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Timber Loan Clients of the New Orleans Federal Land Bank— Characteristics, Attitudes, and Knowledge of Credit

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Forest credit can be instrumental in improving and maintaining the productivity of the nation's privately owned woodlands. Capital requirements in private forestry are potentially large, and during the last several decades a number of institutions began to accept forest land and timber as loan collateral. Forest credit in one form or another is now available nationwide.

One phase of the subject which has received little or no attention concerns the clients of the institutions that offer woodland loans. Why are these persons borrowers? What are their personal characteristics? What are their reasons for borrowing, and what are the characteristics of their woodland holdings? What forestry purposes are being served by borrowing? What knowledge do the borrowers have of credit and its sources, to what extent do they use it, what are their attitudes toward it, and why did they choose the particular institution from which they borrowed? Answers to these and related questions can be used to devise methods of bringing nonborrowers into beneficial contact with existing credit facilities and enable those who do borrow to apply the proceeds most advantageously for forest management.

Among the chief sources of forest credit in the United States today are the Federal Land Banks of the Farm Credit System. A detailed study of the timber loan programs of all the Federal land banks was published in late 1967 by the Southern Forest Experiment Station as Research Paper SO-29 (Siegel 1967). Each bank's forest credit facilities, as well as its loan and borrower characteristics, were described and compared. Additionally, the potentialities and opportunities for improving forest management through land bank credit were analyzed. A similar study of only the New Orleans Federal Land Bank was published by the Station in 1962 as Occasional Paper 194 (Siegel 1962). Both publications described in detail the history and operations of the Federal land banks and the Farm Credit System of which the land banks are a part.

The Study

With the two previous studies as references, an analysis was initiated in late 1968 of a sample of the current timber loan clients of the New Orleans Federal Land Bank (Fifth Farm Credit District). The New Orleans bank lends on collateral in three States—Louisiana, Alabama, and Mississippi.

The New Orleans Federal Land Bank was chosen for study because the three States it serves are essentially a homogeneous timber-producing province. The bank's first timber loan was made in 1944. It now has the second largest timber loan portfolio of the 10 land banks that extend forest credit.

In the Midsouth States served by the bank, timber growing is a more attractive business venture than in most other parts of the country. Many factors contribute to this situation. Trees grow rapidly and markets are generally more favorable than elsewhere. There is a scarcity of high-grade hardwoods. The prospects for increased forest-product and stumpage prices are good. Forest industries are rapidly expanding their operations in the Midsouth, and as a group they depend to a large extent on nonindustrial private woodlands as a source of raw material. Generally, planting and timber management costs are low, and most timber growers enjoy some tax advantages. Finally, the liquidity of forest properties in many areas has increased rapidly since 1950. Timber holdings usually are readily marketable and have high sales values. All of these factors have increased the financial community's interest in providing timber loans.

Timber loan program of the New Orleans Federal Land Bank.—The New Orleans Federal Land Bank operates through local offices called Federal Land Bank Associations—13 in Alabama, 11 in Louisiana, and 12 in Mississippi. It writes loans on merchantable stands of both coniferous and hardwood timber. Some years ago the bank began accepting as collateral excellent stands of very nearly merchantable young timber. In 1967 it began to make selective loans on pine stands as far as 5 years from merchantability. Both plantations and naturally seeded tracts are potentially acceptable security under the new policy. On good sites, plantations 5 to 7 years old are generally considered to be within 5 years of merchantability. Local utilization and marketing practices and various site factors determine the exact point of projected merchantability.

The New Orleans bank will write fully amortized, partially amortized, and unamortized timber loans. Bank appraisers—usually graduate foresters with local experience—make cruises of the prospective collateral. They offer no technical advice or assistance but merely evaluate the timber. The minimum appraisal fee is $35; an additional 20 cents per acre is charged on the portion of the tract in excess of 100 acres, except when this part contains a negligible amount of merchantable timber. If the applicant furnishes a cruise report that can be used to help determine timber volume and values, a refund of 10 cents per acre is made at the time the loan is closed. The bank requires annual inspections of all timber properties that constitute major collateral.

No timber on collateral acreage can be cut without a release from the bank, except for such purposes as fence posts and firewood. If a loan is current and adequately secured, volume growth occurring since loan closure may be released without a requirement that sale proceeds be applied to the loan.

Objectives, procedure, and response.—Primary objectives of the study were to gain knowledge of the distinguishing characteristics of individuals who have borrowed from the New Orleans bank, to describe their timber holdings and operations, and to determine their use or planned use of loan proceeds and their knowledge of credit. The effects of these factors on the decisions of the borrowers in regard to management of their woodland and use of forest credit were then analyzed.

As of March 31, 1968, the bank's portfolio included 216 active timber loans made to individuals. Loans to corporations, partnerships, and trusts were not considered in the study. A timber loan was defined as one in which timber and timber land accounted for more than half of the appraised normal value of the collateral.

The bank provided the name and address of each of the 216 borrowers, and a sample of 108 was drawn at random. The sample was divided among the three States served by the bank in proportion to the number of loans existing in each.

Personal-interview questionnaires were used. Neither land bank nor association employees were present while respondents were interviewed, nor did they contact borrowers to arrange for interviews. They did assist in locating respondents, but all other contacts with borrowers were made by the Forest Service canvasser.

Questionnaires were completed for 79 borrowers. Three of the others had recently died, 12 declined to supply information, and 14 could not be located or interviewed.

The Borrowers And Their Loans

The typical holder of a timber loan from the New Orleans Federal Land Bank is a married Caucasian in his fifties and is either a full-time or part-time farmer. He owns 75 acres of woodland and resides 10 miles from it. His annual net income from all sources is about $11,000, and he has borrowed nearly $20,000 from the land bank.

Age, sex, and marital status.—Of the 7 respondents, only four were women. Six—less than 8 percent of the total—were 40 years of age or younger (table 1). More than one-fourth were over 60 years of age. The youngest was 32 and the oldest 83. The median age was 5

Table 1. *Age and sex of borrowers*

\ge (years)	Male	Female
	Number	*Number*
21—30	..	..
31—40	6	..
11—50	23	1
51—60	25	2
61—70	17	1
71—80	3	..
31+	1	..

These data are consistent with those from ther research on the characteristics of south-rn private nonindustrial woodland owners. Anderson's study (1960) of such landowners ound that those in Georgia averaged 57 years of age and those in North Carolina 53. In a tudy in Arkansas nearly half the owners in-erviewed were over 50 and youths were nota-ly scarce (Perry and Guttenberg 1959). Farmers who borrowed from the Federal land ank in Columbia, South Carolina, averaged 49 ears of age (Von Tungeln 1963).

Only one of the 79 respondents had never een married, and all but three had children. The average number of children was three.

Occupation.—Farming was the most preva-ent principal occupation among the respon-lents—22 were farmers (table 2). Another 13 were self-employed in a forestry-related busi-ess: either as timber growers, forest products manufacturers, logging or pulpwood contractors, or two or more of these in combination. About 15 percent were professional persons and 11 percent were self-employed in non-forestry businesses. Included among the borrowers were two professional foresters and two subprofessional State forestry employees.

Table 2. *Principal occupations of borrowers*

Principal occupation	Male	Female	Total	Proportion
	— —	*Number*	— —	*Percent*
Farmer	21	1	22	27
Self-employed in business other than farming or timber-related industry	9	...	9	11
Professional	12	...	12	15
Self-employed in growing, harvesting, or manu-facturing timber	12	1	13	16
Managerial or executive	6	...	6	8
Retired	6	...	6	8
Clerical	3	...	3	4
Bluecollar	6	...	6	8
Housewife	...	2	2	3

Secondary occupations in addition to timber growing were reported by 52 of the 79 respondents—eight had two secondary occupations. In all but two cases the additional employment was either in farming or forest products. In short, more than two-thirds of the borrowers farmed to some extent and one-third (including some who farmed) were concerned to some degree with the harvesting or manufacturing of forest products.

Income.—Woodland owners served by the New Orleans Federal Land Bank have relatively high incomes (table 3). At the time they applied for their loans well over half of those interviewed reported a total annual income exceeding $10,000, and 75 percent reported at least $7,000. The median was $10,965. The highest was $174,770 and the lowest $3,012. As may be expected, borrowers with the smallest incomes tended to be of the younger ages. More than two-thirds of the borrowers had received some income from timber sales during the 5 years prior to the interview.

Table 3. *Borrowers' annual income at time of loan application*

Income range (dollars)	Borrowers	
	Number	*Percent*
3,000— 4,999	10	13
5,000— 9,999	26	33
10,000—14,999	11	14
15,000—19,999	9	11
20,000—24,999	5	6
25,000—49,999	7	9
50,000—99,999	6	8
100,000+	5	6

Residence.—Only about one-fifth of the respondents resided on their holdings (table 4), but three-fourths lived within 15 miles—mostly within the county where the property was located. Sixteen borrowers resided in a county other than where their woodland was located, but often they were just across the line.

Table 4. *Distance from borrowers' residences to their forest collateral*

Distance (miles)	Borrowers	
	Number	*Percent*
0 (reside on collateral)	17	22
1— 5	23	29
6— 10	9	11
11— 15	10	13
16— 25	5	6
26— 50	7	9
51—100	6	8
101—300	1	1
300+	1	1

The median distance from tract to residence was 10 miles. Only two borrowers lived more than 100 miles away. And only two lived in another State from where their property was located—in both cases, an adjoining State. Because distance is usually considered a handicap in forest management, it is interesting to note the small proportion of absentee owners.

Amount of loans.—Most of the borrowers had rather sizable loans (table 5). Over two-thirds had borrowed more than $10,000, and 10 had loans that exceeded $100,000. The median loan was $15,700. It was previously found that timber loan clients of the New Orleans bank typically borrow the maximum amount available (Siegel 1967).

Table 5. *Range of loan amounts*

Range (dollars)	Borrowers	Proportion
	Number	*Percent*
Below 5,000	9	11
5,000— 9,999	15	19
10,000— 19,999	20	25
20,000— 39,999	18	23
40,000— 99,999	7	9
100,000—499,999	8	10
500,000+	2	3

The size of the loans tended to vary with the borrower's occupation, age, and acreage of woodland owned. Nearly all of the loans under $10,000 had been made to farmers and blue-collar workers, whereas most of those for more than $40,000 had been to self-employed businessmen and borrowers in executive and professional occupations. The larger loans were generally associated with the larger woodland ownerships, since forest acreage is the collateral. More than 80 percent of the respondents with loans smaller than $10,000 owned less than 500 acres of timberland. On the other hand, more than 75 percent of those with loans exceeding $40,000 owned more than 1,000 acres. Larger loans were also generally associated with the younger borrowers.

Timber Operations And Holdings Of The Borrowers

Woodland acres owned by the borrowers ranged from a low of 25 to a high of 33,000. The median was 750. Only three respondents owned less than 100 acres, but six owned 5,000 or more (table 6).

Table 6. *Woodland holdings of borrowers*

Range (acres)	Respondents	Proportion
	Number	*Percent*
0— 99	3	4
100— 199	8	10
200— 499	21	27
500— 999	14	18
1,000—1,999	15	19
2,000—4,999	12	15
5,000—9,999	1	1
10,000+	5	6

Holdings of most borrowers were concentrated in rather small geographical areas rather than being scattered. Two-thirds owned woodland in only one county. The acreage of most of the others was in two counties. Most of the largest ownerships were multicounty holdings—thus, three borrowers owned tracts in as many as six counties, and five owned woodland in two States. One respondent owned forest land outside the three-State area.

Borrowers who resided on their collateral acreage tended to own less woodland than those who lived away from their holdings. The median acreage owned by those who lived on the land was 331, as compared to 750 for the entire sample of respondents. Borrowers whose primary occupation was farming generally owned the least timberland—this was as true for farmers who lived on the property containing the collateral woodland as for farmers who resided elsewhere. While full-time farmers constituted 27 percent of the borrowers interviewed, they made up only 12 percent of those who owned more than 1,000 acres of woodland.

The largest acreages were mostly held by self-employed businessmen, many of whom were in timber-related businesses. These borrowers also tended to live the greatest distance from their mortgaged woodland. Those who lived more than 60 miles from their tracts owned an average of almost 1,400 acres. Virtually all of the clients who resided more than 30 miles from their land were business and professional people.

Woodland ownership and title.—At the time of the interview, more than 80 percent of the respondents had owned forest land for more than 12 years (table 7). Tenure ranged from 1 to 63 years, with the median 25. Half the respondents had acquired additional timberland after their first acquisition—some as many as three more times.

Table 7. *When the borrowers first became owners of woodland*

Years	Borrowers	Proportion
	Number	*Percent*
1905—1915	4	5
1916—1925	2	2
1926—1935	15	19
1936—1945	23	29
1946—1955	22	28
1956—1968	13	17

Virtually all of the 32 borrowers who were woodland owners prior to 1940 were in five occupational classes: farmers; housewives; retired; timber growing; harvesting or manufacturing; and bluecollar. If those in pursuits associated with forest products are excepted, only two borrowers in professional, executive, managerial, or business occupations owned woodland before 1940.

How did the 79 respondents acquire their holdings? As table 8 shows, the majority became owners by purchase. There was no discernible connection between mode of acquisition and occupation of owners or acreage held.

Table 8. *How the borrowers became woodland owners*

Method of obtaining title	Owners	Proportion
	Number	*Percent*
Gift	3	4
Inheritance	11	14
Purchase	48	61
Combination	16	20
No answer	1	1

Timber sales and timber income.—The respondents were asked how many times they had sold timber from their lands in the last 5 years. A total of 116 timber sales had been made by the 55 borrowers who reported sales between 1963 and 1967 (table 9). Twenty-six borrowers had made one sale apiece, but 15 had made more than two. Twenty-three had sold no timber at all during this time.

Table 9. *Number of timber sales made by borrowers during the 5 years prior to interview*

Sales (number)	Borrowers	Proportion
	Number	*Percent*
0	23	29
1	26	33
2	14	18
3	5	6
4	3	4
5	7	9
No answer	1	1

Of the 55 sellers, 32 had cut either partly or entirely from noncollateral acreage—that is, tracts which they owned but which were not security for their land bank loans. In 12 cases, the cutting was entirely on noncollateral properties. Thus, at least 35 of the 79 collateral ownerships were not logged during the 5 years previous to the interviews.

As would be expected, multiple sales were generally associated with borrowers who owned the largest woodland acreages. However, totals of three to five sales were also reported from some small and medium-size properties. Virtually all of the borrowers with multiple sales resided away from their land, and nearly all were professionals or self-employed businessmen. They included most of the borrowers who were in forestry or forest-products occupations. Very few of the farmers had sold timber more than once during the 5 years.

Forty-nine sellers reported the total revenue received from sales. The sums ranged from $70 to $300,000 (table 10). The median was $5,000. The sums comprised from less than 1 percent to 100 percent of the sellers' total gross income during the 5-year period; the median was 9 percent (table 11).

Table 10. *Borrowers' income from timber sales during the 5 years preceding interview*

Range (dollars)	Borrowers[1]	Proportion
	Number	*Percent*
0	23	29
Less than 1,000	4	6
1,000— 2,999	11	14
3,000— 4,999	6	8
5,000— 9,999	10	13
10,000—14,999	1	1
15,000—24,999	6	8
25,000—49,999	6	8
50,000—99,999	1	1
100,000+	4	6

[1] Six borrowers reported timber sales but would not divulge income therefrom, and one borrower would not discuss the question.

Table 11. *Timber income as a proportion of borrowers' total gross income during the 5 years preceding interview*

Proportion of total gross income from timber sales (percent)	Borrowers[1]	Proportion
	Number	*Percent*
0	23	29
1—10	27	34
11—20	11	14
21—40	6	8
41—60	3	4
61—99	0	0
100	2	3

[1] Six borrowers reported timber sales but would not divulge income therefrom, and one borrower would not discuss the question.

The professionals and self-employed businessmen among the borrowers—including those associated with forestry or forest products—tended to have the largest sales in terms of average dollar value per sale. Virtually none of these borrowers resided on their collateral properties and most were among the respondents who owned the largest woodland acreages.

Use of management services.—Two-thirds of the respondents used management services and advice—in most cases from professionals—in operating their woodlands. The sources of the services are shown in table 12. Consulting foresters constituted the largest source of aid, closely followed by industry foresters. These two groups served nearly 60 percent of those borrowers who utilized management services.

Table 12. *Management services used by borrowers*

Source	Borrowers	Proportion
	Number	*Percent*
None	26	33
Consulting foresters	17	22
State foresters	5	6
Industry foresters	13	16
Soil Conservation Service technicians	4	5
Federal foresters	1	1
University foresters	1	1
Friends	2	3
High school agricultural teacher	1	1
Foresters on staff of borrower	1	1
Combination of preceding	6	8
Self[1]	2	3

[1] These two borrowers were professional foresters.

Contrary to what might be expected, most of the nonusers of management services were among those borrowers who bought their tracts, whereas 80 percent of those who acquired their woodland by gift or inheritance had utilized management services. Clients who had owned woodland for more than 25 years tended to rely solely on themselves in the management of their tracts. Two-thirds of the nonusers had owned their acreage since before the median acquisition year of 1943. Most of the nonusers resided either on their tracts or nearby in the same county. The average user owned nearly three times as much woodland as the average nonuser—2,702 acres as compared to 1,006. Virtually all borrowers who lived at considerable distances from their woodland, or in counties other than where their acreage was located were users of management services.

Nonusers included all the housewife and blue-collar respondents plus numerous retirees, farmers, and borrowers in forestry or forest-related occupations. Evidently the borrowers whose occupations were associated with timber or the land felt that their own background and knowledge made professional advice unnecessary. Nearly all of the professionals, self-employed businessmen other than those in timber or farming, and managers and executives used management services. Receipts from timber sales differed greatly between users and nonusers. The nonusers who sold timber averaged $3,707 per sale whereas the users who sold averaged $13,894.

Borrowers' Credit Knowledge

What land bank timber loan clients know about credit may determine how well they are able to obtain and use borrowed capital. Thus the respondents were asked a knowledge-scale (Cronbach, 1949) series of 10 questions about their loans, bank policies, and other loan sources.

Because of the limited number of questions that it was feasible to ask, the scores are not necessarily indicative of some absolute level of credit knowledge among the borrowers. They are, however, a relative measure of the respondents' cognizance of the subjects.

The distribution of the knowledge scores is presented in table 13. The average was 5.6 and the median 6.0, out of a possible maximum of 10.0.

Table 13. *Distribution of knowledge scores*

Knowledge score (number of right answers)	Borrowers	Proportion of borrowers	Cumulative total
	Number	— — — *Percent*	— — —
0	0	0	0
1	0	0	0
2	2	2	2
3	3	4	6
4	12	15	21
5	21	27	48
6	15	19	67
7	19	24	91
8	7	9	100
9	0	0	0
10	0	0	0

Factors Having Significant Correlation with Knowledge Score

Variations in knowledge scores were appraised by Duncan's Multiple Range test, which is designed to rank means after they are known. By this test, scores were found to be significantly (0.05 level) related to amount of loan, size of the woodland ownership, occupation of the borrower, and income of the borrower.

Generally, the higher the loan amount, the higher was the knowledge score of the borrower. This is to be expected, since those who borrow large sums would tend to be cognizant of credit and credit facilities and would be likely to examine the credit alternatives closely. A tabular examination of this relationship appears in table 14.

Table 14. *Average knowledge score by loan size*

Loan size (dollars)	Borrowers	Average knowledge score
	Number	
Below 10,000	24	5.2
10,000—19,999	20	5.4
20,000—39,999	18	5.6
40,000+	17	6.7[1]

[1] Significantly higher than each of the other three average scores.

Secondly, the knowledge level varied significantly by the number of acres of woodland owned. Generally, the larger the acreage, the higher was the knowledge score of the borrower (table 15). Again, this would be expected.

Table 15. *Average knowledge score by size of woodland holdings*

Woodland owned (acres)	Borrowers	Average knowledge score
	Number	
0— 499	32	5.2
500—1,999	31	5.8
2,000+	16	6.3[1]

[1] Significantly higher than the average score of the 0-499 acreage category.

Thirdly, there was a significant correlation between occupation and knowledge score (table 16). Borrowers who were self-employed businessmen, other than those engaged in farming and timber-related businesses, had the highest average score. They were closely followed by those in professional occupations.

Table 16. *Average knowledge score for various occupational groups*

Occupational group	Borrowers	Average knowledge score
	Number[1]	
Salaried managerial and executive	6	5.0
Housewife, bluecollar, clerical	11	5.0
Farmers	22	5.4
Self-employed in timber growing, harvesting, and manufacturing	13	5.6
Professional	12	6.4
Self-employed businessmen other than those in farming or a timber-related business	9	6.6[2]

[1] Totals 73 instead of 79 because the six retired respondents (whose former occupations are unknown) were excluded.

[2] Significantly higher than the average scores of the managerial and executive group and of the housewife, bluecollar, and clerical group.

Farmers and respondents in timber-related businesses were somewhat further down the knowledge scale. At the bottom were the salaried managers and executives, the housewives, and those in clerical and bluecollar occupations. These classes of borrowers do not have the same opportunity to gain credit experience and knowledge as do those who operate their own businesses or are self-employed and have to deal with credit as a part of their day-to-day endeavors.

The last factor found to be significantly related to the knowledge score was the borrower's income. Generally, the higher the income, the higher was the knowledge level, as shown in table 17. The difference is particularly noticeable for those borrowers with incomes of $20,000 or more.

Table 17. *Average knowledge score of borrowers at various income levels*

Income (dollars)	Borrowers	Average knowledge score
	Number	
3,000— 4,999	10	5.0
5,000— 9,999	26	5.3
10,000—19,999	20	5.5
20,000+	23	6.4[1]

[1] Significantly higher than the average score of the borrowers in the $3,000—$4,999 group.

Factors Having Little Correlation with Knowledge Score

Contrary to what might be expected, age had very little relation to knowledge score. The older and more experienced borrowers did not exhibit higher scores than did their younger counterparts. Percent of income from timber also had very little effect upon the knowledge level, probably because few borrowers received more than 10 percent of their income from selling timber.

Finally, very little correlation was noted between knowledge score and the number of years the respondents had owned woodland. This is very likely because of the relative recency of most of the timber loans in the study. Most respondents, despite length of ownership tenure, had only been land bank timber loan clients for a short time and had had little exposure to other kinds of forest credit.

Responses to Specific Knowledge-Scale Questions

Interest rate.—The cost of money has an important bearing on adequate credit management for the woodland owner. If he does not know his interest rate or cannot compute it correctly, he will have difficulty both in comparing alternative sources of credit and in deciding whether additional capital investment will pay. All but five of the 79 respondents knew the interest rate that they were paying on their loans. This finding is indicative of a healthy situation and is consistent with that of Von Tungeln (1963), who reported that only 11 percent of the Federal land bank agricultural loan clients whom he interviewed in Georgia, North Carolina, and South Carolina e ignorant of the interest rate that they e paying.

wenty of those interviewed said that they ined their loan at the Federal land bank ly because it offered the lowest interest rate ilable. And 26 more went to the land bank ially because it offered the lowest interest .

and bank operations and policies.—Borrow- are also very cognizant of the fact that the oer loan interest rate offered by the New eans Federal Land Bank is not fixed but can as economic conditions change. Only seven hose interviewed were unaware of this fact. rly all of the respondents—71—knew that oer loans can be refinanced. And four out five knew that the borrower-stockholders their local Federal land bank association. t of those who answered this question rrectly thought that the association was ed by either the Federal land bank or the eral Government. Less than half of the ner respondents in Von Tungeln's study w that they were the owners of their local ciation.

orrowers were considerably less knowledge- concerning the bank's source of loan funds whether the interest rates are the same timber as for agricultural loans. Only two- s of the respondents were aware that loan ds are primarily derived from the sale of l bank bonds. And only about as many knew the timber loan interest rate at any given e is the same as that for an agricultural . Most of the borrowers who answered wrong about the source of loan funds thought that these monies are obtained from either the Federal Government, the Federal intermediate credit bank, the Federal Reserve bank, or the association's stockholders.

Other forest credit sources.—Nearly one-third of the 79 respondents had had some contact with timber loan sources other than the land bank (table 18). Insurance companies and commercial banks predominated; each of these two loan sources had been contacted by 11 borrowers.

A total of 12 borrowers had had timber loans from lenders other than the land bank. Five of these loans had been with commercial banks, four with insurance companies, one with the Farmers Home Administration, one with a lumber company, and one with an individual. Rather significantly, not one of these 12 respondents tried his old credit source before obtaining his present land bank timber loan. Only two of the land bank clients had timber loans with other institutions at the time they were interviewed—one with a commercial bank and one with an insurance company.

Land bank clients were more aware of commercial banks as a source of timber loans than they were of any other sources. Nearly two-thirds of the borrowers knew that timber loans are available from some commercial banks, whereas only 43 percent realized that such loans can be obtained from some insurance companies. Many commercial banks in the Mid-south have been making timber loans for a number of years. Insurance companies, on the

Table 18. *Respondents' experience with other credit sources*[1]

Credit source	Borrowers with past timber loans	Borrowers with timber loans at time of interview	Borrowers who tried this source before obtaining present land bank loan
	Number		
Commercial bank	5	1	5
Insurance company	4	1	6
Farmers Home Administration	1	...	2
Lumber company	1	...	1
Small loan company	...	...	1
Individual	1	...	...

[1] One borrower is represented in the table three times and two borrowers are represented twice.

other hand, have extended more forest credit in the Southeastern States than in the Mid-south. And then, too, insurance company loan facilities are not located in every community.

Only seven respondents knew that the Farmers Home Administration offers timber loans and only seven knew that such loans can be obtained from a Production Credit Association. The Farmers Home Administration, is, by law, a lender of last resort and also operates under other restrictions. Production Credit Association loans are only for short terms. These circumstances probably contributed to the lack of knowledge concerning these sources of forest credit. About three out of 10 respondents knew of two timber loan sources other than the land bank. But only three of the 79 knew of three such sources, and none knew of four.

Credit Attitude, Use, And Experience

Land bank loan experience.—Most borrowers have been using the New Orleans Federal Land Bank as a forest credit source for a relatively few years. Only eight of the 79 interviewed made their present timber loans before 1960 (table 19). The median year was 1964. And only two borrowers had had a previous timber loan with the bank.

Table 19. *Age of the loans*

Year of original loan	Loans	
	Number	*Percent*
1956	2	2
1959	6	8
1960	5	6
1961	8	10
1962	10	13
1963	3	4
1964	10	13
1965	13	17
1966	9	11
1967	9	11
1968	4	5

Thus, land bank timber loan experience for at least 69 of the 79 respondents had been limited—at the time of the study—to a maximum of 8 years. And, for more than half of them, it had been limited to a maximum of 4 years. However, 13 borrowers had previously made agricultural loans with the land bank. Despite the relative recency of most of the 79 loans a surprisingly high number of them—46—had been refinanced.

Respondents had made a total of 15 unsuccessful attempts to obtain a loan elsewhere mostly with insurance companies and commercial banks, before going to the land bank for their present timber loan. Their experience would seem to indicate that the insurance companies and commercial banks they contacted either have more stringent criteria for timber loans than does the land bank or else offer less flexible terms. In none of the 15 instances did the borrower have past or present loan experience with the institution to which he applied. Only one respondent had had actual loan experience with all three of the major forest credit sources—the land bank, an insurance company, and a commercial bank.

Reasons for choosing the Federal land bank—Respondents gave a variety of answers when asked why they had gone to the Federal land bank for their timber loan (table 20). Two-thirds, however, mentioned either or both the rate of interest and the possibility of getting loans for a long term (up to 40 years). Clients of the New Orleans bank apparently prefer long repayment periods. Most of the existing timber loans in late 1966 were for 20 years or longer (Siegel 1967). Less than 2 percent were for fewer than 10 years.

Table 20. *Why the borrowers chose the Federal land bank for their timber loans*

Reason	Borrowers[1]	Proportion
	Number	*Percent*
Lowest interest rate	47	42
Long terms available	26	23
Reputation for being friendly and helpful	17	16
Satisfied with past experience	11	10
Local servicing of loans	2	2
Couldn't obtain loan elsewhere	2	2
Five-year, partial-amortization plan available	2	2
No prepayment penalties	1	1
Suggestion of commercial bank	1	1
Don't remember	1	1

[1] Totals more than 79 because some respondents gave more than one reason.

Also ranking high with the respondents was ıe bank's reputation for being friendly and elpful. Additionally, a number of borrowers btained their loans because their past experince with the bank had been highly satisfacory.

It was surmised that respondents who were oncerned about interest rate and length of erms would have higher knowledge scores than hose emphasizing personal relationships, such s the banks' "being friendly." However, the onnection could not be substantiated by the ata.

How clients became aware of land bank timer loans.—Respondents learned by a variety f means that the Federal land bank offers imber loans (table 21). Most learned by peronal contact. Exactly half of those who reıembered the source said that it was direct ontact with bank and association employees. Jearly one of every seven borrowers reported hat he or she first learned of land bank timber oans from other timber loan clients—in many ases, relatives. Land bank publications and rticles and advertisements in news media, ave apparently been effective with about an qual number of prospective borrowers. Thus ank and association employees appear to have een the most effective means of publicity. Von 'ungeln (1963) also found that many borrowrs first learned of land bank credit from other orrowers and that advertisements had been elatively ineffective.

Borrowers' characteristics could not be reated to sources of knowledge about the bank.

Table 21. *Sources from which borrowers first learned of land bank timber loans*

ource	Borrowers	Proportion
	Number	*Percent*
and bank or association employees	31	39
ther borrowers	11	14
rticles or advertisements in news media	5	6
and bank publications	7	9
ongressman	1	1
ttorney	2	3
ombination of preceding	5	6
o not remember	17	22

Most effective means of informing others.—The borrowers were asked, what was—in their opinion and on the basis of their experience—the most effective means by which the bank could inform prospective clients of its timber loan services. Three responses predominated. The opinion of 31 borrowers was that advertisements in magazines and newspapers and on radio and television were the most effective. Most of these respondents felt that the bank was not doing enough in this area, particularly in regard to county newspapers and farm and forestry journals. Such media, they said, influenced many of their business decisions.

Another 25 borrowers mentioned personal contact between clients and nonclients. Here little can be done by the bank except to keep its clients satisfied. Eighteen other respondents thought that personal contact by bank and association personnel was the most effective means. Many of these felt that much more such activity would be useful—for example, association personnel could appear at farm and forestry meetings. Although mentioned by only a few clients, several other methods may have merit. They include providing timber-loan information to rural lawyers and to foresters who have contact with the timber-owning public.

Purpose of loans.—After the borrowers obtained their loans, how did they use the money? More than one in four purchased additional woodland with some or all of the funds (table 22). Nine used part or all of their loan money for tree planting or timber stand improvement. Reflecting the number of farmers in the sample, 19 respondents used loan proceeds for general farm operating expenses and 13 purchased more farm land. Fourteen borrowers applied the loan toward buying, constructing, or remodeling a house or a building.

If purchase of timberland is included as a forestry purpose, 35 of the 79 respondents, or 44 percent, used part or all of their proceeds for forestry activities. There was no discernible occupational pattern among these forestry-minded borrowers. Neither was there an age pattern. The median age of those who used loan money for forestry was 54 years, as compared to 53 years for the sample as a whole. Borrowers who used loan funds for forestry, however, held a median acreage of 1,200 as compared to 750 for the sample as a whole. Borrower's income also was correlated with forestry use. Those who used loan proceeds for forestry generally had higher incomes than those who did not; their median income was $15,177 as compared to $10,965 for the sample as a whole.

Table 22. *Purpose of loans*

Purpose	Borrowers[1]	Proportion[1]
	Number	*Percent*
Purchase the woodland collateral	10	13
Purchase other timberland	21	23
Tree planting or timber stand improvement	9	11
General farm operating expenses	19	24
Buy, construct, or remodel house or building	14	18
Purchase farm land	13	16
Miscellaneous[2]	30	38

[1] "Borrowers" column totals 116 because 29 borrowers used their loan proceeds for more than one purpose. Percentages are calculated on the basis of 79 borrowers.

[2] Includes such purposes as hospital expenses, payment of taxes, college expenses, etc.

Plans for using credit to expand timber-growing operations.—About half of the respondents—39—said that they had definite opportunities for expanding their timber-growing operations and that these opportunities would require additional credit. Eighteen of these borrowers were planning such expansion during the next year. When asked what their opportunities were, the respondents stated only three. Purchase of additional woodland was mentioned most often, followed by tree planting, and then timber stand improvement.

There was no significant difference by occupation or age between borrowers who said they had additional timber-growing opportunities and those who said they did not. However, clients who recognized opportunities tended to own more woodland and have higher incomes than did those who reported no opportunities.

Attitude Of Clients Toward The Federal Land Bank

The clients generally seemed well satisfied in their relationships with the bank and with their local association and its personnel. Only three of the 79 said that they would not apply to the bank again if the need arose and would not recommend the bank to others. A fourth borrower said that he would never apply to the bank again but that he was satisfied with the services received.

Reasons given by the three dissatisfied clients did not imply general antagonism toward the associations or the bank, but rather toward loan policies. The reasons were: "Appraisals are too low;" "They would not allow me to cut timber when I wanted to;" and "They told me what to do with timber sale proceeds."

Respondents were asked what changes in bank lending policies they would like to see. Three-fifths were completely satisfied with all the bank's policies and had nothing to suggest. The remaining 40 percent proposed a diversity of changes, some of them in conflict with sound lending policy. Some changes desired—such as lower interest rates—are determined by the state of the economy.

Higher or more accurate appraisals of woodland collateral were mentioned by eight borrowers, some of whom thought that professional foresters should be used for all appraisals. Other factors suggested by a number of respondents were that: the land, as distinguished from the timber on it, should be given a higher loan value than it is at present; the maximum percentage of appraised value that can be loaned should be raised; releases and fees should not be required before a borrower can cut timber; and less collateral should be required for a timber loan. Only some of these factors are controlled solely by the bank.

One borrower felt that he should have access to the cruise report for his timber collateral; another felt that the bank should provide timber casualty insurance, and a third thought that the bank should provide quicker and faster loan refinancing.

Conclusions And Implications

The timber loan program of the New Orleans Federal Land Bank, in addition to being good business for the bank, is contributing to the Midsouth's forest economy. While few of the bank's early timber loans were used for expanding, improving, or managing woodlands, recent changes in lending policies and procedures have facilitated borrowing for these purposes. That borrowers are becoming increasingly forestry-minded is evidenced by the fact hat 44 percent of those interviewed used part r all of their loan proceeds in forestry en-eavors. And nearly one respondent in four lanned to expand his woodland operations dur-ng the next year by using more credit.

It is quite evident, however, that only certain lasses of woodland owners in the Midsouth are eing attracted to the land bank. Most borrow-rs are over 40 years of age and most are local esidents who have some part- or full-time oc-upational contact with the land or its products. The absentee owner who lives more than 100 niles from his holdings is generally not a land ank timber loan client.

Such absentee owners would seem to be ex-ellent prospects for timber loans by the bank. But most of the bank's success in writing tim-er loans has been due to personal contact, and nany absentee owners live at a considerable listance from the association office servicing he area where their woodland is located. Per-aps one way to overcome the barrier of dis-ance would be to work through local foresters vho may be employed by or advising such own-rs. Also, loan applications might be handled hrough the association office nearest the bor-ower rather than the one nearest his land.

Since most of the borrowers who were inter-iewed had learned of the bank's timber loans ither through bank employees or other bor-owers, personal contact in the local communi-ies should continue to be stressed and perhaps ntensified. The two big advantages of land ank loans, as expressed by a majority of re-pondents, are low interest rates and long erms. These two factors should be given spe-ial attention in talks with prospective clients.

Land bank personnel should also stress that nterest rates are the same on timber loans as n agricultural loans, and that the source of oan funds is not the Federal Government. Most borrowers lacked understanding of these points —a situation that might be detrimental in their discussions with prospective bank clients.

Private consulting, industrial conservation, and public farm and extension foresters in the Midsouth are in an ideal position to promote the use of credit for expanding and intensifying private forestry. To gain the greatest returns from their efforts they should concentrate on those types of woodland owners whom this study has shown to be among the most receptive to forest credit.

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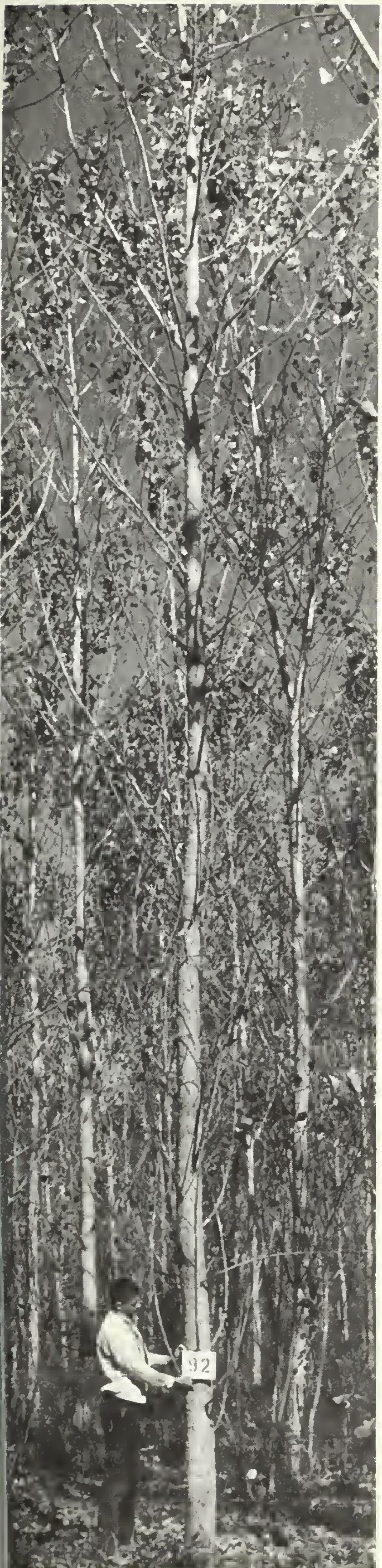

Fourteen Cottonwood Clones Selected for Midsouth Timber Production

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1970

Fourteen Cottonwood Clones

Selected for Midsouth Timber Production

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This paper describes the first 14 cottonwood (**Populus deltoides** Bartr.) clones selected by a team of geneticists and silviculturists from the Southern Forest Experiment Station as part of a program for improving the species' performance in Midsouth plantations. Clones were chosen primarily on the basis of rapid early growth. Their performance in replicated test plantings, one of which has reached pulpwood size, indicates that they have high potential for commercial planting and as breeding material. Both selection procedures and available data on clone performance are presented in the paper.

A program for improving cottonwood was begun by the USDA Forest Service in the early 1960's. At that time it became clear that well-known hybrid poplars from the Northeastern United States and Europe would not perform well in the Midsouth,[2] where interest in **Populus** culture was rapidly increasing. The program was headquartered at the Southern Hardwoods Laboratory in Stoneville, Mississippi. The clones described here were selected from well-adapted natural populations nearby. Parents of all the clones are located within 70 miles of the Laboratory.

Before the replicated tests, most of the clones went through a preliminary evaluation and selection process. Procedures followed in preliminary selection were summarized in a previous paper.[3] Of the 14 chosen, 11 were open-pollinated progeny of phenotypically superior trees in natural stands. The progeny had above-average first-year growth as seedlings in a progeny test and as clones in one or two preliminary tests. The remaining three clones are of unknown parentage and were not evaluated before being placed in long-term tests.

Most of the descriptive data reported in this paper were obtained from two 5-year clonal tests. Both measured performance of 79 clones, 39 selected in preliminary tests and 40 from seedlings collected randomly from sandbars.

The tests had randomized complete blocks with five replications and four-ramet row plots. One planting was established on a Commerce silt-loam soil considered excellent for cottonwood and the other on a Sharkey clay soil that, at best, is marginal for commercial cottonwood plantations. The establishment techniques outlined by McKnight and Biesterfeldt[4] were followed. Unrooted cuttings 20 inches long were planted at a spacing of 10 by 10 feet.

The plantation on the silt-loam soil was thinned after its third growing season to two ramets per plot (218 trees/acre) and again after its fifth growing season to a single ramet per plot (109 trees/acre). Diameters of all surviving trees (usually 10 ramets/clone) were measured after the fifth year and before thinning. Heights were measured on felled trees (usually five ramets per clone). Volumes were determined from measurements made at 4-foot intervals on three stems per clone.

On the clay soil one replication was thinned after the fourth growing season. The remaining four replications were thinned at the end of the fifth growing season. Mean clone diameters for the fifth year were computed from measurements of the 18 ramets per clone standing at the end of the fifth growing season. Height measurements were made on the two cut ramets per clone in each of the four replications thinned during the fifth year.

The fifth-year mean diameter of clones on the silt-loam soil was the primary basis for

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[1] When this paper was prepared the authors were stationed at the Southern Hardwoods Laboratory, which is maintained at Stoneville, Mississippi, by the Southern Forest Experiment Station, USDA Forest Service, in cooperation with the Mississippi Agricultural Experiment Station and the Southern Hardwood Forest Research Group. Mohn is now Assistant Professor, School of Forestry, University of Minnesota. McKnight is Assistant Area Director, Cooperative Forest Management, Southeastern Area, State and Private Forestry.

[2] Maisenhelder, L. C. Eastern cottonwood selections outgrow hybrids on southern sites. J. Forest. 68: 300-301. 1970.

[3] Mohn, C. A., and Randall, W. K. Preliminary selection of eastern cottonwood clones. Tenth S. Forest Tree Impr. Conf. Proc. 1969: 41-48. 1969.

[4] McKnight, J. S., and Biesterfeldt, R. C. Commercial cottonwood planting in the Southern United States. J. Forest. 66: 670-675. 1968.

selection. Evaluation was confined to this plantation because the site is typical of those being planted commercially and because trees had reached pulpwood size. Selected clones were those that had mean fifth-year diameters in the top 25 percent of the test population. Clones that met this requirement were rejected if ramets consistently demonstrated serious defects such as low forking, extremely large persistent branches, or extremely crooked boles. The 14 clones described in this paper are those that were not rejected.

Average 5-year growth of the 14 as a group is compared with that of a control group in table 1. The controls, 40 clones selected at random, are typical of unimproved materials now being planted in the Lower Mississippi Valley. On the silt-loam site the 14 select clones exceeded the control group by approximately 20 percent in mean diameter (7.6 vs. 6.3 inches) and by 10 percent in total height (56.8 vs. 51.2 feet). Volume differences between the two groups were even larger; mean stem volume to a 3-1/2-inch top (bark included) was 6.5 cubic feet in the select group and 3.7 cubic feet in the control group.

On the clay site, differences between diameters in the select and control group were smaller than on the silt loam. Since the two sites are radically different and all variation among clone means in rate of diameter growth is not genetic, this result is not surprising. The differences found on clay were substantial, however. The select group exceeding the control by about 13 percent in diameter (3.8 vs. 3.3 inches) and by 11 percent in height (31.6 vs. 28.4 feet).

Although the data indicate that early plantation growth can be increased substantially with the selected clones, it is important that the limitations of the testing be recognized. The tests were adequately designed, but they were confined to a single geographic location. Trees were planted on only two soil types, and observed for only 5 years. These limitations reduce the accuracy with which the general performance of these clones can be predicted. Accurate predictions will require testing for at least one-half a timber rotation over a wide geographic area and on a range of soils representative of those considered suitable for commercial planting. Such tests are now being established, but 10 to 15 years will be required for their completion. In view of the potential returns from the selected stock on the extensive acreages now being planted, this delay will be unacceptable to most persons. A logical alternative is to plant partially tested materials and accept the associated risks.

These risks are small when reasonable precautions are taken. Gains can be expected in the characters for which the clones were selected. Since selection was based on growth in plantations given intensive care, the clones are likely to improve production most where cultivation and protection from insects are provided early in the life of the stand.

A mixture of at least 10 clones should be included in a plantation to insure against pest

Table 1.—Fifth-year growth data for select and control groups on two soils[1]

Test soil	Mean d.b.h.[2]		Mean height[3]		Mean stem volume[4] to 3½-inch top	
	Select	Control	Select	Control	Select	Control
	—Inches—		—Feet—		—Cubic feet—	
Commerce Silt Loam	7.6	6.3	56.8	51.2	6.5	3.7
Sharkey clay	3.8	3.3	31.6	28.4	----	----

[1] Select values are average for 14 select clones, control values are average for 39 randomly obtained clones.

[2] D.b.h. measurements are based on 10 ramets per clone on silt loam and 18 ramets per clone on clay soil.

[3] Height measurements are based on 5 ramets per clone on silt loam and 8 ramets per clone on clay soil.

[4] Volume measurements are based on 3 ramets per clone.

problems that could be associated with a small proportion of the clones. Planting a mixture also reduces the risk of growth loss due to selection of a clone that is not as good a performer as the limited tests indicated.

Since five of the clones described are open-pollinated progeny of a single female parent, the group of 14 is none too large. A group of 20 to 30 would be more desirable, and if promising clones from other improvement programs can be obtained they should be included in the plantation. Sufficient information for choosing supplementary clones can be obtained in tests such as those described by Farmer and Wilcox.[5]

The clones described are probably best adapted to the climatic conditions near their origin—in the Mississippi River Valley between Memphis, Tennessee, and Vicksburg, Mississippi. Clones from the same area have performed very well in 4- and 5-year-old plantings near Cairo, Illinois, and use of the select clones somewhat north of Memphis can be reasonably considered. No information is currently available concerning their performance south of the test area. Where climatic conditions are significantly different from Greenville, Mississippi, these clones should be used only on an experimental basis.

Only the first step in the cottonwood improvement program has been completed, and the present clone mixture should be viewed as temporary. Individual clones may be replaced after evaluation on a large number of sites over a long period. Clones of equal or more promise will be identified in improvement programs in the region, and these can be used to supplement or upgrade the mixture. Careful maintenance of the identities of the original clones in nurseries will be required to facilitate these changes.

CLONE DESCRIPTIONS

The individual select clones are described on the following pages. Each is identified by the name Stoneville and a number. To insure uniformity, it is suggested that this identification be used exclusively. Descriptions are still incomplete, but they incorporate all currently available information. In the future they will be updated and new selections will be described.

Unless otherwise stated, comparisons made in the descriptions are with the mean performance of

Two select clones of eastern cottonwood. The number shown, preceded by the word Stoneville, should be used to refer to the clone.

[5] Farmer, R. E., Jr., and Wilcox, J. R. Cottonwood improvement system for commercial planters. USDA Forest Serv. Res. Note SO-7, 3 p. S. Forest Exp. Sta., New Orleans, La. 1964.

all clones in the tests described previously. At present, data regarding pest and disease resistance are almost completely lacking. Such data are obviously needed, and they are being sought. No quantitative data on growth habit (branching and stem form) are available, but short subjective descriptions are provided. The sex of some of the clones is unknown because they have not yet flowered. Also lacking is information on rooting characteristics, which were not considered during selection. Recent tests have indicated substantial clonal variation in field survival from unrooted cuttings. Since survival is greatly influenced by treatment of cuttings, weather conditions, and planting techniques, the data given must be interpreted with caution.

STONEVILLE 63

Identification
- Species: Populus deltoides Bartr.
- Origin: Open-pollinated progeny of phenotypically superior tree (Stoneville 4) found in Issaquena County, Mississippi (32°37'N, 91°W)

General Information
- Sex: Unknown
- Foliation date: 42 days after 2/28; mean for tests, 39 days
- Defoliation date: Average relative to local cottonwood

Habit
- Trunk: Below average straightness
- Branches: Average number, small

Pest and Disease Information
- Melampsora rust: Average juvenile incidence
- Other: No serious damage noted to age 5

Cultural Information
- Propagation: Mean first-year survival of unrooted cuttings in 4 tests, 69 percent; mean for 19 or more clones in same tests, 81 percent

Wood Characteristics
- Specific gravity: Mean of 0.32 for disks taken at breast height at age 5; range of 20 clones in same tests, 0.31-0.36. Basis: 3 ramets per clone on each of two soils

Bark
- Surface: Smooth
- Thickness: 0.25 inch (single thickness) at d.b.h. at age 5 on silt-loam soil; mean for 40 randomly obtained clones in same test, 0.30 inch. Basis: 6 determinations per clone

Average 5-year growth of Stoneville 63 on two sites[1]

Character and unit of measure	Commerce silt loam		Sharkey clay	
	Stoneville 63	Control	Stoneville 63	Control
D.b.h. (inches)	7.0	6.3	3.3	3.3
Height (feet)	57.2	51.2	28.6	28.4
Volume, including bark, to 3½-inch top (cubic feet)	5.5	3.7	....	....
Volume, inside bark, to 3-inch top (cubic feet)	5.1	3.2	....	....

[1] Means for Stoneville 63 and the control (made up of 40 randomly obtained clones) are based on measurements of 10 ramets/clone for diameter, 5 ramets/clone for height, and 3 ramets/clone for volume on the silt-loam soil. On the Sharkey clay means are based on 18 ramets/clone for diameter and 8 ramets/clone for height.

STONEVILLE 66

Identification

Species: Populus deltoides Bartr.

Origin: Open-pollinated progeny of phenotypically superior tree (Stoneville 7) found in Issaquena County, Mississippi (32°37'N, 91°W)

General Information

Sex: Male

Foliation date: 37 days after 2/28; mean for tests, 39 days

Defoliation date: Late relative to local cottonwood

Habit

Trunk: Below average straightness

Branches: Above average number, relatively large

Pest and Disease Information

Melampsora rust: Average juvenile incidence

Other: No serious damage noted to age 5

Cultural Information

Propagation: First-year survival of unrooted cuttings in 4 tests, 93 percent; mean for 19 or more clones in same tests, 81 percent

Wood Characteristics

Specific gravity: Mean of 0.34 for disks taken at breast height at age 5; range of 20 clones in same tests, 0.31-0.36. Basis: 3 ramets per clone on each of two soils

Bark

Surface: Average roughness

Thickness: 0.45 inch (single thickness) at d.b.h. at age 5 on silt-loam soil; mean for 40 randomly obtained clones in same test, 0.30 inch. Basis: 6 determinations per clone

Average 5-year growth of Stoneville 66 on two sites[1]

Character and unit of measure	Commerce silt loam		Sharkey clay	
	Stoneville 66	Control	Stoneville 66	Control
D.b.h. (inches)	8.1	6.3	4.0	3.3
Height (feet)	58.6	51.2	32.4	28.4
Volume, including bark, to 3½-inch top (cubic feet)	8.1	3.7	----	----
Volume, inside bark, to 3-inch top (cubic feet)	7.1	3.2	----	----

[1] Means for Stoneville 66 and the control (made up of 40 randomly obtained clones) are based on measurements of 10 ramets/clone for diameter, 5 ramets/clone for height, and 3 ramets/clone for volume on the silt-loam soil. On the Sharkey clay means are based on 18 ramets/clone for diameter and 8 ramets/clone for height.

STONEVILLE 67

Identification

Species:	Populus deltoides Bartr.
Origin:	Open-pollinated progeny of phenotypically superior tree (Stoneville 7) found in Issaquena County, Mississippi (32°37'N, 91°W)

General Information

Sex:	Unknown
Foliation date:	40 days after 2/28; mean for tests, 39 days
Defoliation date:	Average relative to local cottonwood

Habit

Trunk:	Above average straightness
Branches:	Average number, relatively large

Pest and Disease Information

Melampsora rust:	Average juvenile incidence
Other:	No serious damage noted to age 5

Cultural Information

Propagation:	First-year survival of unrooted cuttings in 4 tests, 83 percent; mean for 19 or more clones in same tests, 81 percent

Wood Characteristics

Specific gravity:	Mean of 0.36 for disks taken at breast height at age 5; range of 20 clones in same tests 0.31-0.36. Basis: 3 ramets per clone on each of two soils

Bark

Surface:	Average roughness
Thickness:	0.35 inch (single thickness) at d.b.h. at age 5 on silt-loam soil; mean for 40 randomly obtained clones in same test, 0.30 inch. Basis: 6 determinations per clone

Average 5-year growth of Stoneville 67 on two soils[1]

Character and unit of measure	Commerce silt loam		Sharkey clay	
	Stoneville 67	Control	Stoneville 67	Control
D.b.h. (inches)	7.8	6.3	3.8	3.3
Height (feet)	59.3	51.2	32.7	28.4
Volume, including bark, to 3½-inch top (cubic feet)	6.4	3.7	----	----
Volume, inside bark, to 3-inch top (cubic feet)	5.7	3.2	----	----

[1] Means for Stoneville 67 and the control (made up of 40 randomly obtained clones) are based on measurements of 10 ramets/clone for diameter. 5 ramets/clone for height, and 3 ramets/clone for volume on the silt-loam soil. On the Sharkey clay means are based on 18 ramets/clone for diameter and 8 ramets/clone for height.

STONEVILLE 70

Identification
- Species: Populus deltoides Bartr.
- Origin: Open-pollinated progeny of phenotypically superior tree (Stoneville 7) found in Issaquena County, Mississippi (32°37'N, 91°W)

General Information
- Sex: Unknown
- Foliation date: 37 days after 2/28; mean for tests, 39 days
- Defoliation date: Late relative to local cottonwood

Habit
- Trunk: Average straightness
- Branches: Average number, average size

Pest and Disease Information
- Melampsora rust: Below average juvenile incidence
- Other: No serious damage noted to age 5

Cultural Information
- Propagation: No data available regarding first-year survival of unrooted cuttings

Wood Characteristics
- Specific gravity: Mean of 0.33 for disks taken at breast height at age 5; range of 20 clones in same tests, 0.31-0.36. Basis: 3 ramets per clone on each of two soils

Bark
- Surface: Extremely rough at age 5
- Thickness: 0.45 inch (single thickness) at d.b.h. at age 5 on silt-loam soil; mean for 40 randomly obtained clones in same test, 0.30 inch. Basis: 6 determinations per clone

Average 5-year growth of Stoneville 70 on two sites[1]

Character and unit of measure	Commerce silt loam		Sharkey clay	
	Stoneville 70	Control	Stoneville 70	Control
D.b.h. (inches)	7.4	6.3	4.6	3.3
Height (feet)	53.4	51.2	33.0	28.4
Volume, including bark, to 3½-inch top (cubic feet)	[2]6.0	3.7	----	----
Volume, inside bark, to 3-inch top (cubic feet)	[2]4.0	3.2	----	----

[1] Means for Stoneville 70 and the control (made up of 40 randomly obtained clones) are based on measurements of 10 ramets/clone for diameter, 5 ramets/clone for height, and 3 ramets/clone for volume on the silt-loam soil. On the Sharkey clay means are based on 18 ramets/clone for diameter and 8 ramets/clone for height.

[2] Volume for Stoneville 70 was estimated because poor survival prevented cutting trees.

STONEVILLE 71

Identification	
Species:	Populus deltoides Bartr.
Origin:	Open-pollinated progeny of phenotypically superior tree (Stoneville 7) found in Issaquena County, Mississippi (32°37'N, 91°W)
General Information	
Sex:	Unknown
Foliation date:	42 days after 2/28; mean for tests, 39 days
Defoliation date:	Average relative to local cottonwood
Habit	
Trunk:	Average straightness
Branches:	Above average number, average size
Pest and Disease Information	
Melampsora rust:	Average juvenile incidence
Other:	No serious damage noted to age 5
Cultural Information	
Propagation:	No data available regarding first-year survival of unrooted cuttings
Wood Characteristics	
Specific gravity:	Mean of 0.33 for disks taken at breast height at age 5; range of 20 clones in same tests, 0.31-0.36. Basis: 3 ramets per clone on each of two soils
Bark	
Surface:	Very rough
Thickness:	0.60 inch (single thickness) at d.b.h. at age 5 on silt loam; mean for 40 randomly obtained clones in same test, 0.30 inch. Basis: 6 determinations per clone

Average 5-year growth of Stoneville 71 on two sites[1]

Character and unit of measure	Commerce silt loam		Sharkey clay	
	Stoneville 71	Control	Stoneville 71	Control
D.b.h. (inches)	7.4	6.3	3.9	3.3
Height (feet)	57.2	51.2	32.8	28.4
Volume, including bark, to 3½-inch top (cubic feet)	5.5	3.7	....	....
Volume, inside bark, to 3-inch top (cubic feet)	4.9	3.2	....	....

[1] Means for Stoneville 71 and the control (made up of 40 randomly obtained clones) are based on measurements of 10 ramets/clone for diameter, 5 ramets/clone for height, and 3 ramets/clone for volume on the silt-loam soil. On the Sharkey clay means are based on 18 ramets/clone for diameter and 8 ramets/clone for height.

STONEVILLE 72

Identification
- Species: Populus deltoides Bartr.
- Origin: Open-pollinated progeny of phenotypically superior tree (Stoneville 7) found in Issaquena County, Mississippi (32°37'N, 91°W)

General Information
- Sex: Female
- Foliation date: 40 days after 2/28; mean for tests, 39 days
- Defoliation date: Average relative to local cottonwood

Habit
- Trunk: Average straightness
- Branches: Average number, average size

Pest and Disease Information
- Melampsora rust: Above average juvenile incidence
- Other: No serious damage noted to age 5

Cultural Information
- Propagation: No data available on first-year survival of unrooted cuttings

Wood Characteristics
- Specific gravity: Mean of 0.33 for disks taken at breast height at age 5; range of 20 clones in same tests, 0.31-0.36. Basis: 3 ramets per clone on each of two soils

Bark
- Surface: Very rough
- Thickness: 0.40 inch (single thickness) at d.b.h. at age 5 on silt loam; mean for 40 randomly obtained clones in same test, 0.30 inch. Basis: 6 determinations per clone

Average 5-year growth of Stoneville 72 on two sites[1]

Character and unit of measure	Commerce silt loam		Sharkey clay	
	Stoneville 72	Control	Stoneville 72	Control
D.b.h. (inches)	7.6	6.3	4.0	3.3
Height (feet)	61.4	51.2	34.3	28.4
Volume, including bark, to 3½-inch top (cubic feet)	6.5	3.7	......	......
Volume, inside bark, to 3-inch top (cubic feet)	5.9	3.2	......	......

[1]Means for Stoneville 72 and the control (made up of 40 randomly obtained clones) are based on measurements of 10 ramets/clone for diameter, 5 ramets/clone for height, and 3 ramets/clone for volume on the silt-loam soil. On the Sharkey clay means are based on 18 ramets/clone for diameter and 8 ramets/clone for height.

STONEVILLE 74

Identification	
Species:	Populus deltoides Bartr.
Origin:	Open-pollinated progeny of phenotypically superior tree (Stoneville 8) found in Issaquena County, Mississippi (32°37'N, 91°W)
General Information	
Sex:	Unknown
Foliation date:	44 days after 2/28; mean for tests, 39 days
Defoliation date:	Average relative to local cottonwood
Habit	
Trunk:	Average straightness
Branches:	Average number, average size
Pest and Disease Information	
Melampsora rust:	Below average juvenile incidence
Other:	No serious damage noted to age 5
Cultural Information	
Propagation:	Mean first-year survival of unrooted cuttings in 3 tests, 78 percent; mean for 19 or more clones in same tests, 86 percent
Wood Characteristics	
Specific gravity:	Mean of 0.31 for disks taken at breast height at age 5; range of 20 clones in same tests, 0.31-0.36. Basis: 3 ramets per clone on each of two soils
Bark	
Surface:	Average roughness
Thickness:	0.30 inch (single thickness) at d.b.h. at age 5 on silt-loam soil; mean for 40 randomly obtained clones in same test, 0.30 inch. Basis: 6 determinations per clone

Average 5-year growth of Stoneville 74 on two sites[1]

Character and unit of measure	Commerce silt loam		Sharkey clay	
	Stoneville 74	Control	Stoneville 74	Control
D.b.h. (inches)	8.1	6.3	3.8	3.3
Height (feet)	57.1	51.2	31.6	28.4
Volume, including bark, to 3½-inch top (cubic feet)	7.6	3.7	....	....
Volume, inside bark, to 3-inch top (cubic feet)	6.5	3.2	....	....

[1]Means for Stoneville 74 and the control (made up of 40 randomly obtained clones) are based on measurements of 10 ramets/clone for diameter, 5 ramets/clone for height, and 3 ramets/clone for volume on the silt-loam soil. On the Sharkey clay means are based on 18 ramets/clone for diameter and 8 ramets/clone for height.

STONEVILLE 75

Identification

Species:	Populus deltoides Bartr.
Origin:	Open-pollinated progeny of phenotypically superior tree (Stoneville 11) found in Issaquena County, Mississippi (32°37'N, 91°W)

General Information

Sex:	Male
Foliation date:	43 days after 2/28; mean for tests, 39 days
Defoliation date:	Late relative to local cottonwood

Habit

Trunk:	Average straightness
Branches:	Average number, average size

Pest and Disease Information

Melampsora rust:	Below average juvenile incidence
Other:	No serious damage noted to age 5

Cultural Information

Propagation:	Mean first-year survival of unrooted cuttings in 4 tests, 60 percent; mean for 19 or more clones in same tests, 81 percent

Wood Characteristics

Specific gravity:	Mean of 0.31 for disks taken at breast height at age 5; range of 20 clones in same tests, 0.31-0.36. Basis: 3 ramets per clone on each of two soils

Bark

Surface:	Average roughness
Thickness:	0.30 inch (single thickness) at d.b.h. at age 5 on silt-loam; mean for 40 randomly obtained clones in same test, 0.30 inch. Basis: 6 determinations per clone

Average 5-year growth of Stoneville 75 on two sites[1]

Character and unit of measure	Commerce silt loam		Sharkey clay	
	Stoneville 75	Control	Stoneville 75	Control
D.b.h (inches)	7.6	6.3	3.9	3.3
Height (feet)	55.2	51.2	32.0	28.4
Volume, including bark, to 3½-inch top (cubic feet)	7.8	3.7	------	------
Volume, inside bark, to 3-inch top (cubic feet)	7.1	3.2	------	------

[1]Means for Stoneville 75 and the control (made up of 40 randomly obtained clones) are based on measurements of 10 ramets/clone for diameter, 5 ramets/clone for height, and 3 ramets/clone for volume on the silt-loam soil. On the Sharkey clay means are based on 18 ramets/clone for diameter and 8 ramets/clone for height.

STONEVILLE 81

Identification	
Species:	Populus deltoides Bartr.
Origin:	Open-pollinated progeny of phenotypically superior tree (Stoneville 14) located in Issaquena County, Mississippi (32°40'N, 91°05'W)
General Information	
Sex:	Female
Foliation date:	41 days after 2/28; mean for tests, 39 days
Defoliation date:	Late relative to local cottonwood
Habit	
Trunk:	Average straightness
Branches:	Average number, average size
Pest and Disease Information	
Melampsora rust:	Average juvenile incidence
Other:	No serious damage noted to age 5
Cultural Information	
Propagation:	Mean first-year survival of unrooted cuttings in 4 tests, 56 percent; mean for 19 or more clones in same tests, 81 percent
Wood Characteristics	
Specific gravity:	Mean of 0.32 for disks taken at breast height at age 5; range of 20 clones in same tests, 0.31-0.36. Basis: 3 ramets per clone on each of two soils
Bark	
Surface:	Average roughness
Thickness:	0.40 inch (single thickness) at d.b.h. at age 5 on silt-loam soil; mean for 40 randomly obtained clones in same test, 0.30 inch. Basis: 6 determinations per clone

Average 5-year growth of Stoneville 81 on two sites[1]

Character and unit of measure	Commerce silt loam		Sharkey clay	
	Stoneville 81	Control	Stoneville 81	Control
D.b.h. (inches)	7.4	6.3	3.9	3.3
Height (feet)	55.9	51.2	30.5	28.4
Volume, including bark, to 3½-inch top (cubic feet)	6.3	3.7	------	------
Volume, inside bark, to 3-inch top (cubic feet)	5.7	3.2	------	------

[1]Means of Stoneville 81 and the control (made up of 40 randomly obtained clones) are based on measurements of 10 ramets/clone for diameter, 5 ramets/clone for height, and 3 ramets/clone for volume on the silt-loam soil. On the Sharkey clay means are based on 18 ramets/clone for diameter and 8 ramets/clone for height.

STONEVILLE 91

Identification
- Species: Populus deltoides Bartr.
- Origin: Open-pollinated progeny of phenotypically superior tree (Stoneville 21) found in Issaquena County, Mississippi (32°40'N, 91°05'W)

General Information
- Sex: Male
- Foliation date: 42 days after 2/28; mean for tests, 39 days
- Defoliation date: Late relative to local cottonwood

Habit
- Trunk: Below average straightness
- Branches: Average number, relatively large

Pest and Disease Information
- Melampsora rust: Average juvenile incidence
- Other: No serious damage noted to age 5

Cultural Information
- Propagation: No data available regarding first-year survival of cuttings

Wood Characteristics
- Specific gravity: Mean of 0.32 for disks taken at breast height at age 5; range of 20 clones in same tests, 0.31-0.36. Basis: 3 ramets per clone on each of two soils

Bark
- Surface: Smooth
- Thickness: 0.30 inch (single thickness) at d.b.h. at age 5 on silt-loam soil; mean for 40 randomly obtained clones in same test, 0.30 inch. Basis: 6 determinations per clone

Average 5-year growth of Stoneville 91 on two sites[1]

Character and unit of measure	Commerce silt loam		Sharkey clay	
	Stoneville 91	Control	Stoneville 91	Control
D.b.h. (inches)	7.4	6.3	3.3	3.3
Height (feet)	56.1	51.2	31.5	28.4
Volume, including bark, to 3½-inch top (cubic feet)	6.7	3.7	......	......
Volume, inside bark, to 3-inch top (cubic feet)	6.3	3.2	......	......

[1]Means for Stoneville 91 and the control (made up of 40 randomly obtained clones) are based on measurements of 10 ramets/clone for diameter, 5 ramets/clone for height, and 3 ramets/clone for volume on the silt-loam soil. On the Sharkey clay means are based on 18 ramets/clone for diameter and 8 ramets/clone for height.

STONEVILLE 92

Identification
- Species: Populus deltoides Bartr.
- Origin: Open-pollinated progeny of phenotypically superior tree (Stoneville 21) found in Issaquena County, Mississippi (32°40'N, 91°05'W)

General Information
- Sex: Unknown
- Foliation date: 42 days after 2/28: mean for tests, 39 days
- Defoliation date: Late relative to local cottonwood

Habit
- Trunk: Average straightness
- Branches: Average number, average size

Pest and Disease Information
- Melampsora rust: Less than average juvenile incidence
- Other: No serious damage noted to age 5

Cultural Information
- Propagation: First-year survival of unrooted cuttings in 3 tests, 88 percent; mean for 19 or more clones in same tests, 86 percent

Wood Characteristics
- Specific gravity: Mean of 0.33 for disks taken at breast height at age 5; range of 20 clones in same tests, 0.31-0.36. Basis: 3 ramets per clone on each of two soils

Bark
- Surface: Smooth
- Thickness: 0.30 inch (single thickness) at d.b.h. at age 5 on silt-loam soil; mean for 40 randomly obtained clones in same test, 0.30 inch. Basis: 6 determinations per clone

Average 5-year growth of Stoneville 92 on two sites[1]

Character and unit of measure	Commerce silt loam		Sharkey clay	
	Stoneville 92	Control	Stoneville 92	Control
D.b.h. (inches)	7.4	6.3	3.7	3.3
Height (feet)	54.9	51.2	29.6	28.4
Volume, including bark, to 3½-inch top (cubic feet)	5.9	3.7	------	------
Volume, inside bark, to 3-inch top (cubic feet)	5.3	3.2	------	------

[1]Means for Stoneville 92 and the control (made up of 40 randomly obtained clones) are based on measurements of 10 ramets/clone for diameter, 5 ramets/clone for height, and 3 ramets/clone for volume on the silt-loam soil. On the Sharkey clay means are based on 18 ramets/clone for diameter and 8 ramets/clone for height.

STONEVILLE 107

Identification
- Species: Populus deltoides Bartr.
- Origin: Seedling collected from sandbar in Bolivar County, Mississippi (33°47'N, 91°W)

General Information
- Sex: Male
- Foliation date: 30 days after 2/28; mean for tests, 39 days
- Defoliation date: Early relative to local cottonwood

Habit
- Trunk: Average straightness
- Branches: Average number, average size

Pest and Disease Information
- Melampsora rust: Above average juvenile incidence
- Other: No serious damage noted to age 5

Cultural Information
- Propagation: No data available on first-year survival of unrooted cuttings

Wood Characteristics
- Specific gravity: Mean of 0.33 for disks taken at breast height at age 5; range of 20 clones in same tests, 0.31-0.36. Basis: 3 ramets per clone on each of two soils

Bark
- Surface: Smooth
- Thickness: 0.35 inch (single thickness) at d.b.h. at age 5 on silt-loam soil; mean for 40 randomly obtained clones in same test, 0.30 inch. Basis: 6 determinations per clone

Average 5-year growth of Stoneville 107 on two sites[1]

Character and unit of measure	Commerce silt loam		Sharkey clay	
	Stoneville 107	Control	Stoneville 107	Control
D.b.h. (inches)	7.1	6.3	3.8	3.3
Height (feet)	55.7	51.2	32.7	28.4
Volume, including bark, to 3½-inch top (cubic feet)	5.7	3.7	......	......
Volume, inside bark, to 3-inch top (cubic feet)	5.1	3.2	......	......

[1]Means for Stoneville 107 and the control (made up of 40 randomly obtained clones) are based on measurements of 10 ramets/clone for diameter, 5 ramets/clone for height, and 3 ramets/clone for volume on the silt-loam soil. On the Sharkey clay means are based on 18 ramets/clone for diameter and 8 ramets/clone for height.

STONEVILLE 109

Identification
- Species: Populus deltoides Bartr.
- Origin: Seedling collected from sandbar in Bolivar County, Mississippi (33°47'N, 91°W)

General Information
- Sex: Female
- Foliation date: 32 days after 2/28; mean for tests, 39 days
- Defoliation date: Average relative to local cottonwood

Habit
- Trunk: Average straightness
- Branches: Above average number, relatively large

Pest and Disease Information
- Melampsora rust: Above average juvenile incidence
- Other: No serious damage noted to age 5

Cultural Information
- Propagation: No data available on first-year survival of unrooted cuttings

Wood Characteristics
- Specific gravity: Mean of 0.35 for disks taken at breast height at age 5; range of 20 clones in same tests, 0.31-0.36. Basis: 3 ramets per clone on each of two soils

Bark
- Surface: Average roughness
- Thickness: 0.40 inch (single thickness) at d.b.h. at age 5 on silt-loam soil; mean for 40 randomly obtained clones in same test, 0.30 inch. Basis: 6 determinations per clone

Average 5-year growth of Stoneville 109 on two sites[1]

Character and unit of measure	Commerce silt loam		Sharkey clay	
	Stoneville 109	Control	Stoneville 109	Control
D.b.h. (inches)	7.2	6.3	3.9	3.3
Height (feet)	55.4	51.2	31.6	28.4
Volume, including bark, to 3½-inch top (cubic feet)	5.4	3.7	......	......
Volume, inside bark, to 3-inch top (cubic feet)	5.0	3.2	......	......

[1]Means for Stoneville 109 and the control (made up of 40 randomly obtained clones) are based on measurements of 10 ramets/clone for diameter, 5 ramets/clone for height, and 3 ramets/clone for volume on the silt-loam soil. On the Sharkey clay means are based on 18 ramets/clone for diameter and 8 ramets/clone for height.

STONEVILLE 124

Identification
Species: Populus deltoides Bartr.
Origin: Seedling collected from sandbar in Issaquena County, Mississippi (32°55'N, 91°05'W)

General Information
Sex: Male
Foliation date: 40 days after 2/28; mean for tests, 39 days
Defoliation date: Early relative to local cottonwood

Habit
Trunk: Average straightness
Branches: Above average number, relatively large

Pest and Disease Information
Melampsora rust: Average juvenile incidence
Other: No serious damage noted to age 5

Cultural Information
Propagation: First-year survival of unrooted cuttings in 4 tests, 83 percent; mean for 19 or more clones in same tests, 81 percent

Wood Characteristics
Specific gravity: Mean of 0.32 for disks taken at breast height at age 5; range of 20 clones in same tests, 0.31-0.36. Basis: 3 ramets per clone on each of two soils

Bark
Surface: Average roughness
Thickness: 0.30 inch (single thickness) at d.b.h. at age 5 on silt-loam soil; mean for 40 randomly obtained clones in same test, 0.30 inch. Basis: 6 determinations per clone

Average 5-year growth of Stoneville 124 on two sites[1]

Character and unit of measure	Commerce silt loam		Sharkey clay	
	Stoneville 124	Control	Stoneville 124	Control
D.b.h. (inches)	8.5	6.3	3.6	3.3
Height (feet)	58.3	51.2	29.8	28.4
Volume, including bark, to 3½-inch top (cubic feet)	8.5	3.7	......	......
Volume, inside bark, to 3-inch top (cubic feet)	7.6	3.2	......	......

[1]Means for Stoneville 124 and the control (made up of 40 randomly obtained clones) are based on measurements of 10 ramets/clone for diameter, 5 ramets/clone for height, and 3 ramets/clone for volume on the silt-loam soil. On the Sharkey clay means are based on 18 ramets/clone for diameter and 8 ramets/clone for height.

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Planting Yellow-Poplar in Central Tennessee and Northern Alabama

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Southern Forest Experiment Station
Forest Service
U.S. Department of Agriculture

1970

Planting Yellow-Poplar in Central Tennessee and Northern Alabama

T. E. Russell, N. S. Loftus,
A. L. Mignery, and G. W. Smalley[1]

In a series of studies over a 10-year period, growth and survival of planted yellow-poplar were good on a wide range of wooded sites in Tennessee and Alabama. Success was achieved with ordinary seedlings planted by standard techniques when competing vegetation was adequately controlled.

Excellent form, rapid growth, and useful and easily worked wood nake yellow-poplar (**Liriodendron tulipifera** L.) a prime candidate or planting. Although it reaches optimum development in the southrn Appalachians, recommendations for planting the species have een developed for other regions. Results reported here show that ellow-poplar can be successfully planted over a wide range of sites n the Cumberland Plateau and Highland Rim in central Tennessee nd northern Alabama. Obtaining adequate survival has not been ifficult, and although the plantations studied are still young, they rovide a basis for selecting planting sites where rapid early growth nay reasonably be expected.

Whenever yellow-poplar is a component of the existing stand, bundant natural reproduction can usually be obtained. Since the eeds remain viable for extended periods in litter, seed trees need ot be retained when logging (**4**).

The problem on many suitable sites in the southern highlands s that yellow-poplar has been eliminated by improper cutting, fire, nd grazing. Planting provides a well-spaced new stand quickly. When enetically-superior trees become available, they will have to be inroduced by planting or direct-seeding.

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[1]The authors are stationed at the Sewanee Silviculture Laboratory, which is maintained by the outhern Forest Experiment Station, USDA Forest Service, at Sewanee, Tennessee, in cooperation ith The University of the South.

STUDY AREA

The Cumberland Plateau in Tennessee averages 1,700 to 2,000 feet above sea level, although the northeast section has mountains exceeding 3,000 feet. The major surface, underlain primarily by sandstone, is dissected near the margin by valleys whose steepness and depth increase abruptly into coves or gorges. The plateau extends southwest into northern Alabama, gradually lowering until it disappears beneath the Coastal Plain. Successful yellow-poplar plantations on the plateau have elevations ranging from 1,500 to 1,900 feet in Tennessee, while those in Alabama average about 500 feet.

The Highland Rim is a low plateau formed primarily on limestone. It begins at the base of the Cumberland Escarpment, surrounds the Nashville Basin, and extends south and west to the Tennessee River in northern Alabama and western Tennessee. The western Highland Rim is strongly dissected with long, narrow ridges and steep-sided valleys. Elevations reach 1,300 feet at the foot of the Cumberland Plateau and decrease westward to 700 feet near the Tennessee River. Yellow-poplar plantings on the eastern rim are at elevations nea 1,100 feet, while those to the west average 800 feet.

The two physiographic provinces cover more than 18 million acre in Tennessee and Alabama, of which nearly 11 million acres ar commercial forest land (fig. 1). The Cumberland Plateau is th more heavily forested province; three-fourths of the Tennessee an two-thirds of the Alabama portion are in woodland. Hardwoo forests predominate, although pines become increasingly commo as one moves southward.

The proportion of the region suitable for yellow-poplar growt can be roughly estimated from topography, which is generall related to the species' performance. Contour maps of 10 sampl counties indicate that over 40 percent of the plateau may have aver age or good sites for yellow-poplar growth. Possibly a third of th Highland Rim has average or good yellow-poplar sites.

Rainfall is fairly uniform throughout the region, but highe temperatures make the southern Plateau generally less favorab for yellow-poplar growth than further north. Annual rainfall aver ages from 53 to 56 inches, and it is usually well distributed throug the frost-free period, which ranges from 180 to 241 days. Climate at points near study plantations are shown in table 1.

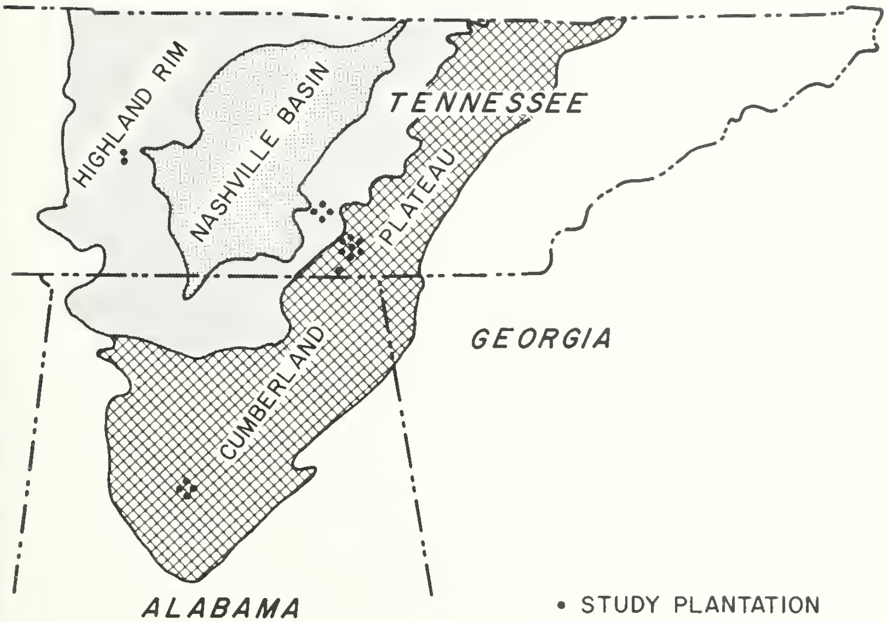

Figure 1.—Physiographic provinces of central Tennessee and northern Alabama.

Table 1. — Climates near planting sites

Planting locality	Average frost-free	Average temperature			Average annual rainfall
		January	July	Annual	
	Days		°F		Inches
Sewanee, Tenn. (Plateau)	201	39	75	[1]57	56
Tullahoma, Tenn. (eastern Highland Rim)	196	42	78	59	53
Waynesboro, Tenn. (western Highland Rim)	180	40	78	59	55
Birmingham, Ala. (Plateau)	241	45	80	63	54

[1]At Monteagle on the plateau 6 miles east of Sewanee plots.

METHODS

This paper describes the early performance of yellow-poplar in 18 plantations in central Tennessee and northern Alabama (fig. 1). Plantations are from 1 to 10 years old (table 2). Twelve were established mainly to compare yellow-poplar performance with that of several other species. At three other locations, growth of yellow-poplars from four Midsouth seed sources is being compared (**2**). Two plantings were established to relate topography to yellow-poplar survival and growth, and one to study the effects of three intensities of release from competing hardwoods. Treatments are replicated from three to seven times at each location on plots ranging from 1/4 to about 1 acre. In all, the study plots encompass 24 acres and include over 24,000 seedlings. In most cases, the original objectives of the studies have not yet been reached, but conclusions about planting success and early performance are possible.

This research was confined to forested areas, mainly because there are no longer many old fields available for planting on the Cumberland Plateau and Highland Rim. Moreover, many past failures show that planting demanding hardwoods on depleted agricultural soils in central Tennessee and northern Alabama seldom pays off.

Planting areas generally supported low-quality, oak-hickory stands. Near the southern end of the plateau they usually had some pine in mixture with the hardwoods. As a result of repeated partial cutting, most stands had an understory of hardwood reproduction and tolerant shrubs. Competition from existing hardwoods is the most serious hindrance to establishment of valuable species on cut-over areas.

One plantation is on an obviously good site that had a saw-timber stand of high-quality, mixed hardwoods before clearcutting and planting to yellow-poplar. Because of past abuse, stands on most other areas were too degraded to reliably indicate site potential for yellow-poplar.

Establishment techniques.—Timber was harvested before planting on areas supporting merchantable volumes. Small hardwoods and brush remaining after logging were removed from one site by bull-dozing (fig. 2). Preparation methods used on the other 17 sites depended upon existing vegetation and topography. Treatments were also modified as experience was gained and improved techniques became available. Except in a study of intensity of release, the objective was to eliminate vegetation that might overtop the yellow-

Table 2. — Performance of yellow-poplar planted at 18 locations on the Cumberland Plateau and Highland Rim

Topographic position and plantation number	Plantation age	Spacing	Survival	Mean heights		Mean annual growth of dominant stand
				Total stand	Dominant stand[1]	
	Years	Feet	Percent	Feet		
Plateau — ridge						
1	10	6 × 8	83	16.2	25.0	2.4
2	10	6 × 8	84	16.6	23.8	2.3
3	8	5 × 5	94	15.8	21.1	2.6
4	5	6 × 8	91	5.7	8.6	1.4
5	5	6 × 8	96	6.7	10.0	1.8
6	4	7 × 7	75	10.5	13.1	3.1
Plateau — hollow						
7	10	5 × 6	70	23.6	35.3	3.5
8	8	5 × 5	77	15.3	20.7	2.4
9	8	8 × 8	82	17.6	22.1	2.6
10	3	7 × 7	97	4.2	6.2	1.7
11	2	7 × 7	90	4.3	5.7	2.4
Plateau — cove						
12	8	5 × 5	85	29.7	36.0	4.4
Highland Rim — ridge						
13	10	6 × 8	89	19.2	26.0	2.5
Highland Rim — flat						
14	5	6 × 8	92	12.4	16.2	3.1
15	5	6 × 8	90	4.4	6.8	1.2
16	4	6 × 8	94	5.1	7.7	1.6
17	1	7 × 7	100	2.0	2.8	1.2
Highland Rim — hollow						
18	3	7 × 7	99	8.2	11.7	3.6

[1]Dominant stand includes the tallest 20 percent of the trees at each location.

Figure 2.—Typical ridge site on the southern end of the Cumberland Plateau in northern Alabama was mechanically prepared with a minimum of soil disturbance.

poplars during the first 2 or 3 years after planting. Results reported for the release study are for plots that received a hardwood control treatment equivalent to those applied on the other 17 areas.

Where understory vegetation was sparse, sites were prepared by girdling overstory hardwoods, or frilling and applying 2,4,5-T. Where understories were dense and there were some large hardwoods in the overstory, the large trees were deadened either by frilling and applying herbicide or by injection. Stems under about 2 inches d.b.h. were treated by basal spraying, or by cutting and spraying the stumps with a 2,4,5-T solution to reduce sprouting.

In the two most recent studies, understory hardwoods were treated about 1 year before planting by mist blowing 2,4,5-T, and overstory hardwoods were injected with undiluted 2,4-D. This combination proved to be the most satisfactory, particularly on cutover areas with a dense understory.

All plantations were established with bare-rooted, 1-0 stock. After receipt from the nursery, seedlings for the first eight plantings were kept in soil pits or in cool cellars, or they were heeled-in until planted. For later plantings, seedlings were refrigerated at about 35°F. Cold storage is the best way to keep yellow-poplar seedlings for long periods; however, all storage methods were satisfactory. Except for Plantation 6 (table 2) where seedlings dried out during shipment, stock was in good condition and dormant until planted.

Seedlings were bar-planted at spacings that varied from 5 by 5 to 8 by 8 feet, depending upon research requirements of the individual studies. Most were planted with the pointed KBC bar (fig. 3), which we found more effective in stony soils than the standard wedge-shaped bar. It also makes a wider planting slit that more readily accommodates the yellow-poplar root system.

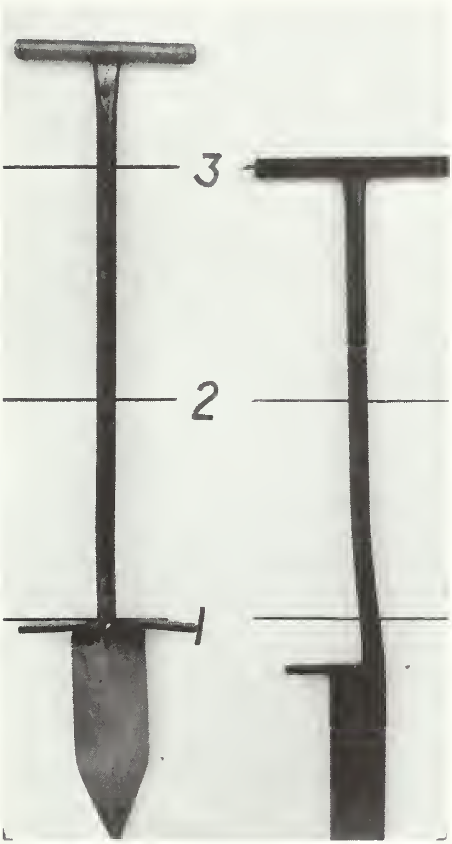

Figure 3.—A KBC planting bar (left) is more effective in stony soils than a standard planting bar (right).

Whenever possible seedlings with rootcollar diameters of 8/32 to 12/32 inch were planted. Because of stock shortages, a number of larger or smaller seedlings were planted in some studies. Roots longer than 10 inches were field-pruned so seedlings could be easily inserted in the planting slit without bending the taproot. In 15 studies planting was done between mid-February and April. Seedlings were planted in January at one location and as late as mid-May at two others. Within this range of dates, seasonal weather fluctuations had no effect on planting success.

The sources of seed for all but two of the plantings are known. Where source is not an experimental variable, seeds were gathered either locally or from an area of approximately the same latitude as the planting site. While geographic seed source is a variable in seven studies, it has had statistically significant effects on growth only in two of the older plantations (2). In these, trends are not strong enough to recommend a particular seed source. Overall differences in growth between plantings are assumed to be mainly functions of site quality and treatment. Results reported for plantings that include more than one seed source are based on average performance at these locations.

Plantations 3 and 12, planted at a 5- by 5-foot spacing, were thinned precommercially in their eighth year to maintain adequate crown ratios and diameter growth. In view of the excellent survival achieved in all studies, planting more than about 900 trees per acre probably cannot be justified.

Planting sites.—The Cumberland Plateau and Highland Rim sites occupied by the 18 experimental plantings are grouped according to recognized similarities in topography and soils. Soil properties are, in part, a function of topography. On the plateau, six plantations occupy ridge sites, five are in hollows, and one is in an escarpment cove. Of the six Highland Rim plantings, one is on a narrow ridgetop, four are on flats in the area known locally as the "Barrens," and one is in a V-shaped hollow bounded by narrow ridges. In the Results section of this paper the six site categories are described in conjunction with reports of tree performance.

RESULTS AND DISCUSSION

Survival

Obtaining adequate survival of planted yellow-poplar proved to be no problem (table 2). In 8- to 10-year-old plantations, survival ranged from 70 to 94 percent, falling below 80 percent at only two locations. Survival was generally better than 90 percent in the 3- to 5-year-old stands. The one exception is a fast-growing plantation in which the relatively poor survival of 75 percent resulted from planting seedlings that had partially dried out during shipment.

Heaviest mortality occurred during the first 2 or 3 years after planting. Differences between locations probably resulted more from variations in competition than from inherent differences in soil moisture. Understory vegetation was denser and more vigorous on better sites than on poor or average sites, and included more hard-to-control species such as black gum, maples, and dogwood. Consequently, seedlings tended to be overtopped by competing hardwoods more often on good sites.

The good survival is extremely encouraging. It indicates that yellow-poplar can be readily planted on the Cumberland Plateau and Highland Rim without resorting to specialized techniques. Ordinary nursery stock will survive if competition from existing hardwoods is adequately controlled.

So far, these plantations have escaped serious injury by insects, diseases, or other agents. A few trees on average or poor sites have cankers, probably caused by **Fusarium solani** (Mart.) Appel. & Wr. **(1).** Forked or multiple stems are also common on poor sites (fig. 4). No seedlings have been killed by frost, even in plantings that include Coastal Plain provenances, although late-spring frosts have occasionally caused slight leaf damage. At one location, newly planted seedlings were damaged by herbicide residues. Here the bases of understory hardwoods had been sprayed with a low-volatile ester of 2,4,5-T in oil 6 weeks before planting in March. Few seedlings died, but this damage emphasizes that 2,4,5-T esters should be applied well in advance of yellow-poplar planting.

Barring unusual droughts, satisfactory survival of bare-rooted seedlings can apparently be expected on soils suitable for yellow-poplar. Good initial survival may be no guarantee of ultimate plantation success, however. Less than 10 percent of the seedlings have died in Plantations 4, 10, 15, and 16, where poor growth and form indicate that sites are marginal or unsuitable for yellow-poplar.

Figure 4.—Dieback and multiple stems occur on ridge sites where moisture is limiting. Trees shown are 6 years old.

Growth

Growth in most of the plantations has been satisfactory, and in several of them it has been extremely good (table 2).

When comparing the performance of different plantations, allowance should be made for their varying ages. On most sites the trees achieved a relatively stable growth rate within about 3 years. Figure 5 shows growth curves for young plantations on a range of sites on the Cumberland Plateau and Highland Rim.

Plateau ridges.—Plateau ridges varied widely as sites for growing yellow-poplar. They are generally considered to be unfavorable for demanding hardwoods, yet in two 10-year-old stands trees average over 16 feet in height and in one 4-year-old plantation they average over 10 feet. Poorest growth is in Plantation 4, where trees averaged only 5.7 feet in height after 5 years in the field.

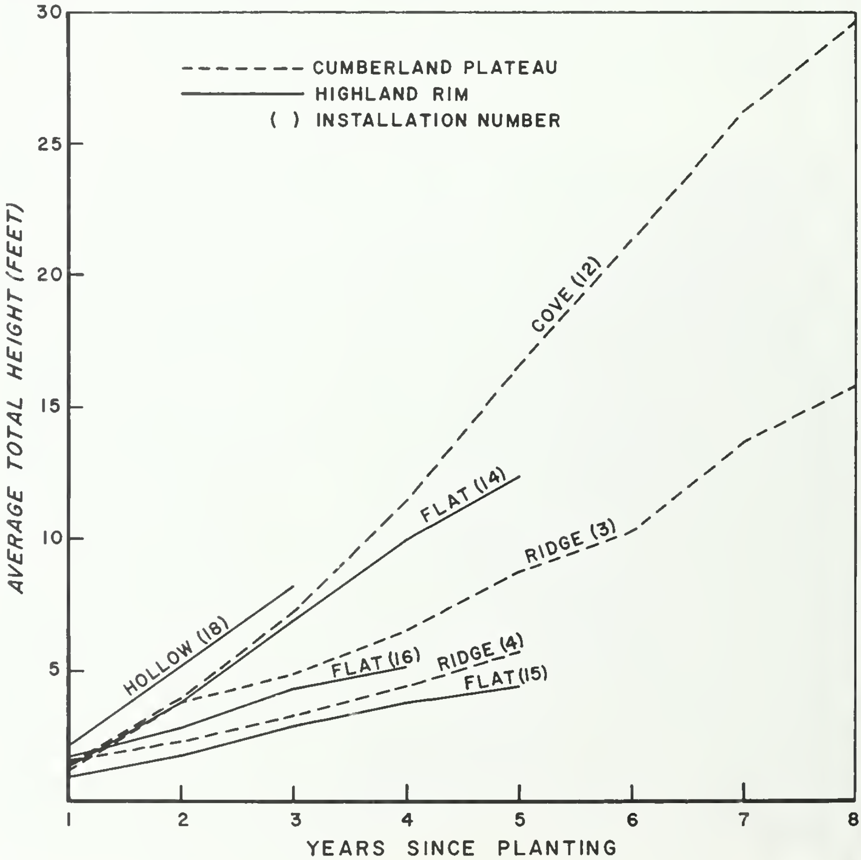

Figure 5.—Average early growth of all surviving yellow-poplar planted on various sites.

Performance of the tallest 20 percent of the stand is perhaps a better measure of yellow-poplar growth potential than the average height of the total stand. Dominance is expressed soon after the crowns close, and many trees in closely spaced plantings over 5 years old are suppressed. If 1,000 trees are planted per acre and survival is similar to that obtained in these studies, the tallest 20 percent will include at least 140 individuals—the group from which crop trees will be selected.

Dominant trees on most of the ridge sites on the Cumberland Plateau have grown more than 2 feet per year (fig. 6). Average growth of this best 20 percent varied from 1.4 feet per year in a 5-year-old plantation to 3.1 feet in a 4-year-old stand.

Figure 6.—An 8-year-old stand (Plantation 3) on a Cumberland Plateau ridge site of average quality.

On the ridgetops that were planted, slopes ranged from 2 to 5 percent and aspect was of little consequence. In the vicinity of Sewanee, Tennessee, where five of the plantings are located, soils commonly occurring on the ridges are of the Hartsells, Ramsey, and Linker series. These coarse-textured soils have formed from residual sandstones; they are well-drained, strongly acid, and of low fertility.

On top of the Cumberland Plateau a reasonable distinction can be made between poor and good sites for yellow-poplar on the basis of soil depth, degree of erosion, and ridge width. For example, the best annual growth rate of 3.1 feet was attained at Plantation 6, which is on a broad, gently sloping ridge; the soil is a deep, uneroded Hartsells loam. In contrast, Plantation 4, which is on a narrow ridge with shallow soils of the Ramsey-Hartsells association, had the poorest growth rate of the plateau plantings, 1.4 feet per year. Shallow soils on narrow ridgetops are droughty during the summer and yellow-poplar should not be planted on them.

One ridge planting (Plantation 5) is on the southern end of the plateau near Birmingham, Alabama, where soils are principally of the Enders, Albertville, and Hartsells series. Enders and Albertville soils are well-drained, moderately deep to bedrock, strongly acid and of low fertility. They are finer textured than the Hartsells.

Growth at Plantation 5 is mediocre, averaging 1.8 feet per year for the dominant stand. Two successive spring droughts following planting may have retarded early growth. In addition, the area was prepared by bulldozing, which may have been detrimental.

Plateau hollows.—In plateau hollows, growth of dominants ranged from 1.7 to 3.5 feet per year. The development of a well-defined dendritic drainage pattern on the plateau surface has resulted in a myriad of hollows containing intermittent streams. Their character varies greatly according to geographic location and is ultimately related to geologic structure and alteration through erosional processes. Since moisture, nutrients, and alluvium accumulate from adjacent ridges, these hollows are generally good yellow-poplar sites.

At Sewanee, Plantations 10 and 11 are in U-shaped hollows with east and southwest slopes averaging 12 percent. Here the hollow character is controlled by a massive, cross-bedded sandstone conglomerate; consequently, slope length is variable, ranging from 100 to 400 feet, and relief is 15 to 50 feet. Soils are of the Hartsells, Ramsey, and Wellston series, with associated narrow strips of alluvium in the bottoms; depth to bedrock is from 18 inches to over 7 feet.

At Plantation 11, where soils are 24 inches or more in depth, growth averaged 2.4 feet per year during 2 years after planting. Plateau hollows are not always excellent yellow-poplar sites, however. Growth in Plantation 10 has been only 1.7 feet per year. Poor growth here is attributed to shallow soils which are less than 24 inches to bedrock. They are saturated through the spring and extremely dry during the summer. As a result, a dense ground cover of herbaceous plants and hardwood sprouts has developed. Growth has been retarded by this competition in conjunction with limited rooting space for yellow-poplar. Fertility is not thought to be a problem on this site.

Three of the hollow plantings are on the southern end of the Cumberland Plateau in northern Alabama. Here, the sandstone caprock has been eroded away, exposing interbedded sandstone and shales; hollows are V-shaped and bounded by narrow ridges. Slopes average 40 percent and are approximately 200 feet long; relief ranges from 60 to 80 feet. Soils on the side slopes are Montevallo, Enders, Townley, and Hartsells. Soil depth ranges from 2 to 4 feet. Soils along the drainageways have formed from local alluvium and colluvium.

Two plantations, which have grown at rates of 2.4 and 2.6 feet per year, are on north-facing slopes. A third (Plantation 7) consists of 10-year-old plantings across seven V-shaped hollows. Dominant stems have maintained an annual growth of 3.5 feet, the second best rate of all the plantings on the plateau (fig. 7). However, growth within these hollows varies significantly according to aspect and slope position; the tallest trees are in the bottoms and the shortest on the upper southern slopes (6). Growth on all positions of the northern slopes exceeds 2 feet per year. Topographic position and aspect have not been related to the growth of yellow-poplar in the shallower and more gently sloping plateau hollows in central Tennessee.

Plateau cove.—The best sites on the plateau are on upper slopes and mountain "coves" of the escarpment, particularly on northerly aspects. Gradients range from 12 to 60 percent. The slopes are mantled with unsorted colluvium and the coves with old alluvial-colluvial deposits.

Plantation 12 is on a slope that faces northwest and averages 40 percent. Rock-controlled benches have favored deep accumulation (20 feet or more) of bouldery and stony colluvium with associated soils of the Allen and Jefferson series. Subirrigation from the plateau surface strongly affects the quality of this site. Site index for yellow-poplar on these slopes ranges from 90 to 110 at 50 years (5). Mean

Figure 7.—Ten-year-old yellow-poplar in a V-shaped plateau hollow in northern Alabama. Good survival and an average growth rate of 3.5 feet per year suggest that yellow-poplar should be favored in the management of these sites.

height of the entire stand averaged 29.7 feet after 8 years in the field and the tallest 20 percent of the trees have grown 4.4 feet per year (fig. 8).

Highland Rim flats.—Plantations 14 through 17 are on a level to undulating section of the eastern Highland Rim known as the "Barrens;" surface drainage is not well developed and dissection is

Figure 8.—Eight growing seasons after planting, dominant trees on a good cove site (Plantation 12) are 4 to 6 inches in diameter and over 35 feet in height.

slight except near permanent streams. Soils are of the Dickson series formed from a well-weathered loess mantle over a cherty limestone residuum. This soil has a strong fragipan, slow internal drainage, and low fertility. Depth to the fragipan is 14 to 25 inches and thickness of the solum is more than 60 inches.

Poor growth in three of the four plantings on Highland Rim flats suggests that site quality for yellow-poplar on Dickson soils varies with depth to the fragipan. A strong fragipan retards drainage so that the soils are saturated with water and therefore cold in the spring. During the summer when the surface soil is extremely dry, the fragipan restricts root penetration to lower soil horizons where moisture may be available. Depth to the fragipan at Plantation 14 averages

25 inches and the growth rate is 3.1 feet per year—almost as good as the best plateau hollow. At the other three installations, however, there is only 14 to 18 inches of soil above the fragipan and annual growth ranges from 1.2 to 1.6 feet.

Highland Rim ridges and hollows.—The ridge and hollow plantations are on the thoroughly dissected western part of the Highland Rim. This area has many narrow, parallel ridges and deeply cut V-shaped hollows with side slopes of 30 to 60 percent. Soils on the ridge site (Plantation 13) are of the Mountview series, developed from loess over cherty limestone. They are strongly acid, low in fertility, and well drained. The thickness of the loess ranges from 16 to 26 inches and averages 19 inches; the underlying chert-derived soil is very dense and restricts moisture movement and root penetration. These soils become extremely dry during extended summer droughts.

The rim-hollow planting (No. 18) extends across several hollows with generally east- and west-facing slopes averaging 100 feet in length. The soil is Bodine cherty loam with chert content ranging from 30 percent at the top of the slopes to 90 percent by volume in the narrow bottoms. Depth to bedrock is variable but usually exceeds 5 feet. This soil at times is excessively drained in the surface horizons, but subirrigation from upper slopes increases the quality of these sites for yellow-poplar which has a capacity for deep rooting.

Five years after planting, growth on the Highland Rim ridge was relatively poor. The many multiple stems in this stand, as well as slow initial height growth, are typical of yellow-poplar planted on narrow ridge sites where moisture and nutrients are limiting. After 5 years of age, however, the trees increased their growth rate and the dominants have averaged 2.5 feet per year for the 10-year period. This is the only planting where seedling growth has accelerated notably after 5 years in the field.

On a similar site in northern Arkansas, with cherty silt loam soils, planted yellow-poplar had a survival of 78 percent and averaged 41 feet in height after 15 years (3). Soils on chert ridges on the Highland Rim may prove more suitable for yellow-poplar growth than would be expected from their topographic position.

In the adjacent hollow, height growth of dominants averages 3.6 feet, generally increasing from the upper slopes to the bottom. On these steep slopes, subsurface flow probably improves moisture conditions downslope. From all present indications, the V-shaped hollows in the western part of the Highland Rim are high-quality sites for yellow-poplar. Growth has been as good during the first 3 years after planting as that obtained on the Cumberland Plateau cove site (fig. 5).

CONCLUSIONS

Experience over the past 10 years demonstrates that yellow-poplar can be successfully planted on forested sites of the Cumberland Plateau and Highland Rim. Ordinary nursery stock is satisfactory if it is handled carefully. Competing vegetation should be controlled as completely as possible. Within 2 or 3 years most yellow-poplars will overtop competition.

Plantations studied are too young for estimation of site index, but except in the youngest installations, early performance has been sufficiently influenced by site factors to identify conditions that should be avoided. Where possible, coves and deep hollows should be chosen. The species should not ordinarily be planted on narrow, dry ridges or on soils shallow to bedrock or fragipan. However, there are indications that yellow-poplar may grow satisfactorily over a wider range of soils than had been anticipated.

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1965. Forest species compared in Ozark plantations. USDA Forest Serv. Res. Note SO-28, 2 p. S. Forest Exp. Sta., New Orleans, La.

Olson, D. F., Jr.
1969. Silvical characteristics of yellow-poplar. USDA Forest Serv. Res. Pap. SE-48, 16 p. Southeast. Forest Exp. Sta., Asheville, N. C.

Russell, T. E.
1966. Planted yellow-poplar thrives on Tennessee's Cumberland Plateau. KTG J. 6(4): 10-11.

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astern Redcedar:
annotated bibliography

E. R. Ferguson

THERN FOREST EXPERIMENTAL STATION
FOREST SERVICE
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1970

CONTENTS

EASTERN REDCEDAR: AN ANNOTATED BIBLIOGRAPHY

E. R. Ferguson

The purpose of this bibliography is to provide a convenient summary of the literature on eastern redcedar (*Juniperus virginiana* L.).

Redcedar has considerable potential for forest management, especially on sites where shallow soil limits the growth of other species. Though stands are now depleted, the trees have a variety of commercial uses and also provide food for wildlife.

Redcedar is widely distributed in the Eastern U. S., and many writers have documented its historical significance, its dendrological and silvical characteristics, and its insect and disease enemies. On other topics pertinent information is in short supply, and it is only when the literature is brought together under some classification scheme that the magnitude of the voids can be appreciated. Thus, of about 330 entries in this bibliography, 128 fall under the general heading of silviculture and almost 100 come under injuries and protection. There is a single entry in the harvesting section, mensuration is represented by eight items, and the entire body of knowledge about forest economics and management is contained in five publications, three of which are from a single location. The literature is most ample on aspects that lend themselves to observation or short-term study, and scanty on subjects that require advanced research techniques or collection of data over significant periods in the lifetime of stands.

The entries include popular as well as scientific articles, and are intended to be complete through 1969. Initial sources of reference were the author's files, the *Journal of Forestry*, and the Oxford Catalogue of World Forestry Literature on Microfilm, as issued by the Commonwealth Agricultural Bureaux, Farnham Royal, England. Citations in specific publications provided additional titles. Though considerable care has been taken, there probably are omissions; notification of these will be appreciated.

Citations are arranged by the Oxford Decimal System. The table of contents provides a key to the classification, and further information is available in the *Oxford System of Decimal Classification for Forestry*, published by the Commonwealth Agricultural Bureaux. Publications have been cross-referenced under such subject-matter heads as seemed appropriate, except that comprehensive or general treatments are listed only once, under classification O.

Entries are for the most part accompanied by brief abstracts. When two or more publications contain virtually the same information, the abstract follows the more complete one, which generally will also be the one most readily available. The complete citation and abstract are printed on the page where the publication is first listed. Later references are abbreviated, for example:

Arend. 1950. (114)

In this cross-reference, the number in parentheses indicates the subject head (Soil) under which the abstract appears. Most abstracts were written by the author after a reading of the original, but some are from summaries or briefs contained in the publications themselves.

0. FOREST, FORESTRY, AND UTILIZATION OF FOREST PRODUCTS

Bailey, L. H. 1933. THE CULTIVATED CONIFERS IN NORTH AMERICA, COMPRISING THE PINE FAMILY AND THE TAXADS. 404 p. N.Y.: Macmillan.
Detailed botanical description of redcedar, with very general information on cultivation and propagation and on insects, diseases, and injuries.

Betts, H. S. 1945. EASTERN RED CEDAR. USDA Forest Serv. Amer. Woods Ser., 4 p.
Distribution, growth, supply, and principal uses.

Collingwood, G. H. 1938. EASTERN RED CEDAR. Amer. Forests 44: 30-31.
Occurrence, growth characteristics, botanical characteristics, wood features, utilization, and common pests.

Ferguson, E. R., Lawson, E. R., Maple, W. R., and Mesavage, C. 1968. MANAGING EASTERN REDCEDAR. USDA Forest Serv. Res. Pap. SO-37, 14 p. S. Forest Exp. Sta., New Orleans, La.
Previous research and recent studies in Arkansas indicate that redcedar should be favored on many areas where trees of other species grow poorly. Planting is feasible, and redcedar responds well to release and thinning.

Mohr, C. 1901. NOTES ON REDCEDAR. USDA Bur. Forest. Bull. 31, 37 p.
Sections on distribution, associated species, products, growth and development, enemies, natural reproduction, forest management, nomenclature and classification, botanical description, and morphology.

Muenscher, W. C. 1949. THE RED CEDAR. Cornell Plant. 5: 47.
Occurrence, range, wood qualities, and tree form.

USDA Forest Service. 1907. RED CEDAR (JUNIPERUS VIRGINIANA). USDA Forest Serv. Circ. 73, 4 p. *Also as* USDA Plant. Leafl. 20, 4 p.
Form and size, range, habits and growth, uses, planting techniques, cultivation, and care.

USDA Forest Service. 1955. EASTERN REDCEDAR (JUNIPERUS VIRGINIANA). USDA Useful Trees of the U.S. 13, 4 p.
Distribution in the United States, resources, growth habits and size, tree and wood characteristics, uses, and enemies.

1. FACTORS OF THE ENVIRONMENT. BIOLOGY

11 SITE FACTORS: SOIL, HYDROLOGY (WATER CONSERVATION, ETC.)

114 SOIL

Arend, J. L. 1948. INFLUENCES ON REDCEDAR DISTRIBUTION IN THE OZARKS. USDA Forest Serv. S. Forest Exp. Sta. S. Forest. Notes 58.
See entry below.

Arend, J. L. 1950. INFLUENCE OF FIRE AND SOIL ON DISTRIBUTION OF EASTERN REDCEDAR IN THE OZARKS. J. Forest. 48: 129-130.
In the Ozarks redcedar characteristically occurs on shallow limestone soils and rough topography, since fire and competition keep it off better sites. Contrary to common belief, soil acidity appears to have little effect on occurrence and distribution of redcedar in the Ozarks. The neutral to alkaline soils found under many stands may be a result rather than a cause of the species' occurrence.

Arend, J. L., and Collins, R. F. 1949. A SITE CLASSIFICATION FOR EASTERN RED CEDAR IN THE OZARKS. Soil Sci. Soc. Amer. Proc. 13:510-511.
Evaluates and describes important site factors. Proposes four site classes: Site I, alluvial soils, deep and well drained, site index 55-60. Site II, upland soils, 24 inches and over in depth, site index 45-50. Site III, upland soils, 12-24 inches in depth, site index 35-40. Site IV, upland soils, less than 12 inches in depth, site index 25-30.

Broadfoot, W. M. 1951. REDCEDAR LITTER IMPROVES SURFACE SOIL. USDA Forest Serv. S. Forest Exp. Sta. S. Forest. Notes 71.
See entry below.

Broadfoot, W. M. 1951. SOIL REHABILITATION UNDER EASTERN REDCEDAR AND LOBLOLLY PINE. J. Forest. 49: 780-781.
In north-central Mississippi, litter and surface soil under even-aged redcedar, loblolly pine, and adjacent herbaceous cover varied chemically, physically, and biologically. Soil rehabilitation proceeds faster under redcedar than under herbaceous or loblolly pine cover.

Chandler, R. F., Jr. 1939. THE CALCIUM CONTENT OF THE FOLIAGE OF FOREST TREES. Cornell Univ. Agr. Exp. Sta. Mem. 228, 15 p.
The calcium content of evergreen foliage increased throughout the growing season but remained fairly constant during winter. The older the foliage the higher was its calcium content. Redcedar litter has a marked effect on the pH and structure of the soil.

Coile, T. S. 1933. SOIL REACTION AND FOREST TYPES IN THE DUKE FOREST. Ecology 14: 323-333.
Redcedar occurs in very small pure stands within other forest types, but seldom is found in the overstory on extensive areas. It tends to raise the pH of normally acid soils.

Fletcher, P. W., and Ochrymowych, J. 1955. MINERAL NUTRITION AND GROWTH OF EASTERN REDCEDAR IN MISSOURI. Mo. Agr. Exp. Sta. Res. Bull. 577, 16 p.
Mineral composition of twigs and foliage was compared with mineral composition of soil on which the plants grew. Conclusions: (1) Rich, calcareous soils produced maximum growth but least ash per unit of ovendry matter. (2) The percentages of total seedling weight in root, stem, and foliage remain almost constant regardless of plant size or soil. (3) Soluble phosphorus and exchangeable calcium in silt-loam soils were directly related to seedling growth. (4) Phosphorus concentration in the foliage of seedlings and mature trees was related directly to phosphorus concentration in the silt-loam soils studied. (5) The foliage contained greater concentrations of potassium, magnesium, and phosphorus than did the twigs, about the same silica and total ash, and less calcium. (6) As the growing season advanced, concentration of phosphorus in the foliage increased.

Lorio, P. L., Jr. 1963. TREE SURVIVAL AND GROWTH ON IOWA COAL-SPOIL MATERIALS. Diss. Abstr. 23: 3583-3584.
Redcedar proved best adapted to calcareous sites.

Lorio, P. L., Jr., and Gathernm, G. E. 1965. RELATIONSHIP OF TREE SURVIVAL AND YIELD TO COAL-SPOIL CHARACTERISTICS. Ia. Agr. Exp. Sta. Res. Bull. 535, p. 394-403.
See entry above.

Read, R. A. 1950. ROCKS MAKE THE TREES. S. Lumberman 181(2273): 217-219.
Where St. Joe limestone is exposed in north Arkansas, redcedar predominates regardless of the direction of the slope. Hardwoods are of poor quality on these sites, and shortleaf pine seldom occurs.

Read, R. A. 1952. TREE SPECIES OCCURRENCE AS INFLUENCED BY GEOLOGY AND SOIL ON AN OZARK NORTH SLOPE. Ecology 33: 239-246.
Natural relationships between tree species occurrence and types of soil, as derived from surface geologic formations in the northern Arkansas Ozarks. Redcedar, northern red oak, winged elm, chinquapin oak, and shagbark hickory predominated on St. Joe limestone.

Read, R. A., and Walker, L. C. 1950. INFLUENCE OF EASTERN REDCEDAR ON SOIL IN CONNECTICUT PINE PLANTATIONS. J. Forest. 48: 337-339.
Physical and chemical properties of surface soil beneath redcedar trees are different from those beneath adjacent pines. Properties of the surface soil beneath redcedars are apparently influenced by the specific chemical nature of the leaflitter and its decomposition products.

Spurr, S. H. 1940. THE INFLUENCE OF TWO JUNIPERUS SPECIES ON SOIL REACTION. Soil Sci. 50: 289-294.
Both Juniperus virginiana *and* communis *alter the pH of soils on abandoned fields near New Haven. The first species raises pH in the upper part of the mineral soil and lowers it at a depth of 6 inches.* Communis, *on the other hand, lowers pH at both depths.*

Voigt, G. K. 1965. NITROGEN RECOVERY FROM DECOMPOSING TREE LEAF TISSUE AND FOREST HUMUS. Soil Sci. Soc. Amer. Proc. 29: 756-759.
In laboratory and greenhouse studies, weight loss and N deficits were more marked in hardwoods than in redcedar and other conifers.

Wherry, E. T. 1922. SOIL ACIDITY PREFERENCES OF SOME EASTERN CONIFERS. J. Forest. 20: 488-496.
Redcedar reaches maximum development in the limestone barrens of Tennessee, where the surface soil is minimalkaline, and the habitat typically circumneutral. It is also abundant in many other limestone regions where conditions are similar. It becomes prominent on basic igneous rocks, calcareous clays, and various other substrata in which lime is available near the surface.

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Study of a subclimax redcedar forest on a shallow soil overlying horizontal limestone. Includes information on soil temperature, weekly course of soil water, hydrogen-ion concentrations, and surface evaporation.

Hahn, H. C., Jr. 1945. CEDAR IMPORTANT TO WILDLIFE. Tex. Game and Fish 3(12): 27-28.
Spread of redcedar on grassland due to absence of fire and excessive grazing. Although it is not important as a food for domestic livestock, it is very valuable in the prevention of erosion, and as habitat and winter food for wildlife.

Van Dersal, W. R. 1938. NATIVE WOODY PLANTS OF THE UNITED STATES. USDA Misc. Publ. 303, 362 p.
Junipers are suitable for dry sites, are desirable in erosion control, and make food and cover for wildlife.

13 GENERAL ZOOLOGY

George, E. J. 1939. TREE PLANTING ON THE DRIER SECTIONS OF THE NORTHERN GREAT PLAINS. J. Forest. 37: 695-698.
Redcedar often reproduces from seed carried by birds.

Parker, J. 1951. NATURAL REPRODUCTION FROM REDCEDAR. J. Forest. 49: 285.
The seed is largely distributed by animals. Excellent reproduction is sometimes found under hardwood stands adjacent to open-grown cedars, because birds feed on the cedar berries and perch in the hardwoods. Recommends removal of some of the hardwoods after establishment of redcedar.

Phillips, F. J. 1910. THE DISSEMINATION OF JUNIPERS BY BIRDS. Forest. Quart. 8: 60-73.
Birds are responsible for most of the dissemination of the junipers. Lists birds that eat juniper berries.

Van Dersal, W. R. 1938. UTILIZATION OF WOODY PLANTS AS FOOD BY WILDLIFE. Third N. Amer. Wildl. Conf. Trans. 1938: 768-775.
Seventy wildlife species were reported using redcedar—the widest use of any woody plant in North America.

16 GENERAL BOTANY

160 PLANT CHEMISTRY

Arend. 1948. (114)

Arend. 1950. (114)

Chandler. 1939. (114)

Voigt. 1965. (114)

161 PHYSIOLOGY

Bifoss, C. G. 1947. THE WATER CONDUCTING CAPACITY AND GROWTH HABITS OF JUNIPERUS HORIZONTALIS MOENCH AND JUNIPERUS VIRGINIANA L. Ecology 28: 281-289.
Measurements on stem tracheids of the two species revealed that (1) conductivity did not vary between species, (2) values for

both species were low, and (3) under favorable conditions J. virginiana *grows much faster than* J. horizontalis.

Pack, D. A. 1925. DISPERSION OF LIPOIDS. Bot. Gaz. 79: 334-338.
As the tissues in redcedar's seeds grew active the lipoids became dispersed.

164 MORPHOLOGY

Agramont, F., Busking, R., Mitchell, J., and Enzinger, E. 1948. THE RED CEDAR. Mo. Bot. Gard. Bull. 36, p. 86-92.
Redcedar distribution in St. Louis (Mo.) area, wood color, and leaf variation.

Blake, S. F. 1910. NOTE ON JUNIPERUS HORIZONTALIS AND J. VIRGINIANA. Rhodora 12: 218.
New England redcedar fruit had one well-developed seed per berry and occasionally two seeds.

Jack, J. G. 1893. THE FRUCTIFICATION OF JUNIPERUS. Bot. Gaz. 18: 369-375.
J. virginiana *is simply annual-fruited, flowering about the latter part of April and maturing its fruit in the autumn of the same year.*

Pack, D. A. 1921. CHEMISTRY OF AFTER-RIPENING, GERMINATION, AND SEEDLING DEVELOPMENT OF JUNIPER SEEDS. Bot. Gaz. 72: 139-150.
Physiological and chemical changes in the fats during after-ripening, and the seedling development of redcedar.

U.S. Department of Agriculture. 1961. SEEDS. USDA Yearb. 1961, p. 556, 558.
Seed characteristics and other data.

165 PHYLOGENY, EVOLUTION. HEREDITY, GENETICS AND BREEDING, VARIATION

Fassett, N. C. 1943. THE VALIDITY OF JUNIPERUS VIRGINIANA VAR. CREBRA. Amer. J. Bot. 30: 469-477.
Var. crebra, *a narrow-crowned extreme, is concentrated on an area from eastern Pennsylvania to southern Maine, and on a second area following a series of moraines from northern Indiana to southeastern Wisconsin. It occurs in sporadic colonies in central New York, Tennessee, western Indiana, eastern Missouri, and probably elsewhere. Degree of acuteness of leaves has no taxonomic value. Seeds are a little less conspicuously pitted than in typical redcedar.*

Fassett, N. C. 1944. JUNIPERUS VIRGINIANA, J. HORIZONTALIS AND J. SCOPULORUM. I. THE SPECIFIC CHARACTERS. Bull. Torrey Bot. Club 71: 410-418.
Mass collections throughout much of the ranges of the species show that the variation within species is often more conspicuous than, but never as constant as, the variation between species, and that many of the distinguishing features are statistical in nature.

Fassett, N. C. 1944. JUNIPERUS VIRGINIANA, J. HORIZONTALIS AND J. SCOPULORUM. II. HYBRID SWARMS OF J. VIRGINIANA AND J. SCOPULORUM. Bull. Torrey Bot. Club 71: 475-483.
Where J. virginiana *grows by itself, and where* J. scopulorum *grows by itself, each species retains pure characteristics, except in areas of the western part of the* J. virginiana *range, where certain tendencies toward* J. scopulorum *suggest an ancient incursion of that species. Where the ranges meet, all recombinations of the characteristics of each occur in the individuals of one colony.*

Fassett, N. C. 1945. JUNIPERUS VIRGINIANA, J. HORIZONTALIS AND J. SCOPULORUM. IV. HYBRID SWARMS OF J. VIRGINIANA AND J. HORIZONTALIS. Bull. Torrey Bot. Club 72: 379-384.
J. virginiana *and* J. horizontalis *show no intergradation except where their ranges overlap. In the Driftless Area of Wisconsin the two species grow together, and in the same colony there may be various intermediates. The most common intermediate, described as var.* ambigens, *combines the habit of* horizontalis *with the foliage and fruit of* virginiana.

Hall, M. T. 1952. A HYBRID SWARM IN JUNIPERUS. Evolution 6: 347-366.
A hybrid swarm between J. ashei *and* J. virginiana *from Platt National Park in the Arbuckle Mountains of southern Oklahoma is illustrated and discussed.*

Hall, M. T. 1952. VARIATION AND HYBRIDIZATION IN JUNIPERUS. Ann. Mo. Bot. Gard. 39: 1-64.
Evidence for hybridization of J. ashei *and* J. virginiana *is the character recombinations in many trees found where these species grow together.*

Hall, M. T. 1955. COMPARISON OF JUNIPER POPULATIONS ON AN OZARK GLADE AND OLD FIELDS. Ann. Mo. Bot. Gard. 42: 171-194.
Variability within and between populations of the northern and Ozark races of junipers suggests three populations. The Glade population of the Ozark race is the most southwestern in affinity, and most closely resembles ashei. *The Cedar Hill population of the Ozark race is intermediate between Glade and typical redcedar and occurs on old fields which are in good condition. The Old Field population of the northern race, with a little mixing from the Ozark race, occurs on worn-out acidic and sandy lands in the vicinity of St. Louis and northeastward.*

Hall, M. T., and Carr, C. J. 1964. DIFFERENTIAL SELECTION IN JUNIPER POPULATIONS FROM THE BAUM LIMESTONE AND TRINITY SAND OF SOUTHERN OKLAHOMA. Butler Univ. Bot. Stud. 14: 21-40.
J. ashei *occupies the Baum limestone in nearly pure stands.* J. virginiana *occupies the Trinity sand on cleared, reverted land normally supporting a post oak-blackjack oak forest. Juniper populations on mixed talus sites are hybrid but closer to* ashei *than to* virginiana.

Mathews, A. C. 1939. THE MORPHOLOGICAL AND CYTOLOGICAL DEVELOPMENT OF THE SPOROPHYLLS AND SEED OF JUNIPERUS VIRGINIANA L. Elisha Mitchell Sci. Soc. J. 55: 7-62.
Chronological development of sporophylls and seed, beginning with staminate and ovulate cones.

Minckler, L. S., and Ryker, R. A. 1959. COLOR, FORM, AND GROWTH VARIATIONS IN EASTERN REDCEDAR. J. Forest. 57: 347-349.
Characteristics such as survival, winter-foliage color, form, and growth rate differ inherently according to location of seed source.

Ottley, A. M. 1909. THE DEVELOPMENT OF THE GAMETOPHYTES AND FERTILIZATION IN JUNIPERUS COMMUNIS AND JUNIPERUS VIRGINIANA. Bot. Gaz. 48: 31-46.
Cytological study.

Ross, J. G., and Duncan, R. E. 1949. CYTOLOGICAL EVIDENCES OF HYBRIDIZATION BETWEEN JUNIPERUS VIRGINIANA AND J. HORIZONTALIS. Bull. Torrey Bot. Club 76: 414-429.
Colonies of presumed hybrids were observed in the eastern fringe of the Driftless Area in Wisconsin, where the geographic ranges and habitats of these species overlap. A comparative study of the somatic chromosome complements of the species and several of the presumed hybrids revealed an unbalance in those of the hybrids, as evidenced by the presence of heterobrachial chromosomes without counterparts.

Sax, K., and Sax, H. J. 1933. CHROMOSOME NUMBER AND MORPHOLOGY IN THE CONIFERS. J. Arnold Arbor. 14: 356-375.
Chromosome counts of representative conifers, including redcedar. The materials studied were chiefly the female gametophyte tissue and the two meiotic divisions of the pollen mother cells.

Williamson, M. J. 1957. SILVICAL CHARACTERISTICS OF EASTERN REDCEDAR. USDA Forest Serv. Cent. States Forest Exp. Sta. Misc. Release 15, 14 p.
See entry below.

Williamson, M. J. 1965. EASTERN REDCEDAR (JUNIPERUS VIRGINIANA L.). *In* Silvics of Forest Trees of the United States, p. 212-216. USDA Agr. Handb. 271.
Habitat conditions, life history, and races. A northern form, var. crebra, *has slightly pitted seeds and a narrower crown than typical redcedar. No hybrids have been recognized, though there is some evidence of hybridization.*

17 SYSTEMATIC BOTANY

Fassett, N. C. 1945. JUNIPERUS VIRGINIANA, J. HORIZONTALIS AND J. SCOPULORUM. V. TAXONOMIC TREATMENT. Bull. Torrey Bot. Club 72: 480-482.
Detailed botanical descriptions, plus a key.

Kent, A. H. 1900. JUNIPERUS VIRGINIANA. *In* Veitch's Manual of the Coniferae, p. 192-196. London: James Veitch and Sons.
Botanical description with a list of varieties. Describes the geographical range but does not distinguish it from ranges of other junipers in the United States.

Little, E. L., Jr. 1949. IMPORTANT TREES OF THE UNITED STATES. *In* Trees, p. 763-814. USDA Yearb.
Key for U. S. trees.

Loudon, J. C., editor. 1829. AN ENCYCLOPEDIA OF PLANTS, p. 848-849. London: Longman, Rees, Orme, Brown, and Green.
History, use, propagation, and culture of Juniperus.

Loudon, J. C. 1838. J. VIRGINIANA L., THE VIRGINIAN JUNIPER, OR RED CEDAR. *In* The Trees and Shrubs of Britain. Vol. 4, p. 2495-2498. London: Longman, Orme, Brown, Green, and Longmans.
Special characteristics, varieties, geography and history, properties and uses, and propagation and culture.

Rehder, A. 1929. JUNIPERUS. *In* Bailey, L. H., Standard Cyclopedia of Horticulture. Ed. 2, p. 1726-1729. N.Y., London: Macmillan.
Botanical description of the genus with specific details on redcedar and its varieties.

Sargent, C. S. 1891-1902. JUNIPERUS VIRGINIANA. *In* Silva of North America. Vol. 10, p. 93-96. Boston: Houghton Mifflin.
See next entry.

Sargent, C. S. 1921. MANUAL OF THE TREES OF NORTH AMERICA (EXCLUSIVE OF MEXICO). 910 p. Boston: Houghton Mifflin.
Botanical description, distribution, and characteristics.

Swingle, C. F. 1937. A PROMISING NEW CEDAR FOR EROSION CONTROL. Soil Conserv. 3: 75-78.
Describes Ozark white cedar, J. ashei, *and compares identifying features with those of redcedar.*

18 PLANT ECOLOGY

181 MODE OF LIFE, AUTECOLOGY. SILVICULTURAL CHARACTER OF TREES

Arend. 1948. (114)

Arend. 1950. (114)

Afanasiev, M. 1949. CEDAR AND PINE AS FARM TREES FOR OKLAHOMA. Okla. Agr. Exp. Sta. Bull. 331, 18 p.
Survival of planted redcedar averaged about 80 percent. Best growth was on light soils and poorest on heavy soils. Cedars removed in thinning were graded for Christmas trees, with 13 percent classed as Grade A.

Agramont, Busking, Mitchell, and Enzinger. 1948. (164)

Bagley, W. T., and Read, R. A. 1960. SOME TEMPERATURE AND PHOTOPERIOD EFFECTS ON GROWTH OF EASTERN REDCEDAR SEEDLINGS. Iowa State J. Sci. 34: 595-601.
Supplemental light increased and sustained height growth of seedlings at a minimum temperature of 75° F. in the greenhouse and in environmental control chambers. Supplemental light increased height growth in early summer in an outdoor environment at Lincoln, Nebraska, but failed to sustain it after mid-August.

Bailey, L. H. 1933. THE CULTIVATED CONIFERS OF NORTH AMERICA, COMPRISING THE PINE FAMILY AND THE TAXADS. 404 p. N.Y.: Macmillan.
Botanical description of redcedar with information on cultivation and propagation and on insects, diseases, and injuries.

Beilmann, A. P., and Brenner, L. G. 1951. THE RECENT INTRUSION OF FORESTS IN THE OZARKS. Ann. Mo. Bot. Gard. 38: 261-282.
Redcedar is a most aggressive invader of grassland and run-down fields. The beginning of its invasion coincides roughly with reduced burning as a result of white settlement.

Broadfoot. 1951. (114)

Buchholz, J. T. 1930. THE OZARK WHITE CEDAR. Bot. Gaz. 90: 326-332.
Juniperus ashei *occurs in association with redcedar and superficially resembles it. However,* J. ashei *has a different habit of growth, its stem usually forking at or near the base, while redcedar is invariably single-stemmed. In general,* J. ashei *has a one-seeded fruit.*

Bunger, M. T., and Thomson, H. J. 1938. ROOT DEVELOPMENT AS A FACTOR IN THE SUCCESS OR FAILURE OF WINDBREAK TREES IN THE SOUTHERN HIGH PLAINS. J. Forest. 36: 790-803.
Roots of Asiatic elm, Osage-orange, redcedar, and black locust

were observed at depths of 24.5-27 feet. Survivals of these deep-rooted species averaged 68 percent, with redcedar showing highest survival.

Coile. 1933. (114)

Crawford, H. S., Jr. 1961. EASTERN REDCEDAR. *In* Deer Browse Plants of Southern Forests, p. 34-35. USDA Forest Serv. S. Forest Exp. Sta., New Orleans, La.
Site requirements, susceptibility to fire, growth habits of foliage and use by deer, use of fruit by wildlife, durability of wood, and aggressiveness on poor range and croplands.

Fletcher and Ochrymowych. 1955. (114)

Fox, W. S., and Soper, J. H. 1952. THE DISTRIBUTION OF SOME TREES AND SHRUBS OF THE CAROLINIAN ZONE OF SOUTHERN ONTARIO. Roy. Can. Inst. Trans. 29: 65-84.
This zone contains some tree species commonly found further south, among which is redcedar.

Fox, W. S., and Soper, J. H. 1953. THE DISTRIBUTION OF SOME TREES AND SHRUBS OF THE CAROLINIAN ZONE OF SOUTHERN ONTARIO. Roy. Can. Inst. Trans. 30: 3-32.
Redcedar commonly occurs on dry sandy or rocky ground, most frequently in soil over limestone. In certain areas it appears to be a primary arborescent species invading abandoned fields and pastures.

Harper, R. M. 1912. THE DIVERSE HABITATS OF THE EASTERN RED CEDAR AND THEIR INTERPRETATION. Torreya 12(7): 145-154.
The species occurs in a variety of habitats and is regarded by some authors as almost indifferent to environmental conditions. However, it is conspicuous by its absence in: (1) the great northern coniferous forests; (2) the common dry woods with oak and hickories, represented in all eastern States; (3) the prairies; and (4) the pine barrens, including the Pinus rigida *barrens of Long Island and New Jersey, the* P. palustris *barrens from North Carolina to Texas, and the* P. caribaea *barrens of south Florida. One primary character is apparent: the coniferous forests, dry woods, prairies, and pine barrens are regularly burned, while redcedar habitats are rarely or never visited by fire.*

Harper, H. J. 1940. RELATION OF CLIMATIC CONDITIONS, SOIL CHARACTERISTICS, AND TREE DEVELOPMENT IN THE SOUTHERN GREAT PLAINS REGION. Soil Sci. Soc. Amer. Proc. 5: 327-335.
Black locust, shortleaf pine, redcedar, and catalpa outgrew many other species on sandy soil containing less than 0.03 percent total nitrogen.

Hawley, F. M. 1937. RELATIONSHIP OF SOUTHERN CEDAR GROWTH TO PRECIPITATION AND RUNOFF. Ecology 18: 398-405.
In eastern Tennessee, cedar growth was more closely correlated with annual precipitation than with stream runoff.

Jackson, L. W. R. 1952. RADIAL GROWTH OF FOREST TREES IN THE GEORGIA PIEDMONT. Ecology 33: 336-341.
Redcedar began growth 80-89 days after January 1. It required 100-109 days to complete 50 percent of total growth, and the grand period of growth was from 200-209, both the longest periods of any species studied. Radial growth of redcedar and pine ceased in October, while hardwood species completed growth by late August.

Kellogg, R. S. 1905. FOREST BELTS OF WESTERN KANSAS AND NEBRASKA. USDA Forest Serv. Bull. 66, 44 p.
Redcedar is the only native conifer of Kansas and while widely distributed is seldom abundant. In Nebraska two Juniperus *species are recognized:* J. virginiana, *of the eastern and central portions of the State, and* J. scopulorum, *of the western part.*

Kent. 1900. (17)

King, D. B., Roberts, E. V., and Winters, R. K. 1949. FOREST RESOURCES AND INDUSTRIES OF MISSOURI. Mo. Agr. Exp. Sta. Res. Bull. 452, 89 p.
The greatest concentration of the cedar-hardwood type is in the White River watershed of the southwestern Ozarks. All together, the area covered by this type totals 492,000 acres, about 3 percent of Missouri's commercial forest area.

Krusekopf, H. H. 1963. FOREST SOIL AREAS IN THE OZARK REGION OF MISSOURI. Mo. Agr. Exp. Sta. Res. Bull. 818, 28 p.
The upland oak forest type prevails over the entire region, but shortleaf pine and redcedar sometimes are the most important species. Redcedar generally occupies dry uplands that have shallow soil and numerous limestone outcrops. Although it will grow on good soil, it usually is replaced by faster growing species. It is a common invader of glades and old prairie openings.

Kucera, C. L., Ehrenreich, J. H., and Brown, C. 1963. SOME EFFECTS OF FIRE ON TREE SPECIES IN MISSOURI PRAIRIE. Iowa J. Sci. 38(2): 179-185.
The effects of prairie fire on young trees of four broadleaved species and redcedar were observed under various burning conditions.

Lorio. 1963. (114)

Lorio and Gatherum. 1965. (114)

Loudon. 1829. (17)

Loudon. 1838. (17)

Lutz, H. J. 1928. TRENDS AND SILVICULTURAL SIGNIFICANCE OF UPLAND FOREST SUCCESSIONS IN SOUTHERN NEW ENGLAND. Yale Univ. Sch. Forest. Bull. 22, 68 p.
One of the three associations reported was redcedar-gray birch. It is classed as xerophytic and is commonly designated "old field" type, since it usually originates on abandoned farmland. Silviculturally the greatest value of this association lies in its beneficial influence on soil conditions.

McAtee, W. L. 1944. NURSE KILLERS. J. Forest. 42: 683.
Volunteer redcedars suppressed apple trees in an abandoned orchard.

McAtee, W. L. 1944. NURSE KILLERS. Nature 37: 146-147.
See entry above.

McCormack, M. L., and Korstian, C. F. 1963. CONVERSION OF POST OAK-BLACKJACK OAK TYPE TO PINE IN NORTH CAROLINA PIEDMONT. J. Forest. 61: 445-446.
Improvement cutting and planting with P. taeda *after clear-cutting both proved satisfactory. In the improvement cuts, redcedar was retained along with pines.*

McDermott, R. E., and Fletcher, P. W. 1955. INFLUENCE OF LIGHT AND NUTRITION ON COLOR AND GROWTH OF REDCEDAR SEEDLINGS. Mo. Agr. Exp. Sta. Res. Bull. 587, 15 p.
Growth responses were the same in one-third sunlight as in full light, but in one-tenth sunlight seedlings were stunted. Fertilizers

did not affect growth under any of three light intensities.

Mann, D. T., and Hays, R. S. 1948. EFFECT OF GRASS ON INVASION OF CEDAR. J. Soil and Water Conserv. 3: 49.
A Texas range in fair condition had 456 cedar trees per acre, while there were only 196 cedars per acre on range in good condition.

Martin, S. C., and Crosby, J. S. 1955. BURNING AND GRAZING ON GLADE RANGE IN MISSOURI. USDA Forest Serv. Cent. States Forest Exp. Sta. Tech. Pap. 147, 13 p.
Carrying capacities of many glade range areas in Missouri are being reduced by the spread of redcedar; Burning cannot be recommended for control of redcedar; the fires damage forage and cover plants. Cutting or chemical control is effective.

Meade, F. M. 1955. CONVERTING LOW-GRADE HARDWOOD STANDS TO CONIFERS IN THE ARKANSAS OZARKS. Ark. Agr. Exp. Sta. Bull. 551, 26 p.
Shortleaf pine and redcedar were planted under four conditions of hardwood overstory. Cedar survived less well than pine and grew much more slowly. Under no condition of overstory tested was the cedar able to compete with the hardwoods.

Michaux, F. A. 1857. THE NORTH AMERICAN SYLVA. Vol. III, 180 p. Philadelphia, Pa.: D. Rice and A. N. Hart.
Distribution of redcedar in the United States. The author reports its occurrence in Oregon but obviously was unaware of species differences that were later documented.

Minckler, L. S. 1953. POOR OAK SITES MAY GROW GOOD PINE. USDA Forest Serv. Cent. States Forest Exp. Sta. Tech. Pap. 134, 6 p.
On clearcut areas cedars were planted in groups of about 25 trees each. Approximately one-third remained after 3 years. Most were thrifty, but required release.

Mohr, C. 1901. PLANT LIFE OF ALABAMA. Contrib. U. S. Nat. Herb. 6: 1-49.
Cedar glades occur on limestone strata which comprise the lower terraces of the higher ridges. Almost bare of soil, these rugged grounds support redcedar; few other trees gain a foothold. Trees grow to 50-75 feet in height, and 15-24 inches in diameter. The large trees average from 140-175 years of age. Redcedar reaches its highest perfection on gentle slopes with deep soil and in narrow valleys with damp, rich soil.

Munns, E. N. 1938. THE DISTRIBUTION OF IMPORTANT FOREST TREES OF THE UNITED STATES. USDA Misc. Publ. 287, 176 p.
Redcedar is mapped on page 63.

Palmer, E. J. 1921. THE FOREST FLORA OF THE OZARK REGION. J. Arnold Arbor. 2: 216-232.
Physiography of the Ozark Uplift and the associated vegetation. Redcedar occurs almost throughout the area but is abundant only along the bluffs.

Read, R. A., and Bagley, W. T. 1967. RESPONSE OF TREE SEEDLINGS TO EXTENDED PHOTOPERIODS. USDA Forest Serv. Res. Pap. RM-30, 16 p. Rocky Mtn. Forest Exp. Sta., Fort Collins, Colo.
Redcedar seedlings were grown under 14- and 24-hour photoperiods, and under 14-hour photoperiods with one and two light interruptions in the dark period. Seedlings were usually tallest and heaviest under continuous light, intermediate under the interrupted dark. Long photoperiods stimulated top growth more than root growth, but did not affect field survival.

Sargent, C. S. 1895. THE RED CEDAR. Gard. and Forest 8: 61-62.
Characteristics, distribution, uses, and culture.

Sargent. 1896. (17)

Shirley, H. L. 1945. LIGHT AS AN ECOLOGICAL FACTOR AND ITS MEASUREMENT. Bot. Rev. 11: 497-532.
Pioneer woody species such as redcedar rarely cast shade dense enough to preclude invasion of other species, but their shade and root competition may markedly reduce the growth of all but the most tolerant species.

Spurr. 1940.(114)

Starker, T. J. 1932. FIRE RESISTANCE OF THE TREES OF THE NORTHEAST UNITED STATES. Forest Worker 3(3): 8-9.
Redcedar was ranked twentieth, with only northern white cedar and balsam fir being considered more susceptible.

Steyermark, J. A. 1940. STUDIES OF THE VEGETATION OF MISSOURI. I. NATURAL PLANT ASSOCIATIONS AND SUCCESSION IN THE OZARKS OF MISSOURI. Field Mus. Natur. Hist., Chicago Bot. Ser. 9(5): 349-475.
A redcedar subclimax occurs over an eroded limestone substratum eventually covered by a sugar maple-white oak association.

USDA Forest Service. 1948. WOODY PLANT SEED MANUAL. USDA Misc. Publ. 654, 416 p.
Specific information on distribution and use; seeding habits; collection, extraction, and storage; germination; and nursery and field practice.

Vimmerstedt, J. P. 1968. ROOT CATION-EXCHANGE CAPACITY AND THE MINERAL NUTRITION OF EASTERN WHITE PINE AND EASTERN REDCEDAR. Soil Sci. Soc. Amer. Proc. 32: 289-292.
Foliage of redcedar had a lower ratio of monovalent to divalent cations than did white pine. The author concluded that root cation exchange capacity did not cause the difference in cation ratios and that cation ratio in the soil had a strong influence on the ratio in trees.

White, L. L. 1907. PRODUCTION OF RED CEDAR FOR PENCIL WOOD. USDA Forest Serv. Circ. 102, 19 p.
The wood and its uses, together with the species' range, silvical characteristics, and reproduction. Also describes logging methods and proposals for management.

Wherry. 1920. (114)

Williamson. 1965. (165)

Wyman, D. D. 1947. GIANT RED CEDARS—VIRGINIA VS. BAY STATE. Horticulture 25: 74.
Dimensions of several redcedars of exceptional size.

Yeager, A. F. 1935. ROOT SYSTEMS OF CERTAIN TREES AND SHRUBS GROWN ON PRAIRIE SOILS. J. Agr. Res. 51: 1085-1092.
In North Dakota, in an area with 22.4 inches of rainfall per year, planted redcedars had roots up to 22 feet long at age 25 years. The greatest depth of roots was over 12 feet.

182 SYNECOLOGY. PLANT SOCIOLOGY (GENERAL, PRINCIPLES, AND METHODS)

Albertson, F. W., and Weaver, J. E. 1945. INJURY AND DEATH OR RECOVERY OF TREES IN PRAIRIE CLIMATE. Ecol. Monogr. 15: 395-433.
Redcedar is limited to steep north-facing slopes with a mantle

of soil at their bases.

Arend. 1948. (114)

Arend. 1950. (114)

Bard, G. E. 1952. SECONDARY SUCCESSION ON THE PIEDMONT OF NEW JERSEY. Ecol. Monogr. 22: 195-215.
Redcedar invades abandoned fields within the first few years and remains the dominant vegetation for 60 years or more.

Beilmann and Brenner. 1951. (181)

Fox and Soper. 1952. (181)

Fox and Soper. 1953. (181)

Freeman. 1933. (116)

Harper, R. M. 1926. THE CEDAR GLADES OF MIDDLE TENNESSEE. Ecology 7: 48-54.
Cedar glades of middle Tennessee are a unique type of vegetation. Although they have been damaged nearly everywhere by lumbering and grazing, there is no immediate prospect of their being destroyed by cultivation.

Krusekopf. 1963. (181)

Lutz. 1928. (181)

Oosting, H. J. 1942. AN ECOLOGICAL ANALYSIS OF THE PLANT COMMUNITIES OF PIEDMONT, NORTH CAROLINA. Amer. Midland Natur. 28: 1-126.
Since redcedar grows in every habitat and is associated with every plant community it can have no bearing on the trend of events (succession). Infrequently it may be the first tree pioneer in old fields. It is never a dominant, never a dependent, and rarely in significant numbers.

Palmer. 1922. (181)

Quarterman, E. 1950. ECOLOGY OF CEDAR GLADES. I. DISTRIBUTION OF GLADE FLORA IN TENNESSEE. Bull. Torrey Bot. Club 77: 1-9.
Cedar glades cover about 5 percent of the Central Basin of middle Tennessee. Open glades and woods dominated by redcedar are the most typical communities of the region.

Quarterman, E. 1950. MAJOR PLANT COMMUNITIES OF TENNESSEE CEDAR GLADES. Ecology 31:234-254.
Cedar glades occur in Lebanon limestone, a dolomitic rock of Ordovician Age.

Read. 1950. (114)

Read. 1952. (114)

Steyermark. 1940. (181)

2. SILVICULTURE

22 SILVICULTURAL SYSTEMS. CONSTITUTION AND COMPOSITION OF STANDS

Arend, J. L. 1946. GROWING EASTERN RED CEDAR ON THE FARM. S. Lumberman 173 (2177): 240, 242, 244.
See entry below.

Arend, J. L. 1947. AN EARLY EASTERN RED CEDAR PLANTATION IN ARKANSAS. J. Forest. 45: 358-360.
A redcedar plantation was established with wildling stock in 1902. After 44 years the average survival was 85 percent and the 1,027 trees were estimated to contain 5,866 fence posts with a value of approximately $800. Under intensive management total returns would have been much larger.

Read, R. A. 1958. THE GREAT PLAINS SHELTERBELT IN 1954. Univ. Nebr. Exp. Sta. Bull. 441, 125 p.
Despite suppression by trees, damage by livestock, competition from sod, and dry, shallow soil, initial survival of redcedar was high and subsequent losses were slight.

23 REGENERATION AND FORMATION OF STANDS

231 NATURAL REGENERATION

George. 1939. (136)

Parker. 1951. (136)

Phillips. 1910. (136)

232 ARTIFICIAL REGENERATION

Collection, cleaning, storage, and stratification of redcedar seed. Nursery techniques.

Anonymous. 1938. JUNIPER SEEDS. Amer. Nurseryman 68(11): 18.

Anonymous. 1946. RED CEDAR GERMINATION. Amer. Nurseryman 84(12): 18-19.
To insure rapid and satisfactory germination the waxy coat must be removed by repeated soakings in alcohol and the seed stratified overwinter in moist sand and peat at about 40°F. Seed should be sown around March 15 to April 1.

Afanasiev, M. 1948. PRELIMINARY STUDY OF TREE PLANTATIONS IN OKLAHOMA: RELATIVE SURVIVAL BY SPECIES AND FACTORS AFFECTING SURVIVAL. Okla. Agr. Exp. Sta. Tech. Bull. T-29, 27 p.
In north-central Oklahoma, six of 14 redcedar plantings had between 80 and 98 percent survival. Adverse weather caused the failure of several plantations. Growth was slow, averaging about 1 foot per year. In western Oklahoma loss was under 10 percent in seven out of 10 plantings, but growth was slow here also. In eastern Oklahoma three of five plantings were complete failures but the surviving plantations were of good health and vigor.

Afanasiev. 1949. (181)

Afanasiev, M. 1949. A STUDY OF RED CEDAR PLANTATIONS IN NORTH CENTRAL OKLAHOMA. Okla. Agr. Exp. Sta. Tech. Bull. T-34, 16 p.
Cedar plantations were established and maintained on sites commonly classed as poor. Survival over 4 years averaged 80 percent; 1-1 seedlings survived better than 1-2 stock. Direct seeding failed in two attempts.

Afanasiev, M. 1955. STORAGE OF AFTERRIPENED SEED OF EASTERN REDCEDAR. USDA Forest Serv. Tree Plant. Notes 21, p. 28-30.
Afterripening and germination can be arrested by storing afterripened but ungerminated seed at +15° to +20° F.

Germinating seed is injured by subfreezing temperature and does not resume growth later.

Afanasiev, M., and Cress, M. 1942. PRODUCING SEEDLINGS OF EASTERN RED CEDAR (JUNIPERUS VIRGINIANA L.). Okla. Agr. Exp. Sta. Bull. B-256, 21 p.
Description of nursery practices, including collecting, storing, and cleaning seed; treating seed to insure germination; and growing seedlings from afterripened seed.

Afanasiev, M., Engstrom, A., and Johnson, E. W. 1959. EFFECTS OF PLANTING DATES AND STORAGE ON SURVIVAL OF EASTERN RED CEDAR IN CENTRAL AND WESTERN OKLAHOMA. Okla. Agr. Exp. Sta. Bull. B-527, 19 p.
Planting dates from November to May and fresh-lifted and stored seedlings were compared for 3 successive years. Plantings made between mid-December and mid-March survived best. There was little difference between freshly lifted stock and that stored for 7 days. Weather and soil conditions at time of planting had a strong effect. Survivals ranged from 40 to 90 percent.

Arend. 1946. (22)

Arend. 1947. (22)

Bailey. 1933. (181)

Barton, L. V. 1952. GERMINATION OF SEEDS OF JUNIPERUS VIRGINIANA L. Contrib. Boyce Thompson Inst. 16: 387-393.
Seeds are dormant and require 3 months at 5^{o} C. to afterripen; 1^{o} C. is less effective and 10^{o} is totally ineffective. Seedcoats may be made permeable (to improve stratification) by exposure to moisture at approximately 25^{o} C. for 2-8 weeks, or by soaking for 30 minutes in concentrated sulphuric acid.

Buckley, A. R. 1957. THE GRAFTING OF JUNIPERUS VIRGINIANA VARIETIES ON UNROOTED CUTTINGS. Plant Propagators Soc. Proc. 7: 81-83.
Cutting-graft combinations are a quick means of ascertaining the stocks which may be used for grafting in the ordinary way.

Caroselli, N. E. 1957. JUNIPER BLIGHT AND PROGRESS ON ITS CONTROL. USDA Plant Dis. Rep. 41: 216-218.
Juniper blight, caused by the fungus Phomopsis juniperovora *Hahn, is a serious disease of 1- and 2-year-old trees. Several chemicals are effective.*

Chadwick, L. C. 1946. ON AND OFF THE NURSERY—SEEDS OF RED CEDAR. Amer. Nurseryman 83(9): 10.
The waxy seedcoat and a resting condition of the embryo delay germination of redcedar. The coat can be removed by soaking for several hours in alcohol or by pouring warm water over the seeds and bringing the water to a boil; this process should be repeated three times. Recommends stratification in moist sand or peat at 40^{o} F. for 3 months.

Cotrufo, C. 1962. PRETREATMENT OF EASTERN WHITE PINE SEED. USDA Forest Serv. Southeast. Forest Exp. Sta. Res. Note 176, 2 p.
Citric-acid treatments were effective on redcedar seed.

Cotrufo, C. 1963. CITRIC ACID STIMULATES SEED GERMINATION. Abstr. Plant Physiol. 38 (Suppl.): 14.
See next entry.

Cotrufo, C. 1963. STIMULATION BY CITRIC ACID OF GERMINATION OF EASTERN RED CEDAR (JUNIPERUS VIRGINIANA L.). Nature 199: 92-93.
Pretreatment with citric acid increases both speed and total germination. The recommended treatment is to soak seed 4 days in a 10,000 p.p.m. solution of citric acid, and then stratify for 90 days.

Davis, W. C., Young, G. Y., Latham, D. H., and Hartley, C. 1938. DISEASES OF CONIFERS IN FOREST NURSERIES. USDA Bur. Plant Ind., 63 p.
Describes two types of diseases found on redcedar in the nursery: cedar blight (Phomopsis juniperovora) *and cedar rusts* (Gymnosporangium *spp.). Gives information on control and precautionary measures.*

Dayharsh, V. J. 1934. STRATIFICATION VS. SCARIFICATION FOR CEDAR SEED. USDA Forest Serv. Plant. Quart. 3: 15-16.
Recommends scarification of the coat to improve germination of freshly gathered seed.

Dean, G. A. 1942. CONTROL OF THREE RED CEDAR SCALES. Kans. Hort. Soc. 6: 80-82.
Life histories and controls for three scale insects: redcedar scale, Cryptaspidiotus shasta; *European fruit lecanium,* Lecanium corni *(or* L. fletcheri); *and redcedar mealy bug,* Pseudococcus juniperi.

Deters, M. E., and Schmitz, H. 1936. DROUGHT DAMAGE TO PRAIRIE SHELTER BELTS IN MINNESOTA. Minn. Agr. Exp. Sta. Bull. 329, 28 p.
Redcedar and Rocky Mountain juniper both appear to be drought-resistant. Although they grow somewhat slowly, they are excellent for border rows and low windbreaks and are fairly long-lived under prairie conditions.

Doran, W. L. 1952. EFFECTS OF TREATING CUTTINGS OF WOODY PLANTS WITH BOTH A ROOT-INDUCING SUBSTANCE AND A FUNGICIDE. Amer. Soc. Hort. Sci. Proc. 60: 487-491.
Combined hormone and fungicidal treatment resulted in a maximum of 83 percent rooting of redcedar cuttings in 200 days.

Ealy, R. P. 1960. THE EFFECT OF A COMBINED FUNGICIDE-HORMONE TREATMENT ON THE PROPAGATION OF REDCEDAR (JUNIPERUS VIRGINIANA L.) BY CUTTINGS. Okla. State Univ. Processed Ser., 5 p.
The combination of a fungicide and a hormone produced the greatest percentage of rooting, but maximum success was only 20 percent and root systems were poor.

Eastman, R. E. 1911. CARE OF THE SEED OF RED CEDAR. Forest. Quart. 9: 173-174.
Recommends stratification of seeds for approximately 17 months in sandboxes buried in soil and mulched with leaves, straw, or grass.

Elk, B. C. M. van. 1965. [POTTING SOIL FOR STOCKS.] (Extr.) Jaarb. Proefsta. Boomkwek. Boskoop. 1964: 74-75.
Table shows relative success in grafting cultivars onto redcedar stocks grown in various mixtures of peat and sand.

Engstrom, A. 1950. MULCHING SEEDBEDS WITH CELLOPHANE. J. Forest. 48: 283.
Cellophane, in conjunction with burlap on wire netting, was used to mulch nursery seedbeds of redcedar.

Engstrom, A. 1955. POLYETHYLENE FILM FOR SEEDBED MULCH. USDA Forest Serv. Tree Plant. Notes 21, p. 26-27.
Polyethylene sheets were a satisfactory mulch for cedar seedbeds. Sowing techniques are as follows: in early December clean,

dry, untreated seed is sown on conventional seedbeds and lightly covered (1/8 to 1/4 inch thick) with sawdust. After watering, polyethylene film is laid over the beds and covered with burlap. All covering is anchored.

Engstrom, H. E., and Stoeckeler, J. H. 1941. NURSERY PRACTICE FOR TREES AND SHRUBS SUITABLE FOR PLANTING ON THE PRAIRIE PLAINS. USDA Misc. Publ. 434, 159 p.
Recommends redcedar for planting in Texas, Oklahoma, Kansas, Nebraska, South Dakota, and southern portions of North Dakota.

Garin, G. I. 1963. CHRISTMAS TREE PRODUCTION IN EASTERN REDCEDAR AND ARIZONA CYPRESS PLANTATIONS. Ala. Agr. Exp. Sta. Circ. 145, 13 p.
In a plantation in central Alabama, both species required some pruning and considerable clipping to shape. Customers preferred Arizona cypress to redcedar for its color and because it was less prickly. It was harvestable earlier and more easily grown from stumps, but survival was slightly poorer.

Garin, G. I., and Moore, J. C. 1951. CHRISTMAS TREE PRODUCTION . Ala. Agr. Exp. Sta. Circ. 92, 15 p.
*In central Alabama seven species were compared for growth and desirability as Christmas trees. Arizona cypress (*Cupressus arizonica *Greene) ranked first and redcedar second.*

George, E. J. 1965. METHODS OF IMPROVING CONIFER SURVIVALS. USDA Forest Serv. Tree Plant. Notes 71, p. 6-13.
Redcedar was planted on 82 plots in the northern Great Plains. Survival averaged 80-100 percent on 65 plots and 50-79 percent on the other 17. The stock required careful handling from the time of lifting in the nursery.

Gerbracht, J. H. 1937. EVERGREENS FROM SEED. N. and S. D. Hort. 10: 46, 48.
Procedures for producing redcedar seedlings from seed.

Gruschow, G. F. 1948. A TEST OF METHODS OF PLANTING EASTERN REDCEDAR IN THE VIRGINIA PIEDMONT. J. Forest. 46: 842-843.
Seven methods of planting were compared but all yielded disappointingly low survivals at the end of 4 years.

Harper. 1940. (181)

Heit, C. E. 1955. THE EXCISED EMBRYO METHOD FOR TESTING GERMINATION QUALITY OF DORMANT SEED. Assoc. Offic. Seed Anal. Proc. 45: 108-117.
The method was successful on Juniperus *spp.*

Hodges, C. S., Jr. 1962. DISEASES IN SOUTHEASTERN FOREST NURSERIES AND THEIR CONTROL. USDA Forest Serv. Southeast. Forest Exp. Sta., Sta. Pap. 142, 16 p.
Two diseases of redcedar nursery seedlings, Phomopsis juniperovora *and* Cercospora sequoiae, *with recommendations for chemical control.*

Hodges, C. S., and Green, H. J. 1960. SURVIVAL IN THE PLANTATION OF EASTERN REDCEDAR SEEDLINGS INFECTED WITH PHOMOPSIS JUNIPEROVORA IN THE NURSERY. Phytopathology 50: 639.
Seedlings showing any symptoms of Phomopsis blight in the nursery should be culled.

Hodges, C. S., and Green, H. J. 1961. SURVIVAL IN THE PLANTATION OF EASTERN REDCEDAR SEEDLINGS INFECTED WITH PHOMOPSIS BLIGHT IN THE NURSERY. USDA Plant Dis. Rep. 45: 134-136.
When blighted nursery seedlings were outplanted, their survival after two growing seasons was 24 to 30 percent.

Jelly, M. E. 1937. EASTERN RED CEDAR. J. Forest. 35: 865-867.
Describes the importance of redcedar in Tennessee and summarizes research on hastening seed germination.

Keen, R. A. 1951. CUTTING GRAFTS OF JUNIPER: A PROGRESS REPORT. Amer. Soc. Hort. Sci. Proc. 58: 298-300.
Cutting-grafts, in which the stock was an unrooted cutting, were used for the propagation of junipers. While the percentage of successes was low, the process was considered satisfactory.

Lorio. 1963. (114)

Lorio and Gatherum. 1965. (114)

Loudon. 1829. (17)

Loudon. 1838. (17)

McCormack and Korstian. 1963. (181)

Mallison, J. W. 1926. GRAFTING RHODODENDRONS, AND CHOICE CONIFERS IN WINTER. III. (JUNIPERS). Fla. Exch. 61: 749, 751.
Procedures and requirements for grafting junipers, including use of redcedar for understock, need for healthy stocks, cutting techniques on scions, and shade requirements.

Maple, W. R. 1965. FOREST SPECIES COMPARED IN OZARK PLANTATIONS. USDA Forest Serv. Res. Note SO-28, 2 p. S. Forest Exp. Sta., New Orleans, La.
Redcedars planted on loamy sand in north Arkansas were 19 feet tall and 3.6 inches in diameter at age 15 years. The seedlings were in low vigor when planted, and survivals ranged from 17 to 44 percent.

Meade, F. M. 1951. FOREST PLANTATIONS IN ARKANSAS. Ark. Agr. Exp. Sta. Bull. 512, 50 p.
In a 9-year-old plantation on a mountaintop field in Pope County, mean annual height growth was 1.2 feet, and survival was 90 percent.

Meade, F. M. 1954. GROWTH AND SURVIVAL OF SHORT LEAF PINE AND EASTERN REDCEDAR IN NORTH ARKANSAS. Ark. Farm Res. 3(2): 4.
After three growing seasons, survival was best where planting sites had been prepared by removal of competing vegetation from areas 2 feet square. There was no appreciable difference in height growth.

Meade. 1955. (181)

Meines, M. K. 1965. JUNIPER GERMINATION SIMPLIFIED. USDA Forest Serv. Tree Plant. Notes 70, p. 6-7.
Recommends sowing fresh seed from berries gathered in September. The seed usually germinates the following spring. Stored seed needs long and variable periods of stratification.

Minckler. 1953. (181)

Minckler, L. S., and Downs, A. A. 1946. MACHINE AND HAND DIRECT SEEDING OF PINE AND CEDAR IN THE PIEDMONT. USDA Forest Serv. Southeast. Forest Exp. Sta. Tech. Note 67, 10 p.
Suggests storing redcedar seed for 1 year and sowing it, after stratification, in the fall. Seed should be sown in drills and covered with 1/4 inch of soil. For machine sowing in furrows, suggests three viable seeds per linear foot, with vegetative mulch.

Moore, J. C. 1945. CHRISTMAS TREE PRODUCTION. Ala. Agr. Exp. Sta. Circ. 92, 15 p.
Arizona cypress and redcedar give promise as Christmas tree selections.

Munns, E. N., and Stoeckeler, J. H. 1946. HOW ARE THE GREAT PLAINS SHELTERBELTS? J. Forest. 44: 237-257.
Considering survival, growth, and adaptation to a wide variety of conditions, redcedar and Rocky Mountain juniper are by far the outstanding conifers in the Plains region.

Newcomer, F. R. 1936. CEDAR FOR GREAT PLAINS PLANTING. USDA Forest Serv. Plant. Quart. 5: 27-28.
Stratification (in boxes buried in the ground for several months) and scarification both resulted in dependable germination. Plantation survivals ranged from failure to 87 percent.

Pack, D. A. 1921. AFTER-RIPENING AND GERMINATION OF JUNIPERUS SEEDS. Bot. Gaz. 71: 32-60.
Describes afterripening, germination, and seedling development, as well as some of the chemical and physiological changes that these processes involve. Because redcedar has a dormant embryo that must afterripen before germination, a number of treatments normally used to force germination in other species were ineffective.

Parker, J. 1950. GERMINATION OF EASTERN REDCEDAR SEEDS. J. Forest. 48: 255-256.
Exposure of seeds to 41° F. for 2-3 months appears essential for germination. Ordinarily, sufficient exposure will be obtained when seeds are planted under natural conditions in the autumn. Scarification speeded but did not increase germination.

Parker, J. 1950. THE EFFECTS OF FLOODING ON THE TRANSPIRATION AND SURVIVAL OF SOME SOUTHEASTERN FOREST TREE SPECIES. Plant Physiol. 25: 453-460.
Redcedar, red oak, loblolly pine, white oak, and swamp chestnut oak all showed a similar response to flooding.

Parker, J. 1952. ESTABLISHMENT OF EASTERN REDCEDAR BY DIRECT SEEDING. J. Forest. 50: 914-917.
Seedling survival was better where the litter had been removed than where it had been left in place, and better under an open canopy than a closed.

Peterson, G. W. 1965. FIELD SURVIVAL AND GROWTH OF PHOMOPSIS-BLIGHTED AND NON-BLIGHTED EASTERN REDCEDAR PLANTING STOCK. USDA Plant Dis. Rep. 49: 121-123.
Blighted stock, even if only slightly damaged, should not be outplanted.

Peterson, G. W., Nuland, D., and Weihing, J. L. 1960. TEST OF FOUR FUNGICIDES FOR CONTROL OF CEDAR BLIGHT. USDA Plant Dis. Rep. 44: 744-746.
Redcedar seedlings in an eastern Nebraska nursery were treated with various formulations to control cedar blight (Phomopsis juniperovora). *Puratized Agricultural Spray gave superior blight control in 1-0 and 2-0 redcedar. The amount of blight in 3-0 seedling was very light, and was unaffected by spraying.*

Peterson, G. W., Sumner, D. R., and Norman, C. 1965. CONTROL OF PHOMOPSIS BLIGHT OF EASTERN REDCEDAR SEEDLINGS. USDA Plant Dis. Rep. 49: 529-531.
Blight in an eastern Nebraska nursery was controlled by Puratized Agricultural Spray, at concentrations of 1, 1-1/2 or 2 pints per 100 gallons of water. Control was not improved by addition of two spreader-stickers.

Poulsen, W. G. 1965. SIMAZINE WEED CONTROL. USDA Forest Serv. Tree Plant. Notes 73, p. 1-2.
In conifer transplant beds Simazine achieved 77-100 percent control of weeds, and reduced costs of weeding by 50-75 percent.

Read and Bagley. 1967. (181)

Sargent. 1895. (181)

Slagg, C. M., and Wright, E. 1944. THE CONTROL OF PHOMOPSIS BLIGHT IN RED CEDAR SEEDBEDS. Kans. Hort. Soc. Trans. 1942-43: 76-79.
Description of the blight, incidence of infection in relation to thickness of stand and method of watering, and control by fungicidal sprays, roguing, and other sanitary measures.

Stiles, E. H., and Melchers, L. E. 1935. THE DROUGHT OF 1934 AND ITS EFFECT ON TREES IN KANSAS. Kans. Acad. Sci. Trans. 38: 107-127.
Of the various species of street trees in Manhattan, redcedar was the most drought-hardy, with 96 percent surviving. In tree nurseries, also, redcedar withstood dry weather to a marked degree.

Stoeckeler, J. H. 1946. ALKALI TOLERANCE OF DROUGHT-HARDY TREES AND SHRUBS IN THE SEED AND SEEDLING STAGE. Minn. Acad. Sci. Proc. 14: 79-83.
Redcedar had one of the lowest alkali tolerances of the 20 species tested.

Stoeckeler, J. H. 1966. TREES FOR THE COULEE REGION. Wis. Conserv. Bull. 31 (1): 14-16.
In 1961 and 1962, some 40,000 trees of 13 species (both conifers and hardwoods) were established on abandoned farmland and pastures on steep slopes in the Coulee Region of southwestern Wisconsin. On a steep, exposed, limestone-strewn, prairie-soil slope that had never carried high forest, redcedar made an outstanding showing.

Stoeckeler, J. H., and Baskin, L. C. 1937. THE DENBIGH DISC SCARIFIER, A NEW METHOD OF SEED TREATMENT. J. Forest. 35: 396-398.
The machine greatly reduces time required for scarification of redcedar seed.

Stoeckeler, J. H., and Jones, G. W. 1957. FOREST NURSERY PRACTICE IN THE LAKE STATES. USDA Agr. Handb. 110, 124 p.
Summary table—for seed collection, extraction, and nursery seeding of redcedar. Discusses treatment for cedar blight and cedar apple rust.

Stoeckeler, J. H., and Slabaugh, P. E. 1965. CONIFER NURSERY PRACTICE IN THE PRAIRIE-PLAINS. USDA Agr. Handb. 279, 93 p.
Nursery practices for growing redcedar seedlings. Includes data on collection and handling of seed, preparation and sowing, care during germination and seedling stage, and nursery protection from insects and diseases.

Strong, F. C., and Cation, D. 1940. CONTROL OF CEDAR RUST WITH SODIUM DINITROCRESYLATE. Phytopathology 30: 983.
A 1-percent solution of sodium dinitrocresylate was applied as a single spray in May, when rust galls were showing signs of activity. It inhibited telial column extension and teliospore germination from galls of Gymnosporangium globosum *and* G. juniperi-virginianae.

Strong, F. C., and Klomparens, W. 1955. THE CONTROL OF

RED CEDAR-APPLE AND HAWTHORN RUSTS WITH ACTIDIONE. USDA Plant Dis. Rep. 39: 569.
Germination of the teliospores and resultant sporidia were prevented by a single application of cycloheximide at 100 p.p.m. The spray was applied to the galls. No injury to the foliage resulted.

Strong, F. C., and Rasmussen, E. J. 1939. SPRAY TRIALS ON ORNAMENTAL RED CEDARS. Mich. Agr. Exp. Sta. Quart. Bull. 21, p. 277-279.
Trees were sprayed with wettable sulphur, alone and with three stickers, to determine whether this fungicide could be used without injury to the foliage and whether the stickers were of value. No conclusions were drawn about the sulphur, but soybean oil (as a sticker) injured the foliage.

Sudworth, G. B. 1900. THE FOREST NURSERY: COLLECTION OF TREE SEEDS AND PROPAGATION OF SEEDLINGS. USDA Div. Forest. Bull. 29, 63 p.
Collecting and storing seed, sowing and care in the nursery. Specific information on redcedar includes number of seeds per ounce, approximate seedling height at 1 year, geographical range of species, character of seed, time to collect, and storage methods.

USDA Forest Service. 1948. (181)

Webster, C. B., and Ratliffe, G. T. 1942. A METHOD OF FORCING QUICK GERMINATION OF JUNIPERUS VIRGINIANA L. SEED. J. Forest. 40: 268.
Satisfactory quick germination was achieved by depulping seed with a hammermill in December, storing dry until February, soaking in a lukewarm sodium-lye solution for 20 minutes, washing in cool water for 1 hour, soaking in fresh water for 8 hours, and stratifying in sand from February 4 to March 29.

Wells, C. G. 1961. UNDERPLANTING TESTS IN PINE STANDS. USDA Forest Serv. Southeast. Forest Exp. Sta. Res. Notes 160, 2 p.
Redcedar was underplanted and fertilized in a recently thinned 19-year-old loblolly pine plantation. Survival ranged from 34 to 44 percent, much poorer than for hardwood species in similar trials.

Westervelt, D. D. , and Keen,R. A. 1960. CUTTING GRAFTS OF JUNIPERS. II. STIONIC EFFECTS. Amer. Soc. Hort. Sci. Proc. 76: 637-643.
Cutting grafts and grafts on potted redcedar stock were compared for compatibility, and survival.

Wilde. 1946. (114)

Wright, E., and Wells, H. R. 1948. TESTS ON THE ADAPTABILITY OF TREES AND SHRUBS TO SHELTERBELT PLANTING ON CERTAIN PHYMATOTRICHUM ROOT ROT INFESTED SOILS OF OKLAHOMA AND TEXAS. J. Forest. 46: 256-262.

Redcedar and Rocky Mountain cedar are recommended for all shelterbelts on soils infested with root rot. They have high resistance to the rot and live long even under adverse climatic conditions.

Wycoff, H. B. 1961. REDCEDAR SEEDING PRACTICES. USDA Forest Serv. Tree Plant. Notes 47, p. 3-4.
Standa:d procedures at the Mason State Tree Nursery in central Illinois.

24 TENDING OF STANDS AND TREES

Afanasiev. 1949. (181)

McCormack and Korstian. 1963. (181)

Maple, W. R. 1957. REDCEDAR GROWTH IN ARKANSAS OZARKS. USDA Forest Serv. S. Forest Exp. Sta. S. Forest. Notes 112.
Improvement cutting and hardwood control stimulated a stand of 161 cubic feet per acre to grow at the rate of 10 percent annually. Annual growth was computed to be worth $3.69 per acre.

Miller, J. K. 1943. FOMES ANNOSUS AND REDCEDAR. J. Forest. 41: 37-40.
Redcedar in the Southeastern United States may be attacked by the polypore Fomes annosus. *This fungus kills trees regardless of age and causes a pocket-rot of butt logs. Cedars competing for light with pines or hardwoods are susceptible. Silvicultural practices that lessen or eliminate competition for light greatly reduce losses from this disease.*

Minckler. 1953. (181)

Parker. 1951. (13)

26 COMBINATIONS OF FORESTRY WITH AGRICULTURE AND PASTORAL HUSBANDRY

Cromie, G. A. 1944. FIELDS OF RED CEDAR. Conn. Woodlands 9: 23-25.
In Connecticut, cedar can be one of the most profitable tree crops on farms edges. Discusses the variety of products and the number of salable trees that can be grown per acre.

George, E. J. 1953. 31-YEAR RESULTS IN GROWING SHELTERBELTS ON THE NORTHERN GREAT PLAINS. USDA Circ. 924, 57 p.
Redcedar has survived and grown well, though it is susceptible to winter burning of foliage. It is recommended for planting on the outside leeward row.

George, E. J. 1957. SHELTERBELTS FOR THE NORTHERN GREAT PLAINS. USDA Farmers' Bull. 2109, 16 p.
Suggests redcedar for planting in outside rows of shelterbelts and rates it as "good" for light, medium, or heavy soil.

Hahn. 1945. (116)

Hansen, N. E. 1930. EVERGREENS IN SOUTH DAKOTA. S. D. Agr. Exp. Sta. Bull. 254, 33 p.
Occurrence, growth habits, and prevalent diseases of redcedar. Discusses variable hardiness of the species and recommends that local seed sources be utilized exclusively.

Mann and Hays. 1948. (181)

Martin and Crosby. 1955. (181)

Munns and Stoeckeler. 1946. (232)

Steavenson, H. A., Gearhart, H. E., and Curtis, R. L. 1943. LIVING FENCES AND SUPPLIES OF FENCE POSTS. J. Wildl. Manage. 7: 257-261.
Redcedar is mentioned as being used in fencerow planting in southern Illinois to replace, ultimately, the existing posts.

Wright and Wells. 1948. (232)

27 ARBORETA. ARBORICULTURE FOR ORNAMENTAL PURPOSES

Lindgren, R. M., True, R. P., and Toole, E. R. 1949. SHADE TREES FOR THE SOUTHEAST. *In* Trees, p. 60-65. USDA Yearb.
Redcedar is described as a medium-sized pyramidal conifer commonly used as an ornamental; it tolerates various soils but is often subject to a complex of pest and environmental troubles.

Wright, E., and Bretz, T. W. 1949. SHADE TREES FOR THE PLAINS. *In* Trees, p. 65-72. USDA Yearb.
Redcedar is among the most desirable species for planting on the Plains.

28 HUSBANDRY OF FOREST PRODUCTS OTHER THAN WOOD

Afanasiev. 1949. (181)

Alvord, B. F. 1957. MARKETING CHRISTMAS TREES IN ALABAMA. Ala. Agr. Exp. Sta. Bull. 309, 26 p.
Redcedar represented about 10 percent of U. S. domestic production in 1947 and 12 percent in 1955. Lack of organization in harvesting and marketing Christmas trees appears to be a serious handicap, particularly with regard to cedar.

Garin. 1963. (232)

Garin and Moore. 1951. (232)

Graeber, R. W. 1944. CHRISTMAS CEDARS BEAT COTTON CROP. S. Plant. 105(2): 19.
At age 6 years a 2-acre redcedar plantation yielded 630 Christmas trees for a value of $785. The plantation still had more than 500 trees per acre for future harvest.

Moore. 1945. (232)

Sowder, A. M. 1966. CHRISTMAS TREES, THE TRADITION AND THE TRADE. USDA Agr. Inform. Bull. 94, 31 p.
Redcedar ranks fifth in popularity among all U. S. species. In 1964 it comprised 7 percent of the Christmas tree harvest, with more than 2 million cedars cut.

3. WORK SCIENCE. HARVESTING OF WOOD: LOGGING AND TRANSPORT

Shoulder, E. 1954. COSTS OF SKIDDING EASTERN REDCEDAR. USDA Forest Serv. S. Forest Exp. Sta. S. Forest. Notes 90.
Skidding redcedar in tree lengths and bucking the stems at loading points appears cheaper than bucking at the stump and skidding the products. Savings increased with the diameter and merchantable length of the trees handled.

4. FOREST INJURIES AND PROTECTION

41 GENERAL TECHNIQUE OF FOREST PROTECTION

Crowell, I. H. 1935. THE CEDAR APPLE RUST AND ITS CONTROL. Eleventh Natur. Shade Tree Conf. Proc., p. 80-83.
Life history of the cedar-apple rust fungus. Recommends sprays for controlling the disease on redcedar and on pomaceous hosts.

Davis, W. C., Wright, E., and Hartley, C. 1942. DISEASES OF FOREST-TREE NURSERY STOCK. U. S. Fed. Secur. Agency, Civ. Conserv. Corps Forest. Publ. 9, p. 58-61.
Cedar rust does not ordinarily appear in nurseries, but the likelihood of an infection increases if apples, quinces, or hawthorns occur in the immediate neighborhood. Cedar blight is a widespread nursery disease. Some control can be achieved by use of sprays. Sanitation should also be practiced.

Hansbrough, J. R. 1952. CEDAR-APPLE RUST. *In* Important Tree Pests of the Northeast, p. 98-99. Soc. Amer. Forest., New England Sect., Concord, N. H.
Distribution and hosts, life history and symptoms, and control.

Livingston, J. E. 1946. CEDAR APPLE RUST. Nebr. Agr. Coll. Ext. Circ. 1806, 4 p.
Symptoms on cedars and on apples, and control methods.

Peterson, Nuland, and Weihing. 1960. (232)

Peterson, Sumner, and Norman. 1965. (232)

Strong, F. C. 1948. RED CEDAR-APPLE AND HAWTHORN RUST DISEASE CONTROL BY SPRAYING RED CEDARS IN THE SPRING. Mich. Agr. Exp. Sta. Quart. Bull. 30, p. 283-288.
Recommends a single application of bordeaux 180 in the spring when the telia are about 1/8 to 1/4 inch extended.

Strong and Cation. 1940. (232)

Strong and Klomparens. 1955. (232)

Strong and Rasmussen. 1939. (232)

42 INJURIES FROM INORGANIC AGENCIES

Afanasiev. 1948. (232)

Albertson, F. W. 1940. STUDIES OF NATIVE RED CEDARS IN WEST CENTRAL KANSAS. Kans. Acad. Sci. Trans. 43: 85-95.
Along its western limit of growth in Kansas, 10 to 80 percent of the cedars were killed by the drought of the early 1930's.

Albertson and Weaver. 1945. (182)

Deters and Schmitz. 1936. (232)

George. 1953. (26)

Kaye, S. V. 1965. USE OF MINIATURE GLASS ROD DOSIMETERS IN RADIATION ECOLOGY. Ecology 46: 201-206.
The rods have been used for estimating exposure of foliage of redcedars adjacent to a stream containing radioactive wastes.

Parker. 1950. (232)

Stiles and Melchers. 1935. (232)

Stoeckeler. 1946. (232)

Stoeckeler, J. H., and Rudolf, P. O. 1949. WINTER INJURY AND RECOVERY OF CONIFERS IN THE UPPER MIDWEST. USDA Forest Serv. Lake States Forest Exp. Sta., Sta. Pap. 18, 20 p.
In several localities in Wisconsin, Minnesota, North Dakota, and South Dakota, redcedar in either natural or planted stands suffered only light damage during the severe winter of 1947-1948.

Van Dersal. 1938. (116)

44 DAMAGE BY HARMFUL PLANTS

Anderson, P. J., Haskell, R. J., Muenscher, W. C., and others. 1926. CHECK LIST OF DISEASES OF ECONOMIC PLANTS IN THE UNITED STATES. USDA Agr. Bull. 1366, 111 p.
Lists 18 specific diseases known to attack redcedar.

Bailey. 1933. (181)

Baxter, D. V. 1943. PATHOLOGY IN FOREST PRACTICE. 618 p. N.Y.: Wiley.
Important diseases of redcedar, with descriptions of organisms and suggested controls.

Berg, A. 1940. A RUST-RESISTANT RED CEDAR. Phytopathology 30: 876-878.
Individual redcedars, ranging from highly resistant to highly susceptible to cedar-apple rust, were observed over a period of 16 years. Grafted scions were grown in a nursery for a year and then transplanted. After 4 years rust injury ranged from very light to fatal. One tree was classed as highly resistant.

Boyce, J. S. 1948. FOREST PATHOLOGY. 550 p. N.Y.: McGraw-Hill.
Important diseases of redcedar.

Boyce, J. S., Jr. 1962. GREENHOUSE INOCULATIONS OF CONIFEROUS SEEDLINGS WITH FOMES ANNOSUS. Phytopathology 52: 4.
Pieces of infected root were placed in pots containing 1- or 2-year-old loblolly and white pines and redcedar. After 1 year, seedlings of each species had infected roots, although the foliage was normal.

Boyce, J. S., Jr. 1968. FOREST DISEASE CONTROL. Forest Farmer 27(7): 46-49.
Important diseases of redcedar are root rot and cedar-apple rust. Symptoms and controls are described.

Caroselli. 1957. (232)

Crowell. 1935. (41)

Davis, W. C., and Latham, D. H. 1939. CEDAR BLIGHT ON WILDING AND FOREST TREE NURSERY STOCK. Phytopathology 29: 991-992.
Infection in native stands is a source of infection in the nursery.

Davis, Wright, and Hartley. 1942. (41)

Davis, Young, Latham, and Hartley. 1938. (232)

Dodge, B. O. 1931. A DESTRUCTIVE RED-CEDAR RUST DISEASE. J. N. Y. Bot. Gard. 32: 101-108.
The destructive effect of what appears to be the effuse type of infection by Gymnosporangium nidus-avis.

Dwyer, W. W., Jr. 1951. FOMES ANNOSUS ON EASTERN REDCEDAR IN TWO PIEDMONT FORESTS. J. Forest. 49: 259-262.
Examination of over 10,300 redcedars in the Piedmont showed that Fomes annosus *is a common and sometimes serious pathogen. In the Piedmont, stands approaching post and pole size can be expected to sustain losses exceeding 10 percent of the trees.*

Ellis, J. B., and Everhart, B. M. 1887. ADDITIONS TO CERCOSPORA, GLOEOSPORIUM AND CYLINDROSPORIUM. J. Mycol. 3: 13-22.
Cercospora sequole *var.* juniperi *on redcedar foliage has dark-colored tufts and dwarfish habit.*

Hahn, G. G. 1920. PHOMOPSIS JUNIPEROVORA, A NEW SPECIES CAUSING BLIGHT OF NURSERY CEDARS. Phytopathology 10: 249-253.
The alpha and beta type spores and the pycnidium establish that the organism belongs to the genus Phomopsis. *It is described as* Phomopsis juniperovora *n. sp., and its characteristics are listed.*

Hahn, G. G. 1926. PHOMOPSIS JUNIPEROVORA AND CLOSELY RELATED STRAINS ON CONIFERS. Phytopathology 16: 899-914.
The cedar blight fungus is now known to be widespread in the United States. The predisposing factors are discussed.

Hahn, G. G. 1930. LIFE-HISTORY STUDIES OF THE SPECIES OF PHOMOPSIS OCCURRING ON CONIFERS. Brit. Mycol. Soc. Trans. 15: 32-93.
Describes and differentiates between eight species of Phomopsis, *including* P. juniperovora. *Includes a dichotomous key.*

Hahn, G. G. 1941. REPORTS OF CEDAR BLIGHT IN 1940 AND NOTES ON ITS PREVIOUS OCCURRENCE IN NURSERIES. USDA Plant Dis. Rep. 25: 186-190.
Records cedar blight in a number of the States of the Mississippi Valley.

Hahn, G. G. 1943. TAXONOMY, DISTRIBUTION, AND PATHOLOGY OF PHOMOPSIS OCCULTA AND P. JUNIPEROVORA. Mycologia 35: 112-119.
P. occulta *is nonpathogenic on redcedar.*

Hahn G. G. 1947. BERG'S RUST-RESISTANT RED CEDAR SUSCEPTIBLE TO PHOMOPSIS JUNIPEROVORA IN GREENHOUSE TESTS. Phytopathology 37: 530-531.
Inoculations indicated that the Berg clone was not resistant.

Hahn, G. G. 1949. JUNIPERS PREVIOUSLY REPORTED BLIGHT RESISTANT NOW PROVED SUSCEPTIBLE TO PHOMOPSIS JUNIPEROVORA. USDA Plant Dis. Rep. 33: 328-330.
The scant number of known junipers reported to be resistant to cedar blight is further reduced by tests showing that the Dundee juniper, J. virginiana *var.* hilli, *and two specimens of* J. virginiana, *are susceptible under experimental conditions.*

Hahn, G. G., Hartley, C., and Pierce, R. G. 1917. A NURSERY BLIGHT OF CEDARS. J. Agr. Res. 10: 533-539.
A disease of unknown origin was tentatively identified as being caused by Phoma *sp.*

Hansbrough. 1952. (41)

Hartley, C. 1910. FOMES ANNOSUS AND TWO SPECIES OF GYMNOSPORANGIUM ON JUNIPERUS VIRGINIANA. Science 31: 639.
Report of mortality from Fomes annosus. *Also an undescribed* Gymnosporangium *suspected of causing gradual death of redcedars.*

Hartley, C. 1913. BARK RUSTS OF JUNIPERUS VIRGINIANA. Phytopathology 8: 249.
The three commonest cedar bark rusts in the District of Columbia appear to be Gymnosporangium clavipes, G. nidus-avis *and* G. effusum, *the first-named being the most abundant.*

Hartley, C. 1913. THE BLIGHTS OF CONIFEROUS NURSERY STOCK. USDA Agr. Bull. 44, 21 p.
A blight of unknown origin affects redcedar in the nursery.

Heald, F. D. 1909. THE LIFE HISTORY OF THE CEDAR RUST FUNGUS. Nebr. Agr. Exp. Sta. Annu. Rep. 22, p. 105-113.
Detailed life history.

Hodges, C. S. 1961. NEW HOSTS FOR CERCOSPORA THUJINA PLAKIDAS. USDA Plant Dis. Rep. 45: 745.
Four genera of Cupressaceae are now known to be hosts to the fungus: Chamaecyparis, Cupressus, Juniperus, *and* Thuja.

Hodges, C. S. 1962. COMPARISON OF FOUR SIMILAR FUNGI FROM JUNIPERUS AND RELATED CONIFERS. Mycologia 54: 62-69.
A fungus causing a serious needle blight of redcedar in the eastern United States was previously thought to be Exosporium glomerulosum *but has been identified as* Cercospora sequoiae *var.* juniperi.

Hodges. 1962. (232)

Hodges and Green. 1960. (232)

Hodges and Green. 1961. (232)

Kelman, A., Hodges, C. S., and Garriss, H. R. 1960. NEEDLE BLIGHT OF REDCEDAR, JUNIPERUS VIRGINIANA L. USDA Plant Dis. Rep. 44: 527-531.
The blight has been observed in North Carolina, Virginia, and South Carolina. It is characterized by an ash-brown color of affected needles, severe defoliation of lower branches, and unusual development of juvenile needles. An associated fungus is considered to be Exosporium glomerulosum.

Livingston. 1946. (41)

Long, W. H. 1945. NOTES ON FOUR EASTERN SPECIES OF GYMNOSPORANGIUM. J. Wash. Acad. Sci. 35: 182-188.
In the District of Columbia and adjacent areas in 1912-1913 G. clavipes *and* G. nidus-avis *were widely distributed,* G. effusum *was in limited occurrence, while* G. juniperi-virginianae *was not abundant.*

Miller, P. R. 1939. PATHOGENICITY, SYMPTOMS, AND THE CAUSATIVE FUNGI OF THREE APPLE RUSTS COMPARED. Phytopathology 29: 801-811.
Three distinct rusts affect apples in the United States: Gymnosporangium juniperi-virginianae, G. globosum, *and* G. clavipes. *Comparative symptomatology of the three diseases and the morphological characters of their causative fungi are tabulated.*

Miller. 1943. (24)

Nichols, L. P. 1968. TREE DISEASES—DESCRIPTION AND CONTROL. Pa. State Univ. Coll. Agr. Spec. Circ. 85, p. 6, 14-15.
Cedar-apple rust and twig blight are described and control methods are suggested.

Palmiter, D. H. 1952. THREE RUST DISEASES OF APPLES AND FUNGICIDE TREATMENTS FOR THEIR CONTROL. N. Y. Agr. Exp. Sta. Bull. 756, p. 1-26.
Life histories of the three common apple rust fungi are briefly reviewed and symptoms on the alternate hosts are described.

Palmiter, D. H. 1953. RUST DISEASES OF APPLE. *In* Plant Diseases, p. 658-663. USDA Yearb.
Identifies the fungi responsible for three rust diseases of apple and discusses life history, symptoms on apple and cedar, and controls.

Peterson. 1965. (232)

Peterson, Nuland, and Weihing. 1960. (232)

Peterson, Sumner, and Norman. 1965. (232)

Pirone, P. P., Dodge, B. O., and Rickett, H. W. 1960. DISEASES AND PESTS OF ORNAMENTAL PLANTS. Ed. 3, p. 439-444. N.Y.: Ronald Press.
Describes phomopsis twig blight, cedar-apple rust, redcedar aphid, bagworm, juniper midge, juniper scale, juniper webworm, redcedar bark beetle, and red spider mite. Suggests controls for each.

Riker, A. J. 1945. SOME POSSIBILITIES FOR DEVELOPING RESISTANCE TO DISEASE IN TREES. Amer. Nurseryman 81(12): 5-7.
A selection of a redcedar resistant to the cedar-apple rust is commercially available under the name "Berg's rust-resistant."

Scheld, H. W., Jr., and Kelman, A. 1963. INFLUENCE OF ENVIRONMENTAL FACTORS ON PHOMOPSIS JUNIPEROVORA. USDA Plant Dis. Rep. 47: 932-935.
The optimum temperature for mycelial growth of the fungus on a solid medium was approximately 26°C. Light was requisite for fertile pycnidia. Both mycelium and conidia in pycnidia survived the winter on live infected seedlings; conidia in pycnidia also survived the winter on surface debris.

Slagg and Wright. 1944. (232)

Stewart, F. C. 1918. THE PHOMA BLIGHT OF RED CEDAR. Phytopathology 8: 33-34.
Documents initial identification as 1896.

Stoeckeler and Jones. 1957. (232)

Strong. 1948. (41)

Strong and Cation. 1940. (232)

Strong and Klomparens. 1955. (232)

Strong and Rasmussen. 1939. (232)

USDA Agricultural Research Service. 1960. INDEX OF PLANT DISEASES IN THE UNITED STATES: PLANT PESTS OF IMPORTANCE TO NORTH AMERICAN AGRICULTURE. USDA Agr. Handb. 165, 531 p.
List of diseases and pathogens known to attack redcedar.

Von Schrenk, H. 1900. TWO DISEASES OF RED CEDAR, CAUSED BY POLYPORUS JUNIPERINUS N. SP. AND POLYPORUS CARNEUS NEES. USDA Bull. 21, 29 p.
Describes mycelium, fruiting bodies, and effects on wood of the white rot and the red rot (pecky cedar).

Waite, M. B. 1927. APPLE TREES ATTACKED BY CEDAR RUST. USDA Yearb., p. 145-151.
Historical importance of cedar rust on apple production in early 1900's. Describes the life cycle of cedar rust and suggests the eradication of redcedar in the vicinity of apple orchards.

Weimer, J. L. 1917. THE ORIGIN AND DEVELOPMENT OF THE GALLS PRODUCED BY TWO CEDAR RUST FUNGI. Amer. J. Bot. 4: 241-251.
Galls produced by G. juniperi-virginianae *and* G. globosum *on* Juniperus virginiana *originate as modified leaves. The vascular systems of the galls are composed of the enlarged and modified leaf-trace bundles.*

Wright and Wells. 1948. (232)

45 DAMAGE BY ANIMALS
451 MAMMALS

Crawford. 1961. (181)

Dunkeson, R. L. 1955. DEER RANGE APPRAISAL FOR THE MISSOURI OZARKS. J. Wildlife Manage. 19: 358-364.
Redcedar and shortleaf pine have been destructively browsed during winter. Both rank low in palatability, and browsing was heaviest during mast shortages.

Hahn. 1945. (116)

Halls, L. K., and Crawford, H. S., Jr. 1960. DEER-FOREST HABITAT RELATIONSHIPS IN NORTH ARKANSAS. J. Wildlife Manage. 24: 387-395.
When deer populations are heavy, young redcedars may have a hedged appearance from being overbrowsed.

Read, R. A. 1948. WINTER BROWSING OF CEDAR BY OZARK DEER. USDA Forest Serv. S. Forest Exp. Sta. S. Forest. Notes 55.
During the winter of 1947-48, white-tailed deer in heavy concentrations browsed almost three-fourths of all cedar trees under 5-1/2 feet high, eating 85 percent of the terminal height growth these trees had made the previous growing season.

Van Dersal. 1939. (13)

453 INSECTS

Appleby, J. E., and Neiswander, R. B. 1965. OLIGOTROPHUS APICIS SP. N., A MIDGE INJURIOUS TO JUNIPERS; WITH KEY TO SPECIES OF OLIGOTROPHUS FOUND IN THE UNITED STATES. Ohio J. Sci. 65: 166-175.
Includes life history of the new species.

Bailey. 1933. (181)

Caveness, F. E. 1957. ROOT-LESION NEMATODE RECOVERED FROM EASTERN REDCEDAR AT HALSEY, NEBRASKA. USDA Plant Dis. Rep. 41: 1058.
One- and 2-year seedlings from the Bessey Nursery at Halsey, Nebraska, had numerous root lesions caused by Pratylenchus penetrans. *Infected 2-year seedlings were 6-8 cm. in height, while unaffected seedlings were 31-37 cm.*

Craighead, F. C. 1950. INSECT ENEMIES OF EASTERN FORESTS. USDA Misc. Publ. 657, 679 p.
Practical keys (based on types of injuries) to the orders, families, and genera of forest insects.

Dean. 1942. (232)

Haseman, L. 1912. THE EVERGREEN BAGWORM. Mo. Agr. Exp. Sta. Bull. 104, p. 309-330.
Extensive account of the bagworm, Thyridopteryx ephemeraeformis.

Jones, F. M., and Parks, H. B. 1928. THE BAGWORMS OF TEXAS. Tex. Agr. Exp. Sta. Bull. 382, 36 p.
Discusses bagworm girdling and attendant gall-like growth around the girdle, and shows that twigs beyond the point of attachment of the bag are weakened or killed. Identifies the evergreen bagworm as attacking cedar.

Peterson, G. W. 1964. HEAT TREATMENT OF NEMATODE-INFESTED EASTERN REDCEDAR ROOTS. USDA Plant Dis. Rep. 48: 862.
Hot-water treatment was used to kill root-lesion nematodes (Pratylenchus penetrans). *Immersion in hot water at 52° C. for 2 minutes was the safest and most effective combination. Hot water was more injurious to roots of healthy plants than to roots of nematode-infested plants.*

Pirone, Dodge, and Rickett. 1960. (44)

Stannard, L. J., Jr. 1964. SECONDARY BAGWORM INJURY. J. Econ. Entomol. 57: 176.
Winds broke off twigs weakened by constrictions caused by the supporting bands of bagworms, 95 percent of which had been killed in the previous year by carbaryl treatment.

Wilford, B. H. 1940. THE SEED-CORN MAGGOT, A PEST OF RED CEDAR SEEDLINGS. J. Forest. 38: 658-659.
In Tennessee, nursery seedlings were seriously injured by seed-corn maggots. Maggots feed in early May, attacking the roots or boring through and beneath the thin bark of the stem. Recommendations for control include delaying sowing so as to avoid seedling development during the wet weather of April and May, substitution of inorganic for organic fertilizers, and application of miscible carbon disulfide when maggots are feeding.

5. FOREST MENSURATION. INCREMENT; DEVELOPMENT AND STRUCTURE

52 MEASUREMENTS: STEM DIMENSIONS AND VOLUMES

Grosenbaugh, L. R., and Arend, J. L. 1949. INTERNATIONAL RULE MODIFIED FOR SMALL EASTERN REDCEDAR LOGS. J. Forest. 47: 736, 738-739.
Greatly improved predictions of the lumber actually cut from logs was achieved by revising the International 1/4-inch rule for a 4-foot section.

Maughan, W. 1936. A CUBIC VOLUME TABLE FOR EASTERN RED CEDAR. J. Forest. 34: 777-778.
A local volume table in cubic feet, presumed to be applicable in most of the middle Atlantic Piedmont.

Maughan, W. 1937. A BOARD FOOT VOLUME TABLE FOR EASTERN RED CEDAR. J. Forest. 35: 734-735.
A board-foot volume table for the middle Atlantic Piedmont.

Zimmerman, A. H., and Cummings, W. H. 1952. REDCEDAR CUMULATIVE VOLUME TALLY. J. Forest. 50: 867.
A form based on volume tables constructed for redcedar in the Tennessee Valley.

54 ASSESSMENT OF SITE QUALITY

Arend and Collins. 1949. (114)

56 INCREMENT; DEVELOPMENT AND STRUCTURE OF STANDS

561 INCREMENT: HEIGHT, DIAMETER, BASAL AREA

Jackson. 1952. (181)

Maple. 1965. (232)

Schulman, E. 1944. NOTES ON DENDROCHRONOLOGIES AT THE ARNOLD ARBORETUM. Tree-Ring Bull. 10, p. 30-32.
The presence of false rings in the junipers make "reading" the chronology very difficult. At least part of the pronounced intraseasonal fluctuation in ring growth of redcedar is related to weather changes.

6. FOREST MANAGEMENT. BUSINESS ECONOMICS OF FORESTRY

61 FOREST MANAGEMENT, GENERAL, THEORY AND PRINCIPLES

Cromie. 1944. (26)

62 METHODS OF MANAGEMENT

Arend. 1946. (22)

Arend. 1947. (22)

Graeber. 1944. (28)

Maple. 1957. (24)

65 SPECIAL BUSINESS PROBLEMS OF TIMBER-GROWING

Arend. 1946. (22)

Arend. 1947. (22)

8. FOREST PRODUCTS AND THEIR UTILIZATION

81 WOOD AND BARK: STRUCTURE AND PROPERTIES

Agramont, Busking, Mitchell, and Enzinger. 1948. (164)

Bannan, M. W. 1942. WOOD STRUCTURE OF THE NATIVE ONTARIO SPECIES OF JUNIPERUS. Amer. J. Bot. 29: 245-252.
Redcedar resembled Thuja occidentalis *in such characters as size of the tracheids, size and distribution of the intertracheary pits, size and number of pits per crossing field, height and distribution of rays, and size of ray cells.*

Brown, H. P., Panshin, A. J., and Forsaith, C. C. 1949. TEXTBOOK OF WOOD TECHNOLOGY. I. STRUCTURE, IDENTIFICATION, DEFECTS, AND USES OF THE COMMERCIAL WOODS OF THE UNITED STATES. 652 p. N.Y.: McGraw-Hill.
General characteristics and properties of redcedar wood, with information on minute anatomy and uses. Wood identification keys.

Hall, W. L., and Maxwell, H. 1911. USES OF COMMERCIAL WOODS OF THE UNITED STATES. I. CEDARS, CYPRESSES, AND SEQUOIAS. USDA Forest Serv. Bull. 95, p. 19-29.
Discusses properties, uses, and supply of redcedar. Cites an essay by Benjamin Franklin in "Poor Richard's Almanack" (1749) on uses, planting, and management of redcedar in eastern Pennsylvania and in New Jersey.

Hallauer, F. J. 1914. TESTS AND SUPPLIES OF PENCIL WOOD. Amer. Lumberman 2049, p. 42.
No species equalled redcedar for pencil manufacture.

Lane, F. W. 1954. THE STRUCTURE OF WORLD TIMBERS. XII. FOUR SPECIES OF THE CEDAR. Timber Technol. 62: 67-69.
Compares wood characteristics of four North American cedars, including redcedar.

Johnson, R. P.A., and Van Hagan, C. E. 1949. THE WOOD FOR THE JOB. *In* Trees, p. 615-619. USDA Yearb.
Redcedar is listed as a wood that is comparatively free from warping.

Koehler, A. 1949. KEY FOR THE IDENTIFICATION OF WOODS WITHOUT THE AID OF A HAND LENS OR MICROSCOPE. *In* Trees, p. 833-838. USDA Yearb.
Includes redcedar.

Mamada, S. 1954. WOOD STUDY ON JUNIPERUS VIRGINIANA L. AND JUNIPERUS CHINENSIS L. Bull. Tokyo Univ. Forest. 105, p. 225-231 (English summary).
Physical and mechanical properties of redcedar wood grown in a plantation in Japan did not differ from properties of wood grown in the U. S.

Markwardt, L. J. 1930. COMPARATIVE STRENGTH PROPERTIES OF WOODS GROWN IN THE UNITED STATES. USDA Tech. Bull. 158, 38 p.
Specific gravity, weight per cubic foot, shrinkage during drying, and composite strength values for redcedar.

Sargent. 1895. (181)

USDA Forest Service. 1955. WOOD HANDBOOK. USDA Agr. Handb. 72, 528 p.
Specific information on wood properties of redcedar, including color and figure, gluability, moisture content, weight per cubic foot and per 1,000 board-feet, and working quality with hand tools.

Veer, J. J. G., and King, F. W. 1963. MOISTURE BLISTERING OF PAINTS ON HOUSE SIDING. Can. Dep. Forest. Publ. 1024, 25 p.
In susceptibility to paint blistering redcedar was intermediate among a number of common siding woods.

White. 1907. (181)

83 TIMBER MANUFACTURING INDUSTRIES AND PRODUCTS

Back, E. A., and Rabak, F. 1922. RED CEDAR CHESTS AS PROTECTORS AGAINST MOTH DAMAGE. USDA Bull. 1051. 14 p.
Chests made of redcedar heartwood protect fabrics from moths.

Blackwell, R. 1945. TO CORRECTLY FINISH AROMATIC RED CEDAR. Ind. Finish. 21(4): 104, 106, 108.
Procedures to treat and finish aromatic redcedar.

Booth, F. L. 1929. MANUFACTURING AND SHIPPING CEDAR CHESTS. Wood-Worker 48, p. 32-33.
Manufacturing techniques and shipping procedures of one large plant are described in detail.

Landani, H., and Clark, P. H. 1954. THE EFFECTS OF RED, WHITE, AND SOUTH AMERICAN CEDAR CHESTS ON THE VARIOUS STAGES OF THE WEBBING CLOTHES MOTH AND THE BLACK CARPET BEETLE. J. Econ. Entomol. 47: 1107-1111.
Test cedar chests had an inhibiting effect on hatching of eggs laid in the chests but little or no effect on eggs introduced after oviposition. Mortality of the young larvae was much higher than that of mature larvae after exposure in the chests. Exposure of mature larvae had little or no effect on the pupation and adult emergence of either species.

Scott, E. W., Abbott, W. S., and Dudley, J. E. 1918. RESULTS OF EXPERIMENTS WITH MISCELLANEOUS SUBSTANCES AGAINST BEDBUGS, COCKROACHES, CLOTHES MOTHS, AND CARPET BEETLES. USDA Bull. 707, 36 p.
Redcedar chests provided protection against clothes moths and carpet beetles, but redcedar chips were only moderately effective.

84 PRESERVATIVE AND OTHER TREATMENTS TO IMPROVE PROPERTIES OF WOOD

Anderson, Haskell, Muenscher, and others. 1926. (44)

Baxter. 1943. (44)

Boyce. 1948. (44)

Morton, H. L., and French, D. W. 1966. FACTORS AFFECTING GERMINATION OF SPORES OF WOOD-ROTTING FUNGI ON WOOD. Forest Prod. J. 16(3): 25-30.
Germination of Lenzites trabea *basidiospores was less on the heartwood than on the sapwood of eastern redcedar. For both types of wood, germination was less on western redcedar* (Thuja plicata *Donn) than on eastern redcedar or Douglas-fir.*

Von Schrent. 1900. (44)

Walters, C. S., and Meek, W. L. 1951. THE COLD-SOAK PRESERVATIVE TREATMENT OF EASTERN RED CEDAR. Ill. Agr. Exp. Sta. Forest. Note 27, 1 p.
Sapwood of redcedar is easy to treat by the cold-soak method.

86 PULP INDUSTRIES. COMPOSITE MATERIALS

Guenther, E. 1943. OIL OF CEDAR WOOD. Soap Sanit. Chem. 19: 94-97.
Oil of cedar wood is distilled almost exclusively from shavings and refuse obtained in the processing of boards, shingles, and specialty wood products.

Huddle, H. B. 1936. OIL OF TENNESSEE RED CEDAR. Ind. and Eng. Chem. 28(1): 18-21.
Production of redcedar oil is dependent on the supply of virgin redcedar, which is being depleted rapidly. Briefly reviews history of oil production, gives detailed description of a typical still, and summarizes physical properties and analyses of samples of oil distilled in 1932, 1933 and 1935.

Huddle, H. B. 1938. A PRELIMINARY REPORT ON THE VACUUM FRACTIONATION OF THE OIL OF JUNIPERUS VIRGINIANA. J. Tenn. Acad. Sci. 13: 259-267.
Describes conditions for fractionation.

Rabak, F. 1929. CEDROL; ITS SOURCE AND DERIVATION. Amer. Perfum. and Essent. Oil Rev. 23: 727-728.
Describes methods of determining the percentage of cedrol in cedar-wood oil and compares properties of oils from fresh and old cedar.

Runeberg, J. 1960. THE CHEMISTRY OF THE NATURAL ORDER CUPRESSALES. XVIII. CONSTITUENTS OF JUNIPERUS VIRGINIANA L. Acta Chem. Scand. 14: 1288-1294.
Commercial cedar-wood oil contains cuparene, cedrol, widdrol, a-cedrene, and thujopsene.

Sweetman, H. L., Benson, D. A., and Kelley, R. W., Jr. 1953. EFFICACY OF AROMA OF CEDAR IN CONTROL OF FABRIC PESTS. J. Econ. Entomol. 46: 29-33.
The aroma of cedar oils from a commercial cedar plaster for wall application was not repellent or toxic to larvae and adults of the webbing clothes moth, black carpet beetle, and furniture carpet beetle.

89 OTHER FOREST PRODUCTS

Bailey, L. F. 1948. LEAF OILS FROM TENNESSEE VALLEY CONIFERS. J. Forest. 46: 882-889.
Aromatic oils recovered from the foliage of the four important coniferous lumber species in the Tennessee Valley are described, and the literature on leaf oils of other North American conifers is reviewed. Optimum yields of leaf oils range from 0.16 percent for redcedar to 0.35, 0.32, and 0.28 percent for loblolly, shortleaf, and Virginia pines, respectively.

Bender, F. 1963. CEDAR LEAF OILS. Can. Dep. Forest. Publ. 1008, 16 p.
Lists species from which cedar leaf oils are prepared, and discusses methods of preparation.

Greaves, C. 1939. CEDAR LEAF OILS. Can. Forest Prod. Lab., 18 p.
Review of species, status of industry in Canada, method of preparation, yields, physical and chemical properties, and uses.

Kupchan, S. M., Hemingway, J. C., and Knox, J. R. 1965.

TUMOR INHIBITORS. VII. PODOPHYLLOTOXIN, THE ACTIVE PRINCIPLE OF JUNIPERUS VIRGINIANA. J. Pharm. Sci. 54: 659-660.
Alcoholic extracts of leaves and twigs showed significant inhibitory effect.

Schwartz, H. 1949. STRUCTURAL BOARDS FROM CEDAR BARK. Pap. Trade J. 128(23): 27-28.
Tests indicated a good possibility of producing insulating boards from eastern and western redcedar barks, but results with hardboards were unsatisfactory.

9. FORESTS AND FORESTRY FROM THE NATIONAL POINT OF VIEW

90 GENERAL

902 HISTORY OF FORESTS AND FORESTRY

Brown, L. E. 1912. TENNESSEE RED CEDAR. S. Lumberman 69(900): 109-111.
Early uses of redcedar.

Brown, L. E. 1926. TENNESSEE RED CEDAR. S. Lumberman 125(1629): 201-202.
See entry above.

Evelyn, J. 1664. SYLVA, OR A DISCOURSE OF FOREST-TREES AND THE PROPAGATION OF TIMBER. 320 p. London: Martyn and Allestay.
"The cedar. . .grows in all extremes: in the moist Barbados; the hot Bermudas, the cold New England; even where the snow lies (as I am assur'd) almost half the year: Why then it should not thrive in Old England, I conceive is from our want of industry: It grows in the bogs of America. . . ."

Hall and Maxwell. 1911. (81)

Morton, T. 1637. NEW ENGLISH CANAAN. *In* Force, P., Tracts Relating to the Colonies in North America. Vol. 2, p. 45-54.
In citing the trees that are found in New England, Morton stated, "Cedar, of this sorte there is an abundance: and this wood was such as Solomon used for the building of that glorious temple at Hierusalem .... This wood cuts red, and is good for bedsteads, tables and chests ...."

904 GENERAL REGIONAL ACCOUNTS OF FORESTS AND FORESTRY

Barton, J. E. 1919. THE AMOUNT OF STANDING TIMBER IN KENTUCKY. *In* Resources of Kentucky. Vol. 1, p. 251-284. Frankfort, Ky.: Ky. Dep. Geol. and Forest.
Redcedar was reported in 24 counties; the aggregate volume was 34, 412 thousand board feet.

DeBald, P. S., and Gansner, D. A. 1966. KENTUCKY FORESTS, WESTERN COALFIELD UNIT. USDA Forest Serv. Resour. Bull. CS-9, 45 p. Cent. States Forest Exp. Sta., Columbus, Ohio.
Over 116,000 acres of redcedar type are reported, with 12.4 million cubic feet of growing stock and 26.3 million board feet of sawtimber.

Gansner, D. A. 1965. MISSOURI'S FORESTS. USDA Forest Serv. Resour. Bull. CS-2, 53 p. Cent. States Forest Exp. Sta., Columbus, Ohio.
Growing-stock volume of redcedar type is 17 million cubic feet and sawtimber volume is 6.6 million board feet.

Gansner, D. A., and DeBald, P. S. 1966. KENTUCKY FORESTS, BLUE GRASS UNIT. USDA Forest Serv. Resour. Bull. CS-7, 33 p. Cent. States Forest Exp. Sta., Columbus, Ohio.
Almost 224,000 acres of redcedar type reported, with 19.0 million cubic feet of growing stock and 39.6 million board feet of sawtimber.

Gansner, D. A., and DeBald, P. S. 1966. KENTUCKY FORESTS, PENNYROYAL UNIT. USDA Forest Serv. Resour. Bull. CS-6, 46 p. Cent. States Forest Exp. Sta., Columbus, Ohio.
Over 190,000 acres of redcedar type reported, with 22.0 million cubic feet of growing stock and 24.8 million board feet of sawtimber.

Hall, W. L. 1900. NOTES IN OKLAHOMA. I. THE EXTERMINATION OF THE RED CEDAR. Forester 6: 163-164.
Redcedar trees have furnished most of the posts used by ranchmen and settlers of Oklahoma and southern Kansas.

Kellogg. 1905. (181)

King, Roberts, and Winters. 1949. (181)

Knight, H. A., and McClure, J. P. 1966. NORTH CAROLINA'S TIMBER. USDA Forest Serv. Resour. Bull. SE-5, 47 p. Southeast. Forest Exp. Sta., Asheville, N. C.
About 28,000 acres of redcedar type reported, with 36 million cubic feet of growing stock and 57 million board feet of sawtimber.

Knight, H. A., and McClure, J. P. 1966. VIRGINIA'S TIMBER, 1966. USDA Forest Serv. Resour. Bull. SE-8, 47 p. Southeast. Forest Exp. Sta., Asheville, N. C.
Some 120,000 acres of cedar type reported, with 50 million cubic feet of growing stock and 65 million board feet of sawtimber.

Larson, R. W. 1960. SOUTH CAROLINA'S TIMBER. USDA Forest Serv. Southeast. Forest Exp. Sta. Forest Surv. Release 55, 103 p.
Redcedar type covers 77,000 acres, and contains 37 million cubic feet of growing stock and 40 million board feet of sawtimber.

Miller, L. C. 1902. THE RED CEDAR IN NEBRASKA. Forest. and Irrig. 8: 282-285.
Considering its wide distribution, annual height and diameter growth, and excellent reproduction, redcedar is destined to be widely used for future planting throughout Nebraska.

Sternitzke, H. S. 1960. ARKANSAS FORESTS. USDA Forest Serv. S. Forest Exp. Sta. Forest Surv. Release 84, 58 p.
Redcedar aggregates more than 595,000 acres, with 28 million cubic feet of growing stock and 43 million board feet of sawtimber.

Sternitzke, H. S. 1962. TENNESSEE FORESTS. USDA Forest Serv. S. Forest Exp. Sta. Forest Surv. Release 86, 29 p.
Redcedar is the dominant species on 600,000 acres, with 66 million cubic feet of growing stock and 105 million board feet of sawtimber.

Ware, E. R., and Smith, L. F. 1939. WOODLANDS OF KANSAS. Kans. Agr. Exp. Sta. Bull. 285, 42 p.
Though little mention is made of redcedar occurring in natural stands, it is listed first among trees found to be suitable for Statewide planting.

INDEX OF AUTHORS

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FUSIFORM RUST OF SOUTHERN PINES— A CRITICAL REVIEW

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Southern Forest Experiment Station
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CONTENTS

Fusiform Rust of Southern Pines — A Critical Review

Felix J. Czabator

This paper attempts a comprehensive summary of present knowledge of fusiform rust. It comprises an exhaustive survey of the literature, and also notes major current research. In addition, it includes references to and comparisons with other plant rusts. The subject is far from closed: there are many admissions of ignorance and suggestions for investigation. I hope the review will facilitate research that will lead to eventual control of the disease.

THE DISEASE—OCCURRENCE, DISTRIBUTION, AND ECONOMIC IMPLICATIONS

The fusiform rust of southern pines, caused by **Cronartium fusiforme** Hedgc. & Hunt ex Cumm., is widely distributed from the eastern shore of Maryland to Florida, Texas, and southeast Arkansas (298, 351). The disease is a major obstacle to the management of slash and loblolly pine plantations (3, 104, 125, 126, 143, 299, 300, 351, 360), and may cause catastrophic losses of nursery seedlings of these species unless intensive control measures are taken. The disease has not been reported from other countries, although species of **Cronartium** with oaks as alternate hosts are found in Canada, Mexico, Honduras, and Guatemala.

Cronartium fusiforme is heteroecious, with one part of the life cycle on the leaves of oaks and the alternate generation on pine stems and branches. The oak hosts comprise more than 20 species. The effect of the fungus on the oaks is slight, though when infection is abundant the premature shedding of diseased leaves causes some reduction in growth (135).

While the most frequent pine hosts are loblolly pine (**Pinus taeda** L.) slash pine (**P. elliottii** var. **elliottii** Engelm.), longleaf pine (**P. palustris** Mill.) and pond pine (**P. serotina** Michx.), 23 other species and varieties of native and exotic pines also may be infected (135, 170, 268, 302). Shortleaf pine (**P. echinata** Mill.) is conceded to be practically immune (140, 169, 298), although Wakeley says that localized infections of shortleaf pine occur in western North and South Carolina (363, p. 92).

On pine hosts, the disease is manifest by a spindle-shaped swelling or gall that develops at or near the point of infection. On nursery seedlings, the gall usually is within 1 to 4 inches of the groundline. The galls may or may not have a witches'-broom of adventitious branches arising from the swollen tissue (31, 60, 134, 139, 298).

Infection occurs through cotyledons, needles, tender stem tissue, and occasionally graft callus (45, 171, 298). The first signs of infection, purple to blue-purple spots or blotches, occur in 4 to 10 weeks after inoculation (171); the spots later become yellow-green (135). When older trees have one or more stem galls, it is a safe assumption that infection occurred on the branches and the fungus grew through the branch to the stem. Growth of the branch galls generally is somewhat faster toward than away from the stem (120, 298). Galls more than 15 inches from the stem usually kill the branch before the fungus can invade the stem (120, 208, 296, 299).

Galled seedlings usually die within 3 or 4 years after infection, when the cambium surrounding the gall is killed. On older trees, the gall usually is restricted to less than half of the circumference of the bole. Frequently the cambium is killed (298, 363) and the gall becomes a canker, an open wound subject to attack by wood-decaying fungi and insects (135, 136, 239, 386). In established plantings, mortality ascribable to fusiform rust may be four to nine times that from other causes. Occasionally seedlings recover from infection

(311); in these cases, the gall tissue becomes discolored and is overgrown by vigorous healthy host tissue. Recovery from the disease may be purely a host reaction, or may be the result of temperature extremes (27, 355).

The gall tissue generally has lower specific gravity than normal wood, and is somewhat weaker (54, 239). Although the increased diameter of the stem at a gall frequently compensates for the weakness of the wood, stem breakage by wind is a major cause of loss in trees of pulpwood size or larger (194, 386).

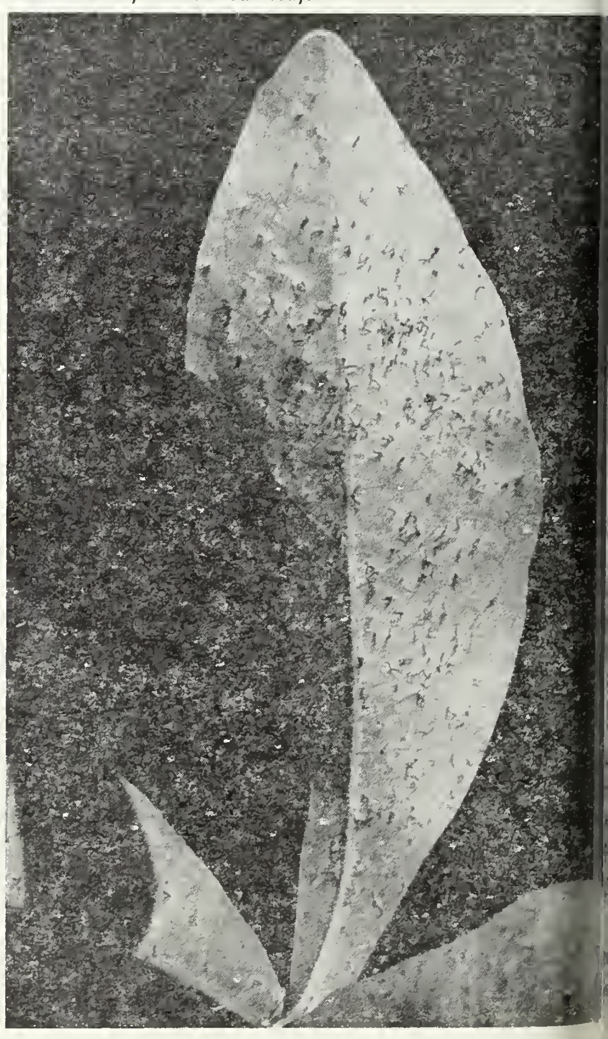
Sections of trees with galls or cankers are unacceptable for either lumber or pulpwood, and must be culled. Young trees with numerous stem and branch cankers are so deformed as to be worthless even for pulpwood (299). The growth rate of infected trees is reduced both by the demands of the parasite and the diversion of wood into multiple branches rather than stem tissue.

Mortality is more frequent in slash pine (194, 195, 225, 238, 299, 363) than in other species. Loblolly pine is more prone to a slowing in growth as a result of multiple stem cankers and witches'-brooms. In slash pine, and to a lesser extent in loblolly, a butt and root rot caused by **Polyporus tomentosus** var. **circinatus** (Fr.) Sartory & Maire is associated with basal galls and cankers (33, 277), and is another source of windthrow and loss.

Pines are susceptible from the cotyledonary stage until they become 50 years or more in age (171, 360, 363), but infections decrease as tree ages increase (103, 104, 299) and progress of the disease is slowed as trees gain size (298). The greatest mortality and deformation are in plantations up to 5 years of age (6, 141, 142, 289, 295, 298, 301, 363). Infection in the latter part of a rotation causes very little mortality and little loss of wood through defect (385).

Within the botanical range of **C. fusiforme**, incidence on the susceptible pines varies from occasional to very high; the most severe infections

Left: Typical fusiform rust galls on branches of slash pine.
Right: Telia of **Cronartium fusiforme** *on the under side of a water oak leaf.*



occur in the southern part of Mississippi and Alabama, and in southeast Louisiana. The zone of moderate to severe infection (10 to 30 percent) generally coincides with the natural range of slash pine.

The coincidence of severe infection with the natural range of slash pine suggests the possibility of mathematically evaluating the effect of climatic conditions on the potential severity of the disease. Hocker (151, 152) and Bethune (25), using multiple regression techniques, determined the climatic factors that limit the natural range of loblolly and slash pine. A similar procedure may be practicable to define the range and local severity zones of fusiform rust.

A systematic survey to delimit the present range and establish severity zones is sorely needed. The last published survey was that made by Lamb and Sleeth (195) in 1938 and 1939. Subsequent reports of distribution, range, and severity (3, 340, 363) are based only on occasional observations by foresters and pathologists.

In spite of the lack of systematic data, there is no doubt but that the incidence of rust is increasing (336, 361). The paucity of early references (11, 230, 334, 335) to observations and collections on pines indicates that the disease was relatively rare prior to 1900. By 1947, Siggers and Lindgren (299) commented that "15 years ago trunk and branch cankers on southern pines were of interest mostly to classifiers of tree diseases," and observed that fusiform rust had become "increasingly prevalent in the Gulf South in the past 35 years." They cited instances of some stands in which 90 percent of the trees had one or more stem cankers. In 1929, Hayes and Wakeley (129) reported that fusiform rust was of minor importance in plantations near Bogalusa, Louisiana. Today, incidence is very high in this same general area. In other parts of the South, severe mortality caused by rust, with 60 to 80 percent of the survivors having trunk infection, is not rare in slash pine plantations still below minimum pulpwood size (351, 363).

The 1938-1939 survey classed central Louisiana and Florida as areas of light infection; in 1959, the writer examined a 3,000-acre slash pine plantation near Alexandria, Louisiana, in which [illegible] percent of the trees had multiple stem and branch cankers.

Weber (378) reported infection of 64 percent of the trees in a stand near Gainesville, Florida; and several plantations near Foley, Florida, have more than 40 percent of the stems infected.

The mere percentage of stems infected, high as it may be, is not the best measure of the disease's economic impact. The reduction in stand productivity that results when growing space is occupied by deformed, dwarfed trees must be considered, as well as actual volume losses caused by death or windthrow of the infected trees (19, 298, 386).

The same increase in infection is evident in nurseries. The presence of rust in nurseries was first recognized about 1937 (194, 299, 329), and losses of 15 to 35 percent were reported for some nurseries in 1938 and 1939 (302). Control measures were initiated at the Ashe Nursery at Brooklyn, Mississippi, in 1939, and by 1941 spraying with bordeaux mixture or ferbam was standard practice in southern nurseries. In 1949, however, infection exceeded 65 percent in some nurseries in spite of routine protective sprays, and losses approached 60 percent in 1957. Part of these sporadically high losses may be attributed to careless spraying, but undoubtedly the greater part resulted from increased inoculum potential, since at one nursery 35 percent infection occurred in 1959, even after a recommended spraying program had been put into effect (95, 96, 297).

Much of the increase is attributed to offsite planting of the host pines, i.e., to the use of susceptible loblolly and slash pine on typical longleaf pine sites and to the planting of slash pine outside its natural range (104, 137, 194, 351, 363). Off-site planting does not account for the severe infection in nurseries, however. Except for a temporary (and unsuccessful) oak-eradication program near some nurseries (194, 297, 302, 363), there has been no serious attempt to reduce spore production by elimination of infected hosts (74, 194, 299).

Genetic susceptibility of the hosts may have a significant effect on incidence (20, 140, 169, 314, 363), and genetic variation (physiologic races) may exist in the rust itself (363).

Phenological variations in both the oak and pine hosts account for some local increase of the rust (30, 102, 104, 291, 292, 293, 294, 363). These variations frequently occur after late winter fires or cultivation of pine plantations (30, 102, 293, 294, 388).

Nearly all of the earlier research on fusiform rust has been on chemical control of the disease in nurseries. This emphasis has been both feasible and practical. The heavy concentration of plants and high values in a nursery justify intensive control. The average southern nursery may produce, per acre, one million trees valued at $5,000 (363). Reducing infection from an average of 30 percent to 10 percent thus would represent a saving of at least $1,000 per acre, considerably more than the cost of control measures now practiced.

Though at present considered uneconomical (299, 300, 351, 363), control in plantations and natural stands is a very important area for future research. Anticipated planting in the South for the two decades 1955-1974 is estimated at approximately 515,000 acres per year (337), and control in these plantations would have far-reaching effects. In addition, every effort should be made to reduce the losses in natural stands. The southern pines are very important to the national economy, accounting for 28 percent of the total annual cut.

THE FUNGUS

The rusts are obligate parasites of higher plants, worldwide in distribution, and cause more economic loss than any other group of fungi which infect plants. Wherever higher plants exist, some rusts occur (11).

The rusts are of unusual scientific interest because of their many spore forms (up to five distinct stages), and most species have a striking change of hosts. The heteroecious rusts, particularly, have an exceptionally high degree of specialization apparently associated with critical nutritional demands. It has been postulated that the rusts obtain from one host certain nutrients for spore development but that establishment of the fungus requires another nutritional complex obtainable only from the alternate hosts (11). The nutrition factor may be part of the mechanism of host specificity (susceptibility-resistance).

Taxonomy and Nomenclature

The genus **Cronartium** is separated from other rusts by the presence of sessile, one-celled teliospores that are united in columns; a prominent aecial periderm; and pedicillate urediospores. The genus is heteroecious, with pycnia and aecia being produced on the plants of the genus **Pinus**, and the uredia and telia on leaves of various herbaceous and woody dicotyledonous plants (12).

For North America, eight to 15 species of **Cronartium** are recognized, according to various interpretations and authorities (12, 31, 57, 58, 76, 88, 135). Several differ so little in taxonomic characteristics that some classifiers consider them as one species, in spite of extreme differences in gross morphological effects on the aecial hosts. (Taxonomic criteria in the rusts are based on the microscopic characters of the spore stages on the host that bears the perfect, or telial stage.) On the other hand, some conifer rusts are classed as species of **Cronartium** by inference, although the telial stage is not known. Strictly speaking, these must be considered species of the form-genus **Peridermium**, the aecial stage of rusts on conifers, with peridia and catenulate aeciospores (255). The inference that species of **Peridermium** are only incompletely known species of **Cronartium** is probably sound, in that all of the previously established species of **Peridermium** were shown to be **Cronartium** when the complete life cycle was determined. It is also possible that some species, as the Woodgate rust (411), may have lost the uredinial-telial stages.

Within the geographic range in which the fusiform rust occurs, several species of **Cronartium** are known:

- **Cronartium quercuum** (Berk.) Miyabe ex Shirai (=**C. cerebrum** Pk.?)
- C. **comandrae** Pk.
- C. **fusiforme** Hedgc. & Hunt ex Cumm.
- C. **strobilinum** Hedgc. & Hahn

Of these species only **C. comandrae** and **C. strobilinum** can be easily distinguished. **C. comandrae** has very distinctive aeciospores, and the telial stage is found on **Comandra umbellata** (L.) Nutt. **C. strobilinum** bears aecia only on the cones of slash and longleaf pine, and both the uredial and telial stages on oak leaves are reported to be very distinctive (135).

Verrall (353) found in east Texas a gall-forming pine-oak rust that differs from **C. quercuum** and **C. fusiforme** in physical appearance and phenology on pine, although the uredia and telia resemble those of **C. fusiforme**.

The pine-oak rusts have been the subject of considerable debate as to whether they are one species, varieties of one species, or three species (9, 10, 133, 255, 377, 381). Arthur (12, 13, 15) classed all of the pine-oak rusts, including **C. strobilinum**, as **Cronartium quercuum** (Berk.) Miyabe ex Shirai. Hedgcock and Siggers, in disagreement with this classification, considered the four American species, **C. cerebrum**, **C. fusiforme**, **C. conigenum** (Pat.) Hedgc. & Hunt, and **C. strobilinum** to be distinct from each other and from C. quercuum (135). This is a change from the earlier conclusion of Hedgcock and Long that C. fusiforme and C. cerebrum are identical, and not even sufficiently differentiated to constitute separate races (134). Spaulding (317) commented that C. quercuum and C. cerebrum have been accepted as identical until recently when significant differences were found. He does not cite any references, and may have been commenting on the publication by Hedgcock and Siggers (135).

Nomenclature in the rusts was confused and ambiguous until 1950, when the adoption of Article 69 of the International Code of Botanical Nomenclature established the basis for naming the rust fungi (197). By this ruling, the name of the perfect (telial) stage is set up without reference to any corresponding epithet for an earlier imperfect stage. Utilizing the earlier publication of Hedgcock and Hunt (268), Cummins (57) legalized the combination **Cronartium fusiforme** by a Latin description and references to the type specimen.

The synonymy of this rust is:

Cronartium fusiforme Hedgc. & Hunt ex Cumm.
Mycologia 48: 603. 1956.

Cronartium fusiforme (Peck) Hedgc. & Hunt
Phytopathology 8: 316. 1918.
(Nomen nudum)

Cronartium cerebrum (Peck) Hedgc. & Long
J. Agr. Res. 2: 247. 1914.
(Pro parte; Nomen nudum)

Peridermium fusiforme A&K
Bull. Torrey Bot. Club 33: 421. 1906.

Cronartium quercuum (Berk.) Miyabe ex Shirai
Bot. Mag. 13: 74. 1899.
(Pro parte)

Peridermium cerebrum Peck
Bull. Buffalo Natur. Sci. 1: 68. 1873.

Hedgcock and Hunt cited **Peridermium** fusi-rme Peck in synonymy when they established the ew combination C. fusiforme (268). This obously was a lapse, since there is no evidence that eck ever used the specific epithet P. fusiforme. y 1914, Hedgcock and Long formed the combiition **Cronartium cerebrum** by using Peck's P. rebrum as a base (134, 248), and later, in 1918, edgcock and Hunt noted Arthur and Kern's P. siforme as a species distinct from Peck's P. cereum (133). However, in 1914, Arthur and Kern had cited their P. fusiforme (14) as a synonym of **P. cerebrum** Peck, thus tacitly acknowledging these to be the same species (15).

Apparently Arthur (12) was on firm ground in relegating C. fusiforme, C. strobilinum, and C. **cerebrum** to synonymy with C. **quercuum.** The type specimen of C. quercuum is American, which makes C. **cerebrum** a synonym (13). Since C. **cerebrum** was the base of C. fusiforme, legally any of the pine-oak rusts must be referred to C. **quercuum** regardless of the pine host or geographical range.

Several alternate possibilities may be developed.

1. The pine-oak gall rusts are all one species, and the gall shape results from the host-reaction only, possibly as an expression of host physiology or genetics. Evidence for this conjecture is the consistent occurrence of only globose galls on shortleaf pine.
2. The rusts are varieties or races of the same species. Both globose and fusiform galls are formed on one host species, loblolly pine; witches'-brooms develop very frequently on the fusiform galls but never on the globose galls (31).
3. The rusts are taxonomically and physiologically distinct species.

The techniques for testing these hypotheses are feasible but time-consuming. The first requirement is a supply of aeciospores collected in various parts of the country and authenticated as to the putative rust species. After oak hosts are successfully inoculated, the sporidia can be used to inoculate the southern pine species, in all combinations. Since multiple infections often occur on the same pine tree it would seem feasible to inoculate different branches of one host tree with various species or races of the rust, thus eliminating variations due to host reaction. After the pine hosts have been successfully inoculated, microchemical or serological tests of the gall tissue can be made to detect similarities or differences. Serological comparisons of homogenates from ungerminated aeciospores of C. fusiforme and C. **quercuum** are reported to be antigenically different (105). Anatomical studies and compatibility tests with the pycnial fluid may also be useful (56). Dwinell reports that black oak, Quercus velutina Lam., is hypersensitive to infection by aeciospores and urediospores of C. fusiforme and normosensitive to C. **quercuum** (80).

Regardless of the reaction of the aecial hosts to the disease, it is impossible to differentiate these species by reference to the legal diagnoses. Boyce (32) comments that the uredia and telia of C. fusiforme cannot be distinguished from those of C. cerebrum. The published descriptions (57, 135, 268) of the uredinal and telial stages are sufficiently broad and generalized to encompass the normal range of variations encountered in the field; the mean dimensions of any spore form of C. fusiforme fall within the published range of that form of C. quercuum. When the intergradation of a major population is so nearly complete that it is difficult to tell where one begins and another ends, the only practical solution is to describe the group as a single variable species.

It would appear, then, that the pine-oak gall rusts in the South probably are no more than specialized forms of C. quercuum. Both globose and fusiform galls may be found on the same tree; frequently a gall may be globose on one end and tapered at the other (255). Globose galls may elongate to a fusiform shape in 1 year. In the nursery, many rust-infected seedlings develop globose galls, although a high percentage have the typical fusiform gall (133). Hedgcock and Siggers report that inoculating pines with sporidia from authentic C. cerebrum resulted in fusiform swellings that later became spherical (135).

Even cross inoculations are not conclusive. Hedgcock and Siggers (135) report that inoculation of slash, longleaf, and loblolly pine seedlings (among others) with telia (sporidia) of C. strobilinum resulted in infection of these seedlings, with small galls on the slash and loblolly, and "a surprising amount of mortality."

Another interesting feature of the taxonomic problem is the possibility that spot identification based on "typical" fusiform galls may be erroneous at times. Cronartium comandrae has been reported recently on shortleaf pine in Missouri and Arkansas (24) and on loblolly pine in Tennessee (266). Earlier records show that this species has been collected on loblolly pine at Mt. Olive and Moss Point, Mississippi, both localities in fusiform rust territory (230). An authenticated herbarium specimen of a comandra gall on shortleaf pine was examined by the writer and appeared to be identical with a fusiform rust gall. Thus, infection by C. comandrae may account for the occasional report of C. fusiforme on shortleaf pine. Minor differences in gross appearances between these two fungi, such as the nature of the peridium, may be overlooked, especially if the peridium is ruptured.

Genetics and Variation

Although physiologic races are common in the cereal rusts (11, 12), races of Cronartium have not been conclusively demonstrated (117, 140). The wide range of host species suggests that the fungus evolved simultaneously with its hosts, and that for the most part a gene-to-gene relationship for susceptibility does not exist (249). In any event, physiologic races usually are less likely in the haploid mycelium (in pine) than in the dicaryotic form (on the oaks). Thus, there may be races with different abilities to produce telia and sporidia.

However, the first recognizable, consistent variation in the fungus was the recent discovery of white aeciospores on two galls (182). These aeciospores were used to inoculate oaks, which produced white uredia and sporidia. Subsequent inoculations of slash and loblolly pine resulted in the development of white aeciospores again (181). It is not known whether the white-spored form is a distinct race of the fungus or only a color mutation. The infection pattern (development of signs and symptoms, incubation time, gross appearance of the galls) of the white-spored form is identical with that of the normal orange-spored form. Lines developed from single uredial pustules show a diffuse pattern of segregation by the pine spore stages, with a range in color of pycnia and aecia from white through intermediate yellow to the typical orange color.

It is of interest that the autoecious Peridermium harknessii J. P. Moore has an albino strain that is widely distributed on ponderosa pine (229).

Life Cycle and Spore Forms

Cronartium fusiforme has five spore forms, which are produced in succession. The life cycle is complete in 2 years or more.

Infection of the pine host by sporidia from the oaks occurs in early spring, producing a septate, branched, intercellular, uninucleate mycelium characterized by wide hyphae (3.0 to 4.3 μ averaging 3.5 μ) and inflated haustoria (166, 176). This mycelium produces pycnia in extensive, shallow cavities under the epidermal layer of the galls.

At maturity, the oblong to elliptical pycniospores average $2 \times 3.8\ \mu$ in size and are exuded in viscid, yellow-tinted drops according to Hedgcock and Siggers (135). Buller, however, working with specimens sent to him by Bailey Sleeth, reported that the exposed pycnidia, including masses of pycnidiospores, are bright orange-red (41). Our own observations agree with Buller's description, and chemical analyses show carotenes, which are characteristically orange-red, within the spores.

The pycnial drops appear to be attractive to many insects. Ants of several species swarm about the bases of infected seedlings in autumn and early winter and often are found on seedlings in which the swelling or gall is barely perceptible.

The function of the pycniospores is still controversial. They are not infective, since repeated attempts to inoculate the hosts with them have been unsuccessful (11, 101). Craigie (51) concluded that they function in diploidization of the rusts, a conclusion supported by Cummins (56). Craigie deduced that the mycelia which produce the pycnia are of two kinds (+ and —), each derived from a uninucleate sporidium. All of the pycniospores of a pycnium are of the same sex, and function as spermatia. Certain hyphae (flexuous hyphae) in the host tissues serve as receptive cells, and upon receiving spermatia of the opposite sex become binucleate and then initiate the dicaryotic phase. The nuclei are conjugate, however, and do not fuse until the telial stage is reached (56).

Hyphal fusion and nuclear migration between cells at the beginning of the aecial stage have been demonstrated in the majority of the rusts (11, 52, 404).

It is unlikely that pycniospores are nonfunctional. The rusts are extremely specialized and variable and unnecessary spore forms have tended to disappear. Physiologic specialization (races) of the cereal rusts is conceded to be genetically controlled, and thus sexuality is implied. Buller (41) observed that specimens of C. fusiforme and C. cerebrum from Mississippi and Florida had flexuous hyphae, similar to those of C. ribicola. He inferred that these hyphae initiate the sexual process.

Pycnia are produced 1 to 2 years after infection, and the pycnia and aecia are formed in alternating generations on the same galls, the aecia appearing the year after the pycnia (the following spring) (135). Wolf and Wolf (404) state that pycnia do not repeat themselves but occur only once in the life cycle.

Pycnial production is reported to occur from October to April (135). However, systematic observation of galls for 4 years disclosed that the pycnial ooze first appeared about mid-October, but ended either in mid-November, early December, or mid-December. Jewell et al. (176) state that pycnial sporulation occurs from late October to mid-December, and agree that aecia follow the pycnia immediately, being produced on the same gall although not in the same area of the gall. In our own laboratory, pycnia developed within 6 months after inoculation of pines with sporidia. The dates that pycnia first appear are considered to be diagnostic criteria to differentiate between C. fusiforme and C. quercuum; C. fusiforme appearing from October to April; C. quercuum from December to February (135, 379). Systematic observations revealed no definite pattern or sequency of pycnial-aecial sporulation. Pycnia were sometimes followed by aecial sporulation for 2 or 3 consecutive years, but usually aecia developed in the same area of a gall where pycnia had been produced the previous autumn.

The mechanism of pycnial and aecial sporulation should be investigated. Pine seedlings maintained in the greenhouse under a uniform temperature (70 to 85° F.) and at a constant day of 20 hours produced pycnia about the end of October, even though the plants were inoculated at different times from early December to mid-June. Thus the date of pycnial sporulation was influenced neither by the length of time the rust had been established in the pines nor by the differences between greenhouse conditions and those in nature.

Of the hundred or more species of rust known to infect pines in the genera Cronartium, Peridermium, Coleosporium, and Melampsora, the pine hosts always bear the aecial stage (11, 12, 414). In Cronartium the aecial mycelium is perennial in the pine host, and may form aeciospores from the same infection many years in succession (11, 41, 50, 66). The aeciospore initials first cut off from two to 10 apical peridial cells with rudimentary intercalary cells, forming the peridium, a tissue enclosing the sorus. Subsequent divisions of the aeciospore initials form binucleate aeciospores, each with an intercalary cell, developing into long chains of aeciospores (50, 82).

Each aecial sorus of C. fusiforme produces tremendous volumes of thick-walled orange spores that average $15.5 \times 25.1\ \mu$ and range from 13-18 $\times$ 22-28 μ (135). The spores are obovate to ellipsoid, and coarsely verrucose but generally with a smooth area at the broader end and extending up one side. A definite germination pore is not present; the germ tube emerges by dissolving or rupturing thin areas of the cell wall. Frequently multiple germ tubes emerge from different parts of the spore (368.)

The aeciospores are capable of germination as soon as they are released from the sorus. They maintain high germinative capacity for 2 months or more when stored at temperatures below 10° C. (290). Successful storage requires careful drying over calcium chloride for several days to reduce contamination and deterioration by **Penicillium** and other species of molds (4, 276, 370), and screening to remove extraneous matter, such as insect larvae. The spores maintain high viability during storage in liquid nitrogen at —196° C. (376). Loss of viability is associated with a gradual change in color from orange to gray (135, 290).

The loss of color is related to a chemical degradation of the carotenes that give the spores their orange appearance. This degradation is not the cause of lessened viability, since faded spores frequently germinate very well. Furthermore, the white-spored form had only traces of the carotenes in any of the five spores, but viability was excellent (182).

The aeciospores are formed and disseminated in early spring, from February to April (135). They apparently are food for insects (11); frequently they disappear abruptly at the close of the season, and the aecial cavities appear to have been scraped clean. Hirt (149) states that the aecial sorus of **C. ribicola** Fischer is a discrete structure, which may be removed intact before the peridium ruptures. This observation holds true for **C. fusiforme** also, and probably accounts for the sudden disappearance of the spores.

The aeciospores are carried by wind and air currents to the oaks, where they germinate on the leaves. Germination in the laboratory takes place in 2¼ to 4 hours, at an optimum temperature of 21° C. Good germination occurs over a range of temperature from 17 to 22° C; the lower and upper limits for germination are 11 and 29° C. (290). The aeciospores require only an endogenous supply of water: nutrients added to the germination medium rarely affect the process, although citric and oleic acids cause some stimulation, especially of spores after storage (368). Products of lipid metabolism, including lower-chain fatty acids, are inhibitory (365). Nc dormancy occurs, but aeciospores produced during prolonged cold wet weather may be nonviable.

Artificial inoculations indicate that infection occurs only on young leaves (135, 313). A decrease in susceptibility with age has also been reported for leaves of **Ribes petiolare** Dougl. inoculated with **C. ribicola** (261). On the other hand, leaves of **Ribes triste** Pall. do not become infected when very young, nor when hardened; infection is limited to fully expanded leaves (116).

One of the gall-forming rusts on pine, **Peridermium harknessii**, is facultatively autoecious; that is, the aeciospores are capable of reinfecting pine (226, 227, 254, 356). On Scotch pine, the Woodgate rust (207, 221, 292) apparently is also propagated by aeciospores, since the telial stage and alternate host are not known. This phenomenon has prompted attempts to show that the aeciospores of **C. fusiforme** may reinfect pine, but all trials have been unsuccessful (135).

It is entirely possible that both autoecious and heteroecious forms of **C. fusiforme** exist. Pine-to-pine infection would not be possible with spores from the heteroecious form (221). The autoecious form, if it exists, must be only a very small part of the rust population, and the probability is very great that it has not been used in inoculation trials. A common criterion for identifying autoecious forms is the absence of pycnia (226, 227, 333). However, the pycnia of **C. fusiforme** are produced 6 months or more before the aecia (135, 176), and the identification of the autoecious form would require very careful, repeated examination of many galls for several years. The attempt might be inconclusive even then, since there is also the possibility that the aecial form may be repeated for several years on the same gall, while the pycnia do not repeat themselves (404).

Germination of the aeciospores results in a binucleate mycelium in the oak leaf tissue, from which uredia and telia are produced. The mycelium in the oak leaf is massed in the mesophyll, but ramifies into the palisade layer and under the upper epidermis. The greater mass of the mycelium develops in the region of the lower epidermis, where the uredia and telia are formed. The haustoria are small in the early stages of infection, but gradually expand. Usually only one uredium, followed by one or more telia, is produced by the mycelium derived from one aeciospore infection (82).

Within about 1 week after inoculation, the hyphal tips of the rust in the oak leaf become aligned into a pseudopalisade beneath the lower epidermis. Two or three cells are cut off from each hypha; these become the peridium. Relatively large rectangular basal cells are then formed under the peridial cells. These basal cells divide, forming an elongated binucleate cell and a residual basal cell. The elongated cell rounds off into a urediospore, and again divides to form a relatively vacant stalk cell (intercalary cell) attached to the urediospore cell. When the urediospores are mature, they detach from the stalk cell (82).

In 9 to 11 days after inoculation the uredium appears as a very small (0.14 × 0.16 mm.), pale green spot on the host leaf (135). The developing uredium ruptures the lower epidermis of the leaf, and the peridium ruptures almost immediately thereafter (82). Occasionally uredia and telia may be formed on both upper and lower leaf surfaces (173). Cummins' (57) type description of the uredia indicated sparse, minute sori with a central opening and a tenuous peridium on the lower surface of the leaf.

The urediospores are ovate to obovate, averaging 13 to 16 × 17 to 24 μ, hyaline, thick-walled (2 to 2.4 μ), echinulate (57). Hedgcock and Siggers (135) indicate average dimensions of 13.3 × 19.1 μ, with the intersextile range of 12 to 15 × 17 to 21 μ, and walls 2.0 μ thick. The presence of carotenes in droplets within the protoplasm gives the spores an orange color. The white-spored form of C. fusiforme produced colorless urediospores, with only traces of carotenes.

The urediospores are capable of reinfecting the oak host under certain conditions. Siggers reported that initial inoculation of oak leaves resulted in secondary uredia in only 33 percent of the cases and that oak inoculation could not be carried beyond the second generation in the greenhouse (135). However, in the greenhouse at Gulfport, successive urediospore inoculations have been carried on for several years at approximately 10-day intervals. On the other hand, the urediospore stage apparently is not essential in the life cycle of C. fusiforme. Aeciospore inoculation of older oak leaves results in the production of telia without intervening uredia (82, 313).

Secondary infections probably are not common in nature. Uredia are relatively rare in the field; the most common signs of oak infection are the telia. At Gulfport, hundreds of susceptible oak seedlings have been grown without infections on the same greenhouse bench with seedlings bearing uredial pustules. Urediospores begin germination in 1 to 1½ hours. The optimum temperature is 18° C., with good germination over a range of 15 to 20° C. The upper and lower thermal limits are 8 and 29° C. (290).

Uredia on oak leaves have been observed to appear and disappear in 18 days (291). The urediospores are capable of limited germination (and infection) after 223 days of storage at 4 to 10° C. (290). For some rusts the temperature at which the urediospores are produced will influence both the germinative capacity of the spores and their response to storage. With cereal rusts, urediospores formed at 16° C. had better viability and germination than those which developed at 22 or 29° C. (150).

Urediospores of selected strains of C. fusiforme, including the white-spored form, are in liquid nitrogen storage in the American Type Culture Collection.

Telia are formed from the same mycelium as the urediospores (82). Inoculations of oaks with aeciospores produce telia more frequently than uredia (135). When the supply of nutrients or condition of the host is unfavorable for production of uredia, the rust may grow directly from the aeciospore mycelium to the telial stage (10).

Hedgcock and Siggers reported that telia were produced on the lower surface of oak leaves in about 20 to 35 days after inoculation with aeciospores (135). Siggers later found that teliospores developed and germinated 8 days after inoculation of oak leaves with aeciospores, and concluded that the primary telium developed in 6 days after inoculation (290). In our own studies at Gulfport, Mississippi, the average time for telia to appear was 7 ± 1.5 days after aeciospore inoculation. Seven percent of the inoculated plants produced telia in 5 days. Urediospore inoculation produced telia in 8.5 ± 1.5 days; 8 percent of these inoculations produced telia in 6 days.

The telia develop from February to June, appearing as dark brown, cylindrical or thread like structures averaging 0.1 mm. in diameter and 3 to 5 mm. in length (57, 135). Neither color nor dimensions of the telia should be considered diagnostic features. In the greenhouse at Gulfport we have observed numerous telia more than 15 mm. long, and Hedgcock and Siggers note that length may be related to age and environment (135).

When telia follow uredia, the teliospores and telia develop from the same mycelium as the uredium; generally one to three telia develop on the circumference of the uredium. Whether telia are produced alone or follow the uredia, their early stage is similar to that of the uredium: a pseudopalisade is formed, with basal cells. After the peridial cells are formed successive divisions of the hyphal tips form chains of teliospores only; there are no intercalary (stalk) cells (82).

Telia normally form on the lower surfaces of oak leaves, but occasionally are amphiphyllous (173), and a telium has been found on young stem tissue (83).

From 10 to 50 or more chains of teliospores appear simultaneously, each chain becoming cemented to its neighbors by a material, called the matrix, that probably is an end product of the process by which the teliospore reaches quick maturity. The average daily growth of a telium is about 100 μ (290). Since the spores are produced by divisions of the teliospore initials at the base of each chain, those at the tip of the column are more mature than those at the base (82, 135), and germinate earlier.

Siggers reported that the teliospores are not viable if separated from the telium matrix (290), but he admits that the techniques used for separation — boiling the telial column in 4-percent hydrochloric acid, or nitric acid — are not likely to maintain viability. Both Siggers (260) and Pierson (290) state that the matrix is pectin, a conclusion supported by our own tests. Microchemical tests (114) for various plant substances were negative for all but pectin, but digestion with a wide range of pectinase solutions for up to 24 hours failed to affect the telium matrix. Digestion for longer periods of time resulted in bacterial decomposition of the telium.

The matrix is considerably harder than the teliospore walls. Attempts at mechanical separation only rupture the spores. Yet the delicate probasidia from spores interior to the column readily make their way through the matrix to the outside.

Teliospores are single-celled, thin-walled, oblong to oblong-fusiform; dimensions are 12 to 16 $\times$ 30 to 44 μ (57) or 10 to 20 $\times$ 25 to 54 μ (135). Their color is masked by the dark matrix. Chemical analyses are inconclusive, because of the matrix, but the teliospores contain the same carotenes found in the other four spore forms, as well as unidentified alcohol-soluble pigments that probably are polyphenol compounds.

As a general rule, germination of the teliospore produces a four-celled probasidium, each cell of which bears a basidiospore or sporidium on a short sterigma. Although nuclear details have not been confirmed for **C. fusiforme**, it is assumed that the paired nuclei fuse during maturation of the teliospore, that reduction division occurs early in the course of probasidial development, and that each of the four daughter nuclei resulting from the reduction division migrate to one of the sporidia and re-establish the uninucleate phase of the rust (50).

The teliospore of most rusts is a resting spore, but in **C. fusiforme** it is capable of germination soon after the telia are formed. That is, the spores apparently do not require a dormant period for maturation. The absence of a resting period for teliospores is characteristic of the microcyclic lepto forms of rust (404), but Arthur (11) observes that it is an adaptive feature, without taxonomic significance.

Teliospores of **C. quercuum** remained viable up to 40 days (241). Siggers (290) observed that only a few telia of **C. fusiforme** had viable spores after approximately 35 days' storage at temperatures up to 35° C., and concluded that most of the fungus in the leaf tissue had been killed by exposure to the heat and dryness. His tests were conducted with only segments of oak leaves, and under natural conditions on intact leaves the telia may be viable for longer periods.

Telia produced substantial numbers of sporidia 32 days after their appearance, but spore production was negligible at 46 days (267). Teliospores began to germinate in less than 1½ hours in an atmosphere of high humidity (306). Germination first occurred at the tip of the telial column and continued in a progressive manner to the base of the telium. Drying the telium soon after teliospore germination began, then incubating it again, resulted in germination of teliospores nearer the base of the telium.

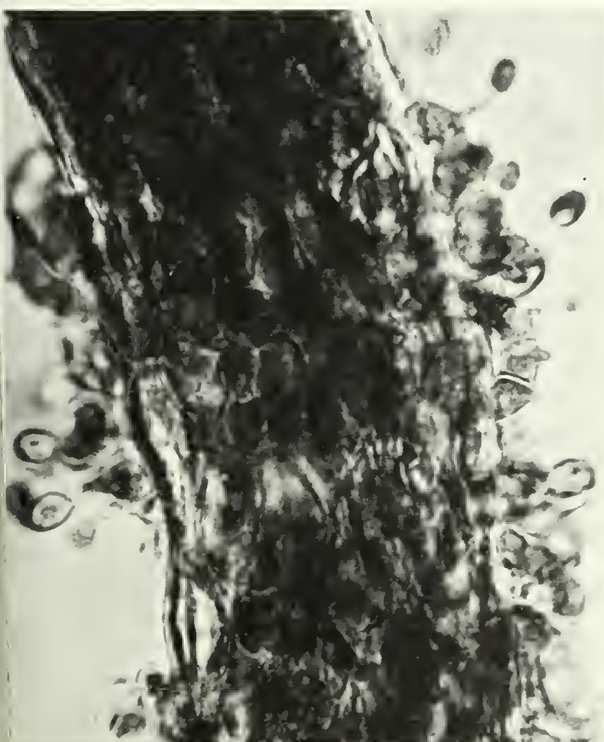
The number of successive germination periods through which the telia may pass depends on the length of the telium and the length of time that high humidity prevails (306). Six to ten hours of high humidity may induce germination of only some of the teliospores, leaving the remainder capable of germination at some later date. Telia of **C. fusiforme** incubated at 20° C. over water agar sporulated continuously for more than 10 days. Telia which germinate under water, or under low oxygen stress, give rise to mycelial-like strands instead of probasidia (188).

Teliospores germinate well at temperatures between 17 and 23° C., and the optimum is about 21°. Siggers (290) found that germination did not occur at temperatures below 15° or above 26° C., but Snow (306) obtained limited and delayed germination at 12° C.

The sporidia are abjected from the pro-mycelium approximately 3 hours after germination of the teliospore, according to Siggers (290), but the time required varies with environmental conditions (188). In a saturated atmosphere, sporidia have been collected 1½ hours after the telia were incubated (306).

The sporidia are considered to be very sensitive to adverse conditions, and quickly lose their germinative capacity. Sporidia which had been deposited on a glass slide became plasmolized in a few minutes after they were removed to the relatively dry atmosphere of a greenhouse (290). They begin germinating in about 2½ hours, at an optimum temperature of 22° C., although germination of 13 to 93 percent occurred at temperatures from 19 to 25° C. Germination failed at temperatures below 15 and above 26° C. (290). The optimum temperature was 20° C. (307). In the laboratory germination occurs only in water, or in a saturated atmosphere (147, 290).

Kais (180) described the sporidia as one-celled, ellipsoid to ovoid, smooth, thin-walled,



Sporidia produced by germinated teliospores in a telial column. (X500)

apiculate, and with a granular content. The mean dimensions of normal orange sporidia are 12.8 $\pm$ 1.3 $\times$ 9.6 $\pm$ 0.8 μ, with maximum range of 9.3 to 18.6 $\times$ 7.0 to 12.8 μ. Dimensions of the white-spored form (182) are not significantly different.

Secondary, tertiary, and quaternary sporidia are commonly formed when primary sporidia germinate (147, 180, 188, 233), and are also capable of infecting pines (275). The successive sporidial forms may have a survival value to the fungus, since they frequently are produced and abjected forcibly when the primary sporidium germinates on plants that do not normally become infected (233).

The abjected sporidia are carried by air currents. They germinate on the surface of the pine needles (occasionally on juvenile bark), and the germ tubes enter the host through stomata or occasionally by direct penetration (16, 148, 246).

Physiology

The physiology of C. fusiforme has been studied in detail only with respect to temperature requirements for spore germination, and to sensitivity to fungicides of the spores and mycelium. Some spore-germination studies have been conducted on the host plants in the greenhouse (82, 181, 307), but most have been done in vitro. Many substrates, humidities, temperatures, and spore ages have been evaluated (135, 290). Temperature requirements for each spore form have already been discussed.

When optimum conditions for spore germination are established, these are assumed to be applicable to field conditions and are made the basis for recommendations on control of the disease (95, 96, 97, 106, 107, 292, 297, 351, 363). Occasionally however, control recommendations fail to allow for the range of favorable conditions, or for the possibility of spore germination under adverse conditions (77, 410).

Practically all investigators agree that the humidity necessary for spore germination must be close to saturation, possibly 97 percent or higher (11, 48, 147, 290, 309, 319, 344), and that urediospores and sporidia germinate best on a free water surface. Germinative capacity will vary considerably with the kind and duration of moisture conditions that the spores encountered prior to incubation (200, 241, 306, 310, 345, 346).

Germination usually is assessed in free water on a microscope slide, or in the humid atmosphere of a Van Tiegham cell (147, 290). Excellent germination is obtained on distilled water agar (123, 233, 241, 365, 366, 368), particularly if the glassware is thoroughly cleaned with sulfuric acid-bichromate solution (211). No particular advantage is gained from various artificial media (11, 46). Use of host plant extracts in the germination substrate (11, 36, 394), has given disappointing results, but it is claimed that the age and maturity of the host tissues have a marked effect on germination (150, 290, 261, 276, 321).

Compounds other than extracts of host tissue have been reported to stimulate germination in vitro. Among these are hydrogen peroxide, sugar solutions, vitamins, and some organic acids (11, 98, 257, 303, 370, 394). However, neither vitamins nor hydrogen peroxide stimulated germination of C. fusiforme aeciospores (365). In some cases, germination of other rust spores is stimulated by fungicides in low concentrations (242).

In the laboratory, both the pH of the medium and the composition of the buffer solutions used to adjust the pH have a decided influence on spore germination. All spore forms of C. fusiforme germinate over a wider range of pH (4.5 to 7.0) in vitro than occurs in or on the host plants. Acetate and bicarbonate buffers are inhibitory to germination, even in the presence of otherwise stimulatory compounds (365).

Inhibition may be caused by environmental factors, such as light intensity (71, 84, 122, 150, 196, 224, 247), an excess of carbon dioxide, or a lack of oxygen (11). Fatty acids C_1-C_{12} inhibit aeciospore germination of C. fusiforme (365, 366, 367). Some complex organic acids, produced within the spores by the metabolism of the rust itself, act as self-inhibitors (5, 322, 327, 365, 400). Self-inhibitors of C. fusiforme aeciospores probably are volatile or water-soluable substances; attempts to germinate aeciospores in mass usually are unsuccessful, although the same spore lot will germinate well when the spores are dispersed. Gelatin granules absorb the self-inhibitor, permitting germination in mass (365). From the ease with which they can be germinated, urediospores and sporidia of C. fusiforme appear not to have a self-inhibitor.

Most inorganic salts (as those of potassium, sodium, magnesium) have no effect on spore germination, but salts of the heavy metals (mercury, copper, iron, zinc) are toxic (49, 70, 99, 157, 183, 258, 316, 373, 396). Nickel chloride is toxic even at low concentrations (93, 365). Toxicity effects probably are the result of protoplasm degradation following penetration of the spore wall by the toxic molecule. The spore walls apparently are highly permeable even to large molecules such as those of cycloheximide (365). Surfactants have been reported to damage the cytoplasmic membrane irreparably, allowing the cell contents to leak out of spores (90).

The influence of light—intensity, duration, wavelength, and alternation of light and dark periods—needs further investigation. In other rusts, even the more resistant aeciospores and urediospores are adversely affected by blue and ultraviolet light but germinate well in red or white light (71, 224). Germination of aeciospores and sporidia of C. fusiforme is almost completely suppressed by irradiation with ultraviolet light (2537A) at 70,000 ergs/cm.^{2}, though the sporidia gradually recover and produce secondary sporidia 2 or 3 days after irradiation. The aeciospores undergo bacterial decomposition without recovering. The significance of suppression and recovery of sporidia after irradiation is obscure. Although 2537A is lethal to most fungi and bacteria (189, 262), this wavelength can produce hydrogen peroxide from water. The peroxide is said to stimulate spore germination (11).

Complete darkness at the time of inoculation and in the early stages of infection reduces incidence and severity of infection by urediospores of Puccinia graminis (122). Teliospores of nearly all rust species germinate more readily if exposed for several days to alternating light and darkness, while continued darkness inhibits germination (11). After germination, establishment of the fungus (formation of appressoria and host penetration) requires light intensities of from 2,000 to 5,000 foot-candles. Above 9,000 foot-candles, the effect of light is inhibitory (84).

The coincidental loss of aeciospore viability with a change in color from bright orange to grey (135, 290) suggests a gradual loss or oxidation of a pigment system within the spore. At Gulfport, chemical analyses showed that approximately 15 percent of the dry weight of aeciospores was lipids, chiefly alpha and gamma carotenes.

Although a gradual loss of carotenes is associated with aging of the aeciospores, it does not appear that the carotenes are sources of energy for germination. High germination rates were found in some aged spore lots with very low carotene content. Aeciospores and urediospores of the white-spored form (182) showed only traces of carotene, perhaps from orange spores remaining in collecting equipment (252, 330, 331). Addition of carotenes to the medium did not stimulate germination. Reduced viability of stored, faded aeciospores can be partially overcome by the addition of citric or oleic acid to the medium (365, 370).

Until recently, studies of spore germination and artificial inoculations were possible only during spring, generally from March to May. Aeciospores are produced in the early part of this range, March and April; but urediospores are usually difficult to find, and telia frequently are nonviable by early May (135, 290). Storage of the rust spores has accordingly received considerable attention. Urediospores and teliospores of the cereal rusts have been stored for up to 3 years (179). Telia of C. ribicola are viable for 3 months, and telia on leaves of Ribes have sporulated after overwintering on the ground (318).

Successful storage of any spore requires that respiration be reduced. The reduction may be accomplished by freeze-drying or by storage in oil, in inert atmospheres, or at low temperatures (44, 47, 85, 118, 121, 165, 190, 200, 212, 213, 285, 286, 325, 366). Storage at 10° C. of **C. fusiforme** aeciospores for several months, and of urediospores for 223 days, was reported by Siggers (290). However, viability declined rapidly. Aeciospores stored at 1 to 4° C. maintain some viability for more than a year, and thus continuous stocks of aeciospore inoculum are available. At about 5° C., urediospores maintain good viability for approximately 3 months. Aeciospores and urediospores of C. fusiforme can be stored in liquid nitrogen (366). Freezing, freeze-drying, or refrigerated storage in an atmosphere of nitrogen has not been successful with any of the other spore forms of C. fusiforme.

The precise interpretation of spore germination tests requires standardized conditions and techniques, replications to establish confidence limits, and an adequate supply of spores (217, 218, 219). Above all, the pattern of germination of each spore form must be established within the effective temperature and humidity ranges. A population of spores represents a heterogeneous mixture of individual spores that vary in maturity, dormancy, and sensitivity; and a plot of germination over time usually results in a sigmoid curve, since the variations follow a normal distribution. A dosage-response curve, converted to a straight line by the use of a logarithmic-probability grid, permits an accurate determination of average germination percent under the conditions of the test (28, 75, 28). (This is the "LD-50" of fungicide tests, and here time may be considered equivalent to a fungicide, "dosage" being the units of time required for germination.) The slope of the dosage-response curve measures the variations in environmental conditions, and the age of the spore population.

The physiology of the fungus cannot, however, be studied by extrapolating from the results of germination tests. Spore germination is a phenomenon distinct from growth or establishment of the fungus. The rusts are obligate parasites, and are capable of only limited development except in the tissues of the host plant (409).

Cultures of rusts are maintained by inoculating plants of the susceptible host, then collecting the spores and inoculating the next host plant, which is usually the alternate host unless the repeating urediospores are used (46, 376). With fusiform rust, artificial inoculation of pine seedlings with sporidia (135, 170, 171, 172) and inoculation of oaks with aeciospores and with urediospores are well-known techniques (9, 10, 132, 134, 135, 290). These inoculations usually are separate and isolated operations; straight-line inoculations, to maintain continuity of the same mycelium, have been made with the white-spored form (181). Single-spore inoculations of pine with sporidia of **C. fusiforme** have been made at Gulfport, but with an extremely low degree of success.

The stage of maturity of the host tissues, both pine and oak, limits establishment of the rust (171, 298, 313). A greenhouse is required to maintain stocks of host plants in a susceptible condition (86, 247, 387), particularly at times of the year when outdoor conditions are unfavorable for infection. At Gulfport we found that a day length of 18 to 20 hours, produced by a combination of incandescent and special fluorescent lights, prevents dormancy of the host plants (86, 202). Temperatures were maintained near those prevailing in the spring (21 to 29° C.). Inoculations frequently were made at night, to take advantage of more favorable temperatures, and high humidities were maintained by intermittent mists actuated by short-cycle timers (344). Plants were covered with plastic bags for 24 hours after inoculation (320). The host plants were kept vigorous by fertilization and watering.

The effectiveness of these procedures may be recognized by the fact that at Gulfport repeated uredinial inoculations have been made at 10-day intervals for more than a year; telia and sporidia can be produced on demand and on schedule for chemical analyses or for inoculating pines. Pines have been successfully inoculated in every month of the year.

Inoculation techniques range from dusting aeciospores, urediospores, and sporidia on the host plant, to procedures such as inserting telia, or strips of agar with cast sporidia, into slits in the pine stem; injecting suspensions of sporidia into pines with a hypodermic syringe; and transferring the active mycelium from one plant to another by bark-patch grafting (46, 116, 135, 169, 171, 185, 245, 278, 344).

The technique developed by Snow (306, 307), is extremely effective. Two clear plastic boxes are connected by a short piece of tubing. Oak leaves bearing germinating telia are placed in the upper portion of one box, and the seedling to be inoculated is positioned in the other, smaller, box near the tube. A vacuum applied to the smaller box draws spore-laden air from the large box across the seedling. The number of spores per unit area of pine tissue may be adjusted by regulating the rate of airflow.

As knowledge of fungus physiology increases, it may be possible to develop procedures for maintaining C. fusiforme in artificial media. Some advances in this line have been made with the cereal rusts; structures similar to appressoria have been developed by manipulation of light and substrate (84, 163, 247, 412), and mycelium of one race of Puccinia graminis has been grown on artificial media (397, 398). Mycelium of the cedar rust has been successfully maintained in excised host-tissue cultures (59, 158, 159) and mycelium of C. ribicola on cambial explants (127) of western white pine.

Mycelium of C. fusiforme also has been maintained in slash pine tissue cultures at the Gulfport laboratory (369). Establishment of slash pine cultures has been more consistent, and with a higher percentage of success, than has been reported for other rusts. The use of infected tissue culture in a modification of the bark-patch grafting procedure (245) has possibilities for establishing clonal lines of the fungus.

The chemical composition of host tissues may limit both germination of the spores and establishment of the fungus. Aeciospores of C. fusiforme germinate equally well on susceptible or resistant oak leaves. The fungus does not become established in the older (resistant) leaves, although appressoria, the earliest infection structures, are common (135, 290, 313).

The nature of stimulation or inhibition of rusts by the host tissues has not been determined (34, 35, 38, 62, 63, 98, 119, 244). Some host plant metabolites, particularly organic acids, have a pronounced effect on in vitro germination and growth of C. fusiforme spores and hyphae (365, 370). They may stimulate or inhibit spore germination, accelerate germ tube growth and increase tube length, or cause reduced tube growth and multiple branching (368). The adaptive function of these modifications needs investigation. Accelerated growth and increased length probably are favorable for entrance and establishment. Multiple branching may interfere with penetration or may allow the fungus a greater number of entry points.

In general, the mode by which the germ tube of a rust fungus enters the host depends on the type of spore from which the hypha has arisen. Aeciospore and urediospore germ tubes generally enter through open stomata (82), while sporidia can penetrate directly (246), as well as through stomata (11, 16, 193). It is entirely possible that differences in mode of entry are strictly random. If stomatal penetration is significantly more frequent than direct penetration for some spore form, however, the tropic response of the germ tube becomes interesting. What are the factors that direct or attract the hypha to the stomate?

Variations in light intensity and moisture stress influence the stomatal mechanism of the hosts. If infection occurs primarily through open stomata, there may be times when the stomata are open for less time than is required for spore germination and penetration of the germ tube. This lack of synchronization may account for low rust infection in some years.

Direct observations have revealed that the aeciospore germ tubes may bypass several oak leaf stomata before penetrating one more distant. Therefore, for fusiform rust, germ tube length in vitro (148) may not be a valid index of capability for infection.

Establishment of the rust in the host is accomplished by the penetration of an absorbing organ, the haustorium, into a host cell (82, 269). After establishment of the fungus, a delicate balance between the rust and the host cells must be achieved. If the parasite withdraws too much nutrient, the invaded cell dies and the mycelium, deprived of nourishment, dies with it. Occasionally the invading mycelium is killed or arrested with little or no mortality of host cells; such host resistance may be either anatomical or physiological (16, 204, 402, 406, 407).

Development of the fungus is influenced by the amount of nutrients absorbed from the host, although there are differences of opinion as to the nutritional levels required for spore production (11, 49, 63, 287, 375). When something happens to reduce vigor of the host, there probably is a reduction in both the number and viability of spores formed. Conversely, incidence of infection and vigor of the rust increases with vigor of the host plants (222, 269).

Sporulation of other fungi in culture has been increased by the use of vitamins and growth-promoting substances (303, 394). With C. fusiforme, manipulation of the host environment and nutrition to increase or decrease the availability of host metabolites and hence to control sporulation has been accomplished with the oak hosts (312, 313) but not with the pines.

Radioactive tracers (389) may be used to evaluate the effect of host nutrition and composition on spore production. They have also been suggested as a means of measuring spore dissemination, but, since very low energy levels may be necessary to avoid injury to the fungus protoplasm, the problems in trapping and identifying tagged spores at any great distance may be insurmountable.

Inorganic nickel salts are absorbed by the host plants, and reduce the incidence of stem rust of wheat (91, 92, 93, 94, 258). There is evidence that these salts adversely affect the respiration of the fungus already established in the host plant (89). Nickel chloride solutions have reduced the incidence of fusiform rust in nursery tests, even when applied several days after inoculation (305).

Metallo-organic complexes, such as ferbam and nickel-amines, are particularly toxic or inhibitory to the rusts (49, 70, 155, 156, 215, 232, 380). Some of these compounds apparently are absorbed by the host plant, thus becoming systemic chemotherapeutants (72). Uptake apparently depends on the cumulative effect of the concentration and frequency of treatment (55, 231, 232). Fungicides also have a pronounced effect on the availability of nutrients to the host plant (70, 253), and indirectly on the parasites. In some cases, the rusts are stimulated by fungicides in very low concentrations (242).

Only a few antibiotics (organic chemicals derived as metabolic byproducts of fungus growth) are known to have any effect on fungi pathogenic to plants. Streptomycin, Terramycin, and cycloheximide are perhaps the most effective (7, 64, 87, 109, 115, 201, 235, 304, 328, 390, 391, 392). Cycloheximide has been relatively successful in reducing rust infections in several species of plants other than pine (8, 115, 203, 236, 391, 401). Its phytotoxicity limits the amount that can be applied, but formulations vary in this respect and the addition of chlorophyllin is reported to reduce the phytotoxic effect (8, 401).

Cycloheximide and its derivatives have a long and controversial history of use against the white pine blister rust (22, 73, 199, 203, 235, 236, 342). Part of its reported effectiveness apparently is due to the fact that, on some of the treated trees, the cankers were parasitized by Tuberculina maxima Rostr. which killed the rust fungus (22, 73, 131, 161, 162, 393). At Gulfport and at the Southeastern Forest Experiment Station, the cycloheximides were found to be phytotoxic to pines at concentrations below which they affected the fungus.

HOST RELATIONSHIPS

Although the most noticeable and damaging effect of fusiform rust is on the pine host, the disease is an interlocking complex of the hosts, the parasite, and the environment. Some part of this complex has been discussed with relation to the physiology of the fungus, and this section will consider the effects of the fungus and the environment on the host plants.

Spore Dissemination and Infection

Infection requires the production and dissemination of spores that must reach, germinate, and become established on and in susceptible host tissues. The number of spores in the environment commonly is summarized by the expression "inoculum potential" (74).

Laboratory studies of spore germination give an incomplete picture of the inoculum potential of fusiform rust. In the first place, the intensity factor is in itself a complex of spore source and the physical factors influencing dissemination of infective spores. Of these factors, perhaps the most important are the number of spores produced by the alternate host, the height from which the spores are released, the distance from the source to the host, wind force and direction, the weight of the spore, and the temperature and humidity.

The number of spores reaching a host will double as production at the source is doubled

(357); in general terms, the probability that a spore will travel a given distance is proportional to the number of spores released at the source. As distance from the source increases, the concentration and deposition of spores decreases very rapidly, the decrease in concentration becoming logarithmic (40, 145, 271, 399, 413). As the sporidia of C. **fusiforme** are produced during periods of high humidity, they are relatively heavy, and the distance to which they are carried by air currents becomes restricted. As humidity decreases they become lighter and may be carried longer distances, but at the same time are exposed longer to the lethal effects of dehydration and sunlight (198, 200, 262, 346, 358). Spore traps (154, 243, 281) have only recently been used in studying the fusiform rust, chiefly because of design inadequacies in older traps and the difficulty of identifying the spores (135, 180). That periodicity of sporidial discharge is related primarily to moisture conditions appears to be well established (309, 310, 346).

The height at which spores are released also influences the distance to which they are carried (145, 220, 405, 413). Spores from high sources generally travel farthest, but those produced near the ground frequently are elevated by successive thermal updrafts and kept aloft by turbulent air (274, 283, 359). Quite insignificant convection currents may be enough to counteract the terminal velocity of falling spores (110, 111, 220).

Attempts have been made to reduce infection in pine nurseries by eradicating nearby oaks (194, 195, 297, 363), but moderate to high percentages of infection have occurred in spite of oak eradication up to 1,500 feet (195, 302, 358). Sporidia of C. ribicola have been carried by wind 10 to 17 miles from their source (343).

The relative numbers and stage of development of telial columns on sample oaks near the nurseries frequently are used by nurserymen as an index of the need for fungicidal spraying. Here also results have been inconsistent, with occasional very high percentages of infection when telial counts were low. It was once thought that telial production in the upper part of the oak crowns is greater than that at 5 or 6 feet above ground, where counts usually are made. However, a recent study showed significantly more telia at the first 6-foot level than at 12 and 18 feet. It is possible that infection of the oaks generally is less severe in the relatively open areas near a nursery, and that more severe infections at considerable distances from the nursery produce enough sporidia to overcome the diluting effect of distance (343, 348, 349, 358).

No effort has been made to reduce the aeciospore load in the environment. To date, most attempts to control fusiform rust appear to have been derived from analogous practices used in controlling or limiting the cereal rusts and the white pine blister rust (332). Since each disease is an individual biological complex, there is no guarantee that procedures which control one disease will be equally effective with another. In the case of fusiform rust, eradication of the oak host, if it were feasible, would be biologically and economically unsound. The oaks are aggressive and persistent plants, and constitute a large and important component of the southern forests. Moreover both the pine and oak hosts must be considered in their capacities as reservoirs of infection. None of the spore forms are known to survive in nature more than a few months after they are produced. There is no evidence that the fungus remains alive in any oak tissue after abscission of the leaves.

The fungus is perennial only in the pine; living mycelia have been found in cankers more than 50 years old. One infected pine may have aeciospores for several years in succession (11, 41, 66), and for the disease to become epidemic on other pines a considerable amount of inoculum must first be formed on the oaks (292). The pines produce tremendous volumes of aeciospores; one small pine with multiple stem and branch galls probably has more infective spores than do several oaks. An average gall releases from 1 to 4 g. of aeciospores; it is calculated that there are approximately 240 million spores per gram (216). If we assume the lower yield of 1 g. per gall, 10 percent dissemination and deposition on oak leaves, and only 10 percent viability of these spores, we still have two million potential infective aeciospores from each gall. From one to three or more telia on oak are derived from each aeciospore or urediospore infection. Probably the host requires more than one spore, and possibly many spores in an infection court, for the disease to become established (171, 251, 349, 358, 402, 407, 410). Refined inoculation techniques will be required to elucidate both this point and the mechanism of hyphal penetration (148, 193, 250). Existing techniques (135, 171, 278, 279) are applicable only to "mass action" effects where an excess of spores is deposited on host plants to insure infection. Lamb and Sleeth calculated that the average infected water oak tree bears 223,000 telia (195). If, as discussed above, 10 percent of the deposited aeciospores germinate and establish a mycelium, more than 10 oak trees could be infected at the same intensity by the aeciospores from one gall. Furthermore, the aeciospores are less sensitive to adverse temperature and humidity, and apparently require less time for germination and establishment than do sporidia (290). Obviously, the pine is the main reservoir of infection, and it is logical to assume that control of the disease would be most effective if concentrated on the aecial stage.

The mechanism of infection on the oaks requires further investigation. In nature deposition of aeciospores on the oak leaf may be equal on both upper and lower surfaces (112), but light intensity and humidity differences may inhibit germination on the upper surfaces (48, 77, 84, 284). In C. **quercuum**, the infection cycle can be broken if the aeciospores are subjected to 2 or more days of adverse environmental conditions (241). While the germ tube penetrates the oak leaf chiefly through the stomata (82), artificial inoculation of the upper surface of oak leaves has occasionally resulted in infection (135).

The time needed for germination and establishment of the parasite in the hosts has been inadequately studied. Infections from aeciospores are reported to require 5 to 11 days for establishment; those from urediospores, 9 to 11 days (135, 290). Infection of pines, expressed as yellow-green (135) or purple spots on infected leaves, requires from 4 to 10 weeks (171). These, however, are gross observations, and the fungus probably becomes established in shorter periods of time. When sporidial germ tubes enter the needle of the pine, establishment of the rust in stem tissue becomes less likely with increasing distance from the stem (265).

In the oaks, C. fusiforme seems to exist only in leaf tissue. On rare occasions telia and uredia have been found on tender stem tissue after artificial inoculations (83), but the fungus has not been found in woody tissues of either naturally or artificially infected oaks. The haploid mycelium in the pine, on the other hand, grows through the leaf tissues and ramifies into the woody tissue (166, 168, 176, 178, 265).

Susceptibility and Resistance

The relative susceptibility or resistance of a host plant results only partly from variations in mechanical barriers to infection, such as the relative thickness of cuticles and the frequency of stomata and epidermal hairs. For the most part, susceptibility depends upon the physiological interrelationship between fungus and host. The host may lack nutrients essential for growth of the fungus, or the pathogen may be stimulated by the composition of the host tissues (119, 164, 222, 354, 407). Toxins may be produced by either host or fungus (29, 38, 204, 406).

For the oak hosts, the term "susceptibility" has been used very loosely. Sometimes it denotes susceptibility to invasion by the fungus, but more often it is used to express the capacity of the fungus to produce telia and sporidia.

From the literature, it is impossible to tabulate the relative susceptibility of species of oaks. Different criteria have been used by different investigators: the frequency with which trees of individual species were found to bear uredia and telia, the number of telia per leaf, the number of telia per unit area of leaf surface, and the number of telia per tree (135, 194, 195, 302). In some cases, failures of artificial inoculation on known natural hosts (135) may have been erroneously interpreted as a reversal of relative susceptibility.

Fifteen species and varieties of oaks are common natural hosts of C. fusiforme. In addition, 30 other species of Castanea, Castanopsis, Lithocarpus, and Quercus have been successfully inoculated with aeciospores and urediospores (132, 134, 135, 194). The known hosts are listed here; an asterisk precedes the name of each common natural host. The names in brackets are the current epithets for the species; the identity of the two Castanea hybrids has not been determined.

Castanea dentata (Marsh.) Borkh.
Castanea mollissima Blume
Castanea pumila Mill.
Castanea sativa Mill.
Castanea henryi × mollissima (?)
Castanea alnifolia × mollissima (?)
Castanopsis chrysophylla (Doug.) A. DC.
Castanopsis diversifolia (Kurz) King
Lithocarpus densiflora [=L. densiflorus (Hook. & Arn.) Rehd.]
Quercus agrifolia Née
*Q. alba L.
Q. bicolor Willd.
Q. borealis Michx. f. [=Q. rubra L.]
Q. californica [=Q. kelloggii Newb.]
Q. cerris L.
*Q. cinerea Michx. [=Q. incana Bartr.]
*Q. coccinea Muenchh.
Q. dentata [=Q. virginiana var. dentata

(Chapm.) Chapm. ex Sarg. = Q. virginiana Mill.]
- Q. digitata (Marsh.) Sudw. [=Q. falcata Michx.]
- Q. douglasii Hook & Arn.
- Q. emoryi Torr.
- Q. frainetto Ten.
- Q. gambelii Nutt.
- *Q. imbricaria Michx.
- Q. kelloggii Newb.
- *Q. laevis Walt.
- *Q. laurifolia Michx.
- Q. lobata Née
- Q. macrocarpa Michx.
- *Q. marilandica Muenchh.
- Q. michauxii Nutt.
- Q. montana Willd. [=Q. prinus L.]
- Q. myrtifolia Willd.
- *Q. nigra L.
- Q. palustris Muenchh.
- *Q. phellos L.
- Q. prinus L.
- Q. robur L.
- *Q. rubra L. [p.p.] [= Q. falcata var. falcata Michx.]
- *Q. shumardii Buckl.
- *Q. stellata Wangenh.
- *Q. stellata var. margaretta (Ashe) Sarg.
- *Q. velutina Lam.
- *Q. virginiana Mill.
- Q. virginiana var. fusiformis (Small) Sarg.

Most references in the literature state that the black oaks are more susceptible than the white oaks (104, 135, 137, 194, 195, 298, 299, 302, 351, 363). If only presence or absence of infection is considered, an analysis of the tabular data in Hedgcock and Siggers (135) shows that the white and black oaks are approximately equal in susceptibility, the weighted infection percentages of the two groups differing by less than 5 percent. If infective capacity is considered, however, the black oaks as a group consistently bear more telia than do the white oaks (20, 194, 195).

The authorities also state that water oak (Quercus nigra) is the most susceptible of the oaks (135, 298, 299, 351), although Lamb (194) considered the blackjack oak (Q. marilandica) and other "scrub oak" species (Q. rubra, Q. cinerea, etc.) to be most susceptible. Here again, the relative susceptibilities depend on the criteria used to evaluate them. The 1938 field notes of Lamb and Sleeth, the basis for the earliest publications on fusiform rust (194, 195), show considerable variation in the occurrence of telia on any oak species, depending on location and date of examination. On the average, Q. marilandica bore 28.9 telia per leaf for all leaves examined, against 14.9 telia per leaf for Q. nigra. When these data were converted to number of telia per average tree, Q. nigra had 223,000 telia and Q. marilandica only 65,000. The dense epidermal hairs on the lower surface of Q. marilandica leaves probably limit aeciospore infections.

There is somewhat more agreement on the relative susceptibility of the pines, as expressed by the formation of galls. Loblolly pine, and then slash and pond pine, are most frequently infected (298, 363). Longleaf pine has a practical degree of resistance; on similar sites, infection of longleaf pine would be only about one-tenth that of slash pine. In the writer's observation, Sonderegger pine (Pinus × sondereggeri H. H. Chapm.), a natural hybrid of longleaf × loblolly pine, apparently is as susceptible as loblolly pine, but it has not been included in any previously published list of susceptible species. The known hosts, native and exotic, are listed here (135, 170, 268, 282, 302):

- Pinus canariensis C. Smith
- P. caribaea Morelet
- P. contorta Dougl.
- P. cooperi var. ornelasi Martinez [=P. lutea var. ornelasi Martinez?]
- P. coulteri D. Don
- P. elliottii var. densa Little and Dorman
- P. elliottii var. elliottii Engelm.
- P. halepensis Mill.
- P. jeffreyi Grev. & Balf.
- P. mugo Turra
- P. muricata D. Don
- P. nigra Arnold
- P. nigra var. calabrica Schneider
- P. palustris Mill.
- P. pinea L.
- P. ponderosa [=P. ponderosa var. ponderosa Laws.]
- P. ponderosa var. scopulorum Engelm.
- P. pseudostrobus Lindl.
- P. radiata D. Don
- P. rigida Mill.
- P. rigida var. serotina [= P. serotina Michx.]
- P. sabiniana Dougl.
- P. × sondereggeri H. H. Chapm.
- P. sylvestris L.
- P. taeda L.

P. thunbergii Parl. [= P. thunbergiana Franco]

P. torreyana Parry.

Shortleaf pine and its hybrids have been considered immune to fusiform rust, although susceptible to eastern gall rust (135, 140, 169, 171, 174, 363). Nevertheless, a high percentage of slash × shortleaf hybrids, and some shortleaf × loblolly hybrids, have been artificially inoculated with fusiform rust (172). Some longleaf × slash hybrids also show significant resistance, apparently the effect of the longleaf parent (69).

Several southern pines are completely resistant, among them **Pinus** echinata Mill., P. virginiana Mill., P. glabra Walt., and P. clausa Vasey. In morphological characteristics and chemical composition of their terpenes (234) these four species are quite similar, being grouped in the same section (Banksia) in Pilger's scheme of classification (79). Whether chemical composition is responsible for their resistance is, however, a speculative matter.

Wakeley (364) measured incidence of fusiform rust in some 30-year-old longleaf pines whose seedling histories he had preserved. At ages 6 to 8 years some of these pines had appeared resistant to the brown-spot needle blight (Scirrhia acicola (Dearn.) Siggers), and these trees eventually developed more rust galls than those that had been infected by brown spot. The phenomenon is unexplained but may be the result of introgression with loblolly pine, which is relatively resistant to brown spot.

Variations in susceptibility of the pines may be a genetic factor not only between species but also between races. Genetic variation in resistance to fusiform rust among progeny of individual trees nas been reported for slash pine (20) and loblolly pine (186). When loblolly pines from widely eparated seed sources were planted on the same sites hey differed significantly in percentage of fusiform ust infection (1, 2, 53, 54, 141, 142, 362, 363, 385). The consistently higher percentage of infecion among trees from the same seed sources appeared to be a clear indication of differences in enetic susceptibility to fusiform rust. There is evience that natural selection operates to weed out isceptible strains and individuals in the pines, the irvivors and their progenies representing new, sistant strains (124, 175). The gradual replaceient or dilution of susceptible populations with sistant strains or hybrids will reduce the proporon of infected trees in our forests (259).

Anatomy and Morphology

Cronartium fusiforme apparently has very little effect on the oak host (135, 351). Except for the rare occurrence of uredia and telia on tender stem tissue (83), the fungus is restricted to the leaves. In the leaves, the mycelium derived from any one infection is limited in extent, and does not enter or cross the vascular system (82, 222, 269). Externally, growth and sporulation of the fungus ruptures the lower epidermis and causes a limited area of necrosis on the upper epidermis, directly opposite the uredium or telium. By late summer the invaded cells of the leaf die, and a "shot-hole" effect occurs if infection was scattered; with heavy infections, the entire leaf usually dies (135).

Detailed morphological studies of infection have been made by Jackson and Parker (166) in loblolly pine and by Jewell et al. (176) in slash pine. The anatomical changes leading to gall formation are similar in both species. As with several other rusts (50, 149, 177, 191, 333), the presence of the fungus stimulates both hypertrophy and hyperplasia in the cambial initials, resulting in an increase in the size and number of various cells. The most noticeable effect, and the one primarily responsible for gall formation, is the greatly increased number of ray cells, accompanied by a slight increase in the size of these cells. Tracheids, on the other hand, are somewhat smaller than in normal wood. Summerwood is not formed in the annual rings of the gall.

The mycelium is intercellular throughout the gall tissue, except in the pith (166), and generally follows the wood rays. Mycelium and haustoria may, however, be found in the pith if infection occurred when the pith parenchyma was being laid down (176). Growth of the hyphae between cell walls is mainly mechanical, but may be facilitated by chemical (enzymatic) degradation of the wall and middle lamellae (407). Haustoria develop from branches of the intercellular hyphae, which are constricted where they pass through the cell walls. After penetrating the cell walls, they expand to the normal size of the hyphae, becoming 20 to 30 μ long. The haustoria penetrate the parenchymatous cells of the cortex, the phloem rays, and the resin ducts. They do not enter tracheids, although occasionally numerous short branches of the hyphae enter the tracheids through bordered pits (166). Jewell et al. (176) report occasional atypical haustoria in the tracheids of slash pine galls.

The parasite is unable to influence the anatomy of the host beyond the invaded tissues (81, 128, 167, 176, 374), but Jackson and Parker (166) report the production of periderm barriers immediately in front of the advancing hyphae in the phloem. It is postulated that the rust has a hormonal influence (34, 35, 164, 166), for infected branches often survive and grow vigorously, even overtaking the terminal, while uninfected branches in the same whorl die. Infected branches also tend to break dormancy earlier than uninfected tissues. The metabolism of the host tissue appears to be stimulated by the pathogen, infected host cell, or both, and the ability to increase the metabolic rate of host cells may be a factor in successful parasitism (407).

A similar mechanism probably stimulates production of the numerous basal branches that frequently arise from the galls (31, 42, 134, 139, 298). Basal branches, without stem swelling, have not been considered infallible evidence of infection (138, 139, 298), but a very high percentage of seedlings with visible galls have one or more adventitious branches arising from the gall itself. These branches are quite distinct; they are closely appressed to the stem, and have pale green primary needles. A high content of indoleacetic acid has been reported for "witches'-broom" diseases caused by some rusts (35, 62, 108, 214, 273), and this growth-promoting substance may be responsible for the formation of basal branches on trees infected by **C. fusiforme.**

In nurseries large seedlings are more frequently infected than small ones. The hormones produced by the rust may stimulate growth of the seedling. However, Sleeth (302) comments that galls develop slowly on unthrifty and undersized stock; by implication, the reverse is also true, i.e., gall development is proportional to the size and vigor of the seedlings (222, 269). On the other hand, since seedling development usually is proportional to age, the larger seedlings may have developed from the earliest germinated seed in the nursery and thus may have become infected soonest. Percentage of infection is higher with early than with late nursery sowing and germination (190, 297, 298, 302), presumably because temperature, humidity, and spore load become less favorable to infection as spring advances.

On nursery stock, galls usually become visible in 6 months (95) to 8 months (171) after infection occurs. The intensity of inoculum (251) influences the size of the gall and its rate of growth. If the plants are subjected to a heavy spore load, there is a measurable localized increase in stem diameter in 2 months or less. In some instances, a high percentage of seedlings have no visible infection at lifting time, but develop galls during the first year after planted (17, 60, 295, 297, 299, 336, 360, 363). The reason for such latent infection is not known. It has been suggested that gall development is almost imperceptible on small seedlings (301), but the writer's experience is that latent infections are equally common in large seedlings.

The length of time required for the development of the galls on stems and branches of large trees has not been determined. It is probable that here, too, there are immediate and latent responses.

The growth rate of galls has been inadequately studied. Growth in diameter (301) and length (39, 120, 298) apparently is correlated with vigor of the host. Galls develop more slowly on larger trees than on seedlings, and growth rate differs among host species (298). The effect of the fungus on diameter growth of the gall reaches a maximum about 6 to 8 months after infection, or about the end of the first growing season. Approximately the same number of abnormal host cells are produced on the gall each growing season, since the percentage increase in cross-sectional areas becomes progressively smaller as stems and branches increase in size, and with each succeeding year of growth (176).

Branch galls elongate at a rate of 2 to 5 inches per year, and usually grow slightly faster toward the stem than away from it (298). Trunk galls grow down the stem faster than upward (298), and only rarely does upward growth exceed the downward growth (288). The growth of stem galls is somewhat faster on slash than on loblolly pine, but branch galls increase in total length faster on loblolly pine than on slash pine (298).

Typically, galls have a reasonably symmetrical fusiform shape tapering in both directions. Many are hemispherical at either or both ends, and may resemble galls of **C. quercuum**, but these hemispherical galls are not consistent and may begin tapered growth in 1 or 2 years. Occasionally a fusiform gall ceases growing in length and becomes cerebroid.

Branch galls more than 15 inches from the stem tend to be self-limiting, since the parasite generally kills the branch before the hyphae can reach the stem (120, 298, 351, 352). There is a progressive increase in branch mortality with age of infections. In the first 1 or 2 years after galls become visible, 10 to 15 percent of the branches with galls are killed; by the third year mortality may be 30 to 35 percent. A gall closer than about 3 inches from the stem indicates that the fungus probably will enter the stem within 1 year, if it is not already there (298). On the other hand, Jewell (168) states that the fungus does not grow beyond the swelling, and has not reached the stem even if the proximal portion of the gall is within ½ inch of the stem. Jackson and Parker (166) also report that the fungus does not occur in branch wood or bark beyond the externally visible margin of the gall. However, because the galls usually are fusiform in shape, with a gradual taper, there is no clear-cut line of demarcation between infected and normal tissues. Other criteria of fungus invasion are needed to supplement the gross morphological changes and delimit the extent of infection.

Host Physiology

The physiological processes of the host plants are influenced by the parasite through all stages of infection, beginning with germination of the spore. Great increases in the respiratory rate of wheat occur immediately after rust spores germinate, and the metabolism of host plants frequently is stimulated by infection (61, 63). The physiologic disturbances leading to proliferation of host tissue already have been discussed briefly, and a few other effects may be mentioned.

In studying the Woodgate rust, Hutchinson (164) found slight changes in host cell composition and structure in resistant pines, similar to the periderm barriers reported by Jackson and Parker (166). These changes occurred immediately after invasion by the rust, preventing further growth of the fungus.

Since death of the host cell precedes the death of the fungus, there is a possibility that host cells are killed by toxins or staling products produced by the parasite, as well as by the imbalance between nutrition of the host cells and that of the fungus (29, 38, 204, 406). It has been reported that benzimidazole or similar compounds regulate the formation of wound periderms in white pines resistant to blister rust (35).

Death of individual cells, then groups of cells, in the cambial region creates extensive open wounds, and the gall technically becomes a canker. Fusiform rust sometimes produces cankers without first forming galls (256). Cankers are fairly common on large trees. Siggers[1] followed a logging operation in Alabama and reported cankers up to 23 feet in length, with a rough correlation between canker length and age.

Four percent of the cankers were more than 50 years old, and 22 percent more than 40 years old. While cankers are spectacular, most of the mortality caused by fusiform rust occurs in seedlings and young trees within the first 5 to 7 years of age; only rarely are cankers formed on these trees, and almost never on seedlings. Death is not due to destruction of tissues per se, but to some systemic cause: toxins (29, 214, 406, 407), or interference with nutrition or water transport (49, 210, 269). Death of infected seedlings, or of individual infected branches, is relatively sudden. Seedlings may be exceptionally vigorous, with the foliage normal in appearance for some time; then there is a rapid development of chlorosis, followed by death. These changes often occur within 2 or 3 weeks, thus eliminating the possibility that death is caused by nutritional effects.

Several abnormal metabolic byproducts have been found in the host cells, produced either by the host or the fungus. Excessive quantities of some organic acids, starch, tannins, and gums are reported (34, 38, 119, 166). A copious flow of pitch from galls and cankers is fairly common (135, 398), even on young seedlings in the nursery. The pitch canker fungus (**Fusarium lateritium f.** pini Hepting) sometimes infects trees at fusiform rust galls, and is said to be the cause of this flow (23). However, because the fusiform rust increases the number of resin ducts (166, 176), it probably is often the sole cause of pitch flow.

Ecology and Phenology

Any change in the character of the host population affects the host-parasite relationship (21), and the severity of fusiform rust is definitely influenced by stand composition, age, and density.

A frequent explanation for the rise in incidence of fusiform rust is that control of forest fires has modified the stand composition of the southern forests by increasing the proportion of oaks (337). In the South the pine type is a fire subclimax, and with protection from fire gradually develops into the oak-hickory association. However, widespread control of fire has been in effect for not more than 20 or 30 years, and probably has not influenced the ecological succession much in this time. A more reasonable explanation for the gradual increase of oaks is that pines make up 60 percent or more of the cut, although the forest inventory is predominantly hardwood (337). In other words, the

[1] Siggers, P.V. A study of the development of old rust cankers in a stand of merchantable loblolly pine trees. Unpublished report. Bur Plant Ind., Soils and Agr. Eng., 7 p. 1943.

proportion of hardwoods (including oak) is increasing because much more pine is being cut.

Another factor contributing to high rust incidence is the increased planting of the most susceptible species, slash pine (298, 299, 351, 363). Although forest managers are concerned about the losses sustained by this species (3), there is no indication that they will replace it with less susceptible pines in the near future. Most of the acreage in the zone of high rust hazard is definitely off-site for shortleaf pine, but some slash-shortleaf hybrids show promise. They have a high degree of resistance to rust, and their silviculture and management apparently will be similar to those of pure slash pine.

Longleaf pine is in disfavor as a planting species, and most of the former longleaf sites are now planted to slash and loblolly pine (299, 300, 363). In spite of its high quality and resistance to fire and fusiform rust, longleaf pine is a difficult species to plant, relatively slow-growing, and subject to considerable mortality and growth reduction from brown-spot needle blight.

The extensive planting program of recent years (338, 339) also contributes to the increased incidence of fusiform rust, because it raises the proportion of very susceptible 1- to 5-year age classes in the forests. Young pines elongate their buds considerably earlier than older ones, weeks earlier in some cases (363), and remain succulent and susceptible for longer periods of time.

The forest stand structure and composition further influence the severity of infection through their effect on the microclimate (100, 158, 358). The amount of ground cover, the density of the overstory, and the presence of windbreaks all influence the temperature and humidity near the ground, and possibly contribute more to the infection of young trees than does the age of the plant per se. In dense vegetative cover, the relative humidity may be at or near the saturation point at the ground level and 30 to 40 percent lower at the 6 foot level (27), which may account for the high proportion of 1- and 2-year-old seedlings which become infected.

Infection of host plants may be limited or reduced by any physical barriers which intercept infective spores and prevent their reaching the susceptible host (74, 111, 283, 324, 358). A mixed forest composed of susceptible and resistant species theoretically should have a lower percentage of infection in the susceptible species than in a pure stand of this species. The same mechanism should also operate where susceptibility varies with age (298, 312, 363); the older, less susceptible plants will intercept some spores and protect the younger, more susceptible individuals. However, Hebb (130) studied pine stands with and without overstories of older trees, and found no difference in the percentage of trees infected with fusiform rust; 28 percent of trees without an overstory were infected, and 30 percent in stands with an overstory.

It has been observed that the percentage of infected trees is lower in dense natural stands than in relatively open stands (205, 207, 223, 237, 298, 363). In part, this is due to the trapping of sporidia, and in part to the more frequent natural pruning of infected branches in dense stands.

Insects, birds, and animals exert little if any effect as vectors of fusiform rust. Flies, wasps, bees, and other insects are attracted to the pycnial ooze and may aid in diploidization of the fungus.

The effect of site quality on the incidence of fusiform rust is not fully known (299). In Alabama, Goggans found that infections increased as the rate of height growth increased, the site quality index being significantly correlated with the number of infections (103, 104). Lindgren stated that vigorous trees appeared to be more susceptible to infection than trees with slower growth rates (207), but Barber (18) found a negligible relationship between height growth and intensity of infection. Dell and Driver (68) reported no correlation of rust incidence with diameter of host trees in plantations.

In general, any cultural practice that stimulates the growth of either host will increase rust infection. Early attempts to improve the growth rate of pine plantations by cultivation and fertilization were found to cause a substantial increase in fusiform rust (17, 30, 102, 103, 104, 209, 298, 351, 363, 388). The explanation is phenological. The cultured trees break dormancy earlier than other pines, have tissues in a succulent stage for longer periods of time, and develop larger areas of succulent tissues.

Winter and spring fires have similar effects. Fire destroys the older, hardened needles, induces an early break in dormancy, and stimulates the production of succulent and susceptible needle tissue (293, 294, 363). Fires destroy some branch galls, but the predominant effect of winter and spring fires is to aggravate the disease.

Weather has a very important influence on both the hosts and the fungus. Climatic differences, more than any other factor, dictate the regional differences in intensity of infection. The phenological cycle of both oak and pine hosts follows a normal pattern dictated by temperature, precipitation, elevation, and latitude (25, 152, 153). The variable factors are temperature and precipitation, and relatively minor variations are enough to change the dates of phenological development of the host plants and produce significant effects on the fungus (150, 291, 292).

In the Gulf States, February temperatures a few degrees above normal usually induce an early break in dormancy of both oaks and pine. If this break follows a winter mild enough to favor sporulation of the aecial stage of fusiform rust, infection of the oaks becomes very severe, as does subsequent infection of the pines (292). Conversely, very cold winters and springs delay the development of both fungus and host, resulting in very low incidence of infection (302, 355, 358).

A short-range fluctuation in aeciospore production, associated with low temperatures, has been observed for several years. If temperatures remain below 13° C. for 2 or more days in the spring, aecia fail to develop for several days after that. Humid or rainy weather associated with subnormal temperatures favors the growth of molds on the aeciospores and drastically reduces their viability. An analysis of the temperature and precipitation patterns required for sporulation and spore germination showed that sporidial dissemination is governed chiefly by high relative humidity for about 9 hours (307, 309, 310). The production and germination of C. quercuum sporidia require a minimum of 13 hours of 100 percent humidity following a measurable rainfall (241).

Analysis of weather patterns shows that an nflow of maritime tropical air from the Caribbean rea into the Gulf States produces a combination of emperature, rainfall, and humidity favorable for asidiospore production and severe fusiform rust nfection (65). Relatively minor differences in emperature and humidity, as affected by plant over and topography, have been correlated to the evelopment of C. ribicola and the incidence of hite pine blister rust (272, 343, 345, 346). ross regional weather patterns as they influence e development of fungi and incidence of other lant diseases have been investigated in detail, and ave been used to forecast the severity of these seases (280, 357, 371, 372).

CONTROL OF THE DISEASE

Fusiform rust has many characteristics of an idemic disease (or more exactly, an epiphytotic disease) in that increasingly large numbers of the population become, and remain, infected. It is difficult to analyze as an epidemic disease, however, because its development in the forest occurs in successive steps, often several years apart, rather than in a regular, geometric pattern.

Even though the fungus is relatively restricted in the tissues of the pine host, the rust has many characteristics of a systemic disease (347). Generally, a systemic pathogen is safe within the host, and if the host is perennial and the disease not immediately lethal, a long life of the host guarantees a long life to the pathogen (348). The disease can be eradicated only by destroying the host. An exception to this statement may be made where systemic chemicals are effective against the pathogen (64, 72, 160, 183, 184, 240, 326, 349, 391).

Where values are sufficiently high, as in nurseries and seed orchards, fungicides give some protection (45, 78, 315, 382, 383). But the source of inoculum must be reduced or eliminated; otherwise, repeated spraying will be necessary in perpetuity, with no assurance that the seedlings may not become infected as soon as they are outplanted. Nursery spraying is only a temporary delay of infection, not control of the disease.

Considering the range and importance of fusiform rust, the inertia exhibited with respect to its control is surprising. Annual losses are estimated to be over $10,600,000 in sawtimber and 97 million cubic feet of growing stock (3, 264, 337), but expenditures for direct control totaled only $9,500 in 1952, the only year for which cost figures were reported. All of this money probably was spent for spraying in nurseries; it is doubtful that any control was attempted in plantations. Yet seedlings are produced for planting on inadequately stocked sites, and preventing losses in these new plantations becomes a matter of major economic importance.

Control in Nurseries

Shortly after the disease was first recognized in the nurseries (194, 299, 302, 329), trials and experiments were conducted and recommendations for control were published (195, 302). Surprisingly enough, there has been little change in these recommendations in 30 years, the differences being in refinement of techniques rather than in basic principles. The early recommendations called for spraying with bordeaux mixture or ferbam at least twice a week, from the beginning of seed germination until mid-June (297, 302).

Ferbam (ferric dimethyl dithiocarbamate) is the most frequently used fungicide, primarily because the spray mixture is easy to prepare and is noncorrosive. As a fungicide it is generally considered at least as efficient as bordeaux mixture (297), though sporidia of C. fusiforme have been observed to germinate while in contact with clumps of ferbam particles (188).

On the basis of small-scale tests, other chemicals appear approximately equal to ferbam in effectiveness (297, 298, 305). Among these are ziram (zinc dimethyl dithiocarbamate), zineb (zinc ethylene bis dithiocarbamate), puratized spray (phenyl mercury triethanol ammonium lactate), and nickel chloride (183). The high effectiveness of nickel chloride against fusiform rust spores in vitro suggests that this compound should be a good fungicidal spray.

Systemic chemicals have had limited trials, but appeared ineffective (302). Antibiotics (phytoactin, cycloheximide) have been unsuccessful as nursery sprays, mainly because of their phytotoxicity.

Current recommendations are to spray twice a week (and more frequently if rain washes off the fungicide) at the rate of 2 pounds of ferbam and 1 pint of spreader-sticker in 75 gallons of water per acre. Sprayer pressure should be at least 300 pounds per square inch. To insure maximum coverage and effectiveness (44), the spray is broken into fine droplets by being forced through No. 2 nozzles, i.e., having an opening no larger than 1/32 inch (0.031 inch) (96). Since the nozzle openings are eroded by the ferbam suspension, they should be frequently checked, and replaced when worn. Mist blowers have also been successfully used; the application rate is 2 pounds of ferbam in 25 to 30 gallons of water per acre (96, 97, 263).

Some of the spreader-stickers used with protective fungicides are phytotoxic, or cause injury to pine seedlings when used at rates higher than 1 pint per acre (308, 341).

Siggers (290) concluded that abundant infection of pines requires a minimum of 18 hours of humidity close to the moisture saturation point, with temperatures between 60 and 79° F., and suggested that control could be secured if spraying were done when these conditions prevailed (290, 297). In areas of high infection hazard, however, results of such "forecast" spraying have been very disappointing. Extensive trials at two nurseries showed that infection percentages were much higher than with routine spraying. In one nursery, test beds sprayed on the basis of weather forecasts had almost as much infection (19 percent) as unsprayed control beds (21 percent).[2]

It has been difficult to account for 20 to 30 percent infection in nursery seedbeds when hygrothermograph records showed that "critical" conditions did not occur. Some of this high infection rate undoubtedly is due to the fact that temperature and humidity in the seedbeds may be more favorable for infection, and may persist for longer periods of time, than in the part of the nursery where the hygrothermograph is located (27, 100).

There is also some confusion between rain and relative humidity. Some authors recommend spraying before rain, on the assumption that rain equals 100 percent relative humidity (95, 305). However, rain washes spores out of the air and off the hosts (11, 111, 112, 113, 145, 146, 220, 283, 343, 399), thus severely restricting infection. Rain also reduces the protective coating of fungicide, and may remove it almost completely if it has not had time to dry (42, 43, 270, 384, 395). A more reasonable recommendation is to spray as soon as possible after rain, especially if the rain had been heavy enough to wash off some of the fungicide.

Recommendations for late sowing are practical and realistic (195, 297, 302); infection in nurseries was reduced by half with every 2 weeks' delay in sowing date. The effect of sowing date is related to weather conditions. Seedlings resulting from early sowing emerge when humidities are high and temperatures remain below 70° F. for considerable lengths of time; late-sown seedlings, on the other hand, begin growth when temperatures frequently exceed 80° F. (the lethal temperature for sporidia) for several hours a day over long periods of time.

The final attempt on the part of the nurseryman to furnish disease-free seedlings is by inspection and culling of infected seedlings at lifting time (363). This practice is not entirely successful. At most nurseries, shipping schedules demand that unskilled laborers examine seedlings at the rate of 30 or 40 per minute, decide on grades, and determine if the seedling is free of disease. The work is too fast to be effective. Seedlings passed by the graders often include about 5 percent with visible rust symptoms. Moreover, in many nurseries a substantial percentage of seedlings have latent

[2] Unpublished data on file at Gulfport, Mississippi, field office of the Southern Forest Experiment Station, USDA Forest Service.

infections, in which the symptoms are not detectable even by careful examination, but develop in the first season after outplanting (32, 60, 295, 297, 299, 301, 302, 336, 360, 363). Latent infections are roughly proportional to the percentage of visible infections but apparently decrease if the lifting date is late, probably because of the continuing development of the galls.

Control in Plantations and Natural Stands

Possibly the first step in controlling fusiform rust in plantations is to plant only rust-free seedlings. In studies where infected seedlings were planted, mortality averaged 71 percent in the first growing season, and 83 percent of the planted seedlings were dead the second year. Less than 1 percent of the trees survived 10 years after planting (289, 301).

Further control of the disease in plantations is primarily through silvicultural measures. Longleaf and shortleaf pines should be planted on their respective sites whenever possible, and plantations of loblolly or slash pine should not be established where susceptible oaks are abundant, especially if native pines on and near the site have numerous galls (195, 298, 363). If a choice of species is possible, preference should be given to loblolly pine (318, 321). When plantings are made on high-hazard sites close spacings are recommended to compensate for future losses and to provide for earlier natural pruning (78, 144, 223, 237, 298, 363). Infections in dense stands tend to form branch galls. The infected branches die very early, thus reducing the possibility of the more damaging stem galls and cankers.

The selection and planting of resistant races or hybrids of loblolly and slash pine is recommended also (20, 26, 78, 124, 140, 174, 363). The adverse effect of intensive culture (fertilization and cultivation) has been mentioned.

Once the disease is established in a plantation or natural stand, practical control measures are almost nonexistent (298, 363). To some extent, future stem infections can be prevented by pruning infected branches (100, 208, 296, 298, 350, 351, 352). Pruning is most effective in 2- to 5-year-old plantations. It is not economically feasible, however, except on individual high-value trees, and even then reduction in numbers of stem galls has been disappointing in some localities. It is possible that pruning stimulates adventitious sprouts which later become infected. The pruning wounds may also allow other diseases to enter the trunks (403). It is recommended that efforts be concentrated on pruning branches with galls approximately 3 to 15 inches from the stem; galls closer than 3 inches may have already infected the stem, and those farther than 15 inches will die before reaching the stem (120, 208, 350). But leaving any active branch galls will also leave a source of aeciospores in the environment (207).

In timber stand improvement work, treating oaks with chemicals, rather than simply cutting them, will prevent sprouting (194, 363) and thus reduce the population of the alternate host in a stand.

Removing infected pine trees by thinning or salvage cuttings is recommended (187, 205, 206, 207, 299, 351, 363, 386), although it is also suggested that as many trees as possible be left for future salvage cuttings, and to avoid excessive opening of the stand. Wenger (386) states that a cankered tree is safe to leave at least 5 years if any sound callus can be seen extending past the canker along both edges when the marker faces the canker. Lindgren (207) proposed at least three categories:

a. If less than 50 percent of the trunk circumference is killed (cankered), there is more than an even chance of salvage for 8 years.

b. If 50 percent or more of the circumference is killed, but there is no bend in the trunk and no deeply sunken canker face, there is at least an even chance of salvage for 5 years, somewhat less for 8 years.

c. If more than 50 percent of the circumference is killed, and there is a bend at the canker or the canker face is deeply sunken, there is less than an even chance of salvage in 5 years.

The question of whether to remove all stem-cankered trees, or to leave as many as possible, should be re-evaluated from a pathologist's point of view. There is no doubt but that removal of many sporulating galls and cankers will drastically reduce the amount of inoculum (74, 357). This measure was first proposed in 1937 by Lamb (194). Lindgren (207) raised objections to it, mostly from the standpoint of forest management but also because he doubted whether less than a complete eradication program would effect any reduction of inoculum. Wakeley (363) states that even a light initial production of aeciospores to infect the oaks is likely to result in heavy infection of pines as a result of subsequent secondary infections.

Small-scale trials of excising galls on stems, and using fungicidal paint or antibiotic sprays on the wounds, have been unsuccessful in eliminating the fungus on individual trees. Surgical procedures may be practical when the value of such trees is high (67). It is reported that the application of sodium arsenite solutions to galls is highly successful in killing the fungus, without phytotoxic effects on the pines (37).

Although biological control has possibilities with other plant diseases, it does not hold any foreseeable promise for fusiform rust (192, 323, 408). Six species of pine rusts, including C. quercuum, are parasitized by the fungus Tuberculina maxima, which grows on the pycnia and aecia but is of no importance in control (131, 161, 162, 393) and has not been reported as a hyperparasite of C. fusiforme. Sporobolomyces sp. and Fusidium sp. overgrow the telia of fusiform rust, and Trichoderma, Hormodendrum, and Penicillium spp. are frequently found on the pycnial exudate in the field and in the greenhouse, but the presence of these fungi does not reduce subsequent aecial sporulation of the parasitized galls.

From this review, we must conclude that direct control of fusiform rust in our forests is impossible in the light of present knowledge. A very considerable amount of research still is required on such fundamentals as the life history and physiology of the fungus, and the host-parasite relationship. Only with more facts will it be possible to design a realistic program for control of the disease.

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Aerated Water Soaks Stimulate Germination of Southern Pine Seeds

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Aerated Water Soaks Stimulate Germination of Southern Pine Seeds

J. P. Barnett[1]

Soaking loblolly, slash, and shortleaf pine seeds in continuously aerated water at 41° F. speeded germination as much as stratification in polyethylene bags. Soaking at 60° stimulated germination as much as colder soaks and in less time. Although dormant loblolly seeds can be soaked at low temperatures for nearly 5 months without harm, periods up to 60 days are usually sufficient. With less dormant seeds and higher soaking temperatures, periods as short as 2 or 3 weeks may be necessary to prevent germination in water and induction of secondary dormancy. The water should be aerated continuously to keep the oxygen content near saturation.

Stratification has been the standard treatment for overcoming dormancy in outhern pine seeds since 1928 when Barton (*3*) reported that it hastened ermination. Although in recent years moistened seeds have usually been stratified ı polyethylene bags rather than between alternating layers of peat moss (*9, 11*), tratification still requires considerable labor and care. No more than 25 pounds of eeds should be placed in individual bags, and the bags should be opened eriodically for aeration.

Many nurserymen may find soaking seeds in cold, aerated water more onvenient. Large lots can be treated with little danger of molding or overheating, ıd with little labor. And research reported here shows that this treatment is as fective as stratification for overcoming dormancy of slash (*Pinus elliottii* ngelm.), loblolly (*P. taeda* L.), and shortleaf (*P. echinata* Mill.) pine seeds.

METHODS AND MATERIALS

The recommendations presented are based on a series of studies into the ıdividual variables affecting treatment success–species, water temperature, ıration of treatment, and method and quantity of aeration. In studies in which ›ecies was not an experimental variable, loblolly pine seeds were treated because ıey are the most dormant. In all but a few instances, seeds were from fresh lots ›llected in central Louisiana.

In most studies treatments were applied to about 3/4 pound sublots in ›lyethylene bottles that had their tops cut off to make containers 3½ inches in

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diameter and 6 inches deep. Seeds were placed in the containers to a depth of about 4 inches, and water was added until it covered them by about 1 inch. Controls were sublots of the same size stratified in polyethylene bags.

Oxygen content of the soaking water was monitored with a galvanic cell oxygen analyzer. Readings were corrected to concentration of dissolved oxygen, by the Winkler method (*15*). In some studies the airflow, usually furnished by aquarium air pumps, was measured with a flowmeter.

Germination of each treatment replication was tested on duplicate 100-seed samples. Tests were run for 28 days at 72° F. under standard laboratory conditions (*14*). Germination percents and germination values (*5*), which take into acount both speed and completeness of germination, were computed and analyzed. Differences due to treatment were tested for statistical significance at the 0.05 leve in all studies.

EFFECTIVENESS

The dependability of aerated soaks was demonstrated many times in the studies. Fowler (*7*) first tried aerated soaks with eastern white pine (*P. strobus* L.). Later preliminary tests with loblolly pine seeds (*2*) proved encouraging, and led to thi studies described.

The first test showed that, in terms of germination values, soaking in continuously aerated or continuously circulated water was about as effective a stratification (table 1). Intermittent aeration, changing water twice weekly, aeratio with oxygen, and soaking in unchanged still water were less effective. In this test treatments were continued for 63 days, and the water temperature was 41° F. Th purpose of subsequent studies was to determine optimum soaking conditions.

CONTINUOUS AERATION

The soaking water should be continuously aerated, either by bubbling ai through it or by splashing it during a continuous recirculation process. The purpos

Table 1. – *Germination values of loblolly pine seeds soaked for 63 days at 41° F. and oxyge contents of water for each treatment*

Pregermination treatment	Germination value[1]	Oxygen content[2]
		Mg./ℓ.
Stratification in polyethylene bags	41.2 a	....
Continuous water circulation	38.8 ab	9.1
Continuous aeration	37.0 ab	11.5
Continuous oxygenation	33.7 bc	41.6
Twice-weekly water changes	29.7 c	5.7
Intermittent aeration	28.6 c	4.1
Intermittent oxygenation	18.8 d	4.5
Unaerated water soak	23.7	3.7

[1] Values followed by the same letter do not differ significantly at the 0.05 level. The data for unaerated water soaks were nc included in the analyses.

[2] Averages from periodic measurements. Contents for intermittent treatments were measured just prior to water resaturatic The oxygen saturation level for water at 41° F. is 11.9 mg./ℓ.

to keep the oxygen content of the water near the saturation level achievable with ːration, but bubbling pure oxygen through the water is not recommended. It is ːry expenisve, results in very high oxygen contents, and is highly damaging to ome seed lots. Logically, high oxygen levels would seem advantageous, but Barton *4*) found that oxygen supplied during the soaking process was deleterious to ːrmination of *Phaseolus* seeds. This effect was attributed to increased water osorption beyond the amount needed for germination. Jones (*10*) later reported ıat higher-than-average moisture contents in lots of loblolly and slash pine seeds uring stratification coincided with lower viability.

Intermittent treatments–twice weekly water changes and periodic bubbling of ıe soaks with air and oxygen–resulted in significantly lower germination values ıan stratification and continuous aeration and water circulation (table 1). The oorer results were probably caused by the failure to keep water in these ıtermittent soaks saturated with oxygen.

Of the most efficient soaking treatments, continuous aeration seems the most ractical. Circulation alone is ineffective unless the recirculated water is splashed nto the surface of the soaking solution. It is this action which recharges the water ith oxygen. Continuous oxygenation is expensive and seems less effective than eration. Although water changes were fairly effective in one study, further valuation indicates that this technique is inferior to continuous bubbling of air ırough the water.

Amounts of aeration needed were estimated for temperatures of 41°, 59°, and 7° F. Twelve ounces and 6 ounces of seed were placed in containers with 1 pint of ater. Soaks of three lots of loblolly seeds were maintained for 28 days.

After the minimal amounts of airflow needed to keep oxygen content near ıturation were determined with an oxygen analyzer, the rates of flow were onitored periodically with a flowmeter. Tests run at the end of the soaks showed ɔ marked changes in total viability at any temperatures, but germination values of eds soaked at 77° were significantly lower than for those soaked at cooler mperatures (table 2). This decrease seems to have resulted from both a slight duction in viability and slower germination. Thus, the lower germination values ay have been caused by the high temperature inducing secondary dormancy in terripened seeds (*1,6,13*). Alternatively, viability may have been reduced through

ɿble 2. – *Germination values of loblolly pine seeds in aerated soaks at different temperatures, and minimal airflow necessary to maintain oxygen saturation*

Temperature (° F)	Germination value[1]		Minimal airflow[2]	
	Initially	After treatment	For 3/4 lb.	For 150 lbs.
			Ml./min.	Cu. in./min.
[illegible]	20.5 a	37.0 a	8	96
[illegible]	21.2 a	34.7 a	14	168
[illegible]	22.1 a	27.0 b	27	324

[1] thin columns, means followed by the same letter do not differ significantly at the 0.05 level

[2] ows for the 3/4-lb. lots were measured; those for the 150-lb. lots were estimated.

collection between the seedcoat and the megagametophyte of excess water from which the oxygen was depleted (*8*).

The minimal amounts of airflow required to supply the oxygen needs of 3/4-pound seed lots and the computed needs for 150-pound lots of loblolly seed are given in table 2. About 1/8 gallon of water was used with each 3/4-pound lot, and 25-30 gallons would be needed for 150 pounds. Although the minimum airflow necessary for a 150-pound lot of loblolly seed is computed, aeration can easily be provided at much higher levels and probably should be to maintain a margin of safety.

Adequate aeration can be assured by measuring the oxygen content of the water and adjusting airflow to achieve saturation. If this procedure is impractical, a general rule to follow is to provide enough aeration to result in vigorous bubble agitation over about three-fourths of the water surface. Air pumps are adequate; the high pressure developed by compressors is not needed.

DURATION

Dormant loblolly pine seeds require treatment for 2 to 3 months to obtain optimum speed of germination if the water temperature is low. Slash and shortleaf pine seeds, which are usually less dormant, need not be soaked longer than 30 days.

Six lots of loblolly pine seeds were given four pregermination treatments at 41° F. and seed germination was tested after 0, 21, 42, 63, 84, 105, 126, and 147 days. Germination percents in the mid-90's were retained in all treatments through 105 days. Beyond that time, they declined up to 10 percentage points when seeds were soaked in unaerated water or in water changed periodically. Germination values were consistently highest for stratified seeds and those soaked in continuously aerated water. At the end of 147 days they averaged 65.0 after stratification and 62.0 after continuous aeration (table 3). The water change and unaerated soaks had peak germination values of 34.3 and 31.9, which were attained after 63 and 42 days, respectively. None of the six seed lots were adversely affected by either aerated soaking or stratification.

Table 3. – *Germination values of loblolly pine seeds soaked or stratified at 41° F. for up to 147 days*

Length of treatment (days)	Stratification	Aerated soak	Water change	Unaerated soak
0	17.4	17.6	16.7	17.0
21	30.0	30.6	21.5	19.0
42	47.0	45.4	30.2	31.9
63	47.0	47.8	34.3	31.5
84	63.2	59.7	33.6	29.6
105	58.0	55.6	31.9	30.0
126	65.4	62.1	26.6	23.3
147	65.0	62.0	26.8	18.0
Average[1]	49.1 a	47.6 a	27.7 b	21.3

[1] Averages followed by the same letter do not differ significantly at the 0.05 level.

Six lots of slash and five of shortleaf were treated in the same way as the loblolly pine seeds in the study above. Since seeds of these species were not nearly as dormant as those of loblolly pine, responses to treatments were not as great. Stratification and aerated soaks were again superior to the other two treatments (table 4).

Table 4. – *Germination values of slash and shortleaf pine seeds subjected to various pregermination treatments at 41° F.*

Length of treatment (days)	Stratification	Aerated soak	Water change	Unaerated soak
		SLASH PINE		
0	26.8	25.7	26.2	25.7
21	34.4	38.2	34.9	33.2
42	34.6	28.3	8.1	18.5
63	39.8	41.0	24.7	25.2
Average[1]	33.9 a	33.3 a	23.5 b	25.6 b
		SHORTLEAF PINE		
0	14.7	15.8	17.3	14.8
21	21.2	19.2	12.3	13.0
42	27.0	19.7	9.9	7.5
63	29.1	20.4	7.8	5.0
Average[1]	23.0 a	18.8 a	11.8 b	10.1 b

[1] Species averages followed by the same letter do not differ significantly at the 0.05 level.

Slash pine seeds stratified and soaked in aerated water germinated 86 and 88 percent after 63 days, and germination values averaged 39.8 and 41.0 respectively. There was no marked improvement in either rate or amount of germination beyond 21 days of treatment. Changing water and unaerated soaking were significantly poorer in promoting and maintaining viability. Dissolved oxygen contents of the water in the aerated soaks were maintained at about 11 mg./1.(near saturation). Oxygen contents of the water change and unaerated treatments were lower and there were no differences–both averaged 1.5 mg./1.–when oxygen measurements were made just prior to the twice-weekly water changes.

The shortleaf seeds were 1 or 2 years old when the study began. The results obtained were essentially the same as with slash seeds (table 4). Germination averaged 74 and 79 percent and germination values averaged 20.4 and 29.1 for aerated water soaking and stratification, respectively, after 63 days. The water-change and unaerated soak treatments resulted in a steady decline in viability and germination values.

TEMPERATURE

Temperatures of 34° to 42° F. are recommended for aerated soaks if there is no need to shorten the period of treatment. Higher temperatures, 60° to 70°, will overcome dormancy faster, but soaks must not be prolonged beyond 2 or 3 weeks or germination will start in the water.

The effects of 41°, 59°, 77° F., and ambient outdoor temperatures on seeds in aerated soaks and stratification were evaluated on three lots of loblolly pine seeds. Ambient air and water temperatures averaged 65° and 61°, respectively, over the duration of the study. Germination was tested initially and after 7, 14, 21, and 28 days of treatment.

The results again confirmed earlier ones in that aerated soaks promoted germination as well as stratification. Viability of all seeds, except those at 77° F., remained high throughout the study. Seeds either stratified or aerated at 41°, 59°, and ambient temperatures germinated 90 percent or more and there were no differences between pregermination methods. Germination was markedly lower at 77°, and at this temperature, stratification was superior. Only at 77° were differences due to length of treatment of sufficient magnitude to be important; viability decreased with each increase in length of treatment beyond 7 days. Germination values followed the same trend (fig. 1).

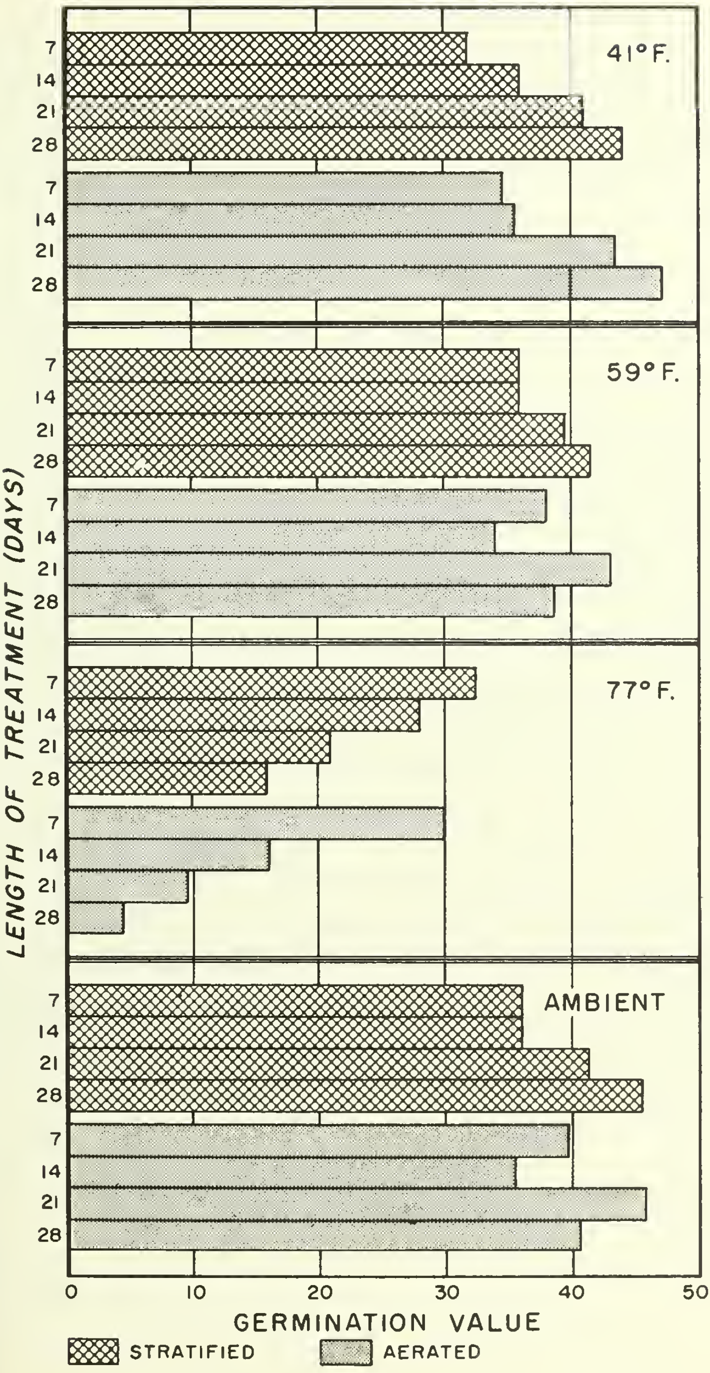
The loss of germinability of seeds soaked at high temperatures and after extended periods cannot be attributed to the temperatures alone. Measurements of oxygen contents in the soaks revealed that aeration was not being provided at rates sufficient to maintain oxygen saturation. Although oxygen contents of the 41° and 59° F. soaks remained near saturation, aeration at 77° was supplying only about half of the saturation level. This deficiency is probably the primary reason for the rapid deterioration at this temperature.

Seeds stratified in polyethylene bags began to mold heavily after 21 days at 59°, 77° F., and ambient temperatures. Even if other problems were overcome, long periods of treatment at warm temperatures would not be practical because germination begins to occur in both stratification and water soaks after about 21 days of treatment.

In soaks, warm temperatures for short periods may be as effective as low ones for long periods. This trend has been noted before (*3, 12, 13*), but until now the danger of heating and molding was too great to use warm temperatures for stratification.

The effect of temperature on rate of oxygen use by seeds was determined for two replications of loblolly seeds placed in oxygen-saturated water at 41°, 59°, and 77° F. Oxygen depletion was measured, the water resaturated, and the cycle repeated. As expected, the water held more dissolved oxygen at cold than at warm temperatures and seeds depleted oxygen faster at warm temperatures. After the seeds were fully imbibed, they depleted available oxygen to an equilibrium level of about 0.9 mg./l. in 4 to 8 hours. The average difference between the high and low temperature in time needed for this depletion was about 3 hours.

The equilibrium level after oxygen depletion is too low to maintain seeds for long periods. It is clear that recharging every few days is insufficient to maintain dissolved oxygen at necessary levels.



gure 1. – *Germination values of loblolly pine seeds after several lengths of pregermination treatment at various temperatures. The average germination value of untreated seeds was 24.6.*

PRACTICAL DEMONSTRATION

Before soaking could be recommended, it was necessary to show that the treatment is effective on seed lots near the size for commercial nursery operations. Accordingly, a 150-pound lot of 1-year-old loblolly pine seeds was divided to test three replications of four treatments: (1) cold stratification in polyethylene bags; (2) aerated soaks at 34° F., (3) aerated soaks at 34° with seeds in burlap sacks; and (4) aerated soaks at ambient temperatures. Five pounds of seeds were used in treatments 1 and 4, and 25 and 15 pounds in treatments 2 and 3, respectively. Average air and water temperatures of the ambient soaks were 55° and 51° for the time the soaks were outside. During about half of the 42-day period, night temperatures were subfreezing and the lots were moved into cold storage at 34°. Oxygen levels were kept near saturation by measuring them and adjusting airflow rates.

Viability of seeds of all treatments averaged 90 percent or more after 42 days. Seeds soaked within burlap bags germinated least, but the difference in germination of 4 percentage points is of little practical importance.

The ambient-temperature soak resulted in the highest germination values, while seeds soaked in burlap sacks again responded least (table 5). An interaction between length of treatments and pregermination methods indicates that germination values of treatments 2 and 4, soaks at 34° F. and ambient temperatures, increased more rapidly than the others as length of treatment increased. Burlap sacks, which were tested as a means of facilitating handling, resulted in slower response, probably because the heavy burlap restricted circulation of well-aerated water.

The results show that aerated soaks are practical for promoting germination of southern pine seeds.

Table 5. – *Germination values of large lots of loblolly pine seeds after various pregermination treatments*

Length of treatment (days)	Cold stratification	Aerated soaks at		
		34° F. Loose seeds	34° F. In bags	Ambient temps. Loose seeds
0	14.6	13.0	12.6	11.9
7	18.5	20.3	20.0	18.8
14	22.9	23.7	21.6	25.6
21	26.0	30.7	21.5	34.6
28	26.5	30.1	26.8	39.0
35	23.9	26.4	22.4	29.2
42	29.5	33.9	28.4	37.5
Average	23.1	25.4	21.9	28.1

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Economic Implications of Silage Sycamore

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Economic Implications of Silage Sycamore

George F. Dutrow

Best estimates of costs and returns indicate that some wood processors would find the growing of silage sycamore profitable. Success, however, requires substantial expenditures for heavy equipment and allocation of 4,000 to 8,000 acres to the project. Unless establishment costs can be substantially reduced and a market created, the system will not be economically feasible for nonindustrial landowners.

Researchers are trying to develop a system for growing sycamore (*Platanus occidentalis* L.) at very close spacings and harvesting the wood every few years in much the same way that silage is harvested. Intrigued by the concept, some industrial forest managers have installed pilot-scale trials. Scientists are convinced that the system is biologically feasible *(4)*. This paper reports an exploratory study of the economic implications. Well-documented input and output data will not be available for some time, but data are sufficient to show, by computer simulation, the general requirements for economic feasibility. These requirements include numbers of coppice crops that must be obtained from initial plantings, intervals between crops, harvesting costs, and market prices.

Advocates of silage sycamore argue that rotation lengths need not exceed 4 years. They believe that fast-growing clones adaptable to a wide range of soils and sites can be developed and vegetatively propagated. Since the envisioned system is highly mechanized, labor costs for harvesting would be low. Highly seasonal planting and harvesting, typical of annual fiber crops such as Kenaf, would be avoided.

At the current stage of development, there are many unanswered questions about silage sycamore. Through simulation, however, costs, yields, and returns necessary for profitable silage sycamore can be largely defined.

Costs

Intensive site preparation is recommended for adequate survival and high growth rates *(1)*, and it is essential for mechanized harvesting with existing agricultural equipment. Sites should be cleared, raked, burned, and disked prior to setting seedlings. Where timber must be cleared, these activities require expenditures of approximately $75 per acre, and are not dependent on the seedling spacing selected. Cultivation costs of $12 per acre, an allowance of $3 per acre for possible control of insects or diseases, and seedling transportation costs of $3 per acre were included in establishment costs.

Sycamore silage is being tested at seedling spacings of 1×4, 2×4, 4×4, and 4×6 feet. Costs for seedlings and planting vary by spacing. The number of seedlings needed ranges from approximately 11,000 per acre for a 1- by 4-foot spacing to 2,000 seedlings per acre for 4- by 6-foot spacing. Price of sycamore seedlings varies from State to State, and the highest probable price, $12 per thousand, was assumed. At this price, seedling cost alone in the densest plantations is $132 per acre—approximately half of the total establishment cost. At wider spacings, seedling costs become less important, but are still substantial.

Planting costs necessarily vary with spacing. Narrow spacing takes $36 per acre, and declines to $15 at the widest spacing. Thus, estimated establishment costs range from $131 at the widest to $261 at the closest spacing (table 1).

Table 1.—*Estimated establishment costs for sycamore silage plantations*

Cost item	Spacing			
	1 × 4′	2 × 4′	4 × 4′	4 × 6′
	$/acre			
Site preparation (clearing, raking, burning, disking)	75	75	75	75
Cultivation	12	12	12	12
Insect and disease control	3	3	3	3
Trucking costs	3	3	3	3
Planting stock (seedlings)	132	66	33	23
Planting	36	25	18	15
Total	261	184	144	131

Land costs are purposely excluded from the analysis. The rate of return associated with the crop as compared to other land use is of greatest importance, not the basic cost of the land. Wood processing industries will be particularly interested in comparing silage sycamore with more conventional methods of fiber production.

In addition to establishment costs, $1.50 per acre per year was allowed for taxes, fire protection, and general management activities. After each cutting, some weed suppression and insect or disease control may be needed. A value of $7 per acre was allocated for cultural treatment associated with coppice reproduction.

An anticipated advantage of silage sycamore is lower harvesting costs per unit volume than in conventional logging. It was assumed that the expenditures would be roughly equal to those for similar operations in agriculture. A piece of heavy equipment, driven by one man, would simultaneously harvest the silage, chip it, and blow the chips into a wagon. When filled with chips, the wagon would be hitched to a tractor and delivered to the mill. Save for the chipping rig, the various equipment costs listed below were taken from Hamill and Woolf's *Data for Farm Planning in the Ouachita River Valley Area of Louisiana (3)*. These costs include depreciation, interest, repair, and fuel. The total of $35.51 for harvesting and hauling was rounded to $36 per acre for the computer simulation.

Estimates of harvesting and hauling costs per acre

	$/acre
Harvesting	
Harvester	5.15
Chipping rig	5.00
Silage wagon	2.52
Silage blower	1.84
Labor (2 man-hours)	4.00
Total	18.51
Hauling	
Trucking (30 mile round trip at $0.50 per mile)	15.00
Labor (1 man-hour)	2.00
Total	17.00

The combined harvesting and hauling costs represent substan-ial savings compared to expenditures for logging bolts. At 3 tons of silage chips per cord, sycamore can be delivered to an industrial receiving point for approximately $4 per cord, compared with $10 o $15 for bolts. The savings are largely attributable to substituting nachinery for manpower. Labor costs for harvesting and delivering cord of silage are estimated at $2, whereas an efficient con-entional logging operation would require some $5 per cord for labor. The cost advantage requires trees to be clearcut by a machine com-arable to a silage cropper. The stems would have to be of small iameter but the machine can chip the entire tree and blow the chips nto tractor-drawn wagons or trucks.

The last cost item is for reestablishment of root stocks to support new series of vigorous coppice crops. Site preparation, cultivation, rotection, and trucking costs for this operation were estimated at 52 per acre; seedling and planting costs were assumed to be the ame as in initial establishment of the plantation. Total values by pacing were:

Spacing	*Reestablishment costs—per acre*
1 by 4′	$220
2 by 4′	$143
4 by 4′	$103
4 by 6′	$ 90

Physical Yields

Pilot studies and other experimental efforts provide only rough indications of sycamore silage yields. These studies were restricted to relatively close spacings and results from successive coppice crops are sparse. How many satisfactory coppice crops will appear before root stocks deteriorate is yet to be determined. Therefore, yields for various spacings, rotation lengths, and numbers of coppice crops were estimated by foresters engaged in cultivating sycamore silage.

Initial seedling yields and those from the first coppice crop have been fairly well established in studies at the Southern and Southeastern Forest Experiment Stations. Yields from the first coppice crops were about 45 percent greater than those from the seedlings. For present purposes, the increased yield of the first coppice crop was assumed to extend over subsequent crops, without diminution from root stock deterioration. In view of the uncertainties, a maximum of four coppice crops was included in the analysis. Table 2 presents predicted yields from sycamore culture.

Table 2.—*Sycamore silage—physical yields*

Cutting cycle (years)	Age of rootstock (years)	Crop type and number	Spacing			
			1 × 4′	2 × 4′	4 × 4′	4 × 6′
			M lbs. per acre [1]			
2	2	seedling	24	14	8	8
	4	coppice, No. 1	32	25	16	14
	6	coppice, No. 2	32	25	16	14
	8	coppice, No. 3	32	25	16	14
	10	coppice, No. 4	32	25	16	14
3	3	seedling	45	39	31	28
	6	coppice, No. 1	65	56	45	41
	9	coppice, No. 2	65	56	45	41
	12	coppice, No. 3	65	56	45	41
	15	coppice, No. 4	65	56	45	41
4	4	seedling	65	60	50	45
	8	coppice, No. 1	94	87	72	65
	12	coppice, No. 2	94	87	72	65
	16	coppice, No. 3	94	87	72	65
	20	coppice, No. 4	94	87	72	65

[1] Weights: without leaves, dormant-season cutting.

Achieving these yields requires careful site selection. In general, sycamore grows best on well-aerated, mildly alkaline soils that are reasonably well drained but have ground water in the root zone *(1)*. Long-term saturation or flooding during the growing season is detrimental. Except for ridges and steeply sloped terraces, the species occurs occasionally or frequently on most sites in the lower Mississippi Valley *(2)*. While relatively dry or infertile sites may be satisfactory for conventional sycamore plantations, they should be avoided for silage sycamore.

Sycamore Silage Prices

In the absence of a silage sycamore stumpage market, crop values are necessarily speculative. The values from analogous wood markets were used as guides to price expectations. As stumpage, sycamore silage would have to compete with conventional hardwood cordwood. In that market, the maximum price that a sycamore grower could hope for would be about $2 per cord (or some $0.34 per M lbs.). Silage prices would probably be lower than this because the leaves, twigs, and bark would reduce the market value.

The other major market is that for delivered hardwood chips. Industry could grow the silage, harvest it, deliver the chips and trash to its own mill, separate the usable from unusable materials, and impute a value to the silage crop. A ton of delivered hardwood chips that includes very little bark or trash is bringing up to $8 per ton, and this value was taken as a maximum in the cost-return calculations. Additional prices of $6, $4, and $2 per ton were included to complete the simulation. These values represent delivered prices, with harvesting and hauling costs charged to the grower who, in most cases, would be the processor.

Options

Foregoing costs, yields, and prices were combined in a wide variety of options to calculate rates of return and present net worths of sycamore silage investments. The first simulation was for the landowner who grows silage sycamore to be sold as stumpage at $0.34 per thousand pounds. The second simulation was for landowners that harvest and deliver chips to a mill at prices of $4, $6, or $8 per ton. Options analyzed were:

1. Cutting cycles of 2, 3, and 4 years;
2. rotations including 2, 3, or 4 coppice crops;
3. spacings of 1 by 4, 2 by 4, 4 by 4, and 4 by 6 feet;
4. single and perpetual rotations.

All together the production possibilities resulted in 72 options. Only results for perpetual series are reported in the tables in this paper.

Implications for Landowners

Individuals contemplating profits from sycamore silage in the stumpage market face bleak prospects! In most of the 72 options, present net worths were negative, indicating losses. Even at discount rates of 3 percent, the present net worths did not even cover the cost of seedlings. Unless prices for sycamore silage rise drastically or seedling and plantation-establishment costs decline sharply there is no apparent incentive for independent landowners to grow silage sycamore for sale as stumpage.

Processors interested in growing silage sycamore on their own lands face different prospects. A hardwood chip market does exist, and the current price for delivered chips is about $8 per ton. If industry can grow silage sycamore, harvest it, and separate usable from nonusable material for less than $8 per ton, the operation may be profitable.

Interpretation of the results requires consideration of two factors not yet discussed. First, a sufficient acreage must be allocated to silage sycamore to justify capital expenditures for specialized cultivating and harvesting equipment. Early advocates of sycamore silage pointed to year-round harvesting as a distinct advantage over annual fiber crops such as Kenaf. However, it now appears that coppice yields may be severely reduced if plants are harvested when they are growing rapidly in spring and early summer. Harvesting can probably be done safely only about 200 days per year. Equipment with a capacity of 10 acres per day, therefore, would be fully occupied only if some 2,000 acres were ready for harvest annually. For 4-year cutting cycles, 8,000 acres would have to be devoted to silage sycamore to fully utilize harvesting equipment.

The second factor is the cost of separating usable from unusable portions of the silage delivered to the plant. The imputed internal value of a ton of silage may have to be reduced from $8 per ton to $6 or even $4 per ton.

Table 3 presents rates of return to industrial growers who are prepared to harvest and deliver silage. The values in this table are for average establishment costs. Profitability of the operation is sensitive to cutting cycle length; the number of coppice crops can be as low as two, and rate of return remains competitive as long as cutting cycles are at least 3 years. At a price of $8 per ton, rates of return soar to some 20 percent for long cutting cycles and more than two coppice crops.

Table 3.—*Rates of return on average establishment costs*[1]—*perpetual series*

Cutting cycle (years)	Number of coppice crops	Spacing											
		1 × 4′			2 × 4′			4 × 4′			4 × 6′		
		Price/ton			Price/ton			Price/ton			Price/ton		
		$4	$6	$8	$4	$6	$8	$4	$6	$8	$4	$6	$8
		Percent											
2	2	N[2]	N	N	N	N	N	N	N	N	N	N	N
2	3	N	N	5	N	N	N	N	N	N	N	N	N
2	4	N	N	8	N	N	5	N	N	N	N	N	N
3	2	N	8	14	N	10	17	N	9	17	N	8	16
3	3	3	10	16	4	13	19	3	11	18	N	11	18
3	4	5	12	17	6	14	20	4	13	19	3	12	18
4	2	5	11	17	8	15	21	8	15	21	7	15	21
4	3	7	13	18	10	17	22	9	17	22	8	17	22
4	4	7	13	17	10	17	23	10	17	23	9	16	22

[1] Average establishment costs/acre:

Spacing	*Cost/acre*
1 × 4′	$261
2 × 4′	$184
4 × 4′	$144
4 × 6′	$131

[2] N represents a negative rate of return, or financial loss on the investment.

For a grower that plans to sell chips rather than process them himself, the rate of $4 per ton is probably most realistic. The current rate of $8 per ton for high quality hardwood chips would have to be reduced to account for the expense of separating usable from nonusable material at the mill, and further reduced to compensate for the less desirable strength properties exhibited by chips from juvenile trees. Furthermore, it is unlikely that markets for silage sycamore chips will be numerous, and additional hauling costs to the nearest market will result in less value per ton of chips. Even so, competitive rates of return of 8 to 10 percent on the investment in establishing silage plantations would be forthcoming for cutting cycles of 4 years with 2, 3, or 4 coppice crops from trees spaced at 2 by 4 feet or 4 by 4 feet in the initial planting.

Implications for Research

Simulation of sycamore silage production clearly indicates that additional research is needed to enhance economic feasibility. Research projects focused on reducing costs, increasing yields, or both, would largely alleviate the area of critical unknowns.

Seedling and planting costs loom as major obstacles to silage-sycamore silviculture as a competitive means of providing wood fiber. Research into costs and yields from cuttings planted horizontally might eliminate or minimize this financial drawback. Horizontal placement of cuttings would reduce the costs of procuring seedlings and of setting them in the soil. An efficient machine for planting cuttings might include a soil chisel, followed by an automatic trough for dropping the cuttings, followed in turn by packing wheels. If such a technique would allow for an establishment cost reduction of 25 or 50 percent, silage sycamore would become a most promising financial endeavor, with rates of return soaring to some 30 percent for 3- or 4-year cutting cycles with as few as two coppice crops (tables 4 and 5).

Internal rates of return and present net worths of sycamore-silage plantations are highly sensitive to length of time between harvests and to number of coppice crops expected from initial rootstock. Much uncertainty would be removed by clearly defining coppice yields at 3 or 4 years for 2 by 4 feet and 4 by 4 feet spacings. Furthermore, the number of coppice crops obtainable from initial rootstocks must be ascertained to determine economic feasibility. To estimate value, the percentage of usable wood fiber in the average crop should be determined.

Table 4.—*Rates of return on establishment costs reduced by 25 percent*[1]—*perpetual series*

Cutting cycle (years)	Number of coppice crops	Spacing											
		1 × 4′			2 × 4′			4 × 4′			4 × 6′		
		Price/ton			Price/ton			Price/ton			Price/ton		
		$4	$6	$8	$4	$6	$8	$4	$6	$8	$4	$6	$8
		Percent											
2	2	N[2]	N	N	N	N	N	N	N	N	N	N	N
2	3	N	N	7	N	N	4	N	N	N	N	N	N
2	4	N	N	11	N	N	8	N	N	N	N	N	N
3	2	N	11	19	N	14	23	N	12	21	N	11	20
3	3	4	14	21	6	17	24	4	15	23	N	14	22
3	4	7	16	23	8	18	26	6	16	24	5	15	23
4	2	7	15	21	10	19	26	10	19	27	9	19	26
4	3	9	17	23	13	21	27	12	21	27	11	20	26
4	4	9	15	21	14	21	27	13	21	27	12	21	27

[1] Average establishment costs/acre reduced by 25 percent:

Spacing	*Cost/acre*
1 × 4′	$196
2 × 4′	$138
4 × 4′	$108
4 × 6′	$ 98

[2] N represents a negative rate of return, or financial loss on the investment.

Table 5.—*Rates of return on establishment costs reduced by 50 percent*[1]—*perpetual series*

Cutting cycle (years)	Number of coppice crops	Spacing											
		1 × 4′			2 × 4′			4 × 4′			4 × 6′		
		Price/ton			Price/ton			Price/ton			Price/ton		
		$4	$6	$8	$4	$6	$8	$4	$6	$8	$4	$6	$8
		Percent											
2	2	N[2]	N	N	N	N	N	N	N	N	N	N	N
2	3	N	N	12	N	N	7	N	N	N	N	N	N
2	4	N	N	18	N	N	12	N	N	N	N	N	N
3	2	N	16	27	4	20	30	N	18	29	N	17	28
3	3	7	20	29	10	24	>30	6	21	30	4	20	30
3	4	11	22	30	12	25	>30	9	23	>30	7	21	30
4	2	10	21	28	15	26	>30	15	26	>30	13	25	>30
4	3	14	23	30	17	27	>30	17	27	>30	16	26	>30
4	4	13	20	25	19	28	>30	18	28	>30	16	26	>30

[1] Average establishment costs/acre reduced by 50 percent:

Spacing	*Cost/acre*
1 × 4′	$130
2 × 4′	$ 92
4 × 4′	$ 72
4 × 6′	$ 66

[2] N represents a negative rate of return, or financial loss on the investment.

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Fusiform Rust In Loblolly and Slash Pines After Cultivation and Fertilization

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Fusiform Rust In Loblolly and Slash Pines After Cultivation and Fertilization

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Cultivation and fertilization increased incidence of rust in slash pine and height growth of slash and loblolly pines in a south Mississippi plantation. Regardless of treatment, the more resistant populations within species remained consistently less infected than their susceptible counterparts. Neither early growth initiation nor tree height appeared to be primarily responsible for the increased amount of rust.

INTRODUCTION

Rising demand for wood has spurred a trend toward intensive nanagement of loblolly *(Pinus taeda* L.) and slash *(P. elliottii* Engelm. var *elliottii)* pines. Surveys indicate plans for increasing he use of intensive site preparation, wider plantation spacings, and ertilizer application to insure adequate survival, rapid early growth, nd short rotations *(4)*. These practices, however, have also been hown to increase the incidence of fusiform rust, a serious disease f loblolly and slash pines caused by *Cronartium fusiforme* Hedgc. Hunt ex Cumm. *(1, 2, 5, 6)*. This report describes the effects of ultivation and fertilization upon height growth and rust incidence n open-pollinated populations of loblolly and slash pines varying n susceptibility. Probable causes for the increased infection are lso examined.

MATERIALS AND METHODS

The planting site, near Gulfport, Mississippi, had been stocked ith second-growth longleaf pine *(P. palustris* Mill.) prior to clear-utting in 1959. Soils are relatively infertile, upland fine sandy loams

(10). The slash pines were open-pollinated progenies from two groups of five parents each—groups A and B. The loblolly pines were open-pollinated progenies from five parents designated group A and two parents designated group B. Wood density and adequate seed yields were the only criteria for selection. All parents were from Harrison and Hancock Counties, Mississippi.

Equal amounts of seed from parents within each group were mixed before sowing in a nursery. One-year-old seedlings were lifted and planted in 1960 at a spacing of 10 $\times$ 10 feet. Field plots for seedlings of a single species were assigned as a group to random positions in each of four replications. Within these main plots, parent group and cultural treatment combinations were assigned randomly to ten 0.25-acre subplots. Each subplot contained 100 trees surrounded by two border rows. Cultural treatments were:

- OO: Control, no cultivation or fertilization;
- CO: Cultivation without fertilization;
- CF-1: Cultivation + 100 lbs. N, 50 lbs. P_20_5, and 50 lbs. K_20 per acre;
- CF-2: Cultivation + 200 lbs. N, 100 lbs. P_20_5, and 100 lbs. K_20 per acre;
- CF-4: Cultivation + 400 lbs. N, 200 lbs. P_20_5, and 100 lbs. K_20 per acre.

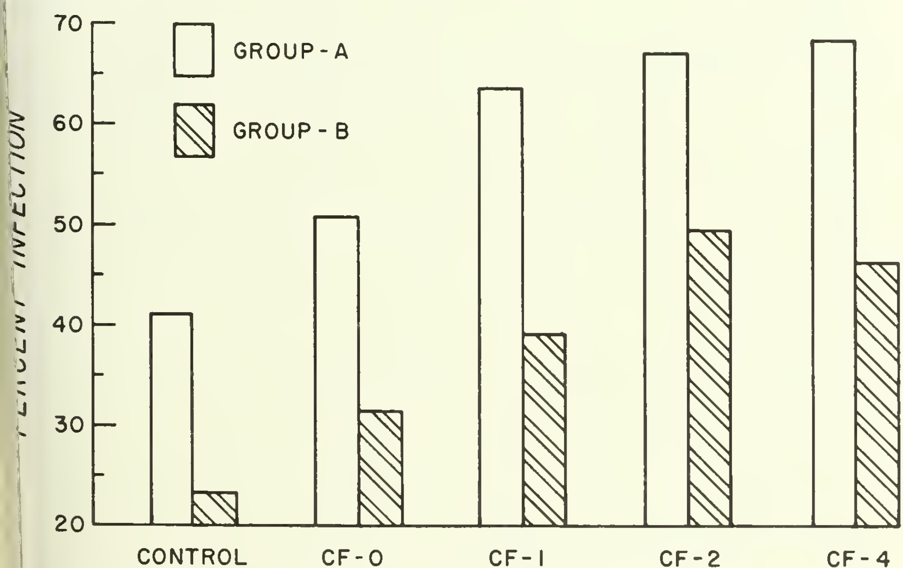
Control plots were not disturbed prior to planting. Cultivated and fertilized plots were cleared, plowed, and disked prior to planting; they were also disked three times during each of the first three growing seasons. In addition, they were mowed during the fourth and fifth seasons. Fertilizer was broadcast and disked into the soil at the beginning of the second season. The few trees dead at the end of the first growing season were replaced with potted stock from the original nursery populations. All plots were sprayed three times with Bordeaux mixture and DDT in both the second and third seasons. Alternate hosts (oaks) were not growing in or around the planting.

Total height and the number of galled or cankered trees were recorded at the end of the fifth and ninth seasons. Trees not infected in the ninth season, but known to have been infected earlier, were tallied as infected. The proportion of trees infected on each plot was transformed to degrees of angle = $\sqrt{\text{percentage}}$. Mean height per plot at age 9 and the transformed proportions were subjected to analyses of variance for the randomized block design *(11)*. Separate analyses were performed for each species. Differences among pairs or groups of means were tested for statistical significance by orthogonal comparisons at the 0.05 level of probability.

The slash pine data were also examined for an association between tree height and infection. All trees from the four replications of each parental group-cultural treatment combination were classed as infected or noninfected and grouped into height classes. Five-year heights were grouped into 1-foot classes, and 9-year heights into 2-foot classes. The number of infected trees observed in each height class was compared to the number expected to occur in that class on the basis of the total number of trees in the class and percent infection over all classes for that particular combination. A chi-square value with degrees of freedom equal to one less than the number of height classes was computed for each combination, using its set of observed and expected numbers of infected trees.

RESULTS AND DISCUSSION

Slash pine.—Cultural treatments increased both rust incidence and height growth (figs. 1 and 2). Percent infection averaged 48.1 and ranged from 31.8 on control to 56.0 on fertilized plots. Total height averaged 29.2 feet and ranged from 18.6 on control to 31.3 feet on fertilized plots. A larger percentage of offspring from group A parents were infected than from group B. Increases in the amount of infection among group B offspring in response to the cultural treatments, however, paralleled those for Group A. In terms of height growth, responses of offspring from the two parental groups were identical.



igure 1.—*Average incidence of rust infection at age 9 in two open-pollinated populations of slash pine grown under five cultural regimes.*

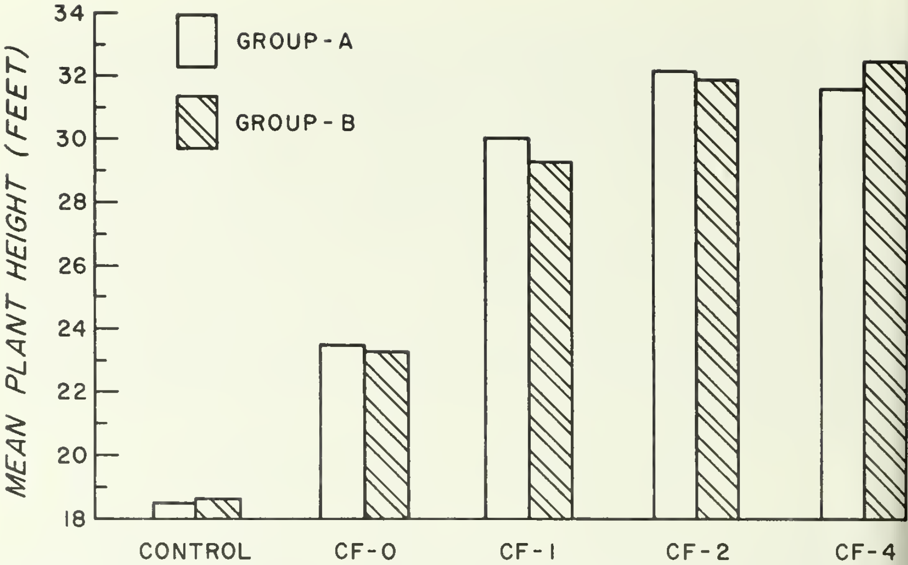


Figure 2.—*Average 9-year height in two open-pollinated populations of slash pine grown under five cultural regimes.*

Slash pines receiving only cultivation were taller and more frequently infected than those on control plots (figs. 1 and 2). These results corroborate earlier work. Cultivation prior to and after planting slash pines has been shown to increase growth and percent infection *(1)*. Even cultivation or site disturbance several seasons prior to planting has been shown to increase rust incidence *(5, 9)*. Moreover, the severity of infection in 8-year-old slash pines has been shown to vary with the intensity of preplanting site preparation *(6)*. Not only were more trees infected but more had potentially lethal galls on intensively prepared sites. It was speculated that yields on prepared plots could exceed those on check plots, but only if the effects of preparation on growth persisted over the rotation. If not, the better survival and early growth on prepared sites would be offset by rust *(6)*.

The application of fertilizer along with cultivation caused even more pronounced increases in growth and percent infection (figs. 1 and 2). Heavier fertilization did not increase growth or rust incidence above that observed on plots given the least fertilizer, but the average fertilized tree was taller and more frequently infected than its counterparts on cultivated and control plots. Average height on fertilized plots was 12.6 feet more than on control plots, but the incidence of rust was also greater by 24.2 percentage points.

Though of obvious economic significance, this gain in height could have been diminished by the accompanying increase in rust infection. Probably as a result of early treatment with Bordeaux mixture and the coincidence of light infection years, the amount of rust observed at age 5 was minimal. Without early protection in even this moderately hazardous area, however, infection and its damaging effects could have been greater by age 9.

Similar increases in growth and rust incidence following cultivation and fertilization have been reported. In one study complete fertilization of slash pines during the first three growing seasons doubled percent infection by age 8 *(2)*. In the same planting at age 19, 65 percent of the fertilized trees had stem galls as compared to 42 percent of the check trees *(3)*. Fertilized plots produced 10 percent more volume, but the additional volume was largely in stem-galled trees. In another instance, the increased growth resulting from cultivation and fertilization of young slash pines was offset by increased rust damage *(13)*. Thus, such practices have often produced mutually antagonistic effects. The development of stable genetic resistance seems to be one way out of this dilemma.

Though rust resistance was not considered when parents were selected for this experiment, the incidence of rust in group B offspring was consistently lower than that in group A offspring by approximately 20 percentage points (fig. 1). Moreover, fertilized offspring of group B grew as rapidly as those of group A (fig. 2), but were only as frequently infected as group A offspring were on control plots. Hence, gains resulting from intensive culture seem less likely to be diminished by rust when resistant progenies are used. Consistency over the range of treatments used indicates that genetic resistance is stable and confirms the findings of a previous study in loblolly pine *(5)*.

It has been suggested that cultural treatments increase the incidence of rust by causing an early break of winter dormancy, thereby extending the period when succulent, susceptible tissue is exposed to inoculum *(8)*. Data from the present investigation, however, contradict this hypothesis; trees on all plots, including controls, broke dormancy on approximately the same date *(10)*. Other findings indirectly contradict the hypothesis. Observation of the weekly elongation rates of 2-year-old seedlings from 14 loblolly pine seed sources in Louisiana indicated that the most susceptible source did not begin growth any earlier than others *(7)*. In another provenance test, flushing dates of loblolly pines from 13 seed sources differed but were not correlated with relative susceptibility *(12)*. Moreover, trees from all these sources had completed their first flush before basidiospores were released.

The increased amount of rust observed in cultivated slash pine has also been attributed to greater height increment *(1)*. That is, the amount of susceptible tissue accessible to basidiospores was said to increase with the length of succulent shoot. In the present study, differences among treatments in terms of percent infection paralleled those in growth (figs. 1 and 2). If faster growing trees are more susceptible because they have more succulent tissue, however, they should also be more frequently infected than their slower growing, but similarly treated neighbors. On the contrary, values of chi-square computed to check the distribution of the observed numbers of infected trees against the expected numbers within individual parental group-cultural treatment combinations were not statistically significant. That is, percent infection was uniform across ninth-year height classes; taller, more vigorous trees were no more frequently infected than those in lower height classes. Since this uniformity might have been associated with reduced growth after infection, similar comparisons were made with 5-year data. As in the foregoing instance, the taller trees at age 5 were no more frequently infected at age 9 than smaller, less vigorous ones.

These findings are supported by previous observations. Height growth and incidence of rust within plots were not correlated despite large differences among cultivated, fertilized, and check plots of slash pine *(2)*. In loblolly pine, growth and the severity of infection were found to be related to site conditions, but not to one another directly *(5)*. Also, weekly elongation rates during the month of greatest rust risk did not differ among resistant and susceptible loblolly pine seed sources *(7)*.

The accumulated evidence thus suggests that neither early growth initiation nor tree height are primarily responsible for the increased infection on slash pine. Instead, the major causes are apparently physiological changes such that the trees both grow faster and become more susceptible. Stated in the sense of Yarwood *(14)*, cultivation and fertilization predisposed slash pines to increased infection.

Loblolly pine.—In contrast to slash pine, the cultural treatments did not multiply the incidence of rust in loblolly pine to such an extent that it jeopardized gains in growth (figs. 3 and 4). The amount of rust in loblolly pine averaged 27.5 percent, considerably less than in slash pine. Total height of loblolly pine averaged 28.8 feet, slightly more than slash pine. Though group A offspring were generally both taller and more frequently infected than those of group B, the results also differed from those in slash pine in that offspring from the two parental groups varied in their response to several treatments.

Percent infection in loblolly pines given only cultivation did not significantly exceed that on control plots (fig. 3). Trees given the

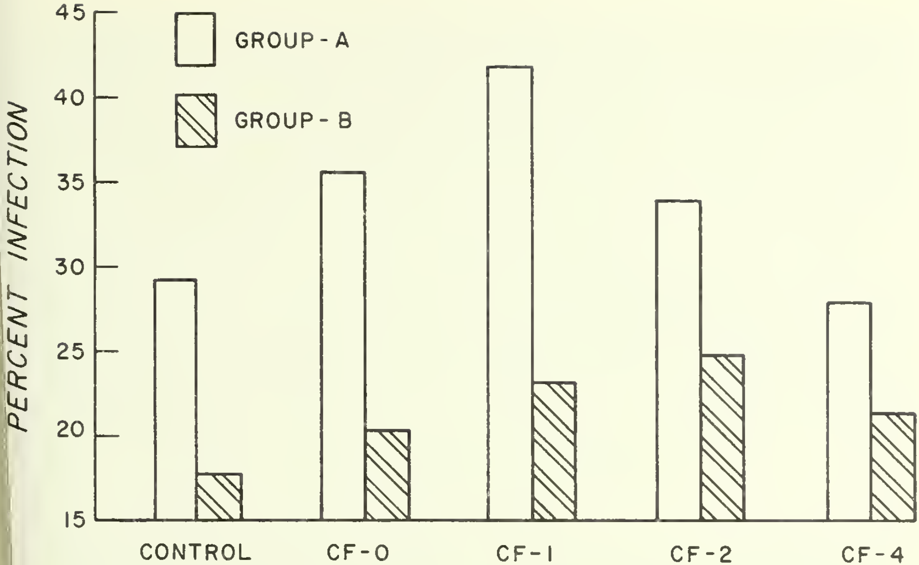


Figure 3.—*Average incidence of rust infection at age 9 in two open-pollinated populations of loblolly pine grown under five cultural regimes.*

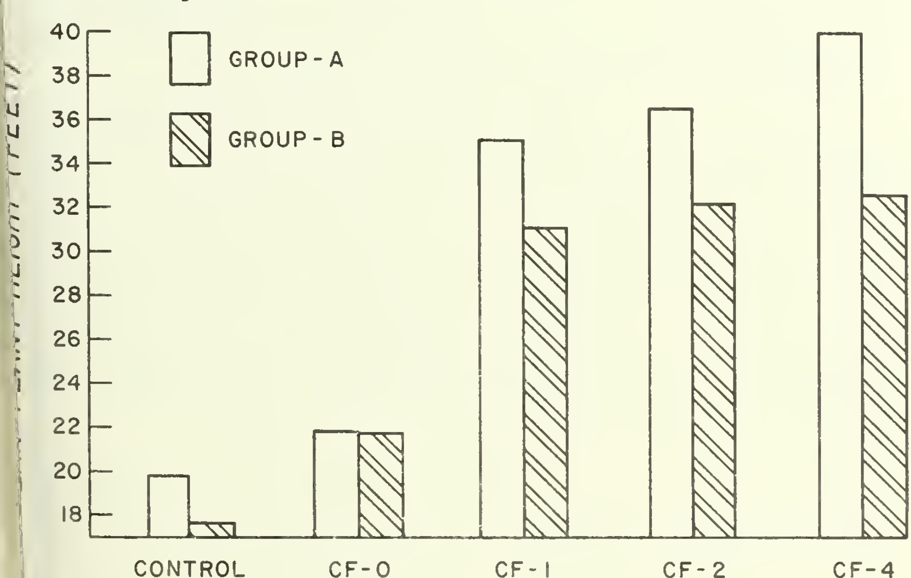


Figure 4.—*Average 9-year height in two open-pollinated populations of loblolly pine grown under five cultural regimes.*

ninimum amount of fertilizer were more frequently infected than hose on control plots, but the increase was small relative to that n slash pine. The incidence of rust on plots given medium and heavy ertilization was lower than that on plots given the least. The largest reduction occurred among group A offspring. On the average, the incidence of rust on fertilized plots was equivalent to that on control and cultivated plots, a result quite unlike that in slash pine. These results seem more a fortuitous outcome peculiar to the test than an expected, repeatable result. Increased rust infection in loblolly pine as a result of site disturbance has been reported *(5)*.

Differences between progenies in terms of percent infection resembled those in slash pine. That is, offspring from parent group B had consistently less rust than those from group A (fig. 3). The largest differences occurred where treatments tended to increase percent infection, and the incidence of rust in group B offspring was increased proportionately less by these treatments. These observations provide further evidence that the utility of resistant planting stock will not be nullified by foreseeable shifts in management practices.

Offspring from both parental groups attained similar heights on the control and cultivated plots (fig. 4). The heaviest fertilizer application did not stimulate growth more than the medium, but trees given the two heavier applications outgrew those given the least. This difference was due largely to the greater responsiveness of group A offspring. Average height on all fertilized plots exceeded that on control plots by 16.3 feet.

On fertilized plots, offspring from group A outgrew the remaining loblolly and all slash pines (figs. 2 and 4). The unexpectedly low amount of infection found on fertilized loblolly plots may be related to this dramatic response. Average height at age 5 on control plots was approximately the same for both species *(10)*. Crowns were of similar size and open. Infection in unfertilized loblolly pines at age 9 was only about 8 percentage points less than that in slash pine. Hence, the amount of rust in the two species was similar on those plots where early growth and crown characteristics were similar.

On the other hand, percent infection in loblolly pine was far less than expected on those plots where differences in growth between species were largest. The tallest trees at age 5 were the fertilized loblolly pines *(10)*. Crown closure was complete on these plots, but crowns of comparably treated slash pines were still in the process of closing. Fertilized loblolly pines increased their height advantage during seasons when most infection occurred and remained the least frequently infected. Indeed, the amount of rust in fertilized offspring from parent group A was inversely proportional to height (figs. 3 and 4). Hence, differences in height and stand conditions may have been responsible for the observed discrepancies in rust incidence between species after fertilization.

Overall, the results indicate that site preparation, cultivation at early ages, and fertilization can increase growth and rust incidence in slash pine. Their effect on rust incidence in loblolly pine remains somewhat uncertain. Nevertheless, these practices should be applied with caution to plantations of both species in areas where rust is a problem. Maximum productivity may be attainable with certainty only after prospective gains in growth have been intelligently weighed against potentially greater losses to rust. Further data are needed to quantify the beneficial and detrimental effects of these practices under a variety of site and stand conditions. The accumulated evidence also emphasizes the utility of and need for resistant planting stock in both current and foreseeable management schemes.

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Cultivation and fertilization increased incidence of rust in slash pine and height growth of slash and loblolly pines in a south Mississippi plantation. Regardless of treatment, the more resistant populations within species remained consistently less infected than their susceptible counterparts.

U. S. Department of Agriculture
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Early Yields Of SLASH PINE Planted On a Cutover Site At Various Spacings

W. F. Mann, Jr.

Southern Forest Experiment Station
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Early Yields Of SLASH PINE Planted On a Cutover Site At Various Spacings

W. F. Mann, Jr. [1]

Tabulates basal areas, cordwood and cubic-foot volumes, average d.b.h., and diameter distributions for 14-year-old slash pine planted in central Louisiana. Also gives regression equations developed to predict these parameters.

Since there is widespread interest in growth and yield of slash pine *(Pinus elliottii* Engelm. var. *elliottii)* plantations in the West Gulf region, it seems timely to reexamine a well-designed study that was established during 1934-35 on a cutover site in central Louisiana. The stands were destroyed by wildfire shortly after they had been measured at age 14 years. A brief account of the findings was published some years ago,[2] but improved computer programs have made possible a more thorough analysis, especially of site effects within the several spacings. In addition, volumes have been recalculated by developing local tables from measurements of individual trees on the study plots. Volumes originally reported were from tables for stands on abandoned fields in Alabama.

The resulting data are the best available for the area. Considerable information is on record for abandoned fields in the Southeast, but such sites differ from those of the West Gulf in soils, climate, and land-use history.

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[1] The author is Principal Silviculturist with the 1102 Timber Management Research Project, located at the Alexandria Forestry Center, Pineville, La. 71360.

[2] Russell, T. E. Spacing—its role in the growth of planted slash pine. South. Lumberman 197(2465): 115-117. 1958.

THE PLANTATION

The 40-acre plantation was about 20 miles southwest of Alexandria, Louisiana. The virgin longleaf stand had been cut in the early 1920's and the land remained idle thereafter. When planted in 1934-35, it supported mostly native grasses and a few small hardwoods and shrubs.

Soils are primarily Caddo and Beauregard silt loams, both characterized by moderately slow internal drainage. Topography is gently rolling. Several small, intermittent streams provide good surface drainage.

The plantation was in four contiguous blocks, each containing sixteen 0.6-acre plots. Planting was by hand at rates of 2,500, 1,600, 1,150, and 250 trees per acre. Each spacing, then, was replicated four times within a block. A wildfire in 1948 caused severe scorching and some mortality on approximately 7 acres in parts of two blocks. Damaged plots were dropped from the study, and the unburned plots were combined into a single block. The result was a total of 48 plots distributed by site index classes as follows:

Site index, age 50 years	Number of trees planted per acre			
	2,500	1,600	1,150	250
	------- *Plots* -------			
81-85	2	2	2	1
86-90	3	1	2	5
91-95	2	6	4	4
96-100	4	3	4	2
101-105	1	...	...	...

Site index for each plot was determined by using the average height of dominant trees at age 14 years and the curves in figure 4 of USDA Miscellaneous Publication 50.[3] Since codominant trees were not included in the sample, site index values probably are 2 to 3 feet too high. The range in site indices is not unusual for small areas in this region. It results primarily from permeability differences that are related in a large measure to depth of the A horizon.

Survival at age 5 was about 75 percent in all spacings. A prescribed burn that killed some small suppressed trees in 1940, an ice storm in 1946, and fusiform rust *(Cronartium fusiforme* Hedgc. & Hunt ex Cumm.) reduced survival by 8 to 21 percentage points over the next 9 years, with heaviest mortality in the denser spacings. At age 14 years, survival was inversely related to number of trees planted per acre, averaging 59, 61, 63, and 78 percent.

[3] USDA Forest Service. Volume, yield, and stand tables for second-growth southern pines. USDA Misc. Publ. 50, 202 p. 1929.

MEASUREMENTS

Measurements for growth and development were taken on the central 0.1 acre of each plot. They included d.b.h. of all trees to the nearest 1 inch, and total height (to nearest 0.5 foot) and d.b.h. of 10 well-spaced dominant trees.

Local volume tables were compiled for each spacing separately by constructing curves of total height over d.b.h. and reading height values for the mean (e.g. 4.0, 5.0) of each 1-inch d.b.h. class. When average total height for each 1-inch d.b.h. class had been computed, volumes in cubic feet of peeled wood and standard rough cords, both to a 3-inch top inside bark, were read from tables 26 and 27 of Miscellaneous Publication 50. Total plot volume was determined by multiplying the number of trees in each diameter class by the average volume in that class.

RESULTS

Determination Of Prediction Equations

With data for individual plots at plantation age 14 years, prediction equations were developed for basal areas per acre, volume per acre expressed in cubic feet and standard rough cords, and average diameter. The equations were derived by combinatorial screening, with Grosenbaugh's REX program,[4] of eight variables:

Site index (S)

S^2

$1/S$

Number of trees planted per acre (P)

P^2

$\text{Log}_{10}\,P$

P/S

$P \times S$

Variables such as survival percent and number of living trees per acre were excluded from the screening because they cannot be estimated at the time of planting.

For all responses, variables S^2, P, $\text{Log}_{10}P$, and $P \times S$ resulted in the best-fitting equations or ones that were essentially as good as those containing other variables. For the sake of consistency, therefore, they were selected for all regressions. Given below is the equation and R^2 value for each of the stand and stocking expressions:

Grosenbaugh, L. R. REX—FORTRAN-4 system for combinatorial screening or conventional analysis of multivariate regressions. USDA Forest Serv. Res. Pap. PSW-44, 47 p. Pac. Southwest Forest and Range Exp. Stn., Berkeley, Calif. 1967.

(1) Basal area per acre for all trees $= -160.96340 + 0.0053427497(S^2) - 0.088644546(P) + 69.462099(\mathrm{Log}_{10}P) + 0.0010416808(P \times S)$

$$R^2 = 0.92$$

(2) Basal area per acre for trees 3.6 inches d.b.h. and larger $= -177.11316 + 0.0054427554(S^2) - 0.10466920(P) + 76.889573(\mathrm{Log}_{10}P) + 0.0010955328(P \times S)$

$$R^2 = 0.91$$

(3) Basal area per acre for trees 4.6 inches d.b.h. and larger $= -199.21865 + 0.0063032989(S^2) - 0.12609176(P) + 84.580910(\mathrm{Log}_{10}P) + 0.0011525739(P \times S)$

$$R^2 = 0.88$$

(4) Cordwood volume per acre in trees 3.6 inches d.b.h. and larger $= -39.066250 + 0.0012328812(S^2) - 0.020412614(P) + 16.066972(\mathrm{Log}_{10}P) + 0.00020739489(P \times S)$

$$R^2 = 0.92$$

(5) Cordwood volume per acre in trees 4.6 inches d.b.h. and larger $= -43.747515 + 0.0013686703(S^2) - 0.024321895(P) + 17.826795(\mathrm{Log}_{10}P) + 0.00021688244(P \times S)$

$$R^2 = 0.89$$

(6) Cubic-foot volume per acre in trees 3.6 inches d.b.h. and larger $= -2516.7721 + 0.094093946(S^2) - 1.3049391(P) + 1009.2515(\mathrm{Log}_{10}P) + 0.012905126(P \times S)$

$$R^2 = 0.90$$

(7) Cubic-foot volume per acre in trees 4.6 inches d.b.h. and larger $= -2765.6518 + 0.10135727(S^2) - 1.5259729(P) + 1103.1979(\mathrm{Log}_{10}P) = 0.013511464(P \times S)$

$$R^2 = 0.88$$

(8) Average d.b.h. of trees 3.6 inches and larger $= 10.101858 + 0.00031119382(S^2) + 0.0013279826(P) - 2.3618647(\mathrm{Log}_{10}P) - 0.000013198202(P \times S)$

$$R^2 = 0.97$$

Basal Area

Equations 1, 2, and 3 account for 88 to 92 percent of the variation in basal areas. When the equations were solved for individual plots, estimated values were within ± 10 percent of actual on about two-thirds of the plots and within ± 15 percent on about 90 percent of the plots. Tables 1, 2, and 3 summarize calculated basal areas for 100-tree steps in planting density within site indices ranging from 80 to 105 feet in 5-foot intervals.

Table 1.--Estimated basal area per acre of all living trees at age 14

Trees planted per acre (No.)	Site index 80	85	90	95	100	105
	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.
200	32	38	43	49	55	62
300	44	50	56	62	69	76
400	52	58	65	72	79	87
500	58	65	72	80	88	96
600	63	71	78	86	95	103
700	67	75	84	92	101	110
800	71	79	88	97	106	116
900	74	83	92	102	112	122
1,000	76	86	96	106	116	127
1,100	79	89	99	110	121	132
1,200	81	91	102	114	125	137
1,300	83	94	105	117	129	141
1,400	84	96	108	120	133	146
1,500	86	98	111	123	136	150
1,600	87	100	113	126	140	154
1,700	89	102	115	129	143	158
1,800	90	104	118	132	146	161
1,900	91	105	120	135	150	165
2,000	92	107	122	137	153	169
2,100	93	108	124	140	156	172
2,200	94	110	126	142	159	176
2,300	94	111	128	144	162	179
2,400	95	112	129	147	164	182
2,500	96	113	131	149	167	186

Total basal area for all stems increased directly with planting rate on all sites, with the steepest rise at the lower rates. Overall, basal areas were almost 2½ times larger at the 2,500-tree planting density than at the 300-tree level. Site also had a strong influence; an increase of site index from 80 to 105 feet about doubled basal area values. The same overall trends were found for trees 3.6 inches d.b.h. and larger, although the differences due to planting density were slightly smaller.

Table 2.--Estimated basal area per acre of trees 3.6 inches d.b.h. and larger at age 14 years

Trees planted per acre (No.)	Site index 80	85	90	95	100	105
	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.
200	31	37	43	49	55	62
300	43	49	56	62	69	76
400	51	58	65	72	79	87
500	57	64	72	79	87	96
600	61	69	77	85	94	103
700	65	73	82	90	100	109
800	67	76	85	95	104	114
900	70	79	89	99	109	119
1,000	71	81	92	102	113	124
1,100	73	83	94	105	116	128
1,200	74	85	96	108	120	132
1,300	75	87	98	111	123	136
1,400	76	88	100	113	126	139
1,500	76	89	102	115	129	143
1,600	77	90	104	117	132	146
1,700	77	91	105	119	134	149
1,800	77	92	106	121	136	152
1,900	78	92	108	123	139	155
2,000	78	93	109	125	141	157
2,100	77	93	110	126	143	160
2,200	77	94	111	128	145	163
2,300	77	94	112	129	147	165
2,400	77	94	112	130	149	168
2,500	76	95	113	132	151	170

Table 3.--Estimated basal area per acre of trees 4.6 inches d.b.h. and larger at age 14 years

Trees planted per acre (No.)	Site index 80	85	90	95	100	105
	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.
200	29	35	42	49	56	64
300	40	47	55	62	70	78
400	48	55	63	71	80	88
500	52	60	69	78	87	96
600	56	64	73	83	92	102
700	58	67	77	87	97	107
800	60	69	80	90	101	112
900	60	71	82	93	104	116
1,000	61	72	83	95	107	119
1,100	61	73	84	97	109	122
1,200	61	73	85	98	111	125
1,300	60	73	86	100	113	127
1,400	60	73	87	100	115	129
1,500	59	73	87	101	116	131
1,600	58	72	87	102	118	133
1,700	57	72	87	103	119	135
1,800	56	71	87	103	120	136
1,900	54	70	87	104	120	138
2,000	53	69	86	104	121	139
2,100	51	68	86	104	122	141
2,200	49	67	85	104	123	142
2,300	48	66	85	104	123	143
2,400	46	65	84	104	124	144
2,500	44	63	83	104	124	145

On sites 100 and 105, basal areas of trees 4.6 inches d.b.h. and arger were directly related to planting density. On sites 80, 85, ınd 90, basal areas reached plateaus beginning at 1,000 to 1,400 trees er acre; at densities above 1,300 to 2,000 trees a decline began. The rend of increasing basal area with increasing planting density will e evident on all sites after ingrowth of 2- and 3-inch trees pro-resses for a few more years.

Cordwood Volumes

Tables 4 and 5 summarize estimated cordwood volumes for trees 3.6 and 4.6 inches d.b.h. and larger. They were calculated from equations 4 and 5, which accounted for 92 and 89 percent of the variation in these volumes. Estimated and actual volumes differed by ± 10 percent on an average of 35 percent of the plots and by ± 15 percent on about 15 percent.

Table 4.--Estimated cordwood volume [1/] per acre for trees 3.6 inches d.b.h. and larger at age 14 years

Trees planted per acre (No.)	Site index 80	85	90	95	100	105
	Cords	Cords	Cords	Cords	Cords	Cords
200	5.0	6.3	7.5	8.9	10.3	11.8
300	7.5	8.8	10.2	11.6	13.2	14.7
400	9.1	10.5	12.0	13.6	15.2	16.9
500	10.3	11.8	13.4	15.1	16.8	18.6
600	11.2	12.8	14.5	16.3	18.1	20.0
700	11.9	13.6	15.4	17.3	19.2	21.2
800	12.4	14.3	16.2	18.1	20.2	22.3
900	12.9	14.8	16.8	18.9	21.0	23.2
1,000	13.2	15.3	17.4	19.6	21.8	24.1
1,100	13.5	15.6	17.9	20.1	22.5	24.9
1,200	13.7	16.0	18.3	20.7	23.1	25.6
1,300	13.9	16.3	18.7	21.2	23.7	26.3
1,400	14.0	16.5	19.0	21.6	24.3	27.0
1,500	14.1	16.7	19.3	22.0	24.8	27.6
1,600	14.2	16.9	19.6	22.4	25.3	28.2
1,700	14.2	17.0	19.9	22.8	25.7	28.7
1,800	14.2	17.1	20.1	23.1	26.2	29.3
1,900	14.2	17.2	20.3	23.4	26.6	29.8
2,000	14.2	17.3	20.5	23.7	27.0	30.3
2,100	14.2	17.4	20.6	23.9	27.3	30.8
2,200	14.1	17.4	20.8	24.2	27.7	31.2
2,300	14.0	17.4	20.9	24.4	28.0	31.7
2,400	14.0	17.5	21.0	24.7	28.4	32.1
2,500	13.9	17.5	21.1	24.9	28.7	32.5

1/ Standard rough cords to a top diameter of 3.0 inches i.b.

Table 5.--Estimated cordwood volume [1/] per acre for trees 4.6 inches d.b.h. and larger at age 14 years

Trees planted per acre (No.)	Site index 80	85	90	95	100	105
	Cords	Cords	Cords	Cords	Cords	Cords
200	4.6	6.0	7.4	8.9	10.4	12.1
300	7.1	8.5	10.1	11.6	13.3	15.0
400	8.6	10.2	11.8	13.5	15.3	17.1
500	9.6	11.3	13.1	14.9	16.7	18.7
600	10.4	12.1	14.0	15.9	17.9	19.9
700	10.9	12.7	14.7	16.7	18.8	21.0
800	11.2	13.2	15.2	17.4	19.6	21.9
900	11.4	13.5	15.7	17.9	20.2	22.6
1,000	11.5	13.7	16.0	18.4	20.8	23.3
1,100	11.6	13.9	16.3	18.7	21.3	23.9
1,200	11.5	14.0	16.5	19.0	21.7	24.4
1,300	11.5	14.0	16.6	19.3	22.0	24.8
1,400	11.3	14.0	16.7	19.5	22.3	25.3
1,500	11.2	13.9	16.8	19.6	22.6	25.6
1,600	11.0	13.8	16.8	19.8	22.8	26.0
1,700	10.7	13.7	16.8	19.9	23.1	26.3
1,800	10.5	13.6	16.7	19.9	23.2	26.6
1,900	10.2	13.4	16.7	20.0	23.4	26.8
2,000	9.9	13.2	16.6	20.0	23.5	27.1
2,100	9.6	13.0	16.5	20.0	23.6	27.3
2,200	9.3	12.8	16.4	20.0	23.7	27.5
2,300	8.9	12.5	16.2	20.0	23.8	27.7
2,400	8.5	12.3	16.1	19.9	23.9	27.9
2,500	8.2	12.0	15.9	19.9	23.9	28.0

1/ Standard rough cords to a top diameter of 3.0 inches i.b.

Volume of trees 3.6 inches d.b.h. and larger increased directly with planting density, except on site 80 where a plateau was reached at the 1,600-tree rate. On all sites, volume gains from planting an additional 100 trees were greatest at the lower densities and gradually diminished at higher levels (fig. 1).

Cordwood growth over the 14-year period was about 1.8 times greater at the 1,200-tree planting rate than at the 300-tree rate. In this array of densities, volumes ranged from 7.5 to 25.6 cords per acre. They were almost twice as great on 105-foot sites as on 80-foot sites. Within comparable stocking levels in the range of 300 to 1,200 trees planted per acre, a 10-foot rise in site index increased the yield by 2.7 to 4.9 cords.

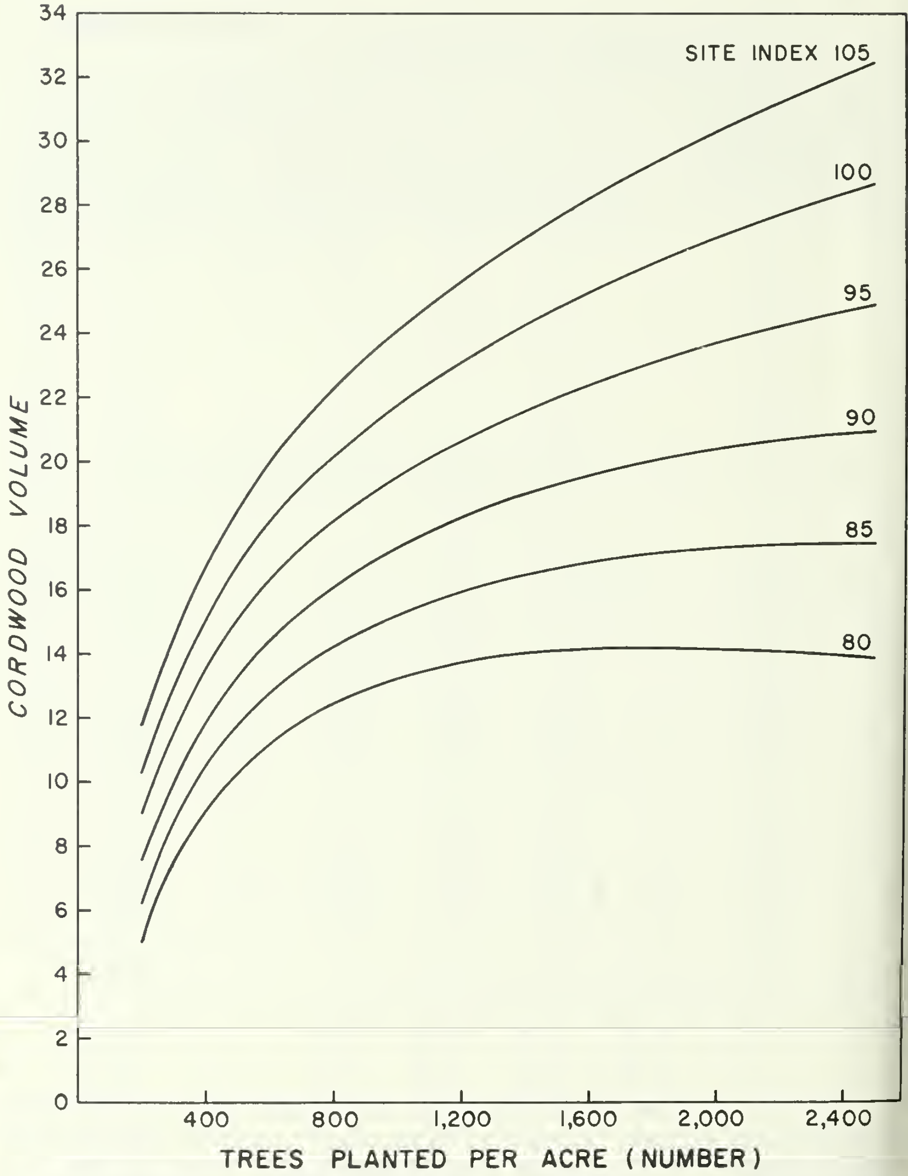

Figure 1.—*Estimated cordwood volumes per acre for slash pines 3.6 inches d.b.h. and larger at age 14 years, by planting densities and site indices.*

When 4.6 inches d.b.h. is taken as the threshold of merchantability, yields ranged from 7.1 cords at 300 trees planted per acre to 28.0 cords at 2,500 trees (table 5). Volumes on 95-foot and lower sites peaked in the range of 1,100 to 1,900 trees and then declined slightly thereafter. On better sites, they increased throughout the range of planting densities studied. Otherwise, trends in volume influenced by site index and planting density were similar to those discussed for trees 3.6 inches d.b.h. and larger. As with basal areas, ingrowth over the next few years will result in uniform trends of increasing volume with higher rates of planting.

Cubic-Foot Volumes

Equations to predict cubic-foot volumes accounted for about the same percentage of variation as did those for cordwood volumes, and the differences between estimated and actual volumes on individual plots were also comparable. Tables 6 and 7 give estimated yields at age 14 years in cubic feet per acre. Trends related to plant-

Table 6.--Estimated cubic-foot volume of peeled wood [1/] per acre in trees 3.6 inches d.b.h. and larger at age 14 years

Trees planted per acre (No.)	Site index 80	85	90	95	100	105
	Cu.ft.	Cu.ft.	Cu.ft.	Cu.ft.	Cu.ft.	Cu.ft.
200	353	444	539	639	744	853
300	504	601	702	809	920	1,036
400	603	706	814	927	1,044	1,167
500	673	783	898	1,017	1,141	1,270
600	726	842	963	1,089	1,219	1,354
700	766	889	1,016	1,149	1,286	1,427
800	797	927	1,061	1,199	1,343	1,491
900	822	957	1,098	1,243	1,393	1,547
1,000	841	983	1,130	1,281	1,438	1,598
1,100	855	1,004	1,157	1,315	1,478	1,645
1,200	866	1,021	1,181	1,345	1,514	1,688
1,300	874	1,035	1,202	1,372	1,548	1,728
1,400	879	1,047	1,220	1,397	1,579	1,766
1,500	882	1,056	1,236	1,420	1,608	1,801
1,600	883	1,064	1,250	1,440	1,635	1,834
1,700	882	1,070	1,262	1,458	1,660	1,866
1,800	880	1,074	1,272	1,476	1,684	1,896
1,900	877	1,077	1,282	1,492	1,706	1,925
2,000	872	1,079	1,290	1,506	1,727	1,952
2,100	866	1,079	1,297	1,520	1,747	1,979
2,200	859	1,079	1,303	1,532	1,766	2,004
2,300	851	1,078	1,308	1,544	1,784	2,029
2,400	843	1,075	1,312	1,554	1,801	2,052
2,500	834	1,072	1,316	1,564	1,818	2,075

1/ To a top diameter of 3 inches i.b.

Table 7.--Estimated cubic-foot volume [1] of peeled wood per acre in trees 4.6 inches d.b.h. and larger at age 14 years

Trees planted per tree (No.)	Site index 80	85	90	95	100	105
	Cu.ft.	Cu.ft.	Cu.ft.	Cu.ft.	Cu.ft.	Cu.ft.
200	332	430	532	639	751	869
300	482	586	695	809	928	1,052
400	576	686	802	923	1,049	1,180
500	638	755	878	1,005	1,138	1,276
600	681	805	934	1,068	1,208	1,352
700	710	841	977	1,118	1,264	1,415
800	730	867	1,010	1,158	1,311	1,469
900	742	886	1,036	1,190	1,350	1,514
1,000	748	899	1,055	1,216	1,383	1,554
1,100	749	907	1,070	1,238	1,411	1,589
1,200	746	911	1,080	1,255	1,435	1,620
1,300	740	911	1,088	1,269	1,456	1,648
1,400	731	909	1,092	1,281	1,474	1,672
1,500	719	904	1,094	1,289	1,490	1,695
1,600	706	897	1,094	1,296	1,503	1,715
1,700	690	889	1,092	1,301	1,514	1,733
1,800	673	878	1,089	1,304	1,524	1,750
1,900	654	866	1,084	1,306	1,533	1,765
2,000	635	853	1,077	1,306	1,540	1,779
2,100	614	839	1,070	1,305	1,546	1,792
2,200	591	824	1,061	1,303	1,551	1,803
2,300	568	807	1,051	1,300	1,554	1,814
2,400	544	790	1,040	1,296	1,557	1,823
2,500	519	772	1,029	1,292	1,560	1,832

1/ To a top diameter of 3 inches i.b.

ing density and site index are almost identical to those already discussed for cordwood volumes.

Average Diameter

Estimated average diameters were derived for 100-tree steps by solving equation 8. This equation accounted for 97 percent of the variation in average diameters. Its high accuracy is confirmed by the fact that predicted and actual values differed by more than ± 5 percent on only one plot.

Both site index and planting density affected average diameter (table 8). On site 80, trees planted at the rate of 300 per acre were 1.5 inches larger than those planted at the rate of 2,500. On site

.00, the difference was 2.2 inches. Within the range of 300 to 1,200 rees per acre, which spans the practical choices today, average liameters varied by 1.1 to 1.5 inches with the greatest differences on the best sites. Between site 80 and site 105 the average diameter lifference was 1.4 inches at the 300-tree planting density and 0.6 inch it the 2,500-tree rate.

'able 8.--Estimated average d.b.h. of trees 3.6 inches d.b.h. and larger at age 14 years

Trees planted per tree (No.)	Site index 80	85	90	95	100	105
	Inches	Inches	Inches	Inches	Inches	Inches
200	6.7	7.0	7.2	7.5	7.8	8.1
300	6.3	6.6	6.8	7.1	7.4	7.7
400	6.1	6.3	6.5	6.8	7.1	7.4
500	5.8	6.1	6.3	6.6	6.8	7.1
600	5.7	5.9	6.1	6.4	6.7	6.9
700	5.6	5.8	6.0	6.2	6.5	6.8
800	5.4	5.7	5.9	6.1	6.4	6.6
900	5.4	5.6	5.8	6.0	6.2	6.5
1,000	5.3	5.5	5.7	5.9	6.1	6.4
1,100	5.2	5.4	5.6	5.8	6.0	6.3
1,200	5.2	5.3	5.5	5.7	6.0	6.2
1,300	5.1	5.3	5.4	5.6	5.9	6.1
1,400	5.0	5.2	5.4	5.6	5.8	6.0
1,500	5.0	5.2	5.3	5.5	5.7	5.9
1,600	5.0	5.1	5.3	5.5	5.7	5.9
1,700	4.9	5.1	5.2	5.4	5.6	5.8
1,800	4.9	5.0	5.2	5.4	5.5	5.7
1,900	4.9	5.0	5.1	5.3	5.5	5.7
2,000	4.8	5.0	5.1	5.3	5.4	5.6
2,100	4.8	4.9	5.1	5.2	5.4	5.6
2,200	4.8	4.9	5.0	5.2	5.3	5.5
2,300	4.8	4.9	5.0	5.1	5.3	5.5
2,400	4.8	4.9	5.0	5.1	5.2	5.4
2,500	4.8	4.8	5.0	5.1	5.2	5.4

Iameter Distributions

Table 9 gives the actual number of trees per acre by 1-inch diameter and 5-foot site index classes at age 14. As expected, planting 20 trees per acre resulted in the greatest number of trees in the t) diameter class (9 inches). For the 8- and 9-inch diameters combined, the low planting rate was superior on sites 81-90, but the

Table 9.--Actual average diameter and diameter distributions per acre by site index classes in each original planting density

Site index class	Average d.b.h. 1/	Trees per acre by diameter classes								
		1	2	3	4	5	6	7	8	9
	Inches	No.	No.	No.	No.	No.	No.	No.	No.	No.
	250 trees planted per acre									
81-85	6.8	--	--	--	--	60	20	80	40	20
86-90	6.8	2	2	4	4	18	50	64	32	12
91-95	7.2	--	--	5	10	5	32	62	50	22
96-100	7.4	--	--	--	--	5	55	50	45	30
	1,150 trees planted per acre									
81-85	5.4	--	65	55	130	190	125	65	5	--
86-90	5.6	40	50	85	125	160	190	85	--	--
91-95	5.6	5	50	95	135	192	165	92	175	--
96-100	5.9	--	25	42	78	85	140	230	132	17
	1,600 trees planted per acre									
81-85	5.2	10	75	180	195	180	145	50	--	--
86-90	5.1	20	70	120	230	260	190	30	--	--
91-95	5.4	60	127	135	178	263	191	88	5	2
96-100	5.6	27	97	123	150	193	220	110	10	3
	2,500 trees planted per acre									
81-85	4.8	30	165	185	345	250	105	10	--	--
86-90	5.0	130	290	343	353	250	173	47	--	--
91-95	5.0	160	280	275	380	390	190	30	5	--
96-100	5.2	120	192	202	285	350	250	47	10	--
100+	5.2	150	180	180	330	410	260	90	--	10

1/ Trees 3.6 inches d.b.h. and larger.

1,150-tree rate excelled on the higher sites. The two densest plantings had only a few 8- and 9-inch trees, but had many in the 7-inch class. On sites of 91 feet or better the 1,600-tree rate had more 7-inch trees than the 250-tree rate. When all trees 6 inches d.b.h. and larger were totaled, the 1,150-tree density ranked first and the 250-tree density ranked last.

DISCUSSION

When this plantation was installed during the mid-30's, close spacing was fairly common. Today emphasis is on wide spacing that permits easy passage of large equipment for mechanized harvesting and allows trees to reach large diameters at an early age. Consequently, that portion of the data between planting densities of 400 and 1,200 trees per acre is of greater interest under prevailing conditions.

The recent trend to wide spacing has some dangerous aspects in the West Gulf region, where summer drouths are frequent. In some years 80 percent or more of the trees survive their first year, but after a dry summer survival may be only 50 percent. On sites where bad drouths are frequent, it seems logical to adopt a planting policy that will insure a minimum stand in most years.

Yearly variations in climatic conditions in this area are quite different from those in many parts of the Southeast, where much of the information on growth and yield of slash pine plantations has been derived. Summer rainfall is usually less, and rainless periods of 4 to 8 weeks are common. The geographic difference in probabilities for high survival suggest different planting polices for the various portions of the southern pine region.

Another factor suggesting careful choice of planting density is the high susceptibility of slash pine to fusiform rust in the West Gulf region. Typically, trunk cankering ranges from 30 to 60 percent at the time of the first thinning, even after some trees have been killed by the disease. When low survival and high incidence of disease are combined in a plantation with wide initial spacing, it is difficult to leave sufficient well-spaced crop trees in an intermediate cutting.

In this study maximum cordwood and cubic-foot volume were obtained in early years by high initial densities. Plots initially having 1,200 trees per acre yielded an average of 6 cords (the range was 4.6 to 8.7 cords) more than plots having 400 trees (in trees 3.6 inches d.b.h.). The larger differences were on the better sites.

Two factors must be considered in assessing these differences in growth. First is planting costs. But they are not in direct proportion to the number of stems planted per acre. Density can be increased by narrowing the planting interval within rows, and the cost of this increase is nominal. Second is the effect of density on diameter growth. In this study, trees planted at the rate of 400 per acre averaged about 1 inch larger in diameter than those planted at 1,200 per acre. However, interpolation strongly indicates that the higher rate had more trees per acre in the 6-inch and larger diameter classes than the 400-tree rate. With a greater number of stems in operable sizes and a higher basal area, thinnings can be started earlier with high than with low initial densities.

It is difficult to say if an added 1 inch in diameter is offset by an increase of an average of 6 cords per acre. The preference will probably vary by landowners, depending on management objectives, finances, market prices for different products, logging costs, and other factors. Then, too, average diameters must be interpreted carefully, for close spacings are penalized by having numerous trees at the lower limit of merchantability even though stocking in the larger sizes is comparable.

In regions where survival is difficult to predict and incidence of disease is high, land managers should consider the consequences of higher and lower stocking than the optimum desired. Figure 1 shows that rapid decline in volume growth starts at a lower initial stocking on poor sites than on good ones. If trees are planted at intervals of 8 by 10 feet on site 80 (about 550 trees per acre), and early survival is about 50 percent instead of the 75 percent recorded in this study, a growth loss of 2 to 3 cords per acre may result with only a small gain in diameter growth. On the other hand, if trees are planted at a 6- by 8-foot spacing and survival is better than in this study, volume growth will be higher with a minimum reduction in diameter growth. Spacing and survival are most critical on the choice sites, because the curve of volume over planting density continues upward at a high rate to the 2,500-tree level.

It is not intended to recommend a planting spacing in this paper. Instead, the purpose is to encourage landowners to consider all factors carefully before chosing a spacing, and to rely on data from a geographic region near the sites to be reforested.

Mann, W. F., Jr.

1971. Early yields of slash pine planted on a cut-over site at various spacings. South. Forest Exp. Stn., New Orleans, La. 16 p. (USDA Forest Serv. Res. Pap. SO-69)

Tabulates basal areas, cordwood and cubic-foot volumes, average d.b.h., and diameter distributions for 14-year-old slash pine planted in central Louisiana. Also gives regression equations developed to predict these parameters.

U. S. Department of Agriculture
Forest Service Research Paper SO-70

Yields of 17-YEAR-OLD LOBLOLLY PINE PLANTED ON A CUTOVER SITE AT VARIOUS SPACINGS

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1971

Mann, W. F., Jr., and Dell, T. R.

1971. Yields of 17-year-old loblolly pine planted on a cutover site at various spacings. South. Forest Exp. Stn., New Orleans, La. 9 p. (USDA Forest Serv. Res. Pap. SO-70)

Tabulates cubic-foot volumes, diameters, and basal areas for loblolly pines planted in southwest Louisiana on a cutover area representing a wide range of site indices. Also gives regression equations for predicting these parameters.

ields Of 17-Year-Old Loblolly Pine Planted On a Cutover Site At Various Spacings

W. F. Mann, Jr., and T. R. Dell [1]

This paper summarizes development and yield of loblolly pine (*Pinus taeda* L.) 17 years after planting. Five spacings and a broad array of site classes are represented. The plantation is on a cutover site in southwest Louisiana, whereas most information previously available was from stands on abandoned fields.

Regression equations to predict volumes, average diameter, and basal area are given, along with solutions of the equations for representative site indices and planting densities. While these results are limited to one age, it is the age when the question of a first thinning arises in most plantations. The plots are to be einventoried every 5 years. They have been thinned to several stocking levels and vill eventually provide more comprehensive information than is contained in this eport.

STUDY AREA

The area was originally dominated by virgin longleaf pine, which was clearcut in he 1930's. The site was left barren and supported a [illegible] stand of native grasses ntil planted with loblolly pines. Wildfires eliminated most of the hardwoods that ecame established.

The study plots are in an 80-acre plantation that was established in the winter of 951-52 near Merryville, Louisiana. The area was divided into four 20-acre blocks, ach measuring 10 by 20 chains. Within each block, trees were planted by machine approximate spacings of 6 by 6, 8 by 8, 9 by 9, 10 by 10, and 12 by 12 feet on rips 2 chains wide and 20 chains long. Thus each spacing was replicated four mes. Overall, initial densities were fairly precise. The site was prepared by burning e grass immediately before planting.

Soils are variable, consisting primarily of Caddo and Beauregard silt loams. All ave slow internal drainage and a high water table during the winter. Topography is ghtly rolling, and hence surface drainage is fair, except on small flats.

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MEASUREMENTS

When the plantation was 17 years old, the long, narrow planting strips wer divided into thinning plots 2 by 2 chains in size. Portions of strips with fev surviving loblolly pines and numerous volunteer longleaf pines were bypassed. Th 88 plots thus established provided the data for all analyses in this paper.

Measurements were taken on the central 0.1 acre of each plot. They include number of trees planted as determined from standing stems and blank spaces, and complete tally of diameters to the nearest 0.1 inch. In addition, volume and basa area of 12 sample trees were determined on each plot, and total plot volume wa calculated by multiplying the volume/basal area ratio of the sample trees by tota basal area. Sample trees were allotted to diameter classes in proportion to th diameter distribution on the plot. Their volumes were obtained by heigh accumulation[2] in 2-inch taper steps to a top of 4 inches outside bark. Diamete points and heights were determined with a Spiegelrelaskop. So that cubic-foo volumes inside and outside bark could be calculated, bark thickness was measure at breast height, at the midpoint of the merchantable stem, and at the 4-inch to diameter on 25 felled trees in each spacing. The ratio of diameter inside bark ove diameter outside bark proved to be unaffected by initial spacing or height in tre data were therefore combined into a single ratio of 0.842. No attempt was made t translate cubic feet into cords, since the conversion factors vary by tree size, ba thickness, and other tree characteristics.

Average total height of 12 dominant and codominant trees on each plot w measured for determination of site index by means of Zahner's curves[3] for poor drained soils in the Gulf Coastal Plain. Indices ranged from 76 to 111 feet (age 5 years); differences in drainage and depth to the water table probably account f much of the variation. Table 1 shows distribution of plots by 5-foot site ind classes within each spacing. It should be noted that site classes are not equal represented in all spacings. However, there is a reasonable cross section of sites f each spacing.

RESULTS

Neither site index nor initial spacing had any influence on survival at 17 ye (table 1). In a droughty year, variations in soils might have caused differences i initial survival, but weather data suggest that the summer of 1952 was abo average. That subsequent mortality was not related to planting density is evidenc by the generally good survival at the closest spacing. Heights were unaffected spacing.

[2] Lohrey, R. E., and Dell, T. R. Computer programs using height accumulation for tree volumes and plot summaries. J. Fo 554-555. 1969.

[3] Zahner, R. Estimating pine sites in the Gulf Coastal Plain. J. For. 52: 448-449. 1954.

Table 1.–*Stand data per acre at age 17 years, by 5-foot site index classes within each spacing*

Spacing (feet)	Site index class (age 50)	Plots	Survival	Basal area per acre[1]
	Feet	*No.*	*Percent*	*Sq. ft.*
6 by 6	81–85	5	74	141
	86–90	3	79	145
	91–95	6	68	145
	96–100	1	79	156
	101–105	1	74	160
	106–110	1	61	163
8 by 8	76–80	1	85	114
	81–85	4	83	124
	86–90	2	74	119
	91–95	9	86	135
	96–100	2	78	150
9 by 9	81–85	1	88	97
	86–90	3	83	112
	91–95	6	83	123
	96–100	5	80	128
	101–105	3	93	138
	106–110	1	81	148
10 by 10	76–80	2	90	83
	81–85	5	81	106
	86–90	0	–	–
	91–95	6	75	109
	96–100	5	73	110
	101–105	1	67	117
12 by 12	76–80	2	72	69
	81–85	0	–	–
	86–90	0	–	–
	91–95	6	71	95
	96–100	3	73	109
	101–105	3	70	100
	106–110	0	–	–
	111–115	1	61	88

[1] Trees 1 inch d.b.h. and larger.

ubic-Foot Volumes

Cubic-foot volumes per acre were specified in four combinations: inside and ıtside bark, and with two d.b.h. thresholds–4.6 and 5.6 inches. In each regression uation, various functions of site index (S), number of trees planted per acre (N), d survival at age 17 years were studied by a combinatorial screening process veloped by Grosenbaugh.[4] The best-fitting equations included functions of

[4] rosenbaugh, L. R. REX-FORTRAN-4 system for combinatorial screening or conventional analysis of multivariate regressions. DA Forest Serv. Res. Pap. PSW-44, 47 p. Pac. Southwest Forest and Range Exp. Stn., Berkeley, Calif. 1967.

survival, but omission of survival data did not appreciably decrease the variation explained. Consequently, it was decided to use only site index and number of trees planted as independent variables. Trends were consistent for each of the volume specifications, indicating that a model of the form given below fitted essentially as well as any other model tested.

The equations are:

V_1 (outside bark, trees 4.6 inches in d.b.h. to a 4.0 inch top o.b.) =
$-10954.973 + 0.22589(S^2) + 4617.4793\,(\text{Log}_{10}N) - 185.10460(N/S)$.

V_2 (same as V_1, but volume inside bark) = $-7887.5822 + 0.16267(S^2) + 3324.4766\,(\text{Log}_{10}N) - 133.21234(N/S)$.

V_3 (outside bark, trees 5.6 inches in d.b.h. to a 4.0 inch top o.b.) =
$-11251.101 + 0.22476(S^2) + 4800.9214\,(\text{Log}_{10}N) - 232.69857\,(N/S)$.

V_4 (same as V_3, but volume inside bark) = $-8098.8957 + 0.16180(S^2) + 3456.0600\,(\text{Log}_{10}N) - 167.51623\,(N/S)$.

Each of the equations explained about 75 percent of the variation. Moreover volumes derived from the equations were within $\pm$ 10 percent of actual volumes on two-thirds of the plots.

Tables 2 to 5 show solutions of these equations for 100-tree steps within an array of site indices. In the range of densities giving maximum or near-maximum volume, the differences within 100-tree steps were small. Solutions for steps of fewer than 100 trees would therefore have no practical value.

Since maximum volumes were obtained with closer initial spacing on good than on poor sites, it appears that planting density should increase with site index. Thus on sites 80 and 85 maximum yields for trees 4.6 inches d.b.h. and larger were attained with about 900 trees per acre. On sites 100 and 105, the maximum was achieved at about 1,100 trees. For a given site, the optimum density was not greatly altered by reasonable differences in the minimum d.b.h. threshold; additiona

Table 2.—*Estimated yields (outside bark) per acre at age 17 years for trees 4.6 inches d.b.h. and larger to a 4.0-inch top*

Trees planted per acre (No.)	Site index							
	70	75	80	85	90	95	100	105
	Cubic feet							
300	798	1,014	1,236	1,463	1,697	1,938	2,188	2,446
400	1,110	1,345	1,581	1,822	2,068	2,320	2,580	2,847
500	1,293	1,545	1,798	2,052	2,310	2,573	2,842	3,118
600	1,395	1,664	1,932	2,200	2,470	2,744	3,023	3,307
700	1,439	1,727	2,010	2,291	2,574	2,858	3,147	3,440
800	1,443	1,748	2,046	2,341	2,636	2,931	3,229	3,532
900	1,415	1,737	2,051	2,360	2,666	2,973	3,281	3,591
1,000	1,361	1,702	2,031	2,353	2,672	2,989	3,307	3,626
1,100	1,288	1,646	1,991	2,327	2,657	2,985	3,313	3,641
1,200	1,198	1,574	1,934	2,283	2,626	2,965	3,302	3,640

Table 3.—*Estimated yields (inside bark) per acre at age 17 years for trees 4.6 inches d.b.h. and larger to a 4.0-inch top*

Trees planted per acre (No.)	Site index							
	70	75	80	85	90	95	100	105
	Cubic feet							
300	573	729	889	1,052	1,221	1,395	1,574	1,760
400	798	967	1,137	1,311	1,488	1,670	1,856	2,048
500	930	1,112	1,293	1,476	1,662	1,852	2,045	2,244
600	1,003	1,197	1,390	1,583	1,777	1,975	2,175	2,380
700	1,035	1,242	1,446	1,649	1,852	2,057	2,265	2,476
800	1,038	1,257	1,472	1,685	1,897	2,110	2,324	2,542
900	1,018	1,250	1,476	1,698	1,919	2,139	2,361	2,585
1,000	979	1,224	1,461	1,694	1,923	2,151	2,380	2,610
1,100	927	1,184	1,432	1,674	1,913	2,149	2,384	2,621
1,200	862	1,132	1,392	1,643	1,890	2,134	2,377	2,620

Table 4.—*Estimated yields (outside bark) per acre at age 17 years for trees 5.6 inches d.b.h. and larger to a 4.0-inch top*

Trees planted per acre (No.)	Site index							
	70	75	80	85	90	95	100	105
	Cubic feet							
300	745	975	1,207	1,444	1,686	1,935	2,191	2,455
400	1,013	1,264	1,516	1,770	2,028	2,290	2,558	2,833
500	1,146	1,419	1,691	1,962	2,234	2,510	2,791	3,076
600	1,193	1,489	1,780	2,068	2,356	2,645	2,938	3,235
700	1,182	1,500	1,810	2,116	2,419	2,722	3,027	3,335
800	1,128	1,469	1,798	2,120	2,439	2,755	3,072	3,391
900	1,041	1,404	1,753	2,092	2,426	2,756	3,085	3,415
1,000	929	1,313	1,681	2,038	2,387	2,731	3,072	3,413
1,100	795	1,202	1,589	1,963	2,327	2,684	3,038	3,391
1,200	644	1,073	1,480	1,871	2,250	2,621	2,987	3,350

Table 5.—*Estimated yields (inside bark) per acre at age 17 years for trees 5.6 inches d.b.h. and larger to a 4.0-inch top*

Trees planted per acre (No.)	Site index							
	70	75	80	85	90	95	100	105
	Cubic feet							
300	537	702	869	1,040	1,214	1,393	1,578	1,767
400	729	911	1,092	1,275	1,460	1,649	1,842	2,040
500	825	1,022	1,217	1,412	1,609	1,807	2,009	2,215
600	859	1,072	1,282	1,489	1,696	1,905	2,115	2,329
700	851	1,080	1,304	1,523	1,741	1,960	2,179	2,401
800	813	1,058	1,295	1,527	1,756	1,984	2,212	2,442
900	750	1,011	1,262	1,506	1,746	1,984	2,221	2,459
1,000	669	946	1,211	1,467	1,718	1,966	2,212	2,458
1,100	573	865	1,144	1,413	1,675	1,933	2,188	2,441
1,200	464	773	1,066	1,347	1,620	1,887	2,151	2,412

computations to impose a threshold of 3.6 inches supported this conclusion. Probably, then, density levels selected in view of current thresholds would be very close to optimum if lower thresholds were accepted in the future.

The tables also clearly show the importance of considering site quality when funds are allocated for land purchase or lease, regeneration, and stand improvement. Yields at 17 years were approximately 2.5 times as great on site 100 as on site 70.

Basal Area

Site for site, basal area per acre of all trees at age 17 years was directly related to number of trees planted (table 1). In the 6 by 6 spacing, basal areas range from 141 to 163 square feet per acre, as against 69 to 109 square feet in the 12 by 12 spacing. As expected, basal areas were also related to site index, with the highest values on the best sites. The independent variables selected for cubic-foot volume equations gave results essentially as good as any other variables and thus were chosen for consistency. The equation is:

$$\text{Basal area (all trees)} = 411.46809 + 0.004924(S^2) + 189.86491\ (\text{Log}_{10}N) - 4.9826\ (N/S).$$

The equation, which explains 80 percent of the variation, was solved for representative planting densities and site indices (table 6). Seventy-six percent of the estimated values were within ± 10 percent of the measured values, and 94 percent were within ± 15 percent. Basal areas increased directly with number of trees planted per acre and with site index. Values on sites 70 and 75 reached a plateau at 1,100 planted trees per acre; on the better sites basal areas continued to increase with planting density up to 1,200 trees. Basal areas on site 105 were about 50 percent higher than on site 70.

Table 6.–*Estimated basal area per acre of all living trees*

Trees planted per acre (No.)	Site index							
	70	75	80	85	90	95	100	105
	Square feet							
300	62	67	72	77	82	87	93	99
400	78	84	89	95	100	106	112	118
500	89	95	101	107	113	119	125	131
600	97	104	110	116	123	129	135	142
700	103	110	117	123	130	136	143	150
800	107	114	121	128	135	142	149	156
900	109	117	125	132	139	147	154	161
1,000	111	119	127	135	143	150	157	165
1,100	112	121	129	137	145	153	160	168
1,200	112	121	130	138	147	155	163	170

verage Diameter

Average diameter is defined here as the diameter associated with the tree of verage basal area. These diameters were estimated from an equation with the same iree independent variables as used for volumes and basal areas. The same variables roved almost as accurate as others that would be more complex to apply. The quation is:

Average d.b.h. (trees 3.6 inches d.b.h. and larger) = $27.8619 + 0.000357(S^2) - 9.31474(\text{Log}_{10}N) + 0.284122(N/S)$.

This equation accounts for about 89 percent of the variability in average iameter. Estimated values differed from measured values by $\pm$10 percent on only ne plot, and 82 percent were within $\pm$ 5 percent of the measured diameters. olutions to the equation are given in table 7.

able 7.—*Estimated average d.b.h. of trees 3.6 inches and larger*

rees planted ər acre (No.)	Site index							
	70	75	80	85	90	95	100	105
	Inches							
300	7.8	7.9	8.1	8.4	8.6	8.9	9.2	9.5
400	7.0	7.1	7.3	7.5	7.8	8.0	8.3	8.6
500	6.5	6.6	6.8	7.0	7.2	7.4	7.7	8.0
600	6.2	6.3	6.4	6.6	6.8	7.0	7.2	7.5
700	6.0	6.0	6.1	6.3	6.5	6.7	6.9	7.2
800	5.8	5.8	5.9	6.1	6.2	6.4	6.7	6.9
900	5.7	5.8	5.8	5.9	6.1	6.2	6.5	6.7
1,000	5.7	5.7	5.7	5.8	6.0	6.1	6.3	6.6
1,100	5.7	5.7	5.7	5.8	5.9	6.0	6.2	6.4
1,200	5.8	5.7	5.7	5.8	5.9	6.0	6.2	6.4

Initial planting density and site index both affected average diameters, though cnsity was the more influential. Over the span of spacings tested, the range of aerage diameters was about 2 inches on the poorest sites and about 3 inches on the bst sites. Site had a greater influence at low than at high densities; for example, the rige in average diameter between the best and the poorest sites was 1.7 inches at tl 300-tree level and 0.6 inch at the 1,200-tree level.

Liameter Distributions

Actual numbers of trees per acre by 10-foot increments of site index and 1-inch dimeter classes are summarized in table 8. Both site index and initial spacing had a pinounced impact on diameter distributions.

The greatest number of trees per acre in the larger diameter classes was in the 12 by 12 spacing, and the number decreased progressively with higher planting desities. This superiority of the widest spacing was retained through the 9-inch d.h. class. When number of trees 8 inches d.b.h. and larger are compared, the four wiest spacings are closely grouped, and none excel in all site index categories. All ha more than double the number of trees in the 6 by 6 spacing. If number of trees in the 7-inch d.b.h. class and larger is the criterion, spacings rank in the following order from highest to lowest: 8 by 8, 9 by 9, 10 by 10, 6 by 6, and 12 by 12. In terms of trees in or above the 6-inch d.b.h. class, the 6 by 6 and 8 by 8 spacings rank best and stocking in other spacings is directly related to the number of trees planted.

Table 8—*Diameter distributions of all trees per acre in each spacing*

Site index class	Diameter classes											Total
	1 and 2	3	4	5	6	7	8	9	10	11	12+	
	No.											
					6 BY 6 SPACING							
76–85	41	89	134	254	193	138	33	...	...	...	...	882
86–95	45	73	117	176	213	144	54	11	1	...	...	834
96–105	18	86	139	157	245	158	57	10	5	...	...	875
106+	...	39	98	137	166	98	117	49	20	...	...	724
					8 BY 8 SPACING							
76–85	12	31	57	116	160	150	57	13	...	...	...	596
86–95	8	21	48	74	129	145	96	25	12	...	...	558
96–105	...	11	42	31	146	166	125	42	10	21	...	594
					9 BY 9 SPACING							
76–85	21	15	56	65	129	117	66	25	5	...	...	499
86–95	6	6	33	46	88	90	104	41	21	5	...	440
96–105	3	12	22	36	69	110	106	66	14	3	3	444
106+	...	...	...	...	49	88	108	98	20	20	10	393
					10 BY 10 SPACING							
76–85	8	12	38	56	78	86	85	20	8	1	...	392
86–95	5	16	12	24	46	81	78	53	26	3	2	346
96–105	4	3	11	25	40	76	69	67	18	9	3	325
					12 BY 12 SPACING							
76–85	4	13	13	17	13	56	60	26	8	13	...	223
86–95	...	2	6	8	24	30	50	70	48	3	3	244
96–105	1	5	6	6	9	25	49	43	63	25	7	239
106+	9	...	9		9	18	27	45	27	54	...	198

DISCUSSION

Data in this paper are from plots ranging from 59 to 100 percent in survival. Most of the mortality is believed to have occurred in the first few years after planting. Since plots were selected to avoid large holes in the stand, mortality was reasonably well distributed. When these data are applied to stands with different mortality rates, volume predictions will probably be fairly accurate if stocking is relatively uniform. Some adjustments will be needed where the stand is patchy.

Site productivity strongly influenced cubic-foot volumes. In addition, stands on the better sites had larger average diameters, although differences were less striking than with volumes.

Planting density also influenced volumes and diameters. Exact relationships, especially on the poorer sites, are somewhat obscure, because many trees are just below the minimum threshold diameter and will contribute considerable ingrowth during the next few years. Approximations can be made, however, from volumes of trees 4.6 inches d.b.h. and larger on the best sites, where most of the ingrowth has already occurred. Yields from planting 1,200 trees per acre (about 6 by 6 spacing) were at least 50 percent greater than those from planting 300 trees per acre (about 12 by 12 spacing). However, most of this gain resulted from increasing the planting rate from 300 to 600 trees per acre. Diameters, on the other hand, varied inversely with planting density, and on the high sites there was a 3-inch difference between the 300- and the 1,200-tree rates. But two-thirds or 2 inches of this difference resulted from planting 300 trees instead of 600 trees per acre.

A landowner must choose, then, between diameter growth and volume growth. In the case above, he must decide if an added 3 inches in average diameter is more important than 1,100 to 1,200 cubic feet (o.b.) of volume. However, average diameters are often misleading because they are distorted by small trees, which are more numerous in close than in wide spacings. A more comprehensive view is provided by diameter distributions, especially in the larger diameters. In this study, wide spacings have a clear superiority when only diameters above 8 or 9 inches are considered. But when all trees 6 inches d.b.h. and larger are included, the differences between spacings narrow considerably.

Thinnings are not yet feasible in the widest spacings, because removal of enough volume to make an operable cut would deplete stocking and reduce future growth. While stocking in the closer spacings is high enough to warrant a substantial thinning, many trees in the smaller diameter classes would have to be cut. Initial stocking of 700 to 800 trees per acre will probably give a good compromise whereby an early return can be obtained by thinning, with only a partial reduction in diameter growth.

The number of trees to plant for maximum volume yields at age 17 varies directly with site index. About 50 percent more trees should be planted on choice than poor sites. However, the curve of yield in cubic feet over number of trees planted per acre has a flat, broad plateau. Thus, precise stocking is not essential for near maximum cubic volume, and the landowner has considerable latitude in choosing a spacing.

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Structure and Changes In the Southern Forest Economy, 1958 – 1967

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Southern Forest Experiment Station
Forest Service
U.S. Department of Agriculture

Structure and Changes In the Southern Forest Economy, 1958 — 1967

Harold F. Kaiser, Jr., and George F. Dutrow

The forest resource has long been important to southern economic development, but major changes have occurred in the types of products manufactured as well as in demands placed on southern forests. Thirty years ago, sawmills had almost exclusive use of southern timber. Since then, papermills, plywood mills, other wood processors, and the public at large have become major users of the forests. The objective of this paper is to analyze the structure of the southern forest economy and determine how changes within the structure have influenced the area's income and employment.

Methodology

Both input-output (I-O) and shift-share analyses vere made. I-O tables show the purchases of each ector of the economy from all other sectors and ccount for the sales of each sector to all others. The ethod is analogous to double-entry bookkeeping. hift-share tabulations relate changes in employment d income in an industry or region to national anges in these statistics. Thus, I-O tables describe the onomy in an absolute sense, while shift-share tables nter on the relative changes.

Data for this paper come primarily from the Census Manufactures. These statistics are categorized cording to the Standard Industrial Classification IC) (Bureau of the Budget 1957). In this system, a porting unit is an establishment classed according to major activity rather than a legal entity or comny. Normally, an establishment is at a single location d is predominantly engaged in only one economic ivity. Where a single location encompasses two or re distinct and separate activities, such activities are treated as separate establishments. Production from establishments engaged in similar activities is aggregated to form an industry, the basic unit of analysis.

The SIC industries selected for the analysis are those that process logs and bolts and those that utilize the wood products of these primary processors. Thirty-one industries ranging from logging contractors to manufacturers of sanitary food containers were included. The industries are in the SIC groups for lumber and wood products (SIC 24), furniture and fixtures (SIC 25), and paper and allied products (SIC 26). Products manufactured by these industries range from such major items as lumber and kraft paper to minor items such as clothespins and toothpicks.

From the selected industries, 28 forest product industries or industrial sectors were formed (see Appendix for definition of classes). The major modification of the SIC classification was in the sawmill and planing-mill category. Production from the special-sawmill and hardwood-dimension industries was combined with the sawmill and planing-mill industry. Special-sawmill output was merged because of its relatively low sales volume, and hardwood dimension was included because over half of the furniture dimension production could not be accounted for by recorded purchases. This underidentification probably arose from different methods of classifying dimension stock by sawmills and furniture manufacturers.

The South was divided into three subregions that correspond to the geographic divisions of the Bureau of Census. The South Atlantic States include Maryland, Delaware, Virginia, West Virginia, North Carolina, South Carolina, Georgia, and Florida. East south central States are Kentucky, Tennessee, Alabama, and Mississippi, while the west south central are Arkansas, Louisiana, Oklahoma, and Texas.

Tables

Input-Output

Forest industries typically market their products to other industrial users only indirectly meeting the demands of final consumers. I-O analysis shows the cash flows that bind industries into a complex network which finally satisfies consumer wants.

Although all I-O models have the same basic structure, each one is tailored to fit a specified segment of the economy. Models must be consistent with the size of the unit to be analyzed, the stage of its economic development, and its resource base. The model for the present study is designed to show the production and distribution characteristics of individual forest industries. It features 28 forest-products industries; other sectors were added to permit analysis of cash flows through the forest economy. Additional input categories were softwood and hardwood stumpage, employment, other inputs, and capital expenditures. Output categories added were manufacturing and transportation, construction and maintenance, and final consumer.

Data were derived primarily from unpublished tabulations of the 1967 Census of Manufactures. In addition information from U.S. Department of Agriculture, Forest Service,[1] was used to divide Census stumpage values into hardwood and softwood categories. The selling sectors of sawmills and planing mills and veneer and plywood plants were divided into softwood and hardwood categories on the basis of price differentials, as reported by the 1967 Census of Manufactures and the Department of Labor (Bureau of Labor Statistics 1967).

Results of the I-O analysis are shown in tables 1-6. Tables 1-4 show the cash flows among the wood-using industries for the South, and for the South Atlantic, east south central, and west south central subregions, respectively. By reading down any column in these tables, one learns how much a forest-products industry or a component of the final demand sector purchased from each selling sector. Similarly, each row shows where an industry's output went. For example, by reading down column P of table 1, one learns that pulpmills in the South purchased cordwood valued at $79.9 million from pulpwood producers and $1.9 million of hardwood chips and $13.3 million of softwood chips from sawmills. Moreover, pulpmills paid their employees $54.3 million and made capital expenditures of $21.7 million, while other inputs totaled $156.9 million. The gross outlay was $328.0 million. On the output side, row 20 shows that pulpmills had sales of $56.8 million to papermills, $21.2 million to paperboard mills, and $0.5 million to building-paper mills. The total sales equal the total outlay of $328.0 million, as the double-entry method requires.

A word of caution regarding the South's total product of $21,530.4 million, found at the intersection of row 36 and column II in table 1: this value is not the contribution of the southern forest economy to Gross National Product (GNP). In computing GNP, efforts are made to eliminate double counting, while input-output analysis deliberately compounds all intermediate transactions through which goods or services pass on the way to the final consumer. The difference is one of objectives. In national income analysis the aim is to measure only the final value of goods and services produced. Input-output analysis strives to account for all transactions to give insight into the structure and operation of the economy.

Table 5 depicts direct and indirect effects of changes in final demand on the southern forest economy. It shows how the outputs in the immediate supplying industries and all related industries expand when one industry's demand is increased exogenously by $1. This dollar might originate from a household, investor, foreign buyer, government agency, or any other buyer included in the final-demand sectors. In general, if the final demand for industry A increases by $1, for example, there will be direct increases in purchases from A's supplying industries, B and C. In addition, there are indirect effects when industry B sells more of its output to industry A, and B in turn needs more products from its own supplying industries. The process continues throughout the economy.

In table 5, values are read only down the columns. For example, if the demand for envelopes (column U) increases by $1, there are associated increases of $0.0011 for hardwood stumpage, $0.0098 for softwood stumpage, $0.0005 for logging contractors, $0.0486 for pulpwood producers, etc. The overall direct and indirect effect is $1.9975 within the southern economy.

[1] USDA Forest Service. **Average stumpage values–sold volume (per MBF)–sawtimber and pulpwood.** USDA Forest Serv. Region 8, Rep. Atlanta, Georgia, 1968.

Table 1.—Cash flow in the southern forest economy, 1967 (in millions of dollars)

Selling sector		Purchasing sector																																		
		Forest industries																												Final demand						
																														Manufacturing and transportation		Construction and maintenance		Final consumer		
		Logging contractors A	Pulpwood producers B	Sawmills and planing mills C	Veneer and plywood plants D	Millwork plants E	Prefabricated wood products F	Nailed wooden boxes G	Other wooden containers H	Wood preserving I	Other wood products J	Wood household furniture K	Upholstered household furniture L	Wood office furniture M	Public building furniture N	Wood partitions and fixtures O	Pulpmills P	Papermills Q	Paperboard mills R	Building paper and board mills S	Paper coating and glazing T	Envelopes U	Bags, except textile V	Sanitary paper products W	Converted paper products X	Paperboard boxes Y	Corrugated shipping containers Z	Sanitary food containers AA	Fiber cans, tubes, and drums BB	South CC	Other regions DD	South EE	Other regions FF	South GG	Other regions HH	Total II
Hardwood stumpage	(1)	44.6	11.9	62.4	3.0																															121.9
Softwood stumpage	(2)	179.7	113.8	79.3	14.9																															387.7
Logging contractors	(3)			316.2	61.2	2.8		3.2	8.3	51.9																										443.6
Pulpwood producers	(4)										20.5						79.9	173.2	303.4	5.4																582.4
Sawmills and planing, hardwood	(5)			124.9	4.6	24.0	3.5	7.8	13.5	14.2	37.5	179.7	40.8	3.1	6.3	1.8	1.9	7.4	9.6	.3												79.2	30.2			590.3
Sawmills and planing, softwood	(6)			82.0		54.8	25.6	15.9	6.0	17.4	14.8	14.5	4.2		.8	.8	13.3	30.4	71.5	1.9												432.9	138.9			925.7
Veneer and plywood, hardwood	(7)				94.7	33.6	.5	.4	7.6			93.5		3.2	3.4	3.2														20.6	14.9					275.6
Veneer and plywood, softwood	(8)				1.7	7.9	3.8	.9	2.5			4.7		.2	1.0	3.0																68.2	32.5			126.4
Millwork plants	(9)																															301.0	61.7			362.7
Prefabricated wood products	(10)																															95.4	10.7			106.1
Nailed wooden boxes	(11)																													51.1	28.9					80.0
Other wooden containers	(12)																													79.8	44.7					124.5
Wood preserving	(13)																															142.4	61.4			203.8
Other wood products	(14)				2.1	2.8					8.5	24.3		.6	2.8	5.0														95.7	89.6	19.8	16.1	35.4	15.4	318.1
Wood household furniture	(15)																													33.6	40.3	29.9	39.3	489.3	685.8	1,318.2
Upholstered household furniture	(16)											4.3	33.0																					250.9	388.5	676.7
Wood office furniture	(17)																																	21.8	28.0	49.8
Public building furniture	(18)																																	52.7	58.0	110.7
Wood partitions and fixtures	(19)																																	43.3	53.7	97.0
Pulpmills	(20)																	56.8	21.7	.5										114.0	135.0					328.0
Papermills	(21)																				24.0	23.8	270.3	62.1	41.6	8.3	1.2	3.5	8.5	201.1	616.2					1,260.6
Paperboard mills	(22)																				5.2	.3	4.2	.9	73.0	101.3	392.9	107.3	24.0	127.0	886.0					1,722.1
Building paper and board mills	(23)																															52.1	80.5			132.6
Paper coating and glazing	(24)																													61.5	49.9					111.4
Envelopes	(25)																																	41.0	34.0	75.0
Bags, except textile	(26)																													345.1	283.3					628.4
Sanitary paper products	(27)																																	103.1	87.9	191.0
Converted paper products	(28)																													146.1	118.7					264.8
Paperboard boxes	(29)					1.2								.5	1.1	.4														189.3	71.5					264.0
Corrugated shipping containers	(30)																													505.3	184.1					689.4
Sanitary food containers	(31)																													216.3	75.5					291.8
Fiber cans, tubes, and drums	(32)																													98.9	37.9					136.8
Employment	(33)	101.3	279.6	386.7	95.2	85.5	21.2	22.6	33.8	35.7	85.3	378.9	193.2	12.3	31.4	31.8	54.3	270.3	290.0	33.3	16.2	21.5	123.7	16.4	26.2	66.6	138.8	47.8	32.0							2,931.6
Capital expenditures	(34)	33.0	45.1	54.1	31.8	6.3	2.0	1.5	2.0	6.5	26.9	43.8	11.6	3.0	2.7	1.3	21.7	259.0	316.8	10.9	2.8	2.3	20.3	30.9	4.8	9.5	36.2	19.3	5.0							1,011.1
Other inputs	(35)	85.0	132.0	410.4	92.8	143.8	49.5	27.7	50.8	78.1	124.6	574.5	393.9	26.9	61.2	49.7	156.9	463.5	709.1	80.3	63.2	27.1	209.9	80.7	119.2	78.3	120.3	113.9	67.3							4,590.6
Total	(36)	443.6	582.4	1,516.0	402.0	362.7	106.1	80.0	124.5	203.8	318.1	1,318.2	676.7	49.8	110.7	97.0	328.0	1,260.6	1,722.1	132.6	111.4	75.0	628.4	191.0	264.8	264.0	689.4	291.8	136.8	2,285.4	2,676.5	1,220.9	471.3	1,037.5	1,351.3	21,530.4

"Other inputs" in table 5 (row 33) represent composite values which are summations of all two-digit SIC classes. This category includes items such as machinery, cement, petroleum, and chemical products required in manufacturing. To obtain these figures, this sector was first partitioned and technical coefficients included based on the 1963 National Input-Output Study (USDA, Office of Business Economics 1969). Coefficients were then adjusted for materials imported into the region based on import-export information derived from the 1967 Census of Transportation (USDC Bureau of the Census 1970). The coefficient matrix was then inverted and "other input" industry values summed. For present purposes it allowed estimates to be developed for individual southern forest industries rather than relying on aggregate multipliers which relate only to the economy as a whole.

Table 6 shows income and employment multipliers for the South. The first three columns show the direct and indirect changes in wages and salaries resulting from $1 change in demand of an industry (Hirsch 1959). The last three columns show the direct and indirect changes in the number of persons employed per year per $1 million of output (Peterson and Moore 1955).

Table 2.–Cash flow in the South Atlantic forest products economy, 1967 (in millions of dollars)

Selling sector		Purchasing sector																																
		Forest industries																										Final demand						
																												Manufacturing and transportation		Construction and maintenance		Final consumer		
		Logging contractors A	Pulpwood producers B	Sawmills and planing mills C	Veneer and plywood plants D	Millwork plants E	Prefabricated wood products F	Nailed wooden boxes G	Other wooden containers H	Wood preserving I	Other wood products J	Wood household furniture K	Upholstered household furniture L	Wood office furniture M	Public building furniture N	Wood partitions and fixtures O	Papermills P	Paperboard mills Q	Building paper and board mills R	Paper coating and glazing S	Envelopes T	Bags except textile U	Converted paper products V	Paperboard boxes W	Corrugated shipping containers X	Sanitary food containers Y	Fiber cans, tubes, and drums Z	South Atlantic AA	Other regions BB	South Atlantic CC	Other regions DD	South Atlantic EE	Other regions FF	Total GG
Hardwood stumpage	(1)	19.9	6.6	33.4	2.1																													62.0
Softwood stumpage	(2)	99.6	68.6	20.1	.3																													188.6
Logging contractors	(3)			177.4	33.8	1.7		1.6	6.0	21.7																								242.2
Pulpwood producers	(4)										5.9						67.3	215.0	2.3															290.5
Sawmills and planing, hardwood	(5)			38.1	4.0	11.7	4.2	4.3	3.8	7.1	17.0	120.0	23.4	2.9	2.8	1.0	5.1	6.9	1											21.4	3.7			277.5
Sawmills and planing, softwood	(6)			45.1		20.6	5.9	5.9	2.5	8.8	5.2	6.6	3.1		.1	.4	6.2	45.7	.8											172.0	28.9			357.8
Veneer and plywood, hardwood	(7)				60.7	17.4	.2	.2	4.1			71.9		2.9	.9	1.7												22.9	8.8					191.7
Veneer and plywood, softwood	(8)				.7	4.9	.3	.3	1.0			3.0		.1	.1	1.5														12.3	9.3			33.5
Millwork plants	(9)																													124.5	48.4			172.9
Prefabricated wood products	(10)																													54.0	9.6			63.6
Nailed wooden boxes	(11)																											22.5	6.7					29.2
Other wooden containers	(12)																											43.0	12.7					55.7
Wood preserving	(13)																													64.7	24.9			89.6
Other wood products	(14)				1.8	1.7					5.9	14.8																35.7	23.1	6.6	2.6	17.8	6.9	116.9
Wood household furniture	(15)																											3.1	8.0	11.0	28.4	242.2	632.7	925.4
Upholstered household furniture	(16)											1.8	19.0	.5	.4	2.7																91.0	301.4	416.8
Wood office furniture	(17)																															7.6	20.1	27.7
Public building furniture	(18)																															8.4	21.9	30.3
Wood partitions and fixtures	(19)																															13.5	35.1	48.6
Papermills	(20)																			9.8	13.7	125.2	17.3	5.5	0.4	2.3	5.9	2.8	352.0					534.9
Paperboard mills	(21)																			2.1	.1	2.2	32.2	66.0	217.0	64.7	16.9		712.9					1,114.1
Building paper and board mills	(22)																													17.0	41.4			58.4
Paper coating and glazing	(23)																											16.4	29.1					45.5
Envelopes	(24)																															15.4	27.3	42.7
Bags, except textile	(25)																											111.9	198.0					309.9
Converted paper products	(26)																															41.4	73.4	114.8
Paperboard boxes	(27)					.6								.3	.3	.3												100.5	74.2					176.2
Corrugated shipping containers	(28)																											217.3	158.0					375.3
Sanitary food containers	(29)																											113.6	82.6					196.2
Fiber cans, tubes, and drums	(30)																											55.1	40.1					95.2
Employment	(31)	57.3	135.1	150.1	55.2	42.0	13.1	9.0	16.3	16.3	30.4	261.0	119.9	6.8	10.7	16.6	109.4	189.6	14.2	7.4	12.4	58.9	12.3	46.7	76.1	35.3	24.6							1,526.7
Capital expenditures	(32)	13.9	22.9	19.7	23.2	2.7	1.3	.7	.8	2.3	8.1	33.1	8.1	1.7	.5	.7	34.5	83.0	10.0	.9	1.5	12.6	·1.8	5.7	23.4	11.5	4.2							328.8
Other inputs	(33)	51.5	57.3	151.4	43.4	69.6	38.6	7.2	21.2	33.4	44.4	413.2	243.3	12.5	14.5	23.7	312.4	573.9	31.0	25.3	15.0	111.0	51.2	52.3	58.4	82.4	43.6							2,581.7
Total	(34)	242.2	290.5	635.3	225.2	172.9	63.6	29.2	55.7	89.6	116.9	925.4	416.8	27.7	30.3	48.6	534.9	1,114.1	58.4	45.5	42.7	309.9	114.8	176.2	375.3	196.2	95.2	744.8	1,706.2	483.5	197.2	437.3	1,118.8	11,120.9

Both income and employment multipliers are based on a linear relationship between wages or employment and output in an industry. For example, from table 5 (Column C, row 5) it can be seen that a $1 change in final demand for the hardwood sawmill or planing mill sector will change economic activity in this sector by $1.0899. Since households receive as income $0.225 of every dollar's change in output (table 6, column 1), an initial change will cause household income to change by $0.245 ($1.0899 X $0.225). But the change in final demand for sawmill products of $1 will also cause a direct and indirect change of $0.227 in the logging sector. From the direct effect, $0.228 of every dollar change in output in the logging sector goes to households. Thus, household income from the logging sector changes by $0.052 as the result of the $1 change in output of the sawmill sector. Similarly, the changes in income as a result of the $1 can be computed for the remaining sectors. The sum of these income changes is $0.386. A FORTRAN IV program for finding the direct and indirect effects of $1 change plus income and employment multipliers is available on request from the Southern Forest Experiment Station.

Table 4.–Cash flow in the west south central forest products economy, 1967 (in millions of dollars)

Selling sector		Purchasing sector																															
		Forest industries																								Final demand						
																										Manufacturing and transportation		Construction and maintenance		Final consumer		
		Logging contractors A	Pulpwood producers B	Sawmills and planing mills C	Veneer and plywood plants D	Millwork plants E	Prefabricated wood products F	Nailed wooden boxes G	Wood preserving H	Other wood products I	Wood household furniture J	Upholstered household furniture K	Wood office furniture L	Public building furniture M	Wood partitions and fixtures N	Papermills O	Paperboard mills P	Building paper and board mills Q	Paper coating and glazing R	Envelopes S	Bags, except textile T	Converted paper products U	Paperboard boxes V	Corrugated shipping containers W	Sanitary food containers X	Fiber cans, tubes, and drums Y	West south central Z	Other regions AA	West south central BB	Other regions CC	West south central DD	Other regions EE	Total FF
Hardwood stumpage	(1)	10.2	2.0	13.2	0.2																												25.6
Softwood stumpage	(2)	46.6	18.2	43.3	7.9																												116.0
Logging contractors	(3)			69.2	18.1	1.1		0.5	14.4																								103.3
Pulpwood producers	(4)									2.0						44.0	46.9	1.6															94.5
Sawmills and planing, hardwood	(5)			29.5	.3	8.6	0.7	1.1	3.3	8.9	21.8	6.1	0.1	2.6	0.5	.6	.8	.1											18.2	12.0			115.2
Sawmills and planing, softwood	(6)			11.9		25.2	5.1	2.2	5.8	6.9	5.4	.1		.7	.2	14.6	22.6	.6											105.7	70.1			277.1
Veneer and plywood, hardwood	(7)				12.7	10.6	.1	.1			6.3		.2	1.8	.8																		36.2
Veneer and plywood, softwood	(8)				.5	2.1	1.0	.2			.3		.1	.8	1.1														18.3	46.2			70.6
Millwork plants	(9)																												85.3	36.5			121.8
Prefabricated wood products	(10)																												15.7	7.1			22.8
Nailed wooden boxes	(11)																										16.0	3.4					19.4
Wood preserving	(12)																												50.3	10.7			61.0
Other wood products	(13)				.1	.8				1.8	2.9			2.1	.8												29.2	7.9	4.6	1.0	10.9	2.4	64.5
Wood household furniture	(14)																										1.2	1.9	4.2	6.9	48.2	80.4	142.8
Upholstered household furniture	(15)										.8	3.5																			24.4	47.8	76.5
Wood office furniture	(16)																														4.1	6.9	11.0
Public building furniture	(17)																														24.1	40.1	64.2
Wood partitions and fixtures	(18)																														11.5	19.2	30.7
Papermills	(19)																		5.8	6.5	86.5	12.8	1.4	0.2	0.7	1.4	28.9	193.4					337.6
Paperboard mills	(20)																		1.2	.1	1.3	40.0	21.7	106.4	27.4	3.4		175.7					377.2
Building paper and board mills	(21)																												8.1	30.8			38.9
Paper coating and glazing	(22)																										11.1	15.6					26.7
Envelopes	(23)																														8.3	11.8	20.1
Bags, except textile	(24)																										78.7	111.0					189.7
Converted paper products	(25)																														46.1	65.0	111.1
Paperboard boxes	(26)					.4							.1	.7	.1												41.4	6.9					49.6
Corrugated shipping containers	(27)																										159.4	25.7					185.1
Sanitary food containers	(28)																										53.0	8.5					61.5
Fiber cans, tubes, and drums	(29)																										18.6	3.0					21.6
Exployment	(30)	20.6	47.3	112.1	21.8	27.3	5.1	5.4	10.7	17.1	40.1	22.3	2.7	16.8	10.5	72.6	64.8	10.4	3.6	5.8	37.6	5.8	10.6	35.8	8.1	2.9							617.8
Capital expenditures	(31)	8.1	7.4	15.3	2.1	2.3	.5	.3	1.7	6.4	4.1	1.2	.7	1.8	.3	178.5	124.7	.4	1.1	.5	4.3	1.0	1.0	6.8	5.3	.3							376.1
Other inputs	(32)	17.8	19.6	97.8	43.1	43.4	10.3	9.6	25.1	21.4	61.1	43.3	7.1	36.9	16.4	27.3	117.4	25.8	15.0	7.2	60.0	51.5	14.9	35.9	20.0	13.6							841.5
Total	(33)	103.3	94.5	392.3	106.8	121.8	22.8	19.4	61.0	64.5	142.8	76.5	11.0	64.2	30.7	337.6	377.2	38.9	26.7	20.1	189.7	111.1	49.6	185.1	61.5	21.6	437.5	553.0	310.4	221.3	177.6	273.6	5,460.3

The shifts in employment and value added were determined by comparing the actual values at the ends of the periods with their respective expected values and recording them as a separate column. These figures represent absolute gains or losses for a given forest-based industry in southern subregions, the South, or in the Nation relative to the all-manufacturing performance for the Nation. Finally, the share of each forest-based industry of gains or losses is recorded as a percentage of the total net shift for each of the regional or national categories.

Analysis of the industrial and regional growth patterns reveals two distinct phenomena, composition and competition. Nationally, some industrial sectors expand more rapidly than others. Regions which are characterized by concentration of fast or slow growing industrial sectors will be affected accordingly. This phenomenon is termed the composition effect. The second phenomenon is regional variation from national norms in individual sectors. It stems from regional differences in access to basic inputs or markets which may give a region a distinct competitive advantage.

Table 3.—Cash flow in the east south central forest economy, 1967 (in millions of dollars)

Selling sector	Purchasing sector: Forest industries													
	Logging contractors A	Pulpwood producers B	Sawmills and planing mills C	Veneer and plywood plants D	Millwork plants E	Prefabricated wood products F	Nailed wooden boxes G	Wood preserving H	Other wood products I	Wood household furniture J	Upholstered household furniture K	Wood office furniture L	Public building furniture M	Wood partitions and fixtures N
Hardwood stumpage (1)	14.5	3.2	15.8	0.7										
Softwood stumpage (2)	33.4	26.8	15.9	6.7										
Logging contractors (3)			69.9	9.3			1.1	15.8						
Pulpwood producers (4)									12.6					
Sawmills and planing, hardwood (5)			57.3	.3	3.8	0.4	2.4	3.8	11.6	38.0	11.3	0.1	1.1	0.3
Sawmills and planing, softwood (6)			25.2		9.0	3.9	7.8	2.7	2.7	2.4	1.0			.1
Veneer and plywood, hardwood (7)				21.3	5.7	.1	.1			15.2		.1	.7	.7
Veneer and plywood, softwood (8)				.5	.9	.4	.4			1.4		.1	.1	.4
Millwork plants (9)														
Prefabricated wood products (10)														
Nailed wooden boxes (11)														
Wood preserving (12)														
Other wood products (13)				.2	.3				.8	6.6			.3	1.5
Wood household furniture (14)														
Upholstered household furniture (15)										1.7	10.5			
Wood office furniture (16)														
Public building furniture (17)														
Wood partitions and fixtures (18)														
Papermills (19)														
Paperboard mills (20)														
Building paper and board mills (21)														
Paper coating and glazing (22)														
Envelopes (23)														
Bags, except textile (24)														
Converted paper products (25)														
Paperboard boxes (26)					.2							.1	.1	
Corrugated shipping containers (27)														
Sanitary food containers (28)														
Fiber cans, tubes, and drums (29)														
Employment (30)	23.1	55.3	124.5	18.3	16.2	2.9	8.2	8.7	37.8	77.8	51.0	2.8	3.9	4.8
Capital expenditures (31)	7.1	8.5	19.1	6.5	1.3	.2	.5	2.4	12.5	6.6	2.3	.6	.3	.2
Other inputs (32)	18.0	23.8	160.6	20.9	30.6	11.7	10.9	19.8	58.7	100.3	107.3	7.3	9.7	9.8
Total (33)	96.1	117.6	488.3	84.7	68.0	19.6	31.4	53.2	136.7	250.0	183.4	11.1	16.2	17.8

Selling sector	Purchasing sector: Forest industries											Final demand: Manufacturing and transportation		Construction and maintenance		Final consumer		
	Papermills O	Paperboard mills P	Building paper and board mills Q	Paper coating and glazing R	Envelopes S	Bags except textile T	Converted paper products U	Paperboard boxes V	Corrugated shipping containers W	Sanitary food containers X	Fiber cans, tubes, and drums Y	East south central Z	Other regions AA	East south central BB	Other regions CC	East south central DD	Other regions EE	Total FF
Hardwood stumpage (1)																		34.2
Softwood stumpage (2)																		82.8
Logging contractors (3)																		96.1
Pulpwood producers (4)	61.9	41.7	1.4															117.6
Sawmills and planing, hardwood (5)	1.8	2.0	.1											20.0	34.0			188.3
Sawmills and planing, softwood (6)	9.6	3.2	.5											86.0	145.9			300.0
Veneer and plywood, hardwood (7)												15.9	6.1					65.9
Veneer and plywood, softwood (8)														3.2	11.4			18.8
Millwork plants (9)														44.2	23.8			68.0
Prefabricated wood products (10)														12.3	7.3			19.6
Nailed wooden boxes (11)												7.7	23.7					31.4
Wood preserving (12)														13.0	40.2			53.2
Other wood products (13)												15.5	77.6	5.2	15.9	3.1	9.7	136.7
Wood household furniture (14)												7.8	51.9	2.4	15.9	22.5	149.5	250.0
Upholstered household furniture (15)																11.8	159.4	183.4
Wood office furniture (16)																1.5	9.6	11.1
Public building furniture (17)																2.1	14.1	16.2
Wood partitions and fixtures (18)																2.3	15.5	17.8
Papermills (19)				8.5	3.7	58.6	11.5	1.4	0.6	0.4	1.2		302.1					388.0
Paperboard mills (20)				1.8	.1	.8	.7	13.5	69.5	15.2	3.6		125.5					230.7
Building paper and board mills (21)														2.6	32.8			35.4
Paper coating and glazing (22)												6.3	32.9					39.2
Envelopes (23)																2.0	10.2	12.2
Bags, except textile (24)												20.7	108.1					128.8
Converted paper products (25)																6.3	32.6	38.9
Paperboard boxes (26)												13.2	24.5					38.1
Corrugated shipping containers (27)												46.1	83.0					129.1
Sanitary food containers (28)												12.2	21.9					34.1
Fiber cans, tubes, and drums (29)												7.1	12.9					20.0
Employment (30)	88.3	35.6	9.2	5.2	3.3	27.2	8.1	9.3	26.8	4.5	4.5							657.3
Capital expenditures (31)	46.0	109.1	.5	.9	.2	3.4	2.0	2.9	6.0	2.5	.4							242.0
Other inputs (32)	180.4	39.1	23.7	22.8	4.9	38.8	16.6	11.0	26.2	11.5	10.3							974.7
Total (33)	388.0	230.7	35.4	39.2	12.2	128.8	38.9	38.1	129.1	34.1	20.0	152.5	870.2	188.9	327.2	51.6	400.6	4,659.6

Shift-Share

The shift-share method is a statistical technique for measuring and explaining regional economic growth; in this case, in terms of employment and value added. The fundamental premise is that a region, subregion, or type of industry can be evaluated economically by revealed relationships to other regions, subregions, industries, or to the Nation as a whole (Perloff 1960) (Dunn 1962). Computational goals are to reveal the shifts in total employment, value added, or other economic components among the subregions and regions relative to national shifts. Several computational steps are required.

Expected employment and value added are based on the changes one would expect if each subregion, region, or industry had gains or losses proportional to the experience of the Nation as a whole. In the present analysis, two time periods were considered, 1958-1963 and 1963-1967, and expected employment and value-added figures were computed for forest-products industries in subregions of the South, in the South as a whole, and in the national forest-products industries.

Table 5.—Total direct and indirect production requirements per dollar of final demand, southern forest products economy, 1967 (in dollars)

		Logging contractors A	Pulpwood producers B	Sawmills and planing mills C	Veneer and plywood plants D	Millwork plants E	Prefabricated wood products F	Nailed wooden boxes G	Other wooden containers H	Wood preserving I	Other wood products J	Wood household furniture K	Upholstered household furniture L	Wood office furniture M	Public building furniture N
Hardwood stumpage	(1)	0.1005	0.0204	0.0678	0.0309	0.0082	0.0024	0.0108	0.0159	0.0304	0.0096	0.0116	0.0043	0.0064	0.0051
Softwood stumpage	(2)	.4051	.1954	.1492	.1317	.0256	.0057	.0315	.0513	.1138	.0311	.0304	.0097	.0185	.0138
Logging contractors	(3)	1.0000		.2274	.2028	.0418	.0085	.0632	.1037	.2707	.0276	.0460	.0145	.0276	.0200
Pulpwood producers	(4)	.0001	1.0001	.0002	.0008	.0012	.0005	.0003	.0003	.0007	.0666	.0019	.0011	.0023	.0036
Sawmills and planing, hardwood	(5)	.0001	.0001	1.0899	.0173	.0749	.0363	.1065	.1193	.0762	.1322	.1526	.0694	.0708	.0663
Sawmills and planing, softwood	(6)	.0001	.0001	.0563	.0017	.1558	.2437	.2046	.0548	.0899	.0550	.0203	.0109	.0051	.0131
Veneer and plywood, hardwood	(7)				1.3083	.1212	.0062	.0066	.0798			.0928	.0001	.0842	.0403
Veneer and plywood, softwood	(8)			.0001	.0055	.0223	.0359	.0114	.0205			.0040	.0002	.0044	.0093
Millwork plants	(9)			.0001	.0002	1.0001	.0002	.0001	.0002	.0002	.0001	.0002	.0001	.0002	.0002
Prefabricated wood products	(10)				.0001	.0001	1.0000			.0001		.0001	.0001	.0001	.0001
Nailed wooden boxes	(11)					.0001	.0001	1.0001	.0001		.0001	.0001	.0001	.0001	.0001
Other wooden containers	(12)								1.0000						.0001
Wood preserving	(13)									1.0000					
Other wood products	(14)	.0001	.0001	.0001	.0072	.0089	.0005	.0004	.0008	.0002	1.0277	.0198	.0007	.0134	.0273
Wood household furniture	(15)			.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	1.0001	.0001	.0001	.0002
Upholstered household furniture	(16)											.0035	1.0513		
Wood office furniture	(17)													1.0000	
Public building furniture	(18)														1.0000
Wood partitions and fixtures	(19)														
Pulpmills	(20)	.0001	.0001	.0001	.0003	.0002	.0004	.0001	.0001	.0009	.0003	.0004	.0005	.0004	.0005
Papermills	(21)	.0005	.0006	.0010	.0014	.0017	.0019	.0012	.0013	.0019	.0018	.0025	.0044	.0035	.0051
Paperboard mills	(22)	.0001	.0001	.0003	.0005	.0017	.0007	.0003	.0004	.0009	.0005	.0008	.0018	.0049	.0055
Building paper and board mills	(23)			.0001	.0001	.0001	.0002	.0001	.0001	.0004	.0001	.0002	.0002	.0001	.0002
Paper coating and glazing	(24)	.0001	.0001	.0002	.0004	.0005	.0006	.0003	.0003	.0006	.0005	.0008	.0019	.0012	.0022
Envelopes	(25)			.0001	.0001	.0001	.0002	.0001	.0001	.0001	.0001	.0002	.0002	.0002	.0002
Bags, except textile	(26)	.0003	.0002	.0007	.0011	.0014	.0019	.0008	.0009	.0017	.0014	.0024	.0056	.0035	.0063
Sanitary paper products	(27)				.0001	.0001	.0001			.0001	.0001	.0001	.0002	.0001	.0001
Converted paper products	(28)	.0001		.0001	.0002	.0003	.0004	.0002	.0002	.0004	.0003	.0005	.0012	.0008	.0014
Paperboard boxes	(29)					.0033				.0001			.0001	.0100	.0100
Corrugated shipping containers	(30)	.0001	.0001	.0002	.0003	.0003	.0004	.0002	.0003	.0006	.0003	.0005	.0010	.0005	.0008
Sanitary food containers	(31)			.0010	.0001	.0001	.0002	.0001	.0001	.0002	.0001	.0002	.0004	.0002	.0003
Fiber cans, tubes, and drums	(32)	.0001	.0001	.0003	.0003	.0003	.0004	.0002	.0002	.0005	.0003	.0004	.0009	.0005	.0007
Other inputs	(33)	.1395	.1396	.2709	.4195	.4284	.6001	.4429	.4730	.6096	.4667	.5765	.9714	.6373	.9053
Total	(34)	1.6469	1.3571	1.8662	2.1310	1.8988	1.9486	1.8821	1.9238	2.2003	1.8226	1.9689	2.1524	1.8964	2.1381

		Wood partitions and fixtures O	Pulpmills P	Papermills Q	Paperboard mills R	Building paper and board mills S	Paper coating and glazing T	Envelopes U	Bags, except textile V	Sanitary paper products W	Converted paper products X	Paperboard boxes Y	Corrugated shipping containers Z	Sanitary food containers AA	Fiber cans, tubes, and drums BB
Hardwood stumpage	(1)	0.0028	0.0054	0.0035	0.0041	0.0010	0.0010	0.0011	0.0016	0.0012	0.0017	0.0017	0.0023	0.0016	0.0009
Softwood stumpage	(2)	.0090	.0486	.0301	.0360	.0084	.0085	.0098	.0135	.0100	.0150	.0149	.0207	.0137	.0083
Logging contractors	(3)	.0124	.0014	.0015	.0014	.0006	.0005	.0005	.0008	.0005	.0007	.0006	.0008	.0006	.0004
Pulpwood producers	(4)	.0045	.2441	.1490	.1797	.0411	.0419	.0486	.0666	.0495	.0743	.0074	.1032	.0684	.0413
Sawmills and planing, hardwood	(5)	.0279	.0065	.0069	.0063	.0027	.0021	.0024	.0033	.0023	.0031	.0028	.0037	.0025	.0017
Sawmills and planing, softwood	(6)	.0129	.0414	.0268	.0427	.0148	.0084	.0090	.0125	.0091	.1664	.0175	.0247	.0163	.0095
Veneer and plywood, hardwood	(7)	.0432	.0001				.0001		.0001		.0001				
Veneer and plywood, softwood	(8)	.0312	.0001				.0001		.0001		.0001				
Millwork plants	(9)	.0002	.0003	.0002	.0002	.0001	.0002	.0002	.0002	.0001	.0002	.0002	.0002	.0002	.0001
Prefabricated wood products	(10)	.0001	.0001	.0001			.0001	.0001	.0001		.0001	.0001	.0001	.0001	
Nailed wooden boxes	(11)	.0001						.0001	.0001		.0001				
Other wooden containers	(12)														
Wood preserving	(13)		.0001												
Other wood products	(14)	.0538	.0002	.0002	.0001	.0001	.0004	.0002	.0005	.0001	.0005	.0002	.0002	.0001	.0002
Wood household furniture	(15)	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
Upholstered household furniture	(16)														
Wood office furniture	(17)														
Public building furniture	(18)														
Wood partitions and fixtures	(19)	1.0000													
Pulpmills	(20)	.0004	1.0002	.0455	.0129	.0003	.0111	.0148	.0203	.0150	.0114	.0067	.0077	.0056	.0054
Papermills	(21)	.0033	.0021	1.0002	.0017	.0016	.2232	.3211	.4383	.3268	.1651	.0346	.0052	.0151	.0650
Paperboard mills	(22)	.0027	.0010	.0010	1.0006	.0006	.0480	.0050	.0082	.0053	.2771	.0843	.5706	.3683	.1759
Building paper and board mills	(23)	.0001	.0001	.0002	.0001	1.0001	.0002	.0001	.0003	.0001	.0002	.0002	.0002	.0002	.0001
Paper coating and glazing	(24)	.0014	.0003	.0005	.0004	.0003	1.0011	.0007	.0012	.0004	.0012	.0004	.0005	.0004	.0003
Envelopes	(25)	.0001	.0001	.0001	.0001	.0001	.0002	1.0001	.0002	.0001	.0002	.0001	.0002	.0001	.0001
Bags, except textile	(26)	.0040	.0009	.0001	.0010	.0010	.0033	.0022	1.0035	.0010	.0035	.0012	.0013	.0011	.0010
Sanitary paper products	(27)	.0001		.0003	.0001	.0001	.0001	.0001	.0001	1.0001	.0001	.0001	.0001	.0001	.0001
Converted paper products	(28)	.0009	.0002	.0001	.0002	.0002	.0007	.0005	.0008	.0002	1.0007	.0003	.0003	.0002	.0002
Paperboard boxes	(29)	.0041	.0001	.0008			.0001	.0001	.0001		.0001	1.0000	.0001		
Corrugated shipping containers	(30)	.0005	.0009	.0003	.0005	.0005	.0008	.0007	.0009	.0005	.0008	.0004	1.0005	.0004	.0004
Sanitary food containers	(31)	.0002	.0004	.0009	.0002	.0002	.0003	.0003	.0004	.0002	.0003	.0002	.0002	1.0002	.0001
Fiber cans, tubes, and drums	(32)	.0005	.0011	.0112	.0005	.0005	.0007	0007	.0009	.0005	.0008	.0004	.0005	.0004	1.0004
Other inputs	(33)	.5983	.6689	.6840	.5086	.4803	.6779	.5790	.8061	.4719	.6043	.5716	.5790	.4835	.4204
Total	(34)	1.8148	2.0247	1.9636	1.7975	1.5547	2.0311	1.9975	2.3808	1.8950	2.3282	2.0460	2.3224	1.9792	1.7319

Table 6.–Income and employment multipliers of the southern forest economy, 1967

Primary product class		Direct income change per $1 (1)	Direct and indirect income change per $1 (2)	Indirect income change per $1 (3)	Direct yearly employment change per $1 million (4)	Direct and indirect yearly employment change per $1 million (5)	Indirect yearly employment change per $1 million (6)
Logging contractors	(1)	0.228	0.260	0.032	64.4	74.5	10.1
Pulpwood producers	(2)	.480	.511	.031	N.A. [1]	N.A.	N.A.
Harvesting		.371	.402	.031	N.A.	N.A.	N.A.
Sawmills and planing mills	(3)	.225	.386	.161	68.2	110.2	42.0
Veneer and plywood plants	(4)	.237	.442	.205	56.0	118.4	62.4
Millwork plants	(5)	.236	.388	.152	48.3	92.4	44.1
Prefabricated wood products	(6)	.200	.337	.137	38.6	75.8	37.2
Nailed wooden boxes	(7)	.283	.423	.140	76.3	117.8	41.5
Other wooden boxes	(8)	.272	.448	.176	73.9	125.2	51.3
Wood preserving	(9)	.175	.357	.182	37.8	96.6	58.8
Other wood products	(10)	.268	.444	.176	61.0	105.5	44.5
Lumber and wood products		.231	.376	.145	61.1	109.7	48.6
Wood household furniture	(11)	.287	.485	.198	66.8	123.8	57.0
Upholstered household furniture	(12)	.286	.546	.260	63.7	124.8	61.1
Wood office furniture	(13)	.247	.440	.193	52.2	101.9	49.7
Public building furniture	(14)	.284	.534	.250	62.3	118.9	56.6
Wood partitions and fixtures	(15)	.328	.497	.169	129.0	172.2	43.2
Furniture and fixtures		.287	.504	.217	67.7	125.2	57.3
Pulpmills	(16)	.166	.597	.431	20.2	75.0	54.8
Papermills	(17)	.214	.530	.316	26.6	66.8	40.2
Paperboard mills	(18)	.168	.394	.226	20.7	76.1	55.4
Building paper and pulpmills	(19)	.255	.402	.147	36.2	73.1	36.9
Paper coating and glazing	(20)	.145	.393	.248	25.1	73.3	48.2
Envelopes	(21)	.287	.537	.250	52.0	99.3	47.3
Bags, except textile	(22)	.197	.542	.345	36.6	95.3	61.7
Sanitary paper	(23)	.086	.318	.232	11.5	54.6	43.1
Converted paper products	(24)	.099	.406	.307	27.2	86.3	59.1
Paperboard boxes	(25)	.252	.481	.229	47.4	95.0	47.6
Corrugated shipping containers	(26)	.201	.487	.286	32.4	90.2	57.8
Sanitary food containers	(27)	.164	.376	.212	29.8	74.8	45.0
Fiber cans, tubes, and drums	(28)	.234	.397	.163	40.2	76.2	36.0
Paper and allied industries		.186	.451	.265	27.5	78.2	50.7
All wood industries		.230	.438	.208	45.2	97.0	51.8

[1] N.A. – Data not available.

Composition and competitive effects may act jointly or in opposition in a given region. Some subregions or regions experience net gains in employment and value added because both the composition and competitive effects have been positive. Conversely, both effects may be negative in the area of interest; or, one may be positive while the other negative, resulting in a relative gain or loss in economic activity, depending on which force is predominant. Several of these patterns are recognizable in an analysis of growth or decline of forest-based industries in the South and in the Nation.

The shift-share results are given in tables 7 and 8. The economic component (value added or employment), the geographic sector, and the period of measurement are defined in the heading. The specific *able 7.–Value added data and computations of net shift for the South*

Primary product class	1958-1963					1963-1967			
	(1) Actual value added 1958 ($1,000)	(2) Actual value added 1963 ($1,000)	(3) Expected value added 1963 ($1,000)	(4) Net shift of value added in or out of South ($1,000)	(5) Percent net shift ($\Sigma = \pm 100\%$)	(6) Actual value added 1967 ($1,000)	(7) Expected value added 1967 ($1,000)	(8) Net shift of value added in or out of South ($1,000)	(9) Percent net shift ($\Sigma = \pm 100\%$)
. Logging contractors	90,660	128,126	123,279	+ 4,847	+ 1.2	204,100	174,738	+ 29,362	+ 8.2
2. Sawmills and planing mills	477,787	588,537	649,695	− 61,158	−18.1	687,700	802,647	−114,947	−39.4
3. Veneer and plywood plants	67,874	95,899	92,295	+ 3,604	+ .9	163,900	130,787	+ 33,113	+ 9.3
4. Millwork plants	82,326	113,555	111,947	+ 1,608	+ .4	143,600	154,866	− 11,266	− 3.9
5. Prefabricated wood products	24,362	38,183	33,127	+ 5,056	+ 1.2	39,700	52,074	− 12,374	− 4.2
6. Nailed wooden boxes	26,820	13,059	36,480	− 23,411	− 6.9	40,900	17,810	+ 23,090	+ 6.5
7. Other wooden boxes	47,197	52,988	64,178	− 11,190	− 3.4	53,300	72,265	− 18,965	− 6.5
8. Wood preserving	43,253	56,006	58,815	− 2,809	− .8	78,900	76,381	+ 2,519	+ .7
9. Other wood products	40,639	119,156	55,261	+ 63,895	+15.4	159,600	162,505	− 2,905	− 1.0
0. Wood household furniture	328,253	508,200	446,358	+ 61,842	+14.9	712,800	693,083	+ 19,717	+ 5.5
1. Upholstered household furniture	152,420	233,364	207,261	+ 26,103	+ 6.3	351,300	318,262	+ 33,038	+ 9.2
2. Wood office furniture	7,914	14,573	10,761	+ 3,812	+ .9	26,900	19,875	+ 7,025	+ 2.0
3. Public building furniture	22,918	32,614	31,164	+ 1,450	+ .4	59,100	44,479	+ 14,621	+ 4.1
. Wood partitions and fixtures	N.A. [1]	33,546	N.A.	N.A.	N.A.	53,200	45,750	+ 7,450	+ 2.1
. Pulpmills	94,561	153,676	128,584	+ 25,092	+ 6.1	155,200	209,583	− 54,383	−18.6
Papermills	444,705	480,729	604,710	−123,981	−36.7	656,400	655,618	+ 782	+ .2
Paper board mills	382,842	683,054	520,588	+162,466	+39.3	897,400	931,549	− 34,149	−11.7

Table 7.—Value added data and computations of net shift for the South (Cont)

Primary product class	1958-1963					1963-1967			
	(1) Actual value added 1958 ($1,000)	(2) Actual value added 1963 ($1,000)	(3) Expected value added 1963 ($1,000)	(4) Net shift of value added in or out of South ($1,000)	(5) Percent net shift (Σ = ±100%)	(6) Actual value added 1967 ($1,000)	(7) Expected value added 1967 ($1,000)	(8) Net shift of value added in or out of South ($1,000)	(9) Percent net shift (Σ = ±100%
18. Building paper and pulpmills	105,438	65,892	143,375	− 77,393	−22.9	74,000	89,864	− 15,864	− 5.4
19. Paper coating and glazing	15,459	34,682	21,021	+ 13,661	+ 3.3	41,400	47,299	− 5,899	− 2.0
20. Envelopes	16,931	26,569	23,023	+ 3,546	+ .8	38,700	36,235	+ 2,465	+ .7
21. Bags, except textiles	117,445	131,306	159,702	− 28,396	− 8.4	244,500	179,075	+ 65,425	+18.3
22. Sanitary paper products	N.A.	40,797	N.A.	N.A.	N.A.	100,900	55,639	+ 45,261	+12.7
23. Converted paper products	N.A.	57,245	N.A.	N.A.	N.A.	86,100	78,071	+ 8,029	+ 2.2
24. Paperboard boxes	75,325	92,977	102,427	− 9,450	− 2.8	105,400	126,802	− 21,402	− 7.3
25. Corrugated shipping containers	98,656	154,688	134,152	+ 20,536	+ 5.0	241,600	210,963	+ 30,637	+ 8.6
26. Sanitary food containers	59,245	87,284	80,561	+ 6,723	+ 1.6	138,400	119,038	+ 19,362	+ 5.4
27. Fiber cans, tubes, and drums	19,139	35,676	26,025	+ 9,651	+ 2.3	64,100	48,655	+ 15,445	+ 4.3

[1] N.A. – Not available.

forest-based industry is listed in the first column as a primary product class. Data columns 1, 2, and 6 provide actual value-added or employment at the beginning and end of the periods. The third and seventh columns provide the expected value added or employment at the end of the period in question if the industry grew at the same rate as that of all-manufacturing industries in the Nation. Columns 4 and 8 provide the difference between actual a[illegible] expected value added or employment. Positive valu[illegible] represent inward shifts, where actual growth excee[illegible] expected levels; negative values represent outwa[illegible] shifts, where the industry failed to grow as fast as t[illegible] national rate for all manufacturing. Columns 5 and [illegible] depict the percentage gain (+) or loss (−) contribut[illegible] by each industrial category in the region.

Table 8.–Employment data and computations of net shift for the South

Primary product class	1958-1963					1963-1967			
	(1) Actual employment 1958	(2) Actual employment 1963	(3) Expected employment 1963	(4) Net shift in or out of South	(5) Percent net shift (Σ = ±100%)	(6) Actual employment 1967	(7) Expected employment 1967	(8) Net shift in or out of South	(9) Percent net shift (Σ = ±100%)
1. Logging contractors	30,275	28,963	31,928	– 2,965	– 5.8	26,000	32,992	– 6,992	–12.6
2. Sawmills and planing mills	146,208	121,083	154,191	–33,108	–65.1	103,500	137,926	–34,426	–61.9
3. Veneer and plywood plants	17,067	17,288	17,999	– 711	– 1.4	22,500	19,693	+ 2,810	+14.4
4. Millwork plants	15,680	17,100	16,536	+ 564	+ 1.4	17,400	19,478	– 2,078	– 3.7
5. Prefabricated wood products	3,462	4,866	3,651	+ 1,215	+ 3.0	4,100	5,543	– 1,443	– 2.6
6. Nailed wooden boxes	6,680	5,007	7,045	– 2,038	– 4.0	6,000	5,703	+ 297	+ 1.5
7. Other wooden boxes	11,662	10,616	12,299	– 1,683	– 3.3	9,200	12,093	– 2,884	– 5.2
8. Wood preserving	7,331	7,270	7,731	– 461	– .9	7,700	8,281	– 581	– 1.1
9. Other wood products	8,948	16,699	9,437	+ 7,262	+18.1	19,300	19,022	+ 278	+ 1.4
10. Wood household furniture	63,881	75,248	67,369	+ 7,879	+19.6	88,000	85,715	+ 2,285	+11.7
11. Upholstered household furniture	26,724	34,971	28,183	+ 6,788	+16.9	43,200	39,835	+ 3,365	+17.3
12. Wood office furniture	1,341	1,740	1,414	+ 326	+ .8	2,600	1,982	+ 618	+ 3.3
13. Public building furniture	4,279	5,522	4,513	+ 1,009	+ 2.5	6,900	6,290	+ 610	+ 3.1
14. Wood partitions and fixtures	N.A. [1]	4,260	N.A.	N.A.	N.A.	5,700	4,853	+ 847	+ 4.4
15. Pulpmills	6,505	7,557	6,860	+ 697	+ 1.7	6,600	8,608	– 2,008	– 3.6
16. Papermills	32,963	30,425	34,763	– 4,338	– 8.5	33,400	34,657	– 1,257	– 2.3
17. Paperboard mills	25,009	32,140	26,374	+ 5,766	+14.3	35,800	36,611	– 811	– 1.5

Table 8.–Employment data and computations of net shift for the South (Cont)

Primary product class	1958-1963					1963-1967			
	(1) Actual employment 1958	(2) Actual employment 1963	(3) Expected employment 1963	(4) Net shift in or out of South	(5) Percent net shift (Σ = ±100%)	(6) Actual employment 1967	(7) Expected employment 1967	(8) Net shift in or out of South	(9) Percent net shift (Σ = ±100
18. Building paper and pulpmills	9,909	4,869	10,450	– 5,581	–11.0	4,800	5,546	– 746	– 1.3
19. Paper coating and glazing	1,662	3,159	1,753	+ 1,406	+ 3.5	2,800	3,598	– 898	– 1.6
20. Envelopes	2,164	2,938	2,282	+ 656	+ 1.6	3,900	3,347	+ 553	+ 2.8
21. Bags, except textiles	16,317	18,409	17,208	+ 1,201	+ 3.0	21,200	20,970	+ 230	+ 1.2
22. Sanitary paper products	N.A.	1,429	N.A.	N.A.	N.A.	2,200	1,628	+ 572	+ 2.9
23. Converted paper products	N.A.	5,055	N.A.	N.A.	N.A.	7,200	5,758	+ 1,442	+ 7.4
24. Paperboard boxes	10,811	12,260	11,401	+ 859	+ 2.1	12,500	13,965	– 1,465	– 2.6
25. Corrugated shipping containers	13,656	16,762	14,402	+ 2,360	+ 5.9	22,300	19,094	+ 3,206	+16.5
26. Sanitary food containers	4,659	6,321	4,913	+ 1,408	+ 3.5	8,700	7,200	+ 1,500	+ 7.7
27. Fiber cans, tubes, and drums	2,989	3,990	3,152	+ 838	+ 2.1	5,400	4,545	+ 855	+ 4.4

[1] N.A. – Not available.

Results

Manufacturers of southern timber products continue to make significant contributions to the regional economy. In terms of value added by manufacturing in 1967, forest-product industries account for about $1 of every $10.62 added to the southern economy; one of every nine industrial workers was employed by these industries.

Recently, southern forest-based industries have expanded output far more rapidly than those in the rest of the Nation. Collectively, the forest-based indu tries in the United States are characterized by slo growth; i.e., rates of growth in employment and valı added in this industrial sector lag behind the growı rates of industries in general. Between 1958 and 196 inward shifts in employment for individual secto occurred only about half as often as outward shift Between 1963 and 1967, the outward shift of worke declined further to the extent that for every gain ı relative employment there were 10 losses. The sar slow-growth pattern prevailed in value-added statisti for the U.S.; relative losses in value added far ou weighed relative gains.

In the South, a similar slow-growth pattern characterized employment in forest-based industries; relative employment outward shifts exceeded inward shifts. However, in terms of value added, the South can be categorized as a rapid grower. The number of southern forest-based industries that gained in value added relative to all-manufacturing changes was approximately twice as great as the number of industries that suffered a relative loss. In dollars, gains exceeded losses by about 20 percent throughout both time periods. Although forest industries qualify as a slow-growing sector nationally, they are rapid growers in the South.

Solid Wood Processors

The number of solid wood processing plants has been drastically reduced, while labor productivity has increased sharply. Overall the solid-wood-product industries (table 1, columns C-J) produced $3,123 million worth of materials from stumpage costing $384 million. This represents an output increased by 25 percent between 1963 and 1967. In turn, southern furniture manufacturers relying primarily on these solid-wood materials (table 1, columns K-O) manufactured goods worth $2,252 million. Collectively the wood products and furniture industries in the South contributed $1,414 million in wages and invested $194 million.

The veneer and plywood industry led wood processors in output growth with a 74-percent increase between 1963 and 1967. The increase was due mainly to the emergence of a softwood plywood industry in the South. Although national production of softwood plywood has increased more than fivefold since 1947, t was not until 1963 that production was started in he South. Since then, the South has gained a 3-percent share of the market.

Construction of new mills in the South permitted he most modern equipment to be installed. Firms ncorporated such labor-saving devices as knothole atching machines, hot presses with automatic charging nd unloading equipment, and a variety of veneer and anel handling equipment. Moreover, development of pid lathe-chuck chargers made economical the conersion of small-diameter logs into veneer.

The establishment of the softwood plywood mills d a significant impact within the South. Computed ultiplier values (table 6, row 4) reveal that for every w $1 of output, household income was increased .44 throughout the South. Also, every $1 million crease led to 118 new jobs.

Sawmills and planing mills, however, have not kept pace with national growth. These mills (table 1, rows 5 and 6) marketed $1,516 million worth of lumber and chips. Although they increased their share of national production by 6 percent between 1963 and 1967, the net shift of value added was 39 percent below the national norm for all manufacturing.

Perhaps even more significant was the large reduction in number of employees. The number of employees was about 18,000 less in 1967 than in 1963 (table 8).

One cause of the dramatic reduction in the sawmill workforce was that the lumber market fluctuations since the early 1950's have been mild compared to former periods. This stability allowed some producers to expand by incorporating efficient capital-intensive methods of production. The Bureau of the Census estimates that the number of mills decreased from 46,000 in 1954 to 25,000 in 1967. While the national decline in number of sawmills was 46 percent, that in the South was 80 percent. Most of the mills terminating operations were small and lacked the willingness or ability to compete when emphasis was placed on efficiency rather than flexibility.

Coupled with market stability was the pressure of rising wages. Minimum wages increased from $0.75 in 1954 to $1.60 in 1968. The South was affected more than other regions because legislation pushed up pay for common labor in this region much faster than it would probably have risen otherwise. In addition, rising costs for workmen's compensation, social security, and other mandatory "fringe benefits" have added to labor costs.

To meet the rising costs of labor, mill managers intensified their effort to improve manpower efficiency. Mills were redesigned with emphasis on mechanization. For instance, handling lumber on conveyor systems and forklifts became commonplace. Many mills also reduced the need for extensive handling by simplifying their product line. An extreme example is the small but highly efficient mill that produces only studs and pulp chips.

As a result, productivity increased by 4.3 percent from 1958-63 and 4.6 percent from 1963-67. With these productivity increases the lumber industry has avoided substantial increases in unit labor costs. But, at the same time, the direct employee/output ratios have dropped, causing direct-employment multiplier values to be reduced (table 6). This trend is likely to continue as the southern sawmills continue to reduce their number of employees per unit of output in response to labor-market forces.

Among secondary wood processing industries in the South, furniture manufacturing had the fastest growth. All furniture industries in the South exceeded national growth norms both in terms of value added and employment (tables 7 and 8). In 1967, southern firms accounted for 47 percent of output by wood furniture manufacturers in the Nation, while providing 146,400 employees $648 million in wages. In addition, southern furniture plants provided major markets for locally produced hardwood lumber and veneer, purchasing wood materials worth $397 million (table 1, columns K-O). Wood household furniture plants were the leaders, purchasing 80 percent of the wood materials. Other purchasers, in order of importance, were manufacturers of upholstered wood furniture, public building furniture, wood partitions, and wood office furniture.

Hardwood lumber was the leading material purchased, because of its widespread availability, workability, strength, and beauty. Southern furniture firms purchased more than 1.3 billion board feet at a cost of $232 million. This represents an 11 percent increase in terms of board-foot usage since 1963.

Plywood is another popular material because of its outstanding strength-weight ratio, dimensional stability, and bonding properties. In addition, a variety of grain patterns can be achieved in veneer. Because of demand for these qualities, southern furniture plants purchased $103 million of hardwood veneer and plywood and $9 million of softwood plywood. Veneer accounted for 47 percent of hardwood expenditures.

Composition board accounted for the remainder of the wood expenditures, $33 million, which is double the value purchased in 1963. Particle board and hardboard each accounted for about one-half of the outlay.

Growth in other solid forest-product industries, excluding furniture, has generally not kept pace with national norms. Although most of these industries had small increases in value added and employment, the increases were not as large as national increases. Overall these industries employed 63,700 individuals in southern communities and paid $284 million in wages.

Part of the lag in relative growth can be attributed to the adjustments that southern wood processors have been making. As with the sawmilling, southern secondary wood processors have traditionally employed more individuals per unit of output than similar industries elsewhere in the Nation. But, because of the differential in regional wage rates, the wage bill per dollar of output was less in the South than in other areas. Rising wages have forced southern processors to substitute capital for labor. In production areas where substitution was not technically or economically possible, industry growth has suffered.

Of the various wood inputs, lumber was the most important. Wood products firms purchased $135 million of softwood lumber and $101 million of hardwood. Millwork plants led in the purchase of softwood lumber, while manufacturers of other wood products led in the purchase of hardwood for pallets. Forest-products firms also purchased $66 million worth of logs and chips and $57 million of plywood and veneer.

Paper and Allied Industries

Southern pulp, paper, and board mills (table 1, columns P-S) made $3,443 million worth of products from $562 million of pulpwood (row 4) and $136 million of chips (rows 5 and 6). The region increased its share of national production by 3 percent between 1963 and 1967. Relying on these outputs as inputs for additional processing stages, southern paper and paperboard converters produced goods worth $2,653 million. Paper and allied industries combined paid out $1,137 million in wages and invested $740 million.

Unlike the solid wood industries, southern mills employ less workers per unit of output than the national norm. Although the South accounted for 39 percent of production, only 34 percent of the workers were employed there. Thus, southern mills averaged $42,720 of output per employee, while the national norm was $37,736.

Paperboard mills led paper-related sectors in valu of shipments. This sector marketed $1,722 millior worth of output, or 59 percent of national shipments The major types of paperboard manufactured wer container board ($722 million) and special food boar ($422 million).

The South's paperboard mills are primarily depend ent on virgin pulp, while paperboard mills in the Nort operate largely on waste paper. Nationally, paperboar mills purchased 22.9 million cords of pulpwood an chips and 7.1 million short tons of wastepaper i 1967. Of these volumes, 16.7 million cords of pul wood and chips and 1.5 million short tons of wast paper were used by southern mills. Thus, the South in 1967 used 73 percent of the Nation's paperboard pulpwood and chips but only 21 percent of the waste paper.

Papermills also are important utilizers of pulpwood. Southern mills produced $1,261 million worth of output or 26 percent of the national total in 1967. All major types of paper were produced, including over 50% of the Nation's coarse paper (wrapping and shipping sacks). Papermills processed 10.1 million cords of pulpwood and chips in 1967.

Northern converters are the major buyers of southern paper and paperboard, but the southern market continues to grow. Southern plants (table 1, columns T-BB), purchased $709 million worth of paperboard and $443 million of paper in 1967. From these inputs, southern converters produced $2,653 million of output, 22 percent of the national total. Southern converters also employed 86,200 people in 1967, up 23 percent from 1963. The leading southern industry was manufacture of corrugated shipping containers, followed closely by paper bag manufacturing. These two sectors accounted for one-half of the production.

Regional Trends

Input and output relationships were similar in the three southern subregions (tables 2-4). However, there was a gradual east-to-west price differential underlying the wood input costs. The most significant change was in pulpwood costs. Pine roundwood prices varied from a high of $23.73 per cord in the South Atlantic region to $21.84 in the east south central and $18.80 in the west south central.

The South Atlantic States showed a steady decline or net outward shift in employment from 1958 through 1967. The ratio of summed positive net shifts (+19,597) to negative net shifts (-24,925) was 0.79 for the 1958-1963 period and fell further to 0.37 for 1963-1967. In absolute numbers, 15 of the industries experienced a net inward shift from 1958-1963, while six experienced an outward shift for a ratio of gains to losses of 2.5. This same ratio fell to 0.92 for the 1963-1967 period as 11 industries registered employment gains and 12, losses. Although the South Atlantic States experienced an overall net outward shift of employment from forest-based industries, much of the loss can be attributed to one industry: sawmills and planing mills. This single industry accounted for 77.1 percent of the relative employment losses from 1958-1963 and 59.3 percent of those from 1963-1967. On the other hand, big gains were experienced by paperboard mills, manufacturers of wood household furniture and upholstered household furniture, and the other-wood-products industries which accounted for 67.7 percent of employment gains in the South Atlantic States in the first period and 32.8 percent of those in the second.

The trend of relative losses in the South Atlantic forest industries is reversed when attention is focused on the value-added component. Throughout both periods, value-added increments for the South Atlantic States exceeded those registered by all manufacturing industries in the Nation. This situation holds for the ratio of total dollar gains to dollar losses as well as for the number of industries experiencing gains relative to those displaying a decline. Largest losses were registered by the papermill sector, which accounted for 42.7 percent of relative value-added declines in the South Atlantic subregion. Paperboard mills, on the other hand, contributed most to value-added gains, 39.8 percent.

East south central and west south central results were similar to those tabulated for the South Atlantic region. In general, employment gains in the forest-related industries fell below national averages, while gains in value added surpassed all-manufacturing increments. However, there were noteworthy exceptions in single industries. Sawmills and planing mills, in both subsectors, contributed substantially to net outward employment shifts from forest industries. Throughout both time periods, this industry alone accounted for over 55 percent of relative employment losses, and over 28 percent of declines in value added from 1963-1967. Papermills were significant value-added losers between 1958 and 1963. Industries that gained relative to the national all-manufacturing figures were scattered, with no single industry contributing significantly and consistently to employment and value-added net inward shifts except veneer and plywood manufacturing. From 1963-1967 in the west south central sector veneer and plywood plants accounted for 44.3 percent of employment gains for all forest industries and 31.5 percent of total inward shifts in value-added. Locational factors which led to the movement of the veneer and plywood industry to the South, and particularly to the west south central subsector, are numerous, but raw material accessibility and availability coupled with expanding markets and projected increases in national demand are significant contributors to the influx.

Implications

Nationally, forest-products manufacturing is a slow-growth sector, but in the South it qualifies as a rapid grower. Here forest industries appear to be progressively improving their competitive position relative to the same industries elsewhere in the Nation as a whole.

Several economic phenomena are contributing to the South's departure from national trends. First, the South is gaining markets for forest products due to shifting regional patterns of industries and populations. According to preliminary 1970 Census reports, immigration exceeded emigration in the South during the 1960's for the first time since the 1870's, and the area is urbanizing at three times the national rate. Second, the South has experienced a relative gain in forest resource availability. A favorable climate, rapid forest growth rates, marketable species, available lands, and productive management practices combine to tip the balance in favor of the South. Third, recent technological innovations in forest-product processes have altered input requirements in favor of the smaller trees characteristic of the South.

However, some of the southern wood products industries such as timber harvesting still must make substantial adjustments to become less labor intensive. Economic change continues to raise the premium on manpower. Contrary to predictions that increased mechanization and automation would create substantial unemployment, manpower has become one of our scarcest resources. Shortages of manpower in manufacturing are due largely to growth in the service sector, which necessarily relies heavily on human effort. For instance, in education emphasis has been placed on reducing the ratio of students to teachers. Overall, the number of people providing services increased 68 percent from 28 million in 1947 to 47 million in 1967. Thus, consumer preferences for more services have expanded jobs in numbers equal to those saved in manufacturing plus the new additions to the labor force. This trend is likely to continue. Quality of life has increasingly become an important national policy. Additional demands will be placed on the Nation's human resources to provide medical care and education, to rebuild cities, and to control pollution.

Overall, implications for the future seem to favor the South as an area of continued expansion for forest products. Southern markets are expected to continue growing as a result of further gains in per-capita income and population. The forest resource in the South should be capable of providing necessary inputs, assuming continuing intensification of forest management practices and technological innovations that allow greater utilization of the tree and of smaller trees.

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Appendix

Definitions of Classes

The definitions given below are based mainly on material in the SIC Manual.

Logging contractors (SIC 2411): Logging contractors are primarily engaged in cutting timber and in producing rough, round, hewn, or riven primary forest or wood raw materials. Logging and woods operations conducted in combination with sawmills and other converting establishments, and not separately reported, are classified in their respective industry groups. Products manufactured in this class include poles, saw logs, posts, and veneer logs.

Pulpwood producers: Pulpwood producers are primarily engaged in cutting wood to be mechanically ground or chemically digested for subsequent manufacture into paper, fiberboard, or other products. This class was formed to isolate pulpwood harvesting from other logging operations.

Sawmills and planing mills (SIC 2421, 2426, and 2429): Establishments engaged in sawing rough wood materials and in operations that produce surfaced lumber and standard pattern material. Hardwood dimension lumber and flooring establishments, conventionally treated as a separate unit are also included in this industry. Outputs include lumber, planed and surfaced materials, furniture dimension stock, dimension lumber, flooring, lath products, and gun stocks.

Veneer and plywood plants (SIC 2432): Establishments primarily engaged in producing commercial veneer and commercial plywood. Typical products include decorative panels, plywood, and veneer.

Millwork plants (SIC 2431): Establishments primarily engaged in manufacturing fabricated millwork. Products manufactured include door trim, cabinet wood, storm-window wood, and interior woodwork.

Prefabricated wood products (SIC 2433): Establishments primarily engaged in manufacturing prefabricated wooden buildings, sections, and panels; or in producing laminated or fabricated trusses, arches, and other structural members.

Nailed wooden boxes (SIC 2441): Establishments primarily engaged in manufacturing nailed and lock-cornered wooden boxes made of lumber or plywood. Products manufactured within this class include ammunition boxes, greenhouse flats, nailed packing cases, carrier trays, and cigar boxes.

Other wooden containers (SIC 2442 and 2443): Industries contained within this class manufacture wire-bound boxes and crates. Also included are establishments that produce veneer and plywood containers or baskets. Items produced include fruit crates, chicken crates, fruit hampers, wooden pails, and plywood drums.

Wood preserving (SIC 2491): Establishments primarily engaged in treating wood with creosote or other preservatives to prevent decay and to protect against fire and insects. The industry produces treated trestles, crossties, mine props, poles, and posts.

Other wood products (SIC 2499): Establishments primarily engaged in turning and shaping wood, and in manufacturing miscellaneous wood products not elsewhere classified, such as hardboard, pressed particleboard, wood pallets, and skids.

Wood furniture, household (SIC 2511): Establishments primarily engaged in the manufacture of unupholstered household wood furniture. The industry makes cabinets, desks, dressers, beds, tables, and bookcases.

Wood furniture, upholstered (SIC 2512): Establishments primarily engaged in manufacturing upholstered furniture on wooden frames, or in manufacturing the wooden frames for upholstered furniture. Shops primarily engaged in reupholstering furniture, or in upholstering frames to individual order, are considered nonmanufacturing industries.

Wood office furniture (SIC 2521): Establishments primarily engaged in manufacturing wood office furniture, whether padded, upholstered, or plain. Items produced by this industry include office bookcases, benches, desks, and chairs.

Public building furniture (SIC 2531): This industry includes establishments that produce furniture for schools, theaters, assembly halls, churches, and libraries. Manufacturers of seats for public conveyance systems and seats for automobiles and aircraft are also included. Typical products are bleachers, railroad seats, and church pews.

Wood partitions and fixtures (SIC 2541): Establishments primarily engaged in manufacturing wood shelving, lockers, office and store fixtures, prefabricated partitions, and related fabricated products. Refrigerator cases or cabinets are not included. Products manufactured by this industry include wooden bar fixtures, show cases, prefabricated partitions, and lockers.

Pulpmills (SIC 2611): This industry is composed of establishments mainly engaged in the manufacture of pulp from wood.

Papermills, except buildings (SIC 2621): This industry is composed of establishments that manufacture paper from woodpulp and other fibers. Items produced include paper bags, facial tissue, text paper, and kraft wrapping paper.

Paperboard mills (SIC 2631): This industry is mainly engaged in the manufacture of paperboard from woodpulp and other fibers. Boxboard, cardboard, leatherboard, and shoeboard are produced by this industry.

Building-paper and board mills (SIC 2661): Establishments primarily engaged in manufacturing building paper and building board from woodpulp and other fibrous material. Products manufactured in this industry include construction paper, insulation board, wood-fiber roofing, and tar paper.

Paper coating and glazing (SIC 2641): Included here are establishments that primarily manufacture coated, glazed, or varnished paper from purchased paper. Typical products include wax paper, waterproof wrapping paper, gummed labels, and litmus paper.

Envelopes (SIC 2642): This industry contains establishments that primarily manufacture envelopes of any description from purchased paper and paperboard.

Bags, except textile (SIC 2643): Establishments primarily engaged in manufacturing bags from purchased paper, cellophane, acetate, polyethylene, pliofilm, foil, and similar sheet or film materials. End products of these establishments include flour bags, freezer bags, shipping sacks, and garment storage bags.

Sanitary paper products (SIC 2647): This industry includes establishments engaged in manufacturing sanitary paper products from purchased paper. Toilet paper, facial tissues, table napkins, and paper diapers are typical products.

Converted paper products (SIC 2645 and 2649): This industry contains establishments primarily engaged in manufacturing purchased paper products into miscellaneous converted paper or paperboard products not elsewhere classified. Products manufactured include paper excelsior, stationary, notebooks, gift wrapping paper, and crepe paper.

Paperboard boxes (SIC 2651 and 2652): Establishments primarily engaged in manufacturing folding and set-in paper boxes from purchased paper. Products include filing boxes and newsboard boxes.

Corrugated shipping containers (SIC 2653): Establishments primarily engaged in manufacturing corrugated and solid fiber boxes and related products from purchased paperboard of fiber stock. Important products of this industry include corrugated and solid fiberboard boxes, pads, partitions, display items, pallets, single-faced products, and corrugated sheets.

Sanitary food containers (SIC 2654): This industry is composed of establishments primarily engaged in manufacturing special food board into food containers such as fluid milk containers, folding paraffined containers, frozen food containers, paper cups, and ice cream cartons.

Fiber cans, tubes, and drums (SIC 2655): Establishments primarily engaged in manufacturing fiber cans, cones, drums, and similar products, with or without metal ends, from purchased material. Typical products are paper bottles, ammunition cans, mailing cases, and fiber wastebaskets.

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INVESTOR'S GUIDE TO CONVERTING SOUTHERN OAK-PINE TYPES

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Forest Service
U. S. Department of Agriculture

INVESTOR'S GUIDE TO CONVERTING SOUTHERN OAK-PINE TYPES

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Forest type conversion is the principal way of increasing southern pine timber supplies. Opportunities exist on 50 million acres, and occur in every ownership class. This paper provides guides for investors who are weighing proposals to remove low-value stands and establish loblolly and slash pine plantations.

Forest type conversion represents the biggest single neans of improving southern pine timber supplies.

In total, the South has 50 million upland acres — ›ne-fourth of the region's commercial forest — where ›ine is the most valuable timber crop and where the full ›roductivity of the land can be realized only if all xisting trees are removed and replaced by pine ›lantations. This area comprises virtually all of the 25 illion acres classified by forest surveys as oak-pine. It lso includes 25 million acres of the oak-hickory type. he accumulation of stands with an unsatisfactory iixture of pine and hardwood species and with ıbstandard growing stock was fostered by improved fire rotection. On most ownerships the trends encouraged y fire protection were accentuated by passive anagement.

Every ownership class has a share of these acres, but e proportion is low for forest industry and high for rmers (table 1). And since farmers own the greatest reage of southern forests, by far the greatest area in ed of conversion is on their lands.

For the past several decades, forest managers were le to improve timber supplies by planting open areas d practicing timber stand improvement. Such latively inexpensive possibilities have largely been hausted, and now attention must be focused on lands at can be restored only by type conversion.

Table 1. – *Distribution of oak-pine and oak-hickory types by ownership in the South*

Ownership	Oak-pine	Oak-hickory on pine sites	Total forest land
		– – – Percent of area – – –	
Public	7	10	8
Forest industry	10	8	19
Farm	49	45	39
Other private	34	37	34
Total	100	100	100

Type conversion is one of the most capital-demanding forestry practices a manager can undertake. A substantial cash outlay is required not only for the great expense of removing a large volume of material in clearing the site, but for the additional cost of planting. Despite the cost, any owner who holds a part of the 50 million acres where hardwoods occupy pine sites will eventually have to evaluate the proposals to replace the present stand. This paper provides him with guides, in the form of charts, for 14 stand-conversion possibilities in the South. Each chart shows the rates of return possible from a range of conversion investments and under several assumptions about pine prices. An earlier section of the report describes the data on which the charts are based: the yields obtainable from loblolly and slash pine plantations on sites presently dominated by hardwoods, stumpage prices for valuing the yields, and outlays for conversion. The investment guides are presented next, and then examples of several kinds of conversion opportunities are described.

The guides cannot be employed in a mechanical fashion. The landowner will need a forester's services to determine the investment possibilities from an examination of his individual stands.

PRODUCTION FUNCTIONS

Together, loblolly (*Pinus taeda* L.) and slash pine (*P. elliottii* Engelm. var. *elliottii*) can replace oak-pine and oak-hickory stands throughout most of the southern uplands. Loblolly grows in the Piedmont and Coastal Plain from Virginia to Texas. Slash pine, whose natural range falls within that of loblolly pine (except in central and southern Florida), will grow in some areas where loblolly pine does poorly.

Yields. – For both species, yields from plantations are based upon data collected mainly from two site-quality classes – medium and good, as defined by the volumes indicated in tables 2, 3, and 4. Generalized site information suggests that these two classes account for about three-fourths of the 50 million acres in need of conversion.

Slash pine yields (table 2) are taken from tables developed by Bennett and Clutter (1968). Those for unthinned loblolly pine plantations (table 3) are from similar tables by Lenhart.[1] Yields for thinned loblolly plantations (table 4) are from Enghardt's study (1970) on the Alexander State Forest, Louisiana.

Table 2. – *Yields of unthinned slash pine plantations*

Age at harvest (years)	Volume harvested per acre		
	All trees as pulpwood	Multiple products	
		Pulpwood	Sawtimber
	Cords	*Cords*	*Bd. ft.*
	MEDIUM SITE		
20	22.5	22.5	. . .
25	25.1	15.3	3,627
30	29.8	16.0	5,360
	GOOD SITE		
20	32.7	24.7	3,085
25	35.0	17.0	7,297
30	41.3	17.5	9,924

These authors reported yields from initial spacings of 4 by 4 feet to 10 by 10 feet. In the past, 6 by 6 spacing was most common, but today it is considered too close, except perhaps for pulpwood from very short rotations. Near maximum board-foot growth is attainable at 10 by 10, but cordwood growth is sacrificed on most sites an natural pruning is delayed to the point that saw lo quality declines. In this paper, all calculations assum initial spacing of 8 by 8 feet.

Table 3. – *Yields of unthinned loblolly pine plantations*

Age at harvest (years)	Volume harvested per acre		
	All trees as pulpwood	Multiple products	
		Pulpwood	Sawtimbe
	Cords	*Cords*	*Bd. ft.*
	MEDIUM SITE		
20	29.2	28.8	184
25	39.4	35.2	2,388
30	47.8	38.0	5,126
	GOOD SITE		
20	41.0	35.4	2,928
25	54.6	37.5	8,594
30	64.8	37.5	13,293

Table 4. – *Yields of loblolly pine plantations, thinned to square feet of basal area at 5-year intervals from 20*

Age when cut (years)	Volume removed per acre		
	All trees as pulpwood	Multiple products	
		Pulpwood	Sawtimb
	Cords	*Cords*	*Bd. ft.*
	MEDIUM SITE		
20	15.8	15.8	. . .
25	3.7	3.0	23[illegible]
30	6.1	4.5	74[illegible]
35	6.6	2.9	1,74[illegible]
40	30.4	6.8	11,28[illegible]
Total	62.6	33.0	14.02[illegible]
	GOOD SITE		
20	24.5	24.5	. . .
25	6.4	5.0	64[illegible]
30	7.4	2.8	1,7[illegible]
35	7.9	1.1	3,0[illegible]
40	40.3	2.1	15,6[illegible]
Total	86.5	35.5	21,0[illegible]

[1] Lenhart, J. D. Yield of old-field loblolly pine plantations in the Georgia Piedmont. Sch. Forest Resour., Univ. Ga. Unpublished doctoral dissertation, Tab. 16, p. 73. 1968.

Rotation ages considered were 20 to 30 years for lash pine and 20 to 40 years for loblolly. Mean annual ordwood increment culminates before 20 years for lash pine, but not until 25 years for loblolly. Though lash pine stops height growth sooner than loblolly, iameter growth appears to continue and unthinned rees move rapidly into sawtimber size. In loblolly lantations thinning substantially increases sawtimber olume, while cordwood production is little affected. nasmuch as loblolly outgrows slash over long periods, a 0-year rotation was considered only for this species.

Prices. – The prices assumed in this analysis are blended. That is, they reflect the proportions of trees hat have reached pulpwood and sawtimber size in tands of various ages, and the stumpage prices for each product. Blending not only simplifies rate-of-return calculations but is in harmony with the trend toward elling stumpage to a single logger who harvests all products at the same time. In effect, the logger pays one blended price for an entire tract.

The blended prices represent more than mere lifferences in average stumpage prices and proportions of pulpwood and sawtimber bole sections. They allow for the recovery of high-value products such as veneer bolts and for differences in stand characteristics which influence costs of logging trees, converting them into products, and delivering these to market.

Three stumpage price levels were assumed for both pulpwood and sawtimber: $5, $10, and $15 per cord for pulpwood, and $30, $45, and $60 per MBF (International 1/4-inch rule) for sawtimber. The blended prices, as adjusted for volume per tree and volume per acre, ranged from $3.40 to $28.60 per cord (table 5). Other influences on sale price are size of sale area, total volume offered, and degree of competition in the timbershed (Anderson 1969, 1969a). The user of this paper must consider these influences in selecting the price assumption that applies to his situation.

Costs. – The capital cost of type conversion in the South has been estimated to be roughly $40 per acre.[2] Approximately half of this cost is for establishing a new stand, including the nursery stock and the work of planting. The average price of a pine seedling is 0.6 cent, or $4.10 for the seedlings required

[2] McClay, T. A. Treatment costs — southern supply study. USDA Forest Serv. Div. Forest Econ. and Marketing Res. Unpublished office report. 1969.

Table 5. – *Blended prices by species, site quality, and tree age*

Age when cut (years)	Medium site			Good site		
	Low price	Medium price	High price	Low price	Medium price	High price
	Dollars per cord					
SLASH PINE						
20	3.40	5.15	6.65	5.60	6.90	8.00
25	7.15	11.00	14.75	8.70	12.60	16.40
30	8.50	13.25	18.00	10.00	15.00	20.00
LOBLOLLY PINE, UNTHINNED						
20	3.45	5.25	6.65	5.40	6.95	8.20
25	6.00	10.00	14.00	8.10	12.40	16.40
30	7.50	12.50	17.50	9.50	14.75	20.00
LOBLOLLY PINE, THINNED						
20	3.45	5.20	6.50	4.30	5.81	7.02
25	5.80	9.60	13.00	7.00	11.00	14.60
30	7.80	12.65	17.45	9.30	14.05	18.60
35	11.15	17.15	22.90	11.85	17.65	24.05
40	13.65	20.50	27.95	14.80	21.58	28.60

to plant an acre at 8 by 8 spacing. Planting by machine is widespread in the Coastal Plain and much of the Piedmont. More expensive hand planting is reserved for areas that are small, rough, or otherwise unsuitable for machine travel. Getting the seedlings into the ground by one method or the other adds an additional 2 or 3 cents per tree, or $14 to $20 per acre.

Expenditures for site preparation, the other half of the stand-conversion job, vary much more widely than do planting costs. While the outlay for removing the old stand and readying the ground for the new one averages around $20 or $25 per acre (Yoho 1969), the high is easily three times this amount. Size of the area, number and size of trees, steepness of slopes, and soil trafficability determine the choice of equipment and the cost of the job. Heavy equipment is needed on most tracts. A variety of techniques are available for pushing over or severing trees with large machines. Among these are dragging an anchor chain or heavy cable between two crawler tractors, rolling vegetation down with tree crushers, and shearing stems with bulldozers. The downed material is frequently windrowed with a rake attached to a crawler tractor. Where sapling-size material predominates, however, double-drum chopping is economical. And girdling alone will suffice where the site is dominated by relatively few large hardwoods.

INVESTMENT GUIDES

To facilitate economic appraisal by and for landowners, a broad simulation analysis of type conversion was performed. Rates of return on investments were determined by computer (Row 1963). The major practical results are presented as rate-of-return charts for the 14 conversion alternatives.

Financial analysis is not difficult in principle, but it is often intricate and tedious to apply. It is simplest when the capital outlay at the beginning of the investment period yields a single return at the end of the period. With compound interest tables, the rate of return can be determined readily from the formula:

$$(1 + i)^y = R/I$$

where

i = annual rate of compound interest

y = length of investment period

I = capital outlay

R = return

Where additional costs, intermediate returns, or botl occur during the period, evaluation becomes mor complex, for each value must be discounted to th beginning of the period. The basic formula is:

$$V_o = V_n/(1 + i)^n$$

where

n = elapsed time since the beginning of th period

V_n = future value (returns have positive an costs negative signs)

V_o = present worth

The rate earned on the investment is that for which th algebraic sum of the discounted costs and discounte returns equals zero.

To evaluate the complex investments in typ conversion, a model was adopted with clarifyi assumptions. Basic to this model were the length of t investment period, the value and time of occurrence the returns, and the level and time of occurrence of t costs.

The present net worth of an investment can calculated on the basis of either a single rotation perpetual rotations. The value is greater for perpet rotations, all other factors being equal. The form (Row 1963) for adjusting the present net worth o single rotation (PNW_s) to that of a pertpetual c (PNW_p) demonstrates this:

$$PNW_p = PNW_s \left[1 + \frac{1}{(1 + i)^n - 1}\right]$$

PNW_p were assumed in all analyses in this pa Consequently, investments in type conversion sh here are somewhat higher than would be justified un a single rotation.

For perpetual rotations, a periodic cost of $20 acre for regeneration occurs at the end of each rotati This cost is largely for planting, since the amount of preparation following harvest would be small. Thus, cost of each periodic regeneration is much less than t originally required for conversion. This benefit conversion is capitalized in the perpetual-rota calculations. Annual costs of $1.25 per acre are assu for ownership, protection, and management.

In valuing the volumes cut (table 5), price per c was varied for tree species, rotation lengths, and quality. For thinned stands, adjustments were made the small volume and small size of material removed.

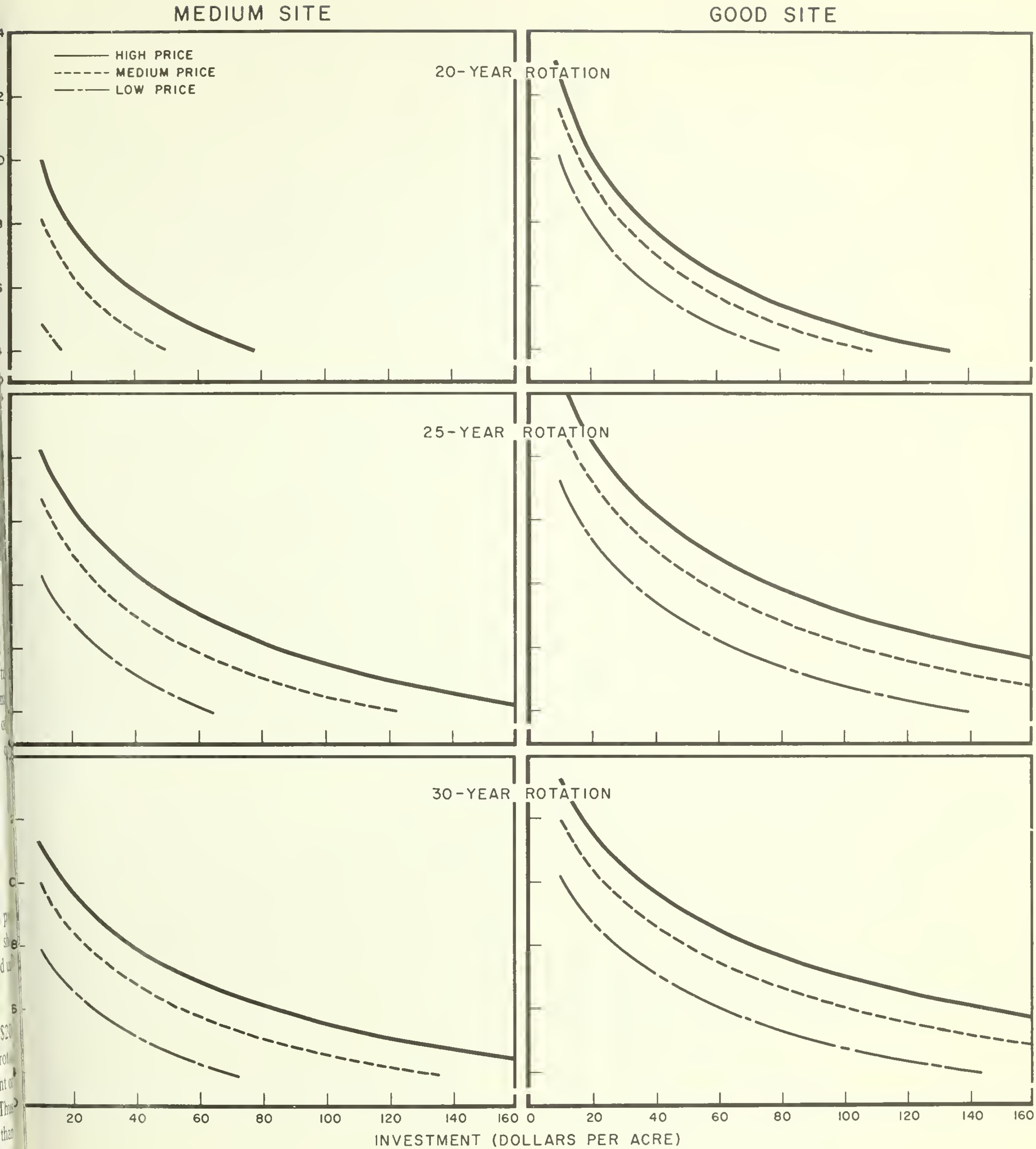


Figure 1. – *Investment justified in conversion to unthinned slash pine plantations.*

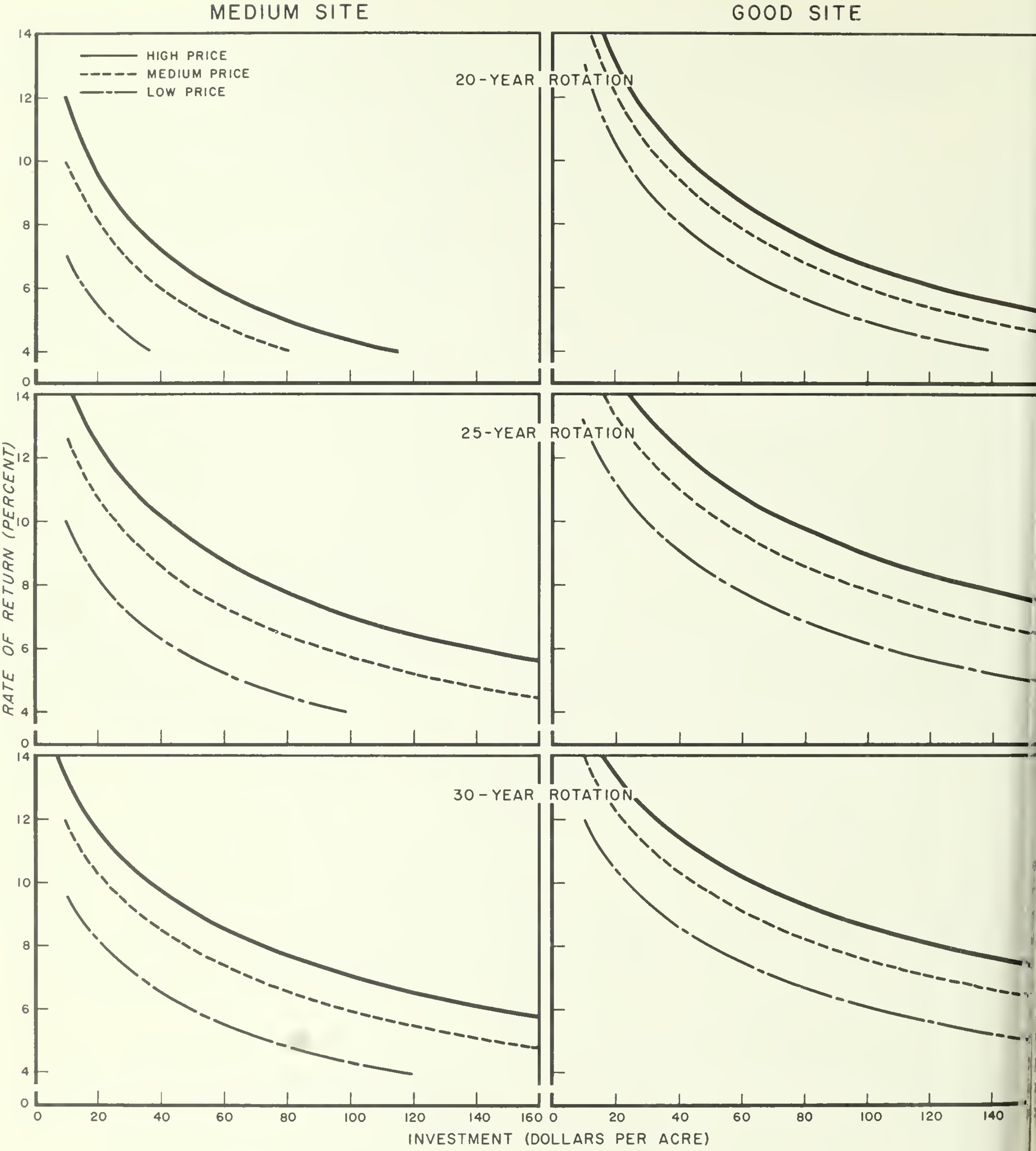
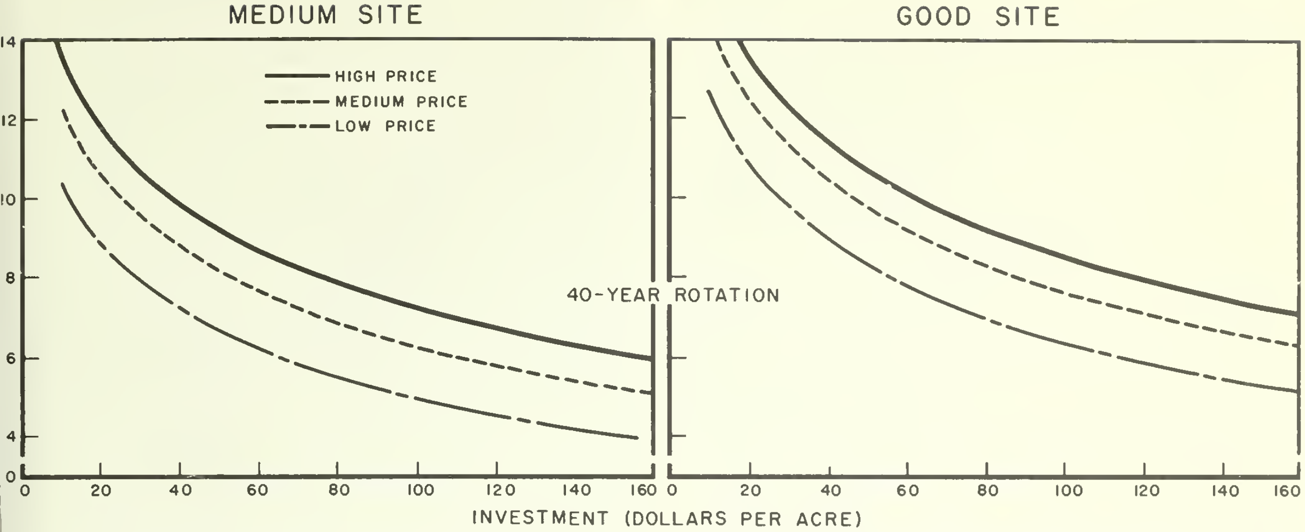


Figure 2. – *Investment justified in conversion to unthinned loblolly pine plantations.*



ure 3. – *Investment justified in conversion to loblolly pine plantations thinned to a basal area of 70 square feet per acre at 5-year intervals from age 20 to harvest at age 40 years.*

The capital that can be justifiably expended on a ırticular proposal can be determined from figures 1, 2, d 3. Before he can enter a chart, however, the investor eds certain information about the proposal and must nsider his own desires and intent. The quality of the se is a physical fact he must learn from a forester's amination. The stumpage price level that will obtain in timbershed is an economic judgment he must make. must select the species of pine to plant, choose a ation age, and decide the minimum rate of return for h capital.

As an illustration, consider an investor who has an c-hickory stand occupying a site that a forester ermines to be of medium quality for slash pine. The estor prefers a rotation of 25 years. These three ces of information – species, site quality, and ation age – determine which chart in figure 1 he will er. Further, it will be assumed that the medium price ve meets his notions about the future and that he ues his capital at 7 percent. Reading across from 7 cent on the vertical axis to the medium-price curve then down to the horizontal axis, he finds that he afford to invest $40 per acre in converting the stand.

onversely, suppose that under the circumstances just ribed the forester estimates that the actual cost of conversion is $30 per acre. Then the rate of return, ad from the chart, would be 7.8 percent. To permit stors to include the value of land in their appraisals, harts extend to $160.

Knowing how much he is justified in spending to convert a tract aids the investor in winnowing out proposals that will not pay. Knowing the rate of return is useful in rationing capital among proposals that will pay.

A wide-ranging sensitivity analysis was made to determine how changes in key assumptions would affect the charted values. Results showed that rate of return is not equally sensitive to all factors.

On good sites, volume growth is greater and cordwood growth culminates earlier than on medium sites. For any rate of return and for either pine species, the investment that can be made on good sites is approximately double that for medium sites.

Differences in growth patterns between loblolly and slash pine cause differences in rates of return at various rotation ages. Mean annual cordwood growth culminates earlier with slash. Hence, at age 20 years the rate of return is higher for slash than for loblolly pine, but at age 30 years the reverse is true.

Lengthening the rotation from 20 to 25 years increases possible capital expenditures by multiples of 1.6 to 2.8. The multiplier is greater for medium than for good sites. But increasing the rotation an additional 5 years has little effect on allowable investment: at 5 percent rate of return there is a slight increase, at 9 percent a drop. On medium sites – not on good – thinning loblolly plantations and holding them to 40 years justifies a 25-percent increase when interest rates are low, e.g., 5 percent. But at 9 percent, the advantage almost disappears.

The effect of stumpage price on possible investment is substantial. If the desired rate of return is from 5 to 9 percent, a $1-per-cord increase in stumpage price permits an increase of $3 to $19 per acre in investment. By rough rule, a 10-percent rise in stumpage prices permits a 10- to 30-percent increase in investment.

The charts assume that prices will not change over time, but the sensitivity analysis tested effects of price advances or declines at the rate of 1 percent per year. The effect is roughly to increase or decrease the justifiable investment by one-third. The effect of an increase is greater at low prices than at high, and also greater at high than at low guiding rates of interest. It is greater for slash than for loblolly pine, and greater for both species on medium than on good sites. The differences between thinned and unthinned loblolly pine, however, is slight.

Periodic and annual costs also influence the level of investment. When regeneration costs are $5 per acre more or less than the $20 charted, justifiable investments will be lowered or raised by about $1 per acre. Annual costs of $0.25 more or less than the $1.25 charted affect investment per acre by about $3.50. And if annual costs increase or decline at the rate of 1 percent annually the level of investment will fall or rise by about $2 per acre.

In selecting the most profitable type-conversion opportunities, the investor's choice will depend mainly on the cost of removing the existing stand.

Park-like stands with a high hardwood overstory and no understory offer the easiest and cheapest opportunity (fig. 4). Pines can be planted without any site preparation beyond a prescribed burn. The overstory trees can be deadened by injection with herbicides or by girdling; they will break up slowly without interfering with the planted pines.

A more abundant low-cost conversion opportunity is the brush patch, generally fully stocked with thousands of hardwood saplings (fig. 5). No heavy machinery is required, for double-disc plowing or drum chopping will suffice. Usually the chopped brush can be left in place rather than windrowed.

In contrast to the cheapness with which high- and low-canopied stands can be removed, the most expensive conversion opportunity is a hardwood poletimber stand with completely closed canopy (fig. 6). Heavy, specialized equipment is required and the large volume of material cleared must be windrowed and burned.

The need for capital rationing, or other reasons, may require delays in conversion. How should the three different stands be scheduled?

Figure 4. – *Open stands can be converted inexpensively by underplanting pines and then deadening the over-story.*

In park-like stands the effect of time on costs will be negligible. The trees are growing slowly, and conditions on the forest floor will remain essentially unaltered. Investors with stands of this type can afford to wait before converting.

The brush patch also is cheap to convert now, but every year of delay runs up the cost because the trees are growing rapidly. Hence, investors cannot afford to delay.

In poletimber stands the trees will continue to grow and thus removal costs will increase somewhat.

In addition to the direct net costs of conversion, there are other factors that influence the investor's decision whether to delay conversion. One is the rate at which he discounts the future. If his discount rate is 5 percent, he is indifferent as to when he treats a stand whose conversion cost is rising at 5 percent per year. An example is a stand whose removal costs is $25 per acre now but will be $31.75 in 5 years. The latter sum exactly equals the value of $25 put aside for 5 years at 5 percent interest. When conversion costs rise faster than the discount rate, an investor cannot afford delay. Other factors – such as the cost of holding the land for 5 years, loss of growth on the plantation, and increased risk – also bear on the decision.

igre 5. – *This brush patch can be converted readily now, but the trees are growing rapidly and delays will run up the costs sharply.*

The existing timber on most tracts proposed for c version is worthless now and prospectively. O asionally, however, it may be possible to conserve c ital by recovering some merchantable hardwood or pi trees whose value partially offsets the direct cost of co version. In entering the charts, only the net cost of co version should be used.

Figure 6. – *Dense pole-size hardwoods require the largest investment, since heavy machinery is necessary to prepare the site for planting.*

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TIMBER LOANS BY U.S. LIFE INSURANCE COMPANIES

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TIMBER LOANS BY U. S. LIFE INSURANCE COMPANIES

William C. Siegel

Timber borrowing opportunities for America's private woodland owners have expanded rapidly during the last few decades. Experience has shown that extending credit on well-managed forest tracts can be sound and profitable business. And forest credit has also proven to be a valuable means of maintaining and increasing woodland productivity.

Responding to the potentially large capital requirements in private forestry, a number of institutions now accept forest land and timber as loan security. Today forest financing—in one form or another—is available in every State. Although good growth rates and favorable markets are found to some extent in all U. S. regions containing commercial forest, opportunities are particularly well developed in the South and the Pacific Northwest.

The financial institutions that accept timber and forest land as security are of three major types: commercial banks, the Federal land banks of the Farm Credit System, and life insurance companies. Of these, life insurance companies are the only major source of truly private long-term lending on timber and timberland.

Technically, the Federal land banks are privately owned cooperative institutions, but they are indirectly favored by several types of Federal subsidies *(5)*. Their operations are chartered by Congress and are supervised by the Federal government's Farm Credit Administration. National banks—governed by the Federal Reserve System—are authorized by Public Law 285, as amended, to accept managed woodlands as security for unamortized 3-year loans and amortized 15-year mortgages. These provisions—and the State statutes which State banks must follow—are more restrictive than those regulating the land banks and insurance companies, who generally can write long-term forestry loans of 30 to 40 years.

This paper reports a study of the life insurance industry's current timber loans. The first part briefly discusses the background of the study. Next, the development and operation of the timber loan programs of the firms are reviewed. Each program is described, with special attention to facilities for making loans to woodland owners. Loan and borrower characteristics are then tabulated and discussed. Last, the opportunities for improving forest management through insurance company credit are analyzed.

Study Background

Life insurance company reserves—composed largely of policyholders' savings—are particularly well adapted to long-term investments. As a result, they provide a major source of the financial community's long-term capital. At the beginning of 1971 the many firms comprising the Nation's life insurance industry had more than $200 billion invested in the American economy. About 35 percent of this total represented mortgage loans.[1]

Although it has been generally known that a number of life insurance companies are writing long-term loans secured by mortgages on forest land and timber, little has been published on the subject and no industry-wide analyses have been made. This is one of the few insurance mortgage areas for which no statistics are available in the public record. Accordingly, numerous firms in the industry were contacted in 1969 to determine whether they would make forest credit data available for analysis. Those known to be in the timber loan business were approached first. Others were contacted on the basis of factors such as communications from within the industry, size of

[1] Source: The tally of life insurance statistics. Division of Statistics and Research, Institute of Life Insurance, New York, N. Y. April, 1971.

firm, and existence of an agricultural mortgage department. Other lesser criteria were also used. These efforts produced a list of six companies with active timber loan programs. All agreed to cooperate in the study and all subsequently furnished data on loans outstanding as of December 31, 1968.

To the extent possible, every effort was made to contact all life insurance companies with timber loan programs. However, because a central contact source does not exist, some may have been overlooked. Thus, omission is no reflection on a firm or its activities. On the other hand, inclusion in the study does not constitute a recommendation.

For many years, life insurance companies have financed large industrial owners and processors of timber through conventional corporate security obligations. Today such financing totals many hundreds of millions of dollars. For instance, at the time of the study the security investment department of one of the participating firms held $150 million of this type of credit obligation. The study, however, did not include these loans. It is concerned, rather, with credit based on timber and forest land as the security. Much of this type of lending, of course, has been done with industry as well as with other classes of clients.

Insurance Company Loan Programs

Long-term investment policies vary among insurance companies, but generally are designed to provide a well diversified portfolio that will yield a maximum return commensurate with the risk. Investment income is a key factor in determining premium costs to policyholders. Thus timber loan programs in the industry have of necessity been developed as sound, well-margined, and diversified accounts whose rates and yields compare favorably with those from other investments.

In the aggregate the life insurance industry's timber loans are big business today. The programs of most firms offering forest credit are rapidly expanding. The six companies who were identified as having active loan facilities are the Mutual Life Insurance Company of New York, Connecticut General Life Insurance Company, Equitable Life Assurance Society of the United States, Travelers Insurance Company, John Hancock Mutual Life Insurance Company, and one firm which requested that it not be identified and which will not be specifically referred to hereafter. Equitable, Travelers, and John Hancock have the bulk of the active timber loans.

A seventh company once wrote timber loans in a limited way *(4)* but reported that it no longer does so. And Connecticut General stated that its woodland lending business in recent years has been restricted by a lack of sufficient informed mortgage representatives in timber-growing areas, and that a majority of its forestry loans were prepaid in full a few years after they were made. The company plans, however, to increase its representatives and become more active, particularly if the money market shows signs of loosening.

Each of the six firms reported that it will lend in all States and geographical areas; no exclusions exist if other criteria are met. As of December 1968, active loans were secured by woodland located in 25 States (fig. 1).

Loan applications are generally made through local offices in the areas in which the timber security is located. A list of such offices will be found at the end of the paper. Mortgage representatives familiar with woodland loans are concentrated in regions of greatest forest credit activity—the South and the Pacific Northwest.

Forest Credit History

Travelers Insurance Company inaugurated its timber loan program in 1950. Equitable followed in 1952, John Hancock in 1953, Connecticut General in 1957, and Mutual of New York in 1964.

All six companies are active in the farm and agricultural mortgage markets, and timber loans have evolved from these activities. Each firm currently handles forest credit as a part of its agricultural mortgage facilities. Three of the six firms, including Equitable and John Hancock, gave woodlands a value as security in farm loans before the start of their formal forest credit programs.

Insurance company lending began in the Southeast a few years after the Federal land bank inaugurated a forest credit program

Figure 1.—*Shaded areas represent counties in which woodlands serve as security for loans from insurance companies.*

there *(5)*. The heaviest loan concentration continues to be in the Southeast. A major factor in the early and sustained lending activity is that private nonindustrial landowners of the region began to practice scientific forestry in advance of most of their counterparts elsewhere.

Lending activity was slow in the early years, and numerous problems arose. One of the first was the significance of wildfire to commercial timber production. One of the companies reported that, a few years after it entered the field, a State insurance department expressed concern that policyholders' funds might be lost because of the lack of fire insurance on forest investments *(1)*. The examiners —influenced by the publicity being given to serious forest fires breaking out at that time in southern Georgia—recommended that the company reexamine its decision to make timber loans.

Foresters, however, soon convinced the loan officers that there was no significant danger of losing merchantable timber from fire, particularly in the South. They pointed out that southern pines are fire-hardy after they have reached 4 or 5 inches in diameter and that if merchantable trees are killed, they can usually be salvaged to reduce the economic loss. The situation was thus favorably resolved.

Another early question was whether managed woodlands could be classed as improved rural property under certain State insurance laws. The statutes in question authorized mortgage loans on improved security only. Favorable decisions in this respect were ultimately reached.

Professional foresters helped the insurance industry considerably. They showed that aerial photographs could be used to determine the extent and location of forest types so that properly balanced samples could be taken by cruisers on the ground. They also pointed out that timber location, quality, and density have as much to do with appraised value as does volume. Additionally, they stressed the importance of accurate growth and income predictions.

Four of the six firms reported that they employ professional foresters in their timber loan programs. One company has four, another three, and the two others one each. Three of these nine foresters, however, also spend part of their time on agricultural and farm loans. The foresters are located in Georgia, North Carolina, South Carolina, Louisiana, and New York. Three additional professional foresters are employed by two companies in general managerial positions.

Three of the firms use both their own foresters and consulting foresters for cruises and appraisals of prospective security. Another company with no foresters on its staff relies solely on consultants. The remaining two, including the one with four foresters employed in its loan program, use appraisers who are not professional foresters.

Eligibility of Applicants

Individuals, partnerships, co-owners, trusts, and corporations are all eligible for timber loans. No firm restricts lending by type of ownership.

Although each company has its individual loan policies, all set certain basic requirements that are very similar to those demanded for any agricultural mortgage investment. Applicants must meet normal credit prerequisites for a sound, long-term mortgage loan; be solvent; and have substantial equity in the property offered as security. All six firms require their borrowers to have the facilities and financial resources to develop and utilize the security on a business-like basis.

Several companies additionally stress managerial experience and ability. That is, borrowers are expected to provide evidence of ability to protect their timberland against hazards and operate it for optimum returns. If the owner has had no actual experience himself, he must operate with the aid and advice of a professional forester.

Loan Size and Security Requirements

None of the six firms sets an arbitrary dollar limit on its forest loans. At the time of the study, four of the lenders had some loans with face values of $1 million or higher.

Minimums exist, but are generally lower than in earlier years *(2)*. Of the factors influencing this trend, the chief has been competition, which forced the experimental lending [illegible] progressively smaller amounts. In most are[illegible] with a substantial timber economy, many sources of local credit are available for soundly planned forest enterprises.

At present, one firm sets no minimum at all. Three have inflexible levels which vary in some cases by region of the country. These range from $15,000 to $75,000. Two prefer, as a practical matter, loans of at least $25,000 and $100,000. They will go lower in special circumstances, as when a company appraiser is located close to the property and the security is of the highest quality.

All six lenders have similar requirements regarding security. The acreage must consist of an economic unit or units and be readily salable in normal times. There are no minimum acreage requirements. At the time of the study, five of the firms had loans on tracts of less than 500 acres and three had loans on parcels of less than 200 acres.

Loans are made only where timber markets are well established and there is evidence that sustained production can be profitable. Three of the six firms specifically require that woodland security be operated under sustained yield management, and that projected growth and receipts from timber harvesting be sufficient to cover all operating costs, fixed costs, and loan installments. The other three are more flexible in this respect: two report that only 10 percent and 25 percent respectively of their active loans meet these criteria. These firms will waive the sustained-yield and self-supporting requirements if the borrower is strong financially and has other substantial assured income with which to meet loan obligations. They will also make liquidation loans on slow-growing, old-growth timber.

Certain additional requirements are specified by some firms. They include such factors as accessibility to roads and markets; topography which permits ready egress and ingress; adequate internal roads and fire lanes; and evidence of adequate fire, insect, and disease control.

None of the companies restrict security by species or timber type. All will lend on hardwoods as well as conifers if other requirements are met, although two indicated that they prefer softwoods. At the time of the study, each firm had some hardwood loans.

In recent years the six companies have been investigating the acceptance of nonmerchantable young timber as security. All will now accept such timber under selective conditions and four have actually done so—mostly with southern pine. Only one firm restricts this type of security to plantations; the others will also accept natural stands or combinations of the two. Most loans with nonmerchantable plantations comprising the sole security have been made in the last decade, although a few were made before then. Even in the 1950's, however, most lenders accepted and gave value to nonmerchantable stems in situations where merchantable material comprised the chief security.

Considerations that are important in conventional timber loans assume added weight with premerchantable plantations. Soil productivity and other site factors affecting growth are of critical importance. The absence of salvageable material focuses close attention on fire and other hazards. The relative importance of various forest products to the local economy and potential alternate uses of the land are often significant. Recent publication of data on early growth and yield has been extremely helpful to some of the lenders in establishing future productivity levels. Since nonmerchantable plantations are deferred-return property, an added consideration is the capacity of the landowner to meet fixed annual expenses until the tract begins to generate a cash return.

All companies require borrowers to have a working timber management plan of some sort, and three insist on formal written documents. All plans, whether formal or informal, must provide for stand protection and for sufficient sustained production to insure orderly retirement of the loan.

Loan Contract Provisions

All six firms require timber loans to be secured by a first mortgage. These provisions, however, do not necessarily prevent another party from holding a second mortgage.

The companies vary in regard to the proportion of the appraised value of the security that may be loaned. Long-term loans are generally based on a combination of two factors: the security's market value, and the lender's estimate of the cash flow to be generated by the security during the loan term. Most of the loans active at the time of the study were for amounts representing 40 to 60 percent of appraised value (table 1), although a considerable number comprised more than 60 percent. One company's entire timber portfolio represented loans of more than 60 percent. This firm's limit is 66-2/3 percent, the same as for most of the other lenders. One company will loan up to 75 percent in certain situations. The maximum loanable on nonmerchantable plantations is generally between 40 and 50 percent of discounted value.

Table 1.—*Face value of current loans as a proportion of the security's appraised value*

Company	Percent of secured value			
	Less than 20	Between 20 and 39	Between 40 and 59	60 or more
	Percent of loans			
1		50	50	
2		6	54	40
3		15	65	20
4	8	15	62	15
5		5	90	5
6		...	..	100

Each lender has its own appraisal methods and of course applies its loan levels against its own valuations. Even so, experience has shown that when circumstances are similar the various firms will lend approximately the same amounts *(3)*.

Interest rates vary with the condition of the money market but at all times must be competitive with returns from other investments of similar risk. Rates were around 5 or 6 percent on the early loans but have been considerably higher in recent years. Four firms reported that rates on most of their timber loans have been the same as those on agricultural notes written concurrently. Another stated that its rates are generally higher for timber than for agricultural loans. The sixth company always charges the same interest for both agricultural loans and "high-quality" timber loans; lower quality timber loans, however, cost more.

Repayment schedules are generally adapted to cutting cycles and tailored to the borrower's particular needs. Thus amortization and payment plans are of many types.

Fully amortized loans—that is, those providing for regular payments of both principal and interest—are most common. Payment intervals with this type of note, however, vary considerably among the lenders. Annual payments are specified most often by two firms, semiannual by one, and quarterly by another. Two did not offer information on this point. One lender requires annual payments with all fully amortized loans; two others permit either annual or semiannual; two more use annual, semiannual, or quarterly; and the sixth annual, semiannual, quarterly, or monthly. One firm reported that it would consider monthly payments if the borrower's income flow expressly fitted such a schedule.

Five of the lenders will write fully amortized timber loans in which the size of payments increases over the term of the loan. This type of arrangement is usually designed for stands that will be cut lightly in the beginning years of the loan and more heavily later on. One company reported that balloon or terminal payments of one-third to one-half of the principal are common with many of its timber loans.

Length of term for fully amortized loans also varies widely. Two firms write them for as little as 5 years. Two others require a minimum of 10 years and the remaining two a minimum of 15. Only one company will extend forest credit for as long as 40 years. For one the maximum is 33 years, for one 30, for one 25 and for the other two 20.

Partially amortized loans are made by all six firms and generally can be written for the same terms as fully amortized notes. Interest is paid periodically, but payments on principal are deferred until some specified date that most often corresponds with the proposed cutting schedule. Exact provisions depend on production possibilities and the value and durability of the security. Three companies will defer principal payments for 10 years, one for [illegible] years, and one for 3 years. The sixth has no set maximum but tailors the postponement to condition of the security and to the owner's cutting plan. Two of the firms with a maximum of 10 years indicated that in exceptional circumstances they would postpone principal payments for slightly longer.

Three companies will write nonamortized loans in which interest is due periodically but the principal payment is deferred until the end of the loan term. This arrangement generally—but not always—is designed for timber stands too light or too young for frequent cutting. Two of the firms will make such loans for terms up to 40 years, while the third restricts them to 10 years.

All six lenders allow their borrowers to reduce the principal faster than would be done with the normal amortization schedule. Two will permit a loan to be retired in full without penalty after 4 years, another after 5 years. A fourth will allow prepayment in full without penalty only after 10 to 15 years, the exact period being subject to negotiation. The fifth firm will allow an additional no-penalty payment each year of up to 10 percent of the original principal; larger prepayments may be made, but incur a penalty. The sixth company allows, without penalty, annual advance payments equal to one-fifth of the original principal.

Applications, Fees, and Appraisal Procedures

Applications to borrow are generally made through the mortgage loan representative of a firm serving the area where the security is located. In certain areas loans from three of the companies may also be negotiated through commercial banks that act as loan correspondents. Since commercial banks are restricted to relatively short-term lending, those associated with insurance companies are able to place applicants who desire long-term contracts. One firm works with correspondent banks in Georgia, and another with banks in Georgia and Alabama. The third has correspondents in every Southern State from North Carolina to Texas.

One lender never requires an application fee. Another requires a fee that is refundable if the loan is made. Three others sometimes—but not always—ask for application fees that are variable in amount, depending on a number of factors. The sixth firm always requires a fee, also variable.

All of the companies insist on an appraisal of the security before deciding whether to grant the loan. Exact requirements differ among firms. With large tracts the appraisal usually involves an inventory or cruise of the merchantable stems by species, timber type, and diameter class. Information is also generally taken on other factors having a direct effect on tract valuation—such as the volume of young stock and its estimated annual growth.

Expenses of formal cruises are in all cases borne by the applicants. In some situations, however, cruises are not required. One firm never demands them, and if the prospective collateral is small enough several of the others will make an informal appraisal at no cost to the applicant.

Supervision and Cutting of Timber

All six lenders inspect their woodland collateral but only one does so on a regular schedule. This firm requires an annual inspection. The interval varies with the others, depending on such factors as whether the borrower is seriously delinquent or in apparent financial distress, a modification or increase in the loan has been requested, a major harvest is imminent, or major casualty damage has been sustained, as from storm or fire. The primary purposes of inspections are to determine whether there has been damage to the stand or unauthorized removal of timber.

All five of the companies that provided information on the subject allow the borrower to log a certain volume—directly or indirectly comprising a percentage of the annual growth —at his own option. The proportion varies by firm and is based on the original cruise data, periodic growth studies, and the reduction of the loan principal to date. At least one lender's contracts specifically provide formulas for determining subsequent annual cuts.

With permission, the borrower may cut greater amounts. As a matter of policy, four of the firms limit the maximum to the annual growth or a specified portion thereof. A few indicated that exceptions are occasionally made. The fifth firm has no limitation *per se* on extra cutting. In all cases, extra loan payments must be made from the proceeds of cuts that require permission. One lender will allow specified improvements on the property to be substituted for extra payments.

In determining whether to authorize timber removal beyond the "free-cut" options, four of the lenders specifically consider such factors as ratio of loan to value of collateral, current loan status, increase in merchantable volume, marketing developments, and land use changes. The fifth is more flexible, but approval by all firms is always contingent upon the loan being current and the residual security being adequate to cover the unpaid balance.

The Loans and the Collateral

Most Loans Written In Recent Years

Life insurance companies had a total of 1,038 timber loans active in December 1968. The aggregate face value was slightly more than $224 million and the outstanding balance about $171 million (table 2).

For the purposes of the study, the definition of timber loan varies among firms. For two firms a timber loan is one in which timber and timberland account for at least 50 percent of the appraised value of the security. Two others require timber and timberland to be more than 50 percent of the value, while another says that these components are to be more than 40 percent. The sixth requires the security to consist entirely of timber and timberland. Each firm reported under its own definition, and the loan data were combined and analyzed as best as could be done under these conditions. This circumstance should be kept in mind during the subsequent discussion.

Before 1960 lending was sparse. Only 207—about one-fifth—of the existing loans were made then. More than a third of the current notes were written between 1965 and 1968, the latest 4 years studied. Four of the firms reported a total of 211 previous loans that had been liquidated prior to the study's cutoff date. One lender furnished no information on this point, and the sixth has not retired any timber notes since beginning its program.

In addition to the 1,038 loans that qualify under the lending companies' definitions, there is a substantial number in which woodland constitutes a minor portion of the total security.

Table 2.—*Number, original amount, and present balance of loans outstanding in December 1968, by year of loan*

Year	Number	Original amount		Present balance		Proportion repaid
		Total value	Average value	Total value	Average value	
		Dollars				*Percent*
1949	1	3,500	3,500	175	175	95
1950	3	22,000	7,333	1,280	427	94
1951	5	36,500	7,300	6,575	1,315	82
1952	6	33,000	5,500	6,546	1,091	80
1953	10	1,427,500	142,750	405,790	40,579	72
1954	13	405,600	31,200	184,603	14,200	54
1955	18	464,000	25,777	128,163	7,120	72
1956	16	549,300	34,331	264,794	16,550	52
1957	17	1,453,250	85,485	873,843	51,403	40
1958	46	10,675,150	232,068	5,743,757	124,864	46
1959	72	2,822,750	39,205	1,368,341	19,005	52
1960	64	3,036,100	47,439	1,859,842	29,060	39
1961	88	12,654,200	143,798	7,467,285	84,856	41
1962	76	8,115,650	106,785	4,298,558	56,560	47
1963	105	8,539,712	81,331	6,302,417	60,023	26
1964	131	7,100,000	54,198	[1] 5,473,413	42,103	23
1965	125	36,789,785	294,318	[1] 33,703,426	271,802	8
1966	102	49,315,240	483,483	42,324,336	414,944	14
1967	84	63,594,000	757,071	44,264,503	526,958	29
1968	56	16,966,000	302,964	16,713,265	298,451	1
All years	1,038	224,003,237	215,803	[2] 171,390,943	165,435	23

[1] Excludes one loan for which no outstanding balance was available.
[2] Excludes the two loans for which no outstanding balance was available.

Two firms were able to report the value of the woodland portion of these loans: the combined total for the two is about $16 million. A third lender was unable to furnish the value attributable to timber but indicated that it presently had 277 such notes in its portfolio. The discussion will exclude this category of loan, as well as those timber notes that have been liquidated.

Loan Refusals and Foreclosures Are Few

Timber loan applications are actively encouraged by the companies, particularly by the three who have the bulk of the business. For the six firms as a whole, the application rejection rate seems to be about equal to that for cultivated land offered as security. Two firms indicated that less than 5 percent of the applications were currently being refused. A third—one of the major lenders—rejects about half of its applications. All three reported that the rejection trend is downward. The other three firms could not supply specific refusal information but indicated that rejections were few. The primary reasons for refusal have been insufficient equity in the property, a lack of sustained earning capacity, inadequate knowledge of operating procedures, and poor financial responsibility.

Only two of the lenders have ever foreclosed on a timber loan. Foreclosures have comprised less than 1 percent of the notes written by one, and 9 percent of those by the other. Both reported that the foreclosure rate is stable.

Lending Concentrated In South

More than 97 percent of the current loans are in the Southern States. All but a handful of the remainder are in the Pacific Northwest (fig. 1). Nine out of every 10 southern loans are in the four States of Alabama, Georgia, Florida, and South Carolina. Nearly 70 percent of the Nation's total are in Georgia alone.

Timber loans in North Carolina are concentrated in the Coastal Plain, whereas those in South Carolina are divided between the Piedmont and Coastal Plain. The division is surprising, for woodland ownerships in the Piedmont and mountains are considerably smaller and less stable than in the Coastal Plain and contain a large volume of low-grade hardwood. Too, the pine stands in the western parts of North and South Carolina are often of lower value than those in the Coastal Plain. Part of the explanation may be that the South Carolina Piedmont is considerably less industrialized than the North Carolina Piedmont and more closely tied to forestry and rural values.

Most Georgia loans have been made in the southern two-thirds of the State. Much of the forest in the mountainous areas of north Georgia is in poor condition, and acceptable security there is scarce. Florida lending has been confined to the northern half of the State, with most of the activity in the northeastern and northwestern counties. North-central Florida contains an abundance of good pineland, but much of the acreage is in large ownerships or Soil Bank plantations or is used primarily for cattle raising—features which would tend to keep the number of loans to a minimum.

Lending in Alabama and Mississippi is concentrated in the southern two-thirds of each State. In Louisiana most loans are in the north-central portion and in the southeast. These areas account for most of the pine production in the three States. However, a number of loans have also been written on hardwood tracts in the bottom lands along the Mississippi River in both Mississippi and Louisiana.

There are good reasons for the scarcity of loans in northern Mississippi and Alabama, and in southern Louisiana. In many upper Mississippi counties soil erosion is severe and woodlands are depleted. And in northern Alabama a sizable portion of the timberland is hilly and in poor condtion. South Louisiana's woodlands are largely cutover tracts of cypress and tupelo. Thus eligible security is limited in these areas.

Texas loans are concentrated in the southern portion of the pineywoods area. There is little lending in the northeast counties, where stands and sites are generally poorer. In Arkansas, the bulk of the security is in the south-central loblolly pine region, although there are some loans in the shortleaf province to the north and a few in the counties bordering the Mississippi River.

West Coast lending has been about equally divided between the coastal Douglas-fir and redwood areas west of the Cascades and Sierras, and the pine regions east of the mountains. Loans in other parts of the United States are scattered, with the greatest concentrations in Michigan's upper peninsula, Maine, and New Hampshire.

Loan Size and Tract Acreage Vary By Year Of Loan

The cumulative number of active timber loans is rapidly increasing. The peak years, however, were 1964 and 1965. The number of loans written declined considerably in 1966 and continued to drop in 1967 and 1968.

The reverse was true for loan size. Prior to 1965 there was no discernible annual pattern in loan size (table 2). The average loan values for each of the years from 1965 through 1968, however, were tremendously higher than for previous years, peaking in 1967 at $757,000. From 1949 through 1964 the average note was only $85,000 as compared to $454,000 for the 4 years thereafter.

These trends partly reflect the tight money market of the late sixties, particularly 1968. There were simultaneous slowdowns in insurance companies' premium income and in optional repayments of loans of all types. This situation, coupled with large increases in policy loans, reduced net investable funds. Available money was often channeled to meet other commitments at the expense of new mortgage business—particularly smaller mortgages and woodland lending.

In December 1968 the smallest and largest active loans were for $3,000 and $24 million. The current contracts included 247 for less than $10,000 and 36 for more than $1 million.

As may be expected, the proportions of cumulated balances that have been repaid are generally larger for loans made in earlier years and become progressively smaller for those written recently (table 2). Two exceptions exist, however. Nearly half the value of 1962 loans had been repaid by 1968 and—quite surprisingly—nearly a third of the value of 1967 loans had been repaid. The average unpaid balance for all outstanding notes at the time of the study was about $165,000, and 23 percent of the original amount of all active loans had been repaid.

There are several discernible patterns in size of secured acreage by year of loan (table 3). The average number of acres was highest in 1961 and nearly three times as large as in the next highest year, 1967. And the average security for each of the first 4 years of lending was considerably smaller than in subsequent years: beginning in 1953, tract size increased considerably. And, beginning in 1966 and continuing through 1968, it took another jump. The average number of acres per loan for all active contracts in December 1968 was 6,209. The smallest and largest tracts secured at that time were 76 and 2,300,375 acres.

Table 3.—*Acreage secured by year of loan, December 1968*

Year	Loans	Aggregate size	Average size
	No.	*Acres*	*Acres*
1949	1	156	156
1950	3	1,254	418
1951	5	2,073	415
1952	6	2,412	402
1953	10	102,306	10,231
1954	13	21,773	1,675
1955	18	21,839	1,213
1956	16	23,270	1,454
1957	17	59,848	3,520
1958	46	378,941	8,238
1959	72	97,034	1,348
[1] 1960	63	69,746	1,107
1961	88	2,571,465	29,221
1962	76	204,994	2,697
1963	105	241,133	2,297
1964	131	176,384	1,346
1965	125	409,559	3,276
[1] 1966	101	722,346	7,152
[1] 1967	83	871,024	10,494
1968	56	448,324	8,006
All years [2]	1,035	6,425,881	6,209

[1] Excludes one loan for which no acreage was given.
[2] Excludes three loans for which no acreage was given.

Most Tracts Only Partly Forested

A breakdown of the security by forested and nonforested acres was reported for 741 of the 1,038 active timber loans. Only 83 of these, or about 11 percent, were on entirely foreste tracts. However, about three-fourths of the total acreage for the 741 loans was woodland. A small number of loans had secured tracts which were less than one-third forest but on which the timberland portion had a value much greater than the open. Few geographical differences are apparent. The loans on entirely forested tracts were well scattered but were somewhat more numerous in Georgia than elsewhere. The smallest all-timbered tract reported was 100 acres and the largest 231,695 acres.

Loan Size and Tract Acreage Vary By State and Region

The size of timber loans varies considerably among States and regions of the country (table 4). Western notes average 31 times as large as those in the Southeast. Those in the Midsouth and North average about eight and six times as large.

Although 85 percent of the active loans had been written in the six Southeastern States, their face value was only slightly more than

Table 4.—*Number of active loans, face value, present value, and acreage secured, December 1968*

Region and State	Loans					Security	
	Number	Total face value	Average face value	Total present value	Average present value	Total	Average
		Dollars				*Acres*	
Southeast							
South Carolina	74	13,626,050	184,136	11,157,926	150,783	210,252	2,841
North Carolina	22	8,192,000	372,364	6,952,631	316,029	252,261	11,466
Georgia	700	29,999,310	42,856	24,355,056	34,793	657,453	939
Florida	69	10,546,452	152,847	8,918,712	129,257	301,006	4,362
Virginia	4	1,905,000	476,250	1,579,138	394,784	2,311,837	577,959
West Virginia	1	1,500,000	1,500,000	1,413,945	1,413,945	64,429	64,429
Multistates	10	10,385,000	1,038,500	9,381,324	938,132	110,627	11,063
Region	880	76,153,812	86,538	63,758,732	72,453	3,907,865	4,441
Midsouth							
Tennessee	3	961,000	320,333	341,212	113,737	54,768	18,256
Arkansas	12	5,640,000	470,000	5,419,159	451,597	141,276	11,773
Mississippi	29	4,367,840	150,615	3,692,917	127,342	108,577	3,744
Louisiana	7	1,820,000	260,000	1,648,594	235,513	33,445	4,778
Texas	8	1,697,000	212,125	1,422,672	177,834	32,558	4,070
Alabama	57	18,673,500	327,605	13,237,343	232,234	711,229	12,478
Oklahoma	2	225,000	112,500	194,000	97,000	13,920	6,960
Multistates	12	56,672,685	4,722,724	34,683,269	2,890,272	695,938	57,995
Region	130	90,057,025	692,746	60,639,166	466,455	1,791,711	13,782
North							
Michigan	2	1,480,000	740,000	1,294,900	647,450	62,788	31,394
New Hampshire	1	125,000	125,000	120,000	120,000	3,658	3,658
Vermont	1	45,000	45,000	41,324	41,324	5,125	5,125
Maine	1	400,000	400,000	370,033	370,033	18,183	18,183
Pennsylvania	1	700,000	700,000	588,885	588,885	13,385	13,385
Multistates	2	1,227,400	613,700	1,208,800	604,400	78,287	39,144
Region	8	3,977,400	497,175	3,623,942	452,993	181,426	22,678
West							
California	5	25,475,000	5,095,000	23,220,076	4,645,015	139,456	27,891
Idaho	1	5,500,000	5,500,000	3,347,500	3,347,500	88,526	88,526
Oregon	9	15,565,000	1,729,444	12,304,609	1,367,179	216,241	24,027
Washington	3	2,725,000	908,333	2,389,278	796,426	41,566	13,855
Arizona	1	4,450,000	4,450,000	2,084,205	2,084,205	58,000	58,000
Multistates	1	100,000	100,000	23,435	23,435	1,090	1,090
Region	20	53,815,000	2,690,750	43,369,103	2,168,455	544,879	27,244
United States	1,038	224,003,237	215,803	171,390,943	165,117	6,425,881	6,191

one-third of the total. At the other extreme, the five Western States with lending activity had less than 2 percent of the active loans but about one-fourth of the total face value. One of the primary reasons for the size of loans in the Southeast is that insurance company lending began there, and in the earlier years the loans were small.

A much larger proportion of the original aggregate amount of loans had been repaid in the Midsouth than in the other three major regions (table 4). The face value of Midsouth notes has been reduced by about a third, as compared to about a fifth for the West, a sixth for the Southeast, and a tenth for the North.

Size and repayment differences are also apparent within regions. Georgia loans average about $43,000, considerably smaller than those in other Southeastern States. The average Florida note is about three and one-half times as large, that in South Carolina more than four times as large, and that in North Carolina almost nine times as large. With the exception of West Virginia, where there is only one loan, the 10 contracts whose security spans more than one State average highest in the Southeast at more than $1 million. The four Virginia notes average next highest at almost a half million dollars.

In the Midsouth, among loans confined to single States, Oklahoma contracts average smallest. Those in Arkansas are largest—more than four times larger than in Oklahoma. The 12 multistate loans, forming about 9 percent of the region's total number, comprise more than three-fifths of its loan value and average nearly $5 million. They are the largest in the country. More of the face value of the contracts has been repaid in Alabama and Tennessee than in other Midsouth States.

In the West and the North loans are so few that interstate differences in size and repayment are meaningless.

The average security for all loans in the United States is 6,191 acres. The range among States and regions (table 4), however, is wide. It is highest in Virginia at 577,959 acres. Idaho, West Virginia, Arizona, and the multistate loans in the Midsouth follow in order—all at more than 50,000. The average security in the remaining States is less than 50,000 acres and is lowest in Georgia at 939.

The smallest acreages are found in the Southeast, followed by the Midsouth, North, and West in that order. The average security is more than six times as large in the West as in the Southeast. States and regions with the most loans and the oldest lending activity generally have the least acreage secured per note.

Loan Terms Differ

Of the 1,029 active loans for which the term was reported, 90 percent were written for 20 years (table 5). The next most prevalent term was 25 years—representing 42 loans, 4 percent of the total. Six notes were for the maximum time of 40 years, while one was for 7. Some differences are apparent among States and regions.

Loans in the Southeast tend to be for shorter terms than in the other three regions. In the Southeast 97 percent of the notes were for 20 years or less whereas the proportion written for these terms in the Midsouth was 72 percent, in the West 65 percent, and in the North 50 percent. In the West, by contrast with other regions, 15-year terms are popular.

Many Loans are Refinanced

About three of every ten of the active loans had been refinanced. There was no discernible pattern among States and regions. But, as may be expected, few of the more recent contracts had been refinanced

Timber Collateral Mostly Softwood

Nearly all the active loans are on tracts where the dominant timber is softwood (table 6). Only a handful of hardwood loans—mostly in the South and Northeast—are included, but many southern and a few northern tracts used as security contain some merchantable hardwood whose value was included in the appraisal. Redwood, Douglas-fir, ponderosa and sugar pine, hemlock, and cedar are all major security in the West.

Loan size varies considerably by forest type Loans on tracts that are predominantly southern pine average smallest. These notes account

Table 5.—*Number of loans by length of term, December 1968* [1]

Term (years)	Southeast		Midsouth		North		West		United States	
	Loans	Proportion of total	Loans	Proportion of total	Loans	Proportion of total	Loans	Proportion of total	Loans	Proportion of total
	No.	*Percent*	*No.*	*Percent*	*No.*	*Percent*	*No.*	*Percent*	*No.*	*Percent*
7	...	...	1	0.8			...	...	1	0.1
10	2	0.2	1	.8			1	5.0	4	.4
11			1	.8					1	.1
12		...	1	.8					1	.1
13		...	1	.8					1	.1
14							1	5.0	1	.1
15	4	.5	4	3.1			6	30.0	14	1.4
16	...	...					1	5.0	1	.1
17	...	...					1	5.0	1	.1
18	...	...	1	.8					1	.1
19	...	...	2	1.6					2	.2
20	842	96.6	81	62.5	4	50.0	3	15.0	930	90.3
21	2	.2	1	.8			2	10.0	5	.5
22	...		3	2.3					3	.3
23			1	.8	1	12.5	1	5.0	3	.3
24			1	.8					1	.1
25	8	.9	27	20.9	3	37.5	4	20.0	42	4.0
28	2	.2	1	.8	...	...		...	3	.3
29			1	.8			...	...	1	.1
30	4	.5			...	...	...	...	4	.4
33	2	.2	1	.8				...	3	.3
40	6	.7			...	...	...	...	6	.6

[1] Length of term not given for nine loans.

Table 6.—*Number and original amount of loans outstanding in December 1968, by predominant forest types of security*

Predominant forest type	Number	Original amount		
		Total value	Average value	Proportion
		— — — *Dollars* — — —		*Percent*
Southern pine	844	96,564,400	114,413	43
Southern hardwood	21	30,630,885	1,458,614	14
Southern pine and hardwood	145	55,340,552	381,659	25
Douglas-fir	6	4,740,000	790,000	2
Other western species	3	23,810,000	7,936,666	11
Douglas-fir and other western species	8	9,875,000	1,234,375	4
Northern hardwood	2	825,000	412,500	(1)
Northern hardwood and pine	5	1,952,400	390,480	1
Not given	4	265,000	66,250	(1)
Total	1,038	224,003,237	215,803	100

[1] Less than 0.5 percent.

for 81 percent of the total number but only 43 percent of the total face value. Southern hardwood loans, by contrast, comprise 2 percent of the total number but 14 percent of the total value. The average southern hardwood loan is almost 13 times as large as the average southern pine contract.

Southern loans on mixed tracts are also comparatively large. They are only 14 percent of the total number, but their value is 25 percent of the total. They average more than three times as large as southern pine loans. Contracts with western timber species as security are less than 2 percent of the total, but their loan value is 17 percent.

Timber Security Primarily Natural Stands

Nearly half the loans are on tracts that are predominantly natural stands containing both sawtimber and pulpwood (table 7). These loans are larger than the average, since their face

Table 7.—*Number and original amount of loans outstanding in December 1968, by security classification*

Predominant security classification	Number	Original amount: Total value	Average value	Proportion
		— — — *Dollars* — — —		*Percent*
Natural stand, sawtimber size	63	25,099,585	398,406	11
Natural stand, pulpwood size	200	9,431,800	47,159	4
Natural stand, sawtimber and pulpwood size	515	149,899,012	291,066	67
Plantation, sawtimber size	5	93,250	18,650	(1)
Plantation, pulpwood size	17	1,999,000	117,588	1
Plantation, sawtimber and pulpwood size	42	1,272,900	30,307	1
Combinations of preceding	179	35,029,690	195,697	16
Not given	17	1,178,000	69,294	(1)
Total	1,038	224,003,237	215,803	100

[1] 0.5 percent or less.

value is two-thirds of the total. Notes on natural stands that are mostly sawtimber size average even larger. There are 63 such contracts comprising 6 percent of the total number and 11 percent of the total value. As may be expected, the smallest loans on natural stands are on tracts that contain predominantly pulpwood. Though these notes are almost one-fifth of the total number they represent only 4 percent of the total value. Loans on natural stands of sawtimber average more than eight times as large as those on natural stands of pulpwood.

The study disclosed 64 loans on plantations, comprising 6 percent of the total number and 2 percent of the total value. Those whose security was pulpwood-size stems averaged more than six times as large as those made on sawtimber. Most plantation loans, however, were on multiage stands containing both sizes of timber. All plantations were of softwood species.

Plantations ranged from 1 to 35 years in age when the loans were made. Two-thirds of the notes were limited to stands with all stems less than 10 years old. Nearly three of every ten contracts had been written on security 5 years of age or younger. Several loans were on security with as much as 24 years' difference between the oldest and youngest trees.

The Borrowers

Most Borrowers Are Individuals

Almost two-thirds of the active loans were made to individuals (table 8). Twenty-three percent were with partnerships, and the remainder with corporations and trusts. This pattern, however, does not prevail in every State and region. The proportion of loans made to individuals was considerably larger in the Southeast than in the Midsouth, North, and West, where most contracts are with corporations. The proportion of corporate loans is highest—75 percent—in the West. The data indicate that most corporate borrowers throughout the U. S. are small, closely held businesses —the proprietorships of yesteryear. Very few are likely to be publicly owned.

Aside from Vermont and Maine, whose one loan each was to an individual, Georgia had the highest proportion of individual borrowers —77 percent. At the other extreme, all loans in nine States were to partnerships, corporations, or trusts.

With the exception of Louisiana, where two of the four contracts were with partnerships, Florida had the highest proportion of partnership notes—38 percent. Four of every five partnerships that borrowed were in the three States of Georgia, South Carolina, and Florida. There were no partnership loans in the North and only two in the West.

In eight States all of the contracts were with corporations. Only three States had no loans in this category. Nearly one-third of the corporate notes were written in two States—Georgia and South Carolina.

Amount Of Loan and Acreage Secured Varies By Type Of Borrower

One-fifth of the money loaned has been to individuals, one-fifth to partnerships, and three-fifths to corporations and trusts (table 9). Partnerships and corporations generally borrow more than individuals do; their loans represent about one-third of the total number but 80 percent of the total amount.
North. Louisiana and Texas are particularly high in this respect.

Table 8.—*Number of loans by type of borrower, December 1968*

Region and State	Individuals		Partnerships		Corporations and trusts		Total
	Loans	Proportion of total	Loans	Proportion of total	Loans	Proportion of total	
	No.	*Percent*	*No.*	*Percent*	*No.*	*Percent*	*No.*
Southeast [1]							
South Carolina	33	45	23	31	18	24	74
North Carolina	4	18	5	23	13	59	22
Georgia	538	77	140	20	21	3	699
Florida	30	43	26	38	13	19	69
Virginia	1	25	1	25	2	50	4
West Virginia	..				1	100	1
Multistates	2	20	2	20	6	60	10
Region	608	69	197	22	74	9	879
Midsouth [2]							
Tennessee	1	34	1	33	1	33	3
Arkansas	..		2	18	9	82	11
Mississippi	16	57	8	29	4	14	28
Louisiana	2	50	2	50			4
Texas	3	38	3	37	2	25	8
Alabama	31	54	13	23	13	23	57
Oklahoma		..			2	100	2
Multistates	5	42	1	8	6	50	12
Region	58	46	30	24	37	30	125
North							
Michigan					2	100	2
New Hampshire					1	100	1
Vermont	1	100					1
Maine	1	100			..		1
Pennsylvania					1	100	1
Multistates	1	50			1	50	2
Region	3	38			5	62	8
West							
California	1	20	1	20	3	60	5
Idaho	..				1	100	1
Oregon	2	22			7	88	9
Washington					3	100	3
Arizona					1	100	1
Multistates			1	100			1
Region	3	15	2	10	15	75	20
United States	672	65	234	23	126	12	[3] 1,032

[1] Type of borrower not given for one loan in this region.
[2] Type of borrower not given for five loans in this region.
[3] Does not include the six loans for which type of borrower was not given.

Differences among States and regions are apparent. A much larger proportion of loan funds has gone to individuals in the Southeast than in the other three regions. The percentages are particularly high in Georgia and Florida. One-third of the amount borrowed in the Midsouth has been by partnerships, as compared to one-fifth in the Southeast, less than 1 percent in the West, and none in the

Virtually all of the money loaned in the North and West has been to corporations. In the North, individuals comprised 38 percent of the borrowers but accounted for only 12 percent of the total loan value. And in the West individuals were 15 percent of the borrowers and received 2 percent of the loan

Table 9.—*Face value of loans by type of borrower, December 1968*

Region and State	Individuals		Partnerships		Corporations and trusts		Total
	Loans	Proportion of total	Loans	Proportion of total	Loans	Proportion of total	
	Dollars	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*	*Dollars*
Southeast [1]							
South Carolina	2,247,750	17	5,909,300	43	5,469,000	40	13,626,050
North Carolina	1,033,000	12	1,372,000	17	5,787,000	71	8,192,000
Georgia	17,841,910	60	6,295,900	21	5,616,500	19	29,835,310
Florida	5,359,852	51	1,827,500	17	3,359,100	32	10,546,452
Virginia	30,000	2	175,000	9	1,700,000	89	1,905,000
West Virginia					1,500,000	100	1,500,000
Multistates	445,000	4	152,000	2	9,788,000	94	10,385,000
Region	27,038,512	35	15,731,700	21	33,219,600	44	75,989,812
Midsouth [2]							
Tennessee	375,000	39	86,000	9	500,000	52	961,000
Arkansas			425,000	9	4,415,000	91	4,840,000
Mississippi	1,784,840	45	423,000	11	1,750,000	44	3,957,840
Louisiana	185,000	15	1,045,000	85	...	..	1,230,000
Texas	325,000	19	955,000	56	417,000	25	1,697,000
Alabama	12,003,000	64	2,511,500	14	4,159,000	22	18,673,500
Oklahoma					225,000	100	225,000
Multistates	1,586,000	3	24,000,000	42	31,086,685	55	56,672,685
Region	16,258,840	19	29,445,500	33	42,552,685	48	88,257,025
North							
Michigan	..				1,480,000	100	1,480,000
New Hampshire					125,000	100	125,000
Vermont	45,000	100				...	45,000
Maine	400,000	100					400,000
Pennsylvania					700,000	100	700,000
Multistates	27,400	2			1,200,000	98	1,227,40
Region	472,400	12			3,505,000	88	3,977,400
West							
California	500,000	2	50,000	([4])	24,925,000	98	25,475,000
Idaho				..	5,500,000	100	5,500,000
Oregon	290,000	2			15,275,000	98	15,565,000
Washington					2,725,000	100	2,725,000
Arizona					4,450,000	100	4,450,000
Multistates			100,000	100	..		100,000
Region	790,000	2	150,000	([4])	52,875,000	98	53,815,000
United States	44,559,752	20	45,327,200	20	132,152,285	60	[3] 222,039,2[illegible]

[1] Type of borrower not given for one loan in this region.
[2] Type of borrower not given for five loans in this region.
[3] Does not include the six loans for which type of borrower was not given.
[4] Less than 0.5 percent.

funds. In 12 States corporations borrowed more than 70 percent of the funds loaned.

In most States and regions the acreage secured by loans to individual borrowers averaged much less than that of corporations and partnerships. The difference was particularly noticeable in the West.

Most Individual Borrowers Are Middle-Ag[e] and Male

Of the 600 individual borrowers whose ag[es] were reported, more than 90 percent were [illegible] years or older when they applied (table 1[illegible]. And almost two-thirds were at least 50 yea[rs]. Only two persons were under 30. Nearly [illegible]

Table 10.—*Age distribution at time of application for individual borrowers with active loans in December 1968*

Region and State	Age (years)											
	0-29		30-39		40-49		50-59		60-69		70+	
	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
Southeast												
South Carolina			5	19	3	12	10	38	7	27	1	4
North Carolina					1	25	3	75				
Georgia	2	([1])	43	8	137	27	161	32	108	21	59	12
Florida			2	12	4	23	7	41	3	18	1	6
Virginia							1	100				
Multistates									1	100		
Region [2]	2	([1])	50	9	145	26	182	33	119	21	61	11
Midsouth												
Tennessee							1	100				
Arkansas												
Mississippi			2	20	4	40	4	40				
Louisiana					1	25	3	75				
Texas							1	100				
Alabama			2	9	5	23	6	27	6	27	3	14
Oklahoma												
Multistates			1	34	1	33	1	33				
Region [3]			5	12	11	27	16	39	6	15	3	7
North and west [4]												
United States [5]	2	([1])	55	9	156	26	198	33	125	21	64	11

[1] Less than 0.5 percent.
[2] Does not include 49 individual borrowers for whom no age was given.
[3] Does not include 17 individual borrowers for whom no age was given.
[4] One individual borrower in these regions was in his fifties, and there were six others for whom no age was reported.
[5] Does not include the 72 individual borrowers for whom no age was given.

percent—64 borrowers—were over 70. The youngest was 29 and the oldest 88.

Borrowers in the Southeast tend to be much older than in the Midsouth. Almost one-third were 60 years or older whereas only one-fifth —all in Alabama—were in this category in the Midsouth.

There were no women borrowers in the North, West, or Midsouth. However, 71 women had made loans in the Southeast—63 in Georgia, 6 in South Carolina, and 2 in Florida. They represent about 13 percent of the individual borrowers in the Southeast and 11 percent of those in the entire United States.

Borrowers' Occupations and Businesses Vary Widely

More than a third of the borrowers, all in the Southern States, were engaged in farming (table 11). Nearly a fifth were in a timber-related business: either as timber growers, forest product manufacturers, logging or pulpwood contractors, or two or more of these in combination. All borrowers in the West and North—where more than two-thirds are corporations—were in this category.

About 12 percent were in businesses not related to timber or farming, and 10 percent were professional persons. Salaried white-collar, bluecollar, and miscellaneous occupations account for the others for whom this information was reported.

Some other interregional differences are apparent. Virtually all borrowers engaged in farming were in the Southeast. Only 5 percent of the Midsouth's borrowers were farmers or farming businesses. On the other hand, nearly half of the Midsouth borrowers were in timber-related businesses, as contrasted to 10 percent in the Southeast. The proportion of Southeast borrowers engaged in businesses not related to timber or farming was nearly twice that of the Midsouth. By contrast, the percentage in professional, executive, managerial, or clerical occupations was much higher in the Midsouth than in the Southeast.

Table 11.—*Principal occupation or type of business of borrowers by region, at time of loan application*

Occupation	Southeast		Midsouth		North		West		United States	
	No.	*Percent*	*No.*	*Percent*	*No.*	*Percent*	*No.*	*Percent*	*No.*	*Percent*
Farming	364	41	7	5					371	36
Growing, harvesting, or manufacturing timber	92	10	63	48	8	100	20	100	183	18
Business other than farming or timber	111	13	9	7					120	12
Professional	86	10	22	17					108	10
Salaried executive, managerial, or clerical	50	6	13	10					63	6
Bluecollar	15	2	1	1					16	1
Miscellaneous	151	17	10	8					161	16
Not given	11	1	5	4					16	1

Loan Purposes Are Varied and Many

The most prevalent reason for borrowing was to refinance other debt. Nearly three of every 10 loans were solely for this purpose (table 12), and many more partially. Only 2 percent of the borrowers, most of them in the South, invested their proceeds in forestry or forest-products industry.

Other important reasons for borrowing were for agricultural and other nonforestry enterprises, working capital, and purchase of the security or other real estate. A few loans were used to pay taxes and estate-settlement expenses.

Agricultural investments were considerably more important in the Southeast than in the Midsouth. Conversely, nearly one Midsouth borrower in five utilized loan funds for working capital, as compared with less than 10 percent of Southeastern borrowers.

In North Carolina, Virginia, Arkansas, Michigan, Pennsylvania, and Oregon, a considerable percentage of borrowers used their proceeds to purchase the security or other real estate. In North Carolina and Georgia borrowing for agricultural investment was more important, and borrowing for working capital was less prevalent, than in other Southern States.

Implications For Forest Resource Development

The timber loan programs of the life insurance industry, in addition to providing good investments for the companies involved, are contributing to the Nation's forest economy. Many loans have been used to purchase forest land. And, while only a small percentage have been used directly for improving or intensifying management of woodlands, most have indirectly influenced these activities. Requirements imposed by the lenders insure that the security will be well managed and protected. Moreover, recent innovations in the various programs are making it more feasible than ever to tailor borrowing to forest practices.

The study has shown that the life insurance industry is a widespread source of funds for forest lending. Competitive interest rates and flexibility in adjusting contracts to individual requirements have made the loans useful to owners of both small and large holdings. Contrary to what is sometimes thought in forestry circles, the study revealed many loans made to owners of small tracts.

Liquidating immature but merchantable timber to raise cash is usually far less profitable in the long run than using the timber as loan security. Young timber in many areas—particularly in parts of the South and West—grows at rates far in excess of what credit costs. But the extent to which credit is used for forestry will depend less on the lenders than on the forestry profession. Private consultants, industrial foresters who work with landowners, and public service foresters are all in an ideal position to promote the use of credit when the rate of return from holding timber exceeds loan costs. To give such foresters their fullest opportunities, insurance companies should periodically reexamine their forestry loan programs for alternatives which will better serve prospective clientele.

Table 12.—*Proportion of loans by purpose, for those current in December 1968*

Region and State	Loans	Refinance other debt	Refinance other debt plus: Agricultural investment	Refinance other debt plus: Nonagricultural investment	Refinance other debt plus: Working capital	Investment: Agricultural	Investment: Nonagricultural	Working capital	Estate settlement expenses	Pay taxes	Purchase the collateral or other real property	Forestry or forest-product investment	Other
	No.	*Percent*											
Southeast													
South Carolina	74	30	5	4	14	3	5	14	1		20	3	1
North Carolina	22	26	5			5		5	5		45	9	
Georgia	700	29	5	4	14	9	9	6	1	1	17	1	[1] 4
Florida	69	35	3	3	4	3	10	16		3	23		
Virginia	4							25			75		
West Virginia	1			100									
Multistates	10	10						30			60		
Region	880	29	4	4	13	8	8	8	1	1	20	1	3
Midsouth													
Tennessee	3				33			67					
Arkansas	12	17						25			33	8	17
Mississippi	29	42			3		10	14			28	3	
Louisiana	7	29	14				14				29	14	
Texas	8	39			25			12		12	12		
Alabama	57	21	6	6	18	3	3	19	2		19	3	
Oklahoma	2							50				50	
Multistates	12	34	8	8				8		8	17	17	
Region	130	27	4	3	11	1	5	18	1	1	22	6	1
North													
Michigan	2										100		
New Hampshire	1							100					
Vermont	1	100											
Maine	1											100	
Pennsylvania	1										100		
Multistates	2										50	50	
Region	8	13						12			50	25	
West													
California	5	40			20						20	20	
Idaho	1		100										
Oregon	9	22						34			34	10	
Washington	3	34						33				33	
Arizona	1								100				
Multistates	1										100		
Region	20	25	5		5			20	5		25	15	
United States	1,038	29	4	4	13	7	8	9	1	([2])	21	2	2

[1] Includes one Georgia loan for which the purpose was unknown.
[2] Less than 0.5 percent.

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Contact Offices for Timber Loan Applications

The addresses that follow include branch offices of the insurance companies as well as associated independent firms.

Connecticut General Life Insurance Co.

Agricultural Investment Division
910 Stemmons Tower North
Dallas, Tex. 75207

Equitable Life Assurance Society of the United States

Room 606, 120 Montgomery St.
San Francisco, Calif. 94104

Room 915, 621 Seventeenth St.
Denver, Colo. 80202

Room 647, 401 North Michigan Ave.
Chicago, Ill. 60611

Ninth Floor, 317 Sixth Ave.
Des Moines, Iowa 50307

Room 1260, 920 Main St.
Kansas City, Mo. 64105

Suite 704, 333 Fayetteville St.
Raleigh, N. C. 27601

266 South Cleveland St.
Memphis, Tenn. 38104

Room 1530, One Main Pl.
Dallas, Tex. 75250

Room 502, 510 Riverside Ave.
Spokane, Wash. 99201

John Hancock Mutual Life Insurance Co.

Suite 5, 2715 K St.
Sacramento, Calif. 95816

114 South Main St.
Statesboro, Ga. 30458

431 Robeson Building
Champaign, Ill. 61820

1030 Badgerow Building
Fourth and Jackson Sts.
Sioux City, Iowa 51101

Room 620, 800 West 47th St.
Kansas City, Mo. 64112

545-550 Commerce Title Building
Memphis, Tenn. 38103

Room 515, 1621 Main St.
Dallas, Tex. 75201

Second Floor, South 176 Stevens St.
Spokane, Wash. 99204

Mutual Life Insurance Co. of New York

Planters Mortgage Co.
P. O. Box 670
321 West Crawford St.
Quincy, Fla. 32351

The Citizens & Southern Bank of Albany
P. O. Box 1309
Albany, Ga. 31702

Mutual of New York
Farm Mortgage Regional Office
4 Executive Park East, N. E.
Atlanta, Ga. 30329

Durant Realty Co.
P. O. Box 308
101 North Franklin St.
Dublin, Ga. 31021

Travelers Insurance Co.

1516 East Colonial Drive
Orlando, Fla. 32803

Bank of California Building
Portland, Oreg. 97205

Meadows Building
Dallas, Tex. 75206

U. S. Department of Agriculture
Forest Service Research Paper SO-74

Mycorrhizal Inoculation Influences Survival, Growth, and Chemical Composition Of Slash Pine Seedlings

Eugene Shoulders

Southern Forest Experiment Station
Forest Service
U. S. Department of Agriculture

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Mycorrhizal Inoculation Influences Survival, Growth, and Chemical Composition of Slash Pine Seedlings

Eugene Shoulders

Seedlings grown in fumigated soil inoculated with root segments from mycorrhizal nursery stock had four times as many bifurcate roots at lifting as uninoculated seedlings. Inoculation produced a fivefold increase in the number of new bifurcate roots formed during 30 days by potted seedlings in a greenhouse. When outplanted, about 1/3 more inoculated than uninoculated seedlings survived. Initial field survival was most closely correlated with number of bifurcate roots at lifting (r = 0.66) and with various expressions of nitrogen and phosphorus content of the plants, especially N/P ratios of needles (r = —0.66) and roots (r = —0.56).

Foresters have long known that mycorrhiza-forming fungi en-ance survival and growth of pines (Hatch 1937, Harley 1969). The ssumption has been that sufficient mycorrhizae will develop natur-lly to ensure establishment of plantations when pines are sown or lanted on soils containing the requisite fungi (Wilde 1944, Mikola 970). This comfortable opinion is probably due for revision. In ecent studies with slash pine *(Pinus elliottii* Engelm.) and loblolly ine *(P. taeda* L.), branched or forked short roots were lacking on s many as half of the plantable seedlings in lots from several nur-eries on sites that had once supported southern pine forests. More-ver, seedlings that lacked these "visible mycorrhizae" survived out-lanting on cutover pine lands in central Louisiana less well than ycorrhizal stock—an indication that indigenous fungi may not have roduced mycorrhizae in time to prevent first-season mortality (Jor-ensen and Shoulders 1967, Shoulders and Jorgensen 1969). In upport of this theory, Laiho (1967) found that nonmycorrhizal cotch pine *(P. silvestris* L.) seedlings survived less well on a variety forest sites in Finland than those successfully inoculated with tendotropic mycorrhizae before planting.

In the study reported here, slash pine seedlings were planted on cutover pine site to determine if prior inoculation enhanced field

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survival when mycorrhiza-forming fungi were present in the soil. In addition, the study measured differences in abilities of inoculated and uninoculated seedlings to produce new roots, determined the effects of inoculation on mineral nutrient and carbohydrate content of the seedlings, and explored relationships between outplanting survival and physical and chemical characteristics of the stock.

Materials and Methods

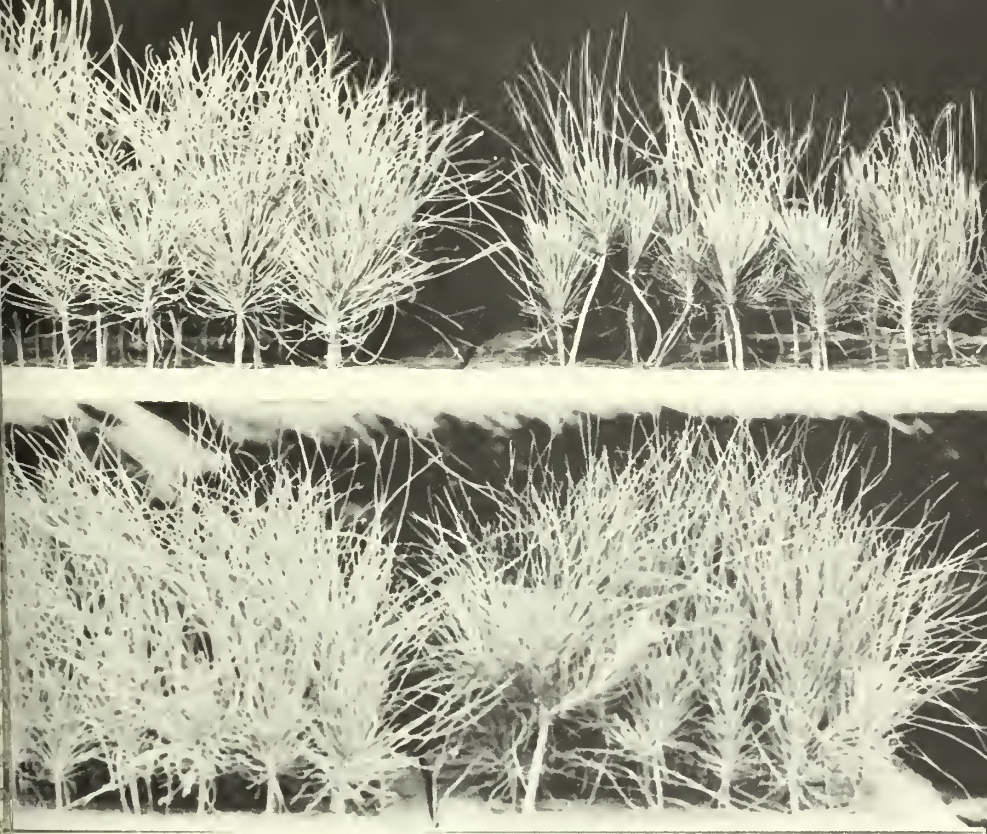
Seedlings were reared in a growth chamber so as to minimize fortuitous inoculation. Twenty-four polyethylene-lined boxes were each filled with about 20 kg. of a 2:1 mixture, by volume, of moist sandy loam topsoil and moss peat. The liners were sealed and the soil medium was fumigated for 3 days with methyl bromide at a rate of 2 g. per kg. of mixture. Inoculum, consisting of 55 g. of fresh mycorrhizal slash pine roots, was mixed with the top 5 cm. of soil in each of 12 boxes 3 weeks after fumigation. On the same day all boxes were individually covered with polyethylene sheets and 36 two-week-old slash pine seedlings were planted through the cover into each box. This stocking corresponded to 590 seedlings per m^2 (55 per $ft.^2$), or 2 seedlings per liter of soil. Seeds for the experiment had been surface sterilized by submergence in a 1-percent sodium hypochlorite solution and were germinated on sterile sand in covered trays.

The chamber was programmed to simulate the seasons and to "harden" the planting stock:

Elapsed time (months)	Day-night temperatures (degrees C.)	Day length (hours)	Watering schedule (area-cm./wk.)
0-2½	24/21	16	1.7
2½-7	32/21	16	2.8
7-8	32/21	16	9.0
8-8½	24/16	12	3.3
8½-9½	16/4	8	3.3

Fluorescent lights only were used at first, but the chamber's incandescent lights were programmed into the schedule when the plants were about 2½ months old.

Uninoculated seedlings were slow to develop secondary needles. An inventory in the fifth month, for example, showed that only 5 percent of them had any fascicled needles as against 75 percent for inoculated plants. Uninoculated plants produced few additional secondary needles during ensuing 2 weeks and by then had lost substantial numbers of lower primary needles (fig. 1, above). Fertilization seemed necessary if these seedlings were to develop into acceptable stock for an outplanting experiment. At 6 months of



'igure 1. Above: *Typical 6-month-old inoculated (right) and uninoculated (left) seedlings before fertilizer was applied.* Below: *Seedlings at lifting time.*

ıge, therefore, all seedlings were fertilized at rates equivalent to 56 kg. per ha. (50 pounds per acre) each of N, P_2O_5, and K_2O. The ertilizer stimulated secondary needle development, especially of ıninoculated seedlings.

One month later, the amount and frequency of watering were ntensified to further promote growth. All seedlings responded by aining 5 to 10 cm. in height during the next month, which was con- iderably more than they had grown during any earlier period of omparable length. The amount of water supplied to the trees was educed by nearly 2/3 when hardening was started at the end of 8 nonths.

Thirty 9½-month-old seedlings having stiff woody stems and ıscicled needles were selected from each of the 24 boxes. The plants vere divided at random into three groups: 20 were selected for ıtplanting, 5 were chosen for potting to determine their ability to row new roots, and 5 were selected for chemical analysis. Roots of ıe seedlings to be planted (in the field or pots) were trimmed to 20 cm. in length. The samples for chemical analysis were rinsed to remove adhering soil from roots and frozen immediately.

In the growth chamber, boxes had been assigned to inoculation treatments in a randomized block design. This design was continued in other phases of the study.

Outplanting was on a Bowie very fine sandy loam in central Louisiana on March 13, 1966. The site was open and supported native grasses, a slash pine plantation having been clearcut several years before. Survival was measured in June and December. Heights were recorded at planting and at the end of the season.

Ability to produce new roots was measured on seedlings grown in perlite in a greenhouse. Nutrients were supplied by irrigating pots to saturation at 1- to 2-day intervals with Hoagland's solution (Hoagland and Arnon 1950) and flushing them weekly to prevent salt accumulation. After 30 days, intact root systems were inspected under 3 diopters' magnification for number and total length of new roots 1.3 cm. or greater in length, and for number of old and new bifurcate roots.

Seedlings for chemical analyses were stored at —18°C. Immediately upon removal from storage, they were separated into roots and tops and freeze-dried for 24 hours. Any moisture that remained was removed by drying samples for an additional 4 hours at 70°C. Stems were separated from needles and buds and plant parts were weighed and ground to pass a 20-mesh screen. Stem samples usually contained too little material for complete carbohydrate and mineral analysis.

Nitrogen in roots and needles (including buds) was determined from 0.5 g. samples by the Kjeldahl method (Jackson 1958). Other mineral constituents were extracted by dry-ashing 1.0 g. samples for 2 hours at 450°C. and dissolving the ash in 100 ml. of 0.3 N HNO_3. Phosphorus in these extracts was determined by the vanadomolybdophosphoric yellow method (Jackson 1958) and metallic ions (Ca, Mg, K, Na, and Mn,) by atomic absorption spectrophotometry.

Carbohydrates were extracted sequentially from 1.0 g. samples of the tissues. Eighty percent ethanol soluble carbohydrates were extracted first by boiling samples in 50 ml. of solution for 5 minutes and then homogenizing the suspension in a high-speed blender for 5 minutes. Samples were centrifuged and supernatants decanted and saved. Residues were resuspended and recentrifuged, and the second supernatants added to the first. Extracts were made to volume and clarified with activated charcoal. Residues were boiled for 1 hour in 75 ml. of 0.2 N H_2SO_4 to hydrolize starch that remained (Smith, Paulsen, and Raguse 1964). Suspensions were cooled, neutralized, filtered, and made to volume.

Reducing sugars in the ethanol and hydrolyzed-starch extracts were determined by a modified Somogyi method (Nelson 1944). Total ethanol-soluble carbohydrates were determined by the phenol-sulfuric acid method of Nalewaja and Smith (1963); sucrose served as a standard in this test.

The 30 measured characteristics were evaluated by analyses of variance. Correlations were then computed betwen characteristics which analysis of variance had shown to be significantly (0.05 level) affected by treatments.

Results and Discussions

At lifting, seedlings were small morphological grade 2 stock (Wakeley 1954, p. 103). Both inoculated and uninoculated plants were well supplied with secondary needles (fig. 1, below), the earlier differences having been overcome by fertilization. The slower development of secondary needles on uninoculated seedlings was not unlike the growth pattern of plantable nonmycorrhizal seedlings from nursery soils of low fertility. Shortness of the seedlings was attributed mostly to the stringent watering schedule imposed during the first 7 months, although low soil fertility probably contributed.

Ninety-five percent of inoculated and 75 percent of uninoculated seedlings had one or more bifurcate roots on the portion of the root system that remained after pruning (table 1). But the branched short roots were four times as numerous on inoculated as on uninoculated plants. Root systems of the two classes of stock were similar in form, color, branching patterns of long roots, and location of bifurcate roots.

Concentrations of minerals, especially nitrogen and phosphorus, in both needles and roots (table 2) were lower than generally reported for pine seedlings (see, for example, May et al. 1962, McComb 1938, Pritchett 1968, Laiho 1967, Brendemuehl 1968, Leaf 1968, Wells 1968). Foliage at lifting, however, showed none of the common visual symptoms of nutrient deficiencies.

Inoculation significantly altered several physical (table 1) and chemical (table 2) properties of the stock. Moreover, it increased field survival by about 1/3 and produced a fivefold increase in the number of bifurcate roots that developed during 30 days in the greenhouse. Because of the apparent contamination of uninoculated stock, this paper emphasizes relationships between survival and physical and chemical properties of the planting stock and their significance, rather than interpretation of differences between inoculated and uninoculated plants.

Table 1. *Physical characteristics of 9½-month-old slash pine seedlings an[illegible] performance of the planting stock in greenhouse and field tes[illegible]*

Seedling characteristic or performance	Units	Inoculated	Uninoculated
Physical properties at lifting			
Top dry weight per plant	g.	2.11	2.06
Root dry weight per plant [1]	g.	.97	.68
Stem length	cm.	11.0	13.1*
Plants with bifurcate roots [2]	pct.	95	75*
Bifurcate roots per plant [2]	No.	16.0	4.2*
Performance in greenhouse			
Plants producing new long roots [3]	pct.	70	58
New long roots per plant	No.	16.8	15.2
Total length of new long roots	cm.	46.2	39.4
New bifurcate roots per plant	No.	20.3	4.0*
Performance in outplanting			
Initial survival	pct.	90	62*
First-year survival	pct.	83	56*
First-year height	cm.	18.2	20.1*

[1] Of intact roots.

[2] On root systems pruned to average length of 20 cm.

[3] Roots 1.3 cm. or greater in length at 30 days.

* Significant at 0.05 level.

Table 2.—*Carbohydrate and mineral nutrient status of needles and roots [illegible] seedlings at lifting*

Chemical constitutents	Units	Needles		Roots	
		Inoculated	Uninoculated	Inoculated	Uninoculated
Carbohydrates					
Total 80% ETOH soluble	pct.	11.8	11.3	10.1	11.4
Reducing sugars	pct.	7.7	8.0	6.2	8.2
Soluble only in 0.2 N H_2SO_4	pct.	4.6	4.1*	4.8	4.6
Minerals					
Nitrogen	pct.	.69	.96*	.53	.6[illegible]
Phosphorus	pct.	.105	.098	.094	.0[illegible]
Calcium	pct.	.31	.30	.20	.2[illegible]
Magnesium	pct.	.105	.106	.063	.0[illegible]
Potassium	pct.	.61	.64*	.50	.4[illegible]
Sodium	pct.	.025	.025	.064	.0[illegible]
Manganese	pct.	.036	.038	.018	.0[illegible]
N/P ratio	...	6.6	9.9*	5.7	10.4

* Significant at 0.05 level.

Laiho (1967) found that nonmycorrhizal Scotch pine seedlings that lived became infected within 1 to 2 months after being planted in soils containing the requisite fungi. Jorgensen and Shoulders (1967) reported that "visible mycorrhizae" had a greater impact on initial than on first-year survival. The relationships reported below, therefore, are usually those between initial survival and seedling characteristics. The basis of comparison was unimportant, since June and December survivals were extremely well correlated (r = 0.95) and were about equally related to other properties of the seedlings.

Initial survival was positively and significantly correlated with the proportion of seedlings with bifurcate roots at lifting (r = 0.57), with the average number of bifurcate roots per plant (r = 0.66), and with the number of new bifurcate roots produced per plant in the greenhouse test (r = 0.57). The three expressions of mycorrhizal infection were also significantly and positively correlated.

Bifurcate or dichotomously branched short roots are not irrefutable evidence of mycorrhizal infection, nor is their absence concrete proof that roots are not infected (Trappe 1967, Slankis 1967, Harley 1969). But together with the higher concentrations and greater total amounts of phosphorus in roots of inoculated seedlings these properties of the stock strongly support the conclusion that most plants were indeed infected, that inoculation markedly increased the intensity of infection, and that survival was thereby enhanced. In the years since Hatch (1937) observed that mycorrhizal seedlings contained higher proportions of phosphorus, nitrogen, and potassium than nonmycorrhizal seedlings and McComb (1938) concluded that phosphorus uptake especially was promoted by infection, researchers too numerous to cite here have confirmed that mycorrhizae increase phosphorus concentration in the host.

The mineral nutrient property most closely associated with initial survival was N/P ratio of needles (r = —0.66). It was followed in descending order of correlation by nitrogen in needles (r = —0.65), N/P ratio in roots (r = —0.47), and manganese in roots (r = 0.50), calcium in roots (r = — 0.47), and manganese in roots (r = —0.44). No other mineral constituents were significantly correlated with either initial or first-year survival (a correlation coefficient greater than 0.40 was required for significance at 0.05 level).

The N/P ratios of needles and roots were closely related (r = 0.94). These ratios were the only chemical characteristics of both roots and needles that were significantly correlated with initial survival, and they displayed about equally strong correlations with abundance of bifurcate roots at lifting and with ability of seedlings to produce new bifurcate roots. Moreover, both survival and physical evidence of mycorrhizal infection declined as N/P ratios increased.

Richards and Wilson (1963) and Richards (1965) observed an inverse relationship between nitrogen concentrations in roots and mycorrhizal infection of Caribbean *(P. caribaea* Mor.) and loblolly pine seedlings. In contrast to procedures following the study reported here, they produced a range in nitrogen contents by fertilizing the seedlings at different rates. Slankis (1967) was able to induce renewed growth of mycorrhizae on roots of eastern white pine *(P. strobus* L.) by increasing nitrogen level in the nutrient solution. Henderson (1968) reported that mycorrhizae had no direct effect on nitrogen uptake of Norway spruce *(Picea abies* (L.) Karst.) and Monterey pine *(P. radiata* D. Don) seedlings, but suggested that greater phosphorus uptake by seedlings, due to high rates of phosphorus fertilization, promoted more rapid development of mycorrhizae. Moreover, Trappe and Strand (1969) found that inoculation of Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) seedlings in nursery beds increased foliar content of phosphorus but had no significant effect on foliar nitrogen. None of these authors suggested that N/P ratios *per se* may influence infection or that these ratios may be influenced by the mycorrhizae. Henderson's (1968), Richards and Wilson's (1963), Richards, (1965), and Slankis' (1967) results are compatible with the former hypothesis, however, and Trappe and Strand's (1969) with the latter. Shemakhanova (1967) believed that ratios between nitrogen and phosphorus in the soil, as well as the absolute amounts of the two elements, were important to mycorrhiza formation.

Other authors (Hatch 1937, Harley 1969, Meyer 1962) have postulated that the fungal symbiont is involved in selective uptake and transfer to the host of mineral nutrients. Moreover, some evidence exists that the fungi are able to tap nutrient reservoirs not ordinarily available to higher plants (Rosendahl 1942, Ritter and Lyr 1963, Henderson 1968).

It may be argued that needles and perhaps roots of uninoculated seedlings were younger and therefore should contain higher concentrations of nitrogen and have larger N/P ratios than inoculated seedlings. Even if this is so, the differential development of tissues was a consequence of the treatments, similar to what might develop between mycorrhizal and nonmycorrhizal seedlings in the nursery, and must enter into any evaluation of the impact of inoculation on seedling characteristics and performance.

Of the carbohydrate fractions, only starch in needles was significantly correlated with initial survival ($r = 0.45$). Reducing sugars in roots were significantly correlated with first-year ($r =$

—0.41) but not with initial survival (r = —0.39) or with any of the visible symptoms of mycorrhizal infection. The evidence presented in table 2 that concentrations of more readily metabolizable carbohydrates were lower in inoculated than in uninoculated seedlings is compatible with theory advanced by many workers (Harley 1969) that mycorrhiza-forming fungi utilize simpler carbohydrates and depend on the host to supply them, but neither these data nor the correlation analyses support Björkman's (1942, 1970) theory that infection depends on high concentrations of reducing substances in roots. Of course, seedlings were infected for several months before they were lifted if infection occurred a few weeks after germination as is usual (Henderson 1968, Harley 1969). Thus, it is possible that carbohydrate concentrations were higher at the time of infection and were depleted later.

In general, then, the results suggest that mycorrhizae either were themselves responsible for the higher survival of inoculated seedlings or influenced survival by modifying chemical composition of the planting stock, especially N/P ratios in roots and needles. Abundance of bifurcate roots on nursery stock appears to be a useful index of outplanting survival.

What nurserymen can do to ensure mycorrhizal development is uncertain, but published studies have suggested some possibilities. Inoculum apparently is present in southern nursery soils, even in the first year after fumigation with methyl bromide (Shoulders, Hollis, Merrifield, and others, 1965). Hacskaylo and Snow (1959) showed that mycorrhizal roots are most abundant on loblolly pine seedlings grown in full sunlight if the nutrient supply is sufficient for adequate but not lush root growth. These authors concluded that fast-growing roots are less apt to be infected than slow-growing ones. They noted, however, that extremely low nutrient levels limited growth of both fungi and roots. These conclusions are supported by the work of Hatch (1937) Björkman (1942) and Slankis (1967). Thus, seedlings should probably be grown at a uniform spacing in low-density beds that are fertilized at moderate rates.

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Seedlings grown in fumigated soil inoculated with root segments from mycorrhizal nursery stock had four times as many bifurcate roots at lifting as uninoculated seedlings, and survived considerably better when outplanted. Initial field survival was most closely correlated with number of bifurcate roots at lifting and with nitrogen and phosphorus content of the plants.

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GROWTH PATTERNS OF DEER-BROWSE PLANTS IN SOUTHERN FORESTS

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Forest Service
U. S. Department of Agriculture

GROWTH-PATTERNS OF DEER-BROWSE PLANTS IN SOUTHERN FORESTS

L. K. Halls and R. Alcaniz [1]

Among plants of 16 browse species growing in an open field and beneath a stand of pines in east Texas, twig elongation began earliest in years when mean March temperatures were high. Growth on plants of six species began a few days earlier in the woods than in the open.

Tree overstory significantly affected growth cessation in only three species. Rainfall variations did not affect beginning date of growth, but twigs ceased growth earlier in a very dry year than in other years.

The combination of the species studied that would furnish succulent green forage earliest in the spring and extend growth latest in the fall includes yellow jessamine, Alabama supplejack, yaupon, rusty blackhaw, and flowering dogwood.

This report describes seasonal growth patterns of 16 southern browse species as influenced by temperature, rainfall, and pine-tree overstory. The effects of environment on growth rate are important because, in general, rapidly growing and recently formed plant tissues are more palatable and nutritious for deer than slow-growing or old tissues (Blair and Epps 1969; Short and Blair 1971). Game managers can alter overstory density and the species composition of the understory to increase the quantity or improve the seasonal distribution of palatable tissue available to deer.

The species observed are common in forests throughout the South. The forage and fruit they produce are eaten by white-tailed deer (*Odocoileus virginianus* L.), for which most of the species are considered medium to choice food (Goodrum and Reid 1959; Lay 1967).

Preliminary results of the studies described here were reported by Halls and Alcaniz (1965). Similar information has been reported for the common trees of eastern forests (Bonck and Penfound 1944; Cook 1941; Farnsworth 1955; Jacobs 1965; Kozlowski and Ward 1961; Kozlowski and Clausen 1966), and for some browse plants in the West (Bedell and Heady 1959; Costello and Price 1939; Watkins and de Forest 1941).

SPECIES

Alabama supplejack *(Berchemia scandens* (Hill) K. Koch) is a high-climbing deciduous vine. It occurs on all except very sandy soils, but prefers moist to wet sites. It tolerates shade and thrives even under fully stocked timber stands. Through spring and fall the leaves and succulent stems within reach are readily eaten by deer, but the vines rapidly twine upward about the trunks and crowns of trees and shrubs and much of the foliage is unavailable. The fruit, a blue drupe, is eaten by many kinds of wildlife, including deer, wild turkey, and bobwhite quail.

American beautyberry *(Callicarpa americana* L.) is a shade-tolerant deciduous shrub. Though its leaves may wilt during droughts, it can persist on very dry sites. The twigs and leaves are eaten by deer and cattle during the growing season and occasionally in early winter. The berrylike fruit is relished by deer. It is eaten by many mammals and birds and is considered an important quail food from August to November. Plants bear fruit at a very early age.

Common trumpetcreeper *(Campsis radicans* (L.) Seem.) is a deciduous woody vine that often forms dense thickets in old fields and forest openings. It survives but does not flourish under fully stocked timber stands. It grows on almost any soil but is most common on those of heavier texture in bottom lands. It is made conspicuous by its bright orange funnel-shaped flowers in summer and the large seed

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pods in the fall. The foliage is eaten by deer in spring and summer.

Flowering dogwood *(Cornus florida* L.) is a deciduous understory tree. It grows on a wide variety of soils but does best in longleaf pine stands and on the moist rich loams along stream bottoms and on northern slopes. The showy white flowers of spring and the bright red fruits and red and yellow leaves of autumn make this species an attractive ornamental in yards and a showpiece in the woods. Larger trees bring a good price because the strong, shock-resistant wood enjoys a continuing market for shuttleblocks, mallet heads, and similar woodenware. Virtually all game species and many songbirds eat dogwood fruit, which ripens in early fall and lasts through much of the winter. The fruit is a special favorite of wild turkeys, squirrels, and white-tailed deer. Leaves and twigs are also a source of food for deer. Even in winter, twigs and fallen leaves may be eaten.

Swamp cyrilla *(Cyrilla racemiflora* L.), an evergreen shrub, is a principal component of titi swamps and thickets and it also forms dense borders along streams and ponds. Whorls of racemes with white-petaled flowers form in the spring at the tip of the previous season's twig. Cyrilla is a preferred browse plant for deer. In thickets, it also provides escape cover for wildlife. Cattle graze new growth of leaves and twigs in spring and consume leaves sparingly through the fall and winter.

Brook euonymus *(Euonymus americanus* L.) is a shade-tolerant shrub that grows in rich, moist soil in the woods. Although widely distributed it usually is not abundant. Its leaves are persistent in the southern part of its range. In fall its pinkish capsules open to expose conspicuous orange-red seeds. The leaves and stems are highly preferred by deer.

Carolina jessamine *(Gelsemium sempervirens* (L.) Ait. f.) is an evergreen vine. It is well distributed throughout forested areas, forming broad interlacing carpets on moist to dry sites and on a variety of soils. It grows best in wooded stream bottoms. Jessamine is eaten yearlong by deer but is taken most readily in late fall and winter when other green feed is scarce. Because plants often climb 20 feet or higher in trees, much of the forage is unavailable to deer on forested sites. All parts of the plant contain alkaloids that are poisonous to livestock and humans, but the plant is apparently not harmful to deer when it is only a part of the diet.

Yaupon *(Ilex vomitoria* Ait.) is an evergreen shrub. It inhabits a variety of sites but is usually most abundant on moist sandy soils. Yaupon grows well beneath trees but best in the open. Yaupon provides fruit for deer, turkey, quail, raccoon, and many songbirds. For deer, yaupon leaves are a reliable source of green forage in late winter and of special significance because they contain sufficient protein for deer maintenance. Yaupon is also grazed by cattle in winter but it is considered a weed species in central Texas because it competes with forage grasses for moisture. It offers little hindrance to tree growth, and is not considered a pest in forest management. Summer burns or a series of hot winter fires will kill yaupon. However, infrequent winter fires of moderate intensity may serve a useful purpose in keeping the new growth near the ground and available to deer. The species withstands heavy grazing.

Sweetbay magnolia *(Magnolia virginiana* L.) is an evergreen, swamp-loving shrub or tree. It grows on acid sandy soils that are poorly drained or often flooded and in alkaline soils of ravines and hammocks. Sweetbay tolerates shade but does best in full sunlight. The leaves and twigs are browsed all year. Utilization by deer is generally moderate. Cattle compete strongly for sweetbay in winter. Songbirds, gray squirrels, and other small mammals eat the seeds. The persistent leaves, fragrant white flowers, and decorative fruit make sweetbay attractive to gardeners.

Red mulberry *(Morus rubra* L.) is a small to medium-sized deciduous tree commonly found on relatively moist sites. It is a minor component of both hardwood and coniferous stands but is more noticeable as a lone tree near streams and other moist sites. All manner of bird life feed profusely on mulberry fruit while it is available for a 2- to 3-week period in the spring. The fruits are also palatable to squirrels and man. Mulberry browse is rated as moderately attractive deer food during spring and summer. Sprouts following a fire are especially palatable but within a few years most growth is beyond reach of deer.

Blackgum *(Nyssa sylvatica* Marsh.) is adapted to a wide variety of sites—from the creek bottoms of the Southern Coastal Plain to altitudes of 3,000 feet. It will tolerate brief spring flooding on alluvial sites and is common on relatively dry upper and middle slopes in the mountains. It is usually found in mixture with other species. It rarely obtains dominance in its age group but is in the intermediate crown class on most sites. The leaves and twigs of blackgum are eaten by cattle and deer through the spring and summer. After a fire the numerous young shoots emerging from the tree base are especially palatable. The fruits are a source of food for deer, small mammals, upland birds, and waterfowl.

Sassafras *(Sassafras albidum* (Nutt.) Nees) grows in open woods on moist well-drained sandy loam soils. It is a pioneer species on abandoned fields and on dry ridges and upper slopes, especially after fire. Sassafras is intolerant and reproduction is sparse and erratic except by sprouting. In forest stands it usually occurs as individual trees or in small groups and is usually in the dominant overstory. If it becomes overtopped in mixed stands it is one of the first species to die. Deer browse the leaves and succulent growth during the spring and summer and the twigs lightly during the winter. Sprouts following a burn are especially palatable to deer. The fruit is eaten by songbirds, wild turkey, bobwhite quail, and many small mammals such as raccoons and squirrels.

Saw greenbrier *(Smilax bona-nox* L.) and common greenbrier *(S. rotundifolia* L.) are thorny, woody vines that grow in thickets, woodlands, roadsides, and fields on a wide variety of soils and moisture conditions throughout the South. Common greenbrier is especially abundant in low, damp flatwoods, where it may overburden young trees. The fast-growing green canes and tender shoots are very palatable and the tardily deciduous leaves are eaten yearlong by deer. The plants can withstand heavy use. The fruits are eaten by many species of upland game birds, songbirds, and small mammals. The tangled vines provide good protective cover for rabbits and other small wildlife.

Rusty blackhaw *(Viburnum rufidulum* Raf.) is a deciduous understory shrub or small tree. It grows on a variety of sites ranging from river bottom to dry upland. Deer eat the leaves and twigs in the spring. The fruit is eaten by many kinds of birds and mammals.

Muscadine grape *(Vitis rotundifolia* Michx.) is a deciduous, strong-climbing vine that grows freely in brushy thickets, fence rows, low grounds, and borders as well as trees. Deer browse the vines in spring and summer and may consume fallen leaves in winter. Fruits mature in September and October, promptly falling but remaining edible for a short period to wild turkey, bobwhite quail, ground-feeding mammals, and many songbirds. The dense foliage provides good escape and shelter cover and nesting sites for songbirds.

PROCEDURES

Growth patterns were observed near Nacogdoches, Texas, in a stand of shortleaf and loblolly pines *(Pinus echinata* Mill., *P. taeda* L.) mixed with hardwoods, and in a nearby open field that had been abandoned for several years. In early 1963, 1-year-old locally grown seedlings of the 16 browse species were planted beneath a sawtimber-size stand of pines recently thinned to a basal area of 70 square feet per acre. Nine plants of each species were equally spaced within each of four contiguous ¼-acre blocks. Vegetation other than pines was either cut or killed with chemicals before the browse plants were set out.

The same planting schedule and arrangement were carried through in the field, where there were no trees. The vegetation between browse plants was mowed.

Soils at the two locations are Ruston and Magnolia fine sandy loams. They are deep, well-drained upland soils with a rapid infiltration and medium percolation rate. They have a medium amount of organic matter and natural plant nutrients, and are acid in reaction. The water table is deep and storage capacity high. The soils usually support a rapidly growing stand of pine and hardwood trees with a mixed and often dense understory of vines, shrubs, and small trees.

From February 1964 through December 1968, the beginning and ending dates of twig elongation were recorded on 12 open-grown and 12 forest-grown plants of each of 12 species (that is, three plants of each species in each of the four blocks at the two planting sites). Some plants of a few species died.

In late winter the plants were checked at least three times during the week for beginning date of growth. Two lateral branches were randomly selected and tagged with a small ribbon each February for growth measurements. Recordings of twig length and numbers were then made at 2-week intervals until the end of June, and at 4-week intervals thereafter through December for all twigs that formed above a marked reference point. The date at which twig elongation terminated was recorded, but since twigs were measured only at scheduled dates through the year, the actual time of growth termination occurred during the measurement interval prior to the recorded date. For four species, twig elongation was not recorded until growth began in 1965.

Temperatures were continuously recorded by hygrothermographs at both study locations, and the daily rainfall by a standard rain gage at a station less than ½ mile from the study site.

WEATHER RECORDS

Temperature

For the 5-year period the average of maximum monthly temperatures was 77.9°F. in the open and 75.8°F. in the woods. Occasionally, however, the recorded temperature in the woods was highest. The widest differences were in the falls of 1966 and 1968, when temperatures in the open were 4°F. to 8°F. above those in the woods. The highest maximum temperature, 94.3°F., was in August.

The average daily minimum temperature was 52.7°F. in the woods and 52.3°F. in the open, but the temperature relations were not always consistent between locations. The lowest mean minimum temperatures were in February, 33.2°F.

In comparison to longtime Weather Bureau temperature records at nearby Nacogdoches, the following winter and early spring months were several degrees colder than normal: January in 1964 and 1966, February in all years of the study, and March in 1965. Spring and summer months hotter than average were August 1964, April 1965, and March and April 1967. Summer months cooler than normal were July and August of 1968.

The dates of the last freeze in the spring varied from March 9 in 1967 to April 5 in 1966, and the first freeze in fall from October 19 in 1967 to November 11 in 1968. The length of the frost-free season ranged from 208 days in 1964 to 235 days in 1968.

Rainfall

There was a wide variation in annual and in seasonal rainfall during the 5 years (table 1). In 1964 and 1965 winter and spring rainfall

Table 1.—*Monthly rainfall at Stephen F. Austin Experimental Forest, 1964-1968*

Month	1964	1965	1966	1967	1968	65-year average [1]
			Inches			
January	3.27	3.77	6.10	0.83	7.40	3.81
February	2.02	4.45	3.20	3.56	3.05	3.72
March	4.07	2.70	2.40	2.16	2.59	4.10
April	8.18	1.25	8.42	3.23	9.08	4.94
May	.89	7.76	5.16	5.52	7.94	5.22
June	4.16	2.88	1.48	2.41	9.63	3.42
July	.50	1.11	.48	3.23	3.45	3.98
August	3.44	2.18	7.51	2.31	1.44	2.39
September	3.21	3.88	4.65	.79	9.06	2.74
October	1.86	.55	2.58	1.78	1.64	2.90
November	3.71	3.40	.59	.95	6.98	4.13
December	3.30	7.70	3.62	5.25	3.75	4.88
Total	38.61	41.63	46.19	32.02	66.01	46.23

[1] From Weather Bureau records at Nacogdoches, approximately 12 miles from study area.

was slightly below average, and July was very dry. The 6-week summer drought in 1964 was broken by 6 inches of rain between August 17 and September 17. In 1965, the drought began in early July and continued until September 21. In 1966, the total rainfall was very close to the 65-year average but it varied considerably seasonally, being above average through May, much below in June and July, and high again in late summer and early fall. The total rainfall in 1967 was 14 inches below average and soil moisture was scarce from June through November. In contrast, rainfall in 1968 was 20 inches above average; the buildups of moisture in spring and again in September counteracted slight deficiencies in late summer and fall and there were no prolonged dry spells of any consequence.

BEGINNING AND ENDING DATES OF TWIG ELONGATION

The species beginning growth earliest in the ear (March 18-19) were Alabama supplejack, Carolina jessamine, and rusty blackhaw. Thus, hese species furnish green forage at a time vhen succulent forage is scarce and when deer nust have nutritious food.

Differences in beginning dates of twig elonation between locations were inconsistent aong species (table 2). For common trumpetreeper, brook euonymus, Carolina jessamine, ed mulberry, common greenbrier, and muscaine grape the beginning date of growth was gnificantly earlier (3 to 6 days) in the woods han in the open. The growth differences were ot related to temperature differences between cations. Where these species are a major comonent of the habitat, deer would benefit by aving access to the earlier green forage of oods-grown plants.

The open versus woods difference was not atistically significant for rusty blackhaw, sassfras, blackgum, swamp cyrilla, or dogwood.

For Alabama supplejack, American beautyrry, yaupon, sweetbay magnolia, and saw eenbrier the difference between locations as significant during certain years, but it was t related to temperature differences.

Other studies have also shown that the effect overstory on beginning date of growth may t always be consistent. Collins (1961) showed that red maple *(Acer rubrum* L.) started growth in both old field and forest at about the same time, whereas Kozlowski (1964) noted that red maples in the open initiated height growth later than those in the forest.

Kozlowski (1964) also showed that there was an increasing delay in growth initiation with an increase in soil moisture content. Under the conditions of the present study, where the fine sandy loam soils were well drained, there was no relation between rainfall and bginning date of growth.

The beginning date of twig elongation varied significantly among years for all species and was closely related to March temperatures. In 1965 the mean monthly temperature for March was the lowest for any year of the study (51.5°F.), and the beginning date of growth was latest. Conversely, March of 1967 was the warmest March (63.7°F.) and the beginning date of growth was earliest. There was no apparent relationship between January or February temperatures and beginning date of growth. Nearly all plants had begun growth prior to the late freeze on April 5, 1966, and were not noticeably affected by it.

The recorded dates for maximum twig elongation varied widely among species (table 2). Muscadine grape plants beneath trees ceased growth earliest. On the average, flowering dogwood, yaupon, and Carolina jessamine plants grew later in summer and fall than plants of other species. Presence of the three late-growing species tends to extend the period when succulent green forage is available for deer.

There was a very wide range in growth termination from year to year among plants of the same species, exceeding 200 days for many species. The variation could not always be attributed to climatic conditions. Even within the same year some plants within a species grew several weeks later than other plants. For example, most plants of yaupon would form new shoots following a late summer rain, but occasionally one or two did not. Likewise, Kozlowski (1964) noted that in a specific area most trees stop growing over a considerable period of time.

Twig elongation ceased significantly later in the open than in the woods for Carolina jessamine and yaupon, the two evergreen, late-

Table 2.—*Beginning and ending dates of twig elongation for browse plants growing in the open and beneath pine trees*

Species and location	Beginning date of growth		Ending date of growth	
	Mean	Range	Mean	Range
Alabama supplejack				
(Berchemia scandens)				
Open	March 19	March 10-March 21	June 16 [1]	April 4-December 17
Woods	March 19	March 13-March 31	June 26	March 16-September 30
American beautyberry				
(Callicarpa americana)				
Open	April 4	March 26-April 11	August 3	May 27-December 17
Woods	April 3	March 28-April 11	August 7	May 14-December 22
Common trumpetcreeper				
(Campsis radicans)				
Open	April 6 [1]	March 21-April 14	August 19	May 28-November 11
Woods	April 2	March 16-April 14	August 18	May 14-October 22
Flowering dogwood				
(Cornus florida)				
Open	March 27	March 21-April 13	September 6	May 8-December 17
Woods	March 25	March 16-April 9	September 14	April 20-December 22
Swamp cyrilla				
(Cyrilla racemiflora)				
Open	March 31	March 21-April 21	August 10	May 14-November 22
Woods	April 1	March 21-April 28	July 29	April 20-December 22
Brook euonymus				
(Euonymus americanus)				
Open	March 27 [1]	March 21-April 7	July 10	April 15-December 17
Woods	March 23	March 16-April 2	July 17	April 12-December 22
Carolina jessamine				
(Gelsemium sempervirens)				
Open	March 22 [1]	March 13-March 31	August 28 [1]	March 27-December 17
Woods	March 19	March 8-March 29	August 19	April 3-December 22
Yaupon				
(Ilex vomitoria)				
Open	March 31	March 21-April 9	September 24 [1]	May 14-November 22
Woods	April 1	March 16-April 15	September 4	June 4-December 21
Sweetbay magnolia				
(Magnolia virginiana)				
Open	April 9	April 4-April 15	July 21	April 30-October 27
Woods	April 10	April 4-April 27	July 22	May 14-October 28
Red mulberry				
(Morus rubra)				
Open	April 4 [1]	March 16-April 19	July 9	April 10-October 27
Woods	March 30	March 16-April 15	July 11	April 20-September 30
Blackgum				
(Nyssa sylvatica)				
Open	April 4	March 23-April 23	August 20	April 30-December 17
Woods	April 2	March 21-May 6	August 7	April 12-December 22
Sassafras				
(Sassafras albidum)				
Open	March 31	March 21-April 13	July 23	May 8-October 27
Woods	March 30	March 21-April 13	July 18	April 12-October 28
Saw greenbrier				
(Smilax bona-nox)				
Open	March 31	March 16-April 9	July 20	April 10-November 9
Woods	March 29	March 16-April 9	June 24	April 12-December 22
Common greenbrier				
(Smilax rotundifolia)				
Open	April 6 [1]	March 21-April 15	July 11	April 10-November 11
Woods	April 1	March 16-April 21	July 6	March 27-December 22
Rusty blackhaw				
(Viburnum rufidulum)				
Open	March 19	March 13-April 5	July 18	April 3-October 27
Woods	March 18	March 16-April 5	July 21	April 5-December 22
Muscadine grape				
(Vitis rotundifolia)				
Open	March 31 [1]	March 21-April 11	June 20	April 30-September 11
Woods	March 25	March 13-April 9	June 8	April 12-September 30

[1] Indicates significant difference between open and woods at probability level of 0.05.

season growers. This result may be partly attributable to the higher maximum temperature in the open during the late summer and early fall. Alabama supplejack was the only species in which growth terminated significantly later in the woods. For other species the differences between open- and woods-grown plants were not statistically significant.

Cessation of twig growth was not closely related to temperature and rainfall except in 1967. During this year when rainfall was extremely light, twig elongation for most species ceased earlier than in other years. These findings agree with Kramer's (1943) observation that severe droughts or excessively high temperatures may check growth but that the usual variations in moisture and temperature have little effect.

TWIG LENGTH

The mean length of measured twigs was greatest for common trumpetcreeper and least for yaupon (table 3). The average twig length was longer in the open than in the woods for eleven species but because of wide variation in length among twigs on the same plant the difference was significant only for American beautyberry. The twig length on brook euonymus and Carolina jessamine, two of the more shade tolerant species, was significantly longer in the woods than in the open.

Table 3.—*Mean length of browse twigs*

Species	Open	Woods
	Inches per season	
Alabama supplejack	10.9	9.5
American beautyberry	31.1	[1] 18.9
Common trumpetcreeper	91.3	121.4
Flowering dogwood	13.3	10.7
Swamp cyrilla	16.3	12.6
Brook euonymus	10.5	[1] 16.5
Carolina jessamine	10.2	[1] 20.2
Yaupon	5.9	7.7
Sweetbay magnolia	14.3	11.7
Red mulberry	30.9	28.7
Blackgum	19.4	13.9
Sassafras	11.8	10.2
Saw greenbrier	14.5	18.3
Common greenbrier	14.1	10.0
Rusty blackhaw	11.2	9.4
Muscadine grape	25.5	20.5

[1] Indicates significant difference between open and woods at probability level of 0.05.

GROWTH RATE

Twig elongation was rapid for all species during the spring. For a few species there was an occasional spurt of growth in late summer.

Similarities in growth patterns suggested arbitrary groupings of species that (1) respond to late summer rains, (2) grow most rapidly in spring, (3) make moderate growth in spring, (4) show consistent rate of growth to early summer, (5) die back at an early age, and (6) show extreme dieback annually. The groupings are slightly different from those previously used by Halls and Alcaniz (1965) because of additional species and some variation in growth patterns between years.

Regrowth Following Summer Rain

Growth patterns of yaupon and Carolina jessamine were associated with summer rainfall (fig. 1). Yaupon growth was slow in early spring but accelerated during the usually moist period in late May and June. Thereafter, plants both in the open and in the woods grew mainly after summer rains. During the protracted droughts in the summers of 1964 and 1966 growth practically ceased. But following the soaking rains of late summer there was a new spurt of growth. Most of the late growth was by new twigs formed from lateral buds rather than a lengthening of previously formed twigs. In 1965 growth was practically nil during the summer, and the September rains came too late to cause formation of any new twigs. In 1967, a very dry year, over 80 percent of the growth had accumulated by mid-July. In the wet year of 1968 growth continued at a fairly constant rate to late August. It then slowed and did not resume a rapid rate after the heavy rains that began in September. Thus, there was a rapid spurt of late summer growth during the 2 years that soaking rains came in August, but the late spurt of growth failed to occur in the 2 years that summer rains did not come until September.

Carolina jessamine also formed new twigs after the August rains of 1964 and 1966, but, like yaupon, it did not respond to September rains in 1965 and 1968. Carolina jessamine always formed some new growth during the summer, even when rainfall was light. Some twigs usually died back during late fall, but

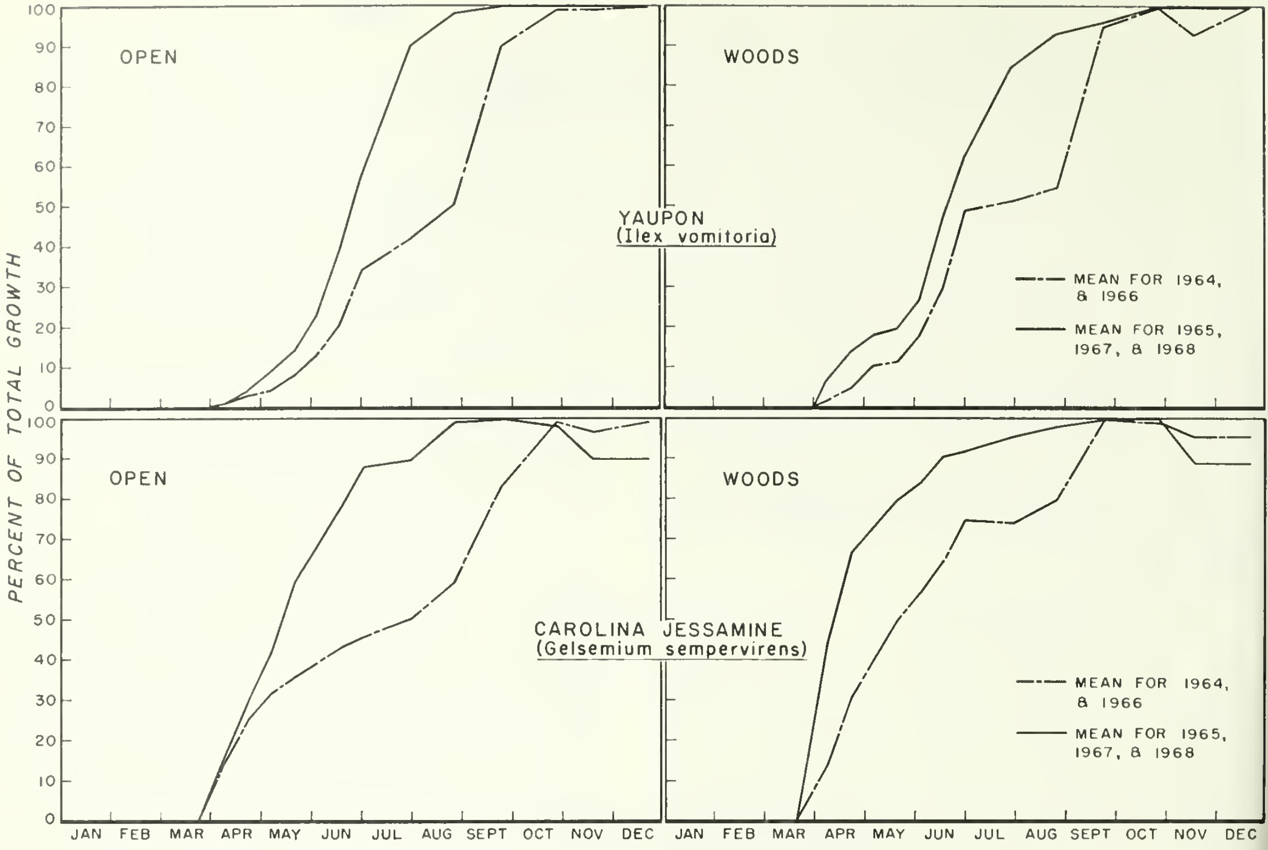

Figure 1.—*Browse plants that grew rapidly after summer rains.*

dieback was severe only in the extremely dry fall of 1967.

The secondary growth spurt of yaupon and Carolina jessamine increases their forage production potential during years when summer rainfall is above average. The intermittent and late-season growth shown by these species has also been noted for certain species of forest trees (Kozlowski 1963, 1964).

Rapid Spring Growers

The species making most rapid growth in early spring were brook euonymus, the greenbriers, rusty blackhaw, and red mulberry (fig. 2). They had one major spurt of growth that was usually 80 to 90 percent complete by April or early May. This relatively high proportion of the total annual growth was formed slightly earlier in the spring on plants in the woods than on those in the open.

The spring growth pattern of common greenbrier was consistent among years. Over 90 percent of growth occurred by May 1 for plants in the woods and by May 20 for plants in the open. Small variations in summer growth were unrelated to rainfall. During 1964 and 1967, the years of lowest rainfall, twig dieback occurred for plants in the open.

Saw greenbrier growth in the woods was usually 95 percent complete by May 5, but frequently some of the plants in the open would continue to form a few new twigs until October, regardless of the rainfall.

Brook euonymus completed over 95 percent of its growth by May 5, except in 1965 when the open-grown plants formed a few new twigs in late September. During the first few years of the study the euonymus plants in the open appeared to be vigorous and healthy, but by 1967 they had begun to deteriorate and several plants were dead by 1969. The species grows naturally in the shade along moist stream bottoms. Euonymus plants in the woods had a longer average twig length than those in the open and they appeared healthy throughout the study.

Rusty blackhaw growth was consistent between years for plants in the woods but in

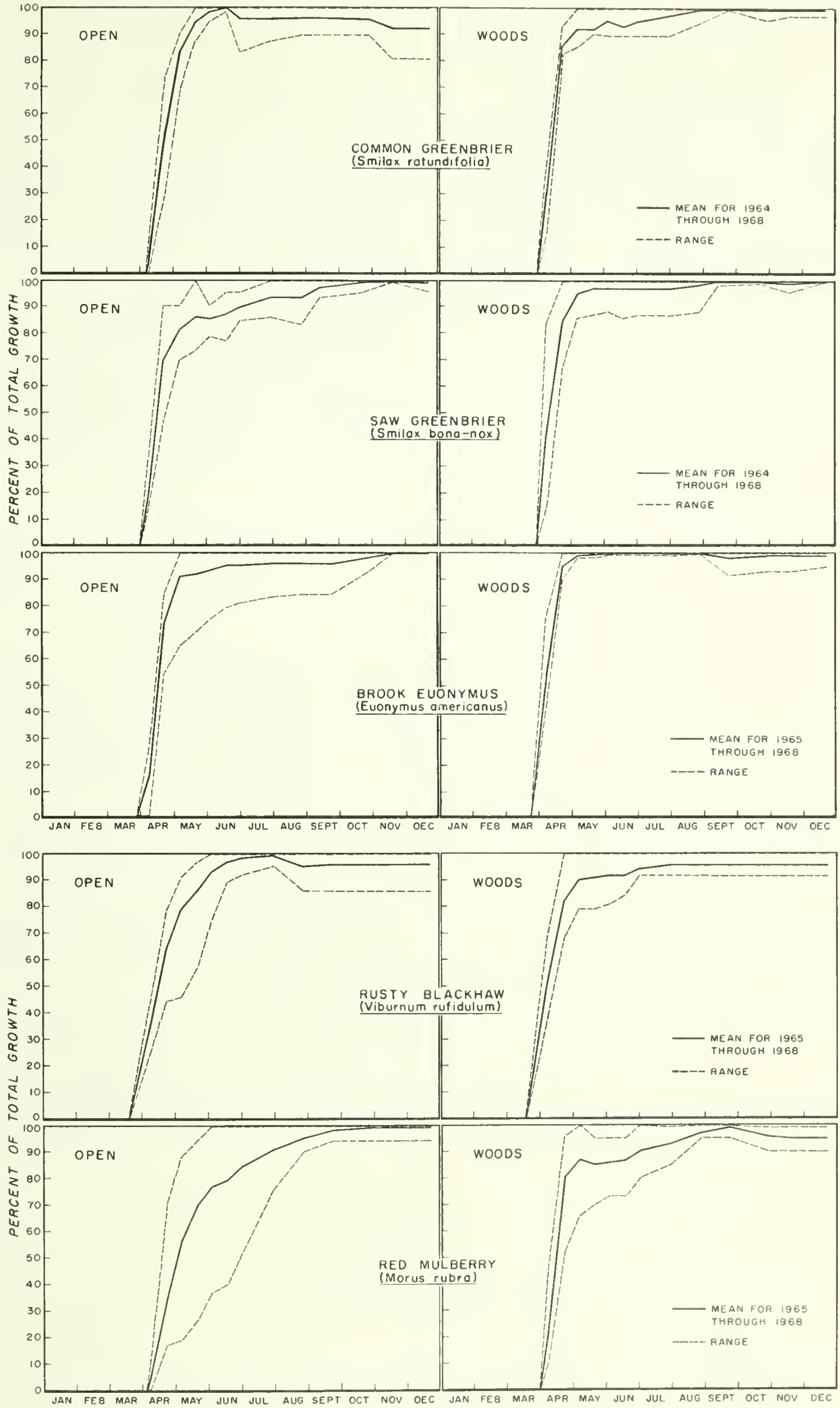

Figure 2.—*Browse plants that completed almost all growth in spring.*

1965 and 1967 the plants in the open accumulated about 25 percent of their total growth during June. This relatively rapid rate of growth was not associated with rainfall.

Red mulberry showed the most inconsistent spring growth pattern of any species in this group. Usually, however, 85 percent or more of the growth had accumulated by May 20. Main exceptions were for open-grown plants in 1965 when about 45 percent of total annual growth occurred in July and August, and for woods-grown plants in 1967 when about 25 percent of growth occurred in June and July even though rainfall was below average. Twig dieback, though of minor extent, was more frequent on plants in the woods than in the open.

In this group of species the shape of the growth curve appeared to be influenced more by internal genetic factors than by the environment, a phenomenon also noted by Kramer (1943) and Gilbert (1961). Because of the minimal amount of summer growth, the total forage production of these species is influenced little by summer rains. Too, since forage value is closely associated with growth (Short and Blair 1971), these species probably have high nutritive value for only a brief period each year.

Moderate Spring Growth Rate

Although similar in growth pattern to the previous group, sweetbay magnolia, Alabama supplejack, and muscadine grape tended to grow a little less rapidly in early spring, but continued to grow slightly later into the season (fig. 3).

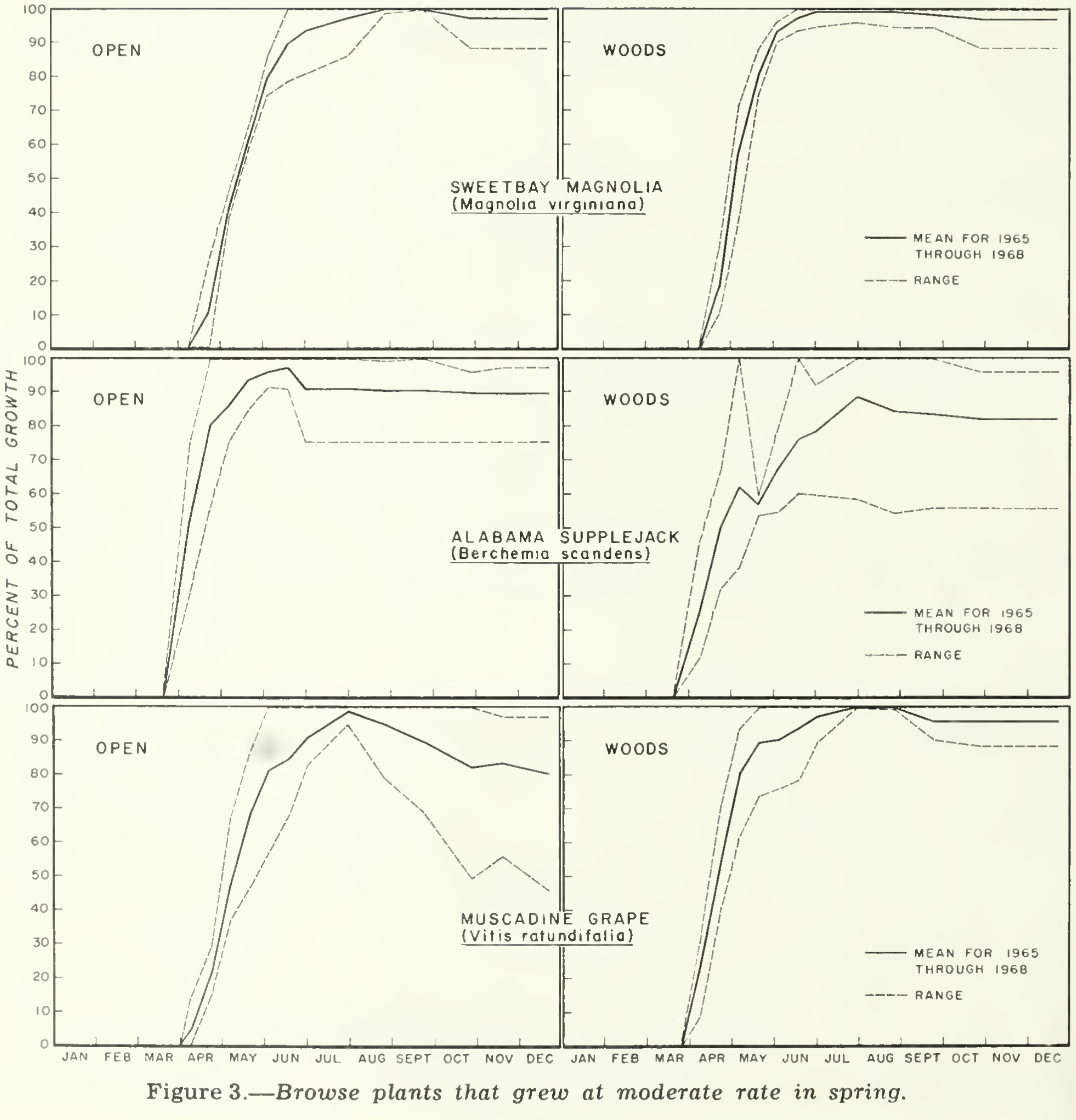

Figure 3.—*Browse plants that grew at moderate rate in spring.*

Sweetbay magnolia had the most consistent pattern among these three species. With the exception of open-grown plants in 1965, annual twig growth was more than 90 percent complete by June 30 on both sites.

Alabama supplejack growth varied considerably between years and sites. For example, in 1965 twig elongation in the woods was complete by May 6 but not in the open until fall. In 1967 maximum twig elongation occurred by May 8 for plants in the open but not until July 20 for plants in the woods. On the average, the major portion of annual growth occurred by June for plants in the open but not until July for plants in the woods. This is the only species where the relative growth rate of open-grown plants exceeded that for woods-grown plants in the spring.

The spring growth pattern of muscadine grape was fairly consistent among years. About 90 percent of the length had accumulated in the woods by May but not until July 1 in the open.

Occasionally, Alabama supplejack and muscadine grape twigs died back considerably, as previously noted by Halls and Alcaniz (1965). In some years this dieback constitutes a considerable loss of green forage.

Growth Rate Consistent To Early Summer

A group of species that showed a fairly constant rate of growth from early spring through June or July included flowering dogwood, swamp cyrilla, blackgum, and sassafras (fig.).

Growth patterns of dogwood were consistent between years and sites. Twig growth was only about 80 percent complete by July 1. Usually, plants continued to grow relatively slowly through July and August and occasionally to late September.

Swamp cyrilla had completed over 90 percent of its growth by July 1, except in 1964 and 1965 for plants growing in the open. Twig dieback was of consequence only in 1967 and was most severe for plants in the woods.

Sassafras grew at a constant rate to mid-June in the woods and to mid-August in the open. Twig dieback was rare, occurring in 1965 on one plant in the woods.

Blackgum growth usually continued through July but in some years the major portion had accumulated by June.

Growth patterns of these four species were noticeably influenced by rainfall only in 1967. During this very dry year summer growth of most plants was less than in other years. Thus, the total forage yields of these species are not likely to be greatly affected by summer rains except during extended droughts.

Dieback At An Early Age

American beautyberry growth patterns were similar to the above group of species, but in 1967 and 1968 severe dieback occurred on plants in the open (fig. 5). During the first few years in the field American beautyberry plants were very robust and produced an abundance of vegetative growth and fruit. In 1967 the dieback appeared to result from the severe drought, but dieback occurred again in 1968 even with an abundance of rainfall. Nearly all of the older stems were dead on most plants at the end of 1968, but on some plants new stems had sprouted from the base. There was no evidence of disease or insect damage.

American beautyberry plants in the woods were smaller than plants in the open, but those in the woods appeared healthy and did not suffer any twig dieback through 1968. The robust nature of open-grown American beautyberry plants up to 6 years of age confirms other observations that they grow best in the open (Halls and Oefinger 1969). However, the apparent longer life span of plants beneath the pines explains why beautyberry is less prevalent in the open.

Extreme Annual Dieback

The growth pattern for trumpetcreeper was erratic and distinct from other species because of the extreme dieback in late fall and winter (fig. 6). These plants usually continued to grow through the summer but the time of maximum elongation ranged from June to late October. Dieback of twigs began on many plants almost immediately after the twigs reached their maximum length. By winter most of the current season's growth was usually dead.

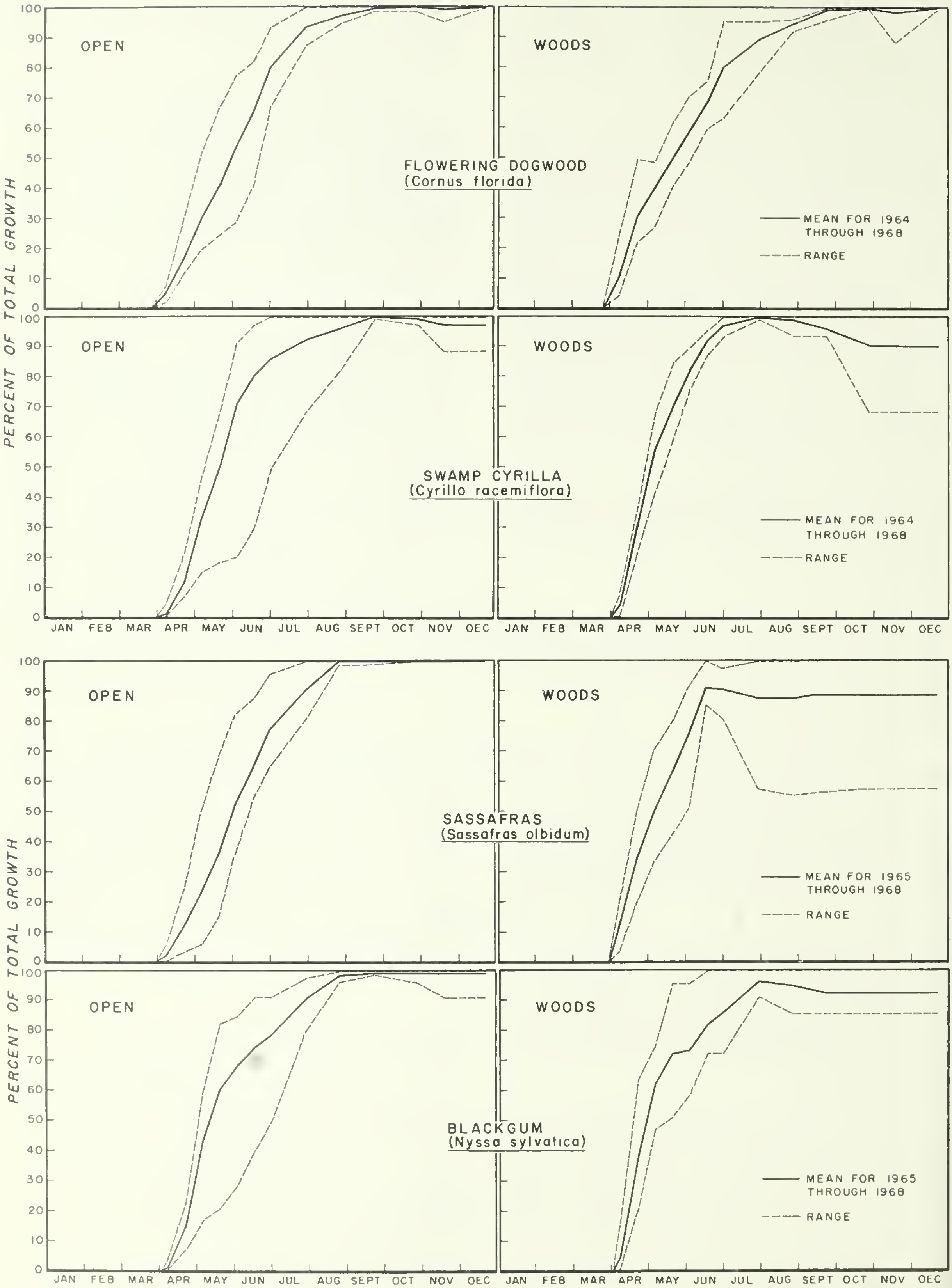

Figure 4.—*Browse plants that continued to grow until early summer.*

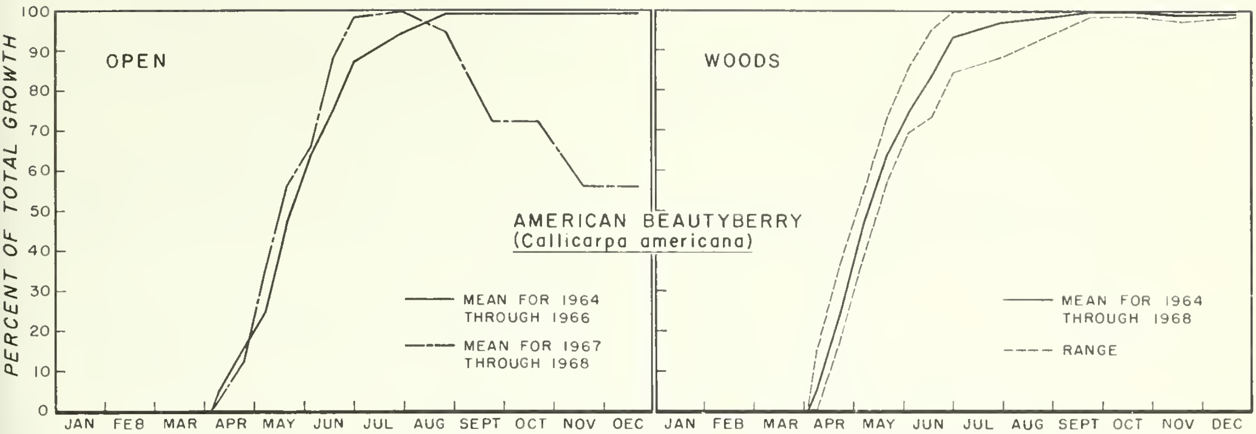

Figure 5.—*American beautyberry plants had severe dieback at early ages.*

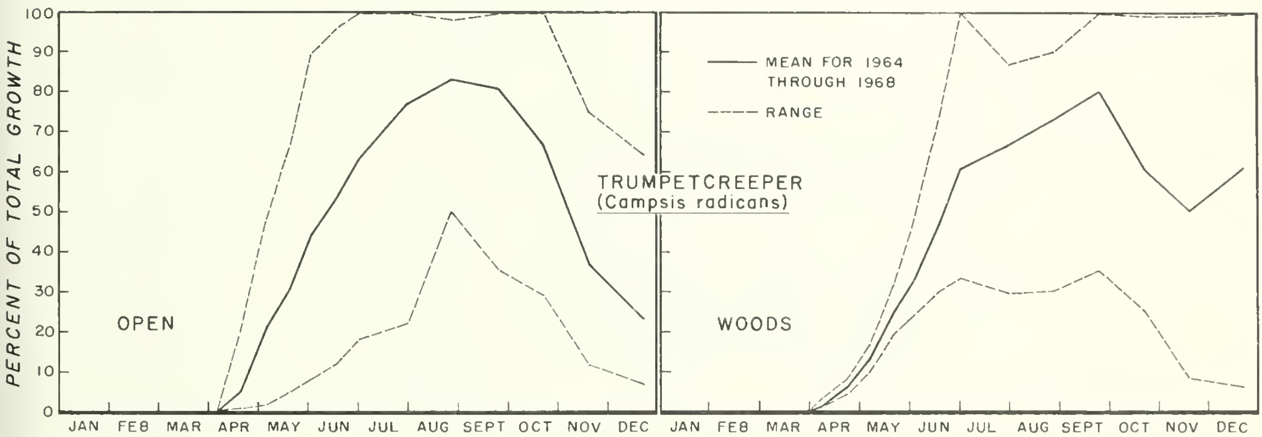

Figure 6.—*Trumpetcreeper stems died back in fall and winter.*

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Among plants of 16 browse species common in east Texas, the combination that would furnish succulent green forage earliest in spring and latest in fall includes yellow jessamine, Alabama supplejack, yaupon, rusty blackhaw, and flowering dogwood.

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Forest Service Research Paper SO-76

Growth of *PLANTED SLASH PINE* Under Several Thinning Regimes

W. F. Mann, Jr.
and
Hans G. Enghardt

Southern Forest Experiment Station
Forest Service
U. S. Department of Agriculture

1972

Growth of Planted Slash Pine Under Several Thinning Regimes

W. F. Mann, Jr., and Hans G. Enghardt

Three intensities of thinning, each started at 10, 13, and 16 years, were applied to slash pine planted on a highly productive, cutover site in central Louisiana. Over a 9-year period, early and heavy thinnings increased diameter growth but reduced volume growth. The longer initial thinnings were deferred, the slower was the response in diameter growth. Growth on unthinned plots was good.

Slash pine *(Pinus elliottii* Engelm. var. *elliottii)* has been planted on about 10 million acres across the South—or on more acreage than all other species combined. It has been planted extensively west of the Mississippi River, beyond its natural range.

Many of the plantations have reached or are approaching merchantable size. Consequently, it is timely to summarize early results of a study that is comparing growth of stands in which thinnings were initiated at ages 10, 13, and 16 years. Three intensities of thinning were applied at each stand age. The plantation is on a cutover site in central Louisiana, where slash pine is an introduced species.

First thinnings removed a high proportion of poor-risk trees, chiefly those with large fusiform rust *(Cronartium fusiforme* Hedgc. & Hunt ex Cumm.) cankers on the trunk. Subsequent thinnings concentrated on release of better stems.

MEASUREMENTS

Measurements were made at 3-year intervals from age 10 to 19 years. They included a complete tally of diameters to the nearest 0.1 inch to obtain basal area. Moreover, volume and basal area of individual sample trees were determined on each plot, and merchantable volume per plot was calculated by multiplying the volume/basal-area ratio of the sample trees by basal area of all trees 4 inches d.b.h. and larger. Volumes of individual trees were taken by height-

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The authors thank the International Paper Company for providing the plantation and assisting in protecting and cutting the plots.

accumulation[2] in 2-inch taper steps to a top diameter of 4 inches outside bark. Diameter points and heights were determined with a Spiegelrelaskop.[3]

At ages 10 and 13 years, three sample trees before and after cutting were measured on each plot to provide a common volume/basal-area ratio for a treatment. At ages 16 and 19 years, 12 sample trees were measured to obtain a ratio for each plot. In the larger sample, the number of trees representing each diameter class was in proportion to the total number in that class. Volume removed was calculated by subtracting residual volume from that present before cutting.

Volumes reported here are cubic feet of rough wood (including bark).

THE STUDY

The site is about 25 miles southwest of Alexandria, Louisiana. After the virgin timber was cut in the 1920's, the land remained idle until it was planted in 1948-49. As frequent wildfires had kept hardwoods in check, native grasses were the main vegetation.

Soils are Arcadia and Beauregard silt loams and Bowie fine sandy loam—all excellent for pine growth. Terrain is flat to gently rolling. Site index (age 50 years) averages 98 feet, and ranges from 93 to 103 feet.

The site was burned before planting. Slash pine seedlings were hand-planted at a spacing of approximately 6 by 7 feet. Initial survival apparently was high, and at age 10 years stocking on individual plots ranged from 670 to 960 stems per acre.

Forty plots were established, selected for high, uniform stocking. Each is square and 0.4 acre in size. Measurements were taken only on the central 0.1-acre. Ten treatments are replicated four times in a randomized block design. They include all combinations of three cutting intensities and three stand ages for the first thinning:

Intensity: Plots cut back to 70, 85, or 100 square feet of basal area per acre at each thinning.

Starting age: thinnings begun at ages 10, 13, or 16 years.

The tenth treatment is an uncut check. Thinnings were repeated at 3-year intervals, but now that the stands are past 19 years of age the cycle will be extended to 5 years.

Table 1 summarizes some of the important stand and stock data during the period covered in this report.

[2] Grosenbaugh, L. R. New tree-measurement concepts: height accumulation, giant tree, taper and shape. USDA Forest Serv. South. Forest Exp. Stn. Occas. Pap. 134, 32 p. 1954.

[3] Mention of trade names is for information only and does not imply endorsement by the U. S. Department of Agriculture.

Table 1.—*Average stand and stock data per acre*[1] *before cutting at 3-year intervals from age 10 to 19 years*

Age at first cut, and stocking level	Site index	Age 10			Age 13		Age 16		Age 19	
		Trees	Basal area	Vol-ume	Basal area	Vol-ume	Basal area	Vol-ume	Basal area	Vol-ume
	Feet	*No.*	*Sq. ft.*	*Cu. ft.*	*Sq. ft.*	*Cu. ft*	*Sq. ft.*	*Cu ft.*	*Sq.ft.*	*Cu. ft.*
10 years										
B.A. 70	98	817	104	1,325	103	1,838	88	1,966	91	2,362
B.A. 85	100	775	106	1,515	117	2,088	104	2,341	105	2,741
B.A. 100	100	888	124	1,853	135	2,513	122	2,856	123	3,298
13 years										
B.A. 70	98	830	103	1,295	138	2,386	88	1,955	92	2,332
B.A. 85	98	862	114	1,507	151	2,474	106	2,306	104	2,722
B.A. 100	96	845	112	1,530	148	2,538	118	2,638	123	3,124
16 years										
B.A. 70	95	795	102	1,304	138	2,306	156	3,159	88	2,159
B.A. 85	96	810	107	1,434	143	2,478	160	3,386	104	2,521
B.A. 100	98	818	115	1,676	151	2,492	164	3,462	117	3,016
Unthinned check	96	793	103	1,386	139	2,282	153	3,117	173	4,045

[1] Number of trees and basal area of trees 1 inch d.b.h. and larger; volumes of trees 3.6 inches d.b.h. and larger outside bark to a 4-inch top.

Mortality, which ranged from 9 to 114 cubic feet per acre by treatments over the 9 years, was included in all growth and yield data. This approach was chosen for two reasons. First, special precautions were taken to minimize insect damage following thinning, and consequently the mortality was unrepresentative of that encountered in normal operations. Second, losses from suppression and trunk cankers were negligible on all plots, including the unthinned checks.

RESULTS

Periodic Annual Volume Growth

Table 2 summarizes volume growth during each of the 3-year measurement periods and the entire 9 years of study. Comparisons between the short periods must be made with caution, for growth is influenced by spring and summer rainfall, which tends to vary considerably in this region.

Table 2.—*Periodic annual volume growth*[1] *per acre from ages 10 to 19 years*

Age at first cut, and stocking level	10-13 years	13-16 years	16-19 years	10-19 years
	Cubic feet			
10 years				
B.A. 70	292	251	250	264
B.A. 85	280	277	284	281
B.A. 100	325	315	310	317
13 years				
B.A. 70	367	230	256	284
B.A. 85	324	275	281	293
B.A. 100	339	269	310	306
16 years				
B.A. 70	339	303	220	287
B.A. 85	351	324	241	305
B.A. 100	275	348	262	295
Unthinned check	300	297	323	306

[1] Trees 3.6 inches d.b.h. and larger, with volumes outside bark.

Periodic annual volume growth from age 10 to 13 years averaged about 9 percent less on thinned plots than on the checks or on plots where thinning was deferred to ages 13 and 16. The reduction was greatest on plots cut back to 70 and 85 square feet of basal area per acre; it was negligible on plots with 100 square feet.

Plots first thinned at age 13 also grew less from age 13 to 16 years than unthinned plots. While the overall difference averaged 20 percent, heavy thinning reduced growth more than medium and light thinning.

The same overall trend of decreased growth following thinning occurred when the first cut was deferred until age 16. The average reduction was 82 cubic feet per acre, or about 25 percent. Decreases ranged from 61 to 103 cubic feet, with the greatest drop on the heavily thinned plots.

Within the range of basal areas on the plots, volume growth was directly related to stand density. Differences in basal areas between thinned and unthinned plots increased as the age of the first thinning advanced. As a consequence, growth differences also became greater.

Average annual volume growth for the 9-year period from age 10 to 19 years reflects the differences discussed for individual 3-year periods. Overall, growth was least when moderate and heavy thinnings were made at 10 years. It was best when thinnings were deferred, because then the plots were uncut for 13 or 16 years. The unthinned checks grew well over the 9-year span.

Covariance analysis was used to adjust for the effects of site index and initial differences in stocking. The 9-year adjusted means were then analyzed statistically, and the findings supported the conclusions above.

One of the noteworthy features on this study so far is the good growth on all plots. Average annual volume growth for 9 years ranged from 264 to 317 cubic feet per acre—undoubtedly a response to the good site.

Total Yield

Total yields through age 19 were also excellent, ranging from 3,703 to 4,705 cubic feet per acre (table 3). However, they cannot be used to appraise treatments, for there were substantial disparities in volume at the start of the study. The largest initial difference, 558 cubic feet per acre, exceeded any that developed between thinning regimes.

The proportion of total growth that was harvested by age 19 ranged from 49 to 53 percent for heavy thinning, 44 to 46 percent for medium, and 37 to 40 percent for light thinning. Time of initial thinning had only a slight effect on the proportion of total growth that was cut.

Table 3.—*Total yield and mean annual growth*[1] *per acre to age 19 years*

Age at first cut, and stocking level	Volume at age 10, before cutting	Age 10 to 19		Total yield, age 19	Mean annual growth to age 19	Proportion of cut to total yield
		Cut	Mortality			
	Cubic feet, outside bark					*Percent*
10 years						
B.A. 70	1,325	1,831	9	3,703	195	49.4
B.A. 85	1,515	1,773	13	4,041	213	43.9
B.A. 100	1,853	1,900	19	4,705	248	40.4
13 years						
B.A. 70	1,295	1,964	9	3,852	203	51.0
B.A. 85	1,507	1,839	71	4,147	218	44.3
B.A. 100	1,530	1,644	22	4,284	226	38.4
16 years						
B.A. 70	1,304	2,060	71	3,890	205	53.0
B.A. 85	1,434	1,912	103	4,184	220	45.7
B.A. 100	1,676	1,602	114	4,330	228	37.0
Unthinned check	1,386	0	103	4,148	218	.0

[1] Trees 3.6 inches d.b.h. and larger.

Diameter Growth

All trees.—Thinning at age 10 stimulated average diameter growth of the entire stand over the following 3 years, and the increase was directly related to the degree of cutting (table 4). Diameter growth from age 10 to 13 years on the unthinned plots (including those scheduled for later cutting) was uniform, averaging 0.26 inch yearly. On thinned plots, it ranged from 0.27 inch on plots cut back to 100 square feet of basal area per acre to 0.33 inch on those reduced to 70 square feet.

From age 13 to 16, two dry summers caused diameter growth to decline substantially in all treatments. It was highest on plots first thinned at age 10, and next best on those initially cut at age 13. The difference between these two treatments was 0.024 inch annually, or about 10 percent. Evidently stands thinned for the first time at age 13 could not respond as well as those thinned at age 10 and again at 13 years. Annual diameter growth on unthinned plots during this period averaged 0.13 inch, or 24 to 41 percent less than on plots thinned initially at age 13.

Diameter growth on all plots, including the checks, was higher from age 16 to 19 than in the previous 3 years, presumably because rainfall was ample. It was greatest on plots thinned earliest and heaviest. With one exception, plots thinned at age 10 and every 3 years thereafter had better diameter growth than those thinned to

Table 4.—*Periodic annual diameter growth of all trees and of 50 largest trees per acre*

Age at first cut, and stocking level	All trees				50 largest trees per acre			
	10-13 years	13-16 years	16-19 years	10-19 years	10-13 years	13-16 years	16-19 years	10-19 years
				Inch				
10 years								
B.A. 70	0.33	0.25	0.33	0.30	0.42	0.32	0.40	0.38
B.A. 85	.30	.22	.26	.26	.44	.30	.36	.37
B.A. 100	.27	.21	.24	.24	.43	.29	.32	.35
13 years								
B.A. 70	.26	.22	.31	.27	.43	.32	.42	.39
B.A. 85	.26	.22	.28	.25	.40	.29	.35	.35
B.A. 100	.26	.17	.23	.22	.38	.25	.32	.32
16 years								
B.A. 70	.27	.15	.24	.22	.40	.25	.32	.32
B.A. 85	.26	.14	.23	.21	.40	.26	.32	.32
B.A. 100	.25	.12	.19	.19	.39	.25	.30	.32
Unthinned check	.26	.12	.15	.18	.41	.22	.27	.30

comparable basal areas at later ages. Similarly, diameter increment was higher when thinning began at age 13 rather than at age 16; differences averaged about 25 precent. Differences between high and low basal areas were 0.09, 0.08, and 0.05 for thinnings initiated at 10, 13, and 16 years.

For the 9-year period, diameter growth was best on plots thinned heavily at age 10, averaging 0.30 inch annually. It was progressively lower as thinning was deferred and residual basal areas were higher. For all residual basal areas combined, delay of the first thinning to age 13 reduced diameter growth by about 7 percent, and a 6-year delay reduced it by 22 percent. Differences between light and heavy thinning averaged about 18 percent for all times of first thinning. As expected, differences due to stocking levels decreased as the first thinning was delayed. Growth on the check plots averaged 0.18 inch annually, or 40 percent less than on plots thinned heavily at age 10.

Fifty largest trees.—Most of the same trends in diameter growth were also evident for the 50 largest trees per acre, although somewhat less pronounced. The most obvious deviation was that thinning intensity had no effect on growth from age 10 to 13, probably because the biggest trees were free of severe competition for crown space. Thereafter, degree of thinning influenced growth of dominants nearly as much as with all trees. Thinned stands outgrew unthinned ones, regardless of the age of first thinning.

It is noteworthy that diameter growth of the large trees on the check plots averaged 0.30 inch annually over the 9 years. This is 67 percent more than the growth of all trees on these plots and only 21 percent less than growth of the large trees on plots thinned heavily starting at age 10.

Average Diameter

Average diameters for all trees at age 10 ranged from 4.7 to 5.1 inches (table 5). Nine years later the range was considerably greater, with the highest averages on plots cut earliest. No consistent differences occurred between stocking levels, however, because average d.b.h. at age 19 was influenced by cutting and mortality, as well as by d.b.h. at age 10. Increment alone accounted for 79 to 91 percent of the increase over the 9 years.

Table 5.—*Average d.b.h. of all trees at ages 10 and 19 years, and amount of increase due to growth*

Age at first cut, and stocking level	Average d.b.h. before cutting		Diameter increase due to growth, 10 to 19 yrs.
	Age 10	Age 19	
	------ *Inches* ------		
10 years			
B.A. 70	4.8	8.0	2.7
B.A. 85	5.0	7.6	2.3
B.A. 100	5.0	7.6	2.2
13 years			
B.A. 70	4.7	7.6	2.4
B.A. 85	4.9	7.6	2.2
B.A. 100	5.0	7.2	2.0
16 years			
B.A. 70	4.8	7.1	2.0
B.A. 85	4.9	7.3	1.9
B.A. 100	5.1	7.1	1.7
Unthinned check	4.9	6.7	1.6

Diameter Distributions

While average d.b.h. serves many useful purposes in appraising stand growth, distribution of trees by diameter classes is of greater importance. From table 6, it can be seen that stands thinned initially at age 10 had about twice as many 9- and 10-inch trees as those in which the first thinning was deferred for 6 years. For thinnings started at age 13, stocking in these two large diameter classes was

Table 6.—*Cumulative number of trees per acre by 1-inch d.b.h. classes, before cutting at age 19*

Age at first cut, and stocking level	<4	4	5	6	7	8	9	10
	----------- *Number* -----------							
10 years								
B.A. 70	262	260	258	258	236	181	83	5
B.A. 85	332	327	322	300	265	165	67	15
B.A. 100	390	380	378	348	313	210	95	10
13 years								
B.A. 70	295	287	277	257	225	153	60	10
B.A. 85	328	323	311	301	276	178	73	8
B.A. 100	435	417	407	385	300	175	50	8
16 years								
B.A. 70	320	310	302	280	215	115	35	2
B.A. 85	365	363	351	319	266	143	43	8
B.A. 100	428	418	410	368	270	145	40	10
Unthinned check	698	690	638	536	381	176	43	8

intermediate. Early thinning retained a slight superiority down to the 7-inch class, but when all trees 6 inches d.b.h. and larger were totaled, thinning initially at age 16 ranked first and thinning at age 10 ranked last.

The effect of thinning intensity on number of trees in the largest diameter classes is not clear, even where thinning started at age 10. Trends are evident for stocking of trees 7 inches d.b.h. and larger, with light thinning having more trees per acre than heavier thinnings. In terms of trees 6 inches d.b.h. and larger, plots thinned to 70 square feet of basal area had 24 to 33 percent fewer than plots cut to 100 square feet.

The unthinned checks had fewer 9- and 10-inch trees than did plots thinned at ages 10 and 13 years, but they equalled plots cut first at 16 years. For trees 8 inches and over, the checks were surpassed only by thinnings started at age 10. They excelled all thinning regimes in number of trees 7 inches and more in d.b.h.

Cutting records show that time and severity of thinning had no important influence on the number of larger trees removed (table 7). In d.b.h. classes of 6 inches and larger, deferred thinning and heavy cutting both removed more large trees per acre than light cuts made at earlier ages.

Table 7.—*Cumulative number of trees harvested per acre between ages 10 to 16 years, by 1-inch d.b.h. classes*

Age at first cut, and stocking level	<4	4	5	6	7	8	9
	Number						
10 years							
B.A. 70	544	504	373	200	66	16	
B.A. 85	420	403	372	195	85	18	3
B.A. 100	475	450	362	204	74	12	2
13 years							
B.A. 70	490	475	405	248	65	25	5
B.A. 85	478	468	411	247	76	23	
B.A. 100	368	360	315	190	62	10	
16 years							
B.A. 70	428	428	393	271	128	23	5
B.A. 85	375	373	345	235	85	27	12
B.A. 100	310	305	287	190	95	35	8
Check							

DISCUSSION

This study gives important information on the consequences of thinning slash pine plantations at various ages.

Age 10 years seems too early. Even though maximum diameter growth was obtained, many small trees—unprofitable to harvest—had to be removed. In addition, volume growth was reduced.

The choice between initiating thinning at age 13 or age 16 depends on the importance of stimulating diameter growth at the earliest practical age. Trees cut at age 13 will be larger than those removed at age 10, but only marginally profitable to harvest. And the value of added diameter growth must be weighed against a reduction in volume. Deferral to age 16 will sacrifice some diameter growth, but this will be offset by higher volume growth and by increases in sizes of trees cut.

For short pulpwood rotations there seems to be merit in leaving stands unthinned. Volume growth is good, no costs are incurred for marking, there are fewer small trees to harvest, and stand disturbances that may attract bark beetles are avoided.

Mann, W. F., Jr., and Enghardt, Hans G.

1972. Growth of planted slash pine under several thinning regimes. South. Forest Exp. Stn., New Orleans, La. 10 p. (USDA Forest Serv. Res. Pap. SO-76)

Three intensities of thinning, each started at 10, 13, and 16 years, were applied to slash pine planted on a highly productive, cutover site in central Louisiana. Over a 9-year period, early and heavy thinnings increased diameter growth but reduced volume growth. The longer initial thinnings were deferred, the slower was the response in diameter growth. Growth on unthinned plots was good.

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Evaluation of Two-Stage 3 P Sampling For Forest Surveys

Dwane D. Van Hooser

Southern Forest Experiment Station
Forest Service
U. S. Department of Agriculture

1972

Van Hooser, Dwane D.

1972. Evaluation of two-stage 3 P sampling for forest surveys. Scuth. Forest Exp. Stn., New Orleans, La. 9 p. (USDA Forest Serv. Res. Pap. SO-77)

Two-stage 3 P sampling appears attractive in forest survey for midcycle volume estimates. A simulated 3 P sample predicted the total cubic volume for five counties in southern Alabama to within 0.7 percent of that predicted by the latest forest survey of the area. Remeasurement of only 259 trees would have been required, as compared to some 6,500 trees needed in the standard sample.

Evaluation of Two-Stage 3 P Sampling For Forest Surveys

Dwane D. Van Hooser [1]

Two-stage 3 P sampling appears attractive in forest surveys for midcycle volume estimates. A simulated 3 P sample predicted the total cubic volume for five counties in southern Alabama to within 0.7 percent of that predicted by the latest forest survey of the area. Remeasurement of only 259 trees would have been required, as compared to some 6,500 trees needed in the standard sample.

Forest sampling techniques have evolved during the past two decades from cluster sampling with constant probability (proportional to individual tree frequency) through cluster sampling with variable probability (proportional to tree size). In each case the number of sample locations and the number of trees measured at each location had to be quite large to reduce the standard error to the desired level. In 1963 Grosenbaugh *(2)* introduced a new sampling concept based upon probability proportional to prediction—commonly called "3 P." In brief, this method selects sample trees with probability proportional to some predicted tree value or volume arbitrarily established by cheap guess or measurement. This system usually substantially reduces the number of trees that must be measured to achieve a desired accuracy level. In 1971 Grosenbaugh extended the system and its associated computer program STX *(4)* to include multistage 3 P sampling. One of the alternatives incorporated in the new version was to take a first-stage point sample to estimate total probabilities (ΣD^2H) and to select only a very small fraction of the first-stage trees for intensive second-stage measurement with a dendrometer. Measured trees are selected with probability proportional to D^2H, where D is d.b.h. and H is merchantable height.

This paper presents the results of an evaluation of the potential of two-stage 3 P sampling in large-scale timber inventories, such as the nationwide forest survey.

[1] The author thanks L. R. Grosenbaugh for assistance in this study and for the constructive comments on the manuscript.

Technique

Data for the study were from the recently completed inventory of a five-county area in southern Alabama *(5)* (fig. 1). The regular forest survey sample served as a first stage, and the 3 P subsample was taken by computer simulation. The area contained 456 10-point clusters that included some 6,500 trees 5 inches d.b.h. and over. Dendrometer measurements taken on the trees included d.b.h., top diameter outside bark (d.o.b.), d.o.b. at the midpoints of the saw-log and poletimber portions of the stem, and saw-log and total merchantable length. Stump d.o.b. was estimated from d.b.h. by regression.

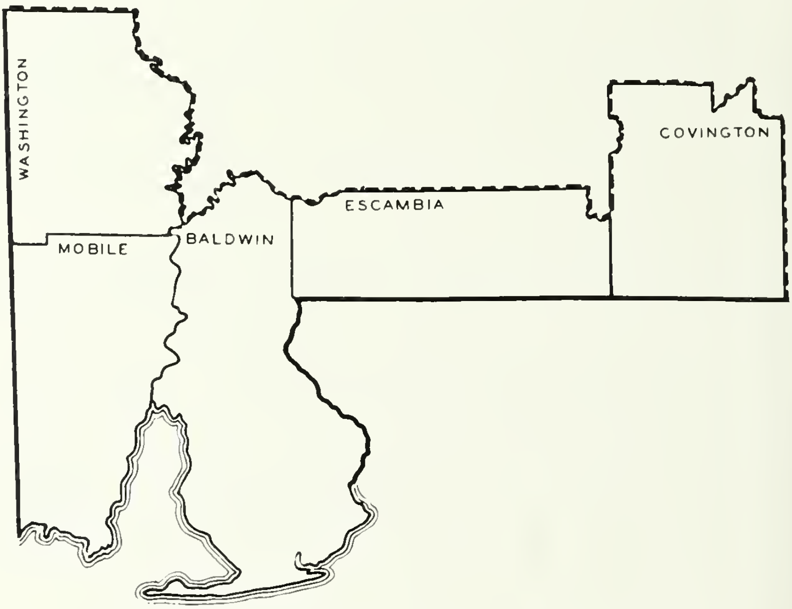

Figure 1.—*Five-county study area in southern Alabama.*

In this simulation an estimate of volume was the primary objective. Since the first-stage sample was a horizontal point sample, i.e., trees were selected with probability proportional to basal area or D^2, and since volume tends to be proportional to basal area times height, only the height of first-stage trees had to be specified to ascertain whether or not a given tree qualified as a 3 P subsample. In this paper, the term KPI will be used instead of height to conform to Grosenbaugh's terminology *(3)*.

To specify a satisfactory 3 P sampling design it is necessary to know the coefficient of variation (CV) for ΣD^2H among locations as well as the CV for the ratio of actual cubic foot volume of individual trees to D^2H. The former was easily computed from the complete forest survey data for the 456 locations ($\pm$ 92 percent). The latter was found to be $\pm$ 21 percent, based on a small sample. It was decided to use all 456 locations as first-stage samples, and to strive for an overall sampling error for volume of about 4.5 percent, even though the first-stage sampling error for the 456 locations was already 4.3 percent. Thus, the number of trees selected by the 3 P subsample was designed to be:

$$(21)^2/\left((4.5)^2 - \frac{(92)^2}{456}\right) = 260,$$ if the usually negligible covariance term is neglected.

The total sample actually selected by the 3 P process was 259 trees, which is 4 percent of the trees selected by prism during the first stage. The number of trees per county ranged from 33 to 72. The variation was due primarily to the amount of D^2H associated with each county. The total 3 P sample involved 170 locations or only 37 percent of the locations taken during the initial inventory. Double-sampling designs would reduce the number of points at which dendrometry is needed; they would probably be more efficient where remeasurement is contemplated.

Once the sample size was selected, the next step was to generate a list of random numbers by computer program RN3P for selection of the simulated 3 P sample. RN3P is a successor program replacing THRP described by Grosenbaugh *(3)*. It required four input parameters (fig. 2): L, an arbitrary positive integer used to begin random number generations; LIM, an estimate of the total number of observations or trees in the first-stage sample; K, an estimate of the largest KPI in the sample (i.e., the largest merchantable height anticipated); and KZ, KPI divided by the number of samples required. In the five-county area L, LIM, K, and KZ were 1,236, 6,500, 95, and 1,000, respectively. Figure 2 is an example of the random number list that was generated.

The next step was to simulate the field work required to obtain the 3 P sample. To do so a computer program called 3PSEL was written in FORTRAN IV to be processed on an IBM 7094. As processing begins the random numbers are read into an array R(I). After they have been stored, a tree record is read and D is checked. If D is less than 5 inches it is passed over and another record is read. If D is 5 inches or more the R(I) index is incremented and the random number associated with the new index is compared to the KPI of the tree. If the random number is greater than the KPI or the random number is null, the KPI is added to a variable called SUMKPI and another record is read. If the KPI is greater than or equal to the random number, the tree becomes a 3 P sample and

RANDOM NUMBERS FOR TWO STAGE 3 P SIMULATION IN SOUTHWEST ALA PAGE 1
L= 1236, LIM= 6500, K= 95, KZ= 1000

-99999	-99999	-99999	35	-99999	-99999	-99999	-99999	-99999	-99999
31	-99999	-99999	-99999	-99999	44	58	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	42
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	76
34	-99999	-99999	-99999	29	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	62	-99999	73	-99999	85	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	88	-99999	-99999	-99999	-99999	-99999	94	-99999
-99999	-99999	26	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	22	-99999	9	-99999	-99999	-99999	50	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	90	-99999
-99999	78	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	60	-99999	-99999	-99999	-99999	-99999	42	-99999	-99999
-99999	-99999	-99999	64	-99999	-99999	-99999	-99999	39	-99999
31	-99999	-99999	-99999	-99999	79	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	79
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
72	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	89	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	76	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	32	-99999	77
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	[illegible]	-99999	-99999	-99999	[illegible]	-99999	-99999	-99999	[illegible]
[illegible]	[illegible]	-99999	-99999	[illegible]	[illegible]	-99999	-99999	[illegible]	[illegible]
[illegible]	-99999	[illegible]	-99999	[illegible]	-99999	[illegible]	-99999	[illegible]	-99999
[illegible]	-99999	[illegible]	-99999	[illegible]	-99999	[illegible]	-99999	[illegible]	-99999
-99999	-99999	[illegible]	[illegible]	-99999	-99999	[illegible]	[illegible]	-99999	-99999
-99999	-99999	-99999	[illegible]	-99999	77	-99999	[illegible]	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	28	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	92	-99999	-99999	11	-99999	-99999	-99999
-99999	-99999	-99999	69	-99999	67	-99999	-99999	-99999	-99999
91	-99999	-99999	10	-99999	2	-99999	-99999	-99999	11
-99999	-99999	-99999	-99999	24	-99999	-99999	-99999	-99999	-99999

RANDOM NUMBERS FOR TWO STAGE 3 P SIMULATION IN SOUTHWEST ALA PAGE 14
L= 1236, LIM= 6500, K= 95, KZ= 1000

	KSUM =	29352,	NK =	601,	NKZ=	6500
EXPECTED	NK*(K+1)/2=	28848,	NKZ*K/KZ=	617,	LIM=	6500

Figure 2.—*Example of random number list.*

the measurements mentioned above, along with certain other tree items, are written on tape to await further manipulation. This process continues until all trees 5 inches or larger have been "visited" and their KPI's have been recorded.

Since the largest number in the set of random numbers must be greater than or equal to the largest KPI + 1, and since the frequency of each number from 1 to the largest tends to be equal, the number of random numbers which qualify any given tree are proportional to the measured height of any given tree. For example, in the test area a prism-selected tree 80 feet tall had a 0.08 probability of selection, while a tree 40 feet tall had a 0.04 probability of selection. In other words, there are about twice as many random numbers available for qualifying a tree with 80 feet of measured length as for a tree with 40 feet of measured length.

To compensate for the fact that taller trees have more chance of being selected, sample trees are expanded to the number of point-sampled trees each represents with the formula:

$$\text{Freq.} = \sum^{N} \text{KPI}/N \cdot \text{KPI}$$

where:

Freq. = number of trees represented by one 3 P sample tree

ΣKPI = sum of estimated or measured heights of *all* trees visited in the first-stage sample, including those selected for tally by the prism but not selected as 3 P samples.

N = number of trees in the 3 P sample.

KPI = height of any given 3 P sample tree.

In the test area unadjusted $\sum^{N}$KPI was equal to 248,712 and after the selection process was completed N was equal to 259; thus the frequency of an 80-foot tree would be:

$$\text{Freq.} = 248{,}712/259 \cdot 80 = 12.$$

The frequency of a 40-foot tree would be:

$$\text{Freq.} = 248{,}712/259 \cdot 40 = 24.$$

In addition, since the first-stage sample was a point-sample cluster, the 3 P trees are further expanded by the factor for a 10-point cluster and a prism with a Basal Area Factor equal to 37.5 square feet per acre per tallied tree, i.e., $687.5/D^2$, and by the number of acres each location represents.

The final phase of the simulation was to reformat data on the selected trees in a format acceptable to STX. This was done by another FORTRAN IV program called STXORD which was written by the author and Grosenbaugh.

Results

For discussion purposes the regular forest survey data *(5)* will be referred to as the standard. Comparison of the STX summaries with the standard for the five-county test area shows that the 3 P sample of 259 trees predicted total cubic volume to within 0.7 percent of the volume computed by regression on some 6,500 prism-selected trees, each of which was actually measured (table 1). 3 P underestimated softwood cubic volume by 2.9 percent and overestimated hardwood cubic volume by 3.7 percent (table 1). These errors are much less than sampling error, but absence of direct measurements of stump d.o.b. might be partially responsible. At the county level, the 3 P estimates of total volume varied from +4.2 percent to —9.8, or from +25.1 million cubic feet to —41.6 million cubic feet, with the same relative differences occurring by species. These differences were anticipated because 3 P selection was done without regard to species distribution.

Table 1.—*Standard and 3 P estimates of volume for the five-county test area, by species*

Source	Baldwin	Covington	Escambia	Mobile	Washington	Total
			Million cubic feet			
Softwood						
Standard	459.5	306.5	361.7	239.1	362.2	1,724.0
3 P estimate	398.5	302.1	336.9	224.4	390.0	1,671.9
Difference	−61.0	− 4.4	− 4.8	− 9.7	+27.8	−52.1
Hardwood						
Standard	285.1	118.5	116.5	137.2	238.9	896.2
3 P estimate	331.3	81.3	120.8	160.3	236.2	929.9
Difference	+46.2	−37.2	+ 4.3	+23.1	− 2.7	+33.7
All species						
Standard	744.6	425.0	478.2	371.3	601.1	2,620.2
3 P estimate	729.8	383.4	477.7	384.7	626.2	2,601.8
Difference	−14.8	−41.6	− .5	+13.4	+25.1	−18.4

To ascertain the effect of failure to stratify by species groups, a separate sample of 34 softwood and 28 hardwood trees was drawn for Baldwin County and processed through the entire system. The estimate of total volume was reduced by 0.5 million cubic feet. By species group the change was more pronounced. The estimate of softwood volume went from 398.5 to 427.1 million cubic feet, reducing the difference from the standard from —13.3 to —7.0 percent. The hardwood estimate went from 331.2 to 302.2 million cubic feet, reducing its variation with the standard from +16.2 to +6.0 percent.

Clearly, as with any type of sampling, 3 P sample selection would benefit from stratification by species groups.

To confirm that the differences, as slight as they were, were due to sampling and not to differences in volume calculations, a subsample of 41 trees was selected and the individual volumes were compared. As expected, the differences between 3 P and regression volumes exhibited randomness. That is, there were nearly as many negative differences as positive ones and the magnitude of each was such that their sum was close to zero.

An analysis of the standard error (table 2) associated with each of the estimates indicates that the 3 P second-stage sample does not appreciably increase overall variability. For example, the first-stage variation among locations for estimated ΣD^2H was 4.3 percent. The sampling error for the multistage estimate of volume was 4.5 percent. The multistage error was computed by taking the square root of the sum of the squared errors for each stage; the covariance term, which is usually negligible, was ignored. Even at the county level the increase in error was small. Baldwin County, which had a first-stage error of 8.9 percent, had a combined total error of 9.3 percent. Thus, it is obvious that the first-stage sample is responsible for most of the total sampling error.

Table 2.—*Sampling errors for each sampling stage for total volume for five-county test area*

Source	Baldwin	Covington	Escambia	Mobile	Washington	Total
			Percent			
First stage (standard)	8.9	10.2	10.2	11.6	7.6	4.3
Second stage (3 P)	2.7	3.0	2.3	3.2	3.0	1.3
Combined error	9.3	10.6	10.5	12.0	8.2	4.5

Discussion

The basic concept underlying multistage 3 P sampling is that efficiency of volume estimation can be increased by intensively dendrometering a few trees appropriately selected with variable probability from a much larger point sample that merely tallied guessed merchantable heights. The results of this study tend to support this assessment. Although 3 P has been in the literature since 1963, to date no one has compared the results of 3 P with those of a simple point sample or a plot sample.

To fully assess the utility of any new concept, it must be compared to some standard and the result evaluated. In the present case, results of 3 P sampling and standard sampling were, for all practical purposes, the same. With a 3 P sample of 259 trees, total cubic volume was predicted to within 0.7 percent of the standard. It would have been necessary to revisit 37 percent of the field locations to measure the 259 trees. Whether a two-stage sample would have saved significant time and manpower is unknown. Double sampling to reduce the number of locations to be visited on remeasurement, and three-stage sampling with first-stage guesses at ΣD^2H, second-stage point samples, and third-stage 3 P dendrometry are attractive possibilities raised by Grosenbaugh *(4)*. Since assessment of these options would require costs and variances not immediately available, only two stage sampling was evaluated here.

It appears that the time involved in establishing a two-stage 3 P sample might be nearly the same as that involved in establishing a single-stage 10-point cluster sample. However, time required to remeasure established locations would be considerly less with a 3 P sample. In the example, only 259 trees on 170 locations would have to be measured, as opposed to 6,500 trees on 456 locations.

It is here that the nationwide forest survey could realize the greatest gain. Since very detailed data are required of the survey, it is necessary to establish and measure many trees to adequately sample all of the required strata. This is done approximately every 10 years for each State in the eastern half of the Nation. Demands to shorten the cycle or reestimate at midcycle have been growing. With a multistage 3 P sample, it would be possible to cheaply estimate growing-stock volume at midcycle. The first-stage cruise would have already been made and all data necessary for selecting the 3 P subsample would be available at a very low cost. By selecting and remeasuring a 3 P subsample and expanding it on the basis of the initial measurement frequencies, updated estimates of volume that are accurate and statistically sound could be obtained. These new estimates could then be used as check points in an updating procedure such as the one being used at the Southern Forest Experiment Station *(1)*. If needed, the new volumes could then be proportioned back over the various strata.

There are two factors that could affect this midcycle estimate. The first is that the multistage design described here does not account for ingrowth at the time of remeasurement. However, if initial point sampling selected all qualifying trees between 0.1 and 5.0 inches in d.b.h. as sure to be measured, merchantable ingrowth could be estimated for all trees except those that grew from less than 4.5 feet tall to 5 inches in d.b.h. in 5 years—a negligible number. These trees could also be estimated if important by taking a second point sample that tallied only trees less than 5 years of age at d.b.h. The second factor, a drastic change in the inventory base, is not unique to 3 P sampling. Any time the base is altered severely, such as the reduction in forest area through land clearing in the Mississippi Delta *(6)*, a new base should be established.

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Wood and Bark Properties of Spruce Pine

Floyd G. Manwiller

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Wood and Bark Properties of Spruce Pine

Floyd G. Manwiller[1]

Weighted stem averages were determined for wood and bark of 72 trees representing the commercial range of Pinus glabra *Walt. The trees were stratified into three age classes (15, 30, and 45 years) and two growth rates (averaging 4.9 and 9.0 rings per inch). Within-stem variation was determined from 1,296 earlywood and latewood sampling points in the 72 stems. Tracheid length increased with tree age and averaged 0.2 mm. longer in fast-grown trees than in slow-grown. Tracheid diameter did not differ with age, but radial and tangential diameters averaged 2 to 4 μm. larger in fast-grown trees. Wall thickness did not differ with age; walls of fast-grown latewood tracheids averaged 0.27 μm. thicker than those from slow-grown stems. Tracheids near the pith were short, of small diameter, and had thin walls with large fibril angles; those near the bark were longest and had greatest diameters, thickest walls, and smallest fibril angles. Extracted specific gravity did not differ with age class or growth rate in earlywood or latewood. However, wood specific gravity averaged lower in fast-grown trees (0.408 unextracted) than in slow-grown (0.442) because fast-grown trees contained a greater proportion of large-diameter, thin-walled earlywood tracheids. Bark specific gravity averaged 0.391 in slow-grown trees and 0.371 in fast-grown. Bark thickness increased with tree age. Wood chemical components did not vary with age class or growth rate, and mechanical properties did not differ greatly. Microtensile strength and longitudinal shrinkage of earlywood and latewood did not vary with position in stem. Green volumes and ovendry weights are tabulated for bark and wood components.*

The research reported here attempted to delineate the effects of tree age and growth rate on the stem wood and bark properties of an entire pine species throughout its commercial range. The data are for spruce pine, *Pinus glabra* Walt., one of the 10 species known as the southern pines. This minor member of the hard pine group was chosen for two reasons. First, the literature contains little information on it, even though it comprises a sizable volume in some States. Second, the species' range is compact enough to permit ready sampling.

The wood properties studied were those deemed of importance in the manufacture of fiber or solid products. Sampling was intensive enough to determine within-stem variation as well as average values for merchantable stems.

Spruce pine (fig. 1) occasionally occurs in pure stands but is more often associated with shortleaf *(Pinus echinata* Mill.) and loblolly *(P. taeda* L.) pines and with various hardwoods. It is a medium-sized tree, 80 to 90 feet high, with distinctive bark resembling that of black oak *(Quercus velutina* Lam.) while it grows in moist, sandy loam soils throughout the coastal region from southern South Carolina to southeastern Louisiana, it occurs in greatest numbers, and attains commercial importance, in the Florida parishes of Louisiana and in southern Alabama and Mississippi (fig. 2). This three-State area contains approximately 80 percent of the standing volume (Sternitzke and Nelson 1970).

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Figure 1.—*A 12-inch, 50-year-old spruce pine.*

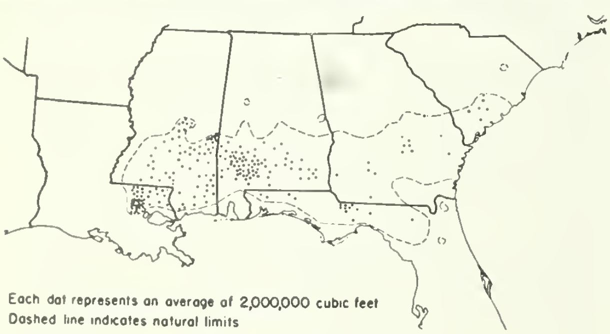

Figure 2.—*Range and volume of spruce pine. (After Sternitzke and Nelson 1970.)*

PROCEDURE

Specimen Collection and Preparation

Twelve sample locations, each considered a replication, were selected within the three-State area (fig. 3). At each location, six trees were cut—one for each combination of two growth rates and three age classes. Fast-grown trees showed less than six annual rings per inch and slow-grown more than six. The three age classes were 15 years (range of 8-22 years), 30 years (23-37), and 45 years (38-52). Tree age and growth rate were determined from increment cores taken at stump height. Only trees with a relatively uniform rate of growth were selected. The location of each tree was recorded for later determination of its latitude and longitude. Each tree was felled and 3 inch-thick disks were removed at 8.25-foot intervals along the stem between stump height (0.75 foot) and a 4-inch top outside bark. Disks were sprayed with fungicide to prevent blue stain, placed in polyethylene bags to prevent loss of moisture, and removed to the laboratory, where they were stored under refrigeration until analyzed.

Figure 3.—*Spruce pine sample locations. One tre of each age and growth rate categor (six trees total) was cut at each loca tion.*

For determination of mechanical propertie a bolt was removed from each tree that wa over 7 inches d.b.h. and fell into the 30- an 45-year age classes. This bolt was 4 feet lor in large-diameter trees and 8 feet long i smaller trees. The bolts were stored under water until processed. By the traditional Standard D143-52 of the American Society for Testing and Materials (ASTM), a minimum of five "representative" trees are selected and a number of specimens taken at several heights for each test conducted. In the present study, however, the approach was that of Krahmer and Snodgrass (1967), in which more trees are sampled less intensively. These authors found that for western hemlock one bolt from each of 39 trees and two specimens from each bolt was most efficient in obtaining a precision of ±5 percent.

To identify heartwood, the appropriate area on the surface of each disk was stained with benzidine—25 percent hydrochloric acid in solution with 10 percent sodium nitrite (Kutscha and Sachs 1962). Annual rings were counted, and heartwood radius, disk diameter, and bark thickness were measured to the nearest 0.01 inch at 45° intervals. Two opposed 30° angles were marked off on the surface of each disk (fig. 4), avoiding concentrations of compression wood. For determination of stem averages, three pairs of samples were removed from each pair of wedges:

Two opposed bark samples, each measuring 2 inches along the grain, for determination of bark specific gravity.

Two opposed 30° wedges, measuring 1 inch along the grain, for determination of chemical content and fiber morphology.

Two opposed 30° wedges, measuring ¼-inch along the grain, one for unextracted and one for extractive-free specific gravity.

Within-stem variability in earlywood and latewood was measured on samples from three of the disks in each tree—at the butt, at a 4-inch top, and approximately halfway between. At each height three annual rings were selected at 1/6, 3/6, and 5/6 of the count from pith to bark (fig. 4). Distance from the pith in both rings and inches and width of earlywood and latewood tissue were recorded for each ring selected. There were a total of 1,296 such sampling points: (three age classes) (two growth rates) (12 replications of trees) (three heights) (three radial positions) (two cell types). At each point two blocks were removed:

a. A block measuring about ¼-inch along the grain, ¾-inch tangentially, and at least three rings radially, for determination of tracheid transverse dimensions and specific gravity.

b. A microtome block measuring ¾-inch tangentially, 1¼ inches along the grain, and at least three rings radially.

Blocks *b* were saturated and a minimum of six wafers cut from the radial face. Wafers were nominally 300 μm. thick in the tangential direction. They supplied specimens for determination of microtensile strength, fiber length, fibril angle, and longitudinal shrinkage.

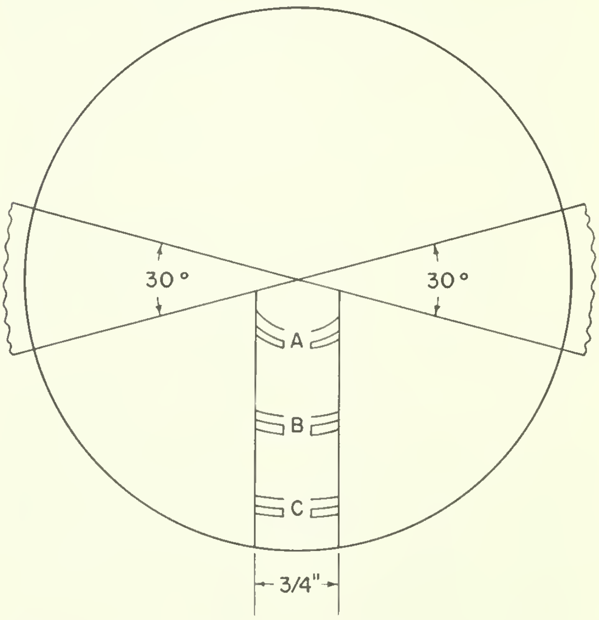

Figure 4.—*Two stem-sampling systems were employed. Two opposed 30° wedges were removed at stem intervals of 8.25 feet to obtain weighted stem averages. At the butt, at the 4-inch top, and at the approximate midpoint, earlywood and latewood samples were removed at 1/6 (A), 3/6 (B), and 5/6 (C) of the ring count for determination of within-stem variation.*

Analytical Techniques

Stem means.—The 1-inch-thick wedges taken in pairs at 8.25-foot intervals sampled the wood of the stem in proportion to its occurrence by volume. Wedges from each tree were reduced to chips of uniform size and combined. The resulting pile of chips furnished material for determination of stem-average values of fiber dimensions, fibril angle, and chemical content.

From each pile, 100 chips were randomly selected, and a sample was split from the radial surface of each. The samples were further reduced to matchstick size and then macerated with equal parts of glacial acetic acid and 6 percent hydrogen peroxide. An ampliscope was used to measure the length of 150 fibers from each tree. Cell and lumen diameters and wall thickness of 100 swollen fibers were measured with a microscope equipped with a micrometer eyepiece.

Mean fibril angle of the S_2 layer was measured by polarization (Preston 1952, p. 116). In this procedure, macerated fibers are glued to a slide and sliced longitudinally with a microtome knife. Only the back wall remains on the slide. The major extinction position, which is parallel with the long axis of the microfibrils, is located with the aid of a Red I retardation plate. The angle between the position of extinction and the long axis of the cell is the fibril angle. This angle was measured with a graduated rotating stage. Fibril angle was determined on 120 fibers per tree.

For analysis of chemical components, the chips representing a tree were ground in a Wiley mill and only that portion passing through a 40-mesh screen used. Stem averages for extractive and lignin contents were determined by ASTM Standard Procedures D1107-56 and D1106-56, respectively. Erickson's (1962) method was followed for holocellulose and alpha-cellulose except that the amount of sodium chlorite solution per cycle was doubled for holocellulose determinations. Hemicellulose content was taken to be the difference between holocellulose and alpha-cellulose contents. For ash determination, the wood flour was first partially decomposed with 5 ml. of concentrated nitric acid in five 1-ml. steps, dried, and then fired in a muffle furnace at 475° C. for 6 hours (McMillin 1969). Weights of analysis samples were 2 g. for extractive content, 1 g. for ash, and 0.5 g. for lignin and for cellulose fractions. Two such samples from each tree were averaged for ash analysis, and five were averaged for each of the other components. Extractive content was expressed as percent of ovendry weight of unextracted wood. Results for the remaining components were expressed as percent of ovendry weight of extractive-free wood.

Stem-average specific gravity was determined for bark and for wood of each tree; values were based on ovendry weight and green volume, with the latter obtained by water immersion. One of the opposed ¼-inch-thick, 30° wedges at each stem height was used for unextracted specific gravity. The other wedge was extracted for 24 hours with acetone. Bark samples taken at each height were used to determine unextracted specific gravity only. To obtain mean unextracted specific gravity of the wood, the combined weight of the ovendry wedges was divided by total weight of the water they displaced. The same procedure was followed to obtain stem-average values for specific gravity of extracted wood and of unextracted bark.

Mechanical properties.—Forty-two trees from the 30- and 45-year age classes yielded a log for determination of mechanical properties. Six of the 30-year-old slow-grown trees were too small. Each tree furnished one or two 4-foot bolts which were sawn into 2½-inch-square sticks, tangentially paired. One stick of each pair was machined to proper size for testing in the green condition. The other was conditioned to a moisture content of approximately 12 percent and then machined to test dimensions. Two pairs from each tree were randomly assigned to each mechanical test and moisture category (Krahmer and Snodgrass 1966). The tests, which were conducted according to ASTM Standard D143-52, included static bending, tension perpendicular to the grain in radial and tangential directions, radial and tangential shear parallel to the grain, radial and tangential toughness, compression parallel and perpendicular to the grain, and end and side hardness.

The air-dry specimens came to equilibrium at 10 to 14 percent moisture content. By Wilson's equation (Markwardt and Wilson 1935, p. 51), strength values were adjusted to what they would be at 12 percent. For a particular property, the equation requires knowledge of the ratio of strength at 12 percent moisture content to that in the green condition. Bendtsen's (1968) spruce pine averages were used for most of these ratios. For maximum tensile strength perpendicular to the grain and for fiber stress at the proportional limit in compression parallel to the grain (which Bendtsen did not evaluate), the ratio used was that given by Markwardt and Wilson (1935, p. 54) for softwoods in general. For spruce pine the literature contains no ratio for toughness, and therefore a ratio was computed from the study means. This procedure seemed reasonable because air-dry moisture content of toughness specimens averaged 11.8 percent.

Within-stem variation.—From data collected at the 1,296 sampling points in the 72 spruce pine stems, within-stem trends were evaluated for several properties of wood and fibers. Three annual rings at each of three heights were sampled in each tree. When data from all trees were combined for regression analysis, however, all heights (in 8.25-foot increments) to the 4-inch top and most annual rings were represented.

For measurement of fiber length and fibril angle, earlywood and latewood tissues of the selected ring were excised from one of the 300-μm.-thick wafers taken from each sampling point. The two tissues were macerated separately. Fiber length was measured with an ampliscope and fibril angle by polarization as described earlier. From each sample point, 20 fibers of each tissue type were measured for each parameter.

Fiber cross-sectional dimensions were measured at each sample point on the transverse surface of blocks *a*, previously described, with a dual-linear micrometer (Smith 1965). The blocks were saturated and the surfaces prepared with a scalpel and stained with fast-green. Four traverses across each tissue type were made in the radial direction. Average tracheid diameter, wall thickness, and lumen diameter were obtained. Four passes of 50 cells each were made in the tangential direction within each tissue type; only average diameter was measured.

Extractive-free specific gravity at each sample point was computed from tracheid dimensions obtained with the dual-linear micrometer. The method was that of Smith (1965), in which percentage of cross-sectional area occupied by the water-swollen cell walls is multiplied by wall specific gravity. The multiplier is considered constant for extractive-free walls of a species. The value used for spruce pine was 0.988 (Kellogg and Wangaard 1969).

Microtensile strength was measured on specimens derived from wafers removed at each of the nine points sampled within each stem. Tensile strength of small specimens has been found to be considerably lower than values obtained from ASTM Standard specimens (Salamon 1966; Biblis 1969). At least part of this difference is caused by cell wall deformation induced during microtomy; the deformations can be minimized by proper positioning of the knife (Dinwoodie 1966; Keith and Côté 1968; Biblis 1970; Kennedy and Chan 1970). Ifju et al. (1965) have shown that rectangular specimens give higher tensile strength values and more reproducible results than necked-down specimens, and Biblis (1970) has demonstrated that tensile strength is positively correlated with thickness of microtome sections.

Radial wafers were therefore cut from saturated blocks with a power microtome at a nominal thickness of 300 μm. Earlywood and latewood rectangular specimens were punched from the selected annual ring with a pair of microtome knives separated by a metal strip. Width of the specimens varied with tissue types and ranged from 100 to 500 μm. A pair of notecard tabs was glued with epoxy to each end of all specimens. The distance between tabs, the gage length, was ½-inch. Specimens were conditioned at 50-percent relative humidity and 73° F. They were pulled to failure in tension with a universal testing machine at a load rate of 0.006 in./min. Cross-sectional dimensions of each specimen were measured (in the vicinity of the failure) with a microscope fitted with a micrometer eyepiece.

Longitudinal shrinkage, from water-swollen to ovendry, was measured in specimens excised from each of the 1,296 sampling points. Shrinkage of three specimens was measured at each point. Radially cut wafers with a nominal thickness of 300 μm. were used. Sadoh and Christensen (1967) have shown that longitudinal shrinkage in sections more than 80 μm. thick differs little from that in thicker sawn specimens. Earlywood and latewood specimens were excised from the air-dry wafers with a razor blade. The radial dimension varied with tissue width, but the smallest measured approximately 1,200 μm. in earlywood and 650 μm. in latewood. Gage length was 1 inch along the grain and was established by two minute notches made in one side of each specimen, one near each end.

The specimens were resaturated and lengths measured in the swollen and ovendry conditions. Total shrinkage is reported as a percentage of the swollen length. Measurements were made with a dual-linear micrometer to the nearest 0.1 μm. To maintain their ovendry condition, the specimens were measured between two hot slides. They could be held for 3 minutes without elongating. To keep the dry specimens straight, they were pressed against a straightedge glued to the bottom slide and held flat by the clips of the microscope stage.

Stem weights and volumes.—Weights and volumes of wood and bark were derived from the measurements made at 8.25-foot intervals along the stem to the 4-inch top. Stumpwood was excluded. For determination of volumes, each 8-foot log was considered to be a truncated cone. The radius at each end was the mean of eight radii. Mean bark thickness was derived from a measurement at each of the eight radii. For wood, heartwood, and bark, log volumes were added to obtain stem volume.

Earlywood and latewood volumes were computed by first determining the percent of latewood at one radius on each end of the log. Latewood percentage was computed by an equation (Miller and Malac 1956) which recognizes that a latewood band near the bark contributes more to area than does one of equal width near the pith:

$$\text{Percent of latewood} = \frac{2\,\Sigma(r_0 x) - \Sigma x^2}{R^2}(100) \quad (1)$$

where:

r_0 = distance from pith to end of the annual ring

x = width of ring's latewood

R = wedge radius

The percentages for the two log ends were averaged and multiplied by log wood volume to arrive at log latewood volume. Earlywood volume was computed as the difference between wood and latewood volumes.

For both wood and bark, total weight (ovendry) was computed from stem volume and specific gravity. Because heartwood specific gravity was not determined, heartwood weight was not calculated.

Tree average specific gravities were not available for conversion of earlywood and latewood volumes to weights. However, earlywood specific gravities calculated from the dual-linear micrometer measurements were found to be relatively uniform. They were highest at the butt and highest near the pith at all levels, but there were no differences among age classes or between growth rates. Therefore, the average of all 648 earlywood samples (0.376, based on green volume and ovendry weight) was used to convert earlywood volume to weight. Latewood weight was taken to be the difference between weights of stem wood and of earlywood.

Data on all aspects of the study were analyzed statistically, and all comparisons mentioned are significant at the 0.05 level of probability.

RESULTS

The 72 spruce pines (table 1) ranged in age from 13 to 56 years. Slow-grown trees averaged 9.0 rings per inch at stump height, while fast-grown trees averaged 4.9 rings. While age classes were nominally 15, 30, and 45 years, they averaged 18.5, 30, and 46.5 years.

Latitude and longitude were not correlated with any of the properties measured.

Tracheid Morphology

As has been described, tracheid dimensions and fibril angle were measured by two approaches. Tree-average values were derived from macerated tissue sampled in proportion to occurrence by volume in the merchantable stem. Within-stem trends were observed by sampling earlywood and latewood tissue at nine locations in each stem. Fiber length and fibril angle were measured on macerated tissue; transverse dimensions were measured on the transverse surface of water-swollen blocks. For all 72 stems there were therefore 648 unweighted sample points within each tissue type; the effect was to sample virtually all annual rings at all heights (in 8-foot incre-

Table 1.—*Average age and size of the 72-tree spruce pine sample*

Tree age class and growth rate (rings/inch)	Age	Growth rate	D.b.h.	Total height	Length of stem to 4-inch top, o.b.
	Years	*Rings/inch*	*Inches*	– – *Feet* – –	
15 years					
>6	19.4	8.3	4.9	38.0	13.5
<6	17.7	4.6	8.0	49.0	31.5
30 years					
>6	30.6	9.2	6.7	50.5	32.0
<6	29.2	4.8	12.1	70.5	56.5
45 years					
>6	49.0	9.6	10.6	67.5	53.0
<6	44.3	5.3	16.7	83.5	72.0

ments). Regression analysis was employed to describe within-stem patterns. It will be recognized that this scheme prohibits removal of between-tree variation.

Tracheid length.—Tree-average tracheid lengths for each age class and growth rate are presented in table 2. Tracheids were longer in fast-grown trees, and length increased with increasing age of trees.

Tree growth rate	Tracheid length
Rings per inch	*Mm.*
>6	3.5
<6	3.7

Tree age class	Tracheid length
Years	*Mm.*
15	3.3
30	3.6
45	4.0

The grand mean for all trees was 3.6 mm., with standard deviation of 0.4 mm.

When earlywood and latewood values were averaged separately and unweighted, growth rate was not significant, but fiber length again increased significantly with each age class for both tissue types.

Table 2.—*Stem-average values for dimensions and fibril angle of macerated tracheids from 72 spruce pines*

Tree age class and growth rate (rings/inch)	Tracheid length [1]	Fibril angle [2]	Tracheid radial diameter [3]	Lumen radial diameter [3]	Tracheid wall thickness [3]
	Mm.	*Degrees*	– – – – – –	$\mu m.$	– – – – – –
15 years					
>6	3.2	36.7	42.1	31.4	5.3
<6	3.4	39.4	44.3	33.5	5.4
30 years					
>6	3.4	35.4	39.5	27.5	6.0
<6	3.7	36.4	45.4	32.5	6.4
45 years					
>6	3.9	33.2	44.2	32.5	5.8
<6	4.0	34.0	48.2	36.4	5.9

[1] Means from 12 trees with 150 tracheids measured per tree.

[2] Means from 12 trees with 120 tracheids measured per tree.

[3] Means from 12 trees with 100 tracheids measured per tree.

Tree age class	Tracheid length	
	Earlywood	Latewood
Years	*- - Mm. - -*	
15	3.0	3.4
30	3.2	3.6
45	3.3	3.7

The grand mean for all earlywood tissue was 3.2 mm., with standard deviation of 0.7 mm.; latewood tracheids averaged 3.5 mm. in length, with standard deviation of 0.7 mm.

Tracheid length varied more with position in stem than did other properties measured. Tracheid length contour lines were hand-fitted to the data, as were curves showing the relationship between length and radial position at various heights in the stem (fig. 5). Length increased radially with age until about the 8th to 12th year and then remained relatively constant. Tracheids were shortest near the pith and at the base of the tree; they tended to be longest near the bark at a height 15 to 25 feet above ground level.

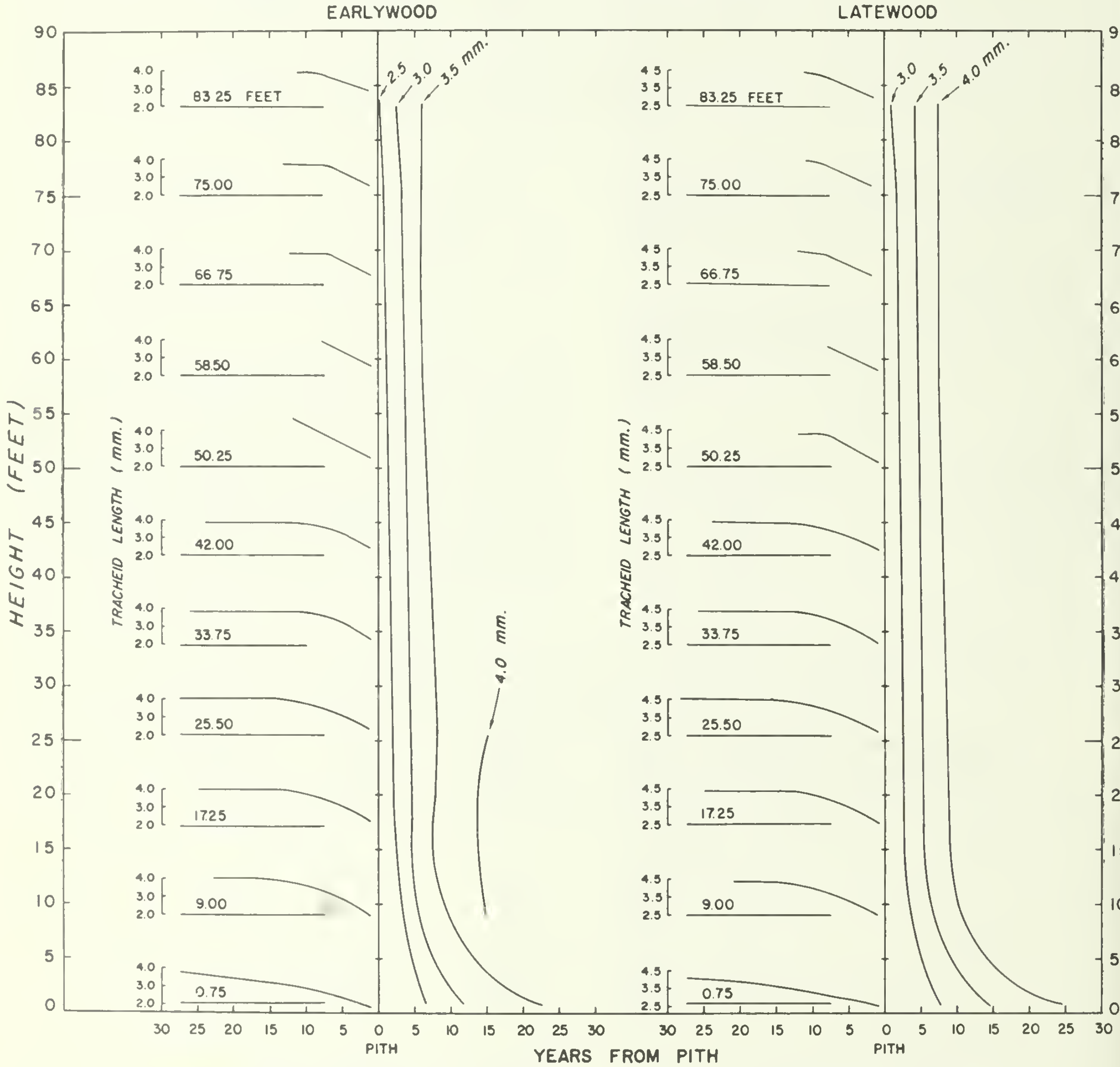

Figure 5.—*Length variation of macerated earlywood and latewood tracheids with position in the stem. To the right of pith are vertical tracheid-length contour lines. To the left are curves showing relationship between tracheid length and years from pith at the heights sampled. No data were extrapolated to make the curves.*

Regression equations were derived in terms of number of rings from pith to specimen and specimen height above ground, in feet:

Earlywood tracheid length,

$$\text{mm.} = 2.142 + 0.08992\,(\text{number of rings}) - 0.001268\,(\text{number of rings})^2 + 0.003129\,(\text{height}) + 0.004484\,(\text{number of rings})(\text{height}) - 0.00003444\,(\text{number of rings})(\text{height})^2 - 0.0001183\,(\text{numberof rings})^2(\text{height}) \quad (2)$$

The equation accounted for 48.6 percent of the variation ($R^2 = 0.486$). Standard error of the estimate (SE), computed as $\sqrt{\text{residual mean square}}$, was 0.49 mm.

Latewood tracheid length,

$$\text{mm.} = 2.56 + 0.08651\,(\text{number of rings}) - 0.001375\,(\text{number of rings})^2 + 0.003154\,(\text{number of rings})(\text{height}) - 0.000003\,(\text{number of rings})^2(\text{height})^2 \quad (3)$$

$R^2 = 0.415$. SE = 0.56 mm.

Tracheid diameter.—For tree-average weighted samples, only radial diameter was measured on the macerated tracheids (table 2). Tracheids from fast-grown trees averaged significantly larger (45.9 μm.) than those from slow-grown (41.9 μm.). There were no significant differences among age classes. The grand mean was 43.9 μm., with standard deviation of 7.4 μm. The chemical treatment required for maceration causes swelling, and diameters therefore are larger than when tracheids are measured in place.

As measured on the surface of water-swollen blocks, earlywood tracheid radial diameter averaged 37.4 μm., with standard deviation of 5.1 μm.; latewood radial diameter averaged 24.3 μm., with standard deviation of 3.6 μm.

In both earlywood and latewood tissue, radial diameter averaged larger in fast-grown trees. The unweighted means (based on nine samples per tree) were:

Tree growth rate	Radial diameter: Earlywood	Radial diameter: Latewood
Rings per inch	— — — μm. — — —	
<6	38.4	25.3
>6	36.4	23.3

Radial diameter (fig. 6) was smallest near the pith and increased radially with distance, tending to reach a maximum. It varied little with height near the pith. In earlywood, radial diameter appeared to reach a maximum near the bark about 20 feet above the ground; in latewood there did not appear to be a clear-cut trend with height in stem.

A greater percentage of the within-stem variation in transverse dimensions was accounted for by expressing distance from the pith in inches rather than in number of annual rings. The regressions were:

Earlywood tracheid radial diameter,

$$\mu\text{m.} = 33.69 + 1.382\,(\text{distance from pith}) - 0.0009352\,(\text{height})^2 + 0.1268\,(\text{distance})(\text{height}) - 0.0005091\,(\text{distance})^2(\text{height})^2 \quad (4)$$

$R^2 = 0.399$. SE = 4.0 μm.

Latewood tracheid radial diameter,

$$\mu\text{m.} = 21.29 + 2.258\,(\text{distance from pith}) - 0.1542\,(\text{distance})^2 - 0.007654\,(\text{distance})^2(\text{height}) + 0.0001381\,(\text{distance})^2(\text{height})^2 \quad (5)$$

$R^2 = 0.226$. SE = 3.2 μm.

Tracheid tangential diameter (unweighted) in both earlywood and latewood varied with growth rate and with tree age. Diameter was larger in fast-grown trees. Latewood tracheids were somewhat narrower than earlywood tracheids.

Tree growth rate	Tangential diameter: Earlywood	Tangential diameter: Latewood
Rings per inch	— — — μm. — — —	
<6	30.7	29.4
>6	29.2	27.5

For earlywood, diameter of the 15-year age class was significantly smaller than that of the 45-year class; in latewood there was no difference between averages for the 15- and 30-year classes, but both were smaller than that of the 45-year class.

Tree age class	Tangential diameter: Earlywood	Tangential diameter: Latewood
Years	— — — μm. — — —	
15	29.2	27.7
30	30.0	28.4
45	30.7	29.4

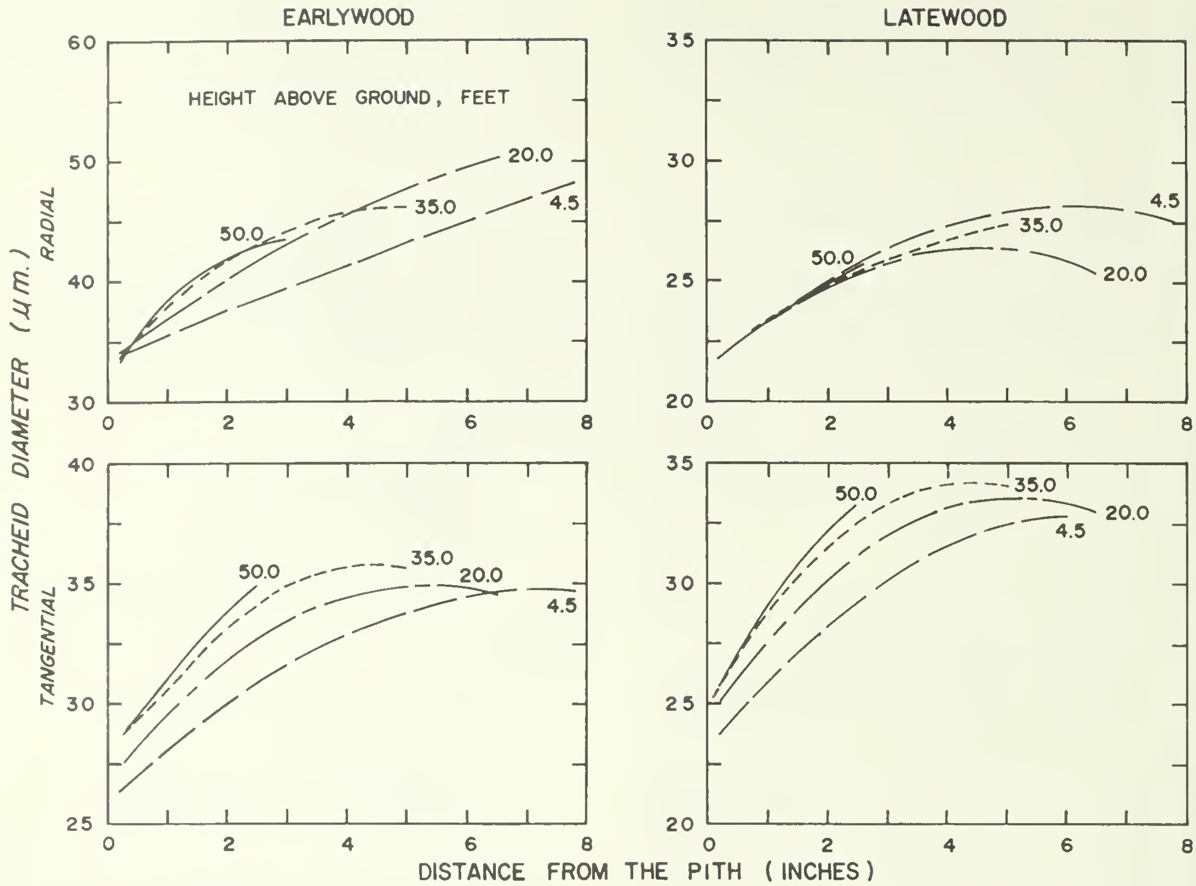

Figure 6.—*Tracheid radial and tangential diameters as related to height above ground and distance from pith. Diameters were measured on surfaces of water-swollen blocks.*

For all samples combined, tangential diameter of earlywood averaged 30.0 μm., with standard deviation of 3.4 μm.; latewood diameter averaged 28.5 μm., with standard deviation of 3.6 μm.

Tangential diameter increased radially from the pith until it reached a maximum (fig. 6). At all radial positions, it increased with increasing height in the stem.

Where distance from pith was expressed in inches, the equation for earlywood accounted for 51.2 percent of the variation.

Earlywood tracheid tangential diameter, μm. = 25.55 (6)
+ 2.121 (distance from pith)
— 0.1158 (distance)^2
+ 0.08707 (height)
— 0.001279 (height)^2
+ 0.05331 (distance)(height)
— 0.009517 (distance)^2(height)
R^2 = 0.512. SE = 2.4 μm.

The equation for latewood was:

Latewood tracheid tangential diameter, μm. = 22.79 (7)
+ 2.715 (distance from pith)
— 0.1684 (distance)^2
+ 0.1059 (height)
— 0.001362 (height)^2
+ 0.04618 (distance)(height)
— 0.00946 (distance)^2(height)
R^2 = 0.532. SE = 2.5 μm.

Tracheid lumen diameter.—For weighted tree-average measurements, only lumen radial diameter was measured in macerated tissue (table 2). For all trees the grand mean was 32.3 μm., with standard deviation of 10.0 μm. Statistically there was no difference between growth rates or among age classes.

As measured on the surface of water-swollen blocks, both earlywood and latewood lumen radial diameter averaged larger in fast-grown trees.

Growth rate	Lumen radial diameter	
	Earlywood	Latewood
Rings per inch	– – – *μm.* – – –	
<6	31.2	13.2
>6	29.5	11.7

The mean for earlywood was 30.4 μm., with standard deviation of 4.9 μm. Latewood lumen radial diameter averaged 12.5 μm., with standard deviation of 2.5 μm.

Diameter increased radially from the pith, tending to reach a maximum and then remain constant (fig. 7). In latewood the radial increase became less pronounced with increasing height in the stem. In both earlywood and latewood, radial diameter was largest near the bark in the lower portion of the stem.

From the 648 within-stem sampling points, the earlywood regression equation accounted for 37.2 percent of the observed variation, with standard error of 3.9 μm.

Earlywood lumen radial diameter,

$$\begin{aligned}\mu m. = {} & 26.26 \\ & + 1.4475 \text{ (distance from pith)} \\ & - 0.0003774 \text{ (height)}^2 \\ & + 0.2442 \text{ (distance)(height)} \\ & - 0.002777 \text{ (distance)(height)}^2 \\ & - 0.04884 \text{ (distance)}^2\text{(height)} \\ & + 0.0006476 \text{ (distance)}^2\text{(height)}^2\end{aligned} \quad (8)$$

The latewood regression equation accounted for only 9.1 percent of the observed variation, with standard error of 2.4 μm.

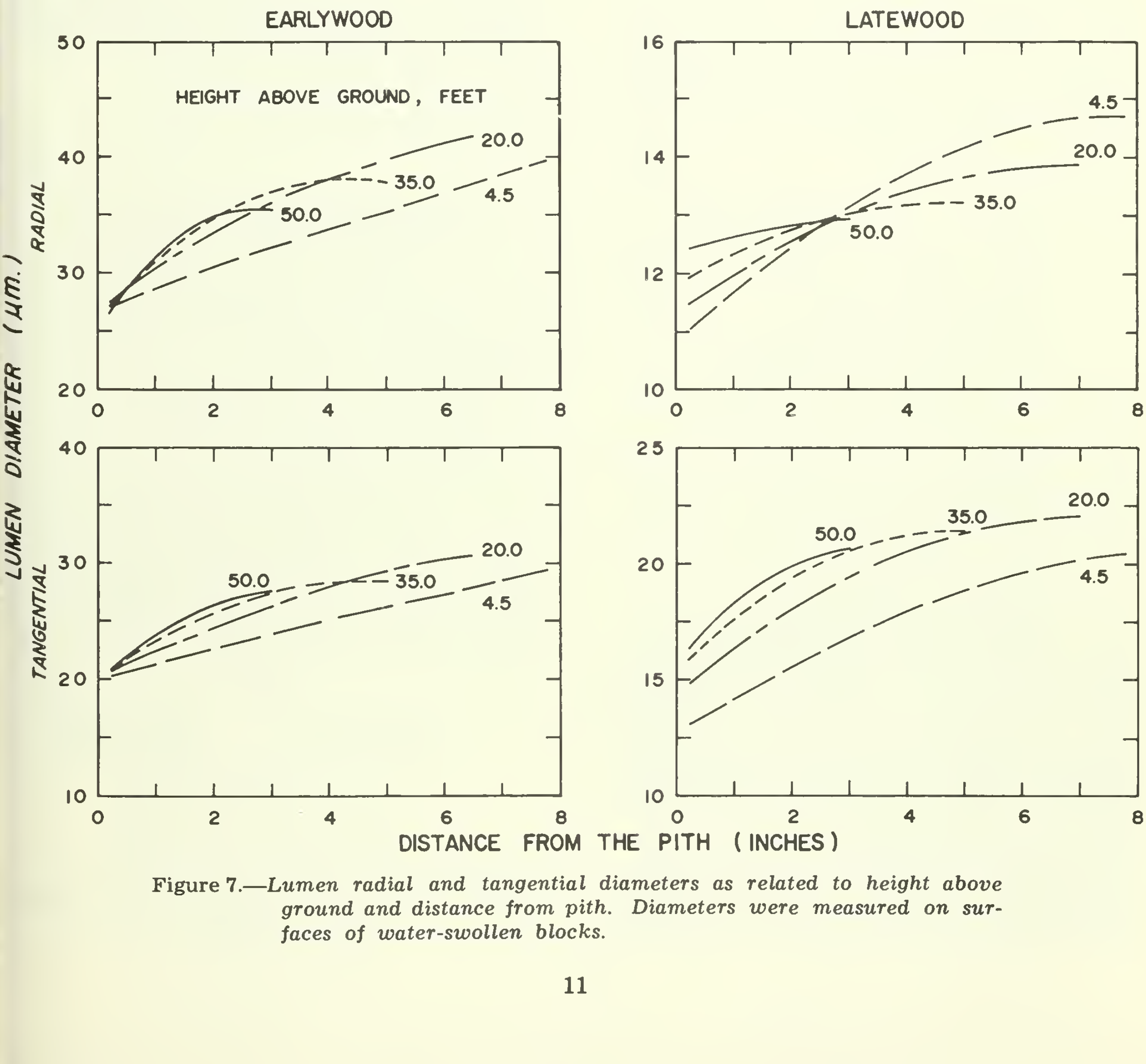

Figure 7.—*Lumen radial and tangential diameters as related to height above ground and distance from pith. Diameters were measured on surfaces of water-swollen blocks.*

Latewood lumen radial diameter,

$$\mu m. = 10.65 + 1.024\ (\text{distance from pith}) + 0.03388\ (\text{height}) - 0.05929\ (\text{distance})^2 - 0.01315\ (\text{distance})(\text{height}) \quad (9)$$

Lumen tangential diameter was calculated for earlywood and latewood by subtracting radial wall thickness from tracheid tangential diameter. The latter value was measured; radial wall thickness, not measured, was assumed to equal tangential wall thickness. Subsequent observations (Koch 1972, p. 164) indicate that this assumption may be in error; i. e., radial walls of latewood (but not earlywood) appear to be slightly thicker than tangential walls.

For both earlywood and latewood, lumen tangential diameter increased radially with distance from the pith (fig. 7); it then tended to remain constant in outer portions of the stem. Changes with height were not pronounced in earlywood. In latewood, diameter increased with height near the pith, but in the outer portion of the stem it tended toward 21-22 μm. at all heights.

The regressions were:

Earlywood lumen tangential diameter,

$$\mu m. = 20.28 + 0.8502\ (\text{distance from pith}) - 0.0002276\ (\text{distance})^2 + 0.08332\ (\text{distance})(\text{height}) - 0.0003482\ (\text{distance})^2(\text{height})^2 \quad (10)$$

$R^2 = 0.390$. SE $= 2.5\ \mu$m.

Latewood lumen tangential diameter,

$$\mu m. = 12.26 + 1.46\ (\text{distance from pith}) - 0.07604\ (\text{distance})^2 + 0.1223\ (\text{height}) - 0.001032\ (\text{height})^2 + 0.03133\ (\text{distance})(\text{height}) - 0.0001626\ (\text{distance})^2(\text{height})^2 \quad (11)$$

$R^2 = 0.370$. SE $= 2.8\ \mu$m.

Wall thickness.—As measured on macerated tissue, the weighted tree average for tracheid tangential wall thickness was 5.8 μm., with standard deviation of 1.7 μm. There was no significant difference between growth rates or among tree age classes (table 2).

Measured on the transverse surface of water-swollen blocks, thickness of earlywood tangential walls did not differ with tree growth rate or age class when the 648 unweighted within-stem averages were compared. The average was 3.5 μm., with standard deviation of 0.6 μm.

Latewood tangential walls averaged 5.9 μm., with standard deviation of 1.1 μm. Tracheids of fast-grown trees had significantly thicker walls than those of slow-grown trees:

Tree growth rate	Thickness of tangential wall
Rings per inch	*μm.*
<6	6.1
>6	5.8

In both earlywood and latewood, wall thickness increased radially outward from the pith for 5 to 6 inches; it then remained relatively constant (fig. 8). The increase was more rapid in latewood than in earlywood. In earlywood, wall thickness did not vary with height, but in latewood it decreased with increasing height in the stem at all radial positions.

The equations were:

Earlywood wall thickness,

$$\mu m. = 3.16 + 0.2877\ (\text{distance from pith}) - 0.02247\ (\text{distance})^2 \quad (12)$$

$R^2 = 0.168$. SE $= 0.51\ \mu$m.

Latewood wall thickness varied with both radial distance and with height in tree.

Latewood wall thickness,

$$\mu m. = 5.24 + 0.6828\ (\text{distance from pith}) - 0.01022\ (\text{height}) - 0.0595\ (\text{distance})^2 \quad (13)$$

$R^2 = 0.273$. SE $= 0.93\ \mu$m.

Fibril angle.—Though tree age was not related to orientation of the S_2 microfibrils in either earlywood or latewood considered separately, stem-average values (table 2) decreased with increasing age:

Tree age class	Fibril angle
Years	*Degrees*
15	38.1
30	35.9
45	33.6

Mean fibril angle for all 72 trees was 35.9°, with standard deviation of 4.1°.

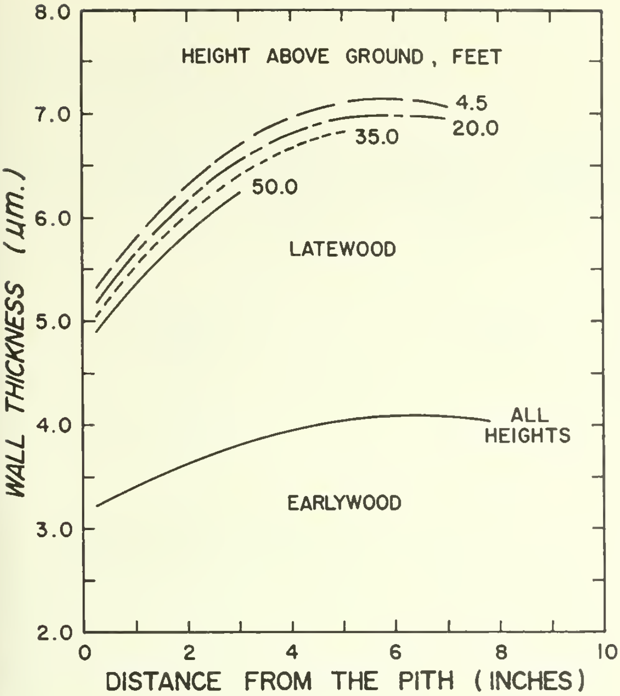

Figure 8.—*Thickness of tracheid tangential walls as related to height above ground and distance from pith. Thicknesses were measured on surfaces of water-swollen blocks.*

Neither tree means nor latewood fibril angle varied with growth rate. In earlywood, however, the angle averaged 37.5° in slow-grown trees and 39.0 in fast-grown, a significant difference. It averaged 38.3° for all trees, with standard deviation of 7.2°. Latewood angle averaged 34.7°, with standard deviation of 6.8°.

It was highest close to the pith near the base of the tree. In the lower portion of the stem it decreased with increasing height, but above approximately 30 feet it remained relatively constant. At all heights it decreased with distance radially from the pith.

Fibril angle did vary significantly with position in the stem (fig. 9).

The equations were:

Earlywood fibril angle,

$$\text{degrees} = 44.03 - 0.08788\,(\text{number of rings}) - 0.3058\,(\text{height}) + 0.002805\,(\text{height})^2 - 0.02326\,(\text{number of rings})(\text{height}) + 0.0003174\,(\text{number of rings})(\text{height})^2 + 0.0004478\,(\text{number of rings})^2(\text{height}) \quad (14)$$

$R^2 = 0.246$. SE $= 6.3°$.

Latewood fibril angle,

$$\text{degrees} = 40.02 - 0.141\,(\text{number of rings}) - 0.3593\,(\text{height}) + 0.004136\,(\text{height})^2 \quad (15)$$

$R^2 = 0.177$. SE $= 6.2°$.

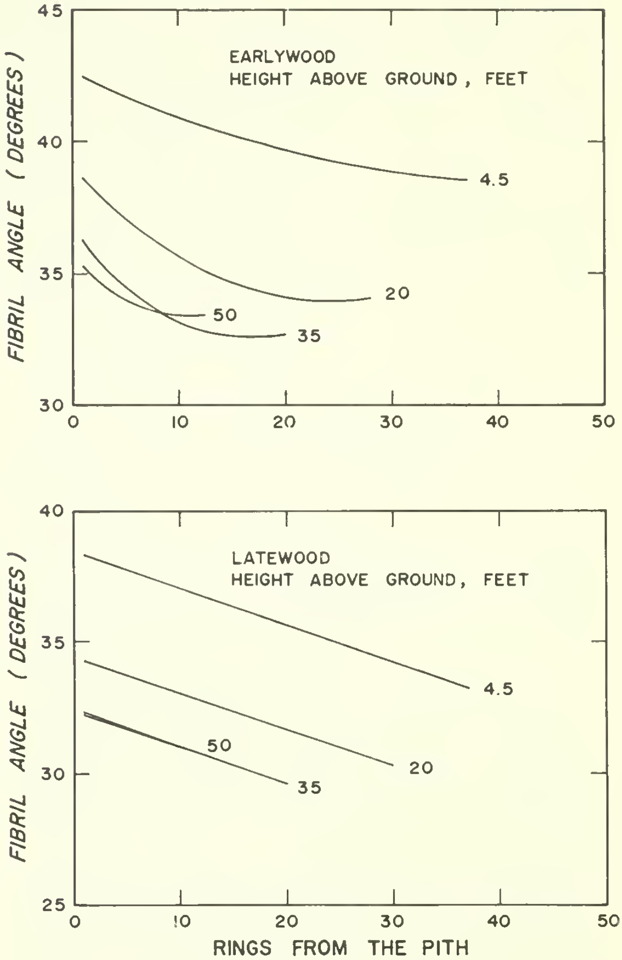

Figure 9.—*Fibril angle as related to height above ground and rings from pith. Angle of macerated tracheids was determined by polarization.*

Correlation coefficients.—Simple correlations were determined between mean values of properties measured at the 1,296 within-stem sampling points. Table 3 lists all correlations whose "r" values were 0.20 or higher.

In addition to the obvious relationships (as that lumen radial diameter is highly correlated with tracheid radial diameter), a few trends were evident. In earlywood, radial and tangential diameters tended to be correlated both in tracheids ($r = 0.61$) and in lumens ($r = 0.69$). To a lesser extent, tracheid and lumen

Table 3.—*Simple correlations for within-stem variables*[1]

Variable	Tracheid: Radial diameter	Tracheid: Tangential diameter	Lumen: Radial diameter	Lumen: Tangential diameter	Tangential wall thickness	Fibril angle	Ring width	Tissue width	Latewood percent	Specimen location: From pith, ring	Specimen location: From pith, inch	Specimen location: Above ground
Specific gravity	−0.32	−0.35	−0.51	−0.62	0.75	..	...	..	0.24	...	..	..
	..	...	*−.41*	*−.60*	*.76*	...	...	.	..	.	..	..
Tracheid												
Length	.53	.57	.50	.52	.22	0.31	...	..	..	0.49	0.50	..
	.26	*.56*	..	*.38*	*.33*	*−.31*	...	.	..	*.46*	.48	...
Radial diameter		.69	.98	.61	.32	..	..	0.26	−.21	.36	.51	..
		.42	*.80*	..	*.73*	.	*0.26*	..	...	*.31*	*.44*	...
Tangential diameter			.65	.94	.30	.	.26	.27	..	.41	.57	..
			.27	*.81*	*.37*	*−.21*	*.30*	.	..	*.38*	*.57*	..
Lumen												
Radial diameter				.65	..	..	.	.25	−.24	.32	.45	..
				.	...	...	*.31*	...	...	...	*.25*	...
Tangential diameter					..	..	.21	.25	.	.34	.46	.
					−.24	..	*.27*	.	.	.	*.32*	*0.38*
Tangential wall thickness						..	..	.	..	.27	.39	..
						..	...	.	..	*.41*	*.44*	*−.29*
Fibril angle							.26	..	.23	.	.	−.36
							.	*.30*	*.24*	..	*.25*	*−.26*

[1] Leaders (. .) indicate correlations of less than 0.20. Upper value of each pair is for earlywood, and lower value (in italics) is for latewood.

diameters were correlated with tracheid length (r = 0.50 and 0.57). These relationships were less evident in latewood, where the coefficient for radial and tangential tracheid diameters was 0.42 and tracheid length was related only to tangential diameters of tracheids (r = 0.56) and of lumens (r = 0.38).

As expected, specific gravity was positively correlated with wall thickness (r = 0.75). In earlywood, specific gravity was related more to lumen radial (r = —0.52) and tangential (r = —0.62) diameters than to tracheid diameters (r = —0.32 and —0.35). The same relations occurred in latewood but were less pronounced.

Wall thickness in latewood was positively correlated with radial diameter (r = 0.73). The relationship was less evident for tangential diameter (r = 0.37) and for earlywood diameters (r = 0.32 and 0.30).

Fibril angle was not highly correlated with any of the other variables.

Longitudinal Shrinkage

Percent of shrinkage from water-swollen to ovendry condition was measured for three specimens at each of the 1,296 within-stem sampling points. Shrinkage did not vary significantly with tree growth rate, age class, or position in the stem. Longitudinal shrinkage averaged 0.49 percent for earlywood and 0.26 for latewood, with standard deviations of 0.09 and 0.08 percent.

The sampling points were separated into those falling into heartwood and those falling into sapwood.

Type of wood	Longitudinal shrinkage	Observations
	Percent	*Number*
Earlywood		
Heartwood	0.54	29
Sapwood	.49	619
Latewood		
Heartwood	.29	29
Sapwood	.26	619

For reasons unclear, heartwood specimens shrank more than sapwood.

Specific Gravity

Specific gravity of bark, based on weighted samples at 8-foot stem intervals, averaged 0.381

(basis of ovendry weight and green volume) for all trees; standard deviation was 0.03.

Tree age class and growth rate (rings per inch)	Bark specific gravity
15 years	
<6	0.355
>6	.380
30 years	
<6	.376
>6	.396
45 years	
<6	.382
>6	.398

Slow-grown trees, with an average gravity of 0.391, had denser bark than fast-grown (0.371). The 30- and 45-year age classes did not differ significantly, but bark of trees in the 15-year age class (0.368) was less dense than that in either of the older classes (0.386 and 0.390).

Figure 10 charts bark specific gravity in terms of butt growth rate (rings per inch) and tree age. The equation was:

$$\text{Tree bark specific gravity} = 0.3308 + 0.004364\ (\text{butt growth rate}) + 0.000635\ (\text{tree age}) \qquad (16)$$

$$R^2 = 0.22. \quad SE = 0.029.$$

Figure 10.—*Tree-average bark specific gravity as related to tree age and growth rate at butt.*

In the merchantable stem, specific gravity of unextracted wood averaged 0.425 (basis of ovendry weight and green volume) for all 72 trees. Extracted specific gravity averaged 0.413, about 2.8 percent less.

A regression equation accounted for 75.7 percent of the variation between tree averages for extracted and unextracted wood; standard error of the estimate was 0.017:

$$\text{Extracted specific gravity} = 0.0713 + 0.8056\ (\text{unextracted specific gravity}) \qquad (17)$$

Slow-grown trees were denser than fast-grown, but there were no differences among age classes.

Condition and tree age class (years)	Less than 6 rings per inch (avg. 4.9)	More than 6 rings per inch (avg. 9.0)
	Tree average specific gravity	
Unextracted		
15	0.414	0.448
30	.406	.450
45	.403	.426
Extracted		
15	.398	.433
30	.397	.442
45	.389	.422

Unextracted specific gravity averaged 0.442 for slow-grown and 0.408 for fast-grown trees. For extractive-free wood, comparable stem means were 0.432 and 0.395.

Taras and Saucier (1968) computed a spruce pine species average from a sample of 1,155 unstratified trees. Their value was 0.426, very close to the present 0.425. They found that increment core gravity at breast height averaged 0.443.

Earlywood and latewood extractive-free specific gravities were determined by dual-linear micrometer from the 648 unweighted sample locations within each tissue type (72 trees × 3 heights × 3 radial positions). Earlywood averaged 0.376, and latewood 0.691. There were no significant differences among age classes or between growth rates for either earlywood or latewood. Within both tissue types, however, some differences occurred with location in the stem.

Regressions illustrated these differences but accounted only for a limited amount of the variation (fig. 11). Earlywood specific gravity was negatively correlated with number of rings from the pith and decreased with increasing height in the stem. Latewood, in contrast, tended to increase with age in the upper stem but to remain constant near the base.

The equations were:

Earlywood specific gravity (extractive-free) = 0.4069 — 0.0008555 (number of rings) — 0.002078 (height) + 0.0000242 (height)² (18)

$R^2 = 0.092$. SE = 0.051.

Latewood specific gravity (extractive-free) = 0.7193 — 0.001685 (height) + 0.000001243 (number of rings)(height)² (19)

$R^2 = 0.174$. SE = 0.06.

Neither earlywood nor latewood gravities differed with growth rate, but stem-average values were lower for fast- than for slow-grown trees.

On the average, an annual ring in fast-grown trees contained greater numbers of both types of tracheids, with no differences among age classes. A radial file averaged 75.5 earlywood cells in slow-grown trees and 116.5 in fast-grown. Latewood averaged 35.2 cells per file in slow-grown trees and 47.2 in fast-grown. The number of latewood tracheids in a radial file thus decreased from 31.8 percent in slow-grown trees to 28.8 percent in fast-grown. In consequence, radial width of latewood tissue decreased from 24.9 percent to 21.1 percent. Finally, by equation (1), the weighted percentage of latewood in the merchantable stem decreased from 30.8 percent in slow-grown trees to 25.4 percent in fast-grown trees; there was no difference among age classes. For these reasons, fast-grown trees contained smaller proportions of latewood and hence had lower density.

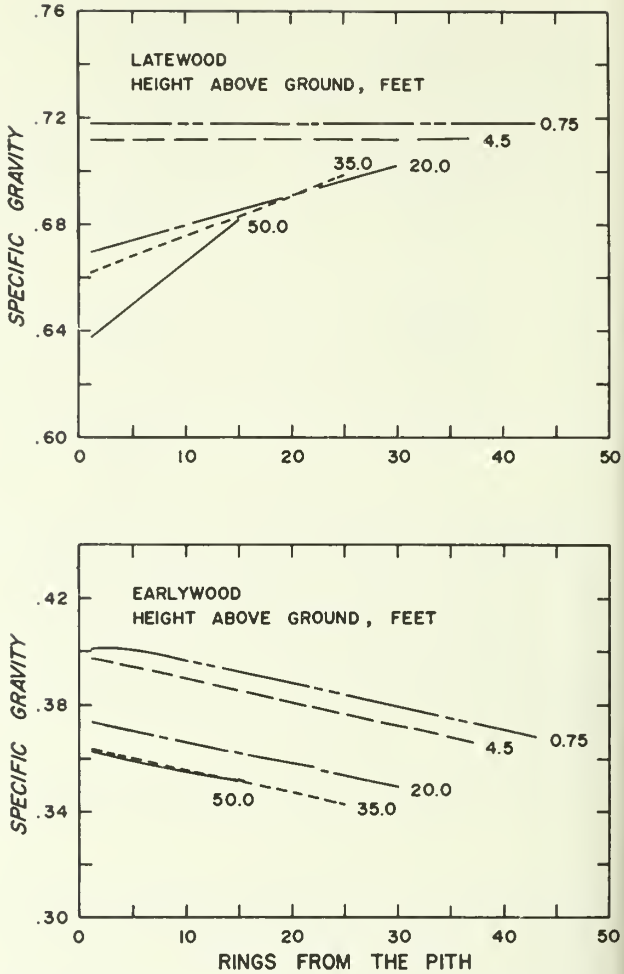

Figure 11.—*Extracted specific gravity (basis of ovendry weight and green volume) as related to height above ground and and rings from the pith.*

Regression analysis, although statistically significant in terms of number of rings from pith and height in tree, explained little of the observed variation of latewood percentage within the stem.

Stem Weights and Volumes

Green volumes and ovendry weights of bark and wood components are presented in table 4. With the exception of heartwood volume, all means for weight and volume follow the same pattern. For stems of the 15-year age class there were no significant differences between growth rates. These trees averaged 0.5 cubic foot of bark to a 4-inch top and 4.2 cubic feet

Table 4.—*Tree-average green volumes and ovendry weights of merchantable stem portions from 72 spruce pines*[1]

Tree age class and growth rate (rings/inch)	Green volume					Ovendry weight			
	Whole wood	Bark	Heart-wood	Early-wood	Late-wood	Whole wood	Bark	Early-wood	Late-wood
	Cu. ft.					*Pounds*			
15 years									
>6	1.4	0.2	0.0	1.0	0.4	38.7	5.4	23.0	15.7
<6	7.0	.8	.0	5.3	1.7	172.3	18.6	124.2	48.1
30 years									
>6	5.5	.7	.0	3.6	1.9	155.3	17.5	86.2	69.1
<6	23.1	2.6	.3	16.9	6.2	581.3	61.1	397.8	183.5
45 years									
>6	18.6	2.1	.6	13.1	5.5	481.5	50.5	308.1	173.4
<6	53.9	4.8	1.9	39.7	14.2	1,338.5	114.4	931.0	407.5

[1] Merchantable stem to a 4-inch (outside bark) top with butt height of 0.75 ft.

of wood—of which 3.2 cubic feet were early-wood and 1.0 cubic foot latewood.

For both the 30- and 45-year age classes, in every column of table 4 (except heartwood) fast-grown trees yielded significantly more wood and bark than did slow-grown. For all ages there were no differences in weights or volumes between fast-grown trees of one age class and slow-grown trees of the next older class; 30-year-old fast-grown trees and 45-year-old slow-grown trees, for example, contained the same weight and volume of wood components and of bark, although there was an average difference of 20 years (table 1).

Spruce pine has little or no heartwood until about age 45. In this age class, fast-grown trees had an average of 1.9 cubic feet of heartwood; slow-grown trees had 0.6 cubic foot. Heartwood volume was measurable in none of the 15-year-old class, in 42 percent of the 30-year class, and in all of the 45-year class. The bark-free portion of the merchantable stems averaged 1.3 percent heartwood by volume in the 30-year class and 3.5 percent in the 45-year class.

Occurrence of heartwood was compared with disk age for each of the 430 disks removed from the 72 trees. Of the 22 disks containing 20 annual rings, approximately 18 percent contained heartwood. Of the 177 disks with 19 or fewer rings only 6 contained any. Heartwood was present in 78 percent of the disks with 27 rings and in 100 percent of the disks with 37 rings.

For those trees containing heartwood, a regression equation was derived for heartwood volume expressed as percent of the merchantable stem. Variables considered were tree age, age^2, crown length, crown width, total height of tree, and butt growth rate. The best equation was:

$$\text{Heartwood volume, percent} = 9.515 - 0.174 \text{ (crown length in feet)} \quad (20)$$

$$R^2 = 0.204. \quad SE = 3.6 \text{ percent.}$$

Equations were derived for ovendry weight and green volume of bark (to a 4-inch top) in terms of diameter (in inches) outside bark at breast height and tree total height in feet (fig. 12).

$$\text{Bark volume, cu. ft.} = 0.003 \text{ (d.b.h.)(tree height)} - 0.616 \quad (21)$$

$$R^2 = 0.938. \quad SE = 0.4 \text{ cu. ft.}$$

$$\text{Bark weight, pounds} = 0.091 \text{ (d.b.h.)(tree height)} - 15.0 \quad (22)$$

$$R^2 = 0.940. \quad SE = 10.6 \text{ lbs.}$$

For trees of all ages, bark comprised about 10.7 percent of stem total volume (to a 4-inch top) and about 9.8 percent of stem ovendry weight.

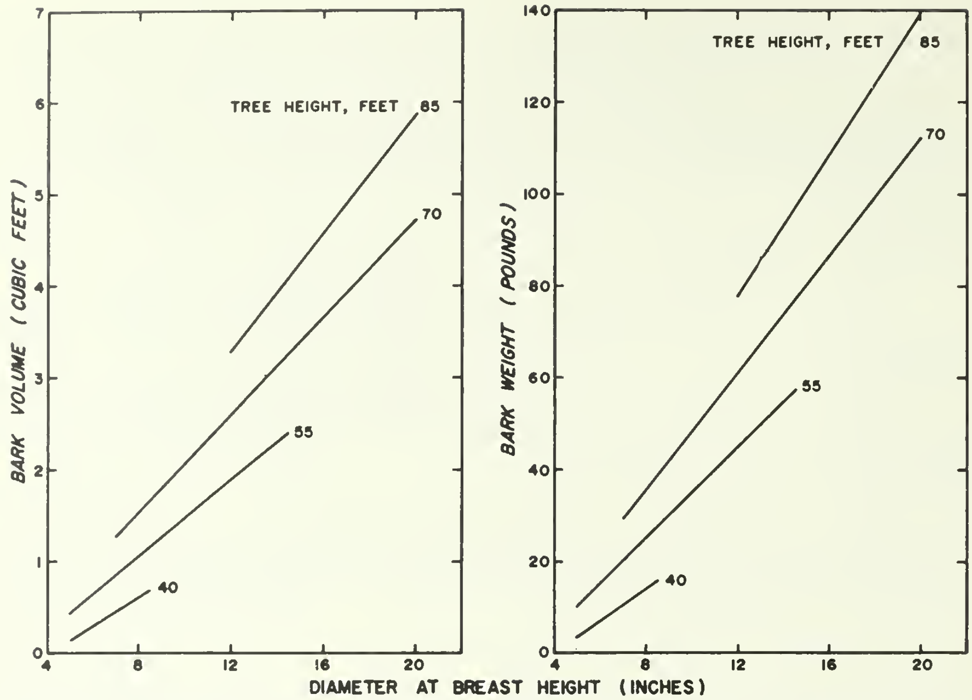

Figure 12.—*Ovendry weight and green volume of stem bark (to a 4-inch top outside bark) as related to diameter outside bark at breast height and total tree height.*

Tree age class and growth rate (rings per inch)	Bark volume	Bark weight	Bark thickness, stump height
	– *Percent* –		*Inch*
15 years			
>6	14.1	12.2	0.22
<6	10.8	9.7	.27
30 years			
>6	11.2	10.1	.25
<6	10.0	9.5	.32
45 years			
>6	10.0	9.5	.28
<6	8.2	7.9	.36

Bark thicknesses from all heights were averaged to obtain a mean thickness for the merchantable stem. Fast-grown trees had thicker bark (0.22 inch) than slow-grown (0.19 inch). Bark thickness increased significantly with age; it averaged 0.18 inch in the 15-year age class, 0.20 in the 30-year class, and 0.23 in the 45-year class.

The best equation for bark thickness at any point was in terms of diameter inside bark, in inches, at that point and height above ground in feet (fig. 13).

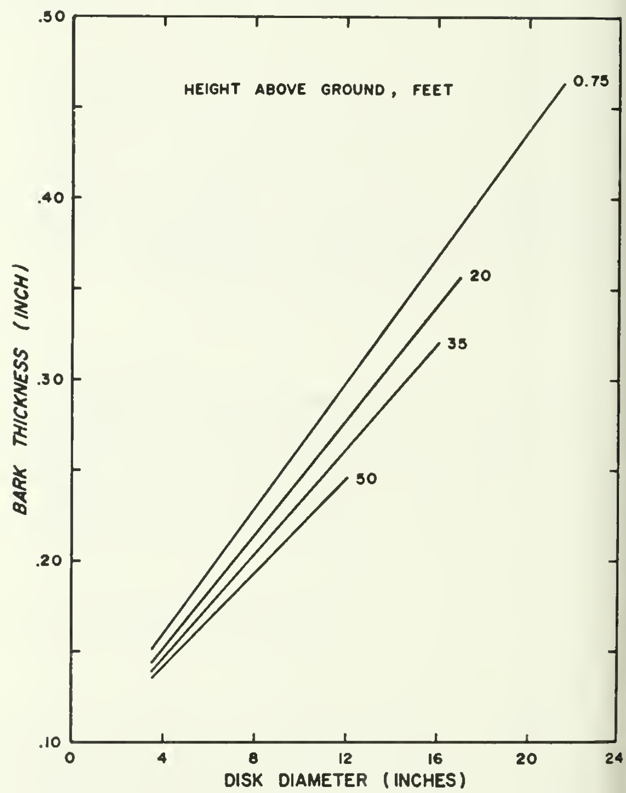

Figure 13.—*Bark thickness as related to disk diameter inside bark at various heights above ground.*

Bark thickness,

$$\text{inch} = 0.0891 + 0.0175\,(\text{diameter inside bark}) - 0.0000871\,(\text{height}) \quad (23)$$

$R^2 = 0.670$. SE = 0.045 inch.

Wood Chemical Constituents

Amounts of chemical constituents in the merchantable stem generally did not differ significantly with tree age or growth rate (table 5). For all trees, extractive content averaged 2.7 percent of the ovendry weight of the unextracted wood.

With extractives removed, ash content averaged 0.46 percent of ovendry weight. Variation among trees was substantial, but may have resulted from the sampling procedure. Two ash samples were run per stem, whereas there were five samples for each of the other components.

Lignin and cellulose means were not adjusted for ash content. Lignin content averaged 28.0 percent of the extractive-free wood for all trees. Only the means for 45-year-old fast- and slow-grown trees, 27.5 and 28.4 percent, were significantly different. Holocellulose content averaged 77.8 percent, of which 49.1 percent was alpha-cellulose and 28.7 percent was hemicellulose.

Mechanical Properties

Standard strength properties were determined for 42 trees of the 30- and 45-year age classes (table 6); the 15-year-old trees and six of the 30-year, slow-grown trees were too small to yield specimens.

Wood from fast-grown trees differed in only a few properties from that of slow-grown trees.

Moisture condition and strength property	Slow grown	Fast grown
Green:		
Modulus of rupture, p.s.i.	7,250	6,470
Modulus of elasticity, p.s.i.	1,430,000	1,130,000
Maximum tensile stress perpendicular to grain (tangential), p.s.i.	270	340
12-percent moisture content:		
Modulus of elasticity, p.s.i.	1,800,000	1,410,000
Hardness (side), pounds	840	700

In general, slow-grown wood was stronger, but only for hardness (12 percent) did specific gravity differ significantly with growth-rate class.

Specimens from the 30-year age class differed significantly from those of the 45-year age class in two properties:

Strength property	Tree age class: 30 years	45 years
Work to maximum load, green specimens, in.-lb. per cu. in.	12.3	9.2
Hardness, side grain, 12-percent specimens, pounds	837	703

Table 5.—*Stem-average values for extractives, ash, lignin, and cellulose fractions of 72 spruce pine trees*

Tree age class and growth rate (rings/inch)	Extractives [1]	Ash [2]	Lignin [3]	Holocellulose [3]	Alpha-cellulose [3]	Hemicellulose [3]
	Percent					
15 years						
>6	2.7	0.46	27.8	78.6	49.2	29.4
<6	2.7	.52	28.2	77.8	48.4	29.4
30 years						
>6	2.8	.51	28.2	80.0	49.6	30.4
<6	2.5	.39	27.9	76.3	48.9	27.5
45 years						
>6	2.6	.43	28.4	76.7	49.0	27.7
<6	2.8	.43	27.5	77.5	49.5	28.0
Mean	2.7	.46	28.0	77.8	49.1	28.7

[1] Based on weight of ovendry, unextracted wood.
[2] Based on weight of ovendry, extractive-free wood.
[3] Based on weight of ovendry, extractive-free wood, not corrected for ash.

Table 6.—*Among-tree variation in clear wood properties of spruce pine*

Strength property	Green			12-percent moisture content		
	42-tree average [1]	Range	Standard deviation	42-tree average [1]	Range	Standard deviation
Static bending						
Fiber stress at proportional limit, p.s.i.	2,830	1,640-4,360	691	4,880	2,710-7,780	1,223
Modulus of rupture, p.s.i.	6,820	3,890-9,480	1,211	10,200	5,530-14,120	2,132
Modulus of elasticity, p.s.i.	1,260,000	480,000-2,240,000	384,000	1,580,000	900,000-3,560,000	500,000
Work to proportional limit, in.-lb. per cu. in.	0.40	0.12-1.01	0.18	0.93	0.28-1.66	0.34
Work to maximum load, in.-lb. per cu. in.	10.54	5.55-19.60	3.54	9.22	0.84-23.30	4.18
Compression parallel to the grain						
Fiber stress at proportional limit, p.s.i.	1,960	1,160-2,730	337	3,660	2,340-5,430	702
Maximum crushing strength, p.s.i.	2,840	1,580-3,940	497	5,670	4,430-7,320	742
Compression perpendicular to the grain						
Fiber stress at proportional limit, p.s.i.	375	245-529	64	796	470-4,705	160
Maximum shear stress parallel to the grain						
Radial, p.s.i.	846	659-1,065	110	1,244	622-1,741	263
Tangential, p.s.i.	841	537-1,048	108	1,214	793-1,631	201
Maximum tensile stress perpendicular to grain						
Radial, p.s.i	288	128-418	63	371	199-583	92
Tangential, p.s.i.	312	123-462	69	397	270-558	79
Hardness (load required to embed a 0.444-inch ball to one-half its diameter)						
Side grain, lb.	535	373-789	107	741	436-1,385	202
End grain, lb.	562	375-889	124	1,064	738-1,620	201
Toughness (specimen 0.79 by 0.79 inch tested over a 9.47-inch span with load applied to radial and tangential faces)						
Radial, in.-lb.	394	109-652	177	148	53-299	56
Tangential, in.-lb.	373	74-648	170	181	49-314	70

[1] Eighteen trees in 30-year class (six slow- and 12 fast-grown) and 24 trees in 45-year class (12 slow- and 12 fast-grown).

In both cases sample specific gravity averaged significantly higher from the 30-year-old trees. For work-to-maximum-load specimens, it was 0.461 and 0.431 (basis of green volume and ovendry weight); for hardness, it was 0.492 and 0.460 (basis of volume at 12 percent moisture content and ovendry weight).

Specific gravity is related to strength, since it is a measure of the cell wall material present per unit volume of wood. Regression equations were derived for most strength properties to determine the degree of linear association with specific gravity (tables 7 and 8). Specific gravity was not measured on air-dry specimens used to determine compression and tension perpendicular to the grain.

Only two strength properties were unrelated to specific gravity. They were work to the proportional limit in static bending and tensile stress perpendicular to the grain when failure is in the tangential plane.

The properties most closely associated with changes in specific gravity (r above 0.75) were modulus of rupture, hardness, and compressive strength parallel to the grain—the latter in green wood only. Properties with correlation coefficients between 0.58 and 0.70 were modulus of elasticity (in both green and dry specimens), maximum crushing strength (dry), and —in green specimens only—work to maximum load, shear stress parallel to the grain, and tensile stress perpendicular to the grain. The specific gravity-strength relationships for four of the properties are shown in figure 14.

Bendtsen (1968) sampled 35 randomly selected spruce pines to obtain a species average for several mechanical properties. His results are summarized in table 9; they are not directly comparable with the values in table 6, since Bendtsen's trees were unstratified while those in the present study were stratified by age and growth rate. Further, specific gravity of test specimens averaged higher in the current study: 0.435 (basis of green volume and ovendry weight) and 0.479 (volume at 12 percent moisture content and ovendry weight), as compared to Bendtsen's 0.413 and 0.441, respectively.

Table 7.—*Linear relationships between strength properties of green spruce pine wood and specific gravity* [1]

Property	Constants a	Constants b	Correlation coefficient	Standard error of the estimate
Static bending				
Fiber stress at proportional limit, p.s.i.	518	5,237	0.29	885
Modulus of rupture, p.s.i.	−2,666	21,355	.87	620
Modulus of elasticity, p.s.i.	−709,240	4,454,145	.58	312,941
Work to maximum load, in.-lb. per cu. in.	−11.8	50.3	.63	3.2
Compression parallel to the grain				
Fiber stress at proportional limit, p.s.i.	585	3,090	.36	426
Maximum crushing strength, p.s.i.	−515	7,571	.77	340
Compression perpendicular to the grain				
Fiber stress at proportional limit, p.s.i.	141	533	.48	70
Maximum shear stress parallel to the grain [2], **p.s.i.**	124	1,675	.70	90
Maximum tensile stress perpendicular to grain				
Radial, p.s.i.	535	62	.63	56
Hardness				
Side grain, lb.	−396	2,116	.94	40
End grain, lb.	−459	2,321	.88	62
Toughness				
Radial, in.-lb.	−121	1,159	.33	171
Tangential, in.-lb.	−78	1,014	.34	162

[1] The constants are from the expression $y = a + bx$. In the equation, y is the strength property of interest and x is unextracted specific gravity (basis of green volume and ovendry weight).
[2] Combined data from wood stressed in both radial and tangential directions.

Table 8.—*Linear relationships between strength properties of airdry spruce pine wood and specific gravity* [1]

Property	Constants a	Constants b	Correlation coefficient	Standard error of the estimate
Static bending				
Fiber stress at proportional limit, p.s.i.	−900	12,443	0.46	1,364
Modulus of rupture, p.s.i.	−4,856	32,401	.76	1,612
Modulus of elasticity, p.s.i.	−1,373,376	6,259,895	.59	364,652
Work to maximum load, in.-lb. per cu. in.	−10.1	41.4	.45	4.7
Compression parallel to the grain				
Fiber stress at proportional limit, p.s.i.	1,108	5,322	.36	831
Maximum crushing strength, p.s.i.	1,454	8,735	.59	705
Maximum shear stress parallel to the grain, [2] **p.s.i.**	201	2,134	.41	258
Hardness				
Side grain, lb.	−982	3,659	.91	89
End grain, lb.	−550	3,420	.81	130
Toughness				
Radial, in.-lb.	−98	503	.46	56
Tangential, in.-lb.	−133	645	.42	80

[1] The constants are from the expression $y = a + bx$. In the equation, y is the strength property of interest and x is unextracted specific gravity (basis of volume at 12 percent moisture content and ovendry weight).
[2] Combined data from wood stressed in both radial and tangential directions.

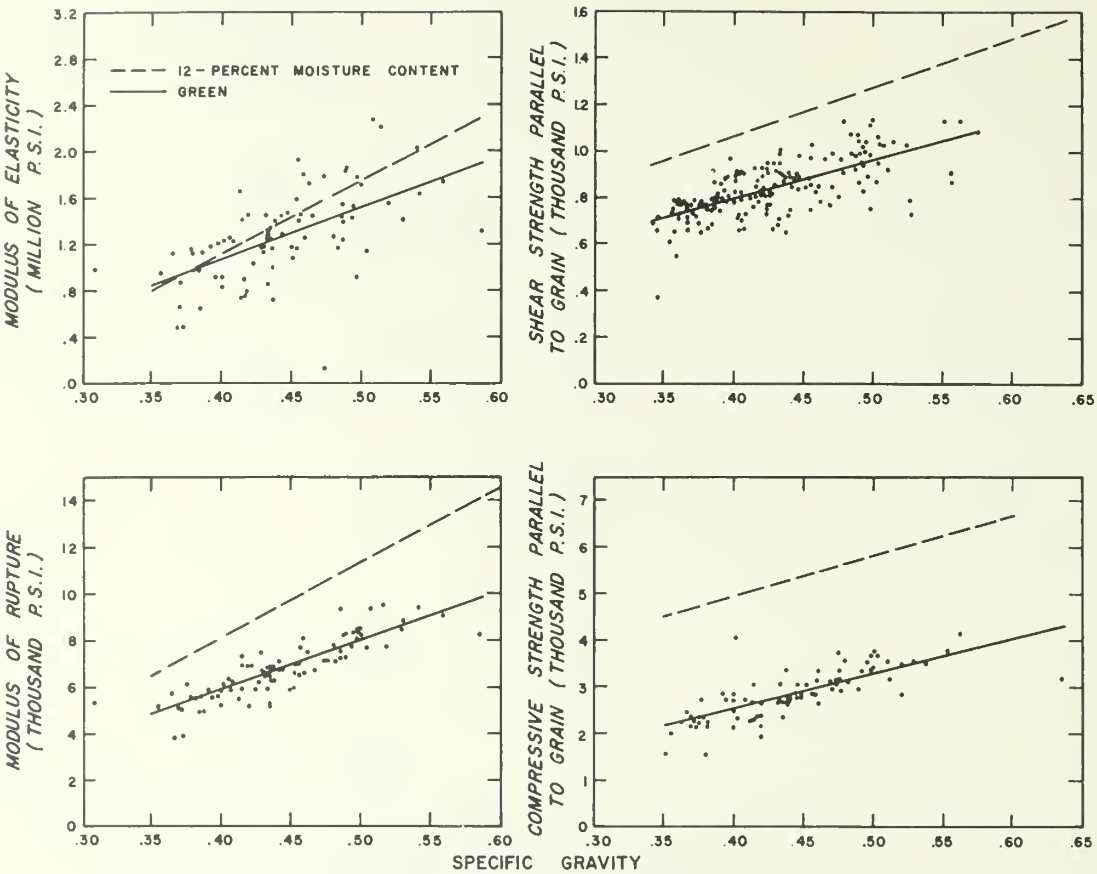

Figure 14.—*Relationship of four strength properties to unextracted specific gravity (basis of ovendry weight and volume at test) of green and air-dry spruce pine wood. Data points are plotted for green specimens only.*

Table 9.—*Species average values for spruce pine mechanical properties based on a 35-tree randomly selected sample (after Bendtsen 1968)*

Property	Green	12% moisture content
Static bending		
Modulus of rupture, p.s.i.	6,004	10,368
Modulus of elasticity, p.s.i.	1,002,000	1,229,000
Stress at proportional limit, p.s.i.	2,939	5,079
Work to proportional limit, in.-lb. per cu. in.	0.510	1.22
Compression parallel to grain		
Maximum crushing strength, p.s.i.	2,835	5,646
Modulus of elasticity, p.s.i.	1,163	1,374
Maximum shearing strength parallel to grain		
Radial, p.s.i.	905	1,485
Tangential, p.s.i.	885	1,491
Compression perpendicular to grain		
Crushing strength at proportional limit, p.s.i.	279	733
Hardness		
End, lb.	477	817
Side, lb.	447	661

Microtensile strength parallel to the grain was measured at each of the 1,296 within-stem sampling points (18 unweighted samples per tree). Values for earlywood and latewood did not differ significantly with tree age class or growth rate.

Property	Earlywood	Latewood
	---- *P.s.i.* ----	
Modulus of elasticity	505,944	1,103,931
Maximum tensile stress	8,233	19,430

DISCUSSION

Probably most properties of southern pines vary more within individual trees and among trees of a single species than they do between species. Nevertheless interspecies differences undoubtedly do exist.

Density of the merchantable stem averaged 0.43 in the present study, and Taras and Saucier (1968) also obtained this value. Species averages compiled by Koch (1972, p. 244) varied from 0.42 for Ocala sand pine *(P. clausa* (Chapm.) Vasey) and 0.45 for Virginia pine *(P. virginiana* Mill.) up to 0.58 for South Florida slash pine *(P. elliottii* var. *densa* Little and Dorman). Thus, spruce pine is in the low end of the range. Values for spruce pine did not differ with tree age class, but data for other species have shown a positive correlation between stand age and tree-average density (e.g., Zobel et al. 1965).

In Koch's compilation (1972, table 10-2, p. 408), wood of spruce pine ranks below that of Virginia pine in mechanical properties, and both of these species are considerably less strong than the four major southern pines. The data in this paper, though not comprising species averages, are in general agreement with those summarized by Koch. The values for modulus of elasticity and compression perpendicular to the grain are higher than those given by Koch but still lower than for most species. Only in work to maximum load (green) and in side hardness do present values compare with those of other species.

Spruce pine wood may contain a smaller proportion of extractives than the other southern pines. Extractive content averaged 2.7 percent of the stem ovendry weight, about one-half of that found in other species (Koch 1972, p. 205).

It is of interest to compare wood properties of trees in the three age classes, since rotation age is generally reduced to the minimum permitted by the market for which wood is grown. Fiber length of spruce pine trees would be reduced by about 0.2 mm. by cutting 15-year-old trees rather than those in the 30-year age class. Tracheid radial diameter and wall thickness apparently would not be reduced, and tangential diameter would be only about 1 μm. less in younger trees. Fibril angle of the S_2 layer would be greater in young trees.

Wood specific gravity would evidently not be affected by rotation age alone, and strength properties would not differ greatly between the two older age classes. Finally, relative proportions of chemical components would not differ with tree age.

Growth rate obviously has a great effect on weights and volumes produced at any age. At the rates study trees were growing (4.9 and 9.0 rings per inch), 30-year-old, fast-grown trees had 320 percent more wood volume than did slow-grown trees. They contained as much wood as 45-year-old, slow-grown trees although averaging 20 years younger. Volume gains were smaller in the 45-year age class, but fast-grown trees contained almost three times as much wood as slow-grown trees and almost double the wood found in 30-year-old, fast-grown trees.

Wood specific gravity, however, averaged lower in fast-grown trees—by about 0.04—than in slow-grown. Specific gravity of earlywood and latewood tissues was not related to tree growth rate, but fast-grown trees contained greater proportions of the low-density earlywood. Most mechanical properties did not differ with growth rate.

Tracheids of fast-grown trees averaged 0.2 mm. longer than those of slow-grown trees, and they were 2 to 4 μm. larger in both radial and tangential diameters. Fibril angle and wall thickness did not differ greatly with growth rate. Regression equations relating tensile stress and modulus of elasticity to position in the stem by height and distance from the pith were significant, but they accounted for less than 10 percent of the variation.

The reader interested in additional study of the utilization of spruce pine should find the following references useful:

Subject	Reference
Anatomy	Côté and Day (1969); Howard and Manwiller (1969); Koch (1972, p. 83-186)
Bark anatomy	Howard (1971); Koch (1972, p. 467-533)
Needle anatomy	Howard (1972b); Koch (1972, p. 575-601)
Distinguishing features	Ward (1963); Koch (1972, p. 30, 47)
Volume in each State	Sternitzke and Nelson (1970); Koch (1972, p. 5-10)
External characteristics of bark	Koch (1972, p. 484)
Moisture content in trees	Choong (1969b); Koch (1972, p. 268)
Hygroscopicity	Choong (1969a)
Specific heat	Koch (1969; 1972, p. 367)
Heat of combustion	Howard (1972a); Koch (1972, p. 378-382)
Friction	Lemoine et al. (1970); McMillin et al. (1970-a,b); Koch (1972, p. 357-366)
Strength	Bendtsen (1968)
Specific gravity	Taras and Saucier (1968); Kellogg and Wangaard (1969); Koch (1972, p. 236-264)

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Geographic Survey of MONOTERPENES *In Loblolly and Shortleaf Pines*

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Forest Service
U. S. Department of Agriculture

1972

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Geographic Survey of Monoterpenes In Loblolly and Shortleaf Pines

John F. Coyne and George C. Keith

Among wood oleoresin samples from 30 loblolly and 15 shortleaf pine sources, concentration of the most plentiful monoterpene, α-pinene, decreased relative to that of other monoterpenes from east to west and from south to north. With loblolly pine, the highest α-pinene concentrations appear to occur mainly on the Ultisol soil types of the Atlantic and Gulf Coastal Plains.

In studies of resistance to the southern pine beetle *(Dendroctonus frontalis* Zimm.), a large number of oleoresin samples were collected from loblolly *(Pinus taeda* L.) and shortleaf *(P. echinata* Mill.) pines and analyzed by gas chromatography for their monoterpene contents. Variations in monoterpene content associated with geographic source are reported in this paper.

Loblolly and shortleaf pine are two of the most susceptible species throughout the range of the beetle in the United States, but extensive areas within their ranges *(3)* have no history of beetle epidemics (fig. 1). Differences in certain oleoresin monoterpenes from such areas might account for the absence of epidemics, but that hypothesis was not rigorously tested in the study described here. The major purpose of the present study was to determine whether monoterpene contents of oleoresin vary qualitatively or quantitatively by geographic location of the tree. In this paper, qualitative refers to presence or absence of a terpene, and quantitative to the relative amount of a particular monoterpene found in a sample or group of samples.

METHODS

Oleoresin samples were collected from counties in east Texas, southwestern Mississippi, and central Louisiana in which active beetle infestations were either in progress or just terminated. Additional selected-county samples were taken from plantations established in south Mississippi (Pearl River and Harrison Counties) in connection with the 16-year-old Southwide Pine Seed Source Study *(14, 15)*. Fifty percent of the loblolly sources and 60 percent of the shortleaf sources were known epidemic areas (fig. 1).

At least five trees of each origin were tapped by inserting a screwtop vial into a hole drilled into the sapwood at breast height or lower. A few trees yielded no gum, but the 1-oz. (30 cc.) vials were usually over half full after a 24-hour collection period. Greater yields were obtained on the warmer south or west side of the bole and away from compression wood. After the 24 hours, the vials were removed, capped with Teflon or aluminum gasketed caps, and stored at about 0°C. until analyzed. All the samples were collected in August or September and chromatographed within 2 months.

The analyses were performed on a Micro-Tek 2500 R hydrogen flame ionization gas chromatograph with a 15 foot, ¼-inch outside diameter copper column packed with 30 percent Carbowax 20 M on 60-80 mesh Chromosorb W. The temperature settings were: Column 125°C., flame detector 280°C., and injector block 215°C. Pressure was 40 pounds. A Microcord Recorder Model 44 was used at 1.0 millivolt and a paper chart speed of 1 inch per minute with an Integraph Model 49 pipping type integrator.

Some of the resin samples were diluted with twice their weight of 95 percent ethyl alcohol; most samples, however, were dissolved with analytical-grade ethyl ether in the same proportion. Sample sizes of 0.3 to 0.6 microliter were injected for analyses, and results of three runs with each sample were averaged to estimate percentage composition.

For known standards, the relative retention times of the elutions compared to that of α-pinene (base of 1.00) were: Ethyl ether 0.31,

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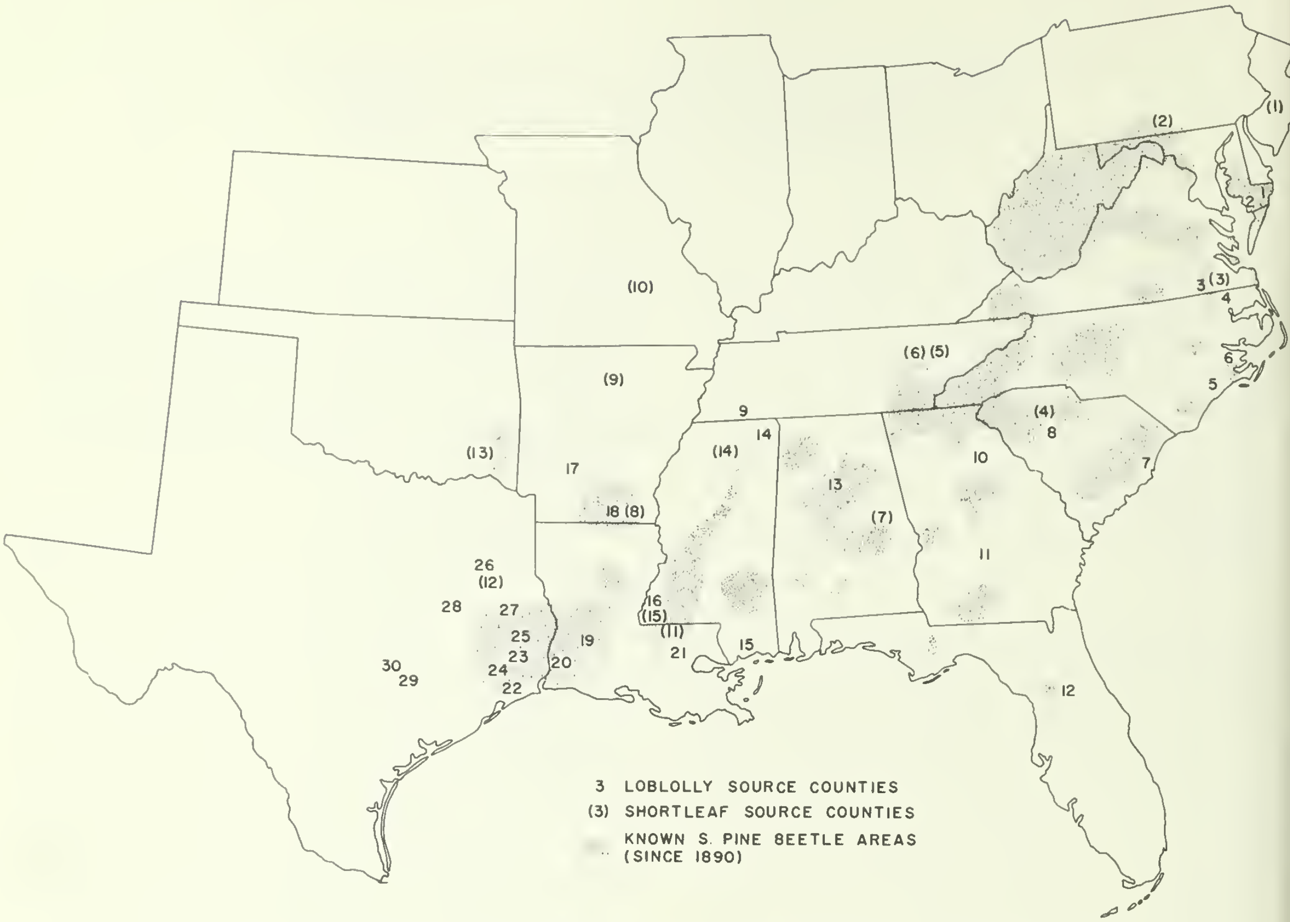


Figure 1.—*Sources of loblolly and shortleaf pine wood oleoresin samples and areas of known outbreaks of the southern pine beetle.*

ethyl alcohol 0.66, α-pinene 1.00, camphene 1.21, β-pinene 1.43, myrcene 1.54, δ-3-carene 1.64, α-terpinene 1.83, limonene 1.98, β-phellandrene 2.12, γ-terpinene 2.38, ρ-cymene 2.69, terpinolene 2.79, 2,4(8) menthadiene 2.91, and allo-ocimene (2 peaks) 3.89 and 4.34.

Twenty loblolly and thirty shortleaf xylem oleoresin samples were randomly selected from 10 different sources and run with an internal standard of ρ-cymene in the gas chromatograph to estimate the turpentine or volatile content. The result indicated an average weight of the terpenic volatiles for loblolly pine xylem gum of 22.8 $\pm$ 3.52 percent ($\pm$2 S.E. at 95-percent level) and for shortleaf 20.7 $\pm$ 1.90 percent. Our analyses pertain entirely to this volatile fraction, which was "normalized" to a base of 100 in determining percentages for the various terpenes in each sample. Since the proportion of oleoresin represented by the volatiles is about 20 percent in both pine species, values for individual terpenes in the two species are approximately comparable.

In most investigations of these and other pine species *(1, 4, 5, 9, 10, 11, 12, 13)*, terpene composition in individual trees has been quite constant regardless of season of collection, annual rings from which the oleoresin was collected, cardinal direction of collection points on the trees, viscosity of the gum samples, or length of storage at 1°C. for up to 6 months. Our findings are contingent on the assumption that any differences due to these factors are minor. Some error may exist in these assumptions; for example, Hanover and Furniss *(7)*, working with Douglas-fir and the Douglas-fir beetle in a study similar to ours, reported small seasonal quantitative differences in terpene composition and recommended sampling oleoresin at a uniform time of year. Also, some evidence suggests the possibility of introgression between the two pine species with consequent hybridizing of their terpene components *(8)*.

RESULTS AND DISCUSSION

There is no clear-cut differentiation, qualitatively or quantitatively, between the monoterpene compositions of loblolly pine and shortleaf pine xylem oleoresin. The same monoterpenes exist in similar proportions in these two pines, and solely on gross monoterpene analysis the two species are inseparable. However, within each species trends for various attributes are apparent.

Loblolly pine

In loblolly pine, α-pinene and β-pinene are the two major monoterpenes. The minor constituents of camphene, myrcene, limonene, and β-phellandrene were found in nearly every sample analyzed (fig. 2). If instrumentation had been sufficient, they could probably have been detected in all samples.

Alpha-pinene was the dominant terpene in most trees, but in some trees, especially from the most western sources, it was secondary to β-pinene. The eastern sources along the Atlantic Coastal Plain were highest in α-pinene content, northern sources had less, and western and central sources had the least (fig. 2 and table 1). The pattern was essentially clinal as is illustrated by the "valleys" of the isograms through the central part of the range (fig. 3). Rangewide, the coefficient of variation at each source (derived from nontransformed data) was less for α-pinene than any other terpene, averaging approximately 16 percent.

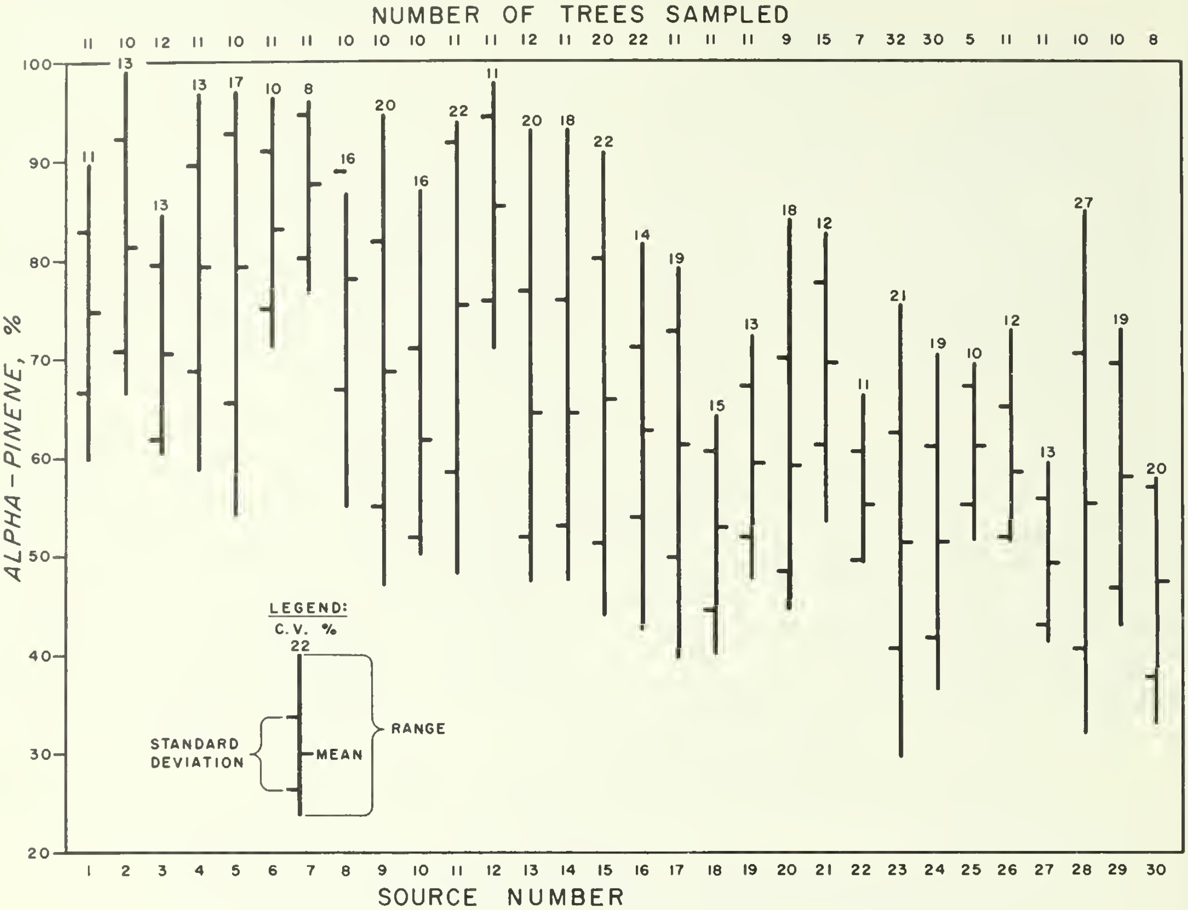
Camphene was found in all but three of the samples analyzed, but in small amounts. Its rather high coefficient of variation illustrated in figure 2 is due mainly to analysis of nontransformed data which magnifies departures from low mean percentages.

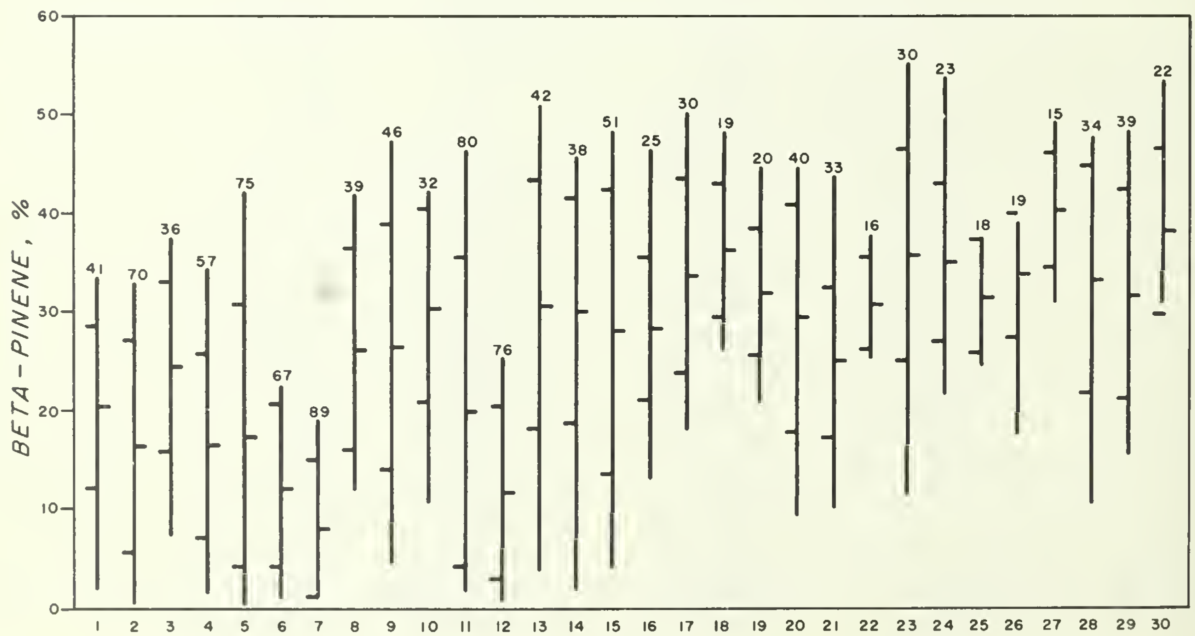
Beta-pinene is, for the most part, complementary to α-pinene with the sum of their percentages accounting for 90 percent or more

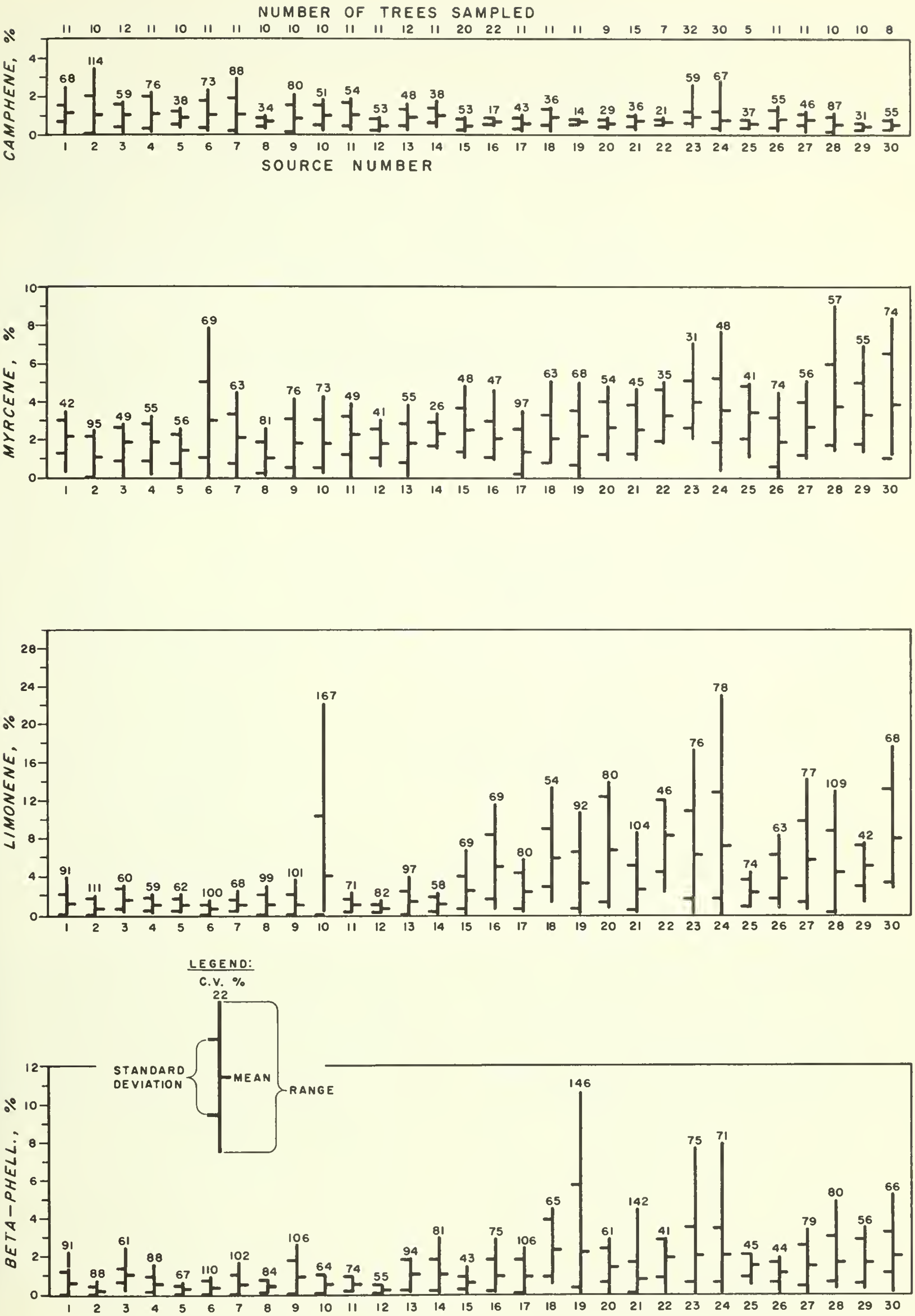
Table 1.—*Origin of collection of xylem oleoresin samples*

Source No.	State	County	Source No.	State	County
	LOBLOLLY PINE				
1	Maryland	Worcester	24	Texas	Liberty
2	Maryland	Somerset	25	Texas	Tyler
3	Virginia	Southampton	26	Texas	Cherokee
4	N. Carolina	Hertford	27	Texas	Angelina
5	N. Carolina	Onslow	28	Texas	Leon
6	N. Carolina	Pamlico	29	Texas	Fayette
7	S. Carolina	Georgetown	30	Texas	Bastrop
8	S. Carolina	Newberry		SHORTLEAF PINE	
9	Tennessee	Hardeman	1	New Jersey	Burlington
10	Georgia	Clarke	2	Pennsylvania	Franklin
11	Georgia	Wilcox	3	Virginia	Southampton
12	Florida	Marion	4	S. Carolina	Union
13	Alabama	Jefferson	5	Tennessee	Anderson
14	Mississippi	Prentiss	6	Tennessee	Morgan
15	Mississippi	Harrison	7	Alabama	Tallapoosa
16	Mississippi	Wilkinson	8	Arkansas	Ashley
17	Arkansas	Clarke	9	Arkansas	Stone
18	Arkansas	Ashley	10	Missouri	Dent
19	Louisiana	Allen	11	Louisiana	St. Helena
20	Louisiana	Calcasieu	12	Texas	Cherokee
21	Louisiana	Livingston	13	Oklahoma	Pushmataha
22	Texas	Chambers	14	Mississippi	Lafayette
23	Texas	Hardin	15	Mississippi	Wilkinson

Figure 2.—*Monoterpene components of loblolly pine wood oleoresin.*






NUMBER OF TREES SAMPLED
11 10 12 11 10 11 11 10 10 10 11 11 12 11 20 22 11 11 11 9 15 7 32 30 5 11 11 10 10 8
CAMPHENE, %
68 114 59 76 38 73 88 34 80 51 54 53 48 38 53 17 43 36 14 29 36 21 59 67 37 55 46 87 31 55
SOURCE NUMBER
MYRCENE, %
42 95 49 55 56 69 63 81 76 73 49 41 55 26 48 47 97 63 68 54 45 35 31 48 41 74 56 57 55 74
LIMONENE, %
91 111 60 59 62 100 68 99 101 167 71 82 97 58 69 69 80 54 92 80 104 46 76 78 74 63 77 109 42 68
LEGEND:
C.V. %
22
STANDARD DEVIATION
MEAN
RANGE
BETA-PHELL., %
91 88 61 88 67 110 102 84 106 64 74 55 94 81 43 75 106 65 146 61 142 41 75 71 45 44 79 80 56 66

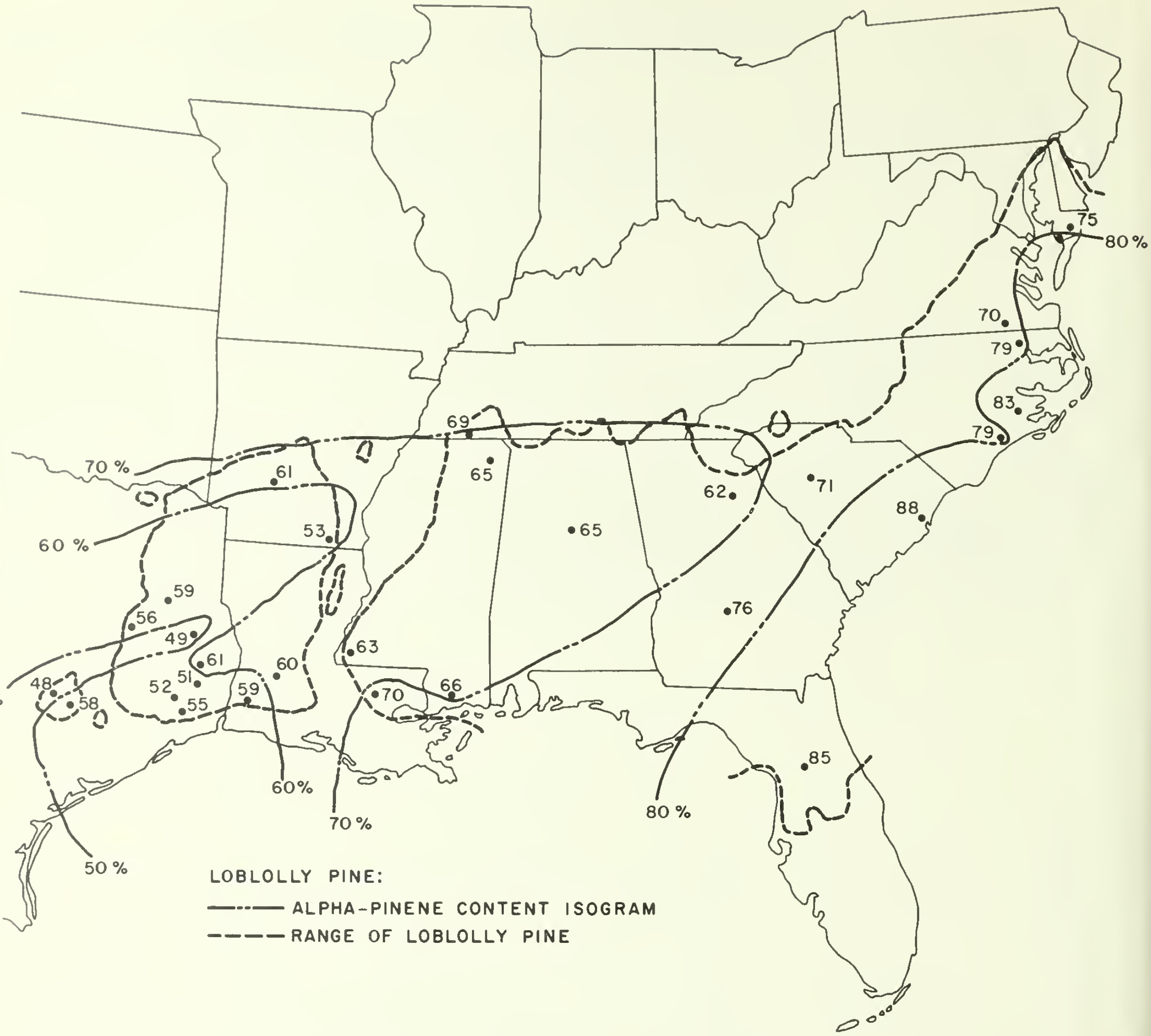


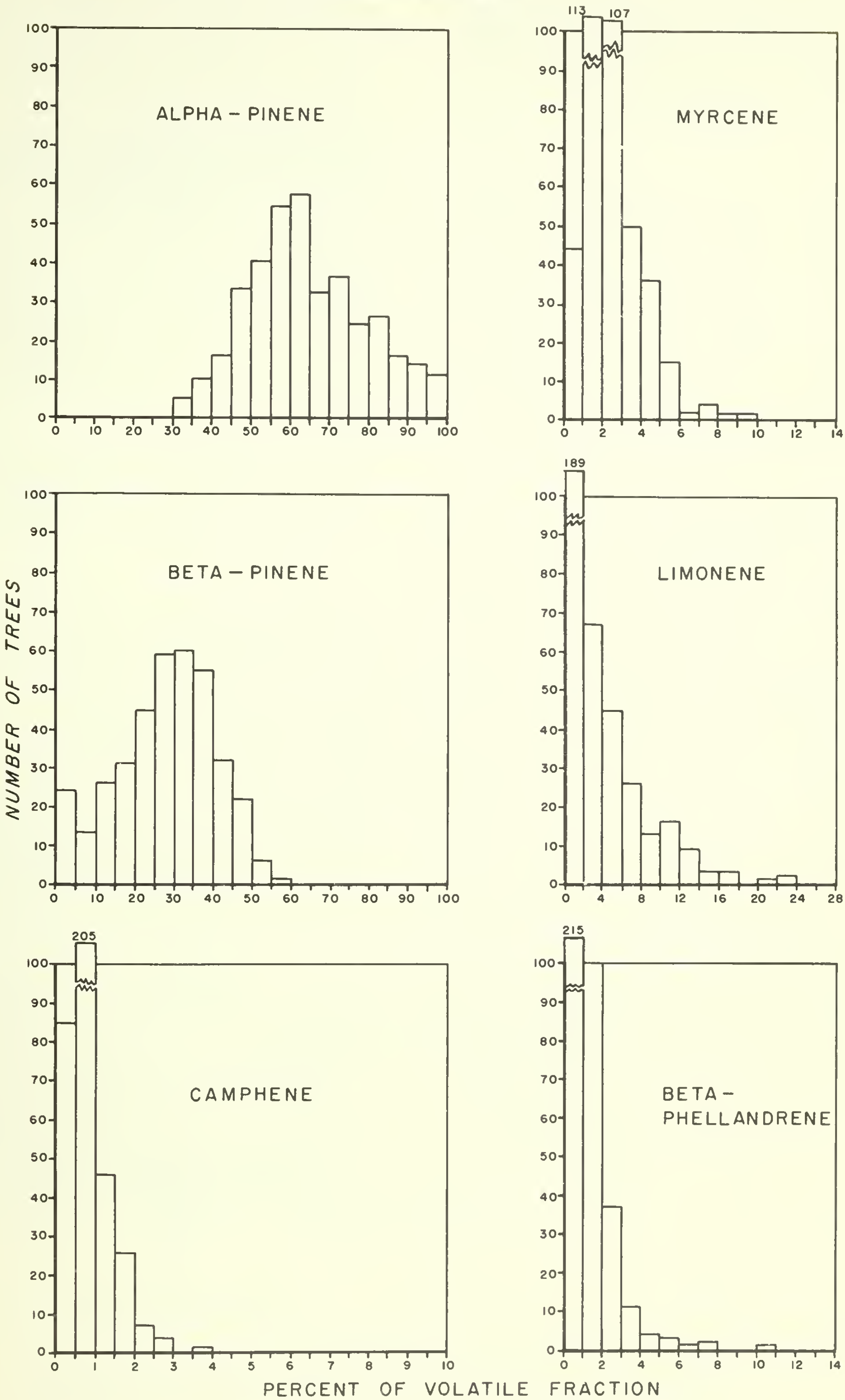
Figure 3.—*Variation in α-pinene content of loblolly pine wood through the range of the species.*

of the volatiles from most samples. Its average coefficient of variation for each source, however, was about 2.5 times as great as α-pinene's (40 percent versus 16 percent). Also, the average coefficient of variation for β-pinene in sources west of the Mississippi Delta is noticeably less than in sources east of the river (25 percent versus 53 percent).

Myrcene, limonene, and β-phellandrene were all very similar in their occurrence. About two-thirds of the samples contained less than 4 percent of each. About one-third of the sources included some trees with no myrcene or limonene, and over half of the sources had occasional trees with no detectable amount of β-phellandrene. The source means for limonene and β-phellandrene were noticeably higher west than east of the Mississippi Delta. This was also true for myrcene but to a lesser degree. The mean coefficient of variation for all sources was high for all three components, 57 percent for myrcene and 80 percent for limonene and β-phellandrene.

Frequency histograms (fig. 4) for the 374 trees sampled show normal distribution for α-pinene, β-pinene, and possibly myrcene contents. Camphene, limonene, and β-phellandrene concentrations are skewed toward the left and indicate a trend towards clustering in the 1 percent to 4 percent range.

Figure 4.—*Frequency distributions of terpene components of loblolly pine wood oleoresin.* ***Basis, 374 trees.***



Shortleaf pine

Monoterpene composition of xylem oleoresin (fig. 5) varied less geographically in shortleaf than in loblolly pine. Shortleaf α-pinene content by source increased from east to west while β-pinene decreased. The opposite was found for loblolly pine. The average coefficients of variation for α-pinene and β-pinene

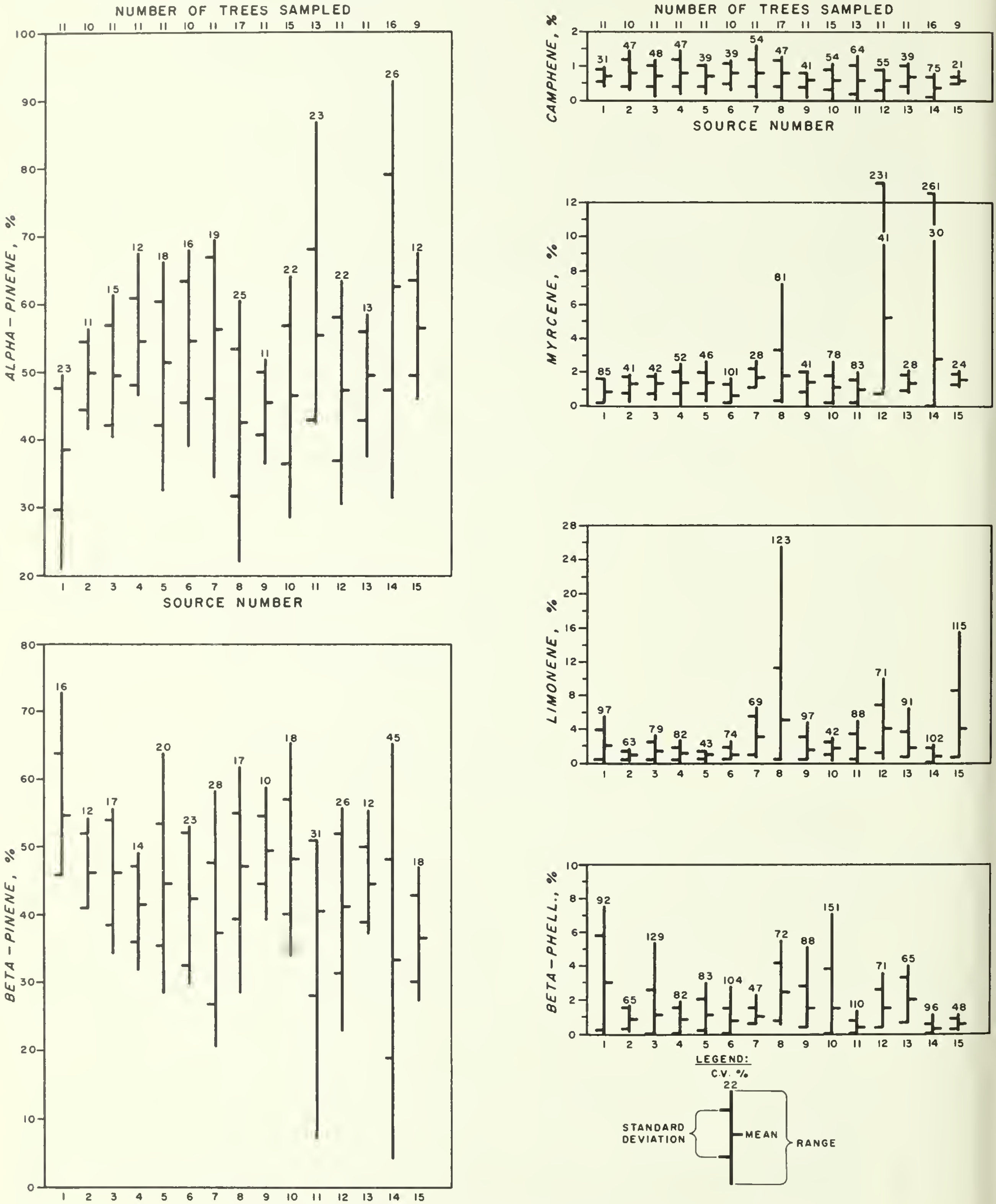


Figure 5.—*Monoterpene components of shortleaf pine wood oleoresin.*

were approximately the same (18 percent and 20 percent) and gave no indication of differing variation east or west of the Mississippi Delta. Rangewide isograms of the mean α-pinene content (fig. 6) show only a little geographic variation.

The minor shortleaf oleoresin components of camphene, myrcene, limonene, and β-phellandrene usually made up less than 4 percent of the volatile fraction. In three sources myrcene exhibited a wide range of measurement as did limonene at three sources and β-phellandrene at six sources. The average coefficient of variation of camphene was 47 percent. The average coefficient of variation of the other three minor components varied from 81 to 87 percent.

Frequency histograms (fig. 7) of shortleaf terpenes showed normal distributions for both α-pinene and β-pinene with medians falling in the 45 to 50 percent range for both. As with loblolly, histograms for the other four components were skewed toward the zero percentage.

In a loblolly planting in southern Illinois established with seed from six States, Gilmore *(6)* found that terpenes differed among sources in varying degrees. None of his samples (16 trees per source) were found to contain β-phellandrene, and his results generally were quantitatively at variance with ours. Mirov *(9)* reported terpene composition of loblolly pine

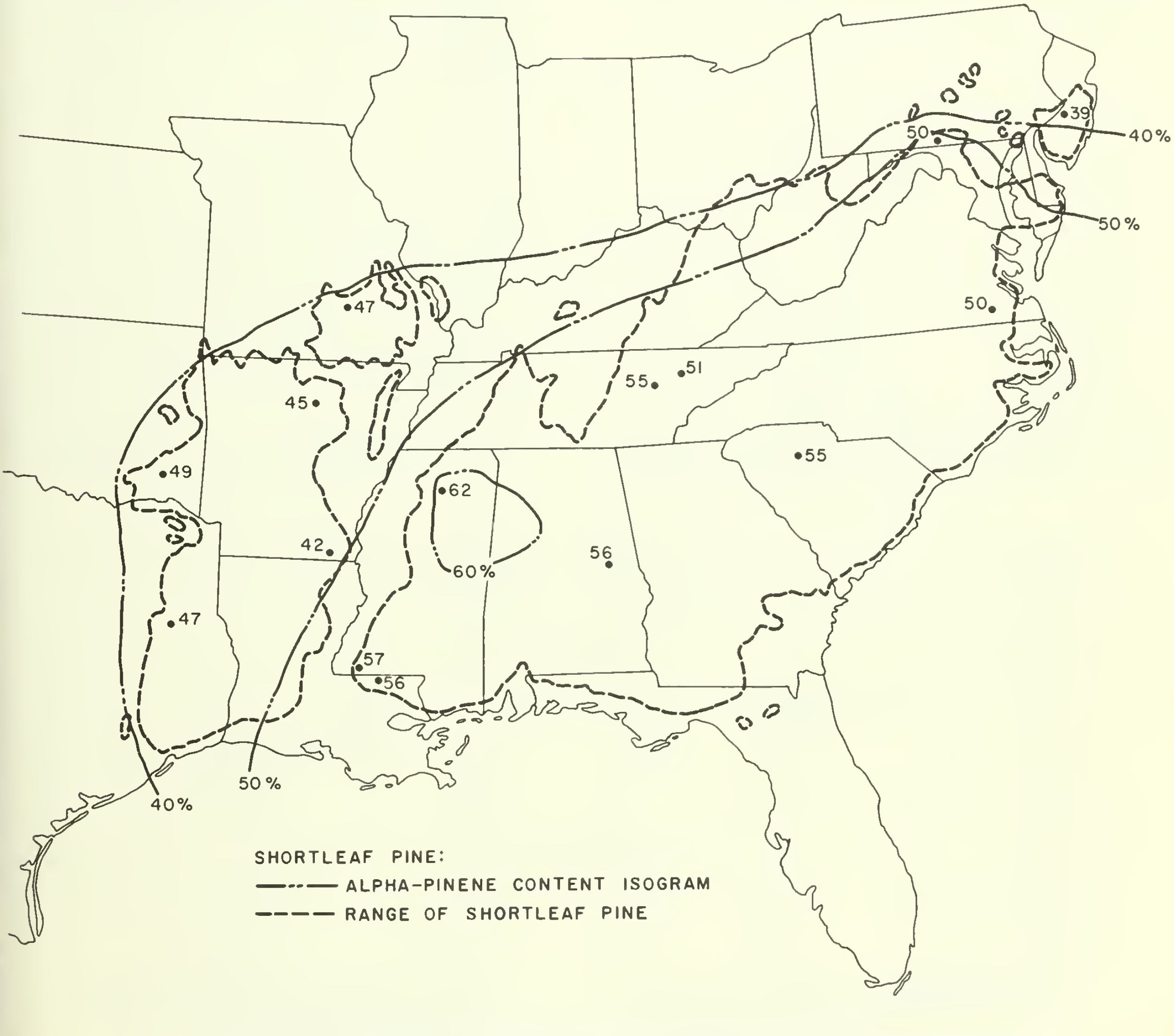


Figure 6.—*Variation in α-pinene content of shortleaf pine wood through the range of the species.*

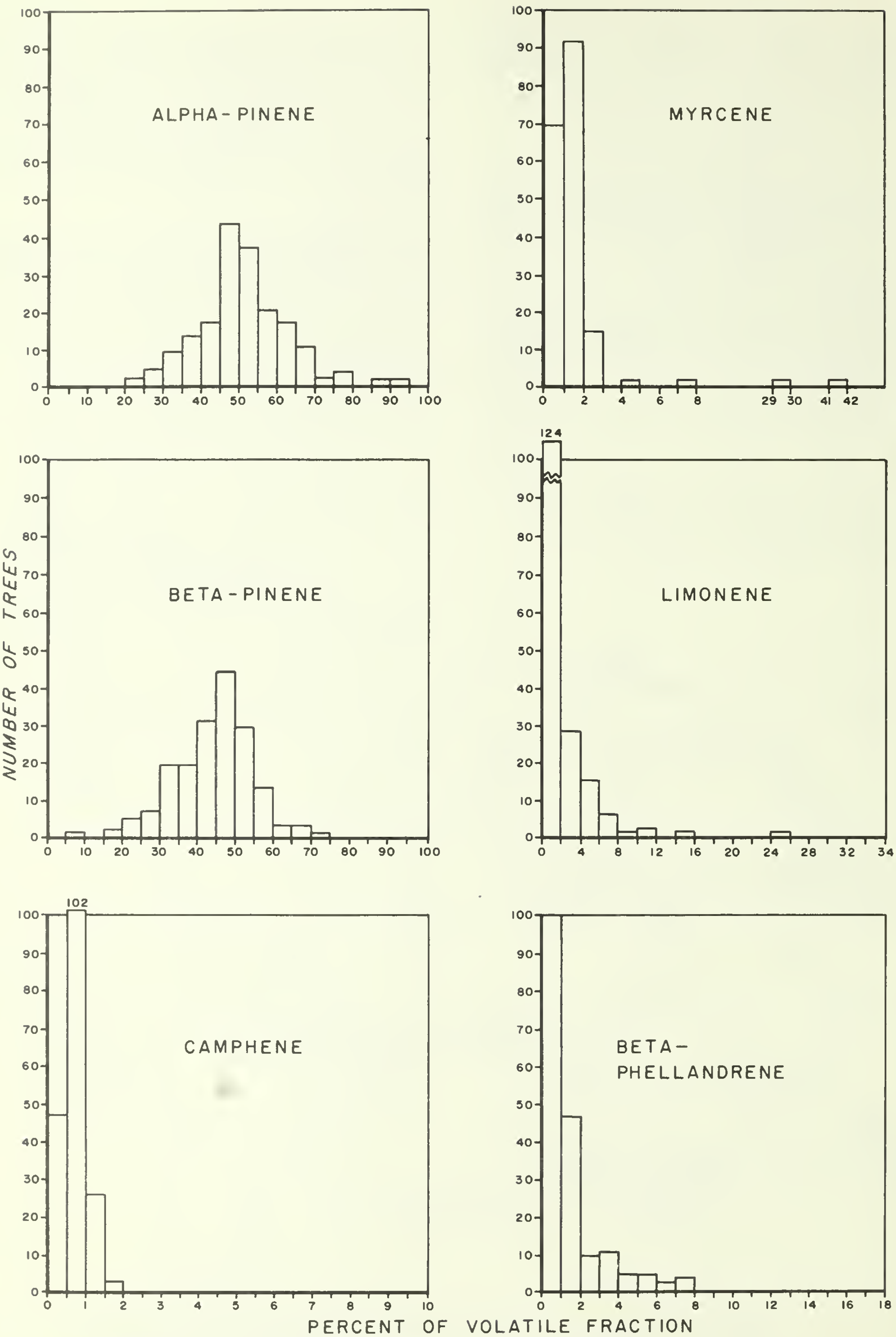


Figure 7.—*Frequency distribution of terpene components of shortleaf pine wood oleoresin. Basis, 178 trees.*

as: α-pinene 71 percent; β-pinene 22 percent; myrcene, limonene, and ρ-cymene 1 percent; and unidentified substances 3 or 4 percent. Our gas chromatographic analyses showed the presence of camphene and β-phellandrene in addition to terpenes found by Mirov. Only two individual oleoresin samples contained δ-3-carene in detectable amounts. Recent findings[2] in regard to deterioration of wood chips in water storage indicate that ρ-cymene is a product of such deterioration. No ρ-cymene was found in our samples.

Mirov *(9)* determined the composition of shortleaf pine oleoresin based on a collection from North Carolina as 85 percent β-pinene and 11 percent α-pinene. Conceivably the relatively small percentages of camphene, myrcene, limonene, and β-phellandrene found in our samples could be missed in gross distillation analysis. Only one of our shortleaf samples contained a relatively large amount of δ-3-carene.

Correlation coefficients, calculated between the mean terpene constituents of the 30 loblolly pine sources and the mean terpene constituents of the 15 shortleaf pine sources, are shown in table 2. For loblolly pine a strong negative correlation is apparent between α-pinene and β-pinene, limonene, and β-phellandrene, respectively, and a strong positive correlation between limonene and β-phellandrene. For shortleaf pine the only meaningful correlations were negative ones between α-pinene and β-pinene, and β-phellandrene, and a positive correlation between β-pinene and β-phellandrene.

By applying Bartlett's statistical test for homogeneity to the monoterpene percentage data, it was found that he variances of the terpene components at all locations for loblolly pine were heterogenous at the 95-percent level of confidence. With shortleaf pine only the α-pinene and β-pinene component variances were homogenous. Tests for statistically significant differences between sources for any particular terpene, therefore, would be invalid. The geographic patterns reported seem plausible without tests, however. Heterogenous variances within sampling units, which were counties, indicate that the sampling unit was too large, that localized populations within the county accounted for considerable variation in the terpene components. Assuming climatic factors have little or no effect within counties, the most obvious causes of such variation are differences in sites on which the localized tree populations have evolved or that variable terpene content is a secondary or pleiotrophic manifestation of more basic natural selection mechanisms.

From the most recent soil classification of the U. S. Geological Survey (National Atlas Sheet 86-1969) it was found that the eight

[2] Tate, D. C. Effects of wood storage on sulfate turpentine. Company Paper, U. S. Plywood-Champion Paper, Inc. (Unpublished)

Table 2.—*Correlation coefficients between individual terpene constituents of loblolly and shortleaf pines*

Terpene	Terpene				
	Camphene	β-pinene	Myrcene	Limonene	β-phellandrene
			LOBLOLLY		
α-pinene	0.489**	−0.976**	−0.558**	−0.848**	−0.851**
Camphene		−.477**	−.361*	−.453*	−.430*
β-pinene			.422*	.725**	.764**
Myrcene				.628**	.653**
Limonene					.818**
			SHORTLEAF		
α-pinene	−.294	−.921**	.060	−.284	−.906**
Camphene		.326	−.389	.090	.261
β-pinene			−.363	−.068	.777**
Myrcene				.431	−.022
Limonene					.371

* Significant ($P < 0.05$)
** Significant ($P < 0.01$)

loblolly sources having the greatest amount of α-pinene were concentrated in five soil types (Ultisols 1-2, 1-4, 5-1, 6-5, 6-9). The four with the highest α-pinene content were on one soil type (Ultisol 1-2). These soil types may also be the best sites for loblolly pine *(2)*. Twenty-three of the sources were on Ultisols, two on Vertisols, three on Alfisols, and two on Inceptisols. No similar comparison was made with shortleaf α-pinene because of the narrow range between sources containing the highest and lowest content. More intensive sampling and analyses of xylem oleoresin from both species would be necessary to substantiate this cursory finding.

No outstanding qualitative or quantitative monoterpene differences were found between samples taken inside and outside documented southern pine beetle epidemic areas.

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Among wood oleoresin samples from 30 loblolly and 15 shortleaf pine sources, concentration of the most plentiful monoterpene, α-pinene, decreased relative to that of other monoterpenes from east to west and from south to north. With loblolly pine, the highest α-pinene concentrations appear to occur mainly on the Ultisol soil types of the Atlantic and Gulf Coastal Plains.

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guying to prevent wind sway influences loblolly pine growth and wood properties

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and

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Forest Service
U. S. Department of Agriculture

1972

Guying to Prevent Wind Sway Influences Loblolly Pine Growth and Wood Properties

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Restraining young loblolly pine (Pinus taeda L.) *trees from normal swaying in the wind markedly reduced radial growth in the immobilized portion of the bole and accelerated it in the upper, free-swaying portion. Guying also reduced specific gravity, numbers of earlywood and latewood tracheids, latewood tracheid diameter, and amount of compression wood, but not percentage of latewood.*

Wind is an important factor in the environment of trees, but its influence on tree development is not well understood. Jacobs *(6)* reported that radial growth of Monterey pine *(Pinus radiata* D. Don) was at a maximum at ground level in free-swaying trees and at the point of support in trees artificially restrained. Moreover, the difference in radial growth was much greater in a heavily thinned plot than in an unthinned plot.

In the present study, loblolly pines *(P. taeda* L.) were guyed, and effects on stem growth and some wood properties were observed. These properties included ring width, earlywood width, latewood width, number of tracheids along the radius in earlywood, latewood, and entire ring, average radial diameter of earlywood and latewood tracheids, frequency of compression wood, and specific gravity.

MATERIALS AND METHODS

Eight dominant 19-year-old loblolly pines from 7.3 to 8.9 inches d.b.h. and spaced at least 25 feet from their nearest neighbors were selected in March 1958. The stand, on an industrial forest in southern Arkansas,[2] had been heavily thinned 2 years earlier. The eight trees were paired on the basis of height growth, and one tree of each pair was randomly chosen for guying. Heights and diameters of these trees at the start of the study are given in table 1.

Table 1.—*Tree height and diameter (inside bark at breast height) at start of study in March 1958*

Pair No.	Height		Diameter	
	Free swaying	Guyed	Free swaying	Guyed
	– *Feet* – –		– *Inches* –	
1	46.4	48.2	5.74	6.67
2	47.4	46.4	7.10	7.06
3	46.6	52.5	6.57	7.51
4	49.0	50.6	7.46	7.14
Average	47.4	49.4	6.72	7.10

Jacobs' *(5)* method of attaching guy wires to trees was followed. Sets of three guys, spaced at 120° intervals around the circumference of the tree, were placed at points coinciding with the tops of the 1946 and 1950 height increments (roughly 18 and 32 feet). The wires were anchored by stakes driven into the ground and were attached to hooks screwed into the bole. Oscillation of the bole below the upper guy attachment was restrained by double staying. Wires frequently snapped in high winds, just as they did in Jacobs' experiments. In fall 1961, stout coil springs were attached to the wires to prevent breakage, but restraint with the springs did not appear to be sufficiently rigid.

In September 1962, one guyed tree blew down in a storm, and the remaining trees were cut the following March, at which time all eight trees were sampled throughout their lengths. Wood sample disks, 1 inch thick, were

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[2] Crossett Division, Georgia-Pacific Corporation.

taken at stump level, breast height, and the midpoint of each annual height increment. A total of 14 disks were taken along the bole: six below the lower guys, four between guys, and four above the upper guys. Taking samples at shoot midpoints rather than specific heights permitted comparisons at bole positions which were equivalent with respect to number of rings from pith. The length of each annual height increment was recorded.

On each disk, measurements were made on the three annual rings formed immediately before and immediately after initiation of the study, the 1955-57 and 1958-60 increments. Although five post-treatment rings were available for measurement, the upper stems of these young trees did not contain five pretreatment rings. Restricting the comparison to these 3-year increments had the additional advantage of eliminating the 1961 and 1962 growth periods, when guys with springs provided insufficient restraint.

Cells and rings were measured on water-soaked disks with a dual-linear traversing micrometer *(12)* along two diameters at right angles to each other. In each ring, the widths of earlywood and latewood zones, according to Mork's *(9)* definition, were measured, and tracheids traversed in each zone were counted. From this information, average radial diameter of the tracheids in each zone was calculated. In addition, diameters of bolewood at the end of the 1954 growing season were recorded so that the cross-sectional area increments could be computed for the 1955 to 1960 annual rings.

Wedges were cut along each measured radius for specific gravity determinations. In these wedges, the volume of each ring in the specimen was proportional to the volume it occupied in the disk. The two parts corresponding to the 3 years before and after treatment were split away, and specific gravity of them, based on ovendry weight and water-soaked volume, was determined by the maximum-moisture method *(11)* after extraction with an alcohol-benzene mixture *(14)*.

To assess the occurrence of compression wood, radial surfaces of specific gravity specimens were smoothed with a microtome knife and examined microscopically for presence of checks in tracheid walls (an indication of compression wood). Five classes were recognized:

(1) Compression wood absent
(2) Isolated compression-wood tracheids
(3) Narrow bands of compression-wood tracheids
(4) Broad bands of compression-wood tracheids
(5) Compression-wood tracheids only.

Since the numerical designations approximate the proportions of compression wood present, these values were averaged for each annual rings examined.

In the analysis, data from separate radii and separate rings were averaged to give single values for the 3-year periods before and after treatment. In addition, effects of initial differences between trees were reduced by taking the difference between the values observed for the post- and pretreatment periods and expressing it as a percentage of the pretreatment value.

Separate statistical tests of treatment differences could be made for each of the 14 bole positions, but this probably would do more to obscure the trends than to clarify them. The data lend themselves better to graphical than statistical analysis, and graphs of results were prepared for each tree and wood character.

RESULTS

Stem Form and Taper

Guying decreased radial growth in the lower bole and increased it in the upper bole (fig. 1). The increase began just below the upper guy. Thus, taper was reduced relative to that in free-swaying trees. Height growth was not significantly influenced by treatment.

These radial growth results agree with those of Jacobs *(6)* for a heavily thinned plot of 16-year-old Monterey pine. He found a difference of 57 percent in bole diameter growth at stump level between free-swaying and guyed trees in the first 2 years after treatment. We found a 3-year difference of 35 percent. We found that radial growth was at a maximum at ground level in free-swaying trees and just above the upper guys in stayed trees and that radial growth in guyed trees exceeded that in free-swaying trees a short distance below the upper guys. These results also agree with those of

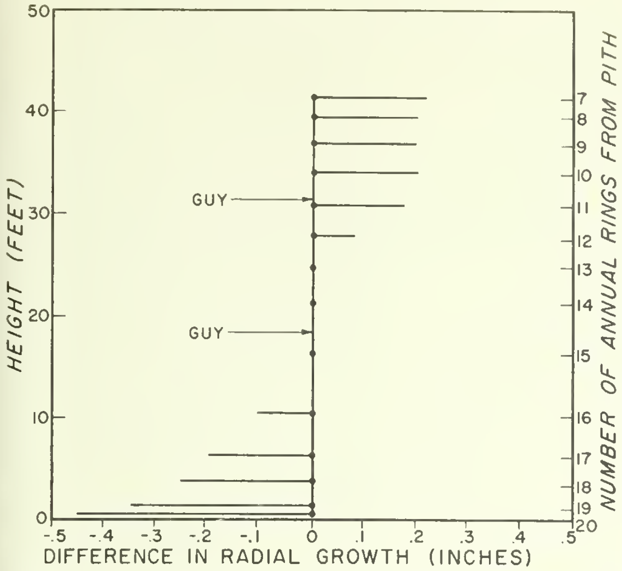

Figure 1.—*Differences in average stem wood radius between trees guyed for 3 years and free-swaying trees at 14 sampling positions.*

Jacobs *(6)*, who offered an explanation for the increased growth below the upper guys. He explained that when the upper stem of a guyed tree is deflected by wind, a sympathetic movement of the bole just below the guy attachment occurs—a repeated flexing.

Similar results also were observed by Larson *(7)* on 4-year-old free-swaying and stayed tamarack *(Larix laricina* Du Roi K. Koch) exposed for 120 days in a greenhouse to multilateral winds from oscillating electric fans.

Wood Characters

Ring width.—Guying significantly reduced average ring width between the stump and the lower guy and markedly increased it above the upper guy (fig. 2A). Earlywood (fig. 2B) and latewood (fig. 2C) zones responded to treatment in the same way as ring width, and in the same proportion. Thus, the trend in percentage of latewood along the bole was not noticeably affected by guying (fig. 2D). This result is not surprising, for Smith had earlier determined, through complete stem analyses of trees in an adjacent stand, that the percentage of latewood within an annual increment at any given position in the tree is a linear function of the number of rings from the pith and the environmental factor most limiting to growth, in this case soil moisture availability *(13)*. In the present study, both factors were controlled by comparing wood formed in the same calendar years, sampled at equivalent positions along the bole with respect to rings from the pith.

Our observations on the width of latewood zone are in partial agreement with Larson's *(7)*. He found the zone of thick-walled tracheids widest in free-swaying trees, thinner in stems restrained more rigidly, and thinnest in trees exposed to no wind at all. He did not find the same variation in latewood thickness along the length of the stem in response to treatment that we did. This lack of complete agreement may be due in part to differences in age class and species. Larson's 4-year-old tamarack stems probably consisted entirely of juvenile wood, while the lower 9 of our 14 sample disks per tree very probably were mature wood. In loblolly pine, the juvenile core consists of the first four to seven rings from the pith.

Radial tracheid count.—Counts of tracheids in earlywood and latewood (figs. 3A to 3D) show trends very similar to those for radial growth (figs. 2A to 2D). Compared with free-swaying trees, guyed trees produced fewer earlywood and latewood tracheids at the lower bole positions and more at positions above the upper guys. The change in number of earlywood tracheids produced in response to guying was accompanied by a proportional change in the number of latewood tracheids. Thus, treatment did not affect the percentage of latewood tracheids in trees (fig. 3D).

Average radial diameter of tracheids.—Although changes in earlywood and latewood widths are primarily explained by changes in numbers of tracheids, there are indications that guying slightly influenced latewood tracheid diameter. For instance, average radial diameter of earlywood tracheids appeared to be largely unaffected by guying (fig. 4A), whereas that of latewood tracheids was influenced to a small degree (fig. 4B). Under free-swaying conditions, the average diameter of latewood tracheids decreased with increasing height in the bole. In guyed trees, average latewood tracheid diameter decreased slightly (about 2 to 3μ) from stump to midway between the two guy positions, but above this point diameter increased somewhat. Thus, in con-

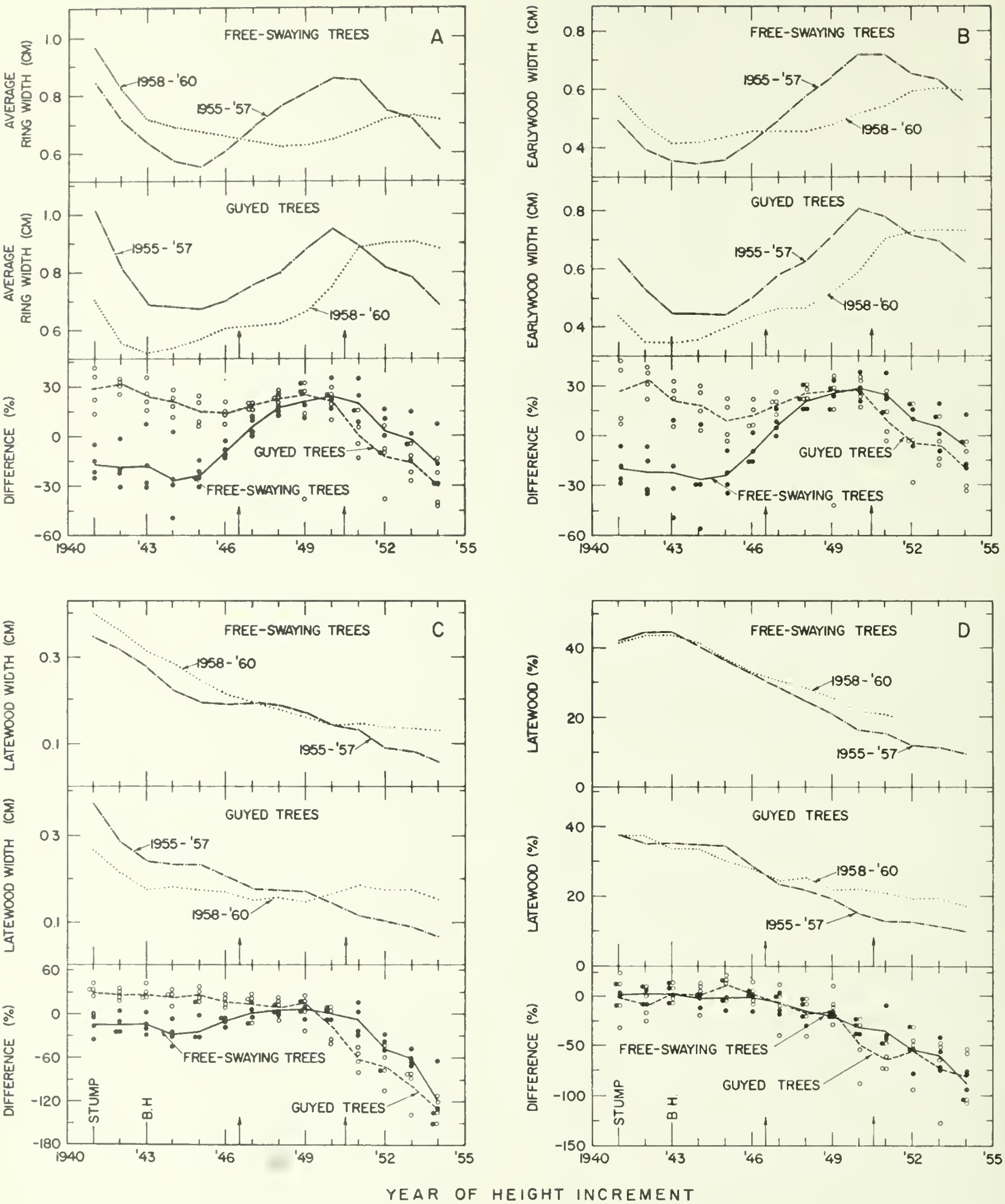

Figure 2.—*Average radial growth at 14 positions along the boles of free-swaying and guyed trees for the pre- and post-treatment years (1955-57 and 1958-60). In the upper and center portion of each block symbols represent the average of four trees. In the lower portion the differences in average radial growth of pre- and post-treatment years are expressed as a percentage of the former for individual trees (solid and open dots) and for the group averages (solid and broken lines). Relative positions of guys are indicated by arrow. A. Ring width. B. Earlywood width. C. Latewood width. D. Percentage of latewood in the annual ring.*

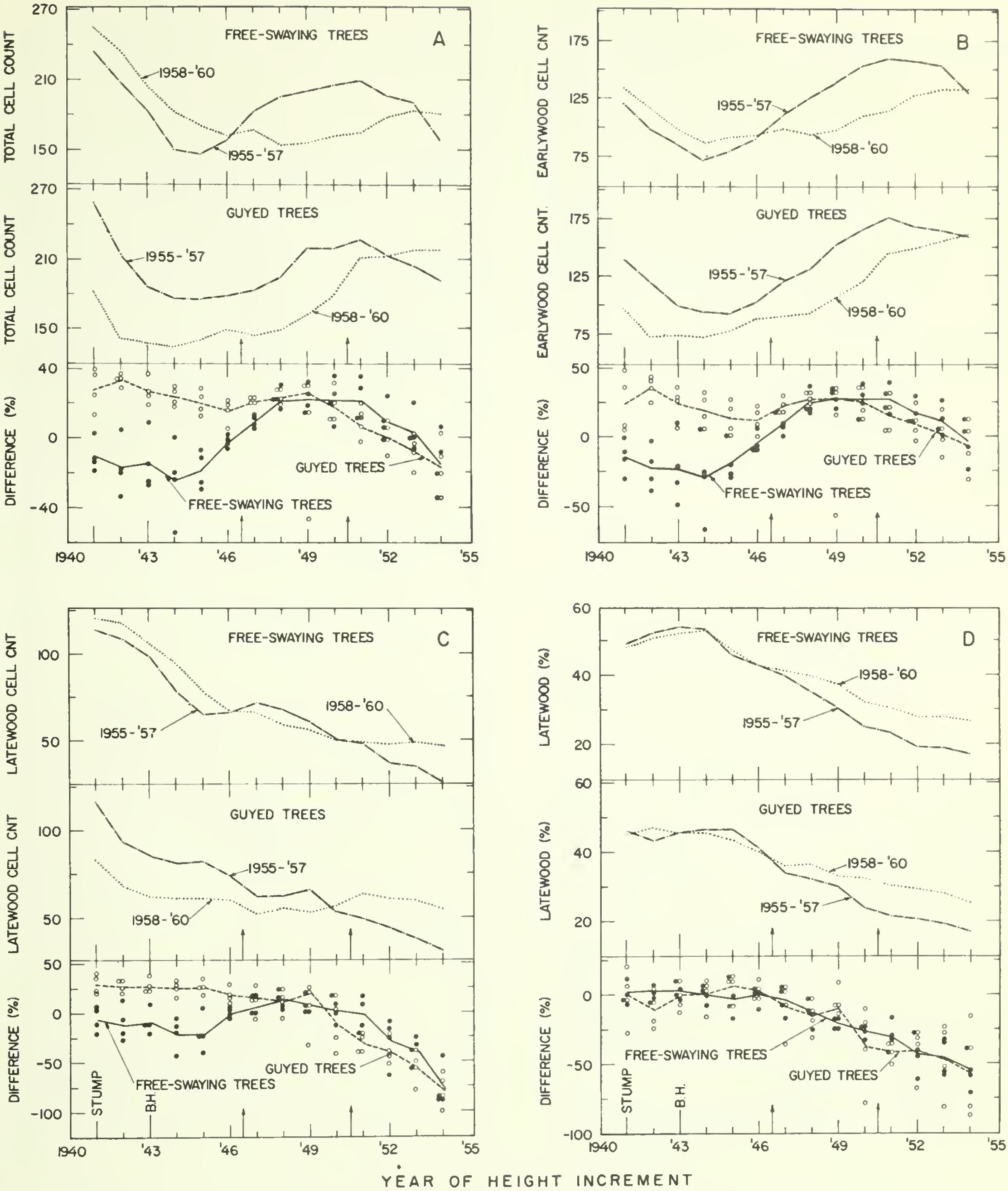

Figure 3.—*Average number of tracheids laid down radially at 14 positions along the boles of free-swaying and guyed trees for the pre- and post-treatment periods (1955-57 and 1958-60). Symbols in the upper and center portion of each block represent averages of four trees. In the lower portion of each figure the differences in number of tracheids formed during pre- and post-treatment years are expressed as a percentage of the former for individual trees (solid and open dots) and for the group averages (solid and broken lines). Relative positions of guys are indicated by arrows. A. Annual ring. B. Earlywood zone. C. Latewood zone. D. Percentage of latewood tracheids in the annual ring.*

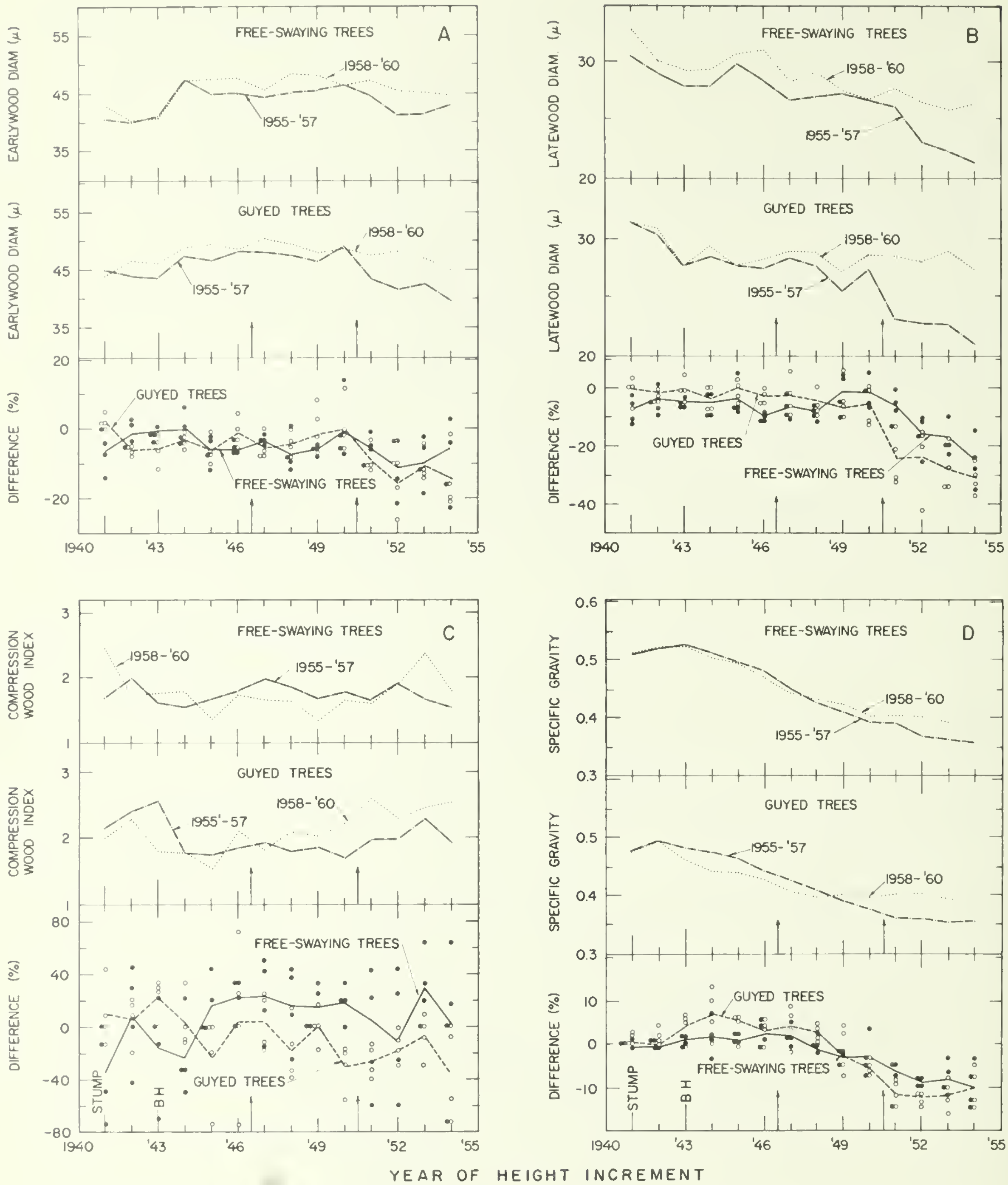

Figure 4.—*Four wood characters at 14 positions along the boles of free-swaying and guyed trees for the pre- and post-treatment periods (1955-57 and 1958-60). Symbols in the upper and center portion of each block represent averages of four trees. In the lower position of each figure the differences between the three pre- and post-treatment increments are expressed as a percentage of the former for individual trees (solid and open dots) and for the group averages (solid and broken lines). Relative positions of guys are indicated by arrows. A. Average radial diameter of earlywood tracheids. B. Average radial diameter of latewood tracheids. C. Frequency of occurrence of compression-wood tracheids. D. Specific gravity.*

trast to the normal trend, guying produced latewood tracheids with a relatively constant radial diameter at all positions along the bole.

One possible explanation for the observed trend in diameter of latewood tracheids in response to guying is the development of compression-wood tracheids, which are characteristically wider in diameter than normal latewood tracheids.

Compression wood.—Guyed trees produced fewer compression-wood tracheids at the lower bole positions and progressively more at increasing heights along the bole than free-swaying trees. This difference between the two groups of trees suggests that unequal tension on the guy wires may have slightly deflected the axes of the tree stems out of normal rest positions. The difference also supports the possibility that the presence of compression-wood tracheids explains the slight increase in average latewood tracheid diameter with height in bole of guyed compared with free-swaying trees.

Specific gravity.—For most utilization purposes, the single most important index of wood quality is specific gravity. In wood produced by guyed trees specific gravity was slightly but consistently lower (approximately 0.02) along the bole from breast height to midway between the two guy positions, above which it averaged slightly higher than in the free-swaying trees (fig. 4D). The difference in specific gravity between the two groups of trees cannot be explained by the differences in the percentage of latewood in the annual rings (fig. 2D), nor can it be explained by differences in the occurrence of compression-wood tracheids, because these usually have lower specific gravity than normal latewood tracheids. Guying may have brought about changes in the amount of cell wall material laid down. We made no attempt to explore this possibility.

DISCUSSION

The study was not designed to test any hypotheses, but to document effects of preventing wind sway on distribution and structure of wood increments. This treatment markedly reduced diameter growth in the lower bole of loblolly pine and accelerated diameter growth at and above the upper guy. Thus, maximum radial growth occurred at positions in the bole where sway tends to impose the greatest strength requirement: at ground level in free-swaying trees and at the upper point of support in trees artificially restrained. These results agree closely with those of Jacobs *(6)* for Monterey pine and Larson *(7)* for 4-year-old tamarack. The significant changes in stem form resulting from guying might lead one to expect equally significant changes in wood characteristics, but these did not occur. Trends in wood structure were observed, but they were small and indicate a conservative anatomical response.

Our observations of stem form and specific gravity distribution along the stem are in general agreement with mechanistic hypotheses. According to these hypotheses, the amount of wood *(8, 10)* and its specific gravity *(15, 16)* at any point along the bole beneath the live crown are proportional to the magnitude of the stress stimulus developed at that point. Accordingly, the shape of the stem is that of a cantilever beam of uniform resistance to bending.

Hall *(4)*, however, attempted to test the mechanistic hypotheses by measuring strain patterns along the red pine *(Pinus resinosa* Ait.) boles generated by natural and simulated wind loads. He concluded that the stems had not developed as beams of uniform stress in either the earlywood or latewood zones. Apparently, factors controlling increment distribution are complex. They may include a hormonal-electrical coordination system as suggested by Asher's *(1)* exploratory experiments on slash pine *(P. elliottii* Engelm. var. *elliottii)*. In a later experiment, Asher *(2)* observed an electrical "response" to leaf fascicle movement in young slash pine that appears to be typical of tissue depolarization. Duffield, in personal communication with Doerner *(3)*, proposed that the cambium is sensitized to hormones to a degree proportional to the amount of static stress and the frequency of application of external loads such as wind. In the present study, guying to restrain the lower bole from sway increased the static load in proportion to the tension on the guy wires. However, we cannot suggest a physiological mechanism for our results until we understand the relationship between mechanical loads and the intermediate biochemical processes of wood formation.

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Restraining young loblolly pine (*Pinus taeda* L.) trees from normal swaying in the wind markedly reduced radial growth in the immobilized portion of the bole and accelerated it in the upper, free-swaying portion. Guying also reduced specific gravity, number of earlywood and latewood tracheids, latewood tracheid diameter, and amount of compression wood, but not percentage of latewood.