefficients for the comparison of specific gravity to sample height and year of deposition.

Area	Sub-Area	Tree	Specific Gravity X Ht.	Sp. Grav. X Year
1[a/]	U[1/]	1	.067	.514
1	U	2	-.091	-.511
1	U	3	.040	-.340
1	B[2/]	1	.597**	.819**
1	B	2	.603**	.824**
1	B	3	-.203	.420
2[b/]	U	1	.399	-.555*
2	U	2	.569**	.477
2	U	3	.461*	.498
2	B	1	-.071	-.577*
2	B	2	.732**	.511
2	B	3	.394	.090
3[c/]	U	1	.228	-.732*
3	U	2	-.441	-.918**
3	U	3	-.374	-.467
3	B	1	.503*	.798**
3	B	2	.130	.171
3	B	3	-.011	.628*

[1/] Upland

[2/] Bottomland

[a/] Kisatchie

[b/] Lee Forest

[c/] Idlewild - Ben Hur

*denotes significance at .05 level

**denotes significance at .01 level

($p < .05$) coefficient (Table 17).

However, when the data were grouped for analysis, all analyses resulted in positive coefficients. The correlation for trees from bottomland sites had a higher coefficient (.284, $p < .01$) than for trees from upland sites (.185, $p < .05$) or for the composite correlation of all trees (.227, $p < .01$).

These correlations provide a stronger evaluation of specific gravity variation with increasing height than the work of Carpenter and Hopkins (1966). They reported a significant difference between heights, but their research was based on only three sample heights per tree. Webb (1964), in his more intensive study, did not find height to be an important source of variation in sweetgum specific gravity. The fact that his results were based on data from bottomland sites further contrasts his work to the present study wherein the highest correlation coefficients were for trees grown on bottomland sites.

Results from stepwise regression analyses of the effect of height on specific gravity are presented in Table 18. The best model based on the coefficient of determination (using $p < .05$) was selected for each regression. Area 2 is the only sample area in which r^2 values are significant for both upland (r^2=.405, $p < .01$) and bottomland (.238, $p < .01$) sites.

The curves for predicting specific gravity at various heights in trees in Area 2 are found in Figure 17. Due to the partial or total lack of significance in results from Areas 1 and 3, the curves for Area 2 are the only ones presented. These curves should be used with caution for two reasons: the r^2 values are rather low and each curve is based

Table 18. Regression equations for the variation of specific gravity with respect to height.

Area	Sub-Area	Equation	Coefficient of Determination (R^2)
1	Upland	$y = .503 - .0027\,(Ht.) + .0001\,(Ht.^2) - .000001\,(Ht.^3)$	.088
1	Bottomland	$y = .452 + .0000045\,(Ht.^2)$	.108**
2	Upland	$y = .498 - .0076\,(Ht.) + .0004\,(Ht.^2) - .000006\,(Ht.^3) + .00000003\,(Ht.^4)$	.405**
2	Bottomland	$y = .476 - .0052\,(Ht.) + .0003\,(Ht.^2) - .000005\,(Ht.^3) + .00000003\,(Ht.^4)$	.238**
3	Upland	$y = .493 - .0038\,(Ht.) + .00014\,(Ht.^2) - .0000013\,(Ht.^3)$	.105
3	Bottomland	$y = .464 + .0000007\,(Ht.^3)$	.042
All	Upland	$y = .499 - .0052\,(Ht.) + .00025\,(Ht.^2) - .000004\,(Ht.^3) + .00000002\,(Ht.^4)$	.118**
All	Bottomland	$y = .459 + .0000048\,(Ht.^2)$	.086**
All	All	$y = .485 - .004\,(Ht.) + .0002\,(Ht.^2) - .000003\,(Ht.^3) + .00000002\,(Ht.^4)$	.103**

** denotes significance of the model at .01 level

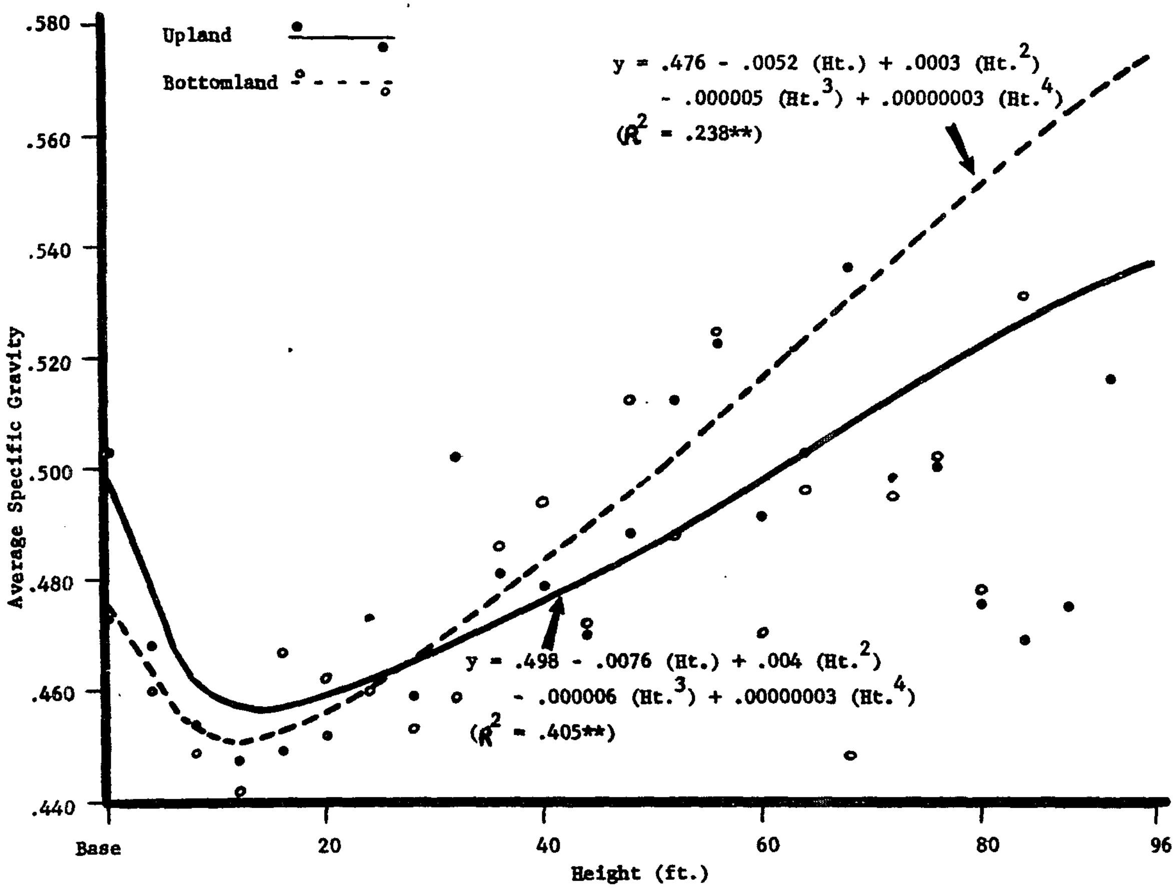


Figure 17. Regression curves for specific gravity vs. height in Area 2.

on the data from only three trees. Scatter diagrams (Figures 18 and 19) are presented for Areas 1 and 3 to show the distribution of specific gravity at all sample heights.

No previous efforts included regression analyses for the effect of height on the specific gravity of sweetgum. However, based on the results of this study, height appears to explain very little of the variation in specific gravity in sweetgum. Very little of the total variation could be explained in group regressions, wherein the highest r^2 value was for trees from upland sites (.118, $p < .01$) as compared to trees from bottomland sites ($r^2 = .086$, $p < .01$) or the regression for all trees (.103, $p < .01$). Consequently, prediction equations are of limited value, especially when considered in conjunction with the fact that sample size (in terms of number of trees) was small.

Overall, results from correlation and regression analyses support the results from inspection of data in Table 15. No trends were ascertained in that evaluation which could explain specific gravity variation at all sample heights, and these two analyses have not yielded results which indicate any trends in the variation of specific gravity with respect to height.

One important consideration which arises from the analysis of grouped data is the fact that all correlation coefficients are positive. If, in fact, specific gravity does increase with increasing height, the butt log of sweetgum trees would contain wood of the lowest average specific gravity in the tree. Utilization evaluations could therefore be biased by any judgments based solely on samples from

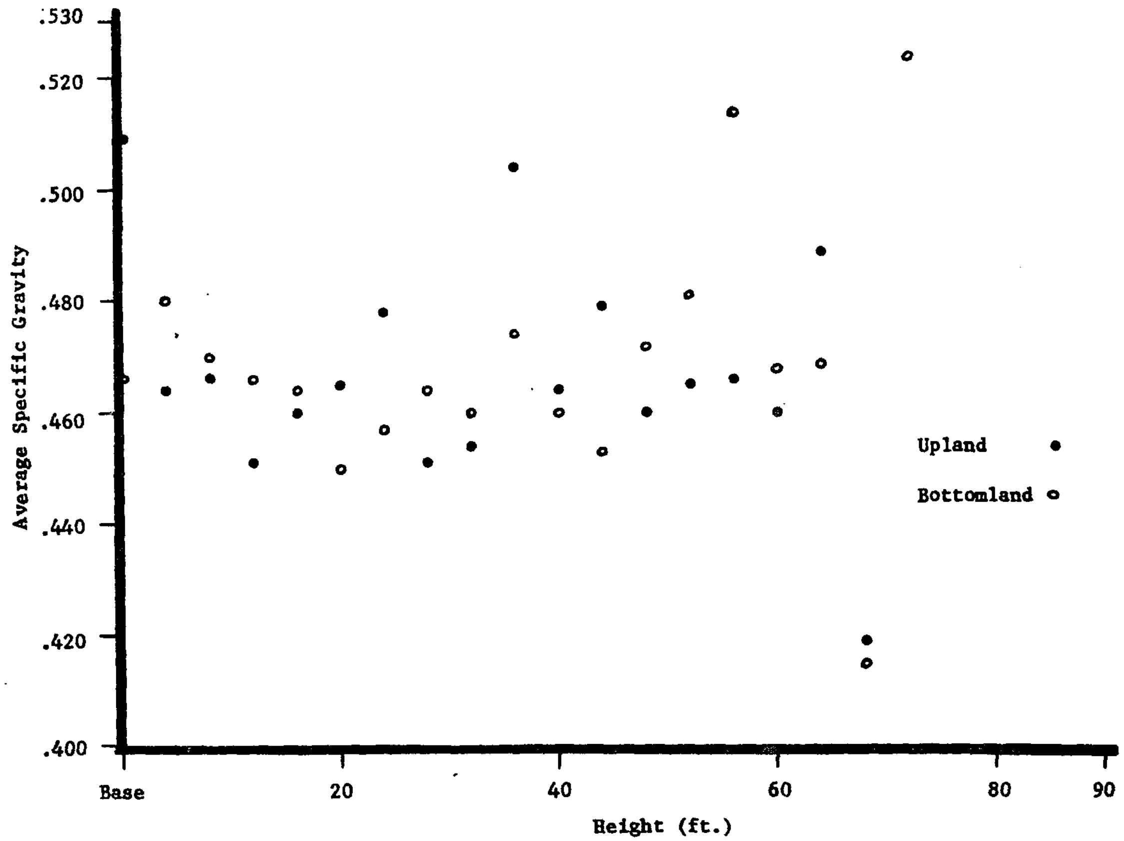


Figure 18. Scatter diagram indicating variation of specific gravity vs. height in Area 1.

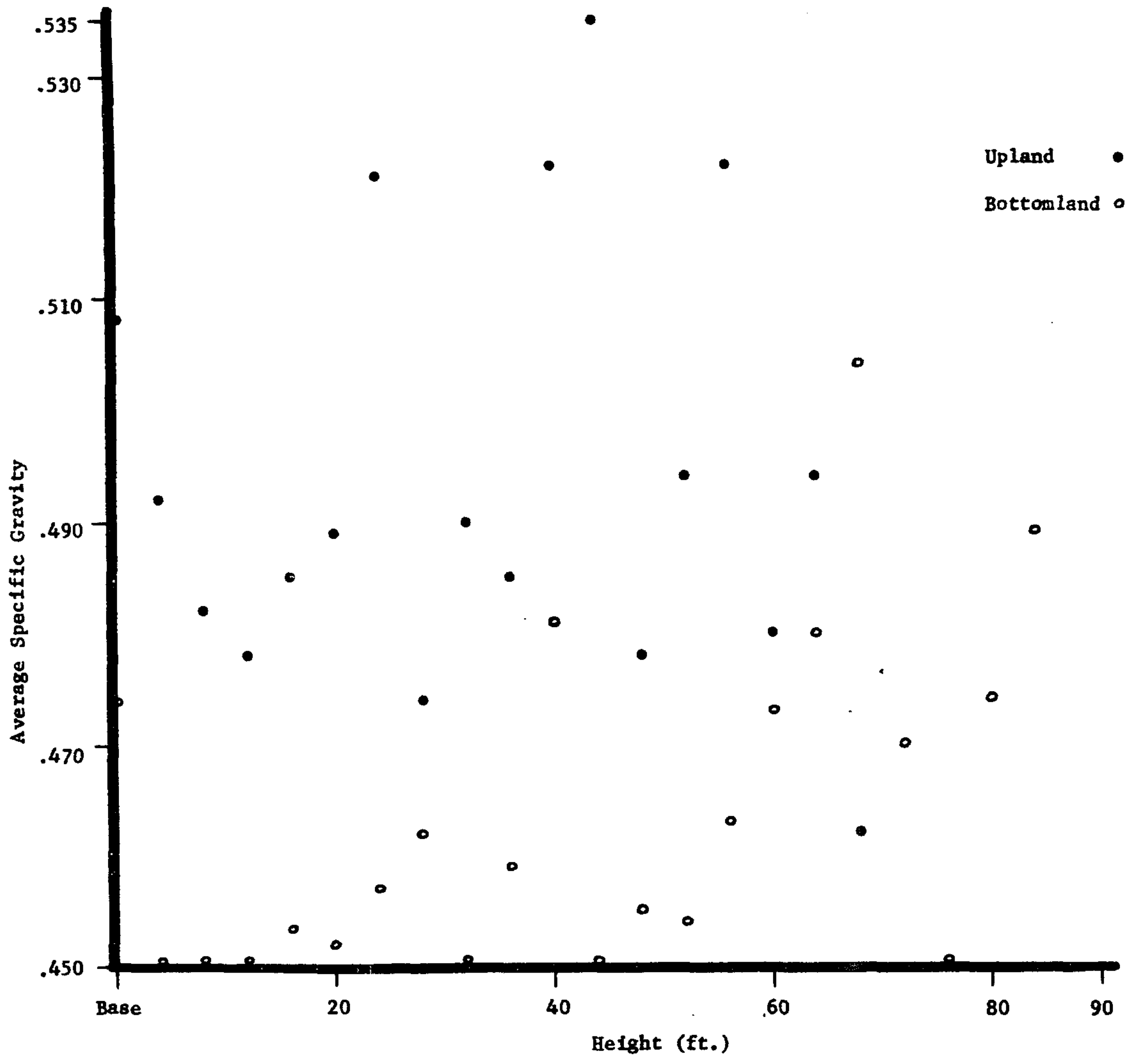


Figure 19. Scatter diagram indicating variation of specific gravity vs. height in Area 3.

butt logs. Since more of the tree can now be utilized due to technological advances, earlier specific gravity values for a species which were based on samples from the lower portion of the stem, such as those in Panshin and de Zeeuw (1970), may need to be adjusted to include samples from the entire stem. Adjustment of this nature is especially important in a property such as specific gravity if it is to be used as a criterion of evaluation.

Relationship of specific gravity to year of deposition - Correlation analyses were used to test the strength of the relationship between specific gravity and year of deposition. Results for these analyses for individual trees are presented in Table 17. Individual correlations are extremely variable, with a range of coefficients from strongly positive (.918, $p < .01$) to strongly negative (-.732, $p < .05$).

Grouping the data for analyses did little to clarify the effect of year on specific gravity. Group correlations were all positive, and though the coefficient for trees from bottomland sites (.161) was again higher than for trees from upland sites (.111), the only significant comparison was for trees from all sites (.145, $p < .05$).

Even though the comparison of year to specific gravity is not completely comparable to an analysis of age or distance from the pith, there are two notable similarities. First, all deal with variation in a radial direction, and second, all compare an increase in the independent variable (i.e. later years, increasing age, or greater distance from the pith) to fluctuations in the dependent variable (in this case, specific gravity). In terms of these two generalities,

restricted comparison to earlier work may be undertaken.

Past research efforts which measured the variation of specific gravity over a radial dimension in sweetgum have yielded variable results. Hunter and Goggans (1968) found both consistent and inconsistent patterns of variation, depending on geographic location of sample sites. Jett and Zobel (1975) found no effect of radial position when testing sweetgum juvenile and mature wood. Webb (1964) reported a very consistent effect of radial position in his extensive work with sweetgum.

Specific gravity fluctuation over a radial dimension in sweetgum therefore appears to be extremely variable, regardless of what radial parameter is used to explain the fluctuation. Based on the results of the analyses in this study, any general statement concerning the effect of year on specific gravity is unadvisable due to low correlations for groups and extreme variation in correlations from individual trees.

Results from stepwise regression analyses of the effect of year on specific gravity are presented in Table 19. All equations are curvilinear and two are significant at the .01 level. These results are consistent with the correlation analyses in that the r^2 value for trees from bottomland sites (.208, $p < .01$) is higher than for trees from upland sites (.019) or for the evaluation of trees from all sites (.087, $p < .01$). Obviously, a small amount of the total variation in specific gravity can be explained by these regression models.

When considered in conjunction with results from correlation analyses, the overall inference from these regression analyses is that

Table 19. Regression equations for the variation of specific gravity with respect to year of deposition.

Sub-Area	Equation	Coefficient of Determination (R^2)
Upland	$y = .476 + .00000001\ (yr.^4)$	.019
Bottomland	$y = .499 - .0024\ (yr.) + .00003\ (yr.^2)$	.208**
All	$y = .491 - .0015\ (yr.) + .000019\ (yr.^2)$	.087**

** denotes significance of the model at .01 level

specific gravity is not strongly related to year of deposition. If the consideration that later years of deposition were of both increased age and greater distance from the pith is acknowledged, the inference may then be drawn that specific gravity in this study is primarily a reflection of environmental fluctuations for any given year. While this inference is conjecture, it seems plausible to assume that annual fluctuations in available soil moisture or other growth-controlling variables could result in specific gravity variation which could not be explained by a regression of specific gravity on year of deposition.

No previous reports have included a regression analyses of specific gravity on year in sweetgum. Thus, no comparison can be made, and for reasons delineated in Chapter II, year is questionable for predictive purposes. Therefore, no regression curves for these analyses are included.

Relationship of specific gravity to age - Regression analyses of the effect of age on specific gravity involved base section samples only, since the only age data were for these sections. Results from these analyses are presented in Table 20. All r^2 values are low, and trees from the upland sites have a coefficient of determination (r^2=.196, $p < .01$) which is higher than that for trees from bottomland sites (r^2=.015) or for the evaluation of trees from all sites (r^2=.042, $p < .01$).

Curves for these regression equations may be found in Figure 20. These curves are considered to be of little predictive utility since they explain so little of the total variation in specific gravity.

Table 20. Regression equations and coefficients of determination for specific gravity vs. age.

Sub area	Equation	r^2
Upland	$y = .545 - .00023(Age^2) + .0000076(Age^3) - .0000006(Age^4)$	$.196^{**}$
Bottomland	$y = .472 - .00000001(Age^4)$	.015
All	$y = .502 - .00054(Age)$	$.042^{**}$

** denotes significance at .01 level

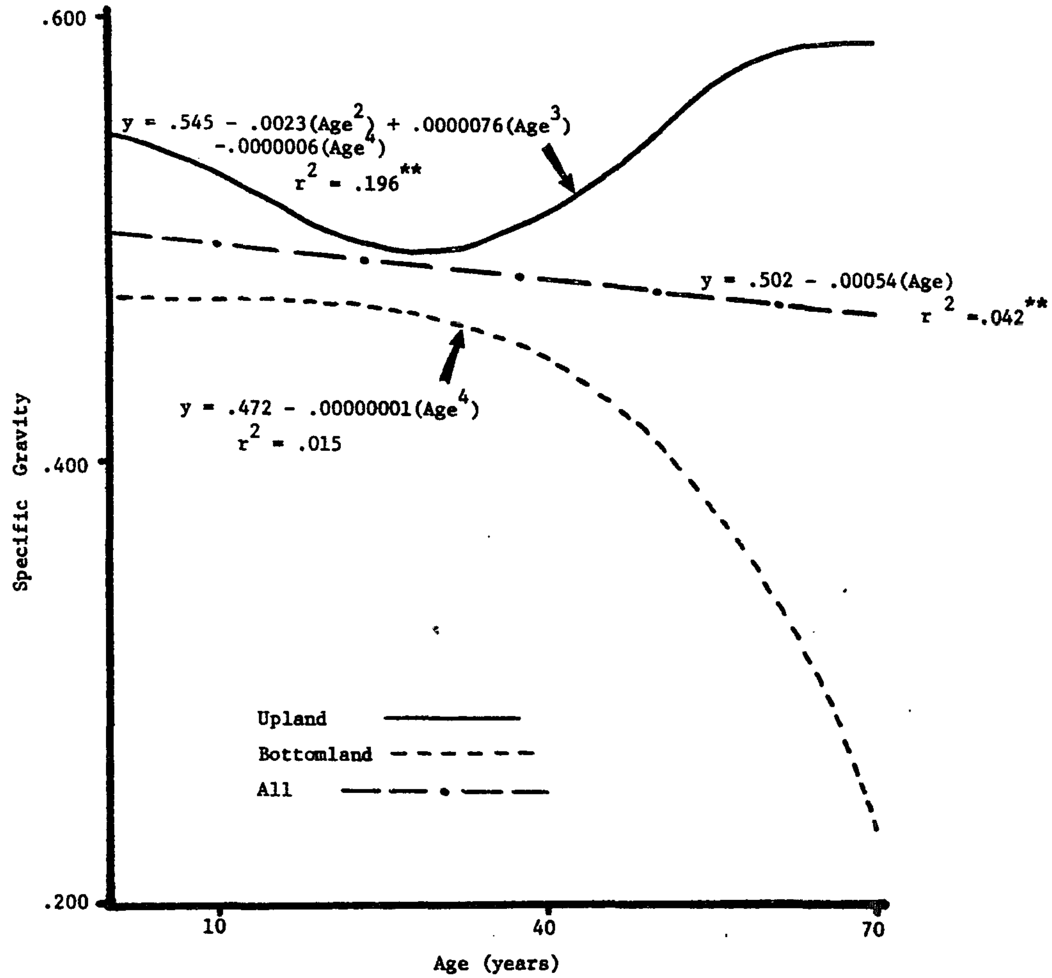


Figure 20. Regression curves for specific gravity vs. age.

Therefore, any broad-spectrum application of the curves should be done with extreme caution.

Overall, the results of these analyses substantiate inferences from analyses of variation with year of deposition. Neither age nor year of deposition explain a large amount of the total variation in specific gravity. In whatever restricted capacity, these findings lend support to the theory that specific gravity in this study is probably under strong external influence, either in conjunction with or exclusive of internal influence.

Two earlier reports (Hunter and Goggans 1968, and Webb 1964) analyzed the variation of specific gravity in sweetgum with respect to age. Both reported significant correlation coefficients for this comparison, but the coefficients in Webb's study (r=.21 and higher) were higher than those of Hunter and Goggans (r=.11 to .15). These results do not represent strong deviations from the results of this study. Both earlier reports concluded that specific gravity did vary with age, but that the variation was a function of individual trees. Results of this nature prohibit any generalizations concerning the effect of age on specific gravity for a broad-spectrum application to the species.

Comparison of whole-tree averages to single samples - Webb (1964) reported that whole-tree average specific gravity of sweetgum could be accurately predicted from breast height sampling. In an attempt to test the utility of single values for relating whole-tree averages in this study, correlation analyses for the relationship between averages of 4-ft. levels and whole-tree averages were completed. Coefficients

for these correlations ranged from r=.437 for trees from upland sites to r=.569, $p < .05$ for trees from all sites, with a coefficient for trees from bottomland sites of r=.553. While these results indicate that whole-tree averages may be related to the 4-ft. level sample, the coefficients are much lower than those of Webb (1964) which ranged from .554, $p < .05$ to .861, $p < .01$, with all but two coefficients being higher than .700.

Results from regression analyses substantiated the correlation analyses (see Table 21). The only significant equation is for the model for trees from all sites (r^2=.378, $p < .01$). Based on these equations and resulting curves, the prediction of whole-tree average specific gravity from a 4-ft. level sample is more precise for trees from bottomland sites (r^2=.365) than for trees from upland sites (r^2=.247), but neither is as precise as the evaluation of trees from all sites.

Curves for the equations in Table 21 may be found in Figure 21. These curves represent initial efforts for predicting whole-tree average specific gravity from 4-ft. level samples in sweetgum, because no previous study of the species has undertaken a similar analysis. Wide scale application of the curves should be employed with caution since r^2 values are moderately low and the curves are based on data from a small number of trees.

The lack of strong predictive ability from a single value supports the earlier conjecture that specific gravity values for a species may be erroneous if based on a single sample source (e.g. from the lower section of the tree).

Table 21. Regression equations for the prediction of whole-tree average specific gravity from samples at the 4-ft. level.

Sub-Area	Equation	Coefficient of Determination (R^2)
Upland	$y = .340 + .2978\ (G)$ 1/	.247
Bottomland	$y = .405 + 1.324\ (G^4)$	.365
All	$y = .245 + .4874\ (G)$	.378**

1/ G = average specific gravity of 4-ft. level samples

** denotes significance at the .01 level

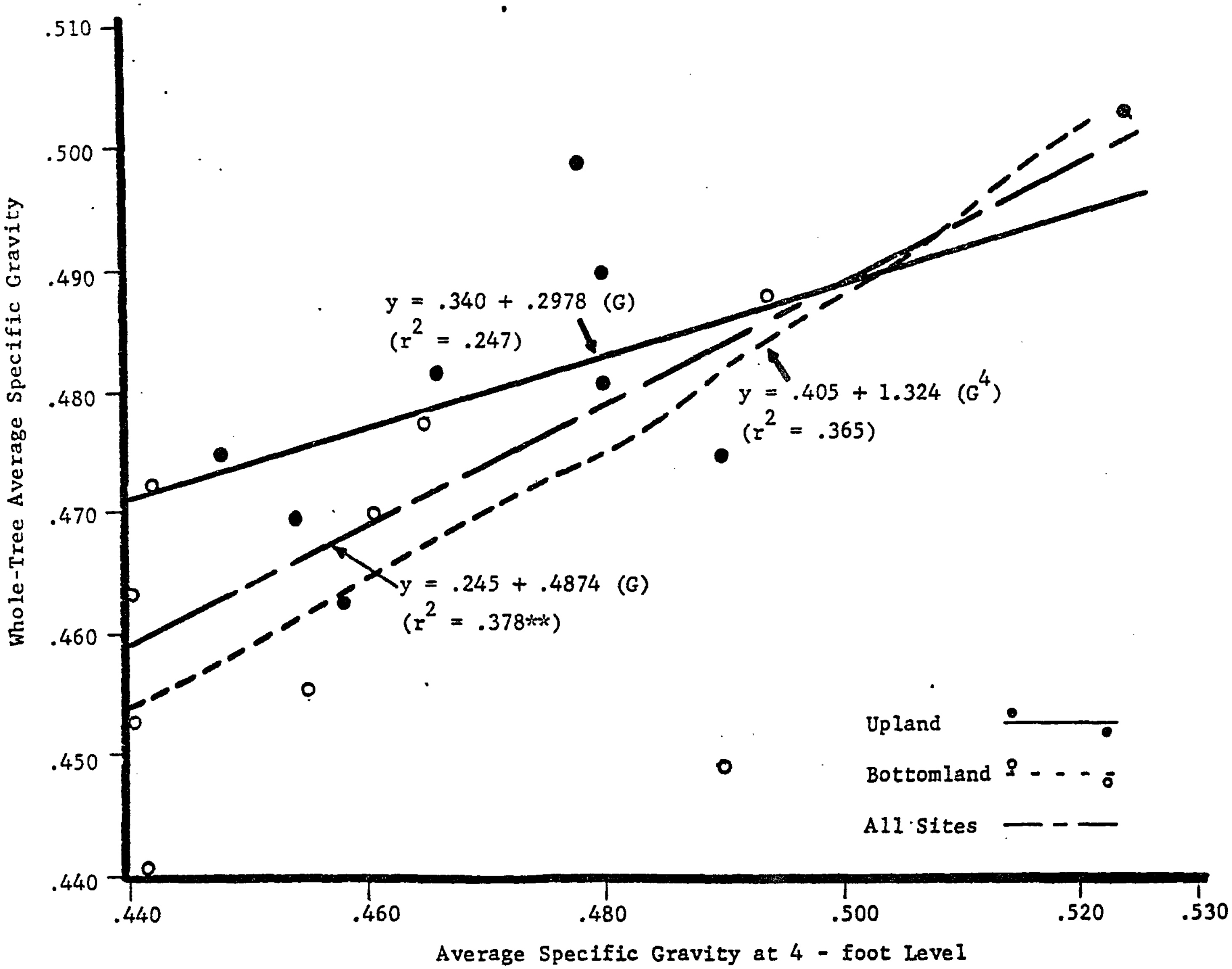


Figure 21. Regression curves for specific gravity at 4-ft. level vs. whole-tree average.

Comparison of branch samples to main stem samples - Specific gravity of branch samples was compared to specific gravity of main stem samples for three sample years. Of the three sample years used in comparison, none had coefficients which were significant. The coefficients did increase from r=.263 in 1965 to r=.408 in 1970 with samples from the year 1974 having the highest correlation coefficient (r=.423).

Regression analyses were not attempted for the specific gravity of branches since there was no significance in any comparison to main stem samples.

Variation among trees within a site

For an evaluation of variation between trees within a stand, whole-tree averages with respective standard deviations were compared in a manner similar to fiber length work. Only one of the 18 trees displayed significant variation. The significantly different variation was in a comparison of trees #3 and 1 from the bottomland site in Area 1 (Figure 22).

Variation between trees in the same stand has generally been accepted as a major component of total variation. Webb (1964) and Hunter and Goggans (1968) both reported that variation between trees in the stand accounted for most of the variation of specific gravity in their respective studies on sweetgum. Johnson and McElwee (1967) reported "surprise" in their inability to detect significant variation of specific gravity in sweetgum between trees in the same stand.

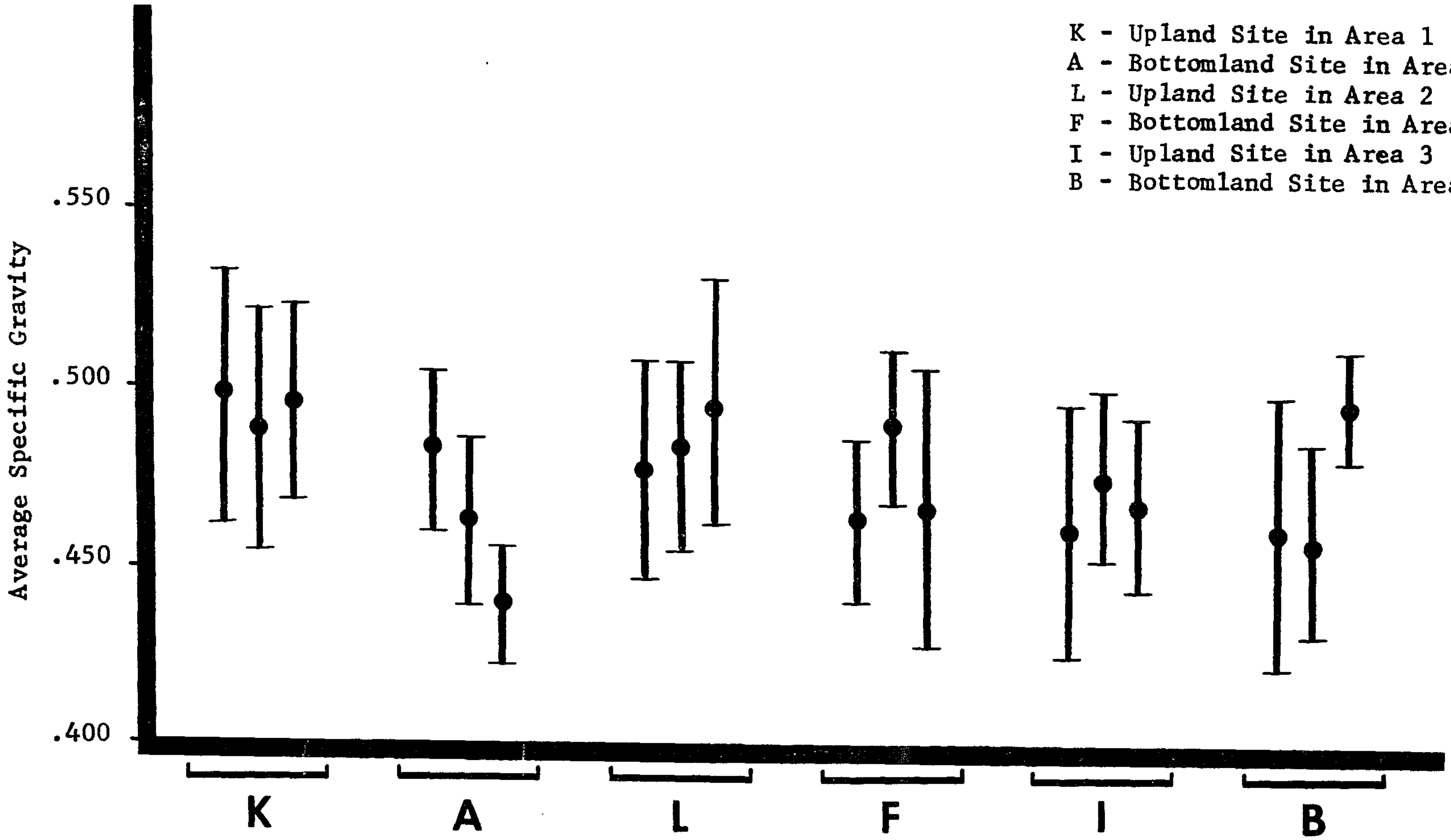


Figure 22. Average tree specific gravity with standard deviations for all sites.

Results of this study again indicate a lack of significant variation between trees in the same stand. However, previous reports of significant variation have applied to sweetgum from bottomland sites, and examination of Figure 22 indicates that trees from bottomland sites were more variable than those from upland sites. A larger sample size from bottomland sites might have revealed more significant variation between trees within a stand, since the only point of significance was in a bottomland stand.

If specific gravity is more variable in trees from bottomland sites, conjecture concerning the cause may not answer the question but could give indications. The first assumption to be made is that specific gravity is a function of the relative proportions of cellular elements. The second assumption is that the relative proportion of cellular elements is controlled by internal mechanisms and external environmental fluctuations. If internal mechanisms are the causative agent, genetic variability as described by Zobel (1977) is probably responsible. However, if external fluctuations are the causative agent, the problem is more complex. It is possible that trees on upland sites utilized in this study are subjected to a more rigid set of environmental factors than trees on bottomland sites. For example, available soil moisture throughout the growing season would probably display a notable discrepancy if compared between upland and bottomland sites in this study, with bottomland sites periodically having more available soil moisture. If this is true, the relative proportions of cellular elements, especially in terms of earlywood and latewood, would be expected to vary more in the bottomland sites,

thus the resultant specific gravity would be more variable depending on the individual tree's ability to utilize available supplies.

Variation among sites within an area

The analyses of variance revealed that specific gravity was significantly different between sub-areas (sites) in two sample years (Table 22). The area X sub-area interaction was significant in only 2 years. Variation of specific gravity was also significant between sample heights from different sites within an area in three sample years (Table 22).

Variation among similar sites

Results from the analyses of variance revealed that specific gravity is significantly or highly significantly different among sub-areas (sites) of the same classification in six of the main sample years examined (Table 22). In all analysis of variance of specific gravity, earlier sample years were not analyzed due to limited sample size.

Grouping the data into a comparison of areas failed to detect any significant differences (Table 22). By combining these analyses, the summation may be drawn that specific gravity varies between upland sites and between bottomland sites, and the variation is not generally isolated into geographic areas as it was in fiber length.

In general terms, this work agrees with previous efforts by Hunter and Goggans (1968), Johnson and McElwee (1967), and Webb (1964). However, all those reports noted differences between geographic areas. The reason for this discrepancy seems to be attributed to the fact

Table 22. Analysis of variance of specific gravity in intensively sampled trees.

	Year of Deposition								
	1935			1940			1945		
	df	MS	F	df	MS	F	df	MS	F
Area	2	.0030	0.81	2	.0001	0.24	2	.0015	0.47
Error (a)	5	.0037		6	.0046		6	.0032	
Sub-Area	1	.0022	1.97	1	.0155	10.68**	1	.0050	5.01*
A X SA [1]	2	.0019	1.67	2	.0011	0.78	2	.0006	0.60
H (A X SA) [2]	30	.0013	1.14	41	.0025	1.69*	59	.0021	2.10**
Error (b)	29	.0011		48	.0015		67	.0010	

	Year of Deposition								
	1950			1955			1960		
	df	MS	F	df	MS	F	df	MS	F
Area	2	.0002	0.11	2	.0017	1.21	2	.0094	2.41
Error (a)	6	.0019		6	.0014		6	.0039	
Sub-Area	1	.0355	30.23**	1	.0216	12.73**	1	.0118	7.22**
A X SA [1]	2	.0015	1.26	2	.0036	2.10	2	.0015	0.89
H (A X SA) [2]	69	.0017	1.41	82	.0019	1.14	93	.0015	0.92
Error (b)	104	.0012		138	.0017		172	.0016	

Table 22. Cont.

	Year of Deposition								
	1965			1970			1974		
	df	MS	F	df	MS	F	df	MS	F
Area	2	.0029	0.66	2	.0133	1.36	2	.0199	0.80
Error (a)	6	.0044		6	.0098		6	.0250	
Sub-Area	1	.0010	0.76	1	.0109	6.20*	1	.0070	3.23
A X SA 1/	2	.0017	1.20	2	.0279	15.54**	2	.0250	11.53**
H (A X SA) 2/	116	.0016	1.21	132	.0015	0.87	136	.0028	1.28*
Error (b)	198	.0014		247	.0018		256	.0022	

1/ Area X Sub-Area

2/ Height (Area X Sub-Area)

* Significant at .05 level

** Significant at .01 level

that those studies involved trees from bottomland sites only. If only bottomland or only upland sites had been utilized in this study, differences between areas would have been significant as evidenced by the evaluation of variation in sub-areas.

In a final examination of variation among similar sites, specific gravity values from the intensively sampled trees were compared to the values from increment cores. This analysis also tested the effectiveness of the intensive sampling, since the increment cores were taken from an expanded geographical region. Results of this comparison revealed significant differences (Table 23). However, further examination indicated that the entire range of specific gravity variation was represented in the intensively sampled trees (Table 14). Therefore, specific gravity results from the intensive sampling scheme are considered to be representative for sweetgum growing in the sample area involved in this study.

In summary, specific gravity is a highly variable property of sweetgum wood. It fluctuates with height and year, but the patterns are not consistent. Overall, specific gravity varies within the tree and among sites of the same classification, but not extensively between trees in the same stand or between the geographic areas used in this study.

Table 23. Analysis of variance of average specific gravity between intensively sampled trees and increment cores.

	Year of Deposition											
	1940			1945			1950			1955		
	df	MS	F	df	MS	F	df	MS	F	df	MS	F
Group	1	0.0042	3.86	1	0.0037	6.36*	1	0.0020	1.01	1	0.0060	4.29*
Error	17	0.0011		26	0.0006		49	0.0020		61	0.0014	

	Year of Deposition											
	1960			1965			1970			1974		
	df	MS	F	df	MS	F	df	MS	F	df	MS	F
Group	1	0.0015	1.50	1	0.0071	6.68*	1	0.0078	8.10**	1	0.0109	7.35**
Error	66	0.0010		66	0.0011		66	0.0010		66	0.0015	

* Significant at .05 level

** Significant at .01 level

Chapter IV

Cell Type

and Fiber Wall Thickness

Introduction and Literature Review

While fiber length and specific gravity are extremely important to any anatomical evaluation, they do not directly define the volumetric composition of wood. The quality of any wood is a function of its composition and arrangement of cellular elements. As was mentioned in earlier chapters, both fiber length and specific gravity are measures of wood quality. Fiber length provides a measure of quality primarily in a utility sense, i.e., certain pulping utilizations require a minimum fiber length for optimal production. Specific gravity is a measure of quality in an intermediate sense, i.e., by knowing the specific gravity, certain pulping yields, mechanical properties, and physical reactions may be anticipated. Very strong relationships have been developed for conifers in these respects.

The fact remains that little is known about tissue composition variation or correlations between measures of wood quality and cellular composition or cell wall thickness in hardwoods. These relationships need to be ascertained for a better utilization of hardwoods.

Tissue Cell Type Percentages- Of the few published reports quantifying relative tissue proportions in hardwoods, none involve sweetgum.

Variation of tissue composition differs among species (Taylor and Wooten 1973). Changes in vessel and fiber volume[1/] with increased sampling height were significant for pecan (*Carya illinoensis* (Wangenh)

[1/] Volume in this study refers to the relative amount of cellular elements. It is used interchangeably with the word "proportion".

Koch), sycamore (Platanus occidentalis L.), willow (Salix nigra Marsh), and yellow poplar (Taylor 1968, Taylor 1969 a and b, Taylor and Wooten 1973, and Wooten and Taylor 1968). However, any change of fiber or vessel volume with increasing sample height was due to chance in willow oak (Quercus phellos L.) and sugarberry (Celtis laevigata Willd.) (Taylor 1971, Taylor and Wooten 1973, and Wooten 1968).

When significant variation does exist in tissue composition, it is usually according to the following generalizations: (1) Vessel volume will increase, and fiber volume will decrease with increasing height with ray volume fluctuating in both directions, depending on species, and (2) vessel volume will increase, fiber volume will decrease, and ray volume will remain constant with increasing age (Taylor and Wooten 1973).

Fiber Wall Thickness - The average wall thickness of fibers in sweetgum is 7μm ± 1.2μm (Panshin and de Zeeuw, 1970). Variation of this measurement has not been tested widely, with only two known reports.

Jett and Zobel (1975) reported that fiber wall thickness increased from 7.65μm in juvenile wood to 8.37μm in mature wood in sweetgum.

Johnson and McElwee (1967) found fiber wall thickness differences of sweetgum to be highly significant when age of the wood or differences between trees within a stand were used as sources.

It is surprising to find so little research involving these properties for sweetgum. These two properties affect pulping qualities, and sweetgum is the principal hardwood pulp species (Putnam et al 1960).

Materials and Methods

Field Sampling-All cell types and fiber wall thickness measurements were taken from the 18 intensively-sampled trees. The field sampling was the same used for the collection of fiber length and specific gravity samples.

Whereas a section from the western axis of each sample disc was utilized for the fiber length and specific gravity work (Figure 6), a section was removed along the eastern axis of sample discs up to and including the sample taken from a height of 56 feet of each tree for these two measurements. No wall thickness or cell types measurements were taken from the bark, branches, or increment cores, and wall thickness was sampled at 8-ft. rather than 4-ft. intervals (example base, 8-ft. level, 16-ft. level, etc.).

Laboratory Sampling- Sample growth rings were identified by the same ocular count method as was employed in fiber length and specific gravity work. The growth rings deposited in 1974, 1970, 1965, 1960, 1955, and 1950 were used for tissue cell type measurements. Growth rings from 1974, 1970, and 1965 were used for wall thickness work. Reduction of the number of sample rings was necessitated by the amount of time required for measurement.

From each sample section removed from the eastern axis, a ½-inch thick sample was cut for use in cell type measurements. Growth rings to be examined were first saturated with water. A smooth surface was then prepared on the cross-sectional facet of the ring using a razor blade, and the sample was stained with a 1:100 aqueous solution of acridine orange.

Selected growth rings were then examined using a Leitz Ortholux II microscope equipped with an ultrapak objective employing 100X magnification. This instrument contained the proper light source and filter system for indirect fluorescence microscopy (Figure 23).

Determination of cell types was based on a combination of size (diameter) and wall thickness. Vessels were the largest cells with walls which were thinner than those of fibers and thicker than those of parenchyma. Fibers were intermediate in size between vessels and parenchyma. All cell types were easily distinguishable when defined with these two criteria.

Recordings were taken according to a method described by Taylor (1971) which involved a point count technique employing a Zeiss integrating eyepiece with Graticule I (Test-Point Graduation). The eyepiece is equipped with a grid system of 25 points asymmetrically arranged within a circle. This grid system was superimposed upon the magnified section and the number of test points coincident with each primary tissue type (vessels, fibers, or parenchyma) was recorded on a manual digital counter (Figure 23). Both longitudinal and ray parenchyma were recorded as parenchyma.

Fields of examination were arranged along a transect aligned at 45 degrees to the direction of growth (see Figure 24). Radial and tangential gradients in the size and frequency of wood elements were avoided by employment of this sample scheme. The number of sample points was determined according to the technique described by Quirk (1975), with a total of 200 points being counted per growth ring.

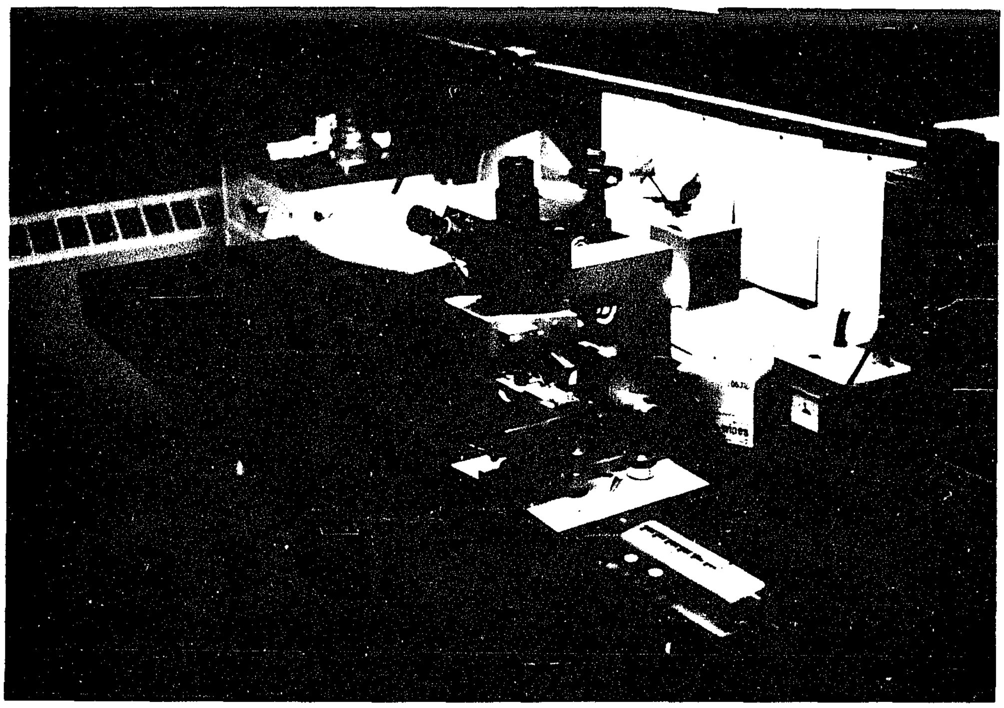


Figure 23. Leitz microscopy equipment with Zeiss integrating eyepiece and manual digital counter.

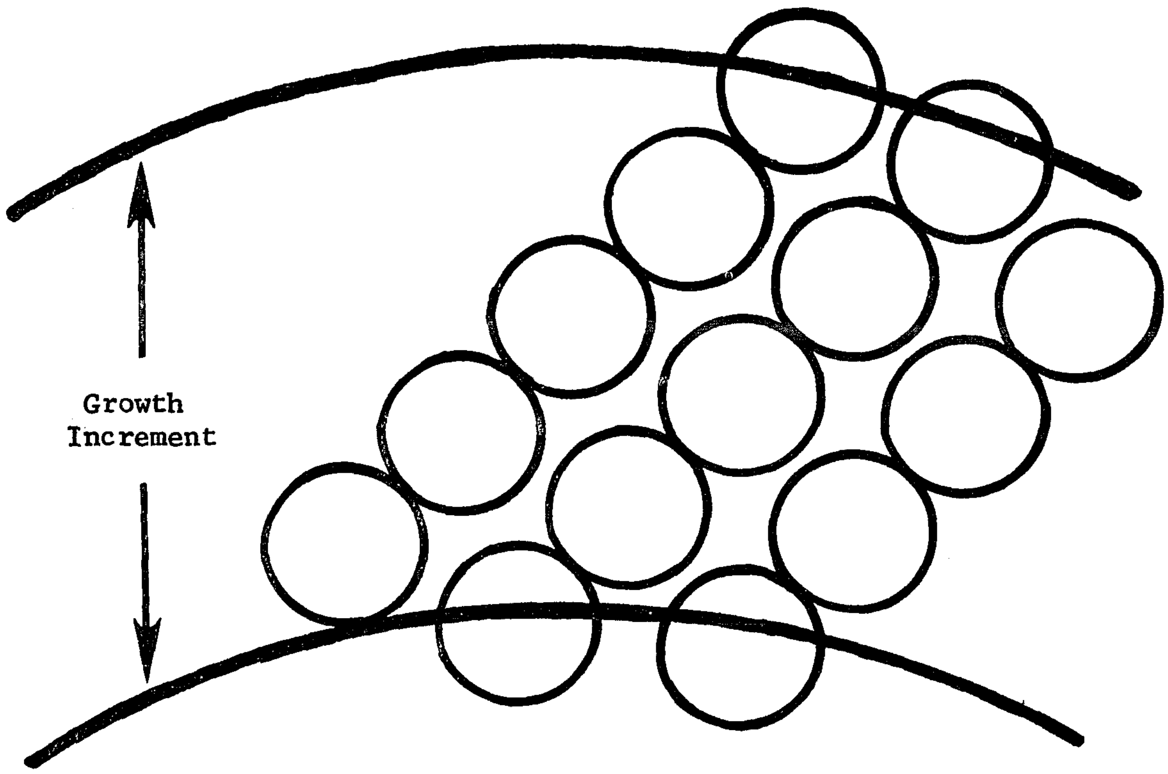


Figure 24. Arrangement of point count fields superimposed on annual ring sections.

The remainder of the section from the eastern axis was utilized for wall thickness measurements. The desired growth rings were identified by the previously described ocular method and removed by splitting with a hammer and large knife. The samples were then macerated with Jeffrey's Solution in the same manner as the fiber length work.

A temporary slide was prepared from each macerated sample and stained with acridine orange. Measurements were completed with the Leitz Ortholux II equipped for indirect fluorescence microscopy using an ocular eyepiece. Use of this eyepiece enabled measurements to be taken to the nearest 0.01 mm.

Only complete fibers were selected for measurement, and all measurements were taken from the mid-50 percent of the length of the fiber. The width of the fiber was first measured. By changing the focal plane, the lumen of the fiber could be measured at the same point. The double wall thickness was obtained by subtracting the lumen width from the overall fiber width. Ten fibers from each growth ring were utilized in wall thickness measurements.

Calibration of the instrument was then completed with a stage micrometer, and projected measurements were converted to microns (μm) before analysis.

Results and Discussions

(A) Tissue Cell Type Proportions

Average values from tissue cell type measurements are found in Tables 24, 25, and 26. Inspection of these tables indicates that fiber and vessel proportions are more variable than the proportion of

Table 24. Average fiber proportion for all sample years in intensively sampled trees.

Area	Sub Area	Tree	Year of Deposition					
			1950	1955	1960	1965	1970	1974
			per cent					
1[a]	U[1]	1	26.6	27.5	27.5	27.7	29.9	32.6
1	U	2	26.3	27.3	25.1	25.5	27.2	30.2
1	U	3	24.8	26.0	26.5	25.5	28.4	30.8
1	B[2]	1	22.6	24.7	24.3	25.5	26.4	26.4
1	B	2	21.2	21.7	22.1	21.8	22.8	21.8
1	B	3	20.0	20.7	22.0	22.8	22.3	21.8
2[b]	U	1	23.6	24.8	28.2	26.6	25.2	23.7
2	U	2	27.3	25.5	24.5	27.1	30.0	25.1
2	U	3	26.1	27.9	25.5	27.7	26.8	28.4
2	B	1	22.8	23.1	25.1	25.2	24.2	23.8
2	B	2	23.6	24.5	26.4	25.6	24.6	28.1
2	B	3	23.1	24.1	26.3	27.0	26.6	21.2
3[c]	U	1	29.1	26.5	25.1	26.0	20.4	22.1
3	U	2	25.6	24.5	24.6	24.9	26.4	27.7
3	U	3	26.2	23.8	26.3	25.3	23.7	24.4
3	B	1	22.1	24.0	23.2	24.1	25.7	24.8
3	B	2	23.8	24.5	21.6	25.2	23.5	23.8
3	B	3	22.7	23.4	25.7	29.9	26.4	35.5

1/ Upland

2/ Bottomland

a/ Kisatchie

b/ Lee forest

c/ Idlewild - Ben Hur

Table 25. Average vessel proportion for all sample years in intensively sampled trees.

Area	Sub Area	Tree	Year of Deposition 1950	1955	1960	1965	1970	1974
			per cent					
1[a]	U[1]	1	54.8	54.5	54.3	55.1	52.4	49.7
1	U	2	54.3	53.8	56.8	56.8	55.3	51.5
1	U	3	55.3	54.5	54.5	57.1	54.4	51.3
1	B[2]	1	58.2	56.9	56.9	54.2	55.4	55.4
1	B	2	60.4	58.7	59.5	60.8	59.6	59.6
1	B	3	62.2	62.9	59.9	60.5	60.8	60.6
2[b]	U	1	59.1	58.5	54.1	55.1	56.0	57.6
2	U	2	55.9	56.8	57.9	55.5	53.1	57.3
2	U	3	56.4	53.8	58.3	55.2	54.6	53.6
2	B	1	58.8	58.6	56.9	56.9	58.2	58.2
2	B	2	58.6	56.8	56.3	56.8	57.2	53.5
2	B	3	58.2	57.8	55.3	55.5	56.1	61.4
3[c]	U	1	52.4	55.4	56.7	55.6	62.4	59.1
3	U	2	54.1	58.1	56.4	57.2	55.2	54.7
3	U	3	53.4	58.6	57.1	58.0	58.7	58.2
3	B	1	59.1	58.1	59.1	57.4	55.5	57.5
3	B	2	58.8	57.1	59.7	57.7	58.4	57.3
3	B	3	58.2	56.7	53.8	51.1	54.5	44.5

1/ Upland

2/ Bottomland

a/ Kisatchie

b/ Lee forest

c/ Idlewild - Ben Hur

Table 26. Average parenchyma proportion for all sample years in intensively sampled trees.

Area	Sub Area	Tree	Year of Deposition 1950	1955	1960	1965	1970	1974
			per cent					
1[a]	U[1]	1	18.6	18.0	18.2	17.2	17.6	17.7
1	U	2	19.4	18.9	18.1	17.6	17.4	18.3
1	U	3	20.0	19.5	19.0	17.3	17.1	17.8
1	B[2]	1	19.2	18.5	18.7	20.2	18.1	18.2
1	B	2	18.4	19.6	18.3	17.3	17.5	18.6
1	B	3	17.8	16.4	18.1	16.7	16.9	17.6
2[b]	U	1	17.3	16.7	17.7	18.3	18.7	18.6
2	U	2	16.8	17.7	17.6	17.4	16.9	17.5
2	U	3	17.5	18.3	16.1	17.0	18.6	17.9
2	B	1	18.1	18.2	18.1	17.8	17.5	18.0
2	B	2	18.9	17.7	17.3	17.6	18.2	18.4
2	B	3	17.9	19.1	18.3	17.4	17.3	17.4
3[c]	U	1	18.5	18.1	18.2	18.4	17.2	18.7
3	U	2	20.2	17.4	19.0	17.8	18.4	17.7
3	U	3	20.4	17.5	16.6	16.6	17.6	17.3
3	B	1	18.8	17.9	17.7	18.4	18.8	17.7
3	B	2	17.4	18.4	18.7	17.0	18.1	18.9
3	B	3	19.2	19.9	20.5	18.9	19.1	19.9

[1] Upland

[2] Bottomland

[a] Kisatchie

[b] Lee forest

[c] Idlewild - Ben Hur

parenchyma. The nature of this variation will be discussed in the immediately ensuing sections of this chapter.

Variation within the tree

Relative proportion of cellular elements were correlated with fiber length, specific gravity, height, and year. The results indicate that the coefficients of element proportion to specific gravity are higher than the coefficients between element proportion and any of the other variables. Vessel and fiber proportions follow the same pattern of height and year variation as specific gravity, with vessel proportion being inversely related and fiber proportion directly related to specific gravity. Variation of this nature is not unexpected, since specific gravity is a function of the relative proportion of cellular elements.

Relationship of fiber proportion to other wood properties - Correlation analyses were used to test the relationship of fiber proportion to fiber length, specific gravity, vessel proportion, and parenchyma proportion. These correlations are presented in Table 27. Fiber proportion was significantly related to average fiber length in only one sample year (1950, $r=.190$, $p<.05$). This lack of significance disagrees with work of Taylor (1971) and Taylor and Wooten (1973) who found a constant significant negative correlation between fiber length and fiber volume (proportion) in sugarberry. In contrast, only one negative correlation could be detected in the present study (-.016). This discrepancy could be due to the fact that the earlier reports dealt with sugarberry, a ring-porous hardwood, whereas sweetgum is diffuse porous.

Table 27. Correlation coefficients for the relationship of fiber proportion to other wood properties for all samples.

	Year of Deposition					
	1950	1955	1960	1965	1970	1974
Avg. Fiber Length	.190*	.020	-.016	.036	.078	.036
Avg. Specific Gravity	.949**	.932**	.913**	.953**	.957**	.952**
% Vessel	-.871**	-.851**	-.848**	-.873**	-.877**	-.923**
% Paren.	-.500**	-.511**	-.473**	-.464**	-.376**	-.376**

* Significant at .05 level

** Significant at .01 level

Fiber proportion is highly significantly related to all other variables (Table 27). Coefficients ranged from .913, $p < .01$ to .957, $p < .01$ in correlations between fiber proportions and average specific gravity. Since specific gravity is directly dependent on the amount of cell wall material and the bulk of cell wall material is found in fibers, high coefficients are not unusual. However, earlier reports have never reported coefficients with this overall level of significance for any other species.

Fiber proportion has highly significant negative correlations to vessel proportion (-.848, $p < .01$ to -.923, $p < .01$) and parenchyma proportion (-.376, $p < .01$ to -.511, $p < .01$). These coefficients are also to be expected, as the increase in one cell type must necessarily result in the decrease of at least one other cell type for all species (Taylor and Wooten 1973).

Results from regression analyses of the effect of specific gravity on fiber proportion are presented in Table 28. The equation for the earliest sample year is linear but equations for all other samply years and the overall regression are curvilinear. All r^2 values are highly significant and range from .790, $p < .01$ to .905, $p < .01$.

The results from these analyses are generally reflective of the correlations in that they display a strong positive relationship between the two variables. The curve for fiber proportions vs. specific gravity in Figure 25 presents a useful device for predicting sweetgum fiber proportion (r^2=.857, $p < .01$).

Table 28. Regression equations and coefficients of determination for fiber volume versus specific gravity.

Year of Deposition	Equation	r^2
1950	$y = -26.34 + 109.03\ (G)$ 1/	.903**
1955	$y = 13.46 + 229.78\ (G^4)$	.828**
1960	$y = 12.54 + 251.72\ (G^4)$	.829**
1965	$y = 11.10 + 280.37\ (G^4)$	.790**
1970	$y = 12.87 + 239.72\ (G^4)$	.905**
1974	$y = 12.34 + 244.18\ (G^4)$	.849**
Overall	$y = 12.84 + 242.18\ (G^4)$	.857**

(G) 1/ = average specific gravity

** denotes significance at .01 level of probability

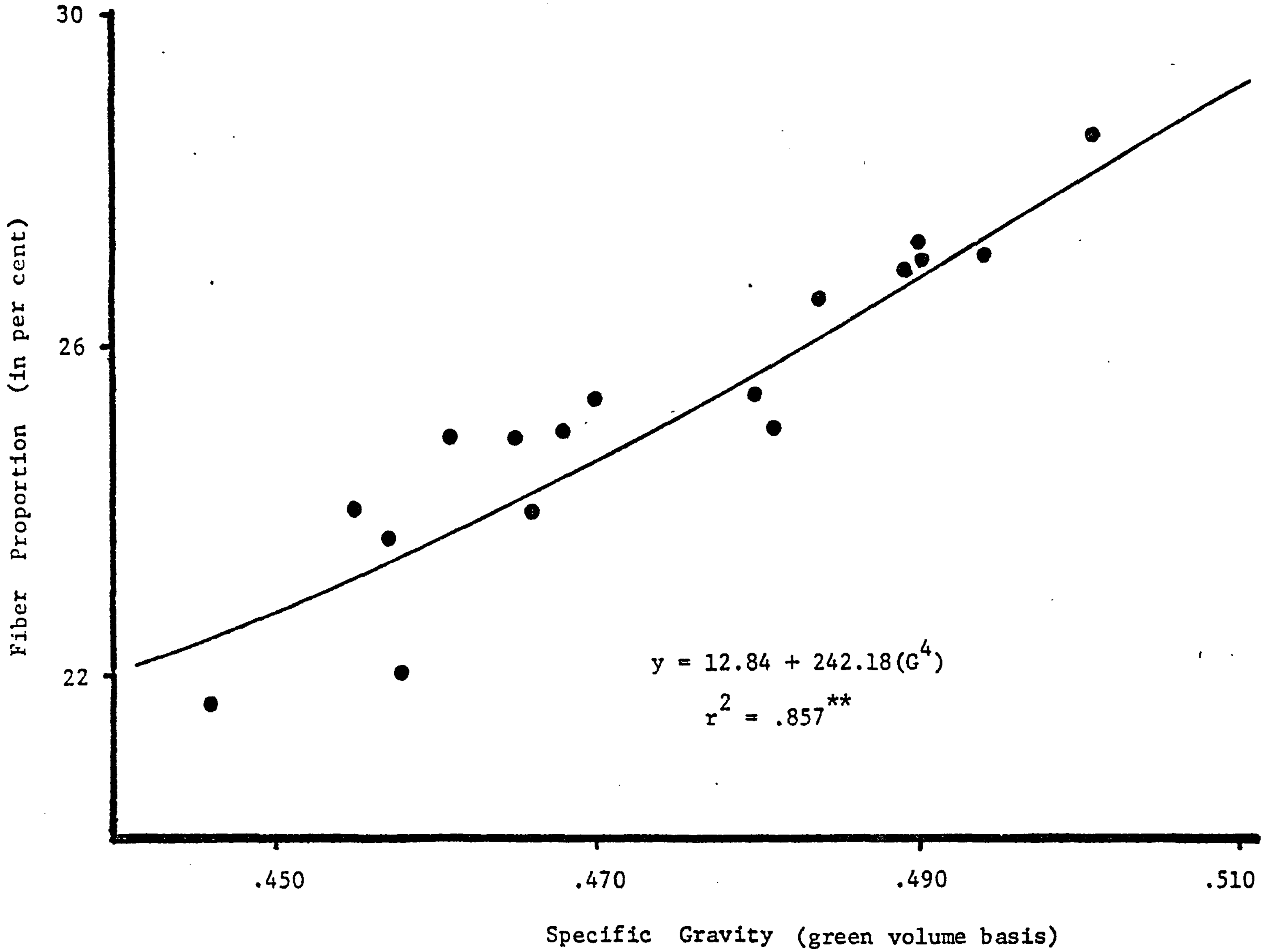


Figure 25 . Regression curve for fiber proportion vs. specific gravity.

The strength of this relation involving fiber proportion could be a tremendous asset to future sweetgum specific gravity studies. If this relationship could be applied to all sweetgum, valuable time could be saved in laboratory analysis by quickly determining the proportion of fibers in the sample and then deriving the specific gravity. While some precision would be lost in this type of operation, savings in time might prove to be worthwhile. This, of course, would depend on the type of research being conducted.

Relationship of vessel proportion to other wood properties - Vessel proportions were correlated to fiber length, specific gravity, fiber proportion, and parenchyma proportion (see Table 29).

Correlations for vessel proportions are somewhat similar to those for fiber proportions in terms of significance. Only one correlation between vessel proportion and fiber length is significant (-.161, $p < .05$). All correlations of this type have negative coefficients which is interesting in comparison to work on sugarberry that constantly revealed significant positive coefficients for the same correlation (Taylor 1971 and Taylor and Wooten 1973). Again, the fact that one species is ring-porous and the other diffuse porous may account for the reversal in results. Otherwise, differences may be attributed to the fact that species differ in many properties and internal relationships, and this may be one of them.

All correlations between vessel proportion and specific gravity are negative. All coefficients for this comparison are also highly significant, ranging from -.797, $p < .01$ to -.875, $p < .01$. These correlations represent a deviation from work on other species both in

Table 29. Correlation coefficients for the relationship of vessel proportion to other wood properties for all samples.

	Year of Deposition					
	1950	1955	1960	1965	1970	1974
Avg. Fiber Length	-.145	-.076	-.093	-.110	-.161**	-.074
$\overline{X}$ Sp. Grav.	-.838**	-.797**	-.799**	-.837**	-.850**	-.875**
% Fibers	-.871**	-.851**	-.848**	-.873**	-.877**	-.923**
% Paren.	-.500**	-.511**	-.473**	-.464**	-.376**	-.376**

* Significant at .05 level

** Significant at .01 level

the nature of the correlation and the significance thereof (Taylor 1971, and Taylor and Wooten 1973).

Correlations to proportions of other cell types were always negative and highly significant. This is to be expected for reasons discussed earlier.

Results from stepwise regression analyses of the effect of specific gravity on vessel proportion are in Table 30. Equations for the two earliest sample years are linear, and those for all other sample years and the overall regression are curvilinear. The coefficients of determination are all highly significant and range from .606, $p < .01$ to .870, $p < .01$.

The curve for vessel proportion vs. specific gravity in Figure 26 provides a useful predictive measure ($r^2 = .778$, $p < .01$). The negative association between the variables is expected due to the fact that the increase in proportion of relatively thin-walled vessel elements will decrease specific gravity, since specific gravity is directly related to the amount of cell wall material per unit area. These regression results reveal no new relationships. However, they do provide a means of evaluating sweetgum specific gravity which did not exist before.

<u>Relationship of parenchyma proportion to other wood properties</u>- The proportion of parenchyma is the most uniform of the three cell types measured, and correlations are notably different. Coefficients for the correlation between parenchyma proportion and fiber length ranged from negative and non-significant (-.040) to highly significant and positive (Table 31). Due to this variation in

Table 30. Regression equations and coefficients of determination for relative vessel volume versus specific gravity.

Year of Deposition	Equation	r^2
1950	$y = 112.08 - 118.35\ (G)$ 1/	.825**
1955	$y = 106.87 - 106.09\ (G)$	.731**
1960	$y = 68.22 - 229.51\ (G^4)$	.606**
1965	$y = 73.29 - 321.37\ (G^4)$	.726**
1970	$y = 81.69 - 109.54\ (G^2)$	.870**
1974	$y = 70.23 - 256.39\ (G^4)$	.832**
Overall	$y = 69.33 - 247.67\ (G^4)$	.778**

G 1/ = average specific gravity

** denotes significance at .01 level of probability

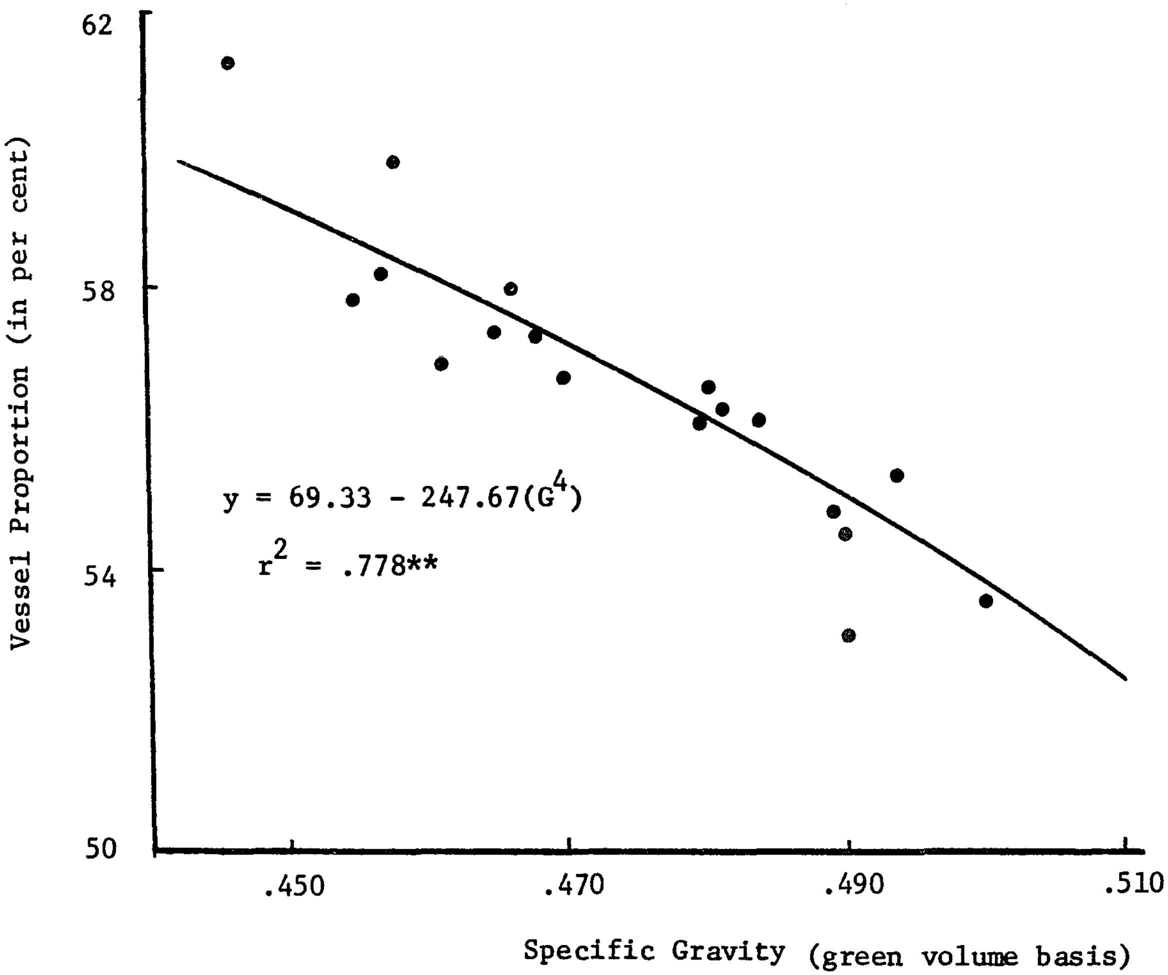


Figure 26. Regression curve for vessel proportion vs. specific gravity

Table 31. Correlation coefficients for the comparison of parenchyma proportion to other wood properties.

	Year of Deposition					
	1950	1955	1960	1965	1970	1974
Avg. Fiber Length	-.040	.113	.201**	.159**	.184**	.105
Avg. Sp. Gravity	.030	-.013	-.015	-.016	-.088	-.019
% Vessel	-.500**	-.511**	-.473**	-.464**	-.376**	-.376**
% Fibers	.010	-.016	-.067	-.027	-.116	-.010

** Significant at .01 level

results from a small number of correlations, it is difficult to make inferences, but the overall relationship was positive. Results of this type are in general agreement with earlier work, but high levels of significance are relatively uncommon in earlier reports. The agreement of this type correlation to earlier reports is reflective of the fact that parenchyma is the most constant cell type (in proportion) in all species examined.

There was no relationship between parenchyma proportion and specific gravity. Coefficients ranged from -.088 to .030 and are very similar to those reported for sugarberry (Taylor 1971).

Parenchyma proportion was negatively correlated ($p < .01$) to vessel proportion. However, there was no significance in any correlations to fiber proportion.

Results from the regression analyses of the effect of specific gravity on parenchyma proportion are not significant. The r^2 values ranged from .004 to .296, but none are presented herein due to the lack of significance.

Since the coefficient of determination for parenchyma proportion vs. specific gravity is almost negligible, no curve was plotted for the overall regression. Predictive capacity is restricted by the fact that parenchyma is a very consistent cellular component of wood, and specific gravity is a highly variable property.

Variation among sites

Analyses of variance for fiber proportions revealed highly significant differences among similar sites for all but one sample

year (1965) (Table 33). The site X area interaction is also significant in one sample year and highly significant in three sample years. Fiber proportions are also highly significantly different between sample heights with an ara X sub-area for one sample year. Specific comparisons reveal that fiber proportions are significantly greater in trees from the upland site in Area 1 for all sample years. Significant differences vary in Areas 2 and 3, depending on the sample year examined (Table 34). From these evaluations, it is obvious that fiber proportions vary between upland and bottomland sites, but the variation is not of a constant definition.

Vessel proportions are not as variable as fiber proportions, but results indicate that this property is site-related. Significant or highly significant differences occur in four of six sample years in a comparison of all sites (Table 35). The site X area interaction is significant or highly significant in four of six sample years. Differences between sampling heights within an area x sub-area are also highly significant in one sample year. However, a comparison of geographic areas yielded no significant differences.

No specific comparisons are needed to determine the nature of vessel proportion variation. This is due to the fact that parenchyma proportions are relatively constant (to be discussed), and fiber and vessel proportions vary inversely. Thus, increased fiber proportions in any given comparison indicate an inverse relationship for vessel proportions in the same comparison.

Parenchyma proportion is the most consistent of the three

Table 32. Analysis of variance of fiber percentages in intensively sampled trees.

	Year of Deposition								
	1950			1955			1960		
	df	MS	F	df	MS	F	df	MS	F
Area	2	28.8762	1.35	2	1.2732	0.08	2	72.3535	2.06
Error (a)	6	21.4350		6	16.1215		6	35.1893	
Sub-Area	1	494.4543	37.05**	1	318.3074	18.34**	1	171.3787	9.37**
A X SA 1/	2	14.5665	1.09	2	76.8512	4.43*	2	47.3495	2.59
H (A X SA) 2/	65	23.9010	1.79**	76	20.7737	1.20	81	17.6616	0.97
Error (b)	104	13.3451		137	17.3523		160	18.2820	

	Year of Deposition								
	1965			1970			1974		
	df	MS	F	df	MS	F	df	MS	F
Area	2	65.3652	1.13	2	109.0037	1.80	2	114.9778	0.68
Error (a)	6	57.8829		6	60.5815		6	169.0963	
Sub-Area	1	53.3056	2.62	1	201.0704	8.37**	1	270.0000	10.67**
A X SA 1/	2	100.0595	4.92**	2	229.7815	9.57**	2	712.1333	28.13**
H (A X SA) 2/	84	24.5610	1.21	84	26.8328	1.12	84	29.0751	1.15
Error (b)	168	20.3187		174	24.0144		174	25.3147	

1/ Area X Sub-Area
2/ Height (Area X Sub-Area)

* Significant at .05 level
** Significant at .01 level

Table 33. Specific comparisons of fiber proportions for all sample years.

Year	Area	Upland	Bottomland	LSD
		--------per cent-------		
1974	1	31.2	23.3	1.80*
	2	25.7	24.4	1.80
	3	24.7	28.0	1.80*
1970	1	28.5	23.8	1.13*
	2	27.3	25.1	1.13*
	3	23.5	25.2	1.13*
1965	1	26.2	23.4	1.92*
	2	27.1	25.9	1.88
	3	25.4	26.4	1.93
1960	1	26.4	22.8	1.86*
	2	26.1	25.9	1.77
	3	25.4	23.5	1.89*
1955	1	27.0	22.4	1.98*
	2	26.1	23.9	1.78*
	3	24.9	24.0	1.78*
1950	1	25.9	21.3	1.99*
	2	25.7	23.2	1.80*
	3	27.0	22.9	1.99*

*denotes significance at .05 level

Table 34. Analysis of variance of vessel percentages in intensively sampled trees.

	Year of Deposition								
	1950			1955			1960		
	df	MS	F	df	MS	F	df	MS	F
Area	2	35.9851	1.39	2	1.6152	0.04	2	17.2055	0.44
Error (a)	6	25.8257		6	39.5809		6	39.3358	
Sub-Area	1	501.7061	27.52**	1	199.5972	8.11**	1	75.2959	2.82
A X SA 1/	2	47.0717	2.58	2	120.1794	4.88**	2	69.0623	2.59
H (A X SA) 2/	65	33.9010	1.86**	76	27.8506	1.13	81	20.0338	0.75
Error (b)	104	18.2280		137	24.6072		160	26.6869	

	Year of Deposition								
	1965			1970			1974		
	df	MS	F	df	MS	F	df	MS	F
Area	2	63.3687	0.75	2	59.8611	0.84	2	128.2815	0.72
Error (a)	6	84.1555		6	71.2185		6	178.7370	
Sub-Area	1	13.7439	0.47	1	154.1333	5.10*	1	187.5000	5.61*
A X SA 1/	2	94.9421	3.37*	2	312.4333	10.34**	2	798.5778	23.91**
H (A X SA) 2/	84	26.5164	0.92	84	26.6116	0.88	84	29.4365	0.88
Error (b)	168	28.7573		174	30.2031		174	33.3960	

1/ Area X Sub-Area

2/ Height (Area X Sub-Area)

* Significant at .05 level

** Significant at .01 level

cellular element variables. No significant differences exist among similar sites or between sites within an area (Table 36). Data from one sample year (1974) indicate significant differences between sample heights within an area x sub-area, and a comparison of geographic areas indicates significant differences in two sample years. However, smaller variations in the proportion of parenchyma may be statistically significant due to lower means in these values.

The relatively small amount of variation in parenchyma proportions is not an important factor in an overall evaluation of cellular element proportions. These results are in general agreement with those of Taylor and Wooten (1973) who reported parenchyma to be relatively constant in all species tested.

(B) Cell Wall Thickness

Average values from fiber cell wall thickness measurements are found in Table 37. Variation in this property is discussed in the same sequence as cellular element proportions.

Within tree variation

Relationship of cell wall thickness to height - Cell wall thickness is negatively correlated to sampling height in 16 of the 18 intensively sampled trees (Table 38). Negative coefficients range from -.365 to -.964, $p < .01$. Of the two exceptions (both from Area 3), one was moderately high (.705, $p < .01$). Grouping the data before analysis yielded highly significant negative coefficients for all correlations. In these group comparisons, trees from bottomland sites had a higher coefficient (-.512, $p < .01$) than the trees from upland sites (-.418,

Table 35. Analysis of variance of parenchyma percentages in intensively sampled trees.

	Year of Deposition								
	1950			1955			1960		
	df	MS	F	df	MS	F	df	MS	F
Area	2	24.8599	8.22*	2	2.1855	0.16	2	19.1426	6.16*
Error (a)	6	3.0261		6	13.4609		6	3.1085	
Sub-Area	1	0.0264	0.01	1	13.7884	1.77	1	19.4821	2.90
A X SA 1/	2	9.4526	1.42	2	5.0797	0.65	2	3.2725	0.49
H (A X SA) 2/	65	6.6486	1.00	76	7.0511	0.90	81	8.1969	1.22
Error (b)	104	6.6603		137	7.8046		160	6.7126	

	Year of Deposition								
	1965			1970			1974		
	df	MS	F	df	MS	F	df	MS	F
Area	2	1.4455	0.11	2	13.2074	4.34	2	3.8370	1.20
Error (a)	6	12.3385		6	3.0511		6	3.2036	
Sub-Area	1	12.9107	1.89	1	3.1148	0.42	1	7.5000	1.36
A X SA 1/	2	2.9107	0.43	2	10.6037	1.44	2	6.1778	1.12
H (A X SA) 2/	84	7.5228	1.10	84	8.4400	1.14	84	8.1778	1.48*
Error (b)	168	6.8212		174	7.3775		174	5.5217	

1/ Area X Sub-Area

2/ Height (Area X Sub-Area)

* Significant at .05 level

Table 36. Average cell wall thickness for all sample years in intensively sampled trees.

Area	Sub-Area	Tree	Year of Deposition 1965	1970	1974
			------------ μ m ------------		
1[a]	U[1]	1	6.63	6.70	6.95
1	U	2	6.77	6.67	6.83
1	U	3	6.78	6.86	6.89
1	B[2]	1	6.66	6.70	6.64
1	B	2	6.31	6.65	6.29
1	B	3	6.50	6.45	6.41
2[b]	U	1	6.44	6.25	6.39
2	U	2	6.51	6.63	6.55
2	U	3	6.57	6.58	6.81
2	B	1	6.67	6.49	6.34
2	B	2	6.63	6.66	6.74
2	B	3	6.49	6.61	6.30
3[c]	U	1	6.30	6.00	6.18
3	U	2	6.76	6.87	6.84
3	U	3	6.65	6.58	6.64
3	B	1	6.69	6.68	6.59
3	B	2	6.56	6.65	6.61
3	B	3	6.69	6.69	6.77

[1]Upland

[2]Bottomland

[a]Kisatchie

[b]Lee Forest

[c]Idlewild - Ben Hur

Table 37. Correlation coefficients indicating relationship between cell wall thickness and sample height in intensively sampled trees.

Area	Sub-Area	Tree	Cell Wall Thickness X Height
1[a/]	U[1/]	1	-.876**
1	U	2	-.701**
1	U	3	-.628*
1	B[2/]	1	-.916**
1	B	2	-.631*
1	B	3	-.848**
2[b/]	U	1	-.875**
2	U	2	-.904**
2	U	3	-.856**
2	B	1	-.918**
2	B	2	-.365
2	B	3	-.640*
3[c/]	U	1	.705**
3	U	2	-.492
3	U	3	-.371
3	B	1	.478
3	B	2	-.678**
3	B	3	-.964**

[1/] Upland

[2/] Bottomland

[a/] Kisatchie

[b/] Lee Forest

[c/] Idlewild - Ben Hur

*denotes significance at .05 level

**denotes significance at .01 level

$p < .01$) or the evaluation of trees from all sites ($-.423$, $p < .01$).

No earlier reports on sweetgum included an analysis of cell wall thickness. However, based on the results of this study, sweetgum fibers generally become shorter and thinner-walled with increasing height within the stem.

Results from regression analyses of the effect of height on cell wall thickness are presented in Table 39. All equations are curvilinear, and r^2 values are all highly significant.

These regression analysis results follow the same trend established in correlation analysis in that trees from bottomland sites have a higher r^2 value than trees from upland sites or the evaluation of trees from all sites.

Even though the curves in Figure 27 have highly significant r^2 values, they explain only 21 to 30 percent of the total variation in cell wall thickness. Therefore, the predictive capacity of the curves is limited, and caution is advised in their use.

More of the total variation might be explained by increasing height, except that dell wall thickness is a function of growth factors involving both the tree and the environment. It appears that environmental fluctuations which control tree growth may be responsible for part of the variation of cell wall thickness encountered in this study.

Relationship of cell wall thickness to other wood properties - The relationship of cell wall thickness to fiber length and specific gravity was determined by correlating average values for sample years. No significant relationship could be detected between wall thickness

Table 38. Regression equations and coefficients of determination for cell wall thickness versus specific gravity and cell wall thickness versus height.

Sample	Equation	r^2
1965	$y = 5.13 + 3.06\ (G)$ 1/	.081
1970	$y = 3.88 + 5.68\ (G)$	.448**
1974	$y = 3.74 + 5.90\ (G)$	.680**
All	$y = 3.97 + 5.48\ (G)$	.478**
Upland	$y = 6.72 - .00000004\ (Ht.^4)$	.215**
Bottomland	$y = 6.71 - .00000282\ (Ht.^3)$	.305**
All	$y = 6.73 - .00000265\ (Ht.^3)$	.255**

(G) 1/ = average specific gravity

** denotes significance at .01 level of probability

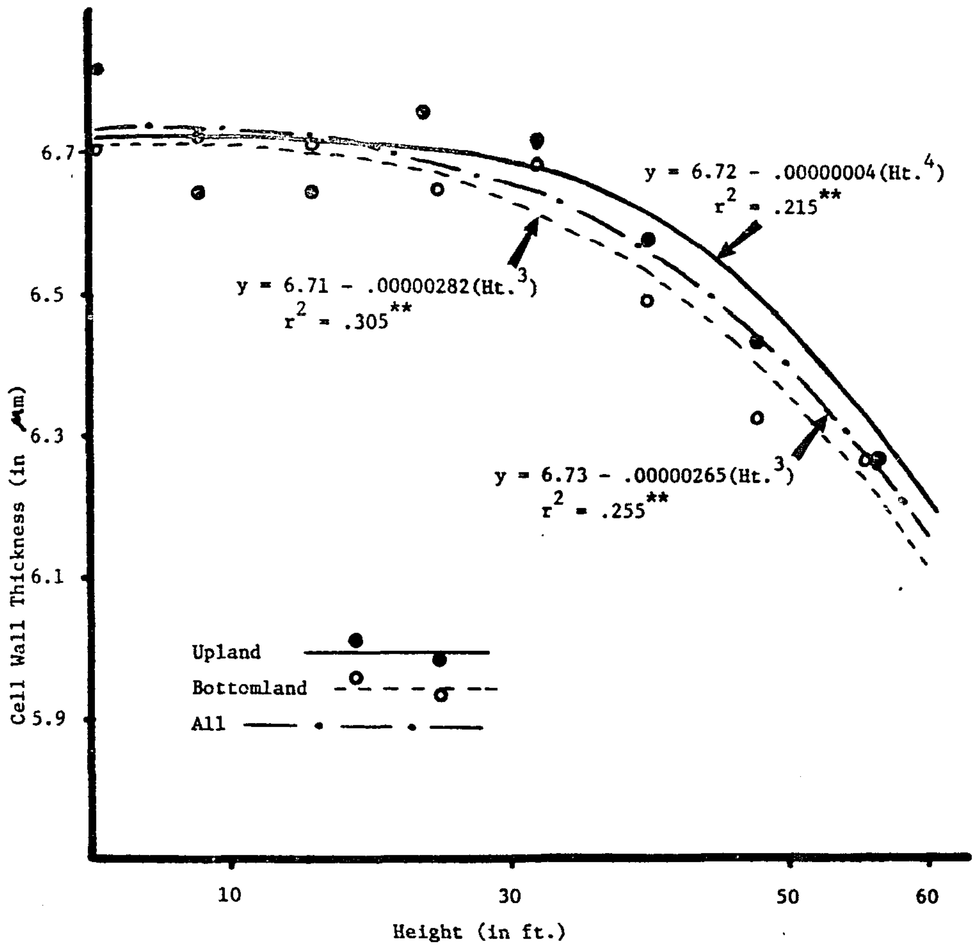


Figure 27. Regression curves for cell wall thickness vs. height.

and fiber length in these comparisons (Table 40). Results for the comparison of wall thickness to specific gravity are varied. Two of the three sample years have highly significant positive coefficients, but comparison for the year 1965 has a coefficient which is low and not significant.

Grouping the data indicated wall thickness is significantly related to fiber length in the evaluation of trees from all sites, but the coefficient is low (Table 41). Trees from upland or bottomland sites display no significance in the coefficients for this comparison. All correlations for grouped data of wall thickness and specific gravity have highly significant positive correlations.

Results for the regression analysis of the effect of specific gravity on cell wall thickness are presented in Table 39. All equations are linear, and r^2 values are highly significant in two of three sample years and in the overall regression. The regression for the year 1965 failed to display significance.

The curve for the regression of all trees is found in Figure 28. The r^2 value is not high and sample size is relatively small; therefore, caution should be exercised in using the curve.

In comparison to results from regression analysis of fiber and vessel proportions, it is obvious that these proportions have a much stronger relationship to specific gravity in sweetgum. The inference may then be drawn that even though specific gravity is a function of both cell wall thickness and cellular element proportions, the latter is more important than the former in determining the specific gravity of sweetgum. This statement appears to be valid if

Table 39. Correlation coefficients indicating strength of relationship of cell wall thickness to fiber length and specific gravity in intensively sampled trees.

	1965	1970	1974
Cell 1/ X Fiber Length 2/	.205	.251	.383
Cell X Specific Gravity 3/	.284	.670**	.825**

1/ Average cell wall thickness for all heights

2/ Average fiber length for all heights

3/ Average specific gravity for all heights

** Significant at .01 level

Table 40. Correlation coefficients indicating strength of relationship of cell wall thickness to fiber length and specific gravity for groups of samples.

	Upland	Bottomland	All
Cell 1/ X Fiber Length 2/	.239	.357	.279*
Cell X Specific Gravity 3/	.767**	.582**	.691**

1/ Average cell wall thickness for all heights

2/ Average fiber length for all heights

3/ Average specific gravity for all heights

* Significant at .05 level

** Significant at .01 level

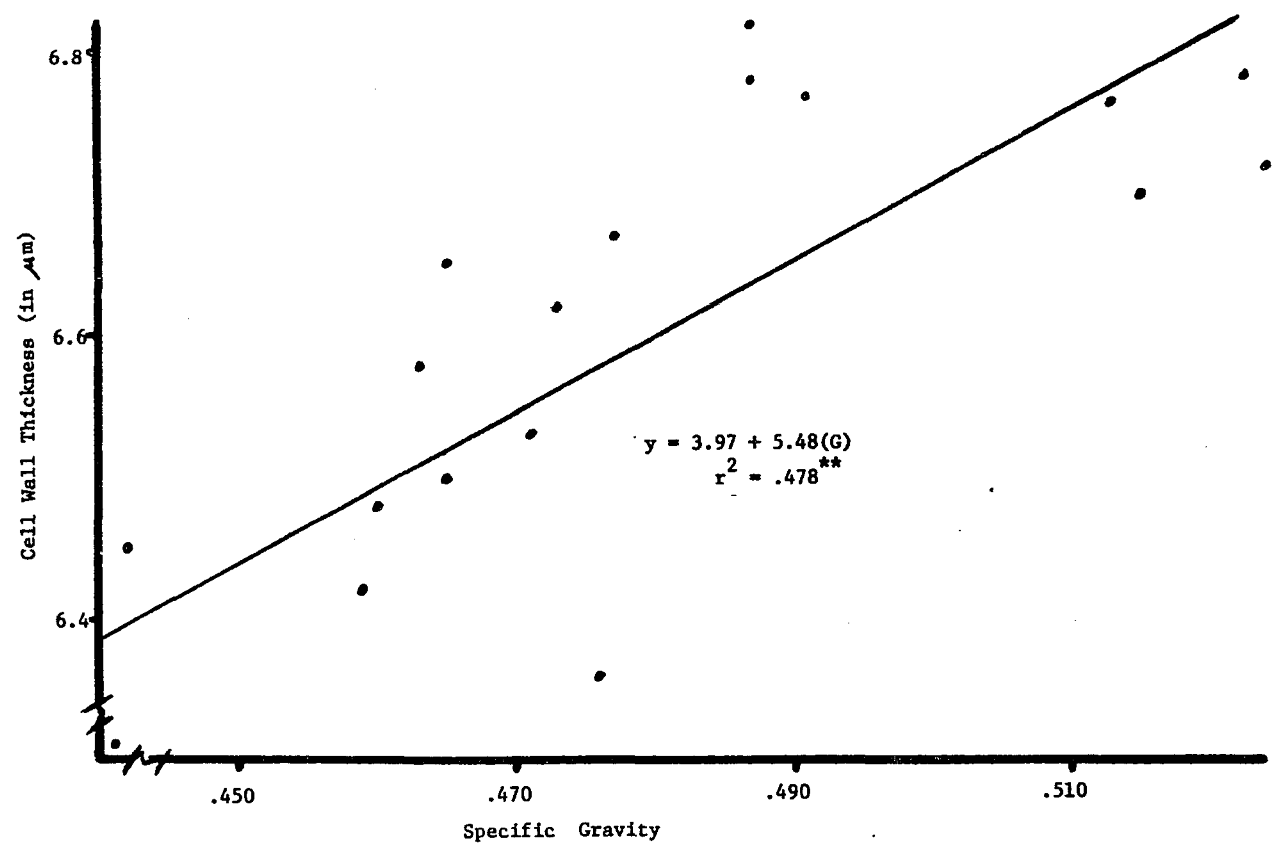


Figure 28. Regression curve for cell wall thickness vs. specific gravity.

considered in conjunction with the fact that the amount of cell wall material is directly related to proportions of cellular elements.

Variation among sites

Analyses of variance revealed that wall thickness was significantly different among similar sites in only one sample year (Table 42). However, the site X area interactions were either significant or highly significant in all sample years. Specific comparisons revealed that differences between sites within an area is due to the fact that values from the upland site in Area 1 are significantly higher than the values from the bottomland site in two of three sample years (Table 43). Also, the values from the upland sites in Areas 2 and 3 are consistently lower than the values from bottomland sites in those areas. Significant variation extended to include differences between heights within an area X sub-area in two of three sample years. However, when geographic areas were compared, no significant differences could be found (Table 42).

In summary, cellular element proportions and cell wall thickness are strongly related to other selected wood properties. The variation of fiber proportion follows the same pattern as specific gravity variation, and vessel proportion generally follows an inverse scheme as compared to specific gravity changes. Proportions of parenchyma are relatively uniform in both height and year perspectives. Cell wall thickness varies in respect to both radial and vertical position in the stem. Vessel proportions, fiber proportions, and cell wall thickness vary between upland and bottomland sites, but the nature and

Table 41. Analysis of variance of cell wall thickness in intensively sampled trees.

	Year of Deposition								
	1965			1970			1974		
	df	MS	F	df	MS	F	df	MS	F
Area	2	.0509	0.80	2	.2236	0.60	2	.2624	0.70
Error (a)	6	.0640		6	.3734		6	.3771	
Sub-Area	1	.0093	0.11	1	.0856	0.98	1	.8771	8.96**
A X SA 1/	2	.3167	3.74*	2	.3516	4.04*	2	.9007	9.20**
H (A X SA) 2/	42	.1852	2.19**	42	.2040	2.34**	42	.1260	1.29
Error (b)	86	.0847		90	.0870		90	.0979	

1/ Area X Sub-Area

2/ Height (Area X Sub-Area)

* Significant at .05 level

** Significant at .01 level

Table 42. Specific comparisons of cell wall thickness values for all sample years.

Year	Area	Upland	Bottomland	LSD
		---------per cent--------		
1974	1	6.72	6.49	.16*
	2	6.51	6.60	.15
	3	6.58	6.65	.17
1970	1	6.74	6.60	.16
	2	6.49	6.58	.15
	3	6.48	6.67	.17*
1974	1	6.90	6.45	.16*
	2	6.59	6.46	.15
	3	6.56	6.66	.17

*denotes significance at .05 level

the magnitude are not constant for all geographic areas or similar sites.

Chapter V

Variation of Anatomical and Physical Properties in Sweetgum (A Summary)

Evaluation of the variation of anatomical and physical properties in natural stands of sweetgum is essential for a better understanding and utilization of the species. Even though a great deal of work has been done with trees growing on bottomland sites, very little is known about sweetgum trees or stands grown on upland sites.

A recent increase in interest in the species is due to an increase in the value of sweetgum wood and a reduction in the supply of quality stumpage. Emphasis must now be placed on identifying sources of superiority in the species and developing harvesting practices which are better suited to the intended utilization.

At present, sweetgum is in great demand and harvested widely, but stems on upland sites are generally considered to be of lower quality. If trees from upland sites are in fact equal to or superior to those from bottomland areas, a waste of resources may be occurring. Tree improvement programs for the species are now starting, and trees that are potentially valuable from a genetic perspective may be lost if not utilized properly.

The initial effort at identifying the variation of anatomical and physical properties in sweetgum between upland and bottomland sites is an intensive sampling examination of 18 phenotypically selected trees. The trees were selected from six natural stands in three separate geographical areas of Louisiana. Three trees were

selected from each stand in such a manner as to result in three comparable pairs of trees per area. The objective of this sampling procedure was to enable a broad spectrum of comparisons ranging from within the tree to between geographical areas.

Measurements were taken from samples which included radial and vertical gradients, and the results provide information upon which other aspects of site evaluation can be based.

Evaluation of fiber length showed considerable variation both within the tree and between sites within two of the three geographic areas. Variation between trees within the stand appears to be greater in bottomland stands, but variation between trees within a stand was not a significant source of total variation in this study. In an overall examination, fiber length appears to be greater in trees from upland sites. Thus, if increased fiber length is a desired character in a tree improvement program, parent selections should be made from stands on upland sites. Also, the longer fibers are generally associated with high quality hardwood pulp, and this may be transposed into an indication that sweetgum from upland sites is more desirable for pulping material. Unfortunately, this study is designed only to ascertain the amount of variation which exists and can not explain in definitive terms why fiber length varies as it does in this research. A number of possible answers have been discussed, and these should be taken into account in future work of a similar nature.

Evaluation of specific gravity yielded interesting results. Variation within the tree appears to be the major source of total variation, and there is a notable lack of consistency of variation

within the tree. Thus, within-tree variation of specific gravity in this study is a specific function of the individual. Average specific gravity in this study was higher in trees from upland sites. This fact does not appear to have any effect on patterns of individual variation, but it is important since specific gravity is an intermediate measure of many physical and mechanical properties. Also, most tree improvement programs involve specific gravity as a desired character due to its high heritability rating, and upland sites represent preferred sources of parent selection if higher specific gravities are desired.

Tissue cell type measurements add a new dimension to anatomical evaluation of sweetgum. Due to the strength of the relationship between fiber proportions and specific gravity, the two measures may be used interchangably, i.e., by knowing the value for either one, the remaining value may be predicted with a very high degree of precision. This relationship may prove to be of great utility for rapid evaluations of sweetgum wood. Also, since the proportion of parenchyma is consistently in a narrow range, the entire tissue composition proportions may be predicted accurately by knowing only the specific gravity of sweetgum wood.

Fiber cell wall thickness proved to be yet another indicator of differences between sites. Variation is significant between upland and bottomland sites but not between geographic areas. This indicates that wall thickness is highly dependent on site quality for sweetgum, and considered in conjunction with the fact that cell walls are of a

greater average thickness in trees from upland sites, another point of support is gained for considering upland sweetgum sites with a new perspective.

Even though this study was based primarily on the intensive sampling, it is considered reflective for the sample area involved in the study. This assumption can be made since extensive geographic sampling was undertaken to test the credibility of the restricted intensive work. In every evaluation, the intensive sampling proved to be representative of the total variation incurred in the 25 sample sites utilized in increment core work.

In an overall evaluation, variation of selected anatomical properties in sweetgum has been established in upland and bottomland sites. Most importantly, this work indicates that sweetgum growing on upland sites is not of lesser quality than that growing on bottomland sites. While not detracting from the value of sweetgum on bottomland sites, the trees from upland sites represent a source of raw material and genetic diversity which could only enhance the role of this species in forest practices if utilized properly.

All measurable traits are a function of genotype/environment interactions, and the only way to evaluate the magnitude of the influence of each of these is through progeny testing.

In general, wood properties of hardwoods are extremely site sensitive and easily modified by the environment. Relative to coniferous species, heritabilities of these traits are low. To date, the heritability of wood properties in sweetgum have not been computed.

Results from this study display the variation which occurs between populations on different sites, but the nature of the research was not such to evaluate the relative influence of genotype or environment.

In order to properly quantify this relationship, progeny tests should be constructed which include selections from both upland and bottomland sites.

Future Work

This study was only the initial investigation of the variation of sweetgum between upland and bottomland sites and the prospects of improving the utilization of this species. The results contained herein are reflective for Louisiana only, and a great amount of sweetgum's natural range is yet untested. A great deal more research will be required to obtain a total understanding of the species and its variation. Future work should include:

(1) Expanding this work to include a greater sample size in an attempt to resolve deviations from past reports;

(2) Testing populations of known genetic material in an attempt to quantify the amount of variation accounted for by genetic variability;

(3) Testing a wide range of environmental variables to gain a better understanding of site influence on anatomical variation;

(4) Constructing similar studies in different regions of sweetgum's range to analyze the variation which may exist elsewhere;

(5) Investigating the effect of spacing in planted stands on anatomical variation;

(6) Investigating the relationship between growth rates and anatomical variation in order to obtain a better statement of site quality;

(7) Detailed investigation into the unusual variation of specific gravity with increasing height.

LITERATURE CITED

Avery, T. E. 1967. Forest measurements. McGraw-Hill Book Co., New York. 290 p.

Briegleb, P. A. and J. S. McKnight. 1960. The place of hardwoods in forest management. in Webb, C. D. 1964. Natural variation in specific gravity, fiber length, and interlocked grain of sweetgum (Liquidambar styraciflua L.) in the South Atlantic states. Ph.D. dissertation, North Carolina State Univ. 138 p.

Carpenter, B. E., Jr. and W. C. Hopkins. 1966. Specific gravity values of sweetgum topwood and bolewood. Forest Prod. J. 16(7): 30.

Choong, E. T. and P. J. Fogg. 1976. Extractives content and cell wall specific gravity in sweetgum. L.S.U. Wood Util. Note #30. 4 p.

Chow, P. 1971. Fiber length variation in the bole of an eccentric sweetgum tree. Forest Sci. 17(2): 186-189.

Ferguson, R. B. and D. T. Cooper. 1977. Sweetgum variation changes with time. South. Forest Tree Imp. Conf. Proc. 14 (in press).

Fogg, P. J. 1967. A tabular aid in the calculation of wood specific gravity. Forest Prod. J. 17(4): 52.

Forest Products Laboratory. 1964. Pulp yields for various processes and wood species. USDA Forest Serv. Res. Note FPL-031.

Forest Products Laboratory. 1974. Wood handbook: wood as an engineering material. USDA Agric. Handb. 72, rev.

Fowells, H. A., ed. 1965. Silvics of forest trees of the United States. USDA Agric. Handb. 271. 762 p.

Goggans, J. F. 1961. The interplay of environment and heredity as factors controlling wood properties in conifers with special emphasis on their effects on specific gravity. Tech. Rep. No. 11. Sch. of Forestry, North Carolina State College, Raleigh.

Harlow, W. M. and E. S. Harrar. 1969. Textbook of dendrology, fifth ed. McGraw-Hill Book Co., New York. 512 p.

Hart, C. A. and B. F. Swindel. 1967. Notes on the laboratory sampling of macerated wood fibers. Tappi 50(7): 379-381.

Hunter, A. G. and J. F. Goggans. 1968. Variation in specific gravity, diameter growth, and colored heartwood of sweetgum in Alabama. Tappi 51(2): 76-79.

Hunter, A. G. and J. F. Goggans. 1969. Variation of fiber length of sweetgum in Alabama. Tappi 52(10): 1952-1954.

Jett, J. B. and B. J. Zobel. 1975. Wood and pulping properties of young hardwoods. Tappi 58(1): 92-96.

Johnson, J. W. and R. L. McElwee. 1967. Geographic variation in specific gravity and three fiber characteristics of sweetgum. Proc. 9th Conf. South. Forest Tree Improv., Knoxville, Tenn. p. 50-55.

Johnson, R. L. 1968. Thinning improves growth in stagnated sweetgum stands. South. Forest Exp. Stn., USDA Forest Serv. Res. Note SO-82. 5 p.

Kaszkurewicz, A. 1975. Planted sweetgum responds to silvicultural treatments. La. Agric. 18(2): 10-11.

Kellison, R. C. 1966. A geographic variation study of yellow-poplar (Liriodendron tulipifera L.) within North Carolina. M.S. thesis, North Carolina State Univ., Raleigh.

Panshin, A. J. and C. deZeeuw. 1970. Textbook of wood technology, third ed. McGraw-Hill Book Co., New York. 705 p.

Perdue, R. E., Jr. and H. J. Nieschlag. 1961. Fiber dimensions of nonwoody plant materials. Tappi 44(11): 776-784.

Putnam, J. A., G. M. Furnival, and J. S. McKnight. 1960. Management and inventory of southern hardwoods. USDA Agric. Handb. 181. 102 p.

Qurik, J. T. 1975. Dot-grid integrating eyepiece: two sampling techniques for estimating cell wall areas. Wood Sci. 8(2): 88-91.

Randel, W. R. and J. E. Winstead. 1976. Environmental influence on cell and wood characters of Liquidambar styraciflua L. Bot. Gaz. 137(1): 45-51.

Santamour, F. S., Jr. 1972. Interspecific hybridization in Liquidambar. Forest Sci. 18(1): 23-26.

Smith, D. M. 1954. Maximum moisture content method for determining specific gravity of small wood samples. Forest Products Laboratory, USDA Forest Serv. Rep. 2014. 8 p.

Smith, W. J. 1967. The heritability of fiber characteristics and its application to wood quality improvement in forest trees. Silvae Genet. 16(2): 41-50.

Spurr, S. H. and M. J. Hyvarinen. 1954. Wood fiber length as related to position in tree and growth. Bot. Rev. 20: 561-575.

Spurr, S. H. and W. Y. Hsiung. 1954. Growth rate and specific gravity in conifers. J. Forestry 52: 191-200.

Staff of Forest Resources Research Work Unit. 1976. Hardwood distribution on pine sites in the South. South. Forest Exp. Stn., USDA Forest Serv. Resour. Bull. SO-59. 27 p.

TAPPI Forest Biology Committee. 1960. Pulpwood properties: response of processing and of paper quality to their variation. Tappi 43: 40A-64A.

TAPPI Forest Biology Committee. 1962. The influence of environment and genetics on pulpwood quality. Tappi Monog. Ser. No. 24. TAPPI, New York.

Taylor, F. W. 1963. Fiber length variation within growth rings of yellow poplar. (Liriodendron tulipifera L.). Tappi 46: 578-581.

Taylor, F. W. 1965. A study of the natural variation of certain properties of the wood of yellow-poplar (Liriodendron tulipifera L.) within trees, between trees and between geographic areas. Ph.D. thesis, North Carolina State Univ., Raleigh, N.C. 203 p.

Taylor, F. W. 1968. Variations in the size and proportions of wood elements in yellow-poplar trees. Wood Sci. Technol. 2(3): 153-165.

Taylor, F. W. 1969a. Variation of wood properties in sycamore. Forest Prod. Util. Lab., Miss. State Univ., Res. Rep. No. 7. 18 p.

Taylor, F. W. 1969b. Variation of wood properties of pecan. Forest Prod. Util. Lab., Miss. State Univ., Res. Rep. No. 8. 17 p.

Taylor, F. W. 1971. Variation of wood properties in sugarberry. Forest Prod. Util. Lab., Miss. State Univ., Res. Rep. No. 11. 17 p.

Taylor, F. W. and T. E. Wooten. 1973. Wood property variation of Mississippi Delta hardwoods. Wood and Fiber 5(1): 2-13.

Thorbjornsen, E. 1961. Variation in density and fiber length in wood of yellow-poplar (Liriodendron tulipifera L.). Tappi 44(3): 192-195.

Webb, C. D. 1964. Natural variation in specific gravity, fiber length, and interlocked grain of the wood of sweetgum (Liquidambar styraciflua L.). Ph.D. thesis, North Carolina State College, Raleigh, N.C. 138 p.

Wilcox, J. R. 1970. Inherent variation in south Mississippi sweetgum. Silvae Genet. 19: 91-94.

Williams, G. J., III. 1971a. Population differentiation in the Hill reaction of United States, Mexico, and Central America Liquidambar styraciflua L. Photosynthetica 5: 139-145.

Williams, G. J., III. 1971b. Levels of soluble sugars and ATP in ecotypes of Liquidambar styraciflua L. Photosynthetica 5: 399-405.

Williams, G. J., III. and C. McMillan. 1971a. Phenology of six United States provenances of Liquidambar styraciflua under controlled conditions. Amer. J. Bot. 58: 24-31.

Williams, G. J., III. and C. McMillan. 1971b. Frost tolerance of Liquidambar styraciflua L. native to the United States, Mexico, and Central America. Canad. J. Bot. 49: 1551-1558.

Winstead, J. E. 1968. Ecotypic differentiation in Liquidambar styraciflua L. Ph.D. thesis, Univ. of Texas, Austin. 148 pp.

Winstead, J. E. 1971. Populational differences in seed germination and stratifications requirements of sweetgum. Forest Sci. 17: 34-36.

Winstead, J. E. 1972. Fiber tracheid length and wood specific gravity of seedlings as ecotypic characters in Liquidambar styraciflua L. Ecology 53(1): 165-172.

Winters, R. K. and J. G. Osborne. 1935. Growth and yield of second growth red gum in fully stocked stands on alluvial lands in the South. South. Forest Exp. Stn., USDA Forest Serv. Occas. Pap. 54. 35 p.

Wooten, T. E. 1968. Variation of wood properties in willow oak. Forest Prod. Util. Lab., Miss. State Univ., Res. Rep. No. 5 12 p.

Wooten, T. E. and F. W. Taylor. 1968. The anatomical and chemical properties of black willow. Forest Prod. Util. Lab., Miss. State Univ., Res. Rep. No. 3. 24 p.

Zobel, B. 1977. Increasing southern pine timber production through tree improvement. South. J. of Applied Forestry 1(1): 3-10.

Appendix

Table 1. Total height and age data for all intensively sampled trees.

Area	Sub Area	Tree	Total Height		Age
			-ft.-	-m-	-years-
1[a]	B[1]	1	90.7	27.66	52
1	B	2	83.8	25.56	58
1	B	3	88.7	27.05	51
1	U[2]	1	73.5	22.42	48
1	U	2	74.5	22.72	39
1	U	3	67.0	20.44	36
2[b]	U	1	92.0	28.06	48
2	U	2	100.0	30.50	39
2	U	3	82.0	25.01	36
2	B	1	85.0	25.93	76
2	B	2	72.5	22.11	62
2	B	3	89.5	27.30	48
3[c]	U	1	68.5	22.42	48
3	U	2	73.0	22.27	42
3	U	3	65.5	19.98	42
3	B	1	67.5	20.59	47
3	B	2	78.0	23.79	46
3	B	3	60.5	18.45	38

a/ Kisatchie
b/ Lee Forest
c/ Idlewild- Ben Hur

1/ Bottomland
2/ Upland

Table 2 . Conversion Equivalents of Height Measurements to Metric Units

Ft.	m
Base	.15
4	1.22
8	2.44
12	3.66
16	4.88
20	6.10
24	7.32
28	8.54
32	9.76
36	10.98
40	12.20
44	13.42
48	14.64
52	15.86
56	17.08
60	18.30
64	19.52
68	20.74
72	21.96
76	23.18
80	24.40
84	25.62
88	26.84
92	28.08
96	29.30

VITA

Andrew William Ezell was born September 7,1950 in Lobelville, Tennessee. He attended public school and graduated from Perry County High School in May, 1968.

He entered the University of Tennessee in September,1968 and received a Bachelor of Science degree in Forestry in June, 1972.

He entered Yale University in September, 1972 and received a Master of Forest Science degree in May, 1974.

Ezell is a member of Phi Kappa Phi, Xi Sigma Pi, Sigma Xi, Alpha Zeta, Gamma Sigma Delta, Society of American Foresters, and the American Forestry Association.

He is now a candidate for the degree of Doctor of Philosophy in forestry.

EXAMINATION AND THESIS REPORT

Candidate: Andrew William Ezell

Major Field: Forestry

Title of Thesis: VARIATION OF SELECTED ANATOMICAL AND PHYSICAL PROPERTIES IN SWEETGUM (*Liquidambar styraciflua* L.) GROWN ON UPLAND AND BOTTOMLAND SITES IN LOUISIANA

Approved:

Elvin T. Choong
Major Professor and Chairman

James G. Traynham
Dean of the Graduate School

EXAMINING COMMITTEE:

Floyd G. Manwiller

Prentiss E. Schilling

Shirley C. Tucker

Peter J. Hogg

Bart A. Hodges

Date of Examination:

November 18, 1977