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Effect of Environment on the Percentage of Summerwood and Specific Gravity of Slash Pine

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EFFECT OF ENVIRONMENT ON THE PERCENTAGE OF SUMMERWOOD AND SPECIFIC GRAVITY OF SLASH PINE

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EFFECT OF ENVIRONMENT ON THE PERCENTAGE OF SUMMERWOOD AND SPECIFIC GRAVITY OF SLASH PINE

INTRODUCTION

THE forests of the southern pine region are becoming increasingly important to the American economy. Among the conditions that have favored this trend are the rapidity of growth and the ease of managing the essentially even-aged, single-species forests. These favorable conditions, together with the demands of our economic system, have provided foresters with an opportunity to practice large-scale forest management more intensively than ever before. The first steps in this intensified program of management have been the improvement of forest conditions and concentration on volume production. With the build-up of growing stock well under way, attention is now being shifted toward growing trees of higher quality.

One of the aspects of wood quality that is widely recognized by wood technologists, but seldom appreciated by foresters, is wood density. In the southern pine lumber industry, wood density and percentage of summerwood are of the utmost importance for it has been repeatedly demonstrated that the strength of the lumber produced varies directly with these two factors. Furthermore, the low-density wood, particularly in the rings nearest the center of the tree, is generally associated with high longitudinal shrinkage which results in a high percentage of degrade and loss.

Wood density and percentage of summerwood are equally important to the southern pine pulp and paper industry, since dense wood with a high summerwood content produces a higher yield of pulp than an equal volume of less dense wood with varying amounts of summerwood. Dense wood is not always desirable for the fiber characteristics of springwood and summerwood vary considerably and therefore influence the processing required and the nature of the pulp produced. A high summerwood content may be most satisfactory for strong kraft papers whereas a high springwood content may be more desirable for higher quality sulphite pulps (Bray and Curran, 1937). In practical application, however, it appears that the best over-all pulp would be obtained by keeping the springwood-summerwood ratio uniform from batch to batch (Curran, 1938).

ENVIRONMENTAL EFFECTS ON SLASH PINE

The growing of wood of uniform density would be largely a matter of conjecture to the practicing forester of today, even if economic conditions warranted such intensive management. The factors responsible for the variation in wood density are still not clearly understood and are open to much controversy, although they have been the subject of many studies both here and abroad. It is well understood, nevertheless, that the intimate relationship of climate, environment, physiology, and inheritance ail combine to form the complex pattern of growth. Yet, it is entirely possible that various expressions of these factors can be segregated and quantitatively defined. Wood of more uniform density could then be grown by modifying the controllable factors by either silvicultural practices or genetic improvement.

The objective of this study was to evaluate by statistical methods the influence of growth rate and age on summerwood percentage and specific gravity as well as the influence of certain environmental factors on summerwood percentage in slash pine. The investigation was also designed to test the feasibility of using increment cores for large-scale wood quality studies.

REVIEW OF THE LITERATURE

THE relationship of specific gravity[1] to its causal factors of growth has been a subject of investigation for many years. During this time a multitude of pertinent facts and data have accumulated, but to the practicing forester and technologist alike, the question of a primary controlling factor still remains unanswered.

The controversial nature of the problem becomes more fully appreciated as one becomes acquainted with the multiplicity of contributing factors. Koehler (1939) and Trendelenburg (1939) have compiled extensive lists of probable contributing factors and these lists would undoubtedly attain tremendous proportions if all the minutiae were included that are visually expressed as growth. Confusion in the literature is no doubt traceable to the persistent effort of investigators to resolve this complex biological system to a single, simple descriptive term—a rule of thumb.

Through the years investigators have employed devious methods of isolating the factors believed to be most closely associated with specific gravity and summerwood percentage. A number of influencing factors of primary importance have emerged from these studies. Yet minimization to even a few primary variables has resulted in highly controversial interpretations. This diversity of opinion can often be attributed to sources of variation which may or may not have been recognized but nevertheless were not accounted for, together with the interrelationships of other variables. In addition, differences in sampling, sample size, and analysis of data add to the discrepancy of seemingly comparable investigations.

VARIATION IN SPECIFIC GRAVITY WITHIN A GIVEN CROSS-SECTION

With few exceptions specific gravity has been found to increase from pith to cambium in the gymnosperms. Coincident with this density increase from pith to cambium there is also a general tendency for ring width to decrease and the percentage of summerwood to increase. These trends have been subjected to various interpretations and the question is still highly controversial as to whether the effect of age or growth rate predominates in influencing the density gradient. An unbiased selection of the true determinant is difficult to arrive at from a literature survey because of the confounding of factors in most investigations. For example, ring width is commonly con-

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[1] The terms specific gravity and wood density will be used synonymously throughout this review.

founded with site, stem class, tree age, and position in the tree but most frequently with age of ring from the pith.

Effect of Summerwood Variation

Variations in specific gravity have been found to be closely correlated with variations in the percentage of summerwood in the annual ring (Schwappach, 1892; Janka, 1909, 1918, 1921; Rochester, 1933; Berkley, 1934; Johansson, 1940; Burger, 1942, 1948, 1951, 1952, 1953; Paul, 1950; Ylinen, 1951; Siren, 1952; Pillow, 1952, 1954; Vorreiter, 1954; Smith, 1955, 1956; and many others) ; hence, the latter expression has been widely accepted as providing a fairly good estimate of specific gravity. For the southern pines of the United States, about 72 percent of the variation in specific gravity has been attributed to the amount of summerwood when rate of growth was ignored and 31 percent to growth rate when the amount of summerwood was ignored (Schafer, 1949; Chidester, 1954).

A detailed study of the summerwood percentage relationships in the southern pines was conducted by Lodewick (1933). The innermost rings were found to be low in summerwood but this was not caused by the greater than average ring widths, since rings of the same widths occurring in the outer portions of the tree invariably possessed greater percentages of summerwood. Age of ring was therefore recognized as having an effect on the width of summerwood. When the inner eight rings were excluded, the relation of percentage of summerwood over ring width resulted in a parabolic curve which was concave downward, that is, increasing ring width was associated with decreasing summerwood. No universal relation was found to exist between ring width and percentage of summerwood. It depended partly on the portion of the tree in which it was formed, partly on the amount of growing space, and possibly on site.

Other investigators have also studied the relationship between ring width and summerwood. Schafer (1949) reported no significant correlation between rate of growth and percentage of summerwood while Klem (1942) and Nylinder (1953) maintained that increasing ring widths were accompanied by decreasing percentages of summerwood. Von Mohl (see Priestly, 1930) and Fegel (1941) concluded that the variable factor was the depth of the zone of thin-walled springwood tracheids and that the denser summerwood remained nearly constant in width. This conclusion is not corroborated by the work of Lodewick (1933) and many others.

The effect of old age on summerwood percentage has been detected by a number of investigators (Hartig, 1874; Mohr and Roth, 1896; Janka, 1909; Berkley, 1934; and Wandt, 1937) who showed that summerwood percentage and density increased until maturity, at which time ring width, summerwood percentage and density decreased simultaneously. Considering all variables, Trendelenburg (1939) concluded that although in larch, pine, and Douglas-fir the density of wood of the same percentage of summerwood was higher in narrow than wide rings, a high percentage of summerwood was of more frequent occurrence in moderate ring widths than in rings either very narrow or very wide. Thus, the density was greater in the zone of moderate ring widths.

Data presented by Paul (1939) and Kollmann (1951) indicated that the density of springwood either decreased or remained constant from pith to cambium whereas, over the same distance, the density of summerwood increased. The density difference between springwood and summerwood was found to be greater, the clearer the boundary between them; this point was also emphasized by Seaman (1926). Furthermore, it has been shown that certain species having light springwood also have light summerwood (Vintila, 1939).

Effect of Ring Width

Nordlinger (see Kollmann, 1951) first expressed the view that in conifers narrow rings resulted in heavy wood and that in hardwoods the reverse was true. Few workers have unquestionably accepted the inverse relationship between growth rate and density over the entire range of ring widths. The data from numerous studies indicate that there is apparently an optimum ring width for the production of maximum specific gravity values (Paul, 1930; Luxford and Markwardt, 1932; Rochester, 1933; Trendelenburg, 1935; Volkert, 1941 ; Burger, 1945; Kollmann, 1951).

According to species, the optimum ring width has been placed between 0.5 to 1.0 mm. for spruce (Wandt, 1937; Burger, 1941, 1942, 1952, 1953); 1.5 mm. for fir (Burger, 1951) ; 1.0 mm. for Douglas-fir (Volkert, 1941) ; 1.0 to 2.0 mm. for larch (Worschitz, 1930; Schonbach, 1938; Volkert, 1941) ; and 1.0 to 2.0 mm. for Scots and white pine (Jalava, 1934b; Wandt, 1937; Burger, 1941; Volkert, 1941; Ylinen, 1951). Bryan (1956) was of the opinion that growth rate was of little importance when it exceeded 4 to 5 rings per inch.

It has also been suggested that maturity in age, size, or both, contributes toward the production of narrow rings and light wood. Thus, the decrease in density below the optimum in very narrow rings may be due either to growth suppression or maturity. Such a decrease in wood density has been reported for the narrow rings of over-mature specimens of practically all the major species studied (Hartig, 1874; Schwappach, 1892; Bertog, 1895; Omeis, 1895; Mohr and Roth, 1896; Janka, 19°9; Hale and Fensom, 1931; Berkley, 1934; Kalnins and Liepins, 1938; Trendelenburg, 1939; Pechmann, 1954).

Variations in stand conditions, consequently variations in growth patterns, have also been considered to influence the cross-sectional density gradient. For example, in the "Mittelwald" of Germany where pine exists as a residual overstory with hardwoods, Pechmann (1950) found a pattern of narrow rings near the pith, increasing in middle age, and a continuing high growth rate in old age. Variations in ring width were relatively slight because of the several hardwood cuttings during the life of the pine overstory. As a result of this uniform ring structure, density was very uniform throughout; however, it was also very low. Chalk (1953) observed a similar tendency in young Douglas-fir of almost uniform ring width. The density of individual rings remained fairly constant from pith to cambium with no increase to the outside.

Similarly, Burger differentiated between selection forest (Burger, 1942, 1952) and even-aged high forest (Burger, 1951, 1953) spruce and fir with respect to ring width. In the even-aged forests, specific gravity of the wood increased from pith to cambium because the annual rings were wide in youth and narrow when older. Quite the opposite was found in the selection forests with slower juyenile development. The wood of the innermost rings was generally somewhat denser than the wood of the outer rings although the trend was not as clear in spruce as in fir.

On the basis of a study of spruce plantations in Germany, Hildebrandt (1954) concluded that with the decrease in ring width from inside outward in a stem was bound an actual mathematical increase in density. If the decrease in ring width failed to be present, then the density distribution would be irregular. Wandt (1937) reached a more positive conclusion and reported that the influence of ring width upon density was so great in the different increments of a stem, that whether density decreased, increased, or varied from below upward could be traced back to the density of stocking at a particular age in the stand. Other workers have also agreed, in general, with the thesis that wood density increases with decreasing growth rate (Janka, 1921; Alexander, 1935; Burger, 1935; Hale and Prince, 1940;

Fegel, 1941; Schrader, Allen and Hughes, 1949; Pillow, 1954; Keylwerth, 1954)·

Volkert (194I) summed up his work on white pine by stating that the normal course of ring width decreased from within outward and density increased accordingly. However, with variations from regularity, the relationship between density and ring width showed less agreement. It therefore appeared that the causal relationship between ring width and density could only be very weak, much weaker in any case than the resulting uniformity of density increase from within outward. In the case of either a strong decrease or increase in ring width after fifty years of age, density still continued to increase but at a slower rate than with the "normal" course of ring width. This was more or less confirmed by the work of Paul (1941, 1946) and Paul and Meagher (1949) who showed that release cutting in mature pine stands did not appreciably decrease wood density althqugh growth rate increased considerably.

Effect of Age of Ring

According to Hartig (1874) previous investigators considered narrow-ringed pine wood heavier than wide-ringed wood but they failed to consider the relation of tree part to age. He credited Sanio (1872) as being the first to show thatsummerwood percentage varied within the stem independent of ring width. Schwappach (1892) also disagreed with the general view that wood quality decreased with increasing ring width. His study disclosed no uniform relationship between ring width and wood density; however, two points stood out: a) the innermost rings were very broad and of low density, b) very narrow rings, in trees over 150 years of age, were of low density. Hartig (1892, 1898a) and his students, Bertog (1895) and Omeis (1895), re-emphasized the predominating influence of age as did Janka (1918). The data of Paul (1913) showed that specific gravity increased with increasing stand age and diameter breast high.

Turnbull (1937, 1946, 1947) has recently revitalized the age-density theory, applying it to pines grown in South Africa. He showed that the density of wood formed in a particular year was not determined by its rate of growth but was proportionate to a function of age. Density continued to increase steadily from the pith outward regardless of whether ring width increased or decreased. He considered the variations in rate of growth as "accidentals" caused by either differential thinning, pathological, or seasonal factors, and the density gradient, on the other hand, as a fixed characteristic of the site sampled. Investigators in other Commonwealth countries have followed Turnbull's lead and stressed the controlling influence of age (New Zealand Forest Service, 1948; Orman, 1952; Scott, 1952; Loe and Mackney, 1953; Australia CSIRO, 1954). In the United States, Lindgren (1949) obtained no correlation between specific gravity and ring width, but specific gravity increased steadily with increasing age of pulpwood bolts from a slash pine plantation. Yandle (1956) found significant differences between lo-year age segments in loblolly pine after the effect of growth rate had been accounted for. No correlation between ring width and wood density could be detected for jack pine by Spurr and Hsiung (1954) but there was a definite correlation between wood density and age. Göhre (1955b) reached the same conclusion for Douglas-fir. Zobel and Rhodes (1955) reported that both ring width and age played but a minor role in accounting for the variation in specific gravity of loblolly pine. Cockrell (1944) also observed no specific gravity differences attributable to age in ponderosa pine.

Effect of Stem and Crown Class

From the material presented in the preceding sections it is apparent that a conclusion cannot be readily drawn concerning the relative influence of age and ring width on wood density. Attempts to arrive at a definite conclusion from the study of single cross-sections is precluded by the intimate relation of ring width to age. Confounding of these variables can best be avoided by comparing ring widths and specific gravities from trees of the same age grown under identical conditions.

Beginning with the early investigators, Hartig (1892) commented on the fact that no previous studies showed the relation of stem class to wood quality in even-aged stands. However, Hartig (1874) had mentioned that suppressed pines with narrow rings formed, in the first stages of suppression, relatively broad summerwood zones, therefore heavy wood. After continued suppression and a further decrease in ring width, the summerwood was conspicuously less than the springwood in the lower tree parts which resulted in lighter wood. Jalava (1945) obtained identical results with pine in Finland. This tendency is of frequent occurrence in pines and a number of workers have noted that density decreases with stem class from suppressed to dominant (Burger, 1929, 1941, 1948; Kalnins, 1929, 1930; Kalnins and Liepins, 1938; Pillow, 1954) and that open-grown trees possess less-dense wood than forest-grown trees (Paul, 1930, 1952; Jalava, 1934b; Hagglund, 1939). These results are not universal, however, since Omeis (1895) found the dominants to be heaviest and Tiebe (1940) observed that strong crowns produced the heaviest wood, while Mohr and Roth (1896) and Turnbull (1937) could find no differences between stem classes. In New Zealand (New Zealand Forest Service, 1949), specific gravity increased from dominant to suppressed in 29-year old trees of *Pinus insignis* whereas in 37-year old *Pinus patula* the reverse was true.

With respect to stem class, wood density has also been found to decrease from suppressed to dominant in spruce, fir, Douglas-fir, and larch (Hartig, 1892,1897, 1898a; Cieslar and Janka, 1902; Klem, 1933; Volkert, 1941; Hirai, 1949; Hirai, 1950; Burger, 1941, 1942, 1951, 1952, 1953; Wellwood, 1952; Pechmann, 1954).

Volkert (1941) attempted to explain the uniform density of the dominants on the basis of growth rate. As a rule, the dominant stems had the fastest growth and the lowest wood density while the lower stem classes had the narrowest outer rings and highest wood density. The difference in ring width between dominants and smaller stems was only slight in youth, whereas it became greater with increasing age. Therefore, the difference between the lowest (inner) and highest (outer) densities was greater in smaller stems than in the large dominants. As a result, in even-aged stands the lesser diameter classes produced denser wood but the larger diameter classes produced wood of more uniform density.

In 50 to 70-year-old pine (Burger, 1929) and spruce (Nylinder, 1953; Hildebrandt, 1954) stands it was observed that the intermediate stem class was heavier than either the dominant or the suppressed classes. However, physiological or mechanical disturbances often resulted in an irregular distribution of wood density within classes. Hartig (1888) showed that for spruce in Bavarian forests, the wood of plantation-grown trees on clear-cut areas was of much lower density than the wood of young trees of the same age growing slowly in a selection forest; but with increasing age the two tended toward the same density. Dense stocking, either in natural forests or plantations, produced heavier wood than less dense stocking according to Luxford and Markwardt (1932), Klem (1942), Schrader, Allen and Hughes (1949), Paul (1930, 1950) and Hildebrandt (1954). A 29-year old white spruce of very rapid growth was reported to be 20 percent lighter than average for the species by Lee (1917).

Hartig (1897, 1898b) advanced a theory in which he attempted to explain the variation in wood density between stem and crown classes in terms of water requirements. He believed that large-crowned trees and open stands in which trees began growth early and grew rapidly, had high water requirements and high transpiration and thus produced much light springwood at the expense of the summerwood. Small-crowned trees in dense stands and trees growing in low, moist locations, had low water requirements and low transpiration and thus produced little springwood and a higher proportion of heavy summerwood. Hartig contended that conditions which affected the water relations, favorably or unfavorably, could be explained on this basis. Other workers have also accepted this view, either wholly or in part, to explain density variations in their data (Schneider, 1896; Cieslar and Janka, 1902; Janka, 1909; Trendelenburg, 1939; Tiebe, 1940; Pechmann, 1950,1954).

Effect of Site and Locality

Site characteristics and geographic locality exert a considerable influence on the factors which contribute to wood density. Certain density factors were the subject of investigation in very early forest research. However, independent of these numerous and often extensive investigations, Hartig (see Schneider, 1896) developed a new method of research which made it possible to differentiate woods not only according to tree height and age but also according to site, management and climate.

The general view of Hartig (1892, 1897, 1898a) was that good sites, by which he meant good soil conditions, produced heavier spruce wood than poor sites. Janka (1909) agreed that good soil conditions produced better spruce wood than poor, dry soils but only when comparably stocked. A poor site due to too much moisture also produced a poor, light wood. He contended that site quality alone could not lead to the production of dense wood unless trees were growing at an optimum density of stocking. Similarly, Török (1933) reached the conclusion that the heaviest spruce would be produced on optimum and favorable sites where soil moisture was considerably higher but where other growth factors were also optimum. This is similar to the view taken by Chancerel (1920). The opposite relationship was found by Klem (1933) and Pechmann (1954) who showed that good spruce sites produced lower density wood than average and poor sites.

In pine, as in spruce, Hartig (see Trendelenburg, 1939) found that poor sites produced the lightest wood. Paul (1939) also showed that shortleaf pine growing on light gravelly sand was less dense than the same species growing on red clay loam for the same age and growth rate. Likewise, the wood produced by longleaf pine on a shallow soil that frequently became dry in summer was much lower in specific gravity than the wood of trees growing on a deep, moist soil in the same vicinity (Paul and Smith, 1950; Paul, 1952). On less critical sites, Trendelenburg (1939) observed the summerwood percentage in pine to be less on sand soils than on loam, although in reworking Schwappach's data he (Trendelenburg, 1939) could find no difference in density of pine attributable to site; Schwappach (1898) had found differences in density between growth regions but practically none between sites in the same region.

Working with Minnesota jack pine, Spurr and Hsiung (1954) could find no correlation between specific gravity and site. In their study, sites varied from upper slope to lower slope in the same stand. Also for jack pine, Wilde, Paul and Mikola (1951) ascertained that, on glacial outwash material, the better sites with faster growth produced the lowest density wood. Contrarily, on an extreme site in the Nebraska sandhills, jack pine produced a light weak wood due to poorly developed summerwood (Koehler, 1938).

Both Paul (1950) and Wellwood (1952) attributed a lower specific gravity to Douglas-fir growing on good sites than on poor. Chalk (1951), on the basis of a study begun by Barrow (1951), determined a greater density in Douglas-fir trees growing near a river than in trees growing some distance away with a less plentiful water supply. The specific gravity of white cedar has been shown to be somewhat greater on limestone soils than on peat bogs (Harlow, 1927). Luxford and Markwardt (1932) reported no definite relation between site class and specific gravity in redwood although Paul (1930), for the same species, considered the difference between the poorest and best sites to be less than the differences due to spacing on the same site.

The site differences brought about by changes in altitude have received considerable attention in European investigations. An increase in altitude generally implies a deterioration of site quality due to the mutual effect of unfavorable climate and poor soil. Thus, the density of spruce (Klem, 1933; Trendelenburg, 1939; Burger, 1941, 1952, 1953; Vorreiter, 1954), of fir (Burger, 1951), of pine (Burger, 1929, 1948) and of larch (Janka, 1918; Worschitz, 1930; Schonbach, 1938) has been found to decrease with increasing elevation. This decrease in density in spite of the decrease in ring width has been attributed to a decrease in summerwood percentage and cell wall thickness.

According to the optimum theory of Mayr (see Rubner, 1929) every species has a territory, determined by climate and other factors of growth, where it produces the best wood material. When it is shifted from this region to a more favorable or unfavorable climate, generally with respect to temperature, the quality of the wood produced is lowered. Janka (1909) maintained that this law could never be tested since it was impossible to find comparable sites or stand conditions in different climatic provinces. Jalava (1933, 1934a, 1934b) also believed that the influence of climate on growth was overemphasized in Mayr's theory, since in addition to the climatic optimum there should also be taken into consideration optimum soil quality, stand density, etc. if one desired fully to understand the conditions of growth and to explain their influences. Jalava's modification of Mayr's theory formed the basis of the forest type theory as it affected wood density, and it was demonstrated in Finland that the forest type in which the best quality wood was found shifted with more favorable climate from the better sites in the north to poorer sites in the south. Thus, in south Finland the best wood was produced on the poorer sites where the tendency for the overly favorable climate to produce light wood was compensated for by poorer soil quality. Although the work of Jalava has been of outstanding interest, Lassila (1929) at an earlier date did considerable work on specific forest types in Finland as did Kalnins (1929, 1930) in Latvia.

Regional differences also occur in which the climatic factors exert a greater influence than on sites locally situated. For Canadian Douglas-fir, Sterns (1918) reported that the variations within regions were probably as great or greater than between regions. Hale and Fensom (1931) could find no differences due to site or locality of white spruce in Saskatchewan and Manitoba but Hale and Prince (1940) did observe differences when greater longitudinal distances were considered. In Great Britain the specific gravity of Sitka spruce has been found to increase from north to south (Bryan and Pearson, 1955). The view of Janka (1904) and others has recently been re-emphasized by Göhre (1955a) who concluded that the differences in density between stems of the same stand are so great that differences between growth regions, races and degrees of management exhibit no systematic trend.

Effect of Heredity

Heredity affects wood density principally through geographic races evolved by climatic and site differences. Janka (1909), Jalava (1933), Kalnins and Liepins (1938), and Zobel and Rhodes (1955) have suggested that observed differences in wood density of spruce and pine could possibly be due to racial variation. A number of other workers have intimated similar possibilities, but actual tests under controlled conditions are limited in number.

Tiebe (1940) recognized 10 different races of Scots pine in Germany. Eight of these races were growing in a 33-year old provenance test area of the Tharandt Experimental Forest. Considering all stems within a race together, Tiebe found that the shape of the frequency curves of density were similar, but between races the means varied indicating that they were "race characteristic". Morath (1937) and Göhre (1955a) found the differences between pine races to be so slight that they fell within the mean values for the species while Rees and Brown (1954) found only one red pine seed source with an exceptionally high wood density out of nineteen tested.

In Switzerland, seed origins of spruce from altitudes of 500 and 1850 meters were planted on sites of 470 and 1600 meters elevation. When the stands were 40 years old, Burger (1941) showed that even with the same summerwood percentage and ring width, wood density varied due to differences in the structure of the summerwood. In 32-year old Scots pine of different origins planted at 4IO, 1070, and 1920 meters elevation, Burger (1941) also found that wood density decreased with altitude due to unfavorable site and decreasing ring width. On each site tested the slowest growing races produced the heaviest wood. As a result of a study of snow-damaged spruce plantations, Pechmann (1953) cautioned that average spruce seed obtained from commercial sources in the "long-period" lowlands and planted on good sites in the mountains would exhibit an unusually long growing season resulting in wood of low density and weak structure. Volkert (1940) also studied the wood of trees subject to excessive snow damage.

In Australia (Australia CSIRO, 1954) it has been shown that the wood of pine hybrids is intermediate between parent species in strength and that their properties vary according to the degree of hybridization. Wood quality has been taken into consideration in the work of the Swedish tree improvement program (Nilsson, 1943) and also of the Texas Forest Service (Texas Forest Service, 1953). The role of heredity in wood research at the Forests Products Laboratory was stressed at an early date by Koehler (1939) and more recently by Mitchell (1954, 1956a, 1956b).

RANGE AND SITE REQUIREMENTS OF SLASH PINE

THE natural range of *Pinus elliottii* Engelm., formerly known as *P. caribaea* Morelet (see Little, 1953), extends from South Carolina westward to the Mississippi River in Louisiana and from the southern limit of the Florida peninsula to points about 50 miles inland in Mississippi, 75 miles in Alabama, and 130 to 150 miles in Georgia (Mattoon, 1916b). The range map (Fig. I) was adapted from those published by Mattoon (1916b) and Munns (1938). Mattoon (1916b) considered that the northern limit of distribution was determined by temperature rather than moisture conditions, since the isotherm marking the mean annual minimum temperature of 20°F. roughly coincided with its northern limit. The absolute minimum

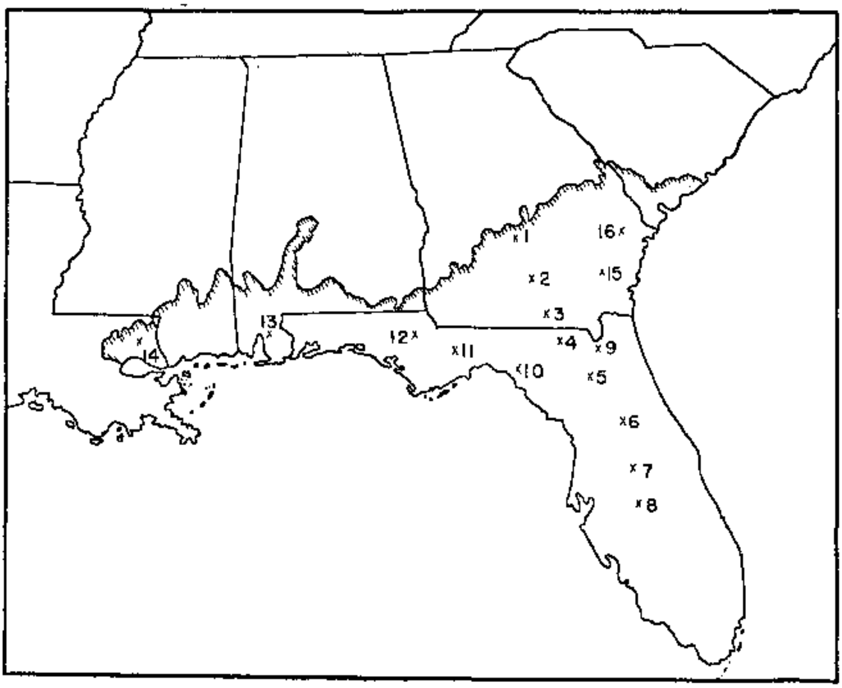

FIGURE 1. Natural range of slash pine and the approximate locations of the 16 geographic sampling areas.

along this line averaged about 5°F. Recent planting has considerably extended the range of slash pine.

In past years slash pine was confined primarily to the poorly drained flatlands and the borders of swamps and bodies of fresh water. With the extensive cutting of longleaf pine and particularly the improved fire protection, slash pine is now invading many of the better upland sites; this invasion has been progressing for about the past 20 to 25 years.

Slash pine reaches its best development in the shallow ponds and along the margins of deeper depressions where grass is abundant as well as on the well-drained sandy loam soils underlain by clay in the uplands. The poorest growth is found in the flats or ponds where the roots are submerged in water for considerable periods of the year, on poorly drained "crayfish flats", on shallow hardpan soils, and on the deep, well-drained, pure sands where scrub oak is mixed with the pine. In the deep sands of Western Florida and on similar soils in other parts of its range, slash pine is often the complimentary species with longleaf pine, the latter covering the ridges and slash pine in the drains and depressions. The characteristics and silvical requirements of slash pine have been adequately covered by Mattoon (1916b, 1939) and McCulley (1950) and the soil-site requirements by Goggans (1951), Coile (1952a, 1952b) and Barnes (1955).

MATERIALS AND METHODS

FIELD PROCEDURE

Plot and Tree Selection

Sixteen geographic sampling areas were selected to include the extremes of the natural range of slash pine in both the north-south and east-west directions (Fig. 1). Sampling was restricted to the range of the North Florida variety of slash pine (*Pinus elliottii* var. *elliottii*, see Little and Dorman, 1952), and thus did not include the southern one-third of the Florida peninsula.

At each geographic location two sample plots were laid out in stands representing a moist and a dry site. Because of the restrictions imposed on stand selection it was impossible to find a suitable wet site in area 11 or dry sites in areas 7 and 12; a total of 29 plots were therefore established rather than the proposed 32. The requirements specified that the stand must be even-aged with a mean age between 25 and 35 years, of natural origin, unthinned, and untapped for naval stores. The latter restrictions made it a difficult task to locate suitable stands because of the nature of slash pine growth and management. Over most of the slash pine area extensive fire control has been in effect for only about 20 years. Consequently, the bulk of the second-growth stands were slightly below the minimum age at the time of sampling. Also, because of the ready accessibility of most areas and the current markets for pulpwood and naval stores, the majority of the stands within the 25- to 35-year bracket had been either thinned or turpentined. These conditions necessitated a greater flexibility in the selection of stands than was originally intended. As a result, plots 15-D and 15-W were below the minimum age and plot 14-D was above the maximum.

Collection of Field Data

On each plot 25 trees were selected within the d.b.h. range of 6 to 14 inches. This arbitrary limitation was imposed merely to define the diameter distribution and maintain a certain degree of uniformity. Within this diameter range, the 25 trees nearest the plot center were selected for sampling. Trees of an obviously older or younger age class than the plot average, leaning trees, and trees suspected of containing excessive amounts of compression wood were excluded.

Two increment cores were extracted from each selected tree at the same cardinal position at 3.5 feet above the ground line; the second core was taken about 2 inches below the first. The lower core was later segmented and used for specific gravity determinations and the upper core was used for ring counts and measurements. No attempt was made to collect cores from predetermined positions related to crown development, exposure, or cardinal direction. The asymmetry of ring formation, prevalent in many trees, was also ignored by use of a single position on the tree. It was essential that each boring pass through the center of the tree so that age could be determined and the rings measured accurately. Re-borings were made slightly above or below the original when the center of the tree was missed. In the field, each core was placed in a paper straw immediately after extraction to avoid breakage and chance mixing with other cores. The straws containing cores from each plot were stored in a cardboard mailing tube.

Each plot was mapped with a plane table and all trees 4 inches d.b.h. and over were recorded by diameter. Directions to trees were determined with a peep-sight alidade and distances measured to the nearest foot with a tape. Plot size was dictated by the distribution of the 25 sample trees. In addition, plot boundaries were extended as necessary so that each sample tree would have a minimum mapped area of 20-foot radius surrounding it. This information was used for the later determination of spacing factors.

Diameter, total height, and height to the base of the live crown were recorded for each of the 25 sample trees on each plot. Site index was computed from the total height measurements of dominant trees included in the sample.

A soil pit was dug on each plot and samples collected from each horizon or characteristic profile change down to a maximum depth of 40 inches. Notes and measurements were made on the depth and thickness of each horizon, mottled layers, hardpan where encountered, and other characteristics that appeared pertinent or conspicuous. Additional measurements were made with a soil auger at various positions on each plot.

LABORATORY PROCEDURE

Determination of tree spacing factors

In this study, where the stand density-wood density relationship was considered for each tree, the need arose for a numerical measure of stocking applicable to the individual tree and not to the plot as a whole. Reineke's (1933) stand-density index was adapted for this purpose by expressing the number of trees per acre on the Y-axis as number of trees within a competition zone; this was defined as a 20-foot radius around each tree after testing competition zones of 10-, 15-, 20- and 25-foot radius on a sample plot basis. The basal area and number of trees were determined directly from the plane-table map of each plot by circumscribing to scale a 20-foot radius circle around each tree. Reineke found that the curve of maximum values for slash pine was not parallel to his reference curve but diverged slightly. Thus, a reference curve was drawn for slash pine based on the loo-percent stocking values given by Stahelin (1949).

Climatic Summarization

Climatic data were obtained from the U. S. Weather Bureau's Annual Climatic Summaries. Weather reporting stations were selected on the basis of proximity to the sample plots and on the length of the precipitation record. In several instances composite data from two stations were required where breaks occurred in the record of the selected station.

The data for each station were summarized by individual months for the 15-year period covered by the 5-year increment core segments 3, 4, and 5 (see *Specific gravity determinations).* Thus, the final values were 15-year monthly precipitation averages. These did not, however, cover the same 15-year period for each plot but varied depending upon the mean ages of the trees on the plots. For example, segments 3, 4, and 5 on plot I-D included the years 1933 to 1947, whereas the same segments on plot I-W included the years 1937 to 1951. Certain of the mean monthly values were later combined for use in the statistical analyses.

Soil Analyses

In the laboratory the moisture equivalents and the proportion of soil separates were determined for all the soil samples. All tests were run in duplicate and the mean values used in later statistical analyses.

Moisture equivalents were determined by the method described by Veihmeyer, Israe1sen, and Conrad (1924) and mechanical analyses by the Bouyoucos method (Bouyoucos, 1936). The soil separates were classified according to the International Classification and textural classes determined from the definitions in the U.S. Department of Agriculture Soil Survey Manual (1951).

MATERIALS AND METHODS

Preparation of Increment Cores

In the laboratory the dry cores were placed in numbered test tubes filled with tap water and soaked for 24 hours. A preliminary test showed that this soaking period was adequate to bring the air-dry cores back to their normal length. Eklund (1951) also found a 24-hour soaking period to be entirely satisfactory for pine and spruce cores.

The counting and measuring of growth rings was facilitated by placing the measurement cores in a clamp fitted with smooth, steel jaws and slicing off the upper transverse surface of the core with a sharp knife. This hand-held instrument was patterned after one in use at the Forest Products Laboratory and was similar in operation to the modified microtome of Krauss and Gärtner (1936).

The springwood-summerwood transition was brought into clearer detail by staining the cores with a saturated solution of fast green in 95-percent ethyl alcohol. Cores to be examined were placed on a simple core-holder consisting of a slotted groove in a block of wood and the device was placed on the stage of a low-power, binocular microscope. Light from a 100-watt microscope lamp was reflected by the substage mirror and transmitted through the core. The combination of stain and transmitted light was extremely effective in delineating the springwood-summerwood transition zones.

Age Determinations

Prior to the measurement of ring widths it was necessary to determine the correct number of annual rings in each increment core. Approximate ring identifications were not acceptable since all subsequent measurements were dependent upon the assignment of a correct age and year of origin to each ring examined. This proved to be one of the most difficult and frustrating tasks of the entire study, for it was readily apparent that the commonly accepted criteria for differentiating between annual rings could seldom be relied upon except in the most clearly defined cases. Thus, it was found desirable to employ the dendrochronological technique of cross-checking.

Cross-checking, in this case, involved the comparison of all increment cores on a particular plot until a ring sequence was observed that was repetitive on all cores. The most expedient procedure was to make a cursory examination of the cores from the dominant and suppressed trees and from these obtain a tentative list of key growth rings. A more intensive examination generally segregated one to several of these key rings that could then be identified on all cores in the plot. The best key rings were either the extremely narrow ones (narrow springwood, summerwood, or both) or conspicuous false rings (Plate II, b). A single key ring was rarely sufficient for dating purposes, but with two or more a reliable ring sequence could be readily established and the difficult rings indentified.

Difficult rings could be classed in three general categories: microscopic rings, discontinuous rings, and false rings. Microscopic, or extremely narrow rings, were of frequent occurrence in many trees of the intermediate and suppressed classes due to the marked slowing down of growth in the unthinned stands. These rings contained both the springwood and summerwood components and were readily discernible under the microscope although indistinguishable to the naked eye. The exceptionally narrow microscopic rings presented the major problem in ring identification. These often existed as fine "lines" with the springwood and summerwood consisting of one to several radial series of cells (Plate I). In extreme cases, the annual ring boundary consisted of a single series of cells whose walls were only slightly thicker or thinner than the adjacent cell series. Such rings could only be identified as true annual rings by means of key rings lying to the inside. For example, if the expected location of a key ring was the 1*1th* ring from the cambium and in the tree in question it was the *10th* ring, then the microscopic ring was assumed to be an annual ring. Verification could also be obtained by cross-checking with other trees, since rings that existed as traces in some trees were most generally very narrow in others.

Closely allied to microscopic rings were the microscopic springwood bands in some trees from the southern-most plots in Florida. The complete rings were not microscopic and were, in fact, often the widest growth rings in the dominant trees. However, the springwood bands in these trees were poorly developed in comparison to normal springwood since they were composed of relatively thick-walled cells in addition to being narrow in width (Plate II, a). These rings with high percentages of summerwood most frequently occurred in the older growth rings, twenty or more years of age.

Discontinuous growth rings may be defined as rings that do not encircle the tree as complete rings; either the springwood or summerwood is missing on a portion of the ring. Fortunately, by restricting the tree selection to merchantable stems with a 6-inch or greater d.b.h., discontinuous rings were rarely encountered in this study. The best examples were the five suppressed trees in plot g-D which were traced by complete stem analyses and described in detail by Larson (1956).

In a method similar to that described for microscopic rings, the presence of discontinuous rings could be determined by means of key rings and their approximate location ascertained by cross-checking. Since all discontinuous rings encountered were of the fused summerwood type, i.e., no intervening springwood between the annual increments, they could often by identified by the occurrence of an unusually wide summerwood band.

False rings (more than one growth ring per year) were common in the young rings near the pith in most of the faster growing trees on all plots. Occasionally, false rings were encountered that were impossible to distinguish from true rings without resorting to cross-checking. Such false rings were rather wide and possessed well-defined transition zones. Yet in other trees of the stand the same ring could be readily identified as a false ring while in still others it would be non-existent. In contrary cases, very narrow annual rings in some trees could easily be mistaken for false rings if not carefully cross-checked with other trees.

The most troublesome false rings were found in the cores from the southern-most plots in Florida (Plate II, c). In some trees it was not uncommon for every annual ring from pith to cambium to be accompanied by one to several false rings. Annual ring identification on a single core was therefore impossible, but with repeated cross-checking a ring sequence could always be established. Once a suitable ring sequence was established, the annual rings with their false components could be readily identified.

The author has concluded from this investigation that the determination of the true age of a slash pine tree from a single increment core is to be questioned. The true age can only be determined by careful cross-checking with neighboring trees in the stand. This conclusion is further strengthened by the observations of Phillips (1941) who noted that in the southern pines, "consistently irregular growth rings having multiple bands of latewood have been observed to occur only in *P. caribaea.*" Numerous investigators have encountered similar difficulties in growth ring identification. Many of these papers have been reviewed by Glock (1937, 1941, 1955).

Ring Width Measurements

The springwood and summerwood of each annual ring from pith to cambium were measured on each measurement core after all rings had been identified and the correct age determined. All measurements were made to the nearest 0.1 mm. with an eye-piece micrometer.

An attempt was made to employ Mork's (1928) definition for summerwood since the cell walls were readily discernible on the smoothed cores. By this definition (as defined for spruce) all cells whose double radial wall thickness is equal to or greater than two times the radial width of the lumen are considered summerwood cells. Strict adherence to this criterion would have entirely eliminated the measurement of summerwood from many of the early growth rings near the pith, for in these rings the summerwood was thick-walled only with respect to the springwood in the same rings.

Mork's criterion for summerwood was further tested on other wide, young rings where the springwood-summerwood transition was somewhat gradual. It was found that the marked color change from springwood to summerwood in slash pine, which was accentuated by the fast green and transmitted light, was equally satisfactory and much simpler to employ. In older rings (6 to 8 years or more) the transition was generally very abrupt and even in the wide rings it was seldom questionable. Exceptional cases were found in the cores from the two southern-most plots in Florida (plots 8-D and 8-W) where exceptionally thick-walled bands of springwood cells frequently occurred in the older growth rings. The presence of these bands of thick-walled springwood cells in addition to the very narrow springwood bands which were mentioned earlier as being found in these same trees, is suggestive of a transitional condition between the distinct growth rings in most trees of temperate regions and the almost complete lack of definite growth rings in many trees of tropical regions.

The springwood and summerwood components of false rings were measured separately and added to the appropriate annual ring with which they were associated. Microscopic rings were measured to 0.05 mm. and rounded to the nearest 0.1 mm. Ring components below 0.05 mm. were entered on the data sheets as "trace" and no numerical value was assigned to them.

Heartwood and "pitch-soaking" often obscured the springwood-summerwood transition in the early growth rings. Although the presence of heartwood masked the color differentiation, the transition could still be determined by the change in cell wall thickness. On the contrary, "pitch-soaking" generally obscured both features. Fortunately, extra increment cores were collected from all trees and the transition zones could be determined on at least one of the cores.

The "pitch-soaked" condition appeared to be independent of visible heartwood. It was found in trees within, as well as extending beyond, the heartwood and also in young trees completely devoid of heartwood. The zones of "pitch-soaking" were frequently differentially distributed and it was often possible to avoid the condition in a tree by shifting the boring position circumferentially or vertically. Trees that contained excessive amounts of "pitch-soaked" wood were excluded from the sample; however, cores were accepted if a small zone occurred within the heartwood. This latter concession was necessary to avoid the exclusion of an excessive number of trees and in some cases entire plots; several stands were dropped from consideration because of excessive "pitch-soaking".

No plots were entirely devoid of "pitch-soaked" trees although the frequency of occurrence varied widely. It is the author's opinion that the condition is rather widespread in the relatively dense, second-growth stands of slash pine. The causal factors are not specifically known but observations suggest that fire during the juvenile period when the trees are still relatively thin-barked may be of some significance. Paul (1955) has recently reported on a similar "pitch-soaked" condition in second-growth ponderosa pine.

Specific Gravity Determinations

The water-soaked specific gravity increment cores, trimmed at the pith and at the terminus of the 1953 annual ring, were sectioned immediately upon completion of the ring measurements on the respective measurement cores. This procedure was adopted so that the measurement cores could be used to assure positive ring identifications on the specific gravity cores. In questionable cases the cores were sectioned under a binocular microscope with the measurement cores as references.

The cores were sectioned by making a shallow incision at the ring boundary with a razor blade and then breaking the core across the cut. This technique resulted in almost perfect separation of adjacent annual rings, but only on well-soaked cores. In this respect, small-diameter increment cores are superior to larger wood samples since the latter are difficult, if not impossible, to dissect accurately into their annual ring components.

Sectioning progressed from the pith to the cambium with three annual rings in the pith segment (Segment 1) and five rings in each succeeding segment. The final segment nearest the cambium was considered part of the previous complete segment if it consisted of one or two rings and a separate segment if it consisted of three or four rings. By beginning the sectioning at the pith, comparable core segments were of identical ages irrespective of total tree age although the segments were not in agreement with respect to the calendar year of origin.

Strict compliance to the sectioning procedure was impossible in trees whose growth was suppressed in the final years prior to sampling. Generally, if a segment or a partial final segment was less than 2.0 to 2.5 mm. in total length, it was considered a part of the previous segment. The specific gravity and percentage of summerwood were then computed on this double segment containing six to ten annual rings. Such cases, however, were not frequently encountered.

The core segments were oven-dried at 103°C. for 36 hours in a constant-temperature oven. To facilitate handling during oven-drying and weighing, the segments were placed in "boats" made from paper straws split lengthwise. The "boats" were placed in a grooved board or tray which was then transferred to the oven as a unit. Each tray sufficed for the segments from all trees within a single plot and two trays, representing two plots, could be maintained in the oven simultaneously over the 36-hour drying period.

During the weighing procedure the "boats" were removed from the oven one at a time and the segments contained therein weighed individually; all weighing was conducted on an analytical balance and weights were recorded to the nearest 0.0001 gram. Since a time lapse naturally occurred between the first and last weighings from each "boat", there was a certain amount of atmospheric moisture absorption by the oven-dry specimens. This was quantitatively tested by weighing a series of "boats" of segments as just outlined and then returning them to the oven for redrying. After the appropriate 36-hour drying period, each segment was removed from the oven individually and reweighed, thus minimizing the gain in weight by moisture absorption. It was found that the gain in weight due to atmospheric moisture increased slightly but steadily from the first to the last segment of each "boat". The average weight gain was about 0.5 percent with a maximum for the fifth segment of approximately 1.0 percent. A limit of five segments per "boat" was therefore arbitrarily established and all increment cores with more than five segments were divided between two "boats" which were then removed from the oven separately for weighing.

Volumes were determined by water displacement on an analytical balance. The displacement vessel was a small, glass vial filled with water which was placed on the balance pan. A core segment holder was constructed with an arm that projected over the vial when the holder was positioned beside the balance pan. A fine silver needle was inserted through a piece of cork mounted on the projecting arm; the cork permitted easy adjustment of the immersion depth of the needle in the water.

Each volume determination involved two weighings. In the first weighing the segment holder was placed beside the balance pan with the needle immersed about ¾-inch in the water and the weight of the vial plus water, with the needle immersed, recorded. The segment holder was then removed from the balance, a core segment mounted on the needle, and the holder replaced in the balance case with both the segment and the needle immersed in the water. The weight of the vial plus water, with the needle and segment immersed, was recorded. The difference between the two readings represented the water displaced. Since one gram of water very closely approximates 1 cc., the displacement weight in grams was assumed to be the volume in cubic centimeters of the specimen. Temperature variations were ignored as the volumes were small and corrections insignificant. All volumes were recorded to 0.0001 cc.

The preceding method of volume determination was employed throughout the experiment although the original plan was to use a mercury displacement technique with an Amsler volumemeter.[1] With this instrument, the maximum attainable accuracy was ±0.003 cc. However, since volume is the denominator in the specific gravity formula and the error is dependent upon the specimen size, even this degree of accuracy can yield considerable variation when dealing with very small specimens, as indicated in the following table:

Small Core Segments			Large Core Segments		
Oven-dry weight	*"Green" volume*	*Specific gravity*	*Oven-dry weight*	*"Green" volume*	*Specific gravity*
grams	cc.		grams	cc.	
.045	.085	.529	.560	1.000	.560
.045	.086	.523	.560	1.001	.559
.045	.088	.511	.560	1.003	.558
.045	.095	.473	.560	1.010	.554

For the small segments, a volume error of 0.003 cc. resulted in a discrepancy of 0.018 in specific gravity whereas for the larger segments the same volume error resulted in a discrepancy of only 0.002 in specific gravity; larger volume errors resulted in proportionately larger specific gravity errors. An accuracy of 0.003 cc. was impossible to maintain with the volumemeter and variations as high as 0.040 cc. were recorded in trials of three remeasurements on the same specimens. On the contrary, with the analytical balance method, volume errors rarely exceeded 0.0030 cc. and were generally well below 0.0020 cc. when measured to the nearest 0.0001 cc. This was particu-

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[1] Distributed by Adolph I. Buehler, Chicago, Illinois.

larly true when a wetting agent[1] was used which considerably reduced the surface tension on the immersed needle. Since both the weight and volume determinations were recorded to four significant figures, specific gravities were also calculated to the nearest 0.0001 and then rounded to the nearest 0.001 for statistical computations.

As previously mentioned, it was originally intended to employ a mercury displacement technique for the determination of segment volumes. Hence, weighing preceded volume measurements to avoid weighing errors due to mercury adherence to the rough core surfaces and penetration into open resin ducts. Because of the prior oven-drying, it was necessary to test whether or not the original green volume could be reattained by soaking in water. The test was conducted on increment cores collected in August, 1955 from 42 slash pine trees representing a wide range of growth rates. The green cores were immersed in FAA solution (formalin-acetic acid-ethyl alcohol) immediately upon extraction and remained in this solution until about two weeks prior to testing. During this two-week period the cores were treated with daily changes of tap water to remove all traces of the FAA. A 5-year segment was cut from each core to simulate the experimental material and the actual green volume determined by water displacement. The core segments were then oven-dried, weighed, and the specific gravities calculated.

The oven-dried segments were resoaked in water for 72 hours, a new set of volumes was obtained, and the specific gravities recalculated. These specific gravities, based on the volumes of resoaked core segments, did not vary appreciably from those based on the original green volumes. When the two specific gravity determinations were considered as paired observations (Bliss and Calhoun, 1954) an analysis of variance showed no significant difference between the two tests; the variance ratio was 2.32 (Table 1, a). Therefore, it was tentatively concluded that a 72-hour soaking period was sufficient for recovering the normal green volume.

Before the above procedure could be adopted as a standard technique it was deemed desirable to test for variation in specific gravity as determined from increment cores and from larger wood samples. The check samples were obtained from the same trees and at a position two inches below the 42 aforementioned increment cores. The samples, ½-inch in diameter, were removed from the trees with a dowel or "plug" cutter[2] fitted to a hand-held

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[1] 0.1% solution by weight of Alconox.

[2] Manufactured by Rockwell Mfg. Co., Delta Power Tool Division, Pittsburgh, Pennsylvania.

carpenter's brace. Upon removal, the samples were placed in FAA solution and thereafter treated in the same manner as the increment cores previously described. In the laboratory, specific gravities were determined on the basis of the green volumes and oven-dry weights. The specific gravities of the check samples (½-inch cores) were consistently lower than those of the increment cores, indicating larger volumes for the former. The mean difference was +3.90 percent; an analysis of variance revealed a highly significant difference between the two sets of data with a variance ratio of 60.93 (Table 2, b).

The foregoing results suggested that the extraction of a wood core with the conventional increment borer may have resulted in a slightly compressed volume which was not completely alleviated by soaking alone. Hence, a more drastic treatment was tested. The core segments were placed in small, glass vials and boiled for one hour in tap water. Volumes were again determined for the "treated" segments and the specific gravities recalculated on the basis of the original oven-dry weights. These specific gravities were retested against those of the green check cores by analysis of variance. The variance ratio was again highly significant (Table 2, c) but it was reduced from 60.93 to 43.83 by boiling while the mean difference was reduced from +3.90 to +2.72 percent. Although this reduction was small, it was nevertheless consistent over all core segments and indicated an increase in volume due to boiling.

An additional analysis of variance was conducted on the specific gravities[1] of the untreated increment cores, based on soaked volumes, and the treated cores, based on the volumes after boiling. The differences were highly significant (Table 2, d) confirming the effect of boiling on the core volumes. These results may be contrasted with those obtained in a previous analysis (Table 2, a) in which there was no significant difference between specific gravities based on green volumes and on volumes after a 72-hour soaking period following oven-drying. A further possibility existed that the boiling treatment may have brought about an abnormal increase in the normal green volumes. This was tested by an analysis of variance in which the specific gravities of the ½-inch check cores were compared both before and after the boiling treatment. No significant differences were found between the two sets of data (Table 2, e).

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[1] Specific gravities were used in the analyses rather than volumes so that comparisons could be made between increment cores and the ½-inch cores as well as between increment cores.

TABLE 1. CORE SPECIFIC GRAVITY COMPARISONS

a Increment Cores: Green vs. 72-Hour Soak

Source of variation	*D.F.*	*S.S.*	*M.S.*	*V.R.*
Pairs	41	0.29300822	0.00714654	69.75**
Treatments	1	0.00023735	0.00023735	2.32
Error	41	0.00420091	0.00010246	
Total	83	0.29744648		

b Increment Cores (Green) vs. ½-Inch Check Cores (Green)

Source of variation	*D.F.*	*S.S.*	*M.S.*	*V.R.*
Pairs	41	0.29236963	0.00713097	39.31**
Treatments	1	0.01105387	0.01105387	60.93**
Error	41	0.00743766	0.00018141	
Total	83	0.31086116		

c Increment Cores (Boiled) vs. ½-Inch Check Cores (Green)

Source of variation	*D.F.*	*S.S.*	*M.S.*	*V.R.*
Pairs	41	0.26771368	0.00652960	83.37**
Treatments	1	0.00343296	0.00343296	43.83**
Error	41	0.00321122	0.00007832	
Total	83	0.27435786		

d Increment Cores: Green vs. Boiled

Source of variation	*D.F.*	*S.S.*	*M.S.*	*V.R.*
Pairs	41	0.30107259	0.00734323	114.83**
Treatments	1	0.00216652	0.00216652	33.88**
Error	41	0.00262185	0.00006395	
Total	83	0.30586096		

e ½-Inch Check Cores: Green vs. Boiled

Source of variation	*D.F.*	*S.S.*	*M.S.*	*V.R.*
Pairs	41	0.24657504	0.00601402	147.15**
Treatments	1	0.00010142	0.00010142	2.48
Error	41	0.00167587	0.00004087	
Total	83	0.24835233		

** = Significant at 1% point

The consistency of the data indicate and the analyses confirm that boiling resulted in increased volumes for the increment core segments. It is assumed, as previously suggested, that the boiling may have relieved a compressive "set" imposed on the increment cores during extraction. The recovery was only partial, however, as the specific gravities of the treated core segments still averaged 2.72 percent higher than the ½-inch check samples. The check samples were removed with a cutting tool that eliminated compression. Thus, the fact that the increment cores responded to the boiling treatment whereas the check samples did not, lends support to the suggestion that increment cores are subjected to a compression force during extraction. This force apparently results in a slight volume reduction that is not recoverable by prolonged soaking in water and is only partially alleviated by boiling for one hour.

The results of the foregoing tests dictated the procedure employed in all subsequent specific gravity determinations. For oven-drying and the actual volume measurements the steps previously described were rigidly adhered to. However, in preparing the oven-dry core segments for volume determinations, they were soaked for 48 hours in tap water followed by one hour of boiling in order to most nearly approximate the true volumes.

RESULTS

In this investigation an attempt was made to determine the effect of growth rate by minimizing the age factor. All comparisons were made between increment core segments covering an identical s-year age period. However, the isolation of age by equilibrating ring age from the pith outward resulted in a partial confounding with the year of origin, i.e., calendar year. This was unavoidable since there was a slight range of variation in the mean ages of the trees on different plots. The method of covariance analysis was employed so that the main effects could be adjusted for the effects of independent variables. By using a completely orthogonal design and eliminating the variation between plots and between trees on the same plot, a highly sensitive test for age was obtained.

The complexity of the problem necessitated that the statistical operations proceed in a stepwise fashion with each analysis either requiring the previous one for its solution or supplementing it in some form or another. As a matter of convenience, as well as to maintain continuity, the statistical results have therefore been presented as individual analyses.

ANALYSIS I

The objective of this analysis was to isolate, within statistical limitations, the independent effect of ring width and of age on the percentage of summerwood and on specific gravity. The main effects-age, plots, trees, and the plot x age interaction-were tested by multiple covariance with the following combinations of dependent and independent variables respectively: I) summerwood percentage on ring width, 2) specific gravity on ring width, and 3) specific gravity on summerwood percentage and ring width.

The data were restricted to segment numbers 3, 4, and S with mean ages of II, 16, and 21 years respectively. Twenty-five trees from each of 26 plots were included in the analysis, giving a total of 6so trees and 19SO observations. Plots IS-D and IS-W were excluded since the trees were too young and plot 7-D was eliminated as no wet-site counterpart was available; II-D and 12-W were paired and treated as a single location. The 26-plot analysis was, therefore, completely orthogonal.

Previous work had indicated a curvilinear trend for summerwood percentage or specific gravity on ring width (Lodewick, 1933; Trendelenburg, 1939; Paul and Smith, 19S0). Although preliminary plotting did not reveal trends of any kind, the quadratic term for ring width was included in this analysis and all that follow.

The analyses of variance for summerwood percentage and specific gravity are shown in Table 11 and the covariance adjustments for the three combinations of variables in Table 12.

Considerable differences in summerwood percentage and specific gravity may be observed and measured among trees growing within a particular stand as well as among trees growing under diversified environmental conditions. In order to evaluate these differences, suspected causes of variation must be eliminated. The most obvious and most divergent variable is rate of growth; consequently, it was the first covariate considered.

Adjustment of summerwood percentage and specific gravity for variation in ring width did not appreciably change the variance ratios for "plots" and "trees" from those obtained by the unadjusted analyses of variance. From this it may be assumed that ring width exerted a negligible effect on the variations in summerwood percentage and specific gravity between plots and between trees on the same plot. In other words, the measurable differences in summerwood percentage and specific gravity between trees and between plots were almost completely independent of rate of growth.

Considerable differences in summerwood percentage and specific gravity may also be observed and measured from pith to cambium on an increment core. This within-tree variation is difficult to isolate since ring width and summerwood percentage both vary with age. Although the effect of age could not be completely eliminated, it was minimized by means of the 5-year age segments. By adjustment for ring width the variance ratios for "age" were reduced from 456.04 to 204.16 for summerwood percentage and from 447.65 to 175.98 for specific gravity. Thus, a strong correlation existed between ring width and age. The reduction of the variance ratios does not, however, imply a relationship between ring width and either summerwood percentage or specific gravity; the adjustment merely corrected these values for the variability in ring width as influenced by increasing age. After adjustment, both summerwood percentage and specific gravity were still very highly significant, indicating that substantial differences existed among the three age segments independent of ring width.

Although the percentage of summerwood has been used as a dependent variable in the preceding part of this analysis, it may also be considered as an independent variable with respect to specific gravity. The inclusion of summerwood percentage as a covariate along with ring width accounted for a considerable part of the variation in specific gravity for "plots"; the variance ratio was reduced from 95.53 to 40.97 (Tables 12, b and c).

With respect to age, it was mentioned previously that increasing age influences both the rate of growth and the percentage of summerwood. The effect of age on ring width was verified by reduction of the variance ratio from 447.65 to 175.98. Inclusion of summerwood percentage as a covariate along with ring width caused a further reduction in the variance ratio to 8.9!. Although this variance ratio (8.91) was highly significant statistically, the differences in adjusted specific gravities between age segments were extremely small and for all practical purposes may be considered non-existent. This can be clearly illustrated by adjusting the mean specific gravity of each age segment to 50 percent summerwood as follows:

	MEAN SPECIFIC GRAVITY		
	Segment 3	Segment 4	Segment 5
Unadjusted	.581	.608	.623
Adjusted to 50% summerwood	.568	·574	.578

It is interesting to note that even though the variance ratios for "age" and "trees" are extremely small and may be of no practical importance after adjustment for ring width and summerwood percentage, they are, nevertheless, highly significant statistically. In the case of "plots" the variance ratio after adjustment is large (40.97) and represents measurable differences. Because of these significant variance ratios, it may be adduced that another factor or set of factors influences specific gravity independent of rate of growth and the percentage of summerwood. One possible factor, variability in summerwood quality, will be considered in the discussion.

The tests of significance for the several combinations of independent variables are given in Table 2. The regression of summerwood percentage on ring width was highly significant. Yet it accounted for only 2.20 percent of the total variation. The cubic term for ring width was not computed but it is doubtful if an appreciable increase in significance could have been attained by its inclusion. Although the linear and quadratic terms may not fit the data exactly, they probably provide a very close approximation.

The regression of specific gravity on summerwood percentage was highly significant with a variance ratio of 1902.52. Summerwood percentage alone accounted for 59.95 percent of the total variation. The addition of the

TABLE 2. ANALYSIS I. TESTS OF SIGNIFICANCE, SEGMENTS 3-4-5

a SUMMERWOOD PERCENTAGE ON RING WIDTH

Source of variation	*D.F.*	*S.S.*	*M.S.*	*V.R.*
X_2 considered alone	1	58.13	58.13	2.55
X_3 when X_2 fixed	1	580.28	580.28	25.45**
Regression on X_2 & X_3	2	638.41	319.20	14.00**
Residuals	1246	28404.59	22.80	
Total, around mean	1248	29043.00		

$R^2_{(X_1.X_2X_3)} = 638.41/29043.00 = 0.021982$

b SPECIFIC GRAVITY ON SUMMERWOOD PERCENTAGE + RING WIDTH

Source of variation	*D.F.*	*S.S.*	*M.S.*	*V.R.*
X_1 considered alone	1	0.479435	0.479435	1902.52**
X_2 when X_1 fixed	1	0.000531	0.000531	2.11
X_3 when X_1 & X_2 fixed	1	0.005494	0.005494	21.80**
Regression on X_1, X_2 & X_3	3	0.485460	0.161820	642.14**
Residuals	1245	0.314206	0.000252	
Total, around mean	1248	0.799666		

$R^2_{(Y.X_1)} = 0.479435/0.799666 = 0.599544$

$R^2_{(Y.X_1X_2X_3)} = 0.485460/0.799666 = 0.607078$

$R^2_{(Y.X_2X_3)} = 0.006025/0.799666 = 0.007534$

X_1 = Summerwood percentage
X_2 = Ring width
Y = Specific gravity
X_3 = Ring width squared
** = Significant at 1% point

linear and quadratic terms for ring width, although highly significant, resulted in a very slight increase in the total variation accounted for, 60.71 percent. Thus, ring width alone accounted for only 0.75 percent of the variation when summerwood percentage was fixed. When ring width was considered first and summerwood percentage was allowed to vary, ring width accounted for only 0.44 percent of the total variation.

Partial regression equations were derived for all the combinations of dependent and independent variables. The curves plotted from these equations appear in Figures 2-4; the regression equations are included in the captions.

In Figure 2, summerwood percentage on ring width, the flat-topped parabola attests to the small amount of the total variation accounted for by ring width. Summerwood percentage decreased with both increasing and decreasing ring widths from the asymptote which occurred at a ring width of 3.25 mm. The fairly large differences in level are indicative of the pronounced effect of age on summerwood percentage.

Figure 3 depicts the regression of specific gravity on summerwood percentage. The steep slope of the regression lines results from the high degree of positive correlation between summerwood percentage and specific gravity. Differences in level between age segments are very slight, and although highly significant (Table 2, b), they are not reproducible differences by conventional methods of determining specific gravity.

In Figure 4, specific gravity on ring width, a very slight negative slope is apparent which, nevertheless, represents highly significant differences in specific gravity (Table 2, b). The relatively large differences in level are primarily due to summerwood percentage which has not been adjusted for in this equation.

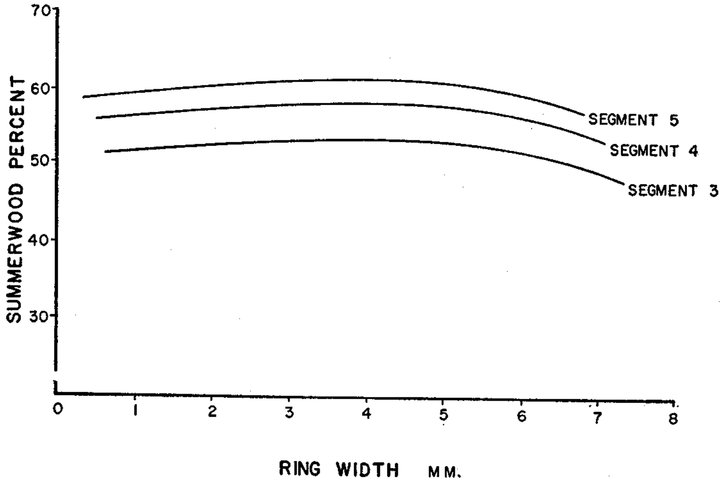

FIGURE 2. Regression of summerwood percentage on ring width for segments 3-4-5.
Regression equations:
Segment 3 (Age 11) $X_1 = 50.07 + 2.3308\ X_2 - 0.3593\ X_3$
Segment 4 (Age 16) $X_1 = 55.02 + 2.3308\ X_2 - 0.3593\ X_3$
Segment 5 (Age 21) $X_1 = 57.97 + 2.3308\ X_2 - 0.3593\ X_3$

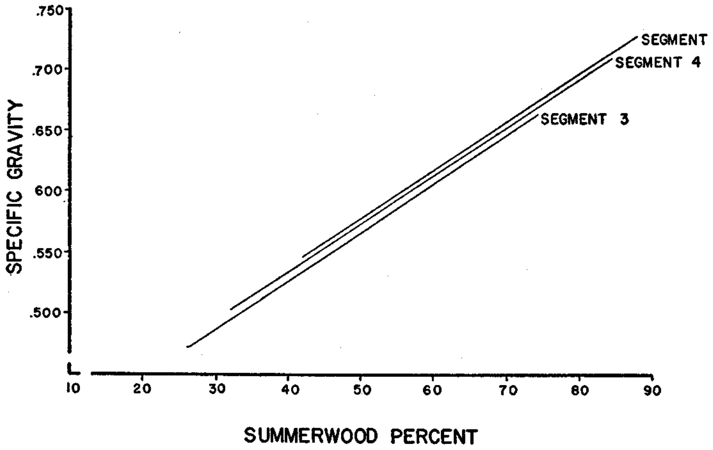

FIGURE 3. Regression of specific gravity on summerwood percentage for segments 3-4-5.
Regression equations:
Segment 3 (Age 11) $Y = 0.365 + 0.004063\ X_1$
Segment 4 (Age 16) $Y = 0.371 + 0.004063\ X_1$
Segment 5 (Age 21) $Y = 0.375 + 0.004063\ X_1$

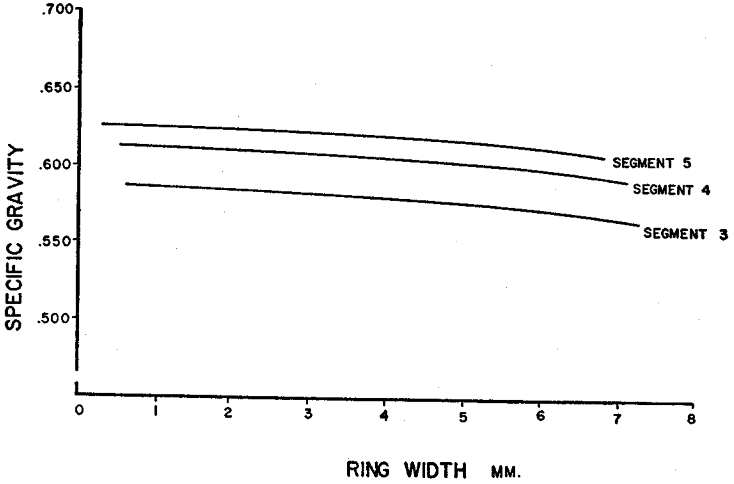

FIGURE 4. Regression of specific gravity on ring width for segments 3-4-5.
Regression equations:
Segment 3 (Age 11) $Y = 0.586 + 0.0001133\ X_2 - 0.0003633\ X_3$
Segment 4 (Age 16) $Y = 0.612 + 0.0001133\ X_2 - 0.0003633\ X_3$
Segment 5 (Age 21) $Y = 0.625 + 0.0001133\ X_2 - 0.0003633\ X_3$

ANALYSIS II

The general objective of this analysis was identical with that of Analysis I but segment number 2, mean age 6 years, was included in addition to segments 3, 4, and 5. It was felt, because of the extreme youthfulness of these rings, that the relationship of ring width with summerwood percentage might be different in the second segment than in the subsequent three segments. Specific gravity was not included in this analysis since the presence of heartwood in many of the number two segments resulted in extremely erratic values. The analysis was therefore based on the single set of variables—summerwood percentage on ring width.

The unadjusted analysis of variance for summerwood percentage is given in Table 13, a and the covariance adjustments in Table 13, b.

As in the previous analysis, adjustment of summerwood percentage for ring width did not alter the variance ratios for "plots", "trees", or the "plot x age" interaction from those obtained by the unadjusted analysis of variance. Thus, it may be assumed that the linear and quadratic terms for ring width exerted no appreciable influence on these main effects. The variance ratio for age, on the other hand, was reduced over 50 percent by adjustment for ring width. Nevertheless, the size of the adjusted variance ratio, 782.78, indicated that considerable differences in summerwood percentage still existed among the four age segments.

The test of significance for the regression of summerwood percentage on ring width is given in Table 3. Although the regression was highly significant, it accounted for only 0.96 percent of the total variation. Partial regression equations were derived for each of the four age segments. The curves plotted from these equations appear in Figure 5. Addition of segment 2 to the data changed the shape of the curve from a parabola that maximated at about 3.25 mm. to a curve with a negative slope from zero ring width. The differences in level of the regression lines indicate the very pronounced effect of age on summerwood percentage, particularly between the young segments 2 and 3.

ANALYSIS III

The analysis of covariance assumes that there is no significant difference between the slopes of the regression lines for the "treatment" effects being tested, although they may differ in level. This assumption was tested for the "age" effect by calculating a complete covariance analysis for each age

TABLE 3. ANALYSIS II. TEST OF SIGNIFICANCE, SEGMENTS 2-3-4-5

SUMMERWOOD PERCENTAGE ON RING WIDTH

Source of variation	*D.F.*	*S.S.*	*M.S.*	*V.R.*
X_2 considered alone	1	414.08	414.08	14.08**
X_3 when X_2 fixed	1	117.38	117.38	3.99*
Regression on X_2 & X_3	2	531.46	265.73	9.04**
Residuals	1870	55005.54	29.41	
Total, around mean	1872	55537.00		

$R^2(X_1.X_2X_3) = 531.46/55537.00 = 0.009569$

X_1 = Summerwood percentage

X_2 = Ring width

X_3 = Ring width squared

* = Significant at 5% point

** = Significant at 1% point

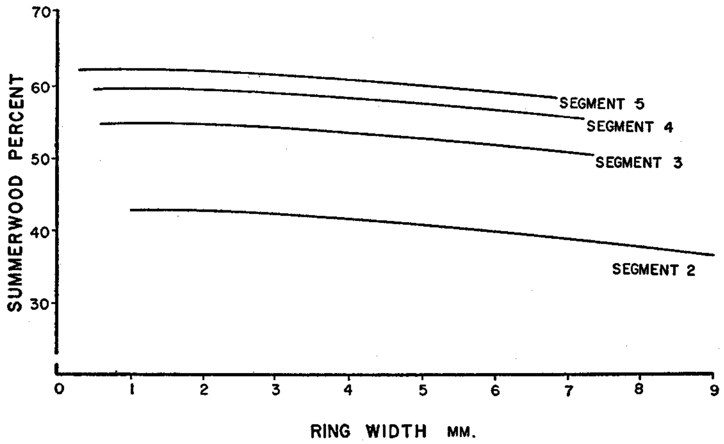

FIGURE 5. Regression of summerwood percentage on ring width for segments 2-3-4-5.

Regression equations:

Segment 2 (Age 6) $X_1 = 42.80 - 0.06246\ X_2 - 0.06899\ X_3$

Segment 3 (Age 11) $X_1 = 54.49 - 0.06246\ X_2 - 0.06899\ X_3$

Segment 4 (Age 16) $X_1 = 59.30 - 0.06246\ X_2 - 0.06899\ X_3$

Segment 5 (Age 21) $X_1 = 61.81 - 0.06246\ X_2 - 0.06899\ X_3$

segment. These analyses were identical in all respects to Analysis I with the exception that age was eliminated.

The tests of significance for the individual segments are shown in Table 4. Ring width was not significant in any individual segment with the exception of the linear term of segment 2. Non-parallelism was tested by analysis of variance. In neither Analysis I nor Analysis II were there significant differences in the slopes of their individual regression lines.

ANALYSIS IV

A number of investigators have shown that summerwood percentage increases rapidly with age up to a point after which it either increases more gradually or fluctuates. In order to establish the leveling off point for slash pine and also to determine the effect of ring width on summerwood percentage at greater ages, a covariance analysis was carried out on segment 6 (mean age 26 years). This segment was not included in Analysis I since only seventeen plots had trees with six complete segments. These seventeen plots were as follows: 1-D, 2-W, 4-D, 4-W, 5-W, 6-W, 7-D, 8-D, 8-W, 9-D, 9-W, 10-D, 12-W, 14-D, 14-W, 16-D, and 16-W. The regression of summerwood percentage on ring width was not significant (Table 5).

The curve of summerwood percentage over age is shown in Figure 6 for segments 2-6. The unadjusted mean summerwood percentage was plotted for each segment since correction of the mean values for ring width involved a negligible adjustment. From Figure 6 it can be seen that summerwood percentage increases rapidly from 6 to 11 years, more gradually from 11 to 21 years, and remains practically constant from 21 to 26 years. Insufficient numbers of observations precluded the plotting of older age segments.

The mean data for segments 2-6 are given in the following table so that the variation from segment to segment can be compared:

Segment number	*Segment age*	*Ring[1] width*	*Percentage[1] of summerwood*	*Specific[1] gravity*
	years	*mm.*	%	
2	6	4.38	41.02	—
3	11	3.77	53.16	.531
4	16	3.10	58.36	.608
5	21	2.52	61.12	.623
6	26	2.19	61.62	.628

[1] Segments 2-5 represent 650 individual observations; segment 6 represents 425 individual observations.

TABLE 4. ANALYSIS III. TESTS OF SIGNIFICANCE, INDIVIDUAL SEGMENTS 2, 3, 4, 5

SUMMERWOOD PERCENTAGE ON RING WIDTH

a SEGMENT 2

Source of variation	*D.F.*	*S.S.*	*M.S.*	*V.R.*
X_2 considered alone	1	340.32	340.32	6.58*
X_3 when X_2 fixed	1	1.29	1.29	0.025
Regression on X_2 & X_3	2	341.61	170.80	3.30*
Residuals	622	32143.35	51.68	
Total, around mean	624	32484.96		

b SEGMENT 3

Source of variation	*D.F.*	*S.S.*	*M.S.*	*V.R.*
X_2 considered alone	1	13.14	13.14	0.29
X_3 when X_2 fixed	1	73.17	73.17	1.60
Regression on X_2 & X_3	2	86.31	43.16	0.94
Residuals	622	28439.69	45.72	
Total, around mean	624	28526.00		

c SEGMENT 4

Source of variation	*D.F.*	*S.S.*	*M.S.*	*V.R.*
X_2 considered alone	1	0.00	0.00	0.00
X_3 when X_2 fixed	1	117.53	117.53	2.47
Regression on X_2 & X_3	2	117.53	58.76	1.23
Residuals	622	29599.36	47.59	
Total, around mean	624	29716.89		

d SEGMENT 5

Source of variation	*D.F.*	*S.S.*	*M.S.*	*V.R.*
X_2 considered alone	1	86.38	86.38	1.52
X_3 when X_2 fixed	1	37.12	37.12	0.65
Regression on X_2 & X_3	2	123.50	61.75	1.08
Residuals	622	35453.95	57.00	
Total, around mean	624	35577.45		

X_2 = Ring width

* = Significant at 5% point

X_3 = Ring width squared

TABLE 5. ANALYSIS IV. TEST OF SIGNIFICANCE, SEGMENT 6

SUMMERWOOD PERCENTAGE ON RING WIDTH

Source of variation	*D.F.*	*S.S.*	*M.S.*	*V.R.*
X_2 considered alone	1	7.5675	7.5675	—
X_3 when X_2 fixed	1	9.7874	9.7874	—
Regression on X_2 & X_3	2	17.3549	8.6774	—
Residuals	406	69128.4456	170.2671	
Total, around mean	408	69145.8005		

X_2 = Ring width
X_3 = Ring width squared

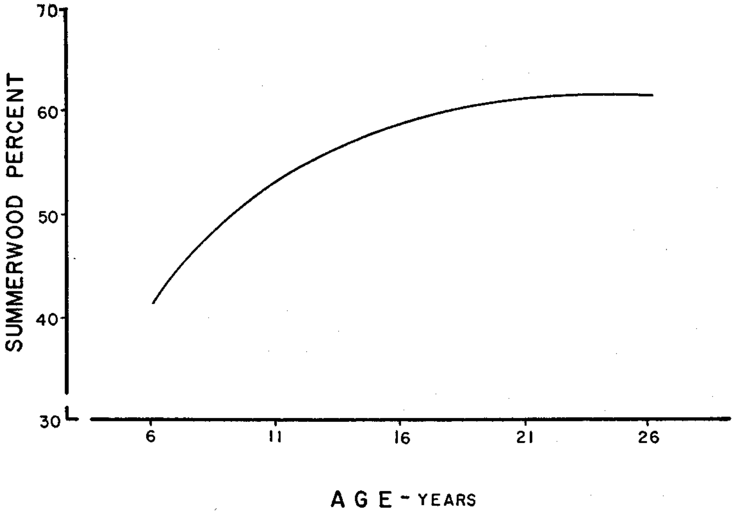

FIGURE 6. Curve of summerwood percentage over age for segments 2-6, mean ages 6-26 years. The curve is based on the measurements from 650 trees.

ANALYSIS V

The results of Analysis I indicated a highly significant difference between plots after the covariance adjustment (Table 2). A series of analyses was therefore conducted to determine whether or not some of this variation could be accounted for by measurable factors of the environment.

The regression equation of Analysis I was used to obtain adjusted values of summerwood percentage. The mean summerwood percentage for each plot was adjusted for ring width by averaging the corrected segment values. Although the adjustments were small, it was considered desirable to eliminate the effect of rate of growth between plots before attempting further analyses. The unadjusted and adjusted summerwood percentages and specific gravity values for each age segment for each plot are given in Tables 14 and 15. Since most of the variation in specific gravity was accounted for by summerwood percentage, the specific gravity differences were not subjected to further analysis.

Examination of the adjusted summerwood percentage values revealed definite trends of variation with geographic sampling location. By plotting the data, a general regional grouping into North, South, East, and West components could be readily made. The original plot location scheme was adhered to in separating the North-South (plots 1-8) from the East-West (plots 9-14) series. The final breakdown of plots by regions was as follows:

Region	*Plots*
North	1-D, 1-W, 2-D, 2-W, 3-D, 3-W, 4-D, 4-W, 16-D, 16-W.
South	5-D, 5-W, 6-D, 6-W, 8-D, 8-W.
East	9-D, 9-W, 10-D, 10-W, 11-D.
West	12-W, 13-D, 13-W, 14-D, 14-W.

An analysis of variance of the data disclosed significant differences between the four regions as shown in Table 6, a. A "t" test showed no significant differences between North and West and between South and East. Therefore, the values for these regions were pooled and a second analysis of variance was conducted on the pooled data. The results are presented in Table 6, b.

A highly significant difference existed between the two broad regions. The mean summerwood percentages for the two regions were 54.14 and 62.03 for North-West and South-East respectively. These differences are relatively small but they nevertheless represent real and consistent differences.

The plot differences were also tested according to site. Since the plots represented a wet and a dry site at each location sampled, the effect of this arbitrary classification could be tested; the results are shown in Table 6, c. Site, classified as either wet or dry, was not significant. Differences, and often rather large differences, could be detected between sites at a particular location, but they were not consistent over the entire range of locations sampled.

TABLE 6. VARIATION OF SUMMERWOOD PERCENTAGE WITH GEOGRAPHIC LOCATION AND SITE

a NORTH-SOUTH-EAST-WEST

Source of variation	*D.F.*	*S.S.*	*M.S.*	*V.R.*
Region	3	426.5991	142.1997	12.44**
Error	22	251.4293	11.4286	
Total	25	678.0284		

b NORTH-WEST VS. SOUTH-EAST

Source of variation	*D.F.*	*S.S.*	*M.S.*	*V.R.*
Region	1	334.0162	334.0162	23.30**
Error	24	344.0122	14.3338	
Total	25	678.0284		

c WET VS. DRY SITE

Source of variation	*D.F.*	*S.S.*	*M.S.*	*V.R.*
Sites	1	27.3984	27.3984	1.01
Error	24	650.6300	27.1096	
Total	25	678.0284		

** = Significant at 1% point

ANALYSIS VI

The previous analysis showed that differences in summerwood percentage existed between the two broad regions but no causal factors were suggested. In the following analyses simple linear regression and multiple regression were employed to test the relationship of a number of stand, site, and climatic factors with summerwood percentage.

The results of these regressions for the "X_{40}" variables are presented in Table 7. The three soil variables, moisture equivalent of the B-horizon (X_{45}), depth to a fine-textured horizon (X_{46}), and silt + clay of the B-horizon (X_{47}) were significant; X_{45} and X_{47} were negatively correlated and X_{46} positively correlated with summerwood percentage.

Various expressions of precipitation distribution were classified as the "X_{60}" variables. The results of these regressions are presented in Table 8. June + July rainfall (X_{67}) gave the highest positive relationship. The addition of May, August, and September in various combinations resulted in progressive reductions in the variance ratio. Similarly, the highest negative relationship was obtained with January + February rainfall (X_{76}) and the variance ratio decreased with additional variables. Thus, it was reasoned that the periods of "effective" rainfall were January + February for springwood

TABLE 7. REGRESSION OF SUMMERWOOD PERCENTAGE ON "X_{40}" VARIABLES

Variable	(X_1)	(X_{40})	(X_1X_{40})	b^2	d^2	M.S.		V.R.
						b^2 D.F. 1	d^2 D.F. 24	
X_1	679.61							
X_{41}		736.05	—249.72	84.7226	594.8874	84.7226	24.7870	3.42
X_{42}		247511.54	—378.19	0.5779	679.0321	0.5779	28.2930	—
X_{43}		3516.04	355.86	36.0168	643.5932	36.0168	26.8164	1.34
X_{44}		9554.62	854.87	76.4868	603.1232	76.4868	25.1301	3.04
X_{45}		1423.98	—395.66	109.9363	569.6737	109.9363	23.7364	4.63*
X_{46}		3846.62	810.97	170.9741	508.6359	170.9741	21.1932	8.06*
X_{47}		4547.00	—839.13	154.8580	524.7520	154.8580	21.8647	7.08*
X_{48}		1690.96	166.28	16.3511	663.2589	16.3511	27.6358	—

X_1 = Summerwood percentage
X_{41} = Mean plot age
X_{42} = Trees per acre 6″ and up
X_{43} = Site index (height of dominants at 50 years; U.S.D.A. Misc. Pub. 50. 1929)
X_{44} = Growing season in days
X_{45} = Moisture equivalent of B-horizon
X_{46} = Depth to fine-textured horizon; 20% silt + clay
X_{47} = Silt + clay of B-horizon
X_{48} = Site quality (height of dominants at 25 years; Barnes, 1955)
$b^2 = (X_1X_{40})^2 / (X_{40})$
$d^2 = (X_1) - b^2$
* = Significant at 5% point

TABLE 8. REGRESSION OF SUMMERWOOD PERCENTAGE ON "X_{60}" VARIABLES

						M.S.		
Variable	(X_1)	(X_{60})	(X_1X_{60})	b^2	d^2	b^2 D.F. 1	d^2 D.F. 24	V.R.
X_1	679.61							
X_{61}		155.2394	191.4134	236.0167	443.5933	236.0167	18.4830	12.77^{**}
X_{62}		343.1333	304.3704	269.9864	409.6236	269.9864	17.0676	15.82^{**}
X_{63}		558.1932	375.8508	253.0734	426.5366	253.0734	17.7724	14.24^{**}
X_{64}		308.9626	262.8938	223.6942	455.9158	223.6942	18.9965	11.78^{**}
X_{65}		395.5937	295.8753	221.2932	458.3168	221.2932	19.0965	11.59^{**}
X_{66}		69.5726	107.6906	166.6930	512.9170	166.6930	21.3715	7.80^{**}
X_{67}		175.8218	223.8344	284.9581	394.6519	284.9581	16.4438	17.33^{**}
X_{68}		47.7988	110.8774	257.1989	422.4111	257.1989	17.6005	14.61^{**}
X_{69}		46.7874	112.9570	272.7077	406.9023	272.7077	16.9543	16.08^{**}
X_{70}		153.5676	—70.7480	32.5933	647.0167	32.5933	26.9590	1.21
X_{71}		202.7641	—104.4826	53.8390	625.7710	53.8390	26.0738	2.06
X_{72}		262.8974	—147.0790	82.2839	597.3261	82.2839	24.8886	3.31
X_{73}		204.8220	—141.8126	98.1868	581.4232	98.1868	24.2260	4.05
X_{74}		94.3033	—103.1263	112.7748	566.8352	112.7748	23.6181	4.77^{*}
X_{75}		184.8366	—163.5682	144.7471	534.8629	144.7471	22.2860	6.49^{*}
X_{76}		50.8500	—103.0383	208.7884	470.8216	208.7884	19.6176	10.64^{**}
X_{77}		154.8765	—152.6198	150.3960	529.2140	150.3960	22.0506	6.82^{*}
X_{78}		20.4756	—60.4419	178.4184	501.1916	178.4184	20.8830	8.54^{**}
X_{79}		8.7085	—42.5963	208.3533	471.2567	208.3533	19.6357	10.61^{**}
X_{80}		1385.8700	682.6700	336.2785	343.3315	336.2785	14.3055	23.51^{**}
X_{81}		1099.1909	87.3895	6.9478	672.6622	6.9478	28.0276	—

TABLE 8.

Legend

X_1 = Summerwood percentage
"X_{60}" = Precipitation variables
X_{61} = July + August
X_{62} = June + July + August
X_{63} = June + July + August + September
X_{64} = July + August + September
X_{65} = May + June + July + August
X_{66} = May + June
X_{67} = June + July
X_{68} = July
X_{69} = June
X_{70} = March + April
* = Significant at 5% point
** = Significant at 1% point

X_{71} = March + April + May
X_{72} = February + March + April + May
X_{73} = February + March + April
X_{74} = February + March
X_{75} = January + February + March
X_{76} = January + February
X_{77} = January + February + December
X_{78} = January
X_{79} = February

$$X_{80} = \frac{\text{June} + \text{July}}{\text{June} + \text{July} + \text{January} + \text{February}} \times 100$$

X_{81} = Total annual rainfall

formation and June + July for summerwood formation. From this it was further reasoned that the "effective" summer rainfall expressed as a percentage of the total "effective" rainfall would yield a "summer precipitation percent" comparable in its derivation to summerwood percentage. This percentage, June + July/January + February + June + July x 100, the "X_{80}" variable, gave a variance ratio of 23.51 and accounted for 49.48 percent of the total variation in summerwood percentage.

A number of multiple regressions were also tried using various combinations of the most significant climatic and soil variables. The results of these analyses appear in Table 9. The only soil factor that showed significance, with precipitation held constant, was depth to a fine-textured horizon (X_{46}) in combination with June + July rainfall (X_{67}) (Table 9, a). This regression accounted for 55.00 percent of the total variation in summerwood percentage between plots. The soil variables were not significant in combination with "summer precipitation percent".

ANALYSIS VII

Data were collected on several variables representing current growth that could not be logically correlated with the percentage of summerwood of the age segments previously considered. Separate covariance analyses were therefore worked out for each variable using data from the final segment of each tree from all 29 plots. The effect of "plots" was removed by covariance and the dependent variable was summerwood percentage in all cases. The independent variables were total age, total height, crown-height ratio, stand-density index, and tree radius. None of the tests was significant.

Age in this analysis is not to be confused with age in the previous analyses; since the effect of "plots" was removed by covariance, age merely represented the within-plot variation. The stands were essentially even-aged and no significance with age was anticipated although it was desirable to check this supposition before proceeding with the remaining tests.

Total height, crown-height ratio, and stand-density index are correlated, to varying degrees, with growth rate. No statistical relationship was found to exist between these covariates and summerwood percentage.

Radius was measured as the total length of the increment core from pith to the terminus of the 1953 ring. If no eccentricity was assumed, it could be taken as a coded value of diameter. Radius was a measure of total growth; it was not significant.

TABLE 9. ANALYSIS VI. TESTS OF SIGNIFICANCE

SUMMERWOOD PERCENTAGE

a	*Source of variation*	*D.F.*	*S.S.*	*M.S.*	*V.R.*
	X_{67} considered alone	1	284.9581	284.9581	21.43**
	X_{46} when X_{67} fixed	1	88.8498	88.8498	6.68*
	Regression on X_{67} & X_{46}	2	373.8079	186.9040	14.06**
	Residuals	23	305.7987	13.2956	
	Total, around mean	25	679.6066		

b	*Source of variation*	*D.F.*	*S.S.*	*M.S.*	*V.R.*
	X_{67} considered alone	1	284.9581	284.9581	19.36**
	X_{47} when X_{67} fixed	1	56.0724	56.0724	3.81
	Regression on X_{67} & X_{47}	2	341.0305	170.5152	11.58**
	Residuals	23	338.5761	14.7207	
	Total, around mean	25	679.6066		

c	*Source of variation*	*D.F.*	*S.S.*	*M.S.*	*V.R.*
	X_{76} considered alone	1	208.7884	208.7884	11.50**
	X_{45} when X_{76} fixed	1	53.3062	53.3062	2.94
	Regression on X_{76} & X_{45}	2	262.0946	131.0473	7.22**
	Residuals	23	417.5120	18.1527	
	Total, around mean	25	679.6066		

d	*Source of variation*	*D.F.*	*S.S.*	*M.S.*	*V.R.*
	X_{80} considered alone	1	336.2760	336.2760	25.12**
	X_{46} when X_{80} fixed	1	35.3948	35.3948	2.64
	Regression on X_{80} & X_{46}	2	371.6708	185.8354	13.88**
	Residuals	23	307.9358	13.3885	
	Total, around mean	25	679.6066		

e	*Source of variation*	*D.F.*	*S.S.*	*M.S.*	*V.R.*
	X_{80} considered alone	1	336.2760	336.2760	24.57**
	X_{47} when X_{80} fixed	1	28.5697	28.5697	2.09
	Regression on X_{80} & X_{47}	2	364.8457	182.3804	13.33**
	Residuals	23	314.7609	13.6852	
	Total, around mean	25	679.6066		

X_{45} = Moisture equivalent of B-horizon
X_{46} = Depth to fine textured horizon; 20% silt + clay
X_{47} = Silt + clay of B-horizon
X_{67} = June + July rainfall
X_{76} = January + February rainfall

$$X_{80} = \frac{\text{June} + \text{July}}{\text{June} + \text{July} + \text{January} + \text{February}} \times 100$$

* = Significant at 5% point
** = Significant at 1% point

DISCUSSION

ONE of the primary objectives of the present investigation was to determine the independent effect of growth rate and of age on summerwood percentage and specific gravity in slash pine. The study was so designed that the effect of age could be isolated by removing the variability between plots and between trees within the plots in a covariance analysis. From this analysis it was found that age accounted for an exceedingly large part of the total variation in summerwood percentage while the percentage of summerwood as a function of age accounted for most of the variability in specific gravity. After the removal of age and other "treatment" effects by covariance, ring width was found to exert a negligible effect on both summerwood percentage and specific gravity.

Although the curves derived from these data (Fig. 2 and 4) indicate that ring width influences both summerwood percentage and specific gravity to a slight degree, particularly in the case of very narrow and very wide rings, the curves alone do not constitute adequate criteria for judging the relationship. Consideration must also be given to the dispersion of the individual observations around the regression lines and the magnitude of this dispersion more or less negates the effect of ring width from a practical point of view. With age held constant, ring width accounted for no more than 2.2 percent of the total variation in summerwood percentage and 0.75 percent of the total variation in specific gravity. In terms of summerwood percentage on a plot basis, adjustments for ring width did not exceed one percent (Table 14), which is well below the limits of ocular estimation.

These results are not in full accord with the findings and conclusions of other investigators who have worked with the southern pines. Nevertheless, it is believed that most of the discrepant conclusions can be explained on the basis of sampling procedures and, consequently, on the subsequent analysis of the data. The very pronounced effect of summerwood percentage on specific gravity and of age on summerwood percentage has been mentioned previously; the latter relationship is presented graphically in Figure 6. Failure to account for this inherent variation in summerwood percentage with age will obviously result in a significant relationship between specific gravity and ring width since summerwood percentage and ring width are influenced concomitantly, yet more or less independently, by age. Samples from all positions on a single cross-section or a number of cross-sections from which age has not been isolated will therefore reflect an effect of growth rate. But, this "apparent" effect of growth rate can be nullified by either appropriate sampling or statistical procedures which allow for the variation due to age.

The interaction of age and growth rate can be lucidly exemplified by an analysis in which age and ring width have been intentionally confounded. Data for this analysis were obtained from Analysis I. The sums of squares for age and the plots x age interactions were combined with the error term resulting in complete confounding of age and ring width over all age segments. The test of significance (Table 10) shows that the linear term for ring width is highly significant with a variance ratio of 740.34. Of far greater interest, however, is the extraordinary increase in the amount of the total variation in summerwood percentage accounted for by ring width. This value increased from a mere 2.20 percent with age eliminated to 27.53 percent when age and ring width were confounded. These data provide convincing evidence of the importance of age and also emphasize the spurious conclusions that can be drawn when age is ignored.

TABLE 10. EFFECT OF CONFOUNDING AGE AND RING WIDTH ON SUMMERWOOD PERCENTAGE

Source of variation	*D.F.*	*S.S.*	*M.S.*	*V.R.*
X_2 considered alone	1	64900.6426	64900.6426	740.34**
X_3 when X_2 fixed	1	108.2599	108.2599	1.23
Regression on X_2 & X_3	2	65008.9025	32504.4512	370.79**
Residuals	1948	170767.0975	87.6628	
Total, around mean	1950	235776.0000		

$r^2 = 64900.6426 / 235776.0000 = 0.275264$

X_2 = Ring width

X_3 = Ring width squared

** = Significant at 1% point

Age may also be confounded with rate of growth by the comparison of young, fast-grown trees with older, slow-grown trees. The "apparent" effect of ring width is again manifest, but it, as in the preceding case, results from failure to recognize the inherent increase in summerwood percentage and specific gravity with age. Although the older, narrow rings of the slow-grown trees will invariably exhibit higher specific gravities than the younger, wide rings of the fast-grown trees, this does not warrant the conclusion that all wide rings are low in density irrespective of age. The fact that there is practically no difference due to ring width when age is held constant has been verified by Analysis III in which no significant relationship was found between either summerwood percentage or specific gravity and ring width in the individual age segments. The predominating influence of age could be similarly visualized in Figure 6 where age 11 years could represent the young tree and age 26 years the older tree. Differences in summerwood percentage, hence specific gravity, may be readily noted; however, the fact that these are age differences is equally apparent.

Figure 6 also exemplifies the exceptionally high summerwood percentage which is typical of slash pine. The mean percentage of summerwood increased from about 40 percent at age 6 years to about 60 percent at age 21 years. Part of this high summerwood content is attributable to sampling the base of the tree at a 3.5-foot height above the ground as opposed to sampling the whole tree, but an inherently high proportion of summerwood must still be recognized. This characteristic of slash pine was also observed by Mattoon (1939), who found that near the base of the tree the summerwood content averaged about 55 percent.

A high degree of statistical sensitivity was attained in the analyses by removing a large portion of the variation by covariance in the form of "treatment" effects and by building up the residual error term with a large number of observations. Hence, the removal of "plots" minimized the influence of both environment and racial variation between plots while the removal of "trees" minimized the influence of environment and inherent variation between individual trees. Still greater sensitivity could probably have been attained by incorporating data from a much larger number of plots and establishing an even greater error term. Although such an analysis would undoubtedly have resulted in slight modifications in the final adjustments for ring width and in the shapes of the plotted curves, it is highly improbable that the amount of total variation accounted for by ring width would have been appreciably increased, provided that the additional plots were based on well-randomized samples of trees. It is therefore felt that the residual error term of Analysis I provided a realistic estimate of the over-all effect of ring width on summerwood percentage and specific gravity in slash pine. Nevertheless, the extremely low correlation between ring width and either summerwood percentage or specific gravity precludes the use of the measure for predicting purposes under any circumstances.

As evidenced by the foregoing discussion, the shapes of the plotted curves are by no means immutable. They are to be regarded as general trends applicable to the data at hand although probably approximating the curves that would be obtained from replicate large-scale samples in slash pine. Small samples, on the other hand, when significant, may yield a relatively wide variety of curves, but each curve would necessarily be limited to the site and conditions of growth upon which it was based; it could not be used to predict the effect of rate of growth in other stands. Most wood-density investigations have seldom exceeded a 2- to 5-tree sample from anyone site. In samples of this size it is almost impossible to statistically eliminate age and still determine the effect of ring width. Age and ring width are therefore invariably confounded, with the result that growth rate is erroneously found significant.

The bias that is inherently present in a small sample is often accentuated by the selection of trees representing extreme conditions of growth. This selection is a natural consequence of small-scale sampling since adequate randomization of a 5- or even a IO-tree sample is generally impractical if not impossible. Non-randomized selection most frequently results in the sampling of an equal number of dominant and intermediate size classes, although codominants may be occasionally included. Considering these extremes, it is conceded that suppressed and intermediate trees may possess higher specific gravities than the dominants and codominants and that the specific gravity of a small-crowned, forest-grown tree may be higher than that of a large-crowned, open-grown tree under certain conditions, although the magnitude of these differences would be debatable. Since these conditions do not represent the typical structure of a normal, managed forest, it would be unrealistic to assign the specific gravity of the large-crowned, open-grown tree to a fast-growing stand and the specific gravity of the small-crowned suppressed or intermediate tree to a slow-growing stand. This would be equivalent to assuming that all fast-growing trees are open-growing and all slow-growing trees are suppressed.

In reality, slow-growing as well as fast-growing stands are composed of trees of all size classes from dominant to suppressed. Thus, a valid test of the differences in specific gravities among stands of varying rates of growth would be to sample each stand by a good representative sample which should be large enough to include all size classes found within the selected stand. Such a sample would include a few dominants, a few suppressed, and a large preponderance of intermediates and codominants. This was the aim of the sampling procedure employed in the present investigation. A plot center was located and the 25 trees closest to this center point were sampled with the qualification that all trees must be within the merchantability range of 6 to 14 inches d.b.h.; leaning trees were also excluded because of excessive compression wood. Once a tree had been selected and numbered, it could only be discarded if it contained excessive "pitch-soaking" or if it was found to represent another age class. Within these limitations it was felt that the 25-tree plots yielded a good representative sample of all tree classes and as near a randomized sample as could be efficiently obtained.

It is assumed that a well-randomized sample of adequate size represents the range and distribution of tree classes with which the silviculturist must work. Similarly, wood density data obtained from this sample should provide the silviculturist with the information necessary for determining the growth conditions that will yield the maximum volume-weight production of wood. Valid silvicultural recommendations of this type can only be made on the basis of well-distributed large-scale samples. These sampling requirements have been more or less fulfilled by the present study, with respect to growth rate, which lends justification to the previously reached conclusion: Over the normal range of ring widths, the effect of growth rate on specific gravity is negligible and for all practical purposes may be ignored in slash pine.

Just what constitutes the normal range of ring widths may need some clarification as well as the seemingly contradictory statement that suppressed trees may have slightly higher specific gravities than dominants. For the most part, the latter statement is based on the literature and represents all species and a variety of sampling conditions. In slash pine, no differences were found in either summerwood percentage or specific gravity between the fast-growing dominants and the slower growing suppressed trees when age was eliminated. This conclusion is substantiated by the fact that the variance ratio for "trees" remained virtually unchanged after covariance adjustment in all analyses. "Trees", in these analyses, tested the within-plot variation between individual trees and each plot represented a wide range of tree classes from dominant to suppressed as well as a relatively wide range of ring widths.

Ring width was also found non-significant within individual age segments (Analysis III), which lends support to the conclusion that dominant and suppressed slash pine trees do not differ in specific gravity. The fact that the curves drop off rather sharply suggests that extremely wide rings may possess somewhat lower specific gravities. In Figure 2 the maximum reduction in summerwood percentage was about 5 percent from rings 3 mm. in width (8 rings per inch) to rings 7 mm. in width (3.5 rings per inch) while over the same range specific gravity (Fig. 4) dropped from .583 to .569 (segment 3). Although extremely wide rings 7 mm. in width and over were of normal occurrence in the youngest growth periods near the pith, rings exceeding 6 mm. in width were infrequently found in the older segments, 3 and above, and then only in the more open-grown trees that were occasionally encountered. When wide rings did occur beyond the juvenile period (approximately 6 to 8 years), they were generally high in summerwood as a result of the inherent increase due to age. The data of this study suggest, but do not conclusively prove, that once the juvenile period is passed even rapid growth rates will maintain a relatively high percentage of summerwood.

The inherent increase in summerwood is further amplified in the dominants growing within a stand as contrasted with open-grown trees by the difference in relative crown size. Stand-grown dominants of slash pine, excluding "wolf" trees, rarely have a crown-height ratio exceeding 40 to 50 percent, whereas 60 to 70 percent crown-height ratios are not uncommon in open-grown trees of comparable age (20 to 25 years). Volkert (1941), Pechmann and Schaile (1955), and others have shown quite conclusively that, within reasonable limits, the greater the distance from crown base to stem base, the greater the percentage of summerwood in the basal section. Marts (1949, 1951) has simulated this effect by drastic pruning in longleaf pine. Although crown-height ratios may vary within an even-aged slash pine stand, the variation in the distance from crown to stem base between tree classes is not great. Hence, the difference in wood density between a suppressed and a dominant within the same stand may be far less than what might be anticipated and it has, indeed, been found to be practically non-existent in slash pine.

The normal range of ring widths, previously mentioned, may be defined as the range of growth rates anticipated by forest management on an average stand basis. No attempt will be made to establish arbitrary limits in terms of ring width. However, some evidence as to anticipated growth rates can be obtained from previously published information.

The best available data on diameter growth rates in slash pine stands are those of Ware and Stahelin (1948) based on a spacing study in Alabama, and of Barnes (1955) based on 101 Florida plantations. Although in both studies the 12 x 12 and 16 x 16-foot spacings produced the most rapid growth rates, they again represent extreme conditions.

The average slash pine plantation would more closely correspond to an 8 x 8 or 10 x 1o-foot spacing. For Barnes' data, maximum 5-year growth for these stand densities occurred between 10 to 15 years of age on site quality[1] 80; Ware and Stahelin's data represent the mean annual growth for the *13th* and *14th* years for a site index[1] of 85 to 100. These values are enclosed within the dashed lines in the following table:

WARE AND STAHELIN (1948)

Age	*Spacing*	*Rings per inch*	*Ring width*
years	*feet*		*mm.*
13-14	6x6	6.2	3·9
	8x8	6.2	3·9
	9.6 x 9.6	5·3	4·7
	12 x 12	4.8	5.2
	16 x 16	3·7	6.6

BARNES (1955)

Age	*Spacing*	*Rings per inch*	*Ring width*
years	*feet*		*mm.*
10-15	6x6	9.1	2·7
	8x8	6.2	3·9
	10 x 10	5·0	4·9
	12 x 12	4·5	5·4

Growth rates for the 8 x 8-foot spacings agree fairly well with the mean ring widths for the comparable age segments in the present study as follows:

PRESENT STUDY

Segment number	*Segment age*	*Rings per inch*	*Ring width*
	years		*mm.*
3	11	6.6	3·7
4	16	7·9	3.1

The somewhat slower growth rate of the trees in this investigation may be attributed to the averaging of ring widths obtained from natural stands growing on a wide range of site conditions whereas most existing plantations were established on old-field sites. The mean site quality for stands in the present study was 65; Barnes considered site quality 60 as average for slash pine.

Ring width has been previously shown to have no appreciable effect on specific gravity over the range covered by this study (Fig. 4). If the data of the three investigations under consideration are assumed to be sound, then it may be concluded that slash pine can be grown on at least a 10 x 10-foot initial spacing without impairing the specific gravity of the wood produced.

Up to this point the juvenile period has been mentioned only briefly in

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[1] Site quality (Barnes, 1955) refers to the height of the dominant trees at age 25. Site index refers to the height of the dominants at age 50 (U. S. Dept. Agr., 1929).

the discussion. This is a period of atypical wood formation with respect to both summerwood percentage and specific gravity which, in this study, was found to include the first 2 segments, or the first eight rings. The first six to eight rings were also considered atypical in southern pines by Lodewick (1933), Cockrell (1949), and Zobel and Rhodes (1955).

It is during this early period in the life of the tree that age exerts its most predominating influence on summerwood percentage as indicated in Figure 6. The confounding of age and ring width in most investigations is due primarily to the wide rings with low summerwood content from this inner region of the cross-section. Even when the effect of age was minimized in this investigation, a certain amount of confounding remained within each of the 5-year segments. The analyses assumed a mean value for each individual observation whereas within each 5-year segment the relationship of ring width to summerwood percentage may be linear or parabolic; this type of confounding occurs on a gross scale when mean values for entire increment cores or cross-sections are compared. Since profound changes in both summerwood percentage and specific gravity undoubtedly occur between ages 4 and 8 years, the within-segment confounding may account for the significance of the linear term in segment 2 (Analysis III). It is the author's opinion that the complete elimination of age from this segment would nullify the effect of ring width and reduce it to non-significance. In older segments the year to year change in summerwood percentage is more gradual and the validity of using the mean 5-year values for statistical evaluation is increased.

Wood formed during the juvenile period is of particular importance to the sawmill industry since it contributes to excessive longitudinal shrinkage in lumber. It is still somewhat controversial as to whether or not such shrinkage is a characteristic of all rapid-grown wood. Cockrell (1949) has recently shown in a number of species, including the southern pines, that, "excessive longitudinal shrinkage seems to be more a function of proximity to pith rather than rate of growth." He believed that the reports of many previous workers were based on the wide-ringed material near the pith of second-growth trees and therefore could not be referred to as typical of rapid growth in general. Figure 2 illustrates this point for slash pine. The maximum growth rate encountered in this investigation for segment 3, mean age 11 years, was approximately 7 mm. or 3.5 rings per inch. Yet this rate of growth still maintained about 48 percent summerwood. Three and one-half rings per inch would not satisfy the requirements for the better grades of southern pine lumber (Southern Pine Inspection Bureau, 1948) ; however, in terms of summerwood percentage it exceeds the requirement for "close grain lumber" (33 percent) and very closely approaches that of "dense southern pine" (50 percent). Although it has been previously emphasized that the results presented herein are not designed for predicting purposes, the data are, nevertheless, indicative of general trends of summerwood percentage. The data are, in part, corroborated by the work of Mattoon (1916a) who found that "even when young and fast-growing, the tree (slash pine) produces a proportionately wide band of summerwood, very dense and resinous, and sharply demarcated from the springwood of the same season's growth."

Regardless of the interpretation with respect to rapid growth *per se,* it must still be recognized that the juvenile wood, up to 6 or 8 years, produces poor-quality lumber. Whether a slow juvenile growth rate could correct for this deficiency or merely confine the low-density wood to a smaller core, cannot be determined on the basis of this investigation. Control of the rate of growth in the central core may mean that wood production will have to be considered in terms of product objectives and the stands managed accordingly.

EFFECT AND VARIABILITY OF SUMMERWOOD PERCENTAGE

In the preceding portion of this discussion it was concluded that the variation in specific gravity within trees, between trees, and between plots was due primarily to variations in the percentage of summerwood, and ring width was more or less ineffective in modifying this relationship. Summerwood percentage accounted for most of the within-tree variation measured by age and reduced the variance ratio from 175.98 to 8.91 (Table 12, b and c) after ring width had been previously removed. The highly significant variance ratio, although small (8.91), suggests that another factor or set of factors influence the specific gravity from pith to cambium independent of either ring width or summerwood percentage. The independence is, of course, assumed for it is possible that ring width and summerwood percentage are neither strictly parabolic nor linear, respectively, as considered in the analyses. It is doubtful, however, if variation from the assumed relationships could account for the significance of specific gravity due to age.

During the course of ring measurements it was repeatedly observed that the summerwood cell walls of the young growth rings were decidedly thinner than those of older rings. No cell wall measurements were made; hence, the relationship with specific gravity could not be determined. Quantitative data from other investigations have shown, however, that summerwood cell wall thickness increases with age (Sanio, 1872; Bertog, 1895; Chalk, 1951; Göhre, 1955b) and, similarly, the specific gravity of summerwood also increases with age (Paul, 1939; Kollmann, 1951; G6hre, 1955b) indicating a gradual change in the quality of the summerwood. Such qualitative differences in the summerwood, and possibly in the springwood, of slash pine could conceivably account for the aforementioned differences in specific gravity on the cross-section.

In a like manner, differences in cell wall thickness could possibly account for the highly significant between-tree as well as the between-plot variation in residual specific gravity remaining after the adjustment for ring width and percentage of summerwood (Table 12, c). Rather large differences have been noted in summerwood wall thickness between sites by other investigators (Kienholz, 1931; Klem, 1933; Koehler, 1938; Trendelenburg, 1939; Burger, 1941, 1952, 1953). Such differences in summerwood quality may also be present in slash pine, particularly among the rather extreme site and climatic conditions encountered throughout its range. These results suggest, therefore, that summerwood not only varies in quantity but may also vary in quality within individual trees, between trees in the same stand, and between sites.

The percentage of summerwood also varied slightly between trees on the same plot and widely between plots (Table 12, a). An attempt was made to account for some of the between-tree variation by Analysis VII; none of the factors considered were significant. Apparently this variation was due to other environmental factors or possibly to the inherent variability of individual trees.

The variation between individual plots, representing different stand and site conditions, is shown for summerwood percentage and specific gravity in Tables 14 and 15, respectively. On a geographic basis, summerwood percentage increased from north to south (plots 1 to 8) and decreased from east to west (plots 9 to 14). Regionally, the south and east plots were significantly higher in summerwood percentage than the north and west plots (Plate III, a and b).

A considerable part of the variation in summerwood percentage between plots was ascribable to environmental factors. Of those considered, all factors that showed significance were in some way related to soil-moisture availability. Moisure equivalent of the B-horizon and the silt + clay of the B-horizon were both negatively correlated with summerwood percentage while the depth to a fine-textured horizon was positively correlated (Analysis

VI). These results may be interpreted as signifying that a greater retentivity of moisture near or relatively near the surface promoted the formation of springwood. Since these variables, which are closely related to one another, are generally associated with good sites, it may be further interpreted that good sites produced a lower percentage of summerwood than poor sites and, consequently, less dense wood. This conflicts with the results of Paul and Marts (1931, 1954) and Kerr (1931) who found that artificial irrigation increased summerwood development and produced heavier wood. It should be recognized, however, that irrigation of a poor sandy site is not the equivalent of high moisture retention under natural conditions. That moisture is not the sole criterion for estimating high summerwood-producing sites is borne out by the non-significance of wet vs. dry sites in Analysis V.

Regressions of summerwood percentage on various expressions of mean monthly precipitation gave a high positive correlation with June + July rainfall and a high negative correlation with January + February rainfall. These correlations suggest that June + July was the period of most "effective" rainfall with respect to summerwood formation and January + February the period of most "effective" rainfall with respect to springwood formation. The latter period may appear to be somewhat early in the season to influence the formation of springwood, but it could very possibly represent the soil-moisture storage utilized for the spring flush of growth. Over the range of slash pine this period may vary considerably, in which case the January + February rainfall would represent the best general average. Coile (1936) found that the annual growth of slash pine in the Coastal Plain of Georgia was influenced most by rainfall in the early spring—February to April, inclusive.

These data do not imply that rainfall in the other months was ineffective, but they do indicate the predominating influence of the "effective" periods. Thus, it may be presumed that the bulk of the springwood formation was dependent upon the January + February rainfall and that it was supplemented by the March, April, and May precipitation. Similarly, the June + July rainfall was supplemented by that in subsequent months. Part of the lessened significance of the in-between months may also be attributed to the fact that they represented an equating period with respect to rainfall distribution. In Figure 7 the distribution of January + February precipitation over the range of plots is a curve with a negative slope, whereas the distribution of June + July precipitation is a curve with a positive slope. The precipitation distribution for March, April, and May (not plotted) presented a gradual shift from negative to positive curvature with the result that the mean monthly precipitation tended to be more uniform over the entire slash pine region.

The foregoing expressions of precipitation considered the "effective" periods of spring and summer rainfall independently, whereas both the springwood and summerwood ring components are incorporated in summerwood percentage. Thus, only a part of the total "effective" rainfall was compared with a measure embodying the entire annual ring. A more satisfactory expression, "summer precipitation percent" (rainfall for June + July/January + February + June +July x 100), is comparable in its derivation to summerwood percentage and therefore tends to equate "effective" precipitation with summerwood percentage (Fig. 7). This single expression accounted for 49.48 percent of the total variation in summerwood percentage between

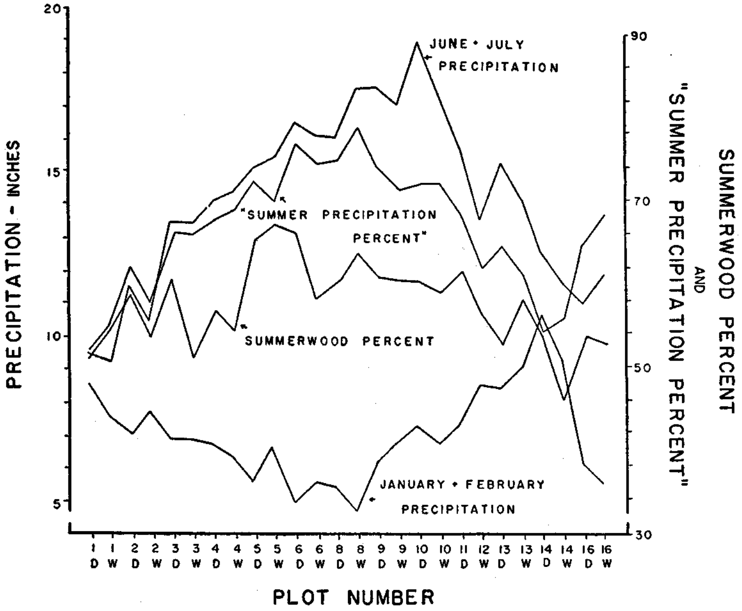

FIGURE 7. Distribution of certain expressions of precipitation and percentage of summerwood by sample plots throughout the range of slash pine. (See text for interpretation.)

plots (Fig. 8). It indicates that the highest percentage of summerwood was formed in those areas where January + February (preseason) precipitation tended to be low and June + July (mid-season) precipitation high.

The best over-all expression, however, was obtained from the combination of June + July rainfall and depth to a fine-textured horizon in a multiple regression equation which accounted for 55.00 percent of the total variation in summerwood percentage between plots. This suggests that a high June + July rainfall on an area with a deep-lying fine-textured horizon produced the highest percentage of summerwood. These results more or less support those obtained with "summer precipitation percent", since the areas with

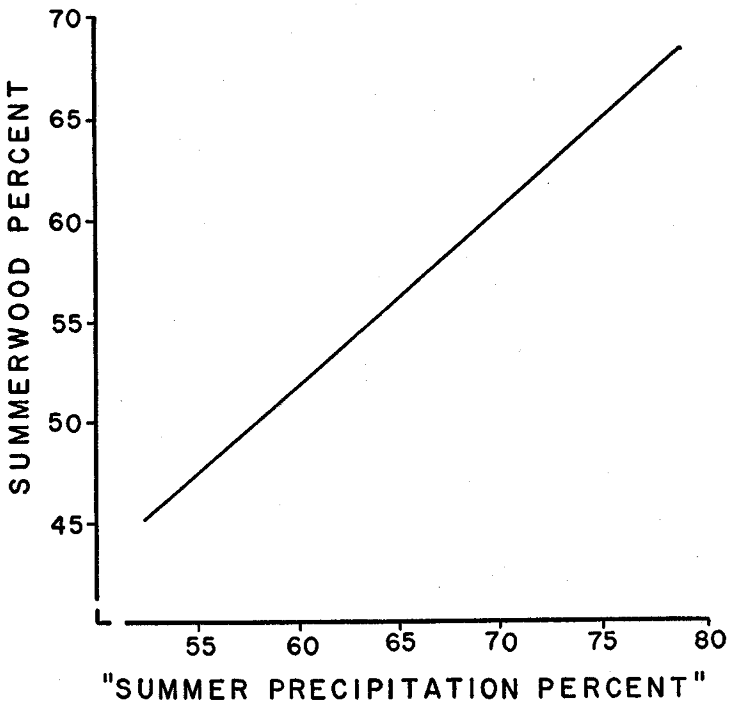

FIGURE 8. Regression of summerwood percentage (X_1) over "summer precipitation percent" (X_{80}). "Summer precipitation percent" accounted for 50 percent of the total variation in summerwood percentage.
Regression equation:
$X_1 = 1.157\ X_{80}$

high June + July rainfall generally had low January + February rainfall; the soil variables were not significant in combination with "summer precipitation percent".

On the basis of these data it appears that the regional differences in summerwood percentage are due primarily to differences in precipitation distribution. In general, the regions with low January + February rainfall and high June + July rainfall produced the highest percentage of summerwood irrespective of growth rate. Within any region soil quality tended to modify this relationship. Soils with a high moisture-holding capacity in the B-horizon promoted the formation of springwood and, conversely, soils with a low moisture-holding capacity produced less springwood. These are, of course, generalizations and exceptions could be found.

One isolated example is plot 6-D which not only produced the most rapid average growth rate of any plot sampled but also the second highest summerwood percentage and specific gravity. Yet this stand was growing on pure, white sand (98.2 percent sand in the A-horiz{)n) and was the only stand with cacti as associated ground-cover vegetation. The modifying factor appeared to be an impenetrable organic hardpan at a depth of 36 inches. It is believed that this hardpan prevented the rapid percolation of late winter rainfall, and similarly the heavy summer rainfall, which resulted in a plentiful moisture supply for both springwood and summerwood formation. The latter would be further enhanced by the long growing season of Central Florida. Paul and Marts (1931) noted that summerwood formation in longleaf pine growing in West Florida continued until December when sufficient soil moisture was available.

The length of the growing season undoubtedly plays an important role in modifying summerwood percentage. In terms of frost-free days, growing season varied from about 240 days in the northernmost to 310+ days in the southernmost parts of the slash pine range. The fact that growing season was not significant in Analysis VI may suggest that the method of determining growing season was in error, or it may have been due to the east-west plots which varied widely in summerwood percentage but very little in the length of the frost-free period. Elimination of the east-west plots may have resulted in a significant correlation between summerwood percentage and growing season for the north-south plots. It would be almost impossible, however, to determine whether the relationship was causal or merely an accidental correlation with both factors varying concomitantly with latitude.

Numerous environmental factors vary with latitude and precipitation is among these. However, precipitation not only showed a rather close agreement with summerwood percentage latitudinally but also longitudinally, and over a considerable period during the year which supports its causal significance. It was, indeed, remarkable that about one-half of the total variation in summerwood percentage between plots could be accounted for by precipitation data since the reporting stations were oftentimes 10 to 15 miles from the plots. These were, however, the only data available. If precipitation data could be obtained directly on each individual plot, supplemented by continuous soil moisture data, then it is very probable that the total amount of summerwood percentage accounted for could be substantially increased.

The data of this investigation do not justify the prediction of either summerwood percentage or specific gravity for any specified set of conditions. The biological complex of factors controlling summerwood percentage, hence specific gravity, are as yet too little understood to be reduced to a simple predicting formula. Nevertheless, the generalization can be made for slash pine that a high preseason rainfall (January + February) promotes springwood development and a high midseason rainfall (June + July) promotes summerwood development. Within a climatic province, good sites will usually produce a lower percentage of summerwood than poorer sites, when site is measured in terms of moisture-holding capacity of the soil.

No conclusions have been drawn with respect to genetic variation although at various points in the discussion the possibility of inherent differences between trees and between stands has been suggested. A considerable part of the total summerwood variation between plots has been accounted for (55 percent) and it is believed that this could be increased substantially by more accurate climatic data. Hereditary differences in summerwood percentage can only be determined by seed source studies where the suspected "races" are grown under identical conditions. Interpretations would still have to be made with caution, however, for summerwood presents an elusive problem since little is known about its physiological development.

CONCLUSIONS

THE results of this investigation permit the following main conclusions to be drawn regarding the specific gravity and percentage of summerwood in slash pine:

1) Age determinations made by visual counts on increment cores are to be questioned if the correct age is of extreme importance. Correct ages can only be determined by carefully cross-checking a representative sample of suitably prepared cores under a microscope.
2) Increment cores provide an efficient and satisfactory method of large-scale sampling for specific gravity and percentage of summerwood investigations. Specific gravities obtained from increment cores were slightly higher than those obtained from larger wood samples. The discrepancy was partially corrected (within a 2 to 3 percent error) by soaking the cores for 48 hours followed by boiling in water for one hour.
3) Within the range of ring widths normally encountered in managed stands of slash pine, rate of growth exerted a negligible influence on both specific gravity and percentage of summerwood and for all practical purposes its effect may be ignored.
4) The percentage of summerwood was strongly correlated with specific gravity, accounting for about 60 percent of the total variation. It is the best single criterion for estimating the specific gravity of slash pine wood.
5) The effect of age predominated in controlling the percentage of summerwood gradient on the cross-section. Mean summerwood percentage increased from about 40 percent at age 6 years to about 60 percent at age 21 years and tended toward uniformity thereafter.
6) On the basis of previously published information on plantation growth rates, it was determined that slash pine could be grown on at least a 10 x 10-foot spacing without impairing the specific gravity of the wood produced.
7) Juvenile wood (up to 6 to 8 years) has been found to be inherently low in summerwood. It may be possible to correct for the excessive longitudinal shrinkage in lumber by confining these rings to a smaller central core by closer initial spacings. If so, it may require that wood be grown on the basis of product objectives and managed accordingly.
8) Considerable differences in adjusted summerwood percentages were found to exist between individual trees. Total age, total height, crown-height ratio, tree spacing (stand-density index) and tree radius were not

correlated with summerwood percentage and none of the between-tree variation could be accounted for by these factors.

9) Considerable differences in adjusted summerwood percentages were found to exist between individual plots representing a range of site conditions and geographic locations. The following relationships were obtained from statistical evaluation of these differences:
   a) Summerwood percentage increased from north to south and from west to east within the slash pine range.
   b) Summerwood percentage was not correlated with the variables, mean plot age, number of trees per acre, site index at 50 years, site quality at 25 years, and growing season as determined by number of frost-free days.
   c) In general, summerwood percentage decreased with increasing moisture equivalent values and increasing silt + clay content of the B-horizon, whereas summerwood percentage increased with increasing depth to a fine-textured horizon.
   d) No differences in summerwood percentages were found to exist between arbitrarily classified wet and dry sites.
   e) The percentage of summerwood increased with increasing June + July precipitation and decreased with increasing January + February precipitation.
   f) The best single variable for accounting for the differences in summerwood percentage between plots was "summer precipitation percent"; it accounted for 50 percent of the total variation.
   g) The best over-all expression for accounting for the differences in summerwood percentage between plots was the multiple variable June + July rainfall in combination with depth to a fine-textured horizon; this expression accounted for 55 percent of the total variation.
   h) The percentage of summerwood, therefore, tended to be highest in those areas favored by a low pre-season and a high mid-season rainfall and on sites with a low moisture holding capacity in the B-horizon and/or a deep-lying fine-textured horizon. Thus, good sites produced a lower percentage of summerwood than poorer sites.

10) Differences in summerwood percentage, hence specific gravity, between individual trees and between plots remained after all quantitative sources of variation had been accounted for. These differences may, in part, represent genetic variation. Proof of this, however, must come from appropriate investigations.

SUMMARY

THE objective of the study was to evaluate by statistical methods the influence of growth rate and of age as well as the effects of geographic location and factors of the environment on the specific gravity and percentage of summerwood in slash pine.

A wide range of climatic and environmental conditions were tested by a systematic distribution of 29 sample plots throughout the natural range of slash pine. Each plot was located in a stand which met prescribed requirements as to size, age, and site conditions. Mensurational data were collected from the stand and from 25 sample trees on each plot. In addition, soil data and soil samples for each plot were obtained from a soil pit. Two increment cores were extracted from each of the 25 sample trees on each plot.

Laboratory analyses included precise determinations of age, ring width, percentage of summerwood and specific gravity for each increment core; specific gravity determinations were made on the basis of 5-year segments of the increment cores to provide an estimate of the within-tree variation. Preliminary tests indicated that 5-year increment core segments provide an efficient method of large-scale sampling for investigations of specific gravity and percentage of summerwood. Precipitation data from U. S. Weather Bureau stations in the vicinity of each sample plot were summarized for the individual years corresponding to the mean ages of the trees on each plot. At the completion of all field and laboratory work the data were statistically evaluated by multiple covariance and regression analyses.

It was found that within the range of ring widths normally encountered in slash pine stands, rate of growth exerted a negligible influence on both specific gravity and percentage of summerwood and for all practical purposes its effect may be ignored. The percentage of summerwood was strongly correlated with specific gravity, accounting for 60 percent of the total variation whereas the effect of age predominated in controlling the percentage of summerwood gradient on the cross-section. Mean summerwood percentage increased from about 40 percent at age 6 years to about 60 percent at age 21 years and tended toward uniformity thereafter. The juvenile wood (up to 6-8 years) tended to be inherently low in summerwood.

Considerable differences in summerwood percentage, hence specific gravity, were found to exist between individual trees and between plots. None of the between-tree variation could be accounted for by the factors tested. On a plot basis, summerwood percentage increased from north to south and from west to east within the slash pine range. The only stand variables that could account for any of this between-plot variation were those related to moisture-holding capacity of the soil; high moisture-holding capacity, hence good sites, produced the lowest percentage of summerwood after adjusting for rate of growth.

Percentage of summerwood increased with increasing June + July precipitation and decreased with increasing January + February precipitation. The multiple regression of the two variables, June + July rainfall and depth to a fine-textured horizon, accounted for 55 percent of the total variation in summerwood between plots.

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APPENDIX

APPENDIX

TABLE 11. ANALYSIS I. ANALYSIS OF VARIANCE, SEGMENTS 3-4-5

a ANALYSIS OF VARIANCE FOR UNADJUSTED SUMMERWOOD PERCENTAGE (X_1)

Source of variation	*D.F.*	(X_1)	*M.S.*	*V.R.*
Plots	25	50869	2034.76	87.44**
Age	2	21224	10612.00	456.04**
Trees	624	64778	103.81	4.46**
Plots x Age	50	16364	327.28	14.06**
Error	1248	29043	23.27	
Total	1949	182278		

b ANALYSIS OF VARIANCE FOR UNADJUSTED SPECIFIC GRAVITY (Y)

Source of variation	*D.F.*	(*Y*)	*M.S.*	*V.R.*
Plots	25	1.522892	0.060916	95.03**
Age	2	0.573844	0.286942	447.65**
Trees	624	2.495237	0.003999	6.24**
Plots x Age	50	0.478488	0.009570	14.93**
Error	1248	0.799666	0.000641	
Total	1949	5.870127		

** = Significant at 1% point

APPENDIX

TABLE 12. ANALYSIS I. COVARIANCE ADJUSTMENTS, SEGMENTS 3-4-5

a SUMMERWOOD PERCENTAGE ON RING WIDTH

Source of variation	*D.F.*	*d'*	*Diff·*	*M.S.*	*F.R.*
Plots	25		51188.94	2047.56	89.80**
Age	2		9309.83	4654.92	204.16**
Trees	624		653 81.00	104.78	4.60**
Plots x Age	50		15788.14	315.76	13.85**
Error	1246	28404.59		22.80	
Plots + Error	1273	79593·53			
Age + Error	1250	37714.42			
Trees + Error	1872	93785.59			
Px A + Error	1298	44192.73			

b SPECIFIC GRAVITY ON RING WIDTH

Source of variation	*D.F.*	d^2	*Diff·*	*M.S.*	*F.R.*
Plots	25		1.526122	0.061045	95·53**
Age	2		0.2249°7	0.112454	175.98**
Trees	624		2.458548	0.003940	6.17**
Plots x Age	50		0416689	0.008334	13.04**
Error	1246	0.796158		0.000639	
Plots + Error	1273	2·322280			
Age + Error	1250	1.021065			
Trees + Error	1872	3.254706			
PxA + Error	1298	1.212847			

c SPECIFIC GRAVITY ON SUMMERWOOD PERCENTAGE + RING WIDTH

Source of variation	*D.F.*	*d'*	*Diff·*	*M.S.*	*F.R.*
Plots	25		0.258122	0.010325	40.97**
Age	2		0.004492	0.002246	8.91**
Trees	624		1.060594	0.0017°0	6·75**
Plots xAge	50		0.060742	0.001215	4.82**
Error	1245	0.314207		0.000252	
Plots + Error	1273	0.572329			
Age + Error	1250	0.318699			
Trees + Error	1872	1.374801			
PxA + Error	1298	0·374949			

** = Significant at 1% point

APPENDIX

TABLE 13. ANALYSIS II. ANALYSIS OF VARIANCE AND COVARIANCE ADJUSTMENTS, SEGMENTS 2-3-4-5

a ANALYSIS OF VARIANCE FOR UNADJUSTED SUMMERWOOD PERCENTAGE (X_1)

Source of variation	*D.F.*	*(X_1)*	*M.S.*	*V.R.*
Plots	25	62447	2497.88	84.33**
Age	3	154268	5142.27	1733.74**
Trees	624	70768	113.41	3.83**
Plots x Age	75	25971	346.28	11.69**
Error	1872	55537	29.62	
Total	2599	368991		

b ANALYSIS OF COVARIANCE ADJUSTMENTS

Source of variation	*D.F.*	*d^2*	*Diff.*	*M.S.*	*V.R.*
Plots	25		62343.89	2493.76	84.79**
Age	3		69064.25	23021.42	782.78**
Trees	624		71169.66	114.05	3.88**
Plots x Age	75		25361.42	338.15	11.50**
Error	1870	55005.54		29.41	
Plots + Error	1897	117349.43			
Age + Error	1875	124069.79			
Trees + Error	2496	126175.20			
P x A + Error	1947	80366.96			

** = Significant at 1% point

TABLE 14. SUMMERWOOD PERCENTAGES FOR AGE SEGMENTS AND PLOTS

	UNADJUSTED				ADJUSTED FOR RING WIDTH			
	SEGMENT NUMBER							
Plot No.	*3*	*4*	*5*	*Mean*	*3*	*4*	*5*	*Mean*
1-D	48.00	50.64	55.16	51.27	47.84	50.57	55.45	51.28
1-W	44.52	56.76	60.64	53.97	44.91	56.79	60.86	54.19
2-D	48.36	63.00	65.56	58.97	48.30	63.13	66.60	59.34
2-W	43.88	52.56	64.80	53.75	44.09	52.48	64.81	53.79
3-D	53.52	63.16	65.04	60.57	53.55	63.05	65.32	60.64
3-W	47.32	52.72	53.64	51.23	47.52	52.74	53.34	51.20
4-D	53.76	55.16	60.08	56.33	53.89	55.31	59.88	56.36
4-W	48.36	58.80	55.72	54.29	47.91	58.67	55.49	54.02
5-D	58.60	70.28	67.24	65.37	58.23	70.18	67.05	65.15
5-W	65.44	65.72	72.08	67.75	65.08	65.67	71.47	67.41
6-D	57.32	70.76	71.52	66.53	57.13	70.79	71.47	66.46
6-W	53.60	57.76	63.96	58.44	53.37	57.88	63.57	58.27
8-D	57.08	60.96	62.88	60.31	56.76	60.95	62.75	60.15
8-W	57.36	61.96	71.48	63.60	57.03	61.92	71.56	63.50
9-D	61.40	60.72	59.68	60.60	61.03	60.63	60.28	60.65
9-W	54.52	59.64	67.16	60.44	55.06	59.56	67.14	60.59
10-D	59.76	56.88	64.40	60.35	59.75	56.80	64.22	60.26
10-W	54.76	59.64	61.56	58.65	55.28	59.63	61.34	58.75
11-D	59.96	62.92	60.28	61.05	60.50	62.87	60.17	61.18
12-W	50.72	59.80	59.68	56.73	50.26	58.59	59.57	56.14
13-D	50.56	56.72	50.60	52.63	50.37	56.62	50.47	52.49
13-W	53.20	58.88	62.08	58.05	53.49	59.10	61.86	58.15
14-D	56.84	49.20	53.68	53.24	57.64	48.88	54.30	53.60
14-W	42.92	44.12	50.52	45.85	42.47	44.11	50.32	45.63
16-D	51.60	53.40	55.96	53.65	51.13	53.15	55.67	53.32
16-W	48.68	56.44	53.44	52.85	48.26	56.25	53.14	52.55

TABLE 15. SPECIFIC GRAVITIES FOR AGE SEGMENTS AND PLOTS

Plot No.	UNADJUSTED				ADJUSTED FOR SUMMERWOOD PERCENTAGE			
	SEGMENT NUMBER							
	3	*4*	*5*	*Mean*	*3*	*4*	*5*	*Mean*
1-D	.545	.554	.593	.564	.566	.585	.617	.589
1-W	.504	.571	.596	.557	.535	.577	.598	.570
2-D	.539	.630	.651	.607	.558	.611	.633	.601
2-W	.513	.548	.618	.560	.551	.572	.603	.575
3-D	.567	.615	.641	.608	.566	.595	.625	.595
3-W	.558	.592	.598	.583	.582	.615	.628	.608
4-D	.589	.598	.629	.605	.587	.611	.633	.610
4-W	.560	.615	.606	.594	.580	.613	.628	.607
5-D	.598	.659	.650	.636	.576	.651	.625	.617
5-W	.636	.652	.681	.656	.586	.622	.636	.615
6-D	.609	.656	.656	.640	.592	.606	.614	.604
6-W	.599	.606	.623	.609	.597	.608	.611	.605
8-D	.622	.637	.641	.633	.608	.626	.634	.623
8-W	.617	.630	.664	.637	.600	.615	.622	.612
9-D	.616	.626	.624	.622	.583	.616	.630	.610
9-W	.595	.618	.662	.625	.589	.613	.635	.612
10-D	.624	.615	.648	.629	.597	.621	.635	.618
10-W	.594	.624	.639	.619	.588	.623	.637	.616
11-D	.606	.634	.624	.621	.578	.616	.627	.607
12-W	.589	.623	.633	.615	.599	.621	.639	.620
13-D	.568	.607	.571	.582	.579	.614	.614	.602
13-W	.572	.599	.616	.596	.572	.597	.612	.594
14-D	.629	.578	.586	.598	.614	.615	.616	.615
14-W	.537	.536	.568	.547	.579	.594	.611	.595
16-D	.580	.584	.601	.588	.586	.604	.622	.604
16-W	.553	.593	.579	.575	.571	.601	.610	.594

PLATE SECTION

PLATE I

A microscopic ring with a single series of summerwood cells separating the springwood zones of two adjacent annual rings. This ring could not be detected with the naked eye. (9x)

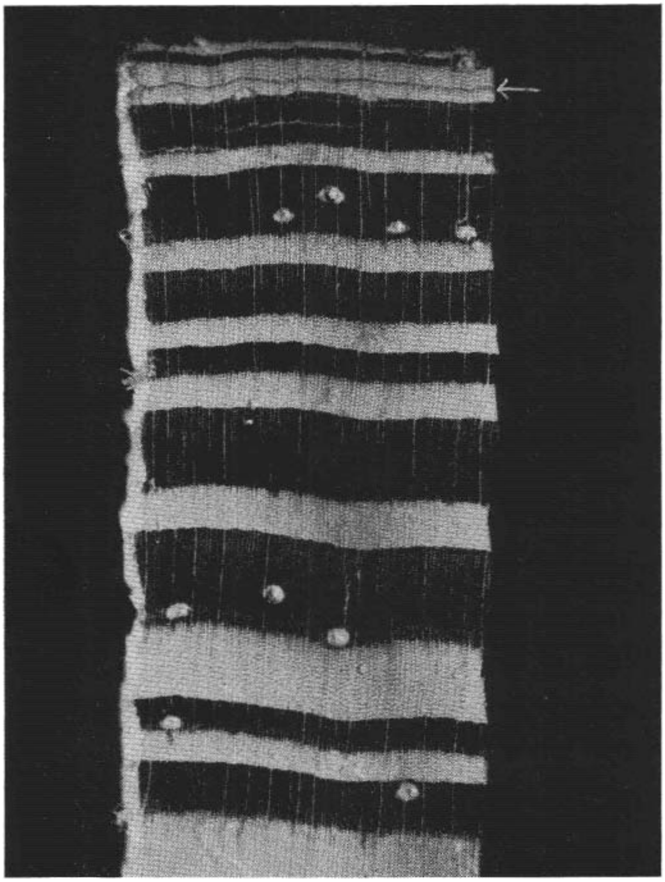


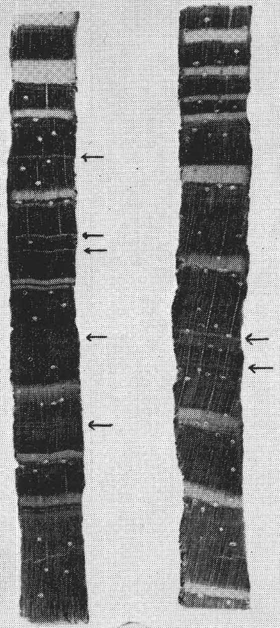
PLATE II

Atypical growth rings in increment cores.

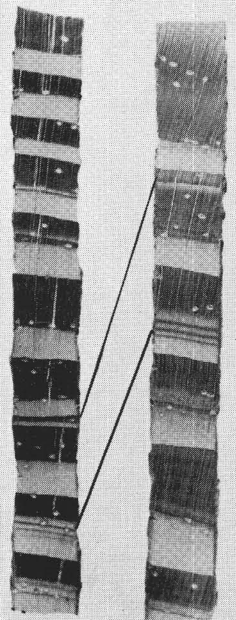
A) The springwood bands in these increment cores with high percentages of summerwood were reduced to a narrow zone of slightly thinner-walled cells indicated by arrows. Plot 8-D.

B) False rings often provided excellent key rings. In these two trees from plot 6-D the 1943 annual ring possessed 3 narrow false rings in the springwood followed by the 1944 annual ring with a relatively wide false ring in the summerwood.

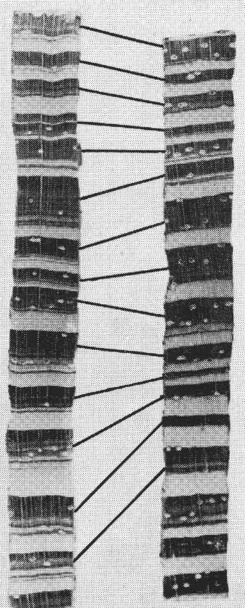
C) Numerous false rings occurred in the trees of the southern-most plots. In the core on the right almost every annual ring possessed at least one false ring. The rings formed in comparable years are connected by solid lines. (2X)



A



B



C

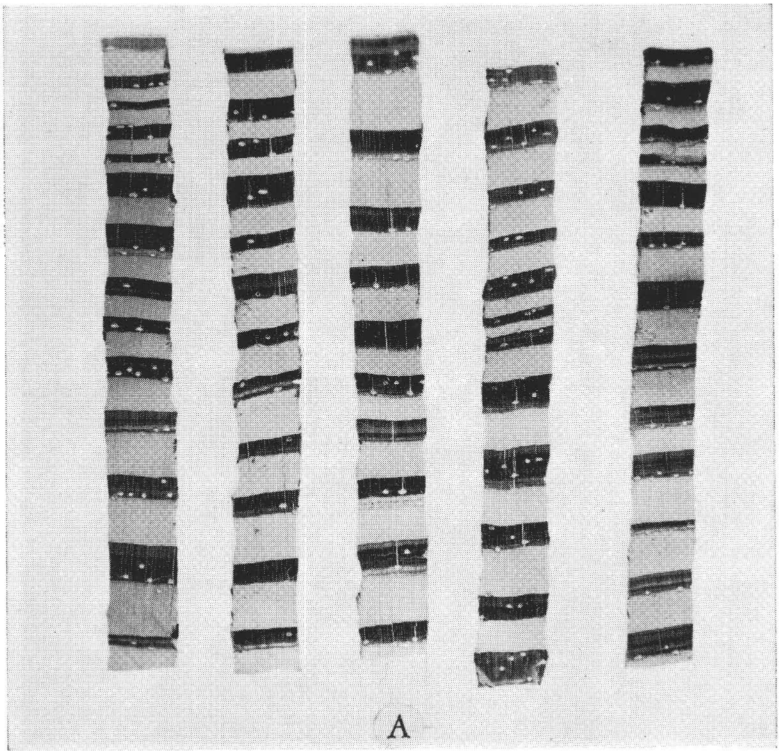
PLATE III

Considerable variation in summerwood percentage was observed between individual trees and between plots.

A) Low-density cores with summerwood averaging 30 to 40 percent.

B) High-density cores with summerwood averaging 75 to 85 percent.

In general, trees low in summerwood were most frequently found in the north and west plots whereas trees high in summerwood were of most frequent occurrence in the south and east plots. (2x)



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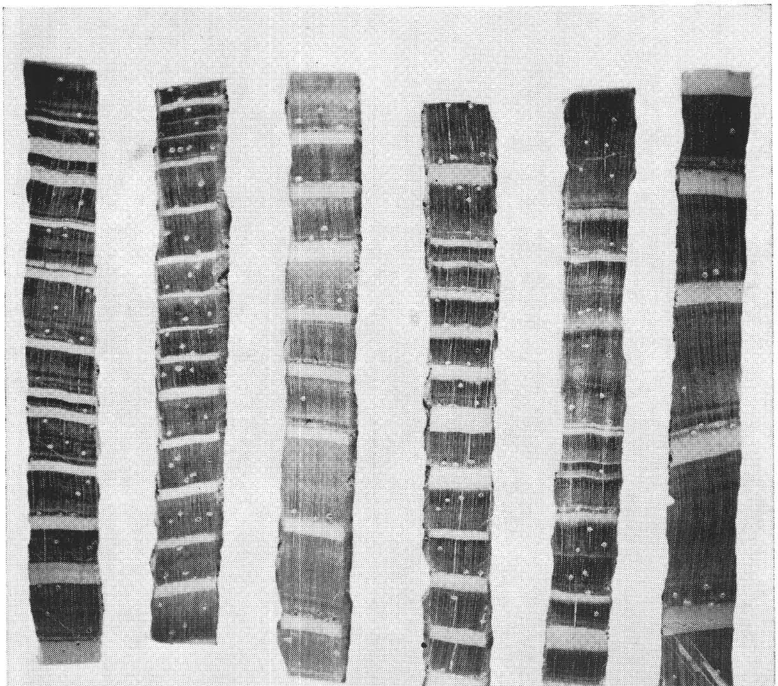
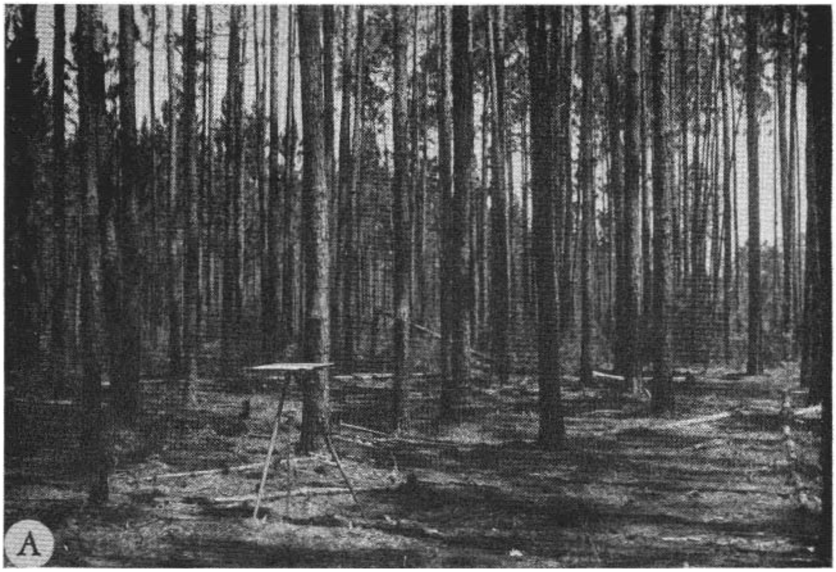


PLATE IV

A) Plot 9-D. Interior view of a well-developed old-field stand of slash pine on a well-drained site. The forest floor contains considerable evidence of heavy natural mortality. The area had been burned frequently in the past and was being grazed heavily at the time of sampling; consequently, there was little ground cover.

B) Plot 9-W. A dense stand of relatively small-sized slash pine growing on a wet site. The dense undergrowth of gallberry *(flex glabra)* is indicative of many years of good fire protection. Hence, the underbrush was heavy and many of the suppressed trees, normally eliminated by fire, had managed to sustain themselves.


A


B

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